UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUE OF SCIENCE AND TECHNOLOGY

INVESTIGATION OF HIERARCHICAL COMMUNICATION METHOD FOR OPTIMIZING LIMITED ENERGY IN WIRELESS SENSOR NETWORKS

MASTER THESIS

Qusay Adil Mohammed Ali Alshawi

THE DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

THE PROGRAM OF ELECTRICAL & ELECTRONICS ENGINEERING

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Supervisor: Assist. Prof. Dr. Javad RAHEBI

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I hereby declare that all the information in this study I presented as my Master's Thesis, called: INVESTIGATION OF HIERARCHICAL COMMUNICATION METHOD FOR OPTIMIZING LIMITED ENERGY IN WIRELESS SENSOR NETWORKS, has been presented in accordance with the academic rules and ethical conduct. I also declare and certify with my honor that I have fully cited and referenced all the sources I made use of in this present study.

12.06.2017

Qusay Adil Mohammed Ali Alshawi

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JUNE 2017 Qusay Adil Mohammed Ali Alshawi

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBRIVIATION

WSN : Wireless Sensor Network
AODV : Ad-Hoc On Demand Distance Vector
CH : Cluster Head node
MN : Member Node
LEACH : Low Energy Adaptive Clustering Hierarchy
MANET : Mobile Ad-Hoc Network
RED : Reduced Function Device
FFD : Full Function Device

ABSTRACT

INVESTIGATION OF HIERARCHICAL COMMUNICATION METHOD FOR OPTIMIZING LIMITED ENERGY IN WIRELESS SENSOR NETWORKS

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In this thesis, we evaluated a clustering based method for heterogeneous wireless sensor networks. In our method we changed the cluster head election probability as dynamically and with more efficiency. Then we compared our protocol performance with low energy adaptive clustering hierarchy and stable election protocol. We used the heterogeneous sensors which they have different value of the probability values for selecting of the cluster heads. We select the three different probabilities value for all sensors to become the cluster head. With this method we improved the life time of the sensors.

Keywords: Clustering method, Wireless Sensor Network, probability value.

ÖZET

KABLOSUZ SENSÖR AĞLARINDA SINIRLI ENERJİ SEVİYESİNİN HİCARİ BİLDİRİM YÖNTEMİNİN İNCELENMESİ

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Bu tezde, heterojen kablosuz sensör ağları için kümeleme tabanlı bir yöntem geliştirdik. Yöntemimizde, küme seçimi olasılığını dinamik ve daha etkin bir şekilde değiştirdik. Ardından protokol performansımızı düşük enerjili uyarlanabilir kümeleme hiyerarşisi ve kararlı seçim protokolü ile karşılaştırdık. Küme başlarının seçiminde olasılık değerlerinin farklı değerlerine sahip olan heterojen sensörleri kullandık. Küme başı olmak için tüm sensörler için üç farklı olasılık değeri seçiyoruz. Bu yöntemle sensörlerin ömrü iyileştirildi.

Anahtar Kelimeler: Kümeleme yöntemi, Kablosuz Algılayıcı Ağı, olasılık değeri.

CHAPTER 1

1. INTRODUCTION

1.1 Background

In addition to the problem of energy consumption one major problem of wireless sensor networks is the difficulty of monitoring these networks. There are different researches in literature for the monitoring of sensor networks. The structure of these protocols differs with their different aims; discover failed nodes, compute the coverage, determine the remaining energy level or topological mapping of the network [1]. The authors in [2] provides a monitoring tool which continuously aggregates and computes different properties of the networks such as loss rates, energy levels or packet loss.

Some of these studies are based on clustering schemes for wireless networks and recently there has been many applications on this area [3].

Detection of these communities has become a new interest in research areas and there are different methods based on different theories such as graph theory. Many of these scientific studies has shown that community detection in wireless networks gives rise to different applications. Wireless network clustering is one of the most used technique in wireless sensor networks in order to extend network lifetime and increase the efficiency of data gathering. Since these networks usually have large scale of nodes the communication based on clustering namely hierarchical routing results an effective communication scheme.

This work deals with operating systems for Wireless Sensor Network (WSN) Motes. The "Wireless Sensor Networks" section describes what a WSN or "Mote" is and how WSNs can be used. The "Operating Systems for WSN-Motes" section discusses why an operating system is useful on a WSN Mote and what functions it should offer. In the "TinyOS", "Contiki" and "cocoOS" sections, the three operating systems mentioned are closer presented. The specific characteristics are presented, as well as the aspects which are particularly relevant for WSNs.

The research area of Wireless Sensor Networks, or WSNs, has gained immensely in importance in recent years. The primary area of application of a WSN is to collect data at different geographic points of the network, process it as necessary, and pass it on to a "data sink" or root node of the network [4]. A node in such a network Is formed by "motes" (see figure 1.1).

Figure 1.1. A Mica 2 Mote [5].

Small autonomous system, consisting of a microcontroller, one or more sensors, usually Stand-alone power supply from a battery, solar cell or an "energy harvesting" unit and a data transfer and communication option, usually a radio transmitter, or a GSM, WLAN or Ethernet module for communication. The Mote should be able to record the results of the measurements locally and then try to transfer them again later What a mote is to measure and transmit is as individual as versatile The following are three examples of using a WSN.

1.2 Problem Definition

Developments in wireless communications and electronics have made designing low-cost sensor networks possible. The sensor networks have many application areas such as health, military, home, agriculture, environmental. Because each sensor has to be low-cost, they have very limited battery and lifetime of the network depends heavily on saving energy. One way of saving energy is designing appropriate routing protocols. In this thesis, we propose some protocol that save more energy and increase the network lifetime comparing to the classical protocols always in large networks with many sensors.

1.3 Proposal Work

In this thesis, we are going to evaluate a clustering based method for heterogeneous wireless sensor networks. In our method we change the cluster head election probability as dynamically and with more efficiency. Also in this thesis we compared our protocol performance with stable election protocol and low energy adaptive clustering hierarchy.

1.4 Aims

The aim of our thesis is to reduce the energy using of each nodes. With changing of the probability value for each cluster head we solved this problem and we saved a lot of energy comparing with LEACH and SEP. Changing the cluster head election probability as dynamically and with more efficiency makes the sensors use low energy and save a lot of energy in whole of network.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Sensor Placement

The first proposed procedure attempts to maximize the average coverage of network points. The second proposed action attempts to maximize the coverage of the network point, which is effectively covered at least. A theorem proved in the paper provides a sufficient condition under which the no grid points are adequately covered by the proposed algorithms. The major drawback of the paper is that although the proposed methods provide coverage for the sensor field, they completely ignore energy consumption and network lifetime issues.

Carbajo et al. present a method for wind turbine monitoring with WSN. They used multi-hop communication and they increase the reliability of wireless sensor network [6].

In [7] an integer linear program (ILP) that determines the optimum sensor locations is proposed. The objective is the minimization of the total sensor deployment cost. The constraint is the coverage of the grid points with the required quality. As in [8] power consumption in sensing and processing, in routing the data packets are ignored in the paper. Moreover, an effective solution method for large instances of the ILP is not provided.

If sensor inputs are continuously operated, this means that the energy supply is quickly consumed. In order to extend the service life of a wireless sensor network, it is therefore useful to temporarily deactivate certain components. As long as data must be sent or received, the corresponding sensor nodes are in the active state. If they are inactive, they are put into a passive state in which they consume much less energy. The more often a sensor node is active, the more energy it consumes.

The following causes of unnecessary energy consumption can be identified:

Overhearing: Monitoring a communication to which a node is not involved. Continuous listening is a simple way to find out if a medium is available for your own data exchange. If the medium is occupied, however, this often results in an unnecessary loss of time and energy [9].

Idle Listening: A node waits for data to be received. If communication takes place without prior notice in a network, Idle Listening is the only way to receive messages. If only a few messages are sent, this can lead to considerable energy consumption [9].

Data collision: loss of data, because several nodes access a common medium at the same time and thus the messages on the recipient side can no longer be deciphered. For possible repetitions, additional energy must be applied [9].

Control messages: In many networks, additional monitoring is generated by control messages, which generally do not contain any information relevant to the application [9]. The goal is to assign suitable operating cycles of active and passive times to the sensor nodes in such a way that they can communicate with each other without causing disproportionate energy loss through overhearing, idle listening, collision or control messages. In the following, we present the most common approaches with which the work cycle can be organized [9].

Mou Wu et al presented an adaptive distributed parameter for wsn. In their method every individual node shares the changes in the surrounding environment with its immediate neighbors [10].

In [11] the sensor network is modelled as a graph with the set of vertices being the set of sensors. An ILP that determines elements of a subset of the vertices is proposed. The objective is the minimization of the number of elements in the subset subject to coverage requirement constraints. A solution procedure based on constructing a feasible solution from the linear programming (LP) relaxation solution of the ILP is also proposed. Although the proposed method finds a set of sensors that cover the sensor field with the required quality, it does not explicitly determine the activity schedules of the sensors, sensor-to-sink data flow routes in order to maximize the network lifetime.

2.2 Sensor Activity Scheduling

In [12] the problem of determining activity schedules of the sensors is addressed. A MILP with the objective of minimizing the total energy consumption is formulated. Constraints of the MILP ensure coverage of the sensor field with the required quality and connectivity of the network in each time period. The MILP optimally determines which sensor is active in which period. In the experimental study section it is shown that the network lifetime value obtained using the MILP is much higher than that obtained without performing any sensor activity scheduling. One drawback of the proposed model is that it does not explicitly consider the routing energy. Sensor placement issue is also disregarded.

In [13] the problem of covering a set of targets with a set of sensors is considered. Only a subset of the sensors that can cover all of the targets are active at any given time, others are in sleep mode. A mixed integer nonlinear program (MINLP) is proposed to maximize the coverage lifetime by determining the sensor subsets and their active time. The constraints guarantee that the active time of a sensor is not greater than an upper bound and every target is covered by the active subset. The major drawback of the paper is that it does not explicitly consider the energy consumed in routing the data packets. Moreover, there is no lower bound on the active time of a sensor subset. One other drawback is that the issue of sensor placement is ignored in the paper. In [14] work on the same problem. They develop a distributed algorithm to obtain suboptimal solutions in an online fashion or large-scale settings. They use game theory in developing the algorithm. The same problem is also considered by [14]. Their mathematical model takes explicitly into account the energy consumption in data routing. They use a column generation algorithm to find active subsets and their active periods.

In [15] sensor network is modelled as an undirected connected graph. At any given time only one of the connected sub graphs rooted at the sink is active, others are in sleep mode in order to save energy. An ILP that determines the connected sub graphs is proposed. The objective of this ILP is the minimization of the shared sensors. The constraints guarantee that each sensor belongs to at least one sub graph, the sub graph is connected and rooted at the sink. Also for each sensor, the number of neighbors belonging to the same sub graph has a limit so that the sensor is close to the active sub graph when the sub graph it belongs to is in sleep mode. One drawback of the proposed ILP is that it does not consider coverage of the sensor field. Moreover the energy spent on sensing, processing and routing is not taken into account.

In [16] the objective is to maximize lifetime of surveillance subject to energy restrictions. A polynomial time algorithm that finds an optimal solution of the described problem is proposed. The major drawback of the paper is that it ignores the energy consumption in data routing. The same problem is also considered in [17]. They take into account the energy consumption in data routing and find sensor-to-sink data flow paths.

2.3 Data Routing

In [18] a LP formulation is presented. The objective is the max imitation of the network lifetime. The first constraint is the flow balance equation. The number of packets received by a sensor should be equal to the number of packets transmitted to other sensors. The second constraint is the energy limitation. The energy spent in transmitting the data packets should be less than the battery energy. The major drawback of this work is that it ignores sensor placement and sensor activity scheduling issues. Also energy spent in receiving the data packets is not taken into account.

In [19] the problem of routing data into the sink node at a way to maximize network lifetime is considered. A node can only use its downstream neighbors (downstream with respect to the sink) to route its traffic. The flow coming from an upstream node j is reduced at node i because some of the information coming from node j is the same as those coming from other neighbors of i. Normalization is done by nodal battery energy. The constraints are linear flow conservation constraints. This min-max objective function is not differentiable. Hence a smoothing function is used. The smoothed objective function is approximately equivalent to the original objective function. The Karush-Kuhn-Tucker conditions are not sufficient for optimality for this reason a set of sufficient conditions and a gradient descent algorithm for a distributed application are developed. At each iteration of the algorithm each node adjusts its downstream flow in the direction of the gradient until each flow link satisfies the sufficient optimality conditions. According to the simulation results it is possible to say that the algorithm converges efficiently.

In this way, it is also possible to include new nodes in the existing network during continuous operation. After receiving a synchronization message, they can be oriented in time and adapt to the day sequence.

CSMA / CA (Carrier Sense Multiple Access / Collision Avoidance) is used to reduce collisions. This is a method by which a transmission medium can be checked before a planned access to occupancy (carrier check). In order to avoid overhearing at the same time, each transmission request contains the corresponding information about the duration of a transmission. These additional data are stored in the NAV (Network Allocation Vector). Monitoring nodes can use this network allocation vector to determine the length of a communication and to sleep again for this time. A timer counts down the value of the vector one by one. If the value is zero, other nodes know that the medium is free again [9].

To reduce the delay in multi-hop traffic, S-MAC has been extended by Adaptive Listening. With this optimization, an additional hop can be overcome in the ideal case per active-passive cycle, in that the corresponding nodes wake up again for a certain time after their actual active phase [20].

In [21] they assumed that each grid could be covered by any sensor in the cell. It is also assumed that a sensor in a cell can transmit data packets to any sensor in the adjacent cell. A LP with the objective of network lifetime maximization is proposed. The constraints are flow balance and battery energy limitation. These constraints are written for the cell not for each sensor. Simulations show that the proposed method increases network lifetime.

In [22] the problem of routing data efficiently from multiple sources to multiple sinks is presented. An ILP which minimizes the number of links used in transmitting data from the sources to the sinks is proposed. The major drawback of the paper is that it does not explicitly consider the energy consumption in sensing and processing the data and in routing the data packets.

2.4 Sink Location

In [23] give a mathematical model that determines the locations of the sinks minimizing the sensors' average distance from the nearest sink. These two algorithms are compared and it is shown that the performance of the second one is very close to the performance of the first one.

One drawback of the paper is that although sinks are optimally located, the energy spent in sensing and processing and in routing the data packets are not explicitly considered.

In [24] a mobile sink is considered. The problem is to determine the starting site and the route for the mobile sink together with the sojourn times of the sink at any visited location so that the network lifetime is maximized. First a MILP formulation is proposed. The objective is the maximization of the sink's total time at sojourning sites. The first constraint guarantees that the total energy spent in receiving and transmitting packets and in setting up/releasing routes when the sink moves to a site for each sensor is less than the battery energy. The remaining constraints ensure the formation of a path for the sink and eliminate cycles that can be obtained. In the second part of the paper the first heuristics for controlled sink movements that are fully distributed and localized are described. Simulations show that the heuristics increase the network lifetime considerably. One drawback of the paper is that it does not explicitely include the energy consumption in sensing and processing and in routing the data packets in the MILP formulation. Besides the sink can do only one hour during the network lifetime, which is fairly unrealistic.

2.5 Works That Integrate Some of the Design Issues

The second MILP model proposed by Patel et al. [25] integrates placement, data routing and sink location issues. The objective is the minimization of the total cost of placing the sensors and the sinks. The constraints guarantee the coverage of the sensor field with the required quality and flow conservation. The MILP finds optimally sensor and sink locations and sensor-to-sink data flow quantities. They also develop another MILP model with network lifetime maximization objective. In this MILP in addition to the coverage and flow balance constraints there is the energy constraint that limits the energy spent in data routing.

In [26] placement and data routing issues are integrated. The problem is to find the locations of a given number of relay sensors, to allocate a given amount of energy to them and to determine sensor-to-sink flow quantities. A mixed-integer nonlinear program (MINLP) with the objective of network lifetime maximization is proposed. The constraints ensure flow balance and the energy limitation in receiving and transmitting the data packets. Solving the MINLP is computationally difficult.

Therefore, a heuristic algorithm is developed. Through numerical results it is shown that the heuristic algorithm offers a very attractive solution and some important insights to the problem addressed.

In [27] integrate data routing and sink location. They consider a static sink. They formulate a MILP where the objective maximizes the minimum amount of data produced by each sensor and the total data packets generated. The MILP optimally determines the locations of a predetermined number of sinks, the sensor-to sink flow routes and the data volume produced by each sensor. The constraints are flow balance and battery energy limitation restrictions. Unfortunately an efficient solution procedure for the MILP is not presented.

2.6 Low-Energy Adaptive Clustering Hierarchy (LEACH)

The LEACH protocol was developed within the μAMPS project at MIT. In the LEACH (Low-Energy Adaptive Clustering Hierarchy) [28, 29] algorithm, the sensors organize themselves into local clusters, with one sensor acting as the local base station or cluster-head. LEACH uses a hierarchical network structure and is a source initiated protocol with proactive routing. Clusters are being re-created every round, and each node decides whether to become a cluster-head for the current round. The node picks a random number; if it is smaller than a threshold T(n), the node becomes a cluster- head for that round. T(n) is the threshold value for each node n.

$$T_n = \frac{p}{1 - p\left(r \bmod 1/p\right)} \tag{2.1}$$

If the cluster header node is not in the last 1/p rounds (2.1) LEACH reduces power connections by up to 8 times compared with direct transmission and minimum power transmission routing. The problem with LEACH is that it requires direct communication to the sink node; LEACH is not designed for networks where the sink node is to be located outside the communication range of sensor nodes. Another problem is dynamic clustering overheads as head changes and advertisements may consume the energy that is gained from communication [28].

In case of any communication between two nodes, the transmitter node just needs to send the message to its cluster head and the remaining parts will be completed by the cluster head. Once the cluster head receives the message it will send the message to receivers cluster head and this node will send the message to the final receiver node. Therefore an effective way of energy consumption is provided and moreover since all of the nodes does not need to know whole topology this communication structure will decrease the complexity.

On the other hand in case of direct communication every node needs to send their messages directly to the BS or another receiver. If the receiver is far away from the node then transmission will require higher amount of energy therefore the transmitter and receiver nodes both will lose a large amount of their energy. This will cause nodes to quickly drain their batteries and reduce the networks lifetime. However this type of communication may also be acceptable if the nodes are located close to each other or BS.

According to the authors in [28] LEACH can achieve more than a factor of 7 reduction in power dissipation compared with direct contacts. Although LEACH provides an adaptive energy consumption and it increases the efficiency of wireless sensor networks there are still some problems with energy consumption and data aggregation.

Since every node can become a cluster head in LEACH algorithm it sometimes may result with undesired topologies. In some cases border nodes can become cluster head and in this case the higher distance between cluster heads and cluster heads members increases energy consumption and results an inefficient network. On the other hand distance between the cluster heads also becomes important for efficiency, one of the undesired state in clustering topology is the small distance between cluster heads. In order for efficiency to be higher, distance between the cluster heads should be adequate enough for occurrence of two different clusters.

LEACH formulation as below;

$$T_n = \frac{p}{1 - p\left(r \bmod \frac{1}{p}\right)} \frac{E_{ncur}}{E_{n\max}} \tag{2.2}$$

E_{ncur} is the current energy of the node and $E_{n\max}$ is the initial energy of that node. Therefore they represent the energy level with the coefficient $E_{ncur} \,/\, E_{n\max}$.

This approach leads higher energy level nodes to become cluster heads and simulation results show that improvement in efficiency can be provided. However there are still some disadvantages also in this case, after certain number of rounds network becomes stuck. Since after some certain rounds most of the nodes will have low level of energy, the threshold for becoming a cluster head will become too low. Although there will be still some nodes which have enough energy to send data due to the low energy level of threshold the network will already become stuck [19]. The equation is modified as in 2.3 with a coefficient for the nodes that has not become a cluster head in 1/p rounds.

$$T_{n_{new}} = T_{n_{LEACH}} \left(\frac{E_{ncur}}{E_{n\max}} + r_s p - \frac{r_s p E_{ncur}}{E_{n\max}} \right) \tag{2.3}$$

In equation 2.3 rs is the number of rounds for a node that had not become a cluster head, if this number reaches 1/p then the formula will be modified the older version as in LEACH then Tnnew=TnLEACH. Therefore remaining nodes will have chance to become cluster head and in other cases rs will be set to 0 in order to achieve modified formula.

By this modification authors has solved the problem of stuck network and also they have reached a more effective energy consumption than LEACH. With these modifications a 30 percent of increase in lifetime of micro sensor networks can be accomplished.

The authors in [19] has discussed two modifications of LEACHs cluster-head selection algorithm. The nodes themselves determine whether they become cluster-heads. A communication with the base station or an arbiter-node is not necessary. Once the clusters and cluster heads are determined cluster heads select a predefined number of head set nodes according to the signal strength of acknowledgement messages. At the end of round, all the clusters are not destroyed; however, each cluster is retained for the number of rounds equal to the head-set size [30]. Therefore nodes of the clusters with the head set size 1 can become candidate for the next round however the nodes of cluster whose head set size is greater than 1 do not participate in the next election. This clustering structure reduces the number of elections and provides more efficient clustering.

2.7 Hybrid Energy Efficient Distributed (HEED)

The authors in [21] has approached a new clustering algorithm based on some probabilistic equations. In this algorithm it is assumed that nodes have no specialties such as having a GPS. The main approach is to cluster all the nodes in an equal way which is based on probability. As the other clustering techniques HEED algorithm also aims to prolong the network lifetime and increase the efficiency. In order to compare network time they defined a certain value as the first or last node depletes its energy. The main factor in the probabilistic approach is the residual energy of nodes.

In HEED algorithm every node is exactly mapped to one cluster and this node has to be able to communicate with the cluster head via single hop. The transmission ranges and energy levels are classified and defined as inter-cluster transmission range, inter-cluster power, intra-cluster transmission range and intra cluster power. Inter cluster transmission range is higher and inter transmission requires more energy than intra cluster transmission as expected.

Cluster head selection is mainly based on two different approaches that are about energy level and cost. In order to consider the energy levels of nodes for cluster head selection authors define an initial set including high energy level nodes. Therefore it is prevented for low energy nodes to become cluster head. The second parameter cost is used to break ties between nodes. If two different nodes in the same intra cluster transmission range sends their willingness to become a cluster head a tie occurs between these two nodes.

The HEED algorithm is mainly based on probability of being a cluster head which is given with the following equation 2.4, all the nodes set their initial probability to become a cluster head as Chprob;

$$C_{h_{prob}} = \frac{C_{prob} E_{res}}{E_{\max}} \tag{2.4}$$

Chprob is the probability of a single node to become a cluster head, Chprob is the small constant that is defined by algorithm.

HEED provides an efficient clustering algorithm based on probabilistic to increase the network lifetime. There are some different approaches on HEED to increase efficiency. O. Younis et all has provided an improved algorithm IHEED which is mainly based on HEED. This algorithm integrates node clustering and multi hop routing in order to increase efficiency of network.

One of the most important challange in IHEED is integration of clusters in data aggregation trees without degrading path quality [22]. In this topology only cluster heads are used to construct the aggregation tree, since cluster heads will be distributed well even if the nodes are not well distributed path quality will be higher inter cluster level.

CHAPTER 3

MAIN CONCEPT OF THE WIRELESS SENSOR NETWORK AND ZIGBEE TECHNOLOGY

3.1 Introduction

The concept of the Wireless Sensor Network (WSN) first appeared in the early 1980s. Along with advances in microelectromechanical systems (MEMS) and advances in wireless communication systems, the 1990s began to become an important research area. Wireless sensor networks that used military bases in the early days; the drop in the cost has been used widely [31]. Sensor nets can contain many different types of sensors, such as thermal, seismic, magnetic, and visual, that can follow situational changes such as humidity, temperature, pressure, sound, light and motion. Military applications of these networks, the environment, health, home and other commercial areas can be classified as. The military arena is used to monitor the movements of animals in environmental practices, to detect chemical fires and flood disasters, to detect forest fires and flood disasters, to monitor the movement of enemy troops and to gather information on war damage. In home applications, it is also used in appliances such as electric vacuum cleaners, microwave ovens, etc. [32] in commercial applications such as ventilation and heating systems of buildings and detection of car thefts. Technological aspects of frequent battery changes are needed to the relatively low power sporadically time is not practical.

3.2 ZigBe Technology and IEEE 802.15.4 Standard

WSNs are one of the most impressive technologies in the industry today. The ZigBee name was taken from the zig-zag road that the bears watched as the bees roamed the flower from the flower. During this circulation, they act with the knowledge that other bees have reached these sources (from where they came from). As a new standard for wireless connectivity, ZigBee is based on the IEEE 802.15.4 standard announced by the IEEE, and the ZigBee Alliance is committed to being used when first implementing the general standard. ZigBee Alliance; Ivensys, Honeywell, Mitsubishi Electric, Motorola and Philips [33].

3.3 IEEE 802.15.4 Technical Infrastructure

ZigBee is based on the strong radio (physical layer, PHY) and Medium Attachment Control (MAC) layers defined by the IEEE 802.15.4 standard. Therefore, it is useful to examine the IEEE 802.15.4 standard first. The IEEE 802.15.4-2003 standard defines the devices and the underlying protocol interfaced with radio communications in a Personal Area Network (PAN). It uses the standard CSMA / CA media access mechanism and supports topologies such as star, peer-to-peer. Media access is based on "contention". An IEEE 802.15.4 (and ZigBee) network needs at least one fully functional device as a network manager, but endpoint devices can be functionally reduced devices to reduce system cost. IEEE 802.15.4 defines three unlicensed frequency bands. The first band uses the 2.4 GHz frequency band (Industrial, Scientific, Medical (ISM) band) and has 16 channels. The second band uses the 902-928 MHz frequency band with 10 channels. The last one uses the frequency band 868-870 MHZ with only one channel. The capacities of these frequency bands are 250 kb / s, 40 kb / s, 20 kb / s [34] respectively. As mentioned above, the IEEE 802.15.4 standard basically defines two layers (PHY and MAC). Radio communication is possible in three different frequency bands in the PHY layer. For the application it is enough to be able to work in only one of these. The 2.4 GHz (2450 MHz) PHY uses a quadrature quasi-orthogonal modulation technique. In each data symbol period, four bits of information are used to select one of 16 near orthogonal pseudo-random noise (PN) sequences to be transmitted. The PN sequences are consecutive data symbols that are concatenated, and the carrier sequence using the recovered chip sequence, offset-quadrature phase-shift keying (O-QPSK) is in a modulated state. Basically, this modulation format can be thought of as O-QPSK coding and is typically implemented for the creation of channel symbols that reduce transmitter cost with a look-up table [35]. Typical transmission distance is reported to be more than 30 meters for different environments without an indoor field of view and more than 80 meters for a field of view. Another point to note here is that the bit rate is a limiting factor if applications want to transmit large amounts of data between network devices.

Table 3.1: IEEE 802.15.4 g enteral characteristics-modulation parameters.

PHY (MHz)	**Frequency band (MHz)**	**Propagation parameters**	
		Chip ratio	**Modulation**
868 & 915	868-868.6	300	BPSK
	902-928	600	BPSK
2400	2400-2483	2000	O-QPSK
Data parameters			
Bit rate (kb / s)	**Symbol rate (k symbols / s)**	**symbols**	
20	20	binary	
40	40	binary	
250	62.5	16 orthogonal	

The frequency bands shown in Table 3.1 [35], 868 MHz for Europe, 902-928 MHz for North America, 2.4 GHz - are considered for worldwide applications. It makes it possible to reposition several channels in different frequency bands in the spectrum. This standard allows dynamic channel selection. A scan function controls the list of supported channels in the beacon search step by step, such as receiving energy detection, link quality indication, channel switching. Low frequencies provide longer distances due to lower propagation losses. Lower rates can be translated into better sensitivity and greater coverage [35]. In all bands, the modulation scheme is Direct Sequence Spread Spectrum (DSSS). It should be noted here that in the 868 and 902-928 MHz bands, the transmitter uses BPSK (Binary Phase-Shift Keying). As mentioned earlier, the transmitter uses offset-QPSK in the 2.4 GHz band. PHY layer features include activation / deactivation of the radio receiver and energy detection / link quality indication, channel selection, clean (empty) channel assignment [35].

3.4 ZigBee Technology Technical Infrastructure

For PANs (Personal Area Networks), there were two main technologies / standards up until now, namely: "Bluetooth" and "WiFi" (ie IEEE 802.11.x). The main idea of applications used in industry was to solve the problems of low complexity of wireless communication and low battery life in many cases. However, low power consumption was possible if the nodes were battery-powered. WiFi and Bluetooth have been struggling to meet these demands (some not both, but all). In 1999 the "FireFly" working group began designing a technology known today as ZigBee. As a development, the process was first based on IEEE 802.15.4-2003, and then the ZigBee Alliance handled it in December 2004. So ZigBee has officially become one of the PAN networks. ZigBee technology uses four basic topologies: Peer-to-Peer (P2P), Star, Mesh, and Cluster Tree. These can be seen in Figure 3.1.

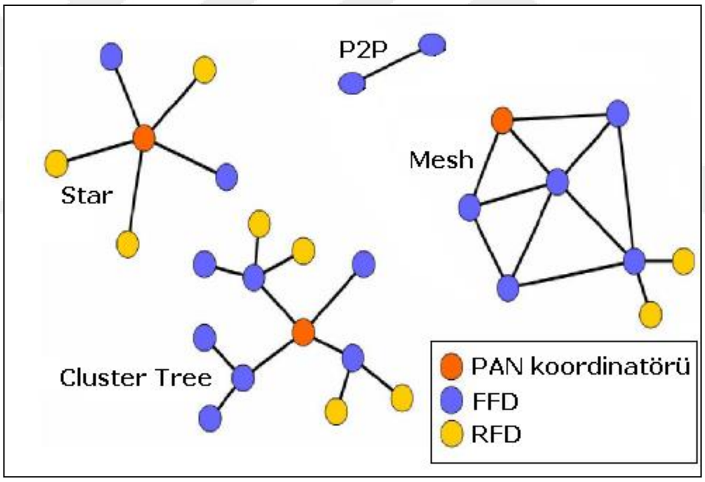

Figure 3.1: ZigBee topologies [36].

The topology depends on the probing and networking scheme of a network. Each topology has its own advantages / disadvantages. FFD in Figure 1 is given as Full Function Device and RFD is Reduced Function Device [36].

Because the ZigBee Alliance follows a configuration based on IEEE 802.15.4, the first two layers (PHY and Data-link (MAC) layer according to the OSI model) have not changed much. ZigBee uses the beacon technique of the IEEE 802.15.4 standard, which means that a node always sends small packets to its neighbors stating that it exists on the network. If two or more nodes are connected in a network form, they can then be intervened by other nodes. ZigBee, "routing DISCOVER y" work out protocol [37]. The node in the ZigBee network is designed to be a battery-powered or sleep-worn structure that can save energy, search for existing networks, transfer data as needed, define data availability, and request data from the network coordinator.

Two types of physical devices are defined by the IEEE for low system cost. These are the Full Function Device (FFD), which can function with any other topology and have network coordinator ability that can talk to other devices. The Reduced Function Device (RFD) is restricted to star topology and can not be a coordinator, it has a very simple application and can only talk to a network coordinator [16]. A ZigBee / IEEE 802.15.4 network requires at least one FFD as a network coordinator, but endpoint devices can be RFD, thus reducing system cost. The ZigBee network supports dynamic network formation, addressing, routing, and discovering a neighbor near a hop. The size of the network address is 16 bits. ZigBee has the ability to accept 65535 networks (18.45 x 1018 devices, thanks to the IEEE 64 bit address). Network addresses are assigned in the tree structure. Since ZigBee supports topologies like star topology as well as mesh topologies, any device can communicate with other devices outside the PAN coordinator, so the network has high scalability and flexibility. Self-forming and self-healing features make ZigBee interesting. ZigBee devices (nodes) can automatically create a network, and joining / leaving devices is automatically reflected in the network configuration [38]. ZigBee provides routing protocols (for routing), "tree-routing" and "t abl-driven routing" enable. In order to get the above things done, three types of modules are used in the ZigBee network: PAN coordinator, FFDs and RFDs.

FFD also works in three modes. We can see it in their ZigBee topologies, where FFD is located in a pan. It serves as PAN coordinator, coordinator or device within the PAN [39]. An RFD is intended for applications, such as light (bulb) keys or passive infrared sensors, which do not need to send large amounts of data, and can only be associated with a single FFD at a time. Hence, RFD can be realized using minimal resources and memory capacity. The IEEE 802.15.4 MAC layer has the flexibility to handle each of these module types. Periodic data can be managed using the beacon system, the sensor can wake up to sleep for the beacon, check for any messages, and continue sleeping again. The ZigBee network coordinator establishes a network, communicates network beacons, manages network nodes, stores network node information, directs messages between paired nodes, and typically runs in the receiver state. If an FFD is used as a coordinator, the network configuration needs processing power to self-configure the data and the network. A router stores and then forwards incoming and outgoing messages, rather than exchanging them directly. A coordinator must use more power than a simple node in the network, and it may be highly needed from a city line or a power supply.

3.5 Areas Where ZigBee Technology Uses Industry

Zheng's work [40] to use ZigBee WSNs in industrial applications (automation) [40] needs to be solved in the first place:

1. Reliability: ZigBee / IEEE 802.15.4 network is one of the most attractive features of the structure of the mesh network. A mesh network is a flexible network where the P2P communication function can be used between nodes. The most important technology required by this network router performs the function ing sturdy, so that even in the most complex systems may be found convenient way [40].

2. Delay: real-time wireless network consists performansınd a delay. ZigBee / IEEE 802.15.4 network delay, can show a lot of variation depending on the hop count. However, in a single hop communication, this delay is quite low (in the order of a few milliseconds), but on a multi-hop path, the delay increases substantially in proportion to the number of hops. The maximum delay time is neither specified by ZigBee nor by IEEE 802.15.4 specifications. Delay between hop on real systems are available to face milliseconds [40].

3. Communication distance: radio output power of 1 mW (0 dBm) so that these are available commercially IEEE 802.15.4 chip RF power through the built-in amplifiers. It has a coverage of 30 meters in-door (indoor) and 100 meters out-door (open space). This is not enough for industrial automation. As a settlement, large factories want to make long distance communications. The multi-hop communication technology, the maximum extensible distance radio output without increasing the power line [40].

4. Power consumption: industrial components (sensors, actuators such as) it may be necessary for several years, as working time without battery change. For

power consumption, the solution is to ensure that the wireless components remain asleep as long as there is no communication. For a well-designed IEEE 802.15.4 RF module, the sleep mode current is at a few microamperes. Available battery life depends on such things as battery capacity, data rate (transmitted). Even using ordinary dry batteries, it is necessary to operate such wireless components.

The use of ZigBee networks is quite common, we will list them and look at their examples;

1. Commercial building automation (supermarket inventory tracking, follow-up of ambient temperature, energy level control etc.), Home Automation (Fire, Domestic heat and humidity control, etc.), Home entertainment (Smart lighting)
2. Livestock sector (monitoring yield of dairy cows, detection of missing animals in the poultry etc.), protection of agricultural and agricultural crops (plant size, leaf size measurements etc.)
3. Mobile applications (m-payment, m-monitoring and control, m-security and access control, m-healthcare and tele-assist etc.)
4. AMR (Automatic Measurement Reading), wireless telemetry, Chemical / Dyestuff / Pharmaceutical industry (Chemical process monitoring, product quality control etc.), Water treatment / Waste cleaning (Detectors in gigantic water treatment plants add real- Time measurement data)

They are like.

3.6 Comparison of other WSN technologies with ZigBee

ZigBee is concerned with the use of a certain amount of data transfer between devices used in personal area networks, network measurement, detection, monitoring and control of applications. However, it is not suitable for large file transfer such as WiFi or Bluetooth. Other low-rate WPAN (LR-WPAN) technologies (Bluetooth, etc.) and some other wireless technologies and ZigBee technology. ZigBee, WiFi, or Bluetooth can communicate with less people by working in a way that is less like the communication approach between multiple devices, working through simple networks with less power consumption and cost.

Table 3.2: Comparison of ZigBee and features some of the wireless technology.

Feature	**ZigBee**
Focus area	Monitoring and Control
System Resource	4-32 Kb
Battery Life (days)	100- 1000+
Network Size	~ Unlimited (2^{64})
Network data width (kbps)	100- 1000+
Coverage Area (meters)	1 - 100+
Success areas	Durability, cost, power consumption

Feature	**GPRS / GSM**	**Wi-Fi**	**Bluetooth**
Focus area	Wide area audio and data	Web, email, Video	Instead of the cable
System Resource	16 Mb +	1 Mb +	250KB +
Battery Life (days)	1-7 Days	0.5-5	1-7
Network Size	16 Mb +	32	7
Network data width (kbps)	64 - 128+	11000-54000	720
Coverage Area (meters)	1000+	1-100	1-10 +
Success areas	Accessibility, quality	Speed, flexible - like	Cost, convenience

HomeRF Lite operates in the frequency band of microwave, Bluetooth and some other devices specified in the IEEE 802.11b standard in the ISM radio band at 2.4 GHz. ZigBee technology, IEEE 802.11b (11 Mbps) and Bluetooth (1 Mbps) to slower, but less "forces" the work.

CHAPTER 4

4. SIMULATION RESULT AND DISCUSSION

4.1 Proposed Method

The flowchart of the proposed method is shown in figure 4.1.

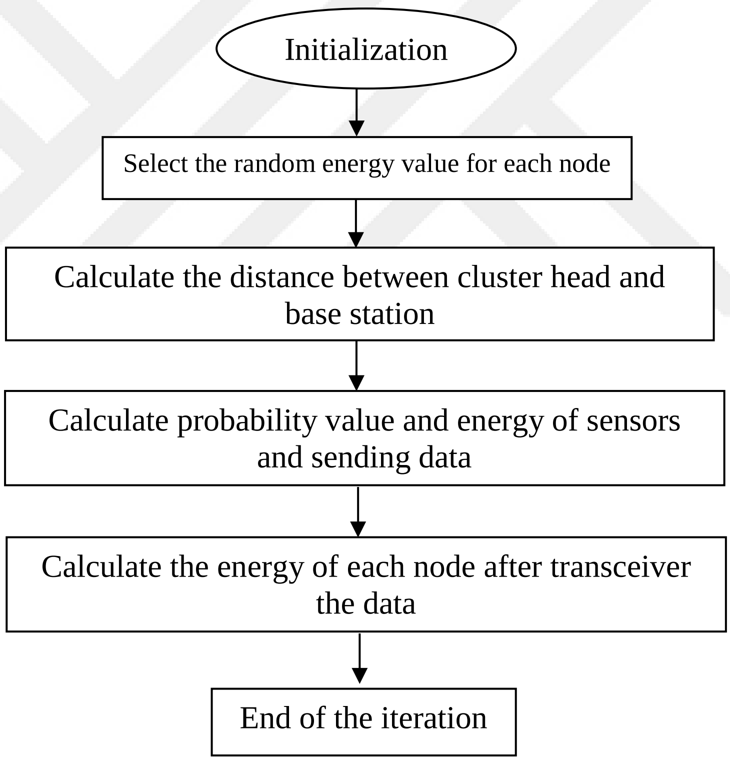

Figure 4.1: Flowchart of the proposed method.

The probability value selection is shown in equation (4.1).

$$P(i)=\begin{cases} a * P * E(i)/((1+(a*m)) * Ea & \text{if } S(i).E < (\frac{E_0}{2}) \\ P * E(i)/((1+(a*m)) * Ea & \textit{if } S(i).E > (\frac{E_0}{2}) \ \& S(i).E <= Eo \\ (1+a) * P * E(i)/((1+(a*m)) * Ea & \text{if } S(i).E > E_0 \end{cases} \quad (4.1)$$

In this equation ***a*** and ***m*** is constant. The ***P*** is initial probability for each node. ***Eo*** is the energy of each node.

4.2 Dataset

In this thesis we used wireless sensor network parameters that illustrated in table (4.1).

Table 4.1: Parameter that used in our thesis.

Parameter	E0	Eelec	Efs	Emp	Base station position	x	y	N (number of nodes)	Message Size
Value	0.5 J	5 nJ/bit	10 pJ/bit	13e-4 pJ/bit	(150, 50)	[0 150] m	[0 150] m	150	4000 Bit

This parameters are included the number of sensors, coordinate of x and y, primary energy, electronics energy and etc. We use radio model which shown in

This parameters are included the number of sensors, coordinate of x and y, primary energy, electronics energy and etc.

Whole of sensors need energy to transmit packet of k bits information to a distance d and to receive an information packet of k bits, is given as:

$$E_{Tx}(k,d)=E_{Tx-elec}(k)+E_{Tx-amp}(k,d)$$
$$E_{Tx}(k,d)=E_{elec}\times k+E_{amp}\times k\times d^{n} \quad (4.1)$$

The n value is depended on the distance between threshold distance values. If the distance is big than the threshold value n will equal to 4 and if the distance is less than the threshold value n will equal to 2.

$$E_{Rx}(k)=E_{Rx-elec}(k)E_{Rx}(k)=E_{elec}\times k$$
$$E_{Rx}(k)=E_{elec}\times k \quad (4.2)$$

The parameter of this table 4.1 is used from the information of the sensor. In this thesis we select the 150m by 150m area. Totally we select the 150 sensor. All sensor are not have the same information and the sensors have different energy value. In this work we used the heterogeneous sensors. In heterogeneous model the sensors have different information like the energy, position of the location, rechargeable position. For the practical work we can use proposed method, but before implementing on the real area this is need to implement on the software for getting the guarantee of the work.

In table 4.1 E0 is initial energy for each sensor. Eelec is energy of each packet. Efs is energy of free space. Emp energy of multi pass. This dataset is get from literatures.

Figure 4.3 shows the schematic of proposed method. As seen in this figure the 150 sensors are selected as randomly and the ID number of each sensors will save in memory of the sensors. Also if the sensors have not any cluster head in duration of the round will be test and check and then with specified random value will select as cluster head.

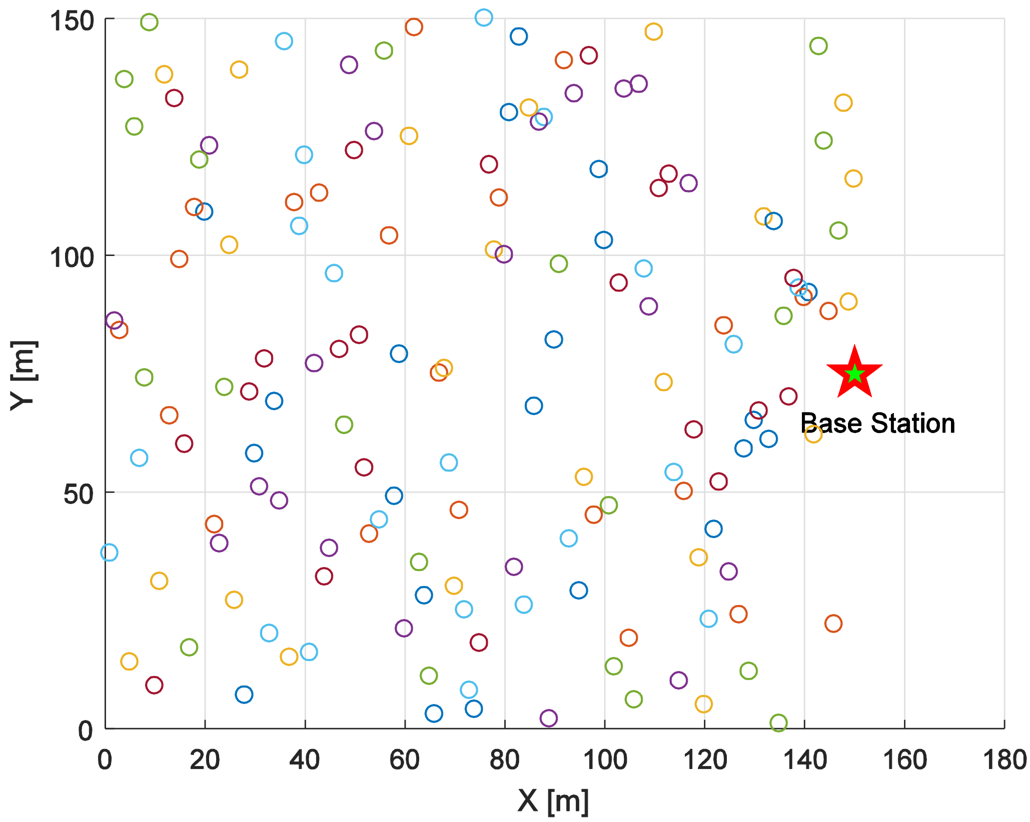

Figure 4.2: Schematic of the sensors in 150m by 150m.

Also as seen in this figure the base station is selected in x=150m and y=50m. All sensors will send their information to the base station.

Figure 4.4 shows the simulation in first round. As shown in this figure at first round about 12 cluster are created and all these clusters have the cluster heads which collect the information and they send to base station. Also in this thesis we set up the base station in x=150m and y=50m.

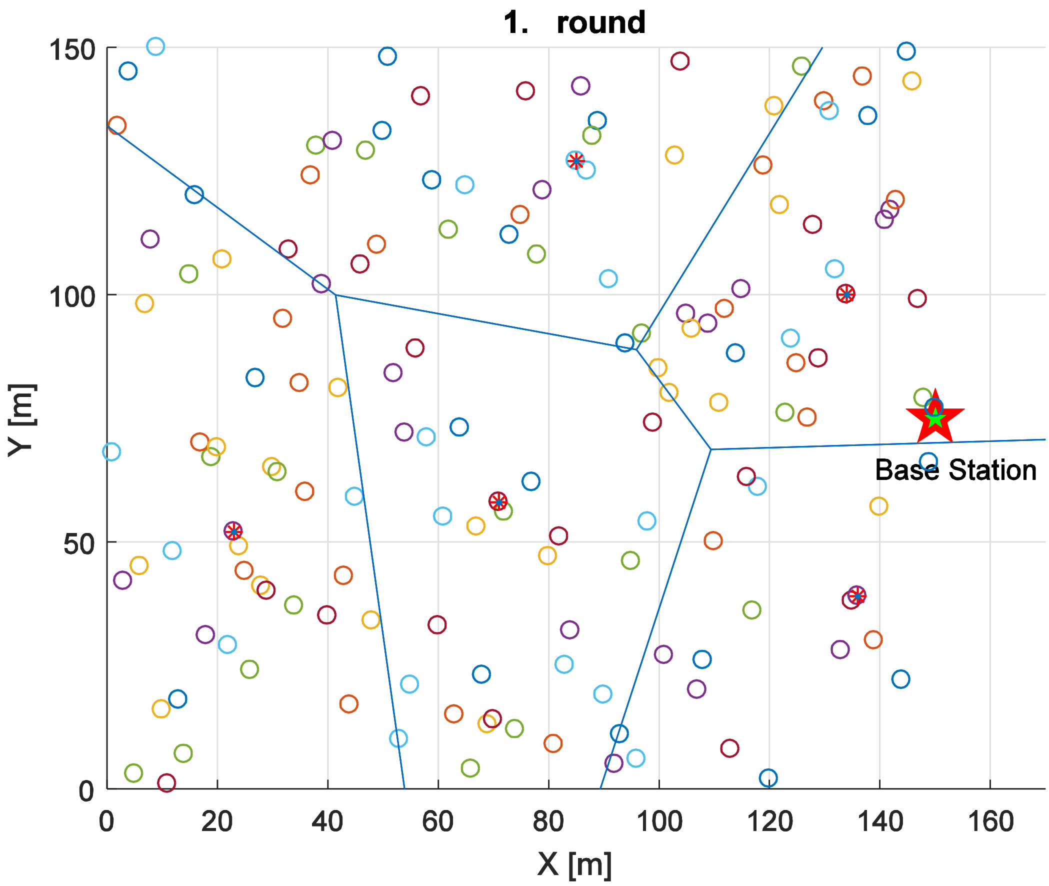

Figure 4.3: Simulation of the sensors in first round.

The number of alive sensors vs. of the rounds are shown in figure 4.5.

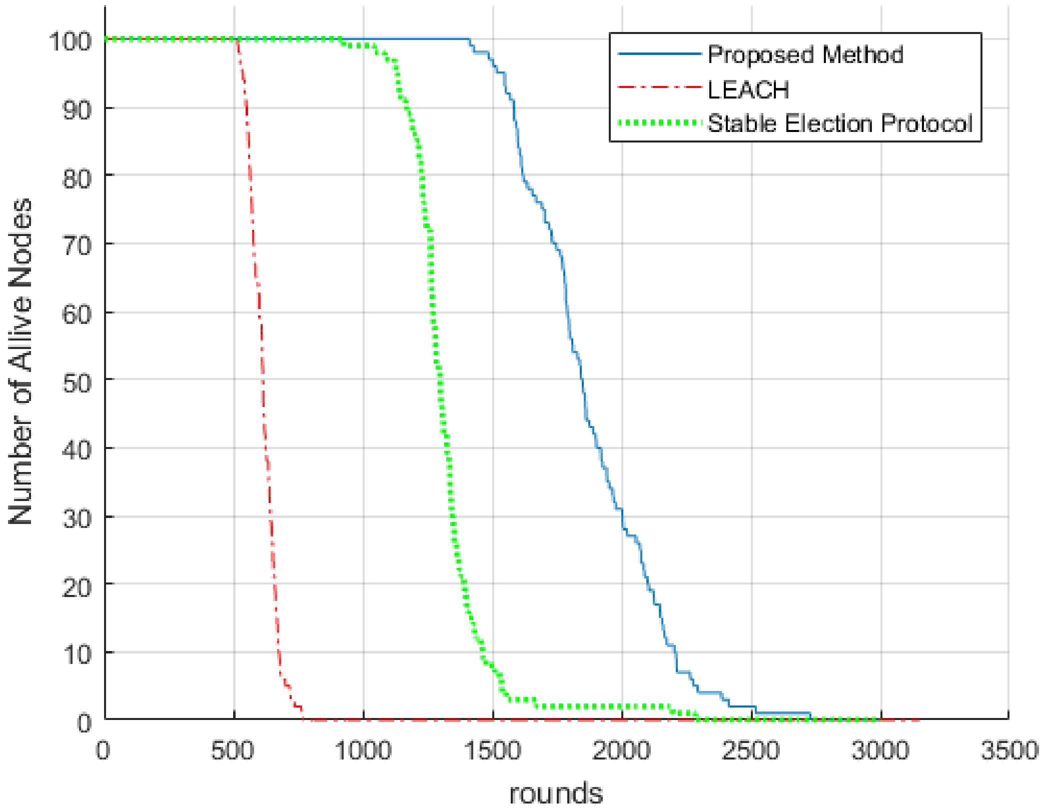

Figure 4.4: Number of alive nodes vs. rounds.

Figure 4.5 shows the number of alive nodes vs. rounds. As shown in this figure the proposed method result is better than the other one. Also in LEACH method the first dead node is start from 500 round, and all nodes are death in 1200. For SEP method the first node for deeding is start at 1500 round. And the all sensors are dead at 2000 round. Finally in proposed method the first node is dead at 1300 round and the all sensors are dead at 3000 round.

Figure 4.6 shows the dead node vs of the round.

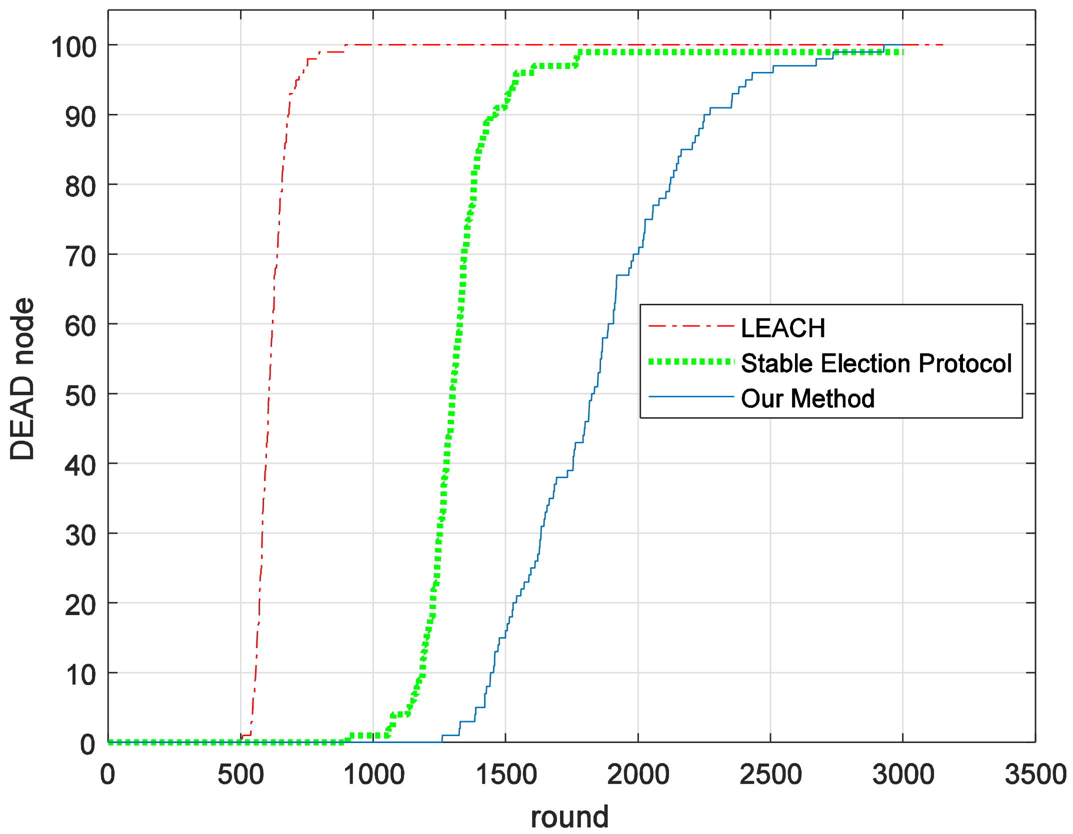

Figure 4.5: Dead nodes vs. round.

The number of packets received at BS is illustrated in figure 4.7. As shown in this figure in the propose method a lot of packet are sent to the BS than the other methods.

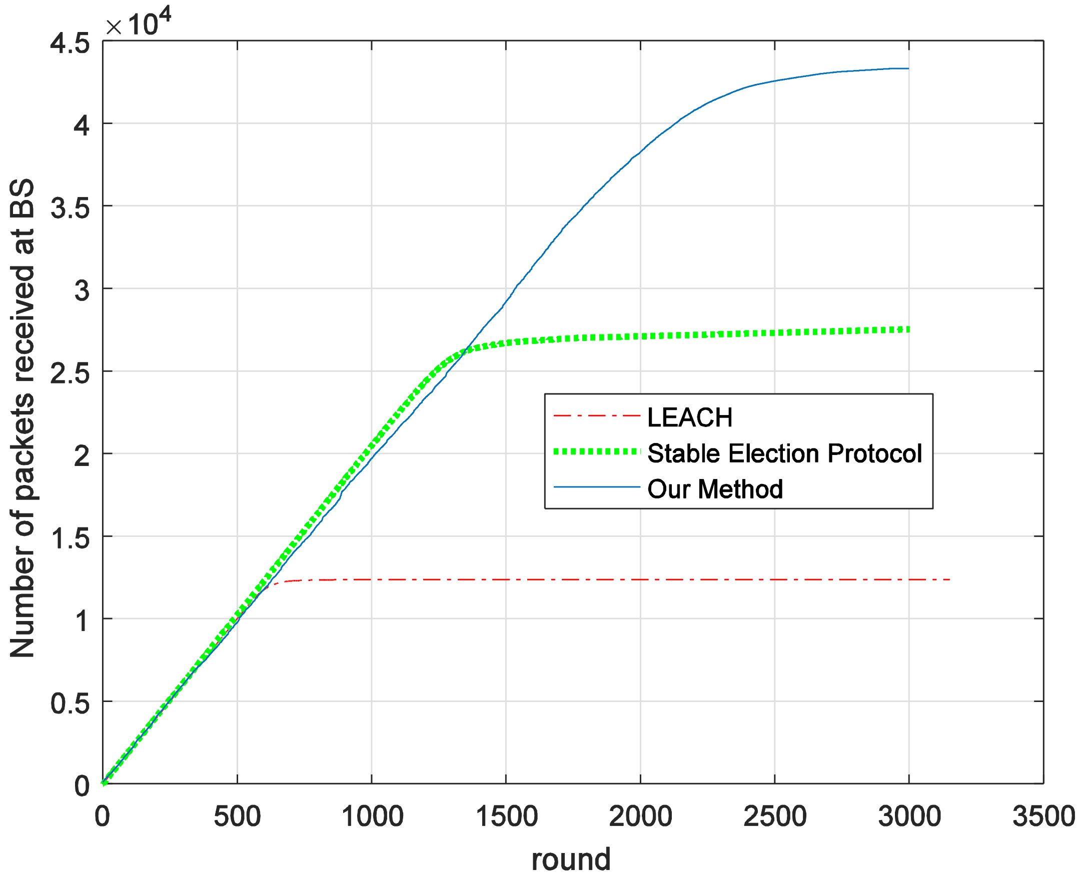

Figure 4.6. Number of packets received at BS

In LEACH method maximum 11000 packet are sent to BS and for SEP method the 28000 packet are sent but in our method the 60000 packet are sent to BS.

Figure 4.7 shows the total dissipated energy vs. round.

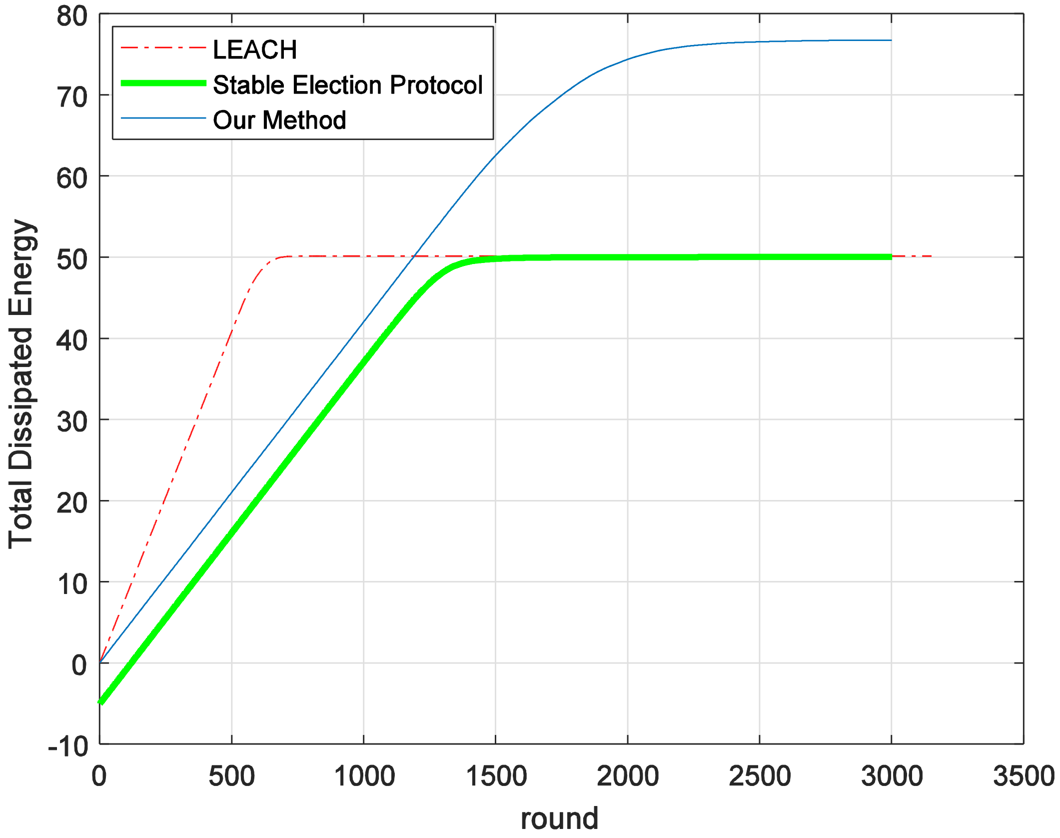

Figure 4.7. Total dissipated energy vs. round.

As shown in this figure the total dissipated energy for our method is high than the other methods.

Figure 4.8 shows the counting of cluster heads vs. round.

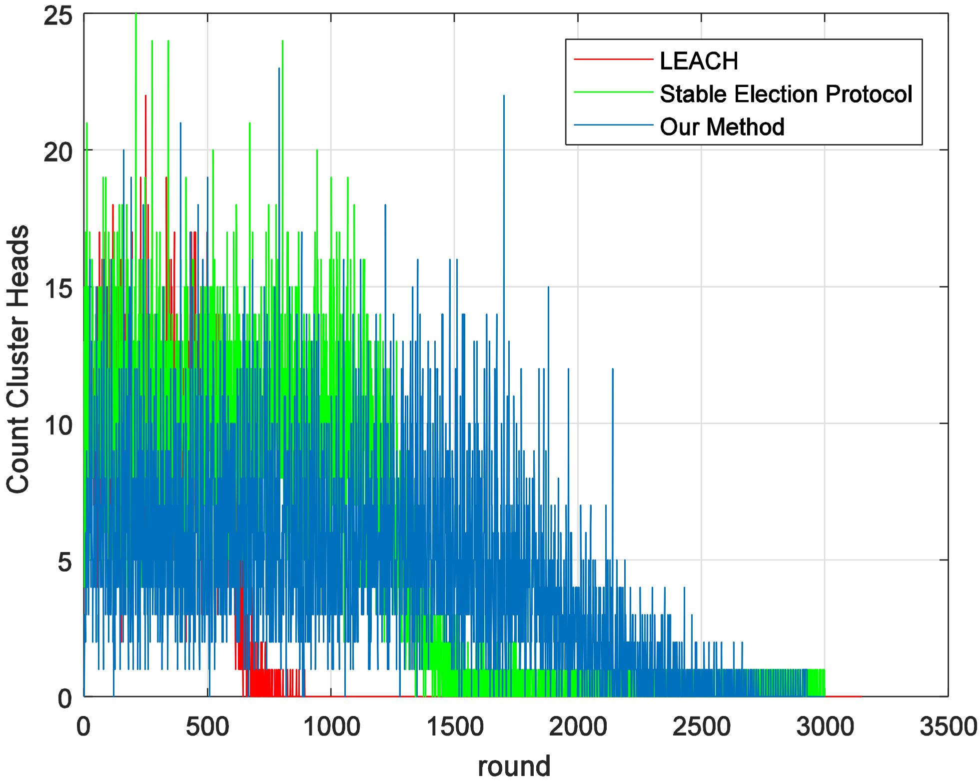

Figure 4.8: The counting of cluster heads vs. round.

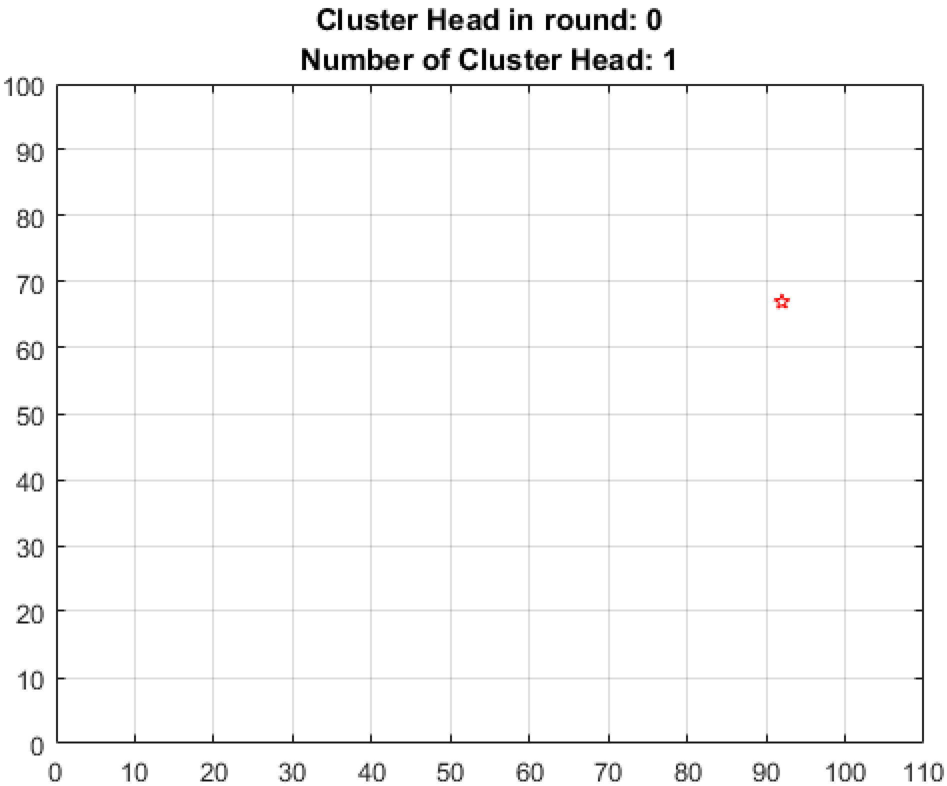

Figure 4.9: Number of cluster head in first round.

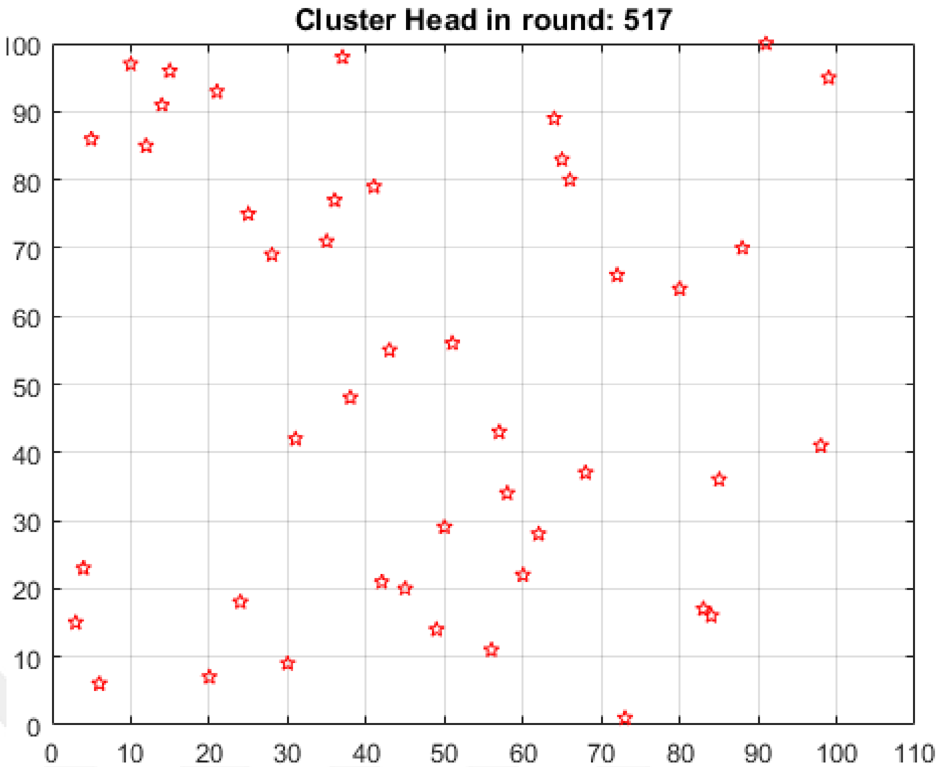

Figure 4.10: Number of cluster head in round 517

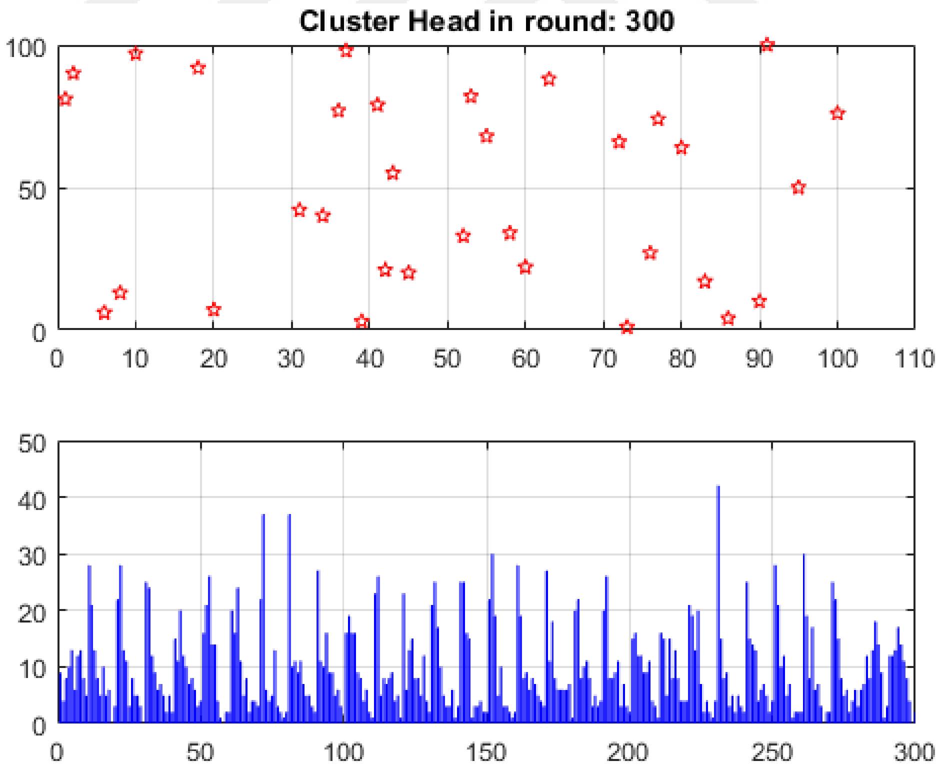

Figure 4.11: Cluster head selection

This figure shows about the cluster head selection. In each round the cluster head is changed and its depended on the situation of the sensors. Some sensors has low energy and then they don’t has more chance to get as a cluster head. The lower figure shows about the value of the cluster head numbers.

CHAPTER 5

CONCLUSION

Wireless Sensor Network is a communication network that allows computing devices to communicate with each other without being connected via a physical communications medium such as networking cable. Sensor Network is a set of interconnected sensor nodes, which perform one or several common tasks in a cooperative way. A sensor node is tiny node, which can compute, transmit, and sense brightness, accelerometer, temperature etc. Technology allows to produce small electronic devices, which can sense, process, stored and communicate. And one of this technology which has attracted much attention and enables new applications is wireless network sensors. First, this technology was used in military medicine but with time, it is also used in environmental and industrial monitoring applications. WSN is used to collect and process environmental information. Security is a vital requirement for many applications of sensor networks, but the issue is that an inexpensive sensor has a limited memory capacity and limited computing capabilities so it cannot create a log file for tracking and identifying the internal attacks and the attacks in wireless sensor networks can be categorized to the ones occurring at physical communication. These attacks can also be divided into two categories: internal and external. In order to face this problem, many universities and research institutions have started to work on these networks. As a project they decided to build an operating system for sensor nodes, creating sensors of very small size.

Future work

In future we can use the homogenous sensors for saving the energy with using the proposed method. Also we can use NS2 software to create the real application in the devices. The proposed method can use in practice with Zigbee sensors. As shown in the results we saved a lot of the energy for sensors. The other protocols can test and compare with proposed method.

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APPENDIX

Appendix A: Matlab Code For Leach

```
%%%%%%%%%%%%%%% PARAMETERS %%%%%%%%%%%%%%%%%%%

%Field Dimensions - x and y maximum (in meters)
xm = 150;
ym = 150;
%x and y Coordinates of the Sink
%sink.x =0.5 * xm;
%sink.y = ym + 50;
sink.x=50;
sink.y=50;
%sink.x=0.5*xm;
%sink.y=0.5*ym;

n = 150; %Number of Nodes in the field
p = 0.1; %Optimal Election Probability of a node to become cluster
head
packetLength = 6400;
ctrPacketLength = 200;
%Energy Model (all values in Joules)
%Initial Energy
Eo = 0.5;
%Eelec=Etx=Erx
ETX=50e-9;
ERX=50e-9;
%Transmit Amplifier types
Efs=10e-12;
Emp=0.0013e-12;
%Data Aggregation Energy
EDA=5e-9;

INFINITY = 999999999999999;
%maximum number of rounds
rmax = 3150;
%%%%%%%%%%%%%%%%%%%%%%%%% END OF PARAMETERS %%%%%%%%%%%%%%%%%%%%%%%%
%Computation of do

do = sqrt(Efs/Emp);

%Creation of the random Sensor Network
figure(1)
% set(figure(1), 'color', 'w')
hold on
plot(sink.x,sink.y,'+r','LineWidth',2,'MarkerSize',15)
hold on
axis([0 130 0 150])
grid on
```

```
% XR = datasample(1:xm,n,'Replace',false);
% YR = datasample(1:xm,n,'Replace',false);
% data = [XR;YR]';
load data
for i=1:1:n
    S(i).xd=data(i,1); %rand(1,1)*xm;
    XR(i)=S(i).xd;
    S(i).yd=data(i,2); %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';
    S(i).E=Eo;
    S(i).ENERGY=0;
    % hold on;
    figure(1)
    plot(S(i).xd, S(i).yd ,'o'),hold on
    pause(0.01)
end

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

%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;
allive = n;
%counter for bit transmitted to Bases Station and to Cluster Heads
packets_TO_BS = 0;
packets_TO_CH = 0;

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

%      hold off;

    %Number of dead nodes
    dead=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)
           dead=dead+1;
         end

         if (S(i).E>0)
            S(i).type='N';
         end
    end

%     if (dead == n)
%        break;
%     end

    STATISTICS.DEAD(r+1)=dead;
    DEAD(r+1)=dead;
    STATISTICS.ALLIVE(r+1) = allive-dead;

    %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: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;

                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;
                distanceBroad = sqrt(xm*xm+ym*ym);
```

```
                if (distanceBroad >=do)
                    S(i).E = S(i).E-(ETX*ctrPacketLength +
Emp*ctrPacketLength*(distanceBroad*distanceBroad*distanceBroad*dista
nceBroad));
                else
                    S(i).E = S(i).E-(ETX*ctrPacketLength +
Efs*ctrPacketLength*(distanceBroad*distanceBroad));
                end
                %Calculation of Energy dissipated
                distance;
                if(distance>=do)
                     S(i).E = S(i).E-((ETX+EDA)*packetLength+
Emp*packetLength*(distance*distance*distance*distance ));
                else
                     S(i).E = S(i).E-((ETX+EDA)*packetLength+
Efs*packetLength*(distance*distance));
                end
                packets_TO_BS = packets_TO_BS+1;
                PACKETS_TO_BS(r+1) = packets_TO_BS;
            end
         end
       end
    end

    STATISTICS.CLUSTERHEADS(r+1) = cluster-1;
    CLUSTERHS(r+1)= cluster-1;
    STATISTICS.COUNTCHS(r+1) = countCHs;
    %Election of Associated Cluster Head for Normal Nodes
    for i=1:1:n
       if (S(i).type=='N' && S(i).E>0)
        % min_dis = sqrt( (S(i).xd-S(n+1).xd)^2 + (S(i).yd-
S(n+1).yd)^2 );
         min_dis = INFINITY;
         if(cluster-1>=1)
             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 ) );
                temp = 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
                S(i).E = S(i).E - ETX * ctrPacketLength;
             end

             %Energy dissipated by associated Cluster Head
             min_dis;
             if (min_dis > do)
                 S(i).E = S(i).E - (ETX*(ctrPacketLength) + Emp *
ctrPacketLength*( min_dis * min_dis * min_dis * min_dis));
                 S(i).E = S(i).E - (ETX*(packetLength) +
Emp*packetLength*( min_dis * min_dis * min_dis * min_dis));
             else
                S(i).E = S(i).E -(ETX*(ctrPacketLength) +
Efs*ctrPacketLength*( min_dis * min_dis));
                S(i).E = S(i).E -(ETX*(packetLength) +
Efs*packetLength*( min_dis * min_dis));
             end
```

```
                S(i).E = S(i).E - ETX*(ctrPacketLength);

                %Energy dissipated
                if(min_dis > 0)
                   S(C(min_dis_cluster).id).E =
S(C(min_dis_cluster).id).E - ((ERX + EDA)*packetLength );
                   S(C(min_dis_cluster).id).E =
S(C(min_dis_cluster).id).E - ERX *ctrPacketLength ;
                   if (min_dis > do)
                       S(C(min_dis_cluster).id).E =
S(C(min_dis_cluster).id).E - ( ETX*(ctrPacketLength) + Emp *
ctrPacketLength*( min_dis * min_dis * min_dis * min_dis));
                   else
                       S(C(min_dis_cluster).id).E =
S(C(min_dis_cluster).id).E - ( ETX*(ctrPacketLength) + Efs *
ctrPacketLength*( min_dis * min_dis));
                   end
                  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;
       Ediss(r+1) = 0;
       for i = 1:n
           Ediss(r+1) = Ediss(r+1) + (Eo - S(i).E);
       end
%        if (r==0)
%            totalpackets(r+1) = PACKETS_TO_BS(r+1);
%        end
%        if (r>0)
%            totalpackets(r+1) = PACKETS_TO_BS(r+1) + totalpackets(r);
%        end

       countCHs;
       rcountCHs = rcountCHs + countCHs;

%      figure(2)
       x(r+1) = r;
       y(r+1) = n - STATISTICS.DEAD(r+1);
%      plot(x,y,'b');
%      iterNum=[num2str(r+1), '   round'];
%      title(iterNum);

%      hold on
STATISTICS.PACKETS_TO_CH(r+1) = packets_TO_CH;
       STATISTICS.PACKETS_TO_BS(r+1) = packets_TO_BS;
end

r = 0:rmax;

figure(2)
plot(STATISTICS.ALLIVE,'-.r');
xlabel('rounds')
ylabel('Number of Allive Nodes')
```

```
ylim([0 105])

figure(3)
plot(STATISTICS.DEAD,'-.r');
xlabel('round');
ylabel('DEAD node');
ylim([0 105])

figure(4)
plot(2*STATISTICS.PACKETS_TO_BS,'-.r');
xlabel('round');
ylabel('Number of packets received at BS');

figure(5)
plot(Ediss,'-.r')
xlabel('round');
ylabel('Total Dissipated Energy');

figure(6)
plot(STATISTICS.COUNTCHS,'r')
xlabel('round');
ylabel('Count Cluster Heads');
```

MATLAB CODE FOR SEP

```
%% "SEP: A Stable Election Protocol for clustered heterogeneous
wireless sensor networks",                                  %
rmax = 3000;
xm=150;
ym=150;

%x and y Coordinates of the Sink
sink.x=50;
sink.y=50;

%Number of Nodes in the field
n=150

%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=0.1;
%\alpha
a=1;
packets_TO_BS=0;
packets_TO_CH=0;

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

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


% XR = datasample(1:xm,n,'Replace',false);
% YR = datasample(1:xm,n,'Replace',false);
% data = [XR;YR]';
load data

%Creation of the random Sensor Network
for i=1:1:n
    S(i).xd=data(i,1);
    XR(i)=S(i).xd;
    S(i).yd=data(i,2);
    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;

%maximum number of rounds
rmax=3000;
for r=0:1:rmax
    r

  %Election Probability for Normal Nodes
  pnrm=( p/ (1+a*m) );
  %Election Probability for Advanced Nodes
  padv= ( p*(1+a)/(1+a*m) );

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

 %Operations for sub-epochs
 if(mod(r, round(1/padv) )==0)
    for i=1:1:n
        if(S(i).ENERGY==1)
            S(i).G=0;
            S(i).cl=0;
        end
    end
  end


hold off;

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

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

% figure(1);

for i=1:1:n
    %checking if there is a dead node
    if (S(i).E<=0)
%          plot(S(i).xd,S(i).yd,'red .');
        dead=dead+1;
```

```
        if(S(i).ENERGY==1)
            dead_a=dead_a+1;
        end
        if(S(i).ENERGY==0)
            dead_n=dead_n+1;
        end
        hold on;
    end
    if S(i).E>0
        S(i).type='N';
        if (S(i).ENERGY==0)
%           plot(S(i).xd,S(i).yd,'o');
        end
        if (S(i).ENERGY==1)
%           plot(S(i).xd,S(i).yd,'+');
        end
        hold on;
    end
end
% plot(S(n+1).xd,S(n+1).yd,'x');


STATISTICS.DEAD(r+1)=dead;
DEAD(r+1)=dead;
STATISTICS.ALLIVE(r+1) = n - 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 for normal nodes
 if( ( S(i).ENERGY==0 && ( temp_rand <= ( pnrm / ( 1 - pnrm *
mod(r,round(1/pnrm)) )) ) )  )

            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=150;
            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



 %Election of Cluster Heads for Advanced nodes
 if( ( S(i).ENERGY==1 && ( temp_rand <= ( padv / ( 1 - padv * 
mod(r,round(1/padv)) )) ) )  )

            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=150;
            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.COUNTCHS(r+1)=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;

    Ediss(r+1) = 0;
    for i = 1:n
        Ediss(r+1) = Ediss(r+1) + (Eo - S(i).E);
    end
%     stat.PACKETS_TO_BS(r+1) = packets_to_bs;
    stat.PACKETS_TO_BS(r+1) = packets_TO_BS;
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
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%
figure(2),hold on
plot(1:length(DEAD),150-DEAD,':g','linewidth',2)
legend('Proposed Method','LEACH','Stable Election Protocol')
grid on

figure(3),hold on
plot(1:length(DEAD),DEAD,':g','linewidth',2)
legend('Proposed Method','LEACH','Stable Election Protocol')
grid on

figure(4),hold on
plot(2*stat.PACKETS_TO_BS,':g','linewidth',2);
legend('Proposed Method','LEACH','Stable Election Protocol')
grid on

figure(5),hold on
plot(1:length(Ediss),Ediss,'g','linewidth',2)
legend('Proposed Method','LEACH','Stable Election Protocol')
grid on

figure(6),hold on
plot(STATISTICS.COUNTCHS,'g')
legend('Proposed Method','LEACH','Stable Election Protocol')
grid on
```

CURRICULUM VITAE

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