ENERGY EFFICIENT ROUTING PROTOCOLS FOR WIRELESS SENSOR NETWORKS

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By

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AUGUST 2016

DECLARATION

I, **Deepa V. Jose**, hereby declare that the thesis titled '**Energy Efficient Routing Protocols for Wireless Sensor Networks**' submitted to Christ University, Bengaluru in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in **Computer Science** is a record of original and independent research work done by me under the supervision of Dr.G**. Sadashivappa, Professor & Head, Department of Telecommunication Engineering, R. V. College of Engineering, Bengaluru-59.** I also declare that this thesis or any part of it has not been submitted to any other University/Institute for the award of any degree.

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CERTIFICATE

This is to certify that the thesis titled "**Energy Efficient Routing Protocols for Wireless Sensor Networks**" submitted by Ms **Deepa V. Jose** to Christ University, Bengaluru in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in **Computer Science** is a record of original research work carried out by her under my supervision. The content of this thesis, in full or in parts, has not been submitted by any other candidate to any other University for the award of any degree or diploma.

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ABSTRACT

Wireless Sensor Networks (WSNs) have gained universal attention now a day's owing to the advancements made in the fields of information and communication technologies and the electronics field. This innovative sensing technology incorporate an immense number of sensor nodes or motes set up in an area to perceive any continuously fluctuating physical phenomena. These tiny sensor nodes sense and process the sensed data and transfer this information to a base station or sink via radio frequency (RF) channel.

The small size of these sensors is an advantage as it can be easily embedded within any device or in any environment. This feature has attracted the use of WSNs in immense applications especially in monitoring and tracking; the most prominent being the surveillance applications. But this tiny size of sensor nodes restricts the resource capabilities. Usually the WSNs are installed in application areas where the human intervention is quite risky or difficult. The sensed information might be needed to take critical decisions in emergency applications. So maintaining the connectivity of the network is of utmost importance. The efficient use of the available resources to the maximum extend is a necessity to prolong the network lifetime. If any node runs out of power, the entire network connectivity collapses and intend of the deployment might become futile. Because of this reason most of the research in the area of WSNs has concentrated on energy efficiency where the design of energy efficient routing protocols plays a major role.

This research work titled “Energy Efficient Routing Protocols for Wireless Sensor Networks” proposes to develop energy efficient routing protocol strategies so as to enhance the lifetime of the WSNs. A thorough study of the existing literature serves as the back bone for attaining acquaintance concerning the pertinent scenario, the problems faced and the application of the WSNs.

The use of clustering and sink mobility to enhance the energy utilisation is explored in this research. A modification of the most traditional energy efficient routing protocol for WSNs, LEACH (Low Energy Adaptive Clustering Hierarchy) is implemented initially by modifying the clustering mechanism. An enhancement of it by incorporating sink mobility, to further augment the energy efficiency is executed next. A modification of HEED (Hybrid Energy Efficient Distributed Clustering Hierarchy) protocol using the unequal clustering technique is also proposed. The modified protocols are simulated using MATLAB under different circumstances by varying the number of sensor nodes and the area of deployment. These modified protocols are intended for delay tolerant applications that require periodic sensing. The performance of the modified protocols is evaluated using metrics like residual energy of the network, packet delivery ratio, energy consumed by the network, delay, and the number of live nodes. The simulation outcomes showcased the effectiveness of the modified protocols compared to the relevant existing protocols in literature.

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LIST OF ABBREVIATIONS

ACK	Acknowledgement
ADV	Advertisement
AMRP	Average Minimum Rechargability Power
APTEEN	Adaptive Threshold sensitive Energy Efficient sensor Network
BS	Base Station
CH	Cluster Head
HEED	Hybrid Energy Efficient Distributed Clustering
LEACH	Low Energy Efficient Adaptive Clustering Hierarchy
MATLAB	Matrix Laboratory
MS	Mobile Sink
OSI	Open System Interconnect
PEGASIS	Power-Efficient Gathering in Sensor Information System
QoS	Quality of Service
REQ	Request
RF	Radio Frequency
RSS	Received Signal Strength
SS	Static Sink
TEEN	Threshold sensitive Energy Efficient sensor Network Protocol
UHEED	Unequal Hybrid Energy Efficient Distributed Clustering
WSN	Wireless Sensor Network

CHAPTER 1
INTRODUCTION

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INTRODUCTION

1.1 Wireless Sensor Networks

The revolutionary progression accomplished in the micro-electro-mechanical systems, digital electronics and wireless communication areas, steered the growth and application of the powerful and multifunctional sensor nodes, which are of small size and low cost. They can sense, process and communicate data unaltered over short distances. This aspect ultimately headed to the collaborative use of these sensor nodes in large numbers, termed as Wireless Sensor Networks (WSNs) (Akyildiz et al. 2002).

A WSN consists of a setup of sensor nodes/motes which perceives the environment under monitoring, and transfer this information through wireless links to the Base Station (BS) or sink. The sensor nodes can be heterogeneous or homogeneous and can be mobile or stationary. The data gathered is forwarded through single/multiple hops to the BS/sink (Buratti et al. 2009). The general structure of a WSN system is depicted in Figure 1.1.

A variety of sensors can be incorporated into the WSNs based on the application requisite. The WSNs typically doesn’t have any infrastructure; it can be structured or unstructured. The sensor nodes possess limited energy source as well as processing and memory capabilities. A radio is implemented for communicating the sensed facts to the BS and then on to the user. Power source of sensor nodes is battery. Energy harvesting techniques are also sometimes leveraged for charging the battery (Yick et al. 2008). The tiny size of the sensor nodes facilitates to embed these sensor nodes conveniently in any equipment or in any environment effortlessly. Because of this feature WSNs finds immense usage in monitoring and tracking applications in diverse fields.

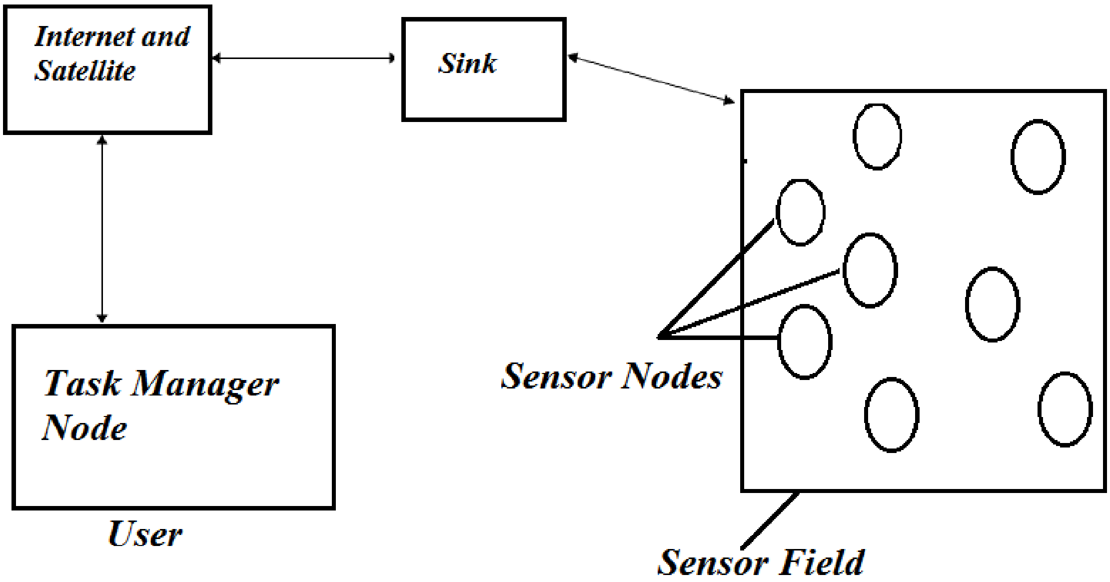

Figure 1.1: WSN Architecture (Akyildiz et al. 2002)

1.1.1 WSN Architecture

The OSI model is most often followed in the WSNs architecture (Abed et al. 2012). Essentially the WSN architecture has five main layers namely the physical layer, data link layer, network layer, transport and application layer. Besides these layers there are three cross layer planes responsible for the coordination of the entire sensors nodes and managing the overall efficiency of the network. They are the power management plane, the mobility management plane and the task management plane. The WSN OSI architecture is given in Figure 1. 2.

The power management plane coordinates the use of power. The mobility management plane is responsible for the tracking of node mobility while the task management plane schedules the sensing process.

These cross layer optimizations augment in conserving the energy and other resources.

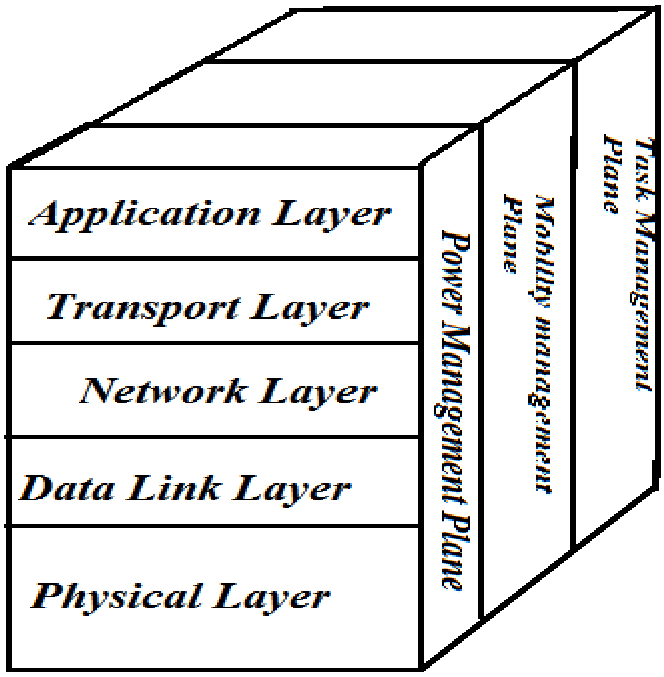

Figure 1.2 : WSN OSI Architecture (Pantazis et al. 2013)

The sensor nodes vary in size and functionality and are designed specifically on the application prerequisite as they are designated for specific application scenarios. The general architecture of a wireless sensor node is given in Figure 1.3.

A sensor node entails a microcontroller, a radio transceiver, a power source and other wireless communicating devices. The entire network functions in chorus, by using sensor nodes of different dimensions and appropriate routing algorithm for data transmission (Pantazis et al. 2013).

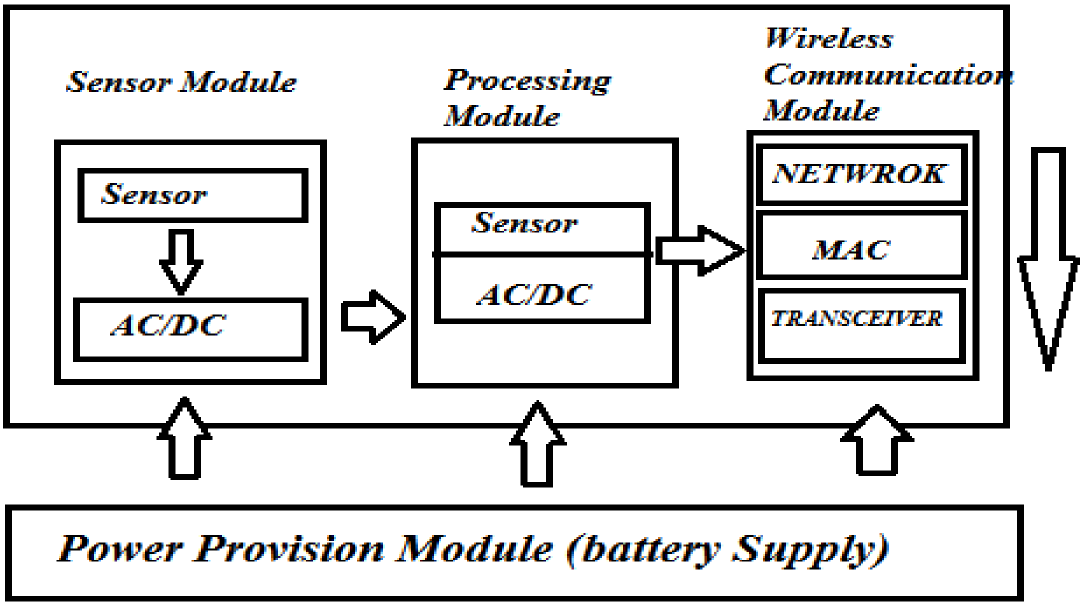

Figure 1.3 : Architecture of a Sensor Node (Pantazis et al. 2013)

The energy consumption of the wireless sensor node is dependent on the amount of energy consumed by each component for its various operations. The sensor module consumes power for sensing (periodic, sleep/wake), signal sampling, modulation, and for the analogue to digital conversion. The processing module spends energy when it is in idle, run or sleep states. The main operations of this module are controlling the sensing process, communication and data processing. The power consumption of wireless communication module is dependent on many factors like the hardware, operating frequency etc. The capacity of the power supply module is dependent on the manufacturer as well as the model of the node.

The unique characteristics and behaviour of WSNs demands a diverse method of traffic flow compared to the traditional networks. WSNs adopt two main traffic patterns; the single hop and multi hop methods for satiating its application requisite. This differentiation is on the basis of the number of nodes involved in the data transfer to destination. It is always preferred to have single hop communication as it more power efficient (Pantazis et al. 2013). But the range limits of the sensor nodes demand multihop communication.

The different multi hop communication patterns are local communication, point to point routing, convergence, aggregation and divergence. It is through the local communication that the status of the node is broadcasted to its neighbours. Figure 1.4(a) represents the local communication. This method is also used if data has to be transmitted between two immediate nodes. For transmitting data in wireless LAN environments point to point routing is used as mentioned in Figure 1.4 (b). The pattern of data movement from multiple nodes to a single BS is convergence while the reverse process is termed divergence. The convergence pattern is represented in Figure 1.4(c) and the divergence in Figure 1.4(e). When data processing happens at the nodes and the results are routed to the BS, it is called as aggregation. The diagrammatic representation of data aggregation is given in Figure 1.4 (d).

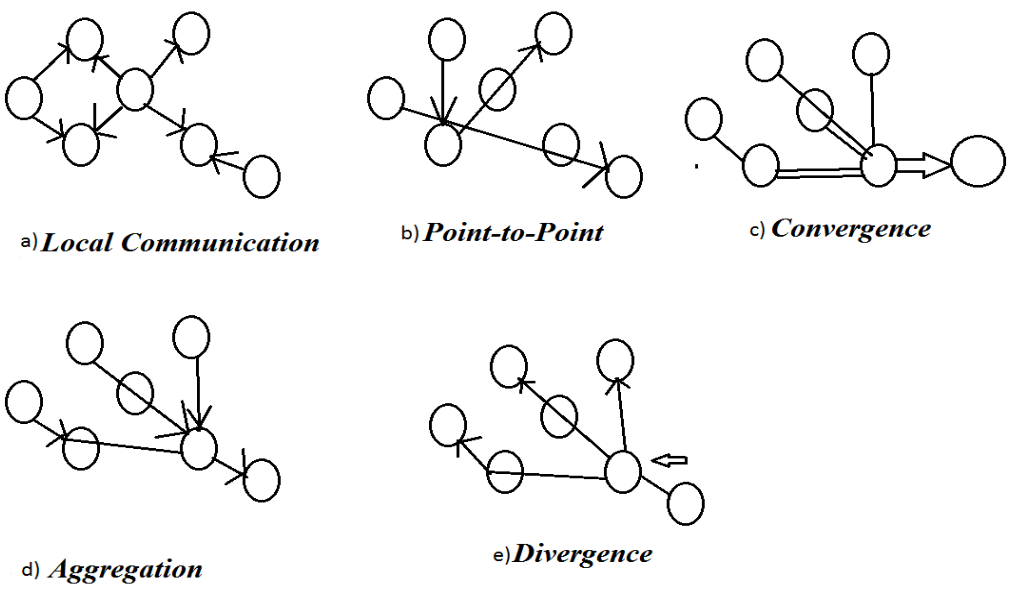

Figure 1.4 : Multihop Traffic Patterns in WSNs (Pantazis et al. 2013)

1.1.2 WSNs Vs Traditional and Ad-hoc Networks

There exist significant variances between wired traditional and ad-hoc networks and the WSNs. The distinctions emerge mostly on account of the resource constrains in WSNs related to energy, communication range, bandwidth, processing and memory capabilities (Sohraby et al. 2007). The stringent constraints in resources make it inevitable to have specific design considerations for protocol developments in WSNs (Buratti et al. 2009). Besides that, the design of WSNs is completely application dependent. The network topology, size of the network and the mode of deployment is based on the application requirement. Because of its unique features and application dependency, the algorithms and protocols used in traditional and ad hoc networks will not suite for WSNs. The major differences among sensor networks and ad hoc networks are (Akyildiz 2002):

- The nodes in WSNs will be of very large number compared to other networks.
- Sensor nodes will be densely deployed.
- Due to harshness of the environment and energy depletion, sensor nodes are susceptible to catastrophes.
- Topology changes will be usual in WSNs.
- Sensor nodes usually adopt broadcast communication while point-to-point communications is adopted by ad hoc networks.
- Sensor nodes face strict constraints in power, computational capacities and memory resource.
- Because of the huge quantity of sensor nodes and the overheads, they usually may not have global identification.

Sensor nodes will be heavily deployed in majority of applications they are involved. As the sensor nodes are placed quite close by, subsequently multihop communication consumes less power and transmission power levels can be kept low, compared to traditional networks. The effects of signal propagation experienced in wide-ranging communication can also be minimised. But because of the constraints in energy resources, WSNs has to focus more on energy conservation techniques.

1.1.3 Node Deployment in WSNs

Node deployment has significant impact on the lifetime and coverage of the network. In WSNs the node deployment strategies are mainly classified into two; static node deployment and dynamic node deployment (Zhang and Liu 2012).The mode of deployment can be random or deterministic.

In static node deployment the nodes remain static throughout their lifetime. Because of this, the positioning of the sensor node has to be determined taking into consideration the factors like maximum coverage, less energy consumption etc. and choosing the best optimization strategy. Based on the application scenario, the node deployment will be random or deterministic. The deterministic approach is used when the requirement and the nature of the deployment region is known prior and is manageable. The random deployment will be needed in situations of emergency like environment hazards and rescue operations. In such case, the sensor nodes will be randomly thrown over the area under monitoring, and later they self-organize.

For dynamic node deployment, backing of additional resources like robots is a must in order to place the sensor nodes in adequate positions to have optimum coverage. Dynamic node deployment is usually employed if the area under deployment is quite risky to have human interventions. Compared to static node deployment, dynamic node deployment has more overheads.

1.1.4 Topology of WSNs

In WSNs the topologies play a vital role in utilising the resources in an effective manner. In WSNs, the traditional network topologies are pursued in a different manner. The sensor node communication is governed by the network topology. Widely used WSN topologies are bus, tree, star, ring, mesh, circular and grid. Cluster, chain and flat topologies are also used in energy efficient WSN applications (Mamun 2012). A brief outline of the different energy efficient topologies single hop star, multi hop mesh and grid topology and the two-tier hierarchical structure topology used in WSNs are mentioned below (Kaur and Garg 2012).

Single hop star topology is the simplest WSN topology in which every node communicates directly with the sink. The single hop star topology is best suitable for applications which require less number of nodes within a small area. The limitation of this type of topology is the lack of scalability. The diagrammatic representation of the single hop star topology is given in Figure 1.5.

Multi hop mesh and grid topology is intended for applications that require large coverage. It provides self-configuration, self-healing and is scalable. The signal gets routed to the destination through multiple hops using some routing protocols.

Figure 1.6 gives the representation of multihop star random structured topology and Figure 1.7 represents the multihop star unstructured network. For large scale WSNs, two-tier hierarchical cluster topology is suited. The whole network is clustered and a CH is elected from each cluster to send data to the BS. Two-tier hierarchical cluster topology is represented in Figure 1.8.

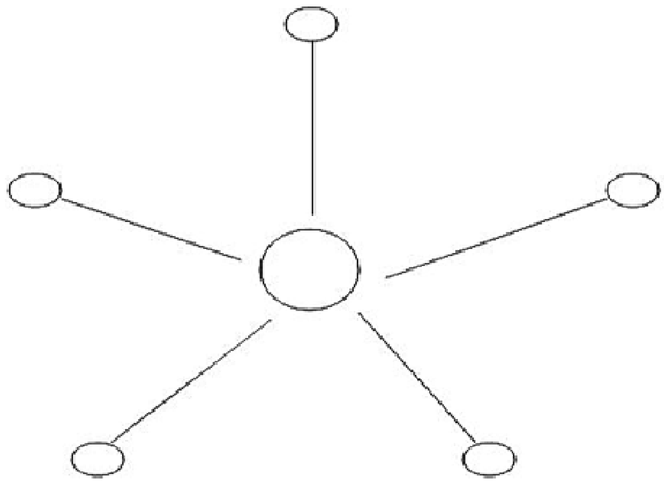

Figure 1.5 : Single Hop Star Topology (Kaur and Garg 2012)

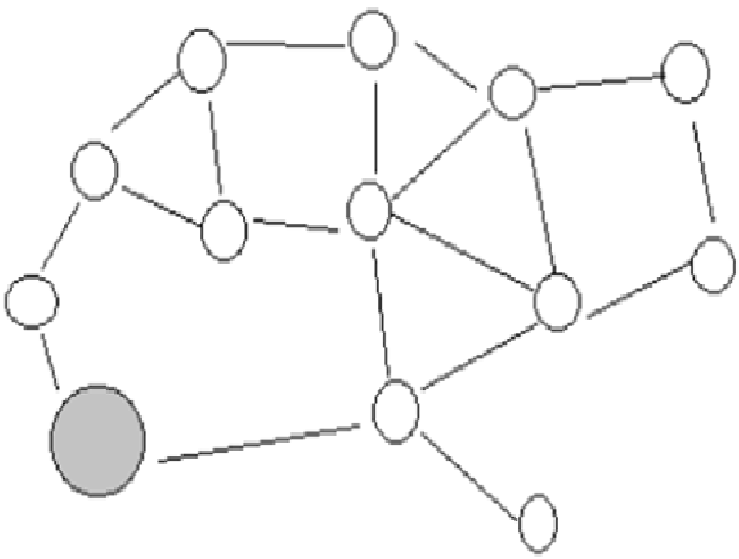

Figure 1.6 : RandomMulti Hop Star Topology(Kaur and Garg 2012)

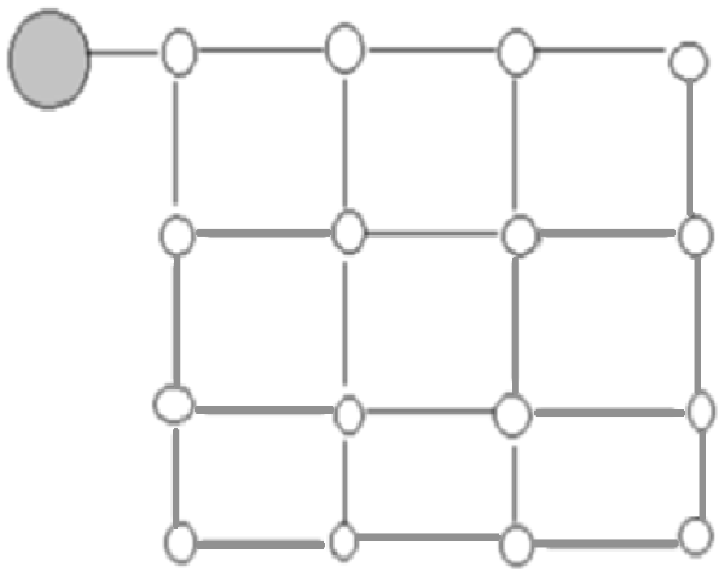

Figure 1.7 : Structured Multi Hop Star Topology(Kaur and Garg 2012)

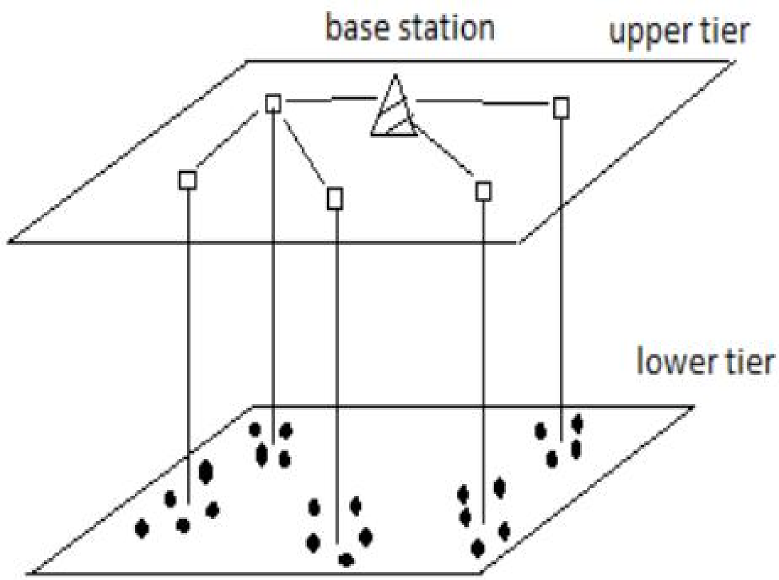

Figure 1.8 : Two Tier Hierarchical Structure (Kaur and Garg 2012)

The densely deployed WSNs in unattended situations with high risk of node catastrophes results in frequent topology changes which is a challenging issue in WSNs. The issues related to topology maintenance are a continuous process throughout the different phases of the WSNs. Issues can occur in post and pre deployment phases and during deployment phase (Akyildiz et al. 2002). In the pre-deployment phase and deployment phases, care has to be taken in the mode of deployment so as to reduce the cost of deployment and avoid the need for reorganising. After the deployment the major challenge is the change in topology due to node failures either due to environmental demolition or energy depletion. Re-deployment is possible in many cases but it requires reorganization of the network. So coping with the frequent and unexpected topology changes is a challenging issue in WSNs.

1.1.5 Types of Wireless Sensor Networks

WSNs are broadly classified as structured and unstructured WSNs. A compact collection of sensor nodes organized in an unplanned fashion intended for monitoring a zone constitutes the unstructured category. They will be left unattended after deployment. In such type of sensor networks maintenance is a challenging issue. In structured WSNs, the deployment is in pre-planned positions so as to have maximum coverage. Fewer number of nodes will be there, compared to that of unstructured WSNs and hence, maintenance and management is easier.

WSNs are used in immense applications in different environment conditions. Based on the application these sensor networks might be deployed in underground, land or underwater or embedded inside some equipment. Normally, the WSNs can be categorised as underground WSN, underwater WSN, terrestrial WSN, mobile WSN and multi-media WSN, (Yick et al. 2008).

1.1.6 Applications of Wireless Sensor Networks

The mere fact that a plethora of applications in our daily lives require the assistance of WSNs showcases the importance of this fast growing technology. The application areas of WSNs include military applications, environment monitoring, logistics support, robotics applications and so on (Arampatzis et al. 2005).WSN applications falls into two major categories: monitoring and tracking.

A variety of indoor and outdoor environmental monitoring applications use WSNs. Other monitoring applications are power monitoring, factory and process automation, seismic and structural monitoring, inventory management and wellness monitoring. Tracking applications include habitat tracking, vehicle tracking and so on. Figure 1.9 represents an overview of sensor applications.

WSNs are an integral part of defence applications. Military applications use sensor networks for the entire control and management of all sorts of surveillance and targeting applications. They are widely used for observing the activities of the regiments and battle fields, arms and ammunitions, exploration of opposing forces and terrain, assisting guidance systems for intelligent ammunition, assessment, revealing and investigation of nuclear, biological and chemical attacks. Some of the various commercial applications of sensor networks include inventory management which includes quality checking and monitoring, estimating the material fatigue, controlling robots and creation of smart environments, security surveillance in factories, chemical and gas industries, vehicular tracking and safety monitoring and so on. Smart home environments are going to be quite common in the near future. The application of WSNs is inevitable for creating such infrastructure.

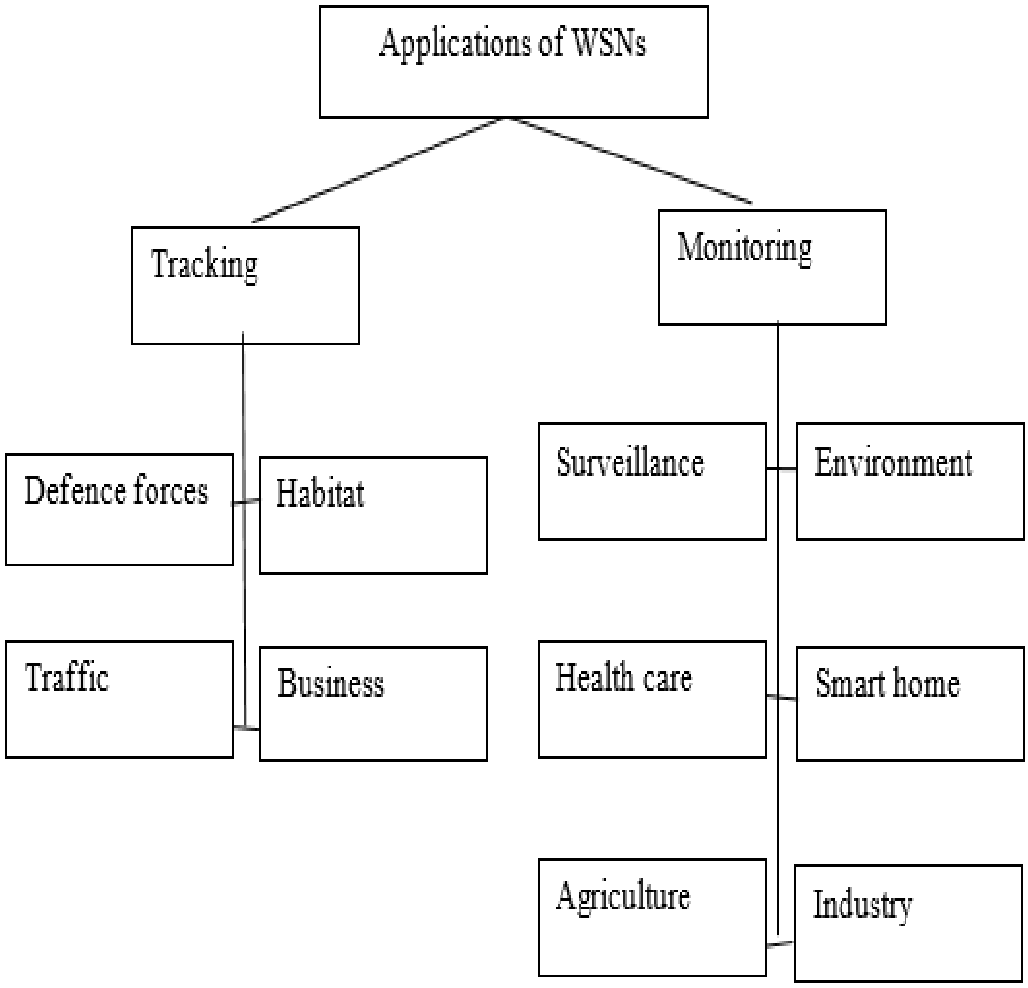

Figure 1.9 : Overview of WSNs Applications

1.1.7 Design Considerations in WSNs

The factors that influence the sensor network performance serves as a directive for strategizing the development of algorithms and protocols in WSNs. The major factors that affect the sensor network design are topology, operating environment, reliability and fault tolerance, scalability, hardware constraints and cost, transmission media, and usage of power (Akyildiz et al. 2002). The node deployment in WSNs can be random or deterministic based on the application scenario. If it is random, effective clustering techniques have to be adopted to save energy for prolonging the network connectivity. Similarly, the WSNs can be of homogeneous or heterogeneous type, and the need of data reporting can be based on time, query or a hybrid one. So handling this diversity is a major challenge. While designing the protocols utmost care has to be taken to achieve scalability and well as fault tolerance. The unstable topology of WSNs, because of the mobility of the sensor nodes, demands the network dynamics. Another major challenge is the problems associated with the wireless transmission media, the coverage and the connectivity issues. Data aggregation and attaining the expected quality of service are also major challenges faced by WSNs (Al-karaki et al. 2005).

1.1.8 Advantages and Limitations of WSNs

In WSNs, the tiny size of the sensor nodes helps to embed and install them easily in environments or in machineries. They find immense applications in monitoring and tracking applications. There are no specific infrastructure requirements for WSNs. Because of this WSNs are ideally suited for applications where human mediation is unsafe or inconceivable. Moreover, the cost component is moderate and the fact that enormous applications utilize WSNs is a confirmation for its prominence.

But the small size imposes stringent restrictions in memory, processing and the power resources in WSNs. The lifetime of the WSNs is dependent on the battery capacity. Hence efficient use of available resources is required for prolonging the lifetime. Another disadvantage of WSNs is related to security. It is complex to configure and has less speed compared to wired networks. The performance of the networks can be degraded because of obstacles in the path, coverage, signal attenuation etc. which is also a major drawback.

1.2 Routing Protocols in WSNs

WSN routing protocols are different from the traditional routing protocols because of its unique characteristics. The main objective in the design of a routing protocol is to lessen the energy consumption as the process of data transmission contributes to the highest in energy consumption in WSNs. The routing techniques adopted vary depending on the application requisite.

1.2.1 Routing Protocol Classification in WSNs

The routing protocols in WSNs can be static or dynamic in nature. They are classified based on different attributes like routing structure, routing decision and adaptive nature, timing and position, communication model, topology used and reliability concerns (Pantazis et al. 2013). Based on the network structure, the routing protocols for WSNs can be divided into flat-based routing, hierarchical-based routing, and location-based routing protocols (Al-Karaki and Kamal 2005). The routing structure where all nodes have same roles and functionality are called flat-based routing structure. In hierarchical based routing, each node has different roles in the network. In location based routing strategy the position of the sensor node is used for routing.

The routing protocols for which the various parameters are changeable for adapting to circumstances and existing energy levels belongs to the adaptive routing category. Based on the operation, they are further categorized based on coherence, multipath, query, negotiation, QoS routing techniques.

Besides these categories, based on the method of routing information from source to destination, the routing protocols are further classified as proactive, reactive, and hybrid categories. Advance computation of routes is done in the case of proactive protocols, while routes are computed on-demand for reactive protocols. A combination of these proactive and reactive ideas is used by hybrid protocols. Cooperative routing protocols are another category of routing protocols where the nodes send data to a central node. The data processing and aggregation is performed at the central node which reduces the energy consumption route cost. An overview of the different categories of routing protocols in WSNs is represented in Figure 1.10. Table 1.1 gives a relative scrutiny of the various routing techniques in WSNs.

Network structure is dependent on the node distribution. The nodes in some networks are organized consistently and in some cases randomly. The core trait of the routing protocols belonging to category of network structure is the way the nodes are interconnected for routing the information. This resulted in two types of node deployments, nodes with the same level of connection called flat protocols and nodes with different hierarchies called hierarchical protocols.

In hierarchical protocols, nodes are structured in clusters where a node with higher residual energy takes the role of a CH that coordinates activities within the cluster and forwards information between clusters. Clustering reduces energy consumption and prolongs the lifespan of the network.

The Communication Model adapted in a routing protocol suggests the way to route packets in the network. The highlight of these protocols is the high data delivery rate for a certain amount of energy for broadcast and point-to-point paradigms. But the data delivery ratio is very less and can’t be guaranteed. The protocols in this scheme are classified as Query-Based, Coherent and Non-Coherent-Based Protocols and Negotiation-Based Protocols (Pantazis et al. 2013).

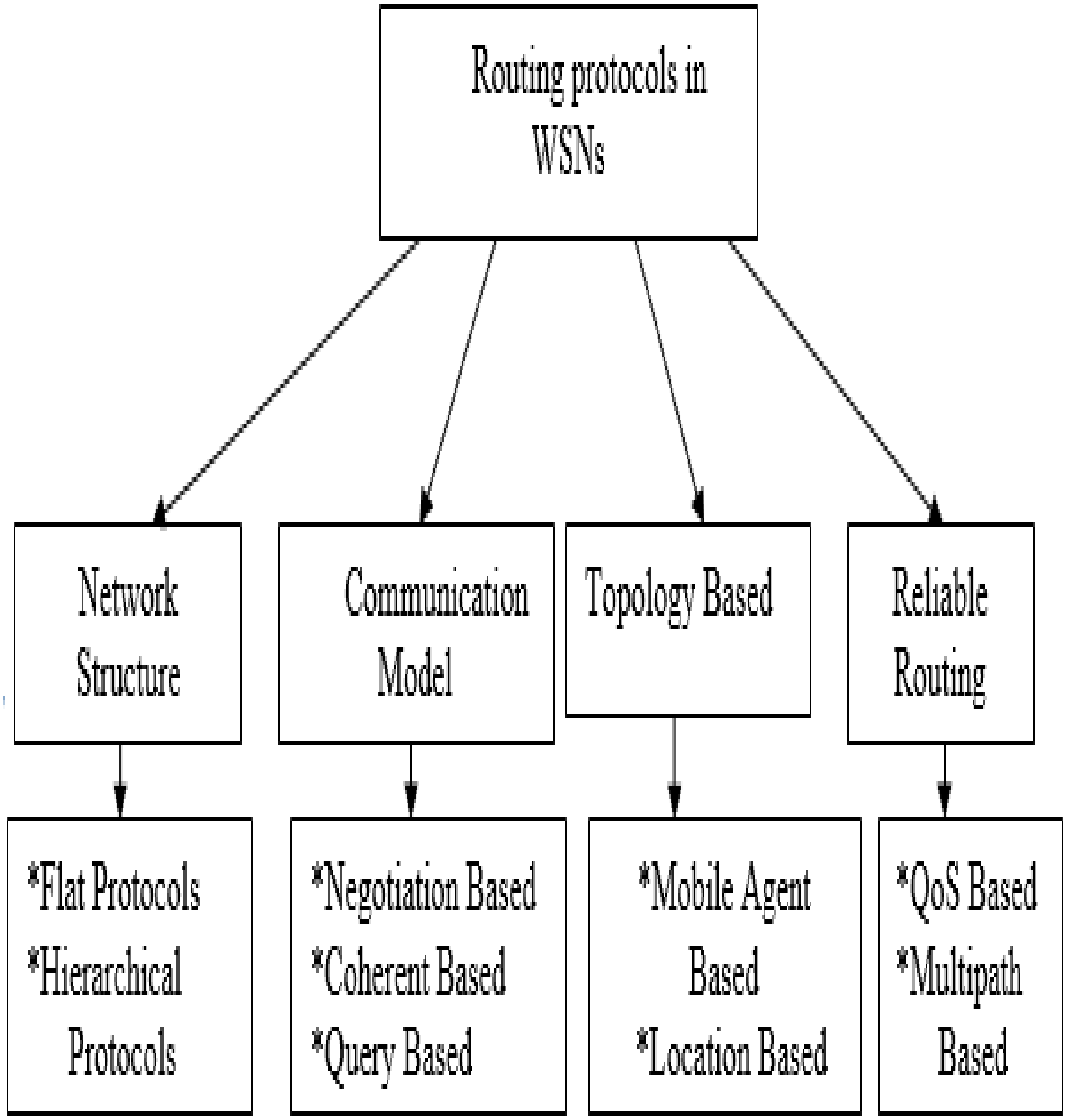

Figure 1.10: Classification of Routing Protocols (Al-Karaki and Kamal 2005)

Table 1.1: Relative Scrutiny of the Various Routing Techniques (Raghunandan and Lakshmi 2011)

Routing Protocols	Classification	Data Aggregation	Overhead	Data delivery model
SPIN	Flat	Yes	Low	Event driven
DD	Flat	Yes	Low	Demand driven
RR	Flat	Yes	Low	Demand driven
GBR	Flat	Yes	Low	Hybrid
CADR	Flat		Low	Continuously
COUGAR	Flat	Yes	High	Query driven
ACQUIRE	Flat	Yes	Low	Complex query
LEACH	Hierarchical	Yes	High	Cluster-head
TEEN & APTEEN	Hierarchical	Yes	High	Active threshold
PEGASIS	Hierarchical	No	Low	Chains based
VGA	Hierarchical	Yes	High	Good
SOP	Hierarchical	No	High	Continuously
GAF	Hierarchical / Location	No	Mod	Virtual grid
SPAN	Hierarchical / Location	Yes	High	Continuously
GEAR	Location	No	Mod	Demand driven
SAR	Data centric	Yes	High	Continuously
SPEED	Location/Data centric	Ltd	Less	Geographic

Reliable Routing Protocol schemes are more resistant towards route catastrophes as they achieve better performance through creating load harmonizing means and satiating certain QoS metrics. But the drawback is the difficulty of retaining routing tables at sensor nodes. The classifications of protocols under this category are Multipath-Based Protocols and QoS-Based Protocols (Pantazis et al. 2013).

1.2.2 Need for Energy Efficient Routing

Extensive research had been carried out over many years to address the possible collaboration among sensors in the various activities like sensing, data gathering and processing. As the WSNs have unique features, innovative techniques to extend the lifetime of the network are of utmost importance. The large number of sensor nodes and the environment restrictions of the deployed area based on the application, impose many restrictions for the strategy and management. Each layer in the WSN protocol stack is responsible in reducing the energy consumption. Among them the vital role is played by the network layer as it performs routing; the operation which consumes more energy (Al-Karaki and Kamal 2005). The communication process devours more energy equalled to that of sensing and processing. If any sensor nodes go out of power the connectivity of the network fails, and the intent of the deployment may become futile. Efficient use of the available resources is very much essential to retain and prolong the lifetime of the network. Adopting an energy efficient routing strategy can save energy to a great extend thereby enhancing the lifetime of the WSNs (Pantazis et al. 2013).

1.2.3 Design Issues and Challenges in Energy Efficient Routing

The major apprehension in WSNs is their stringent resource constraints which have to be utilized efficiently for extending the network lifetime. As it is difficult to replace or recharge the battery in many applications, it is utmost important to reduce the wastage of energy. Each layer in the communication task has an important role in achieving energy efficiency.

Focussing on the network layer, the routing process has a lot to do for efficient energy management. The major challenge in energy efficient routing is to have data communication without losing connectivity by employing stringent energy management techniques. Reducing the occurrence of collision so as to avoid energy requirement of retransmission is one such action. Overhearing by the neighbouring nodes is another cause for energy wastage. Idle listening is also a major reason for energy wastage. Similarly, while designing routing protocols, care has to be taken to avoid the control packet overheads (Gao et al. 2002).

1.2.4 Energy Efficient Routing Techniques

Energy efficiency can be attained through different methods. One commonly used method for energy efficient routing is clustering (Wei et al. 2008). Clustering is the process of dividing the entire sensor nodes into different sections called clusters. Each cluster will be assigned a CH accountable for routing the data. Data transmissions happen through intra cluster and inter cluster routing.

Clustering is again divided into two; equal clustering and unequal clustering. In equal clustering the clusters will be having equal sizes. Because of this the CHs near the BS get depleted fast as they will be continuously taking part in data transmission. Equal clustering can result in energy holes or hot spot issues which terminate the network connectivity.

In order to avoid this issue, unequal clustering is done where the clusters near the BS will be of smaller size compared to farther ones. This arrangement will reduce the burden of CHs near the BS by having less number of nodes to manage which leads to energy saving (Hamed 2013). The clustering process is depicted in Figure 1.11.

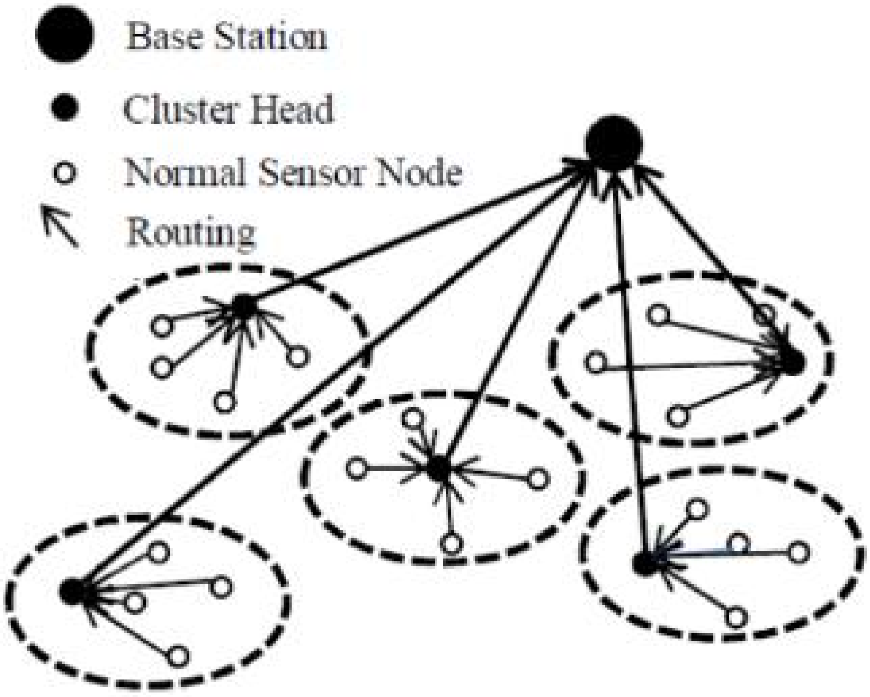

Figure 1.11: Clustering in WSNs (Wei et al. 2008)

There are different types of unequal clustering like Energy Efficient Unequal Clustering, Multihop Routing Protocol with Unequal Clustering, Unequal Hierarchical Energy Efficient Distributed Clustering, Energy Efficient Distributed Unequal Clustering, Energy Driven Unequal Clustering, Unequal Cluster Based Routing and Unequal Clustering Size etc. (Selvi and Manoharan 2013). Figure 1.12 gives an overview of the categorization of the clustering techniques commonly used in WSNs (Liu 2012).

The existing clustering methods vary in the characteristics of the clusters, the clustering process or the way of algorithm design. In random deployment models, the clustering variation will be mainly based on the process of cluster head selection strategies (Liu 2012).

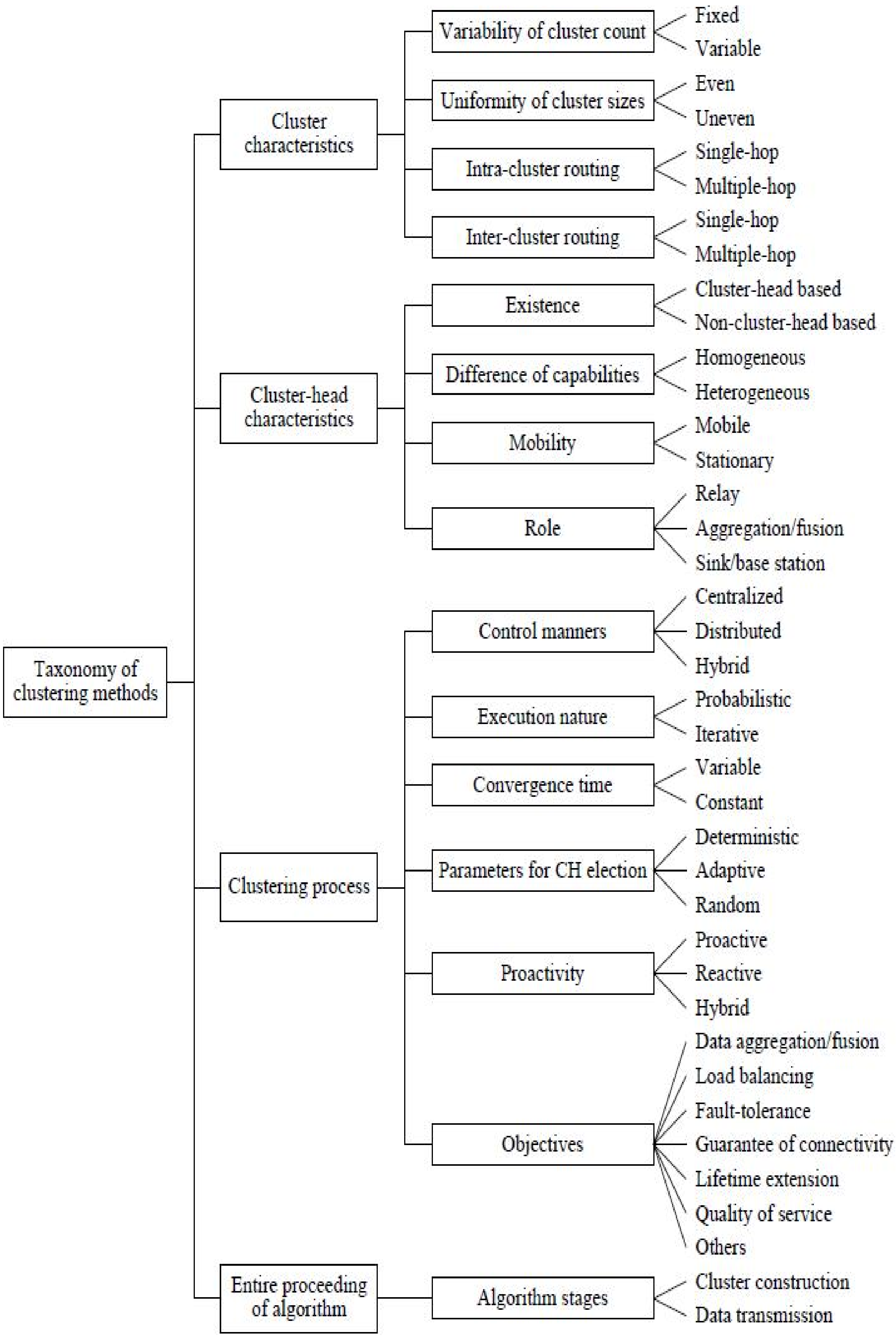

Figure 1.12: An Overview of the Categorization of Clustering Techniques (Liu 2012)

Some of the important decisions to be made during clustering can be summarized as follows (Ramesh and Somasundaram 2011; Liu 2012);

- How CH selection is initiated and how frequently re-election happens?
- What are the decision parameters for assigning different roles for the sensor nodes?
- Does the clustering guarantees even CH distribution and uniform load balance?
- What type of clustering is suitable for the varying network sizes and topologies?

As the wireless sensor nodes are rigorously power-constrained, the major apprehension is to preserve the nodes' energy. Duty cycling is another mechanism where the nodes will go to alternate sleep modes when they don't have sensing or data transmission. This also saves energy of idle listening (Jurdak et al. 2010). Employing only a single static sink can rapidly drain the energy of the nodes near to that sink. Furthermore, following a single path for the entire routing of data can also deplete the energy of the sensor nodes in that route. This results in unbalanced energy consumption in the network which can adversely affect the network lifetime.

Another major technique which can resolve such issues related to faster energy depletion of sensor nodes are the use of multiple sinks and mobile sinks for data gathering, adopting multiple paths to reach the destination and the application of power control and bio-inspired algorithms (Eslamminejad and Razak 2012; Boonosongsrikul et al. 2013). Sink mobility can reduce the number of hops to the BS which saves energy resulting in lifetime enhancement. The major categories of sink mobility are controlled/predictable sink mobility and uncontrolled/random sink mobility. Different mobility models are adopted based on the application demand (Koc and Korpeoglu 2014).

1.2.4 Overview of Energy Efficient Hierarchical Routing Protocols

The hierarchical routing protocols mainly focus on attaining energy efficiency through clustering. This routing structure has many advantages. Clustering at different levels can be done based on the requirement. The scalability can be attained by reducing the complexity of routing tables. Prominent energy efficient routing protocols are deliberated below. Figure 1.13 gives an overview of the classification of clustering algorithms; in which LEACH and HEED are considered as the traditional routing protocols for homogeneous and heterogeneous routing in WSNs (Kazerooni et al. 2015).

Low Energy Adaptive Clustering Hierarchy (LEACH) - It is the traditional energy efficient protocol under hierarchical structure. The entire functioning of LEACH happens in rounds with a steady phase and a set-up phase. It uses probabilistic approach for CH selection. The advantage of LEACH compared to other communicational protocols is that it provides better lifetime, ease for configuration and less energy dissipation. The drawback of LEACH is the overheads incurred in large deployment areas (Heinzelman et al. 2000). Many enhancements of LEACH protocol have been developed. Some of them are LEACH-C, LEACH-V, and M-LEACH etc.

Power-Efficient Gathering in Sensor Information System (PEGASIS) - LEACH modification with a chain based approach where the nodes communicates to its immediate neighbor alone resulted in PEGASIS. It shows more than twice performance improvement than LEACH but caused redundant transmission of data which is a drawback.

This is because of lack of concern in BS's position and nodes energy while selecting the head node (Lindsey and Raghavendra 2002).

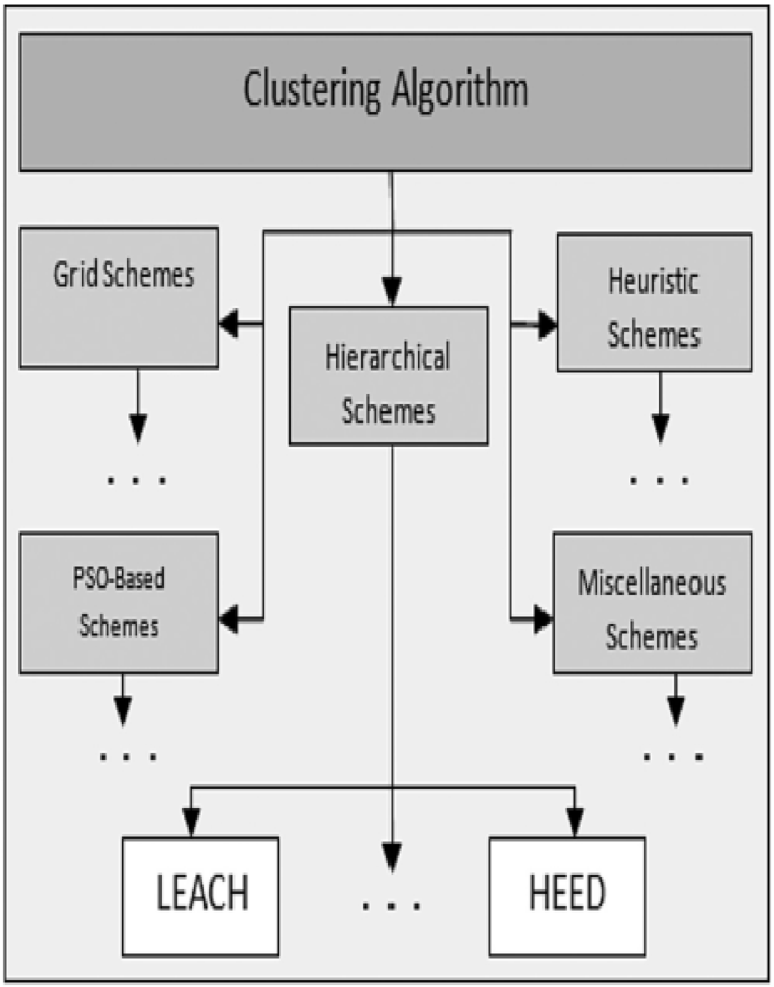

Figure 1.13: Classification of Clustering Algorithms (Kazerooni et al. 2015)

Threshold sensitive Energy Efficient sensor Network protocol (TEEN)-This routing strategy was intended for time precarious applications when continuous environment sensing is required. The nodes close by will group together and form clusters until the point of the sink. Hard and soft thresholds will be transmitted to the cluster members by their CH, based on which the transmitter will be switched on and the sensed value will be transmitted.

This approach works well for small area. If the deployed area is bigger it ended in more energy usage and overheads in the network operation which is a drawback. The ability to respond to immediate alteration in the detected feature is the charm of this protocol (Manjeshwar and Agrawal 2001).

Adaptive Threshold sensitive Energy Efficient sensor Network (APTEEN)- APTEEN, enhancement of TEEN possess the features of episodic data collection and well-timed response to delay intolerant situations. Once the clustering is done by the BS, the CHs broadcast the threshold values, transmission schedule and various attributes to all nodes. CHs aggregates data and transmit to the BS. This will save energy to a great extent. Compared to TEEN, APTEEN consumes less energy but the complexity involved is much higher (Manjeshwar and Agrawal 2002).

Hybrid Energy Efficient Distributed Clustering (HEED)-It uses a distributed clustering approach for enhancing lifetime of ad-hoc sensor networks. Node residual energy and node degree is considered for CH selection. HEED achieves a uniform CH distribution which results in load balance and energy saving. It terminates in $O(1)$ iterations with low message overheads and is a good approach in extending the lifespan of network (Younis and Fahmy 2004).Table 1.2 gives an overview of the performance of various hierarchical protocols based on different parameters (Liu 2012).

Table 1.2: Performance of Various Hierarchical Protocols (Liu 2012)

Protocol Name	Energy Efficiency	Cluster Stability	Scalability	Delivery Delay
LEACH	very low	moderate	very low	very small
HEED	moderate	high	moderate	moderate
DWEHC	very high	high	moderate	moderate
PANEL	moderate	low	low	moderate
TL-LEACH	low	moderate	moderate	small
UCS	very low	high	low	small
EECS	moderate	high	low	small
EEUC	high	high	high	moderate
ACE	moderate	very low	moderate	small
BCDCP	very low	high	very low	small
PEGASIS	low	low	very low	very large
TEEN	very high	high	low	small
APTEEN	moderate	very low	low	small
TTDD	very low	very high	low	very large
CCS	low	low	low	large
HGMR	low	high	very high	moderate

1.2.5 Metrics for Performance Evaluation in WSNs

Based on the application, the performance analysis of the functioning of the system is done using different metrics. The performance metrics categorisation of WSN can be performed based on the topology, signal strength, active probes, mobility and energy. The topology based metrics focus on the number of neighbour nodes and the hop counts. The signal strength is as a good pointer for determining the quality of the link. Active probing methods are used to get active measurements on the go rather than getting the measurements at the end. The mobility based performance evaluation metrics are mainly dependent on the measurements of the Received Signal Strength (RSS) and their variation rate (Rao and Kumar 2012). The most commonly used metrics for performance evaluation in WSNs are delay, throughput, packet delivery ratio, energy consumption, residual energy, reliability, latency and scalability.

The amount of energy required to send a packet from source to destination is calculated as energy per packet. For time driven or delay constrained applications, reliability is an important performance measure. Another performance metric is network lifetime. It is usually observed as the time of first node's death or certain portion or all nodes depletes its energy. Network life time is also measured as period when the network stops functioning. As network life time is an important parameter, in order to sustain the longevity of the network shortest paths are always preferred. The average energy dissipated is another metric for assessing the network lifetime. It is the average dissipation of energy per node for the various operations. Low energy consumption of the network is another evaluation metric. The total number of nodes alive, the number packets that reached the BS the average packet delay also measures the performance efficiency of the system. For reliability of data delivery, packet delivery ratio is an important factor. It is evaluated as the ratio of number of packets sent form the source and that reached the destination. Time till the primary node or last node expires, energy used per round, idle listening time etc. are some of the other performance evaluation metrics (Pentazis et al. 2013).

1.3 Experimental Tools for WSNs

The difficulties incurred in the real time deployment of WSNs for various applications impose the need for having simulators, emulators or test beds for testing and understanding the new algorithms and validate them based on various parameters. These experimental tools help to get an actual experience of the feasibility of the developed software or hardware without much complexity, within stipulated time and minimal cost.

1.3.1 Overview of Simulation Tools

Simulation in WSN can be either discrete-event driven or trace driven. Discrete-event simulation can easily simulate the tasks running on different sensor nodes and is mostly preferred for WSN simulation. Trace-Driven Simulation is commonly used in real system and has more credibility (Yu and Jain 2011).

NS2 (NetworkSimulator2), NS3, OMNeT++, JSim (JavaSim), MannaSim, SensorSim, NRL Sensorsim, NCTUns 6.0 (National Chiao Tung University Network Simulator), SSFNet (Scalable Simulation Framework Network Models), GloMoSim (Global Mobile Information System Simulator), QualNet 7.0 and EXata 5 (Quality Networking commercial network simulation software), sQualNet Simulator (Scalable Quality Networking), OPNET Modeler Suite (Optimized Network Engineering Tool), DRMSim (Dynamic Routing Model Simulator), NetSim (Network Simulator), UWSim (Under Water Simulator), SENS(Sensor Network Simulator and Emulator), SHAWN, SIDnet-

SWANS, WSim /Worldsens Simulator/ WSNet Simulator, WSN Localization Simulator, NetTopo Simulator, SIDH, PROWLER (Probabilistic Wireless Sensor Network Simulator), PiccSIM (Platform for Integrated Communications and Control design, Simulation, Implementation and Modelling), LabVIEW (Laboratory Virtual Instrument Engineering Workbench), MATLAB etc are some of the common simulators used by WSNs (Nayyar and Singh 2015).

MATLAB® which stands for Matrix Laboratory was developed by MathWorks Inc. It is a software which is used for high performance numerical computation and visualization. MATLAB is often used by scientific researchers as it has a combination of various features such as its analysis capabilities, flexibility, reliability and powerful graphics. This high-level language and interactive environment has hundreds of reliable and accurate mathematical functions which are built-in to the software. These functions provide solutions to a broad range of mathematical problems such as matrix algebra, complex arithmetic, linear systems, signal processing and many other types of scientific evaluations.

MATLAB provides an environment for exploring and visualizing ideas and collaborations related to various fields such as signal processing, image processing and others. The software is an easy tool for modelling energy consumption to build smart power grids, developing algorithms, analysing and visualizing data for various simulations. It has multiple features which allow the software to be used for iterative explorations, design and problem solving. MATLAB provides built-in graphics which can be used to visualize data and tools that are used to create custom plots. The development tools provide help in improving code quality and maintainability which maximizes performance. MATLAB's programming capability makes the software easy to learn and use. Users can easily develop their own functions. Through the use of an external interface, MATLAB allows access to FORTRAN algorithms and C codes. The software includes several optional toolboxes which can be used for special applications such as signal processing, control systems design, statistics, neural networks, fuzzy logic and others. The Simulink program, the software package for modelling, simulating and analysing has extensively enhanced MATLAB.

MATLAB 2015A is currently the latest version. It allows for the customization of functions according to our requirement. The toolboxes like Aerospace, Control System Design, Fuzzy Logic, Symbolic Computations, Statistics, Communication and many others are also the attractive features of MATLAB (Ali 2012).

1.4 Organization of the Thesis

Chapter 1 presents the introduction to WSNs and its various characteristics. The architecture of WSNs, difference between traditional wired networks and WSNs, the topology and node deployment strategies, and applications, the various challenges in their design, the different classifications of routing protocols and the various performance metrics are discussed. An overview of the various simulation tools used in WSNs is also mentioned emphasising the features of the MATLAB which is used as the simulation tool for this research work.

Chapter 2 explains the related works in energy efficient routing protocols in WSNs. It includes the literature survey of WSNs and its applications, classification of routing protocols, review on the energy efficient routing strategies and protocols and the simulation and experimental tools for WSN research. It also describes the need of the study and the research objectives.

In Chapter 3, the LEACH algorithm, its architecture and operations, and the advantages and limitations are given. The Modified LEACH algorithm, and the performance analysis based on simulation using MATLAB is elucidated next.

Chapter 4 discusses on the advantages of mobility of the sink nodes for energy efficiency enhancement. The details regarding the impact of sink mobility in the Modified LEACH algorithm and the performance evaluation based on the simulations using MATLAB are explained.

The operation of HEED protocol and the Modified HEED using unequal clustering is given in Chapter 5. It gives the performance analysis of the Modified HEED using simulation in MATLAB.

Chapter 6 mentions the results acquired and the outcomes of this research work and present the conclusions and future extent of the research work carried out.

CHAPTER 2
BRIEF THEORY AND LITERATURE SURVEY

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2.1 Brief Theory

WSNs have immense applications in our day today life. The major limitation of the WSNs is the limited energy resources. A lot of research has been carried out in the area of energy efficiency in WSNs. As the design and the protocol development of WSNs are dependent on the application of these sensor networks, there is no unique solution for achieving energy efficiency.

This Chapter give a glimpse of the major research works carried out in WSNs, its applications, the different classification of routing protocols, energy efficient routing strategies and protocols, and the various simulation and experimental tools for WSNs. Section 2.2 gives an overview of the WSNs and their applications. A brief review of the classification of routing protocols is mentioned in Section 2.3. Section 2.4 reviews the various energy efficient routing protocols in WSNs with special focus on LEACH and HEED protocols. A review on the different energy efficient routing techniques like clustering, duty cycling, data gathering and the use of mobility concept is given in Section 2.5. Section 2.6 mentions the various simulation tools commonly used for WSNs.

The major research carried out in the areas of LEACH, Sink Mobility concept and HEED is focussed more, to understand the works carried out and the latest developments. Section 2.7 gives the summary of the ideas coined through literature review which explains the need of the study and the novelty of the proposed works followed by the statement of the objectives of this research in Section 2.8.

2.2 Review on Wireless Sensor Networks and its Applications

Akyildiz et al. (2002) gave a detailed review of WSNs. The authors describe the sensing tasks and the various applications in detail. A review on the factors influencing the design of WSNs, the different communication architectures of sensor networks and the layer wise algorithms and protocols were also explored. They also gave insight in to the open research issues in different layers.

Lewis (2004) explained the preliminary concepts needed to understand and implement sensor networks. A review of the different communication network topologies, communication protocols and routing, WSN and its applications in real time scenarios like creation of smart home environments were also discussed.

A detailed survey of the applications of wireless sensors and the WSNs was done by Arampatzis et al. (2005). A detailed explanation of the use of sensor networks in military applications, environmental monitoring including both indoor and outdoor, a variety of human centric and robotics applications were also explained.

An application in the area of monitoring, especially for monitoring and protecting oil, water and gas pipelines using WSNs was explained by Jawhar et al. (2008).A routing protocol for linear structure WSNs and a new hierarchical addressing scheme for the same was proposed by them. The authors claims that taking advantage of the linear structure they have optimised the protocols in such a way as to reduce energy requirements, the cost of installation and maintenance and increased the reliability and communication efficiency.

A survey of WSNs was carried out by Yick et al. (2008). An overview of the various new applications of WSNs and an extensive literature review on the different aspects like internal platform and operating system, communication protocol stack, and the network services, provisioning and deployment was performed. The major development and the challenges in all these areas were also highlighted.

Buratti et al. (2009) gave an overview of the evolution of WSN technology. This survey paper also mentioned the main applications of WSNs and the features and standards adopted in the WSN design. Different case studies including the real time implementations were also given. The performance of IEEE 802.15.4 based networks was also analysed.

A real time application, for managing the building fire was proposed by Zeng et al. (2010). The authors explained a routing strategy that can adapt to rapidly changing network scenarios. Through simulation the authors proved that the modified protocol satisfied the criteria necessary for supporting fire emergency situations in buildings.

For assuring safe and well-timed retort for critical situations Zeng and Zheng (2010) developed a unique routing protocol. The main focus was to have delay bounded routing of information avoiding the holes in routing. A comparison of the modified work was carried out with various other existing protocols to ensure the efficiency of the modified work.

Truong et al. (2010) proposed an opportunistic routing scheme for WSNs specifically for sensing and reporting on fire threats in buildings. The fire fighters will be equipped with small computers which can act as mobile sink nodes. The diverse ways in which these uncontrolled mobile sinks could augment performance, and improve protocols for publicizing the attendance of the mobile sinks, collecting data for forwarding, and prioritising disconnected regions was also investigated. The performance of the modified approach was validated through simulation as well as on randomly damaged networks which showed an increase in the data delivery by 50%.

Eslaminejad and Razak (2012) gave a detailed survey of the WSNs emphasising the prominent mechanisms in lifetime enhancement through routing. The authors also presented a detailed explanation of protocols and threw light to the various open research issues which were not addressed.

Davis and Chang (2012) carried out a survey on the architectures of WSNs. Based on the behaviour and characteristics of data flow, they classified the WSN architectures into different groups. The currently existing architectures were evaluated based on different parameters. The advantages and disadvantages of each case were also presented.

Wang et al. (2013) studied the impact of multiple static sinks based on scalability. They modified and validated an energy efficient multi sink clustering algorithm. The impact of node density, the positioning of nodes and the mobile sink velocity was studied and proposed a mobile sink based energy efficient clustering algorithm. According to the validations done using simulations both these protocols are suitable for applications in consumer home network environment.

Khan et al. (2014) modified an energy aware environmental monitoring and conservation application which can be used for monitoring temperature and humidity of a particular region. They developed a model and a shortest path algorithm for the same.

Chin and Chuang (2015) proposed an analytical framework to ensure the corrections of the decisions based on the probability of detection in frequently varying sensor topologies. The authors claim through simulations that the proposed work increases the detection accuracy. Chen et al. (2016) created a frame work for emergency rescue application which helps in the easy crowd evacuation in emergency situation.

2.3 Review on Routing Algorithms, Issues and Challenges

Al-Karaki and Kamal (2004) outlined the issues for routing protocols in WSNs followed by a complete investigation of routing techniques. The authors categorised routing techniques in terms of their specific features. They analysed the design of each routing strategy in connection with the energy and communication overheads. The authors highlighted the pros and cons of each routing categories and mentioned the scope for future research.

Biradar and Patil (2009) analysed the design issues of sensor networks and presented a study on the comparison of routing protocols. This comparison exposed the key features that have to be considered for designing new protocols. They had classified routing protocols into node centric, data-centric, geo-centric and QoS based routing protocols.

Bhattacharyya et al. (2010) had carried out a review on the architecture of WSNs and routing protocols according to some key factors and summarized their mode of operation. They also provided a comparative study on these various protocols. The authors classified the routing protocols into proactive, reactive, hybrid, direct communication, flat, clustering protocols hierarchical, data centric and location based categories.

Anisi et al. (2012) gave an overview of the various data routing methodologies for WSNs.Accoding to the authors, the need for application specific routing strategies is on high demand due to the enormous applications of WSNs. The design of routing strategy depends on the goal of the application scenario. The authors give a detailed classification of the routing protocols which were classified based on the routing goals.

2.4 Review on Energy Efficient Routing Protocols

Heinzelman et al. (2000) modified the innovative energy efficient clustering mechanism for routing named as LEACH, the Low Energy Adaptive Clustering Hierarchy. This protocol is considered to be the traditional energy efficient clustering protocol in WSNs. An application specific architecture of the same was also developed by the authors.

Cheng and Jia (2005) modified a directional routing protocol which is energy efficient. For energy saving, they used duty cycling and scheduling. An election strategy was also adopted to select the next hop to the sink while other nodes will be made to sleep. According to simulation results, the modified algorithm cuts the average dissipated energy nearby 50% percent when matched with directional flooding.

Rahman and Matin (2011) focussed on finding the optimal sink position. Along with normal sensor nodes some relay nodes were also introduced for reducing the hotspot issues near the sink. In order to locate the optimal sink location, they used a particle swarm optimization algorithm. Instead of sending data directly to the BS, the relay node communicates with the sink. According to the authors this approach saved energy up to forty percent and extended the network lifetime.

Manfredi (2012) modified an existing energy efficient and reliable co-operative routing algorithm for wireless monitoring applications. The impact of the modified scheme was evaluated using network simulator. A comparison of the modified scheme with the Ad-hoc On-Distance Vector, shortest non-cooperative path and minimum-power cooperative routing algorithms based on reliability and energy efficiency were also carried out. An application of the modified algorithm in healthcare monitoring was also explained.

2.4.1 Low Energy Adaptive Clustering Hierarchy

A systematic study of the communication networks and the problems associated with the conventional routing protocols was carried out by Heinzelman et al. (2000). They proposed a novel clustering based protocol specifically for WSNs which uses randomised rotation of CHs so as to achieve balance in the energy load among the sensors in the network. This protocol was named as LEACH (Low Energy Adaptive Clustering Hierarchy). The simulation of the same was performed using first order radio model in MATLAB. According to the simulation results, LEACH was able to achieve eight times better energy efficiency compared to the conventional routing protocols.

Later Heinzelman et al. (2002) proposed LEACH protocol for micro sensor wireless networks, with the intend of providing ease of deployment, achieving maximum lifetime extension, latency and providing the application specific quality. In LEACH, local computation is performed which reduced the overheads of data transmission, configuration and operation of the network configuration. Experiment results showcased the high performance of LEACH in the constraints of wireless environment.

Yassein et al. (2009) modified a new version of LEACH protocol called VLEACH, with the addition of a vice CH which will act as the CH when the original cluster head dies off. According to VLEACH, the CHs will only transmit data to the BS, while the normal nodes do the sensing and send data to them. According to the authors, VLEACH outperforms LEACH in energy efficiency and reduces the message overheads.

Kong and Yun (2010) developed an enhancement of LEACH by giving a slight modification in clustering algorithm which incorporated the virtual multiple-input multiple-output based user cooperation. Instead of a single CH, multiple CHs were involved. Analysis and simulation results proved that modified cooperative LEACH protocol saved a large amount of energy compared to LEACH with the same simulation parameters.

Zhao et al. (2012) proposed an enhancement of LEACH by introducing sub CHs to manage the situation of absence of the CHs. They compared the performance of the modified approach with LEACH through simulation. The experiments showed that the proposed method is improved in terms of power consumption and lifetime.

Gupta et al. (2012) proposed an improved version of LEACH algorithm. Using MATLAB simulator performance analysis of developed protocol based on lifetime, dead nodes and live nodes in comparison with LEACH was carried out.

Q-LEACH, proposed by Manzoor et al. (2013) divides the network area based on the location and uses a quadrant based approach. According to the authors the proposed approach gained more stability and extended life time compared to LEACH.

Mahmood et al. (2013) modified LEACH by introducing an alternate CH replacement scheme and dual transmitting power levels. The performance of the modified MODLEACH was evaluated based on the parameters like throughput, formation of CHs and lifetime, keeping hard and soft thresholds. The main aim of all the enhancements of the LEACH protocol is to increase the energy efficiency.

Sondhi and Sood (2015) reviewed the most energy efficient protocol named LEACH along with its advantages and disadvantages. The authors also gave an outline of the various descendants of LEACH protocol.

Arumugam and Ponnuchamy (2015) discussed a new data gathering method using LEACH. They concentrated on effective data gathering and optimal clustering which enhanced the energy efficiency. An overview of the different variants of LEACH and the enhancement method adopted in each is given in Table 2.1.

2.4.2 Hybrid Energy-Efficient Distributed Clustering

Younis and Fahmy (2004) presented a protocol, HEED (Hybrid Energy-Efficient Distributed clustering), that occasionally selected CHs looking into the residual energy and node degree. HEED achieved uniform load balance and the overheads were much lesser. Simulation results confirmed the effectiveness of the modified approach in extending the network lifetime. Kaur and Lal (2006) presented a survey of the energy efficient clustering protocols for WSNs. They have done a comparison of these identified protocols based on different metrics such as power consumed, packet delivery ratio and the number live nodes using MATLAB.

Table 2.1: LEACH Variants

LEACH Variants	Novel Procedure Incorporated
Cooperative LEACH, Kong and Yun (2010)	Introduced multiple CHs
LEACH-B, Tong and Tang (2010)	Considers residual energy of CHs in every round for balancing the energy
Improved LEACH, Zhao et al. (2012)	Introduced sub CHs
LEACH A*, Gupta et al. (2012)	Reduced the cluster size
LEACH-C, Shi et al. (2012)	BS is the central controller, simulated annealing used for CH selection
EEELEACH, Sharma et al. (2012)	Multilevel clustering with CHs and master CHs
N-LEACH, Tripathi et al. (2012)	CH selection is based on the number of nodes supported in the previous rounds.
MG-LEACH, Haneef et al. (2012)	Use of redundant nodes to assist CH, requires GPS assistance.
Cell-LEACH, Yektaparast et al. (2012)	Divided clusters into seven subsections called cells and each cell has a cell head to communicate with the CH.
LEACH-R, Li et al. (2013)	Reappointment of CHs for several rounds, more complex
Q-LEACH, Manzoor et al. (2013)	Quadrant based approach to attain stability.
I-LEACH, Jing et al. (2013)	New energy function to balance energy consumption among CHs.
LS-LEACH, Alshowkant et al. (2013)	Light weight secure LEACH introduced security measures into LEACH
M-LEACH, Salim et al. (2014)	CH selection is based on a threshold value which is set for each node and minimize dead-spots.
EE-LEACH, Arumugam and Ponnuchamy (2015)	LEACH for data gathering, minimise delay, more control overheads

Kour and Sharma (2010) modified an enhancement of HEED called Heterogeneous - Hybrid Energy Efficient Distributed Protocol (H-

HEED which considers node heterogeneity. The modified protocol works similar to HEED According to the authors the simulation results proved efficiency of H-HEED compared to HEED in terms of lifetime and packet delivery ratio.

An improvement of HEED by incorporating fuzzy logic was modified by Taheri et al. (2010). They used a non-probabilistic approach for electing the CH. Remaining energy of the nodes, two fuzzy descriptors, the node degree and node centrality was used to elect CHs. Simulation results demonstrated that the modified approach out performed HEED in terms of cluster formation and lifetime enhancement.

Bala and Aswathi (2012) proposed an enhancement of HEED protocol that supports mobility in homogenous and heterogeneous network. The performance was validated in a random mobility environment based on stability, energy efficiency, lifetime and throughput. The authors concluded that the overall performance of the network noticeably enhanced when the BS was mobile.

Mardini et al. (2014) focussed on scrutinizing inter-cluster routing protocols and HEED and evaluated their performance. Besides that, an enhancement of HEED called RHEED was also proposed where in the rotation of CHs within a cluster was performed. A predefined time for re-clustering was defined. In terms of residual energy and network lifetime, RHEED beats the HEED protocol by over twenty percentages.

Kazerooni et al. (2015) discussed on the clustering mechanisms in WSNs. The authors focussed on the protocols HEED and LEACH and detailed explanation of the clustering mechanism adopted by these protocols are mentioned.

A comparative study of H-HEED and HEED was carried out by Kour and Sharma (2015). Similarly, a comparison of the various clustering techniques based on HEED was carried out by Ullah et al. (2016).Major variations of HEED and the enhancements performed are given in Table 2.2.

Table 2.2: HEED Variants

HEED Variant	Novel Procedure Incorporated
H-HEED, Kour and Sharma (2010)	Node heterogeneity is considered
HEED-NPF, Taheri et al. (2010)	Non probabilistic approach and Fuzzy logic used for CH selection
HEED*, Taheri et al. (2011)	Local clustering, less CH messages, residual energy considered for CH selection
HEED enhancement, Bala and Aswathi (2012)	Mobility of nodes in homogeneous and heterogeneous scenarios considered
Heterogeneous HEED, Sasikumar and Anitha (2014)	Nodes classified into normal nodes and advanced nodes; CHs communicate at two levels
RHEED, Mardini et al. (2014)	Criteria based rotation of CHs within the cluster

2.5 Review on Energy Efficient Routing Techniques

This section describes the various techniques for energy enhancements adopted in WSNs.

2.5.1 Clustering

Wei et al. (2008) discussed on the various existing energy efficient clustering algorithms. They classified the clustering approach and examples were given for each category. A detailed analysis of the characteristics of each protocol highlighting the pros and cons and suggestions for further improvement were also mentioned.

A reliable and energy efficient clustering algorithm was proposed by switching the roles of CHs by Guo et al. (2010) which focussed on prediction of the CHs and control of power levels. Balancing of load among the sensors was also taken care which led to increased lifetime. They introduced a new formula for the probability of CH selection and the CH competition which resulted in lifetime time enhancement compared to LEACH. Singh et al. (2010) gives an overview of the various energy efficient clustering protocols. The authors highlighted the pros and cons of each protocol.

Ramesh and Somasundaram (2011) gave a comparative study of the different CH selection algorithms in WSNs. They mention the criteria used by the different clustering techniques for CH selection, cluster formation etc. and classify them as deterministic, adaptive and combined metric or hybrid CH selection techniques.

A detailed study of the clustering routing protocols was carried out by Liu (2012). The author mentions a complete classification of clustering techniques with their pros and cons.

Nikolidakis et al. (2013) proposed an equalized CH election protocol for routing which used the Gaussian elimination algorithm for effective CH selection. The simulation results proved the efficiency of the modified approach in terms of energy compared to PEGASIS, LEACH etc. A summary of the various unequal clustering techniques is mentioned in Table 2.3.

Table 2.3: Unequal Clustering Techniques

Clustering Technique	Method
Unequal Clustering Size(UCS),Soro and Heinzelman (2005)	CHs determined in priori; CHs arranged symmetrically in concentric circles around Base Station
Energy Efficient Unequal Clustering(EEUC), Li et al. (2005)	Probabilistic method to elect tentative CH
Energy Efficient Distributed Unequal Clustering(EEDUC), Lee et al. (2008)	Introduce waiting time to distribute CH
Multihop Routing with Unequal Clustering(MRPUC), Gong et al. (2008)	Multihop transmission; constructs inter-cluster routing tree
Unequal Cluster Based Routing Protocol(UCR), Chen et al. (2009)	Inter- cluster relay traffic
Energy Driven Unequal Clustering(EDUC), Yu et al. (2011)	Uneven competition ranges to construct uneven sized clusters
Unequal Hybrid Energy Efficient Distributed Clustering (UHEED), Ever et al. (2012).	Unequal sized clusters based on distance of CH from Base Station
Improved Distributed Unequal Clustering (IDUC), Chen et al. (2015)	Unequal clusters based on Inter cluster communication routing tree

2.5.2 Duty Cycling

Wu et al. (2010) designed energy efficient protocols intended for low data rate WSNs. The energy consumption of the sensors will vary according to the state transitions. Specific scheduling algorithms were modified by the authors for different states which proved to be double better than the normal schedule. They also modified active algorithms to build data gathering tree so as to have optimum energy consumption.

Jurdak et al. (2010) studied the impact power level used changing the states of the sensor nodes. Based on the traffic of the network the authors modified adaptive radio low-power sleep mode model. The proposed model was compared against BMAC and IEEE 802.15.4, for both MicaZ and TelosB platforms under variable data rates. The comparison showed an improvement of about twenty times less energy consumption for the modified model.

Hao et al. (2012) carried out a detailed survey related to the challenges involved in the design of energy efficient routing protocols. The different issues like design, end to end delay, control message overheads, network dynamics were addressed. The state of art of the duty cycled routing protocols mentioning their pros and cons were presented in detail.

Li et al. (2013) addressed the issues related to delay constrained least cost paths problem in low duty cycled sensor networks. They proposed an approximated DCLC routing algorithm, called ADRA which was evaluated theoretically and through simulation.

2.5.3 Data Gathering

Ren et al. (2011) designed routing protocol with the aim to force packets towards the sink in such a way that the low energy nodes will be protected. The modified approach was evaluated through extensive simulations which showed substantial developments in lifetime, energy balance etc.

An energy efficient cluster routing for data gathering was modified by Chang and Zhang (2012). The main objective was to reduce energy in data collection. They used multihop approach for data routing. The simulation results showed that the modified approach could evenly distribute energy among the sensor nodes which led to extension of the network lifetime.

According to Liu et al. (2013) pre-calculation of routes of the mobile sink may not be applicable in all situations especially when the nodes are mobile. Constant updating of the locations of these mobile elements increases the complexity of the application. To avoid all these problems, the authors proposed two energy-efficient proactive data reporting protocols, SinkTrail and SinkTrail-S. The highlight of the proposed protocols is the flexibility in sink movement and the non-requirement of additional hardware's for location identification. A systematic analysis of the proposed algorithms both theoretically and by simulation was also carried out.

2.5.4 Sink Mobility

The idea of sink moving in the network to collect data rather than being stationary was investigated by Chatzigiannakis et al. (2006). Different forms of sink mobility along with different data collection methods were experimented. Through the simulation results the authors' claims that the sink mobility can reduce the energy spent for traffic relay which in turn enhances the network lifetime.

Stevanovic and Vlajic (2008) explored the benefits and trials of deploying a single mobile sink in IEEE 802.15.4/ ZigBee WSNs. They experiment the same under different mobility models and suggest that the tree structure is better than mesh for routing in terms of energy efficiency.

The problem related to the energy hole formation near the sinks was addressed by Marta and Cardie (2008). The energy holes near the sink partitions the network and is a threat for the lifetime of the network. The authors modified sink mobility as a solution for this problem. They studied the network performance when sink moves through predefined paths and stops at specific locations. This process was able to achieve up to 4.86 times improvement in the network lifetime. They also modified an algorithm wherein the sink can predict its next movement and presented simulation results to verify this approach.

Basagni et al. (2008) modified different scalable models and centralized heuristics for the simultaneous and coordinated movement of multiple sinks in WSNs.

Faheem et al. (2009) presented the state of the art literature review on mobility of sinks in WSNs and the various data dissemination strategies mentioning the advantages and drawbacks of each.

A detailed survey of the deployment strategies with mobility of sink in WSN mentioning the pros and cons were carried out by Vlajic and Stevanovic (2009). A comparative study of the various approaches based on different performance metrics was also mentioned.

A framework for maximizing the lifetime of the WSNs was modified by Yun and Xia (2010). They also formulated optimization problems for the same. Using extensive computational experiments on the optimization problems the authors concluded that by the proposed approach, increased lifetime can be attained when compared to not only stationary sink model but also traditional mobile sink models. They also claim that delay tolerance level does not affect the maximum lifetime of the WSN.

The problem of data gathering using mobile elements was addressed by Almi'ani et al. (2010). He gave a formal depiction of the mobile element scheduling problem and an integer linear programming formulation to realize optimal solutions. For this they had simulated and compared two main heuristics, one based on the travelling salesman problem and the other based on greedy fashion.

Amutha et al. (2010) presented a novel localization algorithm that helped the mobile sink to locate the sensor nodes. This was implemented in TOSSIM and the authors claimed that the proposed approach is better than other range based schemes.

Khodashahi et al. (2010) proposed an efficient routing procedure based on clustering which used a single mobile BS. An improved method for the movement of the BS to receive data from the CHs was also modified.

According to Gao and Zhang (2010) data delivery latency had an influence on the speed of mobile sink. In real time scenario mobile sink speed is restricted due to many factors. A solution for the same by choosing optimal path as well as minimising the energy consumption was proposedin this work. Theoretical analysis and simulation experiments were performed for the validation of the same in terms of energy consumption with existing algorithms.

Chen et al. (2010) explored an optimal barrier coverage based sensor deployment for event driven WSNs where a dual-sink model was designed to evaluate the energy performance of static sensors, static sinks and mobile sinks based on different evaluation metrics.

Localization of the sensor nodes is a challenge in WSNs. Sarma et al. (2011) modified a cluster based algorithm which supports node and sink mobility. The operation of the protocol took place in two major phases. According to this approach, after the node deployment the sensor field is divided into different logical clusters. The node in each cluster is assigned different roles. Simulation results showed that the modified approach gave better performance compared to CBR mobile protocol.

Faheem et al. (2011) modified a distributive energy efficient sink location update mechanism for mobile sink WSNs. A preemptive data buffering where the roots acts as buffers to prevent data loss due to sink mobility was also proposed. They validated the modified scheme through simulations.

The concept of BS mobility to extend the network lifetime was carried out by Shi and Hou (2012). The main contribution of this work is that it provided theoretical results for the optimal movement of a BS where the transformation of the entire routing from the time domain to the space domain is given. Optimal time span of the BS at specific points so as to increase the overall efficiency is found and based on this, an approximation algorithm or routing was also developed.

Shi and Hou (2012) had done an extensive study on the impact of mobility of sinks and BS. They provided some theoretical results regarding the optimal movement of a mobile BS. Two main results they had presented; the first was; the transformation of routing and BS movement problem in to a location independent problem and the second was the optimal division of discrete steps for the BS movement.

A routing protocol especially with the aim of reducing the energy consumption and balancing the network energy was proposed by

Konstantopoulos et al. (2012).They used clustering and data filtering within the CHs. An application of the proposed protocol where the urban buses carry the mobile sinks was also explained. This application was able to achieve maximum energy balance, connectivity and throughput.

Khan et al. (2013) thoroughly investigated problems related to the energy saving schemes of duty cycling and selection of the path for sink mobility. The key contribution is the analysis of the impact of static and mobile sinks in energy utilisation of WSNs.

Karyakarte et al. (2013) experimented on the various mobility models with different speeds and compared with static environment. The different models of mobility were taken into consideration. An analysis based on simulation was carried out based on different parameters like routing overhead, throughput, packet delivery, delay, residual energy etc.

The detailed survey of the different mobility models in WSNs was carried out by Taleb et al. (2013). According to the authors each sink mobility model has its own properties. A categorization of the mobility models based on their general behaviour was also given in this paper. The basic categories mentioned are homogeneous mobility model and heterogeneous mobility model. Sub categories like controlled mobility, random mobility, totally and partially random mobility, predictable mobility and geographic mobility were also mentioned. The work proposed in this paper provided researchers an insight into the available mobility models and their properties.

Mamalis (2014) proposed a stable and energy efficient data gathering approach using mobile sinks aimed for time critical applications. According to the author for emergency applications, the speed at which the mobile sink moves plays a critical role for data gathering. The modified protocol was validated by comparing against competent protocols in literature.

Alhasanath (2014) proposed a new data gathering algorithm called connectivity based data collection in which the sensor node connectivity is used to find MS path. Reducing the number of multiple hops was also a major concern. The simulation results of the comparison of the new method with LEACH-C algorithm shows that the proposed algorithm prolonged the network life time.

Dekate (2014) developed an optimum path selection for mobile sink in a WSN. They used the hierarchical network structure. The main focus was to enhance the network lifetime.

Khan et al. (2014) proposed a multiple MS path navigation algorithm for the multiple MS to have maximum network coverage. The modified movement pattern was simulated and compared against existing protocols to prove the validity of the modified algorithm in terms of lifetime.

Wang et al. (2014) suggested a routing algorithm with multiple MS. They presented a detailed study of the impact of sink mobility, where sink moves around the boundary to gather data. According to the authors, the number of MS nodes and their parking spot has vital effect on system performance.

Padmavati and Aseri (2014) presented a survey of the different types of WSNs and various routing protocols in WSN using mobile sinks with a comparative analysis of the same.

According to Peixoto et al. (2015) the sink mobility can be used for reducing the energy consumption of the nodes based on the application scenario. The authors proposed a new positing technique for the nodes and the mobile sinks called QoE-aware multiple mobile sinks which was intended for monitoring applications.

Koc and Korpeoglu (2015) proposed an approach for coordinating the movement of multiple sinks which are mobile through a central coordination point. In order to reduce the message overheads of storing the information of the sink movement path in prior, they proposed another mechanism also, which proved to be energy efficient, through simulations.

Snigdh and Gosain (2015) deliberated on the energy consumption rate when the nodes find their route to the mobile sinks with that of the reverse process. Based on the simulations performed they conclude that the energy consumption is less when the mobile sinks are used for data gathering.

2.6 Review on Simulation Tools Used for Routing in WSNs

An overview of sensor network simulation through NS-2 is given by Downard (2004). According to the author the NS-2 simulation environment is a flexible tool for analysing the performance of various protocols under different configurations and topologies. This work describes how the NS-2 framework was extended to include support for sensor networks.

Heimlich et al. (2010) proposed NMLab a combined framework for NS2 and MATLAB a co-simulation framework for MATLAB and NS-2. It was enabled with powerful numerical capabilities and real time support for various networking and communication protocols.

Rensfelt et al. (2011) proposed a testbed that supports mobility of the nodes named Sensei-UU. The aim of this design was to provide a platform for repeated experiments for WSNs with node mobility. The authors claimed that this test bed is inexpensive, expandable, and relocatable and can be reproduced by others.

Ali (2012) carried out a study reviewing the various simulation tools for WSNs focussing on the strength of simulation framework for WSNs using Simulink and MATLAB. A brief description of GloMoSim/ QualNet, Opnet Modeler Wireless Suite, TOSSIM, OMNET++, NS-2, Avrora, J-Sim, ATEMU, EmStar, SENS, SESE and Shawn highlighting their pros and cons was also given.

Nayyar and Singh (2015) presented a detailed survey of the simulation tools for WSNs. They explained almost thirty-one different simulators mentioning their features and drawbacks.

2.7 Summary of the Literature Reviewed

The literature review exhibits the different uses of WSNs, its architecture, advantages, limitations, the various applications they are involved in, and their significance. As the major problem faced by these tiny sensor nodes is the energy constraints, energy efficient routing strategies should be adopted to retain the network lifetime. LEACH and HEED are traditional energy efficient routing protocols in WSNs. Several research is carried out based on these protocols to further enhance the energy efficiency (refer Table 2.1, 2.2). But they lack attention in;

- Uniform load among the CHs to ensure load balancing.
- Reducing the over burden of the sensor nodes as they act in multiple roles of data generators, data collectors and data routers.

- Load balancing through unequal cluster size to reduce hot spot issues.

Hence, the need of this research, wherein three routing strategies are suggested;

- Modification of LEACH using novel clustering mechanism to have load balance
- Incorporation of multiple mobile sinks in modified LEACH to reduce the over burden of sensor nodes
- Modification of HEED using unequal clustering to solve hot spot issues.

2.8 Objectives

The primary objective of this research is to devise energy efficient routing protocols for WSNs. This research work aims to develop energy efficient routing protocols for WSNs, by intensively studying the existing energy efficient routing algorithms and highlighting both the relevance and limitations of them. A modification of the traditional LEACH algorithm, a mobile sink assisted modification of LEACH and a modification of the HEED protocol is carried out, focussing on enhancing the energy efficiency. The scope of this research is to;

- Study the different energy efficient routing techniques like clustering, use of mobile sinks and unequal clustering.
- Study the various categories of energy efficient routing algorithms emphasising their merits and demerits.
- Study the energy efficient hierarchical routing algorithms LEACH and HEED focusing on their advantages and drawbacks.

- Modify LEACH by introducing a novel clustering approach so as to enhance the energy efficiency using MATLAB.
- Introduce sink mobility in the LEACH algorithm to further augment the energy efficiency and to get better performance.
- Modify HEED by using unequal clustering to avoid energy imbalance and there by attaining energy efficiency.

CHAPTER 3
MODIFIED LEACH ALGORITHM

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MODIFIED LEACH ALGORITHM

3.1 Introduction

The major concern of WSN related to routing is the issue of network failure due to energy holes. For a routing protocol to attain energy efficiency, it should have reduced energy consumption which leads to the extension of the network's lifetime. There are many techniques to lessen the energy usage of the sensor nodes. One such method is clustering.

LEACH is a widely accepted traditional cluster-based routing protocol proposed by Heinzelman et al. (2000). This chapter explains the working of LEACH mentioning the advantages and limitations and propose a modification of the same to overcome these limitations.

LEACH randomly rotates the CHs so as to manage load balance among the sensor nodes in the network. A local coordination is achieved through the CHs which help to cope with the network dynamics. In order to reduce the amount of data transfer to the BS, data fusion is also incorporated in routing. These in turn reduces the energy dissipation leading to better lifetime of the networks.

3.2 LEACH Algorithm

The operation of LEACH happens in rounds. Each round is initiated by a set-up phase where clustering happens, and a steady phase for data transmission. The time line showing the LEACH operation is given in Figure 3.1(Heinzelman et al. 2000).

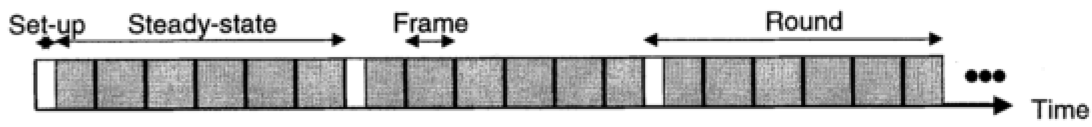

Figure 3.1: TimeLine of LEACH (Heinzelman et al. 2000)

The set-up phase is given in Figure 3.2 (Heinzelman et al. 2000). Each node takes independent choices for clustering supported by a distributed algorithm devoid of any central control during the set-up phase. The cluster formation algorithm is formed in a way which ensures all nodes to have equal chance of becoming the CH with the assumption that all nodes have the same amount of energy at the beginning. The probability of becoming the CH is based on a threshold value T (n), where;

$$T(n) = \begin{cases} \frac{p}{1-p\left(r \bmod \frac{1}{p}\right)}, & n \in G \\ 0, & n \notin G \end{cases} \tag{3.1}$$

Here p is the preferred percentage of CHs in that specific round and G is the set of nodes that have not been the CHs for the last 1/p rounds. Each sensor node chooses a random number, r, between 0 and 1. If this random number is less than the threshold value, T (n), the node becomes a CH for that round. After CH election is done, an advertisement message (ADV) as an announcement is broadcasted. The non-CH nodes respond back through a join-request message (Join-REQ) to the chosen CH. The CH will act as the coordinator in that cluster. The steady-state operation is illustrated in Figure 3.3 (Heinzelman et al. 2000). The data transmissions from sensor nodes to the CH happen only during their allocated time slot.

CHs have to be turned on always to receive the data send by all other nodes. Once this is done, it processes the data and sends to the BS.

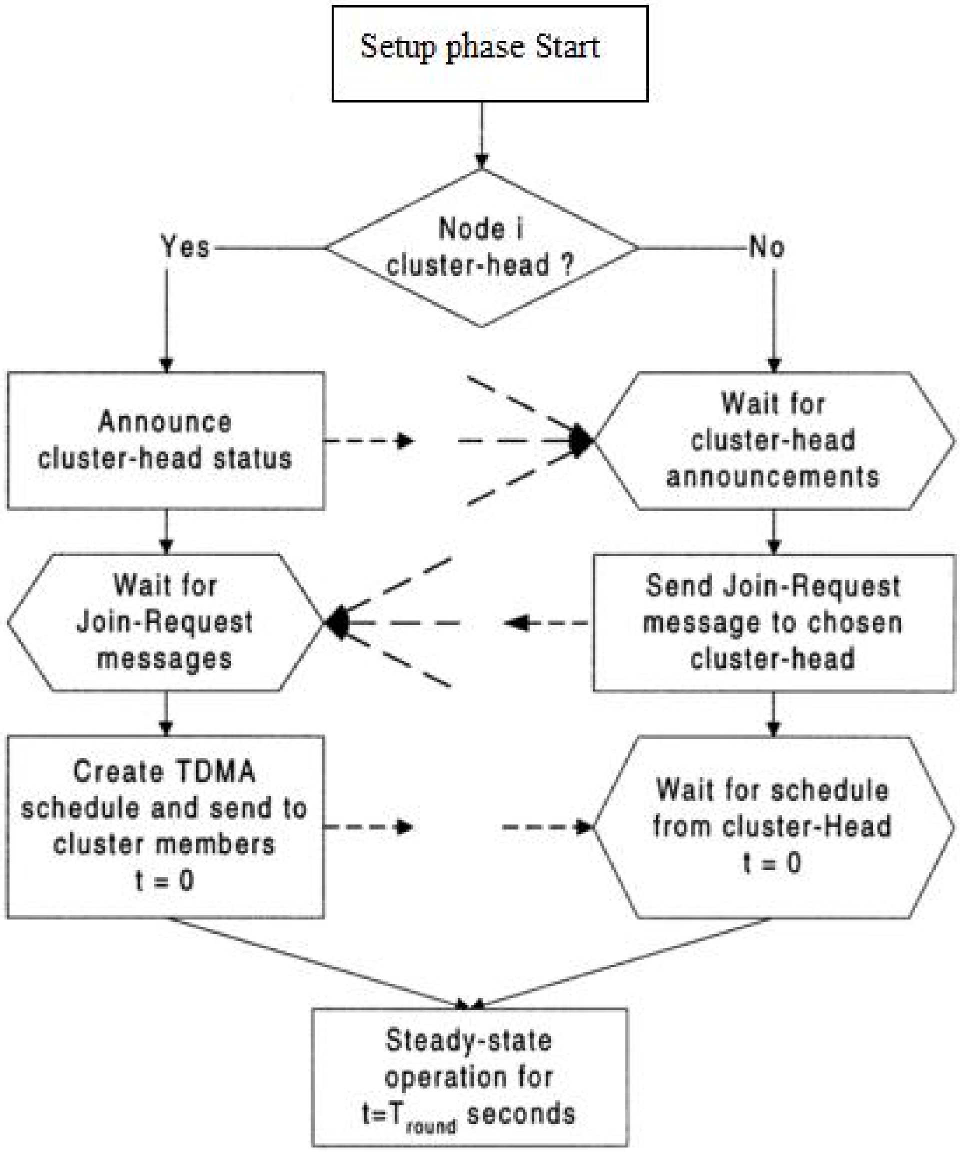

Figure 3.2: Setup Phase of LEACH (Heinzelman et al. 2000)

Figure 3.3: Steady Phase of LEACH (Heinzelman et al. 2000)

3.2.1 Assumptions for LEACH

The following assumptions are made for the sensor network.

- Sensor nodes are randomly dispersed within a sensing field.
- There is only one Base Station (BS).
- After deployment sensor nodes and the BS are stationary. The location of the BS is known by each node and they have the capability of communicating directly with the BS in certain situations.
- Sensor nodes can use power control to vary the amount of transmit power depending on the distance to the receiver. For simplicity it is assumed that the power level is continuous. The process of sensing is also continuous.
- Based on RSS, sensor nodes can compute their relative distance to BS and communication is symmetric.
- Sensor nodes are homogeneous.

3.2.2 Network Model

The energy model used in LEACH is the simple first order radio model. The radio dissipates $E_{elec} = 50$ nJ/bit for the functioning of the transmitter or receiver circuitry and the transmit amplifier uses $\epsilon_{amp} =$ 100pJ/bit/m^2.

The first order radio model is depicted in the Figure 3.4 Heinzelman et al. (2000). The radio characteristics are summarized in the Table 3.1 Heinzelman et al. (2000).

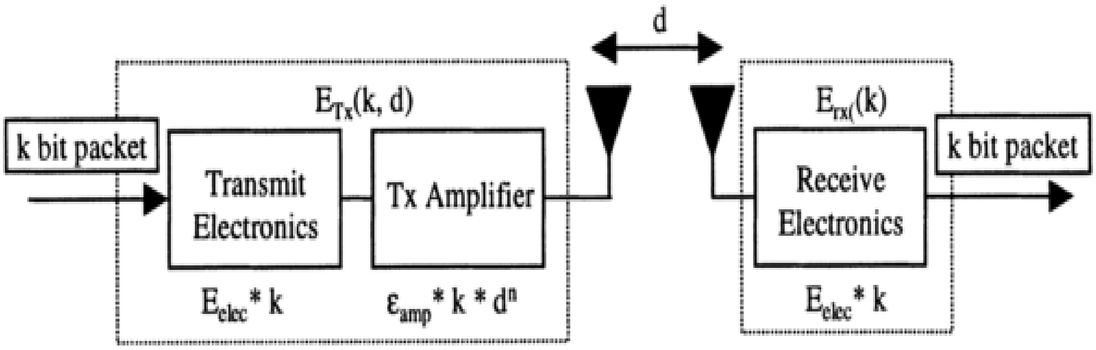

Figure 3.4: Radio Energy Dissipation Model (Heinzelman et al. 2000)

Table 3.1: Radio Model Characteristics (Heinzelman et al. 2000)

Operation Parameters	**Energy Dissipated**
Transmitter Electronics($E_{Tx-elec}$) Receiver Electronics ($E_{Rx-elec}$) $E_{Tx-elec} = E_{Rx-elec} = E_{elec}$	50 nJ/bit
Transmit Amplifier (ϵ_{amp})	100 pJ/bit/m^2

According to this model, for transmitting a k-bit message over a distance d, the radio expends:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \quad (3.2)$$

$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2 \quad (3.3)$$

To receive a message, the radio expends:

$$E_{Rx}(k) = E_{Rx-elec}(k) \quad (3.4)$$

$$E_{Rx}(k) = E_{elec} * k \quad (3.5)$$

E_{Tx} and E_{Rx} is the transmitting energy and receiving energy in Joules.

3.2.3 Advantages

LEACH offers localized coordination and control for cluster set-up and operation through clustering. The randomized rotation of the CHs in each cluster helps to reduce the energy drain of a particular node and balances the energy consumption among them. The compression of sensed data at the cluster level further reduces energy consumption for data transmission to the BS.

3.2.4 Limitations

The LEACH protocol has some drawbacks. During the CH selection, the energy level of that node which can be the CH is not taken into consideration. Even distribution of nodes to CHs is not assured and as a result the data received by each CH varies. For reducing the use of energy, the radio of cluster members should be turned off till its time slot arrives. The CH communicates directly with the sink using multi-hop. Moreover, this protocol is not that scalable also.

3.3 Description of the Modified LEACH Algorithm

The Modified LEACH Algorithm adopts a different clustering approach compared to LEACH. The initial settings are kept same as that of LEACH. The procedure for the Modified LEACH is given below;

[BS is the Base Station, CH is the cluster head, RSS is received signal strength, N represents the number of sensor nodes, A is the area of deployment, max_count is taken as 5% of N, t is the time limit and R is the sensor range which is application dependent.]

- Initially all nodes send their information to the BS as well as to the immediate neighbours and each node maintains a count and max_count information.

- Within time ‘t’ each node identifies its neighbours within range ‘R’.

- Elect node with the count=max_count within the limited ‘t’ as CH; CH sends advertisement messages to its immediate neighbours to confirm it as CH for the next ‘t’ steps.

- Based on RSS each node sends back the information to its respective CH and forms the clusters.

- CHs send the TDMA schedule to all the members in which they can communicate the sensed data to their CHs.

- CHs maintain information about the residual energy of all its members and their relative distance to the BS. Data aggregated from each cluster will be forwarded to the BS/Sink node by the CHs.

The flowchart of the modified approach is given in Figure 3.5. According to the modified approach the remaining energy of the nodes and their approximate distance to the BS and the CHs are taken into consideration for clustering. It also tries to have maximum uniformity in the clustering, by ensuring each cluster will get almost the same number of cluster members. The number of CHs is taken as five percent of the nodes deployed as in LEACH, because it is proved to be having the optimal performance (Heinzelman et al. 2000). In LEACH the CH selection is based on the probability, but in the modified approach it is in terms of the nodes remaining energy and their relative distance to BS. This avoids the chance of less energy nodes being nominated as CH which can lead to premature termination of network connectivity.

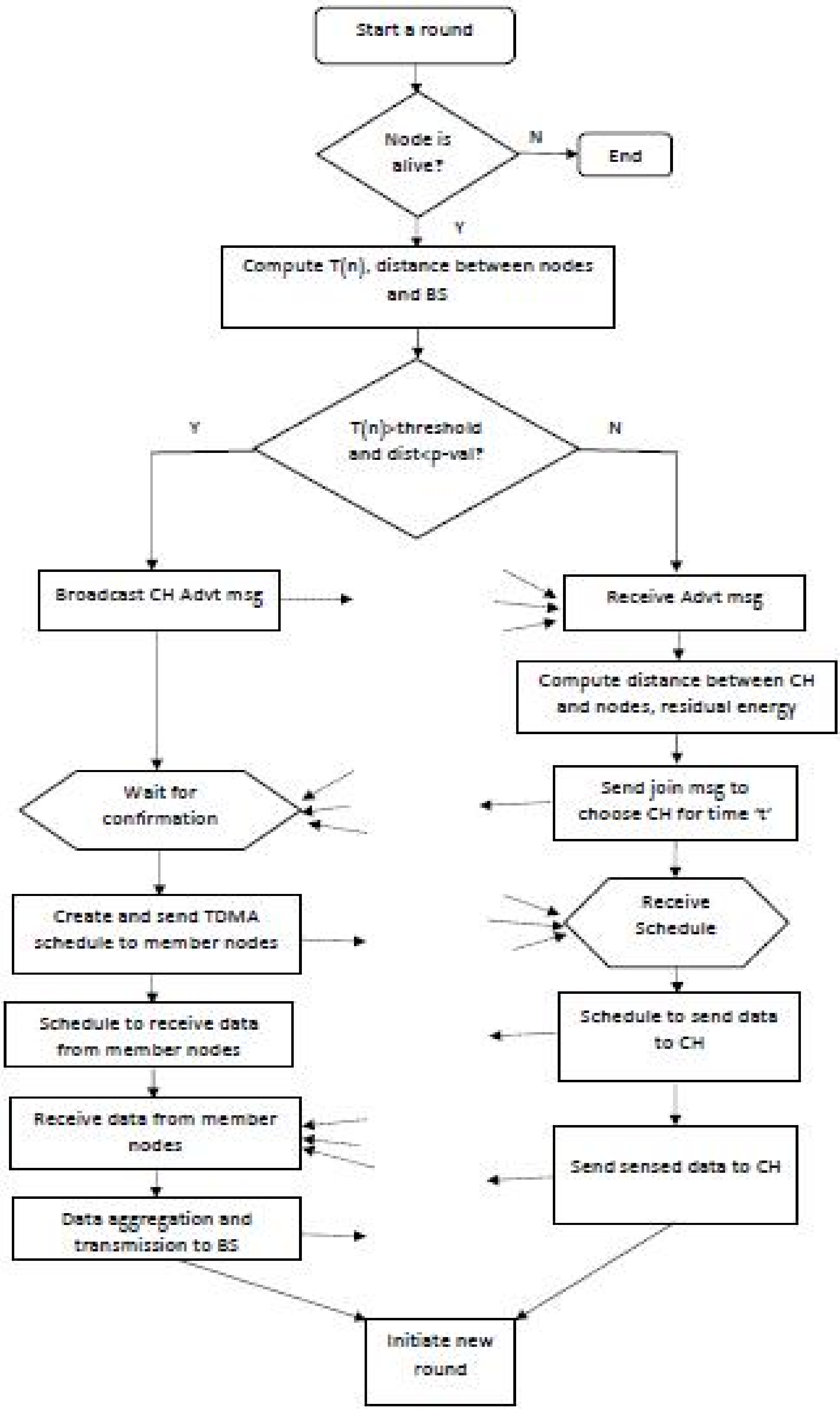

Figure 3.5: Flowchart of Modified LEACH

3.3.1 Simulation Results and Performance Analysis

Simulation was carried out for different cases where the number of nodes and the area of deployment were changed. Three different scenarios were taken into consideration. The area is kept constant as 100m×100m and the number of nodes is varied like 50, 100 and 150 in each case. The transmitting and receiving energy is calculated based on the equations 3.2 and 3.4.

Simulation was also performed by randomly changing the area and the number of nodes and the simulation period as well, following the assumptions adopted by LEACH. The results represent only the simulation results until fifty percent of the nodes are alive in any of the protocols considered with respect to the number of rounds. MATLAB is used for simulation and the simulation parameters are shown in Table 3.2.

Table 3.2: Simulation Parameters for Modified LEACH Protocol

Parameters	**Values**
Number of nodes	50,100,150
Area of simulation (x, y)	100 m×100 m
Initial energy of sensors nodes	50 J
Transmission energy	0.5 J
Receiving energy	0.2 J
Number of static sink	1
Deployment model	Random

Figure 3.6 represents the random deployment of 50 sensor nodes over an area of 100m×100m. The clustering for the same is represented in Figure 3.7. The BS is located at the coordinate position (50, 80) for this scenario.

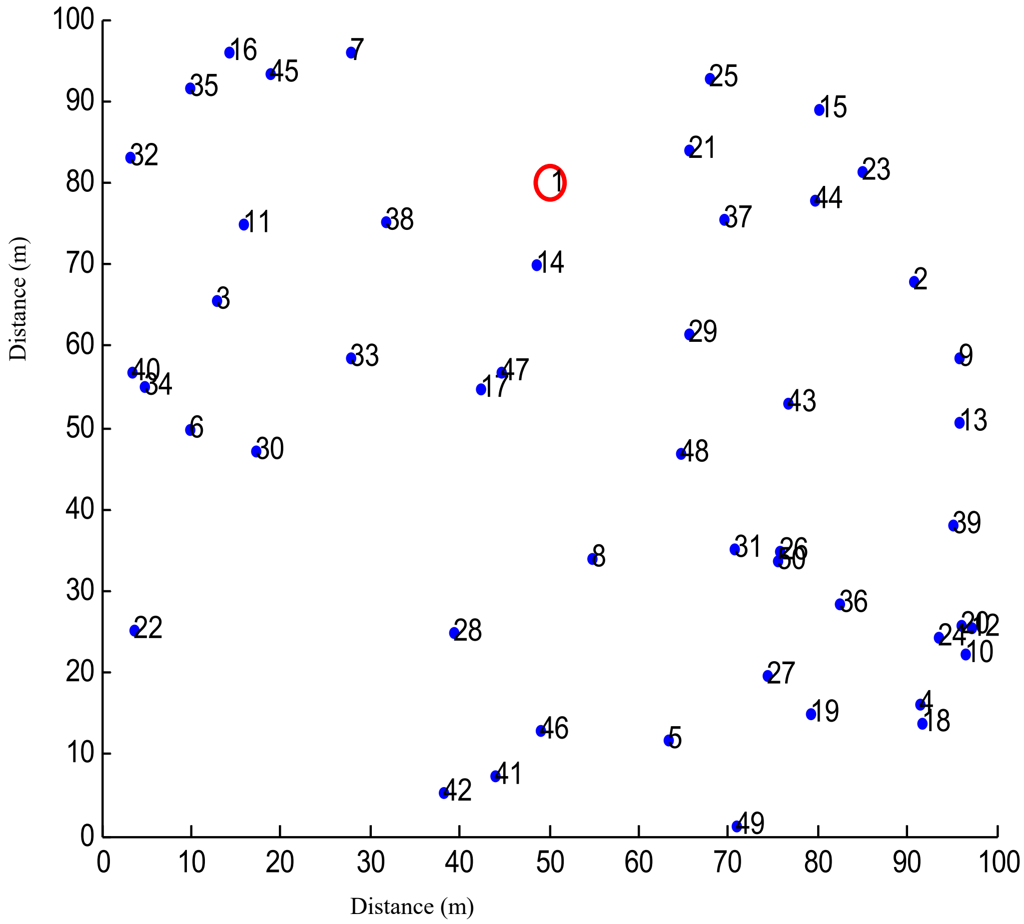

Figure 3.6: Random Node Deployment

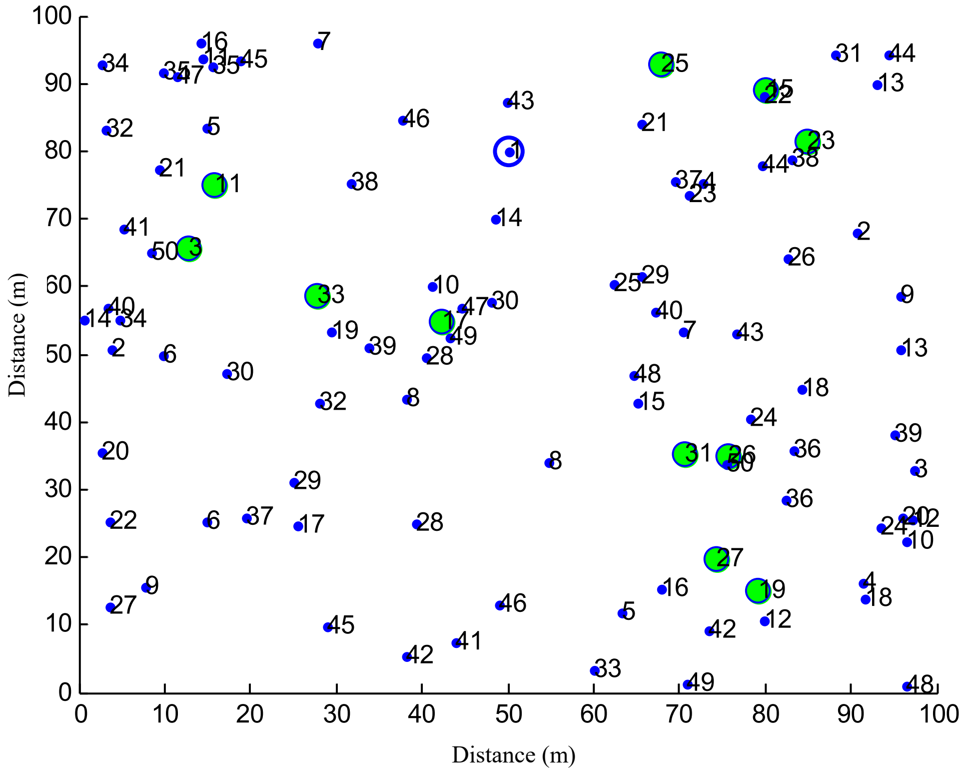

Figure 3.7: Clustering

Three different scenarios are represented below which are taken for the simulation of the Modified LEACH Algorithm; Scenario 1, A=100m×100m, N=50; Scenario 2, A=100m×100m, N=100 and Scenario 3, A=100m×100m, N=150, where A is the area of deployment and N is the number of nodes. A comparison based on the number of live nodes, energy consumed in each round and packet delivery ratio over a particular time period is done against the LEACH algorithm.

Based on different cases the performance evaluation of the Modified LEACH using various parameters are discussed below.

- ***Number of Live Nodes***

Live nodes are a factor which indicates the energy intake of a WSN. If the sensor nodes consume less energy their lifetime will be longer. The performance evaluation of the Modified LEACH with the LEACH protocol in terms of live nodes is mentioned below. The more number of live nodes indicates the efficient usage of energy.

Case i: A=100m×100m, N=50

Figure 3.8 gives the performance analysis of the Modified LEACH and the LEACH protocol in terms of live nodes over the simulation period of 500 rounds. It is evident that the Modified LEACH gives better life time compared to LEACH as the number of live nodes is more for the modified one throughout the simulation period.

Case ii: A=100m×100m, N=100

Figure 3.9 gives the performance analysis of the Modified LEACH and the LEACH protocol in terms of live nodes over the simulation period of 500 rounds.

Case iii: A=100m×100m, N=150

The performance analysis of the Modified LEACH and the LEACH protocol in terms of live nodes over the simulation period of 500 rounds is given in Figure 3.10.

From Figures 3.8 to 3.10, is observed that the Modified LEACH retains a higher number of live nodes for a longer time compared to that of LEACH.

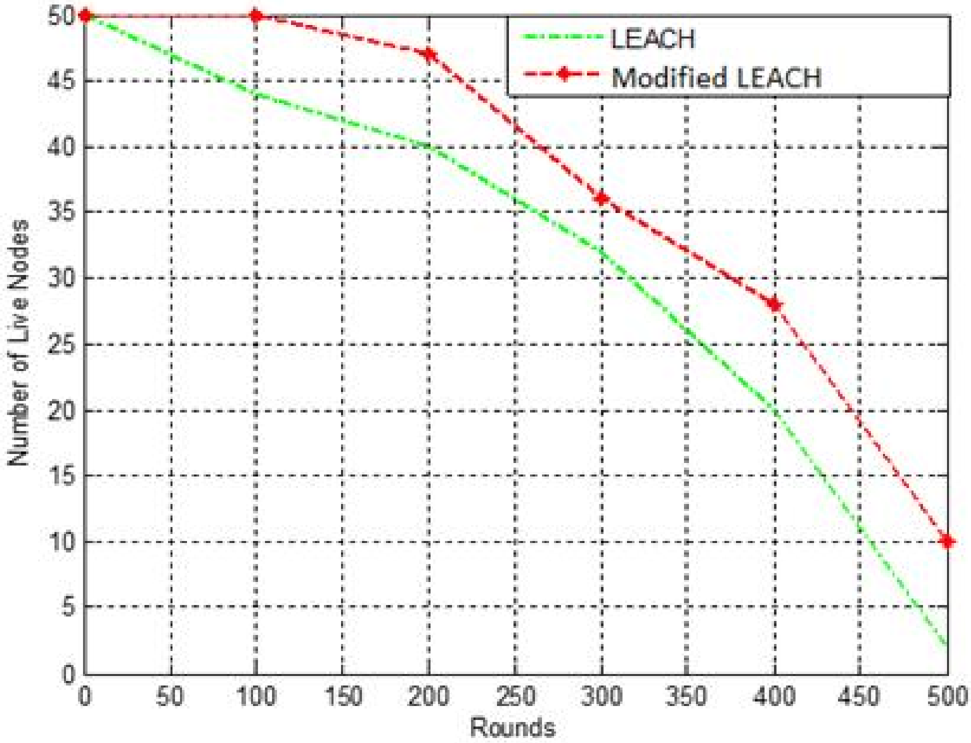

Figure 3.8: Number of Live Nodes Vs Rounds for Modified LEACH (N=50, A=100m×100m)

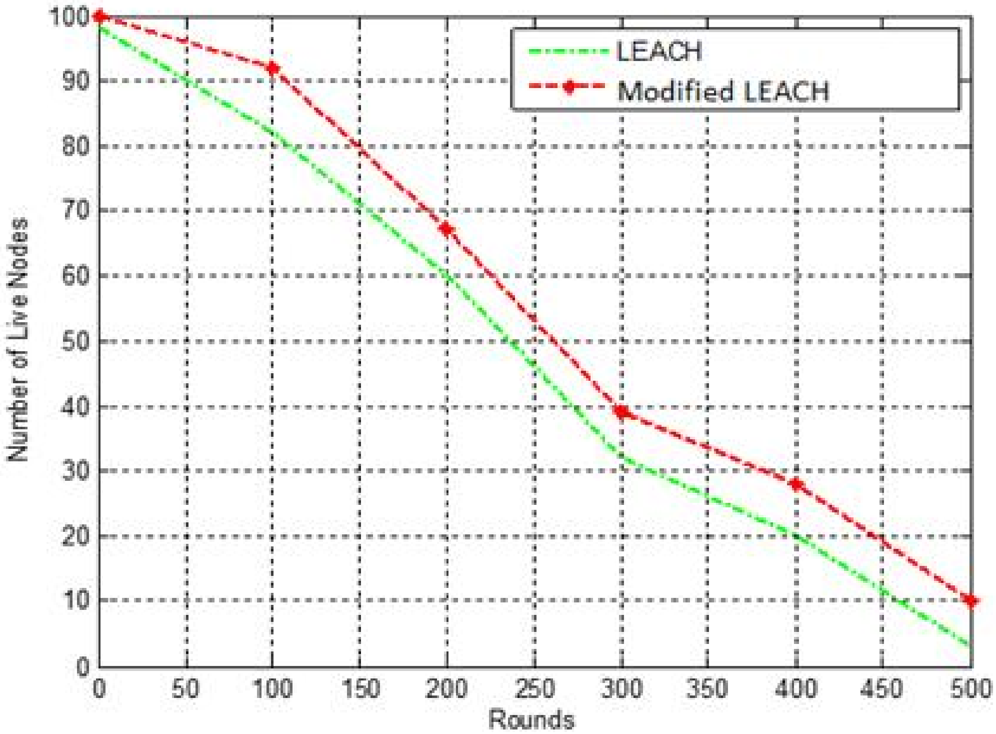

Figure 3.9: Number of Live Nodes Vs Rounds for Modified LEACH (N=100, A=100m×100m)

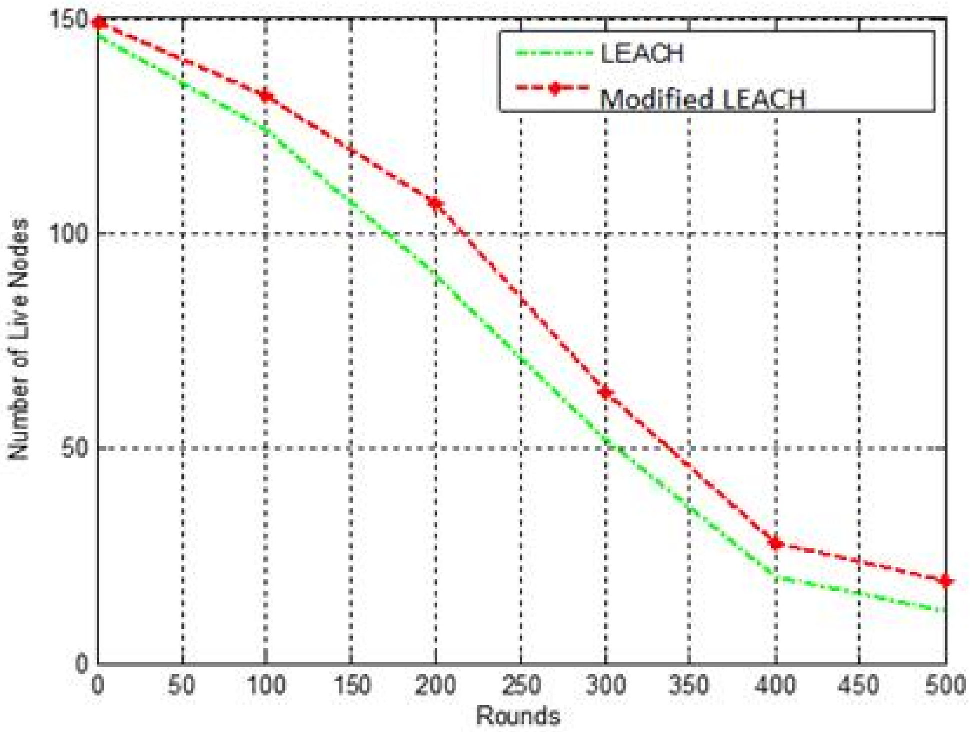

Figure 3.10: Number of Live Nodes Vs Rounds for Modified LEACH (N=150, A=100m×100m)

- ***Energy Consumed***

For comparing the performance of modified approach, another metric used is the energy consumed. Total energy consumed is the energy devoured by the system for all its exchanges. The energy consumption includes the energy consumed for receiving packet (Er), transmitting a packet (Et) and forwarding a packet (Efw). The energy required to forward a packet is represented by Efw = Er + Et.

Less energy consumed indicates the energy efficiency of the protocol compared. The lesser the energy consumption the greater will be the network lifetime. Consider the cases given below.

Case i: A=100m×100m, N=50

Figure 3.11 gives the comparison of the Modified LEACH with the LEACH protocol based on the average energy consumed over the simulation period of 500 rounds.

Case ii: A=100m×100m, N=100

Figure 3.12 compares the Modified LEACH with the LEACH protocol based on the average energy consumed over the simulation period of 500 rounds.

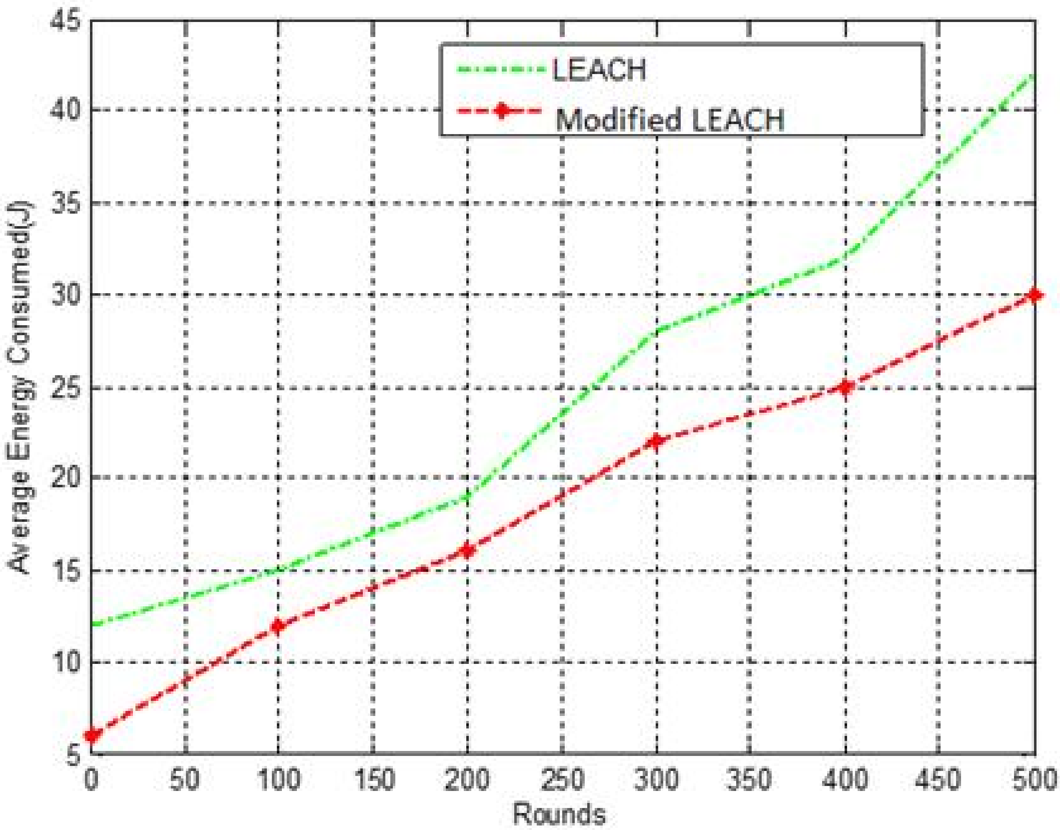

Figure 3.11: Average Energy Consumed Vs Rounds for Modified LEACH (N=50, A=100m×100m)

Case iii: A=100m×100m, N=150

Figure 3.13 gives the performance analysis of the Modified LEACH with the LEACH protocol based on the average energy consumed over the simulation period of 500 rounds.

In all the three cases, it is observed that the energy consumed by the Modified LEACH is much lower than that of LEACH. This shows that based on the energy efficiency the Modified LEACH is better than LEACH.

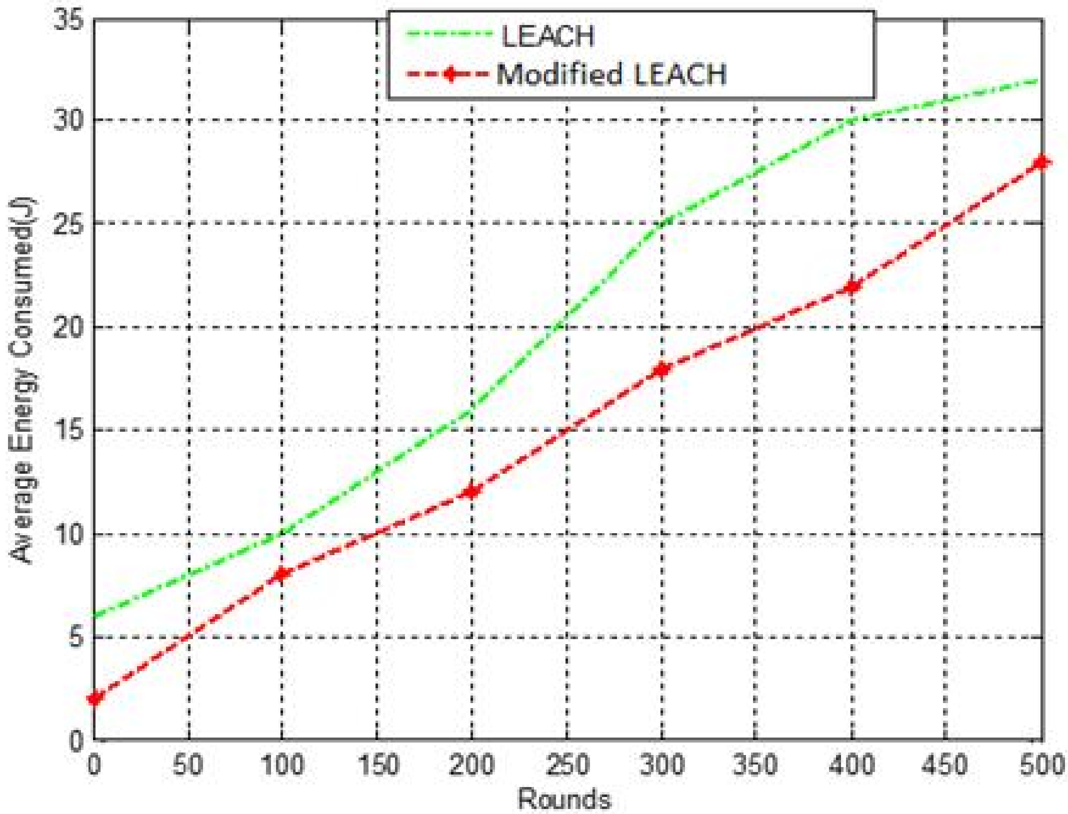

Figure 3.12: Average Energy Consumed Vs Rounds for Modified LEACH (N=100, A=100m×100m)

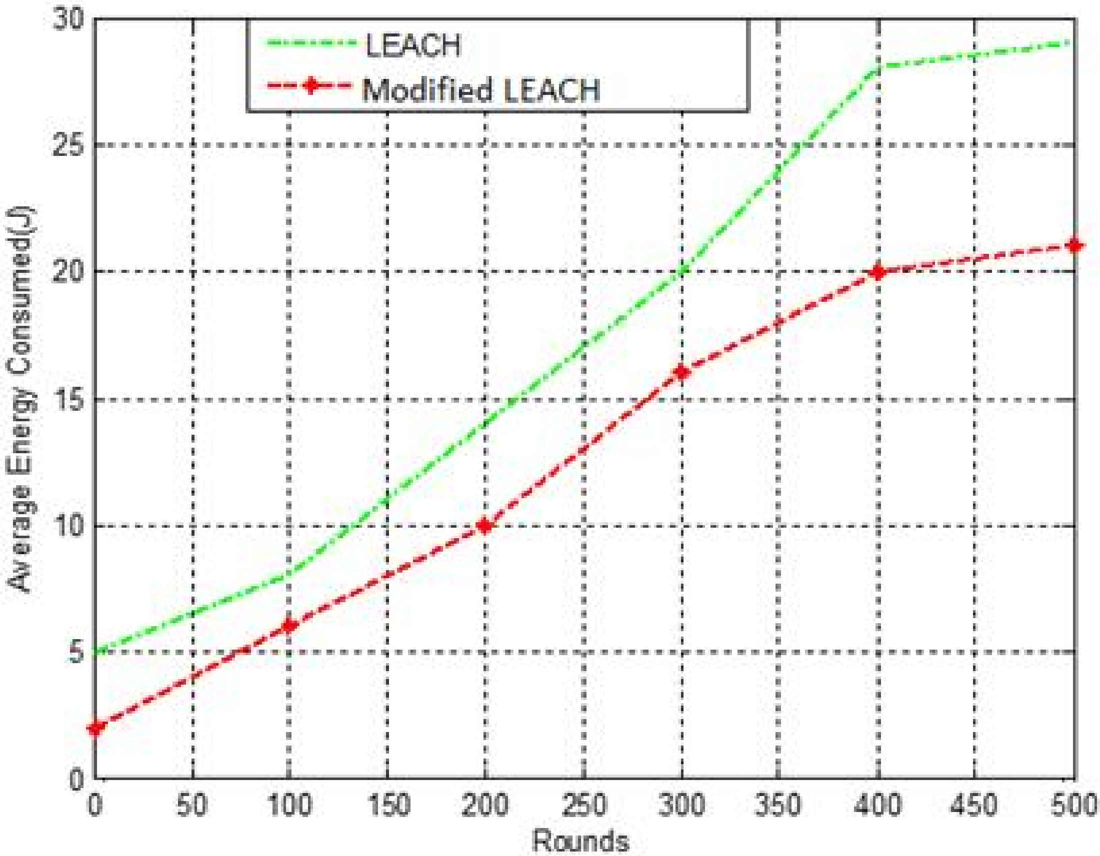

Figure 3.13: Average Energy Consumed Vs Rounds for Modified LEACH (N=150, A=100m×100m)

- ***Packet Delivery Ratio***

Another parameter used for performance evaluation is the packet delivery ratio. The proportion of the packets effectively delivered at destination to that created at the source end indicates the packet delivery ratio. It is an effective performance evaluation measure which shows the reliability of the network. The better value of packet delivery ratio indicates the performance improvement of the protocol. Consider the three scenarios mentioned below.

Case i: A=100m×100m, N=50

Figure 3.14 gives the performance analysis of the Modified LEACH with the LEACH protocol based on the packet delivery ratio over the simulation period of 500 rounds.

Case ii: A=100m×100m, N=100

Figure 3.15 gives the performance analysis of the Modified LEACH with the LEACH protocol based on the packet delivery ratio over the simulation period of 500 rounds.

Case iii: A=100m×100m, N=150

Figure 3.16 gives the performance analysis of the Modified LEACH with the LEACH protocol based on the packet delivery ratio over the simulation period of 500 rounds. In the case of packet delivery ratio also it is observed that, based on different scenarios the Modified LEACH shows better performance compared to that of LEACH. Tables 3.3, 3.4 and 3.5 show the simulation results for the varying simulation area, number of nodes deployed and simulation period.

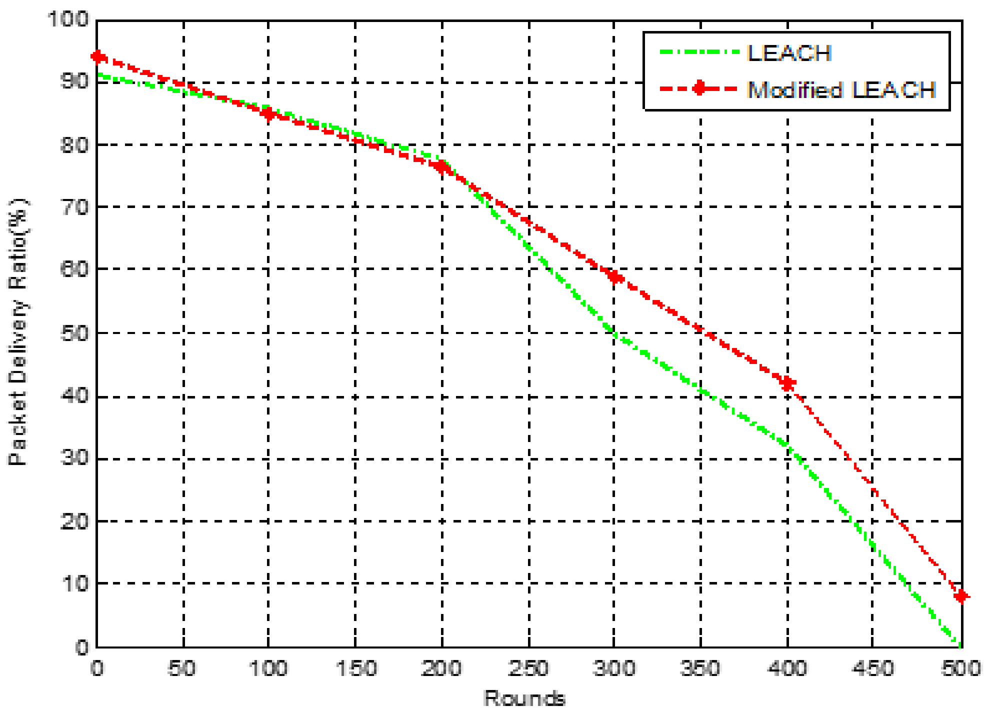

Figure 3.14: Packet Delivery Vs Rounds for Modified LEACH (N=50, A=100m×100m)

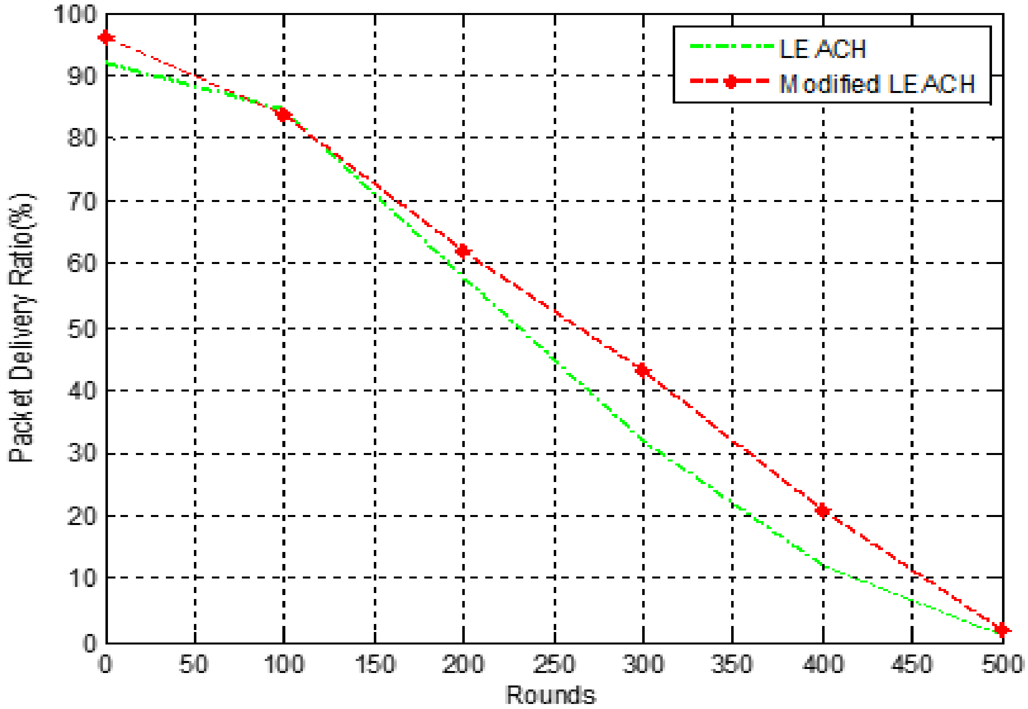

Figure 3.15: Packet Delivery Vs Rounds for Modified LEACH (N=100, A=100m×100m)

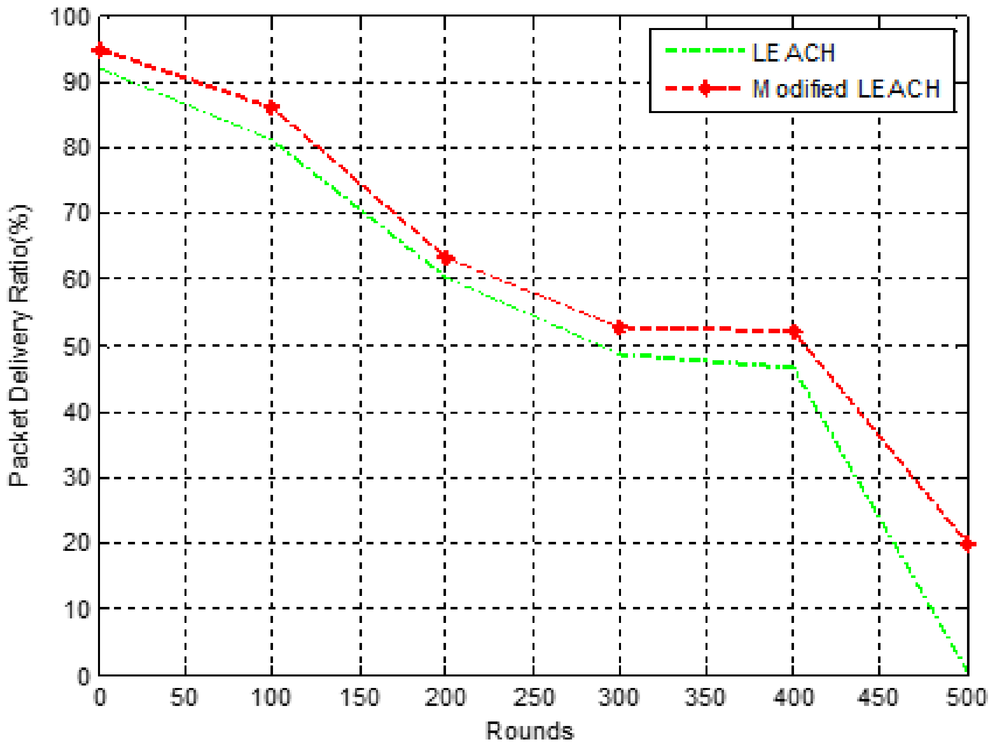

Figure 3.16: Packet Delivery Vs Rounds for Modified LEACH (N=150, A=100m×100m)

Table 3.3: Performance Comparison of LEACH and Modified LEACH (A=120m × 120m)

Performance Metric	Rounds	Protocols											
		LEACH						Modified LEACH					
		Number of nodes						Number of nodes					
		50	100	150	200	250	300	50	100	150	200	250	300
Number of Live Nodes	100	47	87	142	198	243	286	50	96	150	199	248	293
	200	43	71	130	192	230	275	47	83	139	194	242	281
	300	36	63	111	178	190	252	43	77	127	182	230	268
	400	32	58	84	120	143	180	40	66	111	151	221	212
	500	**16**	**26**	**53**	**97**	**111**	**142**	**39**	**45**	**99**	**133**	**192**	**187**
Average Residual Energy(J)	Rounds	Protocols											
		LEACH						Modified LEACH					
		Number of nodes						Number of nodes					
		50	100	150	200	250	300	50	100	150	200	250	300
	100	45.1	38.2	40.7	44.2	56.8	63.4	45.5	45.9	44.0	47	59.8	66.4
	200	32.4	29.6	32.8	44	52.1	59	38.2	31.9	39.2	46	55.1	62
	300	**12.8**	**24.4**	26.3	**32**	44.3	54	33.5	27.3	34.3	41	47.3	57
	400	8.1	12.0	**16.9**	29	**38**	**52**	28.3	**21.4**	28.8	36	41	55
	500	2.3	8.0	10.2	25	36	47	**22.5**	20.1	26.3	32	39	50
Packet Delivery Ratio (%)	Rounds	Protocols											
		LEACH						Modified LEACH					
		Number of nodes						Number of nodes					
		50	100	150	200	250	300	50	100	150	200	250	300
	100	85	91	94	90	91	98	89	95	98	97	99	99
	200	77	85	87	85	85	92	80	90	90	90	94	95
	300	50	58	60	79	82	89	59	63	72	88	89	88
	400	32	42	46	62	78	81	40	48	68	82	85	86
	500	2	12	**32**	44	**69**	**73**	12	22	**53**	72	**71**	**82**

Table 3.4 : Performance Comparison of LEACH and Modified LEACH (A=300m×300m)

Performance Metric	Rounds	Protocols											
		LEACH						Modified LEACH					
		Number of nodes						Number of nodes					
		50	100	200	300	400	500	50	100	200	300	400	500
Number of Live Nodes	100	32	78	179	290	389	497	36	83	182	296	398	498
	200	28	52	138	247	363	488	32	57	141	253	372	496
	300	15	34	88	218	311	459	19	39	91	224	320	473
	400	8	13	58	199	298	412	12	18	61	205	307	426
	500	**2**	**6**	**27**	**84**	**251**	**384**	**6**	**11**	**30**	**90**	**260**	**398**
Average Residual Energy(J)	Rounds	Protocols											
		LEACH						Modified LEACH					
		Number of nodes						Number of nodes					
		50	100	200	300	400	500	50	100	200	300	400	500
	100	32.0	39.0	44.8	48.3	48.6	49.7	36.0	41.5	45.5	49.3	49.8	49.8
	200	28.0	26.0	34.5	41.2	45.4	48.8	32.0	28.5	35.3	42.2	46.5	49.6
	300	15.0	17.0	22.0	36.3	38.9	45.9	19.0	19.5	22.8	37.3	40.0	47.3
	400	8.0	6.5	14.5	33.2	37.3	41.2	12.0	9.0	15.3	34.2	38.4	42.6
	500	2.0	3.0	6.8	14.0	31.4	38.4	6.0	5.5	7.5	15.0	32.5	39.8
Packet Delivery Ratio (%)	Rounds	Protocols											
		LEACH						Modified LEACH					
		Number of nodes						Number of nodes					
		50	100	200	300	400	500	50	100	200	300	400	500
	100	37	39	47	85	87	98	40	45	49	91	92	100
	200	26	27	32	78	77	95	29	33	34	84	82	100
	300	21	24	28	65	74	87	24	30	30	71	79	98
	400	12	18	22	62	66	83	15	24	24	68	71	91
	500	5	12	**18**	59	**61**	**81**	8	20	**20**	65	**66**	**89**

Table 3.5: Performance Comparison of LEACH and Modified LEACH (A=600m×600m)

Performance Metric	Rounds	Protocols											
		LEACH						Modified LEACH					
		Number of nodes						Number of nodes					
		700	800	900	1000	1250	1500	700	800	900	1000	1250	1500
Number of Live Nodes	100	680	787	889	994	1220	1500	698	790	892	1000	1250	1500
	200	659	679	712	860	1030	1250	689	770	863	980	1243	1487
	300	412	520	634	745	974	990	660	698	720	876	1228	1440
	400	290	382	440	630	798	820	532	654	689	813	967	990
	500	**206**	**290**	**320**	**505**	**720**	**780**	**467**	**590**	**612**	**739**	**915**	**923**
Average Residual Energy(J)	Rounds	Protocols											
		LEACH						Modified LEACH					
		Number of nodes						Number of nodes					
		700	800	900	1000	1250	1500	700	800	900	1000	1250	1500
	100	48.6	49.2	49.4	49.7	48.8	50.0	49.9	49.4	49.6	50.0	50.0	50.0
	200	47.1	42.4	39.6	43.0	41.2	41.7	49.2	48.1	47.9	49.0	49.7	49.6
	300	29.4	32.5	35.2	37.3	39.0	33.0	47.1	43.6	40.0	43.8	49.1	48.0
	400	20.7	23.9	24.4	31.5	31.9	27.3	38.0	40.9	38.3	40.7	38.7	33.0
	500	14.7	18.1	17.8	25.3	28.8	26.0	33.4	36.9	34.0	37.0	36.6	30.8
Packet Delivery Ratio (%)	Rounds	Protocols											
		LEACH						Modified LEACH					
		Number of nodes						Number of nodes					
		700	800	900	1000	1250	1500	700	800	900	1000	1250	1500
	100	83	85	92	95	99	100	91	93	92	98	100	100
	200	62	85	89	95	99	99	82	91	90	96	98	100
	300	44	72	87	90	87	95	67	83	87	91	95	97
	400	27	56	79	81	84	82	49	72	74	86	88	92
	500	24	43	**52**	75	**79**	**80**	38	56	**71**	82	**82**	**88**

3.3.2 Summary

In the Modified LEACH, the clustering is carried out at the initial stage and after that are being fixed, until a specific threshold energy level of the CH is met. The CHs are rotated among the cluster members of the same cluster. The benefit of this process compared to LEACH is that, set-up overheads are reduced at the commencement of each round. For cluster formation, Modified LEACH uses the centralized approach initially. It takes the nodes remaining energy and relative distance to the BS for deciding CH.As it does so, always the nodes having more energy will be selected as CHs. The performance of this Modified LEACH is compared with LEACH for average energy consumed, live nodes and the packet delivery ratio. Modified LEACH gives better performance based on these parameters compared to that of LEACH which indicates the energy efficiency of the modified approach.

The limitation of Modified LEACH protocol is that the fixed clusters do not allow dynamic node addition and deletion by different circumstances. An additional overhead of control messages compared to LEACH is another drawback. The number of CHs is fixed as five percent of the total nodes deployed for the simulation. The optimal number of nodes and CHs for a specific area is not calculated as it is application dependent.

CHAPTER 4
MODIFIED MOBILE SINK ASSISTED LEACH ALGORITHM

CHAPTER 4

MODIFIED MOBILE SINK ASSISTED LEACH ALGORITHM

4.1 Introduction

Mobile Sinks (MSs) have a major role in prolonging lifetime of the WSNs. As the nodes near the Static Sink(SS) is prone to earlier energy depletion because of their constant utilization, the use of MSs can overcome this issue, by providing a uniform load among the sensor nodes (Khan et al. 2013). The use of MS will reduce the hops to reach the BS which further reduces energy consumption. This chapter describes the Modified Mobile Sink Assisted LEACH in which the sink mobility concept with multiple sinks is incorporated.

4.1.1 Network Model

The energy model used is the simple first order radio model (Heinzelman et al. 2000). The radio dissipates $E_{elec} = 50$ nJ/bit for running the transmitter or receiver circuitry and the transmit amplifier uses $\epsilon_{amp} =$ 100pJ/bit/m^2. According to this model, for transmitting a k-bit message over a distance d, the radio expends:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \quad (4.1)$$

$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2 \quad (4.2)$$

To receive a message, the radio expends:

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

$$E_{Rx}(k) = E_{elec} * k \quad (4.4)$$

E_{Tx} and E_{Rx} is the transmitting energy and receiving energy in Joules.

4.1.2 Assumptions for Mobile Sink Assisted LEACH

- Sensor nodes are arbitrarily dispersed within a sensing field.
- There is only one Base Station (BS).
- Sensor nodes and the BS are static after deployment. The location of the BS is known by each node and they have the capability of communicating directly with the BS in certain situations.
- Sensor nodes can use power control to vary the amount of transmit power depending on the distance to the receiver. For simplicity it is assumed that the power level is continuous. The process of sensing is also continuous.
- Based on RSS, sensor nodes can compute their relative distance to BS and communication is symmetric.
- Sensor nodes are homogeneous.
- Four MSs are used for data gathering. The MSs are having higher range than that of the normal nodes and are rechargeable.

4.2 Description of the Modified Mobile Sink Assisted LEACH Algorithm

Consider Figure 4.1 and Figure 4.2. The area of deployment is assumed to be square region. Let ‘s’ be the length of each side and v be the uniform velocity. In Figure 4.1 the time required by the sink to move from A to B can be calculated as;

$$t = \frac{s}{v} \tag{4.5}$$

Where v is the velocity or speed in m/s, s is the linear distance travelled in meters and t is the time in seconds. The total time required to cover the four sides will be;

$$t_1 = 4 \times \frac{s}{v} = 4t \qquad (4.6)$$

From the above equation it is clear that the time taken to cover all the sides based on the mobility pattern represented in Figure 4.1 is $4t$. In Figure 4.2 the length of the diagonal is $\sqrt{2}\, s$. Therefore, distance from the centre to B can be calculated as;

$$d = \frac{\sqrt{2S}}{2} \qquad (4.7)$$

$$d = \frac{s}{\sqrt{2}} \qquad (4.8)$$

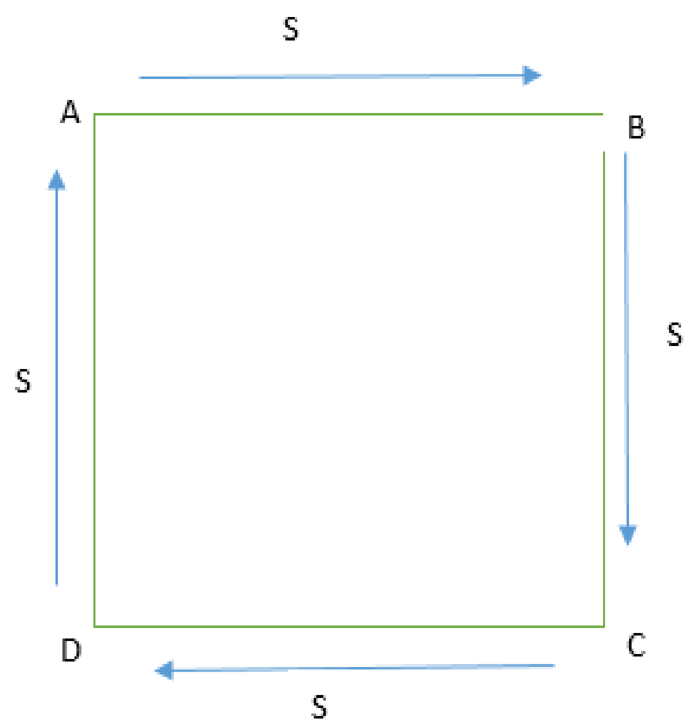

Figure 4.1: Single Mobile Sink Movement Path

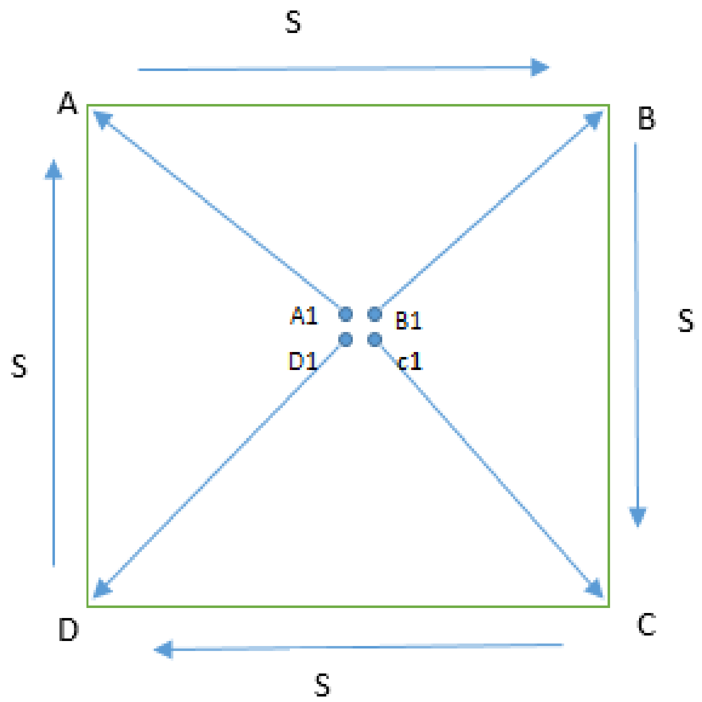

Figure 4.2: Multi Sink Movement Path

The time taken to move from $C1 \quad to\, C\, will\, be;$

$$T = \frac{\frac{s}{\sqrt{2}}}{v} \times 4 \tag{4.9}$$

$$T = \left(\frac{s}{\sqrt{2}v}\right) \tag{4.10}$$

Therefore, the total time taken by all the four sinks to reach the vertices can be calculated as;

$$T_1 = \left(\frac{s}{\sqrt{2}v}\right) \times 4 = 2\sqrt{2}\ t \tag{4.11}$$

From the equation 4.6 and equation 4.11, it can be seen that $t_1 > T_1$

$$t_1 = \sqrt{2}T_1 \tag{4.12}$$

The mobility pattern of the MS as shown in Figure 4.1 takes $\sqrt{2}$ times the time required by the mobility pattern of MSs exhibited in Figure 4.2 which indicates that using multiple MSs is better than using a single MS to cover a particular region. Based on this, the concept of sink mobility was introduced to Modified LEACH algorithm where in four mobile sinks are incorporated. The two conditions were considered for the movement of MSs; one is giving pause times in between, and the other of continuous movement of the MSs. Consider the Figure 4.3. Let OA=OB=OC=OD=d, where d is the half diagonal length.

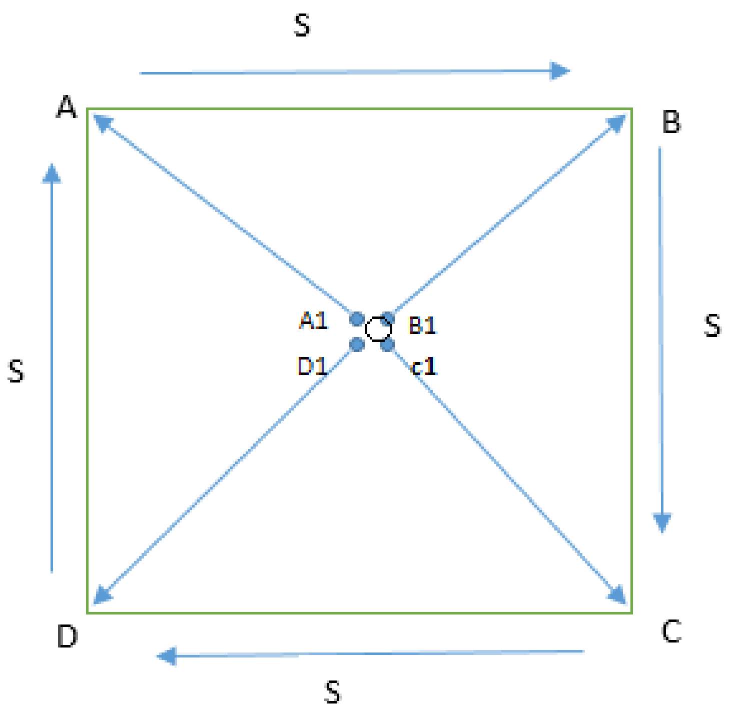

Figure 4.3 : Mobile Sink Path Movement

For the triangle OAB,

$$d^2 + d^2 = L^2 \tag{4.13}$$

$$d = \frac{1}{\sqrt{2}} L \tag{4.14}$$

Let T be the time for continuous motion. Speed at continuous motion is

$$v = \frac{L}{\sqrt{2}T} \tag{4.15}$$

Considering the pause time of MSs for τ seconds and n number of pause times, the total time taken would be T+nτ. Speed for n pause times for τ second duration,

$$v = \frac{L}{\sqrt{2}(T+n\tau)} \qquad (4.16)$$

where v is the speed to be determined in meter/second, L is the length of each square side in meters, T is the time taken in seconds for continuous motion, τ is the duration of pause time in seconds and 'n' is the number of pause times along distance 'd'. The pause times and the number of pause time were randomly varied to decide the speed of MS's mobility.

Modified Mobile Sink Assisted Routing algorithm consists of three major phases namely; Network clustering phase, Mobile sink navigation phase, Data collection phase/Routing. Clustering is carried out as same as that of the Modified LEACH algorithm. The movement of the MSs is designed with a uniform velocity in a particular path so as to have maximum coverage within a limited time. The nodes will communicate to the CHs and the CH will communicate to the MS within its range. MSs will aggregate the data and transfers to the static sink (SS).

The initial phase is the Network Clustering Phase. The network is partitioned to clusters using clustering algorithm of Modified LEACH with fewer number of CHs possible. Once CH nodes are chosen, they broadcast beacon to advertise their presence within their communication range. Based on the RSS each non cluster nodes choose their CHs to which they belong to. The CH nodes send their information to the MS and BS. Because of this arrangement sensor node need only low power for data transmission to CHs. CHs will aggregate this information and wait for MSs to deliver the data.

The next phase is the Mobile Sink Navigation Phase. The path for the MSs is predefined. Initially the four MSs are positioned at the centre of the deployed square region. They will be moving towards its corners and back to the centre throughout the simulation period. Half the diagonal length will be covered by each MS.

The CH’s within the coverage area of the MSs will send the aggregated data from their respective clusters to the MSs. The MSs are assumed to have better range compared to the sensor nodes. Two types of MS mobility pattern are considered; the first in which the MSs move continuously in the predefined path and the second one where MSs will have a pause time of two seconds at different points on its path movement. The CH’s sends their data to the MSs during this time of MS navigation. The routing of the data happens from the cluster members to the CHs and from the CHs to the respective MSs. MSs will further aggregate the information and routes it to the SS/BS.

The procedure of the Modified Mobile Sink Assisted LEACH algorithm is given below. [BS is the base station, CH is the cluster head, MS is the mobile sink, RSS is the received signal strength, N is number of nodes deployed, A is the area of deployment, max_count is taken as 5%of N, t is the time limit and R is the sensor range which is application dependent.]

- Initially all nodes send their information to the BS as well as to the immediate neighbours.
- Each node maintains a count and max_count information.
- Within time ‘t’ each node identifies its neighbours within ‘R’.
- Elect node with the count=max_count within the limited time ‘t’ as CH; CH sends advertisement messages to its immediate neighbours to confirm it as CH for then the time ‘t’ stops.
- Based on RSS each node sends back the information to its respective CH and forms the clusters.

- CHs send the TDMA schedule to all the members in which they can communicate the sensed data to their CHs.
- Path planning for the MS is done and duty cycling for the different clusters is performed.
- CHs maintain information about the residual energy of all its members and their relative distance to the MS. Data aggregated from the cluster members will be forwarded to the MS by the CHs. MSs will aggregate this and further forward to the BS.

The procedure for clustering and duty cycling is given below;
[nodetype is the type of node ,nodeenergy is the node's energy level,
RSS is the received signal strength ,T is the threshold energy,n is the number of nodes ,m is the time limit,neigh [ ] is the array of neighbour nodes,Mindist isthe minimum distance,Mobsinkpos is the position of the mobile sink and CHpos is the position of the cluster head]

```
//Clustering procedure

 for all node i=1 to n
        if nodetype==2 and RSS==high then form cluster
                if nodeenergy>T and nodetype==1
                        elect as CH
                end
        end
 end
//Duty cycling procedure
 for all node cycletime= 1 to m
        for all node to n
                pos=mobsinkpos-CHpos
                if nodedist < range/ 2
                        if pos<Tdist
                            CH sends data to MS end
```

```
                    end
                end
            end
end
```

The data aggregation and routing procedure is mentioned below.

```
//Data aggregation algorithm
RSS is the received signal strength
T is the threshold energy
n is the number of nodes
m is the time limit
neigh [] is the array of neighbour nodes


 for all node i=1 to n
        if data[neigh[i]] ==data[j] then
                data= data [i]
                 flag=1
        else
                 flag=0
         end
if flag==1
        send data to MS
         If MSdata[1] ==MSdata[2]==MSdata[3]==MSdata[4] then
        data= MSdata
         end
end
//Routing algorithm
for all node i=1 to n
        if flag==1
                Nodes sends data to CH
                 CH sends data to MS
                MS sends data to Static Sink
        end

 end
```

The flowchart of the proposed Mobile Sink Assisted LEACH is given in Figure 4.4.

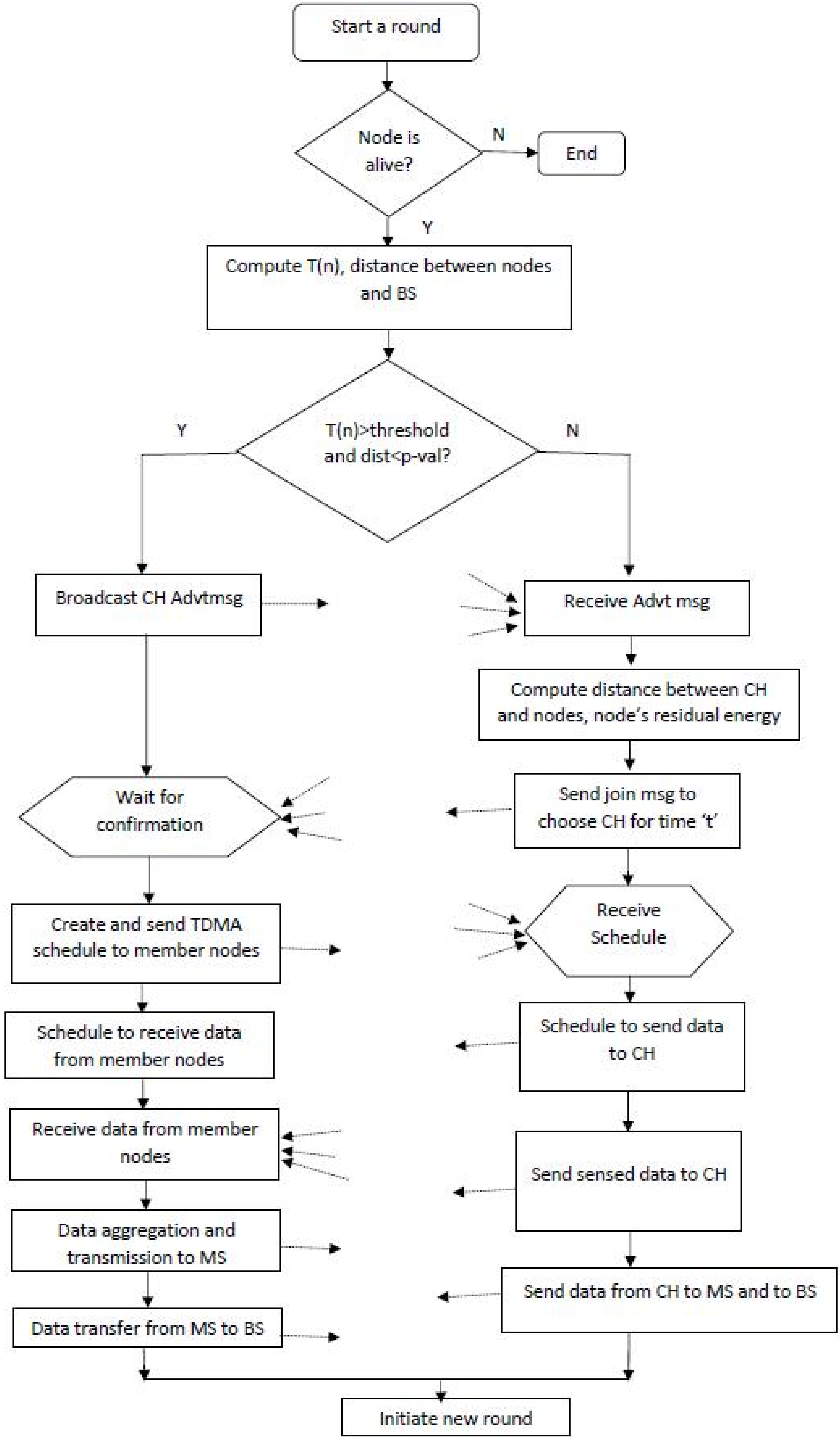

Figure 4.4: Flowchart of Mobile Sink Assisted LEACH

4.2.1 Simulation Results and Performance Analysis

The simulation is performed using MATLAB in different scenarios by varying the simulation parameters. Different cases were considered by keeping the area of deployment constant and varying the number of nodes. Randomly changing the area of simulation as well the numbers of nodes were also carried out. The speed of the MSs is arranged in such a way as it is possible to cover the area up to 500m×500m with in a specific time of fifty seconds. The simulation parameters are given in Table 4.2. The Modified Mobile Sink Assisted Routing algorithm is compared with the LEACH protocol and the M-LEACH protocol (Nguyen et al. 2008). M-LEACH allows the mobility of the nodes both the cluster members as well as CH during the setup and steady state phase. M-LEACH considers the remaining energy of node while selecting the CH. But due to the mobility of nodes overheads are more.

Table 4.1: Simulation Parameters for Mobile Sink Assisted LEACH Protocol

Parameters	**Values**	**Description**
Simulation Area	100× 100 m	XY dimension
Number of Nodes	50,100,150	Simulation nodes
Transmission Range	20 m	Nodes power range
Maximum Speed	24 m/s	Movement
Mobility interval	0s, 2 s	Pause time of node
Transmission Energy	2×10^{-1}joules / pkt	Energy to transmit a packet
Receiving Energy	1 × 10 -1joules / pkt	Energy to receive a packet

Three different scenarios are taken where in the area of deployment is varied with different number of sensor nodes. The different parameters used for performance analysis are delay, packet delivery ratio and the average energy of the network at various simulation periods. Based on different cases the performance evaluation of the Modified Mobile Sink Assisted LEACH using various parameters are discussed below. Tables 4.2, 4.3 and 4.4 shows the simulation results under various scenarios of sink mobility, where the results based on the simulation time till fifty percent of the nodes are alive in all the protocols considered.

- ***Delay***

  In terms of delay the performance of Modified Mobile Sink Assisted LEACH is compared with LEACH and M-LEACH under different simulation parameters as mentioned below.

Case i: A=100m×100m, N=50

Figure 4.5 gives the performance analysis of the Modified Mobile Sink Assisted LEACH Algorithm with the LEACH protocol and M-LEACH based on the delay over the simulation period with 50 nodes.

Case ii: A=100m×100m, N=100

The performance analysis of the Modified Mobile Sink Assisted LEACH Algorithm with the LEACH protocol and M-LEACH based on the delay over the simulation period of 500 rounds with 100 nodes deployed in a 100m×100m square area is given in Figure 4.6.

Case iii: A=100m×100m, N=150

Figure 4.7 gives the performance analysis of the Modified Mobile Sink Assisted LEACH Algorithm with the LEACH protocol and M-LEACH based on the delay over the simulation period of 500 rounds.

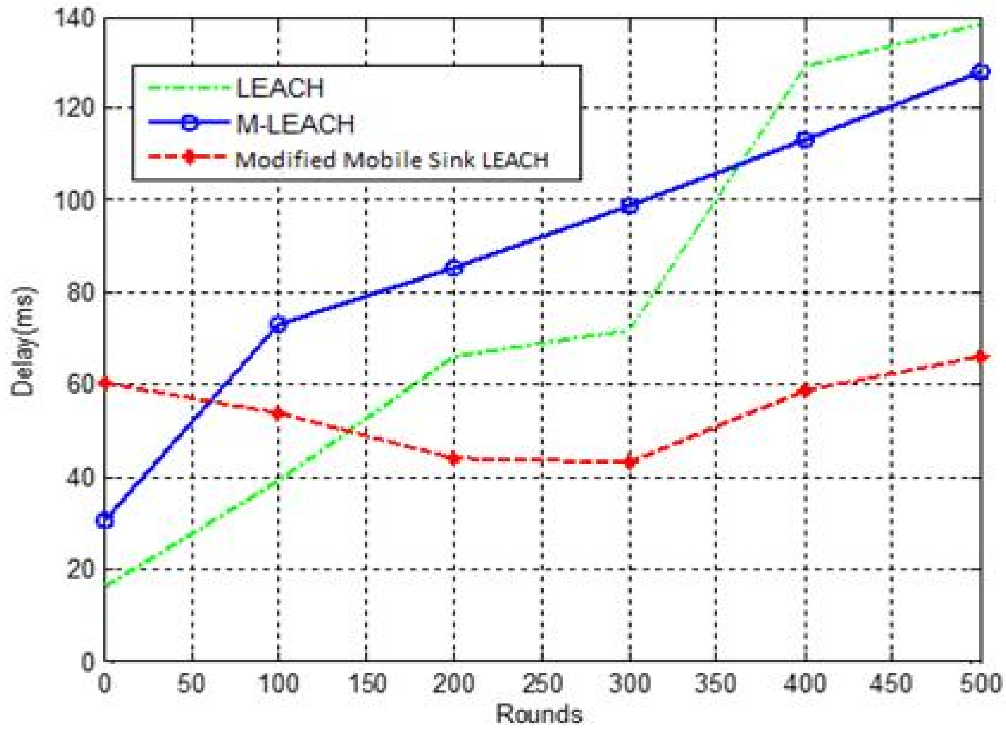

Figure 4.5: Delay Vs Rounds for Modified Mobile Sink Assisted LEACH (N=50, A=100m×100m)

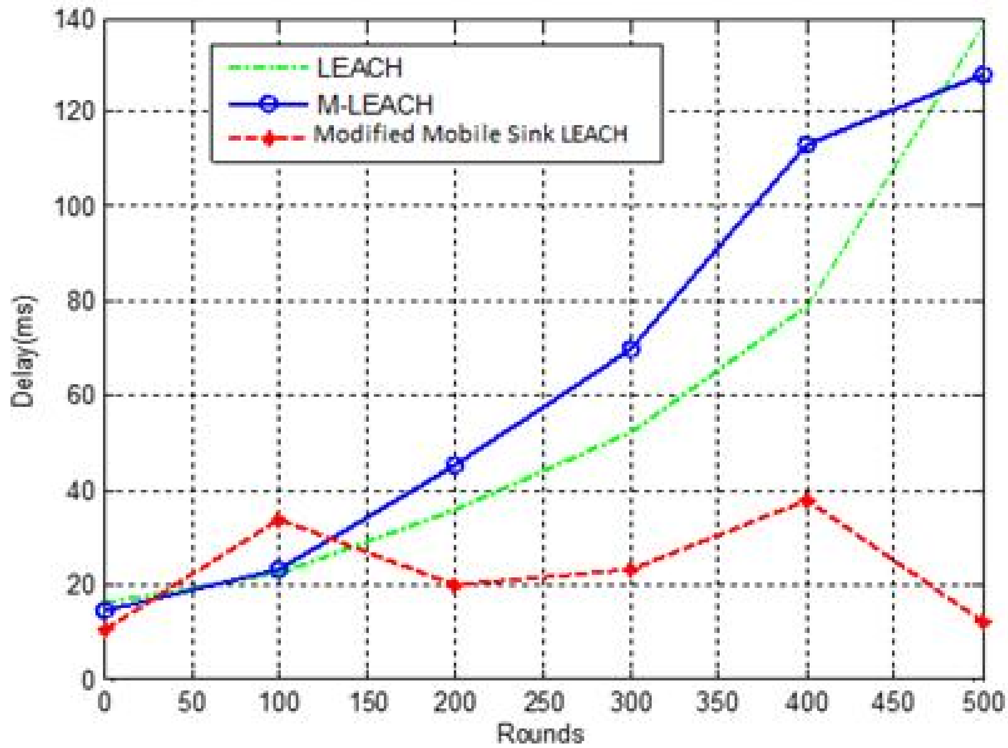

Figure 4.6: Delay Vs Rounds for Modified Mobile Sink Assisted LEACH (N=100, A=100m×100m)

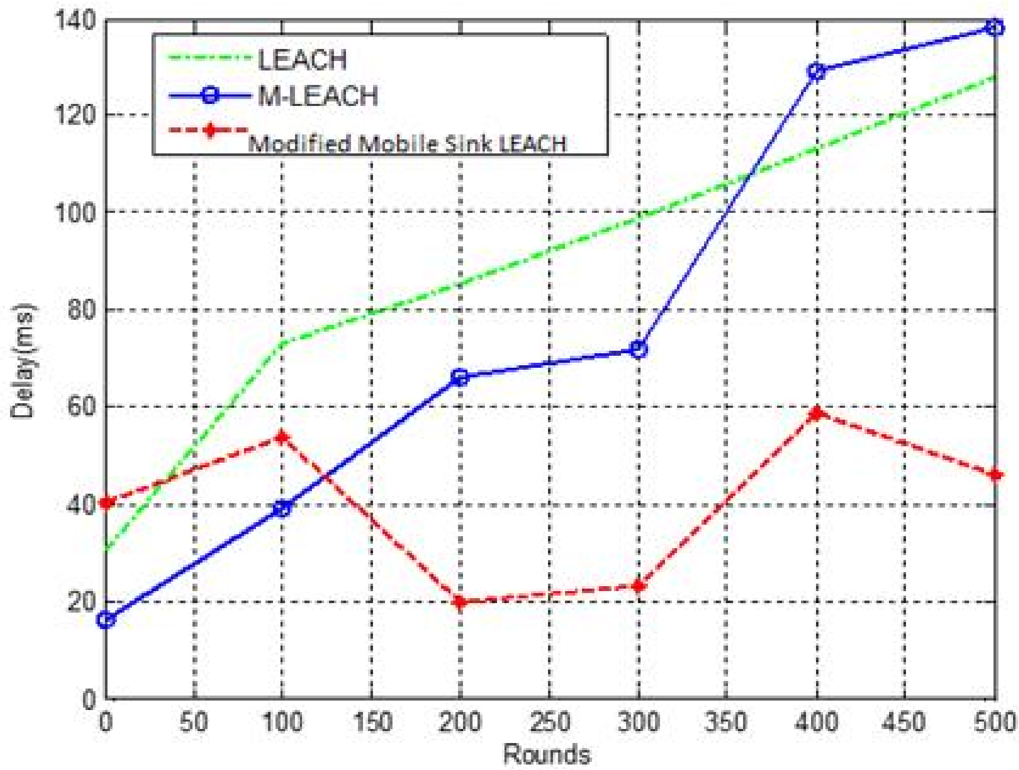

Figure 4.7: Delay Vs Rounds for Modified Mobile Sink Assisted LEACH (N=150, A=100m×100m)

In all the three cases, it can be observed that the Mobile Sink Assisted LEACH gives better performance based on the delay factor. It shows comparatively less delay and maintains stability throughout the simulation period. But it can also be observed that there is a change in the delay due to sink mobility at times during different rounds.

- ***Packet Delivery Ratio***

Packet delivery ratio is another metric used to assess the performance which indicates the number of packets that have successfully reached the destination. Three different scenarios are illustrated based on this performance measure.

Case i: A=100m×100m, N=50

Figure 4.8 gives the performance analysis of the Modified Mobile Sink Assisted LEACH Algorithm with the LEACH protocol and M-LEACH based on the packet delivery ratio over the simulation period of 500 rounds.

Case ii: A=100m×100m, N=100

Figure 4.9 gives the performance analysis of the Modified Mobile Sink Assisted LEACH Algorithm with the LEACH protocol and M-LEACH based on the packet delivery ratio over the simulation period of 500 rounds.

Case iii: A=100m×100m, N=150

Figure 4.10 gives the performance analysis of the Modified Mobile Sink Assisted LEACH Algorithm with the LEACH protocol and M-LEACH based on the packet delivery ratio over the simulation period of 500 ms.

It can be observed that the proposed Mobile Sink Assisted approach attains higher packet delivery ratio in all the cases compared to LEACH and M-LEACH. But due to impact of sink mobility there is a sudden change in the packet delivery ratio at different times.

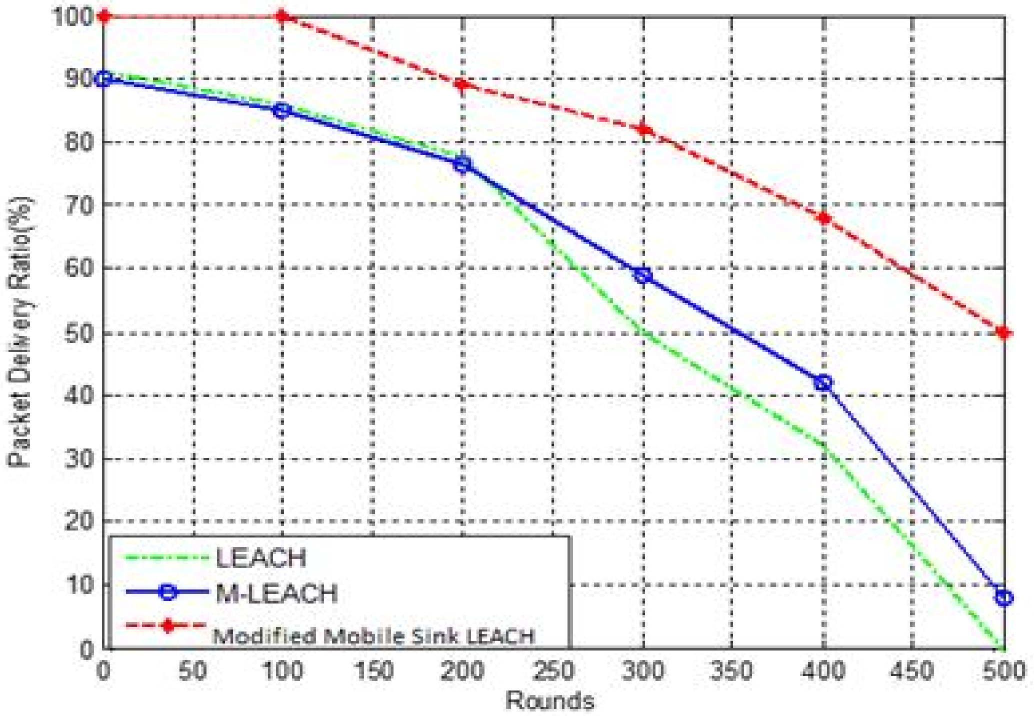

Figure 4.8: Packet Delivery Ratio Vs Rounds for Modified Mobile Sink Assisted LEACH (N=50, A=100m×100m)

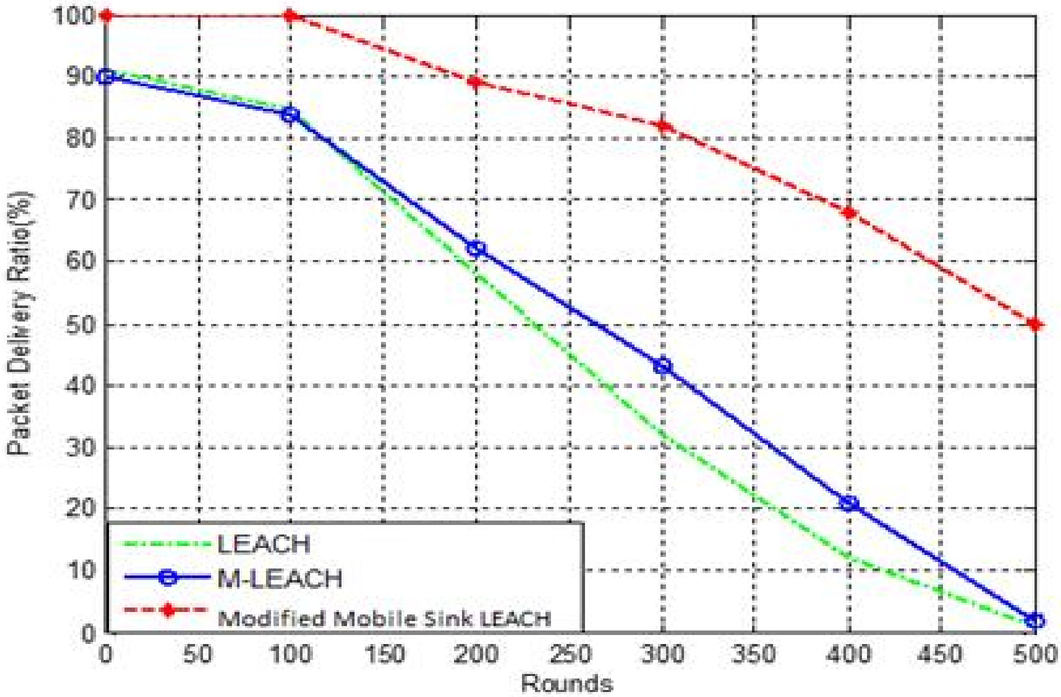

Figure 4.9: Packet Delivery Ratio Vs Rounds for Modified Mobile Sink Assisted LEACH (N=100, A=100m×100m)

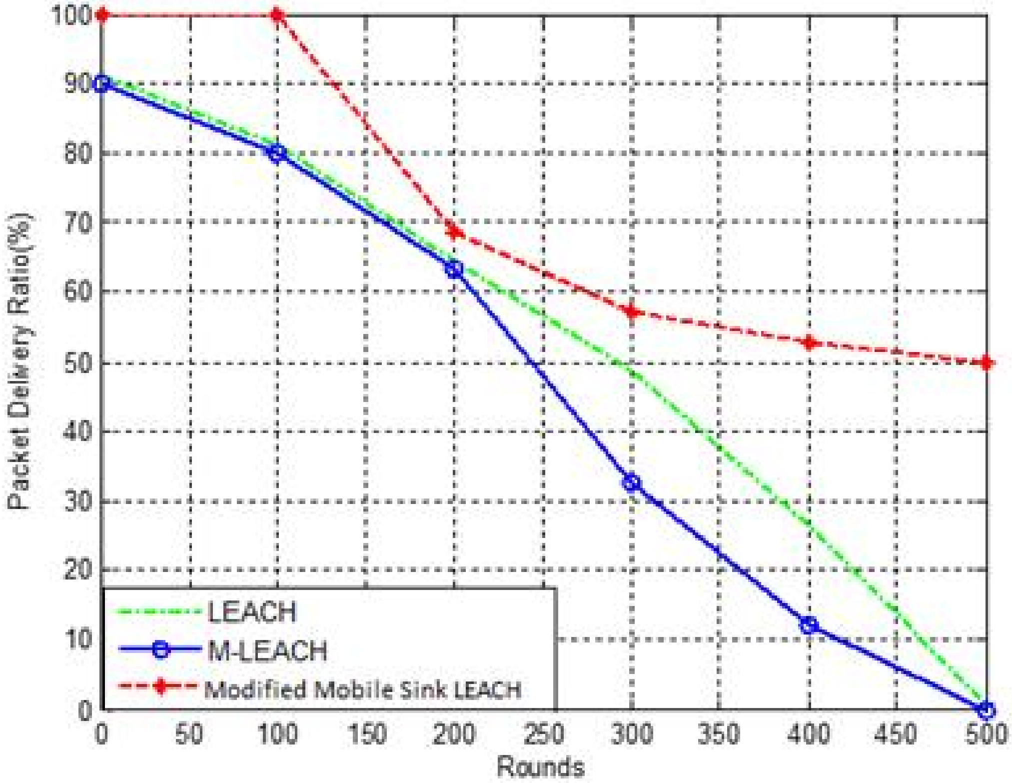

Figure 4.10: Packet Delivery Ratio Vs Rounds for Modified Mobile Sink Assisted LEACH (N=150, A=100m×100m)

- ***Average Residual Energy***

Average residual energy of the network indicates the energy efficiency of the network. Based on the average residual energy of the node in different simulation periods, the performance of the different protocols was compared. The different scenarios are illustrated below.

Case i: A=100m×100m, N=50

Figure 4.11 gives the performance analysis of the Modified Mobile Sink Assisted LEACH Algorithm with the LEACH protocol and M-LEACH based on the average energy consumed over the simulation period of 500 rounds.

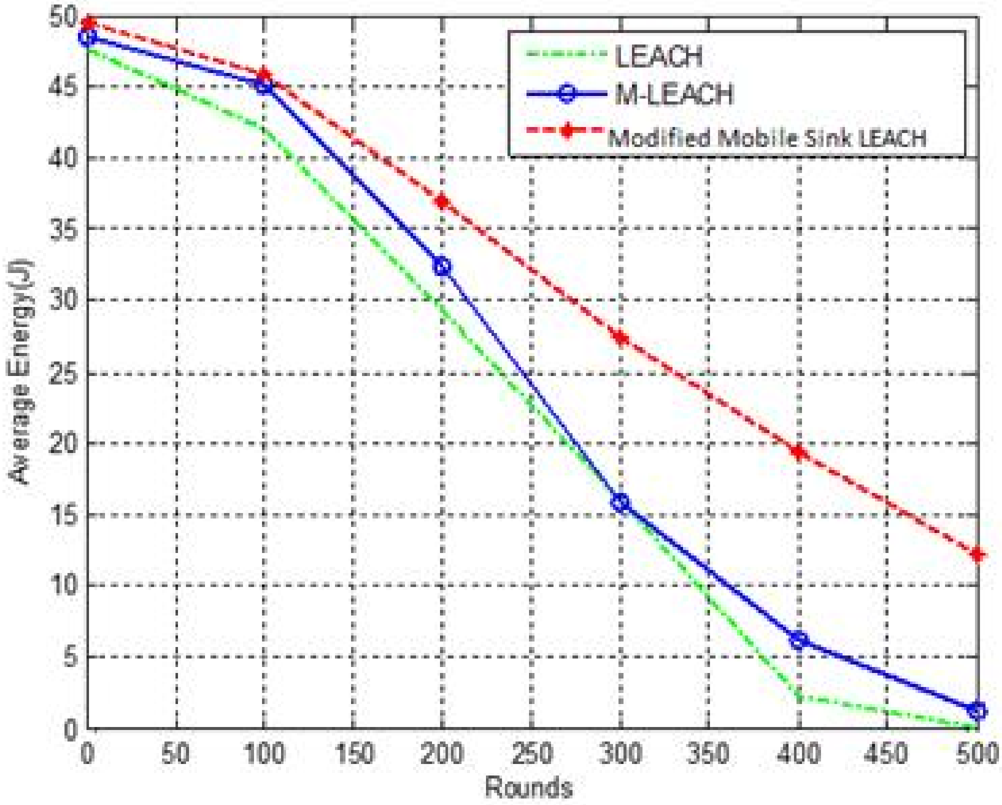

Figure 4.11: Average Energy Vs Rounds for Modified Mobile Sink Assisted LEACH (N=50, A=100m×100m)

Case ii: A=100m×100m, N=100

Figure 4.12 gives the performance analysis of the Modified Mobile Sink Assisted LEACH Algorithm with the LEACH protocol and M-LEACH based on the average energy consumed over the simulation period of 500 rounds.

Case iii: A=100m×100m, N=150

Figure 4.13 gives the performance analysis of the Modified Mobile Sink Assisted LEACH Algorithm with the LEACH protocol and M-LEACH based on the average energy consumed over the simulation period of 500 rounds.

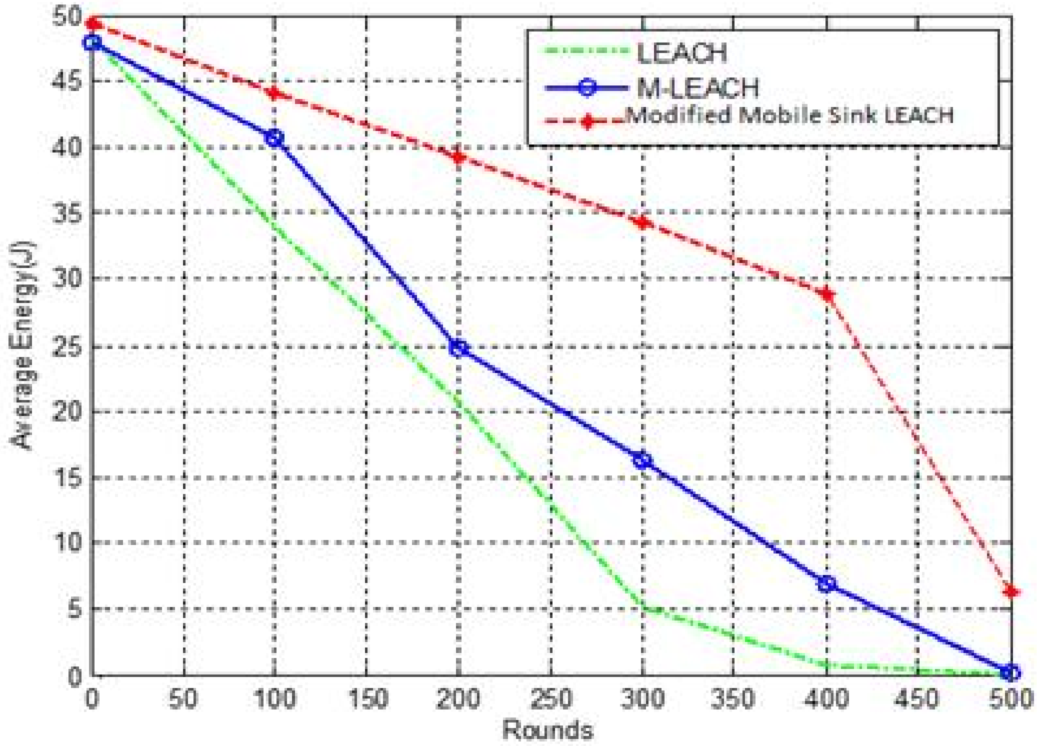

Figure 4.12: Average Energy Vs Rounds for Modified Mobile Sink Assisted LEACH (N=100, A=100m×100m)

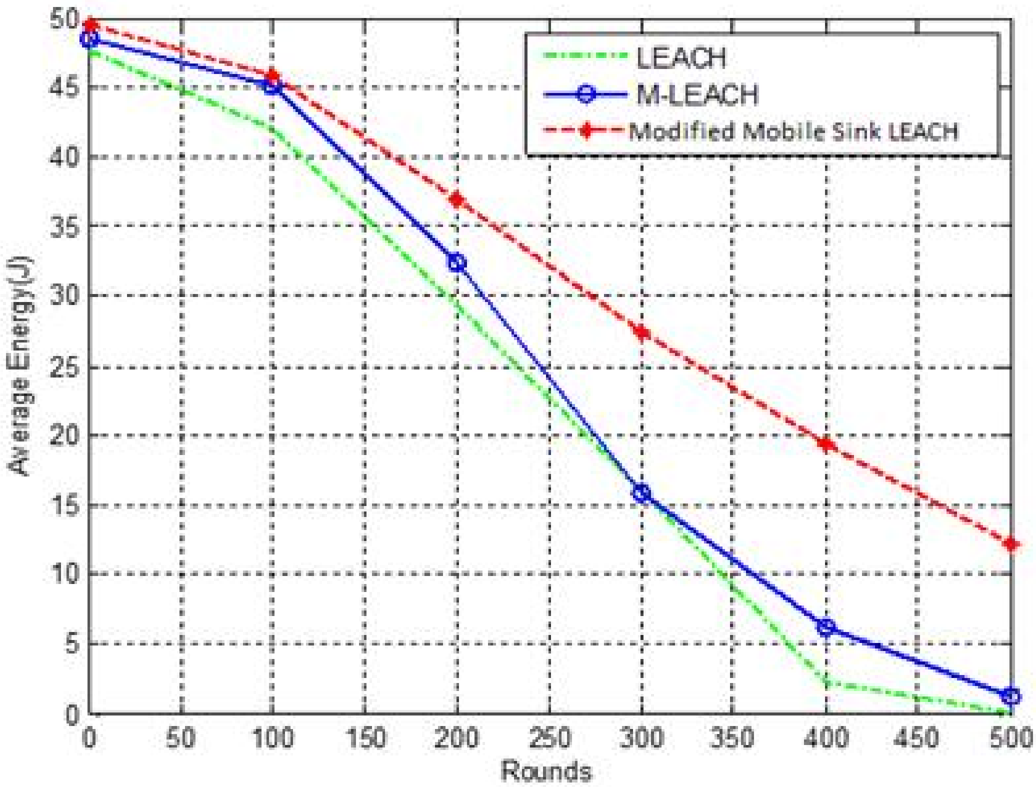

Figure 4.13 : Average Energy Vs Rounds for Modified Mobile Sink Assisted LEACH (N=150, A=100m×100m)

Table 4.2: Performance Comparison of LEACH and Modified Mobile Sink Assisted LEACH (120m×120m)

Performance Metric	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		Number of nodes						Number of nodes					
		50	100	150	200	250	300	50	100	150	200	250	300
Number of Live Nodes	100	47	87	142	198	243	286	50	96	150	199	248	293
	200	43	71	130	192	230	275	47	83	139	194	242	281
	300	36	63	111	178	190	252	43	77	127	182	230	268
	400	32	58	84	120	143	180	40	72	118	168	221	212
	500	**16**	**26**	**53**	**97**	**111**	**142**	**39**	**66**	**112**	**162**	**192**	**187**
Average Residual Energy(J)	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		50	100	150	200	250	300	50	100	150	200	250	300
	100	45.1	38.2	40.7	45.1	38.2	40.7	50.0	48.0	50.0	49.8	49.6	48.8
	200	32.4	29.6	32.8	32.4	29.6	32.8	47.0	41.5	46.3	48.5	48.4	46.8
	300	**12.8**	**24.4**	26.3	**12.8**	**24.4**	26.3	43.0	38.5	42.3	45.5	46.0	44.7
	400	8.1	12.0	**16.9**	8.1	12.0	**16.9**	40.0	36.0	39.3	42.0	44.2	35.3
	500	2.3	8.0	10.2	2.3	8.0	10.2	39.0	33.0	37.3	40.5	38.4	31.2
Packet Delivery Ratio (%)	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		50	100	150	200	250	300	50	100	150	200	250	300
	100	85	91	94	85	91	94	89	95	98	97	99	99
	200	77	85	87	77	85	87	80	90	90	90	94	95
	300	50	58	60	50	58	60	59	63	72	88	89	88
	400	32	42	46	32	42	46	40	48	68	82	85	86
	500	2	12	**32**	2	12	**32**	12	22	**53**	72	**71**	**82**
Delay(ms)	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		50	100	150	200	250	300	50	100	150	200	250	300
	100	20	16	15	10	4	4	12	24	18	10	4	4
	200	48	32	17	18	13	10	30	38	12	38	16	12
	300	63	55	17	20	20	10	12	12	38	22	39	16
	400	120	80	20	30	22	16	16	42	16	28	11	32
	500	138	119	23	30	26	21	84	46	43	28	5	4

Table 4.3: Performance Comparison of LEACH and Modified Mobile Sink Assisted LEACH (300 m×300m)

Performance Metric	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		Number of nodes						Number of nodes					
		50	100	200	300	400	500	50	100	200	300	400	500
Number of Live Nodes	100	32	78	179	290	389	497	36	83	182	296	398	498
	200	28	52	138	247	363	488	32	57	141	253	372	496
	300	15	34	88	218	311	459	19	39	91	224	320	473
	400	8	13	58	199	298	412	12	18	61	205	307	426
	500	**2**	**6**	**27**	**84**	**251**	**384**	**6**	**11**	**30**	**90**	**260**	**398**
Average Residual Energy(J)	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		50	100	200	300	400	500	50	100	200	300	400	500
	100	32.0	39.0	44.8	48.3	48.6	49.7	36.0	41.5	45.5	49.3	49.8	49.8
	200	28.0	26.0	34.5	41.2	45.4	48.8	32.0	28.5	35.3	42.2	46.5	49.6
	300	15.0	17.0	22.0	36.3	38.9	45.9	19.0	19.5	22.8	37.3	40.0	47.3
	400	8.0	6.5	14.5	33.2	37.3	41.2	12.0	9.0	15.3	34.2	38.4	42.6
	500	2.0	3.0	6.8	14.0	31.4	38.4	6.0	5.5	7.5	15.0	32.5	39.8
Packet Delivery Ratio (%)	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		50	100	200	300	400	500	50	100	200	300	400	500
	100	37	39	47	85	87	98	40	45	49	91	92	100
	200	26	27	32	78	77	95	29	33	34	84	82	100
	300	21	24	28	65	74	87	24	30	30	71	79	98
	400	12	18	22	62	66	83	15	24	24	68	71	91
	500	5	12	**18**	59	**61**	**81**	8	20	**20**	65	**66**	**89**
Delay(ms)	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		50	100	200	300	400	500	50	100	200	300	400	500
	100	61	40	15	17	14	14	12	24	18	10	4	4
	200	48	32	17	18	13	10	30	38	12	38	16	12
	300	63	55	17	20	20	10	12	121	138	122	139	16
	400	220	80	20	30	227	16	16	42	16	28	11	32
	500	138	119	23	30	126	21	84	46	43	28	5	4

Table 4.4: Performance Comparison of LEACH and Modified Mobile Sink Assisted LEACH (600m×600m)

Performance Metric	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		Number of nodes						Number of nodes					
		700	800	900	1000	1250	1500	700	800	900	1000	1250	1500
Number of Live Nodes	100	680	787	889	994	1220	1500	698	790	892	1000	1250	1500
	200	659	679	712	860	1030	1250	689	770	863	980	1243	1487
	300	412	520	634	745	974	990	660	698	720	876	1228	1440
	400	290	382	440	630	798	820	532	654	689	813	967	990
	500	**206**	**290**	**320**	**505**	**720**	**780**	**467**	**590**	**612**	**739**	**915**	**923**
Average Residual Energy(J)	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		700	800	900	1000	1250	1500	700	800	900	1000	1250	1500
	100	48.6	49.2	49.4	49.7	48.8	50.0	49.9	49.4	49.6	50.0	50.0	50.0
	200	47.1	42.4	39.6	43.0	41.2	41.7	49.2	48.1	47.9	49.0	49.7	49.6
	300	29.4	32.5	35.2	37.3	39.0	33.0	47.1	43.6	40.0	43.8	49.1	48.0
	400	20.7	23.9	24.4	31.5	31.9	27.3	38.0	40.9	38.3	40.7	38.7	33.0
	500	**14.7**	**18.1**	**17.8**	**25.3**	**28.8**	**26.0**	**33.4**	**36.9**	**34.0**	**37.0**	**36.6**	**30.8**
Packet Delivery Ratio (%)	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		700	800	900	1000	1250	1500	700	800	900	1000	1250	1500
	100	83	85	92	95	99	100	91	93	92	98	100	100
	200	62	85	89	95	99	99	82	91	90	96	98	100
	300	44	72	87	90	87	95	67	83	87	91	95	97
	400	27	56	79	81	84	87	49	72	74	86	88	92
	500	24	43	**73**	75	**84**	**87**	38	56	**66**	82	**82**	**88**
Delay(ms)	Rounds	Protocols											
		LEACH						Modified Mobile Sink Assisted LEACH					
		700	800	900	1000	1250	1500	700	800	900	1000	1250	1500
	100	1729	1674	1774	1212	1220	1198	1809	1998	1854	1784	698	612
	200	1020	1200	1120	1478	1389	1312	1994	2048	1890	1298	1738	893
	300	899	1820	1880	1198	1212	1142	893	1291	1847	1670	984	1135
	400	1640	1580	1589	1823	1734	1413	1398	1045	832	1223	945	530
	500	1320	1290	1070	1887	1677	**1489**	1112	998	1010	1183	512	**497**

4.2.2 Summary

From the simulation results, it is evident that by using MSs, there is considerable amount of saving in the energy. Reduced energy consumption of individual nodes is attained by multi hop transmission through the CH and then by the MSs, directed to the BS. Duty cycling introduced avoids the energy wastage to a good extend. Proper selection of CHs eliminates the energy hole problem that can terminate the network lifetime. Improved reliability can be achieved as there is less contention and collisions within the wireless medium because data can now be collected directly through single or limited hop transmissions since the MSs are involved. Reduced reliance on nodes located close to a static sink to route messages to the sink, resulting in increased energy efficiency and network lifetime is another advantage. Overall the modified method satisfies the objective of the research intended.

The Modified Mobile Sink Assisted Protocol is path constrained and the speed of the mobile sink affects the delay in packet delivery. It is showing better performance in lifetime enhancement in all the cases. But even though it is showing better performance in delay and packet delivery ratio compared to LEACH and M-LEACH, at different times there is large difference in the performance which can be a disadvantage for delay intolerant or emergency applications. The speed of sink mobility and the number and duration of pause times is application dependent and can be customised.

CHAPTER 5
MODIFIED HEED ALGORITHM

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MODIFIED HEED ALGORITHM

5.1 Introduction

Hybrid Energy Efficient Distributed Clustering (HEED) uses a distributed clustering architecture where the clustering is done in a specific number of iterations. The clustering problem defined by HEED is to identify a set of CHs which can cover the entire field, which is deployed with *n* sensor nodes, and each node must belong to exactly one and only one cluster. Each node should be able to communicate with the CH in single hop. Wherein the clustering is performed in iterations of fixed numbers, the nodes will be assigned the role of either CH (considering nodes with high residual energy and high proximity to the BS) or a regular node. It uses a probabilistic approach for CH selection. The main feature of HEED is that it feats the convenience of multiple transmission power levels at sensor nodes. The clusters are formed so as to have maximum load balance and increased life time. This makes HEED flexible to apply for many applications especially for those which require scalability, fault tolerance and extended life time.

5.2 HEED Protocol

The HEED protocol works in three main phases;

- initialization
- main processing
- finalization

In the initialization phase, the sensor nodes prompt probabilities to become CHs, and in the main processing phase the various procedures to elect the CHs is performed. It is in the finalization phase sensor nodes join the least communication-cost CH or announce itself as a CH. The re-clustering in HEED is dynamically occasioned at the beginning of each round which is a pre- defined period of time and is application dependant.

Suppose T_{CP} is the duration for clustering and T_{NO} is time interval for network operation. New clustering and CH selection is elicited every $T_{CP} + T_{NO}$ seconds. The clustering process requires a number of iterations N_{iter}, at each node. For each step a time t_c, should be given which is sufficient to receive messages from any neighbour within the range of the cluster. In the initial stage the probability of CHs, C is set to be 5% of the total nodes and in later stages the probability of becoming CHs, CH_{prob}, is calculated as follows:

$$CH_{prob} = C \times \frac{E_{resi}}{E_m} \tag{5.1}$$

Where C is the initial probability (i.e., a predefined value), E_{resi} is the residual energy in Joules and E_m is the maximum energy of the sensor nodes in Joules. In the iterative phase or main processing phase the competition among tentative CHs to become the next new CHs happens. The one with the most residual energy and in case of any ties, the one with the most node degree or node proximity to the base station will be selected. In the final phase, nodes which are not CHs joins the CH which is nearest to them or declares itself as CH in case they could not find any CH to join.

The main advantage of HEED is that it does not allow any node to be in more than one cluster. It could attain a uniform CH distribution; but terminates after a fixed number of iterations and re-clustering has to be initiated again. HEED also doesn't look into the hotspot problem which is a major threat for the networks life time.

5.2.1 Assumptions for HEED

Following assumptions are made for the sensor network according to HEED protocol.

- Sensor nodes are quasi-stationary.
- Symmetric links are used for communication.
- Sensor nodes are unaware of their location.
- The significance and capabilities of all the nodes are similar.
- The batteries cannot be re-charged as they are left unattended after deployment.
- The number of transmission power levels is fixed for each node.

5.2.2 Network Model for Modified HEED

In a square region of $A \times A$ m^2, a set of n sensor nodes are deployed randomly. The BS is located at the left top side of the deployed area. Once the deployment of the sensor nodes is over, they are assumed to be stationary. Based on the RSS, the approximate distance between the nodes can be calculated. The radio energy dissipation model assumes error free communication links and uses both free space and multipath channel model mentioned by Younis and Fahmy (2004). For the functioning of transmitter and the receiver circuitry, the electronic energy spend by the sensor node is given by E_{elec} = 50nJ/bit. E_a, the energy spent by the transmitter amplifier is dependent on the distance 'd' between the sender and the receiver. i.e. $E_a = E_{fs}$ assuming a free space model when $d < d_0$ and $E_a = E_{mf}$ assuming a multipath model when $d \geq d_0$, where d_0=75m is a constant distance. E_{fs} = 10pJ/bit/m^2 and E_{mf} =0.0013pJ/bit/m^4. Based on the above assumptions for the radio model, the energy consumed for transmission E_{Tx}, for transmitting a k-size packet over a distance d, can be calculated as:

$$E_{TX} = (E_{elec} \times k) + (E_a \times k \times d^n) \tag{5.2}$$

where, n = 2 for the free space model and n = 4 for the multipath model. The amount of energy E_{Rx} spent to receive a k-bit size message is:

$$E_{RX} = E_{elec} \times k \tag{5.3}$$

E_{Tx} and E_{Rx} is the transmitting energy and receiving energy in Joules.

5.2.3 Advantages

The HEED clustering improves network lifetime as it considers the nodes energy level for CH selection. The nodes only require local (neighbourhood) information to form the clusters. Energy distribution is ascertained leading to enhancement in the lifetime of the nodes and stability within the network. The operation of the HEED is not affected or dependent on the node distribution.

5.2.4 Limitations

CHs which are near to the sink, depletes their energy earlier as they have very large workload. Each round clustering process, and the several iterations, imposes too much network overheads. This burden results in remarkable energy dissipation leading to decline in the lifetime of the network.

5.3 Description of Modified HEED Algorithm

The modified HEED algorithm is focussed on enhancing the network life time by lessening the hotspot problem by unequal clustering. So balancing of relay traffic and distributed clustering is the prime focus; considering the residual energy of node and the number of neighbour's node. It consists of three phases; the initiation, main processing and finalization phase.

- the initialization phase- initial network setup and clustering and specific waiting time for re-clustering
- the main processing phase- unequal clustering and CH rotation based on demand
- the finalization phase-clustering and data transmission

The initialization phase starts with the BS broadcasting a signal. All nodes calculate their distance to the BS based on the RSS. Within its communication range '*r*', each node transmits a message consisting of its ID and the residual energy. The average residual energy of the neighbour nodes is calculated using the formula (Dhanpal et al. 2015);

$$E_{ia} = \frac{1}{n} \times \sum_{j=1}^{n} E_{jr} \tag{5.4}$$

where n denotes the total number of neighbour nodes and E_{jr} is the residual energy of the neighbour nodes in Joules. A waiting time t_i in seconds (Dhanpal et al. 2015) is also set for broadcasting the cluster election message in such a way that no two nodes will send this message at the same time. In order to have this, a random value between [0.9, 1] is assigned to V_r. The waiting time is calculated as;

$$t_i = \begin{cases} \frac{E_{ia}}{E_{ir}} T_2 V_r, & E_{ir} \geq E_{ia} \\ T_2 V_r, & E_{ir} < E_{ia} \end{cases} \tag{5.5}$$

where E_{ia} is the average residual energy in Joules, E_{ir} is the residual energy of node i in Joules, T_2 is the time duration in seconds and V_r is the random value between [0.9, 1]. Initial steps of the Modified HEED are similar to HEED. The entire operation happens in different rounds. Nodes will be aware of its residual energy, energy level of neighbour nodes and number of neighbour nodes. The Average Minimum Rechargability Power (AMRP) is calculated. Every round will be initiated with the clustering mechanism leading to clustering and later to data transmission through intra-cluster and inter-cluster mechanisms. After the initial round, a random period of waiting time is introduced as in equation (5.5) for initiating the unequal clustering. In HEED every CH uses the same competition radius irrespective of its distance from the base station which forms equal sized clusters which results in hotspots leading to energy depletion of CHs mainly near the base station. In order to avoid this issue, the Modified HEED uses an unequal clustering method defined for clustering where the cluster radius (Dhanpal et al. 2015) is calculated as;

$$R_{ci} = \left[1 - \propto \left(\frac{d_m - d_i}{d_{ma} - d_{mi}}\right) - \beta \left(\frac{E_i}{E_m}\right)\right] R_m \quad (5.6)$$

where d_{ma} and d_{mi} are the maximum and minimum distance of the sensors from the base station, d_i is the distance of the sensor nodes to the base station, α is a random value which belongs to [0, 1], R_m is the maximum value of available competition radius which is a pre-defined value, β is a real random value in the interval [0, 1] and E_i is the residual energy of the node i. The competition radius of a node is dependent on E_i and d_i; the larger the values of E_i and d_i, the larger will be the competition radius. For the simulation R_m is taken as the diagonal distance divided by ten.

Each node will have information about its energy level and the distance of it from the CH. Based on the message received from the CHs, distance will be calculated and the non-CH nodes will join the nearest CH. The intention is to avoid the premature death of the CHs near the BS by reducing the overload in them. Using the above mentioned cluster radius as in equation (5.6), the clusters near the BS will be small and obviously the CHs have to manage less cluster members which saves the energy for data forwarding. The steps in the modified HEED algorithm are summarized below and the flowchart is represented in Figure 5.1.

Step1: Initially, CHs are constructed according to HEED algorithm.

Step 2: In the next phase re-clustering is done based on the competition radius given in equation (5.6) based on the waiting time given in equation (5.5).

Step 3: Within a cluster the CHs will be rotated based on the residual energy set to a threshold value.

Step 4: If the CHs energy level goes beyond the threshold value, re-clustering is performed; go to Step 2.

Step 5: After CH selection and clustering is done, data is routed (intra-cluster and inter-cluster) to the base station.

5.3.1 Simulation Results and Performance Analysis

For the comparison of the Modified HEED the parameters are set to be same as that in HEED. The area of simulation and the number of nodes deployed are also varied for performance analysis of the modified approach. The simulation parameters for the case where the area of simulation is 100×100 meters and the number of nodes deployed are 50,100 and 150 is given in Table 5.1.

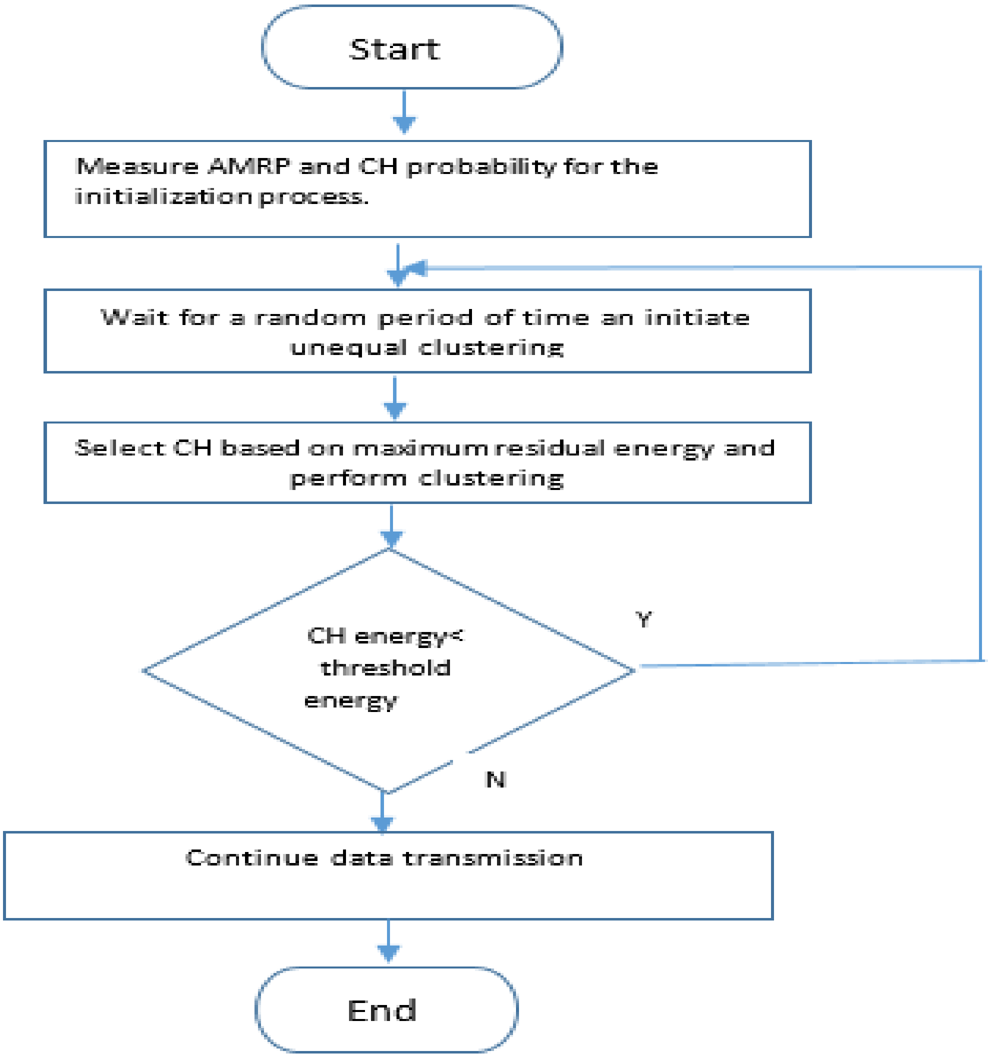

Figure 5.1: Flowchart of Modified HEED

The different parameters used for performance evaluation of the modified HEED algorithm are the lifetime of network, average residual energy of the network and average delay in packet delivery. The lifetime of the network can be calculated based on different parameters like the time when the first node dies or the time till the last node dies or when a certain percentage of the nodes get depleted. For the lifetime comparison here, the time till more than ninety percent of the nodes dies off is considered. Here the simulation of the data transmission and reception is done through energy consumption. Usually for the calculation of the delay for packet delivery, the sum of different delays like queuing delay, processing delay and transmission delay can be considered. Packet delay is the time since the packet is generated till it reaches the destination.

Table 5.1: Simulation Parameters for Modified HEED Protocol

Parameters	**Values**
Area of simulation	100m ×100m
Base station location (x, y)	(20,80)
Number of nodes	50,100,150
E_{elec}	50nJ/bit
E_{fs}	10pJ/bit/m^2
E_{mp}	0.0013pJ/bit/m^4
Initial energy	2J
Deployment model	Random

Three different scenarios are taken in to consideration for the simulation. In the first scenario 50 sensor nodes are deployed randomly in 100m ×100m area. The base station is fixed at the left side of the simulation area; in this case, specifically at (20, 80). In the second scenario 100 sensor nodes are deployed randomly in 100m ×100m area and in the third scenario 150 sensor nodes are deployed. The simulation is done for 500 rounds initially.

The results represented are an average of ten simulations under the same simulation environment. The plain circles represent the normal nodes, the dark circle with BS notation indicates the base station and the black circles indicate the CHs.

Figure 5.2 represents the random deployment of 50 nodes in 100m×100m square region and the clustering of the same according to Modified HEED is represented in Figure 5.3.

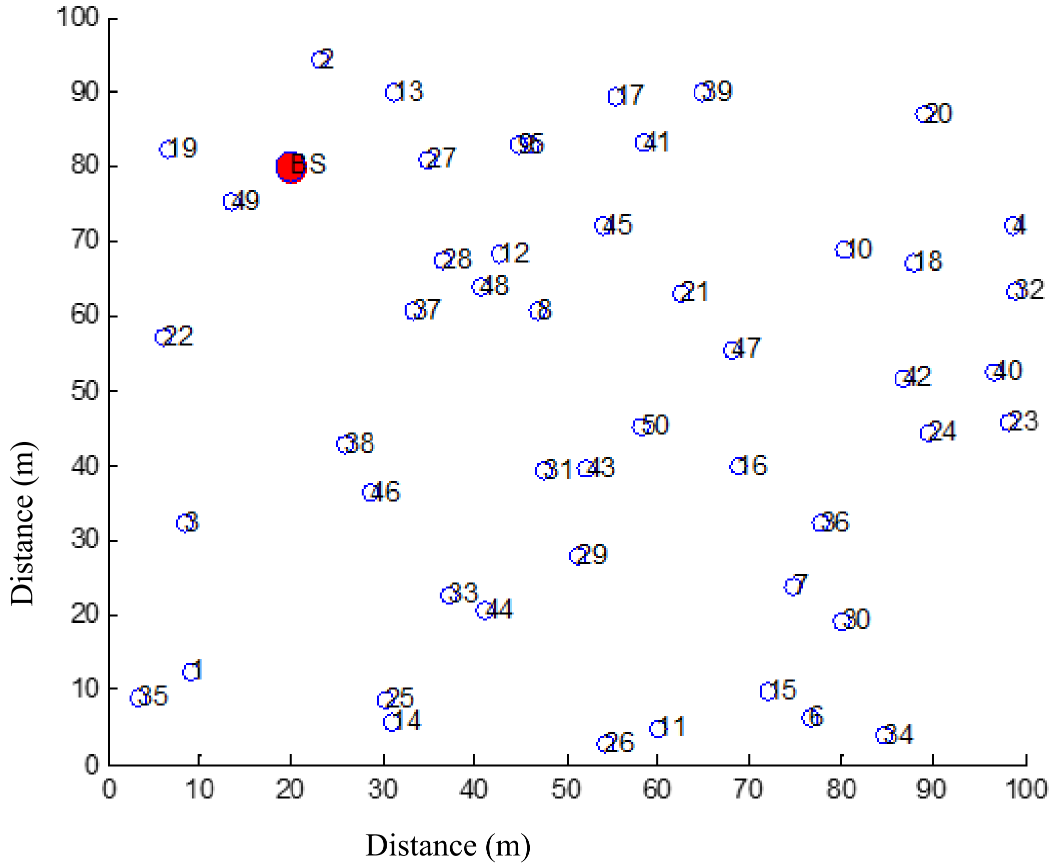

Figure 5.2: Random Deployment of Nodes (A=100m×100m, N=50)

Similarly Figure 5.4 represents the random deployment of 100 nodes in 100m×100m square region and the clustering of the same according to Modified HEED is represented in Figure 5.5.

Figure 5.6 represents the random deployment of 150 nodes in 100m×100m square region and the clustering of the same according to Modified HEED is represented in Figure 5.7.

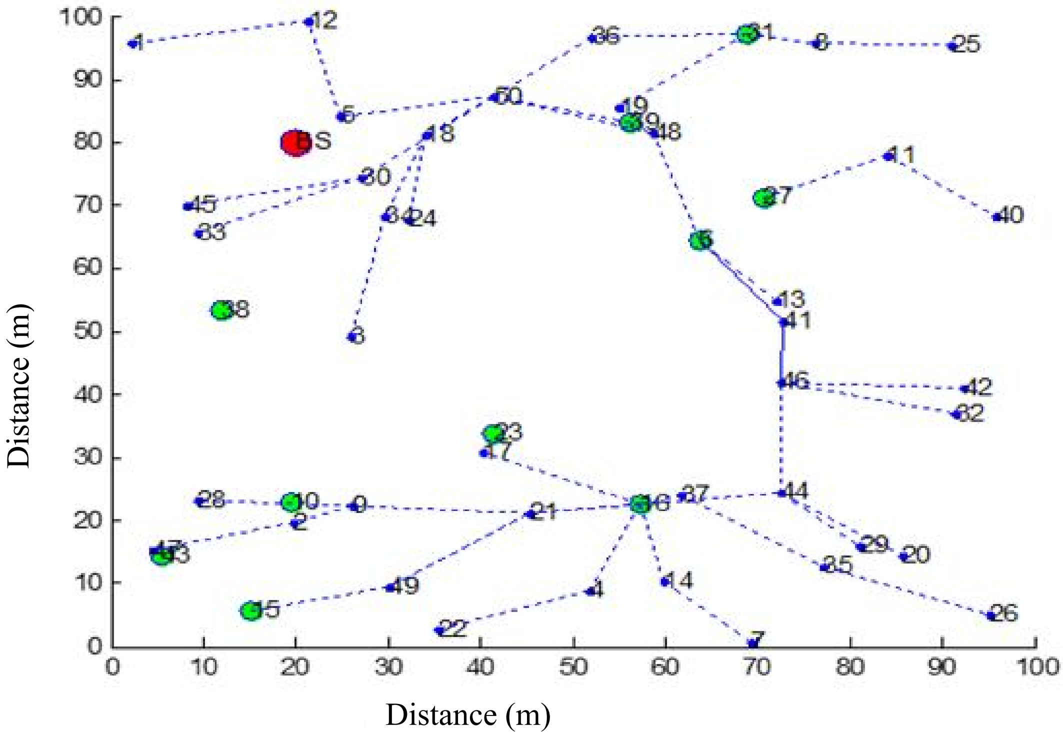

Figure 5.3: Clustering of Nodes(A= 100m×100m, N=50)

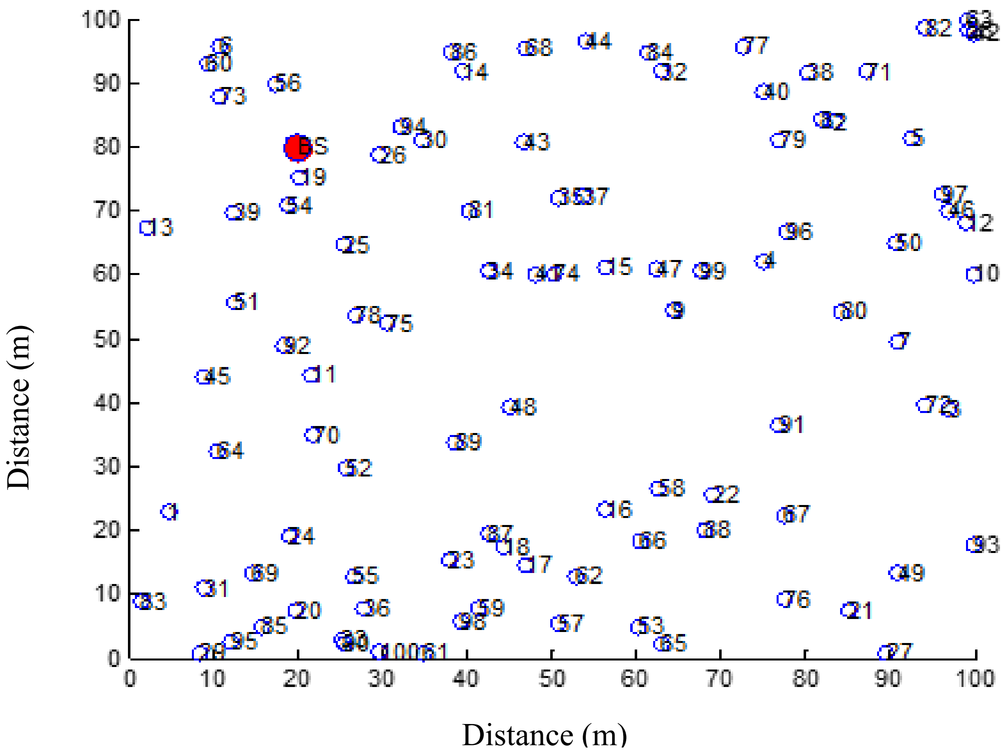

Figure 5.4: Random Deployment of Nodes(A=100m×100m, N=100)

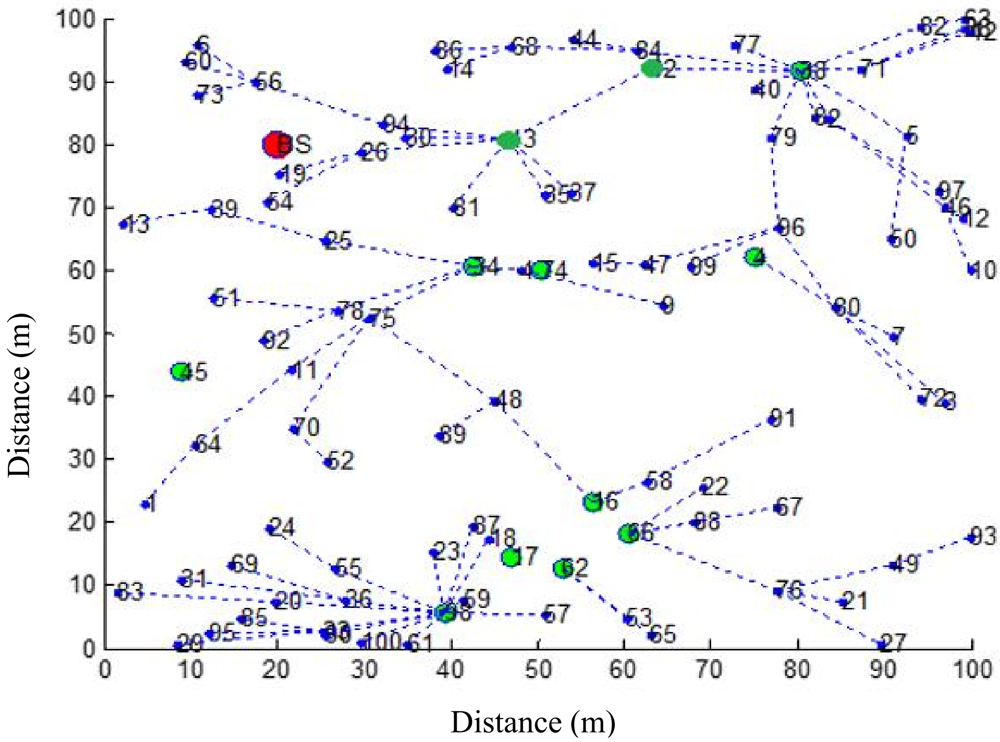

Figure 5.5: Clustering of Nodes (A=100m×100m, N=100)

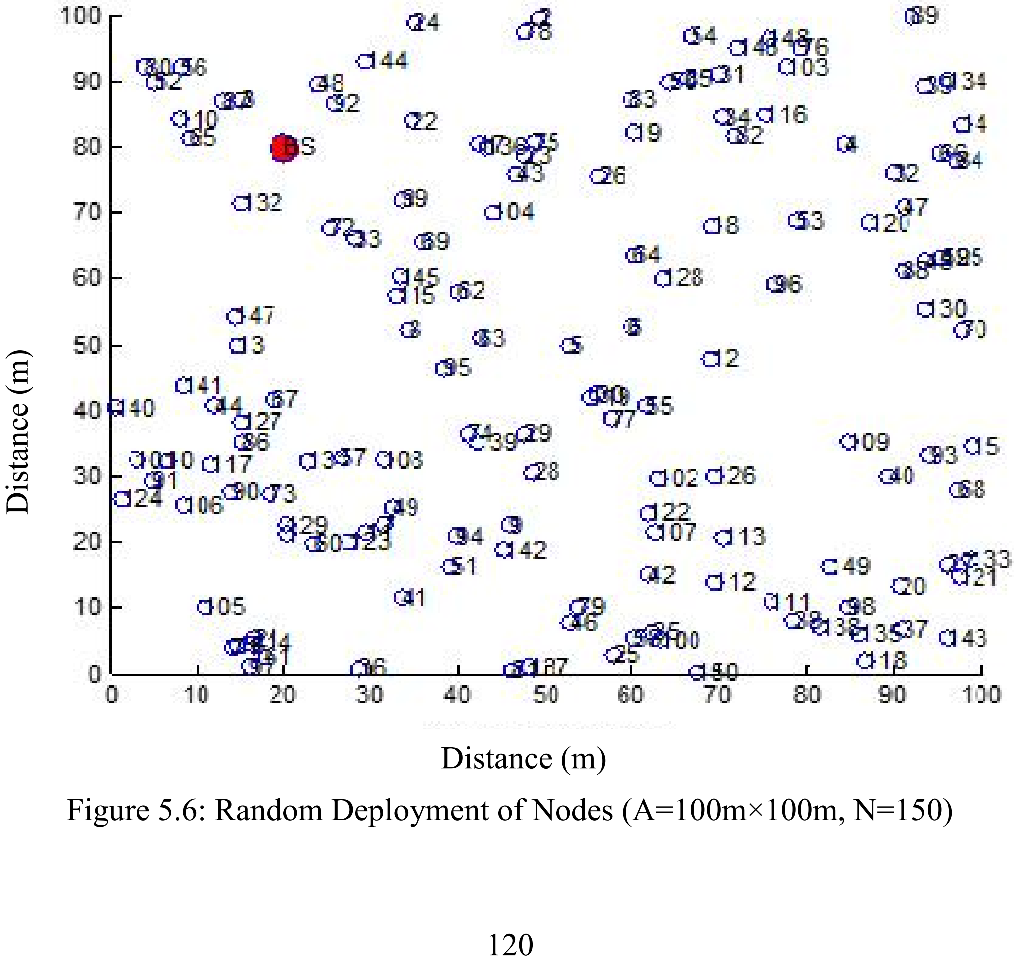

Figure 5.6: Random Deployment of Nodes (A=100m×100m, N=150)

In all the above mentioned scenarios nodes are randomly distributed over the deployed region. Since it is random deployment, overlapping of the nodes can happen. Clustering is done in an unequal manner which can be observed from Figure 5.3, Figure 5.5 and Figure 5.7. The CHs near the BS handles less number of nodes compared to the farther ones.

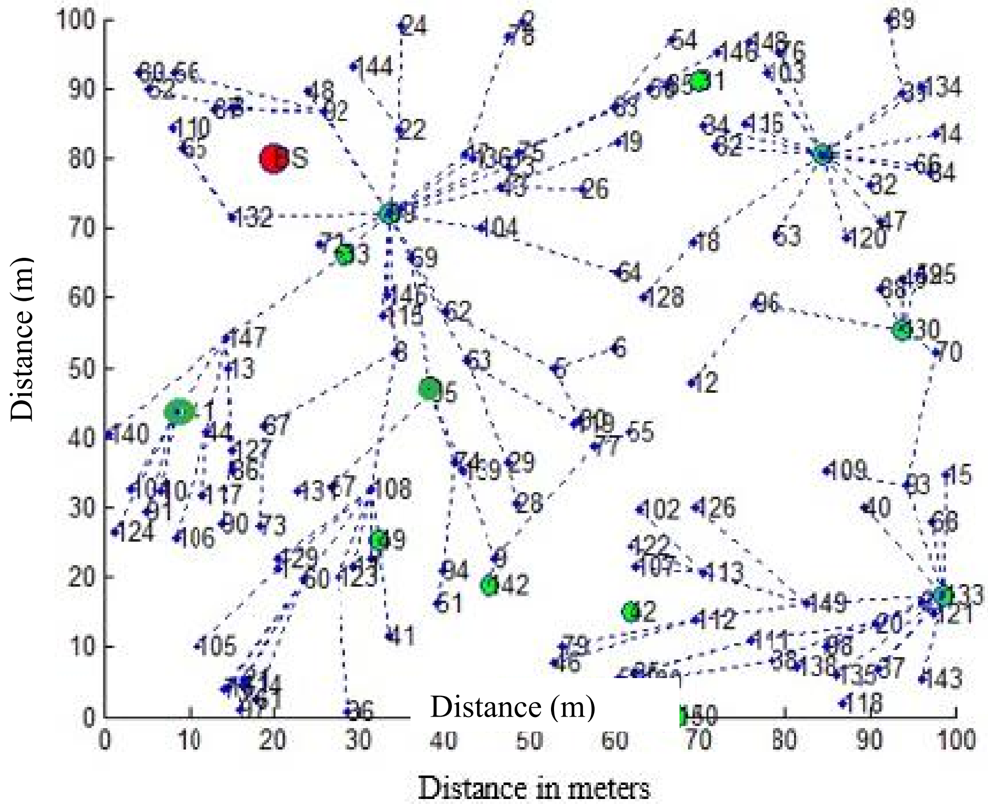

Figure 5.7: Clustering of Nodes (A=100m×100m, N=150)

A performance analysis in terms of live nodes, average residual energy and delay is carried out for different scenarios. Average residual energy of the networks is represented in Figure 5.8, 5.9 and 5.10 for the different cases where A=100m×100m, N=50,100 and 150.

In a similar scenario, the average delay in packet delivery is calculated. Figure 5.11 depicts the simulation result for the case where 50 nodes are deployed in a 100m×100m, Figure 5.12 gives the simulation result for the case where 100 nodes are deployed in a 100m×100m and Figure 5.13 for the same simulation environment with 150 nodes.

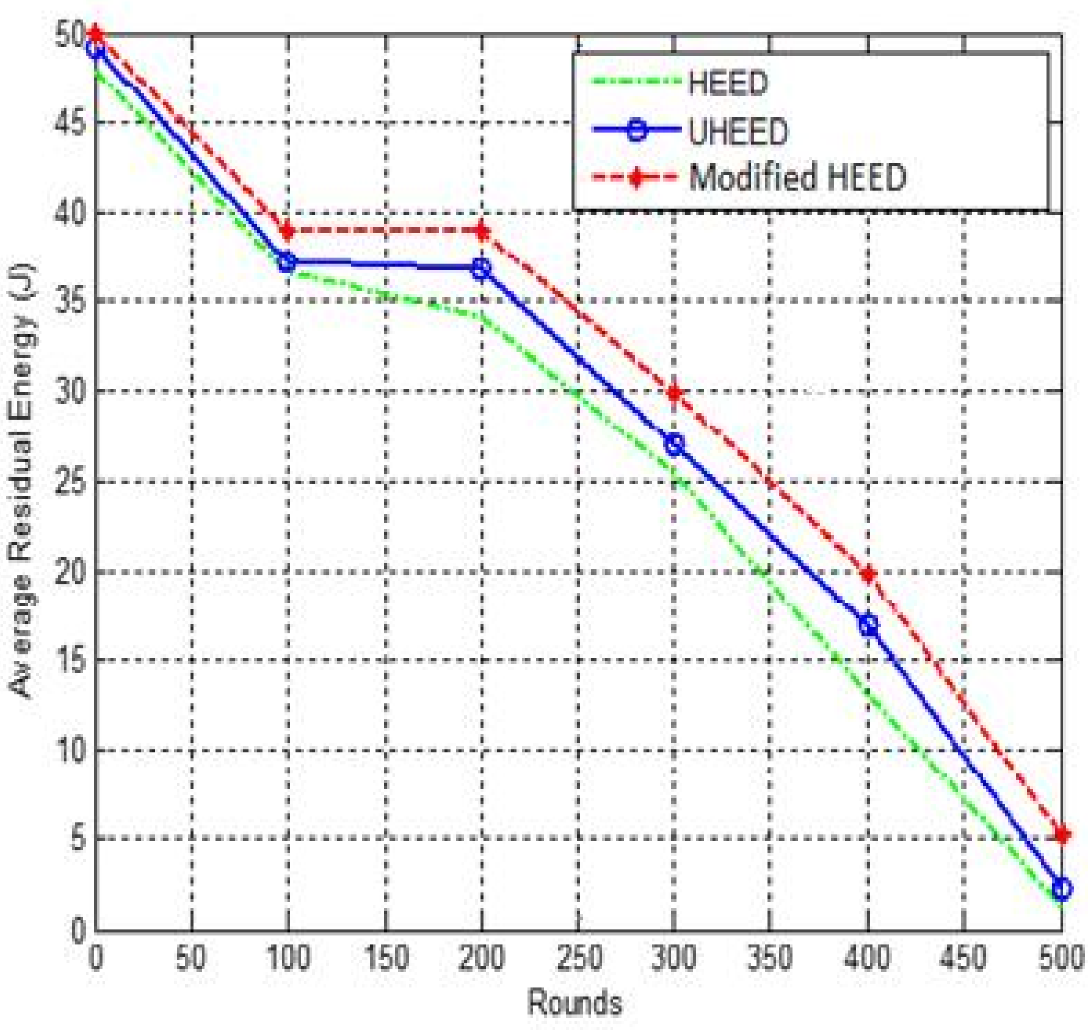

Figure 5.8: Average Residual Energy Vs Rounds for Modified HEED(N=50, A=100m×100m)

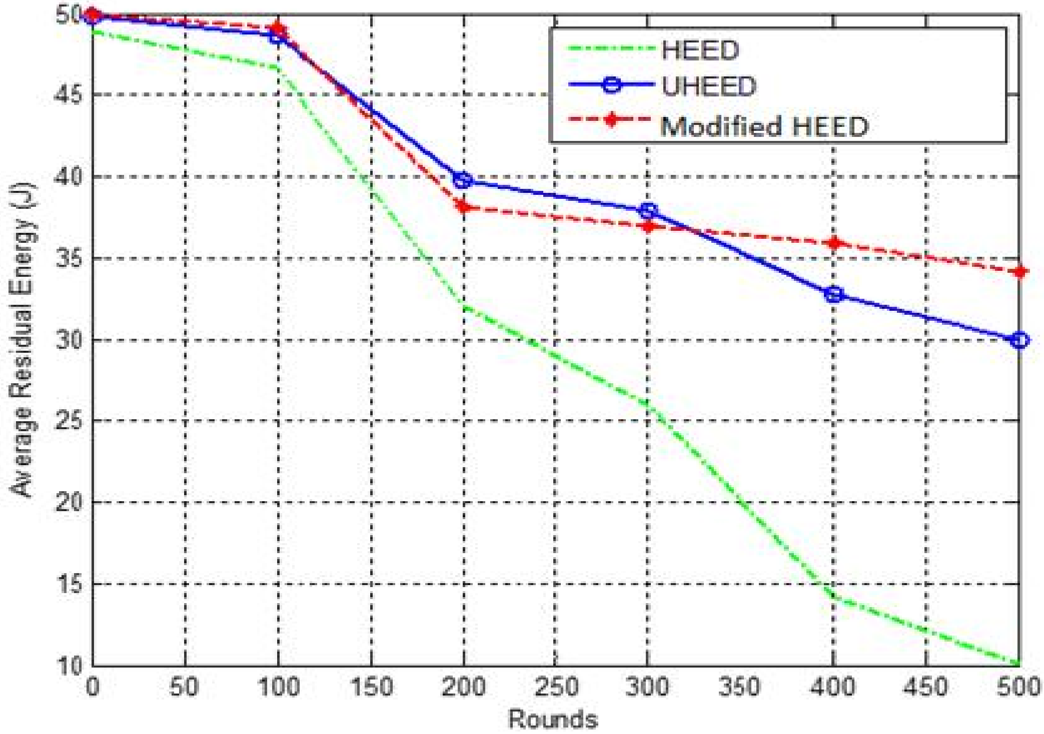

Figure 5.9: Average Residual Energy Vs Timefor Modified HEED (N=100, A=100m×100m)

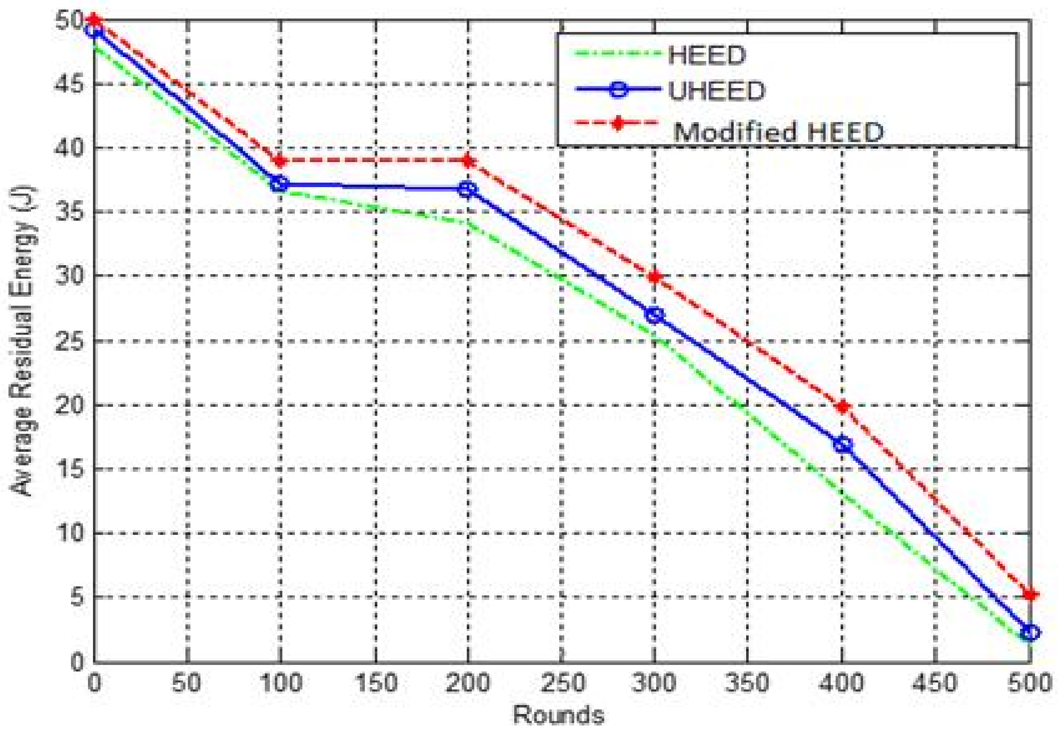

Figure 5.10: Average Residual Energy Vs Rounds for Modified HEED (N=150, A=100m×100m)

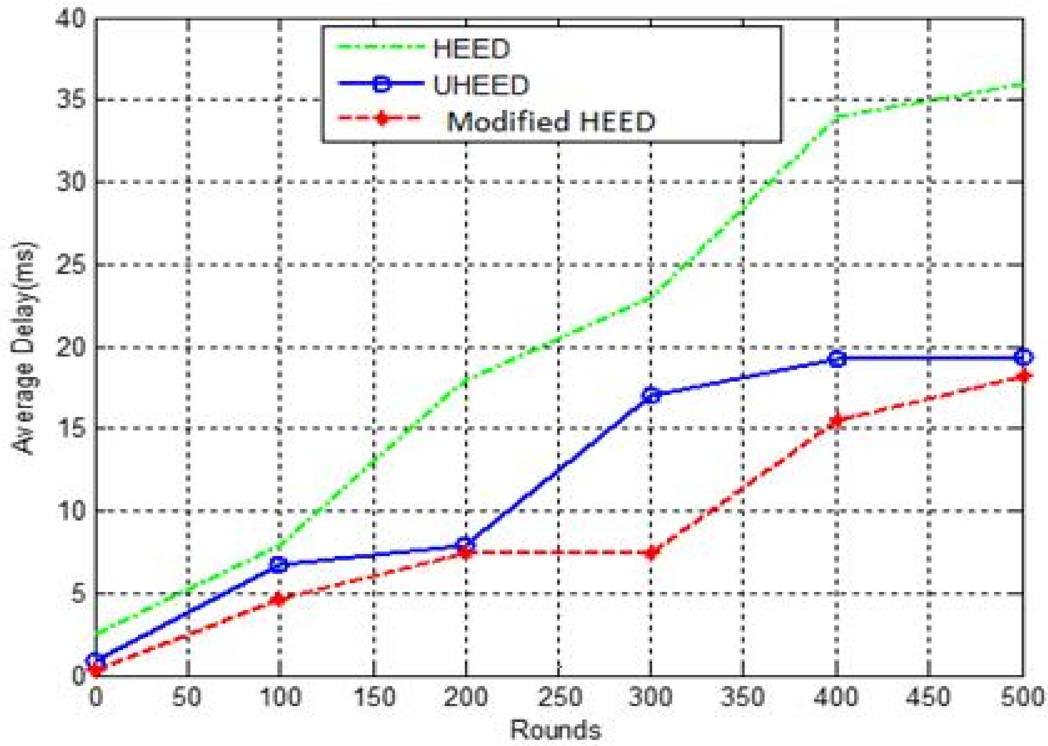

Figure 5.11: Average Delay Vs Rounds for Modified HEED (N=50, A=100m×100m)

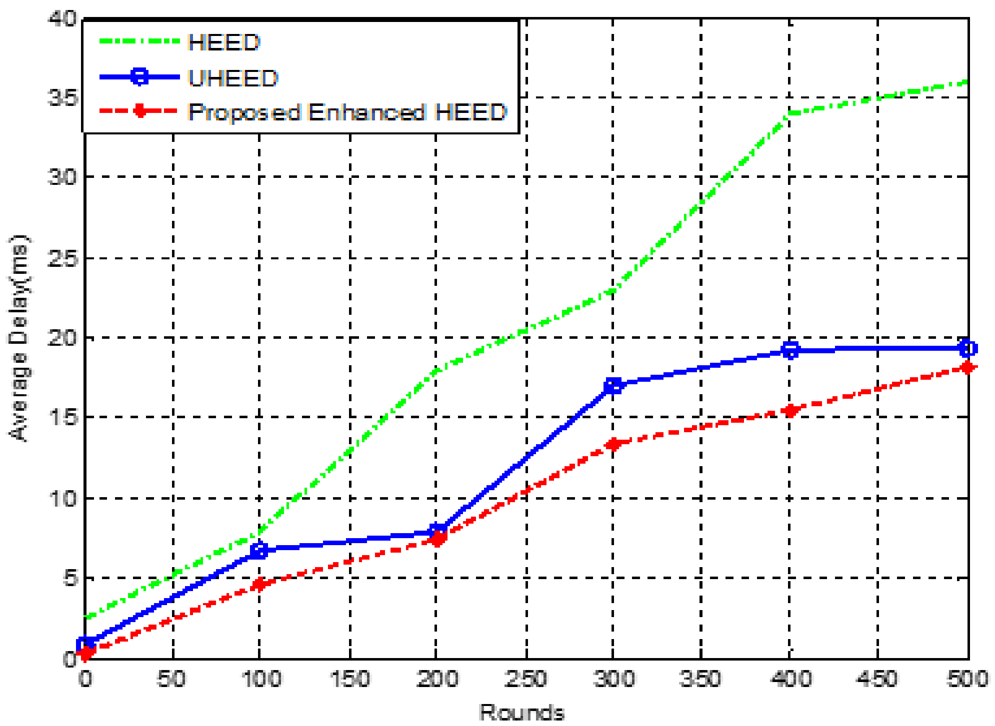

Figure 5.12: Average Delay Vs Rounds for Modified HEED (N=100, A=100m×100m)

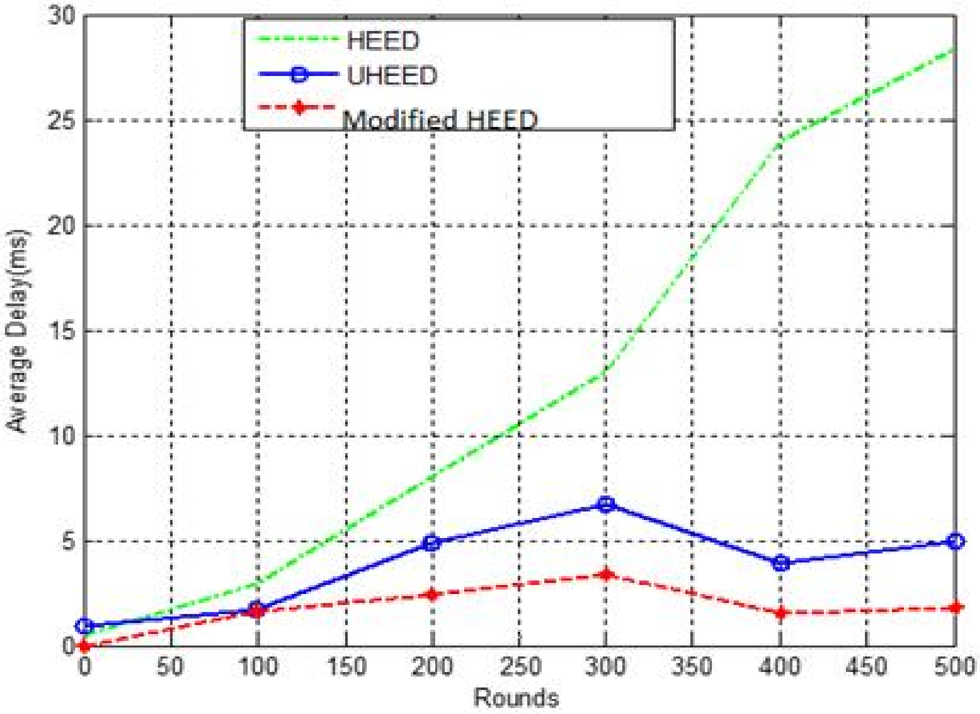

Figure 5.13 : Average Delay Vs Rounds for Modified HEED (N=150, A=100m×100m)

The number of live nodes at the end of the specific simulation period is calculated. The Modified HEED retains more number of nodes compared to HEED and U-HEED. The comparison of the performance of the Modified HEED based on the number of live nodes at the end of different simulation periods in different scenarios is given below. N represents the number of nodes deployed and A represents the area of deployment. Figure 5.14 represents the comparison of the number of live nodes for the deployment scenario is taken as 50 nodes deployed over 100m×100m area. Figure 5.15 and Figure 5.16 gives the simulation results in the same simulation environment for 100 nodes and 150 nodes. Keeping the area of deployment constant, different numbers of nodes are deployed in order to check the behaviour of the sensor network.

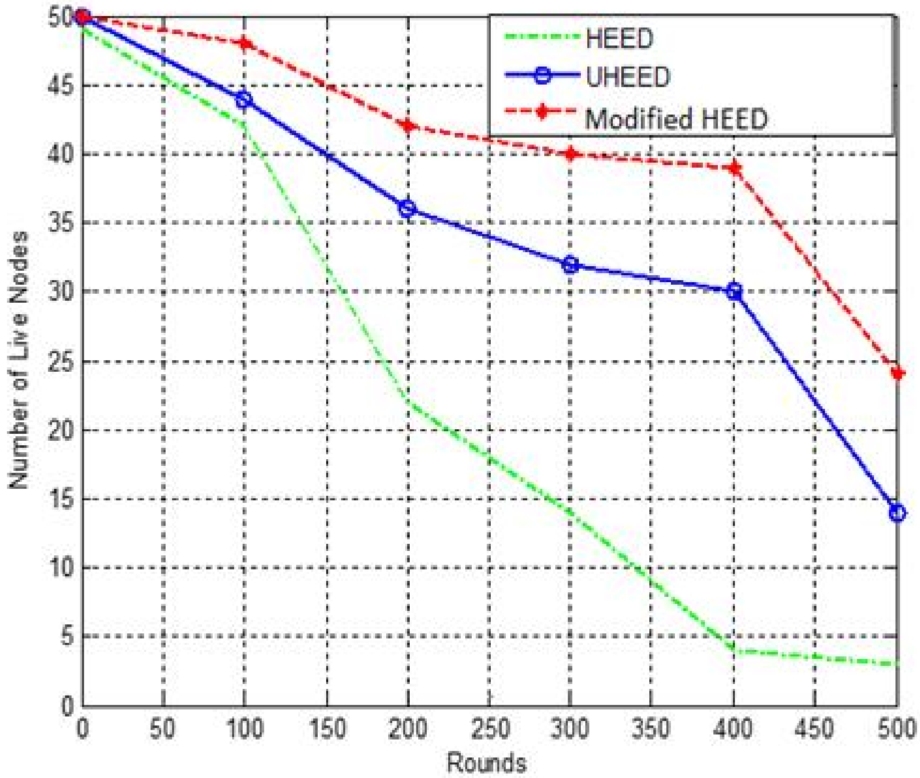

Figure 5.14: Number of Live Nodes Vs Rounds for Modified HEED (N=50, A=100m×100m)

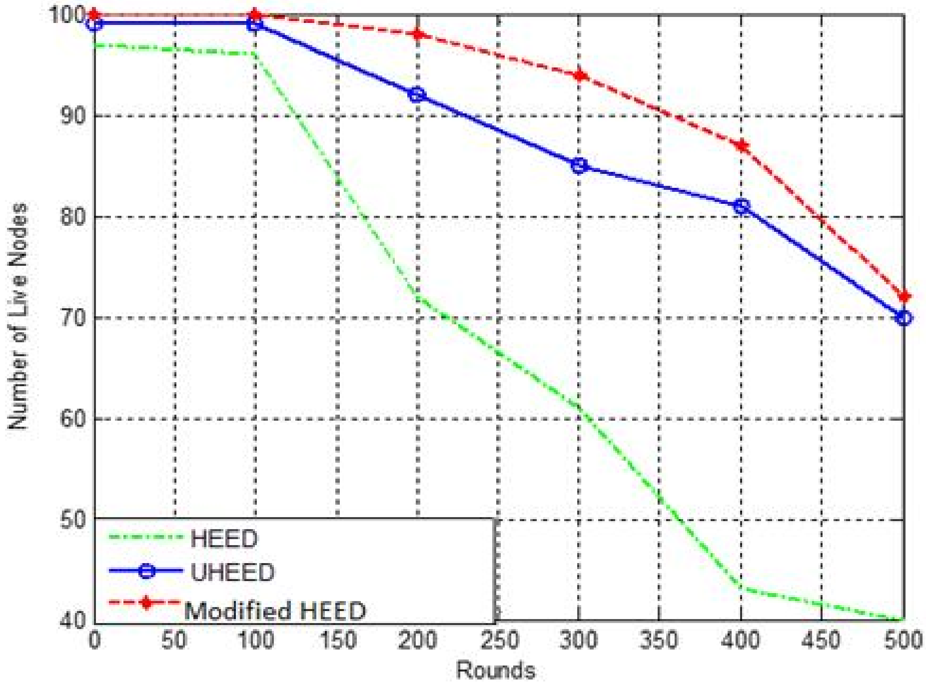

Figure 5.15: Number of Live Nodes Vs Rounds for Modified HEED (N=100, A=100m×100m)

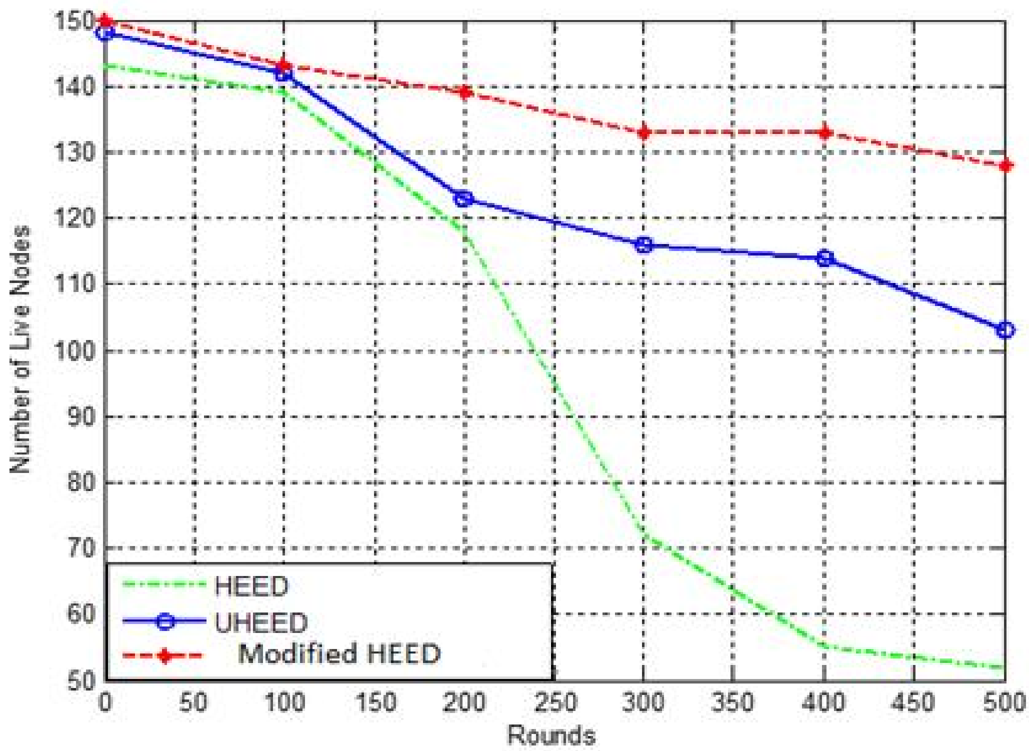

Figure 5.16: Number of Live Nodes Vs Rounds for Modified HEED (N=150, A=100m×100m)

From Figure 5.14, 5.15 and 5.16 it is evident that the number of live nodes is more in the case of Modified HEED compared to HEED and UHEED. In the case of HEED there is a drastic reduction in the number of live nodes as the simulation time increases in all three scenarios. In UHEED there is a gradual depletion of nodes. Compared to these, the Modified HEED Algorithm retains the number of live nodes for a longer duration.

The number of packets that successfully reached the destination is only considered for calculating the delay. The time since their generation to the time it is received by the BS is calculated for each scenario. The Modified HEED shows less delay in packet delivery in all the cases. As the ratio of nodes increases a there is a decrease in the delay in packet delivery.

The calculation of average residual energy, delay and number of live nodes based on the simulation where the imagined situation is random event sensing is discussed below. Table 5.2 represents the simulation results for various number of nodes deployed in an area of 120m × 120m based on the number of live nodes.

Packets are generated randomly by every node. For calculating the average network residual energy for a particular duration, a fixed amount of energy is reduced, for each packet generation, communication to the CH and then to the base station. Each time a node randomly generates a packet, a counter is set to find the total number of packets generated for a particular duration. The number of packets reaching the destination is also tracked. The average time taken by those successful packets to reach the destination is calculated which is the average delay in packet delivery. A threshold energy level is set for the nodes to check the status of the nodes. If the energy level of the node goes below the threshold level, that node is assumed to be dead. The count of the number of nodes who have energy above the threshold level gives the number of live nodes for that particular time.

Table 5.2:Performance Comparison of HEED, U-HEED and Modified (A=120 ×120)

Protocols		HEED			U-HEED			Modified HEED		
No. of Nodes		50	100	150	50	100	150	50	100	150
Rounds	100	48	97	143	50	99	148	50	100	150
	200	46	96	139	50	99	142	50	100	143
	300	**38**	72	**118**	**47**	92	**123**	**50**	98	**139**
	400	32	61	72	44	85	116	49	98	133
	500	26	48	55	44	81	114	48	93	133
	600	26	43	52	42	76	112	48	89	132
	700	18	40	46	36	74	106	42	86	111
	800	12	32	39	35	74	97	40	74	106
	900	8	29	32	34	68	94	39	73	106
	1000	6	24	30	30	59	78	39	69	95

5.3.2 Summary

The main difference between HEED and the Modified HEED is in the method of clustering. While HEED creates clusters of equal size, the Modified HEED uses the unequal clustering technique, energy efficient varying size clustering algorithm. U-HEED also uses a different completion radius for clustering in each round so as to have non uniform cluster sizes. This approach eliminates the premature death of the nodes near the BS which will be continuously participating in the data transmission to the base station. Modified HEED creates clusters of varied sizes and make sure that the clusters near the BS is small compared to that of U-HEED. As the CHs in smaller clusters require coordinating lesser cluster members, the energy of the CHs can be preserved for forwarding the data. This in turn reduces the load on the CHs, avoids their energy depletion at a faster rate and thereby enhances the life time of the network.

According to the Modified HEED the nodes are expected to be homogeneous. The node heterogeneity is not considered which happens practically. The clustering overheads are high compared to that of HEED as the number of control messages involved is more. For the unequal clustering, distance between the nodes and their relative distance to the base station has to be stored, and this is another overhead compared to HEED.

The modified approach attains higher energy efficiency and meets the objective of the research. It gives better lifetime as the energy consumption in various simulation periods at different scenarios is quite low compared to HEED and UHEED. Another major advantage is the elimination of hot spot issues due to the depletion of CHs near the BS. The modified approach also attains better load balance among the clusters.

Chapter 6
Results, Discussion and Conclusions

CHAPTER 6
RESULTS, DISCUSSION AND CONCLUSIONS

6.1 Results and Discussion

The significance of WSNs is prominent in the recent years due to the immense applications they are involved in. WSNs is being used for numerous vital applications like remote environmental monitoring, target tracking, habitat monitoring, agricultural and medical applications, surveillance application and so on. The smaller, cheaper, and intelligent sensor nodes are equipped with wireless interfaces to communicate with one another to form a network.

WSNs comprises of various sensor nodes extending from a couple of tens to thousands, which are arranged together to monitor and sense the information about the area. The design of WSNs is application dependant. Because of the diversity in the application environments of their usage, the design of algorithms and protocols for WSNs should consider aspects such as the location of deployment, the applications design objectives, cost, and hardware system constraints. Besides this the small size of the sensor nodes imposes restrictions on the various resources like processing, memory and energy capabilities. So in order to prolong the lifespan of the WSNs efficient use of the available resources; especially the energy resource is inevitable.

In WSNs, a good amount of the energy is utilized for communication compared to sensing and processing. The communication process includes data transmission at different levels. Because of this, energy efficient routing strategies are always a matter of concern in WSNs.

In this research work, the aim is to design and develop energy efficient routing protocols in WSNs. Three different works are carried out; the first being the modification of the LEACH algorithm, second, the introduction of sink mobility in the modified LEACH algorithm and finally a modification of the HEED using unequal clustering approach. All these algorithms were simulated using MATLAB for performance evaluation based on the difference metrics number of live nodes, average residual energy, end to end delay and packet delivery ratio. These developed protocols are suited for periodic monitoring applications.

Firstly, a modification of the most popular and traditional energy efficient routing protocol in WSNs, LEACH, is performed where a different CH selection strategy is experimented. The Modified LEACH is compared against LEACH in terms of the number of live nodes, average residual energy, and the end to end delay and proved to better than LEACH. The CH selection is based on the residual energy and the relative distance of the node to the base station. Besides that, the selection of the CH is not repeated in each time instead it will remain the same until threshold energy level is met. This reduces the overheads of CH selection in each time which saves energy.

Different scenarios are taken into consideration for simulation using different performance evaluation metrics. The number of nodes deployed and the area of deployment were changed in different manner. First the area was kept constant and the number of nodes was changed to evaluate the performance. A random changing of area as well as the number of nodes was also carried out to observe the changes in the performance of the proposed approach.

The simulations were performed in a 100m ×100m for 500 rounds initially, and the results represented are an average of ten different simulations. Tables 3.4 to 3.5 and 6.1 gives the performance of the Modified LEACH compared to that of LEACH for various scenarios. It is observed that based on the metrics number of live nodes, average energy consumed and the packet delivery ratio, the Modified LEACH shows better performance compared to that of LEACH. The number of live nodes is comparatively high in the case of modified approach compared to LEACH at the end of the 500 rounds. The average residual energy of the network goes below fifty percentages by 300 rounds in LEACH which is not the case with the modified LEACH. Similarly, a significant improvement in the packet delivery ratio is also observed based on their performance given in Table 6.1.

Secondly, mobile sink assisted energy efficient routing algorithm, an enhancement of the Modified LEACH, called Modified Mobile Sink Assisted LEACH is carried out. The path constrained mobility model is used for this approach. Simulations have proved that it gives much better performance than the existing protocols LEACH and LEACH-M in terms of life time, average energy, delay and the average packet delivery ratio. Four different mobile sinks are used for data gathering. These sinks will aggregate the data and send to the BS. Here the mobility of the sinks is pre-planned and the speed of the sink nodes is also fixed. The different pause time in the path is also predefined. Different speeds and pause times for the mobile sinks were simulated to optimize the movement of the mobile sink. It was observed that for an area up to 500m × 500m the speed of the mobile sinks at 4 to 10m/s was achieving better performance in terms of delay and packet delivery.

In all different scenarios it was observed that the number of live nodes and the energy consumption of the network were high compared to that of LEACH and M-LEACH.

Table 6.1: Performance Comparison of LEACH and Modified LEACH (A=100m × 100m)

Performance Metric	Rounds	Protocols					
		LEACH			Modified LEACH		
		Number of nodes			Number of nodes		
		50	100	150	50	100	150
Number of Live Nodes	100	47	87	142	50	96	150
	200	43	71	130	47	83	139
	300	36	63	111	43	77	127
	400	32	58	84	40	66	111
	500	**16**	**26**	**53**	**39**	**45**	**99**
Average Residual Energy(J)	Rounds	Protocols					
		LEACH			Modified LEACH		
		50	100	150	50	100	150
	100	45.1417	38.2505	40.7779	45.5916	45.9006	44.010
	200	32.4155	29.6333	32.8498	38.2986	31.9612	39.2242
	300	**12.8021**	**24.4969**	26.3012	33.5321	27.3964	34.3109
	400	8.1645	12.0282	**16.9136**	28.3933	**21.4339**	28.8370
	500	2.3081	8.0145	10.2863	**22.5282**	20.1745	26.3157
Packet Delivery Ratio (%)	Rounds	Protocols					
		LEACH			Modified LEACH		
		50	100	150	50	100	150
	100	85	91	94	89	95	98
	200	77	85	87	80	90	90
	300	50	58	60	59	63	72
	400	32	42	46	40	48	68
	500	2	12	**32**	12	22	**53**

A comparison of the number of live nodes at different simulation periods for the various protocols is given in Tables 4.2 to 4.4 and 6.2. As energy efficiency is the main concern, focus is given to the comparison number of live nodes even though other parameters like packet delivery ratio, delay etc is also considered. More number of live nodes shows the energy efficiency of the Modified Mobile Sink Assisted LEACH. But it is observed from the simulation results that the sink mobility has significant impact on the delay in the packet delivery. It can be seen that even though better performance is achieved compared to other protocols, at different times the delay is more. The packet delivery ratio also is higher compared to M-LEACH and LEACH. These prove the efficacy of the modified algorithm. From the Table 6.2 it can be observed that the use of mobile sinks retains more number of live nodes throughout the simulation period. It can be seen that sink mobility reduces the energy consumption of the nodes compared to static sink as well as node mobility as in M-LEACH.

A modification of the HEED protocol using an unequal clustering method is also carried out which attained uniform load balance and higher energy efficiency compared to HEED and UHEED protocols. The equal clustering leads to hot spot issues as the CHs near the sink will deplete their energy due to the continuous participation in routing data to the sink. In order to avoid this, an unequal clustering method is adopted where the clusters will be formed in such a way that those near the base station will be of smaller sizes compared to the farther ones. This reduces the overburden of the CHs near the BS. Since they have less number of nodes the energy used for intra cluster communication will be less and this can be utilized for forwarding the data. The extensive simulation results prove the efficacy of the modified algorithm. From the simulation results it is observed that the modified HEED creates unequal clusters and the number of CHs near the BS is more (Figures 5.2, 5.4 and 5.6). This will reduce the immature death of the CHs near the BS. The performance of the modified HEED was evaluated considering average residual energy, delay and the number of live nodes and it showed better results compared to HEED and UHEED. Table 6.3 shows the comparison based on the number of live nodes.

It is observed that until the end of 500 rounds the modified HEED retains the larger number of nodes which shows the energy efficiency of the modified HEED. At the midway through the simulation i.e. at 300 rounds, it is seen that for the maximum number of nodes and minimum number of nodes deployed in the 100m×100m, the modified HEED retains the maximum number of live which shows the energy efficiency of the proposed approach.

Table 6.2: Performance Comparison of Modified Mobile Sink Assisted LEACH based on Number of Live Nodes (A=100m×100m)

Protocols		LEACH			M-LEACH			Modified Mobile Sink Assisted LEACH		
No. of Nodes		50	100	150	50	100	150	50	100	150
Rounds	100	44	83	129	47	87	142	50	96	150
	200	40	68	111	43	71	130	47	83	139
	300	32	50	85	36	63	111	43	77	127
	400	20	32	36	32	58	84	40	66	111
	500	2	9	**12**	16	26	**30**	39	45	**99**

Table 6.3: Performance Comparison of Modified HEED based on number of live nodes (A=100m×100m)

Protocols		HEED			U-HEED			Modified HEED		
No. of Nodes		50	100	150	50	100	150	50	100	150
Rounds	100	48	97	143	50	99	148	50	100	150
	200	46	96	139	50	99	142	50	100	143
	300	**38**	72	**118**	**47**	92	**123**	**50**	98	**139**
	400	32	61	72	44	85	116	49	98	133
	500	26	43	55	44	81	114	48	93	133

6.2 Conclusions

WSNs are used for various applications in our daily life. Since numerous sensors are usually deployed on remote and inaccessible places, specifically for monitoring and surveillance applications, the deployment and maintenance should be easy and scalable. As the sensor nodes are resource constrained, the efficient use of these resources especially the energy resource is very much decisive for retaining the life time of the WSNs. As energy is utilised more for communication purpose, efficient routing protocol design is a need for WSNs for prolonging the network lifetime.

In this research work, an energy efficient hierarchical cluster-based algorithm is developed which is a modification of the traditional LEACH algorithm. A unique clustering approach considering the residual energy of the nodes and their distance to the BS is carried out. This method of clustering proved to be energy efficient compared to LEACH and can be used in WSN applications with homogenous sensor nodes.

To further augment the energy efficiency, sink mobility, an energy efficient technique is introduced in to the enhanced LEACH algorithm. Simulation results showcased the energy efficiency of this algorithm based on different performance evaluation metrics. It is perceived that under different situations the energy efficiency measured in terms of number of live nodes, average energy of the network and packet delivery ratio is high for the proposed modified mobile sink assisted algorithm compared to LEACH and the LEACH variant which supports node mobility.

But it is also observed from the simulation results that the performance of the algorithm degrades as the area of deployment increases especially in terms of delay in the packet delivery. Considering this fact, it can be concluded that, this proposed modified mobile sink assisted LEACH algorithm will be suited for delay tolerant applications which requires continuous monitoring within limited area. As the area of deployment and the number of nodes increases the time for simulation is also quite high; this is practically not acceptable. The simulation time represented in the results is based on the simulation clock.

A modification of the HEED clustering approach, by introducing unequal clustering is also proposed. Unequal clustering solves the hotspot issues and ensures uniform load balance in the network. The modified HEED algorithm proved to be energy efficient compared to HEED and UHEED. This proposed modified HEED algorithm can be applied for all WSN applications where heterogeneous sensor nodes are assimilated.

Table 6.4 gives the modifications introduced in the proposed protocols compared to the existing ones.

Extensive simulations are performed using MATLAB with different performance evaluation metrics to prove the energy efficiency of the modified protocols. These protocols are mainly intended for applications that require periodic monitoring. The clustering implemented in Modified LEACH achieves better load balance and leads to lifetime elongation. The sink mobility approach gains energy efficiency by reducing the number of hops for data transfer to the BS; but requires obstacle free environments. The unequal clustering adopted in Modified HEED helped have energy efficient routing which reduced hot spot issues and prevented immature termination of network connectivity.

The research contributions are the development of energy efficient routing algorithms;

- Modified LEACH Algorithm
- Modified Mobile Sink Assisted LEACH Algorithm
- Modified HEED Algorithm

The protocols developed during this research, attains the basic objective of the research work, energy efficient routing in WSNs. The outcome shows an increase in life time, average energy of nodes and packet delivery ratio and a decrease in the average packet delay which proves the energy efficiency of the modified protocols. These protocols were developed mainly keeping in mind the agriculture sector. They can be customised according to the requirements in the practical scenario.

Table 6.4: Modifications Introduced in the Proposed Protocols

Existing Protocols	Proposed protocols	Modifications Introduced
LEACH	Modified LEACH	Clustering method where node's remaining energy and distance to the BS is used for CH selection, uniform load for CHs
LEACH M-LEACH	Modified Mobile Sink Assisted LEACH	Use of multiple MSs
HEED UHEED	Modified HEED	Unequal clustering

6.3 Future Scope

The following are the future enhancements;

- Prototype modelling of WSNs to test and validate these protocols.
- Incorporation of node heterogeneity.
- Investigation of the influence of node density, CH proportion, position of the BS and the different speeds of sink mobility in the network performance.
- Real time implementation of these protocols for specific applications like hydroponic farming.

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PUBLICATIONS AND PROCEEDINGS

I. Papers in Journals

[1] LEACH Enhancement to Improve the Life Time of Wireless Sensor Networks

Deepa V. J. and Sadashivappa G.

International Journal of Advanced Research in Computer Science and Software Engineering (IJARCSSE), vol. 4, no.5, pp.1414, 2014.

[2] A Novel Energy Efficient Routing Algorithm for Wireless Sensor Networks Using Sink Mobility

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[3] Mobile Sink Assisted Energy Efficient Routing Algorithm for Wireless Sensor Networks

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[4] An Improved Hybrid Energy Efficient Clustering Technique to Enhance the Lifespan of Wireless Sensor Networks

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II. Conference Proceedings

[1] Energy Efficient Routing Protocols for Wireless Sensor Networks with Mobile Nodes- An Overview

Deepa V. J. and Sadashivappa G.

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[2] An Energy Efficient Routing Algorithm Using Novel Cluster Head Selection Strategies

Deepa V. J. and Sadashivappa G

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[3] An Augmented LEACH Strategy to Enhance Energy Efficiency in Wireless Sensor Networks

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[4] A Novel Scheme for Energy Enhancement in Wireless Sensor Networks

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