# Energy Aware Routing Protocol for Wireless Sensor Networks (D-LEACH)

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# ABSTRACT

Energy conservation has a main priority in all technology and engineering fields. During the rise of wireless sensor networks (WSNs) field applications and the critical situation of energy consumption, the optimization of energy dispatch becomes a critical and important field of research. LEACH (Low Energy Adaptive Clustering Hierarchy) is one of the most popular routing protocols in WSNs. However, in LEACH nodes energy are drained quickly and it decreases the network lifespan due to cluster heads that are selected randomly without taking into consideration the residual energy and position of nodes. The goal of this thesis is to introduce a novel routing algorithm named D-LEACH (Decentralized LEACH) to enhance network lifetime by selecting optimum number of cluster heads according to their residual energy and position. This is achieved by decreasing the amount of communication which is needed for selecting cluster heads. The simulation results indicate that the proposed scheme can prolong network's lifespan and also increase the average residual energy of nodes 150%.

**Keywords:** Wireless Sensors Networks, Sensors Clustering, LEACH

# ÖZ

Enerji tasarrufu tüm teknoloji ve mühendislik alanlarında ana önceliğe sahiptir. Kablosuz algılayıcı ağların (WSN) saha uygulamalarının yükselişi ve enerji tüketiminin kritik durumu nedenleriyle, enerji yollama optimizasyonu en kritik ve önemli araştırma alanı haline gelmiştir. LEACH (Düşük Enerji Adaptif Kümeleme Hiyerarşisi), WSN'in en popüler yönlendirme protokollerinden biridir. Ancak, LEACH'da küme başları rastgele seçildiği ve nodların pozisyonu dikkate alınmadığından dolayı, nodların enerjisi hızlı bir şekilde tüketilmekte ve ağın ömrü azalmaktadır. Bu tezin amacı D-LEACH adlı yeni bir yönlendirme algoritması (Merkezi olmayan LEACH) önermektir. Önerilen yeni algoritmada, küme başlarının kalan enerjileri ve pozisyonlarına göre seçilmesinden dolayı ağın ömrü uzamaktadır. Bu hedefe küme başlarının seçilmesi için gerekli olan iletişim miktarı azaltılarak ulaşılmaktadır. Simülasyon sonuçlarına göre, önerilen algoritma normal LEACH algoritmasıyla karşılaştırıldığı zaman, ağın ömrünü uzatmakta ve yaklaşık %150 oranında nodların kalan enerjisini artırmaktadır.

**Anahtar Kelimeler:** Kablosuz Algılayıcı Ağları, Kümeleme, LEACH

This thesis is dedicated to my parents.

For their endless love, support and encouragement

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| | |
|---|---|
| **WSN** | Wireless Sensor Network |
| **LEACH** | Low Energy Adaptive Clustering Hierarchy |
| **D-LEACH** | Decentralized LEACH |
| **ACHTH-LEACH** | Adaptive Cluster Head and Two Hop LEACH |
| **ICCA** | Improvement of Cluster head Choosing Algorithm |
| **U-LEACH** | Universal - Low Energy Adaptive Cluster Hierarchy |
| **DEEC** | Distributed Energy-Efficient Clustering |
| **CH** | Cluster Head |
| **J** | Joule |
| **M** | Meter |

# Chapter 1

# INTRODUCTION

## 1.1 Introduction

Wireless sensor networks consist of independent sensors which monitor the environment and communicate with each other wirelessly for sending information to a base station (BS) [1].

For analyzing analogue data sensors connect the real world with the digital world by capturing and monitoring the environment to gain information, which lead to turn analogue data to digital data. By the use of this information which is obtained from sensors, we can increase productivity, security and it makes us able to consume resources in an efficient manner. Recently, sensors are being used in different environments and for different applications such as in military, agriculture, medical affairs, jungles and cities. In most applications, the single device of wireless sensor networks costs less than $1. They also have low installation costs, smaller sensing transducers and a long lifetime. Moreover, sensors are adaptive and can be reconfigured to work in different areas. To obtain information from the real world, sensor nodes use a technique called sensing. After sensing, sensors convert the energy, which is obtained from the real world, into electrical energy that can be interpretable by a computing system. Note that this operation is done by the transducer part of sensors. Sensors are classified according to their applications in different environments. Table 1.1 shows the different types of sensors which are used for different applications [2].

Table 1.1: Different Types of Sensors

| Type | Examples |
|---|---|
| **Temperature** | Thermistors, thermocouples |
| **Pressure** | Pressure gauges, barometers, ionization gauges |
| **Optical** | Photodiodes, phototransistors, infrared sensors, CCD sensors |
| **Acoustic** | Piezoelectric resonators, microphones |
| **Mechanical** | Strain gauges, tactile sensors, capacitive diaphragms |
| **Motion, Vibration** | Accelerometers, mass air flow sensors |
| **Position** | GPS, ultrasound-based sensors, infrared-based sensors |
| **Electromagnetic** | Hall-effact sensors, magnetometers |
| **Chemical** | pHsensors, electrochemical sensors, infrared gas sensors |
| **Humidity** | Capacitive and resistive sensors, hygrometers |
| **Radiation** | Ionization detectors, Geier-Mueller counters |
| **Flow** | Anemometers, mass air flow sensors |

## 1.2 Wireless Sensor Structure

Wireless sensors are equipped with different parts including sensing part, memory, processor, and communication system. Figure 1.1 illustrate the structure of wireless sensors [2]. Wireless sensors not only gain information from the environment, they can also do some analysis, data fusion and deliver in-network data communication of its own and other node's data [3].

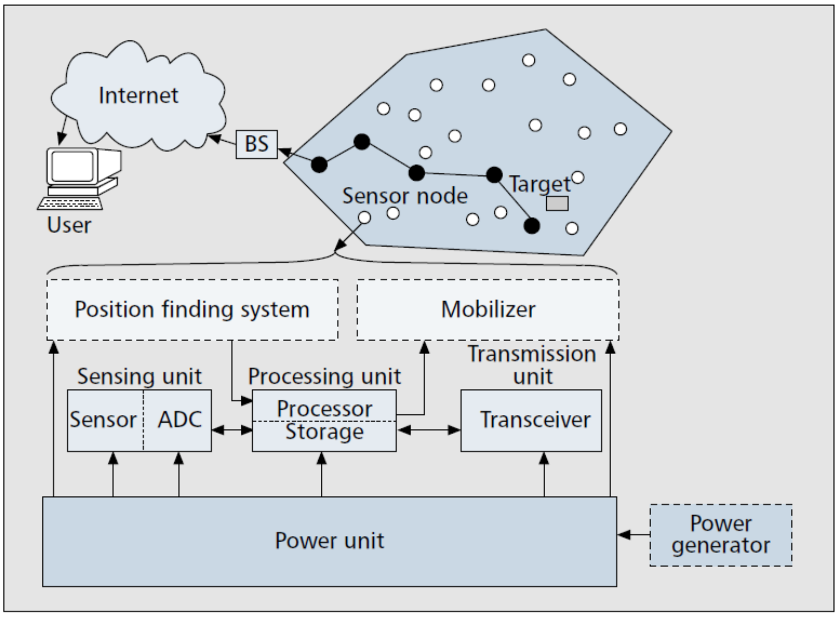


Figure 1.1: The Components of Sensor Nodes

The wireless sensor networks (WSNs) consist of a great number of wireless sensors working and communicating with each other. Sensor nodes can communicate with their neighbor nodes or the base station while the signal strength is sufficient for sending and receiving. Wireless sensor networks can cover a large geographic area by spreading a great number of sensors and using the appropriate routing technique. However, due to resource limitations, it is important to manage energy consumption in an efficient manner.

In a wireless sensor network, nodes can communicate with the base station by single-hop or multi-hop techniques. If nodes are close enough to the base station they can communicate directly with the base station which is called single-hop mode (Figure 1.2a). In multi-hop communication (Figure 1.2b) the base station is not directly reachable by nodes therefore, sensors not only capture and spread their own data but also they should work as relay node for delivering data toward the base station [2].

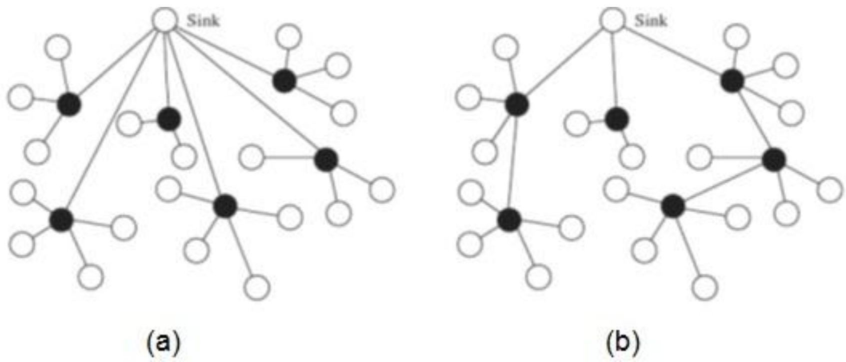


Figure 1.2: Clustering with Single Hop Connections to the Sink (a) and Clustering with Multi Hop Connections to the Sink (b)

## 1.3 Wireless Sensor Networks Applications

Applications of wireless sensors networks are numerous, but the most applicable application is monitoring the low frequency data of remote environments, such as, manufacturing plants, demining, farms, long distance oil and gas lines, etc. [4].

In long distance oil and gas lines, it's very difficult or even impossible to detect the leakage point or spot points in traditional inspection methodologies and techniques. The overall measurements of such lines are capable to be done using the wireless sensor networks protocol and technology. The use of WSN enables us to detect all variables and measurements of such long distance lines with high security and reliability instead of undergoing the costly and difficult installations, and other problems in wired and traditional measurement procedures [5].

The main applications of wireless sensor networks can be divided into three categories; those are:

1. Data collection for environmental applications.

2. Security, surveillance, and monitoring.

3. Object tracing.

## 1.4 Problem Definition and Motivation

A variety of challenges exist in the design of wireless sensor network. Some of the most significant design issues in the WSNs are presented as below:

### 1.4.1 Energy

The most important and critical parameter in wireless sensor network is energy constraint. Sensor nodes are using the limited energy resource, therefore they should be able to manage their energy efficiently to be able to finish their process completely [6].

### 1.4.2 Self-management

Most of the time, sensor nodes in the WSNs operate in harsh environments without any infrastructure and possibility of repair or management, therefore sensors need to handle their own process with minimum human intervention.

### 1.4.3 Security

If wireless sensors are used in a critical environment like battlefields, since the protection of information is essential, it is necessary to provide security for wireless communication among sensors to prevent any intrusion from any anonymous person, groups or devices.

### 1.4.4 Routing

The WSNs need routing algorithms which are designed especially for their conditions due to the use of wireless sensor network for different applications and environments and also the lack of energy resource in sensor nodes. Despite of the vast variety of WSNs applications, they have some limitations such as computing power, energy resource, memory, and communication bandwidth. Hence the WSNs cannot use the same routing protocols which are designed for Ad-hoc networks. There are some parameters which should be considered for designing routing protocols and which are discussed in detail as follow [7].

#### 1.4.4.1 Energy Consumption without Losing Accuracy:

One of the most important parameters which need to be considered is how to consume energy in an efficient way due to the limitation of energy resource and the importance of energy in computation and transmission. Also, it is important to keep both the accuracy of computation and communication as high as possible.

#### 1.4.4.2 Scalability and Flexibility:

Routing protocols need to adapt themselves to different conditions and be scalable because of using a variable number of nodes in different situations.

#### 1.4.4.3 Coverage:

Each sensor node covers a part of environment for gathering information. They are also equipped with a limited transceiver module which has restricted their coverage area of nodes; therefore one of the challenges is how to spread nodes in environments for achieving maximum coverage in our area.

## 1.5 Routing Classification

Routing protocols in wireless sensor networks are classified in three categories based on the sensor network architecture [8]:

1. Flat routing protocol
2. Hierarchical routing protocol
3. Location-based routing protocol

### 1.5.1 Flat Routing Protocol

In this category, the base station sends a query packet to specific parts of the network and waits to receive a response from the sensor nodes. Since the distance between the sender and receiver sensor nodes plays a crucial role in the signal attenuation, the sensor nodes cannot always communicate directly with the base station. Therefore, each sensor sends the data, which is obtained from the environment or other sensor nodes, to all of its neighbors until the data reaches the base station.

In flat routing, it is not feasible to allocate global identification to each node due to the huge number of sensor nodes, therefore it is considered as to data-centric routing protocol.in which sensor nodes do not need to have a unique ID for routing, data is routed based on the nature and value of data collected by sensors.

One of the main drawbacks of flat routing protocol is providing a huge amount of intra network communications, which decrease the network lifetime dramatically especially in the large networks.

### 1.5.2 Hierarchical Routing Protocol

The hierarchical routing protocols try to decrease the amount of energy which is needed to be consumed during communication among nodes and the base station. This is done by employing of the hierarchical network structure for increasing network lifetime in comparison with flat routing protocol.

The hierarchical routing protocols are grouping set of sensor nodes based on some parameters such as closeness or signal strength of sensor nodes in the same group, which is called clustering. Additionally in each cluster one of sensor nodes is selected as cluster head to gather data from other sensor nodes on that cluster and transfer it to the base station.

In the hierarchical architecture, a sensor node with a higher energy level is considered as the cluster head. Cluster heads perform more communication and computation compared to normal nodes, while nodes with lower energy level perform the role of sensing the matter of interest (e.g,temperature, humidity, and etc.) in proximity of the target. The operations of data fusion and data aggregation are done by cluster heads which significantly decrease energy consumption.

### 1.5.3 Location-Based Routing Protocols

In this type of routing protocol, sensor nodes find their distance between each other by two methods:

1. By the measurement of incoming signal strength.
2. Each sensor node is equipped with low power GPS to find a location by the use of satellite.

One of the main disadvantages of these routing protocols is the expense of implementation and the advantage is that they enable routing in a vast environment much easier by using nodes which are equipped with GPS.

This thesis tries to provide an improvement over one of the hierarchical routing protocols called LEACH to make it more scalable and to increase the network lifetime. The specifications and structure of LEACH have been shown below:

## 1.6 LEACH

Low Energy Adaptive Clustering Hierarchical (LEACH) is a hierarchical routing protocol which is introduced by Heinzehmen [6]. LEACH tries to share the energy dissipation fairly among all nodes by selecting cluster heads randomly to prolong the network lifetime. In the LEACH, cluster heads compress and aggregate data after receiving it from sensor nodes, and then they send it to a base station for decreasing energy consumption in comparison with direct communication between each node and the base station. LEACH uses TDMA/CDMA for avoiding a collision in intra and inters clusters. Due to the centralized data collection, it is more appropriate to use LEACH in a non-dynamic environment without any mobility. Figure 1.3 shows a flowchart of LEACH protocol [9].

LEACH routing protocol is made with two phases as it is expressed below:

1. Setup phase: In this phase cluster heads are selected after nodes join each cluster head to create clusters.
2. Steady phase: In this phase gathering data and communicating among nodes, cluster heads and a base station occurre.

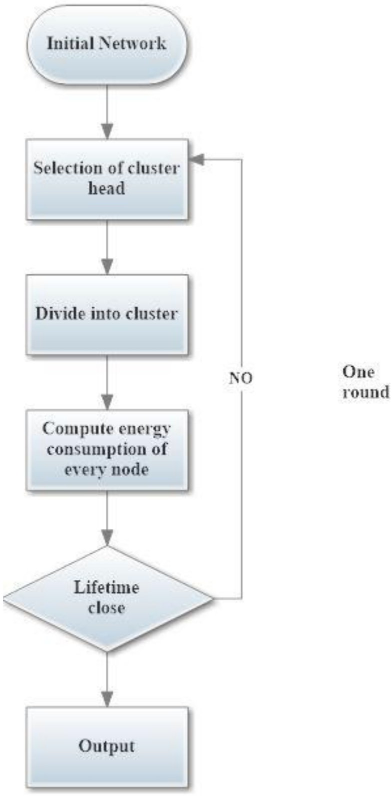


Figure 1.3: Flowchart of LEACH Protocol

The LEACH protocol guarantees that every sensor will become a cluster head exactly once every $\frac{1}{P_{opt}}$ rounds where $P_{opt}$ is a probability of becoming cluster head for each node. Nodes which are selected as cluster heads in the current round cannot become cluster heads in next $\frac{1}{P_{opt}}$ rounds. To make a decision for selecting the cluster head, non-elected nodes which belong to set *G*, select a random number between 0 and 1, and compare it to their threshold value which is obtained from Equation 1.1. If the random number is less than the threshold value, the node becomes the cluster head in the current round. Otherwise node is considered as normal node.

$$T(n) = \begin{cases} \frac{P_{opt}}{1 - P_{opt} \cdot \left(r \bmod \frac{1}{P_{opt}}\right)} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1.1)$$

where *r* represents the number of the current round. The flowchart of cluster formation is shown in Figure 1.4 [9].

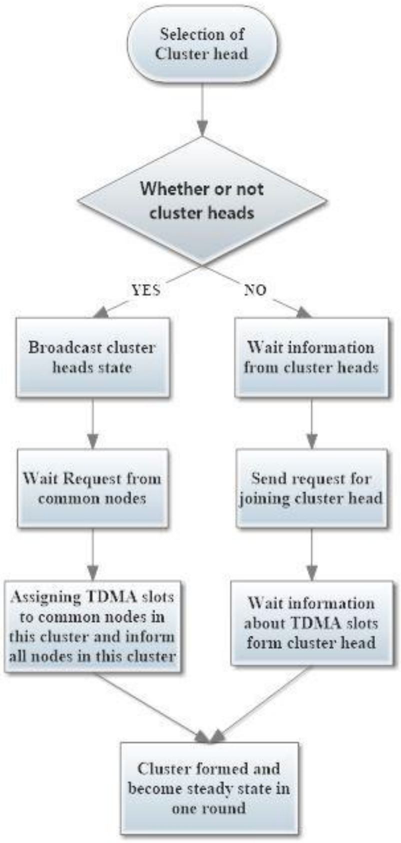


Figure 1.4: Cluster Formation of LEACH Protocol

Although, LEACH can improve network lifetime, it still has some drawbacks which needs to be improved. Some of these drawbacks are briefly explained below:

1. In LEACH routing protocol, it is assumed that all sensor nodes have the ability to communicate directly with the base station. This assumption limits this protocol to only small networks.
2. There is no specific rule or condition for the position of cluster heads, therefore, cluster heads can sometimes be located in part of a network which is far from other nodes and the base station.

3. For load balancing in the network, cluster heads are selected dynamically and they are changed in each round. This causes overhead in the network because of advertising packets which need to be sent before and after selecting cluster heads. Furthermore, this drains the energy of sensor nodes faster and hence may decrease the network lifetime.

## 1.7 Research Objective

In this thesis a novel routing algorithm is introduced that prolong network lifetime compared to LEACH algorithm, with some other benefits.

The main improvements of this research are:

1. Increasing energy saving and network lifetime in comparison with LEACH
2. Introducing a new technique for energy aware routing
3. Providing decentralized protocol
4. Improving the creation of clusters

The rest of the thesis is arranged as follows. In Chapter 2 the main focus will be on analyzing some of related works in hierarchical routing protocols in WSNs. In Chapter 3 D-LEACH routing algorithm is introduced , in Chapter 4 the numerical results are discussed and finally Chapter 6 is for the conclusion.

# Chapter 2

# LITERATURE REVIEW

## 2.1 Literature Review

In recent years, many researches have been carried out concerning wireless sensor network issues, and especially in communication and control protocols. Those researches include energy management and power consumption, optimal clustering, communications structure and topology. In this section some of the major researches related to this proposed work are mentioned below.

### 2.1.1 Energy-LEACH

As discussed in the previous section, one of the disadvantages of LEACH is that cluster heads are selected randomly but in Energy-LEACH routing protocol cluster heads are selected based on their residual energy to improve load balancing between nodes [9]. This routing protocol uses a threshold parameter named as “scheduled energy” for selecting cluster heads. So, a node can be a cluster head when its residual energy is more than the scheduled energy. In this protocol it is assumed that all nodes can directly communicate with the base station, and there is no condition for the position of cluster heads. The flowchart of Energy-LEACH is shown in Figure 2.1 [9].

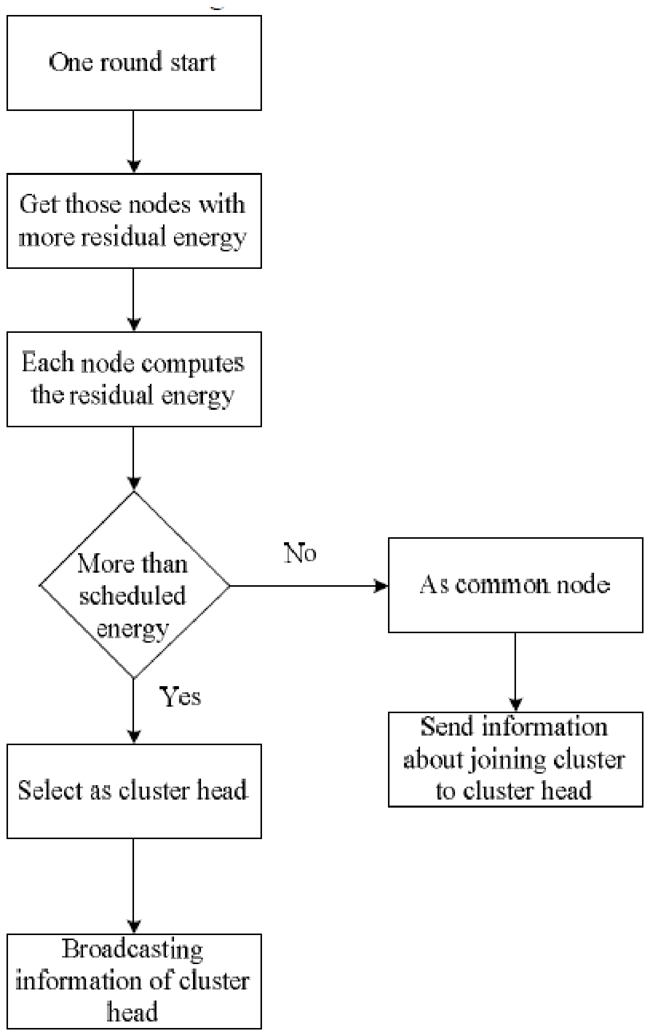


Figure 2.1: Flowchart of Energy-LEACH Protocol

### 2.1.2 Improved LEACH

This routing algorithm uses a new method for selecting cluster heads by applying modification on a formula used by LEACH [5]. According to the modified formula, in addition to selecting nodes randomly, the ratio of remaining energy to initial energy of each node, and the average number that each node is selected as cluster head in previous rounds are taken into considerations. By the use of these parameters, this routing protocol consumes lesser energy than LEACH. Another feature of this routing algorithm is that sensor nodes can communicate with either the cluster head or directly with the base station if the base station is closer than the cluster head. Compared to traditional LEACH, the improved LEACH saves more energy and increases network lifetime. LEACH algorithm and improved algorithm's topology are shown in Figure 2.2 [10].

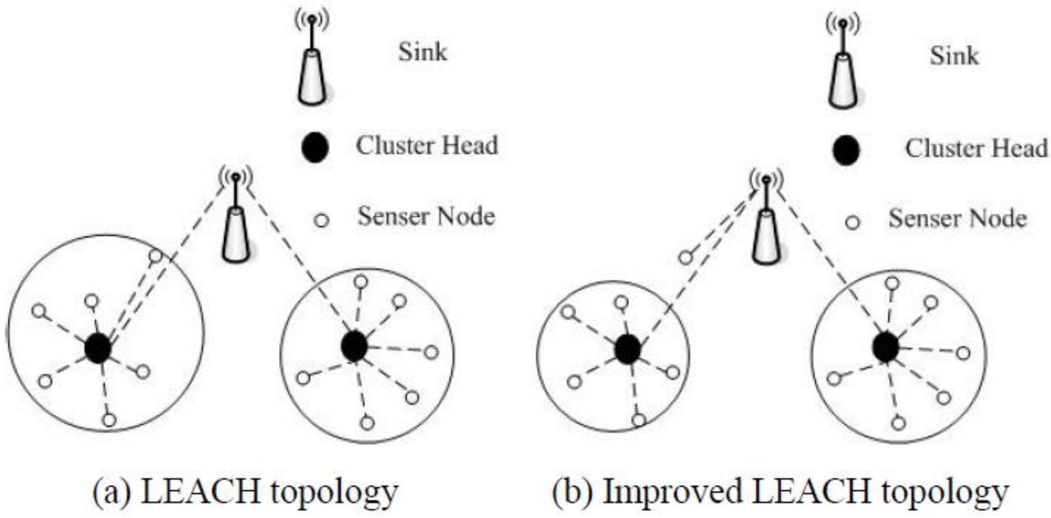


Figure 2.2: LEACH and Improved LEACH Algorithm Topology

### 2.1.3 ACHTH-LEACH

ACHTH-LEACH improves LEACH by using an adaptive algorithm of cluster head election and allowing multi-hop transmission among cluster heads and the base station [11]. In Adaptive Cluster Head Election and Two-Hop LEACH routing protocol sensor nodes are divided in two groups:

1. The nodes which are close to the base station
2. The nodes which are far from the base station

After this classification, the nodes which are closer to the base station are tagged as near nodes and they have been classified in one cluster. On the other hand, the remaining nodes are tagged as far nodes. Then these nodes have been classified in different clusters by a combination of k-means and greedy algorithms. This phase is named by clustering in ACHTH-LEACH. This routing algorithm also has two more phases named by selecting the cluster head and data transmission. In selection cluster head phase, cluster heads are selected based on calculation of residual energy of each node and the node with maximum residual energy has been selected for this role on the network. With this technique which is used in the second phase, the load is equally balanced among all nodes. In addition, network lifetime would be increased too. The main advantage of ACHTH-LEACH in comparison with LEACH is, when a sensor node becomes cluster head it just needs to send information to nodes which are in the same cluster not the whole network like LEACH, therefore the amount of data which needs to communicate between nodes have decreased significantly as a result of energy consumption and network lifetime would be decreased and increased, respectively. The flowchart of cluster heads selection in ACHTH-LEACH algorithm is shown in Figure 2.3 [11].

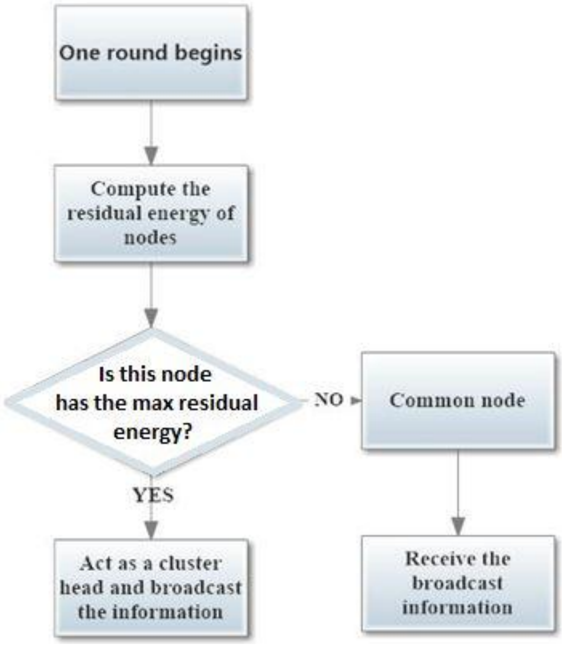


Figure 2.3: Flowchart of Cluster Head Election

Another novel technique which is used by this routing protocol is Two-Hop transmission which is used in the third phase. The flowchart Two-Hop transmission is shown in Figure 2.4 [11]. ACHTH-LEACH has abated one of the main defects of LEACH and made LEACH applicable in a large network. In addition, it reduces energy consumption and increases network lifetime. In data transmission phase when cluster heads have data to send they first check their neighbor clusters. If the closest one is alive then cluster head sends data to the base station with Two-Hop. However, if the cluster head is close to the base station or the neighbor cluster is not alive. It sends data with one-hop directly to the base station.

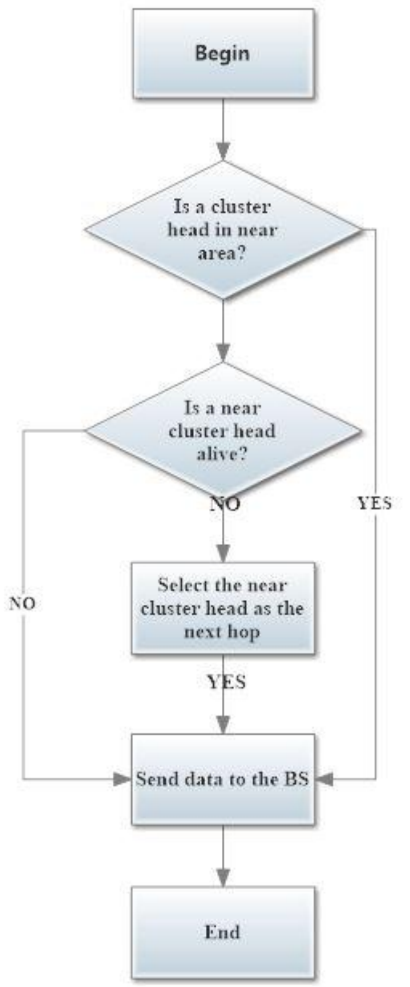


Figure 2.4 Flowchart of Two-Hop Transmission

### 2.1.4 New LEACH

In this routing protocol, a new method for calculating the threshold function is used. In New-LEACH, the threshold function is made based on three parameters which are shown below [12]:

1. Remaining energy of each node
2. The duration of each node is selected as cluster head
3. Distance between node and the base station

The first parameter has been used for providing priority for nodes with higher residual energy in comparison with other sensor nodes.

The second parameter has been used for providing energy balancing between nodes and increasing network lifetime by choosing nodes as cluster head which have been chosen less than the other.

Finally, the third parameter is used for providing priority for nodes which have less distance to the base station. This parameter can decrease the amount of energy which is needed to communicate with the base station. Therefore, it can increase the network lifetime.

In the formula which is used for calculation of threshold in this routing protocol, it is based on the importance of parameters. Several weights are considered for increasing and decreasing the priority of each parameter respectively.

### 2.1.5 ICCA

ICCA presents one cluster head choosing algorithm based on the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol to save the network energy and extend its survival life [13]. This routing algorithm has tried to improve shortages of LEACH in selecting cluster heads. As discussed before although LEACH can distribute the cluster head role among all nodes in an appropriate manner, it didn't select cluster head based on remaining energy. In this routing algorithm (ICCA) cluster heads are selected based on residual energy. In ICCA each node sends its remaining energy to the cluster head in addition of data which has been gained from the environment. Cluster heads gather information from sensor nodes and organize data based on sensors ID and the residual energy of each node. At the end of each round the new cluster is selected based on its remaining energy by current cluster head. Although this algorithm can improve LEACH, but consuming higher memory and processing resources are its shortages.

### 2.1.6 DEEC

DEEC is a distributed energy efficient clustering protocol for heterogeneous wireless sensor networks [14]. In this routing protocol cluster-heads are selected with a probability based on the ratio between the residual energy of each node and the average energy of the whole network. Therefore, each node needs to obtain residual energy of all nodes at each round. Nodes are selected as cluster heads with respect to their residual energy and initial energy. The sensor nodes with high energy level have more chance to be selected as cluster heads.

### 2.1.7 U-LEACH

This routing algorithm uses two different routing protocols named PEGASIS and I-LEACH. They try to provide an improvement over LEACH protocol [15]. In PEGASIS routing algorithm nodes communicate with one of their neighbors. Also they restrict their signal power to be detectable only by one of their neighbors. Meanwhile, a leader is selected at the end of each round based on its remaining energy to transfer data which is obtained by other sensor nodes to the base station. In I-LEACH cluster heads are selected based on their residual energy opposite to LEACH which cluster heads were selected randomly. I-LEACH can cover some of the weak points of LEACH with these modifications on creating clusters and selecting cluster heads that improved network lifetime significantly in comparison with LEACH.

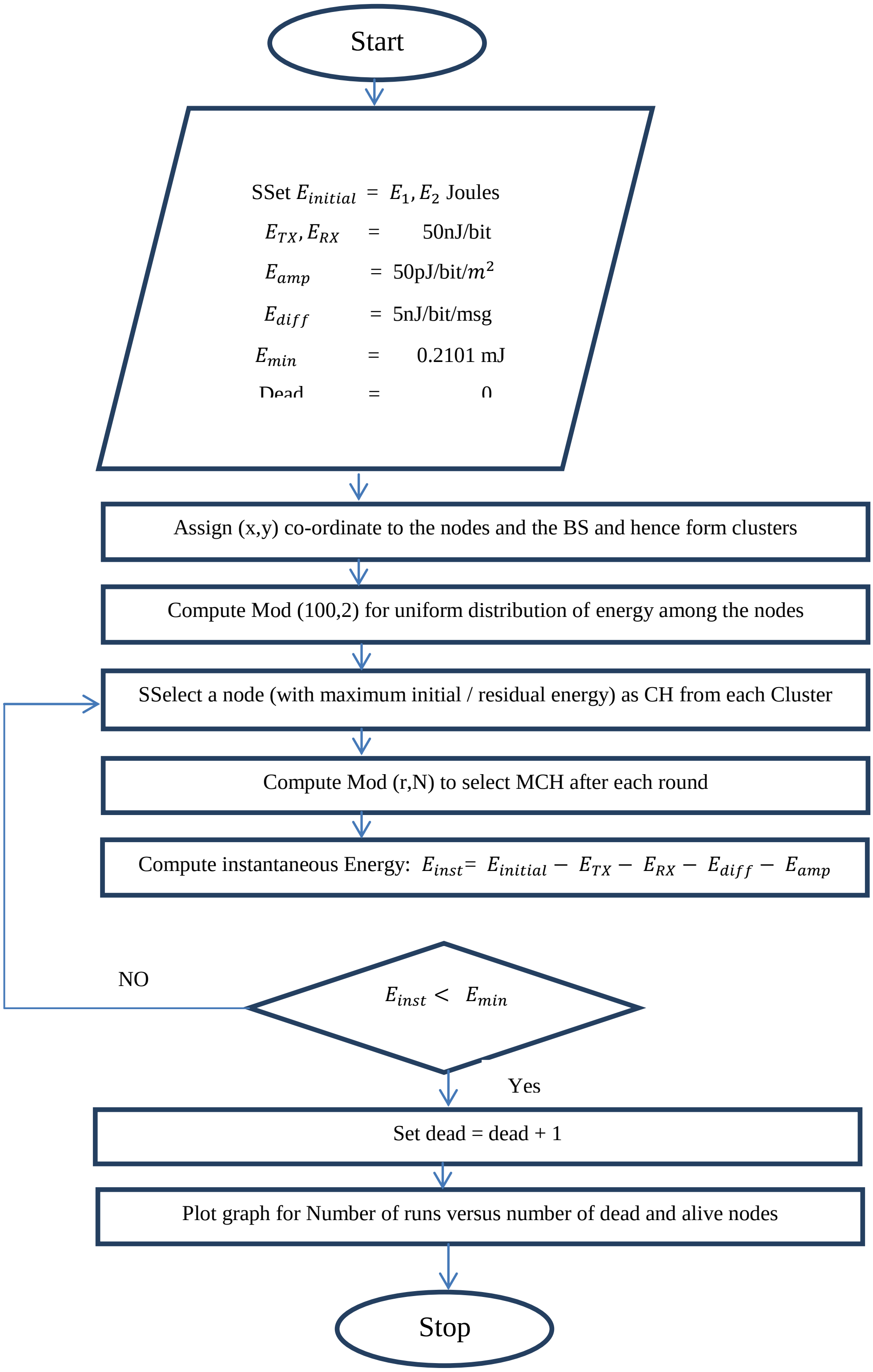


Figure 2.5: Flowchart of U-LEACH

U-LEACH combines these methods which are used in PEGASIS and I-LEACH to make the new routing protocol to improve network lifetime. In U-LEACH clusters are made on the basis of x-coordinate value. Meanwhile in each cluster a node with higher residual energy is selected as cluster head. Following that, in the last phase cluster heads select the MCH to communicate directly with the base station. In U-LEACH sensor nodes after obtaining the information, are transmitted to their data one by one to their adjacent node until data reach cluster heads. Additionally Cluster heads send data to MCH and MCH transfer it to the base station. The MCH in each round periodically is changed by cluster heads. The flowchart of U-LEACH algorithm is shown in figure 2-5.

## 2.2 Drawbacks of Proposed Algorithms

In this section, the following routing protocols were compared according to their designed characteristics as shown in Table 2.1. As it can be seen, all of these routing protocols have the same drawbacks such as:

1. In each round, all sensors must transfer their residual energy to the base station or to cluster heads which increase the cost of sensors due to the need of extra processing, and memory resources. Additionally, transferring the extra data can increase energy consumption and network traffic load which results in less network lifetime.
2. The positions of cluster heads in these routing protocols are not considered, therefore it may cause some of cluster heads to be located on the edges of a cluster or far from the base station. This drawback increases the amount of energy which is needed to transfer data to the cluster heads and in addittion decreases network lifetime.

3. As discussed earlier, cluter heads consume more energy in comparison with normal node. Therefore by considering the optimal number of cluster heads energy consumption can be decreased, resulting increase in the network lifetime.

Table 2.1: Comparison of Routing Protocols in WSNs

| Routing Protocols | Is it considering the optimized number of cluster heads? | Are nodes transferring their residual energy in each round? | Is the cluster head position considered? | Can nodes communicate directly to the base station? |
|---|---|---|---|---|
| Energy-LEACH | NO | YES | NO | NO |
| Improved LEACH | NO | YES | NO | YES |
| ACHTH-LEACH | NO | YES | NO | YES |
| New LEACH | NO | YES | NO | NO |
| ICCA | NO | YES | NO | NO |
| U-LEACH | NO | YES | NO | NO |
| DEEC | NO | YES | NO | NO |

# Chapter 3

# THE D-LEACH ALGORITHM

## 3.1 Proposed System

As it was discussed in section 2, LEACH has some disadvantages which degrade its performance. The drawbacks of LEACH which have been developed are:

1. Making clusters
2. Selecting cluster heads
3. Communication between nodes and cluster heads

This research has developed a novel algorithm named Decentralized LEACH (D-LEACH) that saves energy more than LEACH, with some other benefits.

The main improvements of this routing algorithm in comparison with LEACH are:

1. Increasing energy saving and network lifetime
2. Introducing new technique for energy aware routing
3. Providing decentralized protocol
4. Improving creation of clusters
5. Locating cluster heads in an appropriate position
6. Reducing the number of transmissions which are needed for selecting cluster heads
7. Selecting the optimum number of cluster heads to save more energy

Further information regarding the proposed D-LEACH routing algorithm is given below:

## 3.2 Network Model

Suppose N nodes are distributed in a 100 x 100 meter area randomly. The network is divided into five clusters. One of these clusters contains the base station and all nodes in this cluster transmit their data directly to the base station in each round. However, in the other four clusters, nodes send their data to the cluster heads, and the cluster heads communicate with the base station.

A sensor node joins any cluster based on the signal strength which is received from the base station and neighbor cluster heads. If the received signal from the neighbor cluster head is higher than the received signal from the base station, the sensor node joins the cluster, otherwise the sensor node communicates directly with the base station.

It is assumed that clusters, the base station, and sensor nodes have the following features:

1. Nodes in the network are stationary and there is no mobility in the network.
2. Nodes have the same initial energy at the beginning.
3. Each node can calculate the residual energy and identity of its own.
4. Wireless transmit power of a node is controllable.
5. The data is always available to be sent to the cluster heads or the base station in each round.

6. Nodes send their collected data to the base station or cluster head based on how they are close to each of them.
7. Nodes have no information about their positions.
8. Sink or base station is located in the middle of the network

## 3.3 Wireless Communication Model

The wireless communication model in [2] was used to evaluate the node energy consumption during communication. In this model, energy consumption is calculated by Equation 3.1 which is shown below:

$$E_{Tx}(k,d) = \begin{cases} k \,.\, E_{elec} + k \,.\, \epsilon_{fs} \,.\, d^2 & if\ d \le d_0 \\ k \,.\, E_{elec} + k \,.\, \epsilon_{mp} \,.\, d^4 & if\ d > d_0 \end{cases} \tag{3.1}$$

where $k$ is the number of bits which are transmitted by each node and $d$ represents the distance between sender and receiver. If this distance is less than $d_0$ free space model can be used, otherwise multipath model must be applied.

Note that $E_{elec}$ is considered as the amount of energy consumption during sending and receiving data by wireless transmitters. Also $\epsilon_{fs}$ and $\epsilon_{amp}$ are considered as energy parameters of power amplifier in two-channel model.

### 3.3.1 Radio Model

The radio model which is used for sending and receiving data in D-LEACH is illustrated in Figure 3.1 in following page:

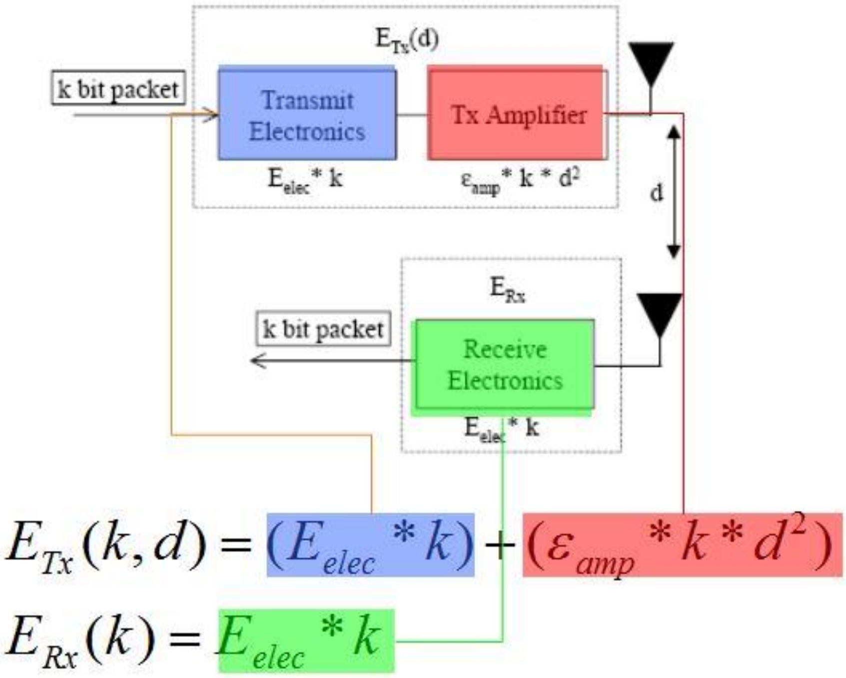


Figure 3.1: Radio Model of D-LEACH

As it shown the amount of energy which is consumed for receiving data is calaculated by Equation 3.2:

$$E_{Rx}(K) = E_{elec} * K \tag{3.2}$$

For more illustration flowchart of wireless model is shown in Figure 3.2 below:

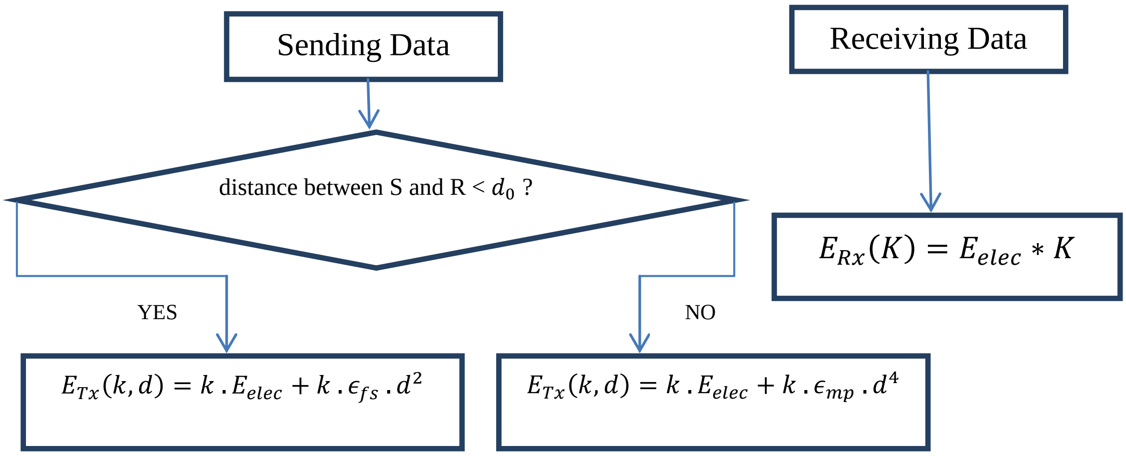

Figure 3.2: Flowchart of Wireless Model

## 3.4 Description of the Algorithm

### 3.4.1 Creating Clusters

In the literature, such as [16] [17] [18] it is usually recommended to have 5% of the total nodes as cluster heads. If the total number of nodes in the network is 100, then the optimum number of nodes which can be cluster heads is 5 in each round. The optimal number of cluster heads is not a constant factor. Optimum number of cluster head is calculated by Equation 3-2 which is shown below [16]:

$$K_{opt} = \sqrt{\frac{(l_1 + l_2 f) N \varepsilon_{fs} M^2}{2\pi[\varepsilon_{mp}\left(l_1 d_{to\ BS}{}^4 + l_2 f d_{to\ BS}{}^4\right) - (2l_1 - l_2 f) E_{elec}]}} \tag{3.2}$$

Where $l_1$is number of bits which are transmitted inside clusters, $l_2$ is number of bits which are transmitted between clusters and the base station, $f$ is the number of frames, $d_{to\ BS}$ is the average distance from cluster heads to base station $M$ is area of a region and $N$ is a number of nodes.

In the first step, the network is divided into five clusters. The first cluster contains the base station with radius “$d_0$” and the other four clusters are formed in the remaining area. We assume that the sink (the base station) is located in the middle of the network. In this case if the area is 100x100 meter square, it means that the sink is located at (50,50) position, and other clusters are formed in four separated sections as shown below:

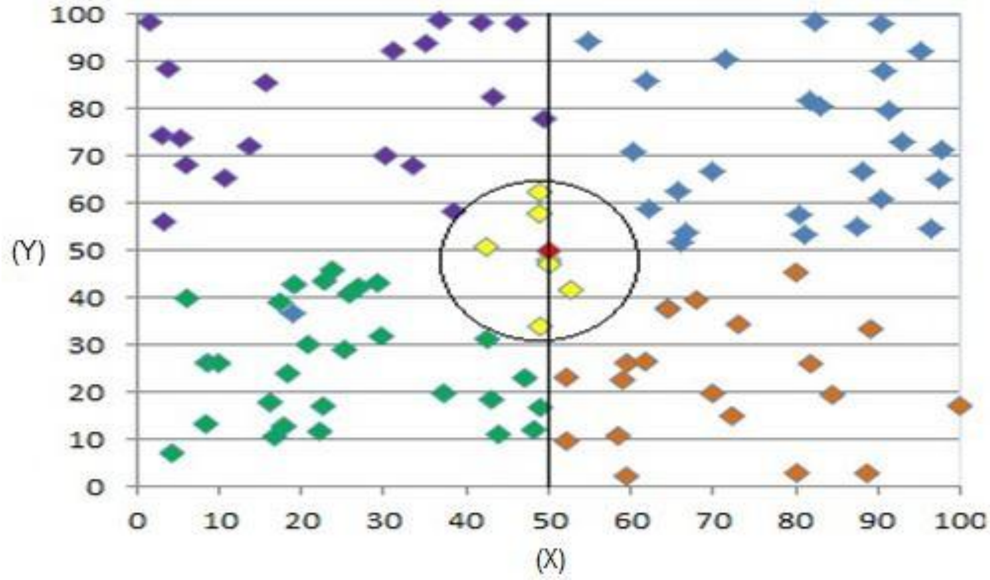


Figure 3.3: Location of Clusters in Network (100m x 100m)

### 3.4.2 Selecting Cluster Head

The next phase after making clusters is selecting the appropriate cluster heads. At the beginning, four cluster heads are selected based on how they are close to the center of each section. Meanwhile, in each round, each cluster head sends a packet to its closest neighbor, and if this neighbor's residual energy is more than a threshold, it becomes the new cluster head. Otherwise, the same procedure will be applied for the next closest neighbor. In the case that there is no neighboring node with residual energy higher than a threshold, the node with minimum distance to the current cluster head is selected as the new cluster head. To be more explicit, a flow chart of the entire process has been shown in Figure 3.2 in the following page.

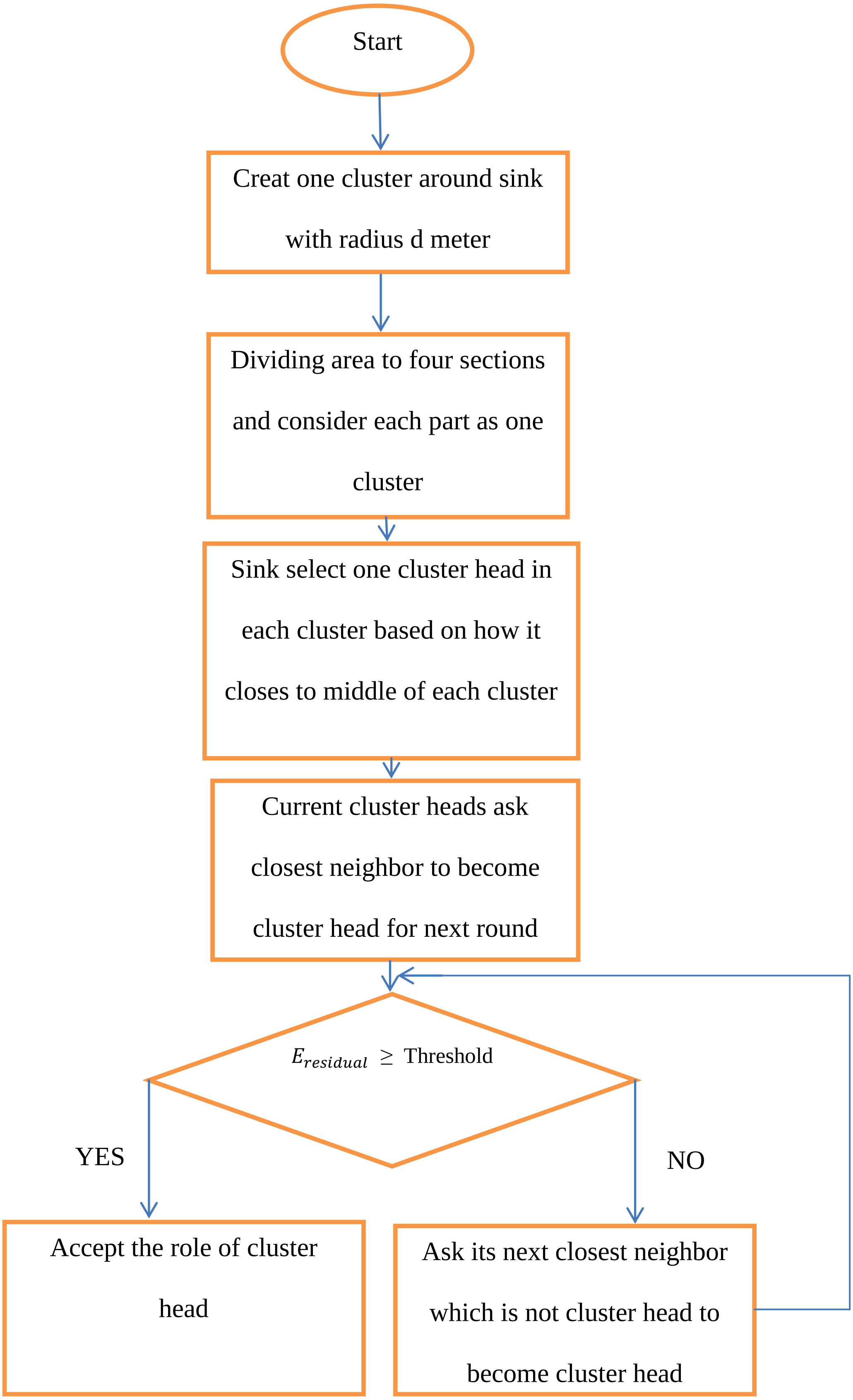


Figure 3.4: Selecting Cluster Head Steps

### 3.4.3 Communication

The last step is named as communication phase. In this phase, a sensor node transmits its data either directly to the base station or to the closest cluster head. By using this technique, the burden over cluster heads is significantly reduced, and hence the amount of energy which is consumed for receiving data from sensor nodes and transfer it to the base station by cluster heads would be decreased.

As discussed previously, wireless sensor nodes lose the most part of their energy by communicating with each other. In this routing algorithm, unlike other routing algorithms which were discussed before, there is no need for a central controller and/or specific information regarding the remaining energy of all other nodes in a cluster. Hence, cluster heads are selected by the minimum number of transmissions which makes D-LEACH algorithm more efficient in saving energy compared to LEACH. Other parameters which affect draining energy and increasing cost of sensors are computing and memory respectively. In D-LEACH, the amount of computation and memory which are necessary for selecting appropriate cluster heads are decreased. Thus, D-LEACH can significantly decrease energy consumption and cost of sensors.

# Chapter 4

# PERFORMANCE EVALUATION RESULTS

## 4.1 Performance Evaluation

In this section, for evaluating the performance of the proposed D-LEACH algorithm, extensive simulation is carried out using Matlab. The basic simulation parameters for our model are mentioned in Table 4.1 [10]. The environment consists of 100 nodes, randomly deployed in a field with a dimension of 100m×100m. As it can be seen from Figure 3.3, the sink node is located at position (50, 50) and all nodes are not mobile. The initial energy of each node is assumed as 1J. In each round 20000-bit packet is transmitted by each sensor node to its cluster head. The numbers of clusters are five and four cluster heads are selected in each round.

Table 4.1: Simulation Parameters

| Description | Symbol | Value |
|---|---|---|
| Number of nodes in the system | n | 100 |
| Energy consumed by the amplifier to transmit at a short distance | $E_{fs}$ | 100 pJ/bit/$m^2$ |
| Energy consumed by the amplifier to transmit at a longer distance | $E_{mp}$ | 0.013 pJ/bit/$m^4$ |
| Energy consumed in the electronic circuit to transmit or receive the signal | $E_{elec}$ | 50 nJ/bit |
| Data aggregation energy | $E_{dd}$ | 50 nJ/bit/message |

The parameters which are considered in evaluating the performance of this algorithm are: residual energy of all nodes, the number of nodes alive and also the number of dead nodes. In this simulation, nodes are considered as dead nodes, when their residual energies become zero.

## 4.2 Experimental Results

### 4.2.1 The Average Residual Energy

Figure 4.1 shows the average residual energy of all sensors in 100 $\boldsymbol{m^2}$ per round. As it shows, the average residual energy of the proposed algorithm is higher than the LEACH. The energy gap between D-LEACH and LEACH started at the beginning and the biggest energy gap occurred at round 280. If the average residual energy of nodes reaches to 5% of their initial energy we consider it as a network failure. As it shown with red lines in Figure 4.1 the network which is used LEACH after round 280 is almost dead while network failure in D-LEACH occur in round 700. Therefor the maximum improvement of D-LEACH in comparison with LEACH can be calculated with Equation 4.1 which is 150%.

$$Improvment = \frac{new\ result - previous\ result}{previous\ result} \tag{4.1}$$

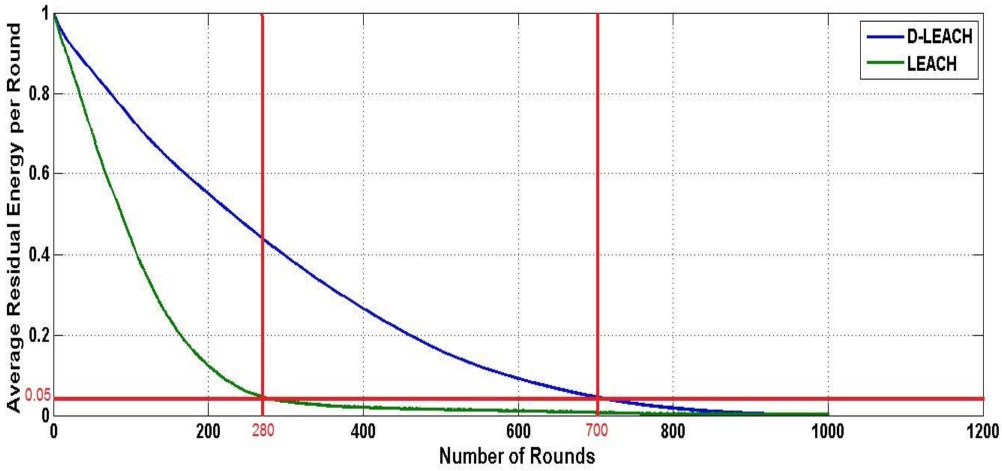


Figure 4.1: The Average Residual Energy per Round

### 4.2.2 The Number of Dead Nodes

The number of dead nodes can demonstrate the balance of energy consumption in the network. In Figure 4.2, x-coordinate represents the number of rounds and y-coordinate shows the number of nodes which died in each round. It is clear from the figure that the proposed algorithm outperforms LEACH in terms of the number of nodes dead. The gap between D-LEACH and LEACH started at round 70 and if the amount of dead nodes reaches to 90% of total nodes we consider it as a network failure. Therefore the amount of improvement in D-LEACH is about 141%.

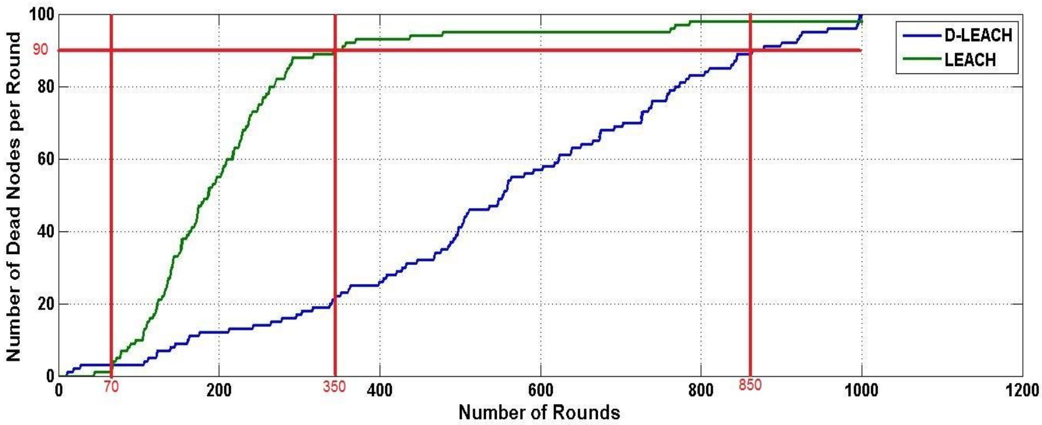


Figure 4.2: The Average Number of Dead Nodes per Round

### 4.2.3 The Number of Alive Node

Figure 4.3 shows the average number of alive nodes per round. As we can see the D-LEACH comprises the minimized power consumption via time unit. So, the backup power of the sensors will be saved for longer time. Therefore, the number of alive nodes using D-LEACH is significantly higher compared with LEACH. This improvement is started at round 70 and it remained till the end.

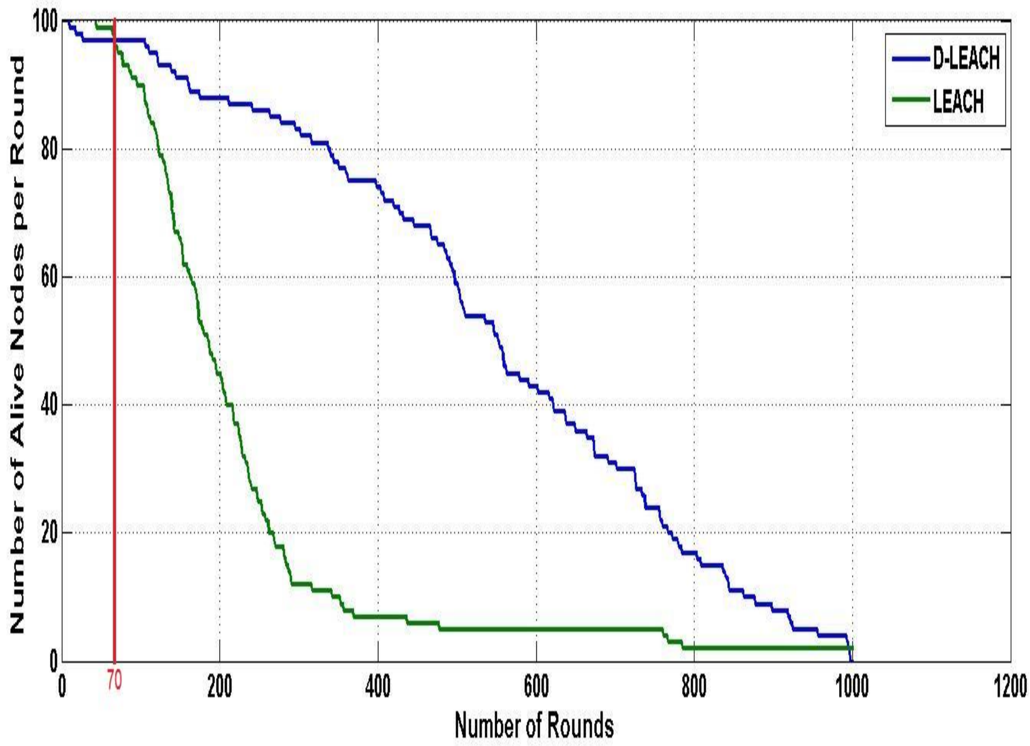


Figure 4.3: The Average of Alive Nodes per Round

### 4.2.4 Comparison of D-LEACH and Improved LEACH

Figure 4-4 [10] shows the improvement obtained by D-LEACH over DEEC and Improved LEACH routing algorithms. As it is clear from the figure, the average residual energy in DEEC and Improved LEACH are decreased dramatically and after round 350 the residual energy in both of them are almost 0 while at same round the average residual energy in D-LEACH is about 0.25 J. It can be seen that D-LEACH can increase network lifetime significantly in comparison with DEEC and Improved LEACH.

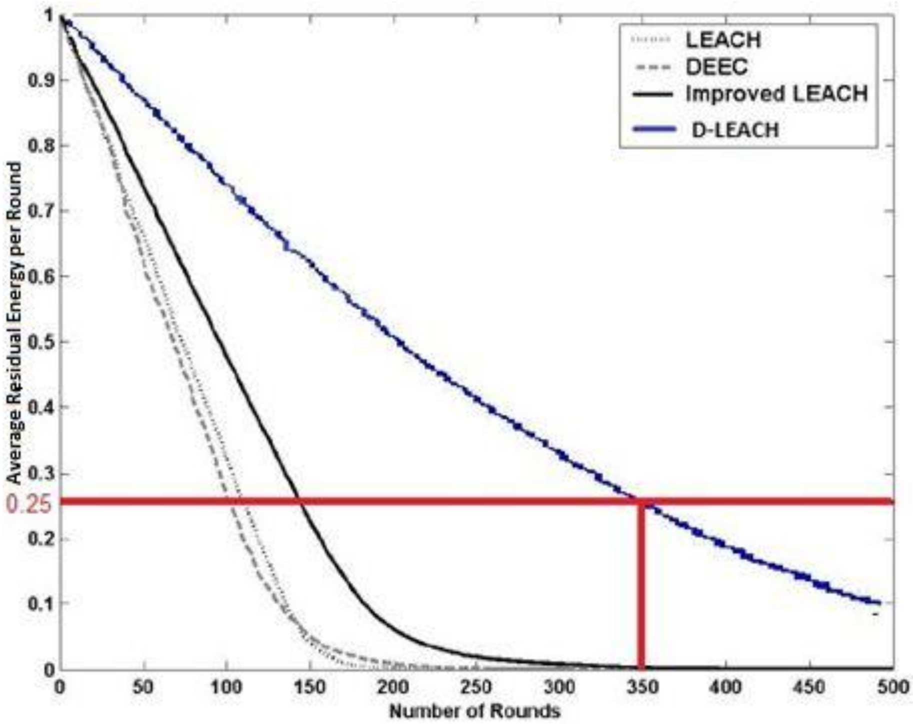


Figure 4.4: The Average Residual Energy per Round

# Chapter 5

# CONCLUSIONS

In this thesis the D-LEACH routing algorithm is compared with traditional LEACH, Improved LEACH, and DEEC routing algorithms. The results obtained show that D-LEACH enhances the network lifetime significantly in comparison with the aforementioned routing algorithms in environment with dimension of 100 $m^2$(The results may change for different conditions) . The major reasons of this improvement are presented below:

One of the main reasons is that in the proposed algorithm cluster heads are selected based on their closeness to the center of each cluster, therefore they can cover more nodes using the minimum distance between the cluster head and the nodes, which decreases the energy consumption and increases the network lifetime.

The second main reason is that in D-LEACH if nodes are closer to the base station than the cluster heads, they do not need to send their data to cluster heads and they can communicate directly with the base station. This can decrease the load over cluster heads and decrease energy consumption in the whole network.

The third reason is related to the number of cluster heads, which consume more energy compared to normal nodes. Therefore by selecting the optimum number of cluster heads we can save more energy and enhance the network lifetime. In many literatures, such as [18], it is recommended that 5% of the total number of nodes should be considered as a cluster head node. If the total number of nodes in the network is 100, then the optimum number of nodes, which can be a cluster head, is 5 in each round. However, after researching the impact of the actual number of cluster head nodes on network performance, in [17] and [3], it is pointed out that the best number of cluster head nodes is 4. Moreover, the simulation results of D-LEACH shows that if the number of cluster head nodes is set to 4, it can reduce energy consumption more and prolong network's lifetime.

The main reason is that the proposed algorithm can increase the network lifetime more than Improved LEACH. In Improved LEACH it is essential that the current cluster head communicates with all nodes in its cluster in order to find out the remaining energy of each node and it is also necessary to have larger memory and higher processing ability in comparison with D-LEACH to select the cluster head for the next round. The amount of communication and processing consume the major part of nodes’ energy level, which decreases network lifetime. On the other hand, in the D-LEACH algorithm the current cluster head sends a packet only towards its closest neighbor and then this node decides whether to become the cluster head or not. This technique makes the system able to reduce the amount of communication and processing time, and as a result, saves more energy in our network. Thus, the network lifetime will increase.

In conclusion, the proposed algorithm improves some drawbacks of LEACH such as lack of energy balancing and improve the average residual energy of all nodes and the number of alive nodes about 150% in comparison with LEACH.

As a future work we can consider the energy dissipation of idle listening, data retransmission and nodes distribution. Also we can improve D-LEACH by considering mobility and making clusters adaptable in different conditions and environment. D-LEACH improve energy consumption, amount of computation and communication, so we can extend D-LEACH to be scalable and also consider fault-tolerance as parameter for routing critical data.

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# APPENDIX

## Appendix A: Simulation Code

```
clear all;
clc;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% PARAMETERS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Field Dimensions - x and y maximum (in meters)
xm=100;
ym=100;

%x and y Coordinates of the Sink
sink.x=0.5*xm;
sink.y=0.5*ym;

%Number of Nodes in the field
n=100;

%Optimal Election Probability of a node
%to become cluster head
p=0.3;

%Energy Model (all values in Joules)
%Initial Energy
Eo=1;
%Eelec=Etx=Erx
ETX=50*0.000000001;
ERX=50*0.000000001;
%Transmit Amplifier types
Efs=100*0.000000000001;
Emp=0.013*0.000000000001;
%Data Aggregation Energy
EDA=50*0.000000001;

%Values for Hetereogeneity
%Percentage of nodes than are advanced
m=0;
%\alpha
a=1;

%maximum number of rounds
rmax=500;
V=13;
%%%%%%%%%%%%%%%%%%%%%%%%% END OF PARAMETERS
%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%Computation of do
do=sqrt(Efs/Emp);

%Creation of the random Sensor Network
figure(1);

for i=1:1:n
    S(i).xd=rand(1,1)*xm;
    XR(i)=S(i).xd;
    S(i).yd=rand(1,1)*ym;
    YR(i)=S(i).yd;
    S(i).G=0;
    %initially there are no cluster heads only nodes
    S(i).type='N';

    temp_rnd0=i;
    %Random Election of Normal Nodes
    if (temp_rnd0>=m*n+1)
        S(i).E=Eo;
        S(i).ENERGY=0;
        plot(S(i).xd,S(i).yd,'o');
        hold on;
    end
    %Random Election of Advanced Nodes
    if (temp_rnd0<m*n+1)
        S(i).E=Eo*(1+a)
        S(i).ENERGY=1;
        plot(S(i).xd,S(i).yd,'+');
        hold on;
    end
end

S(n+1).xd=sink.x;
S(n+1).yd=sink.y;
plot(S(n+1).xd,S(n+1).yd,'x');


%First Iteration
figure(1);

%counter for CHs
countCHs=0;
%counter for CHs per round
rcountCHs=0;
cluster=1;

countCHs;
rcountCHs=rcountCHs+countCHs;
```

```
flag_first_dead=0;
w=1;
r=0;
for q=1:1:n
            if (S(q).xd <= (sink.x-V) && S(q).yd <=
(sink.y-V) && S(q).xd >= 0 && S(q).yd >= 0)
                distancetomid(w)= sqrt( (S(q).xd-
(sink.x/2) )^2 + (S(q).yd-(sink.y/2) )^2 );
                arr(w)=q;
                w=w+1;

            end
end
        [srt,ind]=sort(distancetomid);
            q=arr(ind(1));
            countCHs=countCHs+1;


                     S(q).type='C';
                     %S(q).G=round(1/p)-1;
                     C(cluster).xd=S(q).xd;
                     C(cluster).yd=S(q).yd;
                     plot(S(q).xd,S(q).yd,'k*');

                     distance=sqrt( (S(q).xd-
(S(n+1).xd) )^2 + (S(q).yd-(S(n+1).yd) )^2 );
                     C(cluster).distance=distance;
                     C(cluster).id=q;
                     X(cluster)=S(q).xd;
                     Y(cluster)=S(q).yd;
                     cluster=cluster+1;
%
PACKETS_TO_BS(r+1)=PACKETS_TO_BS(r+1)+1;
                     if (distance>do)
                     S(q).E=S(q).E- (
(ETX+EDA)*(20000) + Emp*20000*(
distance*distance*distance*distance ));
                     end
                     if (distance<=do)
                     S(q).E=S(q).E- (
(ETX+EDA)*(20000)  + Efs*20000*( distance * distance
));
                     end
            for q=1:1:n
            if (S(q).xd <= (sink.x-V) && S(q).yd <=
ym && S(q).xd >= 0 && S(q).yd >= (sink.y+V))
```

```
                distancetomid(w)= sqrt( (S(q).xd-25
)^2 + (S(q).yd-75 )^2 );
                arr(w)=q;
                w=w+1;

            end
end
        [srt,ind]=sort(distancetomid);
            q=arr(ind(1));
            countCHs=countCHs+1;


                     S(q).type='C';
                     %S(q).G=round(1/p)-1;
                     C(cluster).xd=S(q).xd;
                     C(cluster).yd=S(q).yd;
                     plot(S(q).xd,S(q).yd,'k*');

                     distance=sqrt( (S(q).xd-
(S(n+1).xd) )^2 + (S(q).yd-(S(n+1).yd) )^2 );
                     C(cluster).distance=distance;
                     C(cluster).id=q;
                     X(cluster)=S(q).xd;
                     Y(cluster)=S(q).yd;
                     cluster=cluster+1;
%
PACKETS_TO_BS(r+1)=PACKETS_TO_BS(r+1)+1;
                     if (distance>do)
                     S(q).E=S(q).E- (
(ETX+EDA)*(20000) + Emp*20000*(
distance*distance*distance*distance ));
                     end
                     if (distance<=do)
                     S(q).E=S(q).E- (
(ETX+EDA)*(20000)  + Efs*20000*( distance * distance
));
                     end
for q=1:1:n
            if (S(q).xd <= xm && S(q).yd <= (sink.y-
V) && S(q).xd >= (sink.x+V) && S(q).yd >= 0)
                distancetomid(w)= sqrt( (S(q).xd-
((sink.x + xm)/2) )^2 + (S(q).yd-(sink.y /2) )^2 );
                arr(w)=q;
                w=w+1;

            end
end
```

```
         [srt,ind]=sort(distancetomid);
             q=arr(ind(1));
             countCHs=countCHs+1;


                          S(q).type='C';
                          %S(q).G=round(1/p)-1;
                          C(cluster).xd=S(q).xd;
                          C(cluster).yd=S(q).yd;
                          plot(S(q).xd,S(q).yd,'k*');

                          distance=sqrt( (S(q).xd-
(S(n+1).xd) )^2 + (S(q).yd-(S(n+1).yd) )^2 );
                          C(cluster).distance=distance;
                          C(cluster).id=q;
                          X(cluster)=S(q).xd;
                          Y(cluster)=S(q).yd;
                          cluster=cluster+1;
%
PACKETS_TO_BS(r+1)=PACKETS_TO_BS(r+1)+1;
                          if (distance>do)
                          S(q).E=S(q).E- (
(ETX+EDA)*(20000) + Emp*20000*(
distance*distance*distance*distance ));
                          end
                          if (distance<=do)
                          S(q).E=S(q).E- (
(ETX+EDA)*(20000)  + Efs*20000*( distance * distance
));
                          end
             for q=1:1:n
             if (S(q).xd <= xm && S(q).yd <= ym &&
S(q).xd >= (sink.x+V) && S(q).yd >= (sink.y+V))
                 distancetomid(w)= sqrt( (S(q).xd-
((sink.x + xm)/2) )^2 + (S(q).yd-((sink.y + ym)/2)
)^2 );
                 arr(w)=q;
                 w=w+1;

             end
end
         [srt,ind]=sort(distancetomid);
             q=arr(ind(1));
             countCHs=countCHs+1;


                          S(q).type='C';
```

```
                     %S(q).G=round(1/p)-1;
                     C(cluster).xd=S(q).xd;
                     C(cluster).yd=S(q).yd;
                     plot(S(q).xd,S(q).yd,'k*');

                     distance=sqrt( (S(q).xd-
(S(n+1).xd) )^2 + (S(q).yd-(S(n+1).yd) )^2 );
                     C(cluster).distance=distance;
                     C(cluster).id=q;
                     X(cluster)=S(q).xd;
                     Y(cluster)=S(q).yd;
                     cluster=cluster+1;
%
PACKETS_TO_BS(r+1)=PACKETS_TO_BS(r+1)+1;
                     if (distance>do)
                     S(q).E=S(q).E- (
(ETX+EDA)*(20000) + Emp*20000*(
distance*distance*distance*distance ));
                     end
                     if (distance<=do)
                     S(q).E=S(q).E- (
(ETX+EDA)*(20000)  + Efs*20000*( distance * distance
));
                     end



for r=0:1:rmax
    r

  %Operation for epoch
%  if(mod(r, round(1/p) )==0)
 %    for i=1:1:n
  %       S(i).G=0;
   %      S(i).cl=0;
    %end
  %end

hold off;

%Number of dead nodes
dead=0;
%Number of dead Advanced Nodes
dead_a=0;
%Number of dead Normal Nodes
dead_n=0;
```

```
%counter for bit transmitted to Bases Station and to
Cluster Heads
packets_TO_BS=0;
packets_TO_CH=0;
%counter for bit transmitted to Bases Station and to
Cluster Heads
%per round
PACKETS_TO_CH(r+1)=0;
PACKETS_TO_BS(r+1)=0;

figure(1);

for i=1:1:n
    %checking if there is a dead node
    if (S(i).E<=0)
        plot(S(i).xd,S(i).yd,'red .');
        dead=dead+1;
        if(S(i).ENERGY==1)
            dead_a=dead_a+1;
        end
        if(S(i).ENERGY==0)
            dead_n=dead_n+1;
        end
        hold on;
    end
    if S(i).E>0
        S(i).type='N';
        if (S(i).ENERGY==0)
        plot(S(i).xd,S(i).yd,'o');
        end
        if (S(i).ENERGY==1)
        plot(S(i).xd,S(i).yd,'+');
        end
        hold on;
    end
end
plot(S(n+1).xd,S(n+1).yd,'x');


STATISTICS(r+1).DEAD=dead;
DEAD(r+1)=dead;
DEAD_N(r+1)=dead_n;
DEAD_A(r+1)=dead_a;

%When the first node dies
if (dead==1)
    if(flag_first_dead==0)
```

```
          first_dead=r
          flag_first_dead=1;
     end
end


cluster=4;
 for q=1:1:n

      w=1;
               if (S(q).type=='C' )
                   for i=1:n
                   distancetoch(w)= sqrt( (S(q).xd-
S(i).xd)^2 + (S(q).yd-S(i).yd )^2 );
                   arr(w)=i;
                   w=w+1;
                   end


          [srt,ind]=sort(distancetomid);
          Na=0;
          for j=1:w-1
          p=arr(ind(j));
          if( S(p).xd < (sink.x-V) ||S(p).xd >
(sink.x+V)||S(p).yd < (sink.y+V)||S(p).yd > (sink.y-
V))
          if (S(p).E>=0.2 && Na==0)
              Na=1;
              S(p).type='C';
              S(q).type='N';

                         %S(q).G=round(1/p)-1;
                         C(cluster).xd=S(p).xd;
                         C(cluster).yd=S(p).yd;
                         plot(S(p).xd,S(p).yd,'k*');

                         distance=sqrt( (S(p).xd-
(S(n+1).xd) )^2 + (S(p).yd-(S(n+1).yd) )^2 );
                         C(cluster).distance=distance;
                         C(cluster).id=p;
                         X(cluster)=S(p).xd;
                         Y(cluster)=S(p).yd;
                         cluster=cluster+1;

PACKETS_TO_BS(r+1)=PACKETS_TO_BS(r+1)+1;
                         if (distance>do)
```

```
                     S(p).E=S(p).E- (
(ETX+EDA)*(20000) + Emp*20000*(
distance*distance*distance*distance ));
                     end
                     if (distance<=do)
                     S(p).E=S(p).E- (
(ETX+EDA)*(20000)  + Efs*20000*( distance * distance
));
                     end
        end
        end
        end
        for j=1:w-1
        p=arr(ind(j));
         if( S(p).xd < (sink.x-V) ||S(p).xd >
(sink.x+V)||S(p).yd < (sink.y+V)||S(p).yd > (sink.y-
V))
        if (S(p).E>0 && Na==0)
            Na=1;
            S(p).type='C';
            S(q).type='N'

                     %S(q).G=round(1/p)-1;
                     C(cluster).xd=S(q).xd;
                     C(cluster).yd=S(q).yd;
                     plot(S(q).xd,S(q).yd,'k*');

                     distance=sqrt( (S(q).xd-
(S(n+1).xd) )^2 + (S(q).yd-(S(n+1).yd) )^2 );
                     C(cluster).distance=distance;
                     C(cluster).id=q;
                     X(cluster)=S(q).xd;
                     Y(cluster)=S(q).yd;
                     cluster=cluster+1;

PACKETS_TO_BS(r+1)=PACKETS_TO_BS(r+1)+1;
                     if (distance>do)
                     S(q).E=S(q).E- (
(ETX+EDA)*(20000) + Emp*20000*(
distance*distance*distance*distance ));
                     end
                     if (distance<=do)
                     S(q).E=S(q).E- (
(ETX+EDA)*(20000)  + Efs*20000*( distance * distance
));
                     end
        end
```

```
                end
                end
                    end

         end


                    countCHs=countCHs+1;

STATISTICS(r+1).CLUSTERHEADS=cluster-1;
CLUSTERHS(r+1)=cluster-1;

%Election of Associated Cluster Head for Normal 
Nodes
for i=1:1:n
   if ( S(i).type=='N' && S(i).E>0 )
     if(cluster-1>=1)
       min_dis=sqrt( (S(i).xd-S(n+1).xd)^2 + 
(S(i).yd-S(n+1).yd)^2 );
       sink=min_dis;
       min_dis_cluster=1;
       for c=1:1:cluster-1
           temp=min(min_dis,sqrt( (S(i).xd-
C(c).xd)^2 + (S(i).yd-C(c).yd)^2 ) );
           if ( temp<min_dis )
               min_dis=temp;
               min_dis_cluster=c;
           end
       end

       %Energy dissipated by associated Cluster Head
            min_dis;
            if (mod (min_dis_cluster,2)==0)
             plot(S(i).xd,S(i).yd,'green .');
            else

            plot(S(i).xd,S(i).yd,'magenta .');
            end

            if (min_dis>do)
                S(i).E=S(i).E- ( ETX*(20000) + 
Emp*20000*( min_dis * min_dis * min_dis * min_dis));
            end
            if (min_dis<=do)
                S(i).E=S(i).E- ( ETX*(20000) + 
Efs*20000*( min_dis * min_dis));
            end
```

```
        %Energy dissipated
        if(sink >= min_dis)
          S(C(min_dis_cluster).id).E =
S(C(min_dis_cluster).id).E- ( (ERX + EDA)*20000 );
         PACKETS_TO_CH(r+1)=n-dead-cluster+1;
        else
         PACKETS_TO_BS(r+1)=PACKETS_TO_BS(r+1)+1;
        end


       S(i).min_dis=min_dis;
       S(i).min_dis_cluster=min_dis_cluster;

   end
 end
end
hold on;

countCHs;
rcountCHs=rcountCHs+countCHs;
X=n
energy(r+1)=0;
result(r+1)=0;
alive(r+1)=0;
result2(r+1)=0;
  for i=1:n
         if (S(i).E < 0)
             X=X-1;
         end
     end
for i=1:1:n
    if (S(i).E >= 0)
          energy(r+1)= energy(r+1)+S(i).E;
          alive(r+1)=alive(r+1)+1;
         end

 end
  result(r+1)= energy(r+1)/X;
  result2(r+1)= energy(r+1)/n;

%Code for Voronoi Cells
%Unfortynately if there is a small
%number of cells, Matlab's voronoi
%procedure has some problems

%[vx,vy]=voronoi(X,Y);
%plot(X,Y,'r*',vx,vy,'b-');
```

```
% hold on;
% voronoi(X,Y);
% axis([0 xm 0 ym]);

end
```