EVALUATION AND COMPARISON OF ENERGY EFFICIENT NODE DEPLOYMENT STRATEGIES IN WIRELESS SENSOR NETWORKS

OZLAM ABDULHAKEEM MAHMOOD MAHMOOD

AUGUST 2015

EVALUATION AND COMPARISON OF ENERGY EFFICIENT NODE DEPLOYMENT STRATEGIES IN WIRELESS SENSOR NETWORKS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES OF
ÇANKAYA UNIVERSITY

BY
OZLAM ABDULHAKEEM MAHMOOD MAHMOOD

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN
THE DEPARTMENT OF
COMPUTER ENGINEERING

AUGUST 2015

Title of the Thesis: **Evaluation and Comparison of Energy Efficient Node Deployment Strategies in Wireless Sensor Networks**

Submitted by **Ozlam Abdulhakeem Mahmood MAHMOOD**

Approval of the Graduate School of Natural and Applied Sciences, Çankaya University.

Prof. Dr. Taner ALTUNOK
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Müslim BOZYİĞİT
Head of Department

This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Sibel TARIYAN ÖZYER
Supervisor

Examination Date: 04.08.2015

Examining Committee Members:

Assist. Prof. Dr. Sibel TARIYAN ÖZYER	(Çankaya Univ.)	
Assist. Prof. Dr. Abdül Kadir GÖRÜR	(Çankaya Univ.)	
Assoc. Prof. Dr. Fahd JARAD	(THK Univ.)	

STATEMENT OF NON-PLAGIARISM PAGE

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name : Ozlam, MAHMOOD
Signature :
Date : 04.08.2015

iii

ABSTRACT

EVALUATION AND COMPARISON OF ENERGY EFFICIENT NODE DEPLOYMENT STRATEGIES IN WIRELESS SENSOR NETWORKS

MAHMOOD, Ozlam Abdulhakeem Mahmood
M.Sc., Department of Computer Engineering
Supervisor: Assist. Prof. Dr. Sibel TARIYAN ÖZYER

August 2015, 51 pages

The lifetime of wireless sensor network is vital issue. Many wireless sensor networks applications have involve deployed sensors, these sensors are unattended for a long time (months or years). Wireless Sensor Networks (WSNs) lifetime can be enhanced if the data flow traffic in the sensor network is modified in a manner that all sensors consumed their energies in a balanced fashion. In our thesis, we studied the problem of energy depletion and sensor network lifetime improvement in many to one communications networks. In such networks, all sensor nodes collect and transmit data to one base station through multi-hop communications. The data flow traffic model is greatly non-uniform. This situation generates heavy traffic load in the nodes near to the base station. In this thesis, a linear program (LP) method has been studied for modeling the theoretical features of the non-uniform node distributions strategies in wireless sensor networks. Gaussian (normal) and exponential node deployment models have been proposed and we have tried to observe the optimal parameters of normal distribution. Also, the effect of base station location on the lifetime of sensor network has been studied in non-uniform and uniform deployment models. Our results indicated that non-uniform node deployment and base station location have significant effects on the energy consumption of sensor nodes. Proposed node deployment models can affect the energy consumption and can balance energy depletion between sensor nodes reaches a particular level.

Keywords: Wireless Sensor Network, Network Lifetime, Node Deployment

ÖZ

KABLOSUZ ALGILAYICI AĞLARDA ENERJİ VERİMLİ DÜĞÜM DAĞITIM STRATEJİLERİNİN DEĞERLENDİRMESİ VE KARŞILAŞTIRILMASI

MAHMOOD, Ozlam Abdulhakeem Mahmood
Yüksek Lisans, Bilgisayar Mühendisliği Anabilim Dalı
Tez Danışmanı: Yrd. Doç. Dr. Sibel TARIYAN ÖZYER

Ağustos 2015, 51 sayfa

Kablosuz algılayıcı ağların ömrü hayati bir konudur. Birçok kablosuz algılayıcı ağların uygulamaları dağıtılmış algılayıcılar içerir, bu algılayıcılara uzun bir süre (ay veya yıl) dokunulmamıştır. Ağ içinde veri akış trafiği değiştirilirse, tüm algılayıcılar, enerjilerini dengeli bir şekilde tüketebilir böylece kablosuz algılayıcı ağıların (KAA) ömrü iyileştirilebilir. Bizim tezimizde, enerji tüketim problemi ve çoktan bire iletişim ağlarında algılayıcı ağ ömrü iyileştirme sorununu inceledik. Bu tür ağlarda, tüm algılayıcı düğümler, bir baz istasyonuna çok sekmeli iletişim yoluyla veri toplarlar ve iletirler. Veri akışı trafik modeli büyük ölçüde düzensizdir. Bu durum baz istasyonunun yakınındaki düğümlere ağır bir trafik yükü oluşturur. Bu tezde, kablosuz algılayıcı ağlarda, düzensiz düğüm dağılımları stratejilerinin kuramsal özelliklerini modellemek için doğrusal bir programlama (LP) yöntemi çalışılmıştır. Gaussian (Normal) ve üstel düğüm dağıtım modeli sunulmuştur ve biz normal dağılımda optimal parametreleri incelemeye çalıştık. Ayrıca, algılayıcı ağ ömründe baz istasyonunun yerinin etkileri düzensiz ve düzenli dağıtım modelleri ile çalışılmıştır. Bizim sonuçlarımız, düzensiz düğüm dağıtım ve baz istasyonu yerinin algılayıcı düğümlerin enerji tüketiminde önemli etkilere sahip olduğunu gösterdi. Önerilen düğüm dağıtım modelleri enerji tüketimini etkileyebilir ve enerji tükenmesini algılayıcı düğümleri arasında belirli bir seviyeye ulaştığında dengeleyebilir.

Anahtar Sözcükler: Kablosuz Algılayıcı Ağlar, Ağ Ömrü, Düğüm Dağıtım.

ACKNOWLEDGMENTS

Firstly, I am grateful to the god giving me the good health and wellbeing that were necessary to complete this thesis.

I would like to thank my supervisor, Assist. Prof. Dr. Sibel TARIYAN ÖZYER, for her guidance and encouragement. Her supports brought this work toward a completion. This work came into existence with her supervision. There is no enough word to thank for her guidance.

I would like to thank Prof. Dr. Taner ALTUNOK, who is the director of graduate school of natural and applied sciences in Çankaya University, for all supports and motivation throughout my master program.

I deeply thank my parents Nadheera and Abdulhakeem. They raised me, supported me, taught me, and loved me. I dedicate this thesis to them

The last great thank to my family, my husband Mohammed and my son Mustafa who have always stood by me in the worst of time and supported me in all manners during my master program. None of this would have been possible without their love and patience. I also dedicate this thesis to them.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURES

LIST OF TABLES

TABLES

LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
CSMA/CA	Carrier Sense Multiple Access / Collision Avoidance
EDCn	Exponential Node Distribution Base Station in the Center
EDCr	Exponential Node Distribution Base Station in the Corner
EEDMC	Energy-Efficient Distributed Multi-level Clustering
GAMS	General Algebraic Modeling System
LP	Linear Programming
MANETs	Mobile Ad-hoc Networks
NDCn	Normal Node Distribution Base Station in the Center
NDCr	Normal Node Distribution Base Station in the Corner
QoS	Quality of service
SQL	Structured Query Language
TDMA	Time Division Multiple Access
THT	Tri-Hexagon Tiling
UDCn	Uniform Node Distribution Base Station in the Center
UDCr	Uniform Node Distribution Base Station in the Corner
WSN	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

Recently, the studies about the wireless sensor network which sensor nodes form a self- configure network become very common. It is possible to gather and process collected information easily by using wireless channel, without supporting of a superior infrastructure. Thus, once the sensors scattered in the target area, very little human interaction is required and it can function independently. That features made it desirable in many applications.

One of critical issue in wireless sensor networks is power consumption because there are some resource limitations in sensor devices such as small power supply, low-priced transmission devices with limited range, simple processing capability etc. Except some sensors prepared with devices that save energy such as solar cells, the sensor nodes was deployed into target area without any infrastructure for monitoring and data collecting applications. This means that the power must be equipped with either by batteries or by energy gathering tools such as solar cells. The batteries of sensors cannot be recharged or replaced. The first reason for this, the sensor networks consist of great number of sensor nodes (mostly between 100 and 1000 nodes), so it is not possible to change all consumed batteries. The second reason for this, in some applications, sensor nodes are scatter in unreachable places. Nevertheless, even in the case where power gathering is achievable, energy consumptions in sensor node must be accurately accomplished as the provided energy still restricted. Hence, lifetime of each node depends on its battery consumptions and sensor network lifetime is based on the time until the first sensor node dies as we define in the next chapter.

1.1 Thesis Motivation

For maximizing sensor network lifetime, each node in the network needs to utilize it is battery power accurately while perform its job. On the other hand, despite that the battery consumption in each sensor is reduced to the fullest extent is possible, additional procedures must be considered to maximize sensor network lifetime. The most important one among these procedures is balancing the traffic load between the sensors to eliminate battery depletion for some sensor nodes.

During their life sensor node in the network perform two different jobs. The First one is accomplishing sensing task by collecting sensed data. The second task is once a sensor gathers the captured data; it sends it to the sink (base station). According to the transmission range of the node, it is not possible always to send data directly to the base station. Therefore, another node in this way to the base station is acting as rely to forward this data until it reaches to the base station. Therefore, the sensor which forward data consume energy for receiving and transmitting another nodes data in addition to transmitting its generated data. Hence it consumes its battery faster than other nodes. How many established communication paths involve and which operations have to be carried out by each node is determined by location of node with group of deployed nodes. Sometimes nodes placed in area with heavy traffic load (for example near or around base station) so they consume their battery early and die. Therefore the network lifetime ends soon. Hence, the lifetime of WSN depends on node deployment model.

Sensor placement is a vital matter in WSNs. Many aspects of network operations are affected by node deployment in the sensor network. For example, battery management, network routing, network security, etc. There are generally two types of sensor node deployments in sensor networks. There are random and deterministic sensor node deployments. Farther more, random deployment is classified in to uniform and non-uniform deployment models. From here, in this thesis we introduced two different non-uniform node deployment strategies and compared them with uniform node deployment in the term of network lifetime.

1.2 Thesis Contributions

There are three contributions of this thesis. Firstly, we deployed sensor nodes according to Gaussian (normal) distribution and we planned to find the answer of the questions. What is the ideal value of parameters in Gaussian (normal) distribution and how this parameters impact sensor network lifetime? By the other words we can say, what are the optimum normal distribution parameters that maximize sensor network lifetime? Secondly, we evaluated a comparative study between three different node deployments model in the term of lifetime (uniform distribution, non-uniform Gaussian distribution, exponential distribution). We try to answer the question, in different node density, which node deployment model achieves best load balance between nodes and extends network lifetime? Thirdly, we studied new scenario by changing base station location in three deployment models which are uniform, normal (Gaussian) and exponential distributions in order to answer the question, how does the base station location affect network lifetime in different node deployment models?

In order to do our analyses we developed novel Linear Programming (LP) and modeled energy consumptions in the network to investigate the lifetime of sensor network.

1.3 Thesis Organization

The rest of thesis is structured into five chapters.

In Chapter 2, we intended to give the reader comprehensive understanding of wireless sensor networks.

In Chapter 3, we summarized literature survey on different energy balancing methods in wireless sensor networks.

In Chapter 4, we introduced system assumptions and described system model. A unique framework of Linear Programming (LP) was developed to model energy consumption in the network with different node deployment strategies and different base station locations.

In Chapter 5, we displayed our analysis results to examine several aspect of the senor network lifetime. Also, the effects of Gaussian distribution parameters, node density and different node deployment model on energy cost were investigated.

In Chapter 6, we finished the thesis with conclusions of our study.

CHAPTER 2

BACKGROUND ABOUT WIRELESS SENSOR NETWORKS

2.1 Introduction to the WSNs

Wireless sensor network is consisting of a significant number of nodes collaborates to collect data from the environment and deliver collected data to the one special node called sink/base station through wireless links for more processing. Because of evolutions in sensor nodes technologies, so the creation of a wireless sensor network through the deployment of macro sensor nodes became possible. The sensor node characterized by resilient and can be deployed in the areas out of reach for humans, which opens fields to use sensor nodes in large number of applications [1]. Wireless sensor networks have two dissimilar category of nodes, first category is the sensor nodes that are densely disturbed in the target area and second type is the single or multiple sink nodes (base stations) that are located either inside network area or nearby to it.

WSNs can be originated in two various techniques relying on the requirement of the application. The first method includes origination a network where the sensor nodes are coordinated in fixed positions and is called a static sensor network. In this type of wireless sensor network, each sensor node collected related information from the area that lay in its sensing range and transmits collected data to the sink node (base station). Because of restricted transmission range of each nodes, to make sure the delivery of data to the sink node the data needs to be relayed by other sensors using multi hop data transmission [2]. Via the investment of the static WSN, the data gathered from the sensor network can be used to create a locative -temporal view of the environment monitored, thus it can be used in many different fields [3]. But some time, the immobile network structure is not appropriate for some applications. In case where it is needful to continuously get information from moving objects such as animals or moving vehicle, sensor nodes need to be linked directly to objects and move with them [4].

In addition, mobile sensor nodes be used to overcome the problems of static WSN. For example, by moving nodes guarantee full coverage target area in the case random deployment in unreachable area, overcome breaking network connectivity caused by die of some nodes due to the exhaustion of their energy, moving nodes support multiple missions under various conditions and finally some applications may need complicated sensors (expensive) to use in, but the network contains large number of nodes that makes the network expensive. By making some of nodes (not all networks nodes) moved with sophisticated sensing devices we can ensure inexpensive sensor networks [5].

2.2 Requirements and Design Factors for Sensor Networks

In this section, we planned to characterize WSNs communications architecture design factors. Several design factors have been discussed by several authors in this field. These issues serve as indication to build an algorithm or protocol for wireless sensor networks. These design issues are studied below.

- **Reliability:** Reliability or fault tolerance is the capability to preserve functionalities of WSN without any stoppage due to failing in sensor nodes [6-7]. Node may die as a result of energy loss, communications trouble, inactivity (a node becomes pendent), circumferential interference or physical damage. In [7] reliability is explained by the Poisson distribution to deal with no failure probability within the period $(0, t)$, where λ_k is the failure rate of node k and t is the time interval.

$$R_k(t) = \exp(-\lambda_k t) \quad (1)$$

- **Network Scalability and Density:** Hundreds, thousands or millions of sensor nodes possibly scatter to observe an event that important to users. How much of interested network area have been covered depend on sensor density. The WSN size affects accuracy, data processing algorithms and reliability [8]. Sensor node densities can range between a few numbers to a hundred of sensor nodes in the network field that can be fewer than 10 m in diameter. Sensor node density is studied in [8], where N is sensor nodes number that deployed in network area A, and R is sensor node transmission range. Essentially, $\mu(R)$ is the sensor nodes number with in the communication range of each sensor node in area A.

$$\mu(R) = (N\pi R2)/A \tag{2}$$

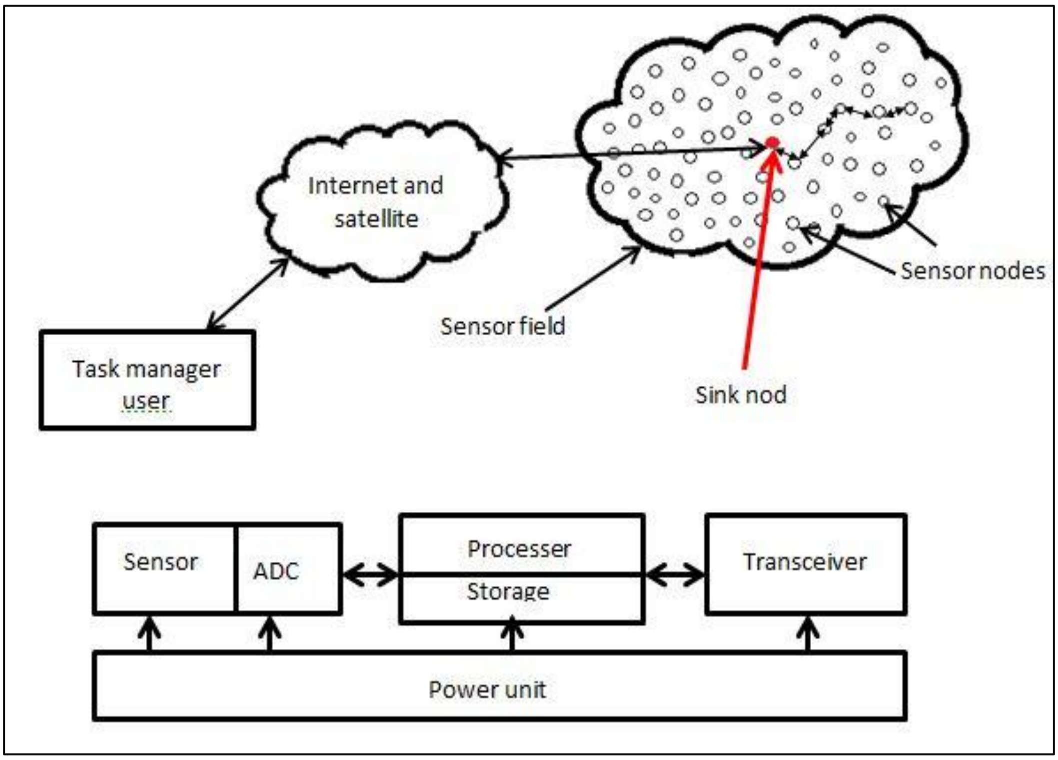

Figure 1 Wireless sensor nodes deployed in a target area and a single sensor node hardware component [1]

- **Topology of Wireless Sensor Network:** Many of the WSN characteristics influenced by network topology such as, robustness, latency and destiny. As well, the complication of data processing and routing based on the sensor network topology. Densely scattering thousands of sensors in network area Fig. 1 requires accurate dealing with WSN topology preservation [1-8]. In [1] three stages related to network topology maintenance and changes are defined (e.g., fail of some sensor nodes), Post deployment stage, deployment and pre-deployment stage and extra nodes redeployment stage.

- **Energy exhaustion:** Power unite is one of the sensor node components of which is very limited. Sensor node is battery powered. From here, sensor node lifetime rely on the lifetime of node battery, particularly in the applications where replacing power unite is not possible. Where the main aims of nodes are gathering events, data transmission and data processing, so the energy of sensor power source is consumed in these three operations (sensing, communications and computation). Furthermore, a sensor node lifetime has the main role on sensor networks robustness and energy efficiency. Therefore, several researches are aiming on building energy efficient algorithms and protocols for wireless sensor networks with the aim of energy consumption minimization [1-9-8]. In this thesis we studied the energy efficiency and maximization the lifetime of sensor network by non-uniform deployment of sensor nodes.

- **Hardware Constraints:** A sensor node involves of four major components Fig. 1, they are sensing unit, storage unit, processing unit, power unit and transmission unit. In some applications sensor nodes can also have application-dependent further components such as power generator, position finding systems and component to provide mobility of nodes. Furthermore, generally sensing units consists of two Sub-units: ADC unit (Analog to Digital Converter) and sensing unit. The analog signals generated by sensing unit depend on the observed event and these analog signals converted by ADC to digital signal and finally it send to the processing unit. Mainly processing unit connected with storage unit, it responsible from the procedures that make the sensor node cooperate with each other to achieve its jobs. Transmission unit is connects sensor nodes to each other by wireless links to form WSN. In some applications power unit may be buttress by a power reserving like solar cells. Because of many of WSN sensing jobs and routing techniques need information about sensor node position accurately. Therefore, in many applications sensor nodes have a location discover system. Occasionally, in mobile sensor network in order to move nodes to perform its jobs mobilizer is required. Hence, one of great design issue in WSN is the size of sensor node [1].

- **Data Fusion or Data Aggregation:** It is the procedure of minimizing data size by recapitulates data into a set of useful information by computation while data are broadcasting through WSN. Hence, sensor networks consist of great number of nodes; this can congest the network and flood it with information [10]. Solving data congestion problem in sensor networks by using computation to fuse or aggregate data in wireless sensor network, now send only the gathered data to the task manager.

  There are three offers in sensor networks to assist data aggregation. Firstly, diffusion algorithms which accept that similar data transmit to target in the sensor network by conveying data from one senor to another, such a data may be gathered by diffusion algorithms. Secondly, streaming queries are based on SQL extension for continuous querying. Thirdly and finally, is event algebra which support in adding simple measures into composite ones [8].

- **Transmission Media:** In the sensor networks with a multi-hop commination's, wireless medium is utilized for communications purposes to connect sensor nodes with each other. These wireless channels can be established by radio signal (e.g., Bluetooth 2.4 GHz), Infrared which is license free and renitent to interference with other electrical devices that work in the same frequency and finally optical media.

- **Security:** In the wireless sensor networks security features have been motivated on the centralized communications methodologies. Several of the sensor networks threats are designated in [11], and it classified as: inactive information Gathering, Node power cut, Wrong Node, Node failure, observation of a Node, denial of service and message dishonesty. There is a necessity to progress distributed security methods for WSNs.

- **Self- organization:** Being self-configure is very necessary for WSN to, as scattering large number of sensor nodes in a target area may be unsuccessful because of several causes (e.g., physical devastation, lack of energy, inactivity, environment interfering, communications trouble, etc.) and extra new sensor may add to the WSN. On the other hand, in a dynamic environment sensor nodes work without censoring. Therefore, in order to supports communications under strict energy limitations sensor network must be to be self-organization to organize a topology. It should be noted that self-configure in wireless sensor networks is a vital factor to preserve properly functions of wireless sensor network and assist its purpose [12].

- **Quality of Service:** In many applications, in a restricted latency data transfer (i.e., time reserved applications) is of great significance. In other way, the data will be unusable if is delivered after certain latency. In other applications (e.g., which isn't time-constrained), the saving of energy is the most important than the delivered data quality. Depending on the applications, there must be a balance between the energy depletion and the quality of service (data sent quality) [13-14].

- **Coverage:** Environment observation by sensor node's that located in it, is restricted both in accuracy and range. In other words we can say that the sensor nodes capability to covering environment physical region is restricted [8-15].

- **Connectivity:** Network connectivity can be described as a perpetual connection between any two various nodes that are heavily scattered in a WSN. The connectivity is considerably importance, as connectivity affects data propagation techniques and communications protocols' design. Furthermore, it is possible to mention that network connectivity might not avoid flexibility in the network topology. It prevents network size from decrease as a result of certain sensor nodes death because of the reasons stated previously in [8-15].

2.3 Why the Wireless Sensor Networks Dissimilar from Ad-hoc Networks?

An investigation of WSNs applications, design and characteristics need wireless ad-hoc networking mechanisms. Between existing ad hoc networks models, the mobile ad hoc networks (MANETs) are similar to WSN. While wireless sensor networks and MANETs share some comparable features such as, energy and bandwidth are restricted resources, network topology is ad hoc (i.e., not fixed infrastructure) and wireless communication mediums are used to link nodes. The algorithms and protocols sophisticated for MANETs are not appropriate for the unique application requirements and structures of sensor networks since these two types of networks have some dissimilar features such as [1].

- Sensor node dissimilar from the node in MANETs, it may not have a unique global IP address as a result of a large number of sensors and the great amount of overhead.
- WSN topology alternate repeatedly.
- Sensor nodes number in wireless sensor networks can be greater than that in MANETs.
- Sensor nodes are more tiny devices and very cheaper, dissimilar from ad hoc network nodes (e.g., Laptops, PDAs, etc.), they commonly scattered in thousands.
- Wireless sensor networks used broadcasting communication pattern, however in MANETs point-to point communications pattern are used.
- Bandwidth and energy saving are the general troubles in the design of wireless sensor network protocol. Since, sensor nodes energy resources are extremely restricted in addition to processing and communication abilities than their equivalents MANETs due to their low cost.
- The nodes in WSN are susceptible to failure much more than in MANETs. Hence, studying new deployment strategies for wireless sensor networks are important to satisfy above requirements. Several researches have been carried

out on developing algorithms and protocols for wireless sensor networks by taking into account development of low cost, energy efficient, fault tolerant and secure sensor networks protocols.

2.4 Types of Sensor Nodes

There are diverse types of sensor nodes which include thermal, seismic, low sampling rate, infrared, visual, magnetic, radar and acoustic that can observe diverse environmental conditions such as: [1]

- Lightning conditions
- Pressure
- The absence or existence of objects certain types
- Temperature
- Humidity
- Vehicular movement
- The levels of mechanical stress on the objects that linked to it
- Noise levels
- Existing features such as direction , size and speed of an object
- Soil makeup

Relying on requirements of application, sensors can cooperatively observe many of the presented physical or environmental conditions at varies locations.

2.5 The Applications of Wireless Sensor Networks

Study on WSNs has been initially motivated by military applications. There are varied from wide range acoustic observation systems for ocean observation to small sensors networks for ground target detection [16]. But, new technological advances make many other potential applications possible such as traffic control, habitat monitoring, infrastructure security, etc., that can be mostly categorized into health, military, home, environmental and other commercial fields as follows: [1]

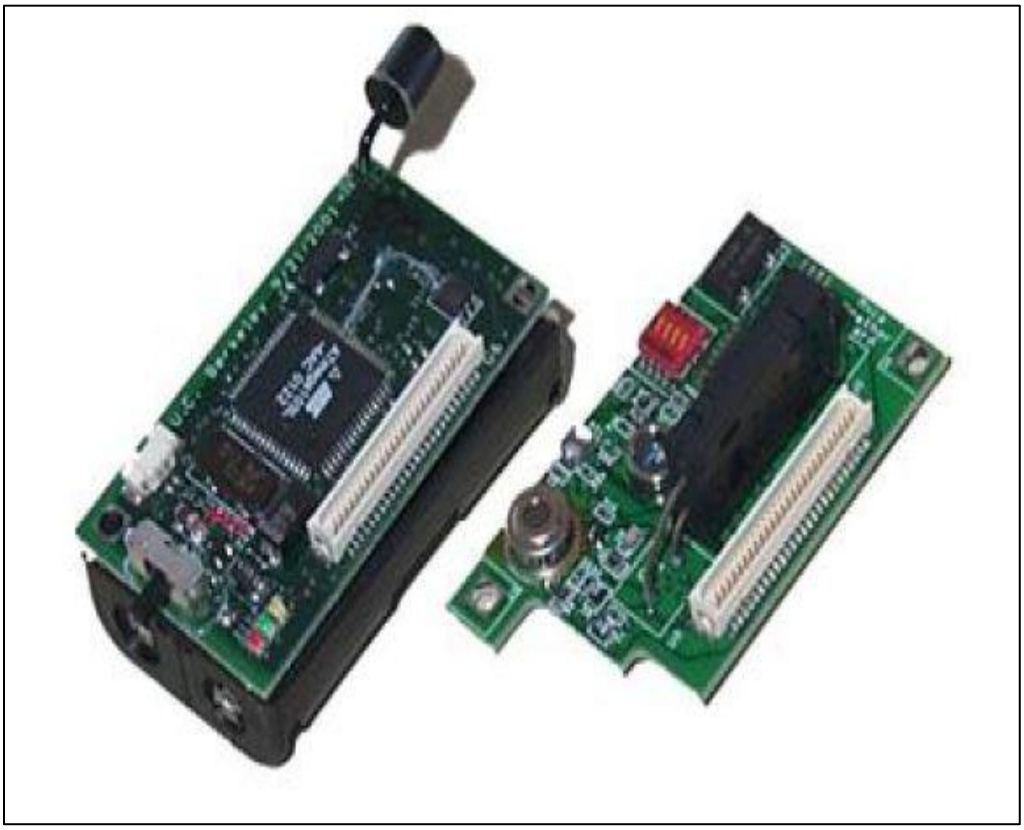

Figure 2 Mica technology [17]

Military Applications: The sensor networks can be utilized in battle fields, since sensor nodes are inexpensive and can easily be deployed nearby a battle field in large amounts. Some military applications can include observing friendly forces, ammunition and equipment in which commanders can get the newest position of the required equipment, vehicle, etc. Battle field observation in which dangerous paths and routes can be carefully observed for the enemy forces, battle harm valuation before or after attacks and atomic, chemical or biological attack discovery and scouting in which a WSN can be utilized as a chemical or biological warning system.

Environmental monitoring Applications: WSN can furthermore be a good methodology for environmental monitoring. In Fig. 2, we explain Mica sensor node (on left) and Mica Weather Board (on right) industrialized for environmental monitoring applications. A sensor node with acrylic fence Scattered in the field can be realized in Figure 3. The first example of environmental applications is forest fire detection, in this application sensor nodes densely scattered in forest. In such application nodes can trace fire starting point before it is spread. Second example is flood discovery, in which several types of sensors such as water level and weather sensors are utilized in an alert system to discover floods and precision agriculture. Therefore, air pollution level or soil erosion level is monitored in real time [17].

Figure 3 Deployed sensor node with acrylic fence [17]

Health Applications: WSNs can be used in the monitoring of human physiological data. By using these applications better liberty of movement is given to patients than treatment centers. These applications also used for following and observing doctors and patients in hospitals. Additionally it used for drug department in hospitals in which nodes linked to medicines, so the opportunity to get the incorrect medicine can be reduced.

Home Applications: Home applications involve home automated where intelligent sensor attached to the home devices, for example vacuum cleaners, fridges, ovens, etc. These sensor nodes used to connect these devices with each other and with an external network so that they can be run and controlled locally or remotely. Smart environment where sensor linked to electrical machine and furniture which can communicate with each other and with devices in other rooms to learn about the services offered.

Other Commercial Applications: the wireless sensor networks may also use in other commercial applications. First application is environmental control in office and buildings, which installed WSN systems, can be set up to sensing and monitoring car robberies and managing air stream. Second application is interactive museums, which children can react with museums objects to absorb more about them. Third application is managing stocking control, which each item may have a sensor node that detect the precise location of the item and vehicle following and revealing system [1].

2.6 Definition of Wireless Sensor Network Lifetime

All energy consumption techniques have a common aim, which is maximizing the lifetime of sensor network. But, sensor network lifetime has no single precise definition that generally decided in the literature works. Numerous network lifetime definitions have been presented, the commonly purposed are:

First definition: period to first node failure due to battery exhaustion. Increase sensor density in certain area is generally used, that prevent sensor failure to affect the network and application.

Second definition: another group of authors defined the lifetime as the time to the certain percentage of the sensor nodes failure (e.g. 30%), but, possible redundancy must be considered.

Third definition: the time of the first break in the network. Once the WSN is lost connectivity, data cannot be transmitted to its target.

In the absence of information about the application supported by the WSN, first definition and second definition are the more convenient to do a comparison between various energy efficient technics. In all situation, an energy exhaustion model most important point in sensor network for increasing network lifetime. In our thesis we use first definition to evaluate network lifetime.

2.7 Sensor Node Energy States

A great amount of sensor node power is consumed in data transmission. Furthermore, sensor nodes consume energy in data process but it is very small by comparison with energy wasted in the communication. It important to know that the sensor node have four energy states: transmit state, receive state, idle or sleep state. Each state has a dissimilar level of energy consumption Tab. 1:

- **Transmit state:** data transmitting by sensor node with transmission energy $E_{t,ij}$.
- **Receive state:** data receiving by sensor node with reception energy E_r . This node may be final destination of received data, or it is only the forwarder of that data.
- **Idle listening state:** where there is no massage to transmit through transmission medium, sensors continue idle and retain listening to the transmission medium for any possible data receiving with E_{idle}.
- **Sleep state:** the transceiver is turned off, therefore, the sensor cannot be able to transmit or receive any signals. The sensor node consumes E_{sleep}that is very small than any other state, the energy exhaustion is minimum.

In Tab. 1 we state the values of energy consumption in each state taken from a Lucent silver wavelan PC card [18] and a ZigBee sensor node employing IEEE 802.15.4 [19]. In either case, we can observe that the sleep state is minimum power exhaustion state. But, the power consumed in receive and transmit state is near for the IEEE 802.15.4 medium access.

Table 1 Power in Each Communication State for Sensor Node

Node State	Power in Watt		Current in mA
	802.11	802.15.4	802.15.4
Transmit State $E_{t,ij}$	1.3	0.1404	33.1
Receive State E_r	0.9	0.1404	33.5
Idle State E_{idle}	0.74	-	-
Sleep State E_{sleep}	0.047	0.000018	0.005

2.8 Reasons of Energy Waste in WSNs

In WSNs, as we explained previously sensor nodes consume energy in processing, transmitting and receiving data. This energy is important for proper working of the wireless sensor networks. Additionally to this consumed energy, there is a large amount of energy consumed in states that are unusable from the point of view of the application, such as:

- **Overhearing:** because of wireless medium have shared nature, when the node transmit packet all nodes that it lay in transmission range of the source node will receive this data though it is destined to only one these nodes. Therefore, overhearing is the energy wastes when the node consumes the energy in receiving packet not relevant to it.

- **Idle listening:** because of the node doesn't know when it will receive massage, it must continuously listen to the medium for any possible transmitted massages that designated to it. By reference to the Tab. 1 we can notice that the power consumed in idle state is close to the power consumed in receive state and the sensor node consume there energy ineffectually.

- **Collision:** In CSMA/CA medium access, when a collision occurs the packet is lost and the energy that consumed for transmission and reception for packet is wasted.

- **Interference:** the sensor node that positioned between interference range and transmission range of source node, this node can receives transmitted packet but it cannot decode it.

CHAPTER 3

LITERATURE REVIEW

3.1 Unbalance Energy Consumption

In a large immobile WSN system many of sensor nodes cannot send data to the sink node directly. Therefore, communication is required between base station and all other sensors in sensor network. Therefore, nodes are deliver data to the base station by multi-hop routes, employing other sensors as forwarder sensors. So, the nodes that can transmit data to sink node directly need to relay the data from other nodes in addition to transmitting data they themselves have generated (this nodes will be traffic source and forwarder). In this situation the sensors that near to the base station need to transmit additional data. Therefore, they will consume their energies faster than the nodes farthest from the sink node and die faster. This reverse-multicast data transmission causes unbalanced energy exhaustion between nodes in the WSN. In Fig. 4, this problem is clarified. Sensor nodes in Area 1 are in the transmission range of the sink or base station. On the other hand, the sensor nodes in Area 2 cannot directly commutate with the sink node. Hence, the nodes in Area 1 need to relay the data from nodes in Area 2 as well as the data from Area 1 that they have received and will die earlier.

After the death of sensor nodes in Area 1 the remainder sensors will be disconnected from the sink node as a result the whole WSN will stop to work. But since in this situation the sensor nodes in Area 2 still have some remaining energy, also the sensor network is essentially disconnected by a hole around the sink node. This problem is called “the energy hole problem” and has been analyzed using a mathematical model by the authors of [20].

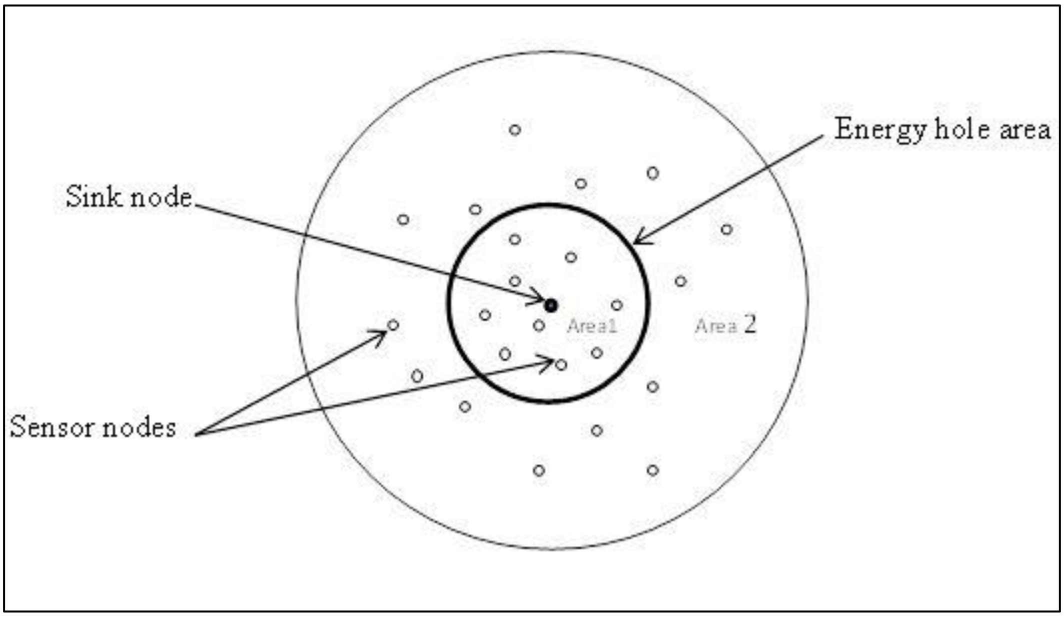

Figure 4 Energy hole problem

3.2 Solving Unbalance Energy Consumption

The aim of this section is to highlight the conditions that must be met for energy balance in WSN. We tried to define the reasons why these conditions may not be met by all wireless sensor networks. In complete load balancing in which all nodes in the WSN carry out the same amount of jobs. Hence all sensor nodes consume same amount of battery power and dies almost simultaneously. Thus, this situation prevents any disconnection in the network and extends sensor network lifetime.

Energy hole problem is first studied by Stojmenovic and Olariu [21]. They studied theoretically mitigating energy hole problem in the sensor network by uniformly data reporting and uniform node deployment. They supposed the model of energy as $E = d\alpha + c$, where d is the distance among receiver node and sender node, α is the parameter of energy depletion that related to particular field and c is a positive constant. By these assumptions they proven that for $\alpha > 2$, unbalanced consumptions of energy is eliminated. However, for $\alpha = 2$, the unbalanced consumptions of energy cannot be prevented and no routing scheme can eliminate the energy hole formation around the base station. After Olariu and Stojmenovic many works have been investigated with load balance to mitigate energy hole and to address energy hole problem in sensor networks different schemes have been purposed. By viewing some of this works we concluded that for producing energy balanced network to prevent energy hole problem in sensor network the WSN must have at least one of this five criteria: exemplary data aggregation, add mobility feature to nodes, controlling transmission power, node clustering and non-uniform node deployment. Below we briefly summarize the existing works relevant with solving the energy hole problem.

3.2.1 Data Aggregation

Data aggregation schema is widespread in WSNs for the purpose of reducing energy depletion. The data generated by the sensor nodes will often be highly associated. Hence, transmitting all the generated data would cause in considerable amounts of redundant or overlapping information. Data aggregation was purposed to filtering certain amount of this redundancy data. It reduces the total work that the sensor network must achieve which provides energy savings.

Data aggregation is one of common methods to extend WSNs lifetime. For example in a sensor network consists of temperature measuring sensor nodes, minimizes the total data amount that should be sent to the sink and the data coming from sensors gathered into a single stream by aggregator nodes. But, data reduction possible level is accurately dependent on application (e.g., is it suitable to transmit only temperature readings arithmetic average? [22].

Yu et al. [23] suggested the model of tunable compression that is capable to adjust the computation complication of loss-less data compression depends on the availability of energy. The model originates from compression tools. For example gzip in which there are ten dissimilar compression levels ratios. As data decompression and compression in the sensors also consume energy, it is vital to identify energy savings accomplished by various compression schemes.

Bista et al. studied a new data aggregation structure for energy-balanced in WSNS. They assume a WSN that convenient for information collecting applications with one stationary sink node, for example target tracking. The model of sensor network that purposed in their work has one base station or sink that can increase its transmission range to cover the complete sensor network area. They supposed that a large number of limited energy sensor nodes are deployed as gird (uniformly) in the target area. Those sensor nodes prepared with energy control abilities to change their output energy. Furthermore, they assumed that each sensor node has sensing, gathering and data forwarding abilities. These sensor nodes can transmit data packets with fixed-length to the sink node periodically. Lastly, sensor nodes can alter state into a sleep state or in to one of low power states to save their energy when they do not have any task to perform [24].

In [25] authors suggested an in-network data aggregation model to extend sensor network lifetime. Each sensor multiplies its reading with a random coefficient and the results send to the next hop to determine weighted sum of all messages. Now, base station will receive weighted sum rather than separate node restore and reading original data. Wholly sensors deplete almost equal amount of energy. As a result of determining weighted sum, each sensor node only achieve one multiplication and one addition and.

3.2.2 Node Mobility

One of the methods to solve energy hole problem is introducing mobility into the sensor nodes in order to balance energy consumptions. Wang et al. [26] one of earliest who introduce a mobility to extend sensor network life time. They purposed routing algorithm for three cases. First case is static sensor node. Second case is sensor network with one mobile base station. A third case is sensor network with one mobile relay node, and compute the lifetime of sensor network. In each case they obtained maximum lifetime by using mobile sink. Wherever in the case of using one mobile rely in sensor network they estimate improvement in lifetime of sensor network by approximately four factors, the mobile relay node only require staying within two hops distance from the base station. They also proposed new routing algorithms which requires only a limited number of nodes (only the sensor nodes within 22 hops of the sink) to be conscious of the location of the mobile rely.

Rao et al. they pointed out that mobile sinks indirectly offer load balancing without extra effort. The energy hole problem around the sink node alternate as the sink node moves, and the increased energy consumption around the sink is distributed through the whole sensor network which supports achieving uniform energy depletion. So, network lifetime was extended [27].

Xie et al. [28] considered the situation of charging the sensor nodes' batteries with a moveable charging vehicle. Thus, this prevents any possible hole in the network due to node dies. This mobile charging device periodically moves inside the wireless sensor network and charge each node's battery wirelessly, aiming at maximizing the ratio of wireless charging vehicle stop from move time over cycle time. The authors have taken advantage of a recent revolution in wireless power transfer technology for a sensor network. They observed that for appropriately designed wireless sensor network, it is possible for WSN remain operational forever. One open question in this schema is this sensor network scale when sensor nodes number increase in the WSN.

Lin et al. [29] developed cellular-topology based clustered scheme for WSN by using mobile agents to achieve energy balancing. They built energy prediction strategy by using mobile agents that have information about all sensor nodes residual energy. Sensor nodes that have small residual energy communicate by means of mobile agents, and that prevents communication for long distance thus minimize unbalance consumption of energy. The disadvantage of this strategy is that consumption of great energy because of the use of two level of transmission power is purposed. First level is high transmission power to grantee inter-cluster communication between mobile agents. Second level is the low transmission power utilized for intra-cluster communication.

3.2.3 Transmission Power Control

Transmission power control is the aptitude of nodes to adjust the amount of energy it puts into transmitted signals to regulator its transmission range and the amount of energy spent during transmission. Energy balance may be achievable by adjusting the transmission power of sensor nodes depending on to their workload so that nodes with more workload loaded use lower transmission energy than the nodes with less workload.

X. Liang et al. start out to equip the dynamic and distributed transmission ranges control system for eliminating collisions. Subsequently this scheme tends to decrease the transmission range of sensor nodes. Therefore, it reduces sensor node energy consumption thus save its energy [30].

Azad and Kamruzzaman [31] introduced regulating transmission range for energy balancing to prolonging sensor networks lifetime. They designed concentric ring based sensor network where base station is located at the center of network area. Initially they have observed the energy consuming and distributions between sensors. They established two criterions, hop size and ring thickness that answerable for balancing energy consumptions between sensor nodes. Depending on their studies, for each sensor node they have built transmission range regulation system and determine the ideal hop size and ring thickness for prolonging WSN lifetime. Simulation results demonstrate considerable enhancements in WSN lifetime and balancing energy consumption over other strategies. However, substantial calculations are necessary before transmission schema transmission schema, which defining the optimal hop size and ring thickness. Furthermore, for system implementation, lowest node density is required.

R. Soua et al. investigated that minimizing sensor node’s transmission range decreases energy consummation. To guarantee good connectivity between sensor nodes the coverage should be broad enough to guarantee good connectivity between sensor nodes in network, they investigated that good result can be obtained by taking into account the residual energy as well as distances between sensor nodes especially in heterogeneous WSNs [32].

3.2.4 Clustering

Another energy balancing method is dividing sensor network into clusters. Therefore each sensor nodes send their collected data to the nearest cluster head and cluster-heads in turn send data to the base station. This produces a hierarchical sensor network in which a sensor node's workload depends on its role instead of its location. In result multi-hop communication has been exchanged with two phases, one phase from each sensor node to cluster head and a second phase from the cluster head to the base station. Load balance is carried out either by rotating the roles (in homogeneous networks) or by providing the cluster heads additional energy (in heterogeneous networks).

Z. H. Yu et al. built (Energy-Efficient Distributed Multi-level Clustering) EEDMC algorithm. Their goal was balancing and minimizing and energy depletion. Sensor node weight is defined as the quotient between its remaining energy average and the remaining energy average of its neighbor nodes. They assumed multi-hops communication between cluster heads. They are choice only one cluster head to communicate with the base station. Their implementation results illustrated that EEDMC algorithm is energy efficient and increase WSN lifetime [33].

V. Kumar et al. introduced a survey which increases WSN lifetime. Data transfer routes was chosen in a way that minimizes total energy consumed along data routing path. For this clustering concept was used as cluster helps energy utilization in limited resources which extends and maximizes network lifetime [34].

J. S. Rauthan et al. described WSN as sensing machines next generation and defined sensor nodes with restricted battery power as most important wireless sensor nodes drawback. In order to distribute energy consumptions fairly over the network, data transmit load must be correctly balanced between sensor nodes. Clustering algorithms may produce several clusters that have additional nodes than other network clusters. Load balancing in the sensor network negatively affected by unbalance cluster. In their studies, cluster algorithm was improved to ensure load balancing in formation of clusters. They determined the efficiency of WSNs by determining total distance between nodes and base station and determining transferred data amount. Cluster performance may affect by cluster head which is completely answerable for the generating cluster and cluster sensor nodes. They built an algorithm in which they select master sensor node and vice master sensor node for regions and sub regions. They divided the region and discover region center to learn master node. If required, each partitioned part divided again and that depends on sensor nodes and master sensor node in that partitioned part [35].

3.2.5 Non- uniform Node Deployment

In [36], X. Wu et al. investigated a non-uniform node deployment scheme and verified that nearly energy depletion balance (sub-balanced) in sensor network is achievable. Their approach was implies increase sensor nodes number in geometric progression in coronas toward base station. A deterministic non uniform node deployment is expected that every sensor node in corona can directly communicate with q sensor nodes in its neighboring corona on the way to sink node. The total sensor nodes number in WSN would be $N = N_R * q^{R-1}$ (R represents the coronas number, N_R represents sensor node number in the outward corona). With purposed traffic model, a simple q −switch routing algorithm has been suggested by which each sensor node dynamically send its collected data to the high residual energy q neighbors. Therefore, they investigate high-energy efficiency by load balance between nodes. But, for random non-uniform node deployment, the q −switch routing algorithm illustrates poor performance with about 30-66% drop in network lifetime. However, it is obvious that the planed node distribution (node are to be distributed manually to fulfill the topology constraints) is not possible for large sensor networks. Furthermore, to choice the next node to forward the data, before every round, each sensor node must obtain the knowledge of the remaining energies of its neighbors toward the sink. That will require additional communication overhead in each node. For example, if the sensor network lifetime is 500 rounds, each sensor node transmits at least 500 extra control packets, one before each round to broadcast its remaining energy to its neighbor nodes.

In [37], the authors have discussed the three ways of deploying the sensor nodes. First one is uniform random, second one is square grid and third one is pattern based (THT) Tri-Hexagon Tiling sensor node deployment. Although THT is an efficient deployment strategy but its planning overhead must be considered and moreover the number of sensor nodes used in this are more.

Liu et al. assumed non uniform sensor node deployment scheme to minimize unbalance consumptions of energy. They reduced sensor nodes density as their distances from base station increasing. The results of simulation showed that once the lifetime of sensor terminate, the inner coronas nearly attain balanced energy depletion [38].

In [39], another was proposed corona-based non-uniform node distribution strategy to eliminate energy hole problem. They distributed sensor nodes in each ring according of the ring work load (the nodes in the inner ring is not only transmitting their collected data, but also forward data for outer rings nodes). The proposed algorithm adds certain sensor nodes from outer ring to inner ring. In each ring nodes uniformly deployed. Under this sensor node deployment strategy, each sensor in its lifetime can transmit approximately equal amount of data. Hence, they considered fixed number of ring and fixed ring radius and no routing model was proposed.

Boukerche et al. have early investigated energy balanced data propagation problem in corona based wireless sensor networks for each of non-uniform and uniform node deployments. They have suggested density based data propagation protocol in order to energy depletion balancing. General idea in this used protocol was that at every step corona's sensor node that carry data determines the data delivery probability either by multi- hop or direct to the last target (base station or sink), depending on the neighboring coronas density information . Particularly, proposed density based data propagation protocol performance is close to optimum solution for uniform sensor node placement. However, proposed data propagation algorithm has better performance under uniform deployment compared to non-uniform deployment [40].

In [41], authors described a corona-based method for deciding the sensor deployment densities so as to equalize the average rates of energy depletion for all sensor nodes in WSN, while minimizing deployed nodes number. Here, nodes can send data to different inner coronas with different probabilities and different data rates. Hence, this method has limitations, because of the routing is at the granularity of the rings, not at the node-level. So, that is requires some co-ordination among the nodes in the same corona, demanding some additional message overhead. Also, it ignores statistical fluctuations, which may be an important factor for low-density networks.

CHAPTER 4

SYSTEM MODEL

4.1 Introduction

The studies described in this thesis are based on observing the effect of different sensor node deployment strategies in wireless sensor network lifetime by using linear programming. We also studied scattering nodes in network area to guarantee balancing data flow among sensor nodes. Therefore, all sensor nodes in WSN exhaust their energy approximately in equal time .In this chapter we identified our network model and basic assumption besides optimization problem formulation.

4.2 Energy Model

In our sensor network model sensor nodes energy consumption is concentrated in communication rather than energy depletion in processing and sensing. Every sensor node is provided with a battery bearing equal amount of energy, which is a common assumption in sensor networks provided with small sensors such as light or temperature sensors. For instance, energy consumptions for communication form 91% of the all consumed energy [42]. Therefore, to increase network lifetime, transmitting data from sensor nodes to the sink is the main operation to be enhanced. Coverage is an important QoS criterion for WSN (especially sensor networks that used for sensitive area surveillance). If any network part cannot be observed because of the early sensor death then complete coverage is lost and functionality of WSN is stopped (e.g., in a surveillance the overall system security at risk if one of the critical nodes dies). Therefore, we adopt the definition of network lifetime as the time when the first sensor node in the network consumes their energy and dies. Our assumptions all are standard assumptions generally passable in community of WSNs [43-44-45].

In our study, we used energy model that presented in [43], where energy amount to transmit a bit is displayed as

$$E_{t,ij} = E_{Elec} + \varepsilon_{amp} d_{ij}^{\alpha} \quad (3.1)$$

And the energy amount to receive one bit of data is displayed as

$$E_r = E_{Elec} \quad (3.2)$$

Where E_{Elec} energy is consumed in the electronic circuitry, ε_{amp}indicates the efficiency of transmitter, α denotes path loss exponent and d_{ij} is the distance among N_i (transmitting node) and N_j (receiving node). In our thesis, to perform numerical analysis, we utilized receiver constant standard value (E_{Elec} is 50 nJ/bit) and transmitter amplifier efficiency standard value (ε_{amp} is 100 pJ/bit/m2). We supposed that our sensor network in open space environment, which there is without any obstructions among the receiver and the transmitter. Therefore, electromagnetic wave propagation can be exhibited as free space propagation model, which use a path loss exponent value equal to tow (α is 2) [46]. Tab. 2 lists the parameters that used in our numerical analysis.

Table 2 Energy Model Parameters Explanations and Values

Parameter	Explanation	Value
E_{Elec}	electronic circuitry Energy dissipated	50nJ/bit
ε_{amp}	Transmitter amplifier efficiency	100 pJ/bit/m2
α	Path loss exponent	2

4.3 Network Assumptions

We make following assumptions in our frameworks:

1. We supposed there is one base station and N sensor nodes scatter in square area with dimension $a\ x\ a$.

2. Very sensor nodes are homogeneous and have an index number (very sensors excepted base station has equal transmission range t_{range}).

3. Our WSN consists of static nodes (both sensor nodes and base station). Dissimilar from mobile ad-hoc networks, the changes of topology in our network model are infrequent. Therefore, the discoveries of topology and route creation are occurring once, these functions are not repeated for total amount of time (epochs) [44]. If network reorganization period is long enough then the amount of battery power consumed for these processes represent minor amount (less than 1 %) from whole WSN energy consumption [47]. Therefore in stationary wireless sensor networks the overhead of routing can be ignored.

4. We represented network topology by a directed graph, $G = (V, A)$ where V is a set that contain all nodes and base station and W is all nodes set excepting base station.

5. The time was organized into rounds with interval T_{rnd}.

6. Equal amount of data (s_i) generate by each sensor node $N_i$at each round in order to transmit to the sink (i.e., sensor nodes produce constant bit rate – CBR – flows). Data collected by each node must deliver to the sink either by direct transmission or by help from other sensor nodes behaving as relays.

7. The traffic amount that send from sensor node N_i to sensor node N_j is denoted as f_{ij}.

8. A TDMA based medium access layer is assumed. It reduces the effects of interference among active links by means of time-slot assignment algorithm which generate a conflict-free transmission schedule. In [48], they presented the possibility of such algorithm. Therefore, the network model that collisions free is achievable if bandwidth requirements are satisfied.

9. In our WSN model we purposed three various node deployment scenarios which are uniform, normal and exponential node distributions under the lifetime performance metrics. We investigated data flow balancing in wireless sensor networks by deploying sensor nodes according various probability density functions therefore balancing energy depleted by each sensor and maximize life time of sensor network.

10. We have studied the effect of base station location on the network performance in different node deployment model. Two scenarios were considered. Firstly base station was positioned in the center of network topology and secondly the base station is positioned in the corner of network topology. Thus, we have studied every possible mixture of the base station locations and node deployment models.

4.4 Sensor Node Deployment Model

In WSNs, the main challenge is deploying sensor nodes in the network field that ensure longest lifetime and continuous sensing however preserving uniform coverage. Based on application requirements, the different sensor node deployment models have been established. In our sensor network we instigated three different node deployment scenarios. In this section, we presented sensor node deployment models with their features.

4.4.1 Uniform random distribution of nodes

In our thesis, uniform random sensor node deployment decided as one of the competitors. In a uniform random node deployment, every N sensor nodes have same chance of being positioned at any position inside network field, as shown in Fig. 5. (a). Therefore, sensor nodes are deployed on places that are not certainty identified. For instance, this node deployment model can achieve by throwing sensor nodes from an airplane. Generally, a uniform random node deployment is supposed to be easy and cost-effective. Various wireless sensor network applications often choose random sensor node distribution.

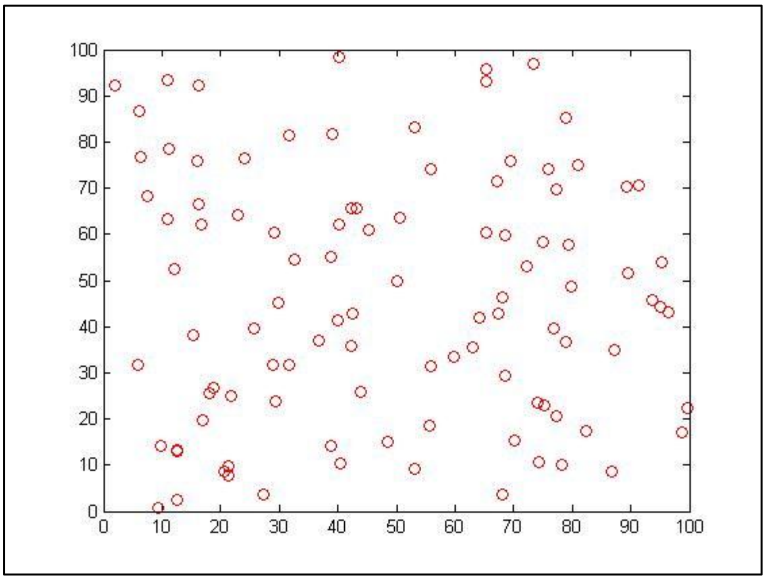

Figure 5 A snapshots of sensor nodes deployed according to uniform distribution

4.4.2 Normal (Gaussian) distribution of nodes

As we explained previously, nodes that close to base station have to transfer additional data compared with other outer regions sensors. Therefore, sensor nodes that near to the base station are exhaust their battery rapidly. So, that minimize expected network lifetime. Unbalance energy depletion phenomenon may cause in entire network early dysfunction, even if the sensor network in other parts still have more residual power. To minimize this problem, our first approach is normal sensor nodes distribution.

Normal or Gaussian distribution is one of the important types of statistical distributions. Every normal distribution is symmetrical and has density with a single peak like bell shape.

There are two important quantities in Normal distribution. First one is mean μ, where the density peak occurs (parameter for location), and second one is the standard deviation σ, which refers to the width or spread of the bell curve(scale parameter). We could see clearly in Fig. 6 which different values of μ and σ produce different curves of normal density, hence dissimilar normal distributions.

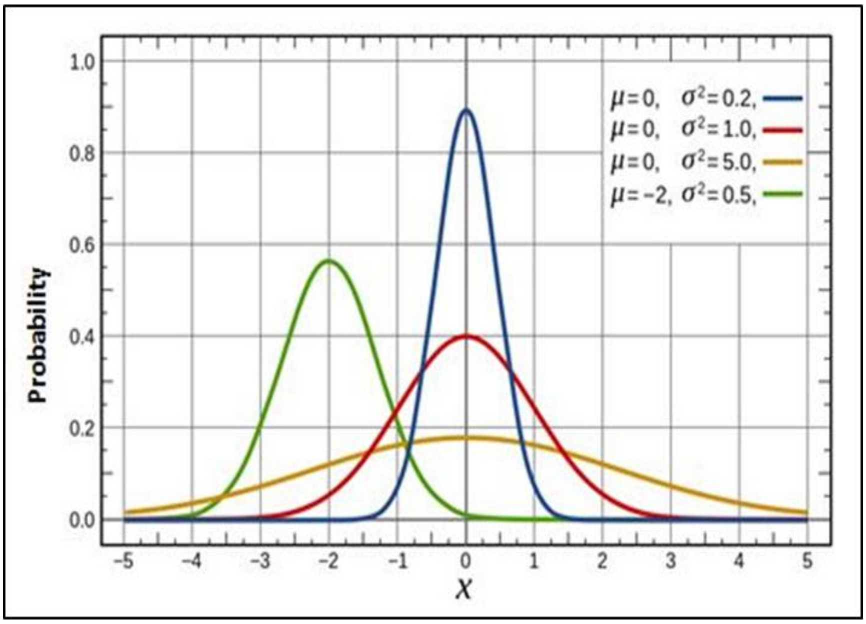

Figure 6 Normal distribution curves with different values of μ and σ

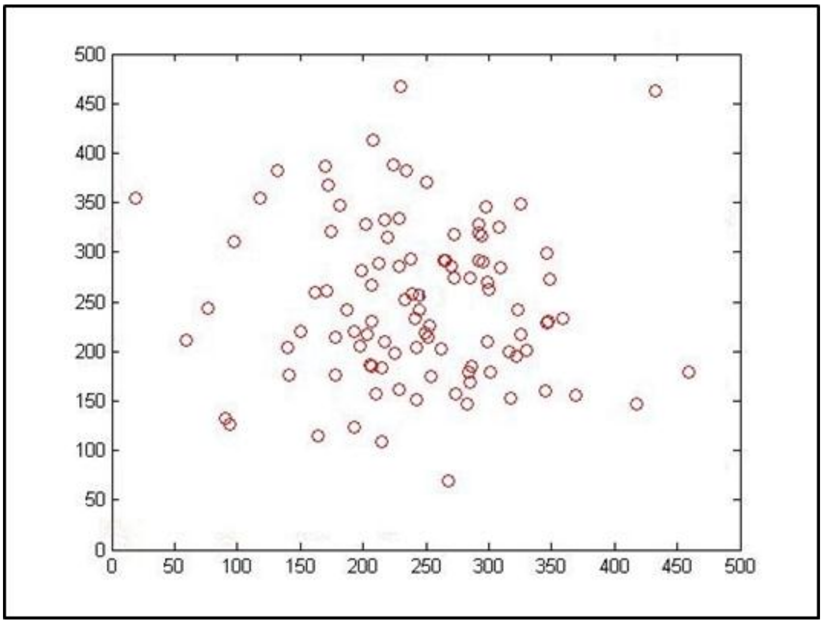

Figure 7 A snapshots of sensor nodes deployed according normal distribution

The general equation for normal distribution probability density function is given by

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{1(x-\mu)^2/(2\sigma^2)} \quad (3.3)$$

The sensor nodes are scattered according Probability density function (3.3) where large number of nodes are intensifies at the network field center Fig. 7.

4.4.3 Exponential distribution of nodes

Second approach that we used in this work is exponential distribution of nodes towards base station, which used to decrease unbalance energy consumption which may cause in early stop of the whole sensor network.

Exponential distribution is a class of a continuous distribution. X is random variable and can be say that it follows the exponential distribution with parameter λ¸ if its distribution function P is set by:

$$p(x) = \lambda\, e^{-\lambda x} \quad (3.4)$$

With mean $\mu = 1/\lambda$ and variance $\sigma^2 = {}^{1}/_{\lambda^2}$ occasionally the probability density is given as:

$$p(x) = \frac{1}{\mu} e^{-x/\mu} \quad (3.5)$$

If the value of location parameter λ is positive, then the beginning of the distribution shifts by a distance of λ to the right of the origin. Fig. 8 shows exponential distribution with different λ values.

The scattered sensor nodes according to probability function (3.5) where large number of nodes are placed at the corner of network field (bottom left) in Fig. 9.

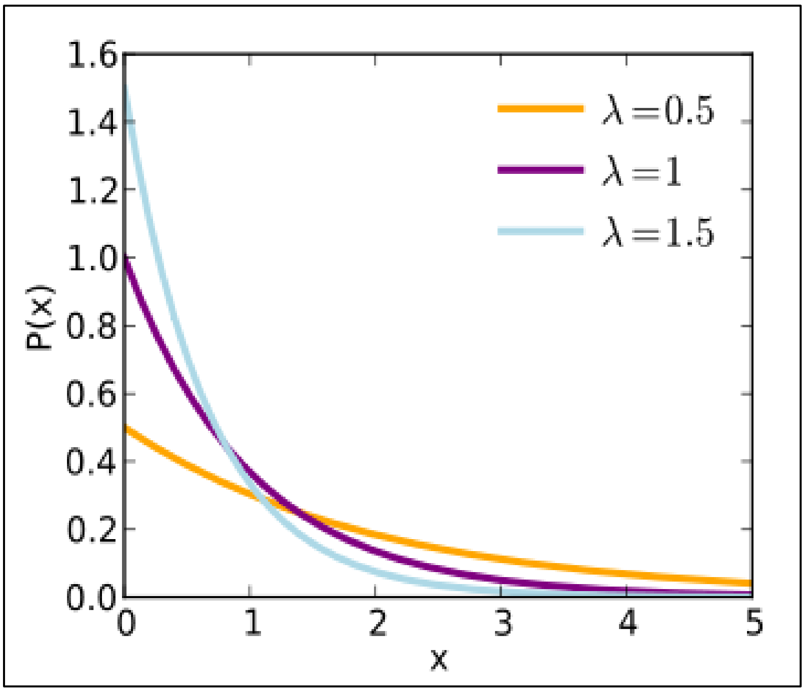

Figure 8 Exponential distribution with different λ values

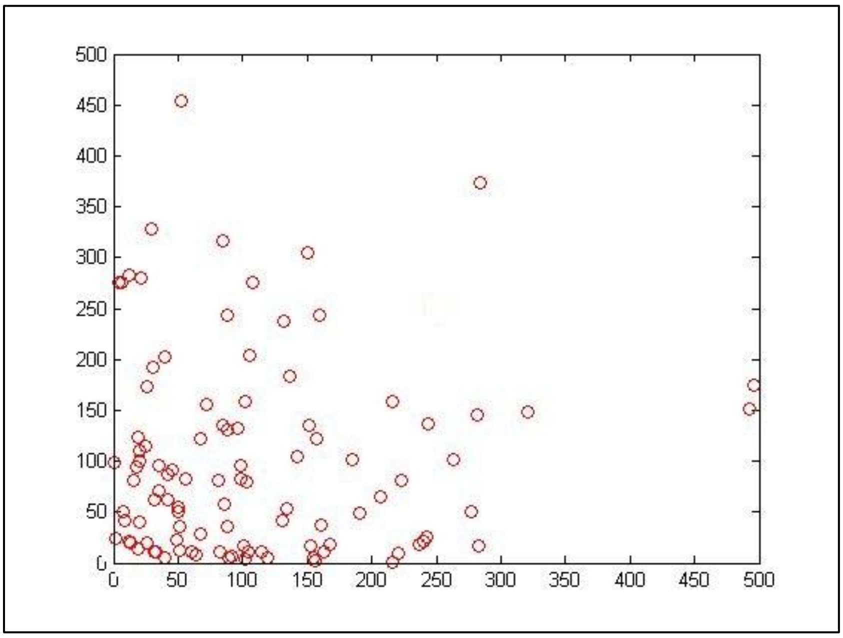

Figure 9 A snapshots of sensor nodes deployed according to exponential distribution

4.5 Mathematical Programming

It is considered one of mathematics subclass that purposes to determine minimum or maximum objective function that subjects to linear, non-linear and integer restrictions on the variables [49]. Commonly problems of mathematical programming contain next components [50]:

Variables: It has a very important role in the decision making. The variable values are identified after resolving mathematical programming problem. Therefore the values of variables are not known at the beginning of mathematical programming problem. For instance, data flow values between nodes are regulated to detect maximum wireless sensor network lifetime or to find minimum energy required for the sensor nodes batteries.

Objective function: It consists of a set of variables. Mathematical programming detects variables values that minimize or maximize objective function. E.g., maximizing the lifetime of WSN is an objective function.

Constraints: It decides the objective function solution space. We can say, if the resulting solution satisfies constraints then values can be assigned to variables. For instance, sensor node transmission range is a constraint and if the distance among two nodes is greater than nodes transmission range then can't be flow between sensor nodes.

Variable bounds: A variable bounds can also be considered as constraints. Even if some values of variables satisfy constraints, but allocating these values to the variables cannot be possible in the real world. Therefore, to find accurate results the variables are bounded. For example, data flows between nodes f_{ij} can't yield negative values.

Linear program is an example of mathematical programming model that purposed to determine the better solution by taking into account given constraints set, which describe the set of real decisions [51]. Another alternative decisions are chooses by their values of objective function and the decisions with the optimal value (may be largest or smallest according function nature) is elected as the optimal.

In this thesis, by optimization problem we expressed as an LP problem, presented in Fig. 10. Subsequently our objective is increasing sensor network lifetime (F). Our problem is expanding minimum network lifetime by determining f_{ij} (flows) that fulfill the constraints. With the help of non-uniform node deployment model can realize required data flow balancing and increase network lifetime. We must point out that variable (F) provides the lifetime of sensor network in terms of rounds number and real lifetime of network can be determined by the product $F \times T_{round}$. The rounds number that network survives (F) is quantity without unit.

Maximize F

Subject to

$$f_{ij} \geq \forall (i,j) \in A \quad (1)$$

$$f_{ij} = 0 \text{ if } i = j \; \forall (i,j) \in A \quad (2)$$

$$\sum_{j \in V} f_{ji} + Fs_i = \sum_{j \in W} f_{ij} \forall i \in W \quad (3)$$

$$E_r \sum_{j \in W} f_{ij} + \sum_{j \in V} E_{t,ij} f_{ij} \leq e_i \forall \in W \quad (4)$$

$$e_i = Battery \, \forall i \in W \quad (5)$$

$$f_{ij} = 0 \text{ if } t_{range} < d_{ij} \quad (6)$$

Figure 10 LP model for lifetime maximization [52]

We represented topology of network as a directed graph $G = (V, A)$. Where V is the group of total sensors, as well as the base station as (N_1) with index value (1). Similarly, we described set W, that contains all the sensors except the node with index value one (base station). $A = \{(i,j) : i \in W, j \in V - i\}$ is the group of arches (links). Should be noted that the description of A indicates that no data are sends from node to itself and base station does not transmit any data to other sensor nodes.

In Fig. 10 we explained LP framework, Equation (1) states that all flows of data in the WSN are not negative (f_{ij} indicates the data flow from N_i to N_j). To prevent infinite loops we used Equation 2, by this equation it can eliminate data flow from the base station to other sensor nodes or from a sensor to itself. Equation 3 is the flow balancing constraint and states that for total nodes except the base station (i.e., there is no balance of incoming and outgoing data flows for the base station because base station does not generate any data or relay data to any other sensor node). The data amount that flowing out from a sensor is equal to amount of flows that received and produced by that node. This equation also indicates that all data produced by sensor nodes delivered to the base station as final destination. We must mentioned that $F\times s_i$ provides whole data amount that generated at node N_i (s_i is constant and it represent data amount hat collected in unit time). Data collect are done periodically in several sensor network applications and all collected data have fixed size [44]. Equation 4 illustrate that for all sensor nodes except the base station energy consumption for data transmission and reception is equal to or below the power saved in sensor battery(e_i). Equation (5) is stats that equal battery power assigned to all network nodes.

Up to Equation 5 presented model is the fundamental model for balancing data flow and increasing network lifetime. The lifetime of network terminates when the first sensor node consumes its battery. Hence, this definition should not be misinterpreted when we observe our LP neatly. We can be observed that to maximize the minimum lifetime of network, it must force all sensor nodes to consume their battery power in a balanced way. Therefore, all of sensor nodes in the sensor network topologies must (if not all) exhaust their battery powers at same time.

Until this point the basic linear programming model absences any limitations that restricts a sensor's transmission range t_{range} (i.e., in the network every sensor node can communicate with any other sensor node). So, Equation 6 was added to the network model to restrict then maximum communication range of sensors to t_{range}

(i.e., any communication pairs that separated by the distance greater than t_{range} cannot communicate directly. On the other hand, multi-hop communication possibility is not prevented). As there is no heterogeneity on transmission power (every nodes have equal t_{range}) so, in such sensor network there are no unidirectional links. Equation 6 and the basic model is purposed to model our standard situation.

In the next chapter we use our system model to examine various node deployment strategies and get the numerical result to observe which deployment model ensure energy balance between sensor nodes and extend network lifetime. Farther more, we get the numerical result by changing base station location in network field in order to study the effect of such change in network lifetime.

CHAPTER 5

SIMULATION ENVIRONMENT AND RESULT ANALYSIS

5.1 Introduction

In the following chapter we observed the lifetime of WSN in uniform, non-uniform (normal) and exponential sensor node deployment strategies. We studied and presented the result of the numerical analysis to study the effect of base station position in network area on WSN lifetime in three different node scattering models (random uniform, non-uniform normal distribution, non-uniform exponential distribution). We used large scale 2D network which consist 10-100 sensor nodes with one base station (N_1). The amount of total traffic generated at each round by N_i (bits), energy stored at each sensor node (J) and transmission range for nodes are taken as 1.0 Kbit/round, 1.0 and 100 respectively. In experimental analysis we focus on the network lifetime as defined in (section 2.6) first definition. For the purpose of comparing various node deployment models with each other and study the impact of various parameters on obtained results, we performed wide range computational study. The parameters that used in this study are presented in Tab. 3.

As there are no closed form solution for LP problems, we use a computer program GAMS (General Algebraic Modeling System) for LP model numerical analysis [53]. GAMS involves high performance solvers for efficiently solving LP model that enhance LP upon the fundamental method in various ways to achieve maximum solution performance. Therefore, by using GAMS to solve our LP model, one of GAMS solvers is used to get optimal solution. Specific details of implementation are out of this thesis domain. Furthermore, we use MATLAB tools to plot the figures in our thesis in order to be useful for comparative study.

Table 3 Parameters List and their Values

Parameters	**Symbol**	**Value**
Number of nodes	N	10-100
Network deployment	No Symbol	Uniform, normal, exponential
Number of sink or base station node	N_1	1
Location of sink in the network	△	Center, Corner
Size of Network area	a x a	500 X500, 100 X100
Amount of total traffic generated at each round by node-i (bits)	s_i	1.0 Kbit/round
Period of one round (s)	T_{rnd}	100.0
Transmission range for nodes	t_{range}	100
Energy stored at each sensor node (J)	e_i	1.0
Battery energy (J)	$Battery$	1.0
Mean parameter of normal distribution	μ	250
Slandered deviation parameter of normal distribution	σ	0 - 200

The data point presents in the figures for next sections are the averages of 1000 in depended runs and in each run node position are randomly generated (1000 random topology). Before we discuss the result obtain from optimization problem it is worth to note that all network lifetime is normalized, the normalization is carried out by dividing each values of lifetime with the greatest lifetime obtained.

To ease our result presentation, we used following abbreviation:

- UDCn: uniform node distribution, base station in the center.
- UDCr: uniform node distribution, base station in the corner.
- NDCn: normal node distribution, base station in the center.

- NDCr: normal node distribution, base station in the corner.
- EDCn: exponential node distribution, base station in the center.
- EDCr: exponential node distribution, base station in the corner.

5.2 Effect of Gaussian Distribution Parameter on Network Lifetime

In this section we evaluated the performance of wireless sensor network in the term of network lifetime by using Gaussian distribution of nodes. In first experimental study we deployed sensor nodes according to probability density function (equation (3.3)) for normal distribution where high number of deployed nodes condensed in the middle of network area (around sink node). We solve our LP problem for 50 sensor nodes with base station (N_1) in the center with network area 500x500. Gaussian distribution parameter is equal for both diminution, where mean values ($\mu = \mu_x = \mu_y$) is 250 (as area is 500 x 500) and we changed the value of standard deviation σ for Gaussian distribution to observe the effect of σ on network lifetime.

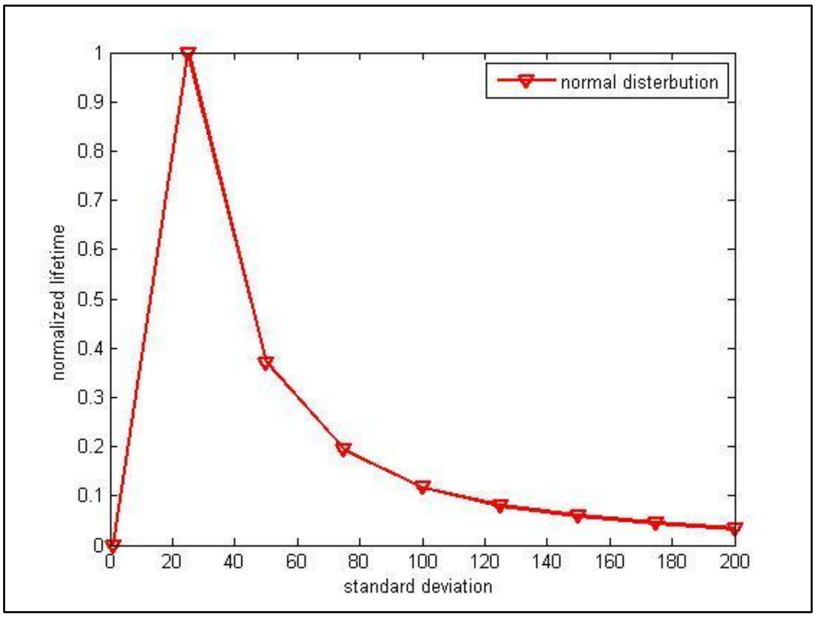

Figure 11 Normalized network lifetime as the function of standard deviation σ

Fig. 11 shows the change in the normalized lifetime as a function of standard deviation σ. As the value of σ increase, the network lifetime increase. Until standard deviation reach 25 (σ = 25), the lifetime reach highest value and after this highest lifetime it start to decrease as standard deviation σ increase. We can see from Fig. 11

there is a sharp rise in normalized network lifetime when $\sigma = 25$. The reason of this sharp rise in lifetime is smallest value of σ, it means a large number of sensor nodes are deployed close to the base station compared with network area that far away from base station. Therefore, the nodes that cannot reach base station directly have few number of nodes deployed in it is transmission range. Hence, there is no relay node in it is range to act as forwarder to deliver data to the base station so network lifetime end soon. In other words, in the smallest value of σ it is fail to deploy satisfied number of sensors in the regions that far away from base station. By increasing of σ we see slight increase on the lifetime until $\sigma = 25$ in such value the deployment strategies are ensure flow balance between network nodes to achieve highest lifetime (consumption of energy could be balanced between sensor network nodes). All these imply that choosing of judicious value of σ is utmost important for fulfilling the objective of energy balancing.

5.3 Comparison Between Different Node Deployment Strategies

In this section we evaluate the performance of three different sensor node deployment models that are uniform, normal and exponential node distribution in the term of network lifetime. Firstly we take the network area 500x500 with base station in the center and fixed all network parameter as in Tab. 3 but we changed the number of sensor node between 10 and 100 by 10 node increments. Fig. 12 shows that lifetime of sensor network as a function of sensor node number. We can observe from the figure that network lifetime increases with increasing the density of sensor node in the network field (increasing nodes number). The reason for such arise in network lifetime, that when we increase node density in the network nodes number that is one hope way from the base station also increase and that can extended the time that the first sensor node exhausted his energy and died. Increasing number of nodes in uniform node deployment it can illuminate the bottleneck around the base station to some extent. Farther more, normal deployment of nodes achieves better performance in the term of the lifetime. As we can see from Fig. 12 there is a gap between lifetime in uniform and normally deployment of nodes. That significant increasing in lifetime due to nature of deploying nodes according to normal distribution probability density function where majority of sensors lay in the center of network field (around base station) and that ensure balancing energy dissipation between nodes(minimize the effect of many to one communications in the network).

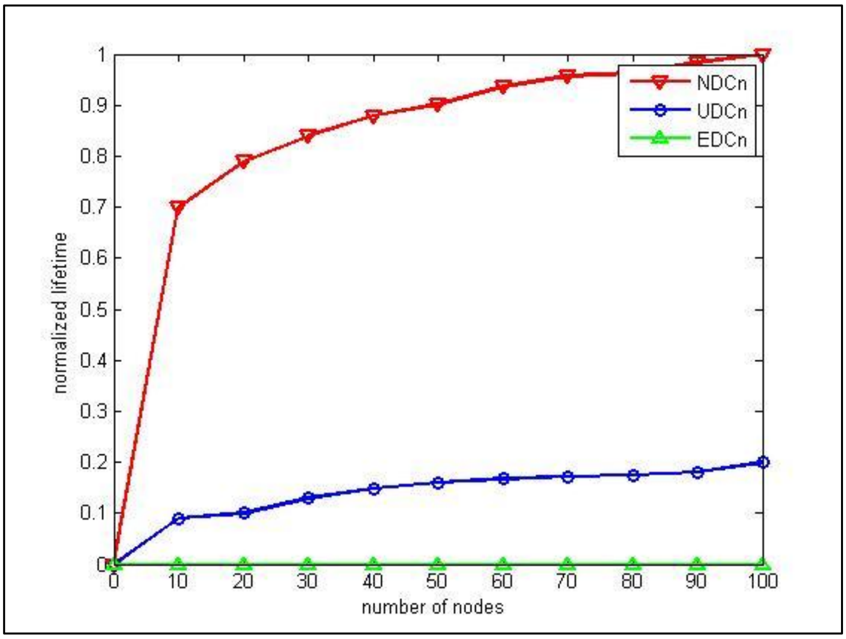

Figure 12 Network lifetime as a function of sensor node numbers (network area 500 x500 base station in the center)

On the other hand, when we deployed sensor node according exponential distribution function Fig. 13 (b). In such distribution the number of deployed nodes increase exponentially towered origin point (0, 0) the majority of nodes deployed in the left corner of square network area. When we take network area 500 x 500 and assume that base station in the center of network field. In such a network assumptions and parameters it fails to create a network as show in Fig. 12 where (EDCn) is still zero in different sensor node densities. This is due to the fact that, in exponential node deployment very few numbers of nodes are deployed around the base station. We can see it clearly in Fig. 13 (b). Therefore, all sensor nodes are out of the transmission range of base station and all that nodes try to transmit their data to the base station so it is impossible to create network under these circumstances.

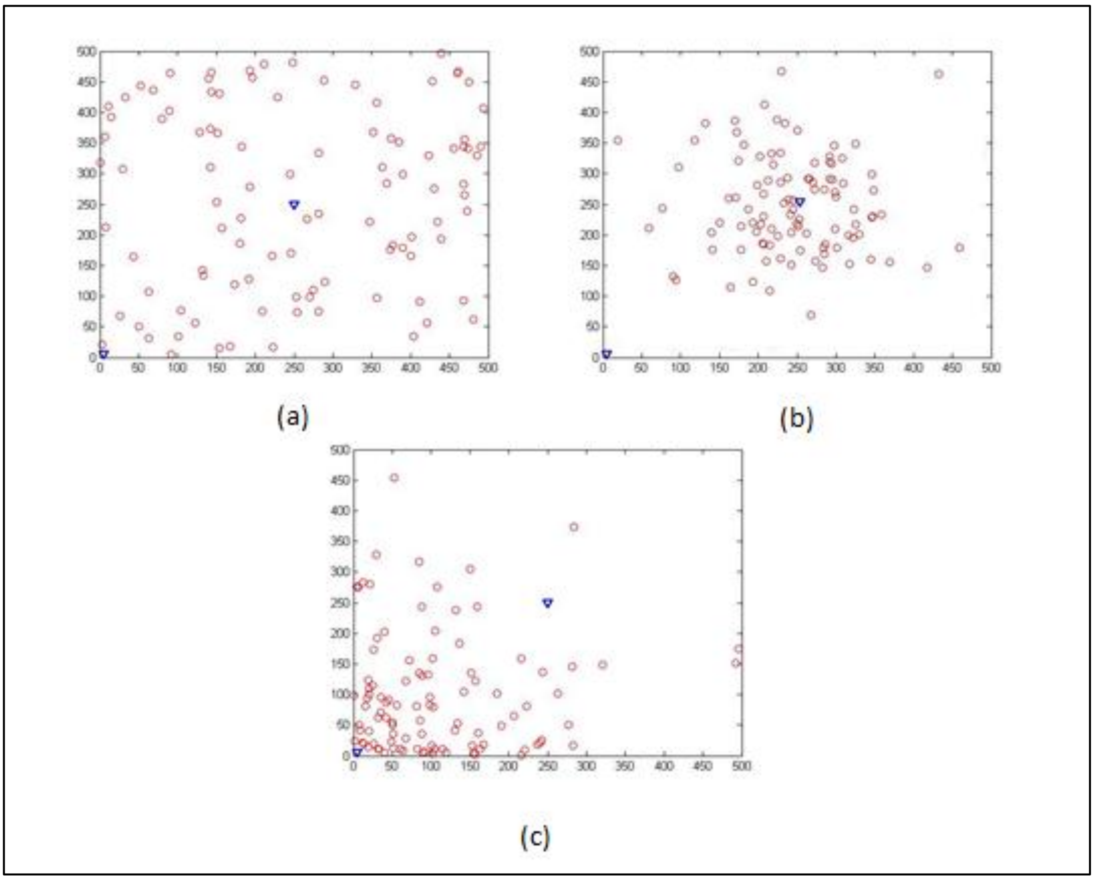

Figure 13 a. Uniform distribution of sensor nodes. b. Normal distribution of sensor nodes. c. Exponential distribution of sensor nodes. (Where o represent sensor nodes ▼ represent the base station)

To compare the network lifetime for different node deployment strategies in a fair manner we change network area to the 100 x 100 but base station still in the center (base station coordinate is x = 50, y = 50) of network field. We altered the node density by increasing total number of nodes and solve our optimization problem for each deployment model. From the data point present in the Fig. 14 displays lifetime of sensor network with different node deployment models. We can observe from the figure that lifetime increases in uniform node distribution with nodes number growth. The reason for such arises in lifetime, because traffic of data is decreased while increasing node numbers. On the other hand in exponential node deployment normalized lifetime decreases while node density increases. This decline is because increasing the number of node in EDCn is done according probability density function (3.5) where the ratio of sensor node increasing in the corner of network field much more than the ratio of increasing in the center of sensor network (around base station). That cause unbalance energy consummation between nodes in WSN. The nodes that base station lay in it are transmission range dies very fast because of the heavy work load for these nodes. Hence, it is responsible for forward the data to the base station from significant sensor nodes and this in turn causes bottleneck around the base station and terminates lifetime of the network faster.

Farther more, the uniform distribution (UDCn) was showed better performance than exponential node deployment (EDCn). We noted that normal distribution (NDCn) performs even better than that uniform node deployment (UDCn) and that indicates the effectiveness of our approach.

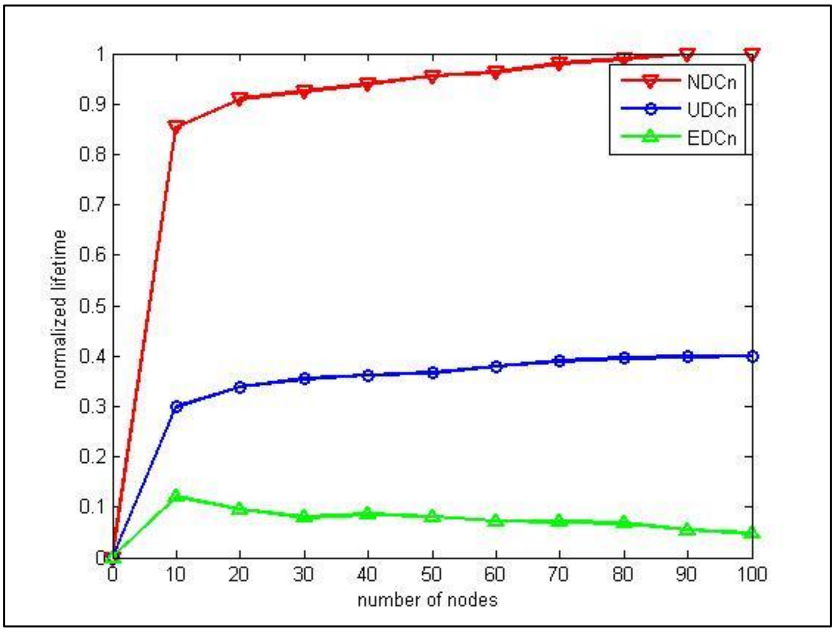

Figure 14 Network normalized lifetime as a function of number of sensor node (Network area 100 x 100 base station in the center)

5.4 The Effect of Base Station Location on WSN Lifetime in Different Deployment Strategies

Until now optimization problem is solved for the network model with base station in the center with coordinate ($x = 250, y = 250$, since area is $500\ x\ 500$). In order to study the effect of base station position on the lifetime of sensor network, we purposed new scenario, where the base station is positioned in the corner of the network topology with coordinate ($x = 1$, $y = 1$) as shown in Fig. 13. We solve the optimization problems for that scenario in order to compare network performance with first scenario where base station in the center of network topology.

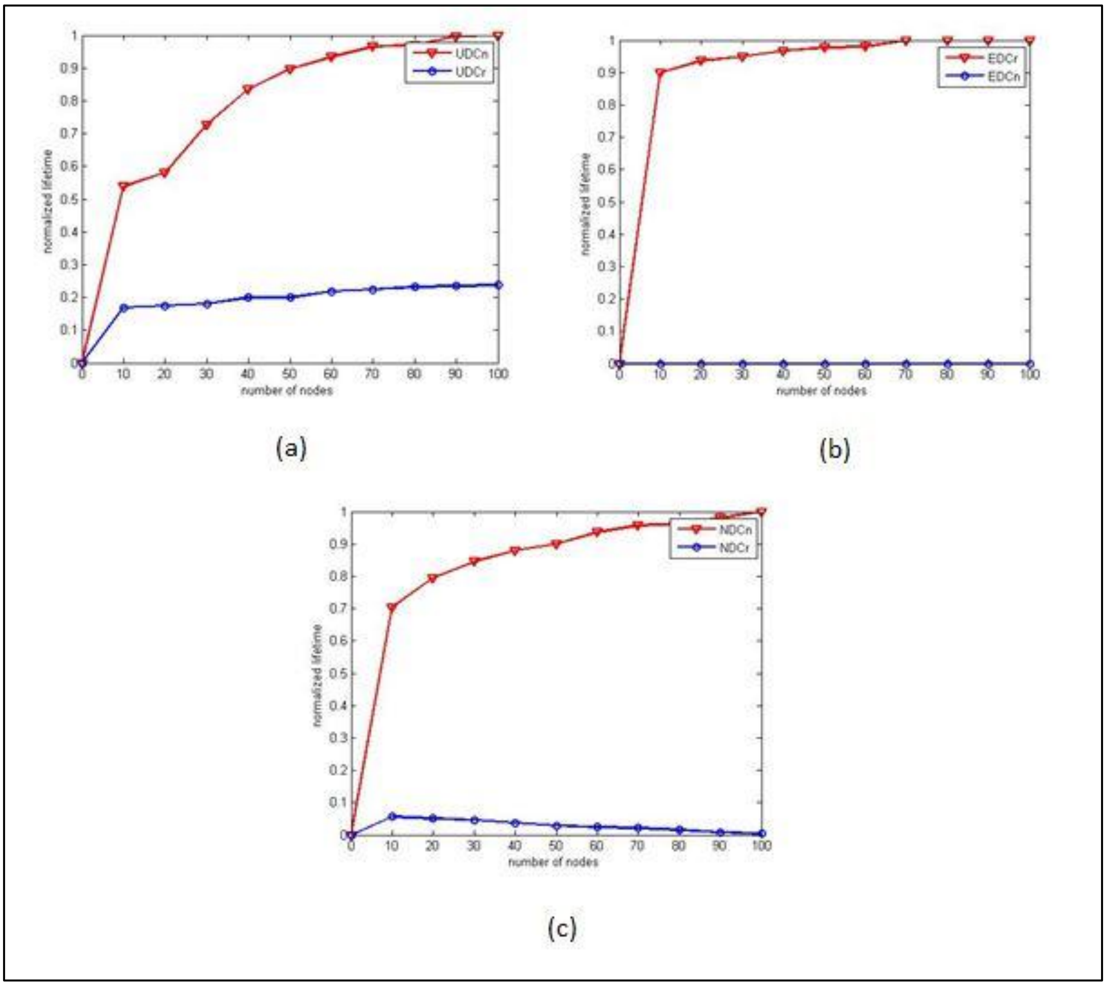

Figure 15 Network lifetime comparison for different base station locations. (a) Uniform distribution. (b) Exponential distribution. (c) Normal distribution

From Fig. 15 we observed that the base station position has a key role in whole network performance. In uniform distribution Fig. 15 (a) we observed that the network lifetime decreases in the scenario where base station in the corner of topology (UDNCr) and we see that energy consumption reduced significantly in (UDNCn). That increase in lifetime is due to in (UDCn) the traffic load is concentrated on the nodes that are one hop away from base station. Hence, base station lays in the center of network and load balance is distributed symmetrically among the nodes that surrounded the base station. In exponential distribution Fig. 15

(b) as we mentioned in pervious section, exponential distribution with base station in the center (EDCn) fails to create a network. However, in the (EDCr) where the base station in the corner of network topology network lifetime increases because the density of nodes are high in the corner of network when we deployed the nodes according to exponential distribution, so numbers of nodes increase near base station. On the other hand, in normal deployment of nodes in Fig. 15 (c) conversely from exponential distribution network lifetime decreases significantly in (NDCr) also we investigated that energy consumption decreases in (NDCn).

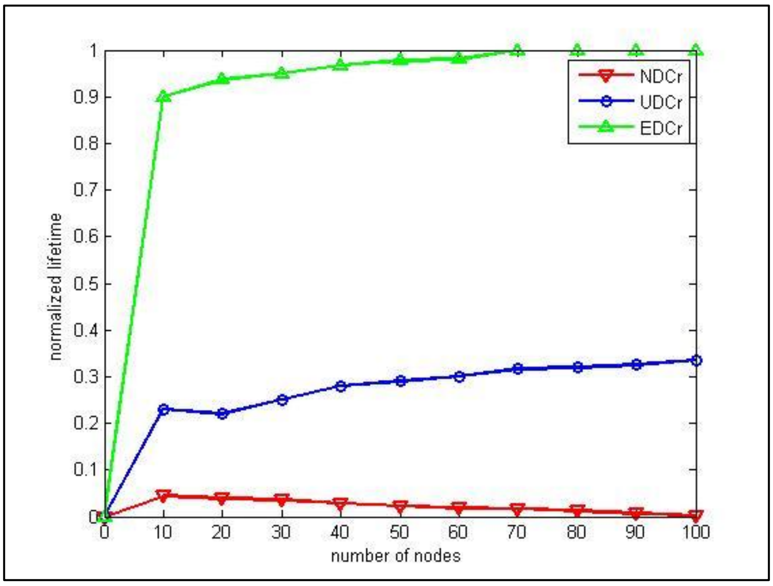

Figure 16 Network lifetime as a function of sensor node number (network area 500 x 500 base station in the corner)

Finally, for the sensor network with base station in the corner, we compared three node deployment models (uniform, normal, exponential) in the term of network lifetime. We take network lifetime as a function of node numbers. However, we got unexpected results in normal distribution of nodes where base station in the corner of network field (NDCr), in such scenario, lifetime decreases by increasing node density. This result could be explained as follows, when the number of nodes increase in normal distribution and according the characteristic of probability density function (3.3), the rate of nodes increase in the center of network area is more than the rate of node increase in the corner (near base station). Therefore, by increasing node density in the network, the traffic load in the nodes near the base station also increases and that ends the network lifetime faster (many to one communication increase). That is clearly illustrated by Fig. 16.

These results refer to the enormous effect of the used distribution topology on energy consumption. Furthermore, these results show the great importance of base station location in the network topology for prolonging the network lifetime.

CHAPTER 6

CONCLUSION

Practical and energy efficient sensor node deployment are enormous need in WSNs. This pushes us to review the existing protocols and find better solutions. In this thesis, we investigate the lifetime of sensor network for uniform and non-uniform distribution of nodes with different base station locations. We studied a mathematical programming (LP) model to explore the impact of base station location on network lifetime and to compare the performance of various node deployment strategies. This approach gives us the chance to do numerical analysis covering a wide range of parameters. Since, the contributions for our thesis are provided in the form of a series of questions, we present our conclusions in reply to these questions. Firstly, we can ensure balancing energy consumption by Gaussian distribution of nodes. We observed that choosing of judicious value of σ (slandered deviation) is utmost important for fulfilling the objective of energy balancing. Secondly, we concluded that by increasing the node density (increasing number of nodes) in network field we can increase the lifetime of network to some extent. Furthermore, Gaussian distribution of nodes with the base station in the center of network area showed better performance than the uniform and exponential distributions. We concluded that assumed distribution topology have great impact on energy utilization. Thirdly, our simulation results show that the base station location in the network topology has great importance for prolonging the network lifetime.

REFERENCES

1. **Akyildiz I. F., Weilian S., Sankarasubramaniam Y., Georgia E. C., (2002),** "*A Survey on Sensor Networks",* IEEE Communications Magazine, pp. 102-114.

2. **Marinho M. A. M., Freitas E. P. D., Costa J. P. C. L., Almeida A. L. F. D., Júnior R. T. D. S., (2013),** "*Using MIMO Techniques to Enhance Communication Among Static and Mobile Nodes in Wireless Sensor Networks*", IEEE 27th International Conference on Advanced Information Networking and Applications, pp. 500-505.

3. **Barbosa P., White N. M., Harris N. R., (2008),** "*Wireless Sensor Network for Localized Maritime Monitoring*", IEEE 22nd International Conference on Advanced Information Networking and Applications – Workshops, pp. 681-686.

4. **Kumar P., Porambage P., Ylianttila M., Gurtov A., (2013),** "*A Mobile Object-based Secret Key Distribution Scheme for Wireless Sensor Networks*", IEEE 10th International Conference on Ubiquitous Intelligence, Computing on Autonomic and Trusted Computing, pp. 656-661.

5. **Rezazadeh J., Moradi M., Ismail A. S., (2012),** "*Mobile Wireless Sensor Networks Overview*", International Journal of Computer Communications and Networks, vol. 2, pp. 17-22.

6. **Shen C., Srisathapornphat C., Jaikaeo C., (2001),** "*Sensor Information Networking Architecture and Applications*", IEEE Personal Communications, pp. 52-59.

7. **Hoblos G., Staroswiecki M., Aitouche A., (2000),** "*Optimal Design of Fault Tolerant Sensor Networks*", IEEE Proceedings of the International Conference on Control Applications, pp. 467-472.

8. **Yoneki E., Bacon J., (2005),** "*A Survey of Wireless Sensor Network Technologies: Research Trends and Middleware's Role*", Technical Reports Published by the University of Cambridge, pp. 1-46.

9. **Shah R. C., Rabaey J. M., (2002),** "*Energy Aware Routing for Low Energy Ad Hoc Sensor Networks*", IEEE Wireless Communications and Networking Conference, vol. 1, pp350-355.

10. **Cum H., Ozdemir S., Nuir P., Muthuavinashiappun D., (2003),** "*ESPDA: Energy-Efficient And Secure Pattern-based Data Aggregation for Wireless Sensor Networks*", IEEE Conference Publications, vol. 1, pp. 732-736.

11. **Perrig A., Stankovic J., Wagner D., (2004),** "*Security in Wireless Sensor Networks*" Communications of the ACM, vol. 47, no. 6, pp. 53-57.

12. **Bulusu N., Estrin D., Girod L., Heidemann J., (2001),** "*Scalable Coordination for Wireless Sensor Networks: Self-configuring Localization Systems*", Proceedings of the 6th International Symposium on Communication Theory and Applications, pp. 1-6.

13. **Iyer R., Kleinrock L., (2003),** "*QoS Control for Sensor Networks*", IEEE International Conference on Communications, vol. 1, pp.517-521.

14. **Kay J., Frolik J., (2004),** "*Quality of Service Analysis and Control for Wireless Sensor Networks*", IEEE International Conference on Mobile Ad-hoc and Sensor Systems, pp. 359-368.

15. **Römer K., Mattern F., (2004),** "*The Design Space of Wireless Sensor Networks*", IEEE Wireless Communications, pp. 54-61.

16. **Chong C., Kumar S. P., (2003),** "*Sensor Networks: Evolution, Opportunities and Challenges*", Proceedings of the IEEE, vol. 91, no. 8, pp. 1247-1256.

17. **Mainwaring A., Culler D., Polastre J., Szewczyk R., Anderson J., (2002),** "*Wireless Sensor Networks for Habitat Monitoring*", ACM Proceedings of the 1st International Workshop on Wireless Sensor Networks and Applications, pp. 88-97.

18. **Feeney L. M., Nilsson M., (2001),** "*Investigating the Energy Consumption of a Wireless Network Interface in an Ad Hoc Networking Environment*", IEEE In Twentieth Annual Joint Conference of the Computer and Communications Societies, Anchorage, vol. 3, pp. 1548-1557.

19. **Heile R. F., Gifford I. C., Shellhammer S. J., Barr J. R., (2003),** "*Standard for Information Technology Telecommunications and Information Exchange Between Systems Local and Metropolitan Area Networks Specific Requirements*", IEEE Computer Society, New York, pp. 13-26.

20. **Li J., Mohapatra P., (2005),** "*An Analytical Model for the Energy Hole Problem in Many-to-one Sensor Networks*", IEEE Vehicular Technology Conference, vol. 4, pp. 1721-1725.

21. **Olariu S., Stojmenovi´c I., (2006),** "*Design Guidelines for Maximizing Lifetime and Avoiding Energy Holes in Sensor Networks with Uniform Distribution and Uniform Reporting*", IEEE Communications Society, pp. 1-12.

22. **Bhardwaj M., Chandrakasan A. P., (2002), "***Bounding the Lifetime of Sensor Networks Via Optimal Role Assignments*", IEEE In Twenty-First Annual Joint Conference of the Computer and Communications Societies INFOCOM, vol. 3, pp. 1587-1596.

23. **Yu Y., Krishnamachari B., Prasanna V., (2008),** "*Data Gathering with Tunable Compression in Sensor Networks*", IEEE Transactions on Parallel and Distributed Systems, pp. 276–287.

24. **Bista R., Kim Y., Choi Y., Chang J., (2009),** "*A New Energy-balanced Data Aggregation Scheme in Wireless Sensor Networks*", IEEE International Conference on Computational Science and Engineering, pp. 558-563.

25. **Liang W., Xu J., Liu Y., (2011),** "*Towards Energy Saving and Load Balancing Data Aggregation for Wireless Sensor Network*", Information Technology Journal, pp. 409-415.

26. **Wang W., Srinivasan V., Chua k., (2005),** "*Using Mobile Relays to Prolong the Lifetime of Wireless Sensor Networks*", ACM In Proceedings of the 11th Annual International Conference on Mobile Computing and Networking, pp. 270-283.

27. **Rao J., Biswas S., (2010),** "*Network-assisted Sink Navigation for Distributed Data Gathering: Stability and Delay-energy Trade-offs*", Computer Communications, vol. 33, no. 2, pp. 160–175.

28. **Xie L., Hou Y. T., Sherali H. D., (2012),** "*Making Sensor Networks Immortal: An Energy-renewal Approach with Wireless Power Transfer*", IEEE Transactions on Networking, vol. 20, no. 6, pp. 1748-1761.

29. Lin K., Chenb M., Zeadally S., Rodrigues J. J. P. C., (2012), "*Balancing Energy Consumption with Mobile Agents in Wireless Sensor Networks*", Future Generation Computer Systems, pp. 446-456.

30. **Liang X., Li W., Gulliver T. A., (2008),** "*Distributed Transmission Power Control for Wireless Sensor Networks*", IEEE Communication Networks and Services Research Conference CNSR, pp. 417-421.

31. **Azad A. K. M., Kamruzzaman J., (2011),** "*Energy-balanced Transmission Policies for Wireless Sensor Networks*", IEEE Transactions on Mobile Computing, vol. 10, no. 7, pp. 927–940.

32. **Soua R., Minet P., (2011),** "*A Survey on Energy Efficient Techniques in Wireless Sensor Networks*", IEEE 4th Joint in Wireless and Mobile Networking Conference (WMNC), pp. 1-9.

33. **Yu Z. H., Liu Y., Cai Y. L., (2008),** "*Design of an Energy- efficient Distributed Multi-level Clustering Algorithm for Wireless Sensor Networks*," Proceedings of IEEE 4th International Conference Wireless Communications, pp. 1-4.

34. **Kumar V., Jain S., Tiwari S., (2011),** "*Energy Efficient Clustering Algorithms in Wireless Sensor Networks: A Survey*", IJCSI International Journal of Computer Science Issues, vol. 8, no. 2, pp. 259-268.

35. **Rauthan J. S., Mishra S., (2012),** "*An Improved Approach in Clustering Algorithm for Load Balancing in Wireless Sensor Networks*", International Journal of Advanced Research in Computer Engineering and Technology, vol. 1, pp.196-202.

36. **Wu X., Chen G., Das S. K., (2008),** "*Avoiding Energy Holes in Wireless Sensor Networks with Nonuniform Node Distribution*", IEEE Transactions on Parallel and Distributed Systems, vol. 19, no. 5, pp. 710-720.

37. **Poe W. Y., Schmitt J. B., (2009),** "*Node Deployment in Large Wireless Sensor Networks: Coverage, Energy Consumption, and Worst-case Delay*", ACM Proceeding of Asian Internet Engineering Conference, pp. 77-84.

38. **Liu A. F., Wu X. Y., Chen Z. G., Gui W. H., (2010),** "*Research on the Energy Hole Problem Based on Unequal Cluster-radius for Wireless Sensor Networks*", Computer Communications, vol. 33, no. 3, pp. 302-321.

39. **Yuan J., Ling Q., Yan J., Zhang W., Gu H., (2011),** "*A Novel Non-uniform Node Distribution Strategy for Wireless Sensor Networks*", IEEE Chinese Control and Decision Conference (CCDC), pp. 3737-3741.

40. **Boukerche A., Efstathiou D., Nikoletseas S. E., Raptopoulos C, (2012),** "*Exploiting Limited Density Information Towards Near-optimal Energy Balanced Data Propagation", Computer Communications*, vol. 35, pp. 2187-2200.

41. **Yun Y., Xia Y., (2013),** "*A Method for Deciding Node Densities in Non-uniform Deployment of Wireless Sensors*", 11th International Symposium and Workshops on Modeling and Optimization in Mobile Ad Hoc and Wireless Networks, pp. 1-8.

42. **Rahimi M., Baer R., Iroezi O. I., Garcia J. C., Warrior J., Estrin D., Srivastava M., (2005),** "*Cyclops: In Situ Image Sensing and Interpretation in Wireless Sensor Networks*", ACM Proceedings of the Conference on Embedded Networked Sensor Systems, pp. 192–204.

43. **Cheng Z., Perillo M. A., Heinzelman W. B., (2008),** "*General Network Lifetime and Cost Models for Evaluating Sensor Network Deployment Strategies*", IEEE Transactions on Mobile Computing, pp. 484-497.

44. **Heinzelman W. B., Chandrakasan A., Balakrishnan H., (2002),** "*An Application Specific Protocol Architecture for Wireless Microsensor Networks*", IEEE Transactions on Wireless Communications, pp. 660-670.

45. **Ergen S. C., Varaiya P., (2005),** "*On Multi-hop Routing for Energy-efficiency*", IEEE Communications Letters, pp. 880-881

46. **Tavli B., Heinzelman W. B., (2006),** "*Mobile Ad Hoc Networks: Energy-efficient Real-Time Group Communications*", Springer, 2006, ISBN.

47. **Bicakci K., Gultekin H., Tavli B., (2009),** "*The Impact of One-time Energy Costs on Network Lifetime in Wireless Sensor Network*s", IEEE Communications Letters, vol. 13, pp. 905–907.

48. **Cheng M., Gong X., Cai L., (2009),** "*Joint Routing and Link Rate Allocation Under Bandwidth and Energy Constraints in Sensor Networks*", IEEE Transactions Wireless Communications, vol. 8, pp. 3770–3779.

49. **Dantzig G. B., (1998),** "*Linear Programming and Extensions*", Princeton university press, pp. 1-656.

50. **Chinneck J. W., (2004),** "*Practical Optimization: a Gentle Introduction*", http://www. sce. carleton. ca/faculty/chinneck/po. html. (Data Download Date: 5 May 2014).

51. **Wolsey L., (1998),** "*Integer Programming*", Wiley Inter Science Publication, pp.1-288.

52. **Ozyer S. T., Tavli B., Dursunc K., Koyuncu M., (2013),** "*Systematic Investigation of the Effects of Unidirectional Links on the Lifetime of Wireless Sensor Networks*", Journal of Computer Standards and Interfaces, pp. 132-142.

53. **Rosenthal R. E., (2015),** "*GAMS: A User's Guide*", GAMS Development Corporation, Washington, pp. 1-295.

APPENDICES A

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: MAHMOOD, Ozlam,

Date and Place of Birth: 06 September 1979, Iraq Kirkuk

Marital Status: Married

Phone: +905398342228, +9647701326110

Email: ozlem_1979@yahoo.com

EDUCATION

Degree	Institution	Year of Graduation
M.Sc.	Çankaya University, Computer Engineering	2015
B.Sc.	Technical College of Mosul, Computer Technology Engineering Department	2002
High School	Al-Huda / Scientific Section	1997

FOREIGN LANGUAGES

Arabic, Turkish, Advanced English.

HOBBIES

Traveling, Crocheting, and Cooking.