Optimization of Clustering Techniques in Wireless Sensor Networks

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AHMEDABAD-382481

May 2014

Optimization of Clustering Techniques in Wireless Sensor Networks

Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Computer Science and Engineering

Prepared By

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May 2014

Certificate

This is to certify that the Major Project Report entitled “**”Optimization of Clustering Techniques in Wireless Sensor Networks”** submitted by **Abhinav N Shah (Roll No: 12MICT20)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Computer Science and Engineering of Nirma University, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven’t been submitted to any other university or institution for award of any degree or diploma.

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I, **Abhinav N Shah**, Roll. No. **12MICT20**, give undertaking that the Major Project entitled "**Optimization of Clustering Techniques in Wireless Sensor Networks**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Computer Science & Engineering** of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Acknowledgements

It gives me immense pleasure in expressing thanks and profound gratitude to **Prof. Gaurang Raval**, Professor, Computer Science Department, Institute of Technology, Nirma University, Ahmedabad for his valuable guidance and continual encouragement throughout this work. The appreciation and continual support he has imparted has been a great motivation to me in reaching a higher goal. His guidance has triggered and nourished my intellectual maturity that I will benefit from, for a long time to come.

It gives me an immense pleasure to thank **Dr. Sanjay Garg**, Hon'ble Head of Computer Science and Engineering Department, Institute of Technology, Nirma University, Ahmedabad for his kind support and providing basic infrastructure and healthy research environment.

A special thank you is expressed wholeheartedly to **Dr K Kotecha**, Hon'ble Director, Institute of Technology, Nirma University, Ahmedabad for the unmentionable motivation he has extended throughout course of this work.

I would also thank the Institution, all faculty members of Computer Engineering Department, Nirma University, and Ahmedabad for their special attention and suggestions towards the project work.

The blessings of God and family members make the way for completion of Project. I am very much grateful to them.

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Abstract

A wireless sensor network is formed by the large number of tiny devices which consists of low-power trans-receivers which can be very efficient tool for gathering information from a particular or different type of environments.But sensor nodes have limited resources, so the path for communication between sensor node and Base Station should be chosen such that very less amount of energy is consumed to transfer this information. Sensor nodes are grouped into clusters for high scalability and better data aggregation. The Hierarchical WSNs are created using clusters, which supports in the appropriate utilization of the resources of the sensors. Here a cluster-head election technique is implemented that optimizes network lifetime with reduced energy consumption. LEACH and LEACH-C are the popular clustering protocol and they provide energy efficient routing. As these protocols are defacto standard for clustering techniques the focus has been on optimizing LEACH-C protocol to achieve better network lifetime energy consumption. Here, the FCM algorithm is used for the clustering startegy in place of simulated annealing algorithm. Also the other optimization techniques are carried out to achieve the better network lifetime than LEACH-C. Simulation results are taken after applying modified algorithm. It selects optimal number of clusterheads in each round and also forms better clusters. It consumes less energy and enhances network lifetime. The energy usage analysis is done and the mathematial derivation of the energy consumption in each phase of the the protocol is carried out.

Key words: LEACH-C, clustering techniques, Fuzzy c-Means (FCM), dynamic clustering, network lifetime

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Chapter 1

Introduction

1.1 Wireless Sensor Network

Wireless Sensor networks comprises of very large number of low power, multi-functional sensor nodes,which operates in an environment that may not be reached, with limited computation capabilities and sensing capabilities. Sensor nodes consistes of small batteries of low power capacities[1]. Current advances in sensor development have resulted in the wide use of Wireless Sensor Networks (WSNs) for remotely monitoring tasks. WSNs are used for physical environment monitoring, security surveillance, military applications, among others. WSNs are consisting of large number of nodes that work together to accomplish a data gathering task. Sensors communicate with each other to relay messages from the network to the Sink, which is the entity interested in monitoring the subject of interest. A sensor node has limited sensing, computing/storing and transmitting capabilities. Figure 1 shows the diagram of components of sensor node. Each sensor node has capability of sensing, processing, transmission, mobilizer, position finding system, and power units. It also shows the communication architecture of a WSN. Sensor nodes coordinate among themselves to generate a data centric information about the physical environment. WSNs are distributed, self-organizing systems. They rely on large numbers of sensor nodes. Self-organizing feature of wireless sensor networks is challenging because of limitation of the bandwidth and energy resources available in these networks. Sensor nodes are typically battery powered devices. Sometimes failure of node from network will fail entire sensor network. The radio is the most power-consuming module of a sensor node. To preserve energy, the nodes should use low duty cycling, i.e. they turn their radios off but are still able to sense the environment. Once the event of interest is sensed, the node turns its radio on. In-network data processing (such as data aggregation, fusion, filtering, etc.) reduces the number of messages to be sent to the Sink, thus preserving energy. Data gathered by all nodes are correlated in WSNs, end user requires only a particular value like there is fire in particular area or not. For that it is required to process data locally. Aggregation techniques are used to perform this operation. Aggregation of data will reduce size of data being propagated to the base station. This aggregated data is transmitted to the end user. Low Energy Adaptive Clustering Hierarchy (LEACH) protocol and LEACH-Centralized protocol are the most popular clustering protocol with efficient aggregation provision. Although these are defacto standards for clustering in WSN it suffers from certain drawbacks. The study is done to optimize these problems such that the throughput increases.

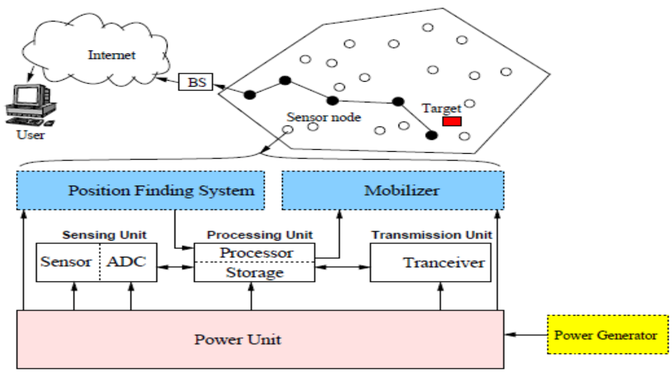

Figure 1.1: The Sensor Node Architecture

1.2 Applications of WSN

WSN has their application in large number of fields, which widely vary in their requirements and characteristics . Its application areas are

- Disaster Handling
- Biodiversity Mapping
- Health care

- Smart Building
- System surveillance
- Tracking
- Nuclear and explosive things

The nodes in WSN can be deployed manually or in random fashion. For example-consider a situation of climate change application where we want to check the amount of rainfall in different regions. Now in this case what we can do is we can drop the sensors from an aircraft in the region under survey randomly. Another example could be the manual deployment of sensor nodes in RADAR which is used to sense any kind of risk in area which it covers. So with the use of these sensor nodes the information regarding any kind of risk can be identified.

1.3 Objective of the Work

The objective of this work is to extend LEACH-C routing algorithm for improvement in the network lifetime and energy effciency.

- To study different hierarchical routing protocols, and analyze LEACH and LEACH-C in particular.
- To study LEACH-C and otherrelevant protocols and analyze its characteristics.
- To propose ideas for the improvements on LEACH-C protocol.
- To test and validate the effectiveness of proposed improvement.

1.4 Scope of the Work

The scope of this work is to optimize LEACH-C,energy efficient routing protocol, implement on existing WSNs. Although there are many protocols and the research is also going on basic protocols, there is scope to optimize LEACH-C to extend network lifetime and for energy efficiency.

Chapter 2

Literature Survey

2.1 Routing Protocols in WSN

In WSN, the communication among the nodes, of the information, is done on very short range. Various different protocols are designed in order to transfer the information in the optimized manner. Indeed, routing is the critical challenge in the wireless sensor network. The limited resources like power supply and transmission bandwidth, no universal addressing scheme for the nodes because of its dynamic nature, and the bounded latency are the main problems in the WSNs.

The routing protocols can be divided into two categories, on the basis of the deployment of the nodes : hierarchical routing and flat routing.

In Flat routing, every node exhibits similar functionalities and also perform same tasks. Data transmission in this type of techniques is done hop-by-hop. The flat routing includes Sequential-Assignment routing, Gradient-Based routing, Directed Diffusion and many others. Though this scheme is effective for small scale networks, but this cannot be applied in large scale networks.

In Hierarchical routing, the nodes have different tasks to perform for successful data transmission. Here the nodes are grouped in the form of clusters, a cluster containing the nodes to fulfill the specific requirements. Each cluster has one cluster-head, a node with high energy, and other nodes in the same cluster are cluster members.

The classification of routing protocols can be done as: proactive, reactive and hybrid, on the basis of the how the route to the sink is decided by the source. In proactive, the routing table is decided even before they are required, while in reactive the routes are decided on the basis of the current tasks, demand. LEACH is one such proactive protocol. Hybrid protocols uses a combination of the two concepts. All the routes are determined beforehand and then are improvised accordingly.

2.2 Low Energy Adaptive Clustering Hierarchy-LEACH protocol

The first energy-efficient hierarchical, clustering protocol is LEACH(Low Energy Adaptive Clustering Hierarchy). This protocol reduces the power consumption in WSN. It divides the network into several clusters. The primary idea was to rotate the clustering tasks among the cluster nodes and to extend the lifespan of the network by distributing the task of communicating to the BS among the nodes.[2] Data aggregation technique is used by CHs to collect the data and to pass only the meaningful data to BS. If only the same nodes will be CHs throughout the lifetime, those nodes can be drained out very fast. In LEACH, the different nodes are chosen as CH periodically which balances the load across the network.[2]

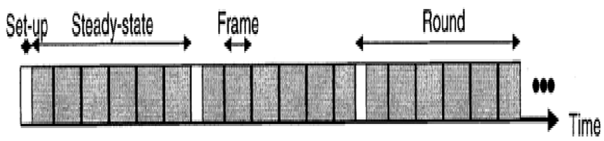

Figure 2.1: LEACH operation: Timeline

The working of LEACH is divided into 2 phase: (1)Setup Phase (2)Steady State Phase.Setup phase is responsible for-(i) cluster formation , (ii) CH selection.[3] In this phase each node checks whether it can be CH or not for the same round. This is done by taking into account how many times the node has become CH till then and the percentage of CHs are required. A number is chosen arbitarirly between 0 and 1 to perform this task. A node is chosen as CH if the chosen number is less than following threshold:

$$T(n)(t) = \begin{cases} \frac{p\_}{1-p\_*\left(r mod \frac{1}{p\_}\right))} : n\varepsilon G \\ 0 : otherwise \end{cases} \tag{2.1}$$

In the above equation, $p\_$ stands for the percentage of the CHs, the value of the current round is given by r, G is the group of nodes which have not become CH since last $\frac{1}{p\_}$ rounds. One round consists of both the phases.

In the following figure, an instance topology is taken and it is tried to explain how the cluster formation takes place using LEACH. The figure shows the cluster formation taken place at two different rounds of the same topology. This shows how randomly the CH selection is done using above equation. This contributes to the load distribution from only few codes to the entire network.

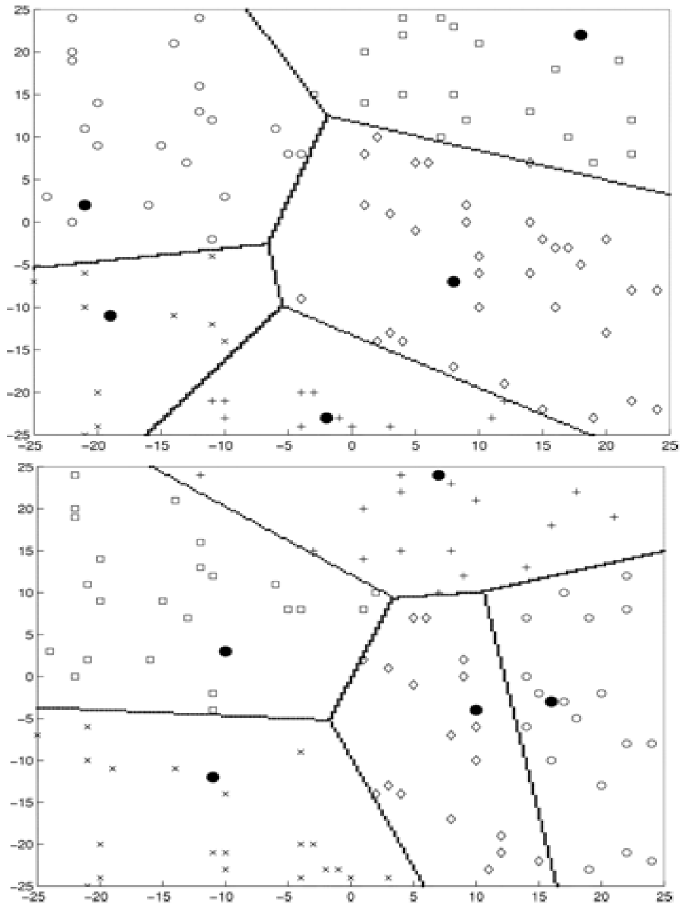

Figure 2.2: Cluster formation at two different rounds.

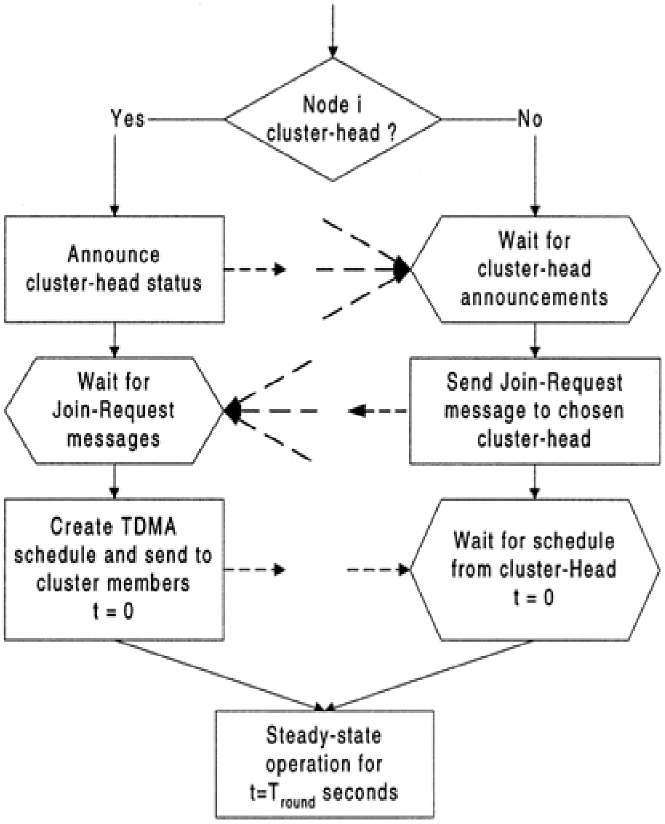

Figure 2.3: Setup Phase.

As shown in the above figure, a node selected as CH broadcasts an advertisement message to all the other nodes in the network. The other nodes decides to be part of which cluster according to the strength of the message received from each CH. Now once the clusters are formed, the CH decides the TDMA order for its member nodes specifying when a node can send data, leading to less inter-cluster and intra-cluster collissions. Due to this a cluster member will turn its radio on only when it is scheduled to transmit the data, and be in sleep mode other times, saving a lot of network energy.

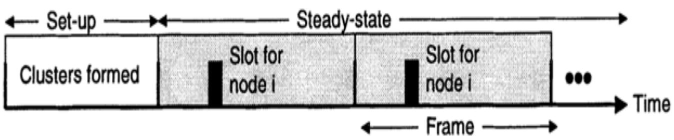

Figure 2.4: Timeline of steady state phase of LEACH.

In Steady State phase the data transfer among CM-CH and CH-BS takes place. The above figure shows how the TDMA slots are already assigned and the nodes have to transmit in the alloted slot only. Here the member nodes will send data to CH which is then aggregated by CH and sent to BS. LEACH uses completely distributed approach. Once this phase completes, the round gets complete and new round starts. Again the new round starts with Setup phase.

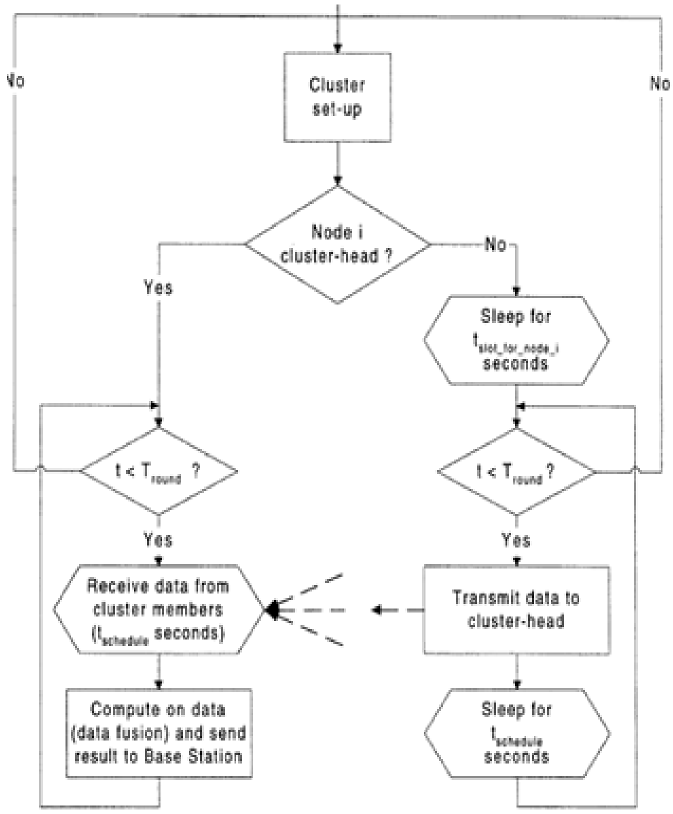

Figure 2.5: Steady State phase.

Advantages of LEACH are

- CHs are elected on the basis of how many times it has been CH previously, distributing the CH load among all the nodes
- Using TDMA schedules to prevent the collisions.

Disadvantages are

- Single hop communication, directly from CHs to BS, which is not optimal in case if any CH is very far from BS so not for large regions
- equal initial energy is assumed which is not realistic assumption
- probabilistic selection of CHs.

2.3 LEACH-C (LEACH-Centralized)

LEACH does not give any guarantee about the placement of the CH nodes. If there is any centralized algorithm to form better clusters, better results can be achieved. LEACH-C was introduced as a centralized algorithm. Likewise LEACH, Leach-C is also divided into two phases: (1) Setup Phase (2) Steady State Phase. The Setup phase of LEACH and Leach-C are different in a way of the selection of the CHs. In Leach-C, setup phase, all the nodes send their location information and the current energy information to the BS. BS computes average energy from the energy information received and all the nodes having energy less than the average energy are taken out of the CH competition. The BS uses the simulated annealing algorithm to decide the CH among the remaining nodes. This algorithm optimizes the energy dissipation by non-CH nodes by selecting the CH in a way that it minimizes the squared distance of cluster members from its CHs. The broadcast message is sent by BS containing CHID for each node, once the clusters and the related members are decided. If the cluster head ID and nodes ID is same, the node itself is CH, else the node will check the TDMA slot assigned to it and goes to sleep till then. The Steady State phase of LEACH and Leach-C are same.

2.4 Base Station Controlled Dynamic Clustering Protocol(BCDCP)

It is a wireless sensor routing protocol having base station as a main component having ability to perform complex computation.[7] So it makes sensor nodes simple and cost effective. BCDCP operates in two major phases: 1. Setup phase and 2. Data communication phase. In wireless sensor networks users are interested in data centric information so it is advisable to use attribute and location for addressing any sensor nodes. BCDCP uses addressing of the form <Location ID , Node Type ID>. Location ID identifies location of the sensing node and Node Type ID describes the functionality of the sensor node such as temperature sensing, seismic sensing.

A. Setup phase

During each setup phase , base station receives information on the current energy status from all the nodes in the network. Based on this, BS first computes the average energy level of all the nodes and then chooses a set of nodes, denoted C, whose energy level is above the average value. Cluster head for current round will be chosen from set C. BCDCP uses iterative cluster splitting algorithm to choose set of cluster head nodes and to group other nodes into cluster such that overall energy consumption during data communication phase is minimized. Time Division Multiple Access(TDMA) scheduling is used to minimize the collision between sensor nods trying to transmit data to the cluster head.

B. Data communication phase

This phase consists mainly three activities:

1. Data gathering : During TDMA schedule each sensor node sends sensed data to the CH
2. Data fusion : Once data are collected from all the nodes , CH performs data fusion to reduce the amount of the received data.
3. Data routing: Compressed data is routed to the BS along with the information needed to decode the compressed data and information of route back to the CH.

BCDCP uses code-division multiple access(CDMA) code for inter cluster communication. Each cluster is assigned a spreading code that the node in the cluster use to distinguish their data transmission from those of nodes in the neighboring cluster.

2.5 Hybrid Energy Efficient Distributed Clustering(HEED)

To optimize power consumption, HEED uses the residual energy and node density to form clusters. Mainly, it is used in Multi-hop networks with the objective of (i) completing clustering process after certain number of iterations, (ii) creating compact clusters with well distributed CHs. Every time CHs are selected from the combination of the two clustering parameters. First parameter is the residual energy of each node in the cluster and second parameter is node degree, number of neighbors of the node. First parameter selects initial set of CHs probabilistically and second parameter is used in case of ties. It improvises the network lifetime over LEACH because in LEACH the clustering is done randomly and there are chances that selected CH may run out of energy. The final set of CHs consists of the nodes that are well distributed. This method takes into account only 2 parameters of WSN and not all and hence its applications are limited. Like LEACH, the initial percentage of CHs C_{prob} is predefined for the given network. This parameter is used to restrict the initial cluster-head announcements. Every node sets the probability of being CH as follows:

$$CH_{prob} = max\left(C_{prob} * \left(\frac{E_{residual}}{E_{max}}\right), p\right) \tag{2.2}$$

where $E_{residual}$ is the assumed current residual energy in this cluster node and E_{max} is the maximum energy related to a fully charged battery, which is same for all the cluster nodes. The value of the CH_{prob} must be greater than a pmin, minimum threshold. If CH_{prob} is <1, a CH is a tentative CH, else a final CH, if its CHprob has reached 1. All the nodes that never listened from a CH elects itself as a CH with probability CH_{prob}, in each round. The current set of CHs consists of the newly selected cluster heads. The selected node broadcasts an advertisement message that it is a selected CH or tentative CH. The CH with the minimum cost is elected from the list of CHs as CH from this set of CHs. All nodes then doubles its CH_{prob} and goes to the next step. A final CH is elected if the node finishes the execution of HEED without selecting itself as CH throughout its lifetime. If lower cost CH announcement is broadcasted by any cluster node, then the tentative node becomes the regular node. Here, a node can be declared as a CH at intervals if it has more residual energy with lower cost. In HEED, the dissemination of energy utilization augments the lifetime of every node in the system, along these lines maintaining, thus increasing the balancing of the neighbor set. Nodes additionally naturally redesign their neighbor sets in multi-hop topology by intermittently sending and accepting messages. The HEED clustering enhances system lifetime over LEACH grouping on the grounds that LEACH haphazardly chooses CHs (and henceforth cluster size), which may bring about speedier demise of a few nodes. The last CHs chose in HEED are well circulated over the network and the correspondence cost is minimized. But the cluster choice arrangements with just a subset of parameters, which can conceivably force demands on the system. These routines are suitable for extending the system lifetime as opposed to for the whole requirements of WSN.

2.6 Advanced LEACH

The cluster head nodes utilizes significant energy in LEACH than others. Thus in Leach-A, it is tried to improve reliable data transfer and energy saving. The data processing is done using mobile agent technique which is based on Leach. Advanced Leach is a heterogeneous energy saving protocol which is proposed to decrease the nodes failure probability and to extend the time interval of the death of first node, which is called the stability period. All the nodes are aware about the starting of the round, by synchronizing the system clocks. There are some nodes in the network which are equipped with significantly more amount of energy than the other nodes in the network. These nodes are called the CAG nodes or gateway nodes, and these are only the fraction of the total number of nodes. The other nodes are normal nodes. The CAG nodes performs the data aggregation task and then transfer of data to BS is done by them. When CAG receives all the messages, it aggregates them in one message and then it sends this message to the BS according to the placement of CAG: If CH is a normal node then it seeks a node which is a nearest CAG node which can be selected as gateway that can route the data to the BS. If CH is a CAG node then the data are sent directly to the BS. The amount of information is thus reduced by merging the data and transmitting them to the BS. Even after all the nodes are expired, CAG nodes will continue the data transmission to the BS. Various functions are performed by the CAG nodes: (i)increase the network lifetime in non-homogeneous WSN (ii)decrease the failure of the nodes probability (iii)the time taken for the death of the first node is extended.[9]

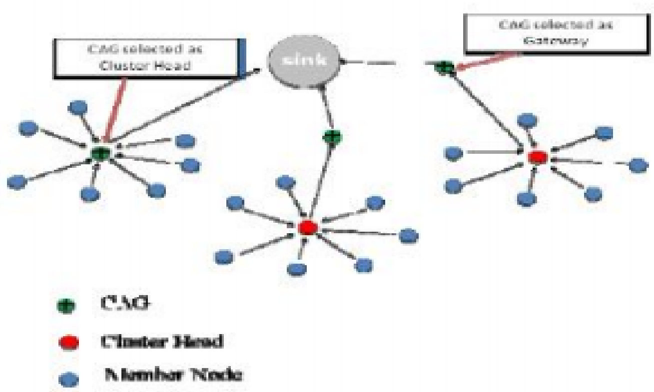

Figure 2.6: Working of Leach-A

2.7 LEACH-B

The functionalities of LEACH are extended by LEACH-B. The residual energy of all the nodes are taken into account for the second selection of CHs to change the number of CH in the setup phase. To reduce the energy consumption and for the extension of the life span of the network, the partition of the network into clusters should be balance and uniform. To achieve this objective, the number of CHs needs to be optimal. It is already proven that optimal number of CH is 3% to 5% for Second selection of CH. [7]

2.8 TL-LEACH (Two-level Hierarchy LEACH)

TL-LEACH (Two-Level Hierarchy LEACH) is extension to the LEACH algorithm. It has two levels of cluster CHs - primary and secondary, instead of only one CH. Here, the primary CH in each cluster communicates with the secondary CH, and the corresponding secondary in turn communicate to the nodes in their sub-cluster. Likewise LEACH, data fusion can also be done. The data transmission among the cluster nodes is done by TDMA time slots. The setup round is organized in a way that firstly primary and secondary CHs are selected, in same way as LEACH. Higher the probability it becomes the primary CH and with less probability it becomes secondary CH. Data communication in this protocol is done in two steps: the data fusion/aggregation is done by the secondary CHs and then sent to the primary CHs. The data fusion process can also be done at primary CH.[4] The energy usage is significantly reduced by the two-level structure of the TL-LEACH as it reduces the number of nodes which need to transmit to the BS. [8]

2.9 LEACH-H (LEACH-Hierarchical)

This is an extension of LEACH having hierarchy of cluster-heads. First level cluster-head is selected as in LEACH. Further another cluster-head is selected from set of cluster-heads and that is called Master Cluster-head (MCH).Master cluster-head is selected based on remaining energy of CHs. In steady state phase for transmission of data to the base station there is hierarchy followed and that is Sensor nodes → Cluster-heads → Master Cluster-head → Basestation.

Sensor nodes send data to the cluster-head. After receiving all data from sensor nodes cluster-head performs data aggregation on it. All cluster-head nodes send aggregated data to the Master cluster-head. Master cluster-head sends all data received from cluster-head nodes to base station. Therefore, energy consumption of cluster-heads can be reduced as it does not directly communicate to the base station.LEACH-H improves network lifetime.[11]

2.10 Multi-Hop LEACH

With the increase in the network deployment region, the distance between BS and CH increases substantially. In this scenario the LEACH routing cannot be done as in that CH should be at single-hop distanced from BS. If LEACH is used, the energy dissipation of the CH node will be very expensive. Multi-hop LEACH, a distributed clustering protocol, is proposed to overcome this problem. It is extended from LEACH protocol to improve the power consumption of the WSN. Likewise LEACH, in Multi-Hop LEACH, the selection of CHs is done by the nodes itself and the other nodes associate themselves with the concerned CHs. In the Steady State phase, the data transmission is done from CM to CH and from CH to BS. In case if any CH is very far from BS, It sends data to another nearest CH that can transmit data to BS. Thus, Multi-Hop LEACH allows two types of communication: (i) Intercluster communication (ii) Intra-cluster communication. Inter-cluster communication is used when the distance between CH and BS is significantly large in which CH sends data to intermediate CH for data transfer.[10]

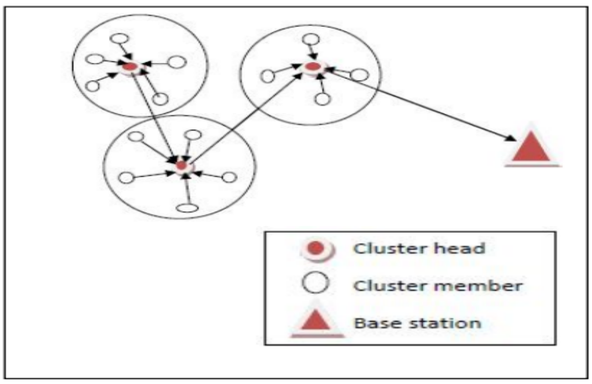

Figure 2.7: Multi-hop

2.11 LEACH-F (LEACH with fixed cluster)

In LEACH-F scheme, the cluster remains identical but the cluster-head task is rotated among the member nodes of the cluster. Like LEACH, LEACH-F works into two phases: (i) Setup phase (ii) Steady state phase. Like LEACH-C, using the centralized algorithm, the clusters are created. To determine the optimal clusters BS uses the simulated annealing algorithm and then it broadcasts the information to the cluster nodes. The broadcast message contains cluster ID of every node, using which the cluster nodes can confirm their TDMA schedule. Also the order to rotate the CH position is included in the message. The CH information is included in a way that the first cluster node listed in the cluster will be CH for first round, the second CH will be the second node listed in the cluster and so forth. In LEACH-F, the setup is done only in first round. Nodes are aware that when they will be cluster-heads and when they are cluster members. Like LEACH-C, the steady state phase in LEACH-F is like LEACH. For dynamic system LEACH-F would not be practical. New nodes cannot be added to the network due to the fixed nature of this protocol and also it cannot adjust its behavior on the basis of the information of the dying nodes. Mobility of the nodes is not supported in LEACH-F. Thus, this is a good protocol to compare the protocols that are advantageous for no-overhead approach, but it cannot be applied for the Real Time systems.[6]

2.12 Performance Metrics

- Network lifetime The network lifetime defined as the time until the network gets disconnected. It represents the maximum time interval that a network can maintain its functionality. We consider a WSN as alive until minimum number of CH are available in the network.

- Energy Consumption Energy Consumption is defined as total amount of energy conserve by sensor nodes in network. Network Energy Consumption = Total Energy Consumed by All Sensor Nodes

- Data bits received at BS. All sensor nodes senses the network and then sends it to the CH.Ch then aggregates this data and sends to the BS. This metric is considered to be number of total data bits received at BS.

Chapter 3

Analysis of Energy Usage

3.1 The Assumptions in the Network Model

In the research work following assumptions are taken for large scale network[12]:

- The nodes deployment is done randomly and all the nodes in the network are static
- Nodes have limited energy and are given equal initial energy
- If the node consumes its complete energy it will die, and it cannot take part in cluster-head competition or can be cluster member
- Every node is aware about its location in the network
- Base Station is allotted with infinite amount of energy

3.2 Radio Energy Dissipation Model

A node utilizes its energy in main 3 cases: data reception, data transmission, and data processing. We are using the same energy model as used in original LEACH. It is assumed that the energy is dissipated by transmitter to allow the radio circuitry and electronics to work.[2][5]

All the terms used in this model are as explained below:
l is the length of message in bits i.e transmitted or received
d is the distance over which data is transferred
n is path loss constant that varies according to the radio propagation model

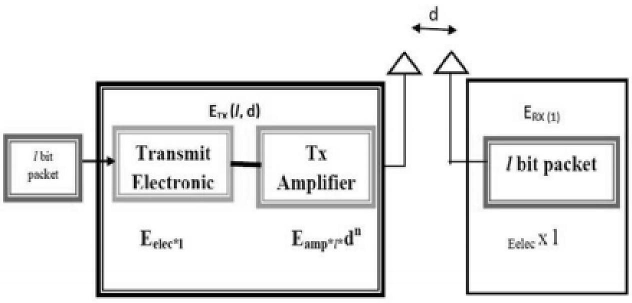

Figure 3.1: Radio-model

ε_{amp} is energy dissipated by amplifier on transmitter side, to convey 1 bit of the messagem to the receiving node which is at 1 meter away
E_{Tx} is energy spent in transmission of the data and it can be calculated as follows :

$$E_{Tx} = lE_{elec}^{Tx} + l\varepsilon_{amp}d^n$$

E_{elec}^{Tx} is the energy spent to run transmitter's circuitry
E_{Rx} is the amout of energy spent in receiption of the data and it can be calculated as follows :

$$E_{Rx} = lE_{elec}^{Rx}$$

E_{elec}^{Rx} is energy spent to run receiver's circuitry

From above equations it is clear that, transmitter uses its energy to run radio electronics circuitry and also the amplifying circuits. But for the reception, the receiver spends its energy just to run radio electronics circuitry. [13]

Here, we are assuming two energy models :

1. Free Space model where

$$n = 2, \varepsilon_{amp} = \varepsilon_{fs}$$

2. Multi-Path model where

$$n = 4, \varepsilon_{mp} = \varepsilon_{mp}$$

3.3 Equations for Set-up Phase

Here, the ratio of the optimal number of clusters (k_{opt}) to the total number of nodes in the entire network (N), i.e.,

$$p = \frac{k_{opt}}{N_{nodes}}$$

is taken to achieve optimal percentage of cluster head nodes (p) . Due to this, the optimal cluster size would be equal N_{nodes}/k_{opt}

Equations for Set-up Phase are :

1. The following equation represents the Energy spent by a Cluster Head during setup phase in a round :

   $$E_{CH} = k_{opt}E_{Rx} + k_{opt}E_{Tx_{CM}} + k_{opt}E_{Tx_{BS}} + k_{opt}E_{Rx_{CM}}$$

   where,

   $k_{opt}E_{Rx}$ shows the energy utilized by CH nodes to Receive BS announcements of the Cluster Heads.
   $k_{opt}E_{Tx_{CM}}$ shows the utilized spent by CH nodes to transmit the information about the member nodes of that cluster to all its Cluster Members
   $k_{opt}E_{Tx_{BS}}$ shows the energy used by CH nodes tfor the transmission of the acknowledgments of the receipt of BS announcements to BS
   $k_{opt}E_{Rx_{CM}}$ shows the energy spent by CH nodes to Receive Cluster Member's join requests
   Further simplifying this equation gives :

   $$E_{CH} = k_{opt}lE_{elec}^{Rx} + k_{opt}[lE_{elec}^{Tx} + l\varepsilon_{fs}d_{toCM}^{2}] + k_{opt}[lE_{elec}^{Tx} + l\varepsilon_{mp}d_{toBS}^{4}] + k_{opt}lE_{elec}^{Rx}$$

2. The following equation represents the Energy spent by a Cluster Member during setup phase in a round :

   $$E_{CM} = (N_{nodes} - k_{opt})E_{Rx} + (N_{nodes} - k_{opt})E_{Tx}$$

   where,

   (N_{nodes} - k_{opt}) is the total number of cluster members

$(N_{nodes}$ - $k_{opt})$ E_{Rx} is the amount of energy utiized by cluster members while receiving the CHs announcements to the cluster members
$(N_{nodes}$ - $k_{opt})$ E_{Tx} is the energy utiized by cluster members while transmitting the join requests to the cluster heads
Further simplifying this equation gives :

$$E_{CM} = (N_{nodes} - k_{opt})lE_{elec}^{Rx} + (N_{nodes} - k_{opt})[lE_{elec}^{Tx} + l\varepsilon_{fs}d_{toCH}^{2}]$$

3.4 Equations for Steady-State Phase

Equations for Steady-State Phase are :

1. The following equation represents the Energy spent by a CH during the Steady State phase in one round :

$$E_{CH} = (\frac{N_{nodes}}{k_{opt}} - 1)lE_{elec}^{Rx} + \frac{N_{nodes}}{k_{opt}}lE_{DA} + lE_{elec}^{Tx} + l\varepsilon_{amp}d_{toBS}^{n}$$

2. The following equation represents the Energy spent by a Cluster Member during steady-state phase in a round :

$$E_{CM} = lE_{elec}^{Tx} + l\varepsilon_{amp}d_{toCH}^{n}$$

3. The following equation represents the Energy spent by a Cluster in a round :

$$E_{cluster} = E_{CH} + (\frac{N_{nodes}}{k_{opt}} - 1)E_{CM}$$

4. The following equation represents the Energy spent one round :

$$E_{round} = k_{opt}E_{Cluster}$$

Chapter 4

Problems And Proposed Approach

4.1 Problems

Throughout the study of literature we have identified the problems in LEACH-C protocol. Some of those are listed below.

1. High congestion during setup phase.
2. In every round each node sends energy/location to BS.
3. No realistic radio model used.
4. Unreliable BS announcements.
5. Direct communication of energy/location to BS.

4.2 Suggested Approach

As listed above there are some problems that is needed to be solved. So to overcome those problems we identified some of the implementation approaches.

1. Static nodes send location only once.
   In LEACH-C protocol, all the sensor nodes sends the information about their location and energy to the BS, at each round. But for static nodes in the field its location remains same throughout the network lifetime. So we need to implement it such that these nodes will send their location only once to the BS so that their energy cosumption will be low and we can improve ntework lifetime.

2. Hybrid approach:

    - BS to Nodes communication : Directly
    - Nodes to BS: For nodes having energy below threshold: Nodes $\rightarrow$ CH $\rightarrow$ BS

    Normally BS is located far away than field where sensors are deployed. And comminication cost from node to BS is very high and more energy consuming. So we can implement an approach which will allow to send data from node to BS directly for nodes having energy above some predined threshold and for nodes having energy below that threshold will send their energy to the CH in its last TDMA scheduled transmission and CH will forward that information to the BS. So by applying this approach we can improve the lifetime of low enregy nodes by reducing their high energy consuming communication.

3. Uniformity in the allocating Cluster members to each cluster :
    In LEACH-C, the number of cluster members of the clusters, in same round, varies a lot. Due to this the nodes which may not be able to reach out just because its message was lost in collission, it can be declared as dead. This is due to the clustering strategy adopted by LEACH-C. If the clustering strategy is replaced by the FCM algorithm rather than using the simulated annealing algorithm, better clusters and hence better results can be obtained.

Chapter 5

Clustering Methods

5.1 Simulated Annealing Algorithm

- Simulated Annealing Algorithm :

  According to the simulated annealing algorithm, in the initial round, random nodes are selected as CHs. These nodes perform all the tasks of the CHs i.e. of announcements of TDMA schedule and data aggregation and also sending aggregated data to the BS. In LEACH-C, in our approach, we have assumed that all the nodes have equal amount of initial energy. So all the nodes which were able to send their location and energy information to the BS, in first round, are considered to be eligible for becoming the CH.

  Now according to the simulated annealing algorithm, random nodes are elected for the CH position. Then the minimum cost of all the nodes is found from all other CHs. Now using the location information of the other nodes, another set of the CHs are selected from the neighborhood of the current CHs. Again the minimum cost of all the nodes is found from newly formed CHs. Now if the cost of newly formed CH is less than any other CHs in the previous set, then it will replace the older CH with more cost.

  This process of forming new set of clusters and then comparing the cost for the optimal set of CHs is repeated random number of times. Then those nodes are selected as CHs which have minimum cost at the time of the termination of the condition. Thus the CHs that are obtained are placed at approximately minimum distance from the other nodes. The nodes becomes the member of those cluster whose CH is at minimum distance as compared to all other CH.

5.2 CHs selection results

- After running the simulations for different number of nodes varying from 50 to 200 nodes, the following observations are taken: The number of CH is fixed but the number of cluster members is not uniform.

  For example for 50 nodes scenario 3 CHs are to be selected. On the basis of simulated annealing algorithm the 3 CHs are selected. According to the Euclidean distance, cluster membership is decided by the nodes itself and the joining request is sent to all the CH accordingly. In the initial phase all the CHs get almost equal number of cluster members around 12-17 members per CH. But somewhere in the middle of the simulation, this distribution of the cluster members becomes non-uniform. For instance, one CH gets around 24 cluster members another get 15 while the last CH may get 7 cluster members. This creates the imbalance in the network i.e. some of the nodes may not be reached out by their CH; some nodes may run out of energy, while some nodes may remain idle and thus waste their energy in the idle state. The above conditions can be clearly seen in the following graphs.

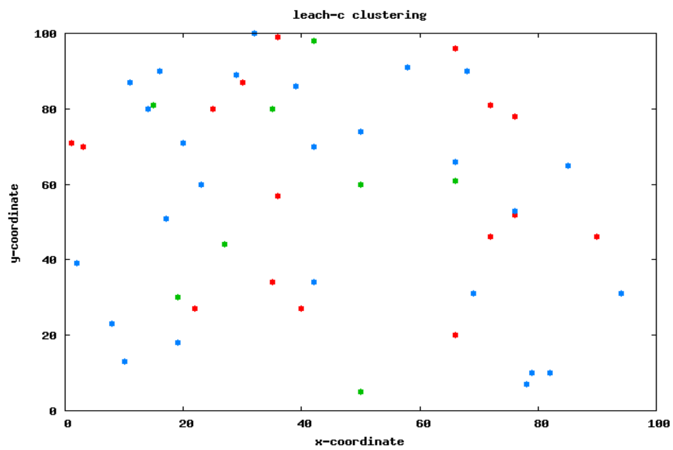

Figure 5.1: 50 nodes cluster formation with LEACH-C

This is due to the clustering strategy applied with simulated annealing algorithm used by the LEACH-C. If this clustering strategy is replaced with some other efficient clustering strategy, the better clusters and hence better results can be obtained.

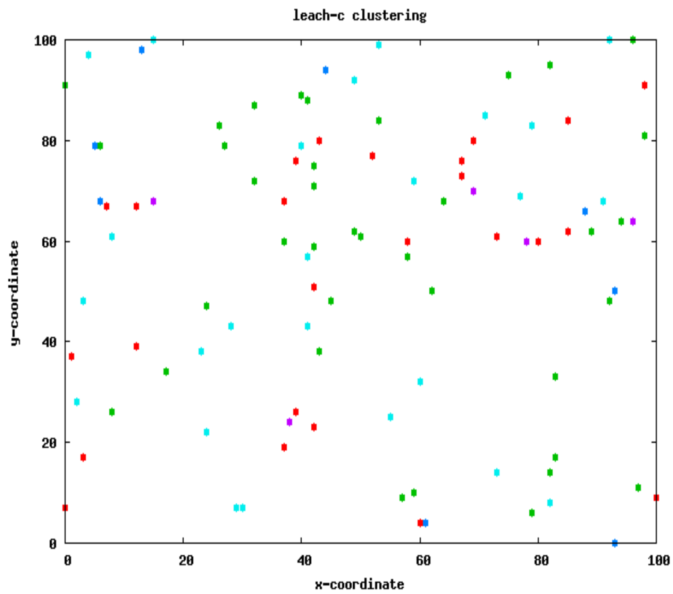

Figure 5.2: 100 nodes cluster formation with LEACH-C

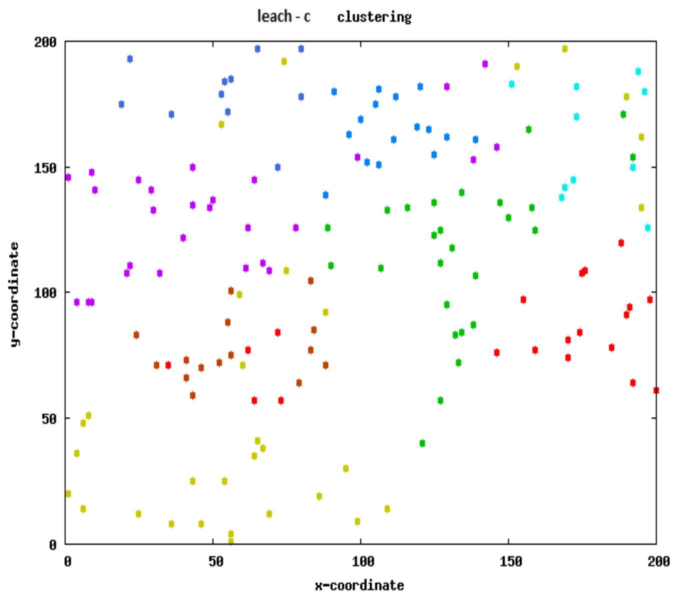

Figure 5.3: 150 nodes cluster formation with LEACH-C

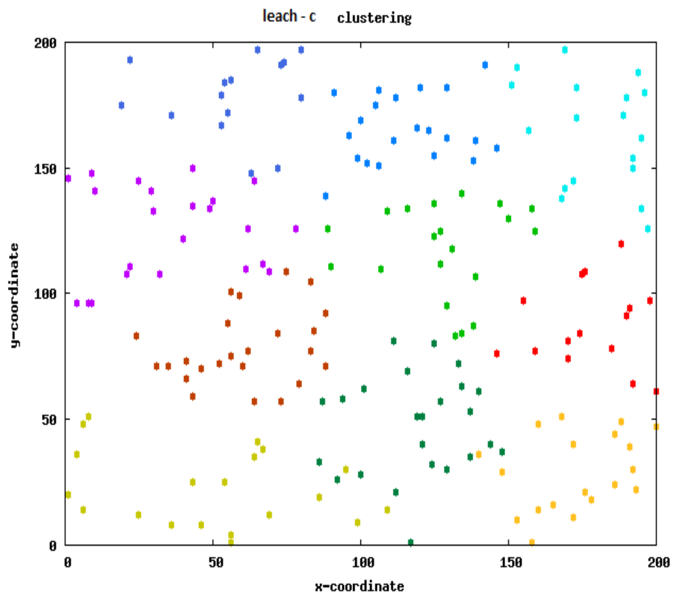

Figure 5.4: 200 nodes cluster formation with LEACH-C

5.3 Fuzzy c-Means algorithm

- One such clustering strategy which can be used is FCM (Fuzzy c-Means) approach. Forming optimal clusters and that too of optimal size affects significantly on the network lifespan. Here, FCM is used for dividing the nodes into different clusters and thus decide the optimal count of the cluster using the Euclidean distance.

  In LEACH-C, it is stated that the optimal number of clusters is 5%. A method based on objective function is used to divide a given dataset into different set of clusters. In Fuzzy clustering approach, there are possibilities of assigning one point to more than one group, in contradiction to the standard approach where one point is assigned to only one group. This is done to handle the overlapping clusters effectively, but the degree of their membership varies accordingly. The degree is calculated as the distance of the cluster node from the CH of each cluster. The cluster node becomes the part of that cluster with which it has highest degree of membership. Many real-time problems are fuzzy in nature. For dividing the data points into a given number of Clusters, Fuzzy algorithms with fuzzy boundaries are used prominently.

In the context of wireless sensor networks, the fuzzy clustering allows a node to be in more than one cluster, to maintain overlapping clusters, with unlike degree of membership. The objective behind the overlapping clusters is to sustain the clustering protocol against the nodes failure and for the provision of multiple paths among the pairs of the overlapping clusters. The number of clusters can be defined on the prior basis or it can be done automatically using different cluster strength measures.

In 2010, Gagarine Yaikhom wrote a program, for Fuzzy c-Means algorithm, while learning CWEB. Dunn developed this algorithm and it is mainly used when the cluster number is already defined. In this algorithm the data points are kept in one of the clusters. The difference in this algorithm and others is that it will calculate the likelihood of the belongingness of node to the cluster and not the absolute membership of the node. For this the accuracy of the clustering process is to be pre-defined. On the basis of that accuracy that is needed, a tolerance value is decided.

As compared to simulated annealing algorithm, it is fast because it does not calculate absolute membership and hence the algorithm will iterate only the number of times the accuracy is needed, cutting down the large number of random iterations. In FCM algorithm, during each iteration, the following function D is minimized:

$$D = \sum_{i=1}^{nn} \sum_{j=1}^{CH} \delta_{ij} \left\| x_i - c_j \right\|^2 \tag{5.1}$$

- Here, nn is the total number of nodes or data points, CH is the predefined number of clusterheads, for cluster j c_j is the centre vector, and ij is the degree of membership for the ith data point x_i in cluster j. The norm function measures the closeness of the data points with the CHs of the cluster to decide the membership in the cluster. For every iteration the array of the CH is maintained in this algorithm.[14][15]

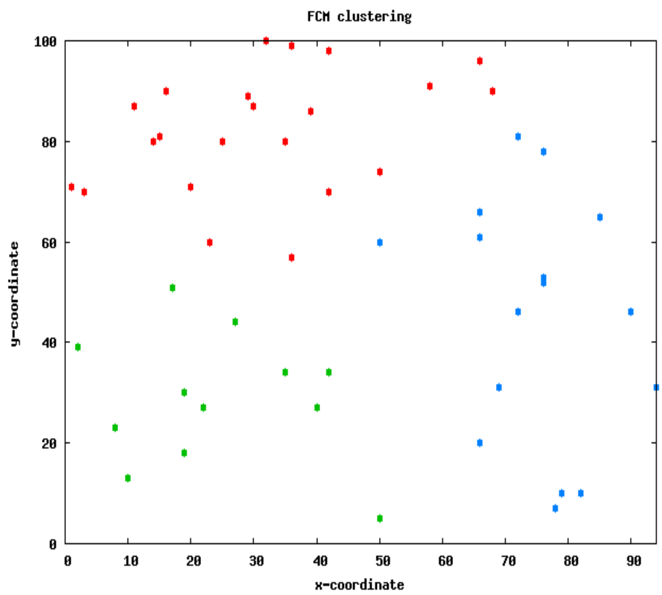

Figure 5.5: 50 nodes cluster formation with FCM

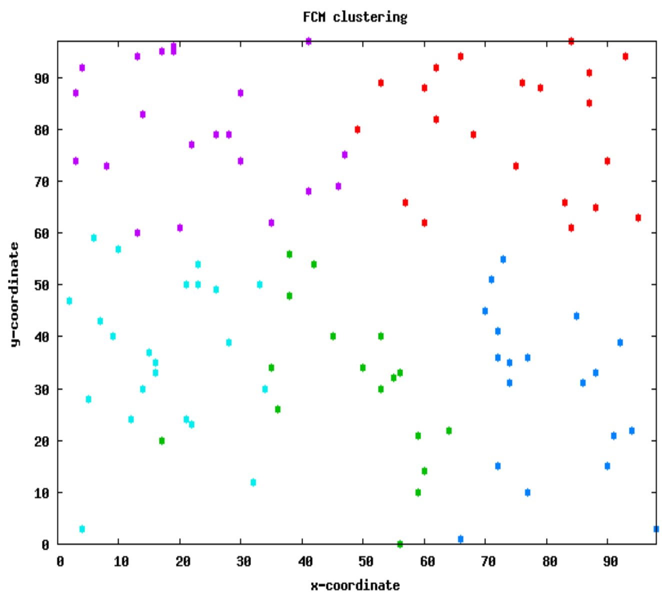

Figure 5.6: 100 nodes cluster formation with FCM

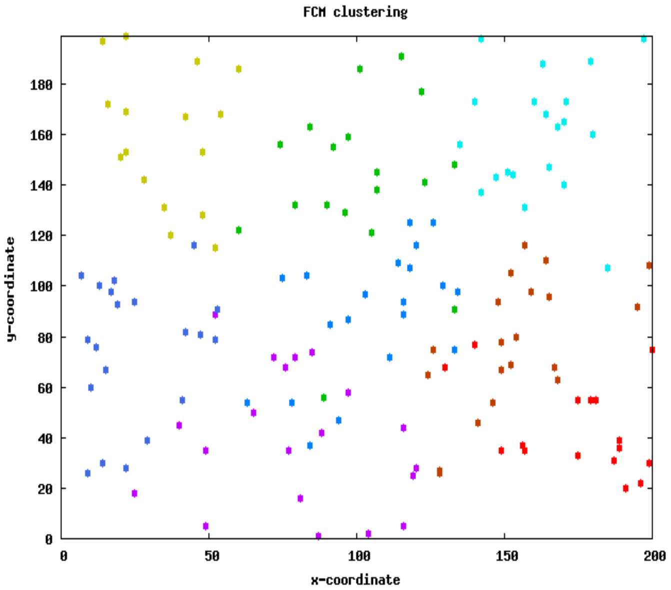

Figure 5.7: 150 nodes cluster formation with FCM

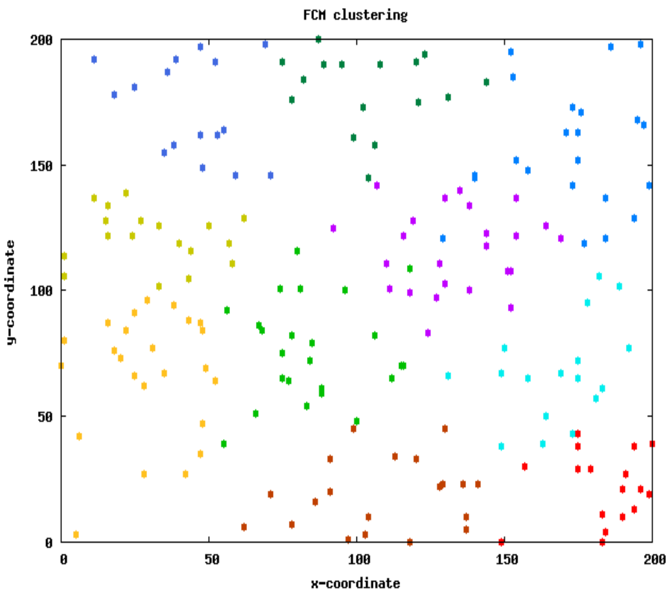

Figure 5.8: 200 nodes cluster formation with FCM

Chapter 6

Simulations

6.1 Network Simulator

Ns2 is the simulation tool used for simulating different network scenarios. This tool is specially used for doing research in the field of networks. There are many other simulators for simulating different routing protocols but the major reason for using NS2 is that it provides inbuilt support for wireless networks, and other routing protocols.

1. Following steps are to be followed to install ns-2 on our Virtual Machine:

    - It is assumed that Fedora 14 is an existing OS.
    - First of all we need to download certain packages:
        (a) Tcl/Tk
        (b) OTcl
        (c) libTck
        (d) ns-2
        (e) nsallinone
    - All the above file should be un-archived and installed in the root directory.
    - Now because we are using Fedora 14, we have to make changes in the following files:
        (a) ns-allinone-2.34/ns-2.34/mobile/nakagami.cc
            – On line 183: replace ErlangRandomVariable::ErlangRandomVariable with ErlangRandomVariable

- On line 185: replace GammaRandomVariable::GammaRandomVariable with GammaRandomVariable

(b) In ranvar.cc, the changes are to be made on line 219.

- Replace GammaRandomVariable::GammaRandomVariable with GammaRandomVariable

- Now installation process is started by: .\install
- Also few instructions to change the PATH of the TCL library are given, which should be followed strictly.
- Now ns is ready for validation .\validate
- At the end we will get the message that validation is successful.

2. Install LEACH on NS-2.34

- For this, ns-2.34 should be installed on the system (follow above steps).
- Let the home directory of ns-2.34 be /abc/ns-allinone-2.34
- Now download the package called ns-234-leach.tar.gz in directory /abc/ns-allinone-2.34/ns-2.34.
- The download the leach-setup.sh bash file in the path /abc/ns-allinone-2.34/ns-2.34.
- Now, if the home directory of "ns-2.34" is not "/abc/...", then find "/abc/ns-allinone-2.34" and replace with "yourpath/ns-allinone-2.34" for the file "leach-setup.sh".
- Then, move to the directory "/opt/ns-allinone-2.34/ns-2.34" and patch the file "leach-setup.sh".

  (a) cd /abc/ns-allinone-2.34/ns-2.34/

  (b) bash leach-setup.sh

- If the home directory of "ns-2.34" is not "/abc/...", then you need to find "/opt/ns-allinone-2.34" and replace with "yourpath/ns-allinone-2.34" for the follwoing two files:

(a) "Makefile" : which can be found in the directory "yourpath/ns-allinone-2.34/ns-2.34".

(b) "Makefile.in" : which can be found in the directory "yourpath/ns-allinone-2.34/ns-2.34".

- After doing all the above changes, run the following commands

  (a) ./configure

  (b) make clean

  (c) make depend

  (d) make

- If the above commands passed successfully then test "Leach" by running test file

6.2 Simulation Parameters for LEACH-C :

Before starting simulation, scenarios are to be defined. For simulation purposes, It is considered a sensor field measuring 1000x1000 and sensor nodes are scattered all over the field. The parameters as set during simulation are:

Table 6.1: for 50 and 100 nodes

Parameter	value
Node distribution	(0,0) to (100,100)
BS location	(50,50)
No. of Nodes	50,100
Initial Node Energy	2J
Simulation Time	3600s

Table 6.2: for 150 and 200 nodes

Parameter	value
Node distribution	(0,0) to (200,200)
BS location	(100,100)
No. of Nodes	150,200
Initial Node Energy	2J
Simulation Time	3600s

6.3 Simulation results of proposed approaches

The steps given below are taken to do the simulation :

- Four scenarios with different number of nodes are simulated. i.e 50,100,150,200 nodes
- For each scenario 5 different topologies are considered. i.e 5 results for 5 random positions for 50 nodes and so on. The results are averaged so that comparison can be done

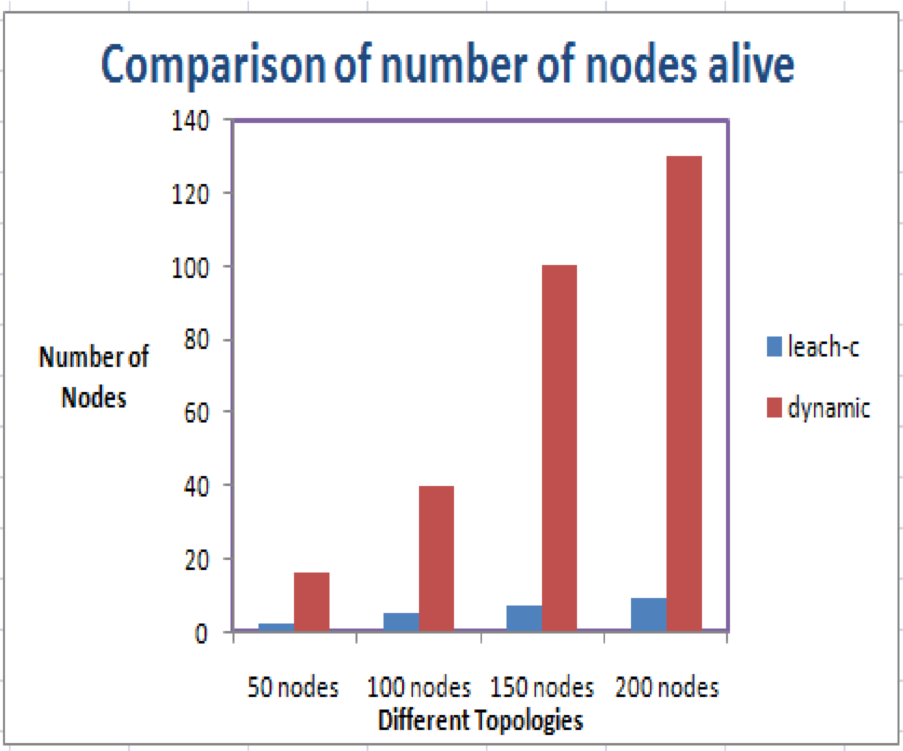

Figure 6.1: Network Lifetime comparison

1. As shown in the Figure 6.1, the network lifetime increases by 9%, when dynamic clustering is implemented in LEACH-C. Also the number of nodes alive for this modified algorithm when all the nodes in the network dies in LEACH-C, is 800% more. The results in the graphs are compared for original LEACH-C and the LEACH-C modified with dynamic clustering.

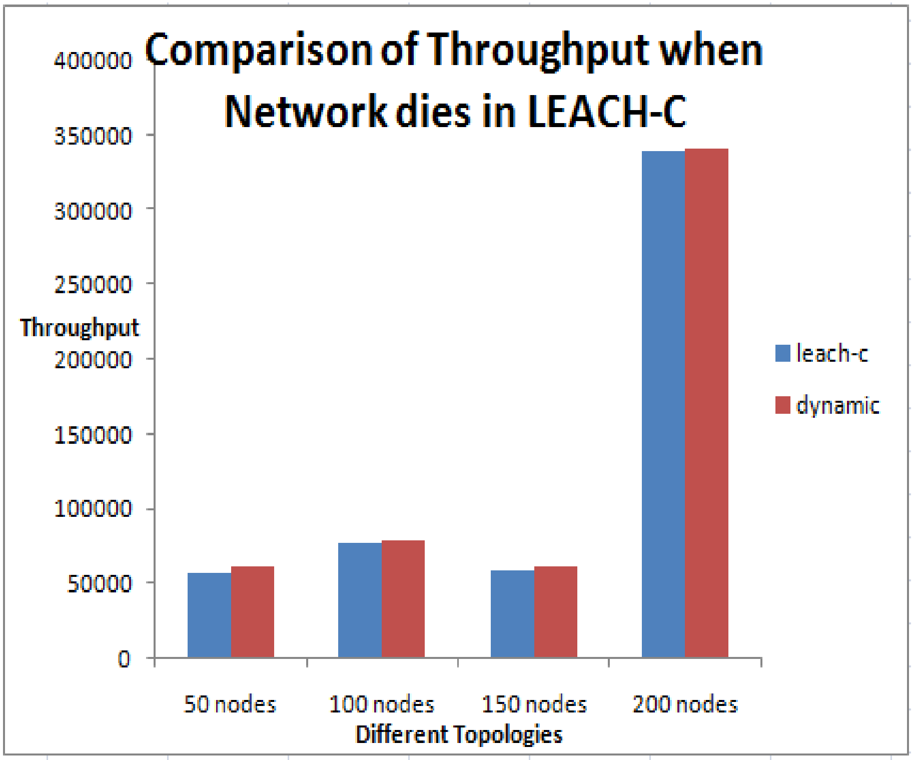

Figure 6.2: Throughput comparison : when leach-c gets completed

2. The Figure 6.2, shows the comparison of the throughput achieved when all the nodes in the network are died in LEACH-C. The throughput achieved is almost similar, but we can say that it is also improving as the network lasts longer.

3. The Figure 6.3, shows the comparison of the throughput achieved when all the nodes in the network are died in both the protocols. The throughput achieved is 3% higher for number of nodes till 150 while it is more than 5% for the network having nodes more than 150. So the dynamic clustering proves to be scalable.

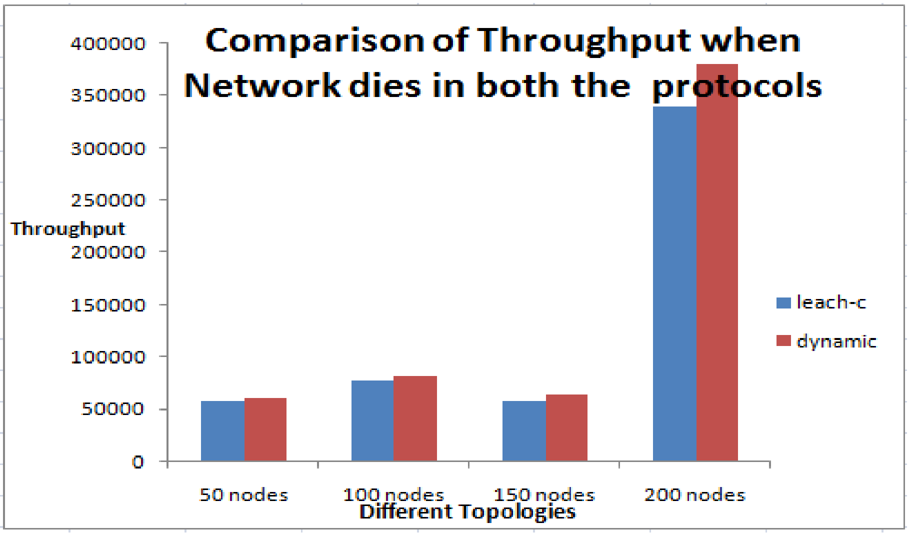

Figure 6.3: Throughput comparison : when both gets completed

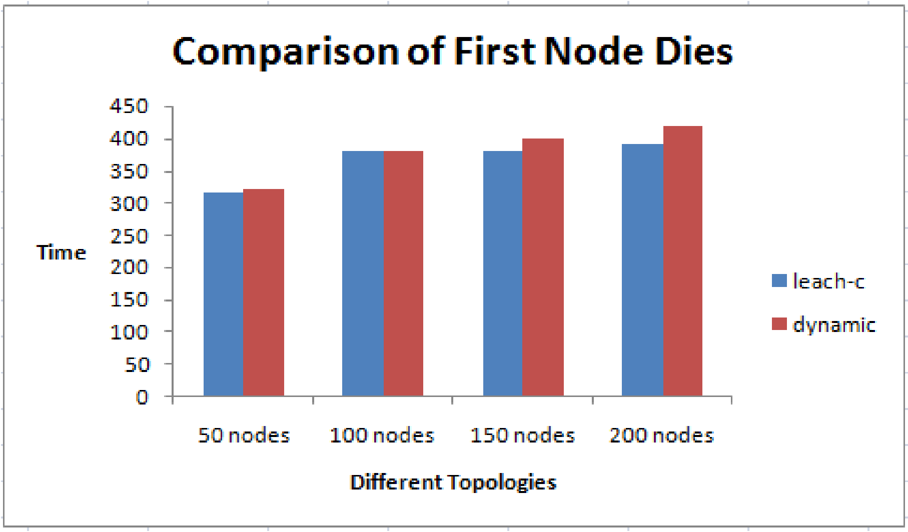

Figure 6.4: Time taken by First node to die

4. The Figure 6.4, shows the comparison of the time when the first node dies in both the protocol. It is clearly seen in the figure that there is not much difference in the time when the first node dies in the network, but if we compare that with the Figure 6.5, we can say that the time taken by the half network to die is 1.5% high. This impact is due to the fact that number of CHs changes dynamically according to the need of the network. This contributes to increase Network Lifetime and hence the

network throughput.

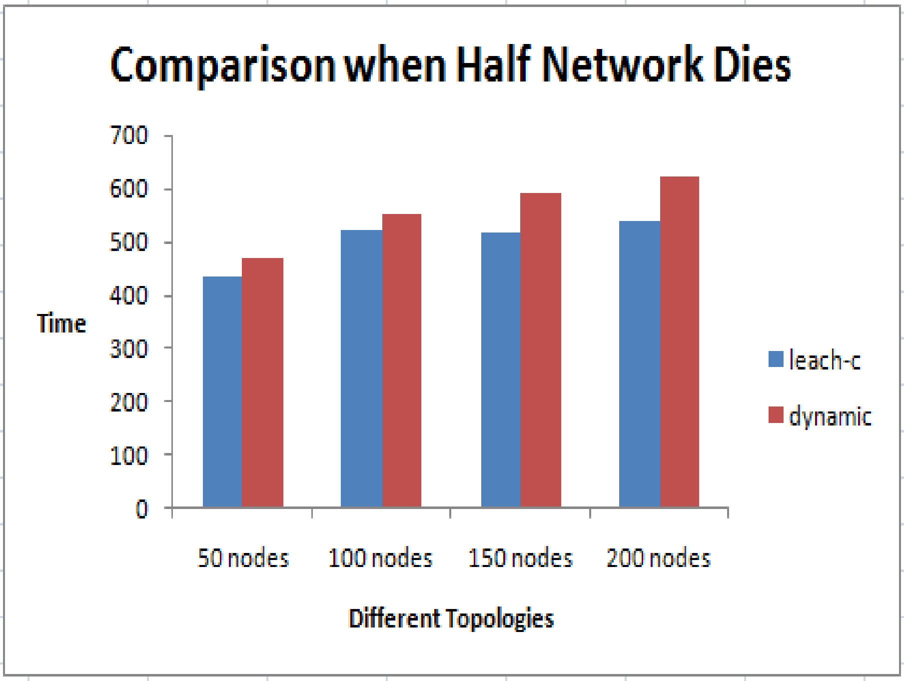

Figure 6.5: Time taken by half network to die

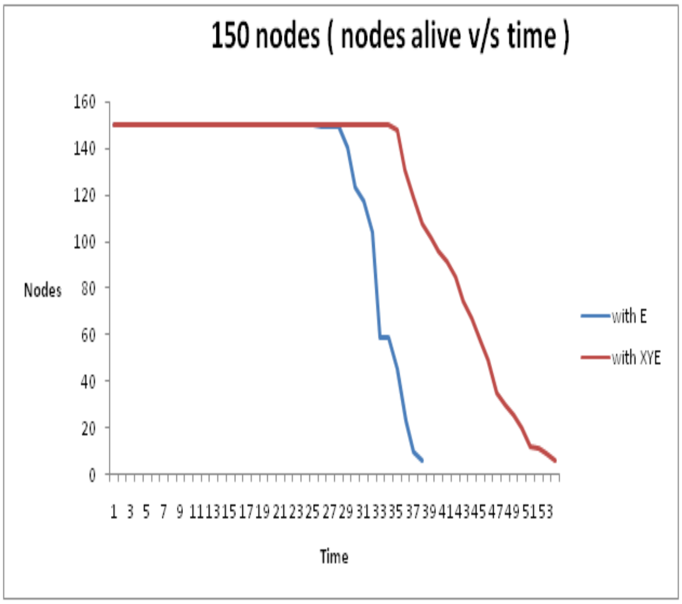

Figure 6.6: Nodes alive v/s Time-150 nodes

6.3.1 Simulation Results for LEACH-C without sending Location information in every round

In the following graphs, the comparison is done between two different scenarios where the parameters like position and energy are changed.In the graphs XY line shows the results taken when the XY locations are sent only once i.e in the first round. Then in all the upcoming rounds the CHs are updated only with Energy.In the graphs XYE line shows the scenario results when energy is not sent in the first round to BS as it is assumed that all the nodes have equal energy in the first round. The comparison results for these two scenario are taken with respect to following two parameters :

1. Nodes Alive v/s Time

2. Energy v/s Time

- The results, Figure 6.6, 6.7, for XY and XYE comparisons,for nodes alive, show that the number of nodes alive is more at any given point of time for XYE then XY. This increases the network lifetime.

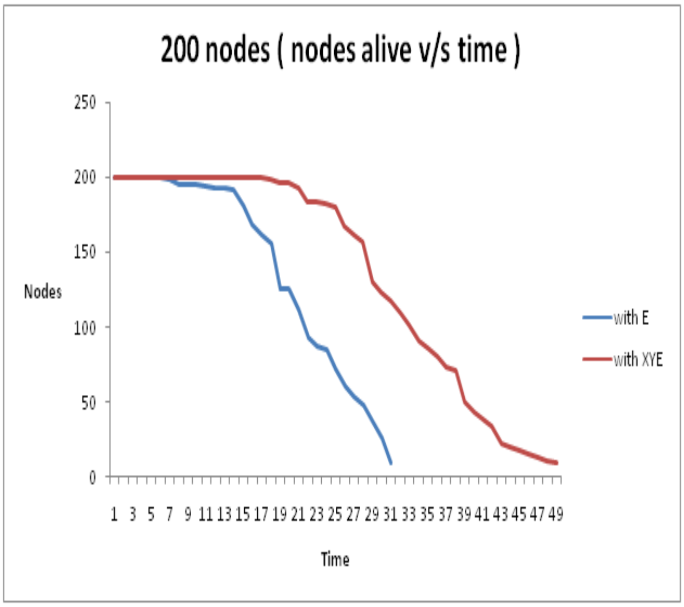

Figure 6.7: Nodes alive v/s Time-200 nodes

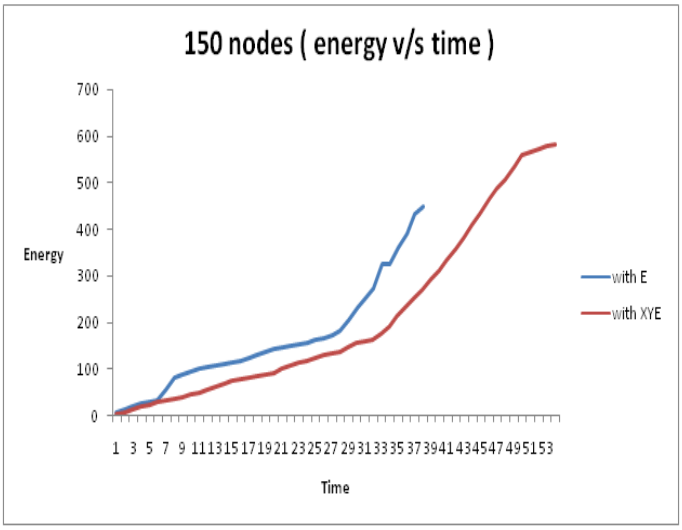

Figure 6.8: Energy Spent v/s Time-150 nodes

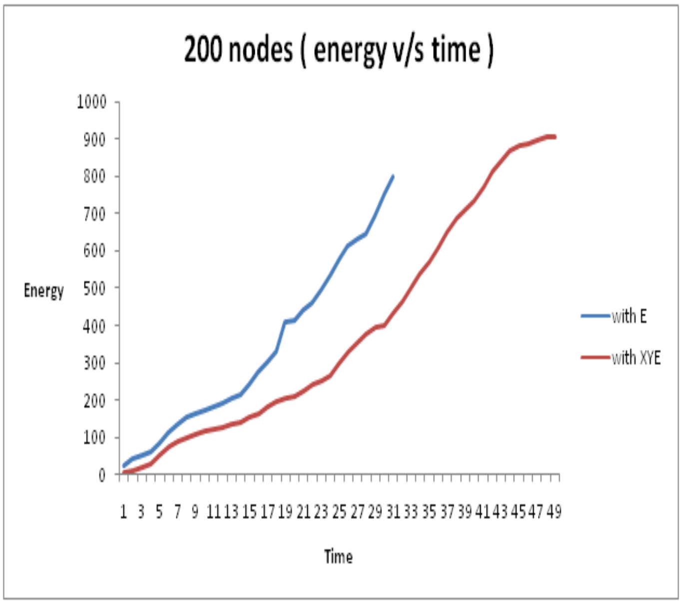

Figure 6.9: Energy Spent v/s Time-200 nodes

- The results for XY and XYE comparisons,for energy spent, Figure 6.8, 6.9, show that the energy spent at any given point of time for XYE is less then XY. This increases the nodes lifetime and hence network lifetime.

  The following graphs are comparison of Three protocols : leach, leach-c, and modified leach-c. Modified leach-c is our third proposed approach, where CH-THR is taken into account for CH election process.

  - The figures 6.10, 6.11, 6.12, clearly states the steadiness in the death of the nodes as compared to the other two protocols. Hence we can also rely on it for the delivery of the messages.

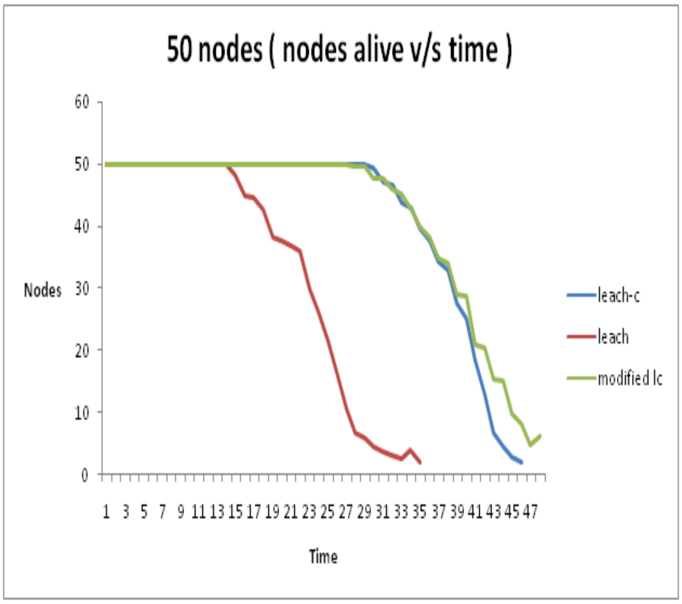

Figure 6.10: Nodes alive v/s Time-50 nodes-Leach-C-Modified

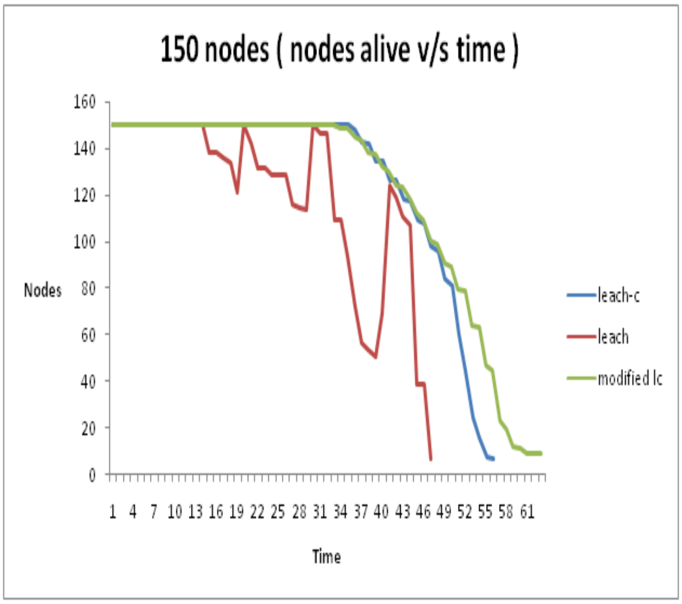

Figure 6.11: Nodes alive v/s Time-150 nodes-Leach-C-Modified

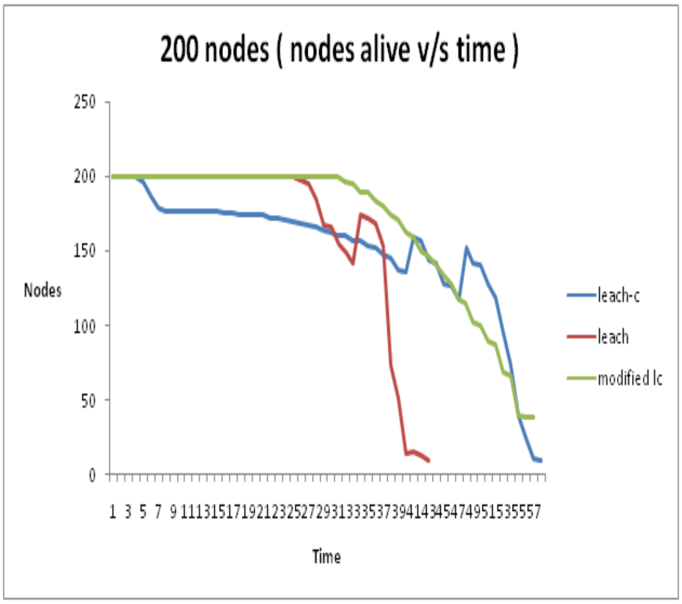

Figure 6.12: Nodes alive v/s Time-200 nodes-Leach-C-Modified

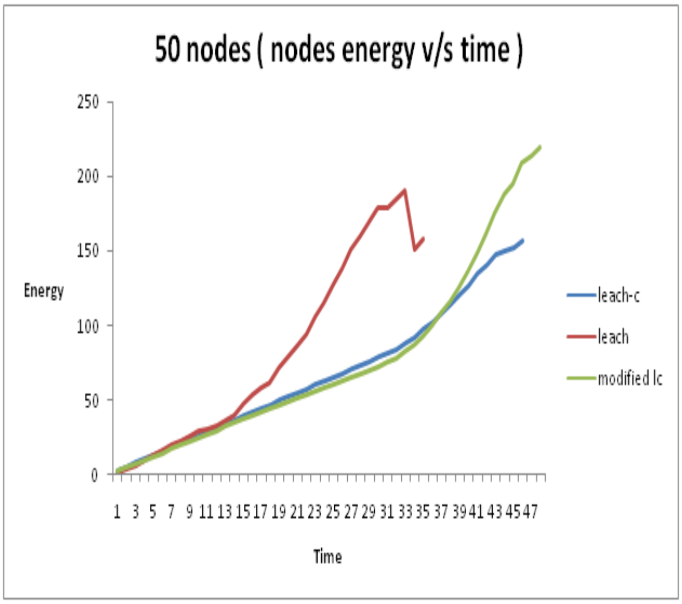

Figure 6.13: Energy Spent v/s Time-50 nodes-Leach-C-Modified

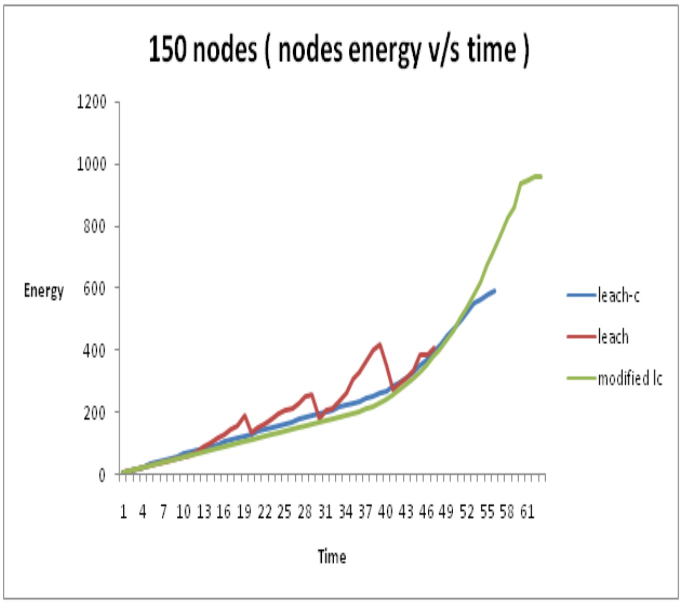

Figure 6.14: Energy Spent v/s Time-150 nodes-Leach-C-Modified

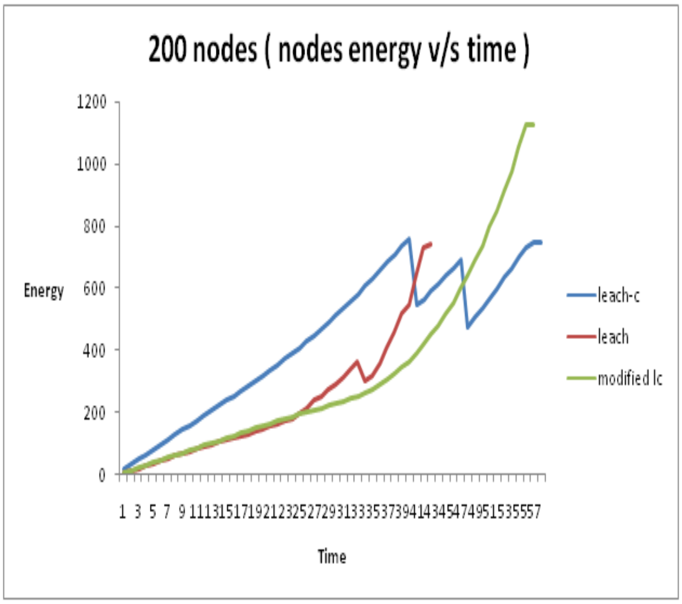

Figure 6.15: Energy Spent v/s Time-200 nodes-Leach-C-Modified

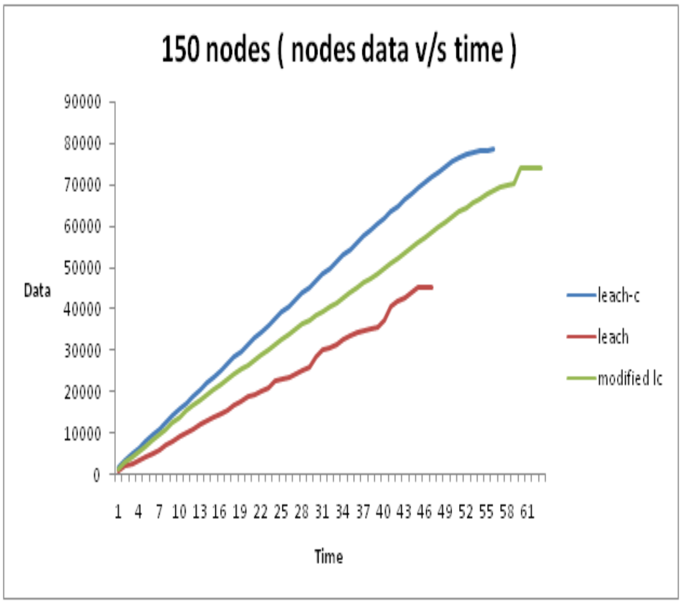

Figure 6.16: Data Sent v/s Time-150 nodes-Leach-C-Modified

- From the graphs 6.13, 6.14, 6.15, we can interpret that the energy usage of modified leach-c is more, but at any given point of time till the network is alive in another two protocols, the energy usage is either less or equal to the energy usage of leach-c. Hence we can say that the modified protocol is energy efficient.

- The graphs 6.16, 6.17 clearly states that the throughput of modified leach-c is between leach and leach-c protocol. The positive note is that it is nearer to the leach-c and may be improved on further modifications.

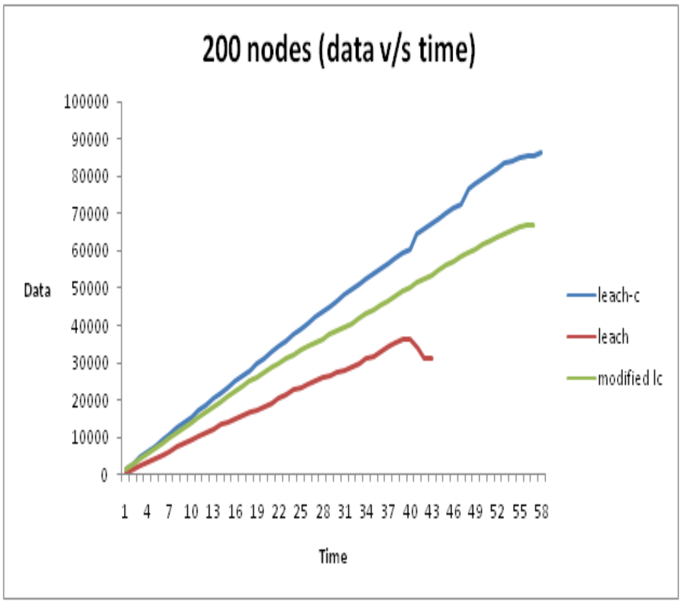

Figure 6.17: Data Sent v/s Time-200 nodes-Leach-C-Modified

Chapter 7

Conclusion and Future Work

The cluster head selection is important parameter in the cluster based routing protocol. Using FCM algorithm the clusters are formed with approximately equal number of cluster members in every cluster. Also the computation is very fast as compared to simulated annealing algorithm.

If we try to implement dynamic clustering in LEACH-C, on the basis of the number of nodes alive in the network at any given point of time, then the results are degraded even with 5% of CHs. But by applying dynamic clustering by selecting different number of CHs, the improving results obtained. Also as the number of nodes increases in the network, more satisfactory results can be obtained. The simulations are done by keeping BS in center each time. If the position of BS is altered, the results are also varying accordingly.

The nodes in the network start dying after certain period of time. If the number of nodes are more, than there is steep fall in the number of nodes alive once the nodes starts dying. To control this node death rate the only nodes that are eligible to become member should be taken into account for minimum cost calculations and a check on the number of iterations of the simulated annealing algorithm can be kept. This can further contribute to reduce energy consumption and higher throughput with more network lifetime.

Chapter 8

Publication

1. Gaurang Raval, Abhinav Shah, Madhuri Bhavsar, "OPTIMIZATION OF CLUSTERING TECHNIQUES USING ENERGY THRESHOLDS IN WIRELESS SENSOR NETWORKS", IJARET, Volume 4, Issue 7, November - December 2013, pp. 247-257.

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