DESIGN OF A NOVEL FRAMEWORK OF CLUSTER-BASED WIRELESS SENSOR NETWORK

By

SURENDER KUMAR
COLLEGE OF ENGINEERING STUDIES

Under the Guidance of
Dr. Manish Prateek
Professor, CIT, UPES, Dehradun
Dr. Neelu Jyoti Ahuja
Associate Professor, CIT, UPES, Dehradun
Dr. Bharat Bhushan
Associate Professor, G.N.Khalsa College, Yamunanagar

Submitted

IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY

To

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES

DEHRADUN

ACKNOWLEDGEMENTS

I am deeply indebted to many people for their support, encouragement and friendship during the completion of this research work. First of all, I am thankful to almighty God, who empowered me with the will and strength for doing this research and enabled me to complete this thesis. This research would not have been possible without the trust, encouragement guidance and support of many different individuals. I would like to give my sincere thanks to my supervisors **Dr. Manish Prateek, Dr. Bharat Bhushan** and **Dr. Neelu Jyothi Ahuja**. I am thankful to their scientific advice, moral support and for providing an enjoyable atmosphere to do this research. Their insightful discussions, useful comments, remarks and valuable suggestions in the most difficult moments of research, helped me a lot during the completion of thesis.

I am thankful to my friends and colleagues at **Govt. Polytechnic, Ambala City** for their kind help and encouragement. I would also like to thank **Mr. Surender Dahiya** and **Dr. Rakesh Kumar** for their tremendous support.

I am extremely grateful to my father, my late mother, my brothers **Rajinder**, **Balvinder**, **Vijay** and brother in law **Anil Dadwal** for their love and prayer to make this long journey short. Words cannot express how grateful I am to my uncle **Sh. Ramsaroop** for his unconditional love and encouragement which has always helped me to do better in life. Special thanks to my wife **Kavita** and lovely son **Sulaksh** for their love, support and patience during the research.

SURENDER KUMAR

CHAPTER - 1

INTRODUCTION

1.1 WIRELESS SENSOR NETWORK

Wireless sensor network is an emerging technology of the twenty first century, which promises a wide range of potential applications in both civilian and military areas [1]. A wireless sensor network (WSN) consists of a hundred or thousands of multi function tiny sensor nodes, which are deployed densely inside or very close to a phenomenon (Figure 1.1). Sensor nodes are equipped with a sensor, embedded microprocessor and radio transceiver. They have not only sensing but also data processing and communication capabilities. In most of wireless sensor network applications nodes are deployed in an ad hoc manner without any pre planning. As a result sensor nodes can be deployed randomly at disaster sites. After deployment sensor nodes can build a wireless communication network itself without taking any assistance from the external world. Sensor network is generally operated for a long period of time without any attention from the external world and nodes get their power from a battery. Sensor nodes battery cannot be recharged or changed because nodes are densely deployed in a harsh environment [2], [3], [4], [5]. WSNs have received tremendous attention from the researchers all over the world in recent years. A voluminous amount of research has been done for exploring the various design and application issues of WSNs. It is envisioned that WSNs will change the way we live, work, and interact with the physical world in near future [4]. The WINS [6] and SmartDust [7] projects for instance, aim to integrate sensing, computing, and wireless communication capabilities to produce low cost tiny nodes in large numbers.

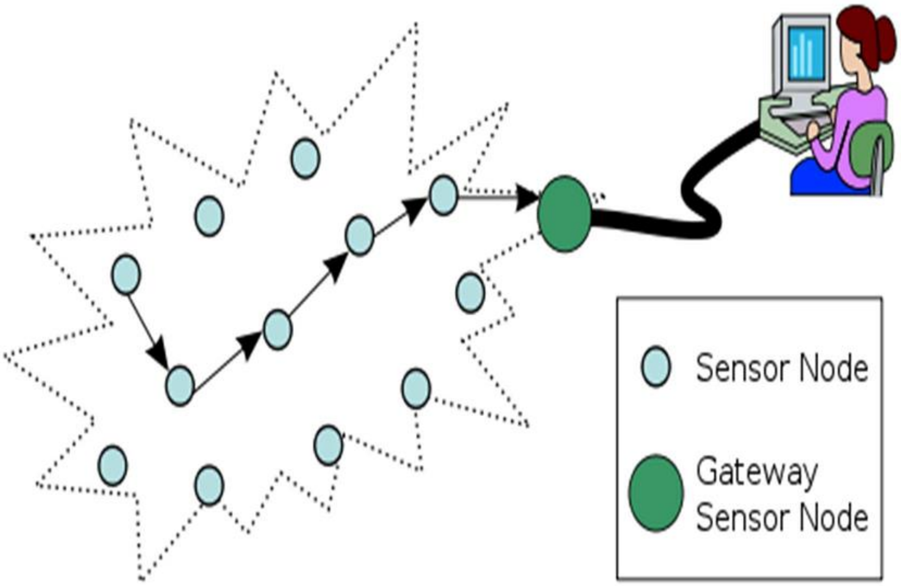


Figure 1.1 Wireless Sensor Network

1.2 SENSOR NODE ARCHITECTURE

The basic block diagram of a wireless sensor node is given in Figure 1.2. Sensor node basically consists of four components: sensing unit, processing unit, communication unit and power unit. Besides these component sensor node may have additional components like position finding system and mobilizer [2], [3],[4], [9], [10]. Mica2 [8] mote picture is shown in Figure 1.3.

Sensing Unit: Sensing unit is the main component of wireless sensor node and it is responsible for sensing the information from the sensing field. For this purpose, it contains one or more sensors to sense a wide variety of physical parameters including light, sound, temperature, pressure, humidity and air or water quality. Sensing unit also has an analog to digital converter which converts the observed physical parameters analog signal into digital signal and then fed into the processing unit for further processing.

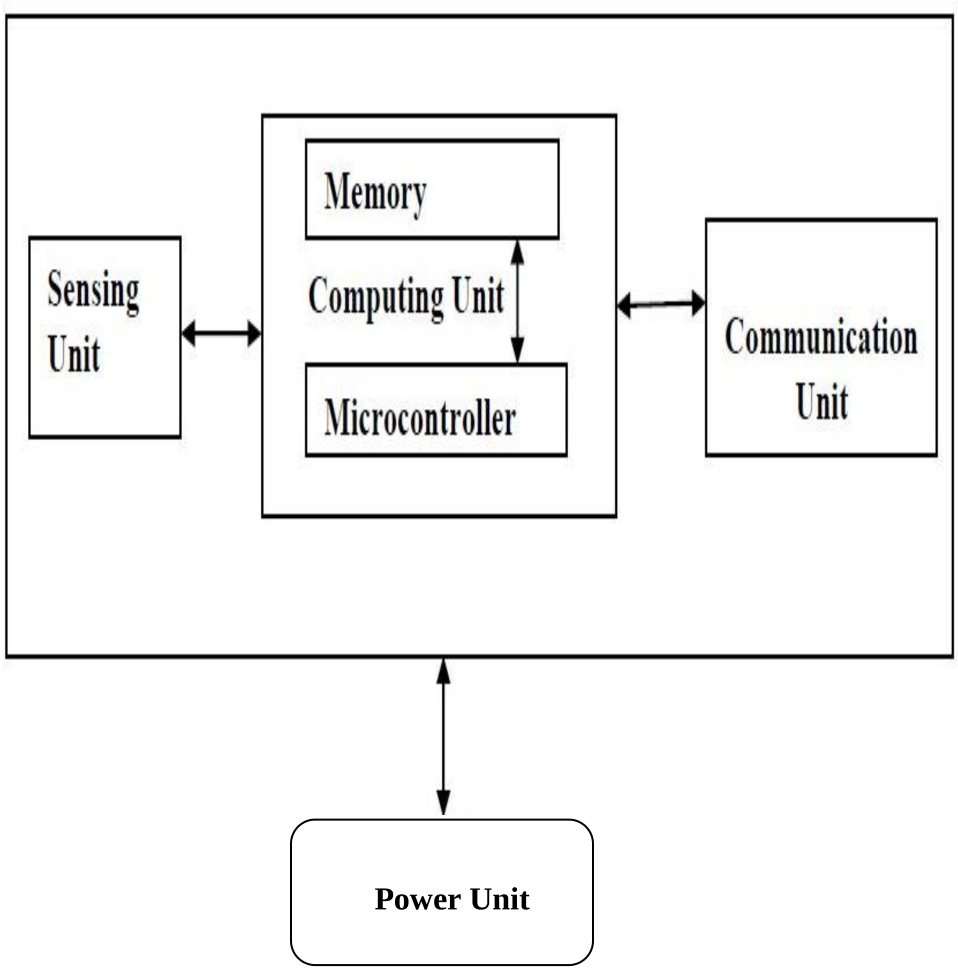


Figure 1.2 Architecture of a Wireless Sensor Node [4]

Processing Unit: Processing unit is the main controller of the sensor node which manages the various procedures that enable the sensor to perform various sensing operations, run associated algorithms and enables the node to collaborate with other nodes through wireless communication. It uses the on-board chip memory or an additional storage unit may be integrated with the embedded board. Various types of embedded processors that can be used in a sensor node include Microcontroller, Digital Signal Processor (DSP), Field Programmable Gate Array (FPGA) & Application Specific Integrated Circuit (ASIC). Among all these alternatives, the microcontroller has been the most used embedded processor for sensor nodes because of its flexibility to connect to other devices and its cheap price. Sensor node may vary significantly in their processing capability according to the application. For example, the Mica2 mote model MPR400CB is based on the Atmel low-power ATmega128L microcontroller. It has only 128 Kbytes of program flash memory, 512 Kbytes of measurement (serial) flash memory and 4 Kbytes of programmable read-only memory. In contrast, the Stargate is a 400-MHz Intel PXA255 X Scale processor with 64 Mbytes of synchronous dynamic random access memory and 32 Mbytes of flash memory [13].

Communication Unit: Communication unit is responsible for all the communication in the sensor network. It sends the data from one node to another and to the base station. The various choices of wireless transmission media include radio Frequency (RF), laser and infrared. Among all these radio frequency based communication is most suitable for WSN applications**.** It consists of a short range radio, which usually has a single channel at a low data rate and operates in unlicensed bands of 868-870 MHz (Europe), 902-928 MHz (USA) or near 2.4 GHz (global ISM band) [5]. Power consumption of a radio is affected by several factors like modulation scheme, data rate; transmit power and the operating duty cycle. When the transmitted power level is -10dBm or below, then mostly transmit mode, power is dissipated in the circuitry and at high transmit levels (over 0 dBm).

Figure 1.3 Mica 2 Motes [8]

The transmit power levels for sensor node applications are roughly in the range of -10 to +3 dBm [11]. Transceivers can operate in four modes: Transmit, Receive, Idle and Sleep mode. One of the important features of most radios is that idle mode significantly consumes high power and it is almost equal to the power consumed in the receiving mode. Thus, when a radio is not transmitting or receiving then to save the energy, it should be completely shut down rather than setting it in the idle mode. Another vital factor is that, when radio's operating mode changes, the transient activity in the radio electronics causes a significant amount of power dissipation. Sleeping mode is an important energy saving feature in WSNs.

Power Unit: Each component of the sensor node gets its power from the power unit. Battery technologies that are commonly used in wireless sensor networks are: Alkaline, Lithium, and Nickel Metal Hydride. Alkaline battery provides a cheap, high capacity, energy source. The major drawbacks of alkaline battery are their wide voltage range and large physical size. Additionally lifetime of beyond 5 years cannot be achieved with alkaline battery because of battery self-discharge nature.

A compact power source is provided by lithium battery. This type of battery has constant voltage supply, very little decay and few millimeters across. Another important thing of lithium battery is that it can operate at the temperature of - 40^0 C. Drawback of lithium battery is that it has a very low discharge current. When compared to an alkaline discharge rate of 25mA, a Tadiran battery has discharge current of just 3mA. Nickel Metal Hydride battery is another majorly used battery type. Easy recharge ability is their main benefit. Significant energy density decrease is the disadvantage of these rechargeable batteries. Nickel Metal Hydride battery of AA size has approximately half the energy density as compared to an alkaline battery and the cost is approximately five times more than an alkaline battery. One thing that should be taken into consideration before using Nickel Metal Hydride battery, they provide only 1.2 V and a number of system components require 2.7 volts or more. Thus many system components cannot be operated directly with these rechargeable batteries [12].

1.3 OBJECTIVE OF THE RESEARCH

One of the most severe constraints of sensor nodes is limited energy supply because they are battery operated devices. Designing energy efficient routing protocol to prolong sensor network life has become one of the hot research topics in recent years. In this research proposal, following aspects have been identified to design cluster based energy efficient protocol for wireless sensor network:

1. Identification of requirements and issues related to routing in a sensor network
2. Development of a framework for sensor network routing simulation
3. Developing cluster based energy efficient routing algorithms for sensor network

1.4. RESEARCH METHODOLOGY

To design new cluster-based energy efficient routing algorithms which prolong the sensor network life, the following methodology has been proposed and implemented.

1.4.1 PROBLEM IDENTIFICATION

A wireless sensor network is usually comprised of a large number of sensor nodes that are physically small, communicate wirelessly and deployed without any prior knowledge of the network topology. Sensor nodes are battery operated devices and due to the limitation of their physical size tend to have limited storage space, energy supply and communication bandwidth. WSNs provide efficient and costs-effective solutions for several monitoring and tracking applications. However, it is necessary to implement mechanisms or procedures to deal with the sensor resource constraints such as energy supply. WSN lifetime, therefore, shows a strong dependence on battery lifetime.

The hierarchical organization of the sensors into groups and assigning specific tasks to group before transferring the information to higher levels is one the mechanisms used to deal with the sensor limitations and is commonly referred to as clustering. A hierarchical architecture typically comprises two layers of routing where one layer is used to select cluster-heads and the other is for routing. Cluster-based algorithms are particularly useful for applications that require scalability to hundreds or thousands of nodes. The hierarchical structure of these algorithms is a promising method for efficiently organizing the sensor network and with the knowledge of their particular role in hierarchy nodes can control their activities for reducing the energy consumption. Thus clustering helps in solving sensors constraints by reducing the cost of transmitting data to base stations, reducing the power consumption in the devices, facilitating the gathering of sense data, maximizing the routing process execution, and allowing scalability.

1.4.2 DEVELOPMENT OF FRAMEWORK

Power conservation and power management are integral parts of any communication protocol in WSNs. The main task of a sensor node is to detect events, perform local data processing and then transmits the data. One of the important goals to develop efficient routing protocols is minimizing the energy consumption in a sensor network. The proposed framework of the cluster based wireless sensor networks has the following main aspects:

(i) Developing novel methods for cluster head election in a sensor network on the basis of distance and residual energy of nodes.

(ii) Integrating multihop short distance communication into the system for minimizing the range of data transmissions

(iii) Maximizing the number of alive nodes over time to prolong the network lifetime

(iv) Minimizing the total energy spent in the sensor network

(v) Balancing of energy dissipation among the sensors to avoid early depletion of certain sensors of network.

1.4.3 DEVELOPING CLUSTER-BASED ENERGY EFFICIENT ROUTING ALGORITHMS

The proposed framework has been used to develop three cluster-based energy efficient routing algorithms. The first algorithm is for the homogeneous sensor network. It has proposed two different probabilistic cluster head election schemes for base station nearer and far nodes in a sensor network. Routing algorithms which are energy-efficient in a homogeneous environment will behave sub optimally in a heterogeneous environment because the nodes have different energy consumptions and reserves. Therefore the second algorithm is for two level heterogeneous networks where some of the sensor nodes have high energy than the other. For taking the advantage of heterogeneity, it proposes three-tier architecture and a flexible framework based on residual energy. The idea behind this contribution is to elect only high residual energy normal nodes as cluster head in a round. For further reducing the transmission load of normal cluster heads, advanced nodes which are not cluster head in a round, act as the relay node for normal cluster heads. The third algorithm is for three level heterogeneous sensor networks. It takes the advantages of multiple levels of fidelity available in a sensor node without making any compromise with the performance of the network. Normal nodes become cluster heads only when they have sufficient residual energy to perform this duty. If a normal node becomes the cluster head, then advance and super nodes further save the energy of it by introducing three-tier architecture for it. They take over the data transmission load of it when they are not itself elected as cluster heads in a round.

CHAPTER - 2

ROUTING CHALLENGES & WSN APPLICATIONS

2.1 WSN vs. ADHOC NETWORK

Many protocols and algorithms have been proposed for traditional mobile ad hoc networks, but they cannot be applied directly to the unique requirements of wireless sensor networks. Some of the unique characteristics of wireless sensor network which distinguish it from other traditional wireless networks like cellular system and MANET are as follows:

- Sensor nodes are densely deployed inside the region of interest or very close to it and node magnitudes are higher as compared to its traditional counterpart Mobile Ad-hoc network (MANET) and the cellular system.
- Sensor nodes are highly constrained in power, processing capabilities, storage and memory.
- Sensor nodes are deployed randomly without careful planning and engineering. After deployment sensor nodes construct a wireless communication network itself without taking any assistance from the external world.

- Sensor nodes are battery operated devices and due to harsh environment deployment it is almost impossible to change or recharge their batteries.
- Mobile- Adhoc networks use point-to-point communication, whereas WSNs generally use broadcast communication.
- Topology of the sensor network changes frequently due to the energy depletion of sensor nodes, damage of the nodes during deployment and the addition of fresh nodes in the network.
- Due to limited storage capacity and large number of sensor nodes developing a global addressing scheme is not feasible for sensor network.
- Sensor nodes co-operate with each other to accomplish a common task so a certain level of correlation between the data items exist in the sensor network.
- Sensor network design is application specific and most of the design specification changes with the application type.
- In the majority of applications, nodes in WSN remain static after deployment and in some rare cases, they are mobile, so some issues that are important in MANET may not be of great importance in WSN [2], [4].

2.2 ROUTING CHALLENGES AND DESIGN ISSUES IN WSN

WSN has made reach to a wide number of monitoring and tracking applications. Constrained energy, limited processing power, limited bandwidth and storage of the sensor nodes should be taken into considerations before using a sensor network for an application. WSN routing protocols design is affected by many challenging factors and these obstacles must be overcome to achieve efficient communication in WSN [9]. WSN an important design goal is to prolong the network lifetime by using energy efficient technique. Some of the major obstacles and design challenges which affect the routing in WSNs are as follows

Node Deployment: Nodes of a WSN are application dependent and they are deployed either randomly or in a deterministic way. In a manual or a deterministic way nodes are placed manually at the predefined location and data of the network is routed through predefined paths. However an adhoc routing infrastructure is created when the nodes are scattered randomly in a sensing region. When the nodes are not distributed uniformly then for maximum connectivity and energy-efficient operation, optimal clustering option should be considered. Multihop communication can be used for selecting an energy efficient route [3].

Energy Consumption without Losing Accuracy: Sensor nodes use its limited energy supply for performing sensing, computations and information transmission. The node lifetime has a strong dependency on the battery [17]. In WSN each node plays a dual role as a data sender and data router. Power failure can cause malfunctioning of some sensor nodes. Thus the network topology has been changed significantly and network reorganization or rerouting of packets may be required.

Data Reporting Method: Data reporting in WSNs is application-dependent. Data reporting may be time-driven, event driven, query-driven, or a hybrid of all these methods. The time-driven delivery method is suitable for applications where data is monitored periodically. Thus nodes switch on their sensor at periodic time interval sense the region and transmit the interested data. In event-driven or query-driven methods, nodes react immediately when there is a significant change occurred in sensed attribute value. This change may be due to the occurrence of a specific event in the network or the nodes respond to a query generated by the base station. Thus, they are good for time-critical applications. A combination of these two methods can also be used for reporting any event occurred in the environment. Data reporting methods highly influence the design of routing protocol in terms of power consumption and route selections for transmitting the data.

Node/Link Heterogeneity: Most applications of WSN, consider nodes in the network are homogeneous (i.e., they have equal capacities). A sensor node may have to perform different roles depending upon the applications. However if some nodes of the network are heterogeneous then many technical issues are raised in data reporting. For example, some applications require a mixture of sensors to monitor a number of physical attributes of the sensing region like temperature, pressure and humidity etc. then specific sensors for sensing theses attributes may be deployed independently or sensor nodes of different functionalities may be deployed in the network. Data reading and reporting at different rates can be generated from these sensors. Multiple data reporting models can be used by sensors depending upon the quality of service constraints e.g. a cluster head node in a hierarchical architecture. Cluster heads are selected from deployed sensors and they are more powerful than normal nodes.

Fault Tolerance: Some nodes of the network cannot work properly due to power failure, physical damage or environmental obstacles. WSNs overall task should not be affected by node failure. When a number of node failures occur, MAC and routing protocols should form new routes for the data collection and reporting to base station. This requires active adjustment of transmitting power and signal rates on the existing links for reducing energy consumption or rerouting of packets to the part of network which have more energy. Thus a fault-tolerant sensor network of multiple redundancies is required.

Scalability: Hundreds or thousands of sensors are deployed for monitoring or tracking of a sensing region. Routing schemes should be able to cope with this large number of sensor nodes and routing protocols is scalable enough for responding to all the events in a sensing region. For energy saving sensors remain in the sleep mode until an interesting event has occurred in the region.

Network Dynamics: In many studies, sensor nodes are assumed fixed. However, in some applications, both the BS or sensor nodes can be mobile [19]. In this type of application in addition to energy and bandwidth saving the routing messages is also a challenging task because topology and route stability become an important issue. Moreover, the phenomenon can also be mobile (e.g. target detection/ tracking application). For the static events network operates in a reactive mode and for dynamic applications, periodic reporting method is used.

Transmission Media: WSN nodes are linked and communicate to each other by using a wireless medium. A radio channel traditional problem (e.g., fading, high error rate) is also affected the performance of a sensor network. Required bandwidth of sensor data is generally low, in the order of 1–100 kb/s. MAC design is generally related to the transmission media. TDMA based protocol is more suitable than contention based protocol (e.g. IEEE 802.11). Bluetooth may also be used for medium access protocol for WSN.

Connectivity: In a sensor network node density is generally high therefore nodes cannot be isolated from each other completely. Hence, sensor nodes are highly connected with each other. Size of a sensor network shrinks due to node failures and as a result topology of the network is also changed frequently. Random distribution of the sensors in a sensing region also affects the node connectivity in WSNs.

Coverage: Each node in WSN has a particular coverage of the region. Coverage of the region is limited in both range and accuracy and it covers only a specific area of the sensing region. Hence coverage should also be taken into consideration while designing new routing algorithms for WSNs.

Data Aggregation: Sensor nodes are densely deployed so a lot of redundant data are produced by the nearby nodes. For reducing the number of transmissions in the network similar data packets from the multiple nodes can be aggregated. Data aggregation reduces the size of the reporting data by using aggregate functions. Aggregate functions combine the data of different sources by using number of operations on the produced data (e.g., duplicate suppression, average, minimum and maximum). With these techniques energy consumption of the network is reduced and data transfer is also optimized because only the aggregated data have to be reported to the sink. Data aggregation can also be performed by using signal processing methods. This method is known as data fusion. With data fusion node produces a more accurate output signal. For this it uses some techniques like beam forming to combine the various incoming signals and reduce the noise signals.

Quality of Service: In some applications from the time data is sensed then it should be reported to the sink within a stipulated period of time otherwise it is useless. Thus for time critical applications data delivery within a particular time span is another important criteria. However, energy conservation for prolonging the network life is more important than quality of service in most of the WSN applications. With the depletion of energy, network may reduce the quality of data reporting to save the energy and as a result life of the network is increased. Thus energy-aware routing protocols are the necessity [9].

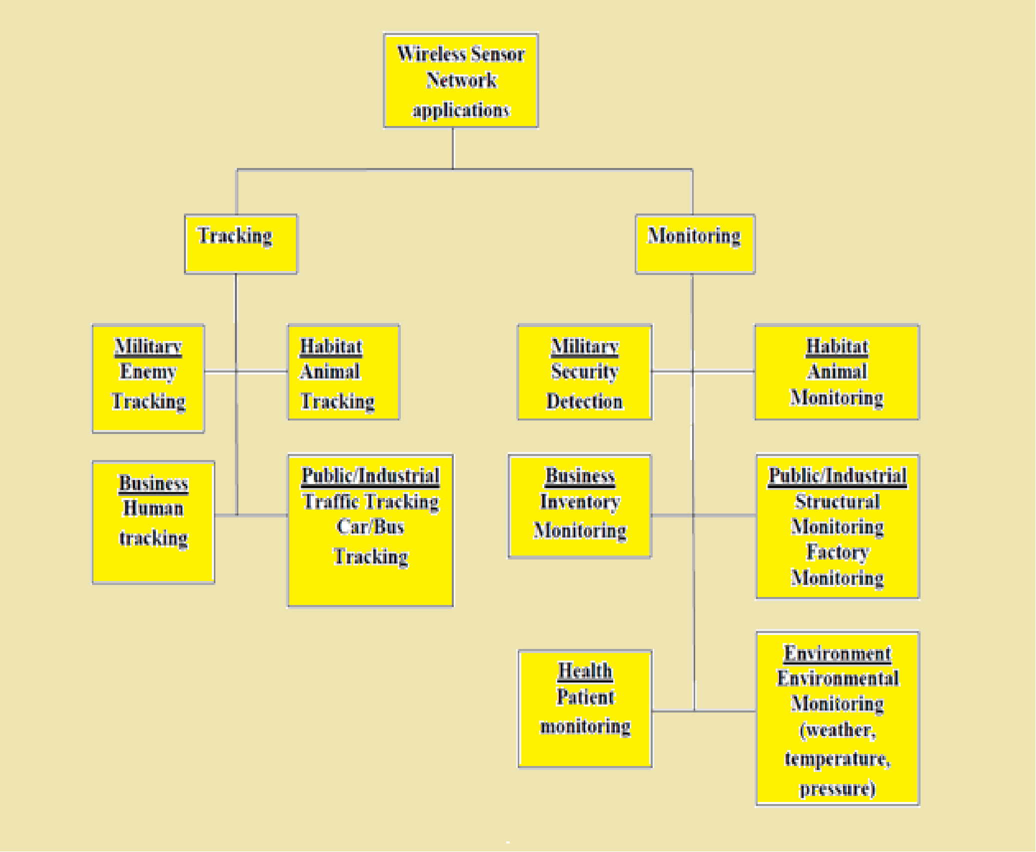


Figure 2.1 WSNs Applications Taxonomy [16]

2.3 WIRELESS SENSOR NETWORK APPLICATIONS TAXONOMY

The main job of a sensor network is to periodically collect the data from the region of interest and then send it to a Base Station (BS) for further analysis, which is usually located at a far distance from the sensing region [14],[15]. Initially wireless sensor network was designed for military applications, but today it has made reach to a wide variety of civil applications also. Sensor nodes can monitor a number of ambient physical parameters like temperature, light, sound, soil composition, pressure, air and water quality [3], [4], [5], [9], [16]. Generally WSN applications are divided into broadly two categories [16] as shown in Figure 2.1.

- **Monitoring**
- **Tracking**

Monitoring applications monitor indoor or outdoor environment, inventory location, power, seismic and structure, factory and process automation, health and wellness [16].

Tracking applications include tracking objects, animals, humans, and vehicles [16]. Thus the applications of WSN may be categorized into environmental, military, healthcare, industry automation, security-surveillance and home intelligence [4], [5] (Figure 2.1 & Figure 2.2).

Environmental Applications: Wireless sensor network can be deployed for the monitoring of wild animals and conditions of habitats. Other environment applications, of WSN include air and water pollution study, chemical plant monitoring, precision agriculture, forest fire detection, volcanic monitoring, flood detection in river, direction and magnitude of earthquakes. Scientists of Harvard University, University of North Carolina, the University of New Hampshire, and the Institute Geofísico in Ecuador study the active volcanoes. They deployed a small wireless sensor network in 2004 on Volcano Tungurahua in central Ecuador for three days, three nodes equipped with microphones collected continuous data from the erupting volcano. In August 2005, they again deployed a larger, more capable network on Volcano Reventador in northern Ecuador. The array consisted of 16 nodes equipped with seism acoustic sensors deployed over 3 km. The system routed the collected data through a multihop network and over a long-distance radio link to an observatory, where a laptop logged the collected data [21].

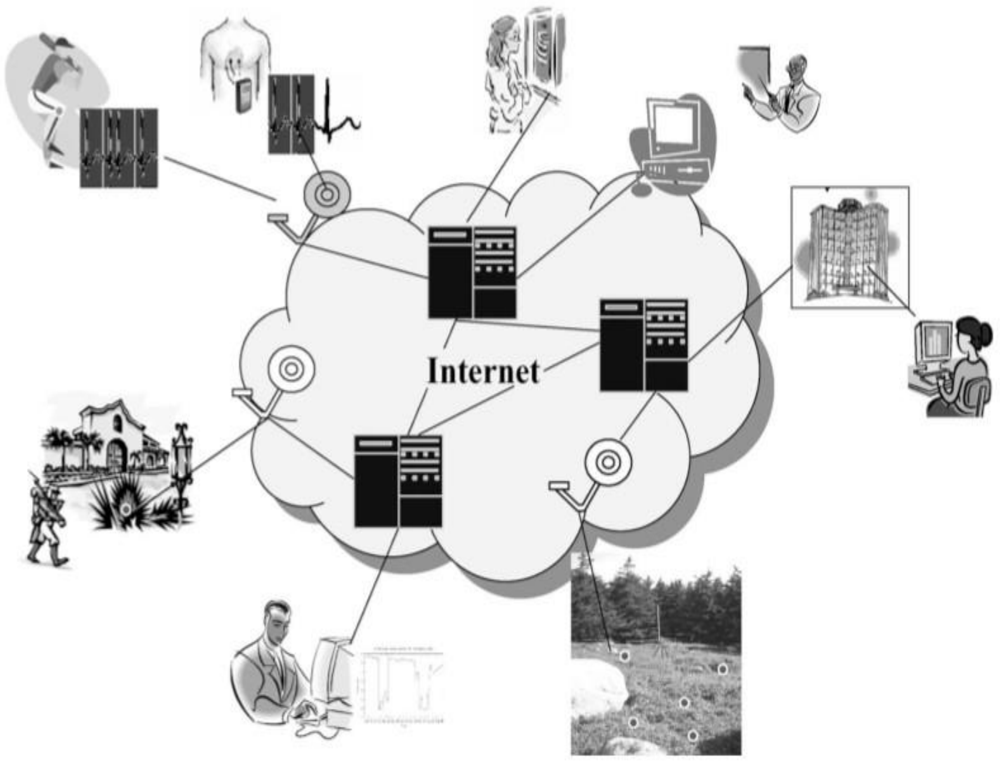


Figure 2.2 WSNs Applications Overview [12]

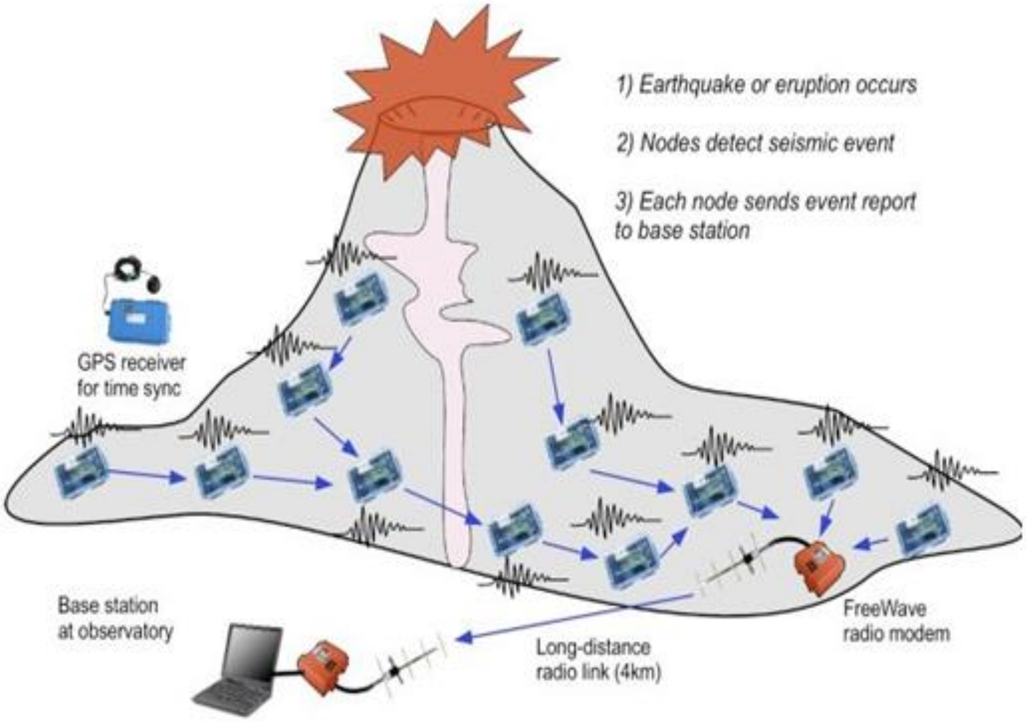


Figure 2.3 Active Volcano Monitoring [21]

Figure 2.4 ZebraNet Sensor Collar Attached to a Zebra [22]

ZebraNet [22] is a wireless sensor network which is used to track animal migrations. Preventive equipment maintenance predicts equipment failure by using remote sensors for oil tanker applications and semiconductor plants [23]. Similarly ALERT [24] is a system used for transmitting data about environmental conditions to a centralized computer. National Weather Service developed this standard in 1970 and it is being used by the National Weather Service, Army Corps of Engineers, U.S. Geological Survey (USGS) and various other international organizations deployed in the US. Several types of sensors deployed in the ALERT system were rainfall, water level and weather sensors. These sensors supply information to the centralized database system in a pre-defined way for making wise decisions to manage floods.

For more than 100 years, the US Geological Survey (USGS) has collected, managed, and disseminated these data, measuring and reporting on the behaviour of US streams. The USGS currently operates and maintains a nationwide stream gauging network of about 7,400 gauges [24]. Intel's wireless vineyard is an example of using sensor network for agricultural monitoring. Here sensor networks use proactive computing, which interpret actionable data and then automatically act on it. For example a vineyard is equipped to spray itself in the appropriate area when there is a risk of fungi on the crop, an irrigation system which uses limited ground water, an automated call to the workers to come in and pick the grapes when the crop is ripe [25]. SensEye is a heterogeneous sensor network of camera to monitor rare species in remote forests and surveillance in disaster management [27]. Figure 2.7 depicts the possible monitoring of a rain forest for the detection of various events such as fire spot and other different environment variables. The operations of the sensors depend upon the data received from a meteorological station, an unmanned airplane or a satellite.

Figure 2.5 USGS Gage Station [24]

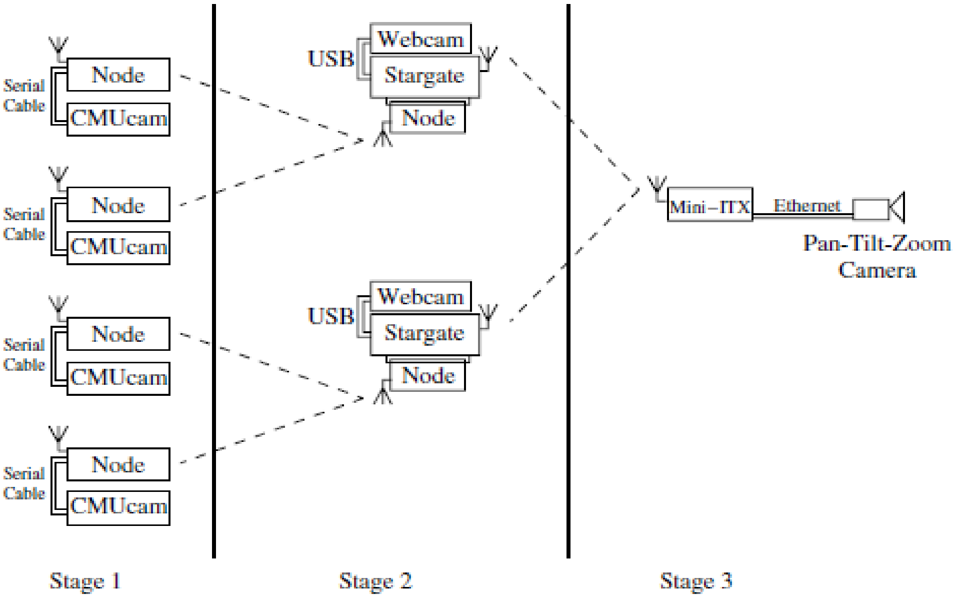


Figure 2.6 Staged Architecture of SensEye [27]

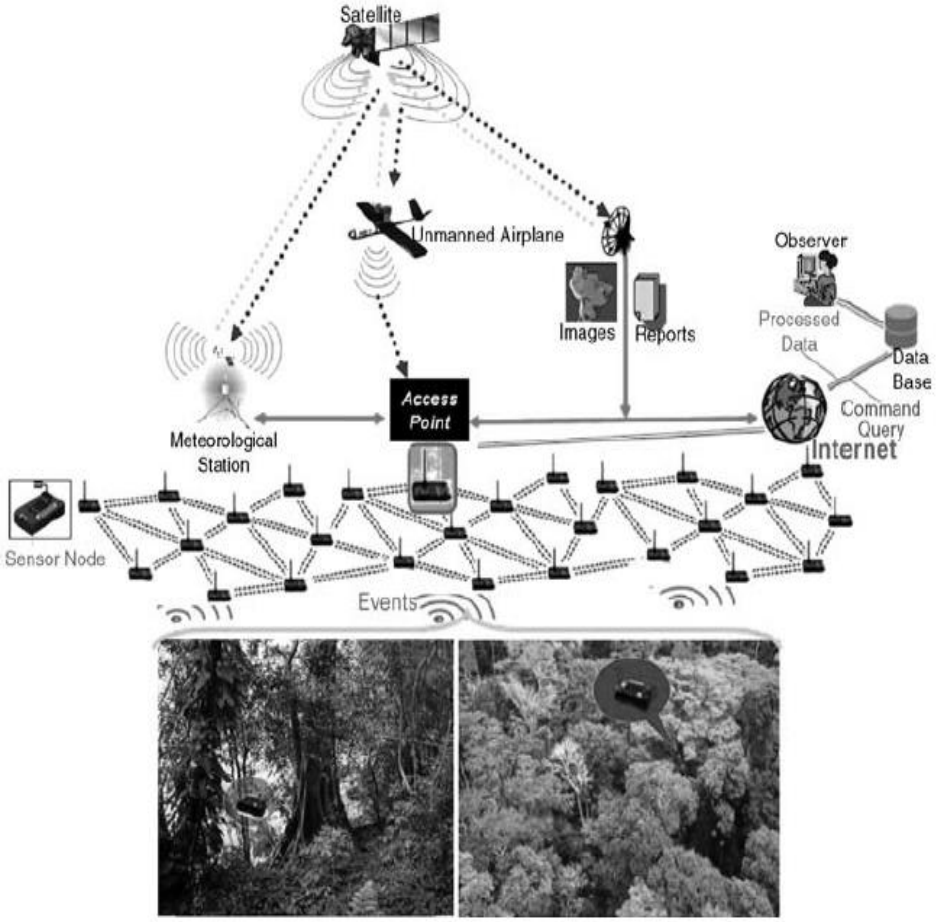


Figure 2.7 Monitoring Application for a Rain Forest [78]

Military Applications: Self organization, random deployment and fault tolerance are some of the characteristics of WSN which makes it a promising technique for military applications. WSN can be used for battlefield monitoring, sensitive object protection like military headquarters, communication centres and nuclear plants. Sensors can be mounted on unmanned robotic vehicles, tanks, fighter planes, submarines, missiles, or torpedoes to guide them around obstacles to their targets and lead them to coordinate with one another to accomplish more effective attacks or defences [4], [5]. For example, Raytheon BBN Technologies provides Boomerang shooter detection systems to the U.K. Ministry of Defence [26].

Figure 2.8 Boomerang Sniper Detection Systems [26]

Health Care Applications: WSN technology can be used for collecting the physiological data of the patients, which may be used for medical exploration. Patient can carry light weight sensors with them, which may observe the various biological parameters like blood pressure, heart rate of the patient. Doctors and patients in a hospital may carry light weight sensors which help in their tracking and monitoring. Sensor nodes can also be attached to medications and as a result wrong medication prescription to patients can be minimized. Mote Track [28] is a patient tracking system developed by Harvard University for tracking patient location by using radio signal information obtained from the sensor attached to the patients. Harvard Sensors Network Lab [29] has also developed wireless pulse oximeter (Figure 2.9) and wireless two-lead EKG (Figure 2.10)

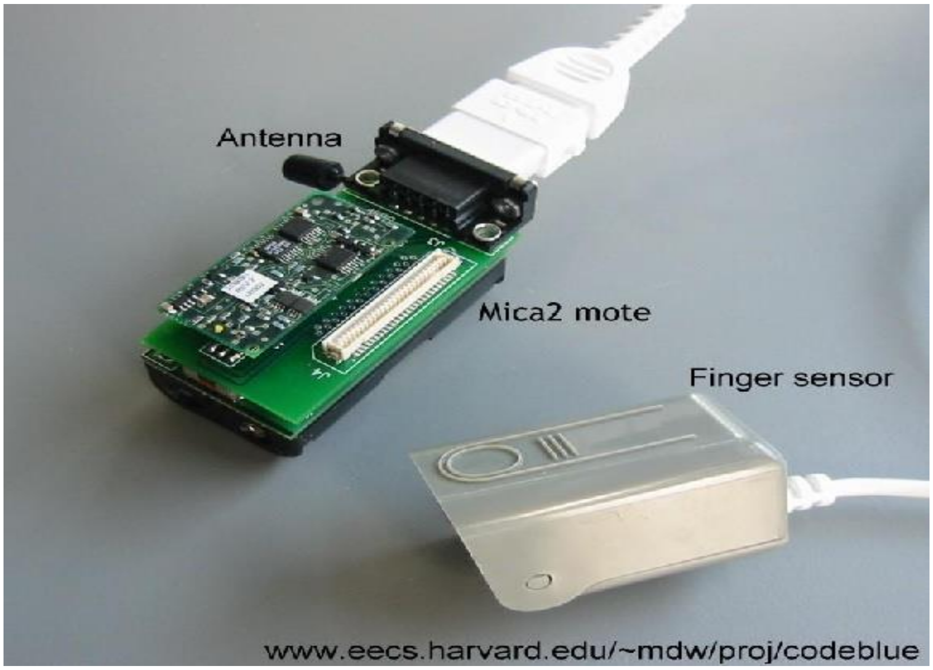


Figure 2.9 Wireless Pulse Oximeter Sensors [29]

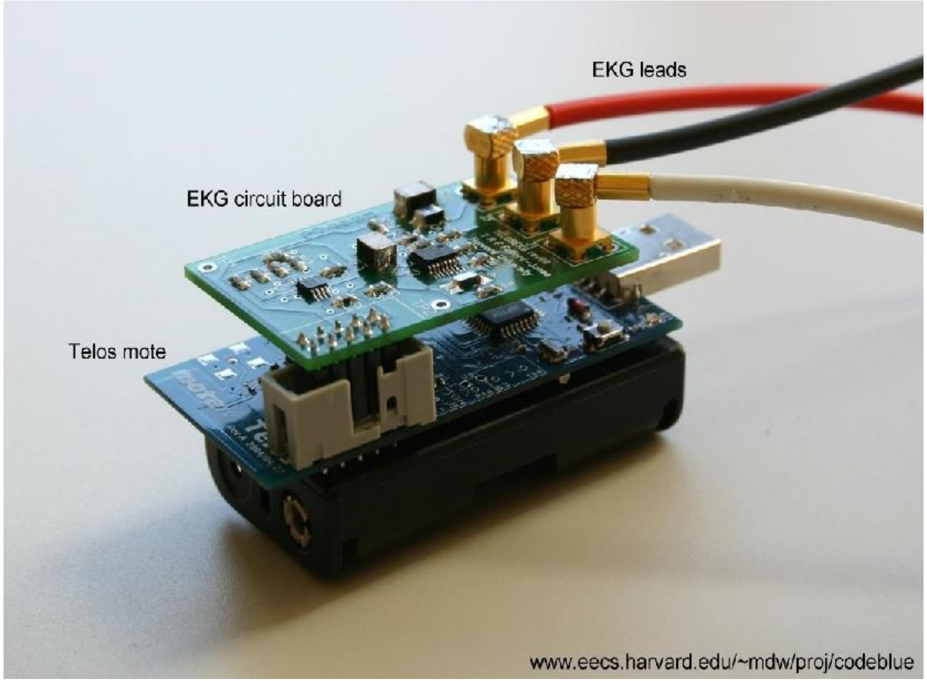


Figure 2.10 Wireless Two-Lead EKG [29]

A number of parameters are collected by, these devices like heart rate, oxygen saturation and EKG data and transmit it to a short-range (100m) wireless network, which may include laptops, PDAs etc. These sensor devices can also be programmed to process the invigorating signs data, e.g. to raise alerts when important parameters fall outside the normal range. Any unfavourable change in patient condition can then be signaled to a nearby paramedic. Sleep Safe [16] is designed for monitoring an infant while they are sleeping because many infants die from sudden infant death syndrome (SIDS) each year. It detects the sleeping position of an infant and alerts the parents when the infant is lying on its stomach.

Industry Automation: In industry, WSNs can be used to monitor manufacturing processes or the condition of manufacturing equipment. For example, wireless sensors can be instrumented to production and assembly lines to monitor and control production processes. Chemical plants or oil refineries can also use sensors to monitor the condition of their miles of pipelines. Tiny sensors can be embedded into the regions of a machine that are inaccessible by humans to monitor the condition of the machine. Traditionally, equipment is usually maintained on a schedule basis e.g. every three months for a checkup, which is costly. According to related statistics, a US equipment manufacturer spends billions of dollars in maintenance every year [30]. With sensor networks, maintenance can be conducted based on the condition of equipment, which reduces the cost of maintenance, increase machine lifetime, and even save lives.

Security and Surveillance: Sensors can be used in many security and surveillance applications. For example acoustic, video, and other kinds of sensors can be deployed in buildings, airports, subways and other critical infrastructure like nuclear power plants or communications centres to identify and track intruders and provide timely alarms and protection from potential attacks [30].

Home Intelligence: Home can be made smart by using sensors. For example, smart sensors of a refrigerator and stove or microwave oven can be connected with each other and a menu may be prepared on the basis of items available in the refrigerator. Remote monitoring of the home and its appliances is also possible by using sensor nodes [4].

2.4 CHAPTER SUMMARY

This chapter summarized the difference between WSNs and other traditional wireless networks like cellular systems and mobile adhoc networks (MANET), routing challenges and various design issues of a wireless sensor network. Last section gave the applications of wireless sensor network along with a taxonomy of applications. Next chapter describes the WSN architecture and a review of the various protocols based on it.

CHAPTER 3

LITERATURE REVIEW OF TOOLS AND TECHNIQUES

3.1 SENSOR NETWORK ARCHITECTURE

A sensor network has a large number of sensor nodes, which are deployed densely in the area of interest and one or more data sinks or base stations that may be located close to or inside the sensing region, as shown in Figure 3.1. The sink sends queries or commands to the sensor nodes in sensing region while the nodes collaborate to accomplish the sensing tasks and send the sensed data to sink. Meanwhile the sink also serves as a gateway to outside networks e.g. Internet, it collects data from sensor nodes, performs simple processing on it and after that sends the relevant information via Internet to the user.

For sending data to base station sensors may use a single hop long distance transmission, which leads to the single hop network architecture as shown in Figure 3.3. However long distance transmission is costly in terms of energy consumption. Energy used in communication is much higher than sensing and computation. For example energy consumed for transferring one bit of data to a receiver at 100m away is equal to the needed to execute 3,000 instructions.

The ratio of energy consumption to communicate one bit over wireless medium to process the same bit is in the range of 1,000 – 10,000 [4]. Hence transmission energy dominates the total energy consumed in communication and as a result the transmission power increases exponentially with transmission distance. Thus, volume of traffic and transmission distance should be decreased to prolong the network life. For this purpose, multihop short-distance communication is highly preferred. In most sensor networks, sensor nodes are densely deployed and neighbour nodes are close to each other, which makes it feasible to use short-distance communication. In multihop communication, a sensor node transmits its sensed data toward the sink via one or more intermediate nodes, which can reduce the communication energy. The architecture of a wireless sensor network can be organized into two types: flat and hierarchical.

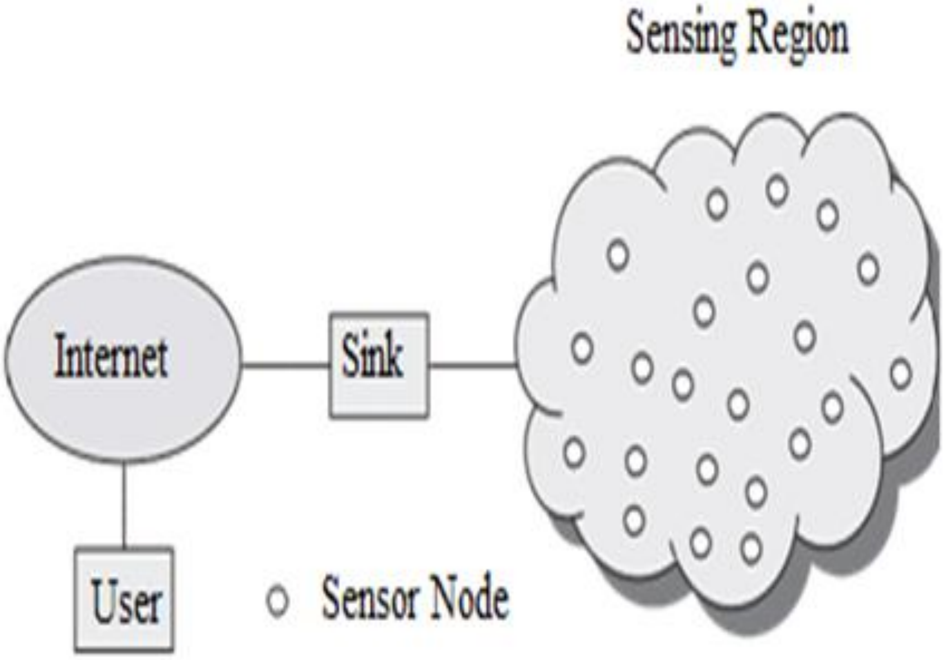


Figure 3.1 Sensor Network Architectures [4]

3.2 FLAT ARCHITECTURE

In flat network, each node plays the same role in performing a sensing task and all the nodes are peers. Global identification of sensor nodes is not feasible in a sensor network because of their large number. Data gathering is usually accomplished by using data-centric routing. The sink transmits a query to all nodes in the sensing region via flooding and only the sensor nodes that have the data for this query, will respond to the sink. Figure 3.2 illustrates the typical architecture of a flat network. The well known protocols considered in flat based routing are**: Sequential Assignment Routing (SAR), Directed Diffusion (DD), Energy Aware Routing (EAR**) etc.

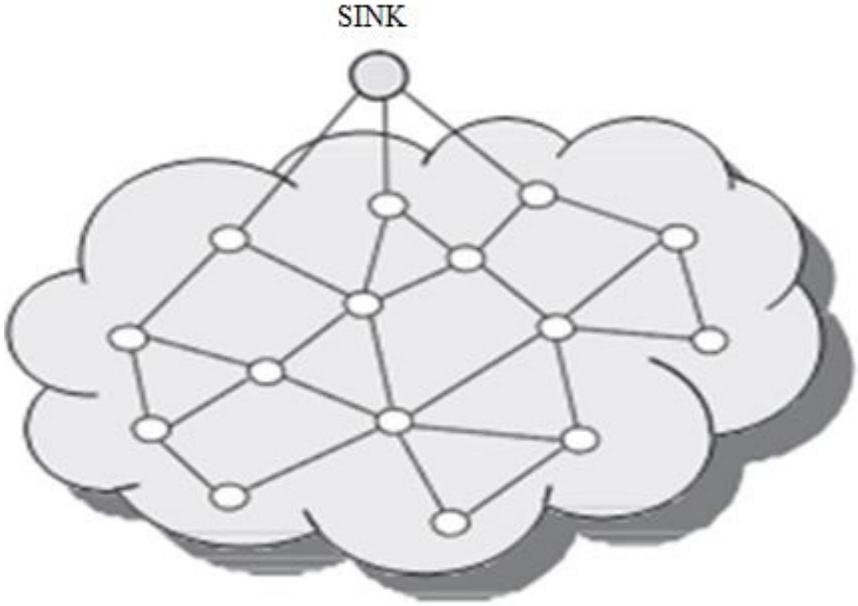


Figure 3.2 Flat Network Architectures [4]

SAR (Sequential Assignment Routing) [31] was one of the first protocols for WSN which considered QoS issues for routing decisions. SAR algorithm minimizes the average weighted quality of service metrics in network life. SAR makes a routing decision based on three factors: energy resources, QoS planned for each path, and the packet‘s traffic type, which is implemented by a priority mechanism. To resolve reliability problems, SAR uses two systems consisting of a multipath approach and localized path. The multipath tree is defined through the avoidance of low-energy nodes and quality of service is guaranteed while taking into account that the root tree is located in the source nodes set and it ends in the link nodes set. In other words, SAR creates a multipath table whose main objective is to obtain energy efficiency and fault tolerance. Fault tolerance and easy recovery are ensured by the protocol, however it suffers from certain overhead when tables and node states must be maintained or refreshed. This problem increases, especially when there are a large number of nodes.

DD (Directed Diffusion) [32] is a data-centric and application aware paradigm. Sensors data are named by attribute value pairs. The objective of the directed diffusion paradigm is to aggregate the data coming from different sources by deleting redundancy, which drastically reduces the number of transmissions. This has two main consequences: first, the network saves energy and extends its life. Secondly, it counts on a higher bandwidth in the links near the sink node. The latter factor could be quite persuasive in deciding to provide QoS in real-time applications. The directed diffusion is based on a query-driven model, which means that the sink node requests data by broadcasting interests. Requests can originate from humans or systems and are defined as pair values, which describe a task to be done by the network. The interests are then disseminated through the network. This dissemination sets up gradients to create data that will satisfy queries to the requesting node. When the events begin to appear, they start to flow toward the originators of interest along multiple paths. This behaviour provides reliability for data transmissions in the network. Another feature of Directed Diffusion is that it caches network data, generally the attribute-value pair‘s interests. Caching can increase efficiency, robustness, and scalability of the network.

REEP (Reliable and Energy Efficient Protocol) [33] is a fault tolerant protocol, which has been motivated by the existing network layer data-centric routing protocol directed diffusion. REEP consists of five important elements. These are: sense event, information event, request event, energy threshold value and request priority queue (RPQ). A sense event is a kind of query, which is generated at the sink node and is supported by the sensor network for acquiring information. The response to this query is the information event, which is generated at the source node. It specifies the detected object type and the location information of the source node. After receiving this information, request events are generated at the sink node and are used for path setup to retrieve the real data. The real data in any sensor network are, the collected or processed information regarding any physical phenomenon. Each node in REEP uses an energy threshold value for checking which each node agrees or denies to take participation in a path setup. It gives more reliable transmission of any event information or real data. RPQ is a kind of first-in-first-out (FIFO) queue, which is used in each node to track over the sequence of information event reception from different neighbours. It is used to select a neighbour with highest priority in order to request for a path setup when it is failed in path setup, without invoking periodic flooding. The authors of REEP used four performance metrics like average packet transmission, average data loss ratio, average delay and average energy consumption to analyze and compare the performance of both protocols DD and REEP. The performance of REEP has been found better than directed-diffusion routing protocol.

EAR (Energy Aware Routing) [34] is a reactive protocol to increase the lifetime of the network. This protocol maintains a set of path instead of maintaining or reinforcing one optimal path. The maintenance and selection depend on a certain probability, which depends upon how low energy consumption of each path can be obtained. The protocol creates routing tables about the paths according to the costs. Localized flooding is performed by the destination node to maintain the paths alive.

3.3 HIERARCHICAL ARCHITECTURE

In hierarchical network, sensor nodes are organized into clusters, where the cluster members send their data to the cluster head and the cluster heads serve as relays for transmitting the data to sink. A node with lower energy can be used to perform the sensing task and sends the sensed data to its cluster head at short distance, while a node with higher energy can be selected as a cluster head to process the data from its cluster members and transmits the processed data to the sink. This process can not only reduce the energy consumption for communication, but also balance traffic load and improve scalability when the network size grows. Since all sensor nodes have the same transmission capability, clustering must be periodically performed in order to balance the traffic load among all sensor nodes. Moreover, data aggregation can also be performed at cluster heads to reduce the amount of data transmitted to the sink and improve the energy efficiency of the network [35]. The major problem of clustering is the cluster heads selection and its organization [15]. Many clustering strategies have been proposed in literature for this. For example, according to the distance between the cluster members and their cluster heads, a sensor network can be organized into a single-hop clustering architecture or a multihop clustering architecture as shown in Figures 3.3 and 3.4 respectively [4]. Figure 3.5 shows multitier clustering architectures [4].

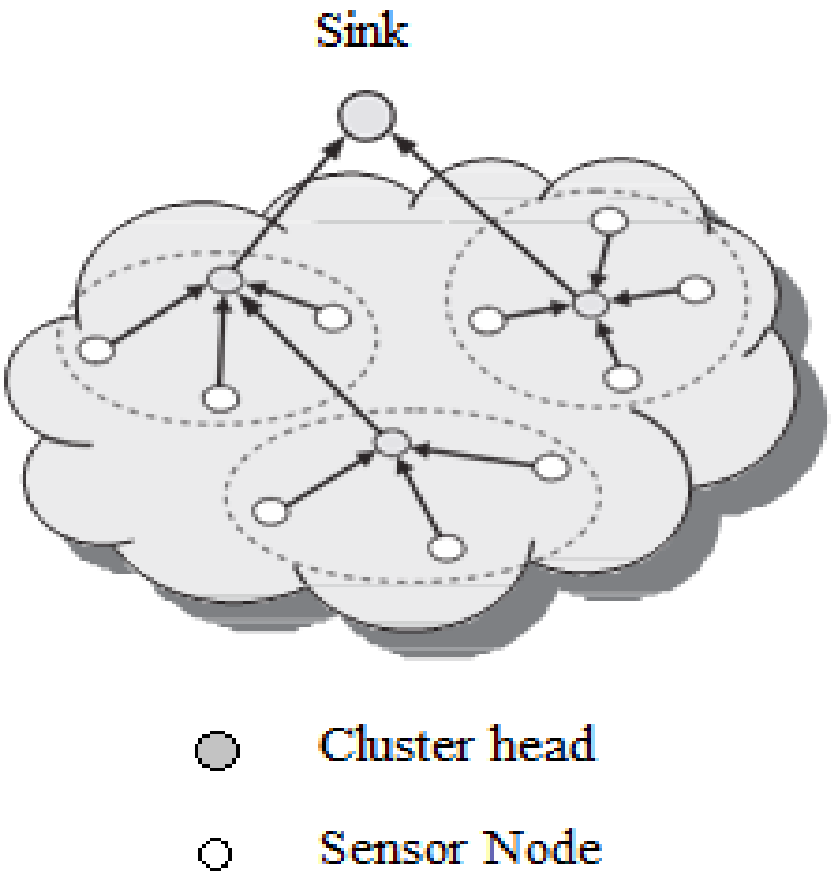


Figure 3.3 Single-hop Network Architecture [4]

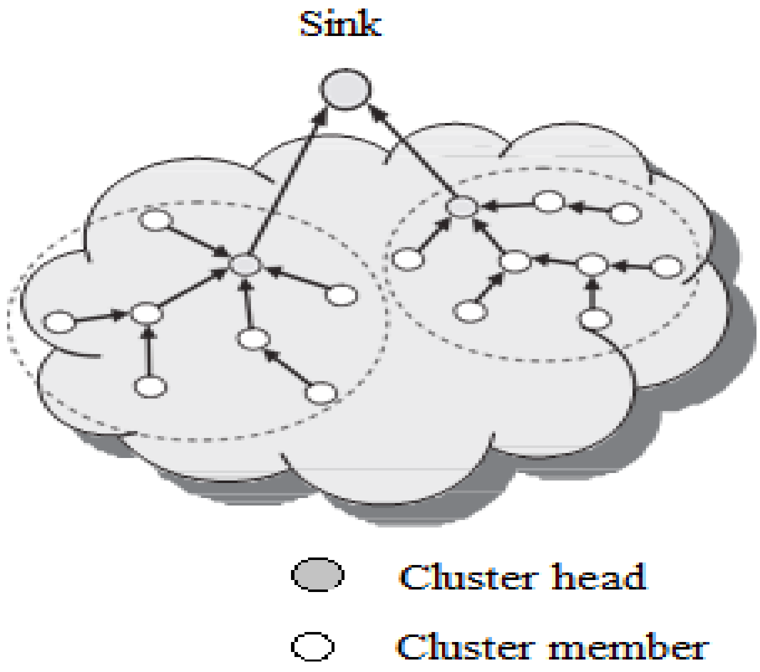


Figure 3.4 Multihop Clustering Architecture [4]

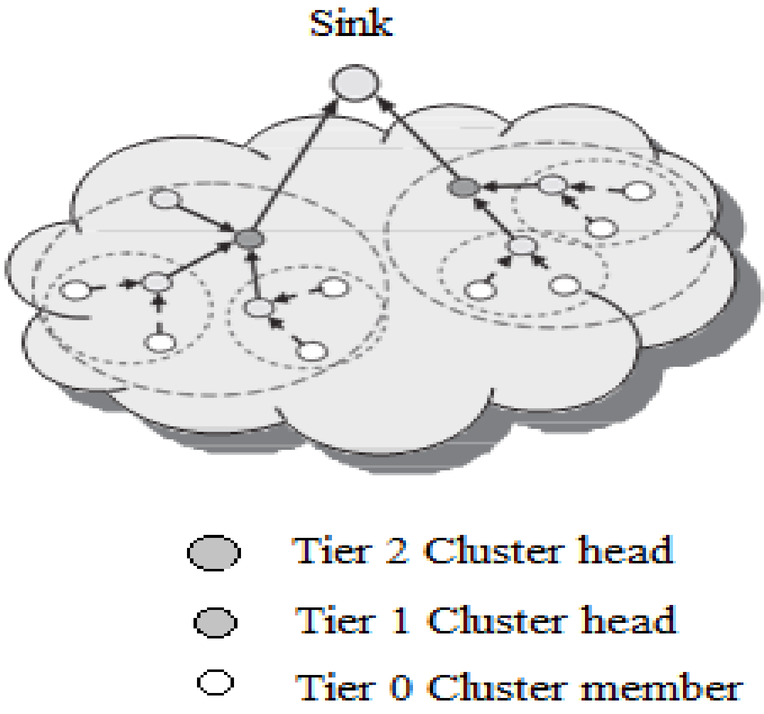


Figure 3.5 Multitier Clustering Architecture [4]

LEACH (Low Energy Adaptive Clustering Hierarchy) [17], [18] is the most popular clustering algorithms with distributed cluster formation for WSNs. It does the selection of cluster head randomly among the nodes during each round. Each round operation is further divided into two phases: set-up phase and steady phase. In set-up phase of a round each sensor node generates a random number between 0 and 1 and if this number is less than threshold value T (n), then sensor becomes a cluster-head for this round. Threshold value T (n) is calculated by using the equation (3.1)

$$T(n) \;=\; \left(\begin{array}{cc} \frac{p}{1-P \times \left(r \;\; mod \;\; \frac{1}{p}\right)} & \text{If n ε G} \\ \\ 0 & \text{otherwise} \end{array} \right) \qquad 3.1$$

Here p is the desired percentage of nodes that can become the cluster head, r denotes the current round and G represents the set of nodes which are not the cluster head in the last 1/p rounds. Once cluster-heads are selected in a round, they advertise about their status to all other nodes in the network that they are new cluster-heads. When sensor nodes receive this advertisement, they determine the cluster with which they can be associated depending upon the advertisement signal strength of various cluster heads. The sensor nodes inform the appropriate cluster head that they are the members of it and cluster head assigns a TDMA schedule for each of its members to get their data. In steady state phase, the sensor nodes transmit data to their respective cluster head. Each node sends data to respective CH during its allotted time slot. Each node minimizes its energy consumption further by entering into a sleep mode for the remaining time. Cluster head further aggregates the data before sending it to the base station. Re-clustering of the network is done after a certain time spent in the steady state phase.

ESCAL (An Energy-Saving Clustering Algorithm Based on LEACH) [37] uses LEACH as its base but in order to save the energy further cluster heads do not send the aggregated data to the base station directly. Cluster heads send the data to nearby cluster heads, which are closer to the base station and in this way the energy of the cluster heads are conserved by avoiding the long distance transmission. One of the disadvantages of the LEACH is that the cluster heads rotations do not take into account the remaining energy of sensor nodes [81]. A node may not have sufficient energy to complete a round and may be selected as a cluster head.

An Energy Efficient Routing Scheme in Wireless Sensor Networks [38] applied both LEACH and a new approach for cluster head selection. When the remaining energy of a node is larger than 50% of the initial energy then LEACH algorithm is used as in equation (3.1). Otherwise a new approach which considers the remaining energy in each node is applied for cluster head selection as shown in equation (3.2).

$$T(n) = \left(\begin{array}{ll} \frac{p}{1-P \times \left(r \ \ mod \ \ \frac{1}{p}\right)} \times \left(2 \times p \times \frac{E_{residual}}{E_{init}}\right) & \text{If n ε G} \\ 0 & \text{otherwise} \end{array} \right) \qquad 3.2$$

Here p is the percentage of nodes that can become the cluster head, $E_{residual}$ is remaining energy of a node and E_{init} is initial energy of a node. When T (n) is greater than generated random number between 0 and 1, it becomes a cluster head. After selection of cluster head, cluster formation is carried out. Joining to a cluster is done by calculating a cost which includes the remaining energy and signal power strength of cluster head. A node joins a cluster head, which have the maximum cost value. Cost of a cluster head i can be calculated by using equation (3.3).

$$Cost\ (i) = CH(i)_{remain} + CH(i)_{signal} \tag{3.3}$$

Here $CH(i)_{remain}$ and $CH(i)_{signal}$ denotes the remaining energy and signal strength of cluster head. CH determines a TDMA schedule for its members and informs the member nodes about this schedule. The nodes, then transmit the sensed data to the cluster head during its time slot. A sensor node sends data to cluster head only when a certain condition is satisfied such as “Does the temperature exceed 30 degrees?” If the condition is not satisfied then node goes to sleep mode to reduce the energy consumption.

Cluster based protocols like LEACH have shown a factor of improvements when compared with its previous protocols. Further improvements were done by forwarding the packets to one of its neighbour node only. This method is named as **PEGASIS (Power Efficient Gathering in Sensor Information System) [39].** Instead of forwarding the packets from many cluster heads as like in LEACH protocol, here in PEGASIS each node will form a chain structure to the base station through which the data would be forwarded to the BS.

In PEGASIS energy efficiency is achieved by transmitting the data to only one of its neighbour node. Here the collected data are fused and this will be further forwarded to its immediate one hop neighbor. Since all the nodes are doing the data fusion at its place there is no rapid power depletion of nodes which are present near to the base station. Also in this method each node will get the chance of forwarding the gathered data to the base station. But when the sensor measurements are aggregated to be a single packet, only a fraction of the data generated by the sensor is given to the base station. In some applications when a particular sensor measurement is needed, it fails to give it to base station. But apart from the function of the routing protocol we can make the sensor network database to follow the multi resolution scheme where the aggregated data will be present in the root node and the finer data can be obtained by further tree traversal mechanism. Though the Directed Diffusion [32] and Rumor routing [40] techniques come under tree based approach, but in terms of energy efficiency they lack behinds PEGASIS model.

H-PEGASIS (Hierarchical PEGASIS) [41] decreases the transmission delay of packets to base station and suggests a solution for data gathering by using energy delay metric. Two approaches are being used here to avoid signal interference and collisions among the sensors. In the first approach signal coding CDMA is used to avoid collisions. Second approach use spatially separated nodes for transmission at the same time. A chain of nodes with CDMA capable nodes construct a node chain to from a hierarchical architecture and low level hierarchy nodes transmit the data to upper level hierarchy. Thus, in this way data is transmitted in parallel, which reduces the transmission delay considerably and this delay can be expressed as O (log N).

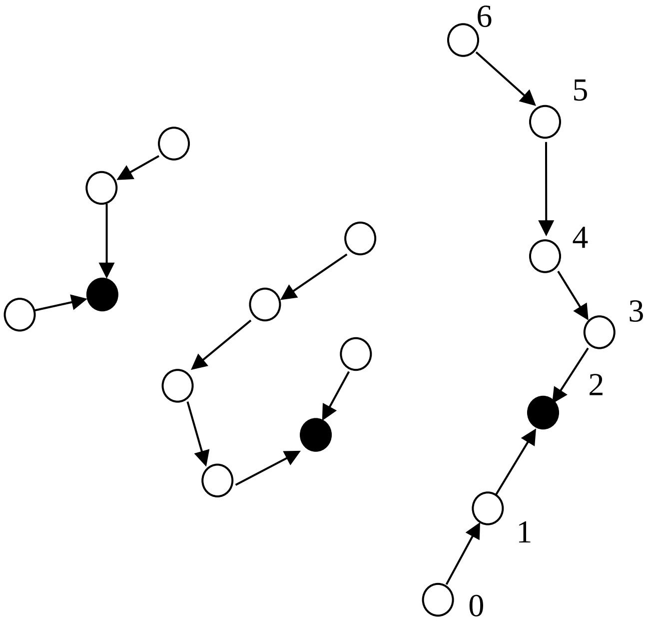


Figure 3.6 Chain Structure of PEGASIS Protocol

EB - PEGASIS (An Energy-Efficient PEGASIS-Based Enhanced Algorithm in Wireless Sensor Networks) [42] is an energy efficient chaining algorithm in which a node will consider the average distance of formed chain. If the distance from the closest node to its upstream node is longer than distance thresh (the distance thresh can be obtained from an average distance of formed chains), the closest node is a "far node". If the closest node joins the chain, it will emerge a "long chain". In this condition, the "far node" will search a nearer node on formed chain. Through this method, the new protocol EB-PEGASIS avoids "long chain" effectively. EB-PEGASIS avoids the dying of some nodes earlier than others to prolong the lifetime of the sensor network. It not only save energy on sensors, but also balance the energy consumption of all sensor nodes

TEEN (Threshold sensitive Energy Efficient Sensor Network protocol) [43] is a protocol which responds immediately to any sudden change in a sensed attributes e.g. temperature, pressure etc. This type of responsiveness is important for time-critical applications where network operates in a reactive mode. TEEN uses data-centric mechanism along with a hierarchical approach for its operation. The nodes which are close to each other, form a cluster and this process continue to next level until the sink is reached. Fig 3.7 depicts the operation of TEEN. After the construction of clusters, the cluster head broadcasts two threshold values: hard and soft thresholds for sensed attributes. The minimum value which triggers a node for transmitting the sensed data to its cluster head is called the hard threshold value. Hence the hard threshold value represents the range of interest of sensing value and reduces the number of transmissions to cluster head significantly. Whenever a node senses a value beyond the hard threshold, it will transmit the data again only when the sensed attributes change by a value equal to or greater than other value known as the soft threshold. Thus the soft threshold further reduces the number of transmissions when there is a very little or no change in the sensed attribute value. For controlling the number of packet transmissions one should adjust hard and soft threshold values. The disadvantage of TEEN is that it cannot be used where periodic reports are required because the user will not get any data if the thresholds have not reached.

APTEEN (Adaptive Threshold Sensitive Energy Efficient Sensor Network protocol) [44] is an extension to TEEN which capture data periodically and also reacts to time critical events. The architecture of the protocol has been just similar to TEEN whereby nearby nodes from clusters. Cluster heads broadcast transmission schedule to all its members along with hard and soft threshold of sensed attributes. Cluster head further performs data aggregation to save the energy of the network. APTEEN uses three different query types, namely: historical, one-time and persistent. Historical query analyses the past data, one-time query is for taking a network snapshot view and persistent query is for monitoring an event for a period of time. The experiment results have shown that energy dissipation and network lifetime of APTEEN are between LEACH and TEEN. Multiple level cluster formations and over head complexity are the main drawbacks of this algorithm.

SEP (Stable Election Protocol) [45] is an extension of the LEACH protocol for heterogeneous network. In SEP a small fraction of the nodes has more power than the normal nodes to create a heterogeneous network. For prolonging the stable region, SEP maintains energy consumption in a balanced manner.

DB-SEP (Distance-based Stable Election Protocol) [46] is a variation of the stable election protocol which elect cluster heads on the basis of initial energy and the distance of nodes from the base station.

EECDA (Energy Efficient Clustering and Data Aggregation Protocol for Heterogeneous Wireless Sensor Networks) [47] proposes a three level heterogeneous model where some percentages of the nodes have more energy than the normal nodes which are known as advanced nodes. Further in advanced nodes some fractions of the nodes have even more energy than the normal nodes which are known as super nodes. EECDA is the protocol for heterogeneous WSNs which improve the network lifetime and stability by combining cluster based routing and data aggregation techniques. Novel cluster head election and a path of a maximum sum of energy residues are used for data transmission in EECDA for achieving the objectives.

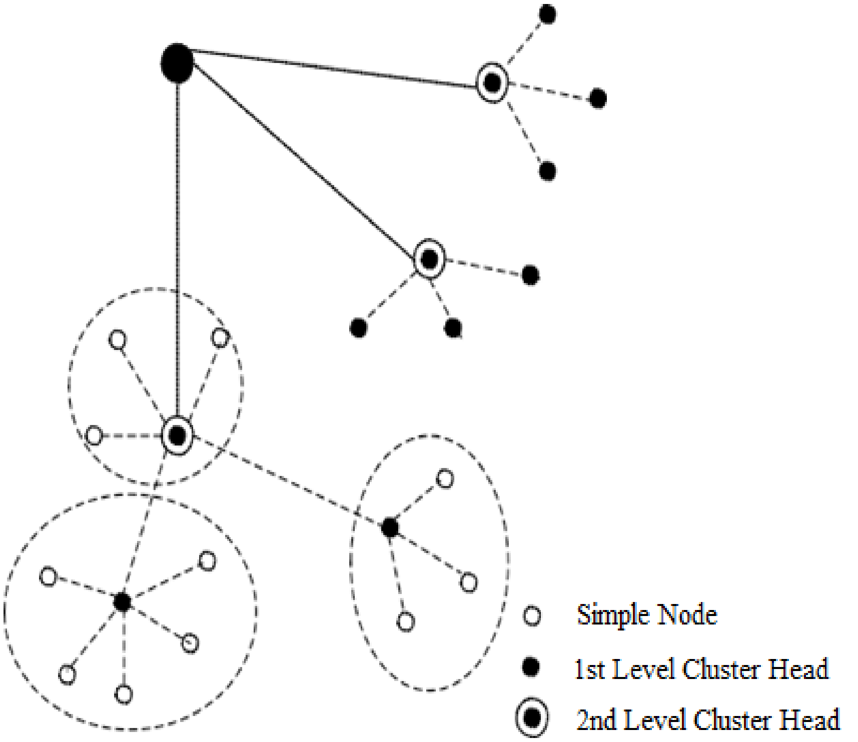


Figure 3.7: Hierarchical Clustering in TEEN and APTEEN [43]

HEED (Hybrid energy-efficient distributed) [48] algorithm is a distributed clustering algorithm for WSN. It favours nodes with high residual energy to become the cluster heads and periodically executes re-clustering to achieve load balancing. So, the nodes that have become cluster heads once will have a low probability of becoming cluster heads again, which ensures that the entire node will carry the role of being a cluster head equally. HEED uses node degree as a fitness function if the requirement is to distribute the load among the cluster heads and the inverse of the node degree if the requirement is to create dense clusters. The mean of the minimum power levels required by all the nodes should be within the node's transmission range to reflect the communication cost within a cluster. In the clustering phase, node sets its probability for becoming a cluster head by using the following equation.

$$p_i = C_{prob} \times \frac{E_{residual}}{E_{max}} \qquad 3.4$$

Where, E_{max} corresponds to a fully charged battery, $E_{residual}$ is the current residual energy and C_{prob} is the initial percentage of nodes that can become cluster head, it only limits the initial cluster head announcements and will not have direct impact on final clusters. Each node iteratively doubles its probability until its probability reaches to 1. It announces itself as a cluster head and the nodes which hear the ADV message withdraw itself from the election process and have joined this advertised cluster head. If it hears from more than one cluster, a regular node breaks ties, according to one of the above fitness function. The announcement messages are delayed based on the node's residual energy, meaning that the nodes with high residual energy will advertise themselves before the low-energy ones do. HEED assumes that a node has two levels of transmission range: low-level transmission range for intra-cluster communication and a high-level transmission range for inter-cluster communication that should be at least double the low- level one to ensure inter-cluster communication since HEED does not adapt the use of gateways to provide the desired connectivity. HEED is completely distributed, terminates within a fixed number of iterations, produces well-distributed clusters over the field in terms of cluster size, scales for very large networks, and significantly increases the network lifetime.

DAEEC (Density-Aware Energy-Efficient Clustering) [49] is a novel clustering algorithm for non-uniformly distributed sensor networks to save energy and prolong the network life.

CELRP (Cluster Based Energy Efficient Location Routing Protocol) [50] is a protocol which utilizes the high-energy of the base station to perform most energy efficient task. By using BS, the sensor nodes are relieved from performing the energy intensive computational task, such as cluster setup, cluster head selection and routing formation. The sensor nodes have made clusters and divided into different quadrants. Each quadrant contains two clustering and sensor nodes that transmit data with two hops data transmission. CH is selected based on the node with maximum residual energy and minimum distance to the base station in each cluster. The CH with the highest energy residual is chosen as the CH leader between all the other CHs. The nodes send data to the CH, and finally the CH sends data to the BS.

A Novel Energy Efficient Routing Algorithm for Hierarchically Clustered Wireless Sensor Networks [51] is a protocol in which sensor nodes are hierarchically divided into different levels using the hop number of transmissions to base station. CHs are selected autonomously and communicate with the base station using multi-hop transmissions which employ the multi-hop planar model, whereas non-CH sensor nodes communicate with CH sensor nodes directly.

DEEC (Design of a Distributed Energy-Efficient Clustering Algorithm for Heterogeneous Wireless Sensor Networks) [52] is an energy-aware adaptive clustering protocol for heterogeneous networks. In DEEC, every sensor node independently elects itself as a cluster-head based on its initial energy and residual energy. To control the energy expenditure of nodes by means of adaptive approach, DEEC use the average energy of the network as the reference energy. Thus, DEEC does not require any global knowledge of energy at every election round. Unlike SEP and LEACH, DEEC can perform well in multi level heterogeneous networks.

EEHC (Energy Efficient Heterogeneous Clustered Scheme for Wireless Sensor Networks) [53] is a robust protocol to improve the lifetime and performance of the network system. EEHC uses weighted probability for the election of cluster heads. Simulations results show that EEHC has extended the lifetime of the network by 10% as compared to LEACH in the presence of the same setting of powerful nodes in a network. Hence, the performance of the proposed system is better in terms of reliability and lifetime.

3.4 LIMITATIONS OF EXISTING ROUTING ALGORITHMS

Based on the network architecture, routing algorithms can be divided into two categories: flat routing and hierarchical routing. In flat, routing protocols are similar to point to point networks; all the nodes play the same role and cooperate with each other to accomplish a sensing task. A major disadvantage of the flat routing protocols is that they are generally based on a data-centric approach. This causes scalability problems as well as increased congestion among the nodes closer to the sink. Distributed aggregation mechanisms are necessary for decreasing the information content, flowing in each part of the sensor network. Protocol such as directed diffusion is applicable to a subset of applications in WSNs, since the communication is initiated by queries generated from the sink. Thus Directed Diffusion (DD) is not a good choice for dynamic applications, where continuous data delivery is required. Moreover, the query types as well as the interest matching procedures need to be defined for each application. Furthermore, the data-centric approach of flat topology results in application-dependent naming schemes. Therefore each change in the application, the schemes should be defined a priori. Flat routing protocols are effective for same-scale network, but not good for large-scale networks. They generate more data processing and bandwidth usage in large-scale networks.

Hierarchical or cluster based routing protocols divide the entire sensing region into a lot of clusters according to the specific requirements. Each cluster has a leader known as cluster head, which communicates directly with the sink for data transmission.

A hierarchical architecture typically comprises two layers of routing where one layer is used to select cluster-heads and the other is for routing [79], [80], [81], [82]. The hierarchical cluster structures facilitate the efficient data gathering and aggregation independent to the growth of the WSN, and generally reduce the total amount of communications as well as the energy spent. Cluster-based routing protocols have a variety of advantages, such as more scalability, less load, less energy consumption and more robustness [81]. Despite their advantages, cluster based protocols significantly rely on cluster heads and face robustness issues such as failure of the cluster heads. Moreover, cluster formation requires additional signaling, which increases the overhead in case of frequent cluster head changes. Therefore a tradeoff between increased energy consumption of the cluster heads and the overhead in cluster formation needs to be considered for efficient operation. Furthermore, intercluster communication is still a major challenge for many hierarchical routing protocols. Generally, cluster heads are assumed to directly communicate with the sink using higher transmit power. This limits the applicability of these protocols to large-scale networks, where single hop communication with the sink is infeasible. Thus hierarchical clustering mechanisms are generally required to provide multi-hop intercluster communication [5].

TABLE 3.1: Comparisons of Different Routing Protocols of WSN [82]

Routing Protocols	Network Type	Communication	Routing Type	Scalability	Energy Efficiency	Latency
SAR	Homogeneous	Multi-hop	Flat	Ltd.	Good	High
DD	Homogeneous	Multi-hop	Flat/ Data Centric	Ltd.	Good	Very High
EAR	Homogeneous	Multi-hop	Flat	Ltd.	Good	High
REEP	Homogeneous	Multi-hop	Flat/ Data Centric	Ltd.	Good	High
LEACH	Homogeneous	Single-hop	Cluster Based	Good	Good	Low
LEACH-C	Homogeneous	Single-hop	Cluster Based	Good	Good	Low
ESCAL	Homogeneous	Multi-hop	Cluster Based	Good	Good	Low
Energy LEACH	Homogeneous	Single-hop	Cluster Based	Good	Very Good	Low
PEGASIS	Homogeneous	Multi-hop	Chain Based	Good	Very Good	Very High
H-PEGASIS	Homogeneous	Multi-hop	Chain Based	Good	Very Good	Very High

EB-PEGASIS	Homogeneous	Multi-hop	Chain Based	Good	Very Good	Very High
TEEN	Homogeneous	Multi-hop	Cluster & Threshold Based	Good	Very Good	Event based
APTEEN	Homogeneous	Multi-hop	Cluster & Threshold Based	Good	Very Good	Event based
HEED	Homogeneous	Multi-hop	Cluster Based	Medium	Good	High
SEP	Heterogeneous	Single-hop	Cluster Based	Good	Good	Low
DB-SEP	Heterogeneous	Single-hop	Cluster Based	Good	Good	Low
DAEEC	Homogeneous	Single-hop	Cluster Based	Good	Good	Low
DEEC	Heterogeneous	Single-hop	Cluster Based	Good	Very Good	Low
EEHC	Heterogeneous	Single-hop	Cluster Based	Good	Very Good	Low
EECDA	Heterogeneous	Single-hop	Cluster Based	Good	Very Good	Low

3.5 NEED OF A SIMULATOR

Wireless sensor network is one of the hot research topics nowadays. A significant number of network details in WSN are still not standardized. It is very costly to build a WSNs testbed and further running a real experiment on it is a cumbersome task. Large number of factors affect an experimental result thus on a testbed it is very difficult to create a variation among the multiple parameters under the same conditions. Hence running a real experiment on a testbed is always time consuming and costly. Thus for the development of wireless sensor network simulation is a very good thing. New ideas, schemes and protocols can be evaluated easily by using a simulation tool. One of the important features of a simulation tool is that it can segregate various factors of sensor network and helps in obtaining the optimum performance for various parameters. Thus simulation is good for studying and testing the new applications and protocols for wireless sensor network. This thing has brought a tremendous boom in the field of simulator development. WSNs simulation tools should have two important points before conducting an experiment and they are:

- Simulation model correctness.
- Suitability of a specific tool for implementing a model.

A right model based on solid assumptions is essential for getting the correct results. One of the fundamental tradeoff is: accuracy and necessity of details versus scalability and performance [54], [55]. The rest of this chapter describes the several main-stream WSNs simulators in more detail.

3.6 GLOMOSIM/QUALNET

Global Mobile Information System Simulator (GloMoSim) [56], [57], [58**]** is a discrete-event simulator for wired and wireless networks. It uses Parsec, which is a C based language for the sequential and parallel execution. GloMoSim and

Parsec both are the product of Parallel Computing Lab at UCLA. Similar to the OSI model, GloMoSim supports layered approach. To communicate between different simulation layers GloMoSim uses a standard API so that new layers and models can be integrated and exchanged easily. Its JAVA based graphical user interface is good for creating the simulation configuration and scenarios. GloMoSim have basic functionality for simulating wireless networks, as well as Adhoc networks (e.g. AODV, DSR). QualNet [59] is a commercial product of GloMoSim and was created in 2000. GloMoSim 2.0 was the last version released under an academic license. QualNet 6.01 is the latest version which includes enhancements such as network security library, WSNs library for ZigBee and new models for energy. QualNet 6.01 key features include scenario designer for creating the various network topologies, visualizer for viewing network scenarios in 2D & 3D, packets tracer to help in debugging, analyzer for statistical analyses and file editor for directly editing the various network scenarios.

3.7 OPNET MODELER WIRELESS SUITE

OPNET Technologies is a leading company that develops and markets software for the simulation, modeling, and analysis of computer networks. IT Guru and Modeler are the most popular products for network simulation. OPNET Technology Inc. has developed a commercial product known as OPNET Modeler Wireless Suite [60] for modeling and simulation of the wireless networks. It is a discrete event simulator and operates on a parallel simulation kernel of 32-bit/64-bit. The OPNET Modeler uses an object-oriented approach with a hierarchical modeling environment. OPNET has not included any special supports for WSN routing protocols, but support for the various propagation and modulation techniques including MAC layer & ZigBee (802.15.4) are provided. For modeling of network, node and process OPNET uses three-tier architecture. Network consists of node, links and subnets. A node represents a network device and groups of devices, i.e. servers, workstations, WLAN nodes and IP clouds etc. Links represent point-to-point and bus-links between the nodes. The node domain covers the building of blocks also referred as modules, including processors, queues and transceivers as well as the specification of interfaces between the modules. The process domain consists of state transition diagrams, clocks of C-code, OPNET Kernel Procedures (KPs) as well as state and temporary variables [60].

3.8 TOSSIM

TOSSIM (TinyOS mote simulator) [61]-[63] is a simulator for TinyOS sensor network. It is designed especially for TinyOS applications running on MICA motes. TOSSIM captures the behaviour and network interactions not only on packet level, but also at the network bit granularity. Thus TOSSIM is equally good for simulating low-level protocols, and top-level applications. TOSSIM with its external communication system can monitor the transmitted packets or can inject new packets into the network. Three types of network model are provided in TOSSIM: simple, static and space connectivity. In simple connectivity one cell is used for all the nodes, static connectivity creates a network graph at start up and it will never be changed again and in space connectivity transmission range of the nodes may be changed and they move randomly in a squared region. TinyViz, a

JAVA based graphical user interface of TOSSIM which is used for visualizations and running all the simulation. Passive observe mechanisms of user interface inspects the radio ranges or debug messages by injecting new packets into the network and it can actively monitor the network.

3.9 OMNET++

OMNeT++ [64]-[66] is an object-oriented discrete event simulation framework for wired and wireless networks. Its generic architecture is good for simulation such as protocol modeling, querying network modeling, modeling of distributed hardware and multiprocessor system, hardware architecture validation etc. OMNeT++ is not a simulator itself but rather it provides tools and infrastructure for writing simulation framework. One of the basic tools of this infrastructure is the component based architecture for simulation models. Reusable components known as modules are integrated together for creating a Model. Modules combined together to form compound modules and are connected through the gates. Module nesting depth is unlimited till the resources of the system permit it. Messages are used by these modules to communicate with each other which may carry an arbitrary data structures. Messages can be passed between modules by using the predefined paths via gates and connections or they may be sent directly to the destination. Direct communication is generally used in wireless simulation. For customizing the modules behaviour or topology, modules have parameters. Lowest level module is known as simple modules and depicts the model behaviour. C++ language is used for the programming of simple modules. Various user interfaces are used in OMNeT++ simulations. For demonstration and debugging purposes graphical, animating user interfaces are highly preferable, and command line interface is used for batch execution. The simulator along with user interfaces are highly portable and tested on the most commonly used operating systems like Linux, Mac OS/X, and Windows. Parallel distributed simulation is also supported by OMNeT++ and it uses several methods for communicating between different partitions of a parallel distributed simulation.

OMNeT++ can also be used for parallel simulation algorithms classroom presentation. The commercially supported version of OMNeT++ is OMNEST. OMNeT++ is available free for academic and non-profit use. For using it commercially, one need to get license from Simulcraft Inc. Mobility Framework, MiXiM, Castalia, INET Framework and NesCT are some of the simulations frameworks based on OMNeT++ that can be used for the simulation of wireless sensor network.

3.10 NS-2

NS-2 (Network Simulator version 2) is a simulator build on OTcl (Object-Oriented extension of Tool Command Language) and C++ language. Initially, NS was focused on wired networks, but over time wireless support was also included in it. NS was developed from REAL network simulator. From 1995 onwards, NS gained support from DARPA (VINT). Currently the development is continued in collaboration with different researchers and institutes, including DARPA (SAMAN), NSF (CONSER) and ICIR. Sun Microsystems and the UCB Daedelus developed the wireless support for Network Simulator. In June 2009 NS-2.34 version was released. Due to its current major version number NS is also often referred to as NS-2. The main idea of NS-2 is based on the separation of control and data. OTcl is used for the control, i.e. the scripting of the model topology and its parameters; C++ is used for the data, i.e. the programming of each object in the simulation topology. The separations of these two areas are achieved by the following approach: Each network component object is written and compiled in C++. For each of these C++-objects a corresponding OTcl-object is created by OTcl linkage. As a result, the C++ objects are controlled by OTcl. In spite of the great number of contributing researchers, NS-2 has still low supports for WSN specific protocols [67], [68]. SensorSim [69] is a framework build upon NS-2, for modeling WSNs. Power models, sensor channel models, lightweight protocol stacks for wireless micro-sensors, hybrid simulation and scenario generation are some of the key features of it. Hybrid simulation mode integrates the real application support and by using this, real node applications can be run on a simulated node without doing any changes.

3.11 AVRORA

Avrora [70] is an open-source cycle accurate simulator for embedded sensing programs. Avrora is language and operating system independent and can be used for simulating and analysis of the programs written for AVR micro-controllers. It supports different sensor platforms like Mica2 and MicaZ. Avrora can simulate at the instruction-level, i.e. a real microcontroller program run in the simulator. This approach provides an accurate simulation of devices and radio communication. For example the energy usage can be predicted according to the number of clock-cycles needed for the used instructions. Avrora is implemented in Java, which offers great flexibility and portability because the simulation of machine code is operating system independent. Avrora runs one thread per node. The synchronization between the threads is only done when necessary, i.e. only to ensure the global timing and the order of radio communication. For the efficient execution of programs an event queue is utilized, which provides a cycle accurate execution of the device and guaranteed communication behaviour. Avrora scales up to networks of 10.000 nodes and performs 20 times faster than previous simulators with the emulating approach and the same accuracy. Moreover, Avrora contains further tools such as profiling utilities, an energy analysis tool, a stack checker, a control flow graph tool etc. However, Avrora lacks an integrated graphical user interface so that everything has to be done manually on the command line.

3.12 J-SIM

J-Sim [71], [72], [73] is based on the ACA (autonomous component architecture) and uses a component-based compositional simulation environment. ACA basic entities are components and they communicate with each other through their ports by sending and receiving data. The component behavior is specified at design time in contracts – their actual binding will be linked at the system integration time. The loosely-coupled component architecture of J-Sim enables the user to design, implement and test single components individually. New components can be easily added or exchanged for existing ones. On top of ACA a generalized packet switched network model called Internetworking Simulation Platform

(INET), is developed. INET defines the generic structure of a node and network components.

The combination of J-Sim as Java implementation and the component-based architecture makes J-Sim a platform independent, extensible and reusable simulation environment. Moreover, J-Sim provides a scripting interface that enables the use of scripting languages such as Perl, Tcl and Python. In the current release, version 1.3, Jacl, the Java implementation of a Tcl interpreter, is completely integrated into J-Sim. J-Sim provides a dual-language environment similar to NS-2. The basic classes are written in Java, while their linkage is glued together using a scripting language such as Tcl/Java. In comparison to NS-2, the classes/methods/fields do not have to be exported to be accessible by Tcl. A framework for sensor networks simulation is included, which has been built upon ACA, INET and the Wireless Protocol Stack. In the framework the following components are specified: sensor and sink nodes; sensor channels and wireless communication channels; and physical media covering seismic channels, mobility models and power models.

3.13 MATLAB

MATLAB (Matrix Laboratory), developed by MathWorks Inc. is a high performance numerical computation and visualization software package. MATLAB attracts the attention of scientists and researchers due to its strong analytical capabilities, flexibility, reliability, and powerful graphics. Its interactive environment provides hundreds of mathematical functions for providing solutions to a number of mathematical problems, including linear systems, nonlinear systems, complex arithmetic, matrix algebra, signal processing, differential equation, optimization and different types of scientific computations. MATLAB has very good and easy to learn programming capability. Through external interfaces algorithm and code written in other scientific languages like FORTRAN and C can also be accessed in MATLAB. A number of optional toolboxes are written for special applications like signal processing, system identification, control system design, statistics, neural networks, fuzzy logic, symbolic computations etc.

MATLAB is enhanced by a very powerful Simulink program which can be used for modeling, simulating, and analysing dynamical systems. Simulink can model linear and nonlinear system in a continuous time, sampled time, or a hybrid of the two. Simulink has a powerful GUI and with it models can be built with simple click and drag mouse operations. Simulink GUI allows the user to draw models just as we draw with pencil and paper. Simulink provides a comprehensive block library of linear and nonlinear components, sinks, sources and connectors. Models are hierarchical and they can be customized to create our own blocks. After defining a model, it can be simulated by using integration methods. Scopes and other display blocks can be used for seeing the results when the simulation is running. MATLAB and Simulink are integrated, so that simulation, analysis and revision of models can be done at any point [55], [74].

TABLE 3.2: Features Comparison of Different WSN Simulators

Simulation Environment	Programming Language	Wireless Sensor Network Support
GloMoSim/ QualNet	C and Parsec	• GloMoSim is freely available • Basic mobility and radio propagation models,802.11 • QualNet is Commercial version of GloMoSim • Support various battery, Energy and ZigBee model
OPNET Modeler Wireless Suite	Configuration by GUI; internals C++	• Support for different propagation, 802.11, ZigBee • MANET protocols available • No special support for WSN • Powerful tool with a nice GUI but expensive

TOSSIM (part of TinyOS)	nesC	• Simulation of all TinyOS based WSN protocols without modifications are available.
OMNeT++	basic modules C++; larger structures NED	• Several frameworks like MiXiM, NesCT Castalia add WSN functionality • Eclipse-based IDE for development • Active project with a huge user base
NS-2	C++; configuration OTcl	• Complex configuration • Low support for WSN specific protocols • Unclear situation due to large number of contributions from different users

Avrora	AVR micro-controller binaries	• Simulators for embedded sensing programs. • Simulate and analysis programs written for AVR micro-controller. • Support different sensor platforms like Mica2 and MicaZ
J-Sim	Java; configuration Tcl/Java	• Support for different models such as propagation, battery, radio and sensor protocol stack including AODV, 802.11
MATLAB SIMULINK	C , Java	• Detailed simulation of sensor nodes and their architecture. • Support physical layer parameters, different modulation & encoding techniques. • Communication channel

		modeling (SNR, effect of different noise schemes, interference, distance, etc.) • Various methods to monitor and record results during simulation • Powerful Simulink program for modelling, simulations and analysing dynamic systems

3.14 REASONS OF MATLAB SELECTION

After reviewing several simulators, MATLAB has been selected as the best simulation tool for doing this research. The selection of MATLAB is based on several factors as listed below:

- MATLAB is a powerful fourth generation programming language and due to its strong programming capability and flexibility it helps in detailed simulation of sensor nodes and their architecture.
- The MATLAB desktop environment allows to work interactively with data, helps to keep track of files and variables and simplifies common programming/debugging tasks

- The ability to auto-generate C code, using MATLAB Coder, for a large (and growing) subset of mathematical functions
- Communication channel modeling (SNR, effect of different noise schemes, interference, distance, etc.
- Support physical layer parameters, different modulation and encoding techniques.
- Powerful Simulink program for modelling, simulations and analysing dynamic systems
- The simulation results can be put in the MATLAB workspace easily for post processing and visualization.
- Using scopes and other display blocks the simulation results can be seen when the simulation is running.

3.15 CHAPTER SUMMARY

The chapter gives an introduction of wireless sensor network architecture and an extensive review of the protocols stack based on it has summarized. Most important considerations for these routing protocols are energy efficiency and network lifetime Network architectural design has a big impact on the energy consumption and lifetime of a sensor network. Sensor nodes are energy constraint devices and they are deployed in a hostile environment so many to one traffic pattern with multihop short distance communication are preferred in sensor networks. In multihop networks, a hierarchical network architecture based on clustering can not only reduce the energy consumption for communication, but also balance the traffic load and improve scalability of a sensor network.

Need of a simulator for sensor network research and an extensive review of the existing simulation tools used in the wireless research community is also presented in the chapter. Various wireless network simulators are investigated to find a suitable candidate for this research. The selection of MATLAB for this research is based on several factors, including its acceptability and credibility among the scientists and researchers community. The key advantage of MATLAB is its strong analytical capabilities, flexibility, reliability, and powerful graphics. Next chapter describes the contribution of the thesis towards cluster based routing protocols for the homogeneous sensor network.

CHAPTER – 4

DISTANCE SENSITIVE ENERGY EFFICIENT PROTOCOL

4.1 INTRODUCTION

Many WSN applications require only an aggregate value to be reported to the observer. In this case, sensors in different regions of the field can collaborate to aggregate their data and provide more accurate reports about their local regions. For example, in a habitat monitoring applications the average reported humidity values may be sufficient for the observer. In military fields where chemical activity or radiation is measured, the maximum value may be required to alert the troops. In WSN large portion of energy is consumed in wireless communication. Hierarchical or cluster based routing protocols are designed to reduce energy consumption by localizing data communications within a cluster and perform aggregation of data to decrease transmissions to the base station.

In cluster based routing two layer approaches are used. First layer selects cluster heads and second layer is for routing. Cluster head is responsible for gathering data from its members, aggregates the collected data and then send it to the far located base station. Clustering considerably improves the primary metrics like network life and energy consumption of sensor network [9], [36]. In this chapter a novel clustering algorithm DEEN (Distance Sensitive Energy Efficient Protocol) is proposed for the homogeneous sensor network.

4.2 DEEN PROTOCOL

The proposed DEEN is an improved version of already existing LEACH [18] algorithm. One of the problems of LEACH is that it does not consider the node residual energy for the election of cluster head. DEEN overcomes this problem by involving node distance and residual energy in the cluster head election process. For this it divides the sensing region into two parts according to the average distance of nodes from the base station. First part whose distance is less than or equal to this average distance uses a distance based threshold for the cluster head election and second part whose distance is greater than average distance select cluster head from the region according to residual energy of sensors. The operation of DEEN is divided into rounds and each round further consists of two phases:

- Setup phase
- Steady-State Phase

4.2.1 SETUP PHASE

In setup phase DEEN elects the cluster head of the network, cluster is formed and the communication schedule of its member is determined. For performing all these operations setup phase consists of three phases: advertisement, cluster setup and schedule creation. In the beginning of each round, DEEN randomly select sensors as cluster head. The cluster head selection is performed through the advertisement phase, where the sensor nodes broadcast a cluster head advertisement message. Firstly, a sensor node generates a random number between 0 and 1. If this random number is less than a threshold value T (n), then the sensor node becomes cluster head.

When the sensor network operates for some time, then there is a considerable difference in the energy of base station nearer and far nodes [46]. The amplifier energy is directly proportional to the square of the distance from the transmitter to the receiver. In a round if the percentage of cluster heads are between 3 and 5 then they are more energy efficient [18].

Thus DEEN uses two different schemes for the cluster head election. Based on the distance from the sink, DEEN divides the entire sensing region into two parts. The part of a sensing region whose distance is less than or equal to the average distance from the base station has higher energy than the other part (After the network operates for some time). Therefore the percentage of nodes, which can become a cluster head, should be higher in this region. The region, whose distance is greater than the average distance from the base station has less energy; nodes lying in this region should respond to the cluster head election only when they have the sufficient energy to perform this duty. Thus, this region uses a residual energy based scheme for the cluster head election.

Let p_{opt1} and p_{opt2} denotes the percentage of nodes that can become a cluster head in first and second region. DEEN uses the value 0.06250 for p_{opt1} and 0.03125 for p_{opt2} i.e. for the cluster head elections base station nearer nodes has a higher probability than far nodes. After deployment phase, each sensor sends a message to the base station. On the basis of this message signal strength each node calculates its distance from the base station. Let d_i is the distance between node s_i and base station, d_{avg} is the average distance of nodes from base station. The average distance d_{avg} of the nodes can be calculated by using the equation (4.1) and this is determined by the base station after getting the location information of all the sensors through initial message sent by them. The value of d_{avg} is broadcasted by the base station in the network for further use.

$$d_{avg} = \frac{1}{n}\sum_{i}^{n} d_i \qquad 4.1$$

The Value of D_{avg} [46] can be further approximated by using equation (4.2)

$$d_{avg} \simeq d_{toCH} + d_{toBS} \qquad 4.2$$

If the distance d_i of a node is less than or equal to d_{avg} then DEEN uses the equation (4.3) to find the threshold value $T(n)$ for cluster-head election

$$T(n) = \left(\begin{array}{ll} \frac{p_{opt1}}{1-P\times\left(r \ mod\frac{1}{p}\right)}\times\left(s \times \frac{d_{avg}}{d_i}\right) & \text{If n } \varepsilon \text{ G} \\ 0 & \text{otherwise} \end{array}\right) \qquad 4.3$$

If the distance d_i is greater than d_{avg} then DEEN uses the equation (4.4) to find the threshold value $T(n)$ for cluster head selection. This threshold also includes the ratio of the residual and the initial energy of the sensor nodes so that the nodes which have the high residual energy can only become the cluster head in a round.

$$T(n) = \begin{pmatrix} \frac{p_{opt2}}{1-P\times\left(r \ mod \ \frac{1}{p}\right)} \times \frac{E_{residual}}{E_{init}} & \text{If n } \varepsilon \text{ G} \\ 0 & \text{otherwise} \end{pmatrix} \quad 4.4$$

Here p_{opt1} and p_{opt2} is the desired percentage of nodes that can become the cluster head, r is the current round, s is a constant and G represents set of nodes which are not the cluster head in the last $\frac{1}{p}$ rounds. $E_{residual}$ is the residual energy of a node in a round and E_{init} is the initial energy of a node. The value of p similar to LEACH protocol is 0.05.

After becoming cluster heads, nodes advertise about their status in the network i.e. they are the new cluster heads for this round. DEEN relies on a CSMA-based random access scheme to avoid advertisement collisions from multiple cluster heads. Once the non CH sensor nodes receive the advertisement, they determine a cluster with which they can attach. If a node receives an advertisement from a single cluster head, then it automatically becomes a member of that cluster. However, if a sensor node receives advertisements from multiple cluster heads, then cluster selection is performed on signal strength of advertisement message from the cluster heads to the sensor node. The cluster head with the highest signal strength has been selected. After the advertisement phase, the sensor nodes inform the associated cluster head that they are the members of it. This is called a cluster setup phase. Finally, the schedule creation phase is performed, where the cluster head assigns a time slot to each sensor node during which nodes can send their sensed data to the cluster head.

4.2.2 STEADY-STATE PHASE

Once the cluster formation is completed, DEEN switches to steady-state phase. During this phase, the sensor nodes begin sensing and transmit their sensed data to the respective cluster head. The cluster head further aggregates the data received from its members before sending it to the base station. At the end of the steady-state phase, the network goes into the setup phase again to enter into another round of cluster heads selection. As a result, energy consumption due to cluster head rotation is equally distributed among sensor nodes.

4.3 ALGORITHM OF DEEN

4.3.1 Setup Phase:

1. For Each (node N)
2. Calculate distance di
3. Find the value of davg
4. N generates a random number between 0 and 1
5. If di ≤ davg and random number < DEEN First Threshold
6. N is a cluster head (CH)
7. N broadcasts an advertising message about its cluster head status
8. Else if di > davg and random number < DEEN Second Threshold
9. N is a cluster head (CH)

```
        N broadcasts an advertising  message about its cluster head status
    Else
        N is a regular node
        N listens to the advertising messages of the CHs
        N selects a CH which is near to it.
        N informs the respective CH and becomes a member of it.
    End If
End For
For Each Cluster Head (CH)
    CH creates a TDMA schedule for its members to transmit data
    CH communicates TDMA schedule to its members
End For
```

4.3.2 Steady State Phase:

```
For Each (regular node N)
    N collects the sensing data
    N transmits the sensed data to CH in its  TDMA time slot
End For
For Each (CH)
    CH receives data from its cluster member
    CH aggregates the correlated data
    CH transmits the aggregated data to base station
End For
```

4.4 SIMULATION AND RESULTS

The performance of DEEN is compared with LEACH. For simulation 100 x 100 square meters region with 100 sensor nodes is used as shown in Figure 4.2. The base station is located at 75 meters away from the sensing region and co-ordinates of it are (50,175). Sensor nodes are denoted by using the symbol (o) and the base station by (x). Various assumptions make about the network model and sensors are as follows.

- Sensors are deployed randomly in the region.
- Base station and sensors become stationary after deployment and base station is 75 meters away from the sensing region.
- Sensors are location unaware i.e. they do not have any information about their location.
- Sensors continuously sense the region and they always have the data for sending to base station.
- Battery of the sensors cannot be changed or recharged as the nodes are densely deployed in a harsh environment.
- All the sensors have the same amount of energy and processing capabilities i.e. network is homogeneous.

4.4.1 PERFORMANCE METRICS

The performance metrics used for evaluating the protocol are as follows.

(i) **Stability Period:** This is the time interval from the start of a network operation until the death of the first sensor node. This period is also called stable region.

(ii) **Network lifetime:** This is the time interval from the start of network operation until the death of the last alive node.

(iii) **Number of cluster heads per round:** This instantaneous measure reflects the number of cluster heads, which would send the aggregated information to the base station.

(iv) **Number of Alive (total, advanced and normal) nodes per round:** This instantaneous measure reflects the total number of live nodes that has not yet expended all of their energy.

(v) **Throughput:** It will measure the total data send over the network. It includes the rate of data sends from cluster heads to the sink and as well as the rate of data sends from the nodes to their cluster heads.

4.4.2 RADIO DISSIPATION ENERGY MODEL

Radio energy model as described in LEACH [18] is used for this research work and the various parameters of this model are given in Table 4.1. Both free space (d^2 power loss) and the multipath fading (d^4 power loss) channel model is used depending upon the distance between the transmitter and receiver. If the distance is less than a particular threshold value, then free space model is used otherwise multipath loss model is considered. The amount of energy required to transmit L bit packet over a distance d is given by equation (4.5).

$$E_{Tx}(L,d) \quad \begin{matrix} L \times E_{elec} + L \times \varepsilon_{fs} \times d^2 & if\ (d < d_0) \\ L \times E_{elec} + L \times \varepsilon_{mp} \times d^4 & if\ (d \geq d_0) \end{matrix} \qquad 4.5$$

E_{elec} is the electricity dissipated to run a transmitter or receiver circuitry. The parameters ε_{mp} and ε_{fs} is the amount of energy dissipated per bit in the radio frequency amplifier according to the distance d_0 which is given by the equation (4.6).

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \qquad 4.6$$

For receiving an L bit message the energy expends by radio is given by

$$E_{Rx}(L) = L \times E_{elec} \qquad 4.7$$

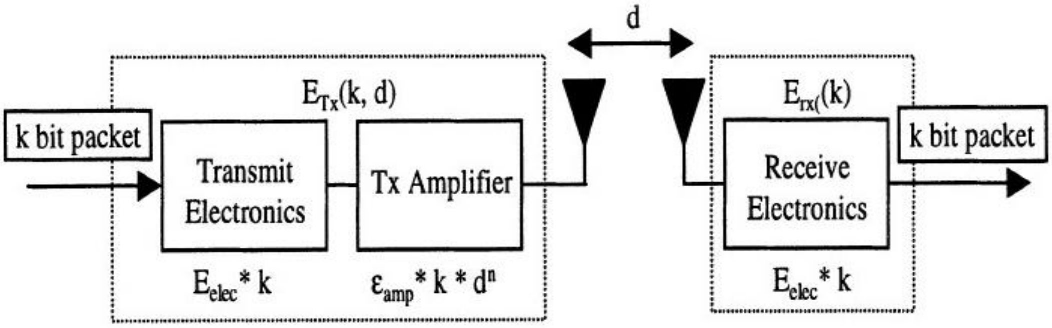


Figure 4.1 Radio Dissipation Energy Models [18]

Parameter	**Value**
E_{elec}	5 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_0	0.5 J
E_{DA}	5 nJ/bit/message
Message Size	4000 bits
p_{opt1}	0.0625
p_{opt2}	0.03125
P	0.05

Table 4.1 Radio Parameters of DEEN

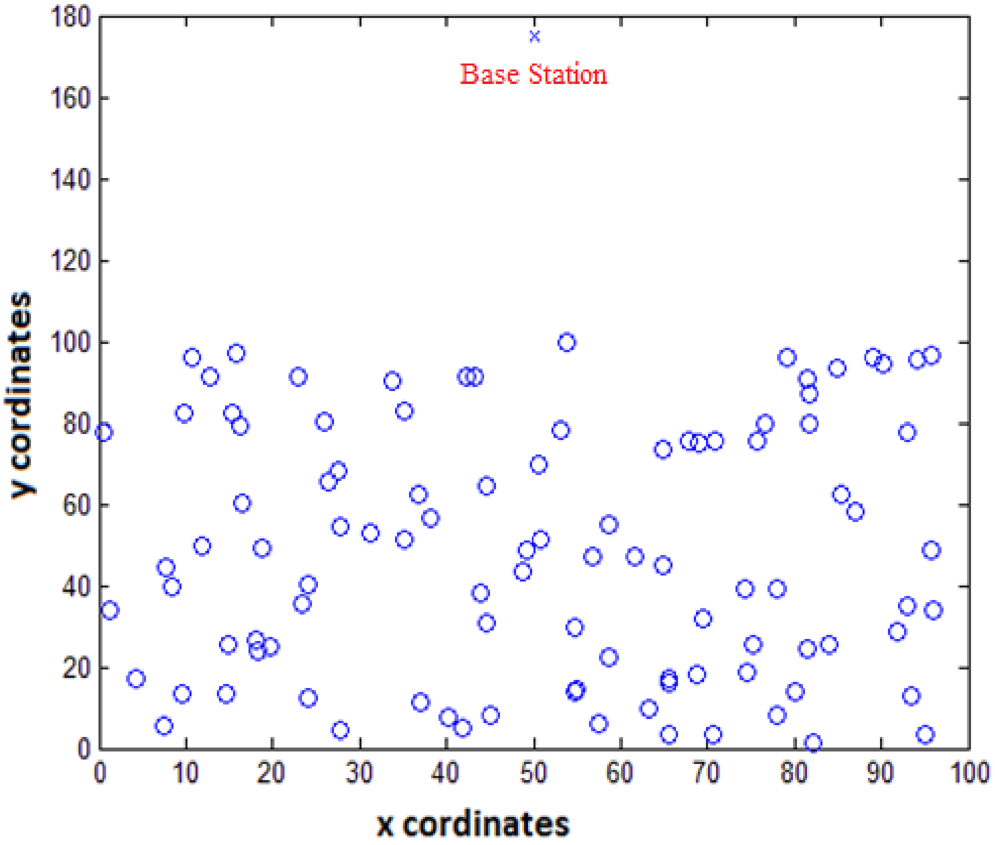


Figure 4.2 Sensing Region of DEEN

(o – Normal Sensor, x – Base Station)

4.4.3 PERFORMANCE EVALUATION

For evaluating the performance of DEEN, the value of constant **s** is varied from 1 to 10 and the number of sensors from 10 to 100. Through simulation of 50 random topologies it is found that the optimal value of constant **s** for the system is **6**. With this optimal value, proposed protocol increases the chance of nodes to become cluster heads which are particularly nearer to the base station. This will reduce the long distance transmissions in sensor network. Far nodes of the network become cluster head only when they have the sufficient energy to perform this duty.

However, when the value of **s** is between **(0 – 5)** the performance of DEEN is similar to LEACH and there is no high gain in performance metrics like stability period, network life and throughput. For higher value of **s (i.e. greater than 6)** the protocol behaves like a flat architecture which is not desirable in a cluster-based routing protocol. But with optimal value of constant **s**, DEEN equally distributes the energy load among the sensors, increases the stability period and the throughput of sensor network.

Figure 4.3 plots the first, half and the last node death against time. The first node dies in LEACH at **684th** round and in DEEN it occurs at **839th** round i.e. stable period of the network is extended by **23%.** Half nodes of the network die in LEACH at **898th** round and in DEEN it happens at **1143th** round. And the last node dies in LEACH at **1865th** round, however in DEEN it occurs at **3601th** round which means that network life is **93%** longer than LEACH. Figure 4.4 plots the number of live nodes per round and from the figure it is clear that the number of live nodes per round is more in DEEN. Figure 4.5 plots the total numbers of packets send to base station (i.e. throughput) with time and DEEN performs better than LEACH in it also. Figure 4.6 shows that total remaining energy of the network (in joules) per round. Initially up to **500th rounds** total remaining energy in DEEN and LEACH is almost equal and after that energy in LEACH starts depleting faster than DEEN and entire energy has been depleted in **1865th** round, however in DEEN it happens at **3601th** round.

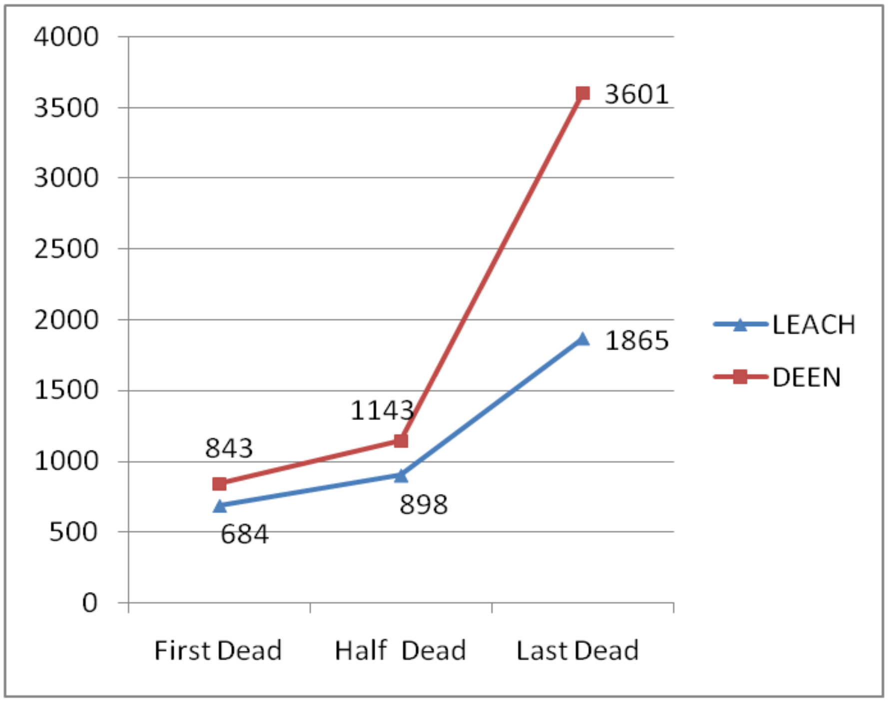


Figure 4.3 Rounds for 1st, Half & Last Node Death in LEACH & DEEN

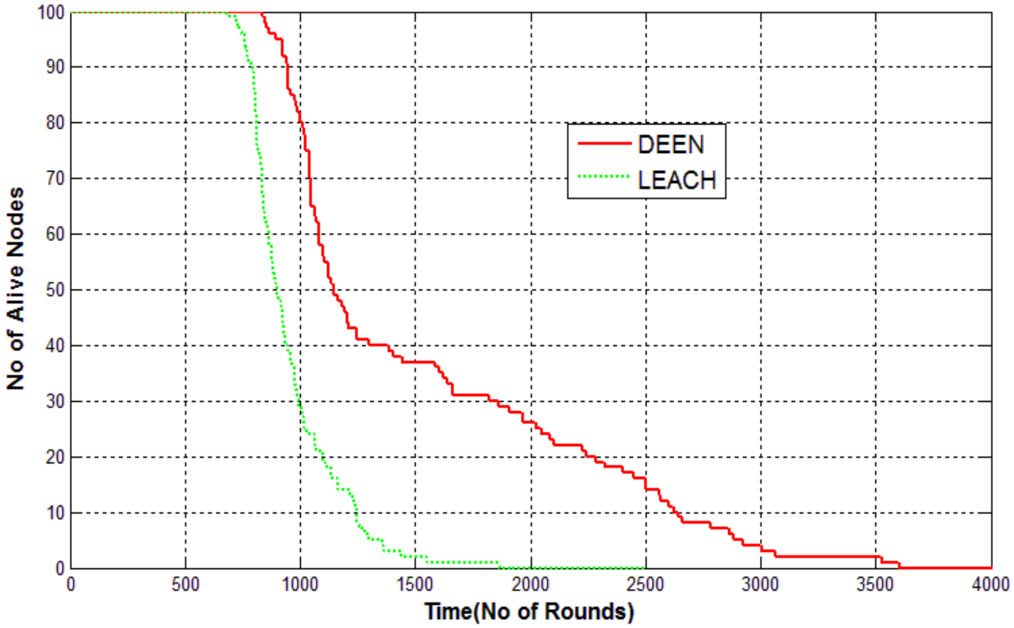


Figure 4.4: Comparisons of Number of Alive Nodes per Round in LEACH & DEEN

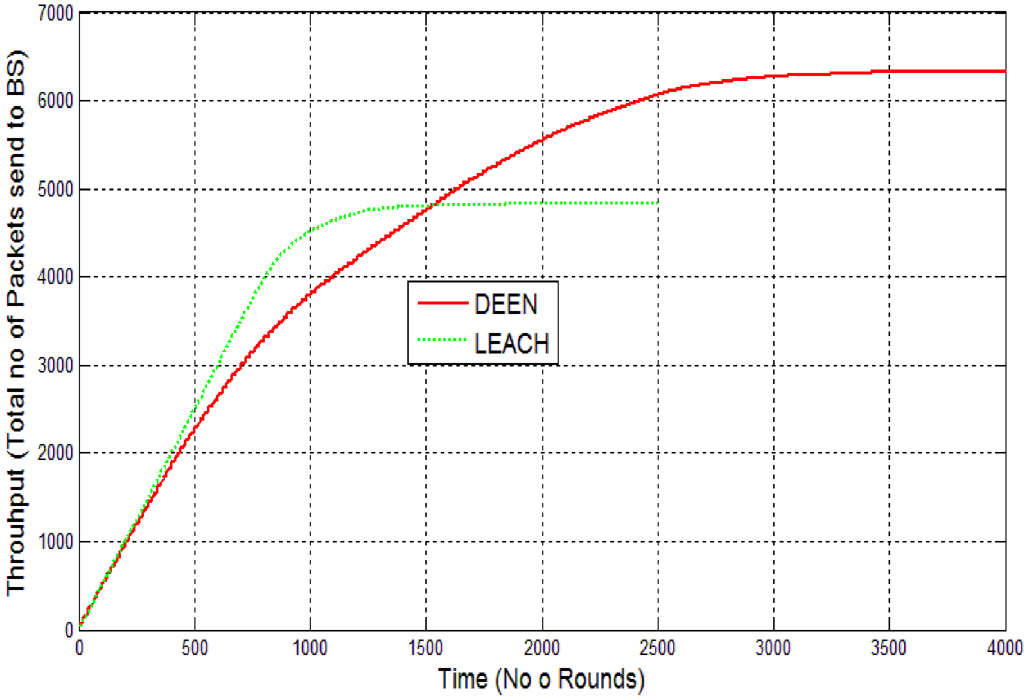


Figure 4.5: Comparisons of Throughput per Round in LEACH & DEEN

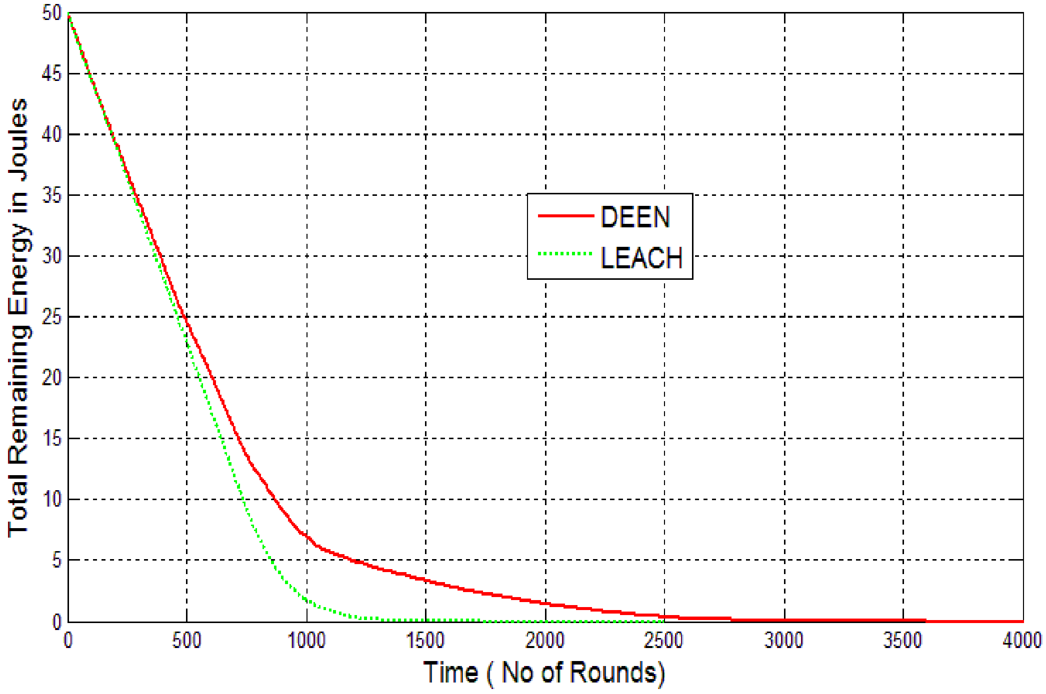


Figure 4.6 Comparisons of Total Remaining Energy per Round in LEACH & DEEN

4.5 CHAPTER SUMAARY

In this chapter, DEEN an efficient routing algorithm for optimizing energy utilization, maximizing stability period and lifetime of the homogeneous sensor network has described. The proposed routing protocol uses a distance based cluster head election scheme for base station nearer nodes and residual energy based scheme for far nodes. The protocol particularly increases the chance of becoming cluster head of the nodes which are lying nearer to the base station and with this approach the proposed protocol has reduced the long distance transmissions in the network. The nodes which are far away from base station become cluster head only when they have the sufficient energy to perform this duty. Simulation results show that DEEN protocol outperforms then LEACH and offering a better exploitation of the network energy to transfer data load towards the base station. Simulation results show that proposed protocol increases the stability period, throughput and network life by **23%, 31%** and **93%** than LEACH. Next chapter describes the contribution of this thesis towards cluster based routing protocol for two level heterogeneous sensor network.

CHAPTER – 5

ENERGY EFFICIENT CLUSTERING PROTOCOL

5.1 INTRODUCTION

Most of the routing and data dissemination protocols of WSN assume a homogeneous network architecture, in which all sensors have the same capabilities in terms of battery power, communication, sensing, storage, and processing. Recently there has been an interest in heterogeneous sensor network, especially for a real deployment. There are three common types of resource heterogeneity in sensor node: computational heterogeneity, link heterogeneity, and energy heterogeneity [53], [75]. For example, Intel has deployed a pilot application of heterogeneous sensor networks. The proposed architecture uses two types of sensors: the sensors attached to pumps and motors in a fabrication plant have no energy constraint (i.e., line powered sensors), whereas the others are battery powered sensors in order to reduce the installation cost and complexity. The battery powered sensors have limited lifetime. To prolong life, WSN should use the available energy efficiently [4]. A real deployment study of heterogeneous sensor networks is discussed in [76]. In this study Mica and iPAQ motes are integrated together in the same architecture. Since Mica motes consume very little power and perform complex computation, it is more efficient to deploy them for sensing. The iPAQ motes are suitable for data fusion because they consume more power and can perform computation quickly. Heterogeneous sensor networks are very attractive as they can potentially extend the network lifetime and improve reliability. For both energy efficiency and cost effectiveness this type of the network requires that a large number of inexpensive sensors perform sensing while a few expensive sensors provide in network processing and data forwarding to the sink [4]. In this chapter an energy efficient clustering protocol (EECP) for two level heterogeneous sensor networks is proposed.

5.2 EECP PROTOCOL

In this section EECP (Energy Efficient Clustering Protocol) is described for two level heterogeneous networks. The proposed protocol is the extension of SEP (Stable Election Protocol) and uses different energy nodes in the network to create energy heterogeneity. EECP has two types of node: normal and advanced nodes. Normal nodes have normal energy and advanced nodes have more energy than the normal nodes. In a round some advanced nodes act as the gateway nodes for normal cluster heads, when they are not itself elected as a cluster head so that the energy consumption of normal cluster heads can be reduced. The main goal of this protocol is to efficiently maintain the energy consumption and increases the lifetime of the network. The vital differences in EECP scheme and SEP are as follows:

(i) EECP uses a residual and initial energy based probability scheme for cluster heads election from normal nodes.

(ii) Advanced nodes act as the relay or gateway node for normal cluster heads and take over their transmission load when they are not performing the role of a cluster head in a particular round.

(iii) Non cluster head nodes of a sensor network attach itself with a nearby cluster. For this, they try to find the distance from all nearby clusters. If the distance between a sensor node and the base station is less than the distance between the sensor node and all nearby clusters then for saving its energy sensor node enters into a sleep state and wait for the next some rounds in which node either itself becomes a cluster head or able to find a cluster head such that the distance between the node and cluster is less than the distance between the node and the base station.

5.3 HETEROGENEOUS SENSOR NETWORK MODEL

This section contains the description of the wireless sensor network model. Model contains n sensor nodes, which are deployed randomly in a 100 × 100 square meters region as shown in Figure 5.1. Various assumptions make about the network model and sensors are as follows.

- Sensors are deployed randomly in the region.
- Base station and sensors become stationary after deployment and base station is located middle of sensing region.

- Sensors are location unaware i.e. they do not have any information about their location.
- Sensors continuously sense the region and they always have the data to send the base station.
- The battery of the sensors cannot be changed or charged as the nodes are densely deployed in a harsh environment.
- In the sensing region, there are two types of sensor nodes i.e. advanced and normal nodes. Advanced nodes have more energy than the normal nodes.

Model have n sensors and they are distributed uniformly in an M × M square meters region. As base station is located middle of the sensing region and the distance of any node to its cluster head or sink is ≤ d_0. The energy dissipated in the cluster head during a single round is given by equation (5.1).

$$E_{CH} = \left(\frac{n}{k} - 1\right) \times L \cdot E_{elec} + \frac{n}{k} L \cdot E_{DA} + L \cdot E_{elec} + L \cdot \varepsilon_{fs} \cdot d_{toBS}^2 \qquad 5.1$$

Where L is the no of bits of the data message, d_{toBS} is the average distance between the base station and cluster head and E_{DA} is the energy required to perform data aggregation in a round. Since cluster members transmit data to its cluster head therefore energy dissipated in a non cluster head follows the free space path and it is given by equation (5.2).

$$E_{NCH} = L \times (E_{elec} + \varepsilon_{fs} \times d_{toCH}^2) \qquad 5.2$$

Where d_{toCH} is the average distance between a node and cluster head and the energy depleted in a round is given by equation (5.3).

$$E_{Cluster} = E_{CH} + \left(\frac{n}{k} - 1\right) E_{NCH} \approx E_{CH} + \left(\frac{n}{k}\right) E_{NCH} \qquad 5.3$$

The total energy dissipated in the network is given by equations (5.4)

$$E_{Total} = L \times \left(2nE_{elec} + nE_{DA} + k\,\varepsilon_{fs} d_{toBS}^{2} + n\varepsilon_{fs} d_{toCH}^{2}\right) \qquad 5.4$$

The optimal number of clusters can be found by finding the derivative of E_{Total} with respect to k and equating it to zero.

$$k_{opt} = \frac{\sqrt{n}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{M}{d_{toBS}^{2}} \qquad 5.5$$

The average distance from the cluster head to the sink can be calculated in the following way [77].

$$d_{toBS} = 0.765 \frac{M}{2} \qquad 5.6$$

Node's optimal probability to become the cluster head in a round is given by equation 5.7.

$$p_{opt} = \frac{k_{opt}}{n} \qquad 5.7$$

5.4 CLUSTER HEAD ELECTION

EECP considers two types of nodes (normal and advanced nodes). Let n be the total number of nodes and m be the fraction of n which are equipped with $\boldsymbol{\alpha}$ times more energy than normal nodes [45]. Powerful nodes are known as advanced nodes, and the rest (1 - m) × n as normal nodes. The initial energy of each normal node is E_0 and advanced node is $E_0 \times (1 + \alpha)$. Intuitively, advanced nodes have to become CHs more often than normal nodes because they have more energy than normal nodes. Network spatial density is not affected by this new setting. The value of p_{opt} does not change, but the total energy of the network is changed. Heterogeneous network total initial energy is given by

$$E_{Total} = N \cdot (1-m)E_0 + N \cdot mE_0(1+\alpha) \; = N \cdot E_0(1+\alpha m) \qquad 5.6$$

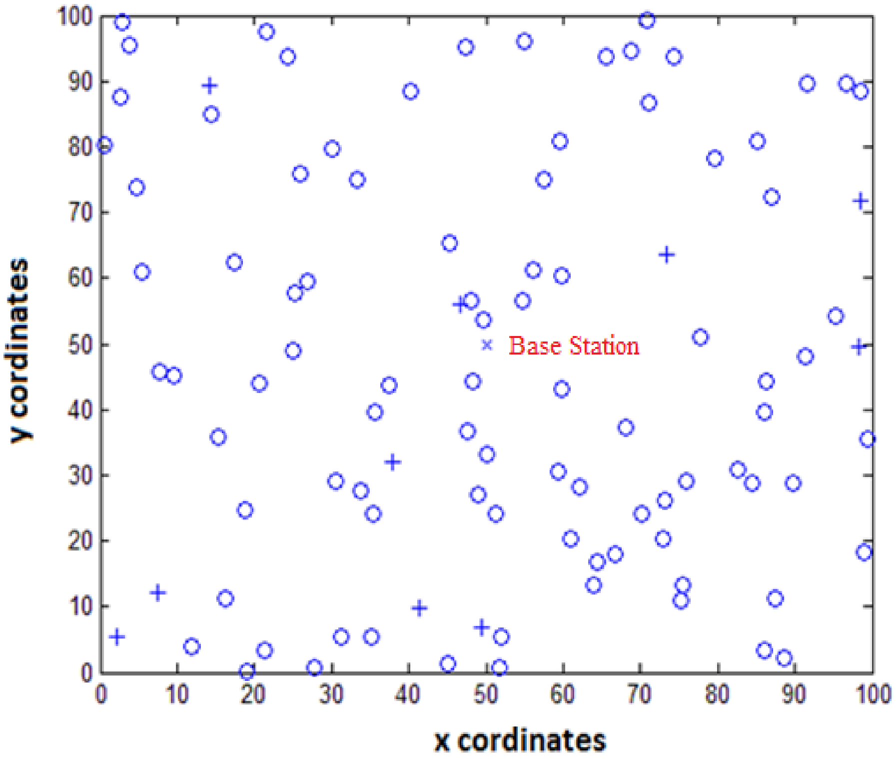


Figure 5.1 Sensing Region of EECP

(o - Normal, + - Advanced Node, x – Base Station)

Epoch of the network increases in proportion of the energy increment. Heterogeneous nodes increase the system energy by $\alpha \cdot m$ times hence for optimizing the stable region, new epoch must become equal to $\frac{1}{p_{opt}} \cdot (1 + \alpha \cdot m)$ [45]. Let p_{nrm}, p_{adv} denotes the weighted election probability for normal and advanced nodes respectively. The average number of cluster heads per round per epoch is equal to$(n \times (1 + \alpha \cdot m) \cdot p_{nrm})$. Normal and advanced nodes weighted probability can be calculated by using the equation 5.7 and 5.8 respectively.

$$p_{nrm} = \frac{p_{opt}}{1 + \alpha \cdot m} \tag{5.7}$$

$$p_{adv} = \frac{p_{opt}}{1 + \alpha \cdot m} \times (1 + \alpha) \tag{5.8}$$

In homogenous networks, to guarantee that there is average n x p_{opt} cluster-heads in every round, each node s_i becomes a cluster-head once every $n_i = \frac{1}{p_{opt}}$ rounds. When the network operates for some time, then the nodes cannot own the same residual energy. Thus energy is not well distributed if the rotating epoch n_i is equal for all nodes. Hence low-energy nodes will die quickly than high-energy nodes of the network. To get rid of this problem EECP protocol chooses different n_i for normal nodes based on the residual energy E_i (r) of node s_i in a round r.

Let $p_i = \frac{1}{n_i}$ be average probability to become a cluster-head during n_i rounds. When nodes have the same amount of energy at each epoch, choosing the average probability p_i to be p_{opt} can ensure that there are $n \times p_{opt}$ cluster-heads in every round and all nodes die approximately at the same time. If the nodes have different amounts of energy, p_i of the nodes with more energy should be larger than p_{opt}. Let $E_i(t)$ denotes the initial energy and $E_i(r)$ represent the residual energy of normal node s_i at round r, using $E_i(t)$ to be the reference energy, for normal nodes we have

$$p_{opt} = \quad p_{opt}\frac{E_i(r)}{E_i(t)} \qquad 5.9$$

p_{opt} is the reference value of the average probability p_i for normal and advanced nodes which determine the rotating epoch n_i and threshold $T(s_i)$ of node s_i. In two-level heterogeneous networks, EECP replaces the reference value p_{opt} with the weighted probabilities given in Equation (5.7) for normal nodes [45], [52], [53] however for advanced nodes the weighted probabilities remain the same as for SEP. Thus p_i is changed into.

$$p_i = \left\{ \begin{array}{ll} \frac{p_{opt} \times E_i(r)}{(1+ \alpha \cdot m) \times E_i(t)} & if\ s_i\ is\ the\ normal\ node \\ \\ \frac{p_{opt} \cdot (1+\alpha)}{(1+ \alpha \cdot m)} & if\ si\ \ the\ advanced\ node \end{array} \right\} \qquad 5.10$$

The probability threshold $T(s_i)$ which node s_i uses to determine whether it can become a cluster-head in a round can be calculated by using the equation 5.11.

$$T(s_i) = \left(\begin{array}{cc} \frac{p_i}{1-p_i\left(r\ mod\ \frac{1}{p_i}\right)} & if\ s_i\ \varepsilon\ G' \\ \\ 0 & \text{otherwise} \end{array} \right) \qquad 5.11$$

Depending upon whether s_i is a normal or advanced node, G' represents the set of either normal or advanced nodes that are not elected as cluster heads within the last $\frac{1}{p_{nrm}}$ or $\frac{1}{p_{adv}}$ rounds.

Further to reduce the energy consumption of wireless sensor network EECP introduces three-tier architecture for normal sensor nodes. In a round if a normal sensor node becomes a cluster head, then after collecting the data from its members, it aggregates the data and instead of sending the data directly to sink it tries to find out an advanced node such that

- That is not a cluster head in this particular round.
- Distance between the normal cluster head and advanced node is less than the distance between the normal cluster head and the base station.

If the normal cluster head is able to find any such advanced node who fulfils the above mentioned conditions i.e. not a cluster head and distance between the normal cluster head and advanced node is less than the distance of the normal cluster head from the base station, then normal cluster head sends its data load to this advanced node which further sends it to the base station. If a normal cluster head does not find any such advanced node that fulfils the above mentioned two conditions, then it will send the aggregated data of its members directly to the base station itself. Thus, by introducing a gateway concept or three-tier architecture for normal cluster heads, EECP has reduced the energy consumed in transmission to prolong the stability period and network lifetime.

After the cluster-heads election in a round, non cluster head nodes try to join a closer (considering the transmission power) cluster-head. However in some cases it is not an optimal choice for energy saving because, if a sensor node exists in the base station direction and distance between node and the base station is less than the distance of node from all nearby clusters (Figure 5.2). Let us consider the figure 5.2, where node n1 has to transmit L-bits message to the base station. The closest cluster-head to n1 is CH1. And, if the node belongs to this cluster, it spends energy (5.12).

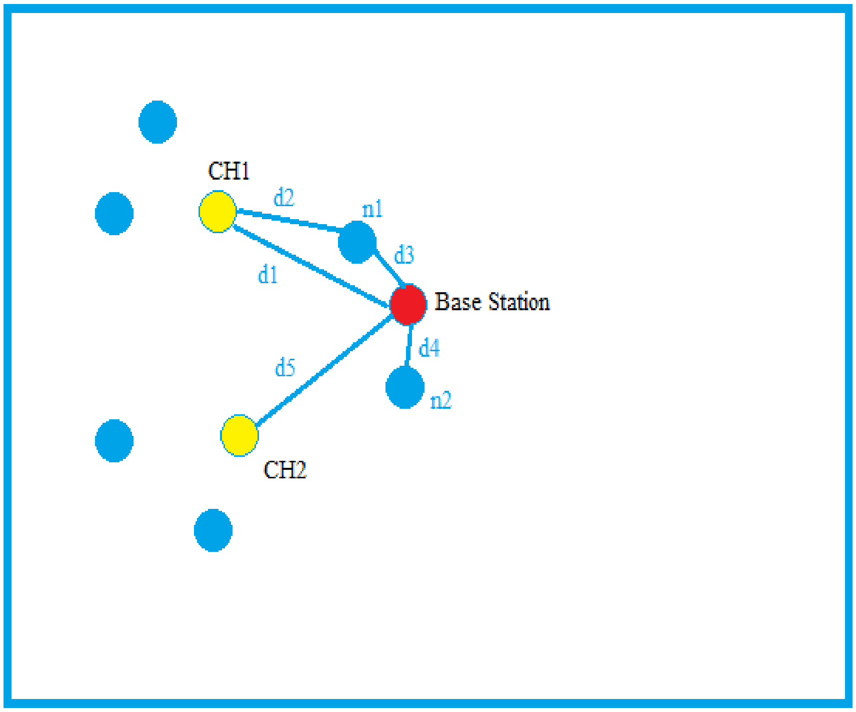


Figure 5.2 Cluster-head Selection for Transmission to Base Station.

$$E1 = L \cdot E_{elec} + L \cdot \epsilon_{d2} \cdot d_2^x \qquad 5.12$$

Where $\begin{cases} x = 2, \epsilon_{d2} = 10 \text{ pj / bit / m}^2, & if\ d_2 < d_0 \\ x = 4, \epsilon_{d2} = 0.0013 \text{ pj / bit / m}^4, & if\ d_2 \geq d_0 \end{cases}$

But if the node n1 chooses to transfer data to the base station directly, this energy will be (5.13):

$$E2 = L \cdot E_{elec} + L \cdot \epsilon_{d3} \cdot d_3^y \qquad 5.13$$

Where $$\begin{cases} y = 2\,, \epsilon_{d3} = 10 \text{ pj / bit / m}^2, & if\ d_3 < d_0 \\ y = 4\,, \epsilon_{d3} = 0.0013 \text{pj/ bit /m}^4, & if\ d_3 \geq d_0 \end{cases}$$

Here positive coefficients $x\ and\ y$ represent the energy dissipation radio model used. Clearly $E2 < E1$ but in this case lot of uncompressed data is collected at the base station. To get rid of this problem EECP has introduced a sleep state in the following manner. When $E1 > E2$ it is not an optimal choice for transmitting data and energy saving , in this case instead of sending the data to cluster head $CH1$, sensor node $n1$ enters into a sleep state and waits for the next round in which it either itself becomes a cluster head or finds a nearby cluster such that $E1 < E2$. Sensor node $n1$ remains in the sleep state for the maximum 4 rounds, if in these next 4 rounds it either becomes a cluster head or finds a nearby cluster such that $E1 < E2$ then it wakes up and performs its respective duty either of a cluster head or the members of a cluster head.

If sensor node $n1$ is neither able to become the members of a cluster such that $E1 < E2$ nor become a cluster head in the next 4 rounds, then the sensor node wakes up and transmit the data load directly to the base station. The choice of maximum 4 rounds of sleep state is based on the fact that advanced nodes rotate the cluster head rotation cycle after every 4th round.

5.5 SIMULTION AND RESULTS

The performance of EECP is compared with SEP. For simulation 100 x 100 square meters region with 100 sensor nodes is used. The base station is located middle of the sensing region as shown in Figure 5.1 The normal nodes are represented by the symbol (o), advanced nodes (i.e. gateway nodes) with (+) and the base Station by (x).

5.5.1 PERFORMANCE METRICS

The performance metrics used for evaluating the protocol are:

(i) **Stability Period:** This is the time interval between the start of network operation until the death of the first sensor node.

(ii) **Network lifetime:** This is the time interval from the start of network operation until the death of the last alive node.

(iii) **Number of cluster heads per round:** This instantaneous measure reflects the number of nodes which would send the aggregated information of their cluster members directly to the base station.

(iv) **Number of Alive (total, advanced and normal) nodes per round:** This instantaneous measure reflects the total number of alive nodes of each type that has not yet expended all of their energy.

(v) **Throughput:** This measures the total rate of data sent over the network, the rate of data send from cluster heads to the sink as well as the rate of data send from the nodes to their cluster heads.

5.5.2 RADIO DISSIPATION ENERGY MODEL

Radio energy model as described in [18] is used for this protocol (Figure 4.1). Free space and multipath fading channel model both are considered here, depending upon the distance between the transmitter and receiver. When distance is less than a specific threshold value, then free space model used otherwise multipath loss model is considered. The amount of energy required to transmit L bit packet over a distance, d *is* given by Equation (5.14).

$$E_{Tx}(L,d) \quad \begin{matrix} L \times E_{elec} + L \times \varepsilon_{fs} \times d^2 & if\ (d < d_0) \\ L \times E_{elec} + L \times \varepsilon_{mp} \times d^4 & if\ (d \geq d_0) \end{matrix} \qquad 5.14$$

E_{elec} is the electricity dissipated to run the transmitter or receiver circuitry. The parameters ε_{mp} and ε_{fs} is the amount of energy dissipated per bit in the radio frequency amplifier according to the distance d_0 which is given by the Equation (5.15).

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \qquad 5.15$$

For receiving an L bit message the energy expends by radio is given by

$$E_{Rx}(L) = L \times E_{elec} \qquad 5.16$$

The various parameters of radio model of EECP are given in TABLE 5.1.

Parameter	**Value**
E_{elec}	5 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_0	0.5 J
E_{DA}	5 nJ/bit/message
Message Size	4000 bits
p_{opt}	0.1
d_0	70m

Table 5.1 Radio Parameters of EECP

5.5.3 PERFORMANCE EVALUATION

The performance of EECP is evaluated by introducing various parameters of heterogeneity in the system and considered following cases for heterogeneity

Case 1: m = 0.1, a =5

Case 2: m = 0.2, a =3

Case 1: m = 0.1, a =5

In this case there are **10** advanced nodes deployed with **5** times more energy than normal nodes and **90** normal nodes. Figure 5.3 shows that the network lifetime of EECP is more than SEP as last node dies in ECCP at **7966th** round and in SEP it dies at **6000th** round i.e. network life is increased by **33%.** First node in SEP dies at **1255th** round and in EECP it occurs at **1538th** round. Thus EECP has extended the stability period of the system by **23%.** Figure 5.4 plots the number of alive nodes per round which is more in EECP. Figure 5.5 compares the throughput i.e. total number of messages send to the base station in EECP and SEP and from the graph it is clear that EECP has sent more messages. Figure 5.6 plots the total residual energy (in joules) of network per round in EECP and SEP and it clearly indicates the advantages of EECP over SEP. Initially up to **500th** round total remaining energy in SEP and EECP is almost equal and after that the energy in SEP starts depleting faster than EECP and entire energy has been depleted at **6000th** round however in EECP it occurs at **7966th** round.

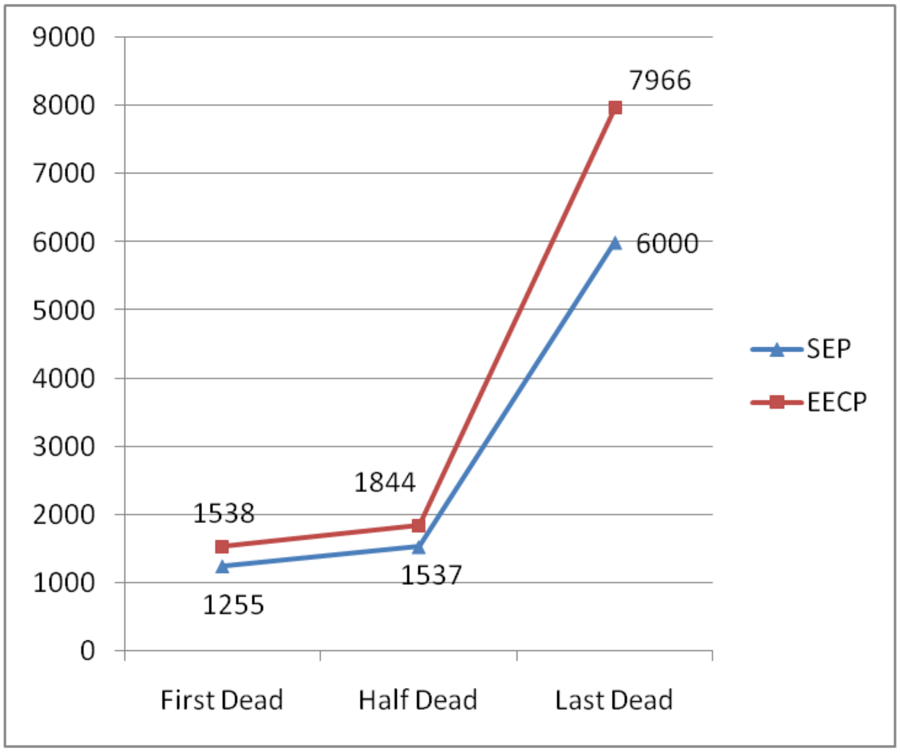


Figure 5.3 Rounds for 1st, Half & Last Node Death in EECP & SEP

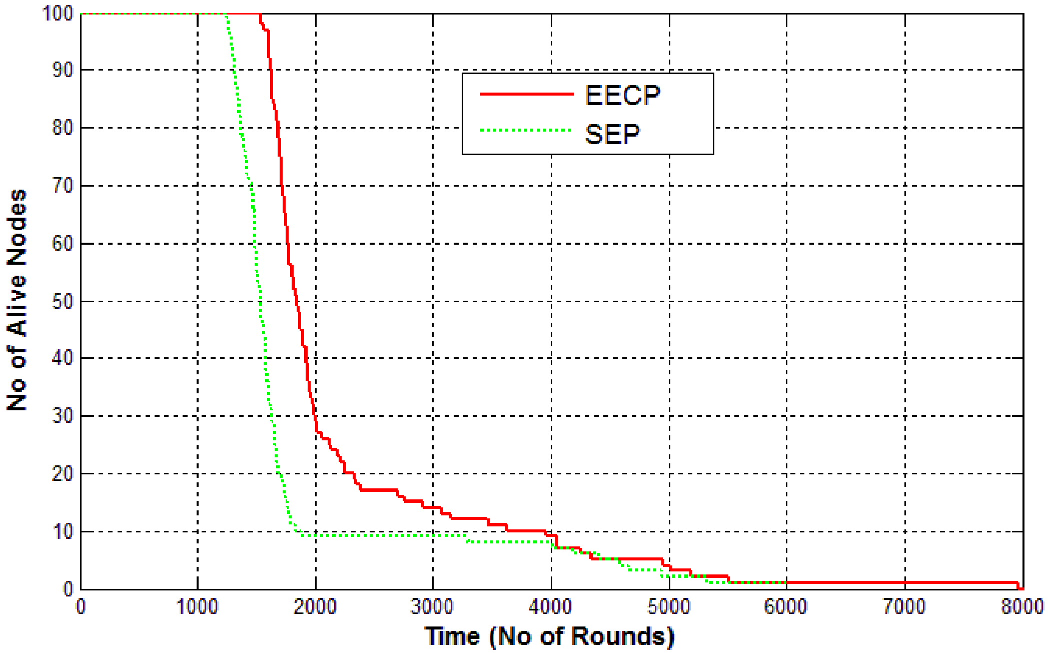


Figure 5.4 Comparisons of No. of Alive Nodes per round in EECP & SEP

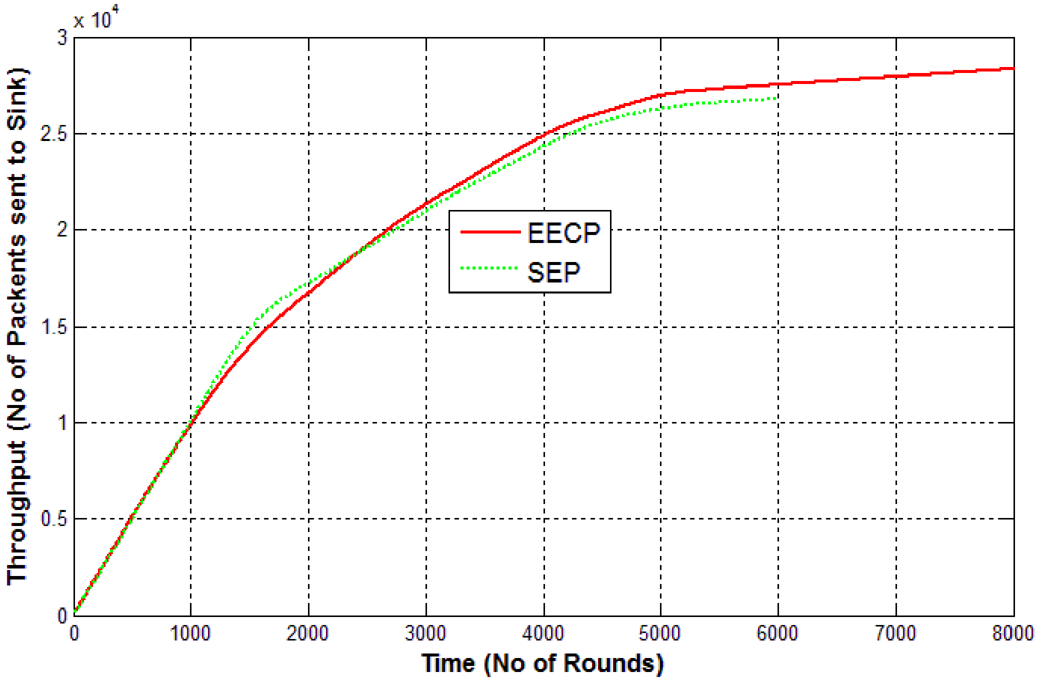


Figure 5.5 Comparisons of Throughput per Round in EECP & SEP

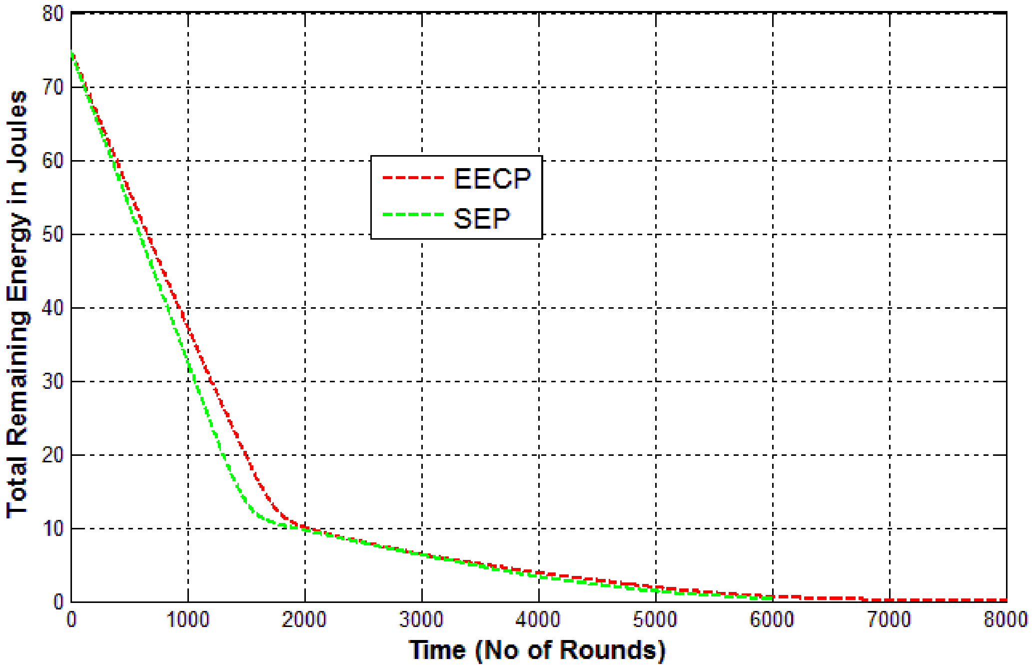


Figure 5.6 Comparisons of Total Remaining Energy per Round in EECP & SEP

Case 2: m = 0.2, a = 3

In this case there are **20** advanced nodes deployed with **3** times more energy than normal nodes and **80** normal nodes. Figure 5.7 shows that the network lifetime of EECP is more than SEP because last node dies in EECP at **7593th** rounds and in SEP it dies at **5452th** rounds. Thus EECP extends the network lifetime approximately by **39%.** First node dies in EECP at **1640th** round and in SEP it happens at **1345th** round. It means that stability period of the system is extended approximately by **22%.** Figure 5.8 show that no of alive nodes per round are more in EECP. Figure 5.9 shows that throughput i.e. total number of messages send to the base station is more in EECP. Figure 5.10 plots the total remaining energy (in joules) per round and from the figure it is clear that EECP has more remaining energy per round.

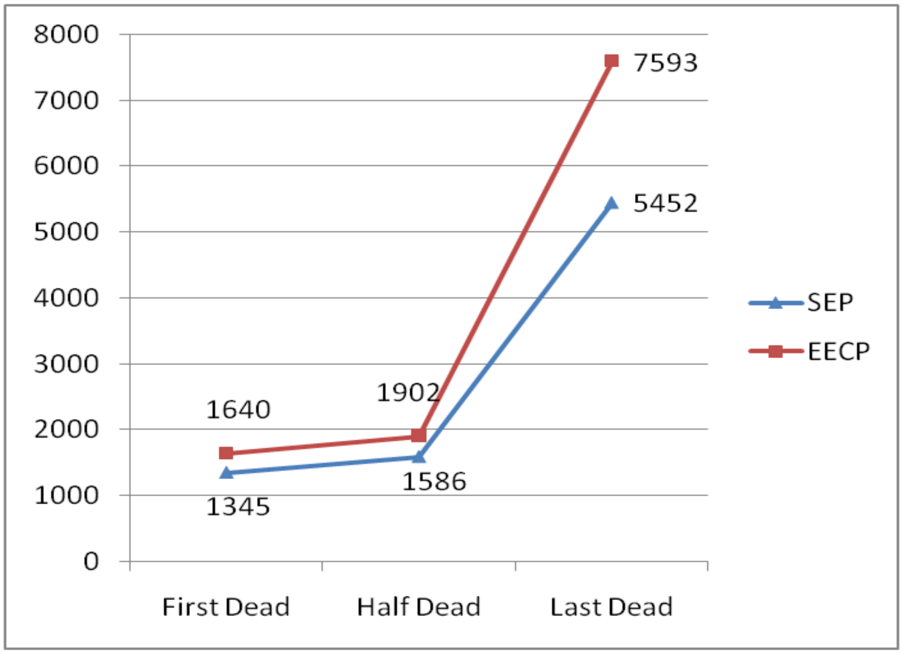


Figure 5.7 Rounds for 1st, Half & Last Node Death in EECP & SEP

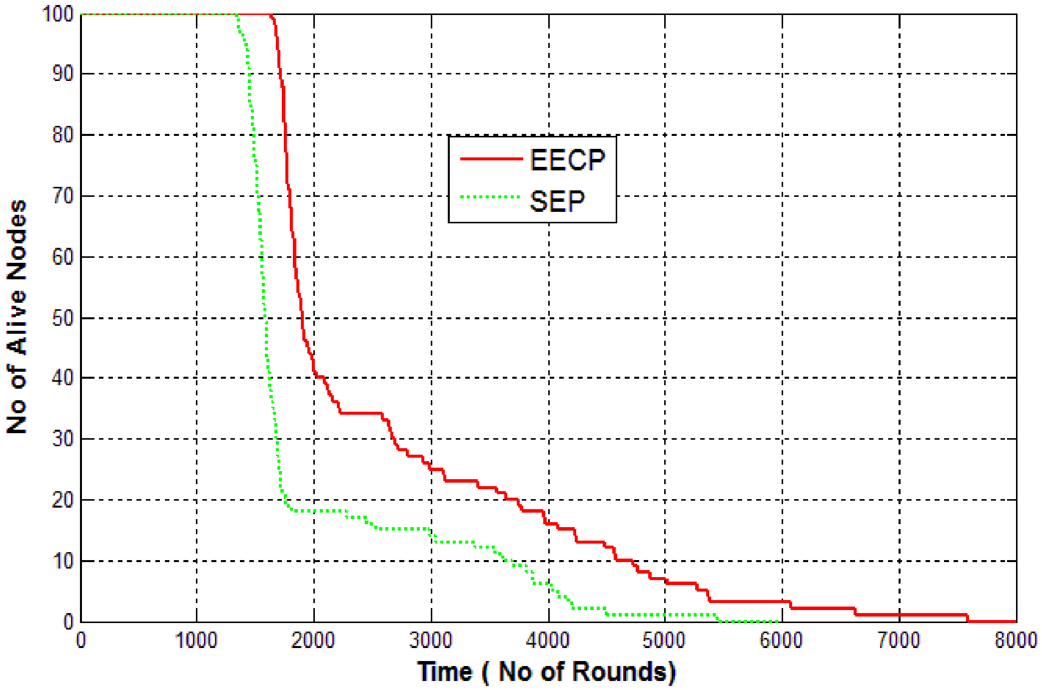


Figure 5.8 Comparisons of No. of Alive Nodes per Round in EECP & SEP

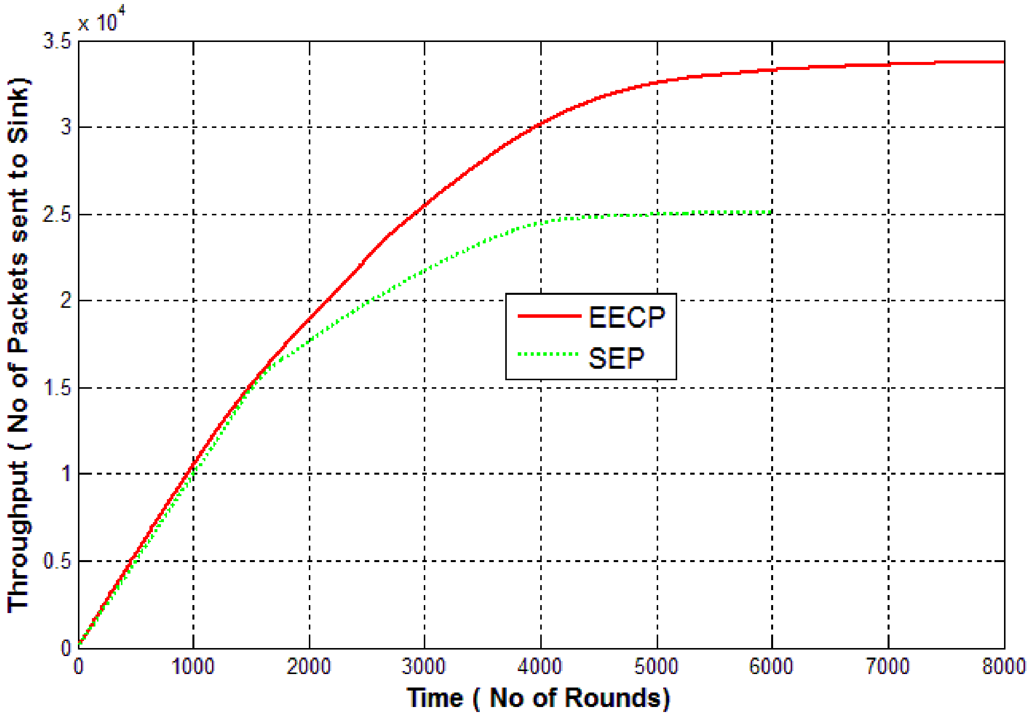


Figure 5.9 Comparisons of Throughput per Round in EECP & SEP

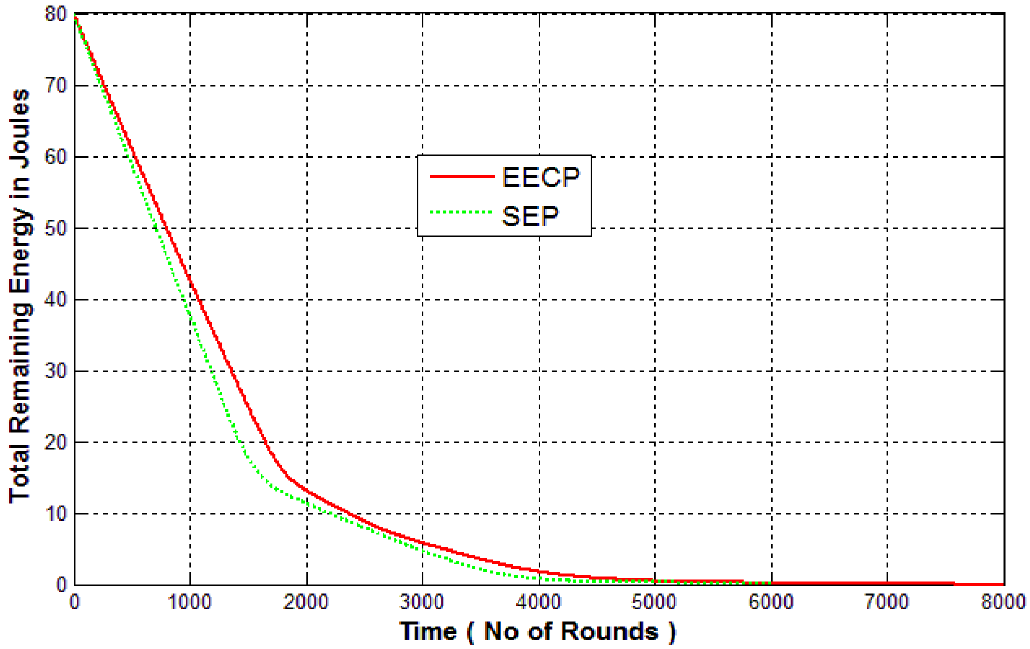


Figure 5.10 Comparisons of Total Remaining Energy per Round in EECP & SEP

5.6 CHAPTER SUMMARY

This chapter has described **EECP (Energy Efficient Clustering Protocol)** for two level heterogeneous sensor networks. The proposed protocol takes the full advantage of heterogeneity and improves the network lifetime, stable region and throughput of the network. EECP introduces three-tier architecture for normal cluster heads and their data load has been taken over by advance nodes when they are not performing the duty of a cluster head. When joining to a nearby cluster head is not energy efficient then the protocol has suggested a sleep state for the nodes so that energy of the network can be saved further. EECP has extended the stable region, network life and throughput of the system by **23%, 33%,** and **6%** respectively when **(m =0.1, a=5)**. Similarly, when (m = **0.2, a =3)** stable region, network life and throughput are improved by **22%, 39%** and **35%** respectively. Next chapter describes the contribution of the thesis towards cluster based protocol for three level heterogeneous sensor networks.

CHAPTER – 6

MULTIHOP ENERGY EFFICIENT CLUSTERING AND DATA AGGREGATION PROTOCOL

6.1 INTRODUCTION

Wireless sensor networks (WSNs) have emerged as an important new class of computation that embeds computing in the physical world and to date; most of the work has focused on homogeneous WSNs, where all of the nodes in the network are of the same type. However the continued advances in miniaturization of processors and low-power communications have enabled the development of a wide variety of nodes. When more than one type of node is integrated into a WSN, it is called heterogeneous. While many of the existing civilian and military applications of heterogeneous wireless sensor networks (H-WSNs) do not differ substantially from their homogeneous counterparts, there are compelling reasons to incorporate heterogeneity into the network. These include:

- Improving the scalability of WSNs
- Addressing the problem of non uniform energy drainage
- Reducing energy requirements without sacrificing performance.

- Taking advantage of the multiple levels of fidelity available in different nodes
- Balancing the cost and functionality of the network
- Supporting new and higher-bandwidth applications [75]

6.2 M-EECDA Protocol

M-EECDA (Multihop Energy Efficient Clustering and Data Aggregation Protocol for Heterogeneous WSNs) main aim is to maintain the energy consumption of the network efficiently. It saves the energy of the system with the introduction of the multiple hop short distance communication for normal cluster heads. M-EECDA consists of three types of sensor nodes (i.e. normal, advanced and super) which are randomly deployed in a sensing region.

Let m be the fraction of normal nodes among total nodes N nodes, and m_0 is the fraction of super nodes which are equipped with β times more energy. $N \times m \times (1 - m_0)$ nodes are advanced nodes and equipped with α times more energy as compared to normal nodes [47]. Let the initial energy of the normal node is E_0. Then initial energy each of the advanced and super nodes are $E_0 \times (1+\alpha)$ and $E_0 \times (1+\beta)$ where α, β means that advanced and super nodes have α, β times more energy than the normal nodes. Heterogeneous network total initial energy will be:

$$
\begin{aligned}
E_{total} &= N.\ (1-m).\ E_0 + N.\ m.\ (1-m_o).\ (1+\alpha).\ E_0 + N.\ m.\ m_0.\ E_0.\ (1+\beta) \\
&= N.\ E_0.\ (1 + m.\ (\alpha + m_0.\ (\beta - \alpha))) \qquad 6.1
\end{aligned}
$$

Thus due to heterogeneous nodes system has (1 + m. (α + m_0. (β – α))) more energy and epoch of this new system is $\left(\frac{1}{p_{opt}}\right) \times \left(1 + m \times \left(\alpha + \ m_0(\beta - \alpha)\right)\right)$.

The weighed probability for the various nodes are given by equations (6.2 – 6.4) [47].

$$p_i = \begin{cases} \dfrac{p_{opt}}{1 + \ m\,.\left(\alpha + m_o.(\beta - \alpha)\right)} & 6.2 \\[2ex] \dfrac{p_{opt}\,.\ (1+\alpha)}{1 + \ m\,.\left(\alpha + m_o.(\beta - \alpha)\right)} & 6.3 \\[2ex] \dfrac{p_{opt}\,.\ (1+\beta)}{1 + \ m\,.\left(\alpha + m_o.(\beta - \alpha)\right)} & 6.4 \end{cases}$$

Threshold for cluster head selection for normal, advanced, super nodes can be calculated by putting above values in equation 6.5.

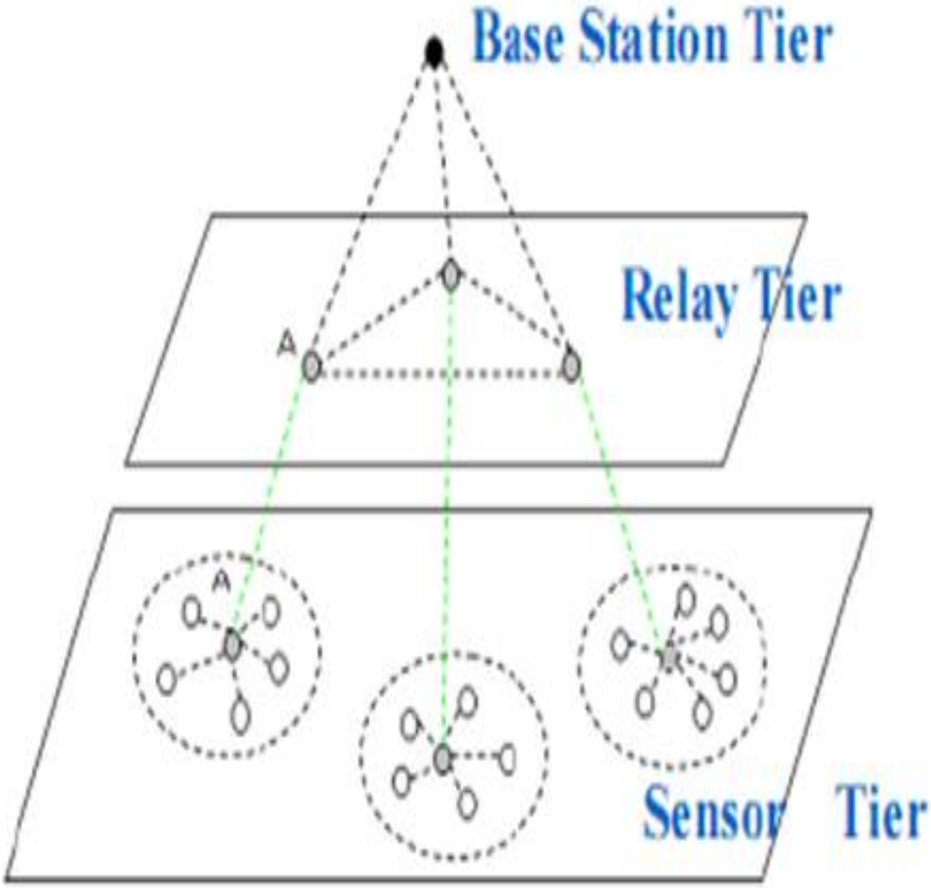
$$T(s_i) \quad = \begin{cases} \dfrac{p_i}{1 - \ p_i\left(\ r \bmod \ \frac{1}{p_i}\ \right)} \times \dfrac{E_{residual}}{E_{init}} & \text{If } \ s_i \ \varepsilon \ G \\[2ex] \dfrac{p_i}{1 - \ p_i\left(\ r \bmod \ \frac{1}{p_i}\ \right)} & \text{If } \ s_i \ \varepsilon \ G' \\[2ex] \dfrac{p_i}{1 - \ p_i\left(\ r \bmod \ \frac{1}{p_i}\ \right)} & \text{If } s_i \ \varepsilon \ G'' \\[2ex] 0 & \text{otherwise} \end{cases} \qquad 6.5$$

Where G, G’ and G’’ represents set of normal , advanced and super nodes that are not selected as cluster heads within the last 1/pi rounds of the epoch, depending upon whether s_i represents a normal, advanced or super node. The cluster head threshold for normal nodes are further multiplied by the ratio of residual and initial energy of the normal node because they have less energy than advanced and super nodes hence they should become the cluster head only when they have sufficient remaining energy to perform this duty.

Nearly 70 percent energy of a WSN is consumed in communication and energy consumed in transmission dominates the total energy consumed for communication. The transmission power grows exponentially with the increase of transmission distance. To reduce energy consumption in a WSN multihop short distance communication is desirable. M-EECDA introduces three-tier architecture for its normal nodes to save their energy (Figure 6.1). In a round if normal sensor node becomes cluster head, then after collecting the data from its members it aggregates the data and instead of sending the data directly to sink it will try to find an out advanced or super node such that

- Distance between the normal cluster head and advanced or super node is less than the distance between the normal cluster head and the base station.
- And which is not a cluster head in this particular round.

If the normal cluster head is able to find any such advanced or super node who fulfils the above mentioned condition i.e. not a cluster head and distance between normal cluster head and advanced or super node is less than distance, of the normal cluster head from the base station, then normal cluster head sends its data load to this advanced or super node which further sends it to the base station. If a normal cluster head does not find any such advanced or super node that fulfils the above mentioned two conditions, then it will send the aggregated data of its members directly to the base station itself. Thus by introducing a multihop or three-tier architecture for normal cluster heads, M-EECDA has reduced the energy consumed in transmission to prolong the network lifetime and stability period.



6.1 Three-tier Sensor Architecture for Normal Cluster head

Moreover, after the cluster-heads election in a round, non cluster head nodes try to join a close (considering the transmission power) cluster. However in some cases it is not an optimal choice for energy saving because, if a sensor node exists in the base station direction and distance between node and base station is less than distance of node from all nearby clusters (Figure 6.2)

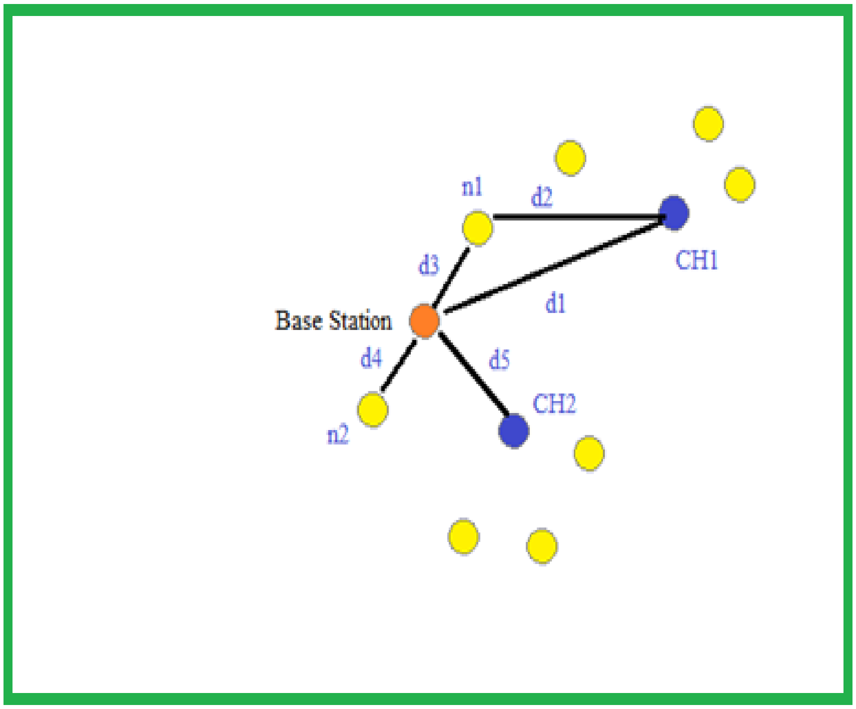


Figure 6.2 Cluster-head Selection for Transmission to Base Station

Let consider this figure, where node n1 has to transmit an L-bits message to the base station. The closest cluster-head to n1 is CH1. And, if the node belongs to this cluster, it will spend energy (6.6).

$$E3 = L \cdot E_{elec} + L \cdot \epsilon_{d2} \cdot d_2^u \qquad 6.6$$

Where $$\begin{cases} u = 2\,,\epsilon_{d2} = 10 \text{ pj / bit / m}^2, & if\ d_2 < d_0 \\ u = 4\,,\epsilon_{d2} = 0.0013 \text{ pj / bit / m}^4, & if\ d_2 \geq d_0 \end{cases}$$

But if the node n1 chooses to transfer data to the base station directly, this energy will be (6.7):

$$E4 = L \cdot E_{elec} + L \cdot \epsilon_{d3} \cdot d_3^v \tag{6.7}$$

Where $$\begin{cases} v = 2\,,\epsilon_{d3} = 10 \text{ pj / bit / m}^2, & if\ d_3 < d_0 \\ v = 4\,,\epsilon_{d3} = 0.0013 \text{ pj / bit / m}^4, & if\ d_3 \geq d_0 \end{cases}$$

Here positive coefficients $u\ and\ v$ represent the energy dissipation radio model used. Clearly E4 < E3 but in this case lot of uncompressed data is collected at the base station.

To get rid of this problem a sleep state is introduced in M-EECDA in the following manner. When $E3 > E4$ it is not an optimal choice for transmitting data and energy saving , in this case instead of sending the data to the cluster head *CH1*, sensor node *n1* enters into a sleep state and waits for the next round in which it either itself becomes a cluster head or finds a nearby cluster such that $E3 < E4$. Sensor node n1 remains in the sleep state for the maximum 8 rounds, if in these next 8 rounds it either becomes a cluster head or finds a nearby cluster such that $E3 < E4$ it wakes up and performs the concerned duty either of a cluster head or the members of a cluster.

If sensor node n1 is neither able to become the members of a cluster such that $E3 < E4$ nor become a cluster head itself in the next 8 rounds , then the sensor node wakes up and transmit the data directly to the base station itself. The choice of maximum 8 rounds of sleep state is based on the fact that advanced nodes rotate the cluster head rotation cycle after every 8th round.

6.3 SIMULATION AND RESULTS

The performance of M-EECDA is compared with EECDA. For evaluation 100 x 100 square meters region with 100 sensor nodes has been used as shown in Figure 6.3. The normal nodes are denoted by using the symbol (o), advanced notes with (+), super nodes by (*) and the base station by (x). The various assumptions make about the nodes and sensing region are given below.

- Sensors are deployed randomly in the region.
- The base station and sensors become stationary after deployment and base station is located in middle of the sensing region.
- Sensors are location unaware i.e. they do not have any information about their location.
- Sensors continuously sense the region and they always have the data to send the base station.
- Battery of the sensors cannot be changed or recharged as the nodes are densely deployed in a harsh environment.

- In the sensing region, there are three types of sensor nodes i.e. super, advanced and normal nodes. Super and advanced nodes have more energy than the normal nodes.

6.3.1 PERFORMANCE METRICS

The performance metrics used for evaluating the protocols are:

(i) **Network Lifetime:** This is the time interval between the network operation start until the death of the last node.

(ii) **Stability Period:** This is the time interval between the network operation start until the death of the first node.

(iii) **Number of Alive Nodes per round:** This will measure the number of live nodes in each round.

(iv) **Number of cluster heads per round:** This will reflect the number of cluster heads formed in each round.

(v) **Numbers of packets send to base station:** This will measure the total number of packets which are sent to base station.

6.3.2 RADIO DISSIPATION ENERGY MODEL

Radio energy model as described in [18] is used for this protocol (Figure 4.1). Free space and the multipath fading channel both the models are used depending upon the distance between the receiver and transmitter. When distance is less than a particular threshold value, then free space model used otherwise multipath loss model is considered. The amount of energy required to transmit L bit packet over a distance d is given by equation (6.8).

$$E_{Tx}(L,d) \quad \begin{matrix} L \times E_{elec} + L \times \varepsilon_{fs} \times d^2 & if\ (d < d_0) \\ L \times E_{elec} + L \times \varepsilon_{mp} \times d^2 & if\ (d \geq d_0) \end{matrix} \qquad 6.8$$

E_{elec} is the electricity dissipated to run the transmitter or receiver circuitry. The parameters ε_{mp} and ε_{fs} is the amount of energy dissipated per bit in the radio frequency amplifier according to the distance d_0 which is given by the equation (6.9).

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \qquad 6.9$$

For receiving an L bit message the energy expends by radio is given by

$$E_{Rx}(L) = L \times E_{elec} \qquad 6.10$$

The various parameters of the radio model are given in TABLE 6.1

Parameter	**Value**
E_{elec}	5 nJ/bit
ε_{fs}	10 pJ/bit/m^2
ε_{mp}	0.0013 pJ/bit/m^4
E_0	0.5 J
E_{DA}	5 nJ/bit/message
Message Size	4000 bits
p_{opt}	0.1

d_0	70m

Table 6.1 Radio Parameters of M-EECDA

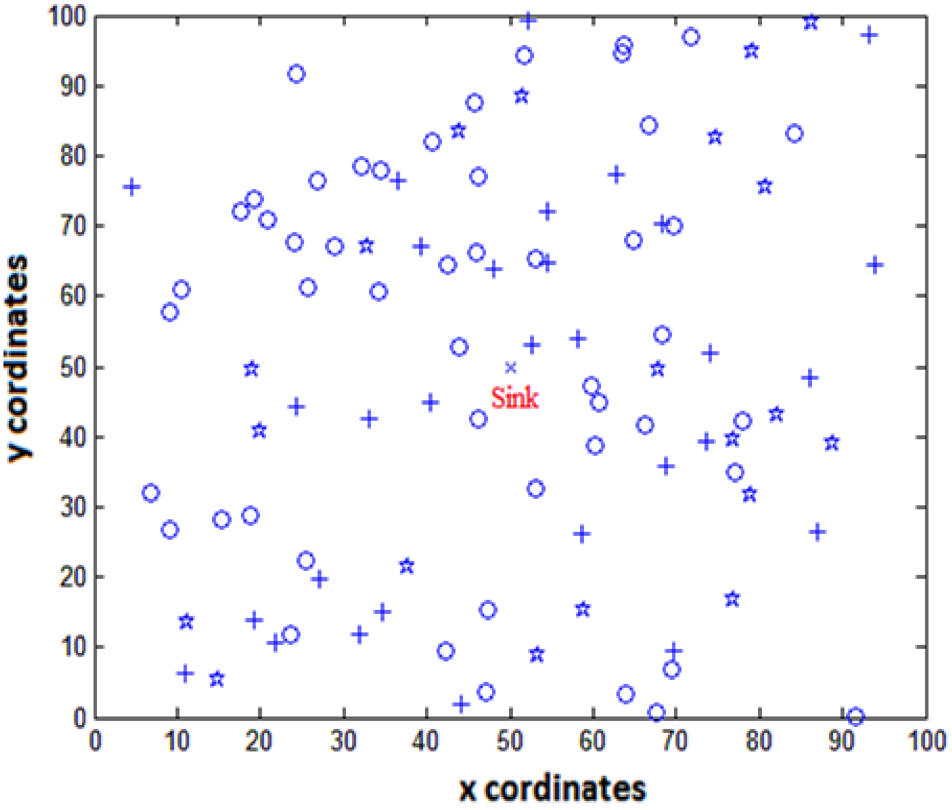


Figure 6.3 Sensing Region of M-EECDA

(o – Normal, + - Advance, * - Super Node, x - BS)

6.3.3 PERFORMANCE EVALUATION

The performance of M-EECDA is evaluated by introducing the following cases of heterogeneity

Case 1: m = 0.5, m_0 = 0.4, a =1, b =2

Case 2: m = 0.5, m_0 = 0.4, a =1.5, b = 3

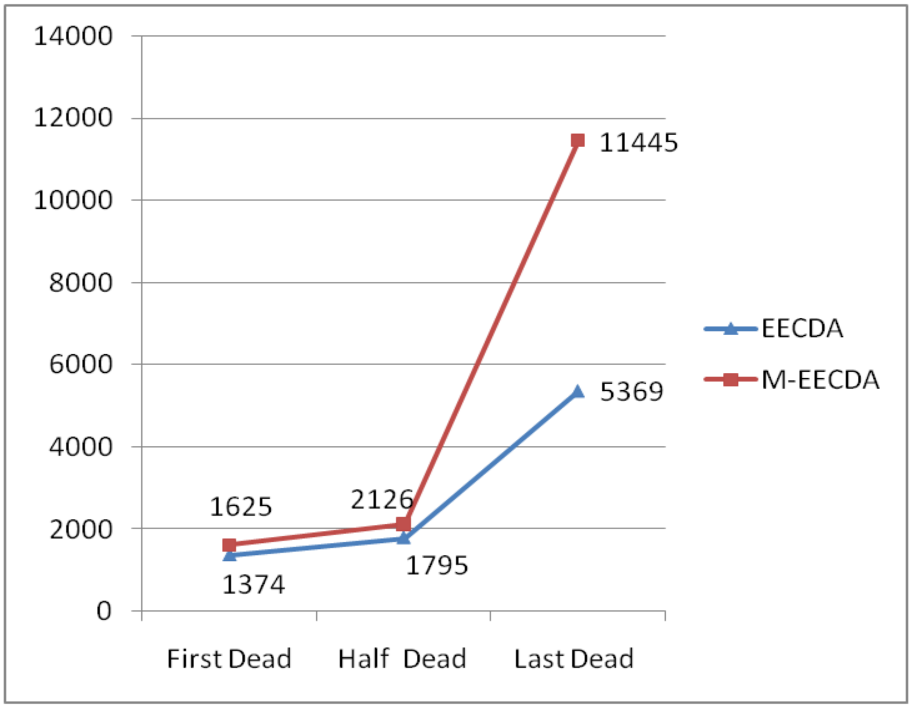


Figure 6.4 Rounds for 1st, Half & Last Node Death in M-EECDA & EECDA

Case 1: m = 0.5, m_0 = 0.4, a =1, b =2

In this case there are **30** advanced nodes having **one** times and **20** super nodes have **two** times more energy as compared to normal nodes. Figure 6.4 shows that the network lifetime of M-EECDA is more than EECDA because last node dies in M-EECDA at **11445th** round and in EECDA it happens at **5369th** round. It means that the network life of the system is extended by **131%.** First node dies in M-EECDA at **1625th** round and in EECDA it occurs at **1374th** round. Thus the stability period of the system is increased by **18%**. Figure 6.5 shows that no of alive nodes per round are more in M-EECDA than EECDA. Figure 6.6 shows that throughput i.e. total number of messages send to the base station are more in M-EECDA. Figure 6.7 plots the total remaining energy (in joules) per round and it is more in M-EECDA than EECDA.

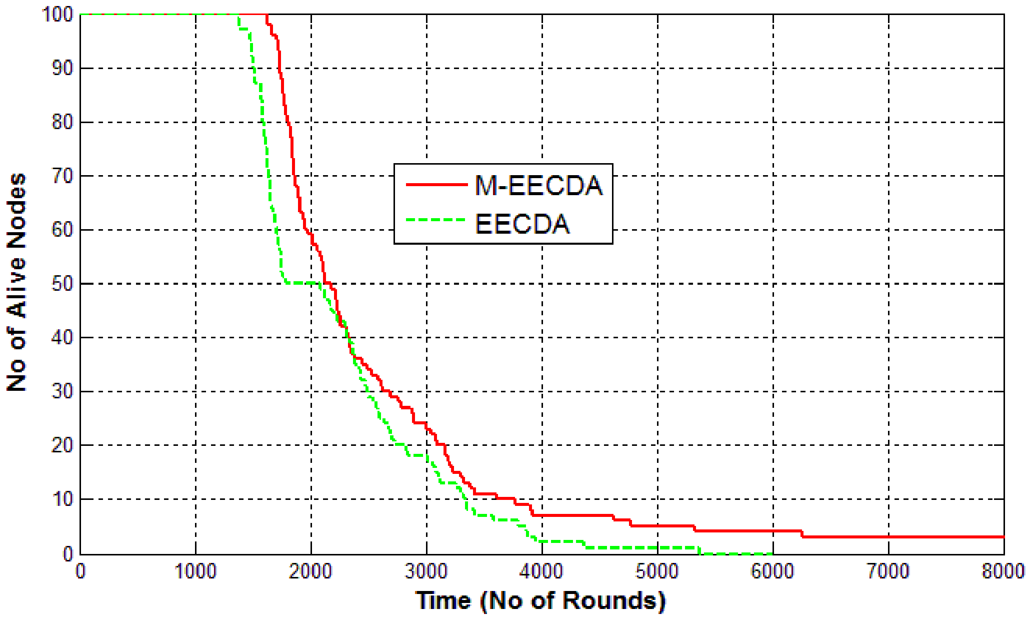


Figure 6.5 Comparisons of No. of Alive Nodes per Round in

M-EECDA & EECDA

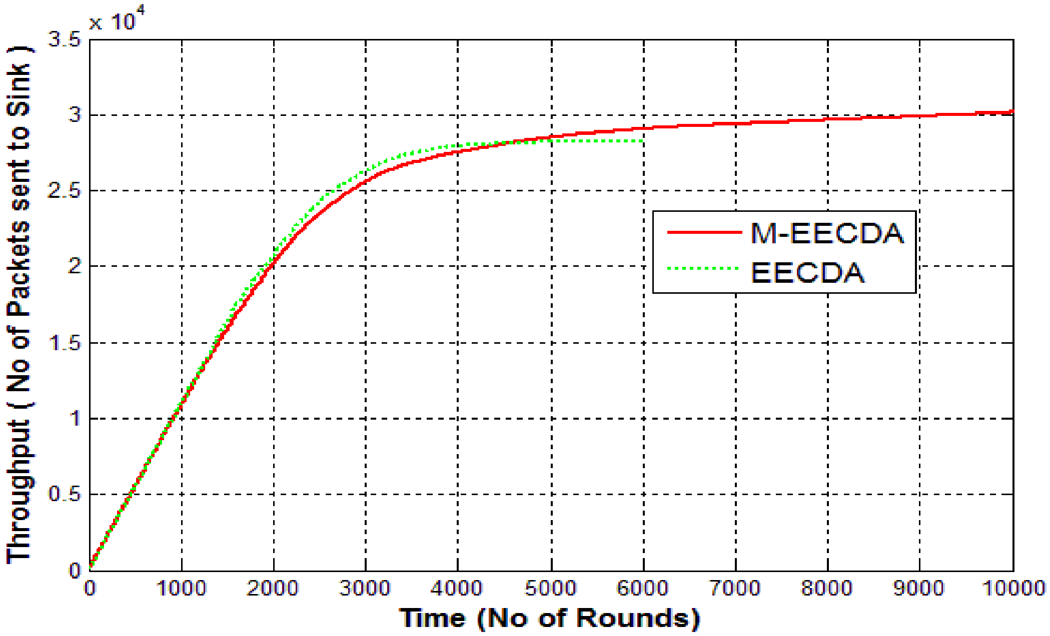


Figure 6.6 Comparisons of Throughput per Round in M-EECDA & EECDA

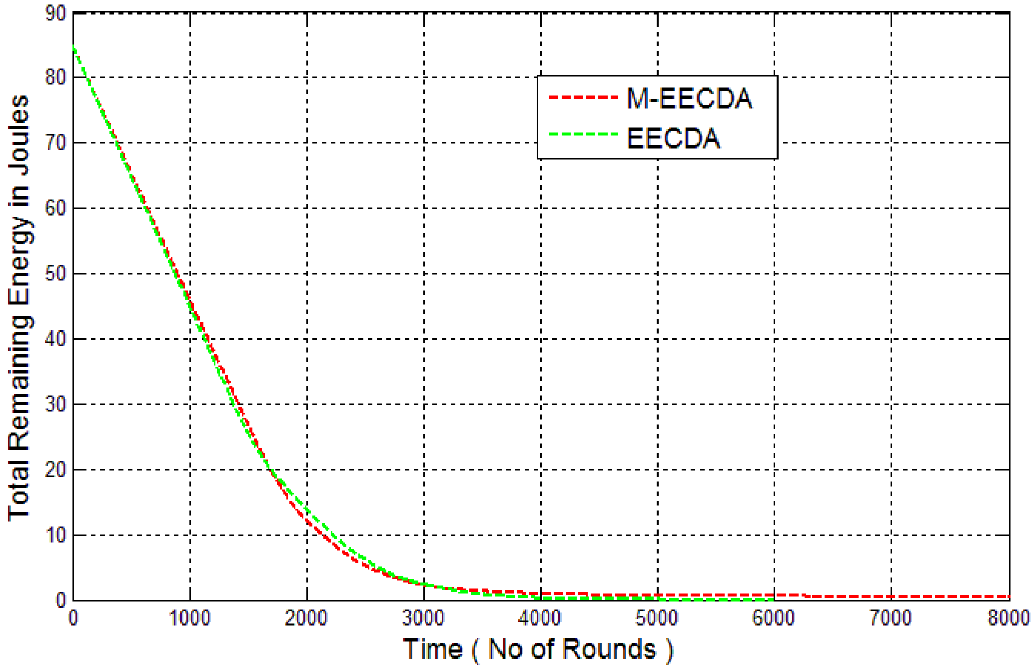


Figure 6.7 Comparisons of Total Remaining Energy per Round in M-EECDA & EECDA

Case 2: $m = 0.5, m_0 = 0.4, a = 1.5, b = 3$

In this case there are **30** advanced nodes and **20** super nodes. Advanced nodes have **1.5** times and super nodes have **3** times more energy than normal nodes. Figure 6.8 shows that the network lifetime of M-EECDA is more than EECDA as last node dies in M-EECDA at **11995th** round and in EECDA it occurs at **7125th** round i.e. the network life is extended by **68%.** First node dies in M-EECDA at **1705th** round and in EECDA it happens at **1480th** round. It means that M-EECDA extends the stability period of system by **15 %.** Figure 6.9 show that no of alive nodes per round are more in M-EECDA than EECDA. Figure 6.10 shows that throughput i.e. total number of packets send to the base station is more in M-EECDA. Figure 6.11 plots the total remaining energy (in joules) per round and it is also more in M-EECDA.

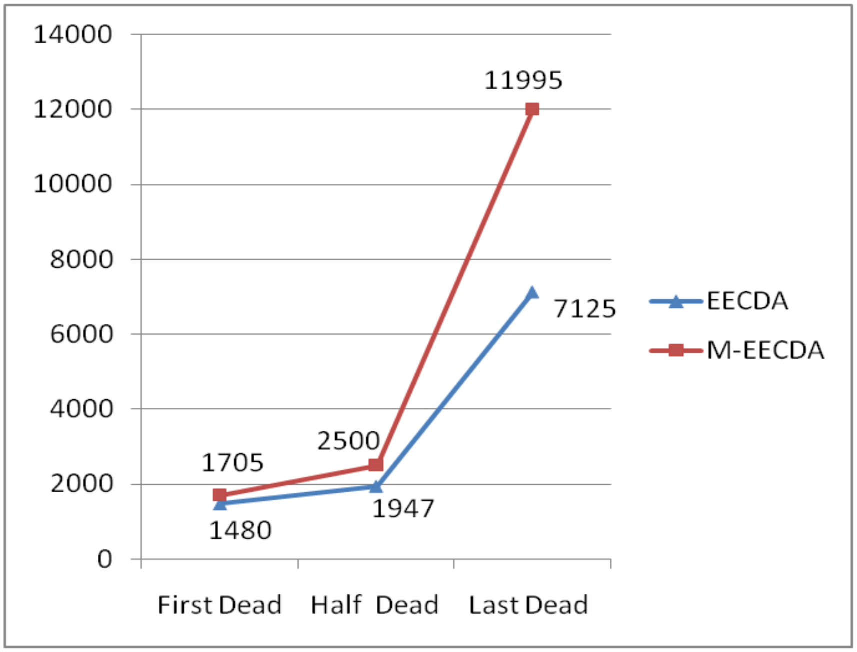


Figure 6.8 Rounds for 1st, Half & Last Node Death in M-EECDA & EECDA

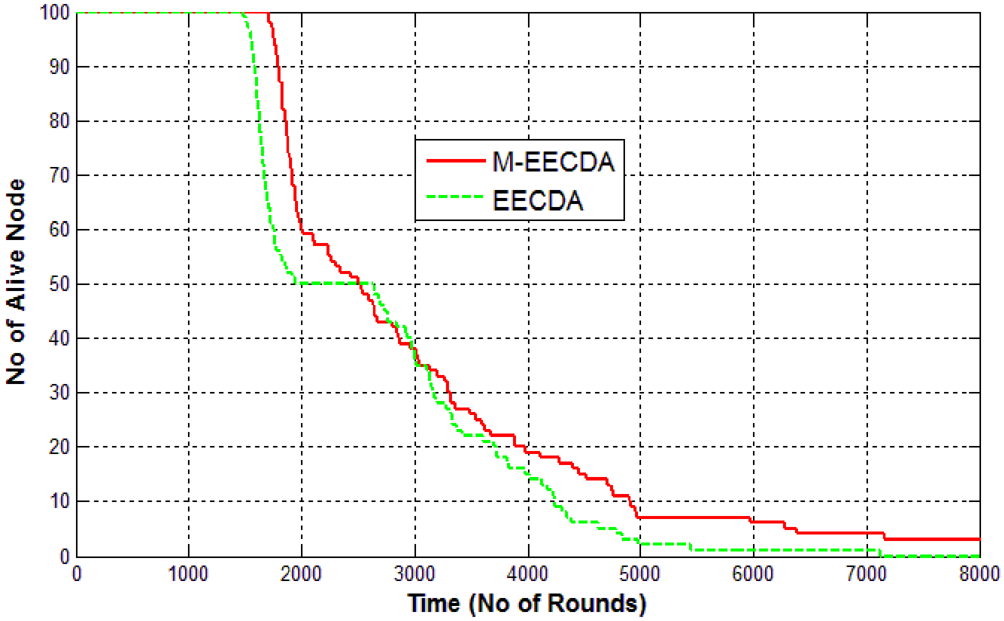


Figure 6.9 Comparisons of No of Alive Nodes per Round in M-EECDA & EECDA

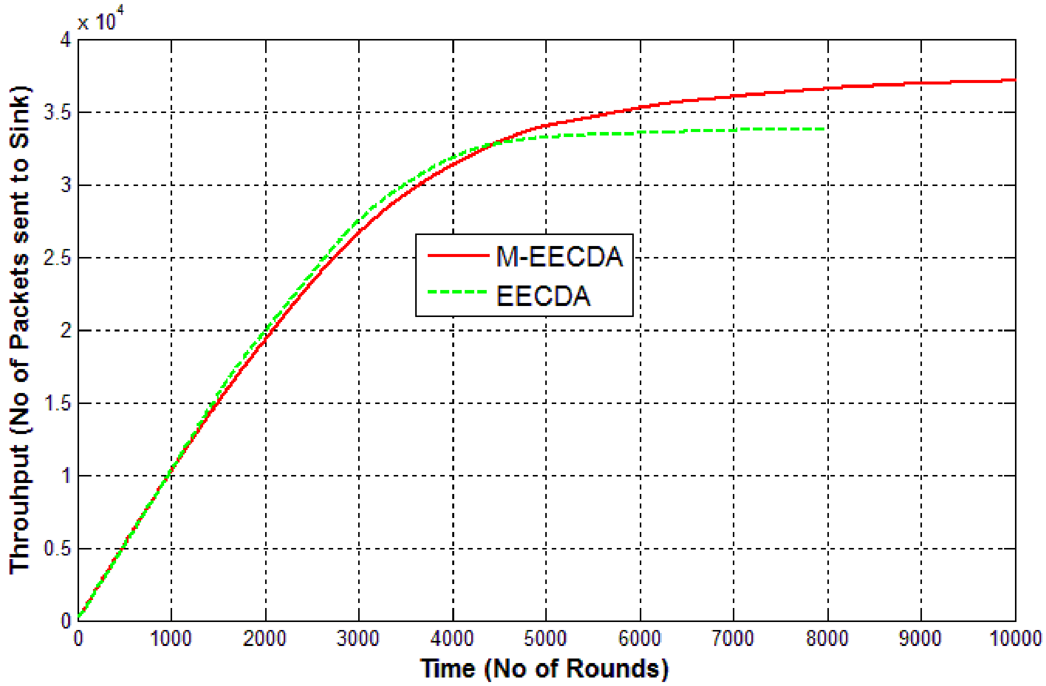


Figure 6.10 Comparisons of Throughput per Round in M-EECDA &EECDA

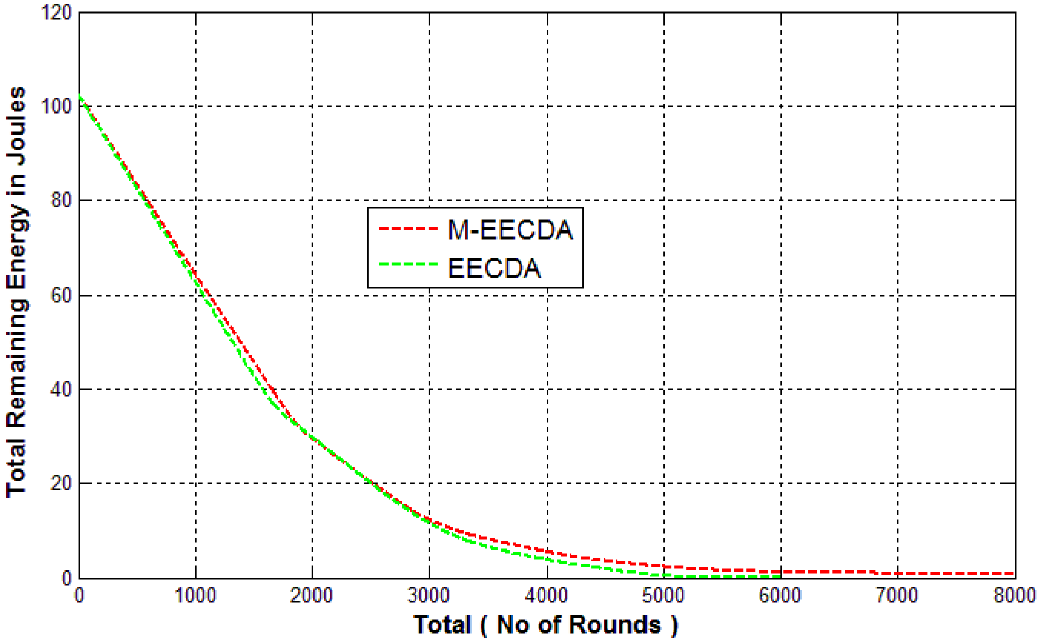


Figure 6.11 Comparisons of Total Remaining Energy per Round in

M-EECDA & EECDA

6.4. CHAPTER SUMMARY

This chapter has described M-EECDA, a multihop clustering protocol for three level heterogeneous sensor networks. The proposed protocol suggests a residual energy based cluster head election scheme for normal nodes because they have less energy. The protocol has also introduced three-tier architecture for normal cluster heads and their data load are taken over by advance and super nodes when they are not performing the duty of a cluster head. When joining to a nearby cluster head is not energy efficient then the protocol has suggested a sleep state for the nodes so that the energy of the network can be saved. Simulation results show that the proposed protocol M-EECDA has extended the stable region, network life and throughput of the system by **18 %, 131 %, 8 %** respectively when **(a = 1, b=2)**. Similarly, when (**a = 1.5, b =3)** stable region, network life and throughput is improved by **15 %, 68%** and **11 %** respectively. Next chapter will conclude the thesis with the directions for future research work.

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 CONCLUSION

Wireless Sensor Networks (WSNs) has become an important technology for monitoring and tracking applications. Reducing power consumption is an important design objective in sensor network. Clustering is a good technique for reducing the power consumption and increasing the network lifetime of sensor networks. This thesis has investigated the various energy efficient clustering algorithms for WSNs. The main aim of this research work is to develop a novel routing model or framework to solve the shortcomings of existing cluster based algorithms. The thesis proposes three novel cluster-based routing algorithms DEEN, EECP and M-EECDA to make the efficient use of critical resources of sensor network such as energy supply and prolong the network lifetime. Nodes in the proposed algorithms have made fast decisions (i.e., to become cluster heads or not) based on some probability or other local information (i.e., on their residual energy, distance from base station). Therefore there is no need of any global knowledge for their operation. The initial probability assigned to serve as the primary criterion for the nodes to decide individually on their election as CHs in a flexible, uniform, fast and completely distributed way. However other local information such as residual energy of a node or the distance of a node from base station serves as secondary criteria for the cluster head election process. EECP and M-EECDA suggest three-tier architecture for heterogeneous environments. They integrate the clustering and multihop short distance communication to reduce the range of data transmissions and save energy of sensor networks significantly. They further suggest a sleep state for nodes which are in base station direction and joining to nearby clusters is not energy efficient.

7.2 FUTURE WORK

Thesis presents some novel methods for routing strategy in wireless sensor network. In the future, a number of interesting research problems require further investigation Some ideas that need to be investigated and developed further are given in the following:

- **Extension of the proposed protocols:** We have proposed three novel routing algorithms for wireless sensor network and proven that the proposed techniques are better than many existing schemes. However, there are certain issues that need to be addressed, in order to use these algorithms from simulations to large-scale real world deployments.
- **Introduction of Mobility:** The entire algorithms presented in this research assumed that the network nodes and the base station are

becoming static after deployment. However in dynamic applications, the base station and/or the nodes can move. This type of work behaviour of both nodes and base station is not studied in the research. In the future work we will try to investigate the effect of mobility on the performance of various algorithms.

- **Study of asymmetric links:** Asymmetric link commonly exists in low power wireless sensor networks. Many reasons contribute to the existence of asymmetric links, including transmission power disparity, interference, obstacles, noise level difference as well as radio irregularity However, in this research the radio links are assumed to be symmetric therefore the network topology may affect this symmetry. The asymmetric links will have an impact on the network performance and in future work we will try to investigate this issue.
- **Combining spatial and temporal aggregation strategies:** Sensed data in Wireless Sensor Networks (WSNs) shows the spatial and temporal correlations in the different physical attributes of the sensed environment. Clustering techniques use the spatial aggregation to reduce the data redundancy. If spatial and temporal data aggregations are combined with each other, then the network performances will be improved considerably i.e. ideally a node should be able to autonomously decide whether to use only spatial or temporal correlations or both, depending on the characteristics of the monitored environment.

REFERENCES

[1] Liu Wei, Zhang Yanchao, Lou Wenjing, and Fang Yuguang "10 emerging technologies that will change the world", Technology Review, vol. 106, no.1, pp. 33-49, Feb. 2003

[2] Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). A survey on sensor networks. Communications magazine, IEEE, 40(8), 102-114.

[3] Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). Wireless sensor networks: a survey. Computer networks, 38(4), 393-422.

[4] Zheng, J., & Jamalipour, A. (2009). Wireless sensor networks: a networking perspective. Wiley. com.

[5] Akyildiz, I. F., & Vuran, M. C. (2010). Wireless Sensor Networks. Wiley. com.

[6] Pottie, G. J., & Kaiser, W. J. (2000). Wireless integrated network sensors. Communications of the ACM, 43(5), 51-58.

[7] Kahn, J. M., Katz, R. H., & Pister, K. S. (1999, August). Next century challenges: mobile networking for "Smart Dust". In Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking (pp. 271-278). ACM.

[8] http://csc.lsu.edu

[9] Al-Karaki, J. N., & Kamal, A. E. (2004). Routing techniques in wireless sensor networks: a survey. Wireless Communications, IEEE, 11(6), 6-28.

[10] Singh, S. K., Singh, M. P., & Singh, D. K. (2010). A survey of energy-efficient hierarchical cluster-based routing in WSN. International Journal of Advanced Networking and Application (IJANA), 2(02), 570-580.

[11] Otis, B., & Rabaey, J. M. (2007). Ultra-low power wireless technologies for sensor networks. Springer.

[12] Hill, J. L. (2003). System architecture for wireless sensor networks (Doctoral dissertation, University of California).

[13] Karl, H., & Willig, A. (2007). Protocols and architectures for wireless sensor networks. Wiley. com.

[14] Akkaya, K., & Younis, M. (2005). A survey on routing protocols for wireless sensor networks. Ad hoc networks, 3(3), 325-349.

[15] Abbasi, A. A., & Younis, M. (2007). A survey on clustering algorithms for wireless sensor networks. Computer communications, 30(14), 2826-2841.

[16] Yick, J., Mukherjee, B., & Ghosal, D. (2008). Wireless sensor network survey. Computer networks, 52(12), 2292-2330.

[17] Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000, January). Energy-efficient communication protocol for wireless microsensor networks. In System Sciences, 2000. Proceedings of the 33rd Annual Hawaii International Conference on (pp. 10-pp). IEEE.

[18] Heinzelman, W. B., Chandrakasan, A. P., & Balakrishnan, H. (2002).An application-specific protocol architecture for wireless microsensor networks. Wireless Communications, IEEE Transactions on, 1(4), 660-670.

[19] Ye, F., Luo, H., Cheng, J., Lu, S., & Zhang, L. (2002, September). A two-tier data dissemination model for large-scale wireless sensor networks. In Proceedings of the 8th annual international conference on Mobile computing and networking (pp. 148-159). ACM.

[20] http://www.ieee802.org/15/

[21] Werner-Allen, G., Lorincz, K., Ruiz, M., Marcillo, O., Johnson, J., Lees, J., & Welsh, M. (2006). Deploying a wireless sensor network on an active volcano. Internet Computing, IEEE, 10(2), 18-25.

[22] Zhang, P., Sadler, C. M., Lyon, S. A., & Martonosi, M. (2004, November). Hardware design experiences in ZebraNet. In Proceedings of the 2nd international conference on Embedded networked sensor systems (pp. 227-238). ACM.

[23] Krishnamurthy, L., Adler, R., Buonadonna, P., Chhabra, J., Flanigan, M., Kushalnagar, N., & Yarvis, M. (2005, November). Design and deployment of industrial sensor networks: experiences from a semiconductor plant and the North Sea. In Proceedings of the 3rd international conference on Embedded networked sensor system (pp. 64-75) ACM.

[24] http://www.alertsystems.org./

[25] Burrell, J., Brooke, T., & Beckwith, R. (2004). Vineyard computing: Sensor networks in agricultural production. Pervasive Computing, IEEE, 3(1), 38-45.

[26] Boomerang shooter detection system. http://bbn.com/boomerang

[27] Kulkarni, P., Ganesan, D., Shenoy, P., & Lu, Q. (2005, November). SensEye: a multi-tier camera sensor network. In Proceedings of the 13th annual ACM international conference on Multimedia (pp. 229-238). ACM.

[28] Lorincz, K., & Welsh, M. (2007). MoteTrack: a robust, decentralized approach to RF-based location tracking. Personal and Ubiquitous Computing, 11(6), 489-503.

[29] http://www.fiji.eecs.harvard.edu/CodeBlue

[30] Zhao, F., & Guibas, L. J. (2004). Wireless sensor networks: an information processing approach. Morgan Kaufmann.

[31] Sohrabi, K., Gao, J., Ailawadhi, V., & Pottie, G. J. (2000). Protocols for self-organization of a wireless sensor network. Personal Communications, IEEE, 7(5), 16-27.

[32] Intanagonwiwat, C., Govindan, R., & Estrin, D. (2000, August). Directed diffusion: a scalable and robust communication paradigm for sensor networks. In Proceedings of the 6th annual international conference on Mobile computing and networking (pp. 56-67).

[33] Zabin, F., Misra, S., Woungang, I., Rashvand, H. F., Ma, N. W., & Ali, M. A. (2008). REEP: Data-centric, energy-efficient and reliable routing protocol for wireless sensor networks. IET communications, 2(8), 995-1008.

[34] Shah, R. C., & Rabaey, J. M. (2002, March).Energy aware routing for low energy adhoc sensor networks. In Wireless Communications & Networking Conference, 2002. WCNC2002. 2002 IEEE (Vol. 1, pp. 350-355). IEEE.

[35] Rajagopalan, R., & Varshney, P. K. (2006). Data aggregation techniques in sensor networks: A survey.

[36] Gupta, G., & Younis, M. (2003, May). Load-balanced clustering of wireless sensor networks. In Communications, 2003. ICC'03. IEEE International Conference on (Vol. 3, pp. 1848-1852). IEEE.

[37] Jing, C., Gu, T., & Chang, L. (2008, December). ESCAL: an energy-saving clustering algorithm based on LEACH. In Knowledge Acquisition and Modeling Workshop, 2008. KAM Workshop 2008. IEEE International Symposium on (pp. 403-406). IEEE.

[38] Jang, K. Y., Kyung Tae Kim, Hee Yong Youn (2007, August). "An Energy Efficient Routing Scheme for Wireless Sensor Networks", Computational Science and its Application 2007. ICCSA 2007. In International Conference on Volume. Issue (pp. 26-29).

[39] Lindsey, S., & Raghavendra, C. S. (2002). PEGASIS: Power-efficient gathering in sensor information systems. In Aerospace conference proceedings, 2002. IEEE (Vol. 3, pp. 1125-1130). IEEE.

[40] Braginsky, D., & Estrin, D. (2002, September). Rumor routing algorithm for sensor networks. In Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications (pp. 22-31). ACM.

[41] Lindsey, S., Raghavendra, C., & Sivalingam, K. M. (2002). Data gathering algorithms in sensor networks using energy metrics. Parallel and Distributed Systems, IEEE Transactions on, 13(9), 924-935.

[42] Yueyang, L., Hong, J., & Guangxin, Y. (2006). An Energy-Efficient PEGASIS-Based Enhanced Algorithm in Wireless Sensor Networks. China Communications, 91-97.

[43] Manjeshwar, A., & Agrawal, D. P. (2001, April). TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks. In IPDPS (Vol. 1, p. 189).

[44] Manjeshwar, A., & Agrawal, D. P. (2002, April). APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks. In IPDPS (Vol. 2, p. 48).

[45] Smaragdakis, G., Matta, I., & Bestavros, A. (2004). SEP: A stable election protocol for clustered heterogeneous wireless sensor networks. In Proceedings of 2nd International Workshop on Sensor and Actor Network Protocols and Applications (SANPA'04), Boston, MA, pp 660-670

[46] Benkirane, S., Benihssane, A., Lahcen Hasnaoui, M., & Laghdir, M. (2012). Distance-based Stable Election Protocol (DB-SEP) for Heterogeneous Wireless Sensor Network. International Journal of Computer Applications,58(16), 9-15.

[47] Kumar, D., Aseri, T. C., & Patel, R. B. (2011). EECDA: energy efficient clustering and data aggregation protocol for heterogeneous wireless sensor networks. International Journal of Computers Communications & Control, 6(1), 113-124.

[48] Younis, O., & Fahmy, S. (2004). HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. Mobile Computing, IEEE Transactions on, 3(4), 366-379.

[49] Su, X., Choi, D., Moh, S., & Chung, I. (2010, February). An energy-efficient clustering for normal distributed sensor networks. In Proceedings of the 9th WSEAS International Conference on VLSI and Signal Processing (ICNVS'10), Cambridge, UK (pp. 81-84).

[50] Nurhayati, S. H. C., & Lee, K. O. (2011). A Cluster Based Energy Efficient Location Routing Protocol in Wireless Sensor Networks. International Journal of Computers and Communications, 2(5).

[51] Lu, H., Li, J., & Wang, G. (2009, December). A novel energy efficient routing algorithm for hierarchically clustered wireless sensor networks. In Frontier of Computer Science and Technology, 2009. FCST'09. Fourth International Conference on (pp. 565-570). IEEE.

[52] Qing, L., Zhu, Q., & Wang, M. (2006). Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. Computer communications, 29(12), 2230-2237.

[53] Kumar, D., Aseri, T. C., & Patel, R. B. (2009). EEHC: Energy efficient heterogeneous clustered scheme for wireless sensor networks. Computer Communications, 32(4), 662-667.

[54] Yu, F. (2011). A Survey of Wireless Sensor Network Simulation Tools. Washington University in St. Louis, Department of Science and Engineering.

[55] Ali, Q. I. (2012). Simulation Framework of Wireless Sensor Network (WSN) Using MATLAB/SIMULINK Software.

[56] Parallel Computing Laboratory at UCLA. (2010, May) GloMoSim. [Online]. Available: http://pcl.cs.ucla.edu/projects/glomosim/

[57] L. Bajaj, M. Takai, R. Ahuja, K. Tang, R. Bagrodia, and M. Gerla, "GloMoSim: A scalable network simulation environment," UCLA Computer Science Department Technical Report, vol. 990027, p. 213, 1999.

[58] J. Nuevo, "A Comprehensible GloMoSim Tutorial. Quebec, Canada, March 2004," 2006.

[59] QualNet Network Simulator [Online].
Available: http://www.scalable-networks.com/products/qualnet/,2012.

[60] OPNET Technologies, Inc. [Online].
Available: http://www.opnet.com/,2012.

[61] Levis, P., Lee, N., Welsh, M., & Culler, D. (2003, November). TOSSIM: Accurate and scalable simulation of entire TinyOS applications. In Proceedings of the 1st international conference on Embedded networked sensor systems (pp. 126-137). ACM.

[62] Levis, P., & Lee, N. (2003). Tossim: A simulator for TinyOS networks. UC Berkeley, September, 24.

[63] Notani, S. A. (2008, February). Performance simulation of multihop routing algorithms for ad-hoc wireless sensor networks using TOSSIM. In Advanced Communication Technology, 2008. ICACT 2008. 10th International Conference on (Vol. 1, pp. 508-513). IEEE.

[64] OMNeT++ Network Simulator [Online].
Available http://www.omnetpp.org/omnetpp/doc_details/2265-omnet-431-win32 source--ide--mingw-zip

[65] Varga, A. (2012). OMNeT++ user manual. OMNeT++ Discrete Event Simulation System [Online].
Available at: http://www.omnetpp. org/doc/manual/usman.html.

[66] Varga, A., & Hornig, R. (2008, March). An overview of the OMNeT++ simulation environment. In Proceedings of the 1st international conference on Simulation tools and techniques for communications, networks and systems & workshops (p. 60). ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).

[67] NS-2 developers. The Network Simulator NS-2. [Online].
Available: http://www.isi.edu/nsnam/ns/, 2012.

[68] NS-2 User Manual [Online].
Available: http://www.isi.edu/nsnam/ns/doc/ns_doc.pdf

[69] Networked and Embedded Systems Laboratory (NESL) at the University of California at Los Angeles (UCLA). SensorSim framework. [Online]. Available: http://nesl.ee.ucla.edu/projects/sensorsim/, 2012.

[70] UCLA Compilers Group). Avrora. [Online].

Available: http://compilers.cs.ucla.edu/avrora/, 2012.

[71] Department of Computer Science at University of Illinois at Urbana-Champaign). J-Sim. [Online].

Available: http://sites.google.com/site/jsimofficial, 2012.

[72] Sobeih, A., Chen, W. P., Hou, J. C., Kung, L. C., Li, N., Lim, H., ... & Zhang, H. (2005, April). J-sim: A simulation environment for wireless sensor networks. In Proceedings of the 38th annual Symposium on Simulation (pp. 175-187). IEEE Computer Society.

[73] Sobeih, A., Hou, J. C., Kung, L. C., Li, N., Zhang, H., Chen, W. P., ... & Lim, H. (2006). J-Sim: a simulation and emulation environment for wireless sensor networks. Wireless Communications, IEEE, 13(4), 104-119.

[74] MATLAB Web Site: http://www.mathworks.com/

[75] M. Yarvis, N. Kushalnagar, H. Singh “Exploiting heterogeneity in sensor networks,” IEEE INFOCOM, 2005.

[76] R. Kumar , V. Tsiatsis , and M. B. Srivastava , “ Computation hierarchy for in network processing ” , Mobile Networks and Applications , vol. 10 , no. 4, Aug. 2005 , pp. 505 – 518

[77] Bandyopadhyay, Seema, and Edward J. Coyle. "Minimizing communication costs in hierarchically-clustered networks of wireless sensors." Computer Networks 44.1 (2004): 1-16.

[78] Boukerche, A. (Ed.). (2008). Algorithms and protocols for wireless sensor networks (Vol. 62). Wiley. com.

[79] Lotf, J. J., Hosseinzadeh, M., & Alguliev, R. M. (2010, April). Hierarchical routing in wireless sensor networks: a survey. In Computer Engineering and Technology (ICCET), 2010 2nd International Conference on (Vol. 3, pp. V3-650). IEEE.

[80] Wei, C., Yang, J., Gao, Y., & Zhang, Z. (2011, December). Cluster-based routing protocols in wireless sensor networks: a survey. In Computer Science and Network Technology (ICCSNT), 2011 International Conference on (Vol. 3, pp. 1659-1663). IEEE.

[81] Liu, X. (2012). A survey on clustering routing protocols in wireless sensor networks. Sensors, 12(8), 11113-11153.

[82] Tyagi, S., & Kumar, N. (2013). A systematic review on clustering and routing techniques based upon LEACH protocol for wireless sensor networks, Journal of Network and Computer Applications, Vol. 36, No. 2, pp. 623-645.

LIST OF PUBLICATIONS

1. Kumar, S., Prateek, M., Ahuja, J., N., & Bhushan, B. (2014).Multihop Energy (MEEP) Efficient Protocol for Heterogeneous Wireless Sensor Network. International Journal of Computer Science and Telecommunications, vol. 5, no. 3, pp 1-8.
2. Kumar, S., Prateek, M., Ahuja, J., N., & Bhushan, B. (2014).Multihop Energy (MEECDA) Efficient Clustering and Data Aggregation Protocol for Heterogeneous Wireless Sensor Networks. International Journal of Computer Applications, vol. 88, no. 9, pp 28-35.
3. Kumar, S., Prateek, M., Ahuja, J., N., & Bhushan, B. (2014). Distance and (DE-LEACH) Energy Aware LEACH. International Journal of Computer Applications, vol. 88, no. 9, pp 36-42
4. Kumar, S., Prateek, M., & Bhushan, B. (2013). Distance Based (DBCP) Cluster Protocol for Heterogeneous Wireless Sensor Network. International Journal of Computer Applications, vol. 76, no. 9, pp 42-47.
5. Kumar, S., Prateek, M., & Bhushan, B. (2013). Energy Efficient (EECP) Clustered Protocol for Heterogeneous Wireless Sensor Network. International Journal of Advanced Research in Computer Science and Software Engineering, vol. 3, no.7, pp 1448-53.