ENERGY EFFICIENCY IN WIRELESS SENSOR NETWORKS

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ENERGY EFFICIENCY IN WIRELESS SENSOR NETWORKS

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ABSTRACT

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Wireless Sensor Networks (WSNs) are consists of small sensor nodes with limited battery power, processing and memory units. There are two important features in WSNs. The first one is the infrastructure-less and second one is the self-organization. These properties make sensors convenient choice for several applications. When we try to investigate algorithms and protocols for wireless sensor networks we must study the features and constraints of WSNs. However, battery recharge is not possible or extremely challenging for sensor nodes. The main aspect in designing wireless sensor networks algorithms and protocols is ensuring energy efficiency and prolong the sensor network lifetime. Farther more the sensor node position within the set of deployed nodes decides which tasks have to be carried out and how many communication paths involve each individual sensor node. On the other hand the sensor networks in more obstructed environments, the path loss exponent value is vary. The high path loss exponent value increases unbalance energy depletion between nodes. In this thesis we investigated two node deployment strategies which are uniform and non-uniform (normal distribution) sensor node deployments with various path loss exponent values. We used a Linear Programming (LP) framework to analyze the effect of node deployment model on the network lifetime. Also we studied the effect of path loss on the wireless sensor network lifetime. Our results showed that by normal node deployment, energy balance can be improved up to certain level. However, increasing path loss exponent in normal node deployment may lead to decrease in improvement ratio.

Keywords: Wireless Sensor Networks, Network Lifetime, Path Loss.

ÖZ

KABLOSUZ ALGILAYICI AĞLARDA ENERJİ VERİMLİLİĞİ

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Kablosuz Algılayıcı Ağlar (KAA), sınırlı pil gücü, işlemci ve bellek birimi ile küçük algılayıcı düğümlerinden oluşmaktadır. KAA' larda iki önemli özellik vardır. Birincisi altyapısızlıktır ve ikincisi özörgütlenmedir. Bu özellikler, algılayıcıları birçok uygulama için uygun bir seçim yapar. KAA' larda algoritma ve protokolleri incelemeye çalışırken, KAA' ların özelliklerini ve kısıtlarını çalışmaktayız. Ancak, algılayıcı düğümler için pil şarjı mümkün değildir veya son derece zordur. KAA' larda algoritma ve protokollerin tasarımında, en önemli husus enerji verimliliğini sağlamak ve algılayıcı ağ ömrünü uzatmaktır. Bundan başka, dağıtılan düğüm kümesi içinde, algılayıcı düğüm pozisyonu hangi görevlerin yürütüleceğine ve her bir algılayıcı düğüm için kaç iletişim yolu içerdiğine karar verir. Öte yandan, KAA' larda engellenmiş ortamlarda, yol kaybı değeri değişir. Yüksek yol kaybı üssü değeri, düğümler arasındaki dengesiz enerji tüketimini artırır. Bu tezde, tekdüze ve düzensiz ağ düğüm dağıtımı olarak, iki düğüm dağıtım stratejisi ile birçok yol kaybı üssü değerleri araştırıldı. Ağ ömründe, düğüm dağıtım modeli etkisini analiz etmek için doğrusal programlama yapısını kullandık. Ayrıca kablosuz algılayıcı ağ ömrü üzerindeki yol kaybının etkilerini inceledik. Bizim sonuçlarımız, normal düğüm dağıtım yoluyla, enerji dengesinin belli bir seviyeye kadar geliştirilebilir olduğunu gösterdi. Ancak; normal düğüm dağıtımında, artan yol kaybı üssü, iyileşme oranı azalmasına yol açabilir.

Anahtar Sözcükler: Kablosuz Algılayıcı Ağlar, Ağ Ömrü, Yol Kaybı.

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LIST OF ABBREVIATIONS

WSNs	Wireless Sensor Networks
LP	Linear Programming
α	Path Loss Exponent
DARPA	Defense Advanced Research Project Agency
TRSS	Tactical Automated Security System
MEMS	Micro Electro Mechanical System
A/D	Analog / Digital
RF	Radio Frequency
PC	Personal Computer
MSN	Mica Sensor Node
MWB	Mica Weather Board
CSMA/CA	Carrier Sense Multiple Access / Collision Avoidance
MAC	Medium Access Control
TDMA	Time Division Multiple Access
E-LEACH	Energy-Low Energy Adaptive Clustering Hierarchy
e3D	Energy Efficient Distributed Dynamic Diffusion Routing Algorithm
BFS	Breadth-First Search
THT	Tri-Hexagon Tiling
GAMS	General Algebraic Modeling System

CHAPTER 1

INTRODUCTION

The wireless sensors nodes are answerable to observe natural events from the target area. Therefore, all data collected by the nodes must be sent to a task manager for extra processing. Development in the techniques helped in manufacturing of low cost, small size, low battery electronic devices are called sensor nodes which are also have sensing and wireless communication abilities. By these nodes it can easily build a self-organizing sensor network for information collecting and sending by using sensor nodes components.

One of the most important design limitations in sensor network is sensor node energy efficiency. The lifetime of each node based on its battery consumptions. In wireless sensor network implementation where the nodes are not prepared with devices acquires energy like solar cells; nodes with consumed batteries cannot work longer. Furthermore, the sensor act as forwarder nodes to forwarding other sensor nodes data to the base station, sensor network connectivity drops progressively. This may cause disconnections in of some parts of the sensor network, by other words; particular fractions of the sensor network cannot be connected to the whole network anymore. Therefore, the level of energy depletion needs to be taken in to account at all phase in sensor network design.

1.1 Thesis Aims and Motivation

Sensor node placement is a vital issue in sensor networks. Many facts of network operation affected by node deployment in the sensor networks, including battery management, network routing, network security, etc. There are generally two types of sensor node deployment classified in to random and deterministic node deployment.

The lifetime of sensor network is based on the sensor node deployment strategy. Because the sensor nodes placed at one hop away from the base station must be transmit data from other sensors to the base station. These transmission causes earlier depletion of energy in these nodes. Because of these nodes consume extra energy for data reception and retransmission. When such first hop sensor nodes have drained their energy, it is useless while other sensor nodes in the network may have enough residual energy. If any of the sensor nodes in the network exhausts its energy and dies, the whole network dies. Therefore, the unbalance depletion of energy in the sensor network affects the entire network and that leads to early ending of sensor network lifetime.

On the other hand, the sensor networks in more obstructed environments where path loss exponent (α) is more than 2 (α is changing between 3 to 5 depending on the network environment) that obstructed environment causes more channel power loss. The path loss exponent α has a large effect on energy waste at the sensors, so the transmitting energy is relative to d_{ij}^{α} according Eq. 4.1. Therefore, where the α is incremented the transmission range t_r reduced for the same values of transmission energy. Thus, the nodes can be communicated with the base station only from shorter connections distance, thus they use the nodes that near to base station as rely to forward their data. Since, all nodes in the network try to deliver collected data to the base station so the nodes near the base station have more traffic load epically in obstructed environments with α great than 2.

From these points, node scattering model is a crucial issue in sensor networks in free space and also in more obstructed environment. The provident deployment of sensor nodes, according to sensor networks environment, is one of the essential techniques for energy saving.

1.2 Thesis Contributions

There are three contributions of this thesis. Firstly, we analyzed the effect of normal and uniform node deployment strategies on the performance of sensor networks in the term of lifetime for different values of transmission range (t_r). Secondly, we also studied the impact of path loss modeling on sensor networks. Indeed, the different path loss exponent α values are given by different models has been studied. Path loss was affected by terrain contours, network environment (urban or rural, vegetation and foliage), transmission medium (dry, wet air and under water) and the distance between the transmitter and the receiver. All that showed significant variations in α values. However, how do these differences in path loss exponent values affect the network lifetime in uniform and normal deployment of sensor nodes? Hence, this question had not been studied well in the wireless sensor networks. Finally, we studied network lifetime as a function of number of nodes in the sensor networks (node density). We evaluated the performance of sensor networks in the term of lifetime on free space and two ray models for uniform and normal sensor node deployment .In order to do our analyses we used a novel LP to model and investigate energy consumptions and determine lifetime of sensor networks.

1.3 Thesis Organization

The rest of the thesis was structured into five chapters. In chapter 2, we intended to give the reader comprehensive understanding of wireless sensor network.

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

In chapter 4, we introduced system assumptions and describe system model .A novel LP framework was developed to model energy consumption in the network with different node deployment strategies and different propagation models.

In chapter 5, we displayed the result of our study to examine several aspect of the network lifetime. The effects of transmission range, node density, path loss exponent 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 Wireless Sensor Networks (WSNs)

In September 1999, business week indicated that wireless sensor networks technology the most important among the 21 technologies for the 21st century. Fundamentally, current research on wireless sensor network technology dating from distributed sensor network program that was originated by Defense Advanced Research Project Agency (DARPA) about 1980. Anyway, sensor nodes have developed by providing smaller and cheaper and current sensor networks may achieve functions that could not be possible at that time. In Fig. 1 [1] we can realize the development of sensor nodes in time. In the figure sensor nodes are classified in to three generations. The first generation of sensors is the Tactical Automated Security System (TRSS) nodes from 1980's to 1990's, which a few kilograms in weight and their size are as large as a shoe-box or even larger size. The next three sensors in the figure are manufactured by crossbow, ember and sensoria companies from 2000 to 2003. These sensors are lighter and smaller than TRSS sensors. Eventually, the sensor nodes from dust, Inc., their size are possible to be as the size of dust particle with the Micro Electro Mechanical System (MEMS) technology. This fast development shows us, in the future, wireless sensor network technology will change our lives significantly [1].

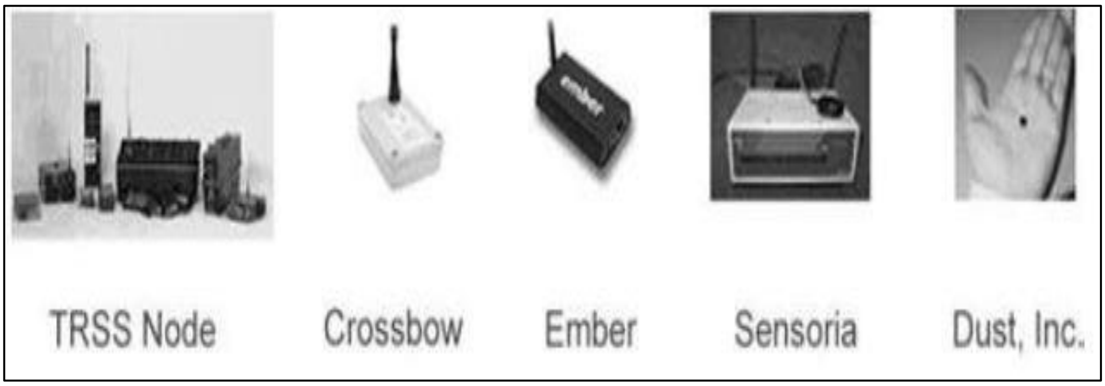

Figure 1 Three groups are of sensor nodes [1]

Usually, a wireless sensor network contains of large number of low energy and low price sensor nodes as we have discussed previously. The locations of nodes are not basically need to be determined and the sensor nodes are typically scatter in an random manner in target area, as we see from Fig. 2 [2]. All of the sensor nodes in the network area have sensing, processing and communication abilities. Via utilization these functionalities, data gathering collaborative action is carried out by creating a wireless sensor networks.

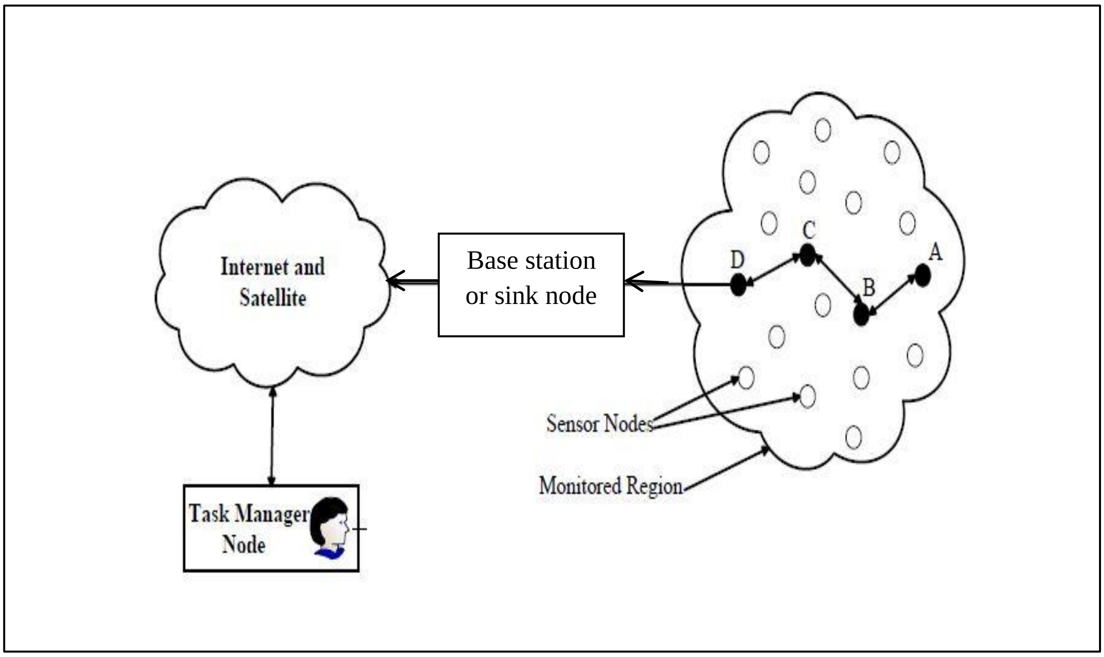

Figure 2 Sensor nodes in a domain [2]

As showed in Fig. 2 the final destination of the gathered data is a base station/sink node that may be positioned in or close to the sensor networks. The major function of all nodes is to transmit data to the base station or sink node. Once data reaches to the sink node, it achieves required activities such as data transmitting over internet or a satellite network to a task manager. The major dissimilarity between normal sensor nodes and sink node is that, the sink node is generally expected to have unlimited battery energy which is not possible in normal sensor nodes. Normal sensor nodes are usually provided with not rechargeable batteries and their batteries are not possible to be replaced. Therefore, sensor nodes must use their energy supply carefully [2].

2.2 Sensor Nodes Hardware's

As shown in Fig. 3 sensor node consists of sensitive cells, which converts physical measured value in to electrical signal to be conveniently for many applications. According to the sensor type, it can measure various physical phenomenon's from environment such as temperature, vehicular movement, lightning conditions, noise levels, etc.

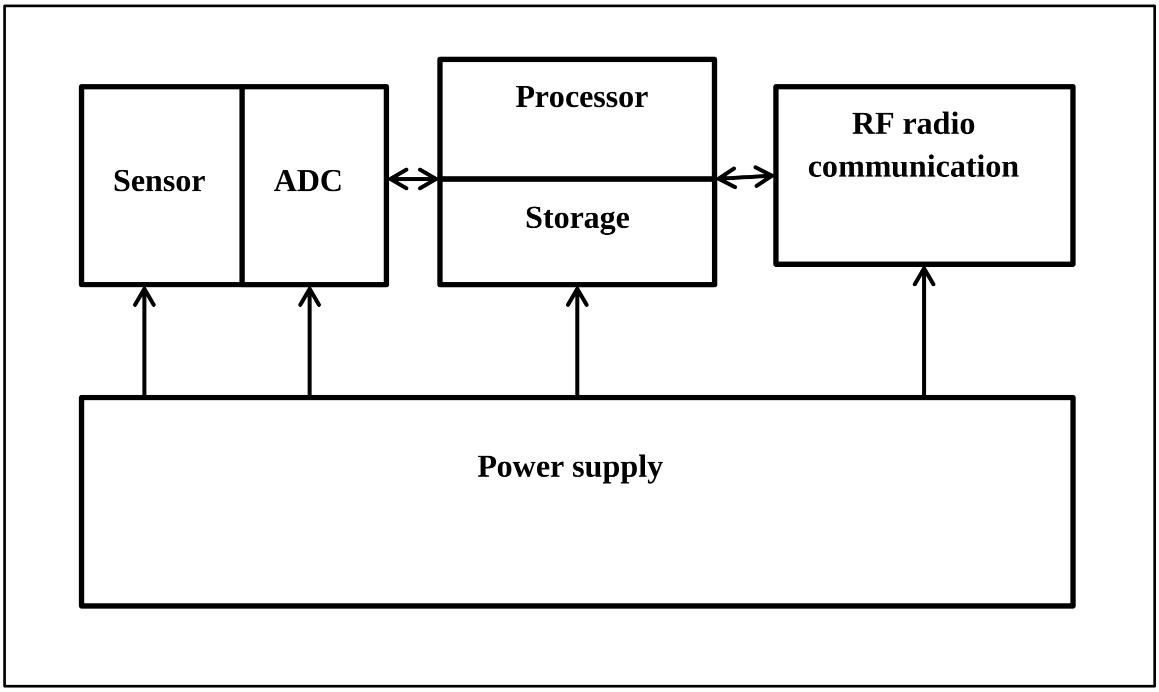

Figure 3 A typical sensor node components

A typical sensor node consists of the following units [3-4-5].

- A power supply or battery unit, which contains of tiny battery with DC-DC converter to provide suitable voltages needed by the electronic circuits of sensor node.

- Physical sensing device, for example thermoelectrically sensors to mensuration temperature of environment, infrared sensors to detect the existence or absence of the objects, acoustic sensors to observer the interesting sounds, and seismic sensors to observe and calculate earthquakes. The types of employed sensors node are decided by the applications according sensing tasks.

- An Analog /Digital (A/D) convertor to convert the analog signals sensed by a sensor node to the digital signals.

- A radio communication RF unit, typically the power of transmitting data by radio communication unit can be turn in to different values.

- A simple microprocessor computer systems for digital signals processing that send from the A/D convertor, and to monitor and control the activities of the sensor node, and to carry out other necessary software such as communication protocols.

2.3 Main Challenge in Sensing with Sensor Nodes

Sensor nodes are physically deployed in target area for data gathering about interesting physical events. Such in-situ sensing method simplifies and controlling physical environments accurately [6]. In addition, sensor nodes are low cost. Farther more In-situ sensing device is more cost-effective, compared with remote sensing devices such as sonars, satellites and radars. These features motivate many researchers' attention [2-7-8].

A sensor node is usually provided with a small battery. Sensor nodes suffer from restricted energy resource. Situation becomes worse where manually recharging of nodes is commonly not possible, also, because the high cost of sensors and it usually operate in unreachable area. Even in some applications where sensor nodes can work in an inimical environment, recharging them is impossible.

To extend the whole lifetime of sensor network to satisfy typical requirements which can be estimated from months to years, so, energy efficiency considered an important software and hardware design consideration of wireless sensor nodes [3-4-5-9].

2.4 Sensor Nodes Networking

During the large research efforts for researchers that put their focus on enable environmental sensing with sensor nodes, a most important problem is how to build network from such sensor nodes. As sensor nodes are with low processing and sensing abilities because of their generally low-cost properties, so, networking a big number of nodes can increase the total number of nodes, in addition to the improve accuracy of the data collected by the sensor nodes [6].

At suggested implementations of environmental sensing and monitoring with sensor nodes, a number of nodes are scattered to gather data about interesting physical phenomena. The ad hoc multi-hops wireless network formed by sensor nodes which it transmit the collected data to collectors, e.g., portable devices such as laptop computers and pads. These collectors of data are named sink nodes or base station. Sinks are generally with unlimited computational abilities and energy. It also has ability to communicate with other computers, if they are linked to the internet. Sink is that special node which the outside world gets the data from the other sensor nodes and also the node which outside world control the performances of the sensors. These networks are stated as wireless sensor networks.

2.5 Applications of Wireless Sensor Networks

WSNs are born to backup various applications, thanks to its abilities in capturing environmental information. Generally, the applications are classified in to tracking and monitoring of environments and events.

The main classifications of wireless sensors networks applications can be separated into three groups and any application will fall into one of these categories; those are:

1. Data aggregation for environmental applications.
2. Monitoring, security and surveillance.
3. Tracking of object.

As we mentioned previously, research on sensor networks has been initially driven by military applications. There applications are varies from acoustic surveillance large-scale systems for ocean surveillance to small sensor networks for Detection of enemy ground [1]. However, recent development in technologies makes many other potential applications possible such as traffic control, habitat monitoring, infrastructure security, etc. That can be widely classified into military, environmental, home and health and other commercial fields as follows: [2].

Military Applications: wireless sensor networks can be utilized in battlegrounds, as sensor nodes are low cost and simply can be deployed with large numbers everywhere in a field. Several of the military applications may include monitoring equipment. That monitors ammunition and friendly forces in which it make possible to see the latest status of the desired equipment by commanders. Battleground observation in which routes and critical paths can be observed carefully for the enemy forces; battle damage estimation simply before or after attacks and biological, chemical or nuclear attack recognition and detection in which a sensor network can be used as a biological or chemical alarming system.

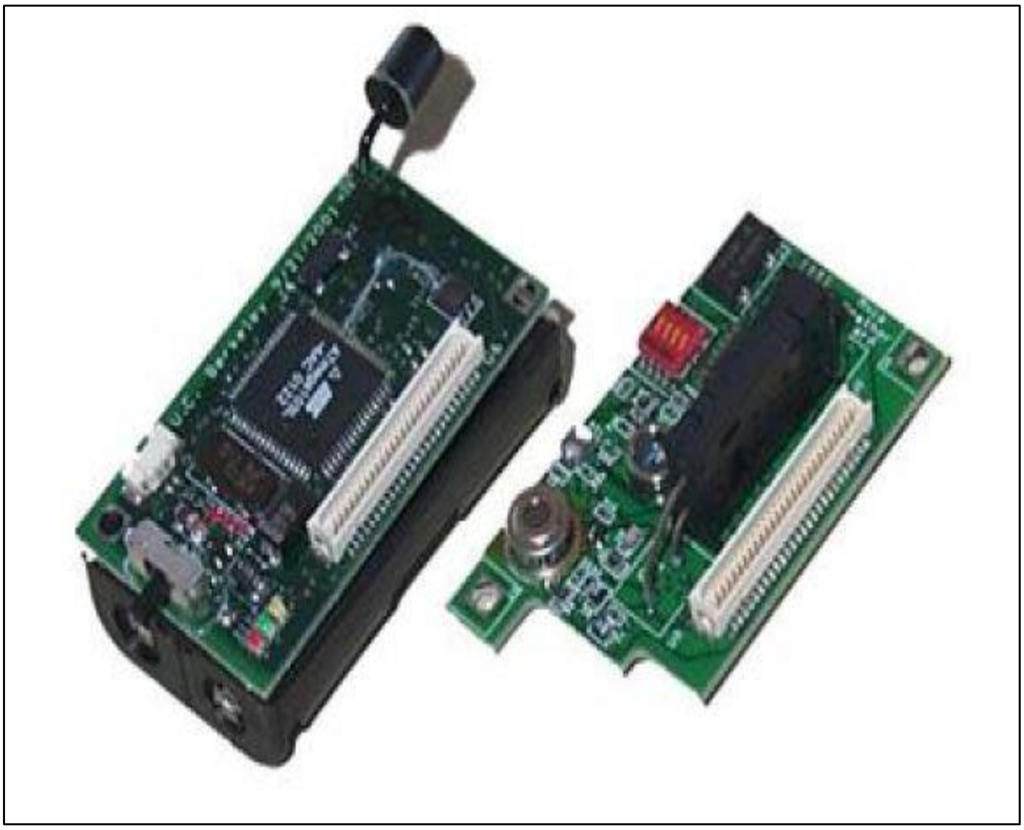

Figure 4 Mica sensor nodes and mica weather board [10]

Environmental Applications: wireless sensor networks can also be a perfect method for environmental monitoring. In Fig. 4 as we showed Mica Sensor Node (MSN) (on the left side) and Mica Weather Board (MWB) (on the right side) involved for the applications of environmental monitoring. A sensor node with acrylic enclosure scatter in the target area can be shown in Fig. 5.

Some of these environmental applications are, forest fires disclosure in which nodes heavily deployed in a forest can forward the exact destination of the node before it is scattered, flood detection in which various classes of nodes such as water level weather, rainfall sensors are utilized in an warning system, discovering precision agriculture and finally it used to observe level of erosion in soil or level of pollution in air [10].

Figure 5 Deployed sensor nodes with acrylic enclosure [10]

Health Applications: wireless sensor networks can also be used in human body to physiological data observing which provide a greater movement freedom to patients than treatment centers, monitoring and tracking patients and doctors in hospitals and medicine administration in hospitals in which nodes can be attached to medicaments so that will minimize the chance of getting the wrong medication.

Home Applications: home applications comprise home automation where smart wireless sensor nodes can be placed into home devices, such as refrigerators, vacuum cleaners, ovens, to provide them interact capability with each other and with an peripheral networks thus, they can be controlled and managed remotely or locally; and build smart environment where nodes can be placed into appliances and furniture's so it can communicate with each other and with devices in other rooms to control the offered services.

Other Commercial Applications: some of the commercial applications such as office buildings environmental control in which wireless sensor network distributed systems can be set up to monitoring the flow of air, interactive museums in which children can interact with museums objects to discover more about them, monitoring or discovering car stealing, inventory control managing in which each item provided with a sensor node that detect the exact position of that item [2-11].

2.6 Research on Network Lifetime

Network lifetime is one of the most important parameters that must be maximized in wireless sensor networks. Many studies deal with this problem, but every time according to the targeted application they derive their own definition of sensor network lifetime. In this section we offer a summarized overview of some of these lifetime definitions and concerning efforts to maximize the sensor network lifetime. Finally, we choose the suitable definition and our sensor network model depends on these definitions.

2.6.1 Definitions of network lifetime

The most challenging issue in wireless sensor networks design that is how to save energy of nodes while preserving the appropriate network performance. Any sensor network can only achieve its task as long as it is considered alive, but not after that. As a result, the aim of any technique of energy efficiency is to maximize sensor network lifetime. Network lifetime depends significantly on any single node`s lifetime. Conversely, in the literature studies, there is no agreement on the definition of network lifetime. The most of authors uses a suitable definition for their network model. This circumstance has motivated to a coexisting plethora definitions. Depending on the preceding works on wireless sensor networks, the most common definition of network lifetime has been provided as a summary.

2.6.1.1 Network lifetime in WSNs based on the number of nodes alive

This is one of the most frequently certified definitions for network lifetime. Within this definition, many works simply consider the time when the first node dies [12]. This definition is sometimes very conservative, as WSNs can still provide a lot of data after the death of the first node unless every node is critical and the application cannot lose even one node. Some other work, such as [13], identifies the network lifetime as the time when part of the nodes in the network dies. This definition is the most suitable for a lot of sensor networks applications. The most overdo definition of network lifetime is the time when all nodes dies [14]. But, this last definition is not suitable when he spoke network partitions. For example, if a live node does not have a path to the sink, the node remaining energy is become useless, but it is still instrument an effective node.

2.6.1.2 Network lifetime on the basis of number of nodes linked to the sink

Compared to the previous definitions, this one is more suitable for carefully data collection applications. Some works additionally dispute that the node importance should also be considered in the definition of sensor network lifetime [15]. But the necessity to include the importance of sensor nodes only applies if there are some special mechanisms running on the network, like data aggregation.

There are several network lifetime definitions, but they are either restricted by particular applications [16] or inflexible to trace [17]. For instance, there is a definition based on sensor coverage which there is only a few vital areas of interest to monitoring [18] but we do not want to use this definition because they are application specific.

In our work, we will use the definition of network lifetime that focuses on the death of the first node. Considering a network of N nodes, we monitor these nodes to realize if it still has energy to communicate.

2.7 Energy Consumption in Wireless Networks

In addition to the send and receive cases, a sensor node can be in the idle or sleep mode. In following section we present and explain each state of sensor nodes.

2.7.1 Energy states

A sensor node can be in one of the following four states: transfer, receive, idle or sleep. In each mode, node consumes a different power level see Tab. 1.

- **Transmit:** sensor node in transmitting mode with transmission power E_{txij}.
- **Receive:** sensor node is in receiving state with reception power E_{rx} . This framework can be interpreted by this node or not, it can be proposed to this node or not.
- **Sleep:** the communication devices are turned off, the sensor node cannot detect signals and communication is not possible. The sensor node use E_{sleep} that is significantly smaller energy than any other sensor modes energy so, the energy depletion is minimum.
- **Idle (listen):** even while no data are transmitted over the medium, the sensors stay idle and still listen to the medium withE_{idle}.

Table 1 Power Value in Each Radio States

State	Power value (Watt)		Current (mA)
	802.11	802.15.4	802.15.4
Transport	1.3	0.1404	33.1
Received	0.9	0.1404	33.5
Idle	0.74	-	-
Sleep	0.047	0.000018	0.005

In Tab. 1 we report the reference values of energy depletion in each mode taken from a Lucent Silver Wavelan PC card [19] employing the IEEE 802.11b medium access and a ZigBee sensor node [20] employing IEEE 802.15.4 medium access. In both cases, we can observe that the smallest energy consumption state is the sleep state. However, the energy used in transmitting and receiving state is near for the IEEE 802.15.4 medium access.

2.7.2 Reasons of energy consumption in the network

In wireless ad hoc and sensor node networks, sensors consume energy in processing, receiving and transmitting data. This energy is required for proper working of the wireless sensor networks. The subsystem of sensing is assigned to data collecting. It is clear that minimizing data removed from transducer will save power of all sensors. Inherent redundancy of wireless sensor networks will yield enormous similar reporting and the sensor network is answerable for routing that reports to the base station. The results of experimental approve that subsystem of communication is a main source of energy consumptions. Additionally to this energy, there is a major amount of energy lost in states that are unusable from the application point of view, such as:

- **Idle Listen:** as a sensor node does not know when it will receive a data it must always listen to the medium and thus it stays in the idle mode. As we mentioned in Tab. 1 the energy used in idle mode is close to the energy used in receive mode.

- **Overhearing:** when a sender node transmits one data packet to next hop, as a result of the shared nature of wireless medium, all neighbor nodes of the source node will receive this data even if it is proposed to only one of them. Therefore the overhearing is the energy wasting when the sensor node is in one hop away from the sender and is not the target destination.

- **Interference:** each sensor node placed between transmitting range and interference range receives this packet but it cannot decode the packet.

- **Collision:** in situation of CSMA/CA medium access, when a collision occurs, the energy consumed for the transmission and reception of colliding frame is lost.

- **Control Packet Overhead:** to support data transmissions a least number of control packets should be used.

The energy constrained nature of wireless nodes requires the use of energy efficient strategies to reduce the wasted energy in these unusable modes and therefore this causes the maximization of sensor network lifetime. Therefore the network lifetime has become the crucial characteristic for wireless sensor networks, full range of techniques intended to minimize energy consumption and improve sensor network lifetime. In the next section, we describe and classify works aimed at minimize energy consumption and improve network lifetime.

CHAPTER 3

LITERATURE REVIEW ABOUT ENERGY EFFECT TECHNIQUES

3.1 Techniques to Prolong Network Lifetime

WSNs application scenarios often contain nodes with battery energies being alive for a long time, without any human interaction after initial deployment of nodes. In the lack of battery saving techniques, sensor node would exhaust its battery energy within a few days. Hence, reducing consumption in battery energy is a main objective in wireless sensor networks. As, the sensor nodes act as both source of data and router for another nodes data [2]. Data flow based on many to one communication model. Sensor nodes closer to the sink or base station have more data transmission load. For this reason, sensor nodes nearby the sink would exhaust their battery energy sooner resulting in that termed as an energy hole around the sink .If this occurs, no data any more can be delivered to the base station or sink . Thus, the sensor network lifetime terminates faster and another nodes residual energy would be wasted.

In this paper Yunxia Chen and Qing Zhao originated a broad method for prolonging lifetime of wireless sensor networks which carry’s autonomously of the fundamental sensor network model, architectures and protocols of sensor network and data gathering beginning. These formulations classified in two main parameters at the network physical layer and that effect sensor network lifetime that means, the status of channel and the residual energy of sensor nodes. It offers performance measure to evaluate network model and improve sensor network lifetime. According to the formula, they suggested a Medium Access Control (MAC) protocol this algorithm has used both the remaining energy information and channel of each sensor node. The approach of protocol is maximizes the minimum remaining energy through the network in each compilation of data [21].

In this paper Fatma Othman, Nizar Bouabdallah and Raouf Boutaba evaluated the saving of available energy which is realized by data flow traffic balancing. They studied and concluded that distributing data traffic by multiple paths save more energy than the using only single path therefore; energy efficiency is improved in multi path model. A new analytical model for load balancing system has been introduced [22].

In this paper Isabel Dietrich and Falko Dressler presented the algorithm that used in analytic estimations in addition to the simulation models to concentrating on a brief and formal definition of sensor network that has been collected and its entire network lifetime. This algorithm presents some additional lifetime computation to the network lifetime. It purposed new idea to create network that disruption and tolerance free. By providing additional is a new feature to satisfy the requirement in certain period of time instead of all time. By this connectivity and coverage is also combined to compose a single requirement named connected coverage. They showed that the connected coverage is dissimilar to non-combined connectivity and coverage. Furthermore, the algorithm supports the graceful degradation idea by providing means of approximating the compliance degree with the requirement of applications [15].

In this paper Rahim Kacimi, Riadh Dhaou and Andr´e-Luc Beylot they analyzed and proposed the schemes for energy consumption balancing in nodes and guarantee improving in network lifetime by balancing data traffic load as equally as possible they assumed that network lifetime is defined to be the instant when the first sensor node dies. They also studied energy balancing strategies to prolong the lifetime of sensor network. Depending on load balancing techniques, they obtain an ideal solution and use an experimental technique that comparison with, other routing techniques like shortest-path routing [23].

After we study the professional works about load balance techniques of energy efficiency we classify some of these strategies.

3.1.1 Energy efficiency clustering

In wireless sensor networks the sensors are sometime grouped into separated groups named cluster, clustering is purposed in wireless sensor networks, as it offers to network resource sharing, scalability and efficient use of limited resources that provides network topology energy saving and stability and characteristics. Clustering model reduced overheads in communication, and offer allocations of efficient resource so that decrease the whole energy consumption and decreasing the interferences between nodes.

In this paper K R Yadav, Vipin Pal, Girdhari Singh and R P Yadav used clustering as an effective method to take advantage of stored energy in sensor nodes which is limited source in wireless sensor networks. Clustering schemes does not ensure creation of cluster with equal number of nodes. So frame of data transmitted by the sensor nodes vary. The TDMA which nodes scheduled with smaller cluster creation than others cluster models resulting in more number of the data frames therefore more energy consumption. The non-stable energy consumptions between network nodes impact on the network load balancing and nodes with heavy load are disposed to exhaust their energy earlier than other nodes. They found that an enhanced model for selection of cluster head where each clusters have changeable frame slots for nodes are applied to E-LEACH and that enhanced E-LEACH by making cluster extra balance in term of communication load. They used NS-2 simulator for E-LEACH performance analyzing and improving E-LEACH with adjustable length of outline [24].

In this paper Ioan Raicu, Loren Schwiebert, Scott Fowler and Sandeep K.S. Gupta developed a new algorithm, E3D (Energy Efficient Distributed Dynamic Diffusion routing algorithm), and compared it with two other algorithms, i.e. random clustering, and directed communication algorithm. The purposed algorithm has been developed through the use of cost of set up with the energy efficiency analyzing and favorable sensor network lifetime. Also they compared the purposed algorithm with the performance of optimum clustering and an optimum counterpart algorithm. This algorithm takes advantage of astronomical prohibitive synchronization costs. The comparison of the new algorithm is done in terms of the network system lifetime, power dissipation distribution, cost of synchronization and algorithm simplicity [25].

In this paper Vinay Kumar, Sanjeev Kumar and Sudharshan Tiwari they presented an overview on increasing the network lifetime in WSNs. Where the data transmit route is selected in such a way which the whole energy used along the path is reduced. For this concept of clustering they used cluster to helps energy usage in limited resources which prolongs and improve network lifetime [26].

In this paper J S Rauthan and S Mishra defined WSNs as sensing machine next generations and structures with restricted battery energy as greatest problem of sensor nodes. For distributing the energy in the WSNs, the load of data transfer in the sensor nodes must be balanced properly. Clustering algorithms is one of the important methods for balancing the commutations load. Sometime clustering algorithms may cause in clusters that have more node members than other clusters in the sensor network and unbalance size of clusters impact adversely load balancing in the WSNs. The proposed approach improve cluster algorithm to ensure load balancing in generation of clusters. Efficiency of wireless sensor networks is measured by the aggregate distance between sensor nods to the base station and transferred data amount. The totally responsible for the creating cluster and cluster nodes is cluster head and is may affect the performance of cluster. They create cluster algorithm which selected master node and alternative master node for sub areas and areas. To determine master node the region is divided and they determined the midpoint of region, by this center point master node is selected. For each partitioned parts is divided once more partition if required and which depends on master node and nodes in that divided parts [27].

3.1.2 Energy efficiency routing

Accordingly, an ideal routing protocol should prevent the unbalance energy consumption creation where some sensor nodes may exhausted their battery fast so die early so that cause failure in the sensor network. Furthermore, routing protocols should not loss the lower layers energy conservation efforts. So, a perfect routing protocol would exhaust battery energy uniformly and slowly among sensor nodes, which resulting in all nodes dies approximately at the same time.

In this paper Hui Dai and Richard Han they observed that by distributing the workload over a sensor network, load balancing decreases hot spots problem in the wireless sensor network and improve lifetime of the sensor network. In this paper, they design a node-centric algorithm that built a load balanced tree in wireless sensor networks with asymmetric structural design. They used metric amount to study by simulation the route trees balancing that created by their algorithm. They observe that implemented algorithm realizes routing trees that are efficiently balanced than the routing according breadth-first search and shortest-path achieved by Dijkstra's [28].

In this paper R Vidhyapriya and Dr. P T Vanathi presented energy efficient adaptive multipath routing procedure .This procedure use the multiple paths between source node and the sink or base station node, it is also adaptive due to low routing overhead. This procedure is proposed to offer a network environment with dependable transmission besides low energy depletion by efficiently using the available battery energy and received signal strength of the sensor nodes, so that multiple routes to the target can be identify. This algorithm showed that the energy efficient adaptive multipath routing model realizes considerably higher performance than the standard routing protocols even in the greater nodes density [29].

In this paper Philipp Hurni and Torsten Braun concluded that multi-path routing is beneficial to achieve improvements in lifetime by load balancing on sensor nodes and utilization from the information of cross-layer in wireless sensor networks. A performance improvement is accomplished by changing path update rules on current on-demand routing algorithms. Problems are specified with synchronous traffic along interfering paths as a direct consequence of special MAC protocol characteristics [30].

3.1.3 Energy efficiency scheduling

In this paper Endre L´aszl´o, K´alm´an Tornai, Gergely Trepl´an and J´anos Levendovszky the optimal scheduling mechanisms presented and method implemented for packet forwarding in wireless sensor networks, where information gathered in cluster heads [25]. The aim is to study real-life processes for a certain time interval and routing packets with minimum loss probabilities to the base station. Achieve this goal they improve an optimal scheduling algorithm, which order the time slots through which packets must be transmit by the sensor nodes. The scheduling methodology guarantees that all the packets will be sent within a defined time slot and so delay constraints is satisfied and also identical packet loss probability is provided for each node [31].

In this paper Yaxiong Zhao, Jie Wu, Feng Li and Sanglu Lu present a new strategy which is use sleep-scheduling. This strategy designed for wireless sensor networks with old fashioned sensor nodes. In this strategy multiple overlap backbones is formed to work alternatively to extend the lifetime of sensor network. The traffic is promoted only by supporting sensor nodes, and all other remaining nodes radios turn off to save battery energy. The multiple backbones turning round grantee that the energy used is balanced in all sensor nodes, which energy fully consumed and a longer network lifetime is achieved in comparison to the other existing techniques [32].

In this paper D.Sharmila, R.Sujitha and G.Rajkumar they presented virtual scheduling backbone technique performance by combining between local replacement and virtual scheduling graph based algorithm so the combined algorithm is called as virtual scheduling backbone replacement algorithm technique. In which node renewal according their battery energy plays a key role in sensor network lifetime improvement [33].

In this paper Moshaddique AlAmeen, S.M. Riazul Islam, and Kyungsup Kwak the time slots is scheduled for synchronized active phases of multiple neighbor sensor nodes that can cause communication substantial simplification between the neighboring sensor nodes; however for an effective application accurately synchronized internal timers is required in this method [34].

3.1.4 Energy efficiency node transmission power tuning

In this paper X. Liang, W. Li and T. A. Gulliver begin by providing the distributed and dynamic transmission range control system for collisions eliminating. Consequently this model aim to decrease the sensor nodes transmission range, the energy consumption is reduced for sensor nodes and so energy is saved [35].

In this paper A.K.M. Azad and Joarder Kamruzzaman purposed energy balanced transmission range tuning strategies for network lifetime prolonging in wireless sensor networks. They have assumed concentric ring based sensor network design where the base station is placed at center. Firstly they have studied the energy consuming and traffic distribution among sensor nodes and propose two parameters hop size and ring thickness responsible for energy balancing among sensor nodes. Depending on the study, they have prepared a transmission range regulation system of all sensor nodes and determined the ideal hop size and ring thickness for sensor network lifetime maximization. The results of simulation show considerable enhancements in terms of energy consumption balance and network lifetime over existing strategies. On the other hand, before implementing the transmission model that proposed the extensive calculations is essential for defining the ideal hop size and ring thickness. Furthermore, smallest sensor node density is required in the system for implement the strategy [36].

3.1.5 Energy efficiency node deployment

In this paper Naregalkar Akshay, M.Praveen Kumar, B.Harish and Sujata Dhanorkar have been describe an efficient sensor deployment method in wireless sensor networks. The grid based node deployment is used and it classified in to three types grid - triangular, hexagonal and square. The size of the each grid is evaluating the accuracy. Smaller sizes result in more accuracy and decreasing the coverage percentage [37].

In this paper Wint Yi Poe and Jens B. Schmitt have discussed three different methods of the sensor nodes deploying there are square grid, uniform random and a pattern based Tri-Hexagon Tiling (THT) sensor node deployment model. Even if THT is an energy efficient node deployment model but its planning overhead must be taken in account and also the sensor nodes amount used in this model is must be high[38].

In this paper Edoardo S. Biagioni and Galen Sasaki have studied and compared three grids based node deployment topologies including square, triangular and hexagonal grids. As sensor nodes are located far from the vertices of grid, the polygons are distorted and some points on the field of sensing may not be covered any longer. This means optimal node deployment is not achievable because of placement errors and they did not take in consideration these errors [39].

In this paper Demin Wang, Bin Xie, and Dharma P. Agrawal have provided an analytical model for network lifetime and coverage problems in wireless sensor networks by using two-dimensional Gaussian distribution. The probability of coverage in the Gaussian distribution is depends on factors such as Gaussian standard deviation, distance between the desired point and the center point etc. By regulating different parameters values that mentioned above, can get the wanted coverage probability and increased lifetime of network. Using the planned node deployment algorithm, longer network lifetime and larger coverage is achieved with using restricted sensor nodes number. But, authors have not verified whether or not the offered deployment algorithm ensures balancing the energy [40].

In this paper Wang, F., Wang, D., and Liu, J. studied an extensive analysis on the traffic aware relay node deployment problem considering locations of sensor node and base station are known in advance. According to the analysis the optimal solution developed for relay node deployment with single sensor node, both with single and multiple data flows. The authors improved a hybrid algorithm that can return relay nodes optimal number and their respective locations successfully. The results indicate that lifetime of sensor network that obtained by the algorithm is very near to the optimal solution upper bound and achieves 6 to 14 times enhancement over existing traffic-aware relay node deployment model. But, the suggested solution works in continuous domain which leads to small number of relay nodes and simple numbers rounding producing sharp degradation in performance [41].

3.2 Path Loss Effect Exponent on Sensor Network Lifetime

In this paper Wendi Rabiner Heinzelman, Anantha Chandrakasan, and Hari Balakrishnan proposed wireless sensor networks communication protocol, based on energy efficiency. In their study, free space propagation model is only supposed and different path loss exponent values impacts are not examined [42].

In this paper Amer Catovic, Sirin Tekinay, and Toru Otsu in their study considered the effects of fading and shadowing. Although the receiver energy importance is not opposed, this issue is ignored in exhaustive analysis [43].

The effect of path loss modeling on wireless sensor networks lifetime has not been studied. Certainly, the variances between path loss values assumed by different models that indicate major differences, but, how do these differences effect sensor network lifetime is not be studied yet [44-45].

CHAPTER 4

NETWORK MODEL

In this chapter our aim is to study the maximum possible lifetime of sensor network with different path loss exponent α values in various node deployment scenarios. In next sections we firstly express the network model with objective function (optimum objective) and a collection of problem restrictions.

4.1 Assumptions

In our network model, we supposed that there are N sensor nodes and only one base station. All sensors are stationary (both sensor nodes and the base station) and all nodes deployed in square area with $M \times M$ diminutions. We introduced two different node deployment models in our network model. They are uniform and normal node distributions. All sensor nodes are identical and each sensor has different index value started from base station which indexed by 1. Each sensor expected base station has the same amount of energy (e_i). Time is regulated into rounds with durationT_{rnd}. Each sensor node N_i creates the equal amount of data (s_i) at each round to be send to the base station (i.e., sensor nodes create constant bit rate flows). Each sensor node produced data ends at the base station either by direct transmission or by helping from other nodes which some time operates as data forwarder (multi hop). The topology of sensor network is characterized by a directed graph $G = (V, A), V$is the group of all sensors, as well as the base station as (N_1). We similarly described set W, which contains all the sensor nodes except the base station (i.e.$W = V \backslash \{1\}$). $A = \{(i, j): i \in W, j \in V - i\}$ is the group of arches (links). It should be noted that the description of A indicates that no data has been send from sensor node to itself and the base station does not transmit any data to other sensor nodes. The quantity of data that send from N_i to N_j is denoted as (f_{ij}).

We assumed MAC layer that based on TDMA and a time-slot assignment algorithm produced a dispute-free communications schedule. In [46], illustrated that using this type of algorithm is possible and therefore, communication with no collision is achievable by satisfying the requirements of bandwidth.

Because network consists of static sensor nodes. Therefore, it is different from the mobile ad-hoc networks and topology changes are not common. Thus, path creation and topology discovery are occurring once for essential total of time (epochs). These operations are not repeated [47]. If the time of the sensor network reorganization is long enough then the costs of these processes compose small percentage (less than 1 %) of the entire network energy consumptions [48]. Therefore, we can ignore routing overhead in static wireless sensor networks without leading to significant decreasing of total energy dissipation.

In our system model, energy depletion of sensor nodes is concentrated in energy consumptions for communication instead of processing and sensing energy consumptions. This supposition is confirmed by the tests outcomes in real wireless sensor network test beds (e.g., the energy consumptions for communication present 91.00% of the total energy depletion in Telos sensor nodes [49]). Our energy depletion model is a commonly acceptable model presented in [47]. The total energy consumed to send one bit of data in this model is

$$E_{txij} = \rho + \varepsilon d_{ij}^{\alpha} \tag{4.1}$$

And the amount of energy consumed to receive one bit of data is

$$E_{rx} = \rho \tag{4.2}$$

Where α is path loss exponent, (ρ) denotes to the energy consumptions in the electronic circuits, ε represent the efficiency of transmitters, d_{ij} is the distance between N_i (transmitter sensor node) and N_j (receiver sensor node).

The value of α it is acceptable to take values between 2 and 5 $(2 < \alpha < 5)$. The motive for take this values is that, in network environment where is no objects between the transmitter node and the receiver node or in the other words in open space network environment the electromagnetic wave propagation can be exhibited as free-space propagation model, which the value of α will be 2 [50]. Conversely if there are objects between sender and receiver nodes and there is no direct line path then electromagnetic wave propagation will propagate in several interfering paths between transmission pairs then it can purpose two-ray model for the description of the propagation model, and the value of α will be more than 2 may be (3, 4, 5). In the Tab. 2 the value of parameters is utilized in our mathematical analysis.

Table 2 Parameters Used in the Energy Model

Parameter	Description	Value
ρ	Energy dissipated in the electronic circuitry	50nJ/bit
ε	Transmitter amplifier efficiency	100 pJ/bit/m2
α	Path loss exponent	2, 3, 4, 5

4.2 Channel Propagation Model

In a wireless channel, the power of electromagnetic signal decreases as the distance between receiver node and sender node increases. In this thesis, free space propagation model is used [51-52]. Free space propagation model calculates the average decrease on received power over a distance d as

$$E_r(d_{ij}) = \frac{p_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{4.3}$$

$E_r\ (d_{ij})$: Received power when the distance between N_i and N_j is d_{ij}

d_{ij}: Distance between N_i and N_j (two communicating parties)

E_t: Transmit power

G_t: Transmitter antenna gains

G_r: Receiver antenna gains

λ: Wavelength

L: System loss factor

Eq. 4.3 models the signal weaken when the receiver node and sender node the have a direct line of sight. If the receiver node and sender node don't have a direct line of eyesight, two-ray ground propagation model can be used [52, 53]. In this model, the average decline on the ability of the receiving over a distance d is calculated as:

$$E_r(d_{ij}) = \frac{p_t G_t G_r h_t^2 \ \ h_r^2}{d^2} \tag{4.4}$$

$E_r(d_{ij})$: Received power when the distance between N_i and N_j is d_{ij}

d_{ij}: Distance between N_i and N_j (two communicating parties)

E_t: Transmit power

G_t: Transmitter antenna gains

G_r: Receiver antenna gains

h_t: Transmitter antenna height above ground

h_r: Receiver antenna height above ground

In the two-ray ground propagation model, that the average decline on the ability of the receiving over a distance d is proportional to d^4 which is more than free space propagation model in which that the average decline on the ability of the receiving over a distance d is commensurate to d^2[51].

4.3 Node Deployment Model

In wireless sensor networks, the main difficult task is sensor node deployment in the target area to ensure continual sensing with prolonged sensor network lifetime but preserving uniform coverage. Various strategies are developed for node deployment in wireless sensor network according application requirement. In our network model we emphasis on two different node deployment model for wireless sensor networks, random uniform distribution and non-uniform normal (Gaussian distribution).

Random uniform deployment is setting the locations of sensor nodes randomly and separately in the target area. In this node deployment model, as presented in Fig. 6 each of the N sensors has same chance of existence at any place into a given network area. Therefore, the places of scattered nodes are not known exactly. For instance, this deployment can produce from flinging nodes from an airplane. Generally, a uniform sensor deployment is supposed to be easy.

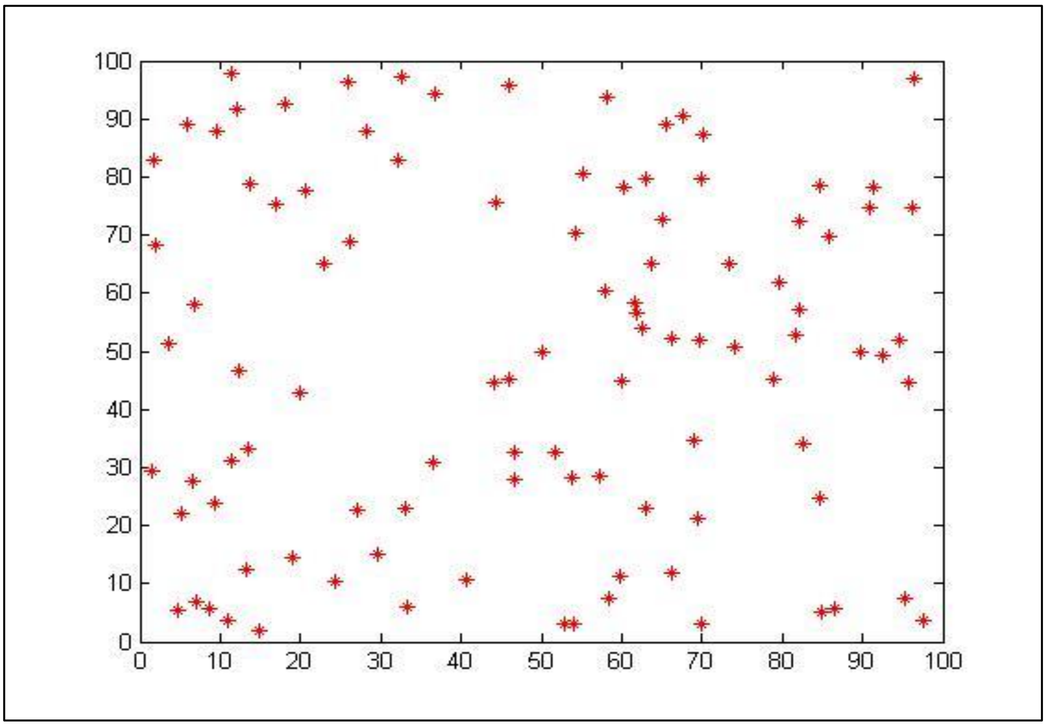

Figure 6 100 Node uniformly deployed in network area

As we mentioned aerially that the sensor nodes act as both source of data and forwarder for another nodes data. The data flow follows many-to-one transmission model. Sensors closed to the base station have to take more data transmitting load. Therefore, sensor nodes around the base station would consume their battery energy more quickly, leading to gap around the base station. If this occurs, no data can be delivered to the base station or sink. As a result, the lifetime of sensor network ends soon and that cause wasting of other nodes residual energy. Therefore in this study we purposed another node deployment scheme, non-uniform normal (Gaussian distribution).

We deployed sensor nodes according normal distribution by using probability density function (the most well-known statistical distribution), for variety x with mean μ and stander deviation σ^2 the general formula for probability density function for normal distribution is given by

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{1(x-\mu)^2/(2\sigma^2)} \tag{4.5}$$

Sometimes normal (Gaussian distribution) is named the bell curve because Gaussian curve look like a bell as we see in Fig. 7 normal distribution curve with various μ and σ value.

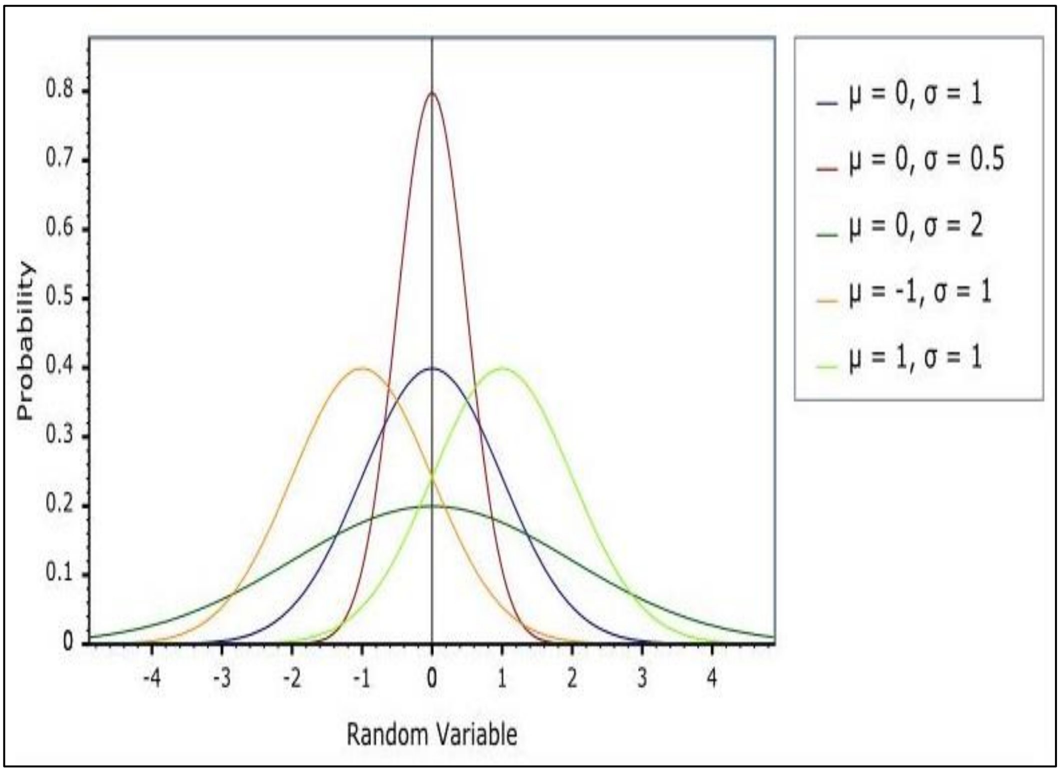

Figure 7 Normal distribution curve with deferent μ and σ

By using normal distribution function in our network model we increased the number of sensor nodes around the base station. Because of the base station is in the center of deployment area. Fig. 8 is the example of sensor network with 100 nodes scattered according normal distribution.

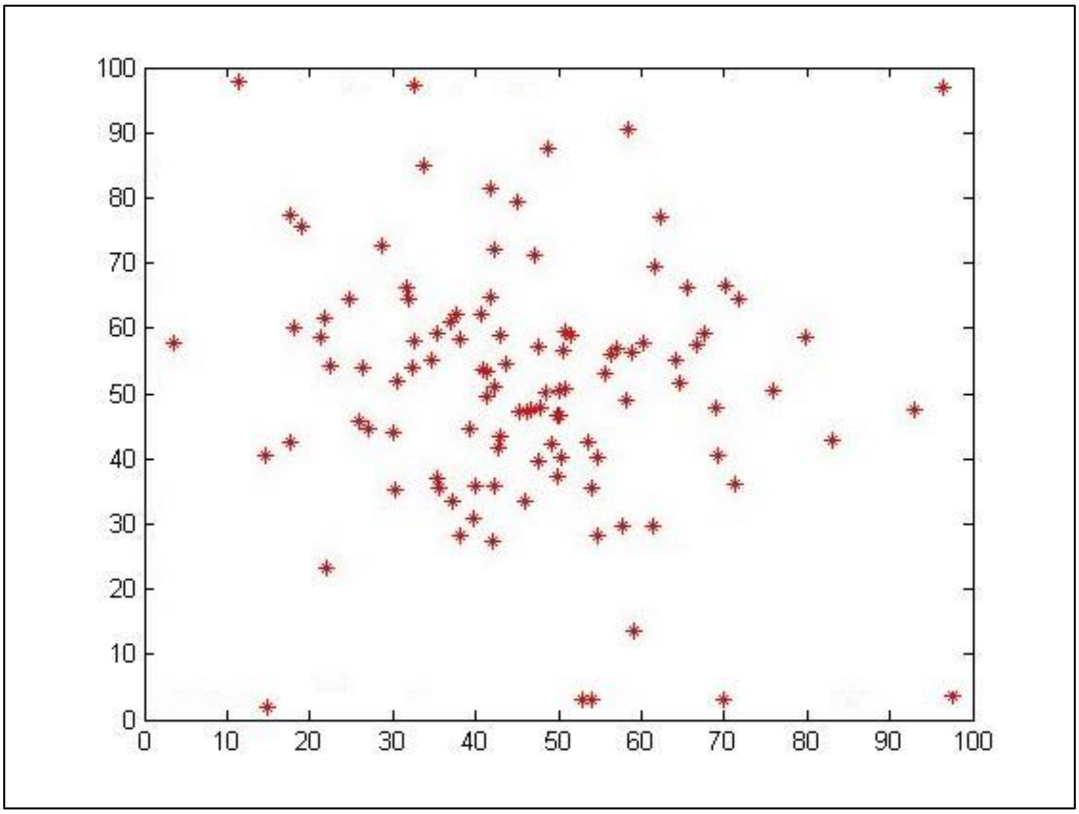

Figure 8 100 Node normally deployed in network area

4.4 Using Linear Program for Lifetime Optimization

For discover the optimum value of a linear objective function under a group of linear equations by using linear programming. The nature of optimality is stated as either minimization or minimization. In a linear programming model, every variables are assigned real and continuous values. The linear programming model generically expressed as in Tab. 3 in which a set of variables denoted by$X$, C and B are coefficients vectors and A is a coefficients matrix.

Linear programming is a strong tool to resolve wireless sensor network optimization problems. For example linear programming can utilized to get the data flow amount between the sensors that increase sensor network lifetime in different value of path loss exponent α. An easy example presented the linear programming application to discover the ideal flow distribution in a simple wireless sensor network contain one base station and two sensor nodes as given in [50].

Table 3 Generic Linear Programming Model

Objective function	$C^T X$
Constraints	$AX \leq B$

In Fig. 9 we presented the optimization problem that expressed as LP problems. Our objective is to achieve maximum network lifetime L with various path loss exponent and find f_{ij}'s (data flows) that meet the constraints. Worth mentioning that variable T provides the network lifetime in terms of number of rounds and the actual lifetime can be denoted by $L \times T_{rnd.}$.

First Eq. in Fig. 9 states that all data flows in the sensor network are non-negative (f_{ij} indicates the data flow from N_i to N_j). To prevent infinite loops we used Eq. 2, by this equation it can eliminate a flow from the base station to other sensor nodes or from a sensor to itself. Eq. 3 is the flow balancing constraint and states that for all nodes except the base station, the data amount that flowing out from a sensor is equal to amount flows that received and produced by that node. This equation also indicates that all data produced by sensor nodes terminate at base station as final destination (i.e., converge cast communication pattern). Eq. 4 illustrate that for all sensor nodes except the base station the consumed energy for data transmission and reception is equal to or less than the energy saved in sensor battery. Eq. 5 states that equal battery energy assigned to all sensor nodes. To take limitations of channel bandwidth (ς) into consideration in a broadcast communication model, we must ensure that the bandwidth required to receive and transmit at each node is restricted by the bandwidth of channel. Such a limitation should take the shared capacity into consideration. We denote to the flows around node N_i which are not flowing out or flowing in to of N_i and impact the bandwidth that available to N_i as interfering flows.

Maximize L

Subject to

$$f_{ij} \geq 0 \; \forall (i,j) \in A \quad (1)$$

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

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

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

$$e_i = \xi \; \forall i \in W \quad (5)$$

Figure 9 The basic linear program model for lifetime maximization

As mentioned previously, the presented model in Fig. 9 clarified up to now is the flow balancing basic model (i.e., all generated data by the sensors finally terminate at the base station) and minimizing energy consumptions (i.e., to minimize the maximum energy consumptions of sensor nodes, all nodes are forced to deplete their batteries in a balanced way). Therefore, sensors in the network cooperate to prevent early death of any node as a result of exhausting of its battery power.

Until this point the basic linear programming model absences any limitations that restricts a sensor's transmission range t_r (i.e., in the network every sensor node can communicate with any other node). Therefore, Eq. 6 is added to the model to restrict then maximum communication range of sensors to t_r (i.e., any communication pair that separated by the distance more than t_r cannot directly communicate, on the other hand, multi-hop communication possibility is prevented). As there is no heterogeneity on transmission power (every nodes have equal t_r) so, in such sensor network there are no unidirectional links. Eq. 6 and the basic model is purposed to model our standard situation.

$$f_{ij} = 0 \text{ if } t_r < d_{ij} \; \forall (i,j) \in A \tag{6}$$

To compare free space propagation model and two ray propagation models with respect to maximum network lifetime for various node deployment schema (uniform and normal), we study the effect of different transmission range t_r in both deployment model and solve different instances of the optimization problem.

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CHAPTER 5

SIMULATION AND EXPERIMENTAL ANALYSIS

In the following chapter we investigated the sensor network lifetime in uniform and non-uniform (normal) node deployment strategies. Also we studied and presented the result of the numerical analysis to investigate the impact of path loss model on wireless sensor networks lifetime in two different node scattering models (random uniform, non-uniform normal distribution). We used large scale network 500 x 500 dimensions consists of 100 sensor nodes with base station (N_1) in the center. In order to compare different path loss values for different node scattering models with each other and to understand the impact of various sensor network parameters on the network lifetime we carried out an expanded analysis's. Network parameters used in sensor network model are given in the Tab. 4.

In LP problems there are no conclusive solution. Therefore, we used GAMS (General Algebraic Modeling System) [54] where is purposed for the mathematical study of the linear programming model. For solving linear programming model effectively GAMS involves high-performance solvers which improve LP on the essential way in various methods to get an improved performance solution. Therefore, once we solve our LP model by GAMS, one of GAMS solvers was used to find the better results. Special implementations are not within the domain of this thesis. Furthermore we used MATLAB tools to plot the figures in our thesis in order to be useful for comparative study.

Table 4 List of Parameters and their Values

Parameters	**Symbol**	**Value**
Number of nodes	N	10-100
Network deployment		Uniform , normal
Number of sink node	N_1	1
Location of sink in the network		Center
Size of Network area	MxM	500x500
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_r	
Energy stored at each sensor node (J)	e_i	1.0
Battery energy (J)	ξ	1.0
Mean parameter of normal distribution	μ	250
Slandered deviation parameter of normal distribution	σ	25

The result showed in the figures and tables in next sections is are the average of 1000 different runs and in each run sensors coordinates are randomly generated (1000 different random network topology). Before we discuss the result obtained from optimization problem it is worth to note that all lifetimes is normalized, the normalization is accomplished by dividing the lifetime values on the best lifetime acquired.

5.1 Effect of Transmission Range of Lifetime in Uniform and Non-uniform Deployment

In our analysis we studied sensor network lifetime in uniform and non-uniform (normal distribution) node scatter as a function of transmission range t_r change. Our LP problem solved for 100 sensor nodes with base station in the center. We assumed that network area was 500x500 for two different deployment scenarios. We changed transmission range in our LP framework. As shown from Fig. 10 we observed that the energy consumption is reduced significantly for normal distribution compared with uniform node deployment. From our numerical result we find that deploying node according Gaussian (normal distribution) is achieve 335% improvement in normalized lifetime compared to uniform node scatter. The sensor nodes act as both data forwarder and data source. The sensor network data transmission follows a many to one communication model. In uniform deployment model nodes near or around the base station must carry out more communication load. Hence, sensors near base station would consume their batteries earlier, resulting in unbalance energy depletion or what is called a hot spot problem around the base station. If that occurs, no data can any more be delivered to the base station. Consequently, the network lifetime ends early and a lot of sensor nodes energy would be lost. On the other hand, deploying sensor nodes according to the probability density function. According Eq. 4.5 for normal distribution the large number of nodes condensed in the center of network area (around sink node). Hence, increasing number of nodes near sink node that increase their ability to transmitting data and solve energy hole problem. Normally distribution of node balance energy depletion between nodes (all sensors exhausted their energy almost at the equal period), therefore that increase network lifetime.

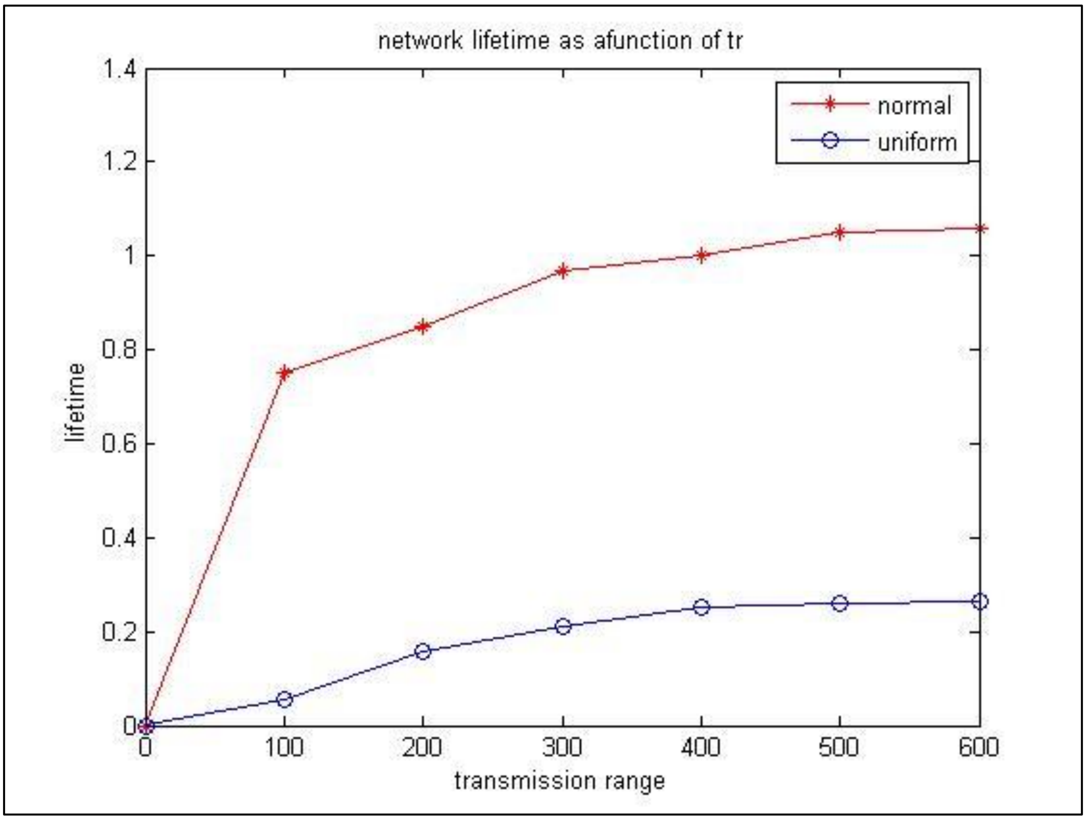

Figure 10 Normalized sensor network lifetime as a function of transmission range (t_r)

Additionally Fig. 10 presents the normalized lifetime in both uniform and non-uniform deployed network as function of transmission range t_r. We observed that maximizing transmission range has deep impact on the energy consumption in both uniform and normally distribution of nodes. Network lifetime increases as t_r increases because increasing in the transmission range increases the number of routes and available links in the network and that leads to improved energy balancing (i.e., as t_r increase so the number of one hop neighbors to the base station and available links increase which result in extra available energy balance paths to the base station). The rate of increasing in network lifetime by increasing t_r decreases, since direct data transmission to long distance is energy ineffectual (i.e., the profit of employing additional routing paths that generated due to t_r increase is restricted by the energy incompetence for transmission to large distances).

5.2 Effect of Path Loss on Lifetime in Uniform and Non-uniform Deployment

Until this section the LP is solved by utilization a path loss exponent value as 2. As we mentioned in section 4.1 this value is not constant in all cases and generally in the previous works it is acceptable to be between 2 and 5.

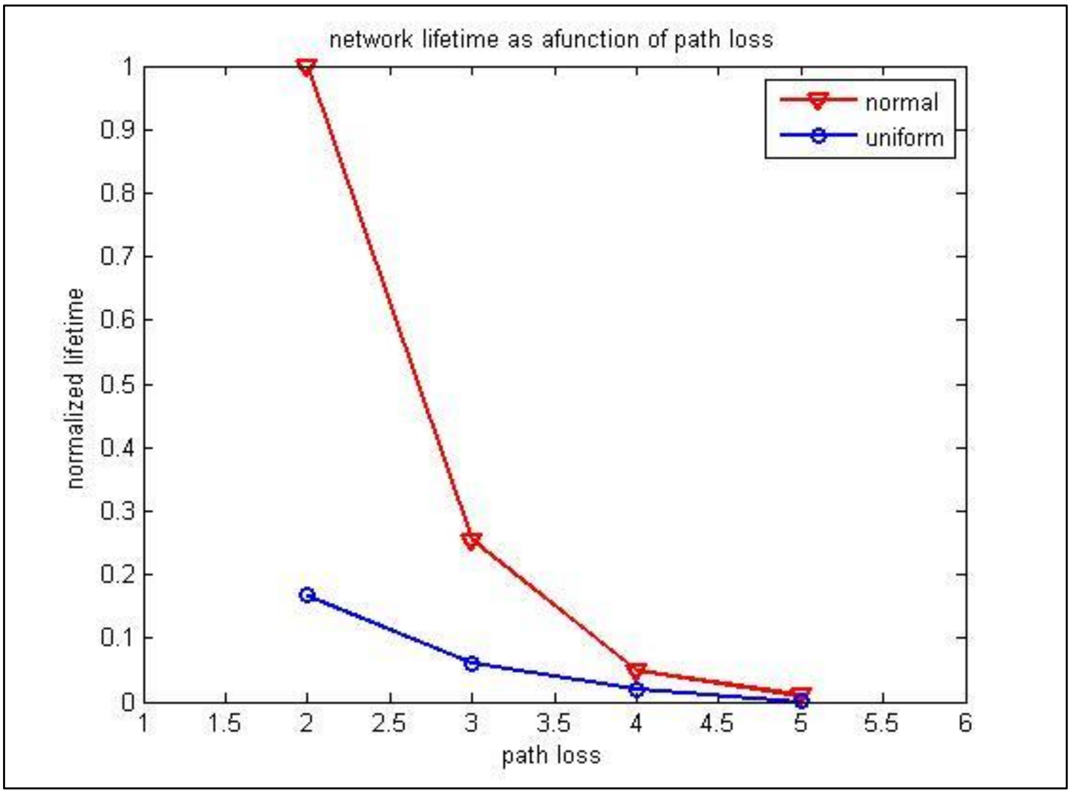

Figure 11 Effect of path loss exponent in normalized sensor network lifetime

We studied the impact of path loss exponent on the network lifetime in this section. We retained network parameters fixed such as node density and network dimensions as well as other parameters but altered the value of α for uniform and normal sensor node deployment. The outcomes are presented in Fig. 11 showed that as α increases, network lifetime decrease in both two purposed node deployment models. However, we observed that as α decrease lifetime enhancement using normal node deployment model becomes more significant. E.g., in normal node deployment network lifetime is approximately 100% longer than the lifetime obtained with uniform node deployment strategy with a path loss exponent value $\alpha = 5$. However, we cannot see that clearly in Fig. 11 because the normalized lifetime obtained for both deployment models is very small values in comparison with normalized lifetime obtained in $\alpha = 2$. To better understanding, normalized lifetime is equal to 0.0020 in normal deployment while in uniform deployment is 0.0013 for $\alpha = 5$. Though, with a path loss exponent of $\alpha = 2$, network lifetime for normal node deployment is 453% longer than the network lifetime that obtained with uniform sensor node deployment. This difference arises from the fact that it is clear that the lifetime of the sensor networks is deeply based on the effect of α, and disregarding the impact of α would be a positive supposition when energy exhausted by each sensor node is considered. The reason for that is, when path loss effects are not considered the problems of associated and retransmissions that effect the energy depletion but that are not considered in our network model however these factors affect the lifetime of the nodes. Therefore, ignoring effects increase network lifetime.

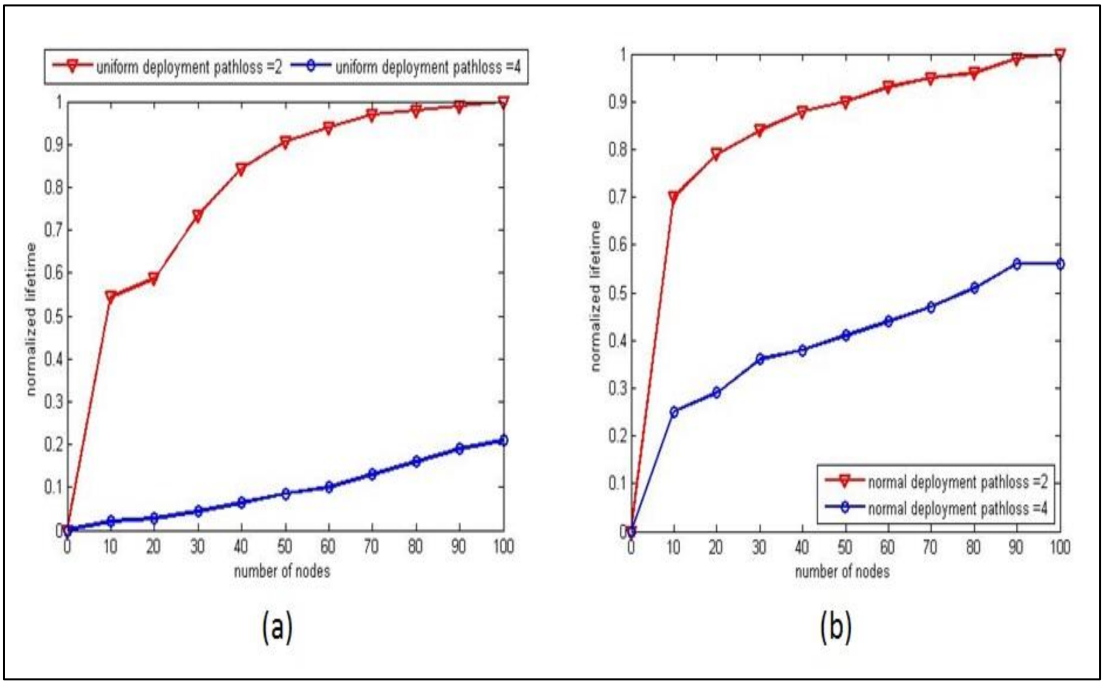

Figure 12 Normalized lifetime as a function of number with different Path loss exponent (a) Uniform node deployment (b) Normal node deployment

From Fig. 12 that showed network lifetime as a function of node number we investigated the performance of network in the term of lifetime on different environmental conditions by varying path loss exponent value. We take the network area 500x500 with base station in the center and fixed all other network parameter as in Tab. 4. The number of deployed sensor nodes is varied from 10 to 100 nodes.

Firstly we observed from the Fig. 12 (a) and (b) that network lifetime increase with increasing of node density in the network field (increasing number of nodes). The reason for such arise in network lifetime is when we increase node density in the network the number of node that is one hope way from the base station also increase. Hence, that can extend the time until the first sensor node does not have any path to the base station (that extend the time of the death of the first node). Therefore, increasing the number of nodes in different node deployment strategies prolong network lifetime to some extent. Secondly we noticed that both in (a) and (b) there is great decrease in lifetime where path loss exponent is 4 which are more typical in environments with more objects such as indoor environments. That occurs because of in more objects in environments, so α increases. Then, transmission range decreases for the equal transmission energy values. Therefore, the nodes can be communicated with base station with smaller links only, so it used additional number of hops. Furthermore, we can clearly observe that increasing in multi-hopping communications in turn increase the energy overhead at some nodes. For α value 4 or greater, even the maximum transmission power in sensor nodes are enough to connect and form network it becomes insufficient to form a linked sensor network after a short time. On the other hand in free space model $\alpha = 2$, the transmission range is higher because there are no objects in the network field to reduce transmitting energy. Then multi hop communications are reduced and that increase network lifetime.

Farther more we can observed very clearly that decreasing in network lifetime in two ray propagation models $\alpha = 4$ with uniform node distribution as in Fig. 12 (a). The lifetime became higher for the network with is more than in normal deployment of nodes Fig. 12 (b). For example when the number of nodes is 100 for the uniform node deployment model network lifetime decrease 400% in the $\alpha = 4$. On the other hand in normal node deployment the percentage of decreases is 82% for $\alpha = 4$. The reason for this great difference that in normal deployment of nodes when $\alpha = 4$ the energy of transmitting decreased because of obstructed environments. Nodes in this case can transmit data for short distances so in order to ensure delivering of transmitted data to the base station multi hope commutation increased in the network. The energy overhead at each sensor node also increases especially for the nodes near base station and that decrease network lifetime. However, as we explained previously in normal node deployment of node density of node increases around base station and that reduce the effect of path loss exponent to some extend. Hence the normal deployment of nodes showed better performance compared with uniform deployment of nodes in obstructed environments (urban areas) where path loss exponent values is 4.

CHAPTER 6

CONCLUSION

The enormous need for energy efficient and practical sensor node deployment of wireless sensor networks especially in harsh or more obstructed environments pushes us to review the existing protocols observing for preferable understanding and better solutions. In this thesis, we investigated network lifetime for uniform distribution and normal distribution of sensor nodes in different environments with various path loss exponent values. We used mathematical programming model to explore the impact of path loss on network lifetime and to compare the performances of various node deployment strategies. This approach gives us the chance to do numerical analysis covering a wide range of parameters. Since the contributions of this thesis is provided in the form of a series of questions in chapter one. We presented our conclusions in reply to these questions. Firstly, we observed that normal deployment of nodes demonstrated better performance in the term of lifetime than uniform node deployment by balancing data flow between network nodes and so balance energy depletion between nodes. Also we observed maximizing transmission range have deep impact on the energy consumption in both uniform and normally distribution of nodes. Network lifetime increases as t_r increases because increasing the transmission range increases the number of links and routes available in the network which results in better energy balancing. Secondly, we concluded that when path loss exponent increases, lifetime decreases in the two different deployment models. However, we observed that as (α) decreases improvement in the sensor network lifetime using normal node deployment approach becomes more considerable. Thirdly and finally, we concluded that by increasing the node density (increasing number of nodes) in network field in uniform and normal node deployment strategies, we prolong network lifetime. Also we observed that both in uniform and normal node deployment there was a great decrease in sensor network lifetime in two ray model with path loss exponent $\alpha = 4$ in comparison to free space model with path loss $\alpha = 2$.These decreases in the lifetime occur because of environments with more objects, path loss α increase. Therefore, transmission ranges t_r decreases for the same transmission energy values. In this thesis we neglected the energy depletion on medium access control layer MAC and on the other sensor network layers. We aim to consider MAC energy consumption in our future works.

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APPENDICES A

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