MOBILE TARGET TRACKING USING MODIFIED LEACH-R PROTOCOL IN WIRELESS SENSOR NETWORKS

A. K. M. Shamiul Islam

ID: 2012-3-60-008

Farhana Nasrin Bristy

ID: 2012-3-60-020

Samira Alam

ID: 2013-1-60-020

Supervisor

Dr. Anisur Rahman

Assistant Professor

Department of Computer Science and Engineering

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Department of Computer Science and Engineering

East West University

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ABSTRACT

Wireless Routing in Wireless Sensor Network (WSN) is usually an important area of research. Rapidly increasing applications of sensor nodes in monitoring of physical environment has led to an increased significance of WSN. Modified LEACH-R introduces the energy efficient clustering scheme for Wireless Sensor Network which is dependent on Low Energy Adaptive Clustering Hierarchy structure and removed many of the limitations of the traditional LEACH protocol. Modified LEACH-R uses the remaining energy of the current cluster head which makes the process of routing better and efficient. In heterogeneous network, a cluster head node aggregate and collects data from their member nodes and send that aggregated data towards the base station. The proposed protocol uses advanced nodes. The role of advanced nodes is to act as cluster head and to perform the task of data aggregation while consuming low power during operation. Modified LEACH-R protocol is tested and simulated in MATLAB software package. This protocol increases the frequency of packets that can be transmitted between base stations to cluster heads and between cluster head and nodes. The findings of the simulation revealed that Modified LEACH-R provides better results as compared to traditional LEACH protocol. Modified LEACH-R protocol enhances the time of first dead node and as well as increases the duration of operation of the last node and hence enhances the overall network lifetime.

DECLARATION

I, hereby, declare that the work presented in this thesis is the outcome of the investigation performed by us under the supervision of Dr. Anisur Rahman, Assistant Professor, Department of Computer Science and Engineering, East West University. We also declare that no part of this thesis has been or is being submitted elsewhere for the award of any degree or diploma.

Countersigned

. . . .

(Dr. Anisur Rahman)

Supervisor

Signature

. . . .

(A. K. M. Shamiul Islam)

ID: 2012-3-60-008

Signature

. . . .

(Farhana Nasrin Bristy)

ID: 2012-3-60-020

Signature

. . . .

(Samira Alam)

ID: 2013-1-60-020

LETTER OF ACCEPTANCE

We, hereby, declare that the thesis is from the student's own work and best effort of us and all other sources of information used in this paper have been acknowledged. This thesis has been submitted with our approval.

Supervisor

Signature

. . . .

Dr. Anisur Rahman

Assistant Professor

Department of Computer Science and Engineering

East West University, Dhaka

Chairperson

Signature

. . . .

Dr. Ahmed Wasif Reza

Associate Professor

Department of Computer Science and Engineering

East West University, Dhaka

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As it is true for everyone, we have also arrived at this point of achieving a goal in our life through various interactions with and help from other people. However, written words are often elusive and harbor diverse interpretations even in one's mother language. Therefore, we would not like to make efforts to find best words to express our thankfulness other than simply listing those people who have contributed to this thesis itself in an essential way. This work was carried out in the Department of Computer Science and Engineering at East West University, Bangladesh.

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CHAPTER 1

INTRODUCTION

Wireless Sensor Network (WSN) consists of self-sufficient sensors which can be devised to monitor the physical and also ecological conditions like temperature, weight and so forth. Wireless Sensor Networks are comprised of hundreds or even a large number of nodes to perform the dedicated task [19]. Sensor node is tiny little gadget which usually incorporates three necessary segments for sensing the physical conditions: processing subsystem, sensing subsystem and remote correspondence subsystem. Environmental conditions tend to be sensed by sensor nodes where data is collected, processed and sent to the base station (Central Support System) [20]. Sensor networks are widely deployed in industries, medical, farming, military and ecological areas. The communication between Central Support System and the other nodes are carried out wirelessly. The network involves sensor nodes which usually communicate with other nodes through wireless links. The sensor nodes are deployed in large numbers and operate in the area of interest [21, 22]. In Wireless Sensor Networks (WSN), the sensor node transmits collected information and also cooperates with some other sensor nodes to perform special functions of routing data in the network [23]. Though a lot of work has been carried out in Clustering and Data Aggregation models but still there are limitations in their energy efficient algorithms. Proposed protocol is specially designed for energy constrained networks as it takes into consideration the heterogeneity of various nodes. Nodes in the cluster are classified based on the attributes they carry like memory, processor etc. This heterogeneity based decision making approach is followed in this paper.

Finally, using the trilateration algorithm, moving target is tracked down. Usage of Modified LEACH-R protocol saves energy of deployed nodes which in turns increase overall network lifetime.

1.1 BACKGROUND

Wireless Sensor Networks (WSN) is group of heterogeneous sensor nodes which are small, low cost, placed randomly and connected by wireless media to form a sensor field. The sensors are spatially distributed to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to the Base Station (BS). WSN has the ability to dynamically adapt to changing environments.

Object tracking is one of the challenging and non-trivial applications for Wireless Sensor Network in which network of wireless sensors are involved in the task of tracking a moving object. Several factors are considered when developing algorithms for tracking moving objects include single vs. multiple targets, stationary vs. mobile nodes, target motion characteristics, energy efficiency and network architecture. Object Tracking is widely used in many applications like military application, commercial applications, field of surveillance, intruder application and traffic applications.

There are various metrics for analysing object tracking such as cluster formation, tracking accuracy, cluster head life time, miss rate, total energy consumed, distance between the source and object, varying speed of the target, etc. The open issues in object tracking are detecting the moving object's change in direction, varying speed of the target, target precision, prediction accuracy, fault tolerance and missing target recovery. In all tracking process, more energy is consumed for messages or data transmission between the sensor nodes or between the sensor and sink.

In a target tracking application, the sensor nodes which can sense the target at a particular time are kept in active mode, while the remaining nodes are to be retained in inactive mode so as to conserve energy until the target approaches them. To continuously monitor mobile target, a group of sensors must be turned in active mode just before target reaches to them. The group of active sensor nodes varies depending on the velocity of moving object and the schedule by cluster head. The sensor nodes detect the moving object and transmit the information to the sink or the base station. The traditional target tracking methodologies make use of a centralized approach.

As the number of sensors increases in the network, more messages are passed on towards the base station and will consume additional bandwidth. Thus, this approach is not fault tolerant as there is single point of failure and lacks scalability. Moreover in traditional target tracking methods, sensing task is usually performed by one node at a time resulting in less accuracy and heavy computation burden on that node. In WSN, each node has very limited power and consequently traditional tracking methods based on complex signal processing algorithm are not applicable.

Therefore, the object tracking algorithm should be designed in such a way that it result in good quality tracking with low energy consumption. The good quality tracking extends the network lifetime and achieves a high accuracy. In order to obtain an energy efficient tracking with low energy consumption, an assumption is made that all the sensor nodes have same energy level. Because, even if a sensor node fails, other sensor node can take the responsibility and carry out the tracking process.

Sensor networks are widely deployed in industries, medical, farming, military and ecological areas. The communication between Central Support System and the other nodes are carried out wirelessly. The network involves sensor nodes which usually communicate with other nodes through wireless links. The sensor nodes are deployed in large numbers and operate in the area of interest [1, 2]. In Wireless Sensor Networks (WSN), the sensor node transmits collected information and also cooperates with some other sensor nodes to perform special functions of routing data in the network [3]. Though a lot of work has been carried out in Clustering and Data Aggregation models but still there are limitations in their energy efficient algorithms. Proposed protocol is specially designed for energy constrained networks as it takes into consideration the heterogeneity of various nodes. Nodes in the cluster are classified based on the attributes they carry like memory, processor etc. This heterogeneity based decision making approach is followed in this paper.

1.2 OBJECTIVES

Our target here is to tracking a moving object using WSN by sensing capability of sensors. Since sensor nodes have limited battery power and replacement of battery power and replacement of battery is quite hard, so energy saving is an issue in tracking process and the increase of lifetime.

For this work, we will use energy efficient prediction based method in a cluster network which consists of nodes at same energy level range of communication. Initially the nodes are deployed in cluster. So to save energy, we will use our Modified version of LEACH-R clustering algorithm instead of traditional LEACH, which will eventually improve network lifetime by reducing power consumption.

It provides us a great opportunity to explore the new area of wireless communication overall.

1.3 RESEARCH QUESTIONS

Our primary target is an exploration and study of the field of wireless sensor networks to find an appropriate clustering algorithm to save the energy of the nodes.

The study addresses the following questions.

What is a sensor network?

What are their main ideas and concepts?

Which clustering algorithm should we use?

How to track the mobile target?

Are they applicable?

1.4 SCOPE

The study area of the thesis is an overview of the wireless sensor-network technology, an evaluation of clustering algorithm, and an idea to implement mobile target tracking wirelessly using small amount of energy. Thus the study is divided into two parts. Part one is an overview of wireless sensor networks. It includes an evaluation of Modified LEACH-R clustering algorithm.

The second part is based on the evaluation results; it describes the result of the simulation of the target-tracking algorithm. Using this algorithm, object-tracking application can be built which will receive and use the raw values returned by the sensor network system to produce clear and meaningful outputs. The outputs then can be easily intergraded into a larger application, or can be used independently as the output of a specific isolated application.

1.5 METHODOLOGY

The design stage is an iterative process and as the most critical stage requires theoretical knowledge of wireless sensor network technology. In addition, it requires sufficient knowledge of object tracking. The implementation part, although it may seem straightforward, has some programming difficulties. The matlab program, which is our programming language choice, must implement precisely in the algorithmic part of the design.

Finally, the desired process for moving object tracking helps us to save energy in order to increase the lifetime of the network.

1.6 WIRELESS SENSOR NETWORKS

A Wireless Sensor Networks (WSN) is a set of thousands of micro sensor nodes that are capable of sensing and establishing wireless communication. A wireless sensor network consists of distributed sensors to monitor physical and environmental conditions which are of autonomous type. These types of sensors are used to measure temperature, pressure etc.

1.6.1 INTRODUCTION TO WIRELESS SENSOR NETWORKS

The wireless sensors were initially used in military applications but nowadays it is used in many industrial and consumer applications for monitoring and controlling. It performs the computational and processing operations between two nodes. Wireless sensor networks generally provides us unique benefits in order to reduce the power consumed and in reducing the cost. The nodes in WSN are battery operated with sensing devices where energy resources are limited. When designing a power-efficient protocols the main issue that is wholly considered is to prolong the life time or to make the system energy efficient.

1.6.1.1 Wireless Sensor Networks

The WSN has a group of nodes which ranges from few to several hundred or even thousands. It consists of small light weighted wireless nodes called sensor nodes. A sensor node varies from the size of a back-pack to the size of grain dust. The cost of sensor nodes depending upon the complexity it ranges from a few dollars to hundreds of dollars, depending on the complexity of the individual sensor nodes. The size and cost constraints on sensor nodes results in changes with the resources such as energy, memory, computational speed and bandwidth.

All sensor nodes in the wireless sensor network are interacting with each other or by intermediate sensor nodes. Nodes sends their report towards a processing of energy compared to data processing. Protocols designed for the network should be prolong the lifetime of the network.

1.6.1.2 Challenges in Deployment

Sensor networks may consists of different types sensors such as seismic, visual, infrared, RADAR, thermal, magnetic etc to monitor wide range of parameters in real time. Deployment of nodes in a wireless sensor node application will be in a random style or this can also be planted physically. Wireless sensor network smooth the progress of monitoring and controlling of physical environment from remote locality with most perfect accuracy. Advancements have been achieved in wireless sensor networks which led to lot of new protocols which is specially designed for sensor networks. Many routing protocols have been designed where energy awareness is an indispensable consideration. WSN is not yet implemented in real time due to its various drawbacks such as low power transmitter, poor battery backup, large energy consumption and lack of security features etc. Our paper proposes a modification in LEACH protocol such that it increases the network lifetime by replacing lifeless nodes by nodes having higher energy level. Various other problems in deployment of WSN include:

- When sensor nodes are deployed there is a chance for either of the two will be accountable for node death either the energy depletion is caused by normal battery discharge or due to short circuit. To minimize data loss problems affecting sink nodes should be detected.
- Deployment of sensor networks leads to network congestion due to many concurrent transmission attempts made of quite a lot of sensor nodes.
- Another issue is the physical length of a link. Two nodes may be nearby still they may not be able to communicate due to physical interfering in the real world while nodes which are far away may communicate with each other.
- The network delivers insufficient amount of information which is also called as low data yield is a common problem.

1.6.1.3 Literature Survey

At the base station networks are portioned into annular rings by using various power rings. The residual energy of each node and distance from the BS of nodes are considered as the principle for cluster head selection. LEACH is a fundamental protocol in the clustering in routing protocol which minimizes the energy consumed. The lifespan of the nodes increases as the battery power in the sensor node increases. The performance metrics conventionally measured are connectivity, power consumption etc. The lifetime and throughput functions related to the time length is found for each round. In order to prolong the lifetime of the network the time length of each node is set and this increases the throughput. The lifetime and throughput functions related to the time length of each round is deduced. To enhance the performance of cluster based wireless sensor networks these functions are used. The suggestions was made that new protocols draws a stable number of cluster head than that of the previous LEACH protocol. The network load balance, residual energy and overhead are the factors that are considered for designing a new protocol. The lifetime of the network gets extended using the new modified LEACH protocol. In the proposed multipath routing protocol two paths are established between source and destination. This finds the next hop node reducing the linking cost and node energy consumption also gets balanced.

A protocol named Modified LEACH-R is proposed based on conventional LEACH protocol. This protocol improves the selection of cluster heads and residual energy is considered, the possibility of selecting low energy node as cluster head is considerably reduced. This protocol balances network energy consumption and extends this life cycle of the network. The threshold level based load balancing is maximum utilized with the help of cluster based routing.

1.6.1.4 Wireless Sensor Network: Overview

The progress in wireless communications, digital electronics, and micro systems has enabled the development of small-size, low-cost, power-efficient multifunctional sensors. Moore's law predicts a great future for this technological field. In the future the typical sensor nodes the size "of a 35 mm film canister" (Wikipedia, Wireless Sensor Network Webpage, 2005), and their development cost will be drastically reduced, generating an explosion in the wireless sensor network usage.

Wireless sensor networks (WSN) is a rich domain that involves both hardware and system design. It consists of sensor devices that are "small in size and able to sense, process data, and communicate with each other, typically over an RF (radio frequency) channel" (Haenggi, 2005). Their purpose is to collect and process data from the environment, produce a detection event and then forward the information to a specific destination.

1.6.1.5 Wireless Sensor Network: Constraints and Challenges

Martin Haenggi (2004) specifies precisely the basic characteristics that the WSN have, including the following:

Self-organizing capabilities

Short-range broadcast communication and multi-hop routing

Dense deployment and cooperative effort of sensor nodes

Frequently changing topology due to fading and node failures

Limitations in energy, transmitted power, memory, and computing power.

They also highlights that the WSN differ from the wireless ad-hoc mesh networks in the latter three characteristics.

Before some of the above concerns are analyzed further, we will discuss in the following section the important WSN applications that set the requirements and drove a WSN development.

1.6.2 CLUSTERING

In clustering, there are several sensor nodes and for a certain group of nodes, they are assigned a cluster leader or cluster head. The ordinary nodes just sense the reading and send them to the cluster thereby shifting the burden from them to the cluster head. The cluster head is normally a high energy and high resource node. The introduction of cluster heads can reduce sufficient cost of network as one can deploy low cost low energy sensor nodes.

1.6.2.1 Need for Clustering

Usage of wireless sensor networks has grown massive in the recent years which is used for energy-efficient routing, data aggregation and data-gathering protocols in significant networks. The routing protocols performance is affected by the number of cluster heads a network have. If the cluster head is less in number it is difficult to cover the members that are far away from the cluster heads. Few clustering doesn't cover the entire network it merely covers a few part or incomplete network. In this case it will consume lot of energy. To increase the scalability, lifetime and energy efficiency clustering is utilized in sensor networks. The challenges that are encountered in clustering are energy which is limited to some extent and capability of the network. Wireless sensor network nodes can be partitioned into a number of small groups called clusters. Each cluster has a coordinator, referred to as a cluster head, and a number of member nodes. Clustering results in a two-tier hierarchy in which cluster heads (CHs) form the superior tier while member nodes form the inferior tier. Clustering has proven to be an efficient approach for organizing the network into a connected ladder. The member nodes report their data to the respective CHs. The CHs aggregate the data and send them to the central base through other CHs. Because CHs often broadcast data over longer distances, they lose more energy compared to member nodes. The network may be clustered periodically in order to select energy-abundant nodes to serve as CHs, thus distributing the load uniformly on all the nodes. Besides achieving energy efficiency, clustering reduces channel contention and packet collisions, resulting in better network throughput under high load.

1.6.2.2 Existing Routing Protocols

A routing protocol that is designed for a sensor network should meet the following conditions:

- ✓ Reliable
- ✓ Integrating awake/sleep nodes
- ✓ Mobile
- ✓ Secured network establishment
- ✓ Power management
- ✓ Congestion control.
- ✓ Real-time oriented

There are lot of routing protocols in practice for Wireless sensor networks such as SPIN, DD, RR, TEEN, APTEEN, PEGASIS, SPEED, LEACH, LEACH-R, Modified LEACH-R etc. Each protocol has their own advantages and drawbacks. Among all these protocols, Modified LEACH-R is considered to be good protocol meeting most of the requirements. The advantages and disadvantages of all existing protocols are as follows.

- ✓ **SPIN**: Sensor Protocols for Information via Negotiation uses Data Centric routing here the network scalability is limited. This cannot be applied over a large network structure.
- ✓ **DD**: Data Driven Routing protocol uses a Destination initiated data transmission where the network scalability is limited and data delivery model is demand driven due to which delay increases.
- ✓ **RR**: Rumor Routing uses flat based routing in which the network structure has good scalability but the data delivery model is demand driven due to which delay increases.
- ✓ **TEEN & APTEEN**: [Adaptive] Threshold sensitive Energy Efficient sensor Network uses Hierarchical routing model in which power usage is high and data delivery model is Active threshold.
- ✓ **PEGASIS**: The Power-Efficient Gathering in Sensor Information Systems uses a Hierarchical routing model which has a maximum power usage among all routing

protocols. The data delivery model employed is Active threshold.

- ✓ **LEACH**: Low Energy Adaptive Clustering Hierarchy uses hierarchical routing model which uses Cluster Head data delivery model. This protocol has a good network scalability compared with all other routing protocols.
- ✓ **Modified LEACH-R**: This protocol uses hierarchical routing model which uses Cluster Head data delivery model based on the higher residual energy. This protocol has a better network scalability compared with all other routing protocols.

Thus comparing most widely used routing protocols, Modified LEACH-R protocol found to best suit for Wireless sensor network.

The various reasons for employing Modified LEACH-R protocol in WSN are

- ➢ Employs Cluster Head mechanism.
- ➢ Network Scalability is better.
- ➢ Load Balancing among all nodes inside a cluster.
- ➢ Supports hierarchical/ Destination Initiated/ Node centric Routing.
- ➢ Supports Data Aggregation.
- ➢ Adaptive cluster members.
- ➢ Random selection of cluster head in rotation based on higher residual energy.

1.6.2.3 LEACH Protocol

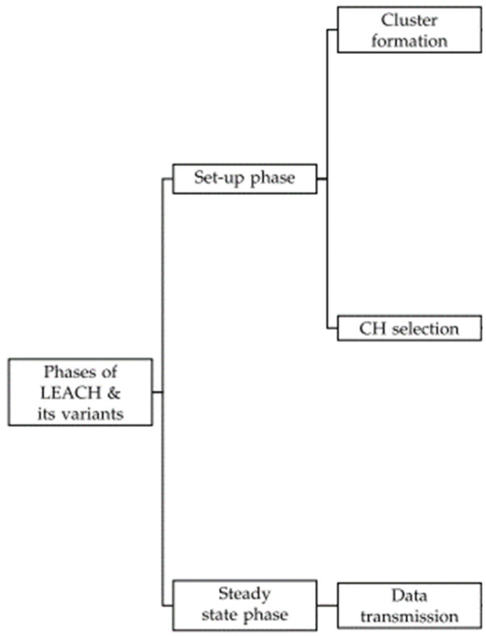

Figure 1. 1 Phases of LEACH and its variants in WSN

LEACH is a pioneer clustering routing protocol for WSN. The main objective of LEACH is to increase the energy efficiency by rotation-based CH selection using a random number. But we will use Modified LEACH-R protocol, which is a successor of LEACH with better throughput and overall better network lifetime. The LEACH protocol architecture is shown in Figure 1.1.

The operation of LEACH consists of several rounds where each round is divided into two phases: the set-up phase and the steady state phase as shown in Figure 1.4. During the set- up phase, CH selection, cluster formation and assignment of a TDMA (Time Division Multiple Access) schedule by the CH for member nodes are performed. In CH selection, each node participates in a CH election process by generating a random priority value between 0 and 1. If the generated random number of a sensor node is less than a threshold value T(n) then that node becomes CH. The value of T (n) is calculated using equation (1).

$$T(n) = \begin{cases} \frac{p}{1-p*\left(r \bmod \frac{1}{p}\right)}; & if\ n \epsilon G \\ 0 \quad ; & otherwise \end{cases} \qquad (1)$$

Where p denotes the desired percentage of sensor nodes to become CHs among all sensor nodes, r denotes the current round and G is the set of sensor nodes that have not participated in CH election in previous $1/p$ rounds. A node that becomes the CH in round r cannot participate in the next $1/p$ rounds. In this way every node gets equal chance to become the CH and energy dissipation among the sensor nodes is distributed uniformly. Once a node is selected as the CH, it broadcasts an advertisement message to all other nodes. Depending on the received signal strength of the advertisement message, sensor nodes decide to join a CH for the current round and send a join message to this CH. By generating a new advertisement message based on Equation (1), CHs rotate in each round in order to evenly distribute the energy load in the sensor nodes. After the formation of the cluster, each CH creates a TDMA schedule and transmits these schedules to their members within the cluster. The TDMA schedule avoids the collision of data sent by member nodes and permits the member nodes to go into sleep mode. The set-up phase is completed if every sensor node knows its TDMA schedule. The steady state phase follows the set-up phase.

In the steady state phase, transmission of sensed data from member nodes to the CH and CH to the BS are performed using the TDMA schedule. Member nodes send data to the CH only during their allocated time slot. When any one member node sends data to the CH during its allocated time slot, another member node of that cluster remains in the sleep state. This property of LEACH reduces intra cluster collision and energy dissipation which increases the battery life of all member nodes. Additionally, CHs aggregate data received from their cluster members and send it directly to the BS. Transmission of data from the CH to the BS is also performed with the help of the alloted TDMA schedule. The CH senses the states of the channel for sending its data. If the channel is busy i.e. it is being used by any other CH then it waits; otherwise it uses the channel to transmit the data to the BS.

Figure 1. 2 Objectives of LEACH and its variants with an increasing priority

1.6.2.3.1 Advantages of LEACH

LEACH is a complete distributed routing protocol in nature. Hence, it does not require global information. The main advantages of LEACH include the following:

1. Concept of clustering used by LEACH protocol enforces less communication between sensor nodes and the BS, which increases the network lifetime.
2. CH reduces correlated data locally by applying data aggregation technique which reduces the significant amount of energy consumption.
3. Allocation of TDMA schedule by the CH to member nodes allows the member nodes to go into sleep mode. This prevents intra cluster collisions and enhances the battery lifetime of sensor nodes.
4. LEACH protocol gives equal chance to every sensor node to become the CH at least once and to become a member node many times throughout its lifetime. This randomized rotation of the CH enhances the network lifetime.

1.6.2.3.2 Disadvantages of LEACH

However, there exist some disadvantages in LEACH which are as follows:

1. In each round the CH is chosen randomly and the probability of becoming the CH is the same for each sensor node. After completion of some rounds, the probability of sensor nodes with high energy as well as low energy becoming the CH is the same. If the sensor node with less energy is chosen as the CH, then it dies quickly. Therefore, robustness of the network is affected and lifetime of the network degrades.
2. LEACH does not guarantee the position and number of CHs in each round. Formation of clusters in basic LEACH is random and leads to unequal distribution of clusters in the network. Further, in some clusters the position of the CH may be in the middle of the clusters, and in some clusters the position of the CH may be near the boundaries of the clusters. As a result, intra cluster communication in such a scenario leads to higher energy dissipation and decreases the overall performance of the sensor network.
3. LEACH follows single hop communication between the CH and the BS. When the sensing area is beyond a certain distance, CHs which are far away from the BS spend more energy compared to CHs which are near to the BS. This leads to uneven energy dissipation which ultimately degrades the lifetime of the sensor network.
4. Boundary Problem: When tracking a target in a surveillance area, multiple nodes surrounding the target collaborate to make the collected information more complete, reliable, and accurate. There is no problem when the target is inside a cluster, as all activated sensors belong to the same cluster, and they can communicate effectively. However, when the target moves across or along the boundaries of multiple clusters, the boundary problem occurs. That is, the local node collaboration becomes incomplete and unreliable because sensor nodes that can monitor the target belong to different clusters, which increases the uncertainty of the localization of the target or even results in the loss of the target due to the insufficient sensing reports or the incorrect prediction of the target's location.

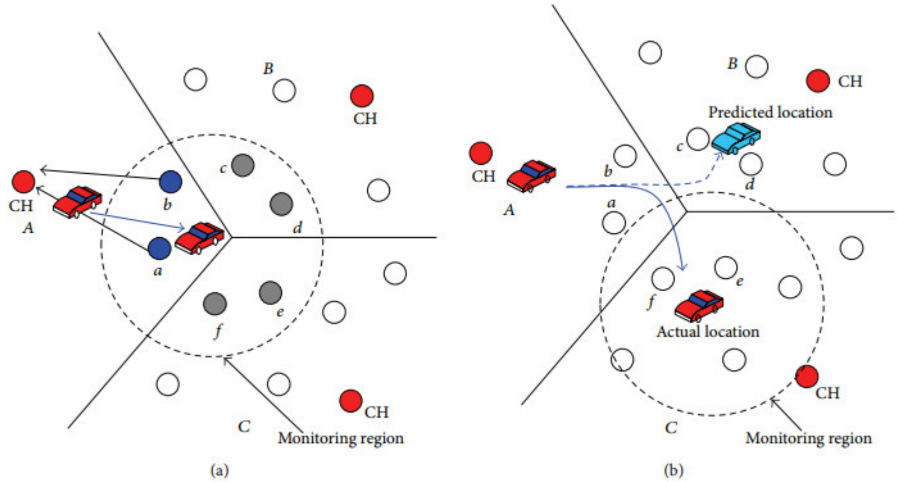

Figure 1. 3 The boundary problem in a cluster-based WSN: (a) high localization uncertainty due to insufficient active nodes, (b) loss of target due to incorrect prediction of the target location.

Figure 1.3 shows two cases of the boundary problem for target tracking in a cluster-based WSN. As the target is inside cluster A, cluster A is activated to track the target, whereas clusters B and C are in the sleep state for energy saving purpose. For the case in Figure 1.3(a), when the target moves close to the boundaries of clusters, nodes a, b, c, d, e, and f, which can monitor the target, belong to three different clusters A, B, and C. Only nodes a and b can sense the target, as they are active, while other nodes cannot, as they are in the sleep state. The network cannot successfully locate the target due to insufficient information, which may affect the accuracy of predicting the target's next position or even result in the loss of the target. For the case shown in Figure 1.3(b), the next location of the target is predicted to be in cluster B whereas the target actually moves into cluster C. Nodes in cluster B, are activated in advance according to the predicted location of the target. However, none of them can sense the target since the target moves into cluster C. Therefore, prediction error may also result in the loss of the target.

To solve this problem, we will use Modified LEACH-R clustering algorithm. LEACH-R algorithm has the capability to solve the prediction error using less energy by repeating a single step by forming a new cluster head. Therefore, boundary problem wouldn't be an issue in our proposed system.

1.6.2.4 LEACH-R (LEACH- Reward) Protocol

LEACH-R is an energy efficient prediction-based method in a clustered network which consists of nodes at same energy level and range of communication. Initially the nodes are clustered using LEACH-R (LEACH- Reward) protocol in which a node is selected as a Cluster Head (CH). When a target enters the wireless sensor network, the CH that detects the target becomes active while other nodes are in sleep mode. Then the active CH selects three sensor nodes of its members for tracking in which one node is selected as Leader node. The selected nodes sense the target and current target location is calculated using trilateration algorithm.

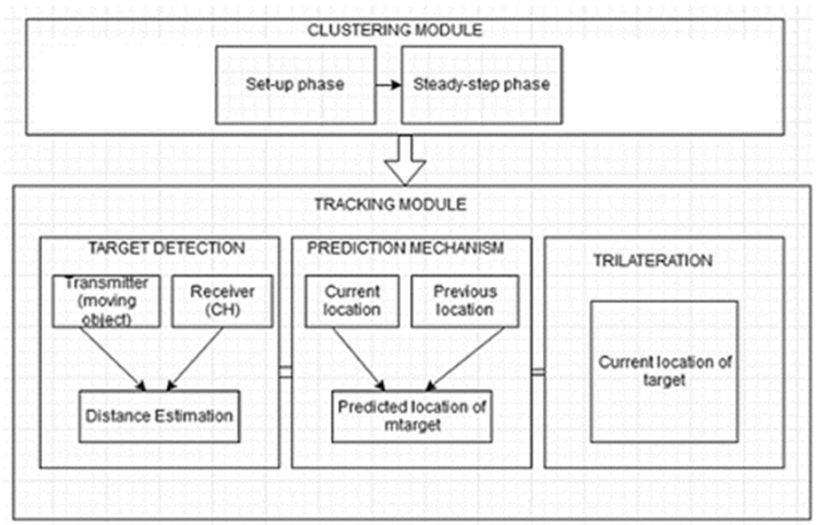

Figure 1. 4 Architecture Diagram

In this algorithm three sensor nodes are selected each time in which two nodes calculates its distance from the moving object and sends the data to the leader node. The localization of the moving object is done by leader node whereas in previous methods it's done by CH.

Using prediction based clustering method energy consumed in the network will be reduced since the transmission power of the nodes is directly proportional to the distances. The three nodes selected for tracking are close to each other, thus the energy consumed for sending a data between the nodes is lower than sending a data from one of the selected nodes to its CH. In LEACH-R, a reward value is calculated by each CH every time in order to eliminate the cluster that has no members and thereby save the energy.

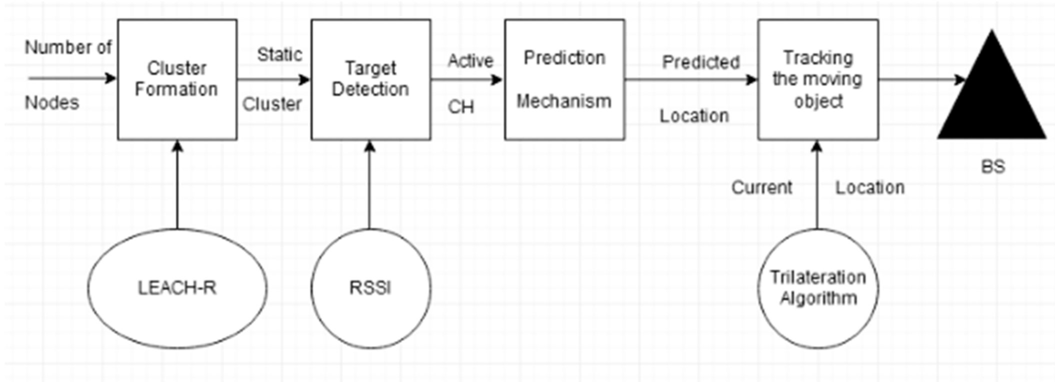

Figure 1. 5 Block Diagram

1.6.2.4.1 Advantages of LEACH-R

The main advantages of LEACH-R include the following:

1. Concept of clustering used by LEACH-R protocol enforces to consider residual energy of the sensor nodes, which increases the network lifetime.
2. CH reduces correlated data locally by applying data aggregation technique which reduces the significant amount of energy consumption.
3. Allocation of TDMA schedule by the CH to member nodes allows the member nodes to go into sleep mode. This prevents intra cluster collisions and enhances the battery lifetime of sensor nodes.
4. LEACH-R protocol gives higher priority to every sensor node to become the CH which has higher residual energy. This method enhances the overall network lifetime.

1.6.2.4.2 Disadvantages of LEACH-R

However, there exist few disadvantages in LEACH-R which are as follows:

1. LEACH-R does not perform better if the number of cluster heads are less than it needed. Then it uses more energy but cannot provide better output.
2. LEACH-R implementation is difficult considering to traditional LEACH.

1.6.2.5 Development of Cluster and Cluster Heads

In each round of the cluster formation, network needs to follow the two steps to select Cluster head and transfer the aggregated data**.** (1) Set-Up Phase, which is again subdivided in to Advertisement, Cluster Set-Up & Schedule Creation phases (2) Steady-State Phase, which provides data transmission using Time Division Multiple Access (TDMA).

The criteria of selecting cluster head in LEACH protocol randomly selects a new cluster head at each round. Due to this some nodes get wear out of energy too quickly. This happens because some nodes get selected as the cluster head repeatedly. So if the node with more residual energy is made the cluster head and this will prevent the whole network to die early. The sink node gets directly get communicated with cluster heads. The energy consumption between cluster head and sink is greater than that of the energy consumed among the cluster heads. This makes the cluster head will exhaust energy soon. By balancing the energy consumption among the network this avoids the whole network from dying quickly. Multi-hop communication avoids the nodes from early death.

Cluster heads can be located even at the edge of the cluster as they are not uniformly distributed. The CH collects and aggregates information from sensors in its own cluster and passes on information to the destination node via other CH's. By rotating the cluster-head randomly, energy consumption is expected to be uniformly distributed. However, LEACH consider all the nodes in clusters to have equal amount of energy and rotates CH in random manner. So there is a possibility of lower energy node to become as a cluster head which results in reducing the lifetime of the entire network. Cluster head selection is randomly performed this does not consider the energy consumption. No overhead is wasted in electing the cluster head from the group of nodes. LEACH is an advanced of the conventional networks.

The parameters that are involved in the clustering of a network are as follows:

- ✓ Cluster count
- ✓ Interaction between members in a cluster.
- ✓ Cluster heads should be portable.
- ✓ Cluster head selection method.

1.6.3 WIRELESS SENSOR NETWORKS: APPLICATIONS

Implementations that use computers have existed for a long time, and computing is already an integral part of our life, heavily used in many aspects of our civilization. In addition to traditional systems, the sensor networks concept began to improve the computer's applicability. Sensor networks' pervasive attributes make them adaptable to a great range of applications. The overview of possible applications for wireless sensor networks is given below:

1.6.3.1 Industrial Control and Monitoring

The deployment of wireless network sensors in the industrial control-and- monitoring field seems very prominent. Normally, a factory has a control room to monitor and control the state of the plant and the condition of the equipment. Specific critical values, like temperature or pressure, are collected from the plant or the equipment. The values describe the plant's or the equipment's condition, which is then forwarded to the control room where it is evaluated. Traditionally, industrial control and monitoring requires the deployment of a complex, expensive wired network. Sensor networks can replace the wired network, providing reliable data transfer and reducing the initial deployment and maintenance cost.

Lighting, ventilation and air-conditioning are other possible areas for wireless sensors. WSN provide the flexibility to support dynamic changes in the environment. This is also enhanced by the WSN programming feature, which offers secure and balanced services (e.g., balanced heating and air conditioning). When used to control and monitor complex equipment like robots, or other rotating and moving equipment, WSN provide the necessary flexibility. Thus, the system's reliability is increased, because damage caused by the machinery's movement is avoided. In addition, small-size sensing nodes can be used where wired implementations are impossible.

1.6.3.2 Home Applications

Home automation is another large application area for wireless sensor networks. The uses in the industrial applications field described above also apply to home implementations. Centralized control of home appliances has already been implemented by using wired solutions or other wireless technology solutions. Their replacement by a wireless sensor network provides a development and maintenance cost reduction, system flexibility, and stretch ability. WSN also provides total, and secure control of the home devices. Another area for the use of WSN that is relevant to home application is the toy industry, a large market. The nature of wireless networks enable toys to behave in complex and logical ways at a reasonable cost.

1.6.3.3 Environmental and Agricultural Monitoring

Wireless networks can be used for habitat monitoring and ecosystem measurements. Haenggi (2004) finds that seismic activity, forest fire, floods and water quality also can be detected and localized by the use of WSNs. Culler and Hong (2004) claim that the outdoor deployment, low power operation, fault tolerance, data quality, and networking characteristics of WSNs are ideal for environmental applications. Moreover, given those characteristics, WSNs can be used for agricultural purposes. Better knowledge of the agricultural environment enables the more precise control of fertilizers, water management cost reduction, quality maximization and environment protection.

1.6.3.4 Military and Security Applications

As with almost any new technology military and security application are recommended uses for wireless sensor networks. WSNs can assist or replace quards around a building or camp perimeter. Target localization and identification is another potential use, whereby friendly troops use WSNs to identify themselves (Callaway, 2004). Haenggi (2005) finds that such implementation can improve “military command, control, communication and computing (C4)” schema. Additionally, he describes an application for “surveillance and battle-space monitoring” in which the proper sensors are deployed in the ground or are carried by unmanned vehicles to monitor opposing forces.

1.6.3.5 Asset Tracking

Among the potential uses of wireless sensor networks, asset tracking is also a large area of interest for military and commercial application. Calllaway (2004) describes a possible use for tracking "shipping containers both in a port and on a ship. By placing WSN nodes inside each container, it and its content become recognizable from a distance.
An exact knowledge of the container's type and position can save handlers a great amount of time by preventing unnecessary errors. The WSNs provide a cost- effective way to increase the "shipper's productivity."

1.6.3.6 Heath Monitoring

Haenggi (2005) identifies two different wireless sensor network medical applications that are expected to rapidly increase. First, he mentions "medical sensing" in which data such as "body temperature, blood pressure, and pulse," collected from the system, can be transmitted to a local or remote computer for health monitoring uses. Additionally, WSNs can be used in the "micro-surgery" field, where tiny medical instruments are used to perform "microscopic and minimal invasive surgery."

1.6.4 POWER MANAGEMENT

Wang, Hassanein and Xu (2005) state that wireless sensor networks "outperform conventional sensor systems, which use large, expensive macrosensors to be placed and wired accurately to an end user." Despite the fact that they are revolutionary, affecting a great volume of applications, wireless networks have many constraints and challenges. One constraint perhaps the most important, is the system's limitation in its power supply lifetime. Most WSN system applications include a requirement for a maximum possible lifetime. In contrast, the core element of a sensor network is normally a battery powered node. As a result, the power management in wireless sensor network is extremely important.

Power management can be divided into two categories: the node's level and architecture and the topology system's power management. The next sections discuss those two approaches.

1.6.4.1 Node's Power Management

A wireless sensor network, in general contains four components. First, the microprocessor and memory unit is capable of performing the node's processing and logic tasks. Second, the sensor component is responsible for monitoring the environment. Third is the communication element which supports data transmission and reception. Finally, "a real-time micro-operating system controls and operates the sensing, computing, and communication units through microdevices drivers and decides which parts to turn off and on" [28].

WSNs' workload is characterized by "burstiness." As a result, some parts of the nodes should switch to a lower power state between consecutive bursts. They identify the possible power states that a node can have as the following: "transmitting, receiving, ready, observing, standby, sleep, and off," (Figure 1.6). To maintain the system's functionality, QoS, and balance between power conservation and latency, the proper design and algorithms must be used. Additional power can be saved by varying the system's performance based on current needs. This variability is called as the "computational workload." They conclude that, currently, the workloads are "mostly nondeterministic" for producing an accurate model.

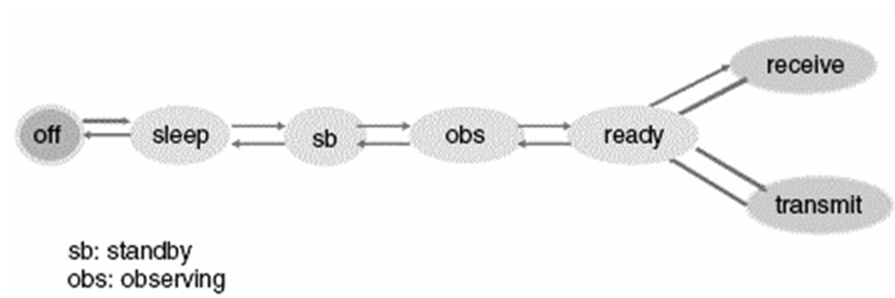

Figure 1. 6 State transition diagram of a sensor node [28]

1.6.4.2 System's Power Management

Another alternative in the nodes' power management is transmission power optimization. It is included in the system's power management because a transmission power level adjustment affects many portions of a wireless sensor network system. The nodes' communication range, network topology and architecture, path selection, and retransmission rate are some of the aspects that are affected by transmission power. A power adjustment is restricted by propagation characteristics of the medium and by the nodes' limitations. The power level tuning can be made at the node level or at the system level.

A proper selection of algorithms and communication protocols, like "rotate the node functionality periodically" or "traffic distribution and system partitioning", helps to maintain the energy balance among the nodes. For data processing to the nodes before its transmission, "data aggregation", or raw data forwarding is another choice that the system's designer has to make, in trying to find the balance between latency and power consumption.

In summary, the power management in wireless sensor network systems is an important but difficult task. The designer has to compromise between the application requirements and the technological hardware restrictions. The nodes' proper configuration, algorithm, and protocol selection, and the system's correct architecture choice are required.

1.6.5 SECURITY AND PRIVACY CONCERNS

Privacy and security are crucial parts of wireless network system architecture. In addition, security and privacy are important requirements for many applications. The primary force for the development of security functions in WSNs is the military application area. Commercial applications also require security, but they are more interesting in the privacy issues. This section will present an overview of the security and privacy aspects of WSNs.

1.6.5.1 Key Establishment and Trust Setup

WSNs properties, especially their node-limited computational capabilities, do not allow the use of traditional "key-establishment" solutions such as public-key cryptography.

Moreover, the key-establishment becomes more complicated because of the system's scale and the communication patterns between the nodes. The shared-key solution also does not work because a node compromise allows decryption of the entire traffic. On the other hand, the solution that uses a symmetric key between each pair of nodes addresses the above problem, but it does not scale well. Another option is the use of a unique key between each node and the base station, but this makes the base a station single point of failure. Key distribution is an active research area. A recent proposal is a "random-key redistribution protocol," in which a pair of nodes uses a share key from a pool. Different pairs of nodes must use different keys.

In this solution, the adversary has to compromise a number of nodes to reconstruct the key pool. Further research and development in the last approach is expected.

1.6.5.2 Secrecy and Authentication

The common approach used to achieve secrecy and authentication is cryptography. Earlier WSN solutions involved link-layer cryptography, which is simple enough. To improve the security performance, later approaches propose "software-only cryptography." The University of California, Berkeley, implementation of TinySec is an example that improves the system's security with only 5%-10% performance overhead.

1.6.5.3 Privacy

Privacy issues have arisen based on the global nature of WSNs, especially for commercial systems. The nodes' size, which become smaller, and the improvement of nodes' capabilities may support improper uses of WSN systems.

1.6.5.4 Communication Robustness

A denial-of-service attack is always possible in a WSN implementation, especially because of the low node transmission power. Currently, the spread-spectrum communication technique is the first measurement. Additionally, the networking characteristics of the WSNs can be used to avoid that kind of attack by rerouting the traffic through the system's unaffected parts.

To summarize, security is always a concern, especially in wireless implementations. As WSNs are a more restricted wireless communication, any kind of security-feature implementation seems more difficult.

1.6 OBJECT TRACKING

Object tracking is one of the challenging and non-trivial applications for Wireless Sensor Network in which network of wireless sensors are involved in the task of tracking a moving object. Several factors are considered when developing algorithms for tracking moving objects include single vs. multiple targets, stationary vs. mobile nodes, target motion characteristics, energy efficiency and network architecture.

1.6.1 INTRODUCTION TO OBJECT TRACKING

Object Tracking is widely used in many applications like military application, commercial applications, field of surveillance, intruder application and traffic applications.

There are various metrics for analyzing object tracking such as cluster formation, tracking accuracy, cluster head life time, miss rate, total energy consumed, distance between the source and object, varying speed of the target, etc. The open issues in object tracking are detecting the moving object's change in direction, varying speed of the target, target precision, prediction accuracy, fault tolerance and missing target recovery. In all tracking process, more energy is consumed for messages or data transmission between the sensor nodes or between the sensor and sink.

In a target tracking application, the sensor nodes which can sense the target at a particular time are kept in active mode, while the remaining nodes are to be retained in inactive mode so as to conserve energy until the target approaches them. To continuously monitor mobile target, a group of sensors must be turned in active mode just before target reaches to them. The group of active sensor nodes varies depending on the velocity of moving object and the schedule by cluster head. The sensor nodes detect the moving object and transmit the information to the sink or the base station.

The traditional target tracking methodologies make use of a centralized approach. As the number of sensors increases in the network, more messages are passed on towards the base station and will consume additional bandwidth. Thus, this approach is not fault tolerant as there is single point of failure and lacks scalability. Moreover in traditional target tracking methods, sensing task is usually performed by one node at a time resulting in less accuracy and heavy computation burden on that node. In WSN, each node has very limited power and consequently traditional tracking methods based on complex signal processing algorithm are not applicable.

Therefore, the object tracking algorithm should be designed in such a way that it result in good quality tracking with low energy consumption. The good quality tracking extends the network lifetime and achieves a high accuracy. In order to obtain an energy efficient tracking with low energy consumption, an assumption is made that all the sensor nodes have same energy level. Because, even if a sensor node fails, other sensor node can take the responsibility and carry out the tracking process.

1.7.2 CHALLENGES IN OBJECT TRACKING

Throughout our research journey, we were able to identify several challenges pertaining to object tracking in wireless sensor networks. Next, we present these challenges as categories that are independent of their applications.

1.7.2.1 Scalability

Scalability is a twofold challenge: The number of sensor nodes in the network and the number of objects need to be tracked simultaneously. It is not uncommon to have a WSN deployment that consists of thousands of sensor nodes. The number may even reach millions in some applications (Li *et al*., 2008). With such large number of nodes, it is not easy to attend to each one due to several factors: Nodes many not be physically reachable, nodes may fail and other new ones may join the network. In such unpredictable, dynamic environment, scalable coordination and management functions are necessary to having robust WSNs. Consequently, designers of tracking algorithms are typically concerned about optimization problems germane to the size of the network, efficient scheduling of active vs. inactive nodes, energy consumption and communication overhead among sensor nodes.

Furthermore, the number of objects needs to be tracked manifests another facet of scalability challenges. For example, tracking algorithms should be able to uniquely identify each object moving especially when the number of issued packets is increased for the sake of increasing accuracy. They also should be optimized and adopt efficient scheduling mechanisms in order to intercept and track multiple objects simultaneously while being energy-conservative.

1.7.2.2 Stability

Since sensor nodes are likely to be installed in harsh conditions outdoors or in hostile environments, they are commonly subject to device failures or may change their initial deployment result from environmental influences such as wind or waterfall. Therefore, it is crucial for any object tracking system to demonstrate a reasonable degree of fault-tolerance and adopt some recovery mechanism.

1.7.2.3 Node Deployment

Depending on the application, the WSN deployment can be either deterministic, where nodes are placed manually in a pre-planned manner at certain Cartesian coordinates, or randomized, where nodes are deployed across certain geographical area in an ad-hoc manner. Compared to random networks, deterministic networks are featured by lower complexity and lower cost of network maintenance and management because their nodes deployed placed at specific locations that ensure coverage. On the other hand, random deployment can spawn uncovered areas. In addition, location identification for each sensor node is a must after deployment and before putting the network in operation. Location can be determined using Global Positioning System (GPS) system or manually by calculations or by finding the relative location given that each node is within the coverage of another node.

Unfortunately, the random deployment is the only choice when we need to setup WSNs in harsh, unsafe or hostile ambiences. However, in a new type of WSNs, some sensor nodes reposition themselves over time in order to maintain coverage.

This goal can be achieved by one of two methods. The first method depends on self-deployment where sensors autonomously reposition themselves in order to improve coverage. The second method depends on the relocation of redundant nodes in order to cover for the failed nodes.

1.7.2.4 Computation and Communication Costs

Any WSN consists of small sensors with constrained capabilities of computation and communication. Typically, the cost of local computation is much lower than communication cost, which makes reducing the communication overhead a priority for any WSN algorithm.

1.7.2.5 Energy Constraints

Due to the difficulty of recharging, the lifetime of the battery in each sensor determines how long it can operate. Therefore, energy conservation should be kept in mind in all cases.

Usually, algorithms tend to minimize energy consumption by: (1) Scheduling when a node should be in active or sleep state, or (2) minimizing the communication and computation cost as much as possible. On the other hand, as the author suggested in, not all sensors that detect the target are in charge with the tracking process. The algorithm uses the sensor's residual energy to check that this sensor is available for the dwelling time that this target will be within range using a prediction formula. Any sensor node that does not meet this criterion is eliminated from the tracking process.

1.7.2.6 Data Aggregation

Data aggregation is a common task in WSNs where data generated from individual sensors are combined and compressed at an intermediate sensor node before relaying them to the final base station, resulting in a minimal number of transmission packets. However, the extent of data aggregation depends on the intra-network spatiotemporal correlation of the signal of interest and the nature of the application. The problem of data aggregation is more apparent when sensor nodes generate duplicate packets. Therefore, it is imperative for any algorithm to reduce travelling packets in order to have a less channel congestion and lower network latency.

1.7.2.7 Sensor Technology and Localization Techniques

Currently there are diverse types of sensors and localization techniques with different accuracies but none of them are highly accurate to be used for all possible WSN application scenarios. The best choice of sensor technology for a specific application is highly reliant on the needed distance range, signal propagation cost, precision, bandwidth etc. For instance, infrared, ultrasonic, electromagnetic, and optical and Radio Frequency Identification (RFID) systems are the typically used technologies.

Other issues that are directly related to algorithm design for tracking an object are-

1.7.2.8 Tracking Accuracy

Accuracy of tracking algorithms implies low probability of missing the moving object, low response latency and low sensitivity to external noise. Furthermore, they should be equipped with a recovery mechanism in case the object is lost.

1.7.2.9 Reporting Frequency

Reporting frequency poses a tradeoff between accuracy and energy consumption. Tracking algorithms face the challenge of creating a balance between keeping the base station informed about the movement of the mobile object at certain frequency and preserving energy that can be highly consumed at high communication frequency. The sink node can adjust the reporting frequency during the network progress and transmit the new value in a single broadcast message so each node will adjust its frequency accordingly. In non-sink centric approach, each node can increase its frequency in case of retransmission and as part of object recovery mechanism.

1.7.2.10 Localization Precision

The precision of determining object's location by the WSN is proportion to the number of sensors used in the localization process. Generally, to determine the location of an object in 2D space, at least three nodes are required and in 3D space, four nodes are required. To that end, object tracking algorithms face the challenging tradeoff between high precision and the need to conserve energy by lowering the number of active nodes participating in the localization process.

1.7.2.11 Sampling Frequency

One of the WSN parameters that an object-tracking algorithm may need to consider optimizing is the frequency of sampling, that is, how often a sensor attempts to detect the existence of an object per time unit. It is a parameter that can directly affect the precision of localization. Low sampling rate hides the minor changes in object movements, resulting in lower tracking accuracy or even failing to intercept the object entirely especially if it moves at a high speed. On the other hand, increasing the sampling rate improves the tracking accuracy but drains sensor's battery.

1.7.2.12 Security

Security is vital in mission-critical applications. In mission-critical WSNs, sensors are deployed in harsh, unsafe or hostile places where they can be easy targets for intruders who may falsify the collected data. Tracking algorithms need to take care of source authentication, data integrity and confidentiality. Violation of one of these security properties can lead to unspeakable risks. For instance, object detection algorithm can be deceived by injecting malicious data into the network, garbling the gathered data or sending phony ones. Therefore, object tracking algorithms, especially those used in sensitive application domains, must keep security vulnerabilities in mind prior to deployment.

1.7.3 SOLUTIONS FOR THE CHALLENGES IN OBJECT TRACKING

The literature is rich with approaches that aim to solve object-tracking challenges from different perspectives and for various goals. In this section, we review the network architectures with emphasis on the prominent approaches used and tracking algorithms that operate on top of each approach. Figure 1.7 depicts our classification of object-tracking architectures, as elucidated in the following subsections.

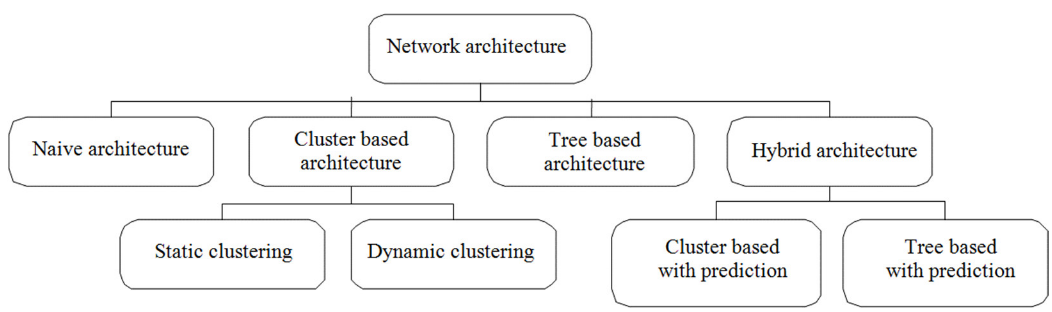

Figure 1. 7 Network architectures used for object tracking in WSN

1.7.3.1 The Naïve Architecture

The naïve architecture is the simplest and the most traditional WSN model in which all sensors are always active trying to intercept and monitor objects in their sensing area and reports to one centralized sink node. With equal responsibility, each sensor independently observes, processes and transmits the monitored data to the sink node. Under this centralized approach, the sink node solely undertakes the heavy computation tasks related to tracking and localizing the monitored objects. Moreover, the more sensors the network has, the more messages are relayed onto the sink node, leading to the increase in communication bandwidth consumption. This model is obviously not fault-tolerant due to the single-point-of- failure and its limited scalability. It usually exhibits the worst energy efficiency because of its heavy communication and computation demands. This renders the naive solution a baseline for comparison with other solutions.

1.7.3.2 Tree-Based Architecture

In this case a tree structure is maintained across the network. The tree is rooted at the node that is closest to the target. Thus as the target moves some nodes get added to the tree and some get deleted. This scheme reduces the overhead in terms of energy and information flow, as the information flows from the root to the end or periphery of the network through a particular route, as the information flows is controlled so energy consumption automatically gets controlled.

1.7.3.3 Cluster-Based Architecture

In cluster based architecture there are several sensor nodes and for a certain group of nodes, they are assigned a cluster leader or cluster head. The ordinary nodes just sense the reading and send them to the cluster thereby shifting the burden from them to the cluster head. The cluster head is normally a high energy and high resource node. The introduction of cluster heads can reduce sufficient cost of network as one can deploy low cost low energy sensor nodes.

In general, any clustering algorithm consists of four main stages:

- Geographical formation of clusters
- Selection of some sensors that are sparsely deployed with high capabilities as cluster heads. The selection is based on their processing capabilities, communication range, residual energy, or location compared to the object. Keep in mind that cluster heads need to be well-distributed over the sensor field to achieve high coverage. Typically, the failure of a cluster head entails re-clustering, however, some approaches can adapt the network topology by resorting to backup cluster heads.

- Data aggregation stage in which the sensed data are gathered and combined in a less number of packets in preparation to be sent to the cluster. Basically, sensor nodes will provide their sensing information upon request.
- Data transmission stage which involves the transfer of the aggregated data from the cluster heads to the sink node

Based on the formation style of clusters, they are classified into static and dynamic, as explained next.

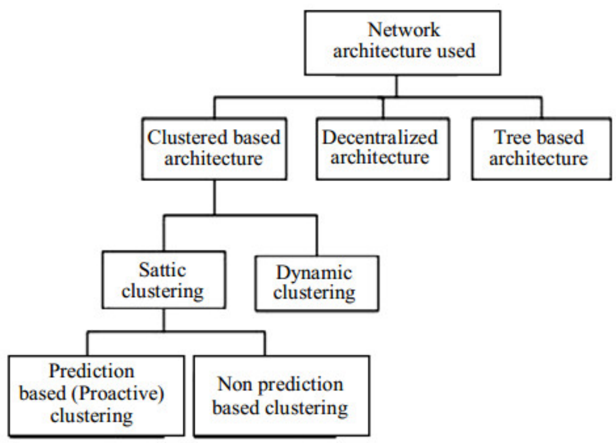

Figure 1. 8 Further classification of techniques on the basis of network architecture used.

1.7.3.3.1 Static Clustering

In static clustering the cluster heads are assigned to the respective sensor nodes at the time of formation of network and they cannot be changed. This means that throughout the working of wireless sensor network the nodes remain attach to the same cluster head as they were pre-assigned.

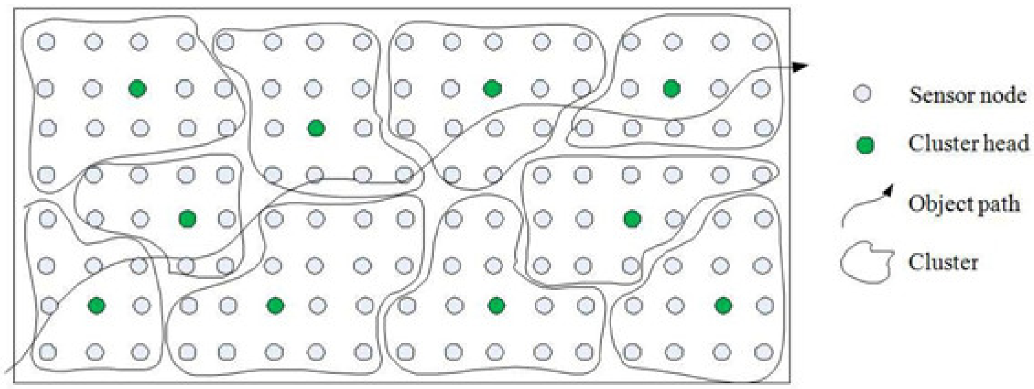

Figure 1. 9 Static clustering scenario

1.7.3.3.2 Dynamic Clustering

Again the dynamic clustering scheme can be of two types-

1.7.3.3.2.1 Prediction Based or Proactive Clustering

This scheme is mostly employed in a network of sleep sensors, where most of the sensors stay in the sleep mode. In prediction based clustering when a target moves from the region of one cluster head to the other, the current cluster head has to make an estimation or prediction about where the target is moving and correspondingly wakeup a cluster head where the target is moving.

1.7.3.3.2.2 Non Prediction Based Clustering

This is similar to the scheme described under the heading of dynamic clustering. This scheme is used in a network of non sleep sensors. Here the energy saving is not an issue instead the proper selection and the life time of clus- ter head is an issue. So based in some criteria based on the application environment a cluster head selection al- gorithm is run on each individual node, and the nodes co- llaboratively select the cluster head.

While static clustering is formed at the network design- time, the construction of adaptive clusters is triggered by a special event of interest, such as the acoustic sounds of a moving object, as shown in Figure 1.10. When a sensor, hopefully the one that is the nearest to the object or the one with the highest energy, detects an object, it volunteers to play the role of a cluster head.

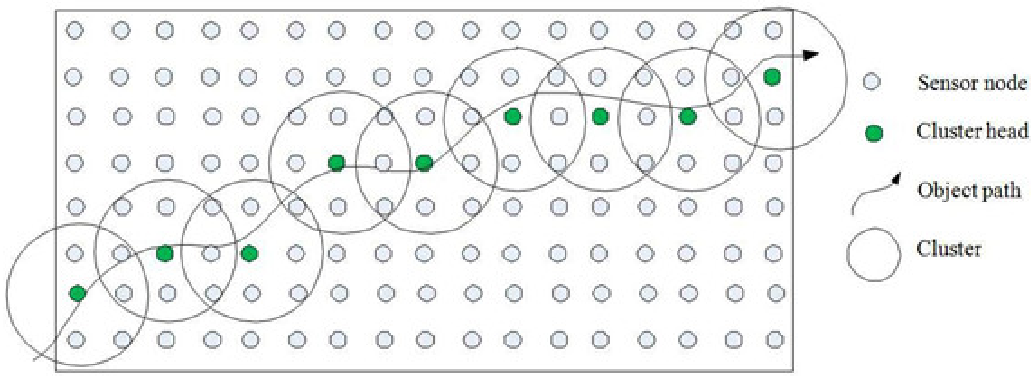

Figure 1. 10 Dynamic clustering scenario

Typically, multiple sensor nodes may detect the event of interest so multiple volunteers may exist. For this reason, some mechanism is used to ensure the selection of only one sensor as a cluster head. Nodes that are close to the cluster head are invited, as members, to form a cluster and report their collected data to the head. The cluster is dismantled when the object is no longer sensed.

1.7.3.4 Hybrid Architecture

Hybrid architecture generally combines one of the previously mentioned architectures with some prediction mechanism. Prediction relies on heuristics and attempts to anticipate the upcoming position of the moving object based on its historical positions observed over time and the spatial and temporal knowledge of sensors. Based on this prediction, sensor nodes get scheduled to be either active or asleep during each defined time step. Due to the inevitable prediction mistakes, these algorithms have recovery mechanisms in order to make up for the inaccuracy of object localization. Unfortunately, such algorithms are typically too complex to be implemented on sensor nodes with constrained resources.

An example of a hybrid approach is the Hierarchical Prediction Strategy (HPS) that augments the cluster- based approach with a prediction mechanism. In the HSP strategy, the cluster is built using Voronoi division and the mobile object's next location is predicted. One of the major shortcomings of such algorithms is the additional complexity resulting from combining the two approaches. Furthermore, the performance overhead incurred was not assessed.

1.7.4 NUMBER OF TARGETS USED

The tracking technique can be either for single target tracking or multiple target tracking. (Figure 1.11).

1.7.4.1 SINGLE TARGET TRACKING

Tracking in single target is relatively simple. Less data is produced that results in a low traffic in the network. Less traffic is easier to handle and the routing mechanism is not complex.

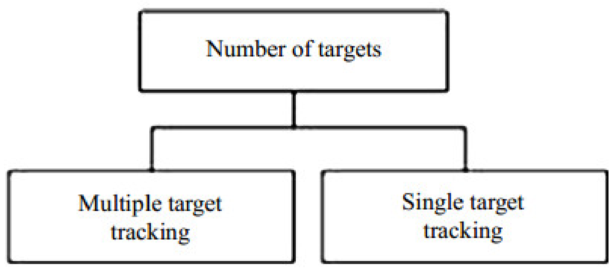

Figure 1. 11 Classification on the basis of number of targets tracked.

1.7.4.2 MULTIPLE TARGET TRACKING

Tracking the path of multiple objects is more challenging than tracking a single one due to the need of identifying each object moving in different directions with different speeds and the need of track continuity with good performance. If all energy- restricted nodes are kept active for the purpose of tracking multiple objects, the network traffic and the probability of failure will increase dramatically. Consequently, more complex routing algorithms and energy minimization techniques have to be used. In addition, as each sensor node is responsible for detecting and tracking multiple objects, it should be able to distinguish objects by some means of signal processing algorithms. In literature, we can find many object classification algorithms that adopt a set of weighted features for the purpose of identifying objects Object's kinematic characteristics such as its movement pattern, position, velocity and acceleration are usually used in tracking multiple objects to narrow the tracking region.

Dense networks are often used to monitor multiple objects in order to maximize the number of sensors that cover all points in the object's area. In such networks, eliminating redundancy is imperative for efficiency. This can be achieved by using hierarchical multi-tier networks or event- triggered solutions.

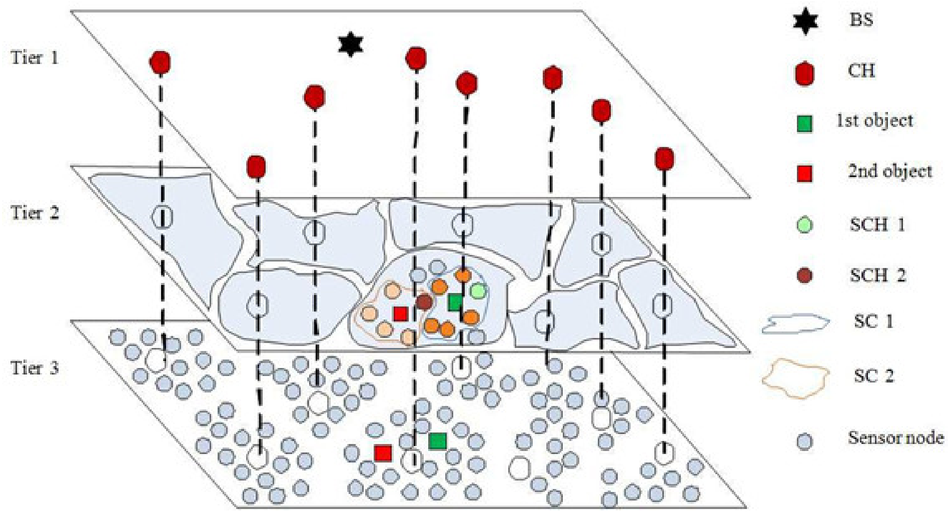

Figure 1. 12 Three-tier cluster-based WSN

As shown in Figure 1.12, three-tier cluster-based network is illustrated where the pre-determined cluster heads keep listening to the medium for any approaching objects then they activate their cluster members based on certain criteria to minimize network traffic and energy consumption. From these members, multiple Sub Cluster Heads (SCHs) could be elected in case of the availability of multiple objects within the same cluster vicinity. The criteria could be a weighted average of multiple factors like the node's remaining energy, the Euclidean distance between the node and the object and the type of sensor or sensor technology (if the network is heterogeneous). If multiple objects are in the vicinity of a certain cluster, we can assign one SCH for each object. These Sub Clusters (SCs) will detect and localize the objects and send their observation to the upper tier cluster heads up to the end base station.

1.8 THESIS ORGANIZATION

Chapter 1 provides an overview of the wireless technology, describes the concepts of wireless sensor networks, and introduces the new area of wireless sensor networks. It also describes possible wireless sensor network applications and related architecture and networking issues, and also introduces the sensor networks constraints and concerns. It's further describes the object-tracking application, including the application's design considerations and the configuration issues. Challenges in object tracking and solutions for those problems.

Chapter 2 gives the idea of related works based on the discussed topic.

Chapter 3 describes our proposed system. Proposed algorithms, necessary mathamatical equation, and values for used variables in the system can be found there.

Chapter 4 inclueds the simulation results and necessary figure based on the topic.

Chapter 5 has our conclusions from the experimental results and makes recommendations for future research.

CHAPTER 2

RELATED WORK

In general, the tracking algorithm is mainly based on the network architecture-Tree based, Cluster based and Prediction based algorithm. Tree-based methods organize the network into a hierarchy tree. Some examples are STUN (Scalable Tracking Using Networked Sensors), DCTC (Dynamic Convoy Tree- based Collaboration) and OCO (Optimized Communication and Organization). H. T. Kung *et al.* [4] have proposed STUN where cost is assigned to each link of network graph, which is computed from the Euclidean distance between the two nodes. Construction of the tree is based on the costs. The leaf nodes are used for tracking the moving target and then sending collected data to the sink through intermediate nodes. Distance travelled by the tracking object is limited (bounded) here.

Wensheng Zhang [5] has proposed DCTC algorithm, dynamically constructs a tree for mobile target tracking and depending on the target location, a subset of nodes participate in tree construction. The tree in the DCTC is a logic tree and does reflect the physical structure of the sensor network. Sam Phu Manh Tran *et al.* Have proposed, OCO [6] is a tree- based method for target tracking that provides self organizing and routing capabilities with low computation overhead on sensor nodes. Authentication and other security features are not considered in OCO.

Li-Hsing Yen *et al.* have proposed, Mobility Profiling Using Markov Chains [7] which estimates the mobility profile (link between nodes and weight of each link) from the historical statistics. By this the problem of energy consumption for update the location information to the sink is reduced, while passing message between the sink and sensor nodes (directly). Cannot get the accurate speed and direct of the objects (random value) and up-to-date information may not be available in the sink.

Some of the examples for Cluster based tracking are RARE, Dynamic Clustering Tracking Algorithm (DCTA) and Adaptive Dynamic Cluster-based Tracking (ADCT). Wei-Peng Chen *et al.* have proposed, Dynamic clustering algorithm [8] for acoustic target tracking in WSNs, constructs a voronoi diagram for CHs and nearest CH to target in each interval time is the CH that the target is placed in its cell. This CH is selected as active CH. Then active CH broadcasts a packet and nodes that receive this packet reply and send the information that have sensed from target for it. Active CH, calculates current target's location and sends it to the sink. Conflict may occur when more than one CH has the same pre-determined threshold, which lead complication in CH selection.

A cluster-based algorithm for tracking proposed by Khin Thanda Soe has proposed [9] consists of three main phases, target detection, acoustic source localization and target state estimation and tracking. Olule, E. *et al.* have proposed [10] is based on two algorithms, RARE-Area (Reduced Area REporting) and RARE-Node (Reduction of Active node REdundancy). RARE-Area reduces number of nodes participating in tracking and RARE-Node reduces redundant information.

Dan Liu, Nihong Wang *et al.* have proposed, Dynamic cluster based algorithm [11] wake up or slept the sensing nodes though predicting the moving track of the target, reduce the number of tracking nodes to minimize network energy consumption. Selecting the optimal nodes to conduct the tracking task along the predicted moving track though the energy consumption of communication function will guarantee load balancing and extend the network lifetime.

Examples of prediction-based algorithm are PES (Prediction-based Energy Saving), DPR (Dual Prediction-based Reporting) and DPT (Distributed Predicted Tracking). These methods focus on reduction of energy consumption by keeping most of nodes in sleeping mode.

Yingqi Xu *et al.* have proposed, DPR [12], where the next location of target is calculated at both sensor nodes and sink. When the difference between real location and predicted location is acceptable, no update message send to sink and therefore the number of packets transmitted decrease.DPR reduces the energy consumption of radio components by minimizing the number of long distance transmissions between sensor nodes and the base station with a reasonable overhead. In DPR, both the base station and sensor nodes make identical predictions about the future movements of mobile objects based on their moving history. Error in sensor detection and communication collisions in network is not recoverable.

H. Yang *et al.* have proposed, Distributed Predictive Tracking [DPT] [13], uses separate algorithms for nodes and CHs. The CH uses the target descriptor to identify target and predicts its next location. The protocol uses a clustering based approach for scalability and a prediction based tracking mechanism to provide a distributed and energy efficient solution. The protocol is robust against node or prediction failures which may result in temporary loss of the target and recovers from such scenarios quickly and with very little additional energy use. To achieve low miss rate, the DPT algorithm should be extended.

Mohammad-Taghi Abdizadeh *et al.* have proposed, Adaptive Prediction-based Tracking (APT) [14] scheme is proposed that enables tracking in the sensor network to achieve a certain level of self cognition for modifying the tracking time interval for movement patterns with acceleration, which results in significantly decreasing the network power consumption and achieving a smaller miss probability.

Guojun Wang *et al.* have proposed, Two-level cooperative and energy-efficient tracking algorithm (CET) [15] reduces energy consumption by requiring only a minimum number of sensor nodes to participate in communication, transaction, and perform sensing for target tracking in wireless sensor networks. It is expected that only the nodes adjacent to the target are responsible for observing the target to save the energy consumption and extend the network lifetime as well by using a wakeup mechanism and a face-aware routing.

CHAPTER 3

PROPOSED SYSTEM

3.1 PROPOSED SCHEME: MODIFIED LEACH-R

Modified LEACH-R protocol tends to improve the procedure of selecting the new cluster head. The prime idea of this protocol is to take decisions depending upon available residual energy in the node. Judging by residual energy, the algorithm decides that which node will be the cluster head among the rest for the next round [16]. Cluster heads are generally randomly selected by the nodes for the first round and in the next round, residual energy of each node is taken into consideration to select the node as a cluster head. In each round, n nodes participate to become cluster head until the last dead node. This protocol furthermore partitions into many rounds as compare for the LEACH protocol. Every round contains established phase and constant state phase [17].

In cluster set-up phase, nodes that have more residual energy become the cluster head. The responsibility of the newly elected cluster head is to inform about its election as a new cluster head. The normal nodes that has less residual energy sends request for joining the cluster to cluster head [17]. In cluster steady state development, nodes send information to the other nodes as well as to cluster head if the destination exists outside the cluster. All this communication is carried out according to the TDMA plan. Cluster head then transmits information to the sink node. As time passes, the network again starts the re-election process of the cluster head [18].

3.1.1 Clustering Of Nodes

LEACH stands for Low Energy Adaptive Clustering Hierarchy: a protocol designed to collect information from various nodes, aggregating it and then passing it to the base station whilst consuming the low power during operation. LEACH distributes the sensor nodes into clusters and each cluster has its own cluster head [38, 39]. To avoid collision, TDMA schedule is followed. TDMA calendar is created by the cluster head and other nodes of the cluster, i.e., member nodes. To all the member nodes, TDMA opportunities are doled out that is utilized to trade the information between member nodes and cluster head. With the exception of their time opportunities, member nodes spend their energy within the slumber state [40]. The cluster head spend huge amount of energy for transmission if the sink node is far away from the cluster head. The cluster heads are energy dependent. This creates a necessity to replace the cluster head with the passage of time. Every node decides autonomously whether alternate nodes change into a cluster head or not. In LEACH protocol, nodes settle over a choice whether they change into a cluster head or not for now. The selection process of whole area into clusters is time variable. Every cluster head node haphazardly selects a CDMA code for communication [41, 42]. The process of clustering is segmented in two parts: Set-up phase and Steady state phase. In set-up phase cluster head is elected and advertised whereas in steady state phase monitoring and relaying of messages via cluster head begins.

3.1.2 Algorithm and Parameters

Proposed protocol is virtually tested in software assuming a heterogeneous sensor network with randomly deployed 100 sensor nodes over a region of (100×100) m^2 area. The base station is located at (50m, 50m). The packet size assumed in the testing procedure is 40000 bits. Initial energy of the each node will be 0. 5J. Modified LEACH-R algorithm is implemented in MATLAB package and performance is evaluated by measuring the parameter values that resulted after simulation. For introspection of protocol, we measured the duration of the network in rounds to see when the 1st node dies. The actual threshold value will be figured out as:

$$Tr(n) = \begin{pmatrix} \dfrac{\mathrm{P}}{1 - \mathrm{P} * \left(\mathrm{r} \bmod \dfrac{1}{\mathrm{p}}\right)} \left(\dfrac{E_{residual}}{E_0}\right) & if\ n \in G \\ 0 & o \quad therwise \end{pmatrix}$$

where, p represents fraction of nodes, cluster head is selected based on the value of threshold value $T_r(n)$. The quantity is dependent upon the percentage with the cluster to turn out to be cluster head **(p)**, r is the number of rounds and G is the number of clusters that did not become a cluster head in the last **($1/p$)** rounds. $E_{residual}$ is residual node energy, E_0 is initial energy.

After the cluster formation, an arbitrary node is selected from cluster based upon the residual energy and distance from base station.

$$lambda = \frac{E_{residual}}{d_{toBS}}$$

where, d_{toBS} is the gap between base station and cluster head. Lambda is calculated among all nodes in the cluster. The node having the greatest value of lambda is considered as the arbitrary node which is further made as a cluster head.

Table 3. 1 Assumed parameters and their dimensions

Parameters	**Dimensions**
Sensor field (m^2)	100*100
Sink position (m^2)	50*50
Number of nodes	100
M (% of advance nodes)	0.3
Packet size (bits)	4000
E_{fs} (free space energy)	10 pJ/bit/m^4
E_{mp} (enrgy consumption due to multipath propagation)	0.0013 pJ/bit/m^2
E_{da} (enrgy consumption due to data aggregation)	50 nJ/bit
E_0 (initial energy)	0.5
p (% to become cluster head)	0.1
a (% of advanced nodes)	4

3.1.2.1 Formation of Clusters:

The suggested work is based upon the hierarchical clustering routing protocol. In this clustering process, where in just about every round clusters are usually re-secured. In this specific clustering network, new cluster heads are chosen in each and every round and burden grows to be all around disseminated and adjusted among all the nodes of the system. Optimal numbers of nodes are selected to be the cluster head in each and every round. To decide the cluster head among the selected nodes, threshold value can be calculated as [19]:

$$T(S_{(nrm)}) = \begin{cases} \frac{P}{1 - P_{nrm}\left(r \bmod \frac{1}{P_{nrm}}\right)}, & if\ S \in G, \\ 0 & otherwise, \end{cases}$$

where *r* is the number of current rounds, *G* is the number of nodes that are not chosen as cluster head before. Cluster heads in the proposed protocol is selected based upon the threshold value which varies between random numbers 0 and 1.

3.1.2.2 Optimum Number of Cluster Heads:

With this investigation, first order LEACH model is employed, with receiving expense $E_{Rx(l)}$ and transmission expense $E_{Tx(l,\ d)}$ of *t* bits per message. The expense can be calculated using the mathematical formula [24]:

$$E_{Tx}(l,d) = \begin{cases} l * E_{elec} + E_{fs} * d^2 * l, & if\ d \le d_0, \\ E_{elec} * l + E_{amp} * d^4 * l, & if\ d \ge d_0, \end{cases}$$

$$E_{Rx}(l) = l * E_{elec},$$

where E_{elec} is the energy every bit dissipates for collecting data and sign data. Two ray design and free space model are used using the distance between receiver and transmitter. d_o is the particular threshold distance and it could be calculated as [24]:

$$do = \sqrt{\frac{E_{fs}}{E_{amp}}}$$

In the event that $d < d_o$ free space model is utilized; otherwise two ray model is utilized.

To locate the ideal number of groups following formula is utilized:

$$k_{opt} = \sqrt{\frac{n}{2\pi}} \cdot \sqrt{\frac{E_{fs}}{E_{amp}}} \cdot \frac{M}{d^2}$$

The optimal probability of a node to show into a cluster head might be calculated as [10]:

$$P_{opt}=\frac{k_{opt}}{n}$$

First, calculate the energy available in the standard or normal nodes and advanced nodes as:

$$E_1= E_o(1+a),$$

where E_0 is the energy of normal nodes and E_1 is the energy of the advanced. The proposed protocol allocates a weight to each node based upon energy. Weight describes the probability of a node to turn into a cluster head. This weight is added up in the initial energy of the node. Every node will turn into a cluster head once either the nodes are heterogeneous or homogenous.

3.2 TARGET DETECTION

The target detection is done using Received Signal Strength Indicator (RSSI) method. It estimates the distance between two sensors by measuring the power of the signal transmitted from sender to receiver. Theoretically, the signal strength is inversely proportional to squared distance, and a known radio propagation model can be used to convert the signal strength into distance. The main advantage is its low cost, because most receivers are capable of estimating the received signal strength. In some cases, there may be inaccuracies of distance estimation due to noise and interference.

But, considering its low cost, it is possible that a more sophisticated and precise use of RSSI (e.g., with better transmitters) could become the most used technology of distance estimation. A sender node sends a signal with a determined strength that fades as the signal propagates. The bigger the distance to the receiver node, the lesser the signal strength when it arrives at that node.

3.3 PREDICTION MECHANISM

A prediction-based algorithm uses a prediction mechanism that predicts the next location of target is a linear prediction method. This mechanism with current and previous location of target, predicts next location of target.

Using (x_i,y_i) and (x_{i-1},y_{i-1}) , co-ordinates of nodes i and i-1 at time t_i and t_{i-1} the target's speed v and the direction is calculated .The predicted location (x_{i+1},y_{i+1}) of the target after the given time *t* is calculated using the target speed and direction. If the predicted location is within the current cluster, then the active CH selects the three nodes which are nearest to the location. If the predicted location is placed out of the current cluster, active CH selects nearest CH to that location as next active CH and gives the tracking task to the new active CH.

3.4 TRILATERATION ALGORITHM

After receiving the distance message from two other selected nodes, the leader node calculates current location of moving object using trilateration algorithm. Trilateration algorithm forms relation between three nodes and by solving three formed relations the coordinate of target (x,y) is obtained.

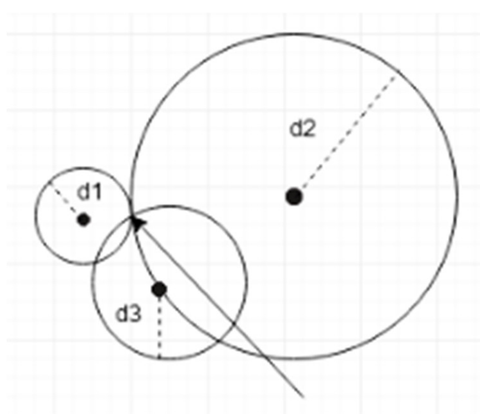

Figure 3. 1 Trilateration Algorithm

In Lateration, the mobile nodes are localized using overlapping circles as shown in Figure 3.1. The circumference radii are equal the estimated distance among nodes.

3.5 TRACKING OF MOVING OBJECT

In general, tracking system track the moving targets in a WSN by sensing capability of sensors (like acoustic, vision, thermal). Since sensor nodes have limited battery power and replacement of battery is impossible, energy saving is an issue in tracking process.

Input : Number of nodes

Output : Current location of the moving target

Steps 1 : Initially the nodes are clustered using Modified LEACH-R.

Steps 2 : The moving object is detected by the sensor using RSSI and the CH which is close to moving target becomes the Active CH.

Steps 3 : The Active CH uses the prediction mechanism and predict the next location of the moving target as (x_{i+1},y_{i+1}).

Steps 4 : If the predicted location is within the cluster members, then the active CH selects the three nodes to calculate the current location using trilateration algorithm.

Steps 5 : Else if the predicted location is outside the current cluster, then the CH near to the predicted location becomes Active CH and Step 4 is followed.

CHAPTER 4

PERFORMANCE EVALUATION

Reliability depends upon the working and efficiency of the protocol. In order to verify it, the protocol is virtually tested and simulated in MATLAB. The parameters and their values used during the simulation are already stated in the previous section. Figure 4.1 shows the initial phase of debugging process which displays the random deployment of sensor nodes in the presumed area. All nodes tend to be randomly deployed in presumed area of 100m*100m, where base station is positioned in the middle 50m*50m which is marked by a small ‘x’.

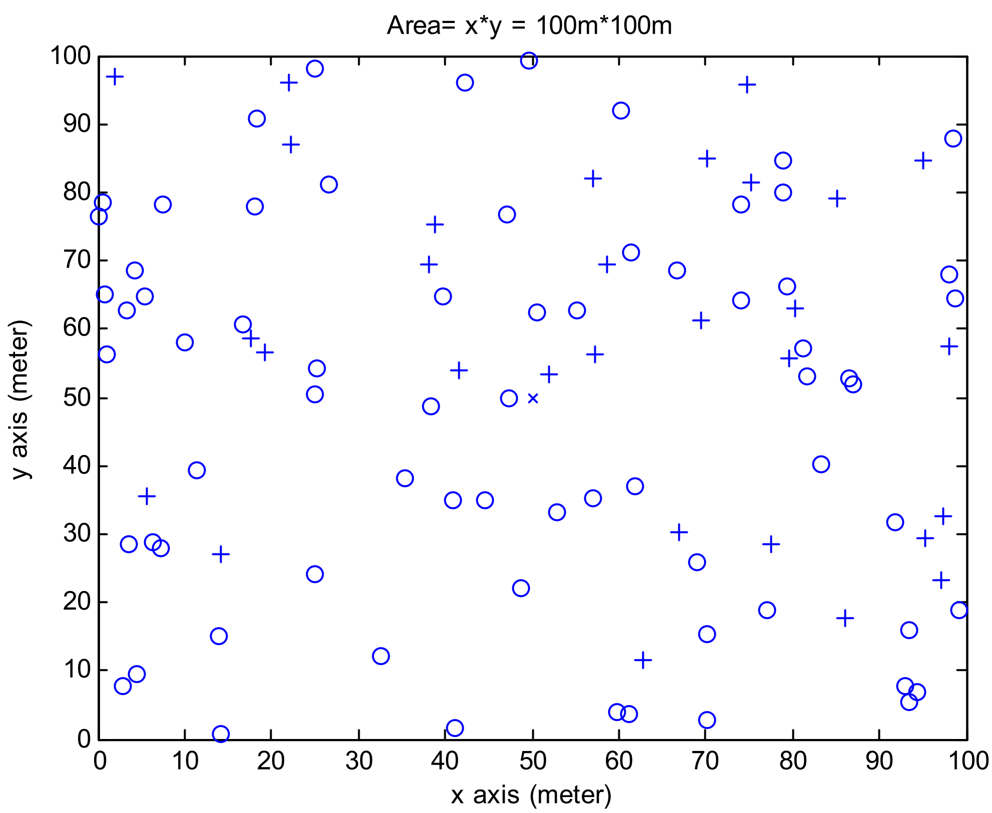

Figure 4. 1 Random deployment of sensor nodes.

Figure 4.2 exhibits the network with half dead nodes. Nodes are brought up to perform some tasks. While in operation, they consume energy. Due to limited resource of battery in nodes, the sensor nodes die early. Figure represents the same scenario where after a certain period of initialization of network, many nodes have due to consumption of whole energy source available. Hence, the scenario is shown where the dead and active nodes are represented by different colors: red – dead nodes.

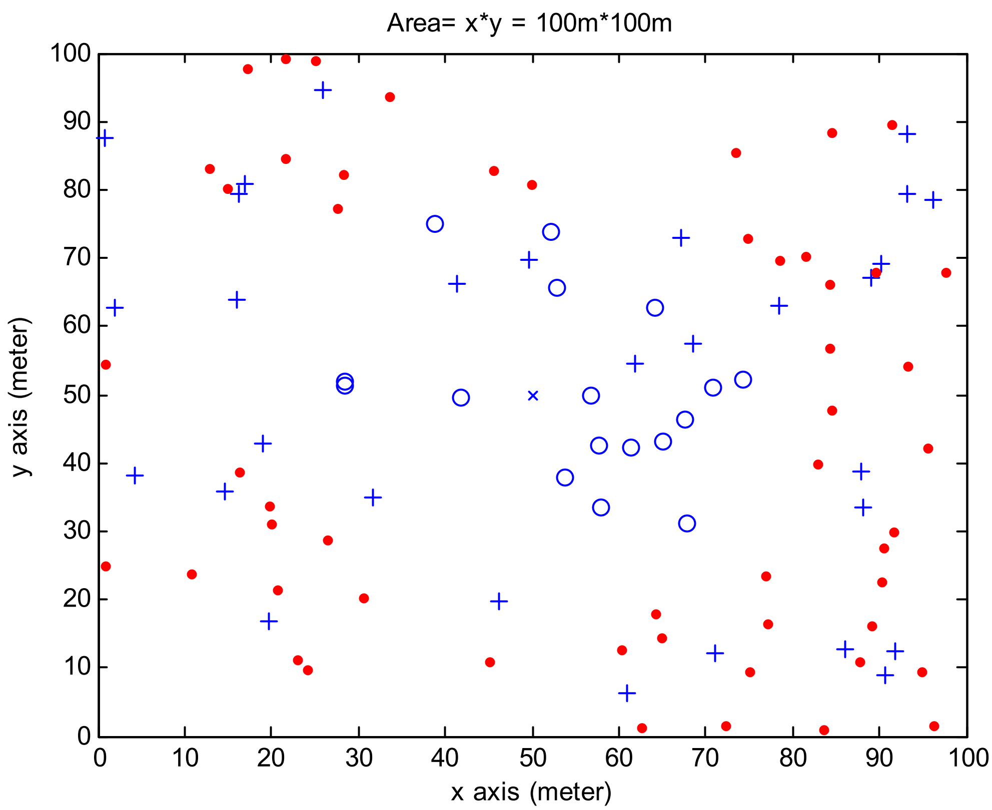

Figure 4. 2 Network with half dead nodes.

Figure 4.3 exhibits the network when all the nodes have died, i.e., no longer operational. Results reveal that the last node of the network operated under modified LEACH-R protocol dies after 15000 rounds. It is far better in comparison with the techniques: traditional LEACH and LEACH-R.

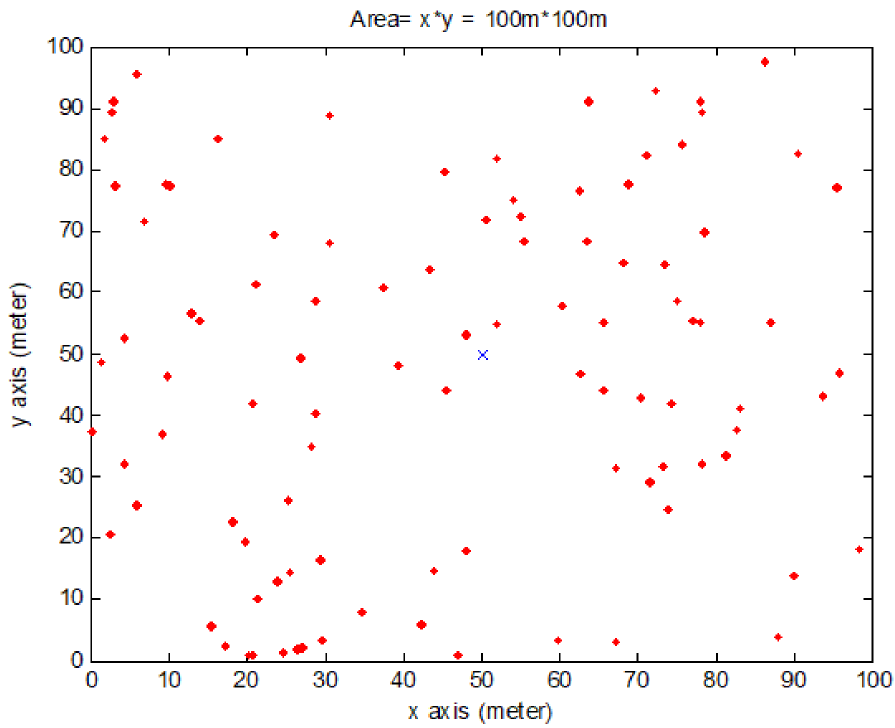

Figure 4. 3 Network with all dead nodes.

Table 4. 1 Calculations for modified LEACH-R protocol

Parameters	**Values**
r_{max} (maximum numbers of rounds)	13999
d (distance between nodes and CH)	22.6409
d_0 (threshold distance)	87.7058
dead_a (advance dead nodes)	23
dead_n (normal dead nodes)	70
dead (number of dead nodes)	93
first dead	1095
flag_first dead	1
m	0.3000
min_dis	28.9051
rcountCHs	3778

Figure 4.4 demonstrates the correlation of the conventional techniques LEACH and modified LEACH-R. In modified LEACH-R, the nodes of the cluster inform about its very own status to the cluster heads. This protocol is quite effective in terms of energy conservation. Thus, protocol improves the regions of cluster based hierarchical course of action using heterogeneity guidelines like determination regarding advanced nodes and extra vitality factor between advance nodes and normal nodes. Hence, modified LEACH-R protocol has increased stability time pertaining to first dead node and correspondingly increasing the time of last dead node.

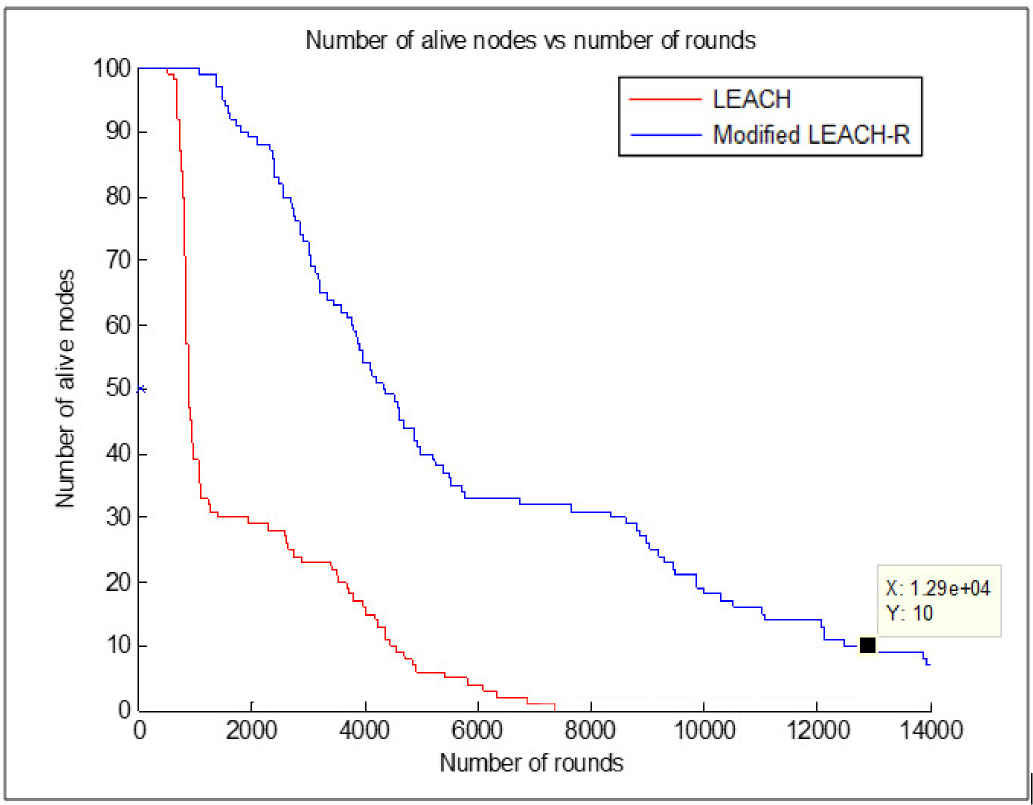

Figure 4. 4 Comparison between LEACH and Modified LEACH-R Protocol

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSIONS

In this thesis we have explored the use of wireless sensor networks for object tracking and motion estimation. We described the revolution in wireless communication and important wireless implementation techniques and protocols. We introduced the wireless sensor networks, theoretical characteristics and system constraints, and current available and possible networking architectures and deployment topologies. We also described some of the related standards. In chapter two we presented an overview of the wireless sensor networks.

Wireless Sensor Networks are designed to extract crucial information where the human intervention is not possible or where the precision is required. Manual inspection does not lead to precision. So WSN plays a vital role in reliable and precision data gathering applications. Unnecessary energy consumption could lead to reduction of network lifespan. But there are many techniques that are designed like LEACH, LEACH-F, and LEACH-C etc to overcome that problem but they are limited in functionality. Therefore, this proposed work is accomplished as a possible improvement to the particular LEACH-R protocol, Modified LEACH-R protocol and thus giving another name for this protocol, i.e., Modified LEACH-R protocol. In this protocol, nodes from the cluster inform about unique status to their cluster heads. This protocol is extremely effective in terms of energy conservation. This protocol has modified the clustering method using heterogeneity parameters like offering of advanced nodes and inclusion of additional energy factor to assist the selection mechanism of clustering.

Finally, we conclude our study of the wireless sensor network field with the observation that it is a promising new technology. It could be a way to achieve global computing and embedded Internet. It seems an efficient solution for many applications that involve deep monitoring of a deployment environment.

5.2 FUTURE WORK

As a future enhancement, the tracking algorithm can be extended for multiple targets by forming dynamic clustering. Dynamic cluster reduces overlapping between the inter-clusters and also avoid duplication and unwanted transmission of data. By this method, the tracking accuracy is increased and reduces energy consumed in the network. Then the received data can be analysed and visualized using an effective visualization tool.

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APPENDIX A

LIST OF ACRONYMS

ADCT	Adaptive Dynamic Cluster-based Tracking
BS	Base Station
CH	Cluster Head
DCTA	Dynamic Clustering Tracking Algorithm
DCTC	Dynamic Convoy Tree- based Collaboration
DD	Data Driven
DPR	Dual Prediction-based Reporting
DPT	Distributed Predicted Tracking
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronic Engineers
HPS	Hierarchical Prediction Strategy
LEACH	Low Energy Adaptive Clustering Hierarchy
LEACH-R	Low Energy Adaptive Clustering Hierarchy - Reward
MAC	Medium Access Control
OCO	Optimized Communication and Organization
PES	Prediction-based Energy Saving
PEGASIS	The Power-Efficient Gathering in Sensor Information Systems

RR	Rumor Routing
RFID	Radio Frequency Identification
SCHs	Sub Cluster Heads
SPIN	Sensor Protocols for Information via Negotiation
RARE-Area	Reduced Area REporting
RARE-Node	Reduction of Active node REdundancy
RSSI	Received Signal Strength Indicator
STUN	Scalable Tracking Using Networked Sensors
TDMA	Time Division Multiple Access
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Networks

APPENDIX B

SOURCE CODE

```
%%%%%%%%%%%%%%% Network lifetime of LEACH %%%%%%%%%%%%%%%

clear;

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

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

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

%Number of Nodes in the field
n=100;

%Optimal Election Probability of a node
%to become cluster head
p=0.1;

%Energy Model (all values in Joules)
%Initial Energy
Eo=0.5;
%Eelec=Etx=Erx
ETX=50*0.000000001;
ERX=50*0.000000001;
%Transmit Amplifier types
Efs=10*0.000000000001;
Emp=0.0013*0.000000000001;
%Data Aggregation Energy
EDA=5*0.000000001;

%Values for Hetereogeneity
%Percentage of nodes that are advanced
m=0.3;

%alpha
a=4;

%maximum number of rounds
rmax=13999;

%%%%%%%%%%%%%%%%%%%%%%%%% END OF PARAMETERS %%%%%%%%%%%%%%%%%%%%%%%%

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

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

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

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


%First Iteration
figure(1);

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

countCHs;
rcountCHs=rcountCHs+countCHs;
flag_first_dead=0;

for r=0:1:rmax
    r

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

hold off;
```

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

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

for i=1:1:n
    %checking if there is a dead node
    if (S(i).E<=0)
        dead=dead+1;
        if(S(i).ENERGY==1)
            dead_a=dead_a+1;
        end
        if(S(i).ENERGY==0)
            dead_n=dead_n+1;
        end
        hold on;
    end

    if S(i).E>0
        S(i).type='N';
        if (S(i).ENERGY==0)
        end
        if (S(i).ENERGY==1)
        end
        hold on;
    end
    totalenergy(i)=S(i).E;
end
total_energy=sum(totalenergy);

STATISTICS(r+1).DEAD=dead;
DEAD(r+1)=dead;

if r+1==1095
    S(i).E=0;
end

%When the first node dies
if (dead==1)
    if(flag_first_dead==0)
        first_dead=r
        flag_first_dead=1;
    end
end

countCHs=0;
cluster=1;
```

```
for i=1:1:n
   if(S(i).E>0)
   temp_rand=rand;
   if ( (S(i).G)<=0)

 %Election of Cluster Heads
 if(temp_rand<= (p/(1-p*mod(r,round(1/p)))))
            countCHs=countCHs+1;
            packets_TO_BS=packets_TO_BS+1;
            PACKETS_TO_BS(r+1)=packets_TO_BS;

            S(i).type='C';
            S(i).G=round(1/p)-1;
            C(cluster).xd=S(i).xd;
            C(cluster).yd=S(i).yd;

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

            %Calculation of Energy dissipated
            distance;
            if (distance>do)
                S(i).E= S(i).E- ( (ETX+EDA)*(4000) + Emp*4000*(
                        distance*distance*distance*distance ));
            end
            if (distance<=do)
                S(i).E= S(i).E- ( (ETX+EDA)*(4000)  + Efs*4000*( distance
                        * distance ));
            end
        end

    end
  end
end

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

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

```
        %Energy dissipated by associated Cluster Head
             min_dis;
             if (min_dis>do)
                 S(i).E= S(i).E- ( ETX*(4000) + Emp*4000*( min_dis *
                         min_dis * min_dis * min_dis));
             end
             if (min_dis<=do)
                 S(i).E= S(i).E- ( ETX*(4000) + Efs*4000*( min_dis *
                         min_dis));
             end
         %Energy dissipated
         if(min_dis>0)
           S(C(min_dis_cluster).id).E =    S(C(min_dis_cluster).id).E- (
                                           (ERX + EDA)*4000 );
          PACKETS_TO_CH(r+1)=n-dead-cluster+1;
         end

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

    end
  end
end
hold on;

countCHs;
rcountCHs=rcountCHs+countCHs;


end

AliveLeach=100-DEAD;


plot(1:14000,AliveLeach,'-r');
xlabel('Number of rounds')
ylabel('Number of alive nodes')
title('Number of alive nodes vs number of rounds')
```

%%%%%%%%%%%%% Network lifetime of LEACH-R %%%%%%%%%%%%%

```
clear;

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

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

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

%Number of Nodes in the field
n=100;

%Optimal Election Probability of a node
%to become cluster head
p=0.1;

%Energy Model (all values in Joules)
%Initial Energy
Eo=0.5;
%Eelec=Etx=Erx
ETX=50*0.000000001;
ERX=50*0.000000001;
%Transmit Amplifier types
Efs=10*0.00000000001;
Emp=0.0013*0.00000000001;
%Data Aggregation Energy
EDA=5*0.000000001;

%Values for Hetereogeneity
%Percentage of nodes that are advanced
m=0.3;

%alpha
a=4;

%maximum number of rounds
rmax=13999;

%%%%%%%%%%%%%%%%%%%%%%%%% END OF PARAMETERS %%%%%%%%%%%%%%%%%%%%%%%%

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



%Creation of the random Sensor Network
for i=1:1:n
    S(i).xd=rand(1,1)*xm;
    XR(i)=S(i).xd;
    S(i).yd=rand(1,1)*ym;
    YR(i)=S(i).yd;
    S(i).G=0;
```

```
    %initially there are no cluster heads only nodes
    S(i).type='N';

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

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


%First Iteration
figure(1);

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

countCHs;
rcountCHs=rcountCHs+countCHs;
flag_first_dead=0;

for r=0:1:rmax
    r

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

hold off;

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

%counter for bit transmitted to Bases Station and to Cluster Heads
```

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

for i=1:1:n
    %checking if there is a dead node
    if (S(i).E<=0)
        dead=dead+1;
        if(S(i).ENERGY==1)
            dead_a=dead_a+1;
        end
        if(S(i).ENERGY==0)
            dead_n=dead_n+1;
        end
        hold on;
    end

    if S(i).E>0
        S(i).type='N';
        if (S(i).ENERGY==0)
        end
        if (S(i).ENERGY==1)
        end
        hold on;
    end
    totalenergy(i)=S(i).E;
end
total_energy=sum(totalenergy);

STATISTICS(r+1).DEAD=dead;
DEAD(r+1)=dead;

if r+1==1095
    S(i).E=0;
end

%When the first node dies
if (dead==1)
    if(flag_first_dead==0)
        first_dead=r
        flag_first_dead=1;
    end
end

countCHs=0;
cluster=1;
for i=1:1:n
   if(S(i).E>0)
   temp_rand=rand;
   if ( (S(i).G)<=0)
```

```
 %Election of Cluster Heads
if(temp_rand<=  (p/(1-p*mod(r,round(1/p))))*(S(i).E/total_energy))
            countCHs=countCHs+1;
            packets_TO_BS=packets_TO_BS+1;
            PACKETS_TO_BS(r+1)=packets_TO_BS;

            S(i).type='C';
            S(i).G=round(1/p)-1;
            C(cluster).xd=S(i).xd;
            C(cluster).yd=S(i).yd;

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

            %Calculation of Energy dissipated
            distance;
            if (distance>do)
                S(i).E= S(i).E- ( (ETX+EDA)*(4000) + Emp*4000*(
                        distance*distance*distance*distance ));
            end
            if (distance<=do)
                S(i).E= S(i).E- ( (ETX+EDA)*(4000)  + Efs*4000*( distance
                        * distance ));
            end
        end

    end
  end
end

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

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

       %Energy dissipated by associated Cluster Head
            min_dis;
            if (min_dis>do)
```

```
                S(i).E= S(i).E- ( ETX*(4000) + Emp*4000*( min_dis *
                        min_dis * min_dis * min_dis));
            end
            if (min_dis<=do)
                S(i).E= S(i).E- ( ETX*(4000) + Efs*4000*( min_dis *
                        min_dis));
            end
        %Energy dissipated
        if(min_dis>0)
          S(C(min_dis_cluster).id).E =    S(C(min_dis_cluster).id).E- (
                                          (ERX + EDA)*4000 );
         PACKETS_TO_CH(r+1)=n-dead-cluster+1;
        end

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

   end
  end
end
hold on;

countCHs;
rcountCHs=rcountCHs+countCHs;


end

AliveLeach=100-DEAD;


plot(1:14000,AliveLeach,'-b');
xlabel('Number of rounds')
ylabel('Number of alive nodes')
title('Number of alive nodes vs number of rounds')
legend('LEACH', 'Modified LEACH-R')




%%%%%%%%%%%%%%%%%%%   STATISTICS    %%%%%%%%%%%%%%%%%%
%
%
%  DEAD  : a rmax x 1 array of number of dead nodes/round
%  DEAD_A : a rmax x 1 array of number of dead Advanced nodes/round
%  DEAD_N : a rmax x 1 array of number of dead Normal nodes/round
%  CLUSTERHS : a rmax x 1 array of number of Cluster Heads/round
%  PACKETS_TO_BS : a rmax x 1 array of number packets send to Base
Station/round
%  PACKETS_TO_CH : a rmax x 1 array of number of packets send to
ClusterHeads/round
%  first_dead: the round where the first node died
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%%%%%%%%%%%% Random Deployment of Nodes %%%%%%%%%%%

clear;

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

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

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

%Number of Nodes in the field
n=100;

%Optimal Election Probability of a node
%to become cluster head
p=0.1;

%Energy Model (all values in Joules)
%Initial Energy
Eo=0.5;
%Eelec=Etx=Erx
ETX=50*0.000000001;
ERX=50*0.000000001;
%Transmit Amplifier types
Efs=10*0.00000000001;
Emp=0.0013*0.00000000001;
%Data Aggregation Energy
EDA=5*0.000000001;

%Values for Hetereogeneity
%Percentage of nodes than are advanced
m=0.3;
%alpha
a=4;

%maximum number of rounds
rmax=1000;

%%%%%%%%%% END OF PARAMETERS %%%%%%%%%%

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

%Creation of the random Sensor Network
figure(1);
for i=1:1:n
    S(i).xd=rand(1,1)*xm;
    XR(i)=S(i).xd;
    S(i).yd=rand(1,1)*ym;
    YR(i)=S(i).yd;
    S(i).G=0;
```

```
    %initially there are no cluster heads only nodes
    S(i).type='N';

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

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


%First Iteration
figure(1);

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

countCHs;
rcountCHs=rcountCHs+countCHs;
flag_first_dead=0;

for r=0:1:rmax
    r

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

hold off;

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

```
%Number of dead Normal Nodes
dead_n=0;

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

figure(1);

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


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

%When the first node dies
if (dead==1)
    if(flag_first_dead==0)
        first_dead=r
        flag_first_dead=1;
    end
end

countCHs=0;
```

```
cluster=1;
for i=1:1:n
   if(S(i).E>0)
   temp_rand=rand;
   if ( (S(i).G)<=0)

 %Election of Cluster Heads
 if(temp_rand<= (p/(1-p*mod(r,round(1/p))))*(S(i).E/total_energy))
             countCHs=countCHs+1;
             packets_TO_BS=packets_TO_BS+1;
             PACKETS_TO_BS(r+1)=packets_TO_BS;

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

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

             %Calculation of Energy dissipated
             distance;
             if (distance>do)
                 S(i).E= S(i).E- ( (ETX+EDA)*(4000) + Emp*4000*(
                         distance*distance*distance*distance ));
             end
             if (distance<=do)
                 S(i).E= S(i).E- ( (ETX+EDA)*(4000)  + Efs*4000*( distance
                         * distance ));
             end
         end

    end
  end
end

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

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

```
            min_dis_cluster=c;
        end
    end

    %Energy dissipated by associated Cluster Head
         min_dis;
         if (min_dis>do)
             S(i).E= S(i).E- ( ETX*(4000) + Emp*4000*( min_dis *
                     min_dis * min_dis * min_dis));
         end
         if (min_dis<=do)
             S(i).E= S(i).E- ( ETX*(4000) + Efs*4000*( min_dis *
                     min_dis));
         end
     %Energy dissipated
     if(min_dis>0)
       S(C(min_dis_cluster).id).E =    S(C(min_dis_cluster).id).E- (
                                       (ERX + EDA)*4000 );
      PACKETS_TO_CH(r+1)=n-dead-cluster+1;
     end

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

   end
 end
end
hold on;

countCHs;
rcountCHs=rcountCHs+countCHs;

xlabel('x axis (meter)')
ylabel('y axis (meter)')
title('Area= x*y = 100m*100m')

end
```

%%%%%%%%%%%% Half Dead Nodes Nodes %%%%%%%%%%%

```
clear;

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

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

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

%Number of Nodes in the field
n=100;

%Optimal Election Probability of a node
%to become cluster head
p=0.1;

%Energy Model (all values in Joules)
%Initial Energy
Eo=0.5;
%Eelec=Etx=Erx
ETX=50*0.000000001;
ERX=50*0.000000001;
%Transmit Amplifier types
Efs=10*0.00000000001;
Emp=0.0013*0.00000000001;
%Data Aggregation Energy
EDA=5*0.000000001;

%Values for Hetereogeneity
%Percentage of nodes than are advanced
m=0.3;
%alpha
a=4;

%maximum number of rounds
rmax=4357;

%%%%%%%%%% END OF PARAMETERS %%%%%%%%%%

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

%Creation of the random Sensor Network
figure(1);
for i=1:1:n
    S(i).xd=rand(1,1)*xm;
    XR(i)=S(i).xd;
    S(i).yd=rand(1,1)*ym;
    YR(i)=S(i).yd;
    S(i).G=0;
```

```
    %initially there are no cluster heads only nodes
    S(i).type='N';

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

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


%First Iteration
figure(1);

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

countCHs;
rcountCHs=rcountCHs+countCHs;
flag_first_dead=0;

for r=0:1:rmax
    r

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

hold off;

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

```
%Number of dead Normal Nodes
dead_n=0;

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

figure(1);

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


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

%When the first node dies
if (dead==1)
    if(flag_first_dead==0)
        first_dead=r
        flag_first_dead=1;
    end
end

countCHs=0;
```

```
cluster=1;
for i=1:1:n
   if(S(i).E>0)
   temp_rand=rand;
   if ( (S(i).G)<=0)

 %Election of Cluster Heads
 if(temp_rand<= (p/(1-p*mod(r,round(1/p))))*(S(i).E/total_energy))
            countCHs=countCHs+1;
            packets_TO_BS=packets_TO_BS+1;
            PACKETS_TO_BS(r+1)=packets_TO_BS;

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

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

            %Calculation of Energy dissipated
            distance;
            if (distance>do)
                S(i).E= S(i).E- ( (ETX+EDA)*(4000) + Emp*4000*(
                        distance*distance*distance*distance ));
            end
            if (distance<=do)
                S(i).E= S(i).E- ( (ETX+EDA)*(4000)  + Efs*4000*( distance
                        * distance ));
            end
        end

    end
  end
end

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

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

```
                min_dis_cluster=c;
            end
        end

        %Energy dissipated by associated Cluster Head
             min_dis;
             if (min_dis>do)
                 S(i).E= S(i).E- ( ETX*(4000) + Emp*4000*( min_dis *
                         min_dis * min_dis * min_dis));
             end
             if (min_dis<=do)
                 S(i).E= S(i).E- ( ETX*(4000) + Efs*4000*( min_dis *
                         min_dis));
             end
         %Energy dissipated
         if(min_dis>0)
           S(C(min_dis_cluster).id).E =    S(C(min_dis_cluster).id).E- (
                                           (ERX + EDA)*4000 );
          PACKETS_TO_CH(r+1)=n-dead-cluster+1;
         end

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

    end
  end
end
hold on;

countCHs;
rcountCHs=rcountCHs+countCHs;

xlabel('x axis (meter)')
ylabel('y axis (meter)')
title('Area= x*y = 100m*100m')

end
```

```
%%%%%%%%%%%% Full Dead Nodes %%%%%%%%%%%

clear;

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

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

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

%Number of Nodes in the field
n=100;

%Optimal Election Probability of a node
%to become cluster head
p=0.1;

%Energy Model (all values in Joules)
%Initial Energy
Eo=0.5;
%Eelec=Etx=Erx
ETX=50*0.000000001;
ERX=50*0.000000001;
%Transmit Amplifier types
Efs=10*0.000000000001;
Emp=0.0013*0.000000000001;
%Data Aggregation Energy
EDA=5*0.000000001;

%Values for Hetereogeneity
%Percentage of nodes than are advanced
m=0.3;
%alpha
a=4;

%maximum number of rounds
rmax=15000;

%%%%%%%%%% END OF PARAMETERS %%%%%%%%%%

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

%Creation of the random Sensor Network
figure(1);
for i=1:1:n
    S(i).xd=rand(1,1)*xm;
    XR(i)=S(i).xd;
    S(i).yd=rand(1,1)*ym;
    YR(i)=S(i).yd;
    S(i).G=0;
```

```
    %initially there are no cluster heads only nodes
    S(i).type='N';

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

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


%First Iteration
figure(1);

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

countCHs;
rcountCHs=rcountCHs+countCHs;
flag_first_dead=0;

for r=0:1:rmax
    r

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

hold off;

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

```
%Number of dead Normal Nodes
dead_n=0;

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

figure(1);

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


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

%When the first node dies
if (dead==1)
    if(flag_first_dead==0)
        first_dead=r
        flag_first_dead=1;
    end
end

countCHs=0;
```

```
cluster=1;
for i=1:1:n
   if(S(i).E>0)
   temp_rand=rand;
   if ( (S(i).G)<=0)

 %Election of Cluster Heads
 if(temp_rand<= (p/(1-p*mod(r,round(1/p))))*(S(i).E/total_energy))
            countCHs=countCHs+1;
            packets_TO_BS=packets_TO_BS+1;
            PACKETS_TO_BS(r+1)=packets_TO_BS;

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

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

            %Calculation of Energy dissipated
            distance;
            if (distance>do)
                S(i).E= S(i).E- ( (ETX+EDA)*(4000) + Emp*4000*(
                        distance*distance*distance*distance ));
            end
            if (distance<=do)
                S(i).E= S(i).E- ( (ETX+EDA)*(4000)  + Efs*4000*( distance
                        * distance ));
            end
        end

    end
  end
end

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

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

```
                min_dis_cluster=c;
            end
        end

        %Energy dissipated by associated Cluster Head
             min_dis;
             if (min_dis>do)
                 S(i).E= S(i).E- ( ETX*(4000) + Emp*4000*( min_dis *
                         min_dis * min_dis * min_dis));
             end
             if (min_dis<=do)
                 S(i).E= S(i).E- ( ETX*(4000) + Efs*4000*( min_dis *
                         min_dis));
             end
         %Energy dissipated
         if(min_dis>0)
           S(C(min_dis_cluster).id).E =    S(C(min_dis_cluster).id).E- (
                                           (ERX + EDA)*4000 );
          PACKETS_TO_CH(r+1)=n-dead-cluster+1;
         end

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

    end
  end
end
hold on;

countCHs;
rcountCHs=rcountCHs+countCHs;

xlabel('x axis (meter)')
ylabel('y axis (meter)')
title('Area= x*y = 100m*100m')

end


%%%%%%%%%%%%%%%%%%%   STATISTICS    %%%%%%%%%%%%%%%%%%
%
%
%  DEAD  : a rmax x 1 array of number of dead nodes/round
%  DEAD_A : a rmax x 1 array of number of dead Advanced nodes/round
%  DEAD_N : a rmax x 1 array of number of dead Normal nodes/round
%  CLUSTERHS : a rmax x 1 array of number of Cluster Heads/round
%  PACKETS_TO_BS : a rmax x 1 array of number packets send to Base
Station/round
%  PACKETS_TO_CH : a rmax x 1 array of number of packets send to
ClusterHeads/round
%  first_dead: the round where the first node died
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```