Modification of LEACH Protocol for Improving the Stability Period and Lifetime of WSN

by

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ABSTRACT

As we are moving towards smart homes and smart cities, the need for wireless sensors are increasing continuously. Most of the sensors are powered with batteries, which have limited amount of power. So, in a wireless sensor network, the main motive is to minimize the energy consumption and increase the lifetime of the network. Communication between the sensors and from sensors to sink is an energy consuming process. Here comes, the LEACH protocol, with the concept of clustering, that makes the network energy efficient and gives longer lifetime to the network. This LEACH protocol has many drawbacks. One among them is the uneven distribution of CHs in the network, in several rounds. This leads to higher consumption of energy by sensor nodes, which in turn reduces the stability period and also the overall lifetime of the network. This problem is solved to majority extent in this research by concept of dividing the sensor field into sub-regions and choosing cluster head from each sub-region. This modification reduces the uneven distribution of CHs to maximum extent. Modified protocol is simulated in MATLAB and its results show that, the stability period as well as overall lifetime is improved than existing basic LEACH protocol.

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LIST OF ABBREVIATIONS

WSN	Wireless Sensor Networks
BS	Base Station
CH	Cluster Head
CM	Cluster nodes other than cluster head
LEACH	Low Energy Adaptive Clustering Protocol
TDMA	Time Division Multiple Access
FND	First Node Death
LND	Last Node Death
HNA	Half of the Nodes Alive
NON-CH	Sensor node which is not a cluster head in that round

LIST OF SYMBOLS AND NOTATIONS

p	Percentage of choosing CHs
G	Set of cluster nodes that have not been CHs in the last $1/p$ rounds
t_{adv-CH}	Cluster head advertisement sending time
E_{TX}	Required energy utilization for packet transmission
r	Number of the current round in the LEACH operation
E_{DA}	Energy for the data aggregation
E_{elec}	Electronic energy in the radio model
E_{amp}	Amplifier energy in the radio model

CHAPTER 1

INTRODUCTION

1.1 Background

WSN consists of many hundreds of little sensors which are having potential to communicate among them, with constrained amount of energy. Various environmental effects like temperature, pressure, speed etc. can be sensed by deploying these motes. BS or sink is nothing but a sensor node which has interest in collecting the sensed information from nodes, that represents the clusters in the WSN.

The compatibility of WSN and the continuous technology enhancements has led to their use in various applications which include survival monitoring, intelligent buildings, military applications, traffic control, object tracking etc.

However, WSNs suffers from many important limitations such as limited energy which is not rechargeable and security that has to be addressed for all the sensors. Energy efficiency is major issue in these network. In addition to this, consumption of energy of sensors system, also depends on requirements for application for which it is being used. Most of the times WSNs are deployed in environments where, manually a person will not be able to able to change or get the power source of sensors recharged.

Key role in WSN are played by batteries, since they are the indicators of the lifetime of system. Most of the energy in wireless networks is used up in sending the packets. This is how the need for greater protocols having higher efficiency has come into demand. Many types of approaches are started to improve this, in the field of research. (Elshrkawey et al., 2018)

The CH will take care of minimizing the repeated sensed information and then apply techniques of aggregation that reduces the size of sensed information and transmits it to sink.

LEACH (Low Energy Adaptive Clustering Hierarchy) protocol is well-known protocol that is being implemented in real world applications consisting of micro-sensors network. (Heinzelman et al., 2002)

It combines both the concepts of energy efficient cluster based routing as well as media access, together. The prime motive, at the back of this protocol lies in minimizing the energy consumed in the sensors to the maximum extent, for improving the system lifespan. In the setup phase, the formation of the cluster takes place, following a threshold. The CHs will be selected at the beginning of each round. Each of the sensor node, will generate a number between $[0,1]$. If the number generated is lesser to threshold, then that sensor will be selected as CH. This sensor will be the CH for that round. (Heinzelman et al., 2002)

1.2 Problem Statement

Despite the fact that, LEACH protocol conserves the energy in nodes. Some of the problems still exist, in this factor too.

The problem is the non-uniform distribution of CHs in WSN. LEACH won't give a guarantee, of the distribution of CHs throughout the network region, in every round. The distribution of CHs which in most of the rounds, when located in only one region makes, the rest of the regions empty. Those sensor nodes that are in the rest of the regions, does not have any cluster head in their proximity.

This makes, the sensor nodes to join the CHs, that are farther from their regions, which in turn causes, high loss of energy to send the sensed information to their respective CHs.

This is one of the major issues which are responsible for higher consumption of energy, which by obvious will lead to reduced lifetime of wireless sensor network.

1.3 Objectives

- a) To study the working process of LEACH protocol
- b) To modify the cluster head selection mechanism based on clustering approach, to the LEACH algorithm.
- c) To study the performance characteristics of the improved protocol by simulating the modified algorithm based on stability period parameters and network lifetime.
- d) To analyze the effectiveness of the proposed approach by comparing its results with the results of LEACH protocol and evaluating it.

1.4 Scope and Limitations

Scope of this research includes to analyze and evaluate the effectiveness of the modified LEACH algorithm based on distributing the CHs uniformly, on the entire network region. Analyzing the working process of LEACH protocol and some of its derivatives and understanding the way they function, will be done in this research. The resulted approach is simulated and outputs will be compared with simulation results of LEACH protocol on stability period parameters and lifetime of the network.

The modified approach's simulated outputs will be compared only with the outputs of the parent LEACH protocol but not with all of its derivatives. This is one of the limitations of the research.

1.5 Organization of the Report

Chapter 1: Gives an overview of the WSN and its problems followed by problem statement and limitations of the research.

Chapter 2: This chapter provides detailed information about the mentioned protocol along with its drawbacks and some summarized literature work.

Chapter 3: Gives detailed methodology for the proposed approach along with the simulation parameters, that were used.

Chapter 4: Provides all the simulation results and analysis on them

Chapter 5: Gives a conclusion of my research study and few future recommendations.

References

Appendix

CHAPTER 2

LITERATURE REVIEW

2.1 Terminology of wireless sensor network

Base station (BS): Base station or sink is a node that is interested in collecting the transmitted data from a group of sensor nodes.

Clusters: Group of nodes

Cluster Head (CH): A node which represents the cluster and is bound to transmitting the data that is sensed by all of its sensor nodes to the base station.

Figure 2.1 WSN consisting of CH, NON-CH and Base station
(Gui et al., 2016)

Network Lifetime: The time period from the starting of the network operation to the death of last node in the network. (Yousaf et al., 2016)

Stability Period: The time period from the starting of the network operation to the first node death. (Yousaf et al., 2016)

Instability Period: The time period between the first node death to the last node death in the network. (Batra & Kant, 2016).

2.2 LEACH (Low Energy Adaptive Clustering Hierarchy)

LEACH protocol is a well-known routing protocol that is used in the real-world applications of micro-sensors network. The prime motive, at the back of this protocol lies in minimizing the energy consumed in the sensors to the maximum extent, for improving the system lifespan (Heinzelman et al., 2002)

LEACH protocol consists of two phases. First one is setup phase and the other phase is steady state phase. It operates follows these two phases in each round.

In the network, the operation is split into rounds. Each round will start with setup phase and will end with steady state phase. This is a recurring process, till last node death in WSN.

$$T(n) = \begin{cases} \frac{p}{1-p^{*(r \bmod \frac{1}{p})}} & \text{if } n \in G \\ 0 & \text{elsewhere} \end{cases} \quad (2.1)$$

where:

p: probability of choosing CHs in each round

r: is the current round.

G: is the set of nodes that haven't been CHs in the previous $1/p$ rounds

2.2.1 Setup Phase

This phase is for the process of selecting the CHs and for the formation of the clusters. Cluster head selection process will be done by the threshold algorithm given in equation 2.1.

- Each node will generate a random number between 0 and 1.
- This random number will be compared with the threshold value obtained from the equation (2.1) $T(n)$.
- If this number is lesser to threshold $T(n)$, then that sensor will get to be CH for that round.
- If condition satisfied by more than one node in the network, then a random node will be selected as CHs.
- The number of CHs in each round, is controlled or limited by the probability of CHs. This is predetermined in the starting of the operation of the system.
- After the selection of CHs, sensor nodes other than CHs in that round, will form a cluster by choosing the cluster head sensor node having least distance to them
- The cluster heads allot TDMA schedule to their respective cluster members, to send their sensed data.
- This completes the formation of clusters in that round, and it indicates the end of setup phase and beginning of steady state phase for that round.

2.2.2 Steady state phase:

This phase is for the process of transmitting the packets. These packets are nothing but sensed information sensors and sending it their respective CHs. This phase is generally broken into frames. Each frame consists of time slot given to cluster head members by the cluster head, to send their sensed data in that round.

The process of data transmission takes place using TDMA scheduling. Once the process of intra-cluster communication is completed, then the CHs transmit the received data as well as sensed data to the base station or sink.

This completes the end of steady state phase and completion of one round. The next round starts with the same process, setup phase again followed by steady state phase. This process goes on until the death of last node in the network. (Heinzelman et al., 2002)

2.3 Flow Chart of Setup Phase in LEACH

Figure 2.2: Setup phase in LEACH
(Heinzelman, Chandrakasan, & Balakrishnan, 2002)

2.4 Dynamic Clustering in LEACH

LEACH is a self-adaptive, self-organizing protocol, since the formation of clusters takes place dynamically for each round, on their own, by following the threshold function, limited by the probability which is predetermined at the beginning of the network operation. (Heinzelman et al., 2002)

Figure 2.3 Dynamic clustering in LEACH, in two different rounds.
(Heinzelman, Chandrakasan, & Balakrishnan, 2002)

In the above figure, all nodes of same symbol belong to one cluster and the black nodes indicates CHs of that cluster, in that round. The two figures indicate, dynamic clustering of LEACH protocol, in two different rounds.

2.5.1 LEACH Operation Timeline

2.5.1 Setup Phase Operation

In the process of being a CH, once the sensors have chosen themselves as CHs, using threshold function, they have to leave message, to remaining sensor nodes in the system, in a way that, they are CHs in that round.

For this process, each CH node, announces advertisement message (ADV). This message is nothing but a message, that consists of identity of the node which has a unique number in it and header, that recognizes this as announcement message. This will be done using a protocol named CSMA MAC (Heinzelman et al., 2002)

Then, each non-CH, sensor chooses its group for that round by choosing CH, which needs, least energy to communicate with, which is based on RSSI announcement. This is for every CH.

Here, considering equal proportional generation, then the CH advertisement heard with strongest RSSI will be the one CH that needs least transmission energy to get connected with.

Typically, that would be the nearest CH, to the member node, until and unless, there is an obstacle, obstructing the communication. If there is a tie, in this situation, then a random CH will be selected.

The non-cluster head members, will identify, their respective clusters. Then, they have to intimate their respective CHs, in a way that, they would like to be part of that cluster, for that round. In the process of this, every normal sensor node, have to transmit a request of joining. This message is (Join- REQ), which has to be transmitted to their respective CHs. This will be done using protocol named CSMA MAC. (Heinzelman et al., 2002)

Figure 2.4: LEACH operation timeline
(Elshrkawey, Elsmere, & Wahed, 2018)

This will also be in the form of short message. This message has information of node's unique identification number (ID). It also has cluster head's unique identification number (ID).

CH in LEACH, acts as coordination centers to correspond transmission of information in the clusters, which they represent. TDMA schedule will be established by the CHs. Then they transmit to all its members in their respective clusters.

This gives an evidence that, there are hardly any collisions between the packets of data. This approach of scheduling also allows the transmitters and receivers of each cluster member node, can put their radio off, every time, except in the slot of theirs to send data, thereby it minimizes the energy consumption by individual sensor nodes.

When all the members of the cluster receive the slots sent by their respective CHs, it indicates the completion of first phase part and the operation of second phase part, begins.

2.5.2 Steady State Phase Operation

The operation of this phase is divided into number of frames. Sensors transmit their packets of sensed information to cluster head, with a max of 1 frame at the allotted transmission time for them. (Heinzelman et al., 2002)

The collected data of the sensor, sent in the time slot allotted to them. The duration of it is same. Then duration of transmitting the frame of packet of sensed information, will depend upon, total count of number of sensors belonging to that cluster.

As an assumption, the consideration is, total of the sensors are synchronized in terms of time. They all begin the first phase part at equivalent point of time.

In order to reduce the dissipation of energy, every cluster member other than the CH, uses its mechanism of controlling of power to configure required transmit power. This depends upon strength of received cluster head announcement. Also, the radio component of every non-CH will be put to in off mode, till it's given transmitting schedule.

Using TDMA schedule to allocate the time slots, is a productive use of bandwidth, since the protocol is optimized and designed in a way, that when every node in the cluster, have data to transmit it to the CH.

In order to collect the packets of information from non-CH sensors, by the CH, in its cluster, it must be awake in its steady state phase. As soon as, the packets of information are collected by the CH, techniques of aggregation of data is performed. This is done to improve the beam formed signal and minimize uncorrelated noise, between the signals.

As an assumption, it is considered perfect correlation, by which a single signal can be represented by the combination of these individual signals.

The combined resultant signal, is sent from cluster heads to sink. If base station is located at a longer distance from the network, if there are large data messages, then it can be identified as high energy transmission.

Using CSMA and fixed spreading code, packets of information can be transmitted to BS by all the CHs which are present on network. If CH is having packets of information, that should be sent to sink, it has to check by sensing channel. This is to be done in order to verify, if some other one, is sending to BS, using the code of spreading by sink. If it is so, then the CH, has wait for the packets of information to be transmitted. If that is not the case, then the CH's transmit the data using BS spreading code. (Heinzelman et al., 2002)

Some channelization techniques like, such as having different types of frequencies for each cluster (e.g: FDMA) are also possible, but it includes lot of challenges.

2.5.3 First Order Radio Energy Model

For calculating the dissipated energy that happens in network, with this protocol, the below mentioned radio model will be put to use.

Figure 2.5: Radio Energy Model
(Elshrkawey, Elsmere, & Wahed, 2018)

The dissipation of energy is done by the transmitter in order to run the components of radio and the amplifier. (Elshrkawey, Elsmere, & Wahed, 2018)

Energy is also dissipated by the receiver to run the radio components of electronics in receiving.

Power loss models will be put to use, that depends upon the measured distance that lies among source and destination. Multipath model amplifier $\epsilon_m d^4$, is the one that comes into calculation part, if the measured distance is more, when compared to the threshold distance. Free space model $\epsilon_f d^2$ is used for lesser than threshold or cross-over distance.

To transmit, a message size of k-bit, with a distance d, the energy that gets dissipated, by radio is given by,

$$E_{TX(k,d)} = E_{TX-elec}(k) + E_{TX-amp}(k,d) \quad \text{Equation 2.1}$$

$$= \begin{cases} k \times E_{elec} + k \times \epsilon_f \times d^2, & d < d_0 \\ k \times E_{elec} + k \times \epsilon_m \times d^4, & d \geq d_0 \end{cases} \quad \text{Equation 2.2}$$

To receive a message of k-bit, at a distance d, then the energy expended by the radio is given by

$$E_{RX}(k) = E_{RX-elec}(k) = k \times E_{elec} \quad \text{Equation 2.3}$$

E_{TX} : energy that is utilized for the transmission of packet

E_{elec} : electronic energy required to run the radio components circuitry

E_{RX} : required energy utilized for receiving the data packet

$d_0 = \sqrt{\frac{\epsilon_f}{\epsilon_m}}$, which is named as threshold distance.

The electronics energy, E_{elec} depends upon several factors like filtering, modulation.

2.7 Advantages of LEACH

LEACH by nature is a complete, distributed routing protocol. The basic version of LEACH does not require any global routing information. Some of its advantages are

- The concept of clustering used by LEACH makes the system to prolong for a longer lifetime, when compared to direct transmission.
- CH minimizes correlated data locally by implementing data aggregation method that minimizes, the consumption of the energy by a significant amount.
- The time slots allotted to the non-CH sensors by the CHs, instructs them to go into sleep mode. This helps in avoiding the collisions inside the cluster and unrelated noise.
- The chances of becoming a CH, to each node in the system, will be given equally, by LEACH protocol. Every node will get a chance of becoming CH, at least once and non-CH, so many times, till the death of sensor nodes. The CH's rotation in a randomized manner is the reason, for the prolonged system lifetime.

Even though LEACH protocol does that, it still has lot of drawbacks and drawbacks which are in detailed here.

2.8 Disadvantages and Limitations of LEACH

- The concept of remaining energy of sensors after every round is not taken into account, in the process of selecting the CHs, in the conventional LEACH protocol.
- Main problem of LEACH protocol is scalability. It is designed to perform well, in smaller regions, since in regions of larger size, sensors which are farther distance to sink, will result to high energy consumption, that too rapidly.
- The schedule allotted in the form of TDMA has some restrictions: Each CH will have its own slot to transmit packets of information in the allocated, time duration, despite of any new information is sensed.
- Some clusters, consists of higher number of sensors when compared to others. This unbalanced clusters causes to drain higher amount of energy than other clusters.
- This protocol takes this assumption, that all sensors consists of high battery energy that can be used to get communicated with BS, directly. When probability factor of selecting clusters is set to zero or hundred, sensors which are at a farther distance far away from the sink, will lose their energy rapidly and that region will go unsensed for the rest of the period of network operation.
- The basic version of LEACH protocol is simulated considering all nodes as homogeneous, which in practical scenario is different.
- Security is one main aspect that has not been looked into, so far for this protocol. Data privacy is an important concern, when used in sensitive real-world applications.

2.9 Lifetime of a Sensor Node

Sensor node's lifetime is defined as the state at which, it depletes its energy to a threshold known as critical energy, at which the node becomes incapable to perform any transmission or reception for 1-bit of data. (Ok et al., 2009)

The sensor node will be treated as dead node, once it depletes its energy to its critical energy, after the network operation begins. Since the LEACH protocol is taken as network of homogeneous sensors, critical energy is same for all of them.

In the LEACH protocol (Lindsey & Raghavendra, 2002) to reduce the complexity, the critical energy of each sensor node is put to zero, as a pre-energy calculation.

But, when it comes to practical scenario, there will be predetermined critical energy, which depends upon different factors, like hardware configuration of the sensor node, the power of transmitter amplifier etc.

2.10 Related Research Work

Long et al. (2011) had proposed an algorithm. It depends upon assistant cluster head approach. A dynamic method is established in checking the ability of a sensor node to become a cluster head or not, that depends upon the geographical location of the node, and the number of members in each cluster as well the energy that is left in the node after a round. This approach has been successful in, extending the system lifetime by minimizing the consumption of energy by the non-CH nodes in a cluster.

The main drawback of this approach is, it requires complex operations to be executed, that causes high delays.

Junping et al. (2008) had proposed a new algorithm. Clusters are formed without the requirement of any global information, but it depends upon random timer. This algorithm still suffers from high energy gap consumption between sensor nodes and their CHs.

Ren et al. (2010) had proposed a new algorithm. It is based on unequal clustering scheme. It solves the problem of minimizing the hotspot, like in LEACH. Concentric circles of unequal size are considered as clusters. Cluster size decreases, if we move far from the sink. CH selection is done, by depending upon the factors like remaining energy on the node, weight factor. Problem with intra cluster communication, for clusters near to sink.

Al-Maaqbeh et al. (2012) had proposed a new algorithm. Concept of fuzzy logic has been used in this protocol. It is done by modifying the existing basic LEACH. Consists of fuzzier, defuzzifier, fuzzy interference system and rules. The concept of fuzzy logic, is used and applied on the count of sensor nodes as well as density of the network. Helps in finding out initial CHs. This algorithm does not consider energy into consideration for calculation.

Mahmood et al. (2013) proposed using different signal amplifications in two values, for inter and intra cluster communications. Significant amount of energy is saved. Changes in selection of CH process is also made. CH is not changed in every round. A predefined threshold is used and compared against with, to choose a new CH. Amplification of two different signals for this purpose is a difficult problem.

Chen et al. (2013) proposed taking uncertainty in number of CHs into account and their location. Optimal CHs are given by the equation proposed. Ensures uniform distribution of CHs. Performs well when compared to existing basic LEACH, on the parameters of consumption of energy and system lifetime.

Bsoul et al. (2013) proposed using multi-hop and centralized approach. Sink calculates the threshold. Sink chooses, the one having higher remaining energy, as the CH. Minimum distance to CH, is calculated. Calculates distance between two CHs and if it is found that the measured distance, is higher or equal to, then second node is chosen as CH, among them.

Salim et al. (2014) proposed to reduce the energy difference between CH and members of that cluster. Main target is to minimize intra cluster communication costs. Pre-steady phase is added to the remaining old phases. Main issues are scalability, control overhead.

Katiyar et al. (2011) proposed to solve, high variations in cluster size. Performance of protocol is affected by this. Concept of far zone is introduced. Sensor nodes other than CHs, send their minimum power to their respective cluster heads. This helps in solving the issue of variations in the sizes of clusters.

Xu et al. (2012) proposed on the issue of optimum number of CHs. Round time is varied in every round. CH is chosen based on the higher remaining residual energy. Main advantage is energy across the network is distributed uniformly.

Zhao et al. (2012) proposed the modification of LEACH protocol by cluster head selection and multi-hop routing. The proposed protocol is able to improve the stability period and network lifetime than basic LEACH protocol. Drawbacks are non-uniform distribution of cluster heads and also selection of a node as cluster head based on the random number, without considering any other factors.

CHAPTER 3

METHODOLOGY

3.1 Contribution

After detailed study, for the improvement of LEACH protocol through its derivatives, the possibility of proposed approach is derived.

The resulted protocol will be simulated along with the original LEACH protocol and the outputs will be compared based on network's stability period and total network lifetime as the parameters in order to check the effectiveness of proposed approach.

The contributed work of the modified approach can be used by the researchers for further analysis like adding security to the approach from or deploying it in different scenarios etc.

3.2 Proposed Approach

The proposed method has one simple modification to the existing LEACH. The existing basic LEACH protocol cannot guarantee, distribution of CHs on the entire network. In this modification, this problem will be solved to major extent. The sensor network will be divided into number of rectangular sub-regions, depending upon the probability of the CHs, and number of nodes in the network, which are predetermined at the beginning of the operation of the network. This makes the sensor nodes in the network, to have a cluster head in their vicinity for every round, unlike existing basic LEACH protocol, which might have all the CHs, to be in the same region for several rounds, because of the process followed in the CH's selection.

3.3 Cluster Head Selection Modification

Random deployment of sensors is implemented in a geographic region of predetermined dimensions. In this modified approach, it divides the whole network region into sub regions. A cluster head will be selected from each sub-region, for every round. This makes the CHs in the network more distributed or more uniformly located in the whole network for every round. This by obvious, makes, any of the region go un-sensed, till the last node death in that region.

- Sensors nodes are spread on the entire network in a random based scenario.
- Let 'L' and 'W' be the number of length and breadth of the sensor region
- 'numRx' be the number of segments on each side
- Calculate $\text{numRx} = \sqrt{p \times N}$ where 'p' is the probability of cluster heads given and N is the total number of nodes in the network.
- Then $dx = L / \text{numRx}$ and $dy = W / \text{numRx}$ be the sub-region length and breadth respectively
- Divide the sensor field into sub-regions.
- Number of sub-regions in the network will be equal to $(\text{numRx}) \times (\text{numRx})$
- Each sub-region acts as individual wireless sensor network
- In the setup phase, select a random node as CH from each-sub region.

- All the rest of the nodes in the sub-region, join that CH and forms clusters for each sub-region
- In the steady state phase, sensor nodes send their sensed data to their CHs and the CHs, transmit the data to the base station. This completes a round.
- In the next round, just select a random node again, from each sub-region to become a cluster head, and repeat both the phases one by one, setup and steady state.
- Repeat the steps, until every sensor node get to be become a cluster head once, in each sub-region.
- Once every node in each sub-region gets to be a CH, then consider all of them as normal nodes and continue the process
- Continue this process of selection of cluster heads, till the death of last node in each sub-region.
- The sensor network is considered as dead, once all the nodes in the network are dead.

3.4 **Methodology for the Proposed Approach**

This section depicts the methodology for the proposed approach. Flow chart is shown below.

Figure 3.1: Methodology of the proposed modified approach

3.5 Pseudocode for Proposed Cluster Head Selection Modification:

Initialize WSN parameters

N= Total number of nodes in the network

W= Width of the network

L=Length of the network

p= Probability of cluster heads

Rmax= maximum number of simulated rounds

E_i= Initial energy in each node

Initialize all energy parameters

(SX, SY) Base station position

Pre allocations for calculations

E_{crit} = critical energy left in each node to call it alive

N_{critical}= Critical number of nodes left to stop the simulation

Status of nodes; 0: Alive; 1; Dead

Process:

Deploy 'N' nodes randomly in the given area

Simulations for each round:

Declarations:

dx= length of the sub-region divided

dy= width of the sub-region divided

X= Set of X-axis coordinates for all the 'N' nodes

Y= Set of Y- axis coordinates for all the 'N' nodes

numRx= number of segments on each side

I_n = Unique number for each sensor node from (1 to N)

Simulation process for each round:

Loop: for r= 1 to rmax

/* Dividing sensor network into sub-regions*/

Calculate numRx = sqrt(p×N); /*number of segments on each side*/ Round it off to the nearest integer towards zero

Calculate dx = Divide L by numRx; /*length of each sub-region divided*/

Calculate dy = Divide W by numRx; /* width of each sub-region divided*/

X= X_{i=1:N} set of x-axis coordinates for all 'N' nodes

Y= Y_{i=1:N} set of y-axis coordinates for all 'N' nodes

/*Select a node as cluster head from each sub-region*/

Loop: for i = 1 to numRx

for j = 1 to numRx

```

choose a node from each sub-region having higher unique number
If
    chosen node is alive,
    Then
        select it as CH for that sub-region, for that round
    Else
        choose other node from sub-region, having next higher unique number
        Continue;

/*Update cluster head for every round and for each sub-region*/

Check if the selected node is alive or dead
If
    Chosen node from each sub-region is alive
    Then
        Choose it in the process of clustering
    Else
        Select other node in each sub-region, in the same order
        Continue;
    If
        All the nodes in a sub-region are dead
        Then
            Choose no node as CH from that region and
            go to next cluster and continue the process
            Continue;

     $CH_{i=1:rmax}$  = circular shift in the order of
                    descending order of nodes
                    having higher unique id's

end
end
end

```

3.6 Simulation Parameters for Scenario 1

Table 3.1 Simulation parameters (i)
(Lindsey & Raghavendra, 2002)

No of nodes	N=50,100,150
Probability of CHs (p)	p=0.05 for N= 100,150 & p= 0.1 for N=50
Network size (L×W)	50×50 square meter ; 100×100 square meter
Initial energy of each node E_i	$E_i = 1$ J
Base station location for 50×50 network size	(25,150)
Base station location for 100×100 network size	(50,300)
Energy model	First order radio energy model
Multipath model amplifier	$\epsilon_{amp} = 100$ pJ/bit/m ²
Packet size	2000 bits, 100bits
Energy for data aggregation E_{DA}	$E_{DA} = 5$ nJ/bit
Energy for data transmission	$E_{tr} = 50$ nJ/bit
Energy for data receiving	$E_{re} = 50$ nJ/bit
Packet transmission rate	1 packet/round
Deployment type	Random based deployment
Number of simulations per one data point	10

3.7 Simulation Parameters for Scenario 2

Table 3.2 Simulation parameters (ii)

No of nodes	N=100
Probability of CHs (p)	p=0.05
Network size (L×W)	100×100 square meter
Initial energy of each node E_i	$E_i = 0.03J$
Base station location for 100×100 network size	(150,50)
Energy model	First order radio energy model
Multipath model amplifier	$\epsilon_{amp} = 100 \text{ pJ/bit/m}^2$
Packet size	100bits
Energy for data aggregation E_{DA}	$E_{DA} = 5\text{nJ/bit}$
Energy for data transmission	$E_{tr} = 50\text{nJ/bit}$
Energy for data receiving	$E_{re} = 50 \text{ nJ/bit}$
Packet transmission rate	1 packet/round
Deployment type	Random based deployment
Number of simulations per one data point	10

3.8 Simulation Environment

The proposed approach will be simulated using MATLAB 2017a. Sensors are spread in a random fashion. Network has hundred sensors in $100 \times 100 \text{ m}^2$ and $50 \times 50 \text{ m}^2$ dimensions. The initial energy of every sensor node is 1J, 0.03J.

In this study, it will be considered that all sensors are scattered on the 2-D coordinate system between (x =0, y=0) and (x=50, y=50); (x =0, y=0) and (x=100, y=100); and sink is at (25,150) and at (50,300), (150,50) respectively, in the network regions.

2000 bits and 100 bits are the packet sizes for scenario 1 and scenario 2 respectively. For energy dissipations, the radio energy model is followed. The energy dissipated to receive or transmit one bit of data is taken as 50nJ/bit. The energy for data fusion is taken as 5nJ/bit. Multipath model amplifier is taken as 100pJ/bit/m^2 .

This modified approach is simulated with these parameters and compared with the existing basic LEACH protocol (Lindsey & Raghavendra, 2002) and existing ILEACH protocol (Zhao et al., 2012)

CHAPTER 4

SIMULATION RESULTS & DISCUSSIONS

4.1 Simulation Environment

Simulation of modified protocol is done with two scenarios. WSN consisting of 100 sensors, scattered in a random fashion in 50m×50m, 100m×100m, varying the beginning energy of each node with 1J, 0.03J. It is compared against the existing LEACH protocol (Lindsey & Raghavendra, 2002) and existing ILEACH protocol (Zhao et al., 2012) with simulation parameter of scenario 1 and scenario 2 respectively. Network lifetime parameters are taken into consideration, for evaluating the performance of modified protocol.

4.2 Performance Evaluation Metrics

Network Lifetime: It is defined as the total time period from starting of the network operation to the death of last sensor node in the network. (Yousaf et al., 2016)

Stability Period: It is defined as the time period from starting of the network operation to the death of first sensor node in the network. (Yousaf et al., 2016)

Instability Period: It is defined as the time period between first node death to last node death in the network. (Batra & Kant, 2016)

Network Lifetime = Stability period + Instability period. (Yousaf et al., 2016)

HNA: Half of the nodes alive in the network

4.3 Simulation Results

This part depicts the graphs of lifetime of the network with bar graphs and line graphs indicating percentage of node deaths including first node death and last node death.

Performance results are taken as an average of 10 simulations, which were performed

Bar graphs and line graphs indicating first node deaths, 20% of the node deaths, 50% of the node deaths and 100% of the node deaths.

Stability period and lifetime of system are noted down to evaluate performance of proposed protocol.

4.4 Deployment Scenario A

A snapshot of simulation scenario for $50 \times 50 m^2$ size network. Location of sink at (25,150).

Figure 4.1: Deployment scenario for $50 \times 50 m^2$ size network

4.5 Deployment Scenario B

A snapshot of simulation scenario for $100 \times 100 m^2$ size network. Location of sink at (50,300).

Figure 4.2: Deployment scenario for $100 \times 100 m^2$ size network.

4.6 Performance Graphs

Figure 4.3: Performance results of LEACH and modified LEACH of 50 nodes in 50m×50m network size, with initial energy = 1J/node, $p=0.1$ (i)

Figure 4.4: Performance results of LEACH and modified LEACH of 50 nodes in 50m×50m network size, with initial energy = 1 J/node, $p=0.1$ (ii)

Table 4.1: Network lifetime of LEACH and modified LEACH of 50 nodes in 50m×50m network size, initial energy = 1 J/node

Protocol	2% of node death	20% of node death	50% of node death	100% of node death
LEACH	1214.6	1419	1705.4	2056.8
Modified LEACH	1220.1	1470.2	1765.7	2061.1

The above results are an average of 10 simulations that were performed.

Average stability period of LEACH protocol = 1214.6 rounds

Average stability period of Modified LEACH protocol = 1220.1 rounds

Average network lifetime of LEACH = 2056.8 rounds

Average network lifetime of Modified LEACH protocol = 2061.1 rounds

In a network size of 50 nodes, 2% of node deaths include the first node death (FND) of the network. In a 50m×50m network of 50 nodes, the modified LEACH protocol is able to improve the stability period of the network and total lifetime of the network, slightly better than basic LEACH protocol.

This can be used in the applications, where longer stability period of the network is required as well as longer total network lifetime is the requirement.

Figure 4.5: Performance results of LEACH and modified LEACH of 50 nodes in $100m \times 100$ network size, with initial energy = 1 J/node, $p=0.1$ (i)

Figure 4.6: Performance results of LEACH and modified LEACH of 50 nodes in $100m \times 100$ network size, with initial energy = 1 J/node, $p=0.1$ (ii)

Table 4.2: Network lifetime of LEACH and modified LEACH of 50 nodes in 100m×100m network size, with initial energy = 1 J/node

Protocol	2% of node death	20% of node death	50% of node death	100% of node death
LEACH	403.4	511.3	650.3	882.2
Modified LEACH	438.8	543.2	731.2	913.6

The above results are plotted taking an average of 10 simulations that were performed.

Average stability period of LEACH protocol = 403.4 rounds

Average stability period of Modified LEACH protocol = 538.8 rounds

Average network lifetime of LEACH protocol = 882.2 rounds

Average network lifetime of Modified LEACH protocol = 913.6 rounds

In a 50 nodes network, 2% of the node deaths indicate first node death (FND) in the network.

In a network size of 100m×100m with 50 nodes, modified LEACH protocol is able to improve the stability period as well as the overall lifetime of the network when compared to basic LEACH protocol.

Figure 4.7: Performance results of LEACH and modified LEACH of 100 nodes in 50m×50m network size, with initial energy = 1 J/node, $p=0.05$ (i).

Figure 4.8: Performance results of LEACH and modified LEACH of 100 nodes in 50m×50m size with initial energy =1 J/node, $p=0.05$ (ii)

Table 4.3: Network lifetime of LEACH and modified LEACH of 100 nodes in 50m×50m network size, initial energy = 1 J/node

Protocol	1% of node death	20% of node death	50% of node death	100% of node death
LEACH	1649.9	1868.3	2063.2	2340.5
Modified LEACH	1772.1	2003.3	2224.9	2430.3

The above results are plotted on an average of 10 simulations that were performed.

Average stability period of LEACH protocol = 1649.9 rounds

Average stability period of modified LEACH protocol = 1772.1 rounds

Average network lifetime of LEACH protocol = 2340.5 rounds

Average network lifetime of modified LEACH protocol = 2430.3 rounds

In a 100 nodes network, 1% of the node deaths indicate first node death in the network (FND). In a network of 50m×50m of 100 nodes, modified LEACH is able to improve stability period as well as the overall lifetime of the network, when compared to basic LEACH protocol.

Figure 4.9: Performance results of LEACH and modified LEACH of 100 nodes in 100m×100m network size with initial energy =1 J/node, $p=0.05$ (i)

Figure 4.10: Performance results of LEACH and modified LEACH of 100 nodes in 100m×100m network size, with initial energy =1 J/node, $p=0.05$ (ii)

Table 4.4: Network lifetime of LEACH and modified LEACH of 100 nodes in 100m×100m network size, with initial energy = 1 J/node

Protocol	1% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
LEACH	627.7	749.5	861.5	1068
Modified LEACH	743.5	910.8	1068.4	1256.4

The above results are plotted taking an average of 10 simulations that were performed.

Average stability period of LEACH protocol = 627.7 rounds

Average stability period of Modified LEACH protocol = 749.5 rounds

Average network lifetime of LEACH protocol = 1068 rounds

Average network lifetime of Modified LEACH protocol = 1256.4 rounds

In a network of 100 nodes, 1% of node deaths indicate the first node death in the network.

In this 100m×100m, of 100 nodes, modified LEACH protocol is able to improve the stability period as well as the overall lifetime of the network.

Figure 4.11: Performance results of LEACH and modified LEACH of 150 nodes in 50m×50m network size with initial energy =1 J/node, $p=0.05$ (i)

Figure 4.12: Performance results of LEACH and modified LEACH of 150 nodes in 50m×50m network size with initial energy =1 J/node (ii)

Table 4.5: Network lifetime of LEACH and modified LEACH of 150 nodes in 50m×50m network size, with initial energy = 1 J/node

Protocol	0.66% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
LEACH	1713.6	1923.6	2112.8	2418.5
Modified LEACH	2004.1	2257.7	2451.8	2611.2

The above results are plotted taking an average of 10 simulations that were performed.

Average stability period of LEACH protocol = 1713.6 rounds

Average stability period of Modified LEACH protocol = 2004.1 rounds

Average network lifetime of LEACH protocol = 2418.5 rounds

Average network lifetime of Modified LEACH protocol = 2611.2 rounds

In a network of 150 nodes, 0.66% of node deaths indicate the first node death (FND) i.e. first node death in the network is noted down and plotted on the graph. In this 50m×50m network, of 150 nodes, modified LEACH protocol is able to improve the stability period as well as the overall lifetime of the network, when compared to basic LEACH protocol.

Figure 4.13: Performance results of LEACH and modified LEACH of 150 nodes in 100m×100m network size with initial energy =1 J/node, $p=0.05$ (i)

Figure 4.14: Performance results of LEACH and modified LEACH of 150 nodes in 100m×100m network size with initial energy =1 J/node, $p=0.05$ (ii)

Table 4.6: Network lifetime of LEACH and modified LEACH of 150 nodes in 100m×100m network size, with initial energy = 1 J/node

Protocol	0.66% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
LEACH	676.8	805.6	914.8	1134.8
Modified LEACH	933	1152.4	1315	1507.9

The above results are plotted taking an average of 10 simulations that were performed.

Average stability period of LEACH protocol = 676.8 rounds

Average stability period of Modified LEACH protocol = 933 rounds

Average network lifetime of LEACH protocol = 1134.8 rounds

Average network lifetime of Modified LEACH protocol = 1507.9 rounds

In a network of 150 nodes, 0.66% of node deaths indicate the first node death (FND) i.e. first node death in the network is noted down and plotted on the graph. In this 100m×100m network, of 150 nodes, modified LEACH protocol is able to improve the stability period as well as the overall lifetime of the network.

Figure 4.15: Performance results of ILEACH (Zhao et al., 2012) and modified LEACH of 100 nodes in 100m×100m network size with initial energy =0.03 J/node, scenario 2, $p=0.05$ (i)

Figure 4.16: Performance results of ILEACH (Zhao et al., 2012) and modified LEACH of 100 nodes in 100m×100m network size with initial energy = 0.03 J/node, scenario 2, $p=0.05$ (ii)

Table 4.7: Network lifetime of ILEACH (Zhao et al., 2012) and modified LEACH of 100 nodes in 100m×100m network size, with initial energy = 0.03 J/node, scenario 2

Protocol	1% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
ILEACH (Zhao et al., 2012)	320	534	770	1200
Modified LEACH	781.1	1017.2	1134.4	1327

The above results are plotted taking an average of 10 simulations that were performed.

Average stability period of ILEACH (Zhao et al., 2012) protocol = 320 rounds

Average stability period of Modified LEACH protocol = 781.1 rounds

Average network lifetime of LEACH (Zhao et al., 2012) protocol = 1200 rounds

Average network lifetime of Modified LEACH protocol = 1327 rounds

In a network of 100 nodes, 1% of node deaths indicate the first node death (FND) in the network. In this 100m×100m network, of 100 nodes, modified LEACH protocol is able to improve the stability period as well as the overall lifetime of the network.

4.7 Analysis on the Simulation Results

All the above results, depicts clearly, the first node death of the modified LEACH protocol is higher than LEACH protocol and ILEACH (Zhao et al., 2012). This means, the stability period of the network is improved.

Some applications require higher stability period, than the overall lifetime of the network. For such applications of smaller network size, modified LEACH protocol can be used.

For a network size of 50, 100 and 150 nodes in both 50m×50m and 100m×100m, both stability period as well as overall lifetime of the network is improved with the modified LEACH protocol.

At the same time, in all the above scenarios when it is tested with different energies, not only the first node death but the overall lifetime is also improved when compared to the original leach protocol for 50, 100 and 150 nodes and also with ILEACH (Zhao et al., 2012) for 100 nodes. It is because of the modification in CH selection.

LEACH protocol has a lot of randomness in the process of CH selection for each round. So, in every round, after the selection of the CHs, the normal sensor nodes suffer from heavy energy consumption, to transmit the packets of information to their respective CHs which are far away from their vicinity.

In this research, the problem of uneven distribution of CHs is solved to some major extent by choosing one node as CH from each sub-region and count of CHs for every round depends upon the death of last dead node in each sub-region.

In the modified protocol, by the proposed approach of dividing the sensor network into equal sub-regions in the beginning itself, makes sure that, all CHs are spread throughout network, that makes the non-CH nodes, will always have a CH in their vicinity for every round. This modification has a greater impact on reducing the energy consumption to a lot extent, when compared to the existing basic LEACH protocol.

This preserves the unnecessary energy consumption, that happens when the cluster head is far from their vicinity. This preserved energy will be useful in the increased lifetime of the network. This depicts, impact in uneven distribution of CHs, is quite high. This results in higher usage of energy in network.

Results are plotted depending upon deaths of sensors taken in percentage, happened in system. Lifetime of the network depends upon the number of alive nodes in the network. The lesser the number of node deaths in the network, the more will be the system lifetime.

CHAPTER 5

CONCLUSION & FUTURE RECOMMENDATIONS

5.1 Conclusion

LEACH protocol have many drawbacks. One among them is the huge randomness in the selection process of cluster head during its setup phase. Spreading of CHs, in a non-uniform manner makes the system, less energy efficient, less stable.

This problem has been addressed in this research by some extent, in the form of spreading CHs, entirely on the region, by dividing sensor network into equal-sub regions before the starting of setup phase itself. This makes sure that, all the CHs are spread uniformly, despite number of nodes in their vicinity. By this way, there is CH for all sensors in their proximity, for every round.

This modification reduces the energy consumption in system, that helps to improve the lifetime of system. This improved protocol has better lifespan in terms of FND, as well as HND, also overall lifetime of the network.

Time period till first node death technically defined as stability period in WSN. Here, improved protocol has better stability period than existing basic LEACH protocol and ILEACH (Zhao et al., 2012) protocol.

Requirement of LEACH protocol varies from application to application. Some applications require higher overall lifetime of the network to collect the data. Some applications require first node death to be in a longer period, since loss of one sensor data can lead to huge loss for their purpose.

A rapid increase in the usage of wireless sensors in different fields like medical, military, traffic, environmental monitoring, automobiles, mobile phones, industries has pushed for a greater demand in the supply and increased research in the field of these protocols.

5.2 Future Recommendations

LEACH protocol can be improved in several factors. In this research, that all sensors are spread in a random fashion as well as static including sink. All the sensor nodes are considered as homogenous nodes. But in the practical scenario, it might be different. Some nodes may have greater initial energy than others. So, research should be done, considering some advanced nodes also in the simulation.

Security is one another aspect, which should be taken care of. Since nodes are deployed in a remote location. There is a chance that, a sensor node can be attacked through virtual networks and wrong information can be placed. This leads to a massive failure, when it comes to sensitive applications like military and hospitals. Apart this, there are factors like number of nodes in their vicinity, residual energy of sensors, that to be taken for consideration, for CH selection, to have a much improved and efficient protocol.

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APPENDICES

Appendix 1: System Validation

LEACH protocol is simulated with the following simulation parameters taken and for validating it, it is compared against the performance results taken from (Lindsey & Raghavendra, 2002) LEACH.

The performance results are plotted by taking Network lifetime as the parameters. They include 1% of the node deaths, 20% of the node deaths, 50% of the node deaths, 100% of the node deaths.

Table 7.1 Simulation Parameters
(Lindsey & Raghavendra, 2002)

Number of nodes	N=100
Probability of CHs	P= 0.05
Network size (L×W)	50×50 square meter ; 100×100 square meter
Initial energy of each node	0.25J/node, 0.5J/node, 1J/node
Base station location for 50×50 network size	(25,150)
Base station location for 100×100 network size	(50,300)
Energy model	First order radio energy model
Multipath model amplifier	$\epsilon_{amp} = 100 \text{ pJ/bit/m}^2$
Packet size	2000 bits
Energy for data aggregation E_{DA}	$E_{DA} = 5\text{nJ/bit}$
Energy for data transmission	$E_{tr} = 50\text{nJ/bit}$
Energy for data receiving	$E_{re} = 50 \text{ nJ/bit}$
Packet transmission rate	1 packet/ round
Deployment type	Random based deployment
Number of simulations per one data point	10

1% of node deaths indicate first node death (FND) in the network.

50% of node deaths indicate half node deaths (HND) in the network.

100% of node deaths indicate last node death (LND) in the network.

Figure 7.1: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 50m×50m network, initial energy =0.25J/node (i)

Figure 7.2: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 50m×50m network, initial energy =0.25J/node (ii)

Table 7.1: Network lifetime of LEACH (Lindsey & Raghavendra) and simulated LEACH in 50m×50 network size, initial energy = 0.25J/node

Protocol	1% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
LEACH (Lindsey et al., 2002)	402	480	523	635
Simulated LEACH	404	465.4	515.1	591.4

Figure 7.3: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 50m×50m network, initial energy =0.5J/node (i)

Figure 7.4: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 50m×50m network, initial energy =0.5J/node (ii)

Table 7.2: Network lifetime of LEACH (Lindsey & Raghavendra) and simulated LEACH in 50m×50 network size, initial energy = 0.5J/node

Protocol	1% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
LEACH (Lindsey et al., 2002)	803	962	1036	1208
Simulated LEACH	819.5	939.5	1026.6	1174

Figure 7.5: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 50m×50m network, initial energy = 1 J/node (i)

Figure 7.6: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 50m×50m network, initial energy =1 J/node (ii)

Table 7.3: Network lifetime of LEACH (Lindsey & Raghavendra) and simulated LEACH in 50m×50 network size, initial energy = 1 J/node

Protocol	1% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
LEACH (Lindsey et al., 2002)	1610	1921	2055	2351
Simulated LEACH	1649.9	1868.3	2063.2	2340.5

Figure 7.7: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 100m×100m network, initial energy =0.25 J/node (i)

Figure 7.8: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 100m×100m network, initial energy =0.25 J/node (ii)

Table 7.5: Network lifetime of LEACH (Lindsey & Raghavendra) and simulated LEACH in 100m×100 network size, initial energy = 0.25 J/node

Protocol	1% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
LEACH (Lindsey et al.,2002)	166	204	232	308
Simulated LEACH	157.2	189.9	219.4	268

Figure 7.9: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 100m×100m network, initial energy = 0.5 J/node (i)

Figure 7.10: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 100m×100m network, initial energy = 0.5 J/node (ii)

Table 7.5: Network lifetime of LEACH (Lindsey & Raghavendra) and simulated LEACH in 100m×100 network size, initial energy = 0.5 J/node

Protocol	1% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
LEACH (Lindsey et al., 2002)	339	408	461	576
Simulated LEACH	307.2	378.5	434	527

Figure 7.11: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 100m×100m network, initial energy = 1 J/node (i)

Figure 7.12: Performance results of LEACH (Lindsey & Raghavendra) and simulated LEACH in 100m×100m network, initial energy = 1 J/node (ii)

Table 7.6: Network lifetime of LEACH (Lindsey & Raghavendra) and simulated LEACH in 100m×100 network size, initial energy = 1 J/node

Protocol	1% of node deaths	20% of node deaths	50% of node deaths	100% of node deaths
LEACH (Lindsey et al.,2002)	690	812	911	1077
Simulated LEACH	627.7	749.5	861.5	1068

Simulated LEACH results are plotted taking an average of 10 simulations. It is compared against the results of LEACH (Lindsey & Raghavendra, 2002). It can be seen that the simulated LEACH protocol gives closer results, by which it justifies the system validation.