ANALYSIS OF ENERGY CONSERVATIVE ARCHITECTURES AND PROTOCOLS IN CLUSTER BASED WIRELESS SENSOR NETWORKS

by

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APPROVAL PAGE

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ABSTRACT

Limited energy is the major driving factor for the researches conducted on wireless sensor networks. Clustering alleviates this energy shortage problem by reducing the data traffic conveyed over the network and therefore various clustering methods are proposed in the literature. Researchers put forward their methods by making serious assumptions such as always locating single sink at one side of the topology or making clusters near to the sink with smaller sizes. However, to the best of our knowledge, there is no comprehensive research that investigates the effects of various structural alternatives on energy consumption of wireless sensor networks. In this master thesis, we thoroughly analyze the impact of the various structural approaches such as cluster size, number of tiers in the topology, node density, position and number of sinks. Extensive simulation results are provided. The results show that the best performance about lifetime prolongation is achieved by locating enough number of sinks around the network area.

Keywords*:* Wireless Sensor Networks, Clustering, Energy Conservation, Network Lifetime

KÜMESEL YAPILI KABLOSUZ ALGILAYICI AĞLARDA ENERJİ KORUNUMLU YAPILARIN ve PROTOKOLLERİN İNCELENMESİ

Fatih ÖZYURT

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ÖZET

Kısıtlı enerji miktarı kablosuz algılayıcı ağların ömrünü belirleyen en önemli faktördür. Kümeleme, ağ üzerinden taşınan veri trafiğini azaltarak bu enerji sıkıntısı sorunu hafifletir. Kablosuz algılayıcı ağlarıyla ilgili çeşitli kümeleme yöntemleri önerilebilir. Araştırmacılar genellikle çalışmalarını ortaya koyarken, topolojinin tek bir tarafında tek bir veri toplama merkezi konumlandırma ya da alıcının yakınındaki kümelerin boyutlarını küçültme gibi çeşitli kabullerde bulunmuşlardır. Ancak, bildiğimiz kadarıyla, çeşitli yapısal alternatiflerin, kablosuz algılayıcı ağlar ve enerji tüketimleri üzerindeki etkileri ile ilgili detaylı bir araştırma yapılmamıştır. Bu tezde, kümelerin boyutları, topolojideki düğüm yoğunluğu, veri toplama merkezi sayısı ve bunların konumları ile topolojideki kademe sayısı gibi çeşitli yapısal yaklaşımların etkisinin analizini yapacağız. Simülasyon sonuçları, algılayıcı ağların yaşam sürelerinin uzaması konusunda en iyi performansın, topoloji etrafında alıcılarının yeterli sayıda olmasıyla elde edildiğini göstermektedir.

Anahtar kelimeler: Kablosuz algılayıcı ağlar, Kümeleme, Enerji korunumu, Ağ Ömrü

To my parents

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LIST OF ABBREVATIONS

SYMBOL/ABBREVIATION

WSN	**:** Wireless Sensor Network
ID	**:** Identification
QoS	**:** Quality of Service
CH	**:** Cluster Head
GPS	: Global Positioning System
GAF	: Geographic Adaptive Fidelity
OSI	: Open Systems Interconnection
MAC	: Media Access Controller
DLL	: Data Link Layer
TDMA	: Time Division Multiple Access
FDMA	: Frequency Division Multiple Access
CDMA	: Code Division Multiple Access
ARQ	: Automatic Repeat request
FEC	: Forward Error Correction
FNR	: Flat Networks Routing Protocols
HNR	: Hierarchical Networks Routing
LBR	: Location Based Routing
POBR	: Protocol Operation Based Routing
LEACH	: Low Energy Adaptive Clustering Hierarchy
PEGASIS	: Power-Efficient Gathering in Sensor Information Systems
HEED	: Hybrid Energy-Efficient Distributed Clustering
AMRP	: Average Minimum Reachability Power
CROSS	: Clustered routing for selfish sensors

LGCA	: Localized Game Theoretical Clustering Algorithm
EECS	: Energy Efficient Clustering Scheme
ANCAEE	: A Novel Clustering Algorithm for Energy Efficiency
RTS	: Request to Send
CTS	: Clear to Send

CHAPTER 1

INTRODUCTION

Computers and electronics occupy a significant place in our lives. Technological developments facilitated processes (e.g. data gathering, calculation, data transfer and evaluation) previously difficult and costly to be performed. Computers and electronics come into play in such an environment. For instance, it was just an imagination for people to enter dangerous geographical environment and gather physical data continuously. Recently, humans use cheap and tiny electronic devices instead of using manpower for such dangerous and labor intensive operations. Devices and systems used in such operations either previously were not available or too expensive.

Wireless Sensor Network consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions (air, water, indoor), resource (polar, solar, wind farm monitoring), industrial management (structural health, machine condition, process monitoring) and to pass their data through the network to a main location.

Figure 1.1 WSN Application Areas.

The devices of sensor nodes constitute mainly three sub-units:

a) Sensing unit collects data from the physical environment in order to evaluate.
b) Processor unit is charged with the evaluation of data and internal operations of the sensor node.
c) Communication unit is responsible for the transfer of data to the sink [1].

There is a crucial problem due to lack of sources of sensor nodes. There are some situations such as replacing the energy-exhausted nodes with the new ones which are the main obstacle because of the limited power supply.

On the other hand, our main goal is to use the sensor nodes lifetime depending on the purpose of the application. Therefore, it should be used its energy effectively. For this reason, researchers try to develop communication techniques that can be used with minimum energy.

The WSN presents many inter-disciplinary workspaces, and is designed by using Circuit-chip design, wireless communication techniques, and artificial intelligence. In addition, a physical carrier must be conceived to carry the data and communication protocols [2].

The purpose of WSN is to perform a set of high-level information processing tasks such as detection, tracking or classification. However, its measures of performance are well defined such as detection of false alarms or misses, classification errors, and track quality.

Applications of sensor networks are used wide areas and can vary significantly. In addition to this, based on application requirements it can be easily deployment, sensing modality and its power supply.

Wireless Sensor Networks, Figure 1.2-1.5 in samples, as shown

a) Environmental monitoring (e.g. traffic, habitat, security)
b) Industrial sensing and diagnostics (e.g. appliances, factory, supply chains)
c) Infrastructure protection (e.g. power grid, water distribution)
d) Context-aware computing (e.g. intelligent home, responsive environment)

Figure 1.2 Environments.

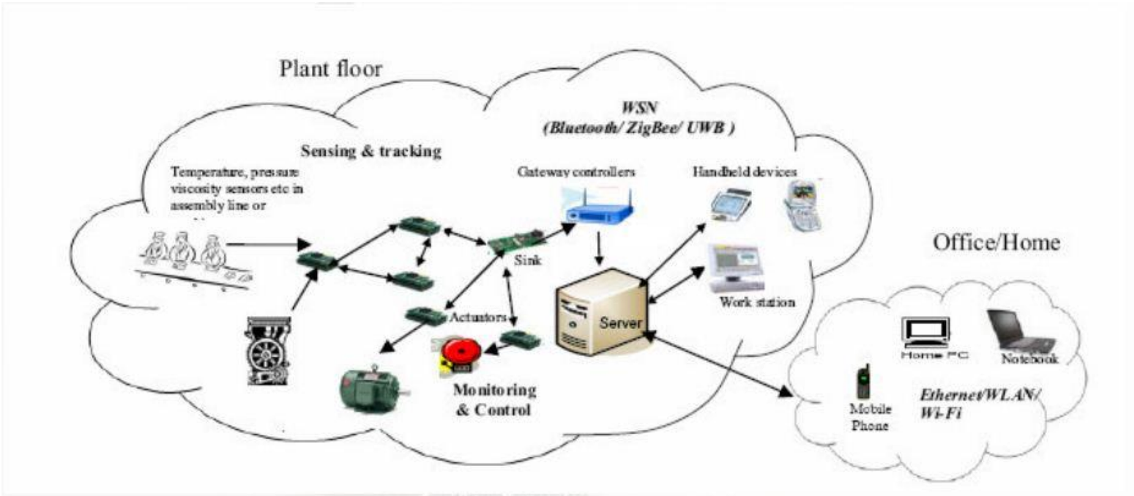


Figure 1.3 Industrial Sensing and Diagnostics.

Figure 1.4 Infrastructure Protections.

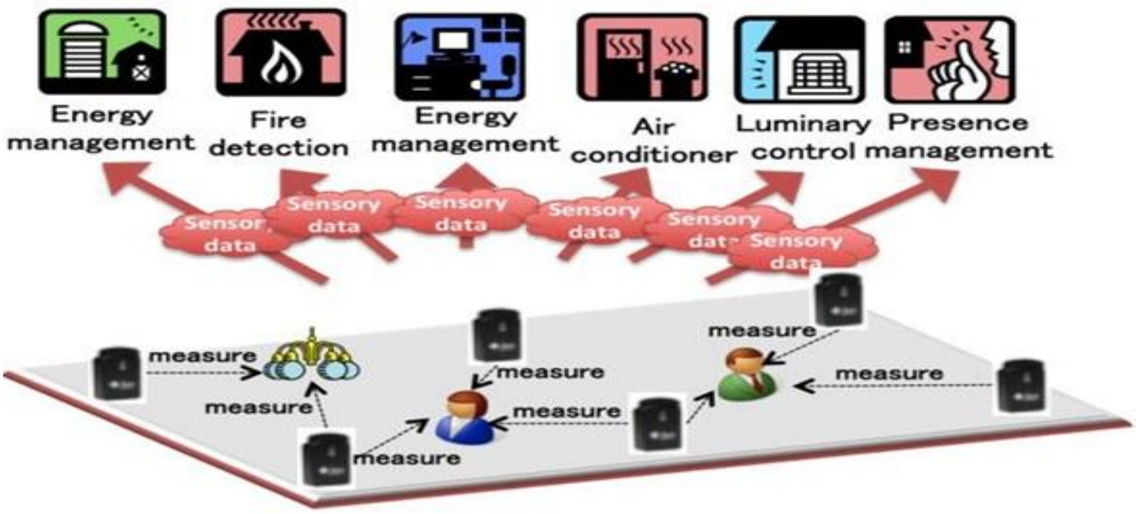


Figure 1.5 Context-Aware Systems.

In advanced development of electronics, sensor nodes physical sizes are much smaller. Figure 1.6 shows better understandable information.

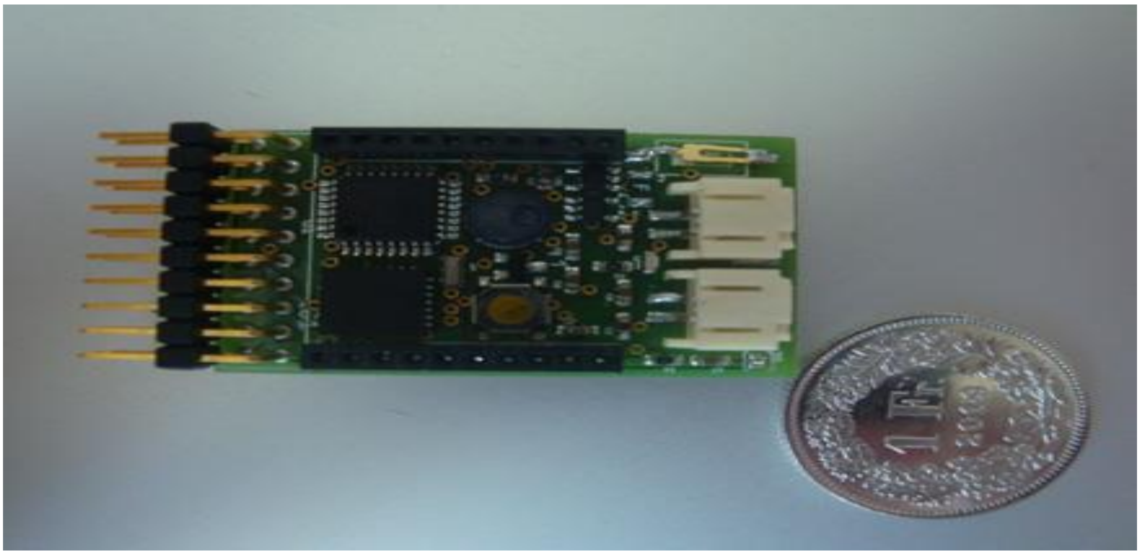


Figure 1.6 Sizes of Sensor Nodes as a Coin.

Figure 1.7 is shown the internal structure of the wireless sensor nodes generally

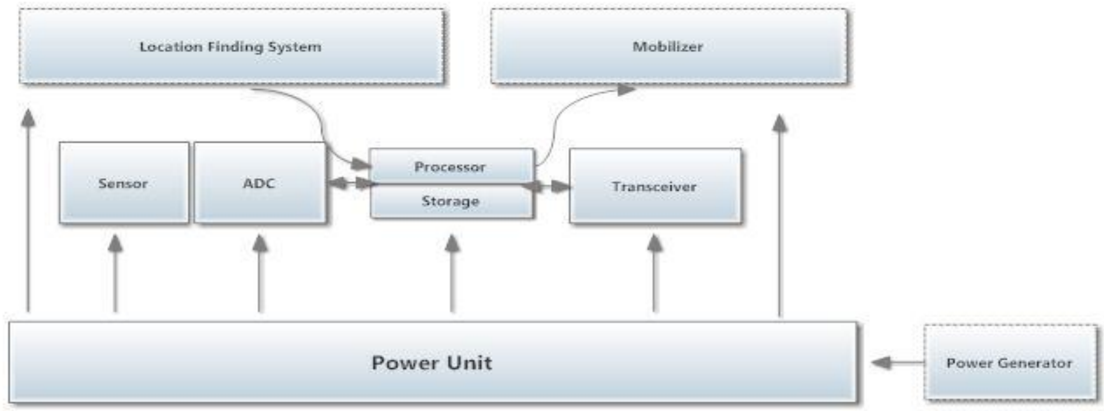


Figure 1.7 Architecture of WSN.

A wireless sensor node evaluates the physical data from the environment sensing mechanism as shown in figure 1.7. This collected data is sent to the processing unit for processing data. Sensor nodes, which collect this data directly, instead of forwarding data collection and assessment center, evaluates in itself (In-Node Processing) and sends the simplified data as a result of evaluations itself. These simplified data is sent to the receiver-transmitter units to transmit the center. [3]

One of the biggest advantages of Wireless Sensor Network is ability to become self-organized. In another way, these devices are called as one kind of ad-hoc network [4]. However, there are significant differences between WSNs and other ad-hoc counterparts. Firstly, the nodes in traditional ad-hoc networks communicate mostly in a point-to-point manner, whereas WSN nodes can communicate in multi-hop manner because of the limited energy sources. Secondly, WSN nodes are deployed in using a number of nodes rather than the nodes deployed in traditional ad-hoc networks [3]. Therefore, protocols and the methods utilized for ad-hoc networks will not be suitable for WSNs.

It can strongly predicted that wireless sensor networks will be a significant part of our lives. Although many protocols and algorithms have been proposed for traditional wireless ad hoc networks, they are not well suited for the unique features and application requirements of sensor networks. To illustrate this point, the differences between sensor networks and ad hoc networks as stated [3]:

(a) The number of sensor nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network.
(b) Sensor nodes are densely deployed.
(c) Sensor nodes are prone to failures.
(d) The topology of a sensor network changes very frequently.
(e) Sensor nodes mainly use broadcast communication paradigm whereas most ad hoc networks are based on point-to-point communications.
(f) Sensor nodes are limited in power, computational capacities, and memory.
(g) Sensor nodes may not have global identification (ID) because of the large amount of overhead and large number of sensors.

Due to the above reasons, many researchers attempt to develop purely communication techniques and structure of its protocol. In many areas small nodes are used because of its manufacturing cost as low rather than other devices. However, another major problem is occurring for its limited resources. Since one of the most important constraints is the low power consumption requirement of sensor nodes. In general, sensor nodes are irreplaceable and limited power sources. Therefore, the aim of traditional networks is the high quality of service (QoS) whereas sensor network protocols are focused primarily on power conservation.

In Figure 1.8 shows the structure of Wireless Sensor Networks placed on a volcanic mountain. It is impossible to change the consumed nodes with new ones and dangerous. We face some problems in order to access the physical data of the location because of the unchangeable nodes which energy are consumed. It will cause the lack of efficiency and accurate results. Therefore, we have to change the network’s structure because of inaccessibility of the region.

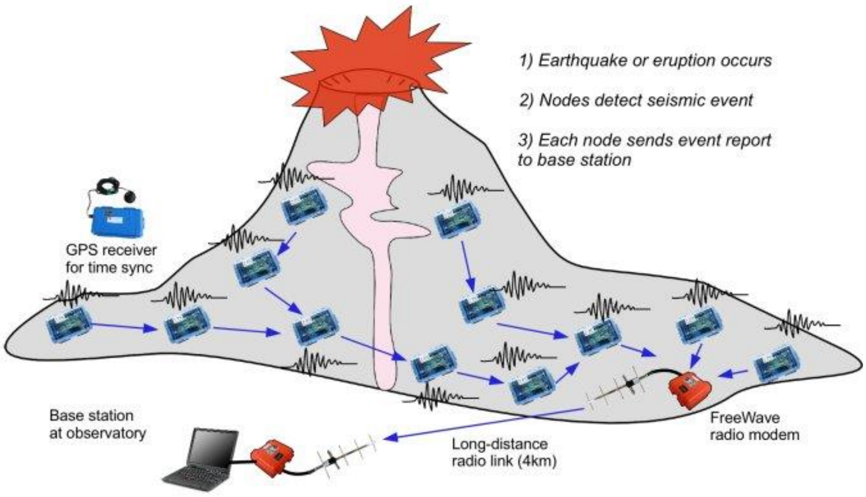


Figure 1.8 Dangerous Geographic Areas for Humans.

In order to extend the life of the nodes from external sources (such as solar) energy is required [5-7]. As a result of above reasons, the energy supply of nodes should be used carefully because of the limited amount of power as well as a scarce resource. For these reasons, the researchers overseeing energy consumption, in other words, they are working on less energy consumption on communication techniques. Scientists have studied and proposed several techniques for wireless sensor networks in order to overcome the energy shortage. The techniques which can be applied to other wireless networks and communications have not implemented for wireless sensor networks. Hence, a lot of special techniques have been developed for wireless sensor networks.

Communication process is one of the major factors in energy consumption. Studies [8-12] have shown that, the spent of energy in data transmission is much more than the spent in processor. Also the amount of energy consumed during the transmission of a single bit between two wireless sensor nodes is almost equal to the amount of energy consumed by a sensor node performing thousands transactions[9]. Thus, the mainly contribution for reducing energy consumption of nodes will be by improving the communication mechanism. We have worked impacts of various structural factors on energy consumption and analysis of energy conservative; however, a lot of studies [8-12] have shown us communication techniques.

When radio data transmission is not in progress, namely wireless sensor nodes is idle, it spent the similar amount of energy during the data exchange. Therefore, if there is no data transmission itself or another node, it is unnecessary to open radio sub-unit. In order to use proper energy consumption, radio transceiver must be in the sleep mode when communication is not required. Also radio should be resuming when new data packets becomes ready [6]. This behavior called the duty cycle.

Because of the limited coverage areas of nodes, data is transmitted to the adjacent with multi-hop transmission (multi-hop) method instead of passing directly to the center [13]. In addition to this, packet transmission reaches the data collection center with multi-hop methods. However, if all nodes go to the center through same nodes, always those nodes' energy will be decreased in a short period. When selecting the next packet forwarder node, selection must be made at the energy levels of neighboring nodes. Thus a load distribution will be provided.

In addition to this, when system used in a single data collection center (sink), those nodes are deployed in close to the target device for transmitting all incoming packets from other nodes on the network. Therefore, all incoming packets from the network data collection center to undergo before reaching the final destination which nodes are active (hotspot area) in the region. Therefore, energies of the nodes near the target sink consumed in a short time according the all the other nodes.

Depletion of their energy means that come to end of their life time. If these nodes become unable their duty, packets coming from other nodes will not be able to be transmitted to the final destination. For this reason, instead of using a single data collection center to use more than several sinks will expand active zone. Also, having more nodes near the target sink area provides longer life for network. So in my thesis one of my studies based on this issue. We have compared with one sink and several sinks on various structural factors.

In wireless sensor networks, in order to minimize energy consumption, one of the most important methods is cluster approach on network structure. As previously mentioned, the main factor that causes the energy consumption is data transmission mechanism. For this reason, it is very important to minimize the amount of data transmitted. Based on this idea, instead of transmitting their data to the center on the entire network, divide into clusters of the network structure, select a cluster head in each cluster and all nodes in that cluster transmit their data through cluster head. For each cluster, CH sends the summary or filtered data (simple data) over the other CH of adjacent cluster.

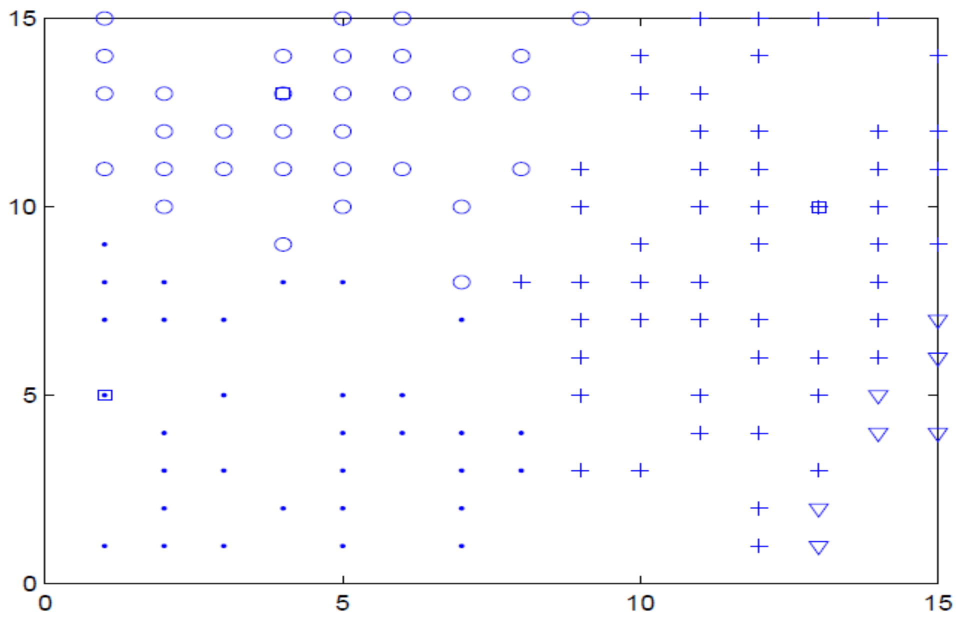


Figure 1.9 Example of Clustering.

So far, the studies of cluster based sensor network are usually focused on intra-cluster communication.

As far as we know, nobody has made a research about the effects of various structural alternatives on energy consumption of wireless sensor networks. In this thesis, we analyze the impact of various structural approaches such as the sizes of clusters, the number of tiers in the topology, the node density, the position and the number of sinks.

CHAPTER 2

WIRELESS SENSOR NETWORKS

Wireless sensor networks (WSN) are the networks containing intelligent sensors in order to measure certain physical values which have different properties such as sensing, processing or communicating. Therefore, sensors are usually equipped with data processing and communication capabilities. The basic structure of WSN nodes are data collection from the physical environment, data processing according to predefined criteria with sensing circuit that transform these measures to electrical signal [14].

WSN design requires interdisciplinary studies: circuit design; artificial intelligence, wireless communications techniques, data compression and coding techniques [15]. The sensor nodes can detect a wide variety of sizes and measure depending on the application. These applications can be classified under three major categories [10].

(a) Measuring physical values: Light, temperature, humidity, pressure, radiation levels like measured physical values.
(b) Measurement of chemical values: ratio of the liquid level measurement any one component in the mixture etc.
(c) Detection of events: Safely control of a given geographical area, in real time detection of external intervention.

Wireless sensor networks are used especially in dangerous and difficult areas [1].In addition, WSN offers the more accurate data opportunity over a geographical area in order to collect data from various points instead of hundreds of people occupied for hours. However, while performing thousands of sensor nodes that need to be used, the productive cost of these nodes should be as much as less and its size. In order to obtain the above target, the developments in hardware design are required [16].

2.1 DIFFERENCES OF WSN FROM OTHER WIRELESS NETWORKS

There are some differences between traditional networks and WSN [16].

- **Small size of the nodes:** Wireless Sensor Networks sensor`s nodes are very small size. Therefore there is a constraint in terms of data processing, storage and energy sources. In some geographical location, it is very difficult to replace consumed nodes with new one.

- **High number of sensor nodes:** Number of nodes in wireless sensor is much more than other sensor networks. The high number of nodes provide to intensively distribution of nodes in the environment.

- **Self-adjustability:** In wireless sensor network, depending on the application, Sensor nodes may distribute from air, and there is no need to configure it. These nodes can adjust themselves.

- **Application basicity:** Each application has its own requirements and specifications. Therefore, according to the characteristics of application protocols and structures must be developed.

- **The frequency of changes in topologies:** Sensor nodes can use difficult conditions. Therefore, it can be easily damaged and can be disabled. In addition to this, because of their small size they have limited energy sources.

- **Data redundancy:** The number of nodes in WSN is very dense in geographical area where are several multiple nodes which try to send data simultaneously to data collection center. This causes unnecessary data redundancy.

2.2 GENERAL APPROACHES TO ENERGY CONSERVATION

As mentioned in the previous section, the most important problems of Wireless Sensor Networks are limited energy resources. Due to this reason, other traditional methods and protocols cannot show the similar performance for wireless sensor networks. Because of the energy shortage problems in Wireless Sensor Networks nodes, the methods developed for different kind of networks are usually not suitable. In general the techniques which used in these networks apply service quality, accurate and timely delivery of data. For this reason, while developing a communication protocol method, almost all level of the structure, researchers focused to answer the question "How can we spend less energy on nodes?”. There have been several studies on energy conservation techniques for wireless sensor networks [6]. However, without going into much detail, these studies can be grouped under four main headings outlined:

Figure 2.1 Energy Conservative Categories.

The most energy-consuming units of sensor nodes are data gathering and data transmission communication [6]. Also it is known that the amount of energy consumed during the transmission of a single bit between two wireless sensor nodes is almost the same to the amount of energy consumed by a sensor node performing thousands transactions[9]. In addition to this, when radio data transmission is not in progress namely wireless sensor nodes is idle, it spent closely same amount of energy during the data exchange. Therefore, there is no need to active when the node belonging to radios not to exchange data. So radios should pass the sleep state and unnecessary energy consumption will be prevented. The radio process of node is active during the data transmission after completing the transition process performing going to sleep again called “Duty Cycle”.

Error control is one of the important tasks. Error-control techniques are designed with the goal to achieve a certain level of reliability in the transmission of packets despite errors on the transmission channel. Control and correction mechanisms schemes typically use are redundancy, retransmissions, and choice of transmit parameters like packet sizes and transmit powers. The most important tasks of the link layer such as adjacent sensor nodes, the connections association reliable and efficient transfer of information are the direct communication between the formation and maintenance. Despite the variable conditions of the wireless link reliability, time error should be obtained. In this thesis we handle Mac Protocol and Error Control issues [17].

Sensor nodes are usually resource constraints and battery-limited. In order to conserve resources and energy, to avoid overwhelming amount of traffic network data aggregation must be required. In sensor networks, there has been an extensive study on data collection plans. The purpose of data aggregation is to eliminate these unnecessary data transmission and improve the wireless sensor network life energy. Data aggregation is the process of several sensors which collects the detection result from other sensors. In order to reduce the transmission, collected data must be processed by the sensor [18].

Also data routing technique is great significance for Wireless Sensor Network in terms of energy conservation. During data transmission, nodes which have more energy must be used to prolong lifetime. In this way, nodes with low levels of energy in data transmission will work less, so the network will extend the life of the structure. So, all the corresponding nodes in the network have to know the energy levels of their adjacent nodes. If all nodes on the network broadcast their energy levels to the neighborhood, it causes very large amount of energy consumption and leads to congestion on the network. For this reason, in order to prevent energy consumption scientists, continue to work on different routing techniques.

2.2.1 Duty cycle

As stated in the previous section, in studies data transmission communication was determined maximum energy consuming units of sensor nodes [6]. In one survey conducted the amount of energy consumed during the transmission of a single bit between two wireless sensor nodes is almost equal to the amount of energy consumed by a sensor node performing thousands transactions[9]. In addition to this, when radio data transmission is not in progress namely wireless sensor nodes is idle, it spent closely same amount of energy during the data exchange. Therefore, there is no need to active when the node not to exchange data. So radios should pass the sleep state and unnecessary energy consumption will be prevented.

Generally studies on duty cycle are divided into two complementary sub categories which are Topology Control and Power Management [6]. However, we will focus on the topic of Topology control. On the network to provide full connectivity for the selection of enough nodes is called Topology Control. Thus, all nodes on a network structure according to the state is active, only using a sufficient number of nodes in the session with the network can increase the life time 2 or 3 times[19-21].

2.2.1.1 Topology Control

Topology Control Protocols provide data transfer within the network not using all number of active nodes. In Topology Control protocols a question will come in our mind. “Which nodes will remain active or passive states?” Decision can be made in two different ways. Studies, these generally based on two approaches [6].

In many studies related to Wireless Sensor Networks, there are assumptions; all nodes on the network have sufficient knowledge about their geographical location, adjacent nodes in its coverage area and data collection center (Sink). This is called Location Driven protocols.

There are two kinds of methods knowing coverage area from the adjacent nodes: GPS (Global Positioning System) and GAF (Geographic Adaptive Fidelity). GPS is device which has satellite communications for transmitting location coordinates. Developments in technology allow many electronic devices have been produced in much cheaper cost. In this way, in Wireless Sensor Networks for each of the nodes using GPS is not difficult and costly. GAF is an energy aware location-based routing algorithm designed primarily for mobile ad hoc networks, but it is used in sensor networks as well. The aim of this is optimizing the performance of wireless sensor networks by identifying equivalent nodes with respect by forwarding packets. In GAF protocol, entire area is divided into several square grids, each node uses location information based on GPS to associate itself with a “virtual grid”.

Figure 2.2 GAF Grids.

In this study, shown in Figure 2.2, the topology sliced into parcels which have equal size therefore each node is located within a parcel. Thus, in each parcel more than one node is located. To ensure equal load distribution active nodes in each plot, after a long active status within that parcel should leave the task of data transmission and change their transmission duty to reduce quickly energy of those nodes.

2.2.2 Link Layer Protocols

The most important tasks of the link layer are direct contact associations and connections ("links") between reliable and efficient transfer neighboring sensor nodes. Although time of the varying conditions on the reliability wireless link; many mechanisms have been suggested error conditions. Within the OSI reference model, the MAC is considered as a part of the Data Link Layer (DLL). It determines for a node in time to transmit data with unicast, multicast or broadcast. However there are two important responsibilities of the DLL: error control and flow control. Error control is used to ensure correctness of transmission and to take appropriate actions in case of transmission errors, and flow control regulates the rate of transmission to protect a slow receiver from being overwhelmed with data.

2.2.2.1 Mac Protocol

Energy efficiency is one of the most important issues in the design of MAC protocol for wireless sensor nodes. Collision is the first source of energy waste, which occurs when two or more sensor nodes try to transmit same time. If a packet retransmit that increases energy consumption. The second source of energy waste is idle listening. When traffic is not active a sensor node enters sleep mode. This mode, energy expended for monitoring a silent channel can be high from several sensor network applications. The third source of energy waste is overhearing which occurs when a sensor node receives packets that are destined to other nodes. Due to their low transmitter output, receivers in sensor nodes may dissipate a large amount of power. The fourth major source of energy waste is caused by control packet overhead. Control packets are required to regulate access to the transmission channel. A high number of control packets transmitted, relative to the number of data packets delivered indicates low energy efficiency.

The choice of the MAC method is the major determining factor in the performance of a WSN. Several strategies have been proposed to solve the shared medium access problem. Some of these;

Time Division Multiple Access (TDMA): TDMA is digital transmission technology that allows a number of communicating nodes to access a single radio-frequency channel without interference. This is achieved by dividing the radio frequency into time slots and then allocating unique time slots to each communicating node. Nodes take turns transmitting and receiving in a round-robin fashion. However, that only one node is actually using the channel at any given time for the duration of a time slot.

Frequency Division Multiple Access (FDMA): The FDMA scheme is used by radio systems to share the radio spectrum. Based on this scheme, the available bandwidth is divided into sub channels. Multiple channel access is achieved by allocating communicating nodes with different carrier frequencies of the radio spectrum. The bandwidth of each node's carrier is constrained within certain limits between different nodes such as no interference, or overlap.

Code Division Multiple Access (CDMA): CDMA is a spread spectrum (SS)–based on scheme that allows multiple communicating nodes to transmit simultaneously. Spread spectrum is a radio frequency modulation technique in which the radio energy is spread over a much wider bandwidth than needed data rate.

2.2.2.2 Error Control

Error control has a great importance due to severe energy constraints and low power communication requirements of Wireless Sensor Networks (WSNs). This function defines corruption useless packets transmission in all transmission media and wireless media. With error control mechanisms, the error effect is compensated for. The efficiency and energy consumption of different error control mechanisms depends on the patterns of link errors. Because any radio signal is affected by random noise and channel fading [22-23]. If a node receives a corrupted or erroneous data packet, the data can be discarded and the node keeps waiting for a new transmission or the node run an Automatic Repeat request (ARQ) procedure. There is a waste of energy in the network. Because of causing successive retransmissions undesirable situation occurs when the channel condition is bad. Another method to increase the energy conservation in WSN is to apply forward error correction (FEC) strategies, reducing the frame error rate and consequently the number of retransmissions.

2.2.3 Data aggregation

Sensor nodes are usually resource constraints and battery-limited. In order to conserve resources, energy and avoid overwhelming amount of traffic network data aggregation must be required. In sensor networks, there has been an extensive study on data collection plans. The purpose of data aggregation is to eliminate these unnecessary data transmission and improve the wireless sensor network life energy. Data aggregation is the process of several sensors that collects the detection result from other sensors. To reduce the transmission, collected data must be processed by the sensor [18]. We can enhance the robustness and accuracy of information which is obtained by entire network by data aggregation process. Data aggregation processing is needed to reduce the redundant information. Those redundant data reduces the traffic load and conserve energy of the sensors.

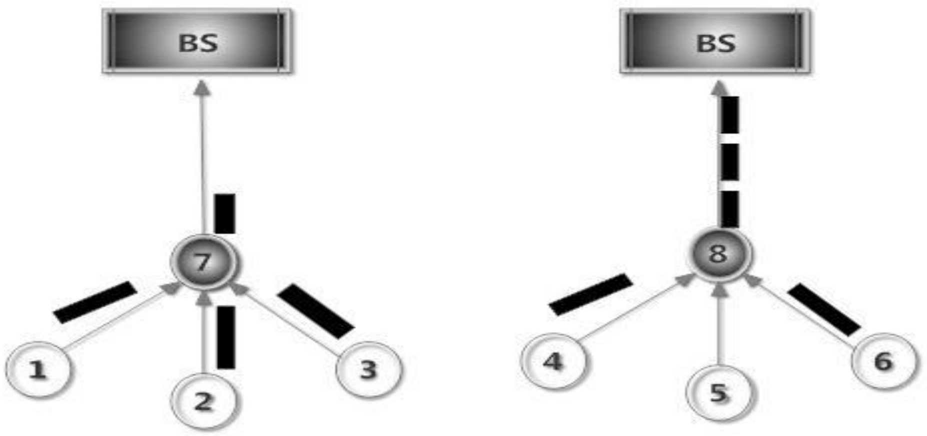


Figure 2.3 Data Aggregation Model and Non-data Aggregation Model.

Data transmissions of sensor nodes in wireless sensor networks consume a lot of energy between aggregators and queries. Figure 2.3 show us two models one is data aggregation model and second is non-data aggregation model in which sensor nodes 1, 2, 3,4,5,6 are regular of the nodes packet of data collection and reporting them back to the upper nodes where sensor nodes 7, 8 are aggregators that perform sensing and aggregating together at the same time. This aggregation model, 4 data packets travelled in the network, and only one data packet is transmitted the base station (sink).And other non-data aggregation model also 4 data packet travelled within the network and all data packets are sent to the base station (sink), means we can say with the help of the data aggregation process we decrease the number of data burden before they are transmitted to the base station or sink.

2.2.4 Routing Protocols

Routing technique is great significance for Wireless Sensor Network in terms of energy conservation. During data transmission, nodes with more energy must be used for energy conservation. In this way, nodes with low levels of energy in data transmission will work less, so the network will extend the life of the structure. So all the nodes in network have to know each energy level of the adjacent nodes. If all nodes on the network broadcast their energy levels to the neighborhood, it causes very large amount of energy consumption and leads to congestion on the network. For this reason, in order to prevent energy consumption scientists continue to work on the different routing techniques. Moving methods of data packet from the source node to the destination node is determined by the routing techniques. There are many problem comes with routing techniques. To overcome these problems researchers focuses some routing algorithms and protocols. Studies on WSN routing techniques is shown table 2.1.

Table 2.1 Wireless Sensor Network Routing Techniques.

Category	**Suggested Routing Techniques**
Flat Networks Routing Protocols	SPIN, DY, RR, GBR, CADR, EAR, MCFA, COUGAR, ACQUIRE, RPRW
Hierarchical Networks Routing	LEACH, PEGASIS, TEEN, VGA
Location Based Routing	GAF, GEAR, SPAN, TBF, BVGF, GeRaF, MECN, SMECN
Protocol Operation Based Routing	Query Based Routing, Multi-Path Based Routing, QoS Based Routing, Negotiation

2.2.4.1 Flat Networks Routing Protocols (FNR)

All sensor nodes in the network have equal status. Each node responsible performs same tasks. The aim of FNR is helping transmission with sensor nodes from source nodes to destination nodes. FNR is using data-centric routing architecture. This means that the source node on the network as effectively check the routing stage. Flat routing protocol is implemented in flat networks where each router node routinely collects and distributes routing information with its neighboring routers. The entire participating node addressed by flat routing protocol performs an equal role in the overall routing mechanism. Routing Information Protocol, Interior Gateway Routing Protocol and Enhanced Interior Gateway Routing Protocol are popular examples of flat routing protocols [24-26].

2.2.4.2 Hierarchical Networks Routing (HNR)

Hierarchical routing (Hierarchical Routing Networks - HNR) or called cluster-based routing, the main purpose of this group of protocols is to ensure the efficient use of energy. In HNR network structure, if sensor nodes having a low amount of energy just making detection. However a sensor node with high energy is used for detection, processing and routing. Sensor nodes are divided into clusters in HNR. Sensor nodes in cluster make only sense or shall perform all the functions according to the energy level in order to prolong the life time. An advantage of HNR is in the cluster; necessary data node is processed and transmitted to the target nodes. This is important occurring within the network to avoid unnecessary traffic [27] [28].

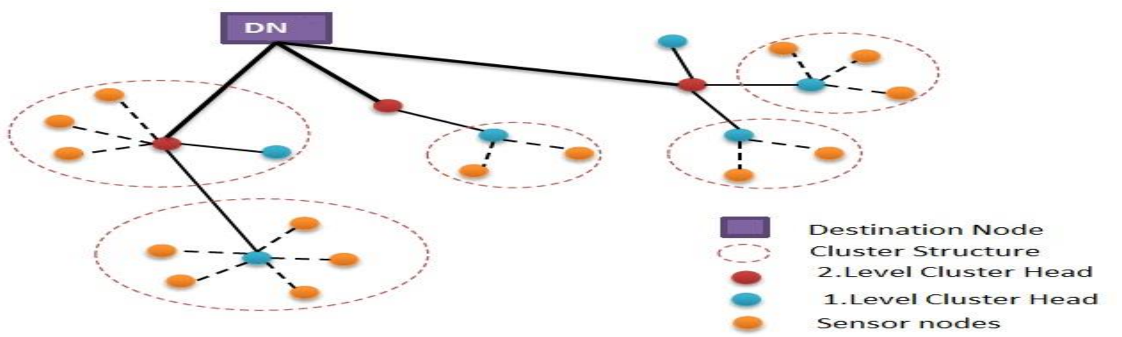


Figure 2.4 Hierarchical Routing [27].

2.2.4.3 Location Based Routing (LBR)

LBR is a protocol which gives in a way to determine position of sensor nodes, identified neighborly relations and routing issues in Wireless sensor network. In these protocols nodes is calculated by examining the signal strength from the neighboring sensor nodes [29] [30]. While studying on signal strength if LBR, also working on routing determination of sensor nodes. While Location Based routing;

a) When communication sensor nodes with each other, their data determines relative coordinates.
b) Determine the positions of sensor nodes via satellites.
c) Located on nodes with small powerful GPS receivers, positioning and direction determination is made. Consuming energy of finding direction with GPS or satellite in LBR more than FNR and HNR [31] [32].
Figure 2.5 shows the general structure of the LBR protocols.

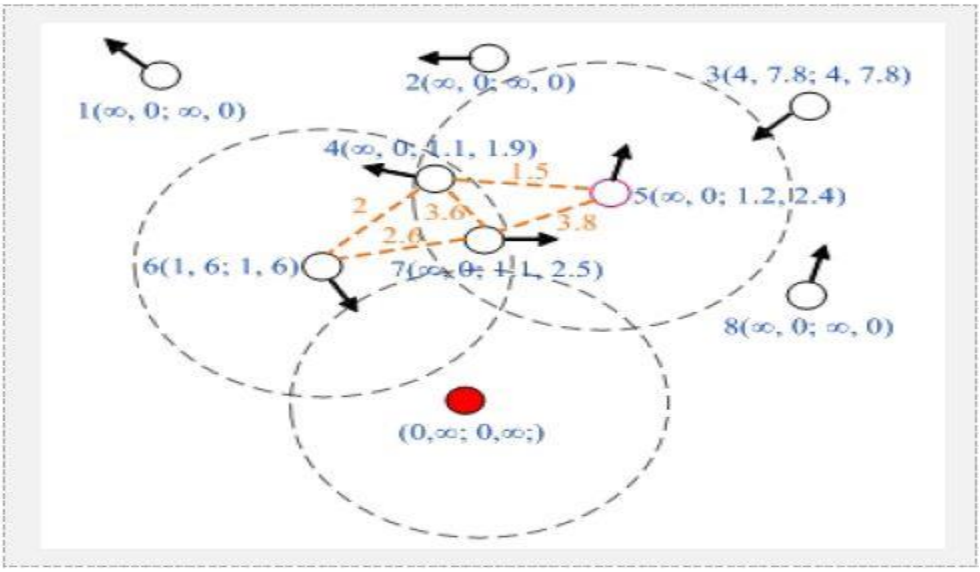


Figure 2.5 Structures of LBR Protocols [31].

2.2.4.4 Protocol Operation Based Routing (POBR)

When Protocol Operation Based Routing studies is examined in wireless sensor networks, in addition to developed routing protocols, focusing network communication with multiple layers and algorithms based studies in the structure. These studies are usually present development of protocols; studies of the structure are used together with multiple protocols and study of all related routing software based process. This kind of routing methods is generally preferred when routing protocols is not sufficient by themselves and needed different network structure. According to the routing process method POBR can be gathered under five separate headings. Figure 2.6 shows these methods.

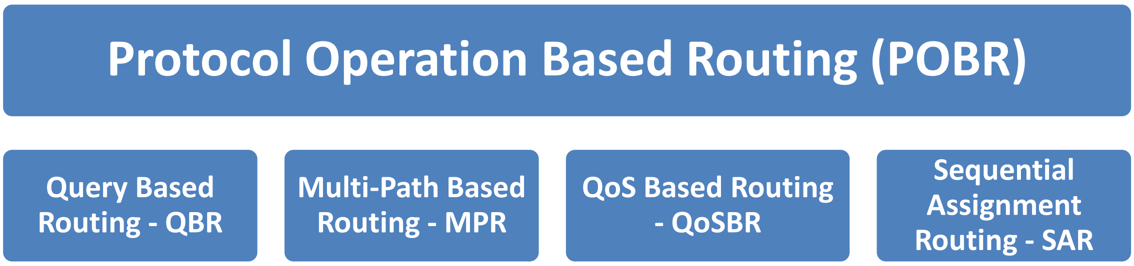


Figure 2.6 Protocol Operation Based Routing Techniques.

CHAPTER 3

EXPERIMENTAL ARCHITECTURE and DETAILS

This thesis presents an analysis of the effects of the various structural factors in terms of energy consumption in WSNs. General belief about cluster-based WSNs is that in order to alleviate the hot-spot problem, clusters located near the sink should be smaller-sized than the ones further to the sink. Other possible factors that may affect the lifetime of the network are the number of tiers, the node density, the communication radio coverage radius, the number and the location of the sinks. All these parameters are examined for all possible combinations in detail.

Clustering is virtually slicing the network topology into grids (Figure 3.1) and grouping the sensor nodes under these grids according to a number of benchmarks.

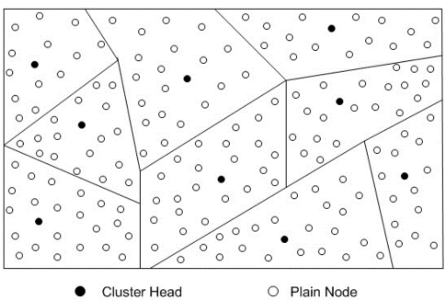


Figure 3.1 Voronoi Based Clustering.

One of the nodes in each cluster is charged with being cluster head (CH). Other nodes in the cluster which are called plain nodes gather data from the environment and deliver to the CH node. The CH node is responsible for conveying the overall data gathered in its cluster to the sink. In traditional non-cluster based sensor networks, each sensor node gathers data from physical environment and aims to transmit its data to the sink somehow. If it is thought that all the nodes in the topology try to deliver their data at the same time by flooding, a huge amount of data transmission will occur. Besides, since all the nodes try to access to the common transmission media at the same time, serious delays will be suffered as a result of collision prevention mechanisms. Moreover, in consequence of routing loops and multiple routes, redundant energy consumptions will emerge. Therefore, in terms of preventing redundant energy consumption during data transmission, clustering approach provides very significant gains by means of simplifying the communication and enhancing the scalability [33]. The point is that, how the clusters are defined and according to what the CHs are selected.

Many studies have been proposed about cluster-based WSNs. LEACH [34-35], is one of the first and fundamental studies conducted on WSNs and has led to many subsequent studies about clustering. Lifetime of the network is partitioned into rounds in LEACH. Cluster formation is done in an autonomous and distributed manner by the nodes without a centralized supervision. Each round is divided into two phases: set-up and data transmission states. At set-up phase, each node in the topology holds a random number and depending on this number elects for being a cluster head. Load is evenly distributed by rotating the charge of being CH among all nodes. Thus, the case that the nodes in the topology quickly drain battery is prevented. Another impressive solution proposed in LEACH is the CHs making data aggregation in order to reduce the amount of data to be transmitted.

Another work done about clustering is PEGASIS [36] which is a follower of LEACH. Although PEGASIS is perceived as an improvement of LEACH, its basic principle is based on the chain structure rather than a cluster scheme.

HEED [37], is another work which achieves considerable amendments on energy conservation in WSNs. As in LEACH, CH selection is done periodically but not at each round. In contrast with LEACH, CH selection is not done randomly, but is rather made according to a hybrid parameter which is a combination of the residual energy levels of the nodes and a cost value called the average minimum reachability power (AMRP).

AMRP is the total energy consumed by all the other nodes in the cluster if the aforementioned node becomes CH.

Clustered routing for selfish sensors (CROSS) [28] and its improved version localized game theoretical clustering algorithm (LGCA) [39] is based on the game theory for cluster formation and CH election. CROSS depends on global knowledge about the topology which is not very practical and realistic. In contrast, LGCA employs localized information which is more suitable for energy poor WSNs.

In 2009, Zhu et al. have proposed an architecture [40] in which clustering is basically performed by utilizing Hausdroff Distance [41]. The first criterion that is considered during CH selection phase is the residual energy level of the nodes. Secondly, if the residual energy levels are same, then the proximity off the nodes is taken into care. Inter-cluster routing is performed by means of utilizing classical Bellman-Ford's shortest path approach [42].

In EECS (An Energy Efficient Clustering Scheme in Wireless Sensor Networks) [43], the residual energy levels of the nodes is again considered. Another factor impacting the CH selection is the distance between the CH candidates and the sink because of the reason that inter-cluster communication is performed directly between the CHs and the sink.

In order to prevent redundant message exchange suffered during CH election phase, Cui et al., proposes an efficient idea which is called passive clustering [44]. With passive clustering, each CH candidate determines a random waiting time inversely proportional with the residual energy levels of the nodes. That is, a node with little energy level waits longer time to announce its leadership. Therefore, timers of the nodes with higher energy levels expire earlier and announce their leadership before the others. Thus, other nodes hearing the announcement give up the competition.

Inter-cluster communication is another challenge to be considered in cluster-based networks. Data delivered at the end of intra-communication phase must be conveyed to the sink by the CH. This can be achieved either by single-hop or multi-hop communication. ANCAEE (A Novel Clustering Algorithm for Energy Efficiency in

Wireless Sensor Networks) offers single-hop transmission for intra-cluster communication and multi-hop transmission for inter-cluster communication [31].

Well beyond the studies mentioned above there have been several other research conducted on cluster-based sensor networks [45-49]. Next section gives details about the methods and architectures utilized in the system while analyzing the impacts of different structural variations on energy consumption.

3.1 METHODOLOGY

This section describes the outlines of the methodology and some significant concepts we utilized in our analysis. We performed a large set of simulations with various combinations of node density, tier count, sink settlement, radio coverage and cluster sizing. Each simulation was run until the first node death which implies the network lifetime. Since the primary challenge to be accomplished for WSNs is prolonging the working life of the network, for performance measurement we considered the network lifetime.

Instead of considering an event-based system, simulations based on the scenario that all nodes in the topology periodically gather data and try to transmit that data to the sink(s). For convenience, sensor nodes are assumed to be fixed and randomly distributed in a two-dimensional plane. Since all nodes might participate during inter-cluster communication, they do not apply any sleep-wake-up schedule.

Details about the main figures utilized during simulations are described in the following subsections.

3.1.1 Energy Consumption Model

In this study, the classical energy model as described in LEACH is used. As is known, primary factors affecting the energy consumption are the number of bits transmitted and the distance between the communicating pairs. If the distance between the communicating nodes is greater than the threshold value, then the impact of the distance on the energy consumption grows exponentially as shown in Equations (3.5-3.7).

$$E_{snd}(l,d) = E_{snd\text{-}elec}(l) + E_{snd\text{-}amp}(l,d) \quad (3.5)$$

$$Esnd(l,d) = \begin{cases} (l * E_{elec}) + (l * \varepsilon_{fs} * d^2), & d < d_o \\ (l * E_{elec}) + (l * \varepsilon_{mp} * d^4), & d \geq d_o \end{cases} \quad (3.6)$$

$$E_{rcv} = l * E_{elec} \quad (3.7)$$

3.1.2 Network Lifetime

Several network lifetime definitions are proposed in the literature [50-55]. Some of them consider the time that a certain amount of the nodes die. Another idea to consider is the time that there is a region that is no longer covered by the network. The one that makes the most sense and which we applied in this study is the time when the first node fails. When a node dies, it would not be accurate and realistic to make an assumption that the remaining network will work well. Eventually, the node is dead and no data can be obtained from the area that the dead node is responsible for. Besides, this can result in a network partition situation which means there are two nodes cannot communicate with each other anymore.

3.1.3 Cluster Head Election

Cluster Heads (CHs) have the responsibility of relaying the aggregated data of the corresponding cluster to the sink. Therefore, this heavy mission should be shared among different nodes as much as possible. Otherwise, the node assigned as CH drains its battery quickly. In this study, three types of CH election methods are analyzed.

CH Election Model 1: Every node in a cluster runs the same algorithm similar to the one proposed in [44]. The result of the algorithm is a time value that determines the access time of a node to the common media for announcing its leadership. Other nodes hearing this announcement gives up the election and assigns that node as the master node. Calculated waiting time (Tw(i)) at each node is reversely proportional with the distance of the node to the centre of the corresponding cluster and the residual energy level of that node:

$$Tw(i) = d(node(i), ClsCentre) / EngRes\_node(i) \quad (3.1)$$

where;

d (node(i), ClsCentre) is the euclidean distance between node(i) and the centre point of the cluster it belongs;

EngRes_node(i) is the residual energy of node(i).

According to Equation (1), nodes positioned around the cluster centre with more residual energy levels wait shorter durations and probability of being elected as CH is higher than the others.

CH Election Model 2: It uses a similar method to the one identified in model 1. This time, an extra parameter is involved during CH election phase as presented in Equation (3.2). Nodes, positioned between the centre of the corresponding cluster and the sink can be a CH. Furthermore, the distance between the node and the target sink is considered rather than the distance from the node to the centre of the cluster (Equation (3.3)).

$$isCHCnd = \begin{cases} 1 & node(i)_{ypos} < ClsCentre_{ypos} \\ \infty & \end{cases} \quad (3.2)$$

where;

isCHCnd is a value that determines the possibility of a node to be a CH;
node(i)ypos, and ClsCentreypos denote the (y) coordinates of node(i) and the center point of the cluster it belongs respectively.
Obviously, according to Equation (3.2), CHs are elected among the nodes that are positioned between the centre point of the corresponding cluster and the target sink.

$$Tw(i)= (isCHCnd * d(node(i),TrgSink)) / EngRes\_node(i) \quad (3.3)$$

where:

isCHCnd is a value that determines the possibility of a node to be a CH;

d(node(i), TrgSink) is the euclidean distance between node(i) and the target sink;

EngRes_node(i) is the residual energy of node(i).

CH Election Model 3: In this method, every node in the cluster can be elected as a CH. There is no constraint like the one defined in Model 2. Again, target is the sink(s) and nodes closer to the sink(s) with more residual energies have greater chance to be elected as CH (Equation (3.4)).

$$Tw(i)= d(node(i),TrgSink) / EngRes\_node(i) \tag{3.4}$$

3.1.4 Routing

Next-hop selection is performed depending on the geographical positions of the nodes. It is assumed that all nodes are aware of their relative two dimensional coordinates in the topology. Besides, they are assumed to be informed about the coordinates of their neighbors and the sinks settled in the topology. A number of techniques have been proposed in the literature about the localization and the positioning concepts. The first coming to mind is that equipping the sensor node with Global Positioning System (GPS) receiver. However, that is not a promising solution because of deployment and cost limitations. There are other alternative solutions proposed such as lateration and angulation techniques [56]. Since it is out of scope of this study, no specific positioning method is studied in the thesis.

3.1.4.1 Intra-Cluster Communication

Data gathered by each plain node in the cluster is delivered directly to the CH in a single-hop manner if it is in the coverage area of the sender node. Otherwise, multi-hop transmission is utilized. The packet emerging from the plane sensor node is forwarded to one of the neighbor’s belonging to the same cluster which is closest to the CH. Next-hop selection method for intra-cluster packet transmission is given below:

Algorithm 1 Intra-Cluster Next-Hop Selection Method

```
findNextIntraClsHop(){
  if (isInCov(this, CH)) then
     sendPckDirectlyToCH()
  end if
  else
    distance ← ∞
    for (i←1 to numOfNgbs ) do
       if (d(this,CH) < dist(ngb(i),CH))    then
        if (isInSameCls(this,ngb(i)))      then
          if (dist(ngb(i),CH) < distance) then
             distance = dist(ngb(i),CH)
             nexthop = ngb[i]
          end if
       end if
      end if
    end for
    sendIntraClsPckToNxtHop(nexthop)
  end if
}
```

3.1.4.2 Inter-Cluster Communication

Data aggregated at each cluster is delivered by the CHs directly to the closest sink if the sink is in the coverage. Otherwise, the aggregated packet is forwarded to the node that is closest to the target sink. If noticed, the next hop candidate of the inter-cluster packet is not required to be in the same cluster. Next-hop calculation method for Inter-cluster communication is given below:

Algorithm 2 Inter-Cluster Next-Hop Selection Method

```
findNextInterClsHop(){
  TrgSink ← calcTrgSink();
  if (isInCov(this, TrgSink)) then
     sendPckDirectlyToTrgSink(TrgSink)
  end if
  else
    distance ← ∞
    for (i←1 to numOfNgbs ) do
       if (d(this,TrgSink) > dist(ngb(i),TrgSink))    then
          if (dist(ngb(i),TrgSink) < distance) then
             distance = dist(ngb(i), TrgSink)
             nexthop = ngb[i]
          end if
       end if
    end for
    sendInterClsPckToNxtHop(nexthop)
  end if
}
```

3.1.5 Packet Structures

Length of an Intra-cluster packet is 52 bytes that takes 1625μs to transmit with the utilized radio data rate. As is known, WSNs are data-centric applications, not id-based like other traditional networks. That is, data collection centre does not deal with the ID of the data source. It is only interested with the content. ID is only needed during forwarding operations inside the topology. Thus, there is no need to apply conventional, redundant IP or MAC addresses during in-network forwarding. It is sufficient to define short in-network unique addresses for forwarding purposes. Since all nodes assumed to be aware of their geographical positions of themselves and their neighbors, and it is also assumed that two distinct nodes do not overlap, these relative two-dimensional coordinates constitute the ID of the nodes.

Intra-cluster packet structure is presented in Figure 3.2.

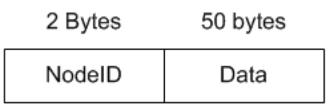


Figure 3.2 Intra-Cluster Packet Structure.

CHs aggregate the data delivered by the plain nodes in its corresponding cluster and generate an Inter-Cluster packet to be transmitted to the sink. Structure of an Inter-Cluster Packet is depicted in Figure 3.3.

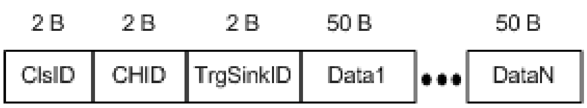


Figure 3.3 Inter-Cluster Packet Structure.

As shown in Figure 3.3, first 6 octets of the Inter-Cluster packet are fixed for every Inter-Cluster packet. ClsID and CHID slots contain the IDs of the owner cluster and the corresponding CH. By this way, when the aggregated packet arrives at the data collection centre, this information identifies the region to which that packet belongs. Each round, a new sensor node is elected as a CH. Therefore, the value of the second octet part changes each round. Field TrgSinkID denotes the ID of the target sink. Like the sensor nodes, relative two-dimensional coordinates of the sinks constitutes their IDs. Topology is virtually divided into clusters uniformly and permanently and each cluster defines its target sink at the beginning of the lifecycle. That is the closest one relative to the centre point of the cluster. Remaining parts of the Inter-cluster packet comprises of the data delivered by each plane node in the cluster. Since the number of nodes varies for each cluster, a general formula identifying the total length of an Inter-Cluster packet is as follows:

$$\text{LengthInterClsPck} = 48 + (\text{LengthIntraClsPck} * \text{NumOfNodes}) \tag{3.8}$$

3.1.6 Cluster Size

One of the most important challenges encountered in WSNs is the hot-spot problem. As stated above, since sensor nodes are very tiny devices, their resources have limited capacities. Same limitation is also valid for the communication coverage radius. Sensor nodes far from the sink cannot transmit their data directly to the sink. Moreover, conveying the data directly which is actually single-hop transmission is not preferred because the energy consumed during data transmission is exponentially proportional by the distance. Therefore, multi-hop communication is preferred in WSNs. Though multi-hop communication seems to be advantageous, another vital challenge to be considered is called the hot-spot problem. Nodes closer to the sink act like a relay and convey the data incoming from the remote nodes to the sink as shown in Figure 3.4. Hence, all of the data traffic passes over a limited number of nodes that will cause these nodes quickly drain battery. As a consequence, batteries of these nodes quickly drain which is called the hot-spot problem.

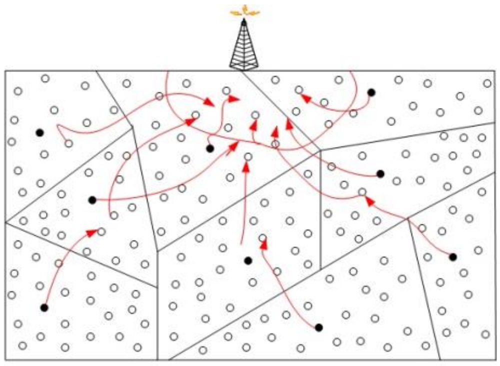


Figure 3.4 Hot-spot Problem.

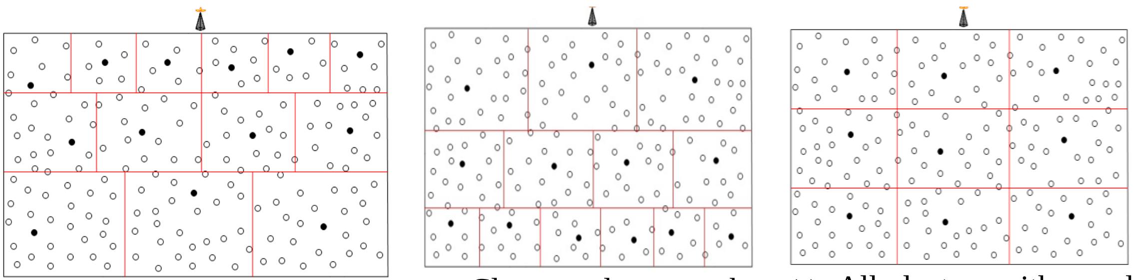
One of the challenging proposals for the hot-spot problem is the unequal clustering method. Researchers claim that forming the cluster located closer to the sink with smaller sizes and the remote ones with larger sizes provides considerable gains in terms of energy conservation [56-62].

In this part, we inspect the effect of cluster sizes on energy consumption for three types of methods:

- Clusters closer to the sink with smaller sizes and remote clusters with larger sizes (ClsSizeModel1 - Figure 3.5(a))

- Clusters closer to the sink with larger sizes and remote clusters with smaller sizes (ClsSizeModel2 - Figure 3.5(b))

- All clusters with equal size (ClsSizeModel3 - Figure 3.5(c))



(a) Clusters closer to the sink with smaller sizes and remote clusters with larger sizes.

(b) Clusters closer to the sink with larger sizes and remote clusters with smaller

(c) All clusters with equal size.

Figure 3.5 Sizes of the Clusters.

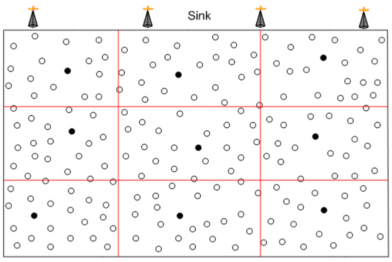
3.1.7 The Number and Location of the Sinks

Generally, researchers locate a single sink at one side or at the centre of the topology. However, position and number of the sinks can affect the energy consumed in the topology. Therefore, another important point examined in this thesis is the variation in network lifetime depending on the position and the number of the sink(s) in the network. Simulations performed according to three different sink(s) localization types.

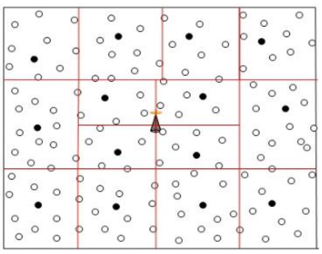
- Sink(s) located at one side of the topology (Figure 3.6(a))

- Sink located at the centre of the topology (Figure 3.6(b))

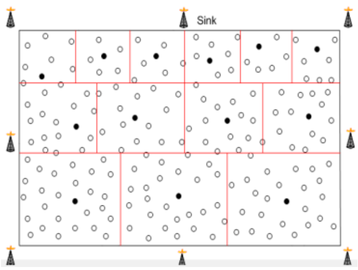
- Sink(s) positioned around the topology (Figure 3.6(c))



(a) Sink(s) located at one side of the topology.



(b) Sink located at the center of the topology.



(c) Sink(s) positioned around the topology.

Figure 3.6 Sink(s) Positioning.

CHAPTER 4

EVALUATION AND PERFORMANCE ANALYSIS

In this section, we analyze the performance and the impact of five structural factors on energy consumption: the number of tiers, the cluster sizes, the number and the location of the sinks, the node density and the radio coverage. While analyzing the effects of these factors, different types of CH election methods are utilized and performances are compared. The simulations are performed in a 500*500 squarely shaped area where the nodes are randomly deployed. Lifetime comprises of periodic rounds that each consists of CH election, data aggregation, intra-cluster data transmission and inter-cluster data communication phases. Topology is virtually divided into tiers and clusters.

In order to prevent common media access collisions, a MAC protocol similar to 802.11 with RTS/CTS mechanism is used. As mentioned in the previous section, we employed the classical energy calculation model that depends primarily on the distance. Parameters utilized during simulations are given in Table 4.1.

Table 4.1 Simulation Parameters.

Radio transmission data rate	250 Kbps
d_0 (threshold distance)	85 m
R_0 (coverage radius)	100 m
Eelec	50 nJ/bit
ε_{fs}	10 pJ/bit/m2
E_{mp}	0.0013

As mentioned earlier, the impacts of cluster sizing, the number and the location of the sink(s), the number of tiers and the node density on energy consumption is represented comprehensively. Simulations are performed under three structural titles depending on how the clusters are sized. As clarified previously, these are: clusters closer to the sink with smaller sizes and remote clusters with larger sizes (ClsSizeModel1), clusters closer to the sink with larger sizes and remote clusters with smaller sizes (ClsSizeModel2) and all clusters with equal sizes (ClsSizeModel3).

4.1 CLUSTERS NEAR the SINK with SMALLER SIZES (ClsSizeModel1)

Another alternative solution proposed by the researchers is slicing the topology to tiers. As shown in Figure 4.1, incrementing the number of tiers redundantly makes a negative impact on the lifetime of the network. With a topology of containing 500 nodes, the best performance is provided with 2 tiers. SelectCH_Center, SelectCH_EN_AfterCenter and SelectCH_EN_withNoCons correspond to the CH election schemes CH Election Model 1, CH Election Model 2 and CH Election Model 3 respectively.

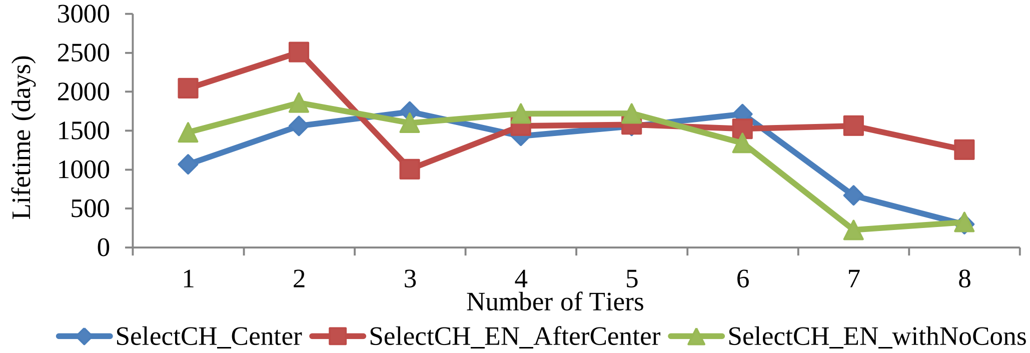


Figure 4.1 Changes in the Network Lifetime Depending on the Number of Tiers.

Another possible factor that may affect the network lifetime is the number of nodes in the network. By holding the size of the topology area constant, increasing the number of nodes increases the node density. However, more nodes means more data packets to be transmitted. Thus, the load is seemed to be shared by the time the density increases; however, increase in the network traffic balances this factor. Figure 4.2-4.4

shows the lifetime performance depending on the node density for the networks sink(s) at one side, sink at the centre and sinks surrounding the nodes respectively.

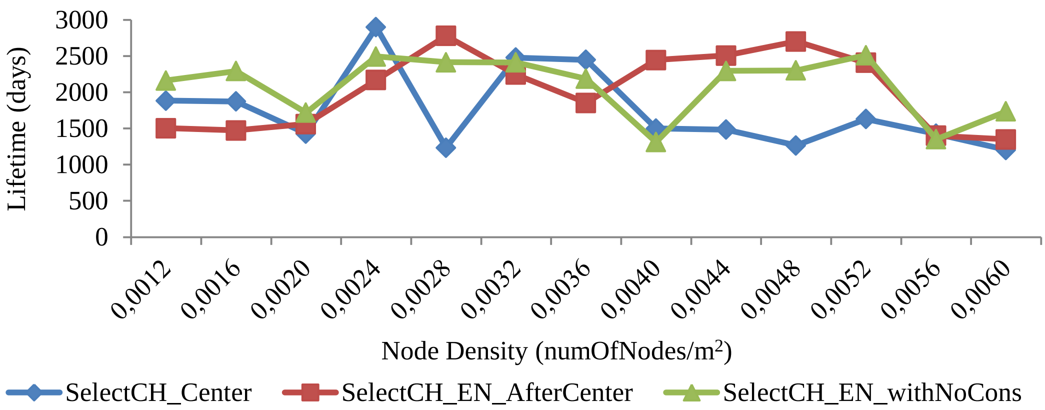


Figure 4.2 Changes in the Network Lifetime Depending on the Node Density for (SinkPositionModel1- ClsSizeModel1) Pair.

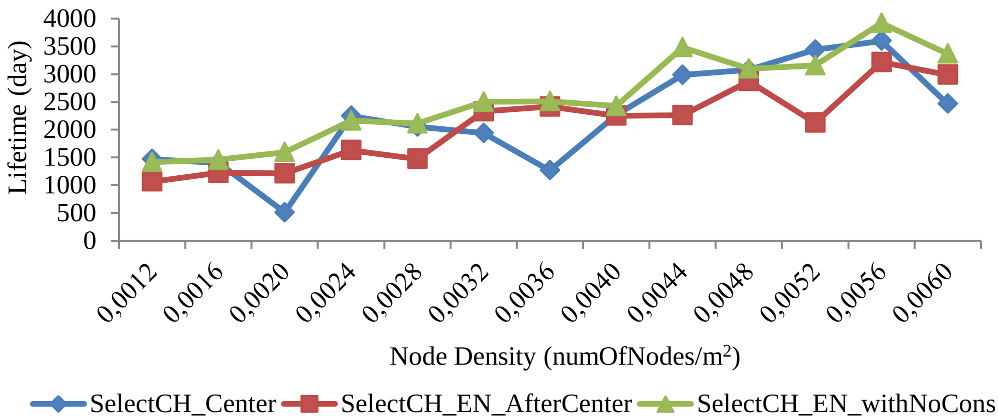


Figure 4.3 Changes in the Network Lifetime Depending on the Node Density for (SinkPositionModel2, ClsSizeModel1) Pair.

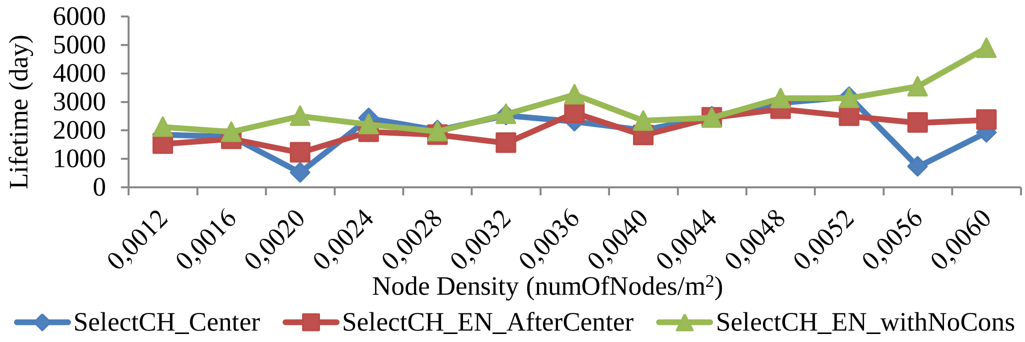


Figure 4.4 Changes in the Network Lifetime Depending on the Node Density for (SinkPositionModel3, ClsSizeModel1) Pair.

Figure 4.2-4.4 clarifies that a topology model surrounded with the sinks provides the best performance in terms of network lifetime.

Another possible factor that can affect the network performance is the number of sinks in the system. We examined if an increase in the number of sinks prolongs the lifetime of the network.

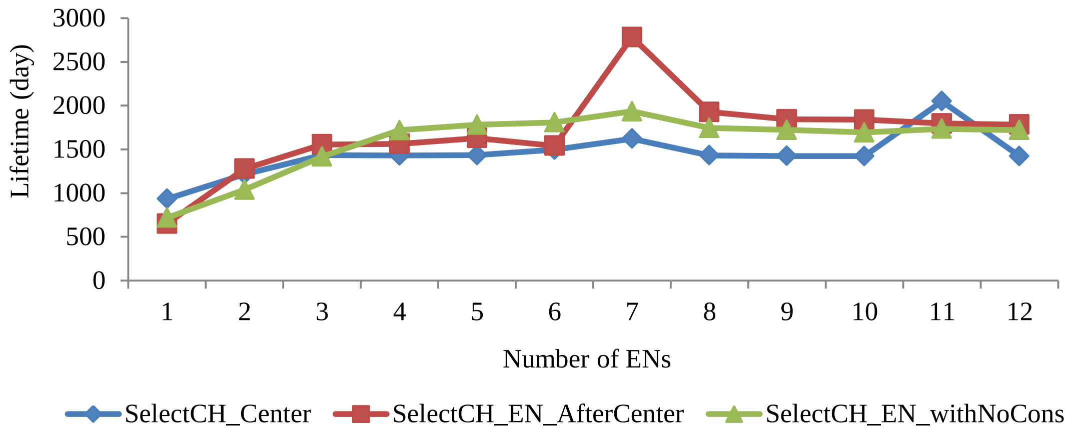


Figure 4.5 Changes in the Network Lifetime Depending on the Number of Sinks for (SinkPositionModel1, ClsSizeModel1) Pair.

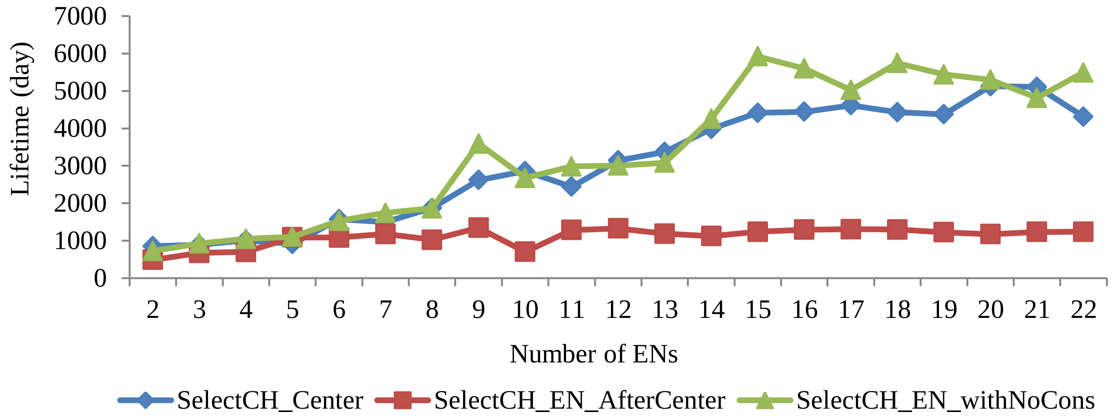


Figure 4.6 Changes in the Network Lifetime Depending on the Number of Sinks for (SinkPositionModel3, ClsSizeModel1) Pair.

Figures 4.5-4.6 reproves that with SinkPositionModel3, network lifetime is doubled by increasing the number of sinks in the network. Since, the sensor nodes have limited coverage capacities and the energy consumption is proportional with the communication distance, multi-hop communication is preferred in WSNs. In our simulation model, CHs directly forward the aggregated data to the sink(s) if they are in the communication range. However, this causes an extra burden. As mentioned in the previous section, energy consumption of the communication unit is exponentially proportional with the distance between the receiver and the sender. This idea is supported by Figures 4.7-4.9. Increased radio coverage does not bring an extra advantage in terms of energy conservation.

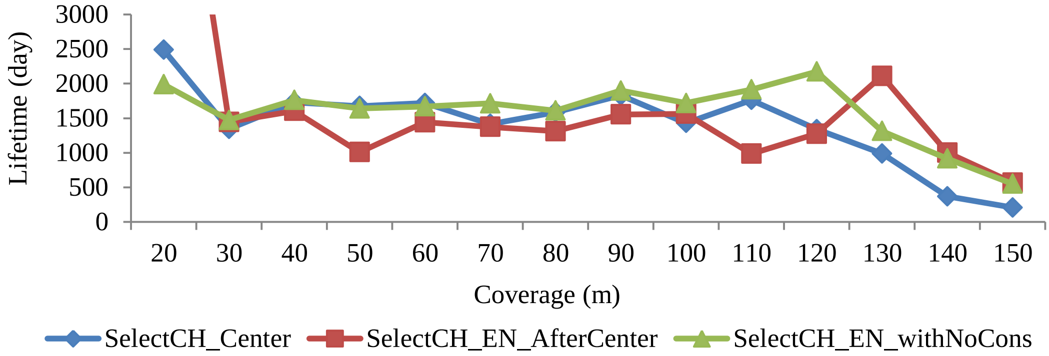


Figure 4.7 Changes in the Network Lifetime Depending on the Radio Coverage for (SinkPositionModel1, ClsSizeModel1) Pair.

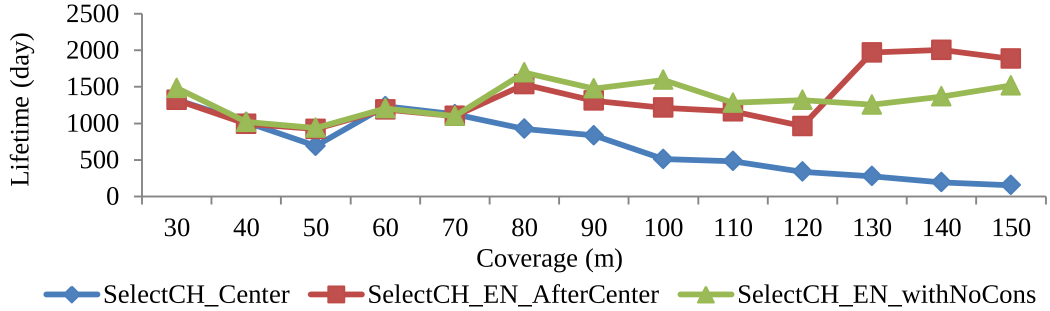


Figure 4.8 Changes in the Network Lifetime Depending on the RadioCoverage for (SinkPositionModel2, ClsSizeModel1) Pair.

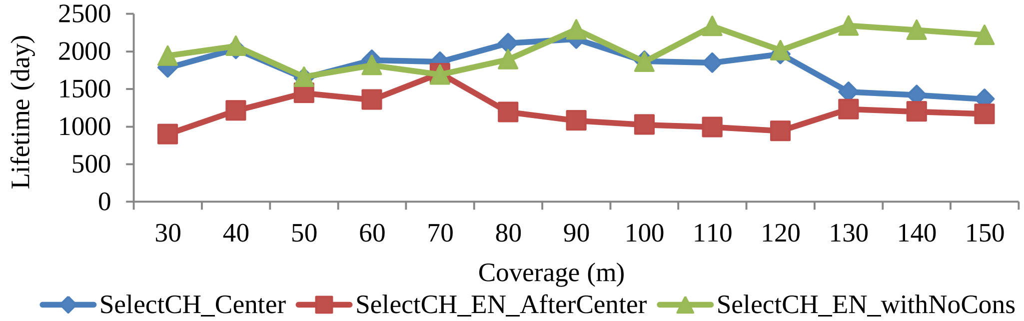


Figure 4.9 Changes in the Network Lifetime Depending on the Radio Coverage for (SinkPositionModel3, ClsSizeModel1) Pair.

4.2 CLUSTERS NEAR the SINK with LARGER SIZES (ClsSizeModel2)

Figures 4.10-4.17 present the changes occur in the network lifetime depending on the parameters presented in the previous section. This time, clusters closer to the sink(s) have larger sizes and the further ones with smaller sizes.

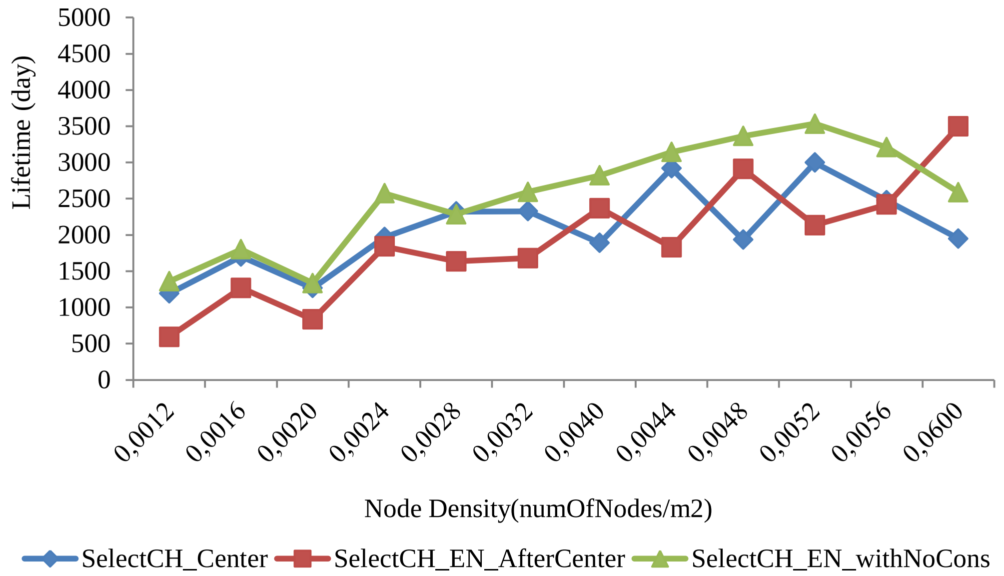


Figure 4.10 Changes in the Network Lifetime Depending on the Node Density for (SinkPositionModel1, ClsSizeModel2) Pair.

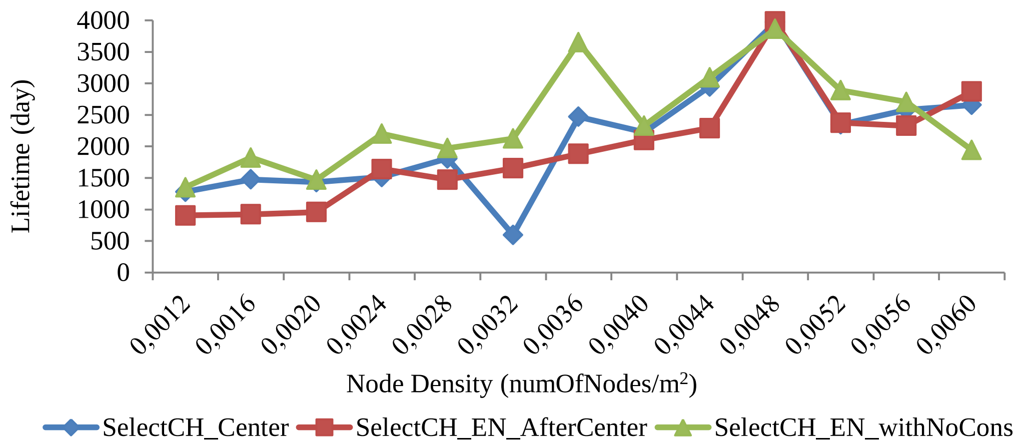


Figure 4.11 Changes in the Network Lifetime Depending on the Node Density for (SinkPositionModel2, ClsSizeModel2) Pair.

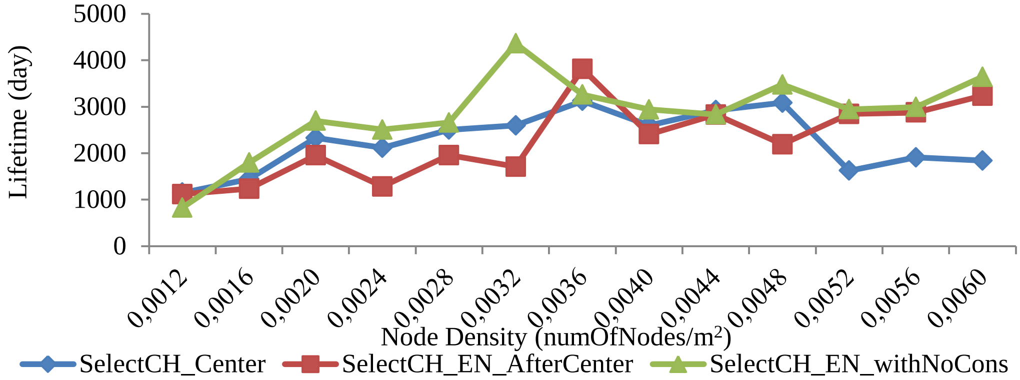


Figure 4.12 Changes in the Network Lifetime Depending on the Node Density for (SinkPositionModel3, ClsSizeModel2) Pair.

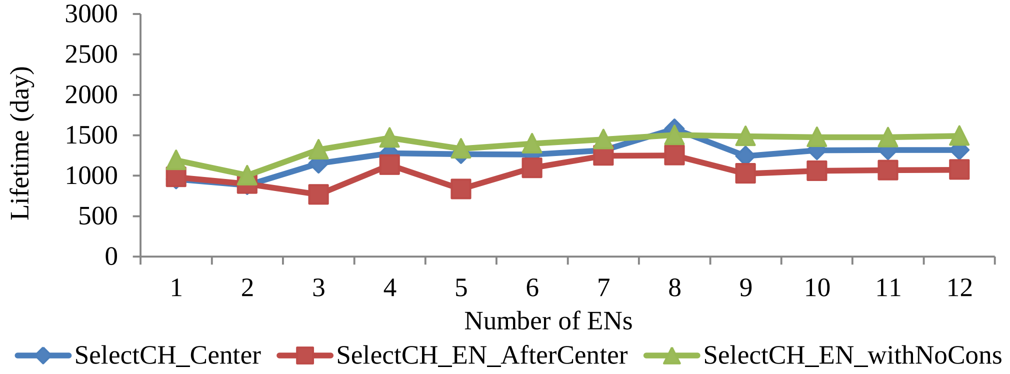


Figure 4.13 Changes in the Network Lifetime Depending on the Number of Sinks for (SinkPositionModel1, ClsSizeModel2) Pair.

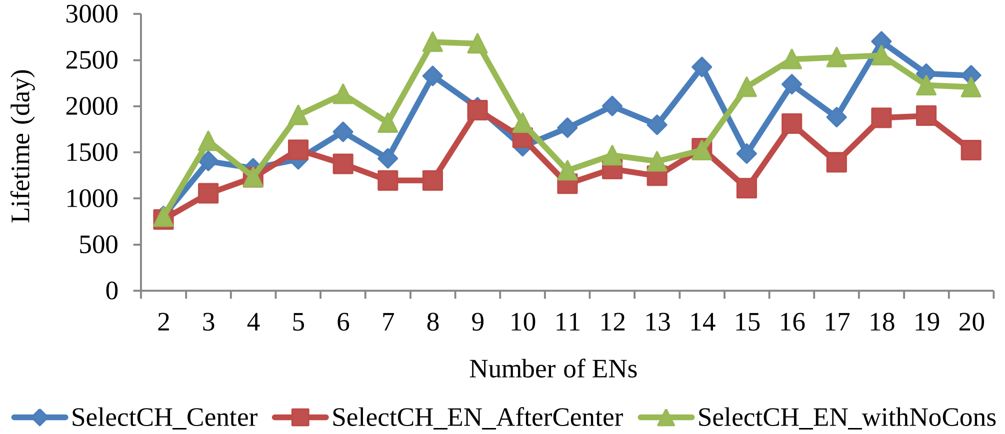


Figure 4.14 Changes in the Network Lifetime Depending on the Number of Sinks for (SinkPositionModel3, ClsSizeModel2) Pair.

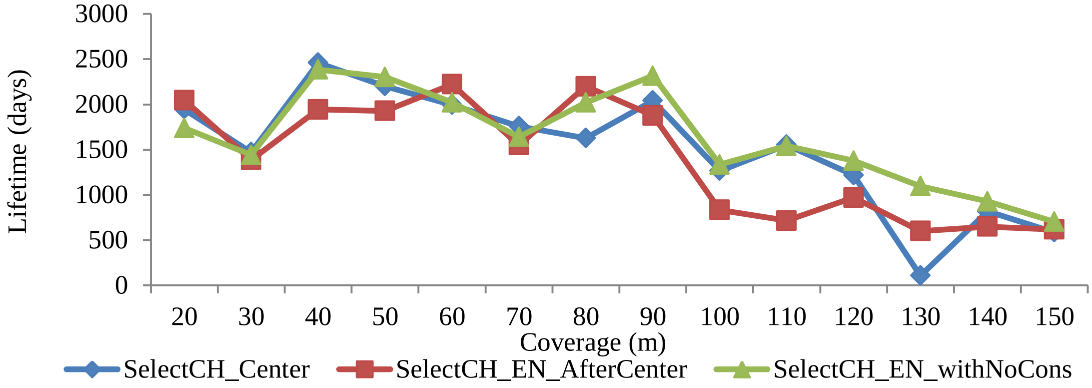


Figure 4.15 Changes in the Network Lifetime Depending on the Radio Coverage for (SinkPositionModel1, ClsSizeModel2) Pair.

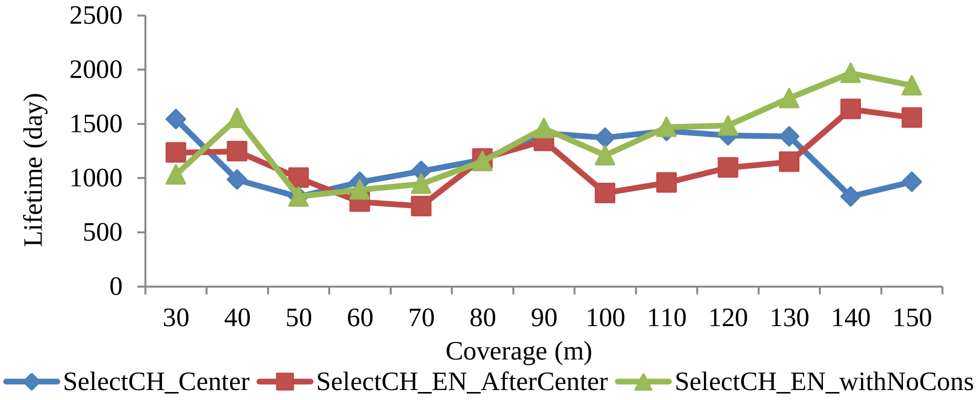


Figure 4.16 Changes in the Network Lifetime Depending on the Radio Coverage for (SinkPositionModel2, ClsSizeModel2) Pair.

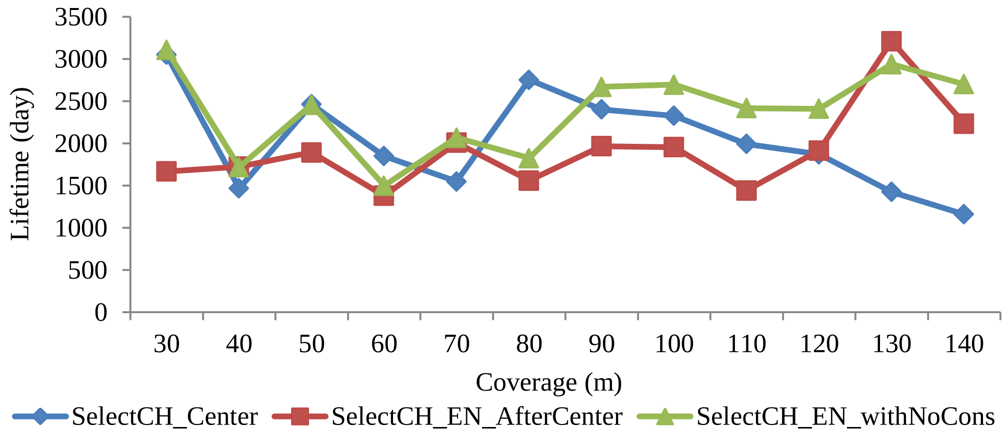


Figure 4.17 Changes in the Network Lifetime Depending on the Radio Coverage for (SinkPositionModel3, ClsSizeModel2) Pair.

4.3 ALL CLUSTERS with EQUAL SIZES (ClsSizeModel3)

Finally, Figures 4.18-4.25 present the changes occurring in the network lifetime depending on the parameters presented in the previous section. This time, all the clusters in the network have equal sizes.

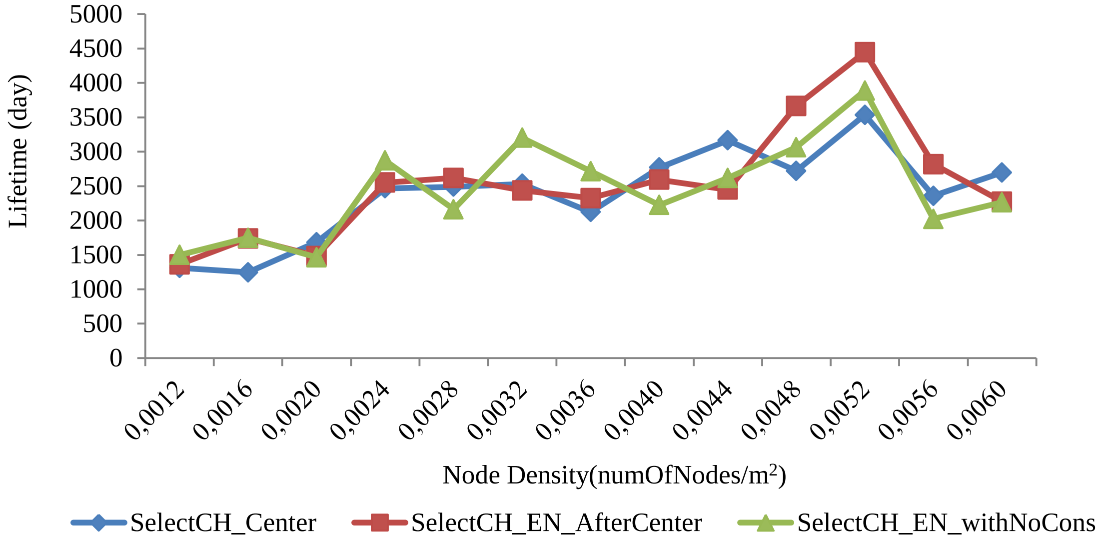


Figure 4.18 Changes in the Network Lifetime Depending on the Node Density for (SinkPositionModel1, ClsSizeModel3) Pair.

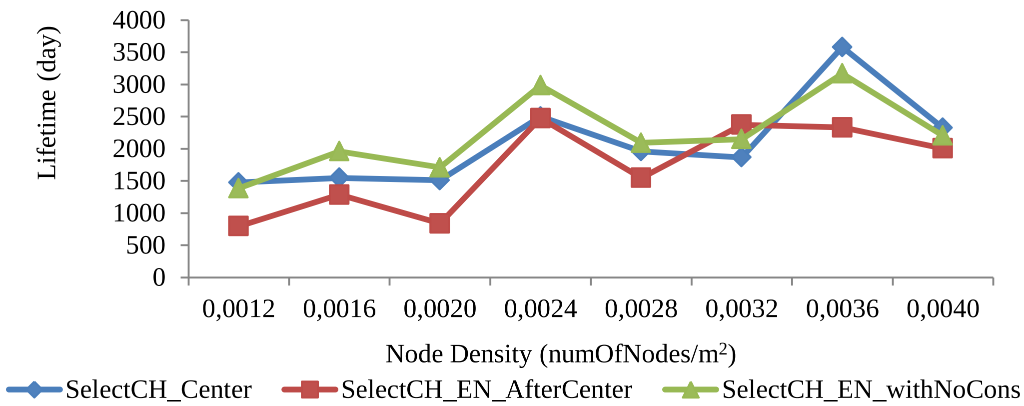


Figure 4.19 Changes in the Network Lifetime Depending on the Node Density for (SinkPositionModel2, ClsSizeModel3) Pair.

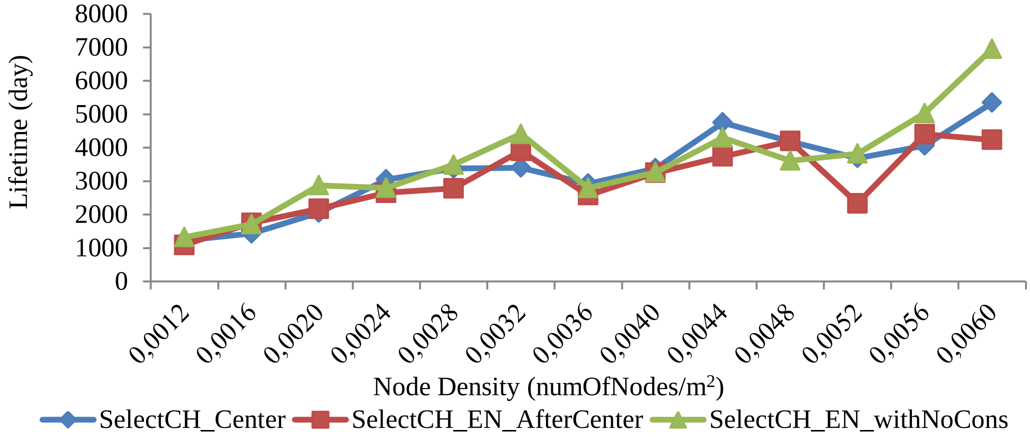


Figure 4.20 Changes in the Network Lifetime Depending on the Node Density for (SinkPositionModel3, ClsSizeModel3) Pair.

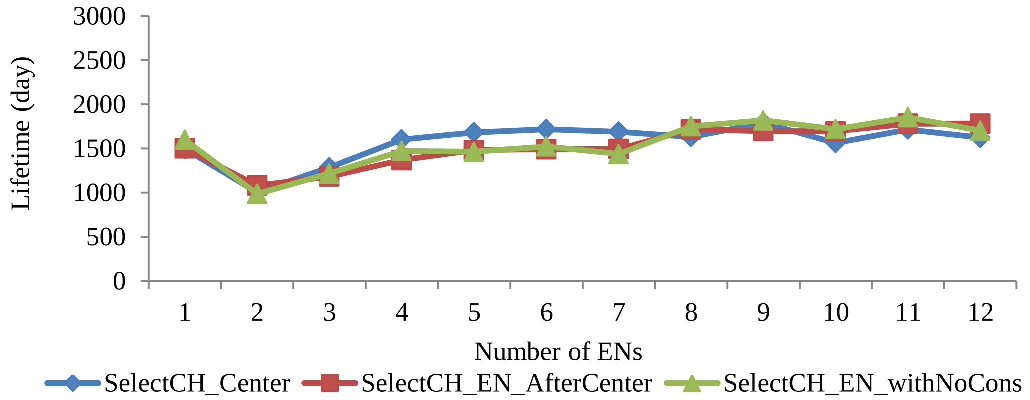


Figure 21 Changes in the Network Lifetime Depending on the Number of Sinks for (SinkPositionModel1, ClsSizeModel3) Pair.

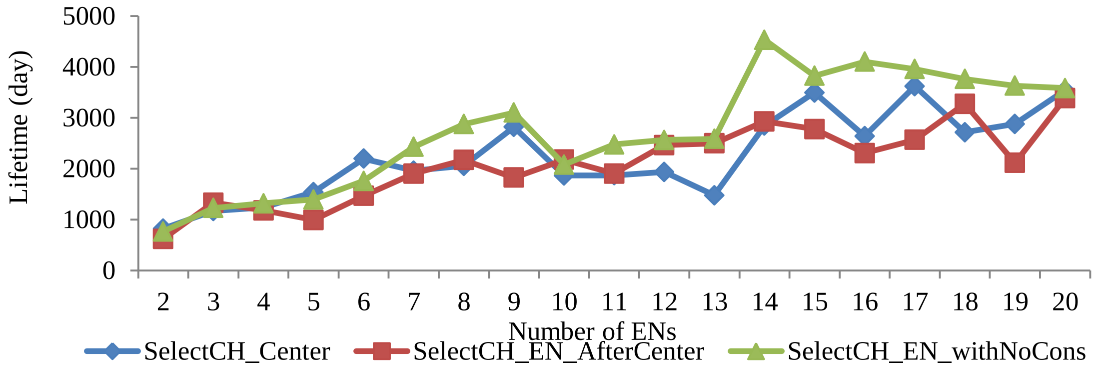


Figure 4.22 Changes in the Network Lifetime Depending on the Number of Sinks for (SinkPositionModel3, ClsSizeModel3) Pair.

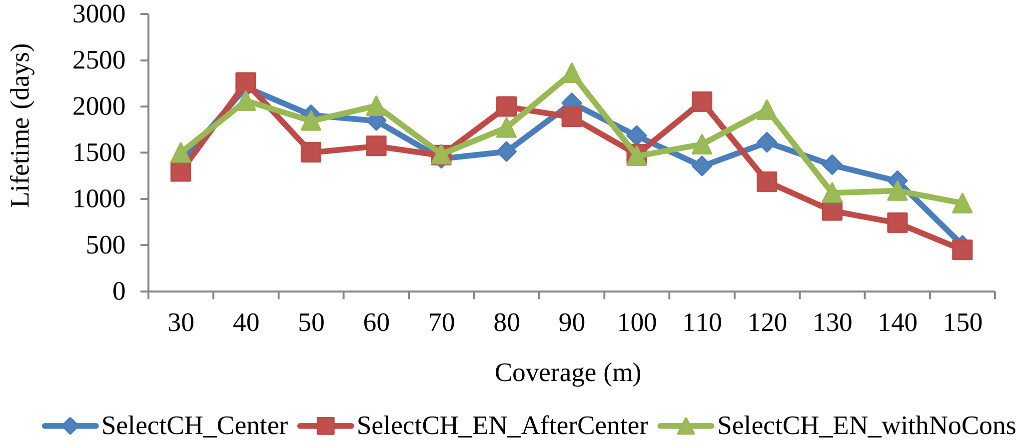


Figure 4.23 Changes in the Network Lifetime Depending on the Radio Coverage for (SinkPositionModel1, ClsSizeModel3) Pair.

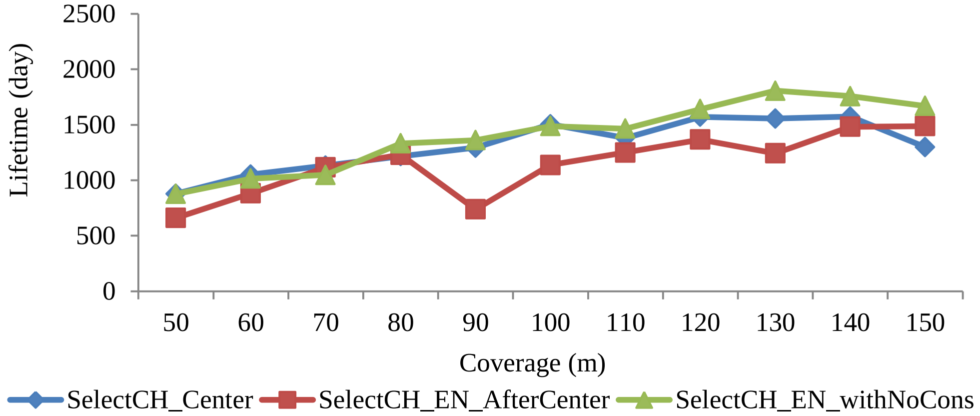


Figure 4.24 Changes in the Network Lifetime Depending on the Radio Coverage for (SinkPositionModel2, ClsSizeModel3) Pair.

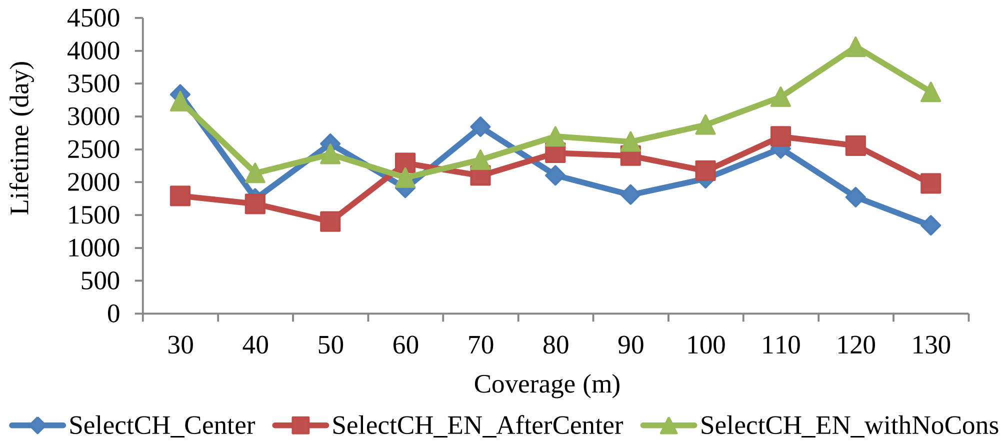


Figure 4.25 Changes in the Network Lifetime Depending on the Radio Coverage for (SinkPositionModel3, ClsSizeModel3) Pair.

CHAPTER 5

CONCLUSION

In this thesis, our research topic is one of the most important problems of wireless sensor networks: energy saving. Today, sensor networks are well-known; but properties, problems, and general solution methods are known by the researchers. Due to this reason, we did not go into too much detail explaining the topic. We have explained the sensor network structure and sensor nodes' architecture, in general terms. Then, we explained why energy saving has become the biggest research issue in the field.

As mentioned in the previous sections, the most important problem of Wireless Sensor Networks is due to small sizes of nodes which caused limited amount of energy. Another disadvantage of small sizes of nodes is the transmission power of limited radio. Therefore, conventional and multi-hop communication logic is applying. Conveying the data directly which is actually single-hop transmission is not preferred because of the energy consumed during data transmission exponentially proportional by the distance. Therefore, multi-hop communication is preferred in WSNs.

Communication process is one of the biggest factors in energy consumption. Studies shown that when radio data transmission is not in progress namely wireless sensor nodes is idle, it spent closely same amount of energy during the data exchange. Therefore, if there is no data to transmit node itself or another node. It is unnecessary to open radio sub-unit. In this way, to conserve energy consumption, radio transceiver must be in the sleep mode whenever communication is not required. In other words, if there is no more data send/receive radio should be switched off as soon as possible, and should be resume as soon as when new data packets becomes ready[6].In previous chapter we mention that this behavior called the duty cycle.

Some result of studies has been found that cluster based network structure is more energy conserved rather than other network types. As mentioned previous section located near the center of data collection nodes are receive and send the data that are far from the center which are active(hotspot area) in the region. Therefore, energies of these nodes consumed in a short time than other nodes. Depletion of their energy means that come to end of their life time. If these nodes cannot perform their duty, packets coming from other nodes will not be able to be transmitted to the data collection center.

Several research activities performed and various methods have been proposed about cluster-based WSNs. This thesis presents a brief analysis of the effects of the various structural factors in terms of energy consumption in cluster-based WSNs. General belief about cluster-based WSNs is that in order to alleviate the hot-spot problem, clusters located near the sink should be smaller-sized than the remote ones. Other possible factors that may affect the lifetime of the network are the number of tiers, the node density, the communication radio coverage radius, the number and the location of the sinks. All these parameters are examined for all possible combinations in detail. Depending on our simulations, the best performance in terms of the network lifetime is provided by positioning the sinks around the network. Another factor affecting the energy consumption in positive direction is increasing the node density up to a level. Also, it is proved that sizing the clusters closer to the sink smaller than the further ones enhances the energy conservation. Furthermore, it is also clarified that larger radio coverage does not have a definite positive effect in terms of energy conservation.

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