Study of
Energy Efficient Clustering Algorithms
for Wireless Sensor Network

Abhimanyu Kumar Gupta
(109CS0145)

Rupali Patro
(109CS0173)

Department of Computer Science and Engineering
National Institute of Technology Rourkela
Rourkela-769 008, Orissa, India

Study of Energy Efficient Clustering Algorithms for Wireless Sensor Network

Thesis submitted in partial fulfillment

of the requirements for the degree of

Bachelor of Technology

in

Computer Science and Engineering

by

Abhimanyu Kumar Gupta

(Roll: 109CS0145)

&

Rupali Patro

(Roll: 109CS0173)

under the guidance of

Prof. Suchismita Chinara

NIT Rourkela

Department of Computer Science and Engineering
National Institute of Technology Rourkela
Rourkela-769 008, Orissa, India

May 2013

Department of Computer Science and Engineering
National Institute of Technology Rourkela
Rourkela-769 008, Orissa, India.

May 10, 2013

Certificate

This is to certify that the work in the thesis entitled ***Study of Energy Efficient Clustering Algorithms for Wireless Sensor Network*** by ***Abhimanyu Kumar Gupta*** & ***Rupali Patro*** is a record of an original research work carried out under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Computer Science and Engineering. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

Dr. Suchismita Chinara
Assistant Professor
CSE department of NIT Rourkela

Acknowledgment

We would like to express our earnest gratitude to our project guide, Prof. Suchismita Chinara for believing in our ability to work on the challenging domain of WSN routing. Her profound insights has enriched our research work. The flexibility of work she has offered us has deeply encouraged us producing the research.

We are highly indebted to Prof. Ashok Kumar Turuk, Head-CSE Department, for his continuous encouragement and support, as he has always been eager to help. We are also thankful to Prof. S.K. Rath, Prof. S. K. Jena, Prof. B. Majhi and all the faculty members and staffs of the department for their support.

We are thankful to all our friends. Our sincere thanks to everyone who has provided us with inspirational words, a welcome ear, new ideas, constructive criticism, and their invaluable time, we are truly indebted.

We must acknowledge the academic resources that we have acquired from NIT Rourkela. We would like to thank the administrative and technical staff members of the department who have been kind enough to advise and help in their respective roles.

Last, but not the least, we would like to dedicate this project to our families, for their love, patience, and understanding.

Abhimanyu Kumar Gupta

Rupali Patro

Abstract

Wireless sensor networks (WSNs) have a wide range of applicability in many industrial and civilian applications such as industrial process monitoring and control, environment and habitat monitoring, machine health monitoring, home automation, health care applications, nuclear reactor control, fire detection, object tracking and traffic control. A WSN consists of spatially distributed autonomous sensors those cooperatively monitor the physical or environmental conditions including temperature, sound, vibration, motion, pressure or pollutants. In sensor networks where the environment is needed to be remotely monitored, the data from the individual sensor nodes is sent to a central base station (often located far from the network), through which the end-user can access data. A number of routing protocols for WSN are designed in this context.

Energy utilization and network life time are key issues in design of routing protocols for Wireless sensor network. Many algorithms have been proposed for reducing energy consumption and to increase network life time of the WSN. Clustering algorithms have gained popularity in this field, because of their approach in cluster head selection and data aggregation. LEACH (distributed) is the first clustering routing protocol which is proven to be better compared to other such algorithms.

TL-LEACH is one of the descendants of LEACH that saves better the energy consumption by building a two-level hierarchy. It uses random rotation of local cluster base stations (primary cluster-heads and secondary cluster-heads) to better distribute the energy load among the sensors in the network especially when the density of network is higher. As the clusters are adaptive in LEACH and TL-LEACH, poor clustering set-up during a round will affect overall performance. However, using a central control scheme for cluster set-up may produce better clusters by distributing the cluster head nodes throughout the network. LEACH-C (centralised) is another modification to LEACH that realizes the above idea and provides better results through uniform distribution of cluster heads avoiding redundant creation of cluster heads in a small area.

In our project, we propose a centralized multilevel scheme called CML-LEACH for energy efficient clustering that assumes random distribution of sensor nodes which are not mobile. The proposed scheme merges the idea of multilevel hierarchy, with that of the central control algorithm providing uniform distribution of cluster heads throughout the network, better distribution of load among the sensors and improved packet aggregation. This scheme reduces energy consumption and prolongs network life time significantly as compared to LEACH, TL-LEACH and LEACH-C. The simulation results show comparisons of our scheme with the existing LEACH, TL-LEACH and LEACH-C protocols against chosen performance metrics, using Omnet++.

Contents

List of Figures

List of Abbreviations

DR_{CH}	Diffusion Ratio at CH
DR_{MCH}	Diffusion Ratio at MCH
E_{amp}	Energy in Amplification
E_{elec}	Energy by Electric Circuitry
BS	Base Station
CDMA	Code Division Multiple Access
CH	Cluster Head
CML-LEACH	Centralized Multilevel LEACH
EDA	Energy for Diffusion or Aggregation
GPS	Global Positioning System
LEACH	Low-Energy Adaptive Clustering Hierarchy
LEACH-C	LEACH-Centralized
MCH	Master Cluster Head
PDA	Personal Digital Assistant
TDMA	Time Division Multiple Access
TL-LEACH	Two-Level LEACH
WSN	Wireless Sensor Network

Chapter 1

Introduction

With the advancement in micro-fabrication technology, Wireless Sensor Networks (WSNs) have started to play a vital role in our daily lives. It is because of the reduction in cost of the sensor nodes, leading to increasing deployments of WSNs to a larger extent. Potential applications for wireless sensor networks exist in a variety of fields, including industrial process monitoring and control, environment and habitat monitoring, machine health monitoring, home automation, health care applications, nuclear reactor control, fire detection, object tracking and traffic control. Efficient design and implementation of wireless sensor networks have become a hot area of research in recent years, due to the immense capacity of sensor networks to enable applications connecting the physical world with the virtual world.

It is possible to obtain data about physical or environmental phenomena by networking large number of tiny sensor nodes that was difficult or impossible to obtain in more conventional ways.

1.1 Wireless Sensor Network

A wireless sensor network consists of spatially distributed autonomous sensors those cooperatively monitor the physical or environmental conditions such as temperature, sound, vibration, motion, pressure or pollutants. The WSN is built of "nodes"- from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. A structure of a WSN is shown in Figure 1.1.

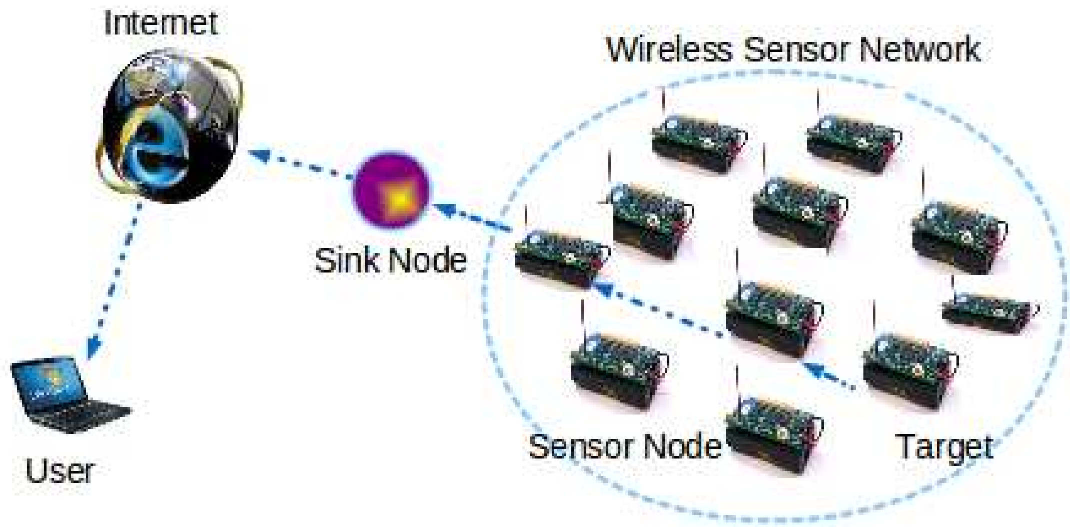


Figure 1.1: Wireless Sensor Network

In sensor networks where the environment is needed to be remotely monitored, the data from the individual sensor nodes is sent to a central base station (often located far from the network), through which the end-user can access data.

The main characteristics of WSNs include,

- Ease of use
- Ability to cope with node failures
- Communication failures
- Scalability to large scale deployment
- Power consumption constrains for nodes that use batteries or Energy harvesting
- Ability to cooperate with harsh environmental conditions, etc.

1.2 Routing in WSN

WSNs are intended for monitoring an environment. The main aim of a wireless sensor node is to collect data from a certain domain, process them and forward it to the sink, where the application lies. However, by guaranteeing the direct communication between a sensor and the sink may drain the nodes' power very quickly, because of higher energy requirement in transferring messages. Therefore, it is sometimes required that the nodes are collaborated to ensure communication of distant nodes with the sink. In this way, messages are propagated through intermediate nodes by establishing a route to the sink. Routing protocols for WSN are in charge of discovering and maintaining the routes in the network [1].

According to the participation style of sensor nodes, routing protocols in WSN can be classified into three categories.

Direct Communication:

In the case of direct communication, any node can send information directly to the Base Station (BS). Applying this routing technique in a very large network may drain the energy of sensor nodes quickly. Its scalability is very small. Example: SPIN.

Flat:

In this type of protocols, if any node desires to transmit data, it first searches for a route to the BS and then transmits the data. In this way, nodes around the BS may drain their energy quickly. Its scalability is average. Example: Rumor routing.

Clustering:

According to the clustering routing protocols, the total area is divided into numbers of clusters. Each cluster has a cluster head (CH) and this cluster head directly communicates with the BS. Nodes in a cluster send their data to their corresponding CHs. Example: TEEN.

1.3 Key Issues in the Design of Routing Protocols for WSN

There are some issues in the design of routing protocols for WSNs because of several constraints in the network. WSNs suffer from the limitations of several network resources such as, energy, bandwidth, computation power and storage. The design challenges in sensor networks involve the following key aspects [2]:

Limited energy capacity:

Since the sensor nodes are battery powered having limited energy capacity, energy is a big challenge for the network designers in hostile environments. For example, in a battlefield, it is almost impossible to access the sensors and recharge their batteries. Also, when the energy of a sensor reaches a certain threshold, it may become faulty and may not be able to function properly, which can have a major impact on the network performance. Thus, routing protocols designed for WSN should be as energy efficient as possible to extend the lifetime of the sensors and hence prolong the network lifetime while guaranteeing decent overall performance.

Sensor locations:

Another challenge that is faced during the design of routing protocols is to manage the locations of the sensors. Most of the protocols assume that the sensors either are equipped with GPS receivers or use some localization technique to learn about their positions.

Limited hardware resources:

The processing and storage capacities of sensors are also limited as the energy capacity. Thus, they can only perform limited computational functionality. These constraints give rise to many challenges in network protocol design for WSN, which must consider not only the energy efficiency of sensor nodes, but also the processing power and storage capacities.

Massive and random node deployment:

Sensor node deployment in WSNs is application dependent and affects the performance of the routing protocol. Sensor nodes can be scattered randomly in a specified area or dropped massively over a remote or hostile region in most of the applications. When the resultant distribution of nodes is un-uniform, optimal clustering helps in connectivity and enabling energy efficient network operation.

Network characteristics and dynamic environment:

A sensor network generally operates in a dynamic and unreliable environment. The network topology, defined by the sensors and communication links between them, changes frequently because of sensor addition, deletion, damages, node failures or energy depletion. Furthermore, the sensor nodes are linked by a wireless medium, which is noisy, susceptible to errors and time varying. Therefore, routing protocols should consider network topology dynamics to maintain particular application requirements in terms of coverage and connectivity.

Data Aggregation:

Sensor nodes may generate significant redundant data. So, similar packets from multiple sensors can be aggregated to reduce number of transmissions. Data aggregation techniques are used to achieve energy efficiency and to optimize data transfer in the routing protocols.

Diverse application requirements:

WSNs have a wide range of applications each having different requirements. No network protocol can meet all the requirements of every application. Hence, routing protocols should guarantee data delivery and its accuracy to provide the sink with the required knowledge about the physical and environmental condition on time.

Scalability:

Routing protocols should be capable of scaling with the network size. Also, sensors need not necessarily have the same capabilities in terms of energy, processing and communication. So, communication links between sensors may not be symmetric (i.e. a pair of sensors may not be able to have communication in both directions). This should be taken care of in the design of routing protocols.

1.4 Clustering in WSN

The major advantage of WSN is the ability to deploy it in an ad-hoc manner[3], as organizing these nodes into groups pre-deployment is not feasible. For this reason, a lot of research has been conducted into ways of creating these organizational structures (or clusters)[4]. A clustering scheme divides the sensor nodes in a WSN into different virtual groups, according to some set of rules. In a cluster structure, sensor nodes may be assigned a different status or function, such as cluster head or cluster member[5].

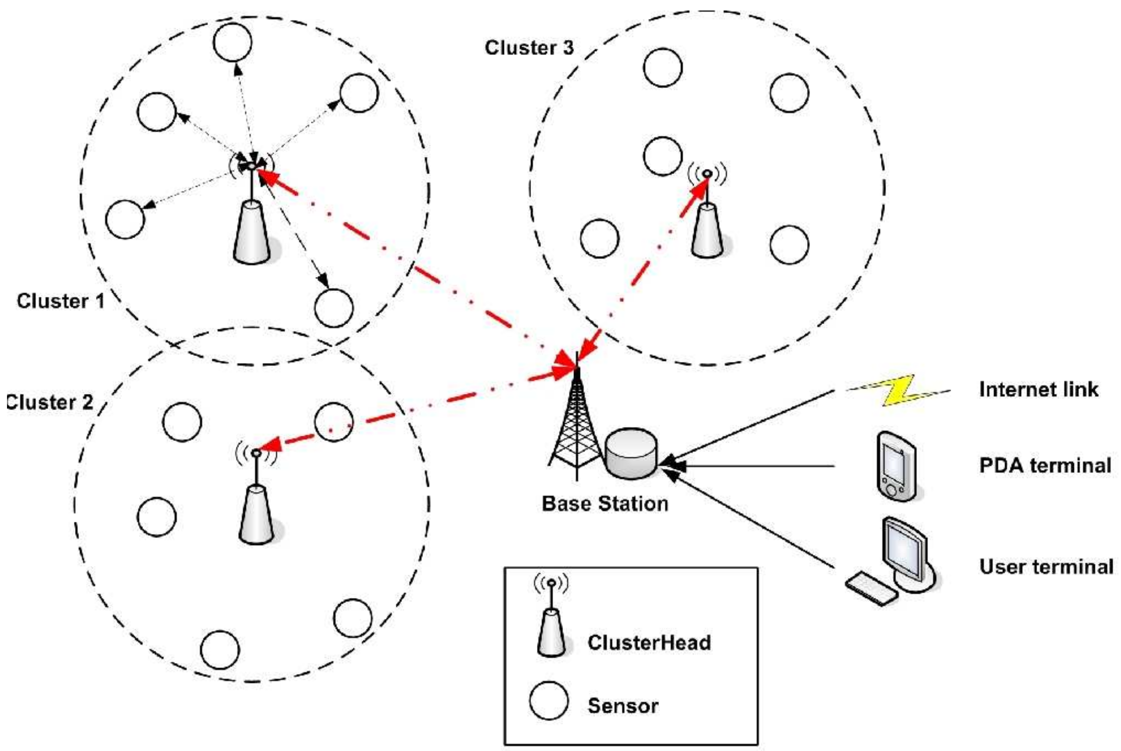


Figure 1.2: Clusters in WSN

We can see in the Figure 1.2, the architecture of a generic WSN, and examine how clustering is an essential part of the organizational structure [4].

Sensor Nodes: Sensor nodes are the building blocks of a WSN. They can play multiple roles in a WSN, such as simple sensing, data processing, data storage and routing.

Clusters: Clusters are the organizational unit of WSNs. The dense nature of WSNs requires them to be broken down into clusters to simplify tasks such as routing.

Cluster heads: Cluster head is the organizational leader of a cluster. It organizes the activities in a cluster. The activities include data-aggregation, diffusion, organizing the communication schedule of the cluster, etc.

Base Station: The base station is often located far from the network. It provides the communication link between the WSN and the end-user.

End User: The data obtained from sensor network can be used for a wide-range of applications. A particular application can make use of the network data over the internet, using a PDA, or even a personal computer. In a queried sensor network, queries are generated by the end user.

1.5 Clustering Algorithms

Many algorithms have been proposed for routing in WSN. Clustering algorithms have gained popularity in this field. Clustering algorithms can be classified as:

- Distributed algorithm,
- Centralized algorithm &
- Hybrid algorithm

In distributed clustering techniques, any node can choose itself as a CH or join an already formed cluster on its own initiative, independent of other nodes. Distributed clustering techniques are further classified into four sub types based on the cluster formation criteria and parameters used for CH election as identity based, neighbourhood information based, probabilistic and iterative. In centralized methods [6], the BS requires global information of the network to control the network. CHs are elected by the base station. Hybrid schemes are composed of centralized and distributed approaches. In a hybrid environment, distributed approaches are used for coordination between CHs, and centralized schemes are followed for CHs to build individual clusters.

In design of routing protocols for WSN, clustering algorithms have following advantages:

- Clustering reduces number of nodes taking part in long distance transmission.
- Clustering algorithms are scalable for large number of nodes.
- They reduce communication overhead.
- Energy is utilized properly by the use of clustering algorithms.

1.6 Problem Statement

The objective of this project is to develop a new clustering algorithm for WSN, improving on the existing LEACH Algorithm and its variations to outperform:

- The network life time.
- Consumption of energy in the network.
- Number of data signals received at the BS.

Chapter 2

Literature Review

LEACH (Low-Energy Adaptive Clustering Hierarchy) is the first clustering routing protocol which is proven to be better compared to other clustering algorithms. It is a distributed clustering algorithm, first proposed in 2000 by W. R. Heinzelman et al. [7]. The authors have suggested a hierarchical adaptive approach in which CHs are selected with a random probability independent of others to organize the nodes into clusters. TL-LEACH is one of the descendants of LEACH proposed by V. Loscri et al. in the year 2005 [8], which introduces a two level hierarchy for cluster formation. It uses random rotation of local cluster base stations (primary cluster-heads and secondary cluster-heads) to better distribute the energy load among the sensors in the network, especially when the density of network is higher. As the clusters are adaptive in LEACH and TL-LEACH, poor clustering set-up during a round will affect overall performance. However, using a central control scheme for cluster set-up may produce better clusters by distributing the cluster head nodes throughout the network. In 2007 Taewook Kang et al. [9] proposed a centralized clustering algorithm, LEACH-C that realizes the above idea and provides better results through uniform distribution of CHs avoiding their redundant creation of in a small area.

2.1 LEACH

The main objectives of LEACH, was to find a way to low consumption of energy in the cluster and to improve the life time of WSN.

LEACH adopts a hierarchical and adaptive approach to organize the network into a set of clusters, managed by selected CHs. The CH carries out multiple tasks, such as periodic collection of data from the members of the cluster, aggregation of data to remove redundancy among correlated values, transmission of the aggregated data directly to the base station through a single hop method, creation and advertisement of a TDMA schedule. In the schedule created by the CH, each node of the cluster is assigned a time slot that can be used by non-CH nodes for transmission. The CHs broadcast the schedule to their corresponding cluster members. For reducing the likelihood of collisions among sensor nodes, LEACH nodes use a code division multiple access (CDMA) based scheme for communication. The network model used by LEACH is depicted in Figure 2.1.

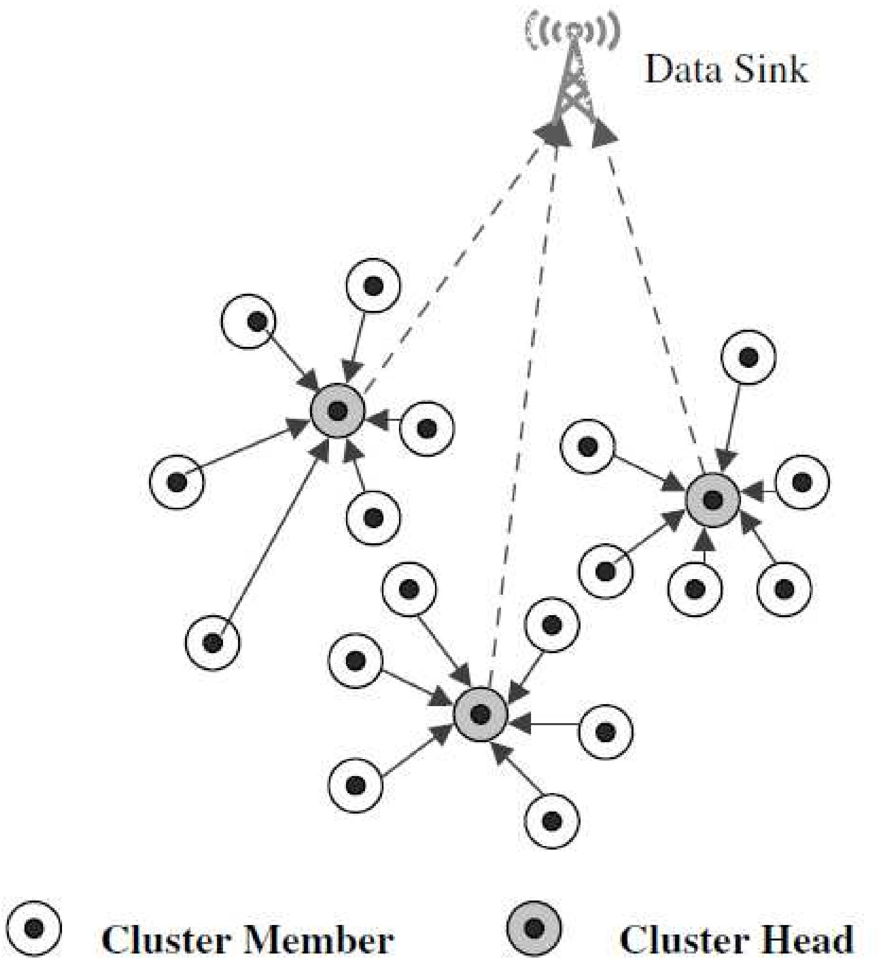


Figure 2.1: A Network Model of LEACH

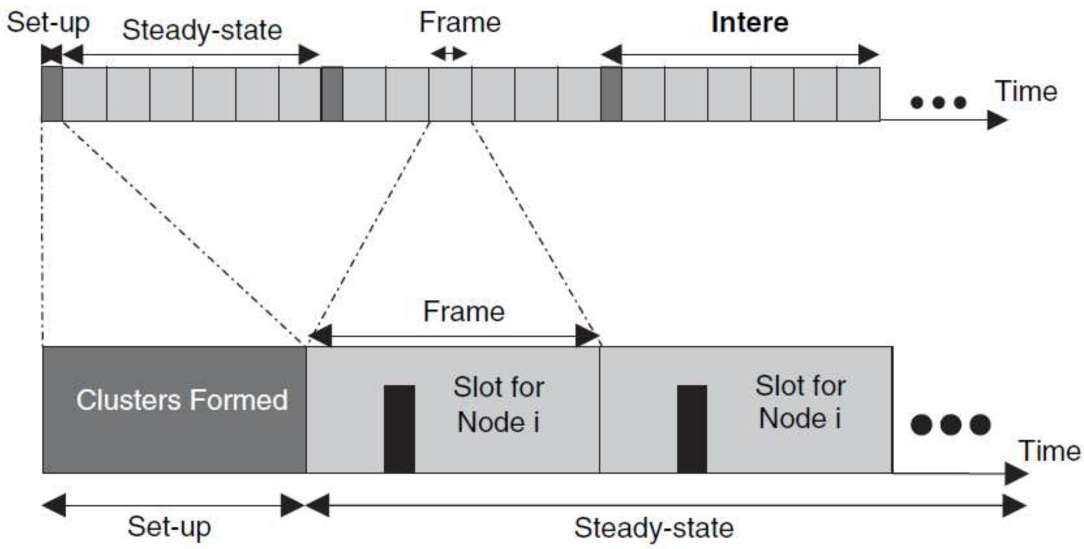


Figure 2.2: Two Phases of LEACH

2.1.1 Operations of LEACH

The basic operation of LEACH consists of many rounds, each round being divided into two phases. The phases of LEACH are illustrated in Figure 2.2.

The first phase called the setup phase consists of three steps,

(i) Cluster-head advertisement,

(ii) Cluster set-up and

(iii) Transmission schedule creation.

The second phase, the steady-state phase, focuses on,

(i) Data transmission to cluster heads,

(ii) Signal processing (data aggregation/fusion) and

(iii) Delivery to the base station.

To minimize the protocol overhead, the duration of the setup phase is assumed to be relatively shorter than the steady-state phase.

At the beginning of the setup phase, cluster-head selection takes place. The role of CH rotates among sensor nodes, thereby distributing energy consumption evenly across the network nodes. To determine if it is its turn to become a CH, a node n, generates a random number x (between 0 and 1), and compares it with the CH selection threshold T(n).

$$T(n) = \begin{cases} \frac{P}{1-P*\left(r mod \frac{1}{P}\right)} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \tag{2.1}$$

Where,

P is the desired percentage of cluster heads,

r is the current round and

G represents the set of nodes that have not been selected as CHs in last 1/P rounds.

The node becomes a CH if its generated value, x, is less than T(n). The CH selection threshold, T(n) is aimed to ensure with high possibility that a predetermined fraction of nodes, P, should be elected as CHs at each round. Further, the threshold ensures that the nodes, those have been CHs in last 1/P rounds, will not again be selected in the current round. At the completion of the CH selection process, every node that is selected as a CH, advertises its new role to the rest of the network. Upon receiving the advertisements, each remaining node selects a cluster to join based on the received signal strength (or Euclidian distance). Then the nodes inform their corresponding CHs of their desire to become a member of the cluster. Once the cluster is formed, each CH creates and distributes a TDMA schedule that specifies the time slots allocated to each member of the cluster for transmission. CHs also select CDMA code so as to reduce inter-cluster interference, which is then distributed to all members of its cluster [10].

The completion of the setup phase signals the start of the steady-state phase. In this phase, nodes collect the required data and use their allocated slots to transmit those to the CH. Data collection is performed periodically. Then, the CH nodes receive all the data, aggregate them before sending to the base-station. The network goes back into the setup phase after a certain time, which is determined a priori.

2.1.2 Advantages and Drawbacks of LEACH

Major advantages of LEACH include,

- It incorporates data fusion into routing protocol.
- It is 4-8 times effective over direct communication in prolonging the network lifetime.

Some drawbacks of LEACH are

- It may lead to large number of clusters.
- CHs are un-uniformly distributed in the network.
- There is less number of data signals received at BS.

2.2 TL-LEACH

The main objectives of TL-LEACH was to find a way to minimize the consumption of energy than LEACH and hence to improve the life time of WSN.

TL-LEACH uses the concept of data-fusion rigorously through a two-level hierarchy in order to avoid the overloading of data. Large energy gain can be resulted from data fusion, as less data is needed to be transmitted to the base station. TL-LEACH uses the following techniques to realise energy and latency efficiency:

- Randomized, adaptive and self-configuring cluster formation,
- Localized control for data transfer.

TL-LEACH introduces a two-level hierarchy: a top level represented by cluster-head called primary cluster-head or master cluster head (MCH), a second level represented by secondary cluster-head or CH and simple nodes. The two-level hierarchy of TL-LEACH is shown in the Figure 2.3. In TL-LEACH, a partial local computation starts in each secondary CH and completes at primary CHs at the top level, from where data is transmitted to the base station directly.

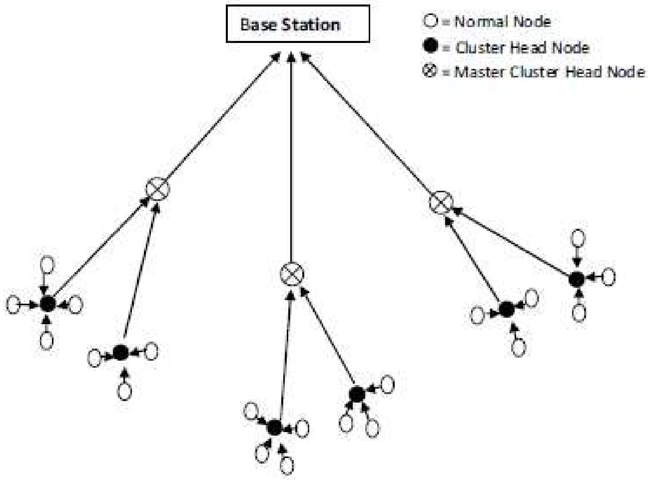


Figure 2.3: A Network Model of TL-LEACH

2.2.1 Operations of TL-LEACH

As LEACH, the basic operation of TL-LEACH consists of many rounds, each round being divided into two phases.

In the setup phase initially each node decides if it wants to be, in current round, primary cluster-head (MCH), secondary cluster-head (CH) or simple node. A node that has elected itself as MCH has to advertise other nodes. The mechanism used in this phase is the CSMA. Subsequently CHs send the advertisement to the simple nodes. In the cluster set-up step each CH decides which primary cluster it belongs to and each simple node decides its secondary cluster based on the received signal strength of advertisement (or Euclidian distance), and both confirm their joining. A MCH knows which nodes are in its group (either simple nodes and CH) and creates a TDMA schedule, assigning each node a slot to transmit. It also chooses a CDMA code and informs all the nodes at the second level in its group to transmit using this code. Each CH transmits the information to nodes in its cluster, both the code to be used use to transmit and the schedule.

In the steady-state phase, each node transmits according to the TDMA schedule decided by its corresponding primary CH. Non-CH nodes transmit data to their respective secondary cluster heads. CHs retransmit the aggregate data to their respective primary cluster heads. MCHs forward the fused data to the Base Station.

2.2.2 Advantages and Drawbacks of TL-LEACH

Major advantages of TL-LEACH include,

- The use of two-levels of clusters for data transmissions is advantageous as compared to LEACH because of the small transmit distances for more nodes. In this way only a few nodes are required to transmit through a long distances to the base station.
- It incorporates improved data aggregation and fusion than LEACH.
- Number of primary clusters in TL-LEACH is less, so it can be applied for larger networks.

TL-LEACH also has some drawbacks, like

- It may lead to non-uniform distribution of CHs in the network.
- No. of cluster heads formed in each round are not uniform, which may otherwise have increased the network lifetime to some extent.

2.3 LEACH-C

The main objectives of LEACH-C was to produce better performance in terms of energy consumption, by dispersing the cluster heads throughout the network and hence to improve the life time of WSN.

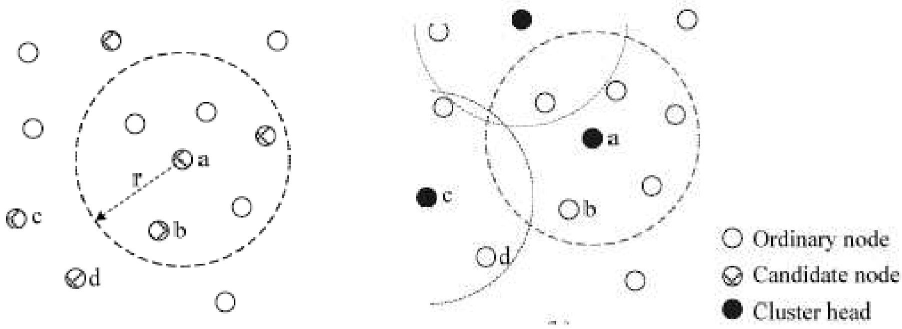
LEACH is distributed cluster formation algorithm, which offers no guarantee about the placement and/or number of cluster head nodes. LEACH-centralized (LEACH-C) is a protocol that uses a centralized clustering algorithm for cluster set-up and the same steady-state phase as LEACH [11, 9]. Leach-C tries to avoid redundant creation of cluster heads in a small area. It attempts to minimize the amount of energy for the ordinary nodes to transmit their data to the cluster head.

2.3.1 Operation of LEACH-C

As LEACH and TL-LEACH, the basic operation of LEACH-C consists of many rounds, each round being divided into two phases.

In the set-up phase of LEACH-C, information about a node's current location and residual energy level is sent to the BS [11]. The BS ensures better distribution of energy load among all the nodes, in addition to determining good clusters. To do this, BS computes the average energy of nodes, and determines the nodes having energy above this average as candidates for CH. BS selects CHs from the candidate nodes in a random basis such that a CH does not lie inside a predefined radius of any other CH [9]. In the CH selection process shown in Figure 2.4 (a), node a, b, c, and d are elected for candidate nodes for CHs among the sensor nodes. First, the BS selects node a as CH. As node b is within radius r of a, it is ruled out of the qualification of candidate nodes. Similarly, node d is also ruled out of the qualification. As a result, node a and c are actually selected as CHs as shown in Figure 2.4 (b). This approach does not find the optimal clusters but one of the beneficial parts is the computation, which is not NP-hard anymore as in conventional LEACH-C [11]. Once the CHs and associated clusters (formed on the basis of Euclidian distance) are found, the BS broadcasts a message that contains the CH ID for each node. If the node ID matches with the CH ID, then it becomes a cluster head; otherwise the node determines its TDMA slot for data transmission, from the TDMA schedule and goes to sleep until its time to transmit data.

The steady-state phase of LEACH-C is identical to that of the LEACH protocol, i.e. the nodes collect data and send them to their CHs during the TDMA slot allocated, where the data are aggregated or diffused. The diffused data is then trans-



(a) (b)

Figure 2.4: Basic Concept Used in LEACH-C for CH Selection

mitted to the BS.

2.3.2 Advantages and Drawbacks of LEACH-C

Major advantages of LEACH-C include,

- CHs are evenly distributed among the nodes in the network.
- No. of cluster heads formed in each round are almost uniform, which results in more number of nodes being alive till the end of the network lifetime.
- Life time of network will be more compared to LEACH.

LEACH-C has also a drawback of being a single hop protocol that will not be able to provide more data aggregation and fusion. And hence BS may receive more number of redundant data causing wastage of energy.

Chapter 3

Proposed Work

The study conducted on LEACH and some of its variants motivated us in the following perspectives.

I. Poor clustering set-up during a round will affect the overall performance in case of adaptive clusters. But using a central control algorithm to form the clusters, as in LEACH-C can produce better clusters by distributing the cluster head nodes throughout the network.

II. A multilevel approach for cluster formation improves packet aggregation/diffusion. It decreases the number of nodes taking part in long distance transmission. Hence energy is consumed to a greater extent in this approach.

Through the motivations obtained and as a solution to the problem described in Chapter 1, we propose a centralized multilevel scheme called CML-LEACH, for energy efficient clustering, which merges the idea of multilevel hierarchy and centralised scheme for cluster formation, to provide a better solution.

3.1 CML-LEACH

The main objectives of this scheme is to have **a multilevel hierarchy** in routing, that incorporates more data aggregation and fusion (even performing better in denser networks) and requires only a few nodes to transmit through far distances, along with following a **centralised approach of cluster formation** to get better distribution of CHs throughout the network hence providing with better energy utilization. Both the objectives help in better distribution of load among the sensors in the network.

3.1.1 Operation of CML-LEACH

The basic operation of CML-LEACH consists of a number of rounds each round being divided into two phases.

The setup phase of CML-LEACH is almost similar to that of LEACH-C, but the only difference comes because of the multilevel hierarchy as two types of CHs (primary and secondary) are selected in it. So, in the set-up phase of CML-LEACH, first, the information about a node's current location and residual energy level is sent to the BS. Then the BS computes the average energy of nodes, and determines the nodes having energy above this average as candidates for secondary CH. From this candidate set, it selects candidates for primary CHs again based on average energy criteria. This time, the energy of the candidate nodes for CH is only taken into consideration for calculating the average energy. Then the BS selects MCHs from the candidates for MCHs, in a random basis, such that a MCH does not lie inside a predefined radius (for primary clusters) of any other MCH. Out of the remaining candidate nodes for secondary CH (leaving the selected MCHs), the base station choses some as secondary CHs on the predefined radius for secondary cluster heads. Once the CHs, MCHs and their associated clusters (formed on the basis of Euclidian distance) are found, the sink broadcasts a message that obtains the CH ID (for both primary and secondary CHs) for each node. If a CH ID matches its own ID, the node is a cluster head (either primary or secondary). A MCH knows which CHs come under its primary cluster and creates a TDMA schedule, assigning each of them a slot to transmit. Secondary CHs create TDMA schedules for the sensor nodes belonging to the corresponding secondary cluster.

The steady-state phase of CML-LEACH is same as that of TL-LEACH. In this phase each node transmits its data according to the TDMA schedule created by its corresponding primary cluster- head. Non-CH nodes transmit data to their respective Secondary Cluster Heads (CHs).CHs retransmit the aggregate data to their respective Primary Cluster Heads (MCHs). MCHs forward the fused data to the base station.

Chapter 4

Implementation

4.1 Omnet++

The implementation of the clustering algorithms including the proposed CML-LEACH is done using omnet++.

4.1.1 What is OMNeT++?

OMNeT++ is a discrete event simulation environment. Now a days it is becoming very much popular as a network simulation platform in the scientific community. It is also used for industrial settings, and building up a large user community [12].

4.1.2 Features of OMNET++:

Some important features of omnet++ include,

(i) Flexibility

(ii) Programming model

(iii) Model management

(iv) Debugging, tracing, and experiment specifications

(v) Simulation modes

Flexibility:

- Omnet++ is a core framework for discrete event simulation having different add-ons for specific purposes.
- It is fully implemented in C++.
- Functionality can be added by deriving classes following some specified rules.

Programming model:

- Simulated objects in omnet++ are represented through modules.
  - Modules can be simple or compound.
  - The modules communicate with each other by message passing (directly or via gates).
  - The programming model in omnet++ consists of interface description (through .NED files) and functional description (through C++ class).
- Modules, gates and links in omnet++ can be created,
  - Statically, at the beginning of the simulation (NED file) or
  - Dynamically, during the simulation.

Model management:

- There is clear separation among the simulation kernel and the developed models.
- It is easy to make packages from developed modules for reuse.
- Patching the simulation kernel is not needed to install a model.

Debugging, tracing, and experiment specifications:

- Omnet++ supports,

  - Recording of data vectors and scalars in output files.
  - Random numbers having several distribution and different starting kernels.
  - Displaying information about the activities, snapshots and breakpoints of modules.

- It is easy to configure using .ini file.
- It also includes batch execution of the same simulation for different parameters.

Simulation modes:
Omnet++ simulations can be done using two different modes,

- Command line and
- Interactive GUI.

4.2 Assumptions

We have taken into account the following assumptions for implementing the clustering algorithms for WSN.

1. The network is homogeneous i.e initial energy of each node is the same.
2. Nodes are static.
3. Nodes are assumed to have sufficient transmission range to reach other nodes.
4. Homogeneous distribution of nodes.
5. Nodes always have to send the data.
6. BS is located far from the sensor network.

4.3 Parameters

The parameters and their values taken for simulation of each algorithm is shown in the following table 4.1.

Sl. No	**Parameters**	**Values**	**LEACH**	**TL-LEACH**	**LEACH -C**	**CML-LEACH**
1.	Environment Size	100m×100m	✓	✓	✓	✓
2.	Number of nodes	100	✓	✓	✓	✓
3.	Position of BS	[150,50]	✓	✓	✓	✓
4.	Packet Size	4000bits	✓	✓	✓	✓
5.	Election probability value of CHs(P)	0.15	✓	✓	✗	✗
6.	Election probability value of MCHs(P_m)	0.05	✗	✓	✗	✗
7.	Maximum number of rounds(r_{max})	4000	✓	✓	✓	✓
8.	Initial energy per node (E_0)	2J	✓	✓	✓	✓
9.	E_{elec}	50nJ/bit	✓	✓	✓	✓
10.	E_{amp}	10pJ/bit/m^2	✓	✓	✓	✓
11.	EDA	5nJ/bit	✓	✓	✓	✓
12.	CH_{radius}	20m	✗	✗	✓	✓
13.	MCH_{radius}	40m	✗	✗	✗	✓
14.	DR_{CH}	5	✓	✓	✓	✓
15.	DR_{MCH}	3	✗	✓	✗	✓

Table 4.1: Parameters Used in Simulation of Different Clustering Algorithms

** E_{elec} denotes the amount of energy consumed per bit of message in the transmitter/receiver circuitry. E_{amp} is the amount of energy consumed per bit per metre square by the transmit amplifier. EDA refers the amount of energy required in diffusion per bit by the CHs. DR_{CH} and DR_{MCH} represent the diffusion ratios at CHs and MCHs respectively.

4.4 Simulation snapshots

In this section we show some screenshots of the simulation of our proposed algorithm CML-LEACH through Omnet++.

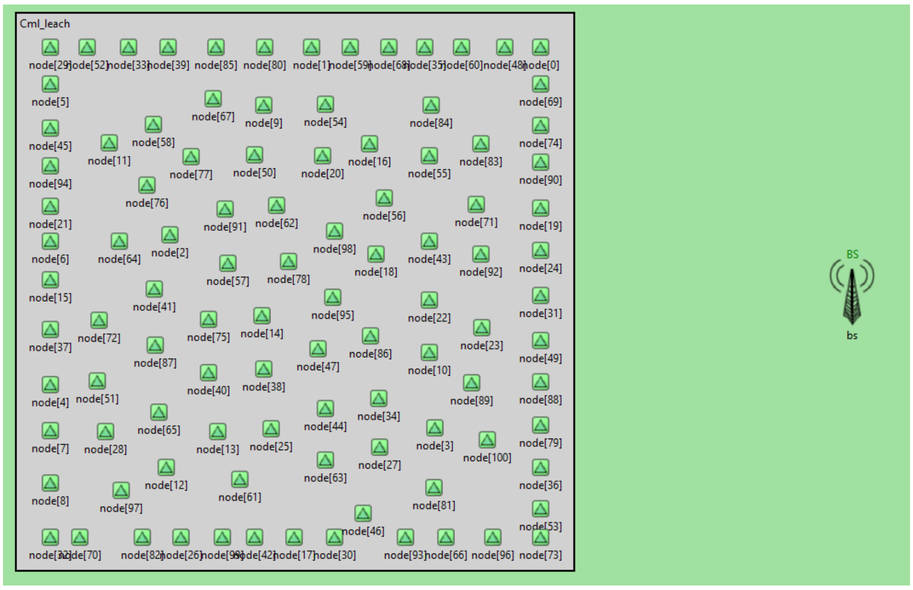


Figure 4.1: The Network Structure and BS in Omnet++

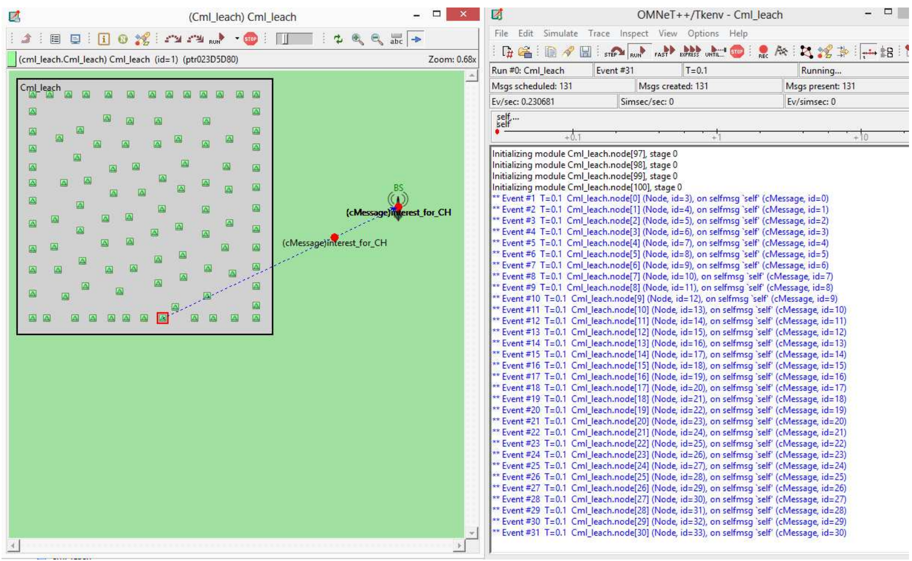


Figure 4.2: Information Message from a Node to BS

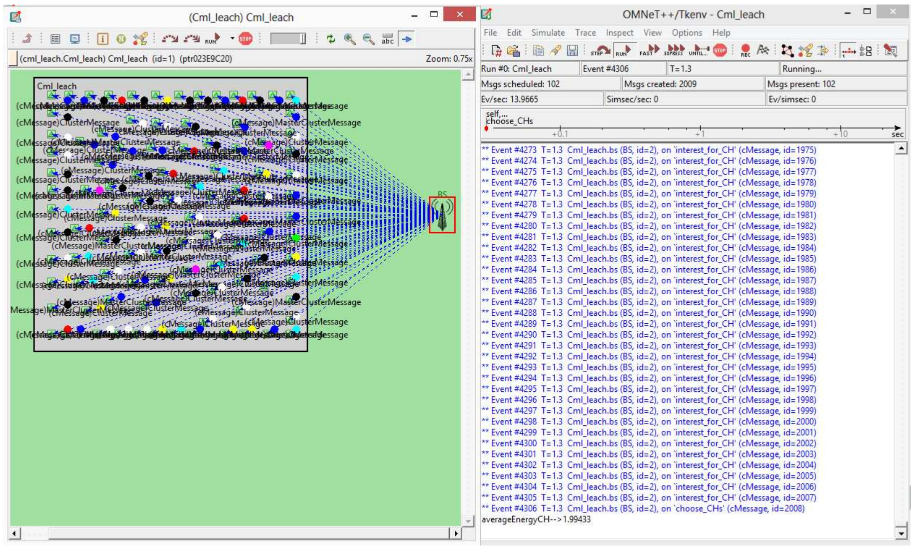


Figure 4.3: Broadcasting of CH Selection Message

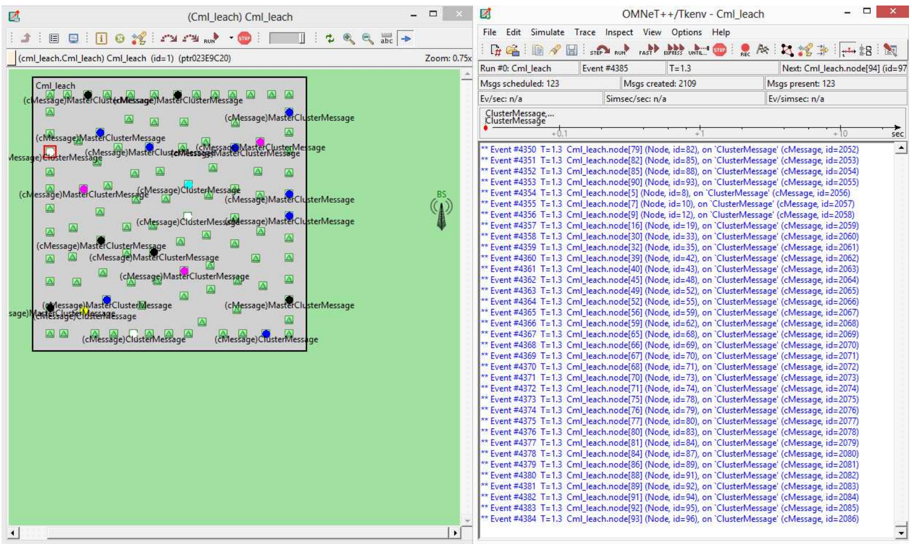


Figure 4.4: Nodes Processing CH Selection Message from BS

Figure 4.1 represents the homogeneous network structure in omnet++ consisting of 100 nodes along with the base station located at position [150, 50]. Figure 4.2 shows a message from a node to the base station that contains information about its current position and energy level. After the BS has selected the primary and secondary CHs, it broadcasts their ids to the network, to form clusters as shown in Figure 4.3. Figure 4.4 represent processing of the information send by BS at nodes to decide whether it will become a MCH, a CH, or a simple node for the current round.

Chapter 5

Results and Analysis

This section shows the simulation results and analysis of LEACH, TL-LEACH, LEACH-C and the proposed CML-LEACH in omnet++. The parameters taken into consideration for evaluating all the four algorithms are as follows:

- Time v/s Number of primary CHs formed,
- Time v/s Number of nodes alive,
- Time v/s Total energy dissipation,
- Time v/s No of data signals received at BS.

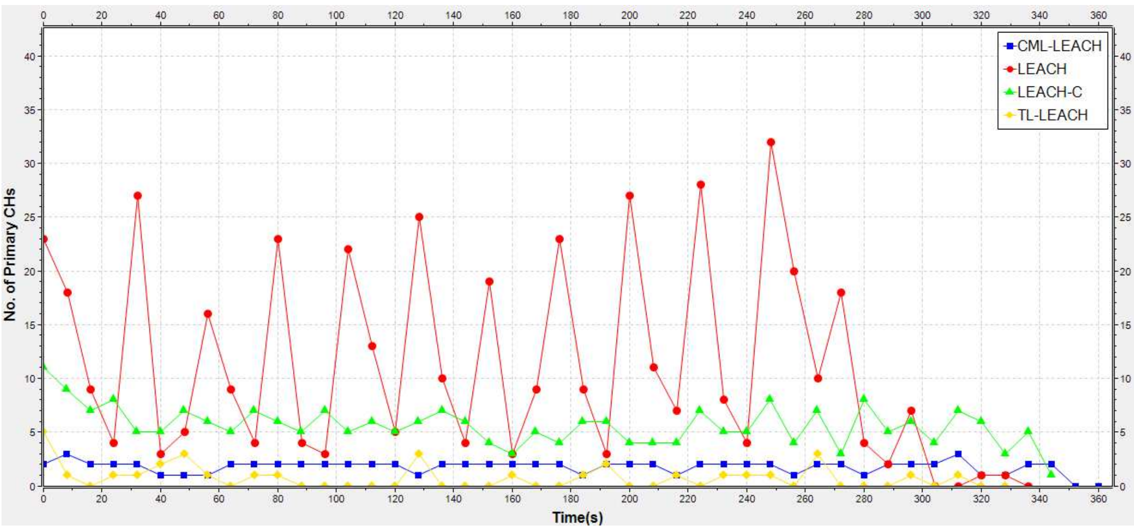


Figure 5.1: Time v/s Number of primary CHs formed

It is observed from the graph in Figure 5.1 that the primary CHs formed in LEACH-C and CML-LEACH are almost uniform in each round, unlike LEACH and TL-LEACH.

This is because of the centralised scheme used for cluster formation that selects CHs based upon position and average energy of nodes instead of the probabilistic approach followed in LEACH and TL-LEACH.

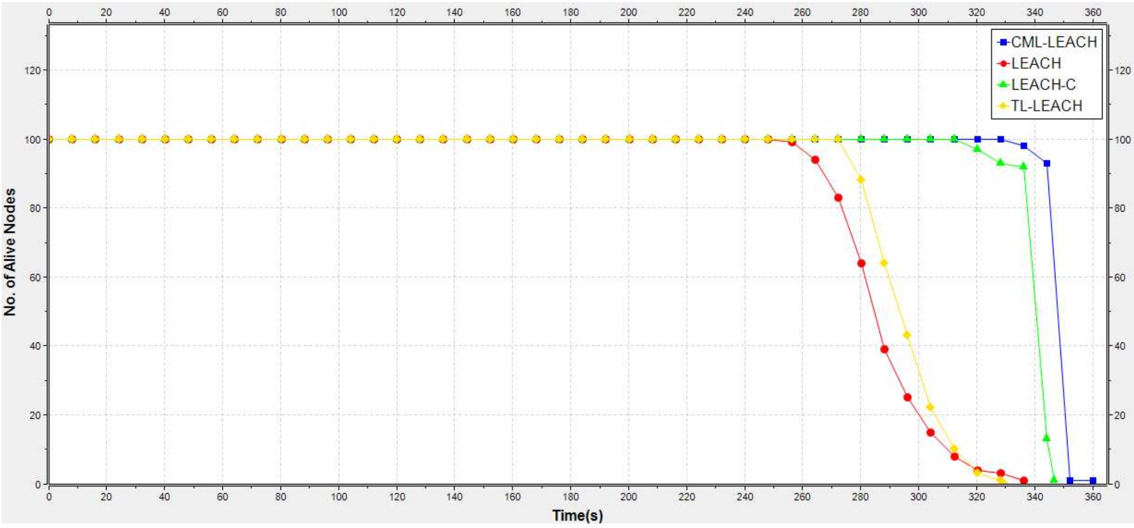


Figure 5.2: Time v/s Number of nodes alive

Graph in Figure 5.2 shows that the proposed scheme, CML-LEACH outperforms others in terms of network life time and number of nodes alive, which decreases less with time as compared to others. This is because of the uneven distribution and undesired number of primary CHs formed in LEACH and TL-LEACH. In case of LEACH-C (single-hop) some specific nodes die sooner because of the long transmission distance needed to be covered. On the other hand, in CML-LEACH, primary CHs are evenly distributed and as it is centralised, BS forms an appropriate number of clusters. It even uses multi-hop scheme.

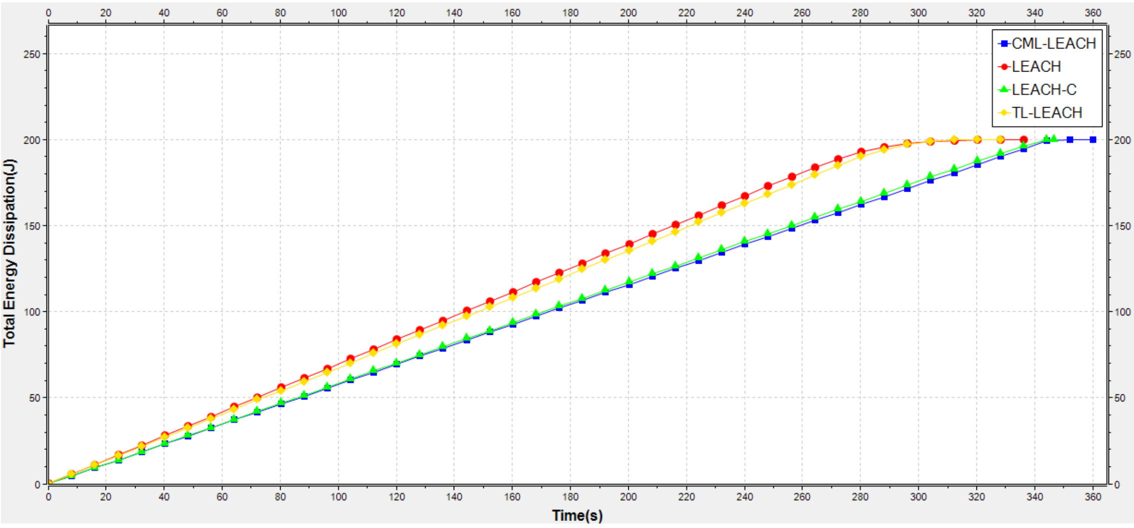


Figure 5.3: Time v/s Total energy dissipation

Graph in Figure 5.3 shows that the total energy dissipation increases linearly in LEACH-C and CML-LEACH compared to that of LEACH and TL-LEACH. Because in LEACH-C and CML-LEACH BS creates desired number of primary and secondary CHs and evenly distribute them, so that appropriate clusters can be formed and hence change in total energy dissipation is less compared to that of LEACH and TL-LEACH. As LEACH follows probabilistic approach of CH selection, uneven distribution of CHs may be possible sometimes which leads to sudden increase in energy dissipation.

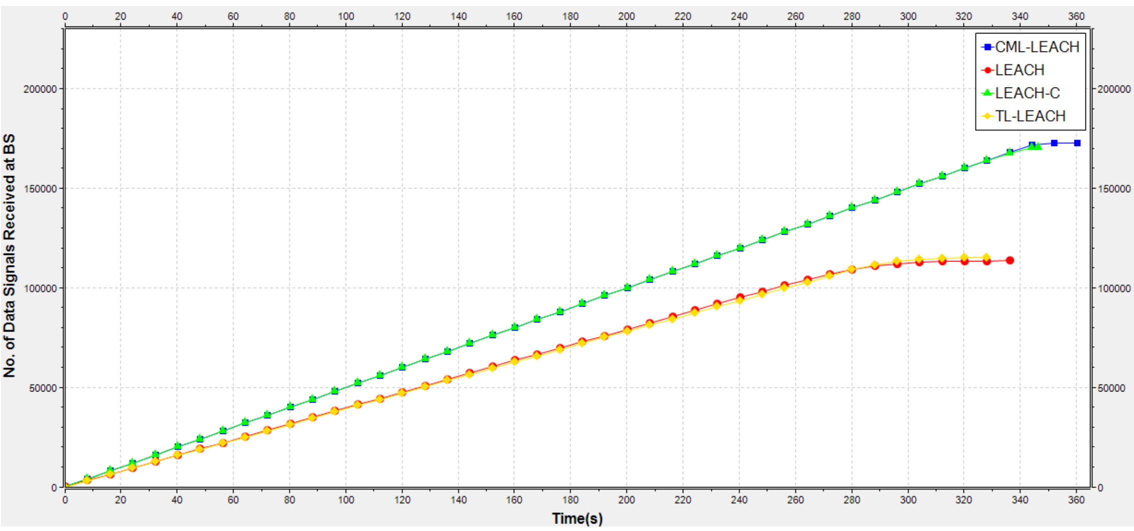


Figure 5.4: Time v/s No. of data signals received at BS

Graph in Figure 5.4 conveys that as the time increases, number of data signals received at BS through CML-LEACH and LEACH-C linearly increase compared to that of LEACH and TL-LEACH. CML-LEACH is able to deliver more no of data signals compared to that of LEACH and TL-LEACH because, in CML-LEACH, BS knows the network topology and hence it can form good clusters compared to others.

From the analysis of above results following conclusions can be made about the proposed CML-LEACH:

1. Primary and secondary CHs are evenly distributed throughout the network and number of CHs formed in each round are almost uniform. In this way each node gets enough TDMA slots to transfer, hence improving the number of data signals received at BS.

2. The uniformity in number of CHs formed and the multilevel approach allow less number of nodes to participate in long distance transmission, resulting in less energy consumption in the network and more number of nodes being alive till the end of network lifetime.

Chapter 6

Conclusions

Wireless Sensor Networks, which may be spread over a vast geographical area, have their applications in many fields. In this context, there is a need of approaches which can manage these WSNs in a better way possible. In this regard, this thesis, presents an improved clustering routing protocol to overcome several limitations of WSNs. Detailed discussion about the existing well-known protocol for WSNs called LEACH and some of its variants is provided. The proposed scheme is an improvement on it, that merges the ideas of multiple levels in the cluster (we have considered two levels in our version of protocol) and the centralised scheme of cluster formation. The simulation results in Omnet++ (shown in Chapter 4) demonstrated that the proposed algorithm CML-LEACH outperforms the existing protocols LEACH, TL-LEACH and LEACH-C in energy consumption and network lifetime. Also this scheme allows more no. of nodes to be alive till the end of network lifetime. We obtained that our protocol is able to deliver more data signals to the BS than the others. So, leaving apart the criticism that multilevel level approach may lead to wastage of cost and effort in cases of smaller and less dense network, our proposed scheme gives high performance under the tight constraints of wireless channel.

Bibliography

[1] L.J.G. Villalba, A.L.S. Orozco, A.T. Cabrera, and C.J.B. Abbas. Routing protocols in wireless sensor networks. *Sensors*, 9(11):8399–8421, 2009.

[2] S. K. Singh, M. P. Singh, and D. K. Singh. Routing protocols in wireless sensor networks- a survey. *International Journal of Computer Science & Engineering Survey*, 1:63–83, 2010.

[3] Chao SHA, Ru chuan WANG, Hai ping HUANG, and Li juan SUN. Energy efficient clustering algorithm for data aggregation in wireless sensor networks. *The Journal of China Universities of Posts and Telecommunications*, 17, Supplement 2(0):104 – 122, 2010.

[4] D.J. Dechene, A.E.Jardali, and M.L.A. Sauer. *A Survey of Clustering Algorithms for Wireless Sensor Networks, Computer Communications.* Butterworth-Heinemann Newton, MA USA, 2007.

[5] Suchismita Chinara and Santanu Kumar Rath. A survey on one-hop clustering algorithms in mobile ad hoc networks. *Journal of Network and Systems Management*, 17(1-2):183–207, 2009.

[6] V. Geetha, P.V. Kallapur, and S. Tellajeera. Clustering in wireless sensor networks: Performance comparison of leach & leach-c protocols using {NS2}. *Procedia Technology*, 4(0):163 – 170, 2012.

[7] W.R. Heinzelman, A.P. Chandrakasan, and H. Balakrishnan. Energy-efficient communication protocol for wireless microsensor networks. In *Proceedings of the 33rd Hawaii International Conference on System Sciences*, volume 8, pages 8020–8029, Washington, DC, USA, 2000. IEEE Computer Society.

[8] V. Loscri, G. Morabito, and S. Marano. A two-levels hierarchy for low-energy adaptive clustering hierarchy (tl-leach). In *Vehicular Technology Conference. 2005 IEEE 62nd*, volume 3, pages 1809–1813, 2005.

[9] Taewook Kang, Jangkyu Yun, Hoseung Lee, Icksoo Lee, Hyunsook Kim, Byunghwa Lee, Byeongjik Lee, and Kijun Han. A clustering method for energy efficient routing in wireless sensor networks. In *Proceedings of the 6th WSEAS International Conference on Electronics, Hardware, Wireless and Optical Communications*, EHAC'07, pages 133–138, Stevens Point, Wisconsin, USA, 2007. World Scientific and Engineering Academy and Society (WSEAS).

[10] K. Sohraby, D. Minoli, and T. Znati. *Wireless Sensor Networks: Technology, Protocols, and Applications*. Wiley, 2007.

[11] W.R. Heinzelman, A.P. Chandrakasan, and H. Balakrishnan. An application-specific protocol architecture for wireless microsensor networks. *Wireless Communications, IEEE Transactions on*, 1(4):660–670, 2002.

[12] OMNeT++ user manual, Version 4.2.2. http://www.omnetpp.org/doc/omnetpp/manual/usman.html.

[13] O. Boyinbode, Hanh Le, A. Mbogho, M. Takizawa, and R. Poliah. A survey on clustering algorithms for wireless sensor networks. In *Network-Based Information Systems, 2010 13th International Conference*, pages 358–364, 2010.

[14] Vinay Kumar, Sanjeev Jain, and Sudarshan Tiwari. Energy efficient clustering algorithms in wireless sensor networks: A survey. *International Journal of Computer Science Issues*, 8:259–268, 2011.

[15] Anjali Bharti and Kanika Sharma. Article: Comparative study of clustering based routing protocols for wireless sensor network. *International Journal of Computer Applications*, 66(21):9–12, March 2013. Published by Foundation of Computer Science, New York, USA.