Energy-Efficient Clustering for Wireless Sensor Networks with Mobile Base Station (ECMBS)

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ABSTRACT

In recent years, wireless sensor networks (WSNs) have received increasing attention from both the research community and actual users. As sensor nodes are generally battery-powered devices, an important aspect concerns how to reduce the energy consumption of nodes, so that the network lifetime can be extended to reasonable time. In addition to delivering data to the base station, a routing protocol must be energy efficient. An efficient routing technique is known as hierarchical routing based on clustering. In this study, the energy consumption for the components of a typical sensor node is initially broken down, and the main directions to energy conservation in WSNs are discussed. What's more, a survey of the energy conservation schemes, which are recently proposed in the literature, will be carried out. Special attention will be devoted to promising solutions which have not yet been focused widely in the literature, such as techniques for energy efficient data acquisition. The main contribution will be carrying out a performance study of prominent schemes throughout simulation and modifying an efficient scheme to further improve its performance. In this thesis, a wireless sensor network is considered by using a mobile base station, and an Energy-Efficient Clustering algorithm named as ECMBS is proposed. After clustering the nodes and selecting the cluster heads, the minimum distance is calculated so that the minimum energy cost is imposed for data communication. Simulation results are provided to prove the efficiency of this technique. The results are compared with the old LEACH algorithm.

Keywords: Wireless sensors networks, Mobile base station, LEACH.

ÖZ

Son yıllarda, hem araştırmacılar hem de kullanıcıların kablosuz algılayıcı ağlara (WSNs) olan ilgisi artmıştır. Algılayıcı düğümler genellikle pil gücüyle çalışan araçlar olduklarından dolayı ağ ömrünü mantıklı bir şekilde uzatmak için düğümlerin enerji harcamasını azaltmak önemli bir konu olmuştur. Baz istasyonuna veri iletmeye ek olarak rotalama protokolünün enerji verimliliği olması gerekmektedir. Etkili bir rotalama tekniği, kümelemeye dayalı olan hiyerarşik yönlendirme olarak bilinmektedir. Bu araştırmada öncelikle tipik bir algılayıcı düğümün bileşenlerinin enerji tüketimi belirlenip, kablosuz algılayıcı ağlarında enerji tasarrufu sağlama yolları ele alınmıştır. Daha sonra ise son zamanlarda literatürde önerilen enerji tasarrufu planı üzerine bir anket uygulaması yapılmıştır. Araştırmada enerji koruyucu veya enerji tasarruflu veri edinme teknikleri gibi literatürde yeterince dikkat çekmemiş, gelecek vadeden çözümlere özel bir ilgi gösterilmiştir. Araştırmanın ana katkısı seçkin uygulama ve planlar üzerine simulasyon ve verimli bir planı değiştirme yöntemiyle performanslarını artıracak bir çalışma yürütmektir. Bu araştırmada kablosuz algılayıcı ağları, mobil baz istasyonu kapsamında dikkate alınmış ve ECMBS isimli bir enerji tasarruflu kümeleme algoritması önerilmiştir. Düğümleri kümeleme ve kümeleme başlıklarını seçme işleminden sonra asgari uzaklık hesaplanmış, böylece veri iletişimi için harcanacak asgari enerji maliyetinden yararlanılmıştır. Bu tekniğin etkinliğini kanıtlamak için simulasyon sonuçları verilmiş ve sonuçlar önceki LEACH algoritması ile karşılaştırılmışlardır.

Anahtar Kelimeler : Kablosuz algılayıcı ağları, mobil baz istasyonu, LEACH.

To Mum and Dad ...... for your love.

To my Brother and Sisters

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LIST OF ABBREVIATIONS

WSN	Wireless Sensors Network
LEACH	Low Energy Adaptive Clustering Hierarchy
MAC	Media Access Control
CH	Cluster Head
BS	Base Station
MBS	Mobile Base Station
CDMA	Code Division Multiple Access
TDMA	Time Division Multiple Access
d_{min}	minimum distance
P_{opt}	Optimal probability of becoming cluster-heads
E_{elec}	Energy dissipation per bit for the transceiver circuit
E_{Tx}	Transmission energy
E_{Rx}	Reception energy
E_{CH}	Energy dissipation by a cluster Head node
G	Set of non-cluster heads
E_{CH}	Energy dissipation by a cluster-head node
MEMS	micro-electro mechanical systems

SEP	Stable Election Protocol
NWGN	New wireless Generation Networks
CCPAR	Clustered Chain based Power Aware Routing
DCs	Data Collectors
SENMA	SEnsor Networks with Mobile Agents
SEAD	Scalable Energy-efficient Asynchronous Dissemination
AIMMS	Autonomous Intelligent Mobile Micro-server
ILP	Integer Linear Programming
PLLs	phase locked loops
OSI	Open System Interconnection
FEC	Forward Error Correction
SMP	Symmetric multiprocessing
ARQ	Automatic repeat request
FEC	Forward error correction
SMAC	Sensors MAC
ECMBS	Energy-Efficient Clustering for Wireless Sensor Networks with Mobile Base Station

Chapter 1

INTRODUCTION

1.1 Motivation

Wireless Sensor Networks (WSNs) are networks of light-weight sensors that are battery powered mainly used for monitoring purposes. The advances in micro-electro mechanical systems (MEMS) technologies have made the improvising of such sensors a possibility [1]. Recently, WSNs have been heavily researched by several organizations and by the military where we can find some of the applications in battle field surveillance. With the recent situations on climate change, WSNs can be utilized to track changes that affect the climate by using a network of sensors to gather environmental variables such as temperature, humidity and pressure. One of the numerous advantages of these sensors is their ability to operate unattended which is ideal for inaccessible areas [1].

However, while WSNs are increasingly equipped to handle some of these complex functions, in-network processing such as data aggregation, information fusion, computation and transmission activities require these sensors to use their energy efficiently in order to extend their effective network lifetime. Sensor nodes are prone to energy drainage and failure, and their battery source might be irreplaceable, instead new sensors are deployed. Thus, the constant re-energizing of wireless sensor networks as old sensor nodes die out and/or the uneven terrain of the region being sensed can lead to energy imbalances or heterogeneity among the sensor nodes. This can negatively impact the stability and performance of the network system if the extra energy is not properly utilized and leveraged. Several clustering schemes and algorithm such as LEACH [2] have been proposed with varying objectives such as load balancing, fault-tolerance, increased connectivity with reduced delay and network longevity. A balance of the above objectives can yield a more robust protocol.

LEACH protocol (Low-Energy Adaptive Clustering Hierarchy) and the likes assume a near to perfect system , an energy homogeneous system where a node is not likely to fail due to uneven terrain, failure in connectivity and packet dropping. But more recent protocols like SEP [3] considered the reverse, that is energy heterogeneity where the factors mentioned above is a possibility, which is more applicable to real life scenario for WSN.

Thus, energy heterogeneity should therefore be one of the key factors to be considered when designing a protocol that is robust for WSN. This research investigates the existing work that has been done in this area. The goal is to present a modified protocol design that is more robust and can ensure longer network life-time while taking other performance measures into consideration. Mathematical modeling and computer simulations are used as proof of concept and testing.

1.2 Problem Definition and Motivation

The wireless sensor depends on its battery to run along its life time, thus, the life time depends on the consumption of the power. This is related to many variables, including the distance between the sender (the cluster head) and the reserve (Base Station).

In the wireless sensors network, once the first sensors' battery is consumed, the sensor is considered to be dead. Not all sensors in the wireless network are dying at the same time. So, once the first one is dead, the network and/or the cell will be unbalanced. In this case, if the network continues to be running – collecting data, logging, and transferring the data to base station – the overall data will have a shortage. Therefore, if the dead sensor(s) cannot send any data, part of the data is lost. However, distant communication to the sink is consuming energy greatly for sensor nodes. In hierarchical routing based on clustering, it is the responsibility of cluster heads to send the information to the sink.

Thus, it makes them to deplete their energy much faster. Recently, some ideas have been proposed in the literature based on mobile sink. In these approaches, the sink moves around in the network in order to reduce the distance of communication and decrease the energy consumption.

1.3 Research Objectives

The research aims to investigate a method to reduce the energy expenditure, hence providing a considerable increase in the lifetime of a wireless sensor network. This will be achieved through the combination of energy management, information control and transmission range adaptation. Routing algorithm is considered for a wireless sensor network in which the BS (base station) position is mobile. The developed system is analyzed and validated through simulation which is performed by using the MATLAB Programming Language. WSN environment to be simulated is a network consisting of a few sensor nodes and it is suitable for small-scale industrial and commercial applications. A few sensor nodes are chosen for the simulation, as scalability (the ability of the network to operate efficiently when the number of nodes increases) is not the primary concern in this research.

The majority of the research considers sensor networks to be entirely static. However, it should be considered that networks should be able to cope with the mobility of the Base Station (BS). This new approach raises the possibility of developing new methods to spare energy. In this study, the mobility of the base station is considered which can move inside the area throwing the sensor network (for example the BS is mounted on a robot plane).

The research objectives of this thesis are as follows:

1. Developing a protocol that can distribute the energy consumption across all nodes equally.
2. Electing leaders based on the nodes residual energies.
3. Guaranteeing that additional energies in the network are used efficiently and effectively.
4. Ensuring that the nodes in the network are adaptive and sensitive to the changing environment.
5. Balancing the running and transfer load of each cell in the network.

The result of the introductory protocol will be compared to the LEACH protocol (Low-Energy Adaptive Clustering Hierarchy).

1.4 Contributions

In the era of New wireless Generation Networks (NWGN) many emerging and future enabled technologies accomplish the requirements of ubiquitous communication networks. Enormous concerns of these networks are gathering data with energy efficiency. Routing protocol acts as middleware, which is responsible to enhance the network performance with less energy consumption.

The contributions of this thesis are :

1. increasing the lifetime of the node, like twice the time related to the original LEACH Protocol.

2. developing and validating algorithms (Chapter 3). This approach is an enhancement to the existing LEACH protocol (Low-Energy Adaptive Clustering Hierarchy).

3. analyzing and validating Mobile base station (MBS) based on LEACH routing protocol for environmental application areas that cannot be accessed or be difficult to reach which is based on multi-hop routing strategy.

4. each cluster head (CH) calculate minimum distance (d_{min}) and make the decision either by sending its data to the BS directly or to the closest CH to the BS.

5. the present study's approach shows the significant improvement in terms of energy consumption of sensor nodes, enhanced network lifetime and data gathering at base station are outperformed when compared with LEACH protocol .

1.5 Thesis Outline

This thesis is organized as follows:

In Chapter 2, a detailed discussion of the Wireless Sensor Network (WSN) and existing work done in the area of interest are presented. It also presents some critiques of the WSNs with respect to energy management, information control, and transmission range adaptation. Chapter 3 introduces the details of (ECMBS) algorithm developed in this research. Chapter 4 provides the result obtained from the simulation of a WSN using algorithm developed (ECMBS). Chapter 5 concludes the report and outlines possible for future research.

Chapter 2

LITERATURE REVIEW AND RELATED WORK

This chapter provides a review of wireless sensor networks and some existing schemes that have been employed in these networks. Different improvements in energy models of these schemes based on this thesis are also presented.

2.1 Introduction

Wireless communication technologies continue to grow in diverse areas to provide new opportunities for networking and services. One fast-moving area is wireless sensor networks (WSN). With the advances in micro-electro mechanical systems, sensor devices can be built as small as lightweight wireless nodes. WSNs are highly distributed networks of such kind of sensor nodes and have been deployed in large numbers to monitor the environment or production systems. There is a growing need for the nodes to handle more complex functions in data acquisition and processing, and energy saving solutions remain as a major requirement for these battery-powered sensor nodes.

Three major functions are performed by three sensor subsystems, i.e. the environment sensor; the data processor that performs local computations on the data sensed; and the communicator that performs information exchange between neighboring nodes. Each sensor is usually limited in their energy level, processing power and sensing ability. However, networks of these sensors give rise to a robust, reliability and accurate network. The sensors can collaborate and cooperate among each other, elect leaders or heads, gather their data and then transmits a more refined result from the sensing field to a central location which might in most of the case be a Base Station (BS), or more powerful nodes [4].

2.2 What is Wireless Sensor Network (WSN)?

With the development of embedded system and network technology, there has been growing interest in providing fine-grained metering and controlling of living environments using low power devices. Wireless Sensor Networks (WSNs), which consist of spatially distributed self-configurable sensors, perfectly meet the requirement. The sensors provide the ability to monitor physical or environmental conditions, such as temperature, humidity, vibration, pressure, sound, motion and etc., with very low energy consumption.

The sensors also have the ability to transmit and forward sensing data to the base station. Most modern WSNs are bi-directional, enabling two way communication, which could collect sensing data from sensors to the base station as well as disseminate commands from base station to end sensors. The development of WSNs was motivated by military applications such as battlefield surveillance. WSNs are widely used in industrial environments, residential environments and wildlife environments. Structure health monitoring, healthcare applications, home automation, and animal tracking become representative of WSNs applications.

A typical Wireless Sensor Network (WSN) is built of several hundreds or even thousands of “sensor nodes”. The topology of WSNs can vary among star network, tree network, and mesh network. Each node has the ability to communicate with every other node wirelessly, thus a typical sensor node has several components: a radio transceiver with an antenna which has the ability to send or receive packets, a microcontroller which could process the data and schedule relative tasks, several kinds of sensors sensing the environment data, and batteries providing energy supply which can be seen in Figure 2.1 [1].

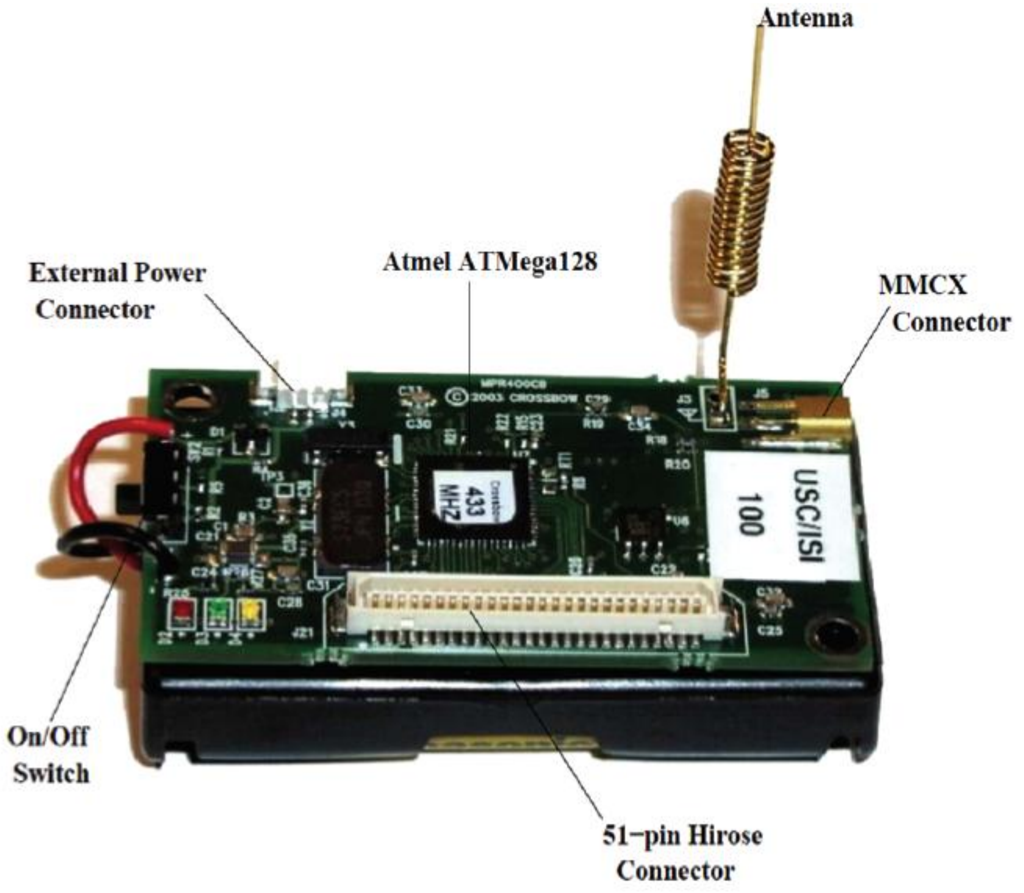

Figure 2.1: A typical Wireless sensor node [1]

2.3 Basic Components of Wireless Sensor Node

A sensor node is made up of four basic components :

2.3.1 A Sensing/Actuating Unit.

The sensing unit is usually made up of two subunits; the sensors themselves and analog-to-digital converters (AD- Cs). The signals generated by the sensors, based on the phenomenon to be sensed, are analog in nature and hence need to be converted to a digital to aid further processing (see Figure 2.2). These signals are then fed to the processing unit [1].

2.3.2 A Processing Unit.

This unit, in association with a small storage unit, manages the procedures that make the sensor node collaborate with the other nodes to carry the sensing tasks [1].

2.3.3 Transceiver Section.

The transceiver unit connects wirelessly through the RF channel and is linked to an omni-directional antenna that allows for communication in all directions. The main task of a transceiver is to convert a bit stream arriving from the processing unit into electromagnetic radio waves. The transceiver unit may be passive or an active optical device or a RF device. RF communication requires modulation, band pass filtering, demodulation and multiplexing circuitry, which make them more complex and expensive. Moreover, the path loss of the transmitted signal between two sensor nodes may be as high as the fourth order exponent of the distance between them, because the antennas of the sensor nodes are close to the ground. Nevertheless, RF communication is preferred in most of the ongoing sensor network research because the packets conveyed in sensor networks are small, data rates are low and frequency reuse is high due to short communication distances. These characteristics also make it possible to use low duty cycle radio electronics for sensor networks [1].

In the three domains, a sensor node expends maximum energy in data communications. Mixers, frequency synthesizers, voltage controlled oscillators, phase locked loops (PLLs) and power amplifiers all consume valuable power in the transceiver circuitry [1].

2.3.4 Power Supply Unit.

The wireless sensor nodes can be powered from energy storage devices or by energy scavenging. The former technique employs a variety of tiny batteries made up of thin films of vanadium oxide and molybdenum oxide. These are fabricated by using micro-machined cavities containing an electrolyte, in addition to chemical energy storage. The latter technique employs energy scavenging from the environment in order that the wireless sensor node can operate uninterrupted.

The most widely used energy scavenging technique is the solar radiation. There is a possibility of energy-harnessing from body heat in bio-medical applications. The battery forms the heart of the sensor system as it decides the lifetime of the system. The battery lifetime needs to be prolonged to maximize the network lifetime. Network Lifetime is defined as the maximum number of times a certain data collection function or task that can be carried out without any node running out of energy. It is also defined as the time elapsed until the first node in the network is completely depleted of its energy and is determined by the ability to conserve energy in the network. The requirement is that the size of the battery should be as small as possible, at the same time being energy efficient. Batteries with energy scavenging capabilities are being designed to increase the lifetime of the sensor system. Two AA sized batteries of 1.2 V each are employed in the battery subsection as shown in Figure 2.2 [1].

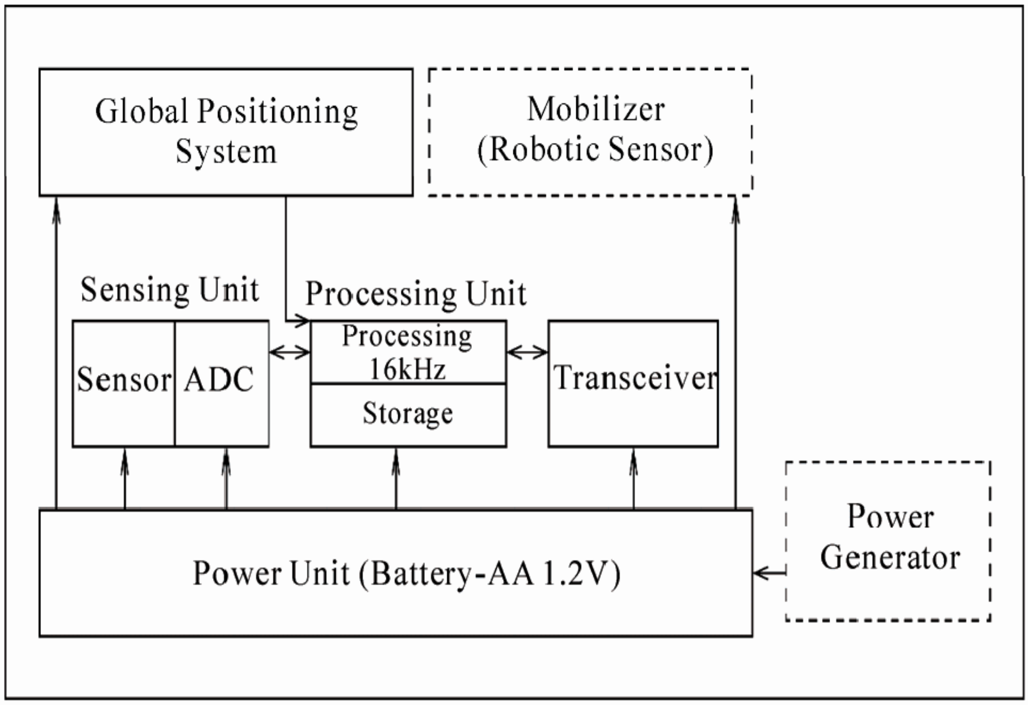

Figure 2.2: Sensor node architecture [1]

2.4 Wireless Sensor Network Concept

Wireless sensor network is composed of a large number of micro-sensor nodes deployed in the area of monitoring by no line communication mode of the formation of a multi-hop, which is the self-organization of a network system (see Figure 2.3). The purpose of this is to be in cooperation, perception and acquisition of various environments and monitoring the object information and to send it to the corresponding user in the process network coverage area [1]. Wireless Sensor network integrated microelectronics technology, embedded technology, sensor technology, wireless communication technology as well as sub-distributed information processing technology, and other areas of technology. It has experienced a wired transmission from a single intelligent mode to the development process of the wireless transmission mode.

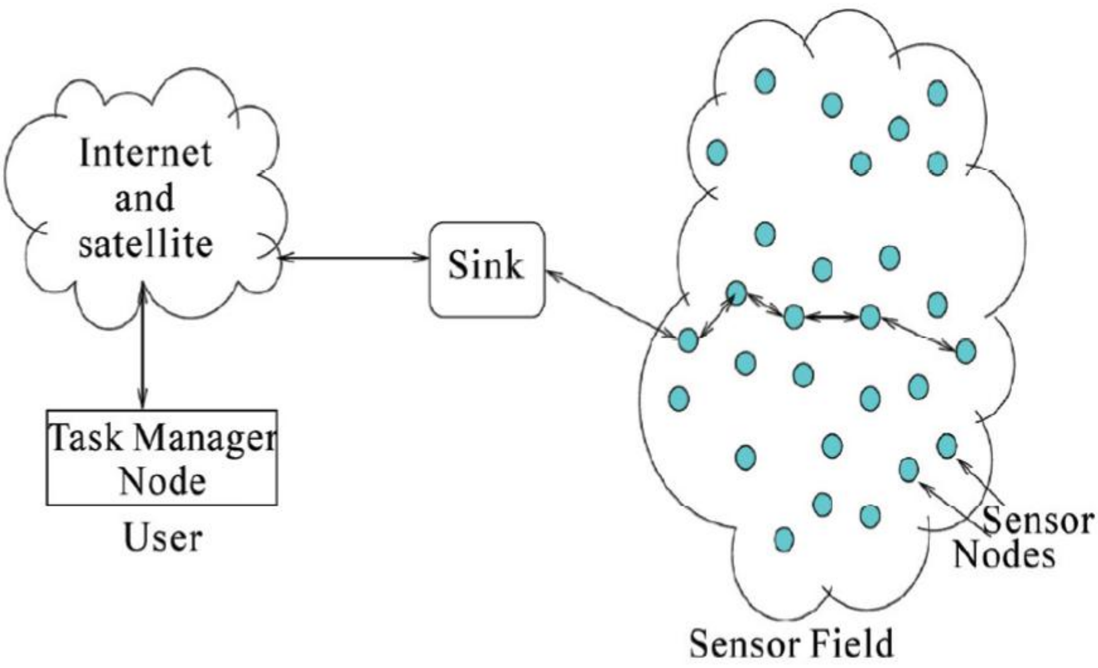

Figure 2.3: A typical scenario of a Wireless Sensor Network (WSN) [1].

2.5 Wireless Sensor Network Layers Architecture

Sensor nodes are normally scattered in a sensing field. Every sensor has the capability of sensing, processing in form of aggregating and communicating the data to the sink or base station using various schemes. The underlying protocol scheme in the OSI model for WSNs includes the application layer, transport layer, network layer, data link layer and the physical layer. As described in [1], the protocol stack shown in Figure 2.4, combines power and routing awareness, integrates data with networking protocols to communicates power efficiently through wireless medium and promotes cooperative efforts of sensor nodes.

The application layer supports different application software depending on the task. The transport layer maintains the data flow, while the network layer does the routing of data from the transport layer. Depending on the deployment of the sensors, they can either be mobile or static, if the former then the data link layer, specifically the

MAC protocol design must have a power control mechanism, forwarding mechanism and should be able to perform communication confidentiality through encryption - decryption techniques. Finally, the task of the physical layer involves modulation and demodulation of radio carrier stream, forward error correction (FEC) and performing efficient synchronization between the sender and receiver.

In [1], the power, mobility, and task management planes were proposed to monitor the power, movement, and task distribution among the sensor nodes. Most often sensor network protocols are designed with two basic kinds of architectures; the layered and the clustering architectures. These architectures are discussed in the next sections.

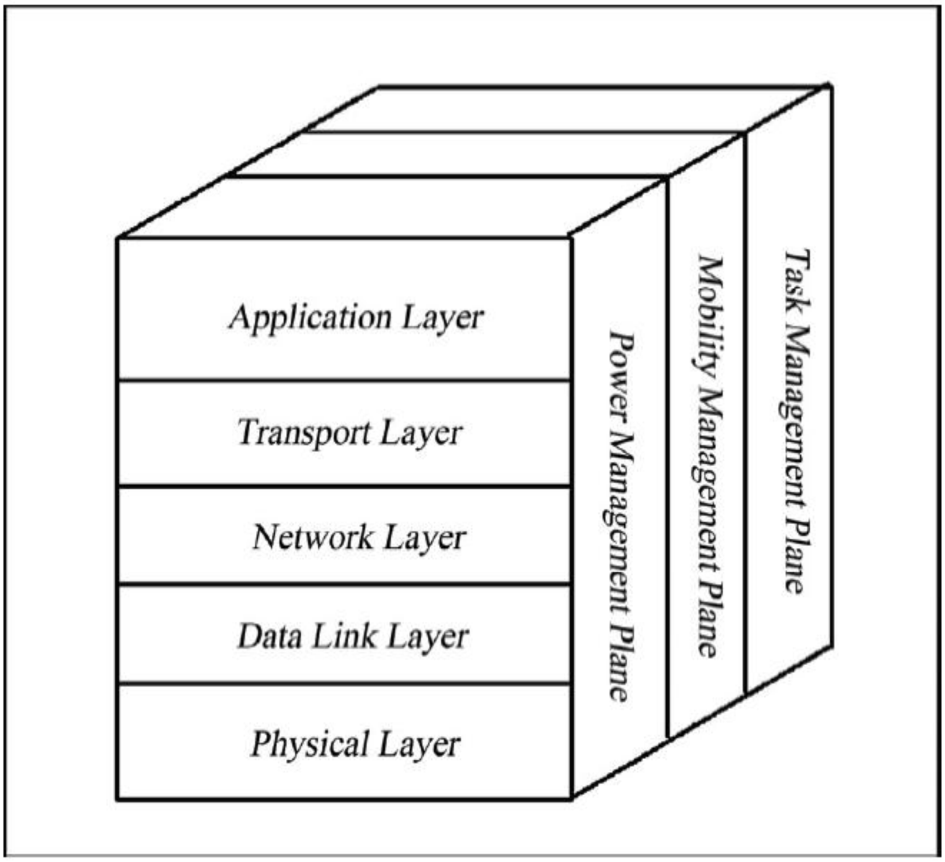

Figure 2.4 : Wireless Sensor Network protocol stack [1]

2.5.1 Application Layer

1. This layer mainly focuses on how to manage and arrange different types of applications, such as dealing with incoming events and generating new ones.
2. Sensor management protocol makes hardware and software of the lower layers transparent to sensor network management applications. The system interacts with sensor networks only with SMP. Its tasks include turning node on and off, etc.
3. Task assignment and data advertisement protocol is for interest dissemination. Users send interests to a subset of nodes. Nodes advertise available data to users and users query the data which they are interested in. (co-work with routing?)
4. Sensor query and data dissemination protocol is for users to deal with queries and incoming replies. Queries are usually associated with attribute-based or location based naming. SOTL supports 3 types of events: receive, every and expire [5].

2.5.2 Transport Layer

1. for end-to-end communication and monitoring the transmission

2. TCP for communication between users and sink; UDP for communication between sink and sensor nodes.

3. considering attributed-based and location-based naming for end-to-end packet transmission.

4. more factors in sensor network : power consumption, scalability, data - centric routing, etc. Nodes cannot store large amount of data and ACK is too costly.

2.5.3 Network Layer

1. routing information.

2. More factors: power, data centric, data aggregation vs. collaboration, naming.

3. Maximum available power route/minimum energy route/minimum hop route.

4. Data centric: users are more interested in an attribute of a phenomenon rather than

querying an individual node. Reverse multicast tree.

5. Provides inter-networking with external networks - gateway/backbone.

6. Examples: small minimum energy communication network, flooding, gossiping, sensor protocol for information via negotiation.

2.5.4 Data link Layer

1. For multiplexing of data streams, data frame detection, medium access and error control.

2. Medium access control creates the network infrastructure and fairly share communication resources between sensor nodes; SMACS and EAR: distributed neighbor-finding and scheduling, time-slot seamless connection of nodes; CSMA-based; Hybrid TDMA/FDMA.

3. Power saving modes of operation: different operation modes for hardware as to different functions and tasks. (switching power consumption)

4. Error control: ARQ and FEC, but retransmission is impossible for power saving and decode complexity for FEC is too much. Simple coding with low complexity is needed.[5].

2.5.5 Physical Layer

1. Frequency selection, carrier frequency generation, signal detection, modulation and data encryption.

2. Multi-hop communication: to overcome path loss and shadowing

3. The choice of different modulations: increased radio power consumption and transmission efficiency.

2.6 Applications of Sensor Networks

Traditionally, sensor networks have been used in the context of high-end applications such as radiation and nuclear-threat detection systems, ‘‘over-the-horizon’’ weapon sensors for ships, biomedical applications, habitat sensing, and seismic monitoring. More recently, interest has focused on networked biological and chemical sensors for national security applications. Furthermore, evolving interest extends to direct consumer applications. Existing and potential applications of sensor networks include, among others, military sensing, physical security, air traffic control, traffic surveillance, video surveillance, industrial and manufacturing automation, process control, inventory management, distributed robotics, weather sensing, environment monitoring, national border monitoring, and building and structures monitoring [6][7]. A short list of applications are as follows;

2.6.1 Military Applications

- Monitoring inimical forces
- Monitoring friendly forces and equipment
- Military-theater or battlefield surveillance
- Targeting
- Battle damage assessment
- Nuclear, biological, and chemical attack detection

2.6.2 Environmental Applications

- Microclimates
- Forest fire detection
- Flood detection
- Precision agriculture

2.6.3 Health Applications

- Remote monitoring of physiological data
- Tracking and monitoring doctors and patients inside a hospital
- Drug administration
- Elderly assistance

2.6.4 Home Applications

- Home automation
- Instrumented environment
- Automated meter reading

2.6.5 Commercial Applications

- Environmental control in industrial and office buildings
- Inventory control
- Vehicle tracking and detection
- Traffic flow surveillance

Chemical-, physical-, acoustic-, and image-based sensors can be utilized to study ecosystems (e.g., in support of global parameters such as temperature and microorganism populations). Defense applications have fostered research and development in sensor networks during the past half-century. On the battlefield, sensors can be used to identify and/or track friendly or inimical objects, vehicles, aircraft, and personnel. Here, a system of networked sensors can detect and track threats and can be utilized for weapon targeting and area denial [6][7].

‘‘Smart’’ disposable micro-sensors can be deployed on the ground, in the air, under water, in (or on) human bodies, in vehicles, and inside buildings. Homes, buildings, and locales equipped with this technology are called smart spaces. Wireless sensors can be used where wire-line systems cannot be deployed (e.g., a dangerous location or an area that might be contaminated with toxins or be subject to high temperatures). The rapid deployment, self-organization, and fault-tolerance characteristics of WSNs make them versatile for military command, control, communications, intelligence, surveillance, reconnaissance, and targeting systems [8][9]. Many of these features also make them ideal for national security. Sensor networking is also seen in the context of pervasive computing [6].

The deployment scope for sensing and control networks is poised for significant expansion in the next three to five years as we have already mentioned. This expansion relates not only to science and engineering applications but also to a plethora of ‘‘new’’ consumer applications. Industry players expect that in the near future it will become possible to integrate sensors into commercial products and systems to improve the performance and lifetime of a variety of products. Industry planners also expect that with sensors, one can decrease product life-cycle costs. Consumer applications include, but are not limited to, critical infrastructure protection and security, health care, the environment, energy, food safety, production processing, and quality of life [6][10].

WSNs are also expected to afford consumers a new set of conveniences, including remote-controlled home heating and lighting, personal health diagnosis, automated automobile maintenance telemetry, and automated in-marina boat-engine telemetry, to list just a few. The ultimate expectation is that eventually wireless sensor network technologies will enable consumers to keep track of their belongings, pets, and young children. Ubiquitous high reliability public-safety applications covering a multi-threat management are also on the horizon [6][10].

2.7 Key Issues and Challenges of WSN Designs

To design an efficient algorithm for wireless sensor network, the following issues must be considered:

1. Sensor nodes are battery-operated and most often constrained in their energy due to the inability of recharging the nodes. Hence, one of the most important bottlenecks in the protocol design is the energy consumption. The design should be able to balance network life-time and other heuristics for accuracy of results.

2. Sensor network should be adaptive and sensitive to the dynamic environment where they are deployed.

3. Since nodes are battery-powered and communications are radio-based, nodes are more susceptible to failures. The information collected by individual node should be aggregated to give more accurate and reliable results. Sensor network should be reliable and be able to provide relevant data through information gathering techniques.

4. The hardware design should incorporate methods to conserve energy using low powered processors and the system software should use minimal power as possible.

5. A sensor network algorithm should be distributed and self-organizing since WSN is infrastructure-less.

6. The security of the network should also be considered. An intrusion might defeat the entire purpose of the network system.

7. Scalability is another important factor to be considered when designing a topology for WSN. Some applications might require hundreds or thousands of nodes to monitor a trend intermittently.

8. Sensor network should be able to share communication resources efficiently and support real-time communication while providing a guaranteed quality of service.

All the attributes mentioned above reflects the role and importance of specific layers of the OSI (Open System Interconnection) model in wireless communication, which will be discussed briefly in the next section.

2.8 Literature Review

Sensors are disposed of small batteries that are impossible or impractical to change or recharge, so energy-efficiency is the most important feature of a WSN. In such conditions it is of paramount importance to develop dedicated communication solutions that handle sensor data gathering in an energy-sparing manner, prolonging thus the lifetime of the network.

Communication over a wireless medium, even at short ranges, consumes several orders of magnitude of more energy than processing. This tendency is foreseen not to change in the near future [11]. There are some straightforward ways to decrease the energy used for communication: reducing the amount of data that is transmitted, reducing the number of reporting sensors and/or shortening the communication range. In the following, a short survey on different solutions is presented that build on these ideas.

In [12] propos, proposed cluster based routing algorithm has exploited threshold level based load balancing and role transfer techniques along with multi-assistant cluster heads to cope with the aforementioned power hungry issues. Merger of multi-hop and direct routing has ameliorated the energy utilization efficiency of the protocol.

In [13] a new cluster based routing algorithm, the redundancy properties of the sensor networks are exploited in order to address the traditional problem of load balancing and energy efficiency in the WSNs. The algorithm makes use of the nodes in a sensor network of which area coverage is covered by the neighbors of the nodes and marks them as temporary cluster heads. The algorithm then forms two layers of multi hop communication; The bottom layer which involves intra cluster communication and the top layer which involves inter cluster communication involving the temporary cluster heads.

In [14], the researchers proposed a new power-aware, adaptive, hierarchical and chain based protocol - CCPAR (Clustered Chain based Power Aware Routing) that utilizes the periodic assignments of the cluster head role to different nodes based on the highest residual battery capacity for ensuring the even dissipation of power by all the nodes. Transmission from a single cluster head to the base station in each round and the distribution of the data aggregation workload among all the nodes, save the cluster heads from early exhaustion.

The use of data aggregation also reduces the amount of information to be transmitted to the base station. By chaining the nodes in each cluster and using a separate chain for the cluster heads, CCPAR offers the advantage of small transmit distances for most of the nodes and thus helps them to be operational for a longer period of time by conserving their limited energy (see Figure 2.5) [14].

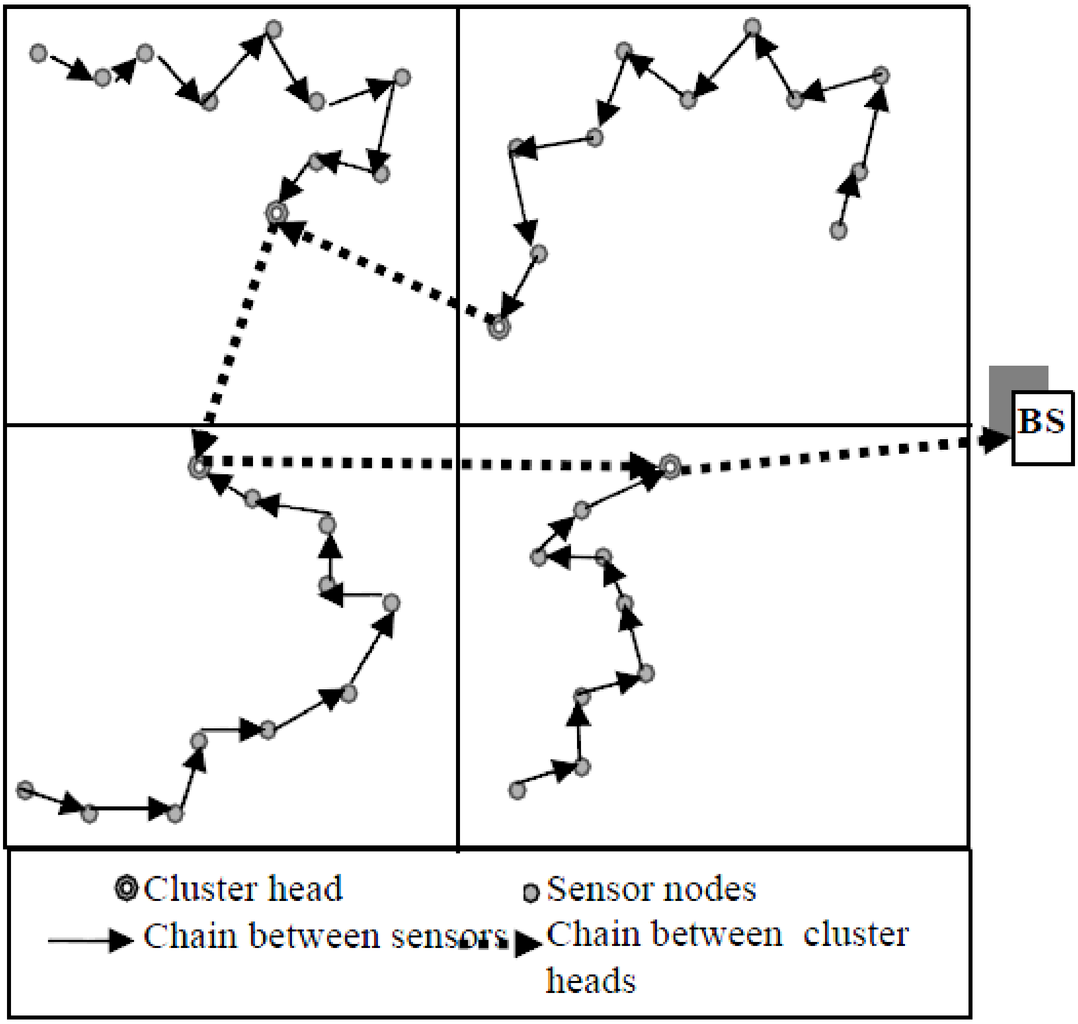

Figure 2.5: Network structure of CCPAR [14]

In the paper [15], the researchers studied energy aware routing protocols. Then they proposed a new energy saver/balancer routing protocol. The base of their study was SEER routing protocol. They simulated and compared the routing protocol with traditional SEER. Results showed that their protocol generally was better than SEER in energy.

Their BEAR protocol had very low failure. It was more balanced than SEER routing protocol especially in high-density networks. In general, they found that BEAR gives better performance compared to SEER. The amount of data to be transmitted can be reduced by dividing the network into small clusters, a cluster head being responsible for aggregating and relaying to the sink the information gathered from the sensors of its clusters [16][17].

In [18], the researchers focus on maximizing network lifetime of a Wireless Sensor Network (WSN) using mobile Data Collectors (DCs) without compromising on the reliability requirements. They consider a heterogeneous WSN which consists of a large number of sensor nodes, a few DCs, and a static Base Station (BS). The sensor nodes are static and are deployed uniformly in the terrain (see Figure 2.6).

The DCs have locomotion capabilities and their movement can be controlled. Each sensor node periodically sends sensed event packets to its nearest DC. The DCs aggregate the event packets received from the sensor nodes and send these aggregate event packets to the static BS. The following problem is addressed: the DCs should send the aggregate event packets to the BS with a given reliability while avoiding the hotspot regions such that the network lifetime is improved [18].

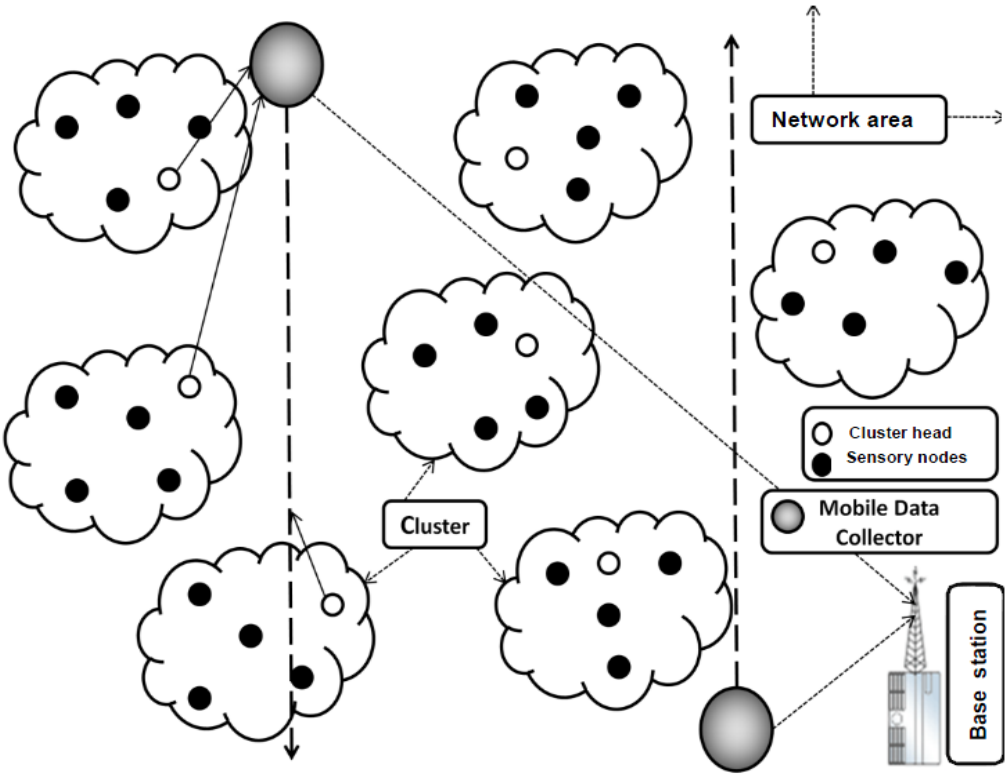

Figure 2.6: Mobile Data Collectors [18]

There are several papers that propose improvements of the basic (LEACH) algorithm. In [19], the researchers introduce an energy factor in the cluster head election process; a candidate that has more residual energy has a higher probability to become cluster head, equilibrating thus energy consumption among the nodes.

In [20], nodes form a chain and send data only to the neighboring node on the chain. The cluster head role is assumed in turns along this chain. The data collected on the chain is aggregated by the CH and sent to the sink. In ASCENT [21] the researchers probe the surrounding environment and look for neighboring cluster heads. Based on the received feedback, they take local decisions whether or not to switch into CH mode.

While in HEED [22], researchers propose a hybrid, distributed clustering approach, where CH nodes are elected based on their residual energy level and secondary parameters such as node proximity to its neighbors or node degree.

Sensors consume energy for sensing the field, for digitizing and processing the data, but the most penalizing task is by far the transmission of the information [23]. In the most commonly accepted power attenuation model [24], signal power falls as 1/da , where (d) is the distance from the transmitter antenna and (a) is the attenuation exponent, a constant dependent on the wireless transmission environment, with values typically between 2 and 5. Therefore, assuming that all receivers have the same power threshold for signal detection, typically normalized to one, the energy required to support communication between two nodes located at a distance d, one from the other is da. In such conditions it is straightforward to assert that by minimizing the distance between a sensor and a sink node we can efficiently reduce power consumption, both for single- and multi-hop communications (reducing the length of the multi-hop path results in fewer and/or shorter hops, i.e., less energy is needed to relay data to the sink) [24].

There is a recent trend to explore mobility as a way of enhancing the networking capabilities of wireless systems. Besides increasing the capacity of ad-hoc wireless networks [5], it was also recognized that mobility can be used to support energy efficient operation of sensor networks. By introducing the mobility of either the sensors or the sink node(s), the communication distance can be reduced. There are some approaches that rely on sensor mobility, not for energy-efficiency but mostly for coverage problems. As an example, in [25] sensors are mobile only at the deployment phase, to eliminate coverage holes discovered through the use of Voronoi diagrams, while in [26], sensors dynamically react to environmental changes and move towards areas where events occur frequently. Mobile sensors are also considered in [27] to provide an extension of a stationary sensor network.

However, using mobile sink nodes to get near the reporting sensors is a more common solution. The approaches based on sink mobility can be classified into three categories: random, predictable and controlled mobility. In [28], randomly moving mobile agents, called Data MULEs (Mobile Ubiquitous LAN Extension) are used to collect data in sparsely populated sensor networks. A similar approach, but for dense networks, is used by SENMA (SEnsor Networks with Mobile Agents) [29]; a mobile agent randomly flies above the sensor field and gathers data from sensors that are triggered based on the estimated fading state of their communication with the agent.

Researchers of [30] use a random walk model for a mobile relay to theoretically derive parameters such as delay and data delivery ratio. Finally, randomly moving sink nodes are also assumed in the SEAD (Scalable Energy-efficient Asynchronous Dissemination) protocol [31], but in a scenario where there is a single sensor to transmit data to all these mobile sinks; the goal of the protocol is to build and maintain an energy-efficient multicast dissemination tree that covers all the interested nodes.

A predictable movement of the sink is also proposed in several papers. In [32], the observer (i.e., the sink) moves along a predefined path, and pulls data from the sensors when it arrives close to them. In [33], the predefined path is the periphery of the covered circular region itself; it should be noted that the researchers assume here multi-hop communication between the sensors and the sink, as opposed to the previous approaches where the sensors have waited for the best moment to send their report directly to the sink.

There are also solutions based on controlled mobility. In AIMMS (Autonomous Intelligent Mobile Micro-server) [34][35] a mobile micro-server moves across the network, along a specific trail, to route data from the deeply embedded nodes. Its mobility is controlled in the sense that it spends extra time (e.g., it stops or slows down) in areas where there is a large amount of data to send, or where the channel capacity requires so. Controlled mobile nodes are used for message ferrying also in [36]; these nodes provide non-random proactive routes in highly-partitioned wireless ad-hoc networks.

An attempt to determine specific sink movements for energy optimization is presented in [37]. The researchers argue that multi-hop communication results in the sensors neighboring the sink being depleted at a fast pace. Therefore, they propose to employ multiple sink nodes that periodically change their locations, and present an ILP (Integer Linear Programming) model to obtain the optimal positions of these sinks. A linear programming solution to determine the movement of the sink and its sojourn time in different points of the network is given in [38] as well.

Both the sensors and the sink are placed on a bi-dimensional grid. The sink moves along the grid, sojourns times in the specific grid points being calculated so as to maximize the network lifetime.

A solution that is significantly different from all the above is presented in [39]. The researchers define an adaptive strategy for sink mobility in an event-driven scenario, so as to continuously move the sink towards an optimal position as far as energy-consumption is concerned, taking into account the current events in the network. Most of the previous solutions addressed time-driven scenarios.

In such cases all the sensors measure and send data periodically to the sink. Therefore, moving the sink node has mainly a load balancing role: in case of multi-hop communication, it would spare near-by nodes that relay packets from all the others, while in case of single-hop communication it would spare far-away nodes that have to spend much energy to reach the sink. As opposed to these, in an event-driven scenario the adaptive mobility of the sink could result in energy saving benefits that reach far-beyond simple load balancing. If not all the sensors are active at a given moment, only those that sensed a specific event, it might worth moving the sink towards those nodes [39].

There are other approaches as well in the literature that addressed the problem of optimal sink placement. In [40], the researchers assume a time-driven scenario, and solve the problem of placing sink nodes so as to optimize energy-consumption. A similar issue is raised in [41]: an algorithm is proposed to find the optimal location of multiple sinks in sparse networks of aggregator points that report directly to these sinks.

Base station (BS) positioning is an effective method for improving the performance of wireless sensor networks (WSNs). A metric-aware optimal BS positioning and relocation mechanism for WSNs is proposed. This technique locates the BS with respect to the available resources and the amount of traffic travelling through the sensor nodes [41].

The BS calculates its own position over time in response to the dynamic environment in which the sensor nodes operate. In most (WSN) environments, communication channel experiences nonlinearity that is influenced by path loss, attenuation of signal as it propagated through space, greater than 2. In this work, the problem of BS positioning in nonlinear environments is solved [41].

In [42], researchers propose a weighted linear or nonlinear least squares optimization depending on the value of the path loss exponent. A distributed algorithm is also proposed which can effectively handle the required computation by exploiting node cooperation. The goal is to minimize the total energy consumption and to prolong lifetime of the WSNs.

The paper from [8] considers nodes which cooperate in data transmission in terms of a *group*. A mobile node may move to a new location, in which it is desirable for the node to join a group. The researchers propose a protocol to allow nodes to choose the best group in their signal range, using coalitional game theory to determine what is beneficial in terms of power consumption. The protocol is formalized as an SOS-style transition system. This formalization forms the basis for an implementation in the rewriting logic tool Maude, so the protocol can be validated using Maude's model exploration facilities. First, they prove the correctness of their proposed protocol, by searching for failures through all possible behaviors for given initial states. For these searches, the grouping is done correctly in all reachable final states of the model. Second, they simulate the model behavior to quantitatively analyze the efficiency of the proposed protocol [8].

Using a mobile instead of a static base station (BS) to reduce or alleviate the non-uniform energy consumption among sensor nodes is an efficient mechanism to prolong the network lifetime. In [9], researchers deal with the problem of prolonging network lifetime in data gathering by employing a mobile BS. To achieve that, they devise a novel clustering-based heuristic algorithm for finding a trajectory of the mobile BS that strikes the trade-off between the traffic load among sensor nodes and the tour time constraint of the mobile BS. They also conduct experiments by simulations to evaluate the performance of their algorithm. The experimental results show that the use of clustering in conjunction with a mobile BS for data gathering can prolong network lifetime significantly [9].

2.9 LEACH Protocol (Low-Energy Adaptive Clustering Hierarchy)

Low-energy adaptive clustering hierarchy (LEACH) is a routing algorithm designed to collect and deliver data to the data sink, typically a base station [2]. The main objectives of LEACH are:

- Extension of the network lifetime
- Reduced energy consumption by each network sensor node
- Use of data aggregation to reduce the number of communication messages

Clustering techniques have been employed to deal with energy management in WSNs.

LEACH is a pioneering work in this respect. LEACH is a clustering-based protocol, that used a randomized election and rotation of local cluster base station (so called `cluster-heads' for transferring data to the BS or sink node), (see figure 2.7), to evenly preserve the energy among the sensors in network. The rotation of cluster-head can also be a means of fault tolerance [43].

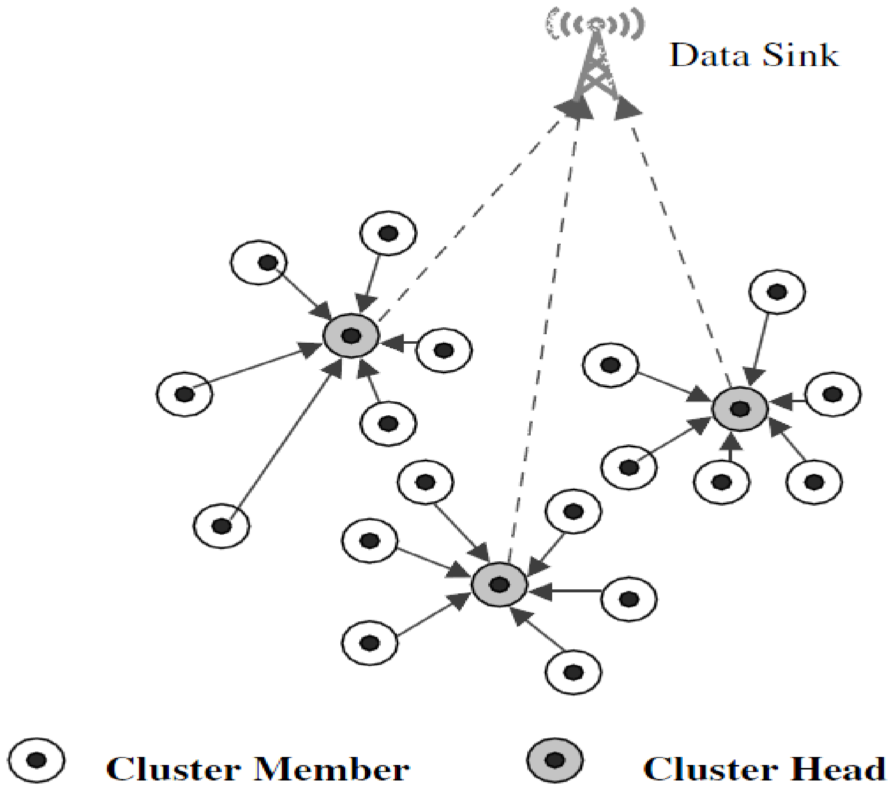

Figure 2.7: LEACH network model.

The sensors organize themselves into clusters using a probabilistic approach to randomly elect themselves as heads in an epoch. However, LEACH protocol is not heterogeneity-aware, in the sense that when there is an energy difference to some threshold between these nodes in the network, the sensors die out faster than a more uniform energy setting [3].

In real life situation, it is difficult for the sensors to maintain their energy uniformly, this results easily in energy imbalance between the sensor nodes. LEACH assumes that the energy usage of each node with respect to the overall energy of the system or network is homogeneous. Although LEACH suggested a way to cope with heterogeneity if it arises; by setting the probability of becoming a cluster-head as a function of the node's energy level, it is relative to the aggregate energy in the network. The fault in this model is that, it requires the assistance of routing protocol, to allow each node to know the total energy of the network; which will increase the overhead of the network [44].

2.9.1 LEACH Architecture

LEACH was developed to monitor remote environment. Since individual nodes' data are often correlated in a micro-sensor network, the end user does not require all the redundant data, rather the end user needs a high-level function of the data that describes the events occurring in the environment [2]. The motivation behind LEACH protocol is to correlate data among nodes that are close to each other by using data aggregation techniques to reduce the amount of raw data, this is mostly done by the elected cluster-head before transmission to the base station.

In LEACH [45] the following assumptions were used for the propagation model of each node:

1. That each node has the capability to transmit with enough power to reach the BS.
2. The nodes can use power control to vary the level of transmission power.
3. Each node has the computational power to support different MAC protocols and performs signal processing functions.

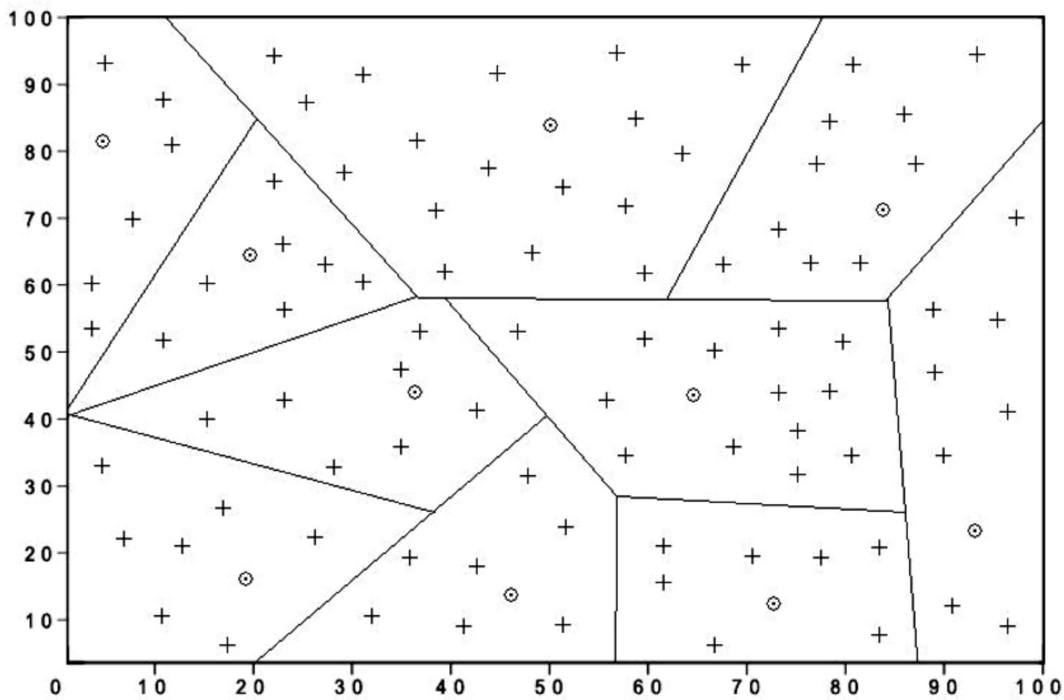

Figure 2.8: Cluster Formation diagram [45]

Figure 2.8 shows the clustering architecture of LEACH, with cluster-heads using a single hop to reach the BS. The " + " is the cluster member, " Θ " is the cluster-heads and the BS is assumed to be located outside the sensing field. The non-cluster heads send their data periodically using a time division multiple access (TDMA) schedule to the elected cluster-heads, the cluster-head in-turn performs some data compression and aggregates the data before sending to the BS.

However, being a cluster-head node consumes so much energy than a non-cluster head, hence the need for randomized rotation of the cluster-heads by LEACH. If the cluster-heads were to be fixed throughout the network life-time of the system, there would be a huge waste in residual energy of the live nodes.

Since the cluster-heads would definitely die out first, LEACH protocol has two phases, the set-up phase and the steady phase (see figure 2.9). In the set-up phase, clusters are formed, then followed by a steady state where cluster members send data to their cluster-heads and then to the BS. A completed set-up and steady-phase makes up a round; and a series of rounds constitute an epoch [3].

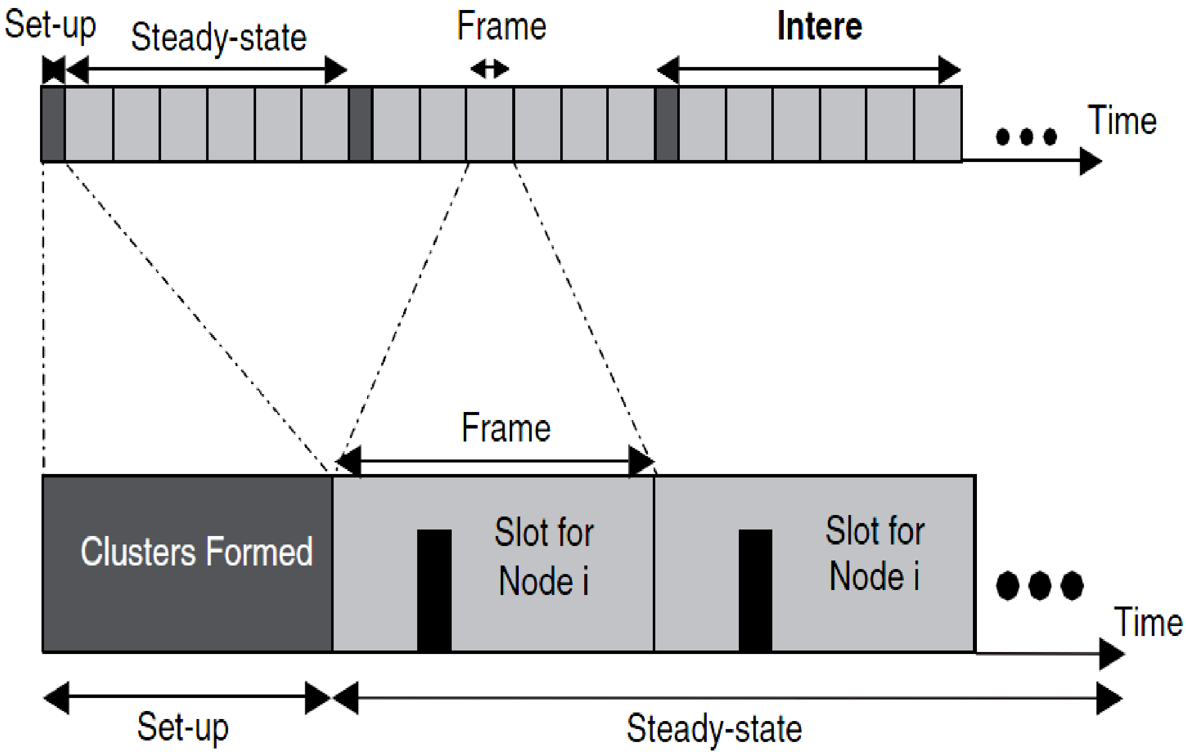

Figure 2.9 : LEACH phases [3]

2.9.2 Cluster Formation Process of LEACH

The set-up phase begins with cluster formation. If there are N nodes in the network, in order to ensure certain number of cluster, *kc* is formed during each round,

each sensor *i* elects itself at the beginning of the round with a probability *Pi(t)* chosen in such a way that the expected number of cluster head nodes for this round is *kc* [2].

$$E[\#CH] = \sum_{i=1}^{n} Pi(t) * 1 \ = \ kc. \qquad (2.1)$$

An indicator function $C_i(t)$ is defined so that $C_i(t) = 0$ if the sensor i is a cluster-head, otherwise $C_i(t) = 1$. A node chooses to become cluster-head in a given round r, if the probability function below is satisfied:

$$P_i(t) = \begin{cases} \frac{k_c}{N - k_c * [r \mod (N/k_c)]} & \text{if } C_i(t) = 1; \\ 0 & \text{if } C_i(t) = 0. \end{cases} \tag{2.2}$$

From [1], the choice of probability is based on the assumption that every node has the same level of energy at the beginning of the network and also each node has data to send in each round. The flowchart of LEACH algorithm is presented in figure 2.10. To complete the set-up phase, each node sends a join-request message after they receive a broadcast from the elected cluster-heads using a non-persistent CSMA MAC protocol.

The cluster-head creates a TDMA as shown in the LEACH flow chart and finally the nodes forming each cluster wait for their schedule before transmission. The steady phase starts immediately after the set-up phase. The cluster-heads gather all data from their respective cluster members. The cluster-heads performs data aggregation using signal processing techniques before sending the refined data to the BS in each round [45].

The idea of the TDMA schedule ensures the efficient use of the bandwidth and the data aggregation process reduces communication cost and energy, thus, improving the network life-time. The sections that follow discuss variants to LEACH protocol that were proposed as an improvement by extending the network life-time. Most of these schemes are more of energy management techniques rather than cost-based models.

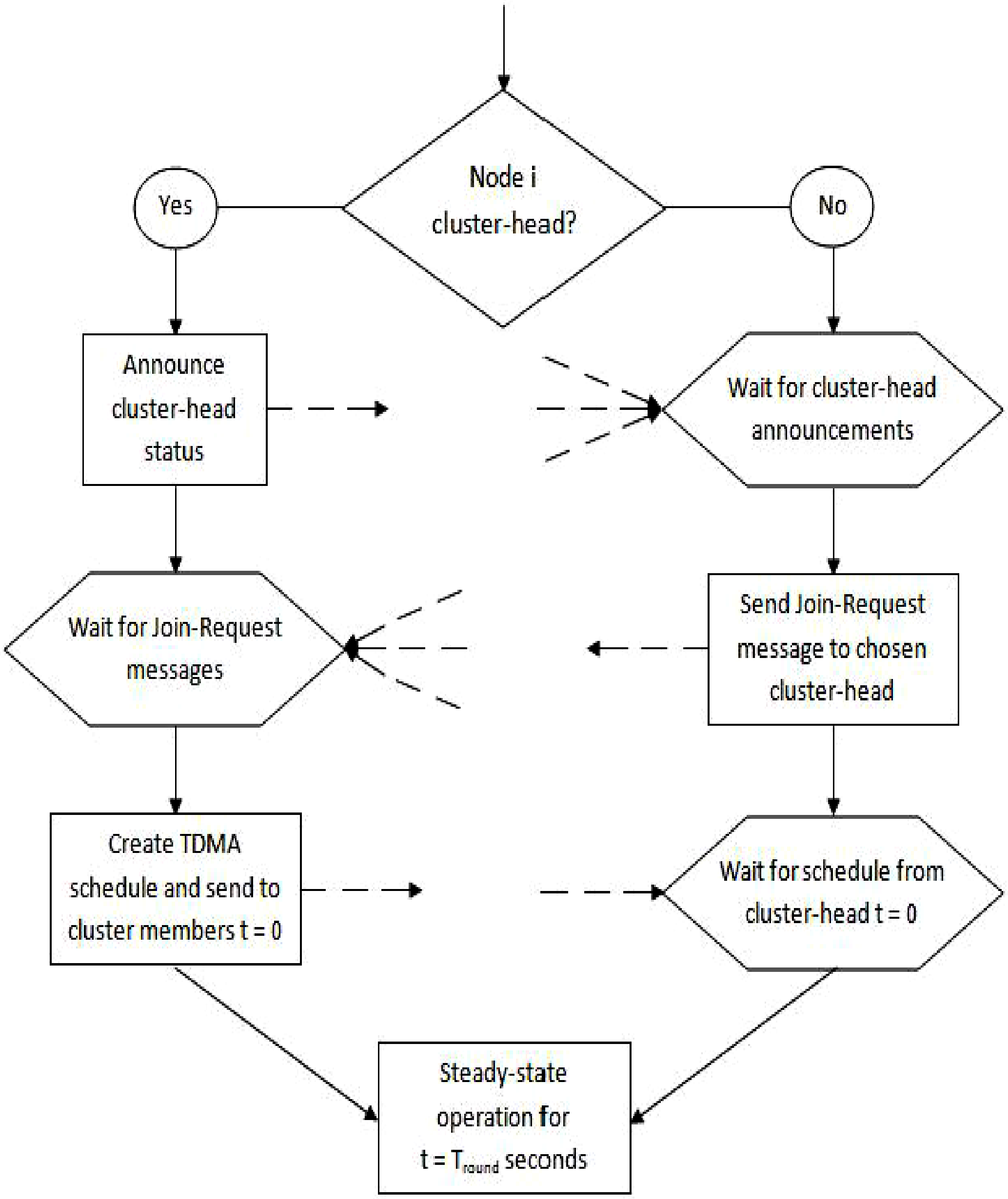

Figure 2.10: LEACH Flow Chart diagram [45]

2.10 MAC protocol for WSNs

The need to conserve energy is the most critical issue in the design of scalable and stable MAC layer protocols for WSNs. Several factors contribute to energy waste, including excessive overhead, idle listening, packet collisions, and overhearing. Regulating access to the media requires the exchange of control and synchronization information among the competing nodes. The explicit exchange of a large number of these control and synchronization packets may result in significant energy consumption. Long periods of idle listening may also increase energy consumption and decrease network throughput. In some cases, energy wasted by idle listening accounts for over a half of the total energy consumed by a sensor during its lifetime. The retransmission of colliding packets is yet another source of significant energy waste [46].

There is a specific kind of MAC protocol that is specially designated for wireless sensors networks which is called SMAC. The SMAC operates the sensor's node at cycle with low duty which commands the sensors to sleep periodically that will save more power. The protocols that use a fixed duty over all running time aren't energy efficient. This also minimizes the traffic load and saves the power of the sensor with low traffic. And this is much more reliable than other protocols such as 802.11 [46].

Chapter 3

ENERGY-EFFICIENT CLUSTERING FOR WIRELESS SENSOR NETWORKS WITH MOBILE BASE STATION (ECMBS)

This chapter presents the network model and cluster formation process for WSNs that are hierarchically clustered. The path loss model, data aggregation model and the expression for the energy expended are also discussed. The description of the experiments done and analysis of the proposed enhancement to LEACH is presented thereafter.

3.1 Introduction

The network model described in this section is similar to the one proposed in LEACH and other clustering protocols. The same path loss models, for communication from cluster members to cluster-heads and from cluster-heads to BS are briefly enumerated. The intra-cluster and inter-cluster transmission distance is estimated for each node and the energy model is formulated, as used in [2].

3.2 Proposed Algorithm

Our proposed algorithm is Energy-Efficient Clustering for Wireless Sensor Networks with Mobile Base Station (ECMBS). This theory can be applied in places inaccessible or impossible for human to reached Such as volcanoes and rugged mountains, or even this theory can be used for early detection of forest fires. The mobile base station is moved through the field in a horizontal manner with a speed 10 m/s in the middle of the field. The base station could be placed on a telefreak that could aggregate information or data packets from the cluster head. For wireless sensor network algorithm applying a systematic control on the number and size of clusters has been a challenge which requires using energy efficient and load balanced clustering algorithms in the network. The dynamic nature of the problem due to the frequent changes of cluster head (*CHs*) in each round complicates the problem. Finding the best routing for optimum energy consumptions of cluster heads is very important in these hierarchical algorithms.

In our (ECMBS) algorithm, selecting the *CHs* and Clustering are performed on the base is of LEACH as discussed earlier. The network gets ready to operate for *T* rounds while *P* percent of all sensor nodes are supposed to be selected in each round as *CHs* to send their data to the BS. Making the BS mobile and choosing the highest energy for electing *CH* is determined so that the energy consumed by CHs through multi-hop communications is minimized.

A routing algorithm is considered for a wireless sensor network in which the BS position is mobile. The nodes are organized into clusters. After the cluster formation, the BS broadcasts message about its location and path to all *CHs* and nodes in the field. Each *CH* calculate the optimal distance for data communications in the current round. The process is performed by exchanging some information between *CHs*, and each *CH* makes the final dissection (calculate minimum distance d_{min}) and the decision is made either sending its data to the BS directly or to the closest *CH* to the BS. Thus, routing protocol with optimum distance will be more efficient because cluster-head at the corner of the network have to transmit to next cluster-head towards Base station while in LEACH cluster-heads have to transmit directly to Base station at longer distance. That will result into poor signal strength and less successful data transmission.

Finally all *CHs* adjust their transmission power. Then, the BS starts moving across the path from an initial point and collects the gathered data from *CHs* and then returns back to the beginning after passing all *CH*s and the field (see Figure 3.1 for ECMBS flow chart).

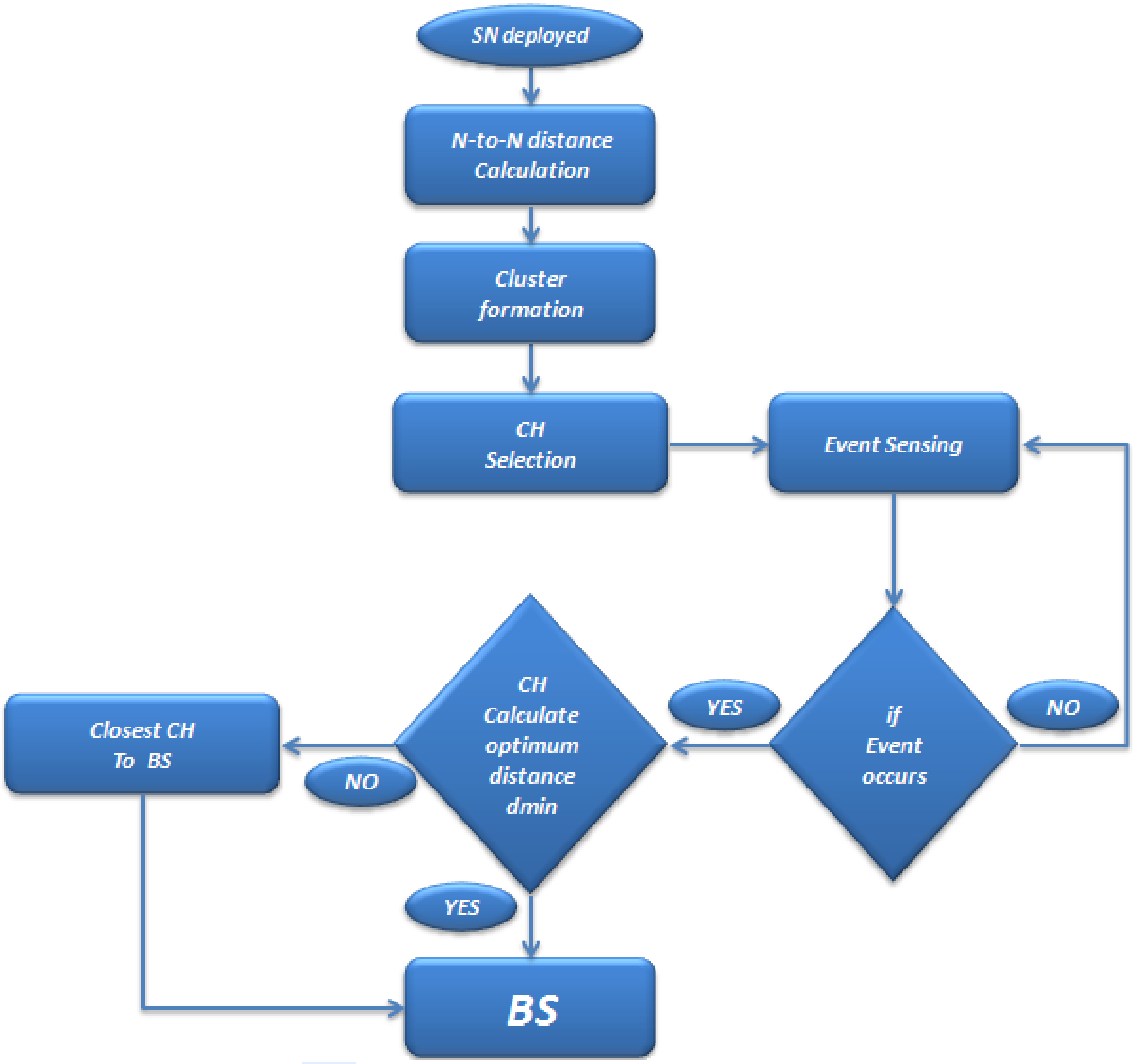

Figure 3.1: ECMBS Flow Chart

d_{min} depends on the energy consumption of the *CH*, E_{CH} for the current round.

$$d_{min} \ \alpha \ E_{CH} \tag{3.1}$$

The question is that how does it make sense? If E_{res} denotes the residual energy of the node to be spent in the current round, *r* and future remaining rounds, *T*-*r*. E_{CH} and E_{CM} denote energy consumption of a node when it is a *CH* and the energy consumption of that node when it is a cluster member (*CM*) respectively. Thus, the node is supposed to use this energy as a *CH* for *A* rounds and as a *CM* for *B* rounds:

$$E_{res} = A.E_{CH} + B \,.\, E_{CM}$$

where

$$A = T \,.\, P - \lfloor r \,.\, p \rfloor$$

$$B = T - R - A \tag{3.2}$$

The approximate energy consumption of the node acting as a CH in the current round would be:

$$E_{CH} = \frac{E_{res} - B \,.\, E_{cm}}{A} \tag{3.3}$$

On the other hand, E_{CH} is the total consumed energy for receiving packets from *n* number of *CMs* plus the energy required for transmission a packet to BS:

$$E_{CH} = nE_{rx} + E_{tx} \tag{3.4}$$

Where E_{tx} and E_{rx} are the consumed energy for sending an l bit packet to distance d_{min} and receiving an l bit packet respectively:

$$Etx = lE_{elec} + l\,\varepsilon d^{\beta}_{min}$$

$$E_{rx} = lE_{elec} \tag{3.5}$$

Where the E_{elec} is the energy required for running the electronic circuits. ε and β are the parameter which depend on the noise figure, channel's characteristics and the required *SNR* for proper signal detection at the receiver. By inserting 5 into 4, d_{min} can be easily determined as:

$$d_{min} = \sqrt[\beta]{\frac{E_{CH} - nl\,E_{elec} - lE_{elec}}{l\varepsilon}} \tag{3.6}$$

3.3 Cluster Formation

In our protocol ECMBS, data gathering in a mobile BS is considered by adopting a clustering-based approach. To reduce the energy consumption of a cluster head to forward sensing data, the mobile BS roams the sensing field and visits only the cluster heads to gather sensing data.

The proposed algorithm ECMBS used a hierarchical approach to organize nodes into clusters. Within each cluster, nodes take turns to assume the role of a cluster head. Therefore, the distribution of the cluster heads in the entire network affects the load balance among the sensor nodes and hence the network lifetime.

This section presents a cluster formation method that used a distributed algorithm as in [2]. The main idea is for the sensor nodes to elect themselves with respect to their energy levels autonomously. The goal is to minimize communication cost and maximize network resources in order to ensure concise information is sent to the sink or BS. Each node transmits data to the closest cluster-head and this cluster-heads perform data aggregation [2].

The indicator function of choosing a cluster-head is:

$$T(n) = \begin{cases} \frac{P_{opt}}{1-P_{opt}[r \ mod(1/P_{opt})]} & \text{if } n \in G; \\ 0 & \text{otherwise.} \end{cases} \quad (3.7)$$

Assuming an optimal number of clusters in each round, it is expected that as a cluster-head, more energy will be expended than being a cluster member. Each node can become a cluster-head with a probability P_{opt} and every node must become cluster-head once every $\frac{1}{P_{opt}}$ rounds. Intuitively, it means we have nP_{opt} clusters and cluster-heads per round. The non-elected nodes should be a member of set G in the past $\frac{1}{P_{opt}}$ rounds. Each sensor chooses a random number between 0 and 1. If this is lower than the threshold for node n; T(n), the sensor node becomes a cluster-head [2].

3.4 Data Aggregation Model

The most commonly used data aggregation protocols assumes a perfect aggregation in which multiple packets are sent from all cluster members to their respective cluster-head but only a single packet is forwarded to the BS. By definition, data aggregation is referred to as gathering of multiple data packets by using spatial correlation to reduce the received data into a single packet. Thus, in the context of the experiments performed in this thesis, a perfect data aggregation model is assumed as used in LEACH [2].

ECMBS used TDMA to achieve communication between nodes and their cluster head. The cluster head forwards to the base station messages received from its cluster nodes. The cluster head node sets up a TDMA schedule and transmits this schedule to all nodes in its cluster. The schedule prevents collisions among data messages.

Furthermore, the schedule can be used by the nodes to determine the time slots during which they must be active. This allows each cluster node, except for the head cluster, to turn off their radio components until its allocated time slots.

ECMBS assumes that cluster nodes start the cluster setup phase at the same time and remain synchronized thereafter. One possible mechanism to achieve synchronization is to have the base station send out synchronization pulses to the all the nodes. To reduce inter-cluster interference, ECMBS uses a transmitter-based code assignment scheme. Communications between a node and its cluster head are achieved using direct-sequence spread spectrum (DSSS), whereby each cluster is assigned a unique spreading code, which is used by all nodes in the cluster to transmit their data to the cluster head. Spreading codes are assigned to cluster heads on a first-in, first-served basis, starting with the first cluster head to announce its position, followed by subsequent cluster heads.

Nodes are also required to adjust their transmit powers to reduce interference with nearby clusters. Upon receiving data packets from its cluster nodes, the cluster head aggregates the data before sending them to the base station. The communication between a cluster head and a base station is achieved using fixed spreading code and CSMA. Before transmitting data to the base station, the cluster head must sense the channel to ensure that no other cluster head is currently transmitting data using the base station spreading code. If the channel is sensed busy, the cluster head delays the data transmission until the channel becomes idle. When this event occurs, the cluster head sends the data using the base station spreading code.

In general, schedule-based protocols are contention-free, and as such, they eliminate energy waste caused by collisions. Furthermore, sensor nodes need only turn their radios on during those slots where data are to be transmitted or received. In all other slots, the sensor node can turn off its radio, thereby avoiding overhearing. This results in low-duty-cycle node operations, which may extend the network lifetime significantly. Schedule-based MAC protocols have several disadvantages, however, which limit their use in WSNs.

The use of TDMA requires the organization of nodes into clusters. This hierarchical structure often restricts nodes to communicate only with their cluster head. Consequently, peer-to-peer communication cannot be supported directly, unless nodes are required to listen during all time slots. Most of the schedule-based schemes depend on distributed, fine-grained time synchronization to align slot boundaries. Achieving time synchronization among distributed sensor nodes is difficult and costly, especially in energy-constrained wireless networks. Schedule-based schemes also require additional mechanisms such as FDMA or CDMA to overcome inter-cluster communications and interference.

Finally, TDMA-based MAC-layer protocols have limited scalability and are not easily adaptable to node mobility and changes in network traffic and topology. As nodes join or leave a cluster, the frame length as well as the slot assignment must be adjusted. Frequent changes may be expensive or slow to take effect.

3.5 Energy Model for Data Transmission and Network Model

In recent years, a number of research has been done into low-energy propagation radio models. ECMBS based LEACH routing protocol employs a simple First Order Radio Model as shown in Figure 3.2, where the transmitter and receiver dissipate E_{elec} 50 nj/bit and transmit amplifier circuit ϵ_{amp} 100 pj/bit/m^2 (see Table 3.1) [2].

Table 3.1: Radio characteristics [2]

Operation	Energy Dissipated
Transmitter Electronics ($E_{Tx-elec}$) Receiver Electronics ($E_{Rx-elec}$) ($E_{Tx-elec} = E_{Rx-elec} = E_{elec}$)	50 nJ/bit
Transmit Amplifier (ϵ_{amp})	100 pJ/bit/m^2

The current state-of-the-art in radio design, the First Order Radio Model parameters are slightly better than the other models. If r^2 is energy loss within channel transmission, when a k-bit message is sent at a distance d by the help of radio model, the transmission end calculations are in equations 1 and 2 .[2].

Radio expends:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k;d)$$

$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2 \qquad (3.8)$$

And to receive this message, the radio expends:

$$E_{Rx}(k) = E_{Rx-elec} * (k)$$

$$E_{Rx}(k) = E_{elec} * k \qquad (3.9)$$

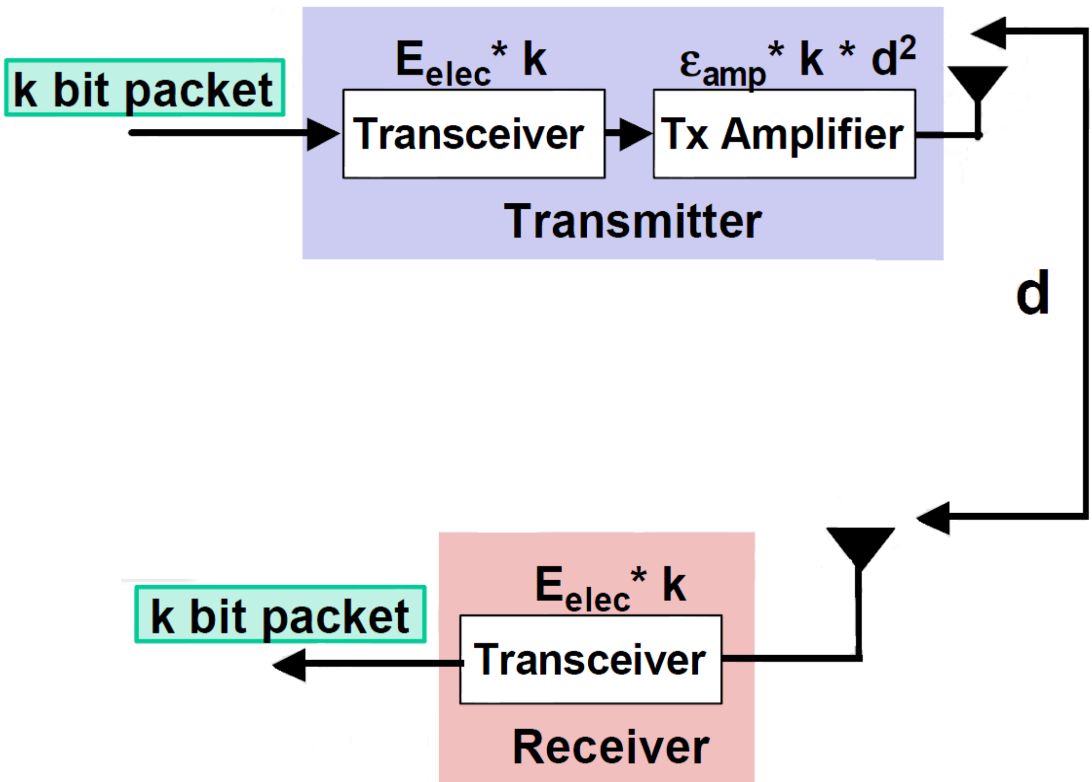

Figure 3.2: First order radio model diagram

3.7 Evaluation Cluster Head Communication

In this section an improvement of ECMBS protocol is presented in two different forms, first by considering a multi-hop system of communication using a concentric circle of radius *R* among cluster-heads, and secondly, by using a dual-communication between two types of cluster-heads with the same initial energy. In LEACH, each cluster-head communicates directly with the BS. This approach proves to consume more energy as cluster-heads farther away from the BS, it will use more energy to transmit their data to the BS since the energy expended is a function of the distance.

The proposition is the same as LEACH in terms of the probability model of choosing cluster-heads but differs in terms of communication modes. According to [2], the set-up phase begins when all sensor nodes elect cluster-heads among themselves with a probability indicator function and announce their status. The rest of the non-cluster heads wait for the announcements and send a join-request message to the chosen cluster-head that is the closest in terms of communication energy estimated by the distance required to reach it.

The cluster-heads wait for join-request messages and then creates a TDMA schedule before sending the schedule to the cluster members. When the cluster members receive this schedule, the steady state operation of data transmission begins. However, they proposed a multi-hop system among all nodes at a fixed power level. Data exchanged between sensors is not within each other's radio range. It is forwarded by other sensors in the network regardless of whether a node is a cluster-head or a cluster member.

This thesis, on the other hand, uses a similar approach, except it considers a dual-hop and a multi-hop system between elected cluster-heads to transmit data to the BS. In both cases, the following assumptions were made:

1. All sensors can transmit enough power to reach the BS if needed, and the nodes can vary their transmission power.

2. Each node possesses enough computational power to perform various signal processing duties and supports different MAC protocols.

3. The model used assumes that the nodes always have data to send to the end user throughout the network operation. The sensors are randomly distributed according to distribution in a 2-dimensional space.

4. All sensor nodes have equal energy at the beginning of the network operation.

5. Finally, the BS is assumed to have wide transmission range cover, hence it can use a single broadcast to reach all the sensor nodes.

Chapter 4

PERFORMANCE STUDY OF ECMBS

Chapter 3 presented a discussion of the ECMBS, which is Energy-Efficient Clustering for WSNs with Mobile Base Station. This chapter presents the evaluation of the ECMBS simulation by using the MATLAB Programming Language to show its advantages.

The ECMBS algorithm is evaluated based on the LEACH protocol and it is compared with it. The simulation results show a considerable advantage of the ECMBS over the LEACH protocol energy saving schemes. Simulation is the modeling of a system over time, with state variables changing instantly at separate points in time. Simulation is used for two purposes: in the design of a new system in order to check design variants before implementation and in the analysis of an existing system in order to investigate different models of operation outside the real system.

During simulation, the parameters are varied and the behavior of the system is studied over time. The main advantage of the simulation is that no expensive resources are required since a system can be tested under different environments without building it.

However, the main disadvantage of the simulation is that it requires a lot of computing time. A right decision should be made during the selection of the right simulation program. There are many types of simulation languages, general programming language and special-purpose simulation language. General programming language like; C++, Fortran, and MTLAB, etc. The most important advantage of this language is the availability of this language. If someone already knew the language, simulation would finish fast.

4.1 Simulation Settings

The simulation program works as follows:

Assuming a 100m * 100m region of 100 sensor nodes scattered randomly for the purpose of testing, MATLAB is used to implement the simulation to have a fair comparison with the LEACH.

Simulations were ran by using the random 100-node network as shown in Figure 4.1 and had each sensor sends a 2000-bit data packet to the base station during each time step or “round” of the simulation, with each node initially given 0.5 J of energy.

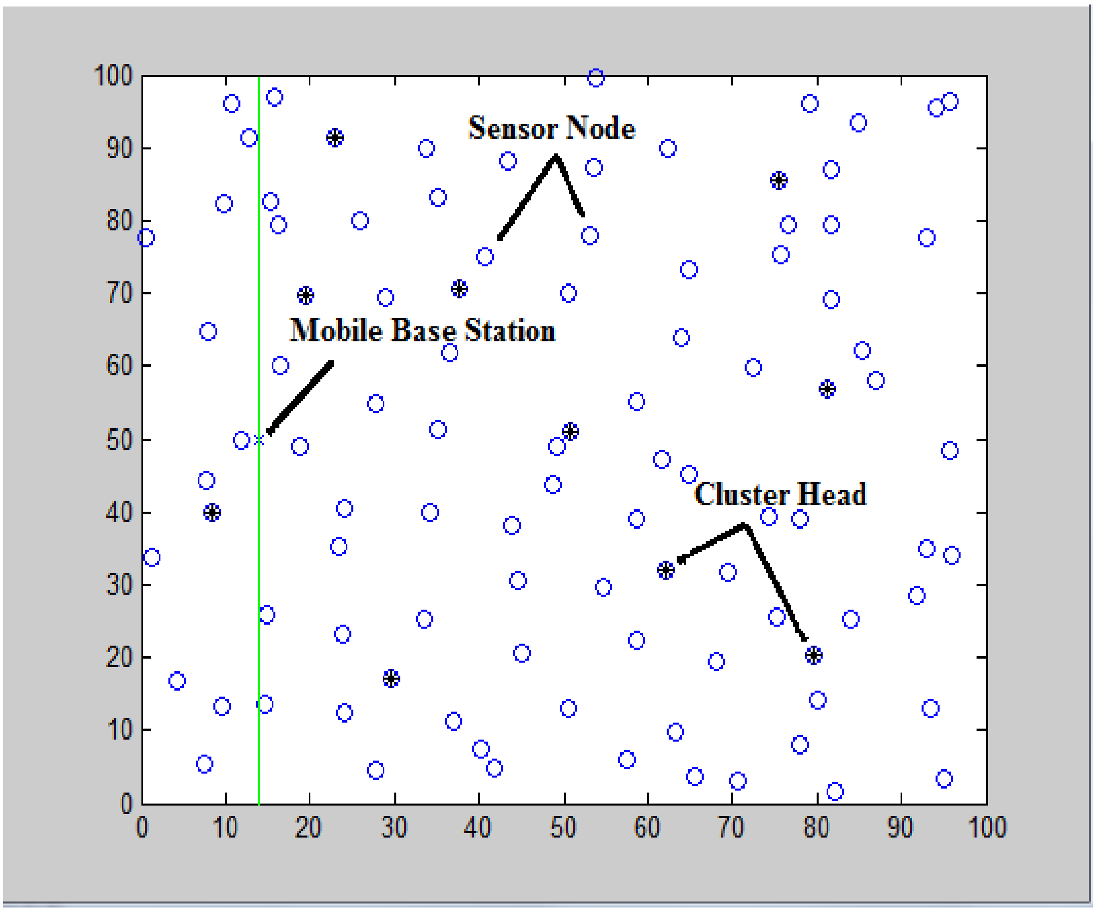

Figure 4.1: simulation area 100m * 100m

After the energy dissipated in a given node reached a set threshold, that node was considered dead for the remainder of the simulation. Let us introduce advanced and intermediate nodes with the same energy levels as in the ECMBS protocol. Table 4.1 below illustrated the assumed parameters that have been implemented in simulation for the testing purpose.

Table 4.1: Simulation parameters

Parameter	***Values***
Transmission electronics ($E_{TX\text{-}elec}$) ***Receiver electronics (E_{RXelec})***	***50nJ/bit***
Data Aggregation ***Energy cost E_{DA}***	***5nJ/bit/message***
Node energy E_o	***0.5J***
Packet size k	***2000 bit***
Probability P_{opt}	***0.1***
Transmit Amplifier *Єmp*	***0.0013pJ/bit/m^4***
No # of wireless sensors	***100***
Simulation area	***1km^2***
BS location	***Mobile***
BS speed	***10 m/s***

The parameters are selected in order to make the comparison between our ECMBS protocol and the original LEACH protocols more meaningful. The initial energy of each node has been set to $E=0.5J$ (equal to one AA battery). The radio characteristics used in our simulations for both transmission electronics ($E_{TX\text{-}elec}$) and receiver electronics (E_{RXelec}) is *50nJ/bit*.

Where the size of the message that nodes send to their cluster heads as well as the size of the message that a cluster head sends to the sink is set to 2000 bits. Each node can become a cluster-head with a probability $p = 0.1$ and every node must become cluster-head once every $1/p$ rounds. Intuitively, it means we have nP clusters and cluster-heads per round. The speed of the base station movement is 10 m/s and it is moved in a horizontal manner through the field.

Thus, the new modifications, improvements, and optimization – especially in energy – are clearer in the figures. The next trends and figures illustrated the energy scope and performance. The energy consumption will be shown in next Figures that show how the energy is being consumed. The dead node trends show the node activity until it died. The overall nodes death displays the performance of the network optimization.

The general ECMBS simulation steps will be as shown in flow-chart as shown in Figure 4.2

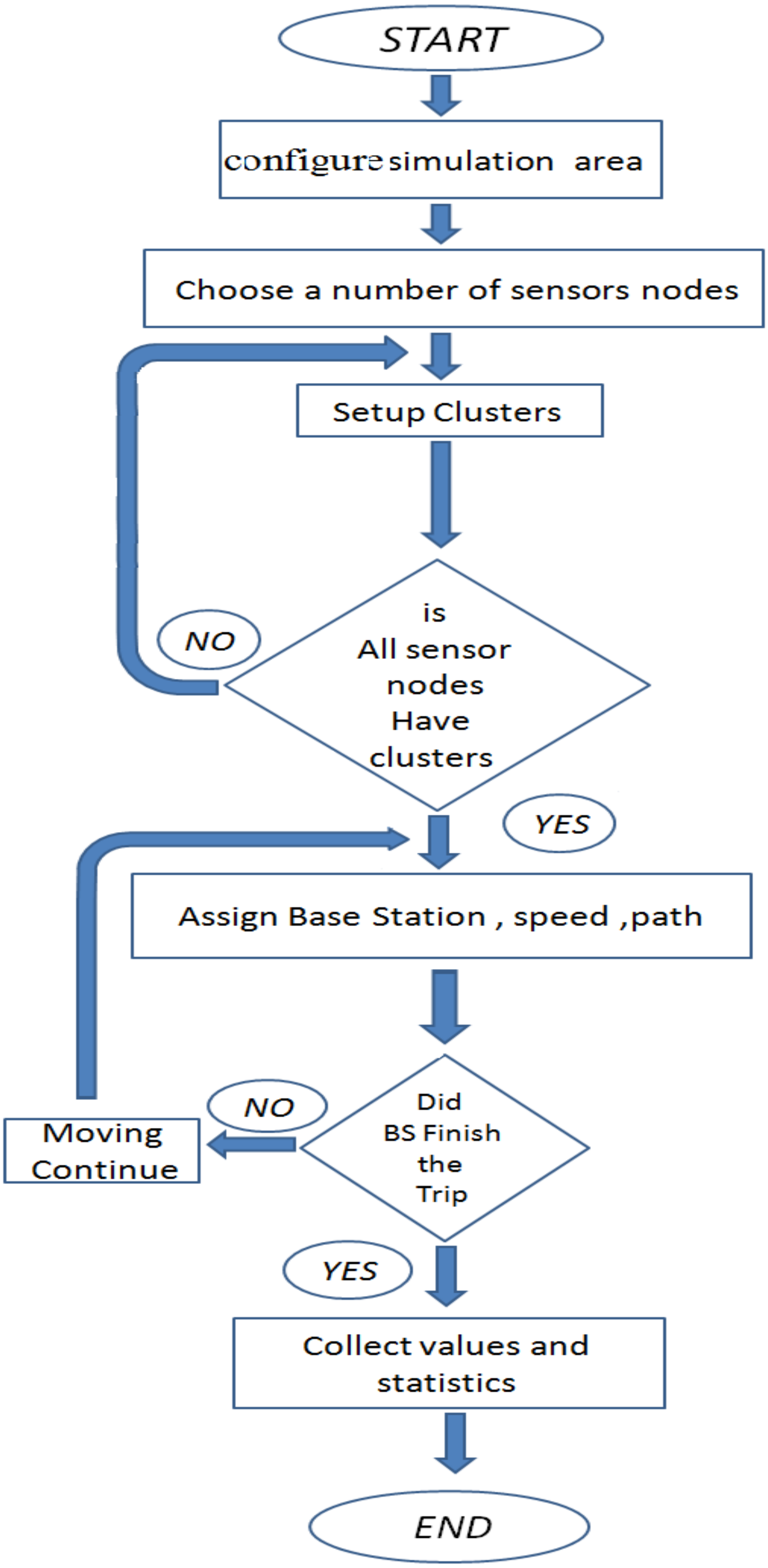

Figure 4.2: ECMBS Flow-chart simulation

4.2 Experimental Result

From the Figures below, it’s easy and clear to see that the contributed Energy-Efficient Clustering Algorithm “ECMBS” comprises the minimized power consumption via time unit. So, the backup power of the sensors will be saved for longer time.

The simulation results are provided of the proposed algorithm performed in which the BS is mobile in MATLAB environment and compared with the results of the LEACH algorithm. Comparison is done in the number of alive nodes, energy of the network and the number of received packets to the BS. Simulation parameters are listed above in previous table 4.1. In addition, a free space model with $\beta = 2$ is assumed for communication channel. It is assumed that clustering is performed in each round and the data of every node is gathered by *CHs* and sent to the mobile BS.

In Figure 4.3, the number of alive nodes during the network lifetime for the suggested algorithm is depicted. Compared with the LEACH protocol, the proposed algorithm has prolonged the First Node dying time, which is when the first node runs out of energy in the network. This shows the balance in energy consumption.

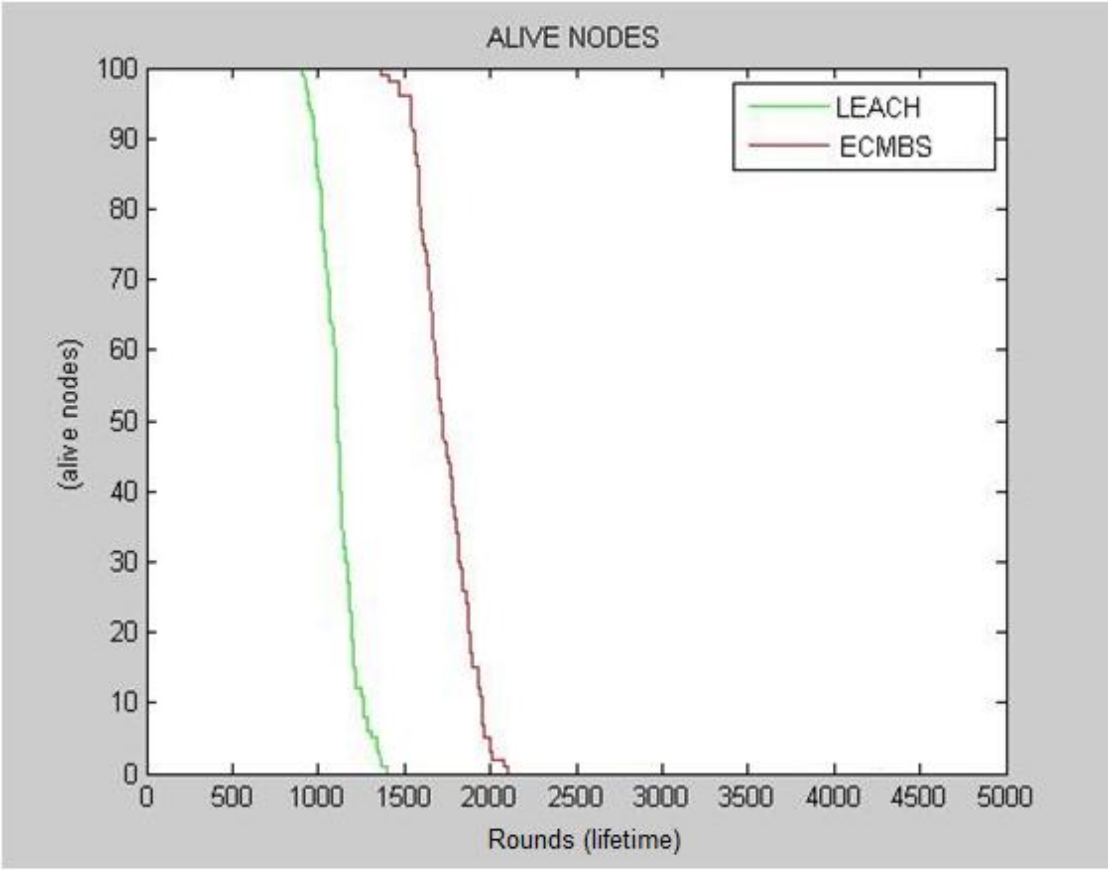

Figure 4.3: Number of alive nodes versus lifetime

This figure illustrates the effective mobility of the base station on life time of the network. It can be seen in Figure 4.3 that network lifetime has increased significantly in the mobile schemes as compared to the static base station of the LEACH. This happens because the sensor node spends less energy in transmitting data to the mobile base station which is closer to them as compared to the static BS and therefore they live much longer than the node in static BS network.

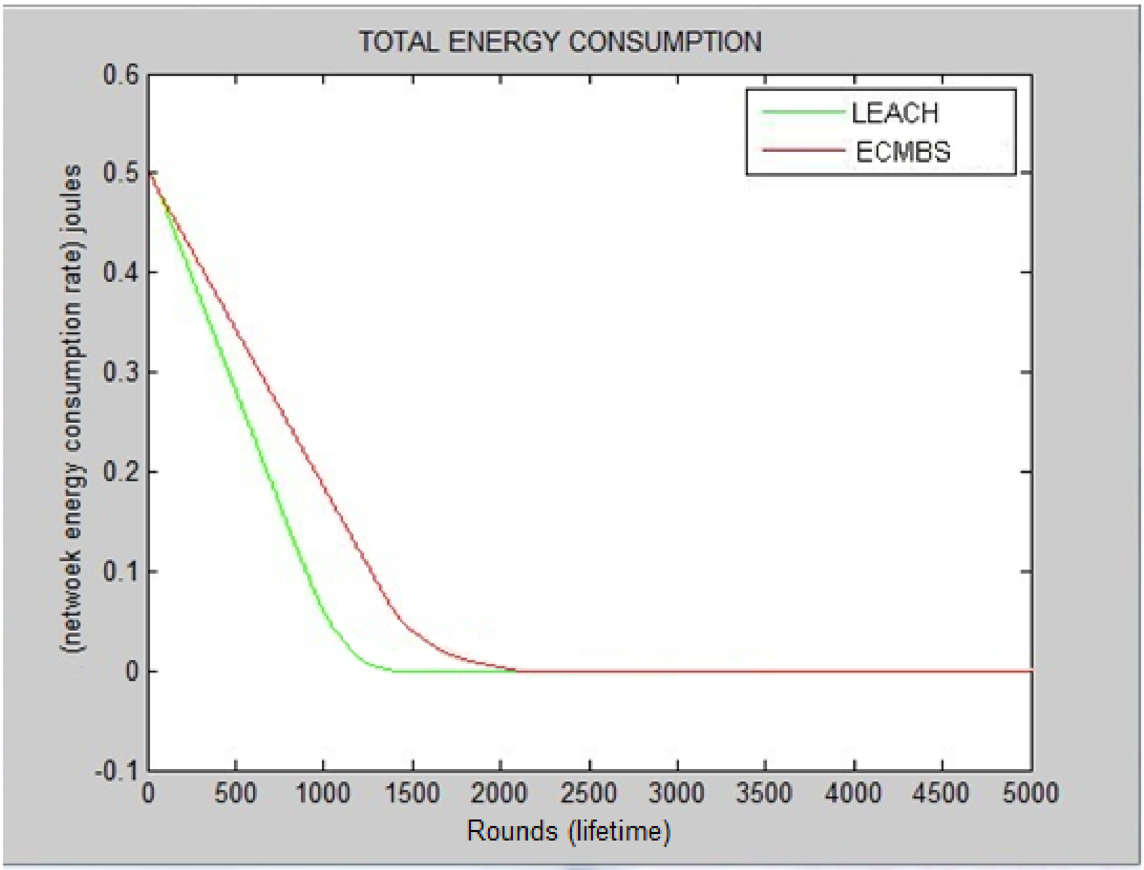

Figure 4.4: shows the comparison of energy consumption
rate in theses algorithm in 5000 rounds.

Figure 4.4 depicts overall network energy consumption for a network with mobile base station compared to network with static base station like the LEACH protocol. We can see that the energy consumption has significantly decreased for BS that are mobile.

The total running time of the network results are displayed in Figure 4.5. From the Figure, it’s clear that, the nodes using the ECMBS algorithm are running for more number of cycles than LEACH.

So, it can be seen that ECMBS system minimizes the death nodes interval, reduces the power consumption, saves more energy and prolongs the lifetime of the nodes.

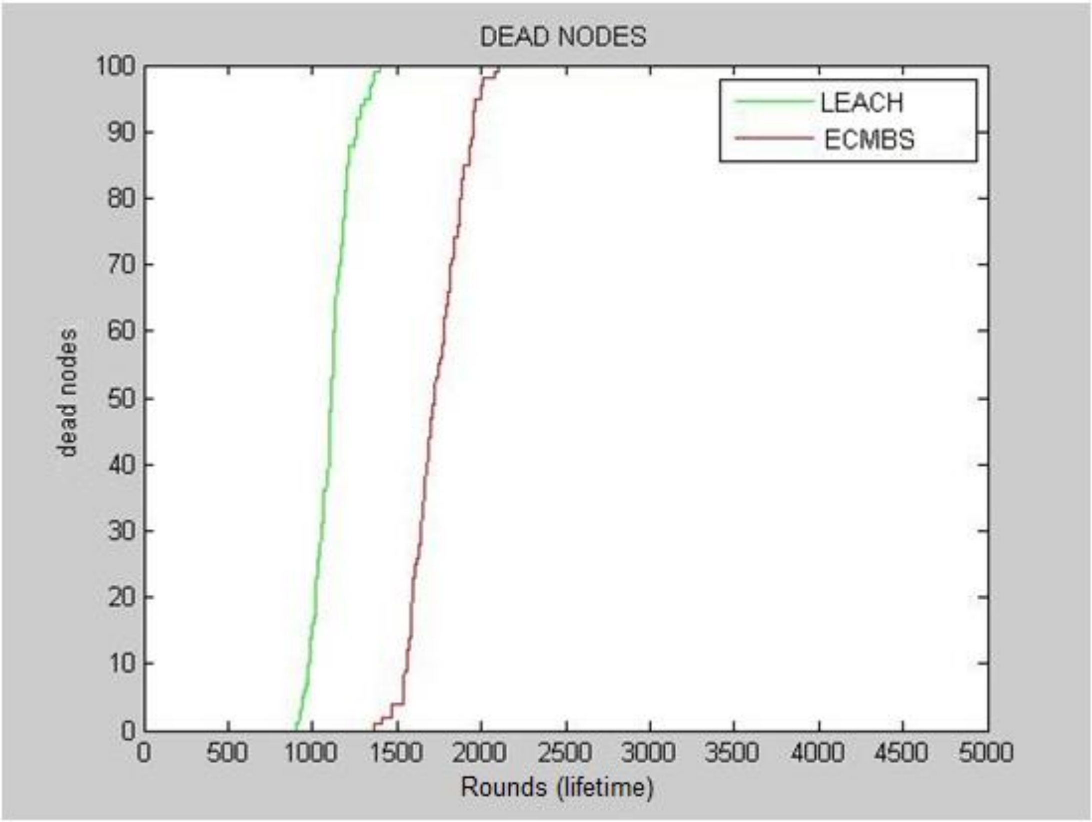

Figure 4.5: Dead Nodes over rounds

Figure 4.6 depicts the percentage of exhausted node with mobile BS with increasing number of packets received or delivered simultaneously to the BS.

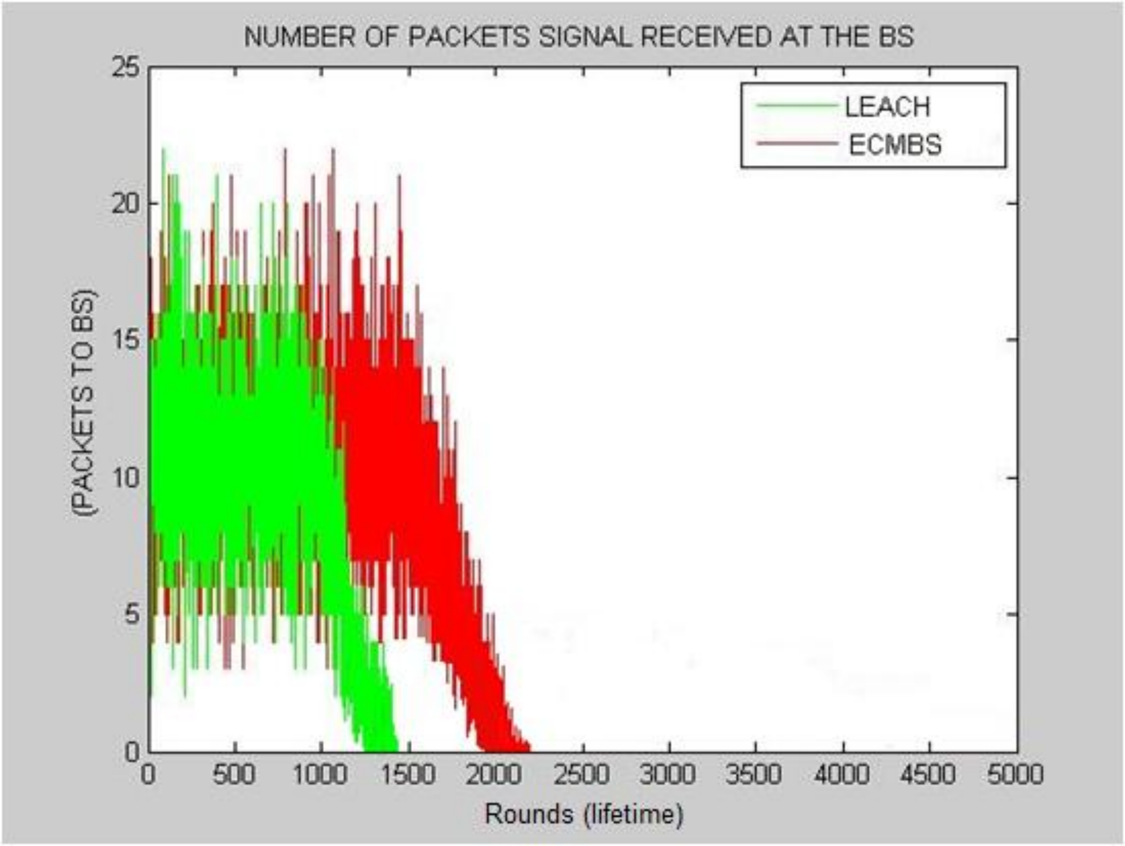

Figure 4.6: Received packets to the BS.

This figure shows that the percentage of packets received to the BS is consistently much lower in case of the LEACH protocol. This observation conforms with the earlier discussion that decreasing the distance between the cluster head and the BS, the cluster head has to relay data packets for much shorter distance than before by reducing the energy consumption per delivered packets. Therefore, energy of the sensor is conserved for a longer period of time.

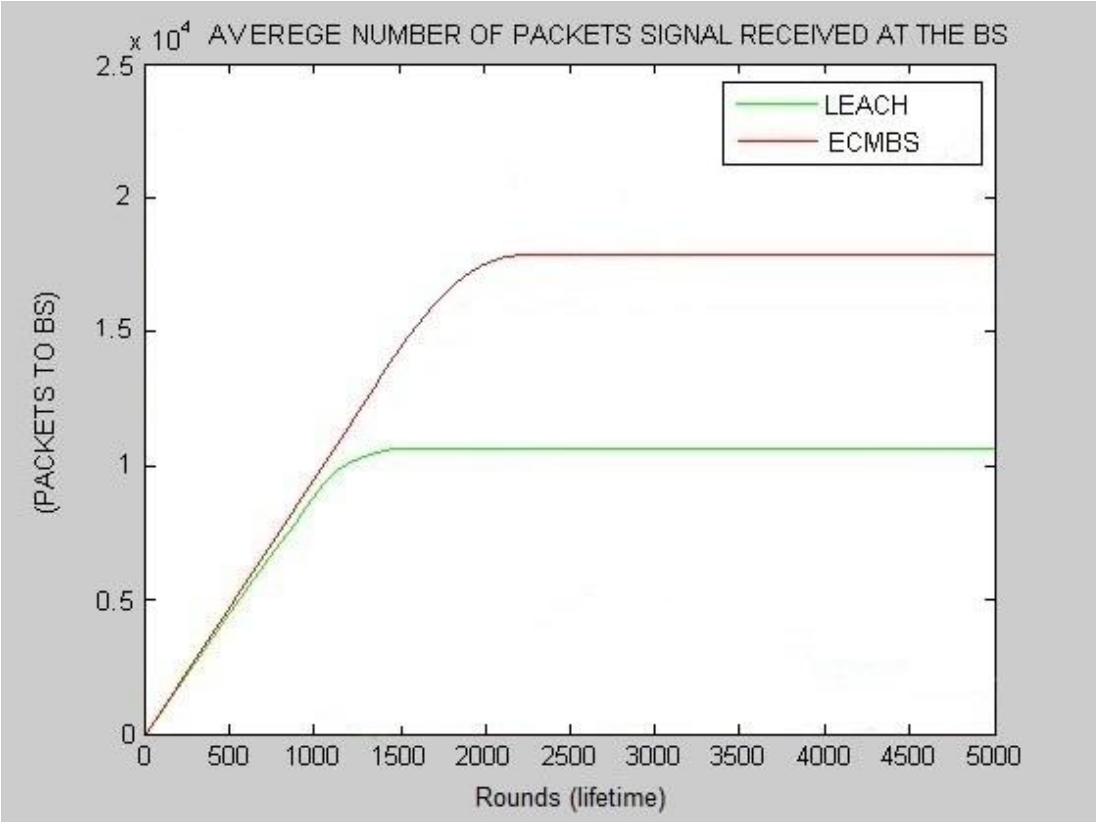

Figure 4.7: Average number packets that received to the BS.

This figure shows that the average packets that delivered to the BS, it's clear that our algorithm (ECMBS) Energy-Efficient Clustering for Wireless Sensor Networks with Mobile Base Station is consistently much higher in case of the original LEACH protocol.

Table 4.2 shows the energy optimization efficiency that is achieved using the ECMBS By developing a good new adaptive clustering and mobile base station of the network, it can be save energy by 86% or more in large scale wireless sensors network related to the original LEACH Protocol.

Table 4.2 Improvement percentage of ECMBS

Category	Average Improvement percentage
Number of alive nodes	86%
energy consumption rate	82%
Number of Dead Nodes	86%
Received packets to the BS	89%

Chapter 5

CONCLUSION

In the introductory chapters of this thesis, the background information of a WSN was discussed whereby a WSN was defined as a network which comprise of large number of tiny sensor nodes which are deployed in close proximity to each other so as to sense information in an environment and communicate this sensed information wirelessly using multi-hop routing to the sink node.

WSNs are suited for wide range of applications. Therefore, they receive great research interest in academic, industrial and commercial. One of the greatest challenges in WSN is how to improve the network lifetime. For that reason, this research among many ongoing researches developed a technique to increase the lifetime of WSNs whether it's in industrial or commercial.

The energy saving technique proposed in this thesis was simulated with another related energy saving technique from another research by using MATLAB Programming language. The proposed energy saving technique for this thesis showed a considerable increase in network lifetime.

Energy-aware, information-aware and transmission range adjustment operations theme was investigated via our proposal of ECMBS. ECMBS is a technique that offers significant energy savings and extends the network lifetime by adjustment of node transmission ranges and ignores low information. The extension in network life was possible through making the base station mobile and adjusting the transmission power to minimum power as possible.

In this thesis, Mobile Sink protocols were gone through and data gathering schemes by the base station in wireless sensor networks. Inspecting the weaknesses of the previously proposed schemes, an algorithm was proposed which covers their weaknesses such as less energy balancing.

At the beginning of each round, clustering is performed and cluster heads (CHs) are selected. Then all CHs make information exchanging with each other, while each CH adjusts its transmission power distance. This distance is derived mathematically based on the nodes remaining energy and lifetime. This data communication is efficient for all CHs. A specific node makes the final decision and either sends it data to base station or to the closest CH to BS after inspecting the energy efficiency of all CHs in the network for data communications to mobile BS.

The proposed algorithm was simulated and the results were compared with the original LEACH algorithm in the BS static. Comparisons were done with the number of alive nodes, energy of the network and the number of received packets in the BS. The simulation results demonstrated the better operation of the proposed algorithm.

The energy optimization efficiency that is achieved using our Energy-Efficient Clustering for Wireless Sensor Networks with Mobile Base Station (ECMBS) By developing a good new adaptive clustering and making the base station are mobile through the network, it can be save energy by 86 % in total related to the original LEACH Protocol.

5.1 Suggestions for Future Work

Abundant researches concerning the wireless sensor networks energy optimization are being introduced nowadays. The research that can obtain a perfect score and add an significant contribution is the research that settle the important problematic issues. Those include energy optimization and power transmission, security, packets transfer, hardware reliability and management.

As a future work, we suggest to study the heuristic position search algorithm, which can derive more optimal results by using genetic algorithm (GA) to determine the optimum path for the base station. Proposed a comparison for the base station in different speed by making the base station moved in various speed and get the optimum speed to collect or aggregate data packets from the cluster heads.

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APPENDIX

Simulation Code

```
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=0.1;

%\alpha

a=1;

%maximum number of rounds

rmax=5000;

%%%%%%%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,'o');
        hold on;
    end
end
%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;
Eall=zeros(rmax,1);
for r=0:1:rmax
  r
   for i=1:n
    Eall(r+1)=(Eall(r+1)+S(i).E);
  end
   S(n+1).xd=mod(r,100);
   S(n+1).yd=sink.y;
   plot(S(n+1).xd,S(n+1).yd,'x');
   line([S(n+1).xd,S(n+1).xd],[0,100],'color','g');
  %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,'o');
        end
        hold on;
    end
end
%%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)))))
            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
            if(r==10)
            distance
            S(10)
            end
            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
```