DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DESIGNING NEW ROUTING ALGORITHMS FOR WIRELESS SENSOR NETWORKS

by
Farzad KIANI

January, 2014
İZMİR

DESIGNING NEW ROUTING ALGORITHMS FOR WIRELESS SENSOR NETWORKS

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PhD. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DESIGNING NEW ROUTING ALGORITHMS FOR WIRELESS SENSOR NETWORKS"** completed by **FARZAD KIANI** under supervision of **PROFESSOR DR. ALP KUT** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor Philosophy.

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Farzad KIANI

DESIGNING NEW ROUTING ALGORITHMS
FOR WIRELESS SENSOR NETWORKS

ABSTRACT

In wireless sensor networks, energy is very important issue because these networks are consisting of low-power sensors. The thesis proposes three new protocols to reach energy efficiency.

The first protocol is based on dynamic clustering and tree structure to increase lifetime of network. The protocol has two phases. The first is deployment of clusters and determination cluster head nodes for every cluster and creation communication models between nodes by a dynamic spanning tree schema. The second phase is data transmission between sensor nodes and BS/sink.

In the second protocol, an intelligent routing protocol algorithm is proposed so that is based on reinforcement learning technique. In the first step of the protocol a new clustering method is applied to network and the network is established with using the connected graph and then data will transmit with using the Q-value parameter of reinforcement learning.

The third protocol is an energy efficient approach so its major goal is reach to energy efficiency with using some of the methods such as topology control, sleep/wake up and data aggregation schemas. It is consisting of three phases. In the first phase, the sensors are placed into virtual layers. In the second phase, all nodes in each layer could be modeled as a random graph and then began to manage by duty cycle method. The third phase is routing and data transferring so it is based on Dijkstra algorithm.

All new protocols are simulated by C# tool with same input parameters. The first protocol is compared with Improved-LEACH, EESR and HEED. Also, the second protocol is compared with LEACH, HEED-NPF and EECS. The third approach is compared with GBR, Naps and GAF. The simulation results show that new protocols have optimizing in different parameters such as network lifetime, packet delivery, packet delay and latency and network balance.

Keywords: Wireless sensor network, routing, energy efficiency, clustering, cluster head node, virtual layer, reinforcement learning, spanning tree, sleep/wake up mode, power management.

KABLOSUZ SENSÖR AĞLARI İÇİN ÖZEL YÖNLENDİRME ALGORİTMALARININ TASARIMI

ÖZ

Kablosuz sensör ağlar küçük-güç aygıtlardan oluşmaktadır, dolayısıyla enerji en önemli ve hayati konulardandır. Tezde, enerji verimliliğine ulaşmak için üç yeni protokol önerilmektedir.

Birinci yöntemde, ağın ömrünü uzatmak için dinamik kümeleme ve ağaç yapısı üzerinde bir protokol önerilmiştir. Bu protokol iki aşamadan oluşmaktadır. Birinci aşamada, kümeleme yapılmakta, onlar için dinamik şekilde birer baş küme seçilmekte ve tüm aygıtların birbirleri ile irtibatları kapsama ağacı formatında tutulmaktadır. Ayrıca bu fazda, sistemin ömrünü arttırmak amacıyla aygıtlar üzerinde uyku uyandırma modülleri kullanılır. İkinci aşama veri transferidir. Bu fazda, ağaç teorisinden oluşan yollardan faydalanılarak veri paketleri istenilen diğer aygıtlara gönderilmektedir.

İkinci protokolde, destekleyici öğrenme tekniğine dayanan akıllı bir yönlendirme mekanizması önerilmektedir. İlk olarak, yeni kümeleme yöntemi uygulanmakta, sonra ağ bir çizge şeklinde ortaya çıkarılmakta ve sonunda veri paketleri akıllı yönlendirme metodu ile aygıtlar arası gönderilmektedir. Baş küme aygıtın seçimi bu protokolde farklıdır ve diğer benzer yöntemler gibi bu seçim fazla yük sisteme taşımadan akıllı sistemi kullanarak kendi verimliğini koruyarak bu aşamayı atlatır.

Üçüncü protokolün enerji verimliliği, topoloji kontrolüne, veri toplama ve uyku/uyandırma yöntemlerine dayalıdır. Bu protokolün üç aşaması vardır. Birinci aşamada aygıtlar sanal katman denilen gruplara bölünürler. İkinci aşamada, bu aygıtlar bir çizge üzerinden kendi aralarında irtibat bağı kurarlar. Son aşamada, paket yönlendirme işlemleri Dikstra algoritmasından ilham alınarak gerçekleştirilmektedir.

Tüm yeni yöntemler aynı giriş parametreleri ile C# programında simüle edilmiştir. Birinci protokol, Improved-LEACH, EESR ve HEED ile kıyaslanmaktadır. İkinci protokol ise, LEACH, HEED-NPF ve EECS ile kıyaslanmaktadır. Üçüncü yöntem GBR, Naps ve GAF ile kıyaslanmaktadır. Simulasyon sonuçları; ağ ömrü, paket iletilme, gecikme ve ağ dengesi gibi çeşitli parametrelerde bu protokollerin optimize olduğunu göstermektedir.

Anahtar sözcükler: Kablosuz sensör ağı, yönlendirme, enerji verimliliği, kümeleme, küme baş düğümü, sanal katman, destekleyici öğrenme, kapsama ağacı, uyku/uyandırma modu, güç yönetimi.

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CHAPTER ONE
INTRODUCE WIRELESS SENSOR NETWORKS

1.1 Introduction of Wireless Sensor Networks

The wireless sensor networks (WSN) are introduced in Mid-twentieth century (Chong & Kumar, 2003). They are different from the other wireless networks such as Mobile Ad-hoc Network. These networks are combining of large number of mini size sensor nodes and a few Base Stations (BS) or sink. The nodes have low battery and limited memory. The need of them was felt in many applications and began to spread gradually. Beside the sensor nodes, WSN has one or some of BS or sink. For example, they can be a computer server. In the network environment, sensor nodes sense phenomenon then collect and process data and send to BS/sink in the end. One of the reasons of development and progression of the WSNs is using the inexpensive and affordable sensor nodes. Therefore, WSNs are used in many applications such as civil, medical, military, governmental and probability-based applications as volcano.

At the beginning, most researchers had focused on bandwidth and Quality of Service (QoS) factors but then energy was considered due to some of the limitations of the networks as battery and memory. Despite the researchers use different techniques to different applications, limitations of WSNs are fix and without change in any application (Akyildiz et. al., 2002). Hence, one of the most important aims in the WSN is to save energy. The others factors can be different such as QoS and bandwidth so they are the second plan in the network design (Chong & Kumar, 2003). There are two kinds of energy consumption between sensor nodes. The first is energy consumption in communications and the second is consumption in computations. The communications consume more energy. Therefore, minimizing communication costs is an important issue. Researchers propose different approaches for this goal such as energy efficiency by routing techniques, data aggregation, duty-cycle techniques, and topology control and medium-access decision.

The Figure 1.1 shows an example state of a WSN that sensor nodes communicate together and sensed data send to BS/sink finally. On the other side, BS/sink send collected data to remote user (Akyildiz et. al., 2002).

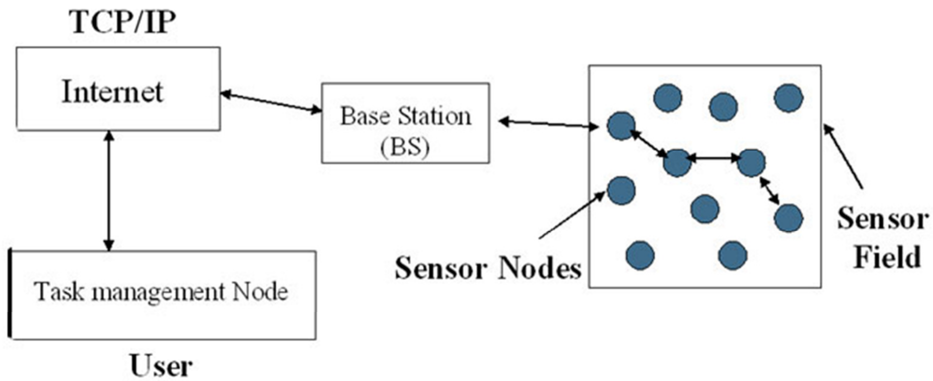


Figure 1.1 Sensor network architecture.

1.2 Differences of Wireless Sensor and Wireless Ad-hoc Networks

WSN have different structures than other networks. Despite many similarities to ad-hoc network, they have different structures of this type (Akyildiz et. al., 2003). In the WSN, the numbers of nodes are very and their network topology changes continuously. Deployment of sensor nodes is densely base and can be manually or randomly distributed in the environment. Sensor nodes are prone to failures due to limitation of battery and memory. Charge of sensor nodes is impractical or difficult. Communication in WSN is based on broadcasting but in ad-hoc network is P2P.

In WSNs, the nodes don't have any global ID because of the large amount of overhead and large number of sensors. Densely in WSNs is more than ad-hoc networks due to distribution of sensors are often randomly. Sensor nodes have to autonomously configure themselves into a communication network. Indeed, in the general state, WSNs offer a number of advantages over these systems, such as self-configuring and adaptable, quickly deployable, low cost and usable in unkind regions.

1.3 Challenges at Wireless Sensor Networks

In the WSNs many challenges are still to be faced before they can be deployed on a large scale. The principal challenges related to WSN implementation are the following (Srivastava, 2010):

Energy efficiency: Reduce energy consumption in the WSNs is a critical issue of them. However, it is expected that network live for a relatively long time. Given that replacing/refilling batteries is usually impossible, one of the primary design goals is to use this limited amount of energy as efficiently as possible. The possible approaches are explained in the chapter two.

Communications: Sensor networks are often deployed in infrequency areas and sometimes they operate under extreme weather conditions. In these cases, the quality of the radio communication might be strongly poor and performing the requested collective sensing task might become very difficult.

Operation areas: Carefully in sensor nodes is essential because to work in bad conditions. Furthermore, the protocols for network operation should be resilient to sensor faults, which can be considered a relatively likely event.

Data processing: Data compressing and data aggregation are important issues in the WSNs because limitation of energy in nodes and low quality communication. Therefore, the data collected by the sensor node must be locally compressed and aggregated with similar data generated by neighboring nodes. This way, relatively few resources are used to communicate the data to the external observer. For example, data aggregation technique should be able to provide different levels of compression/aggregation, addressing the data trueness/resource consumption trade-off As soon as an event occurs.

Resources: The resources are scare in the WSNs than ad-hoc networks protocols. Protocols for sensor networks must try hard to provide the desired QoS by the minimum consumption of resources.

Scalability: WSNs are consisting of many nodes which they have low energy. Therefore their lifetime is short. So, we can expand helper nodes to network depending on the application. Thus, the scalability of protocols for WSNs must be explicitly considered at the design stage. It should be noted that scalability measure should not seriously harmed to other design parameters.

Lack of easy-to-commercialize applications: Unfortunately, the most sensor network application scenarios are very specific, and a company would have little or no profit in developing an application for a very specific scenario since the potential buyers would be very few. On the other hand, number of sensor nodes production companies is low. Therefore creation balancing and efficiency is a big movement in the field.

These challenges are caused to make a distinction in design sensor networks structure. Therefore we must have a fix strategy in design of the networks. We review on them in the design factors in build and restructure of WSNs in the following.

1.4 Structure of a Wireless Sensor Network

The networks have different topologies for radio communications (Jerome & Kenneth, 2006). As mentioned, network topology in the WSNs has changeable schema. A general view of the network topologies are described in the following.

1.4.1 Star Network

In this topology, a single BS/sink can transmit/receive a message packet to remote sensor nodes. The nodes can’t send the message packets to each other. Home control systems are an example for the model. Their advantages are simplicity, ability to hold down the energy consumption and communications delays between the remote node and the BS/sink. On the other hand, BS/sink must be within all nodes` radio transmission range. Also, management of the structure has depending to a single sensor node. The last two cases are disadvantages of star structure (Wilson, 2005).

1.4.2 Mesh Network

In this structure, the sensor nodes can communicate together when they are within radio range of each other. This case realizes multi-hop communication between nodes. Indeed a node can send data to any node (inside self-RF or outside) by intermediate nodes. Scalability and reliability is advantage of the model. If a node is failure then a remote node still can communicate to any other node in its range, which in turn, can forward the message to the suitable place.

Energy consumption in multi-hopping system is high generally. Therefore energy issue is a problem and disadvantage of the model. Moreover, the number of hops and packet delay time increases (Wilson, 2005).

1.4.3 Hybrid Network

Hybrid model is between the star and the mesh structures that provide a robust and self-around communications network. In this model, the sensor nodes with minimum energy are not send message to other nodes and allow to them to saving energy (Wilson, 2005).

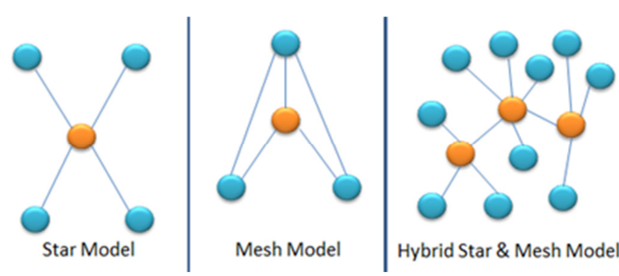


Figure 1.2 Structure of a WSN (Wilson, 2005).

1.5 Hardware Components of a Sensor Node

Let's describe sensor nodes structure. The nodes are consisting of sensing, processing and transmission units. Therefore, they sense a physical event of phenomenon and convert them to digital signals by Sensing unit (Figure 1.3). Processing unit has two ımportant parts. Realizing events processing done with the processor part. Processed data store in storage part (Figure 1.4). In third unit per node receive or send data. Transmission unit connects the nodes to network (Akyildiz et. al., 2003). Also, the nodes` antennas are nearby the ground and therefore path loss of the signal is possible and this possibility can be high. RF is preferred in sensor network for its small data rate and frequency reuse.

It is worth mentioning that transmission media in WSN is RF usually but it can infrared if between transmitter and receiver is not obstacle indeed to be Light of Sight (LoS). One of important of units is power unit. Power unit is includes a battery with limited energy to requirement power supply of other units. It usually cannot revive and re-feeding due to the nodes locates unavailable and risky environments. Power generator is to supply power for the nodes. The method used varies depending on the application. The power unit can is provided by power supplies resources as solar cells (Akyildiz et. al., 2002).

For management power must to be a mechanism. This unit control energy nodes and how to use it. For example, sensor node broadcast non-cooperation message to neighbors when it has little energy. Mobilizer unit is external unit depend on application kind like power management and location finding system units. Mobilizer unit is to change position of per node and movement it node in its geographic range. Location finding system is to geographical position determination and location of each node to sink or other nodes.

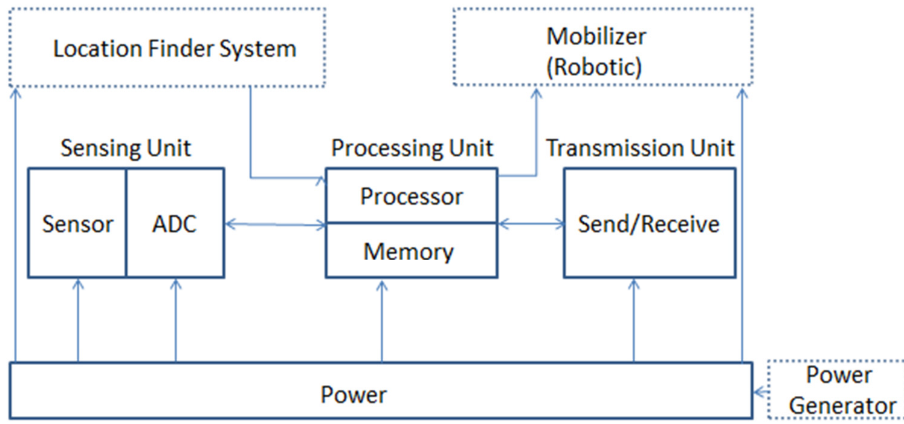


Figure 1.3 Components of senor node (Akyildiz et. al., 2003).

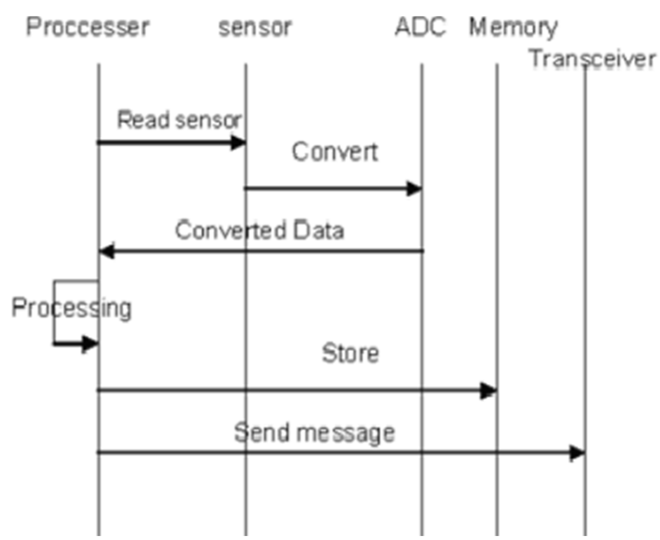


Figure 1.4 Communication between units in a sensor node.

1.6 Design Factors in Wireless Sensor Networks

As mentioned, sensor nodes have energy problem therefore lifetime of the networks is critical issue. So, researchers standardize some factors to design the networks. They are necessary for protocol or algorithm designers. In fact, they play a guideline role and designers can use them even to compare with other models (Pottie et. al., 2000). Some of the factors are described in following briefly.

1.6.1 Reliability or Fault Tolerance

Simply, while node failure or route, the network is still in existence (Shen et al, 2001). Sensor node may fail due to energy shortage, log-out, environmental damage from physical or non-physical. The reliability in (Hoblos et al, 2000) uses the Poisson distribution to investigate the possibility of a failing within the time period between zero and t. Here λ_k is the failure rate of sensor node k and t is the period.

$$R_k(t) = e^{-\lambda . k\, t} \qquad (1.1)$$

1.6.2 Scalability

We may make use of a large number of sensors to observe a phenomenon. The density model and network size are one of the important issues in WSNs and affects system reliability and data processing approaches. Also, it affects the degree of coverage area of interest directly. For example, we can use one or hundreds of sensors in a 50-meters environment. The density μ is gained as in (Bulusu, 2001):

$$\mu (R) = (N.\Pi R^2) / A \qquad (1.2)$$

In this case, R is the radio transmission range and N is the scattered nodes in region A. Essentially, μ (R) shows sensible number of nodes to each sensor in region A.

1.6.3 Network Topology

The network topology affects several parameters such as latency, robustness and network capacity and data routing models. Also, large number of sensor nodes in the network cause to frequent changes of network topology (Kahn et. al., 1999). Pre-deployment and deployment, post-deployment and re-deployment phases are various topologies phases in WSNs.

1.6.4 Power Consumption

As mentioned power unit is one of the sensor parts that is limited and its charge is often impossible. The sensor lifetime is depending on the power unit lifetime. Therefore power management can be a critical issue in designing process. It should be noted that power resource can be dividing among sensing, processing and transmission operations that usually transmission operations consume more energy than others.

1.6.5 Transmission Media

Transmission media in WSNs is usually RF but it can infrared if between transmitter and receiver is not obstacle. In other words, they are Light of Sight (LoS). Transmit models are often direct transmission or multi-hop in mesh or star categories (Wilson, 2005) and are used in dynamic base routing protocols. Almost mesh-based systems have multi-hop radio connectivity and it is admissible for wireless and wired networks (Shih et. al., 2001). P2P based systems generally have one-hop connectivity to wireless networks and are used in static routing protocols. Home monitoring systems are an example of this kind.

1.6.6 Hardware Constraints

The networks have limited memory and battery nodes. Moreover, they have to consume low energy and operate in massive density. On the other hand, sensor nodes construction costs are low and can work in a variety of environments so are affordable but the limitations are managed via designers.

1.6.7 Data Delivery

It is collected by time-driven approach or query or event-based methods. Also, hybrid model is possible. For example, time-driven methods are used in surveillance application. Event based methods are used in target-tracking in enemy environments applications and for query-driven could note habitat monitoring applications. In the time-based approach, every node sends data packets periodically. In the event and query-based approaches, if an event happens or a query is sent by the BS/sink to all sensor nodes, then data packets transmission will realize. Data delivery is one of the important parameters in routing algorithms (Mainwaring, 2002).

1.6.8 Network Model

This model can be static or dynamic. In the static model is uses of star base connectivity model generally. In the dynamic model is uses of mesh base type. Other factors such as production costs and operating environment are discussed (Akyildiz et. al., 2002).

1.7 Communication Architecture and Stack Protocol of WSN

The architecture of protocol stack is used by the sink and sensor nodes that are shown in Figure 1.5. This protocol stack is consisting of five layers and three planes. The layers are physical layer, data link layer, network layer, transport layer, application layer. The planes are power management plane, mobility management plane and task management plane. They will describe in next section with their details.

1.7.1 Physical Layer

The physical layer supplies some of the system requirements such as good modulation and transmission approaches. Also, their tasks are various as modulation, frequency selection, data encryption, multi-hopping to avoidance the path loss and efficient transmission methods. Modulations are often DSSS or FHSS based. Discussed frequencies in the networks are often in three categories and have 10-75m ranges. ISM group is used usually.

- 2.4GHz, 250Kbps, QPSK, 16 channels, Unlicensed Geographic Usage: Worldwide

- 915MHz, 40Kbps, BPSK, 10 channels-ISM, Unlicensed Geographic Usage: America's (approx.)
- 868 MHz, 20Kbps, BPSK, 1 channel, Unlicensed Geographic Usage: Europe

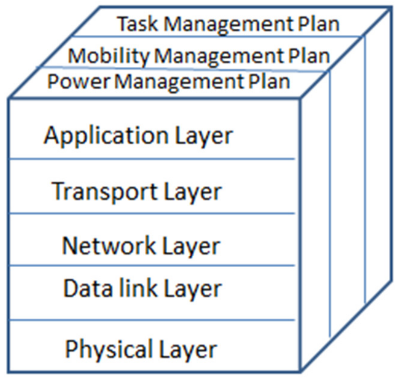


Figure 1.5 The wireless sensor networks protocol stack (Akyildiz et. al., 2002).

1.7.2 Data Link Layer and MAC

The some tasks of data link layer are detection data framework, multiplexing data streams, flow and error control and Medium Access Control (MAC) (Demirkol, 2006). It ensures reliable P2P and point-to-multipoint connections in a communication network. In a WSN, the MAC protocols must achieve two aims.

Creation of the network infrastructure to realizing communication links between all network resources is the first aim. The links are used to transmit data packets. Due to millions nodes in a network, its control is important and critical. This forms the basic infrastructure needed for wireless communication hop by hop and gives the sensor network self-organizing ability. The second goal is communication resources sharing between sensor nodes. It should be done fairly and efficiently (Riduan, 2011). In brief, the most important objectives of MAC are collision control, bandwidth efficiency, QoS, neighbors' discovery, resource sharing, failure recovery and mobility control. The energy consumption is important issue. For example, main goal of MAC protocol in normal and wired networks is focus on QoS and efficient bandwidth and power management is the second category of objectives. However, WSNs are different from those. If the environment is noisy and sensor nodes are mobile then the MAC protocol must be energy efficient and has ability to minimize collision with neighbors' broadcasts. The broadcast information is including sensor nodes updates and queries and also system control packets. The information is almost transmitted by BS/sink to network nodes. Generally, sensor nodes sense phenomenon and send it to other nodes or CH or BS/sink. The CH node communicates with their group members or other CH nodes of other clusters in hierarchical based protocols.

The MAC protocols are two categories in collision control and power management. The first category is content-based protocols. These protocols are often competing for the shared channel such as MACA and MACAW. In the second group, channel is divided between all nodes and any node has a bandwidth independently. EAR (Sohrabi, 2000), SMACS (Woo, 2001), Hybrid TDMA and FDMA or TDMA and CSMA (Hoiydi, 2002), SMAC (Ye et. al., 2004), TMAC (Dam et. al., 2003), LMAC (Lu et. al., 2004), Wise-MAC (Enz, 2004) are examples of MAC protocols.

A good MAC protocol must be energy efficient. This property is caused prolonging network lifetime. Also, it must be scalable and adaptable to changes. The changes are considered in node density, network size, packet delays and delivery rate, throughput and bandwidth utilization and network topology. It should be noted that some of properties have trade-off together. For example, if scalability of system is high then network lifetime will reduce. Therefore, a good MAC protocol has a high degree of consistency.

1.7.3 Network Layer

The network layer handles routing data from source to destination. Routing protocols in WSNs are different with traditional routing protocols in several respects as they don't use ID-addresses schema to routing. Therefore, the IP-based routing protocols can't be used in such networks. Necessary to design network layer protocols in these networks is because of their scalability so that the design manages communications between nodes and transmits data to BS/sink easily. A routing protocol should consider the limitations of network resources such as energy, communication bandwidth, memory and computational capabilities. Management restrictions may be cause increasing network lifetime. Also, a routing protocol can consider faulting tolerance, latency, security and etc. It should be noted that responsibility of packet delivery for node to node is data link task but in network layer is for source to destination packet delivery. In other words, the data link layer handles how two nodes talk to each other and the network layer is responsible to decide which node to talk. The network layer focuses on the data aggregation, energy efficiency and providing inter-networking with external networks-gateway/backbone principles. One of the energy saving approaches in the WSNs is optimized routing protocols that will be described in the second chapter.

In Figure 1.6, node S is the sink node and node T is the source node. The nodes A, B, C, D, E, F, G and H are intermediate nodes. P refers to the energy efficiency based on the available power and R refers to the energy efficient based on the energy required to data transmission through the paths. Table 1.1 shows 6 routes from the source to the sink with their energy efficiency based on the available power and energy needed.

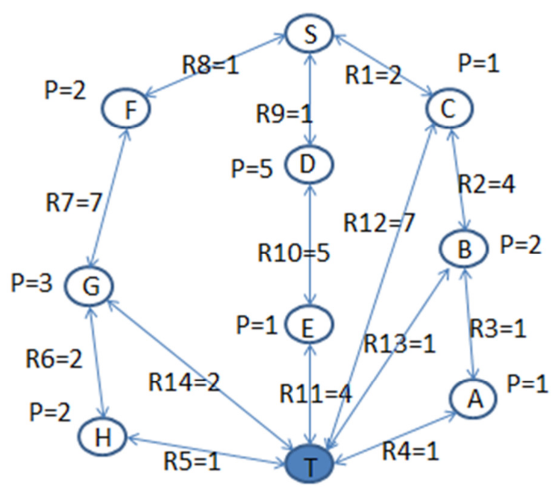


Figure 1.6 The power efficiency of the routes (Intanagonwiwat et. al., 2000).

Table 1.1 The possible routes to communicate with the S (sink) (Intanagonwiwat et. al., 2000).

		Sum of energy based on available power	Sum of energy based on energy required
Route 1	S-C-B-T	3	7
Route 2	S-C-B-A-T	4	8
Route 3	S-D-E-T	6	10
Route 4	S-F-G-T	5	10
Route 5	S-F-G-H-T	7	11
Route 6	S-C-T	1	9

There are different approaches to select energy efficient routes:

1- Maximum available power route: The selected route is the one with the maximum sum value of the available power to transmit data packets from the source node to the sink node. Although in Table 1.1, route 5 has the maximum sum value 7 but it is not power efficient because route 4 is included in it. After eliminating route 5 the preferred one is route 3.

2- Minimum energy route: The selected route is the one that needs minimum energy to transmit the data packets from the source node to the sink node. In Table 1.1 this is route 1.

3- Minimum hop route: The selected route is the one with the minimum number of hops from the source node to the sink node. In Table 1.1 this is route 6.

1.7.4 Transport Layer

Transport layer guarantees the reliability and quality of the data in the source and destination nodes. The transport layer protocols in WSNs should support reliability, recovery of lost packets and congestion control mechanisms in different applications. Development of a transport layer protocol should be applied to the whole and independent programs. Each application can withstand at a rate of packets lost and data packets may are eliminated by poor radio communications, congestion, collisions, high memory capacity and the resulting error in the sensor nodes. Packet loss can lead to wasted energy and lowering the QoS delivery needs. While the diagnosis and repair lost packets can improve throughput and power consumption. There are two ways to recover the lost packets which are hop by hop and end to end. Retransmission of lost packets in hop by hop method is need to storing data packets via intermediate nodes in its memory. It is very energy efficient for short distances transmissions. Retransmission of lost packets in end to end method is need to storing all information belongs to any packets via each node in self-memory.

Also, the layer is used for transmission information between systems via internet or other networks. Generally, communications between end users and BS/sink is realized by TCP and communications between inter-network nodes is done by UDP. Nodes can’t store large amount of data and ACK is too costly. The connection of the layer is based on the end-to-end model. It is a reliable connection and uses ACK or NACK messages. The reliability realize via upstream or downstream methods generally (Rabaey et. al., 2000).

1.7.5 Application Layer

Variety of software applications can be used on the application layer. The layer focuses on their management and optimization. Sensor Management Protocol (SMP) is one the layer protocols that makes hardware and software of the lower layers transparent to sensor network management applications (Shen et al, 2001). Their tasks include sleep/wake up nodes, data aggregation, attribute-based naming and clustering. Data exchange related to the time synchronization (Kiyani et. al., 2011), movement of network nodes, querying WSN configuration status, reconfiguring the WSN, authentication, key distribution and security. The Sensor Query and Data Dissemination Protocol (SQDDP) (Shen et al, 2001) and the Sensor Query and Tasking Language (SQTL) (Akyildiz et. al., 2002) are another of techniques in the application layer. Although many sensor network applications have been proposed, their corresponding application layer protocols still need to develop activities and research on them still open.

1.7.6 Management Plans

The power management plane manages and controls any node energy. A method for this plan is broadcasting inability message to continue working from low energy nodes to adjacent nodes. The mobility plan detects and registers the movement of nodes. Therefore, a return path to user is always managed. In fact, it keeps table of route back to the user and neighbors` nodes. The task plan schedules task nodes and balances them. For example, if sensing task is assigned to a certain area then all sensor nodes that the area does not need to sense and only this task can be performed by some sensors.

1.8 Applications of Wireless Sensor Networks

WSNs have widespread applications by using small size and low cost sensor nodes. Due to the many advances in technology and the increasing needs and needs of users, the networks convert to most role and effective technologies in many applications such as habitat monitoring, military, health and volcano/fire detections. As mentioned, the sensor nodes start to work upon sensing an event. This event or phenomena can be static or dynamic. In this dynamic case, target must be track and sensor nodes teams should not loss target as much as possible. If accuracy of target tracking is high then system reliability will be high. WSNs applications differ widely in their characteristics and own requirements. A protocol designed to support one application may not be appropriate for another. Therefore, the design of protocols for such networks should take their diverse characteristics into consideration. Some of the applications are described in follows.

1.8.1 Supervision Application

It is a military system that obtains and verifies information about enemy areas and positions of hostile targets. In (He et. al., 2006) refer an approach in this field that it has been successfully designed, built and delivered to the Defense Intelligence Agency for realistic deployment. Another example of this case is spy based applications. We can use of some of the sensor nodes for any emissary of Defense Intelligence Agency that this nodes communicate together for creation WSN.

1.8.2 Prediction of Volcanic Eruption Application

Volcanic activity prediction has become one of the most important applications nowadays. This kind of system requires manual supervision to monitor each sensor, which makes the monitoring work not flexible and efficient enough to adapt to variable volcano environments. With the development of WSN the accuracy and coverage of volcano observations can be improved by deploying networked sensors.

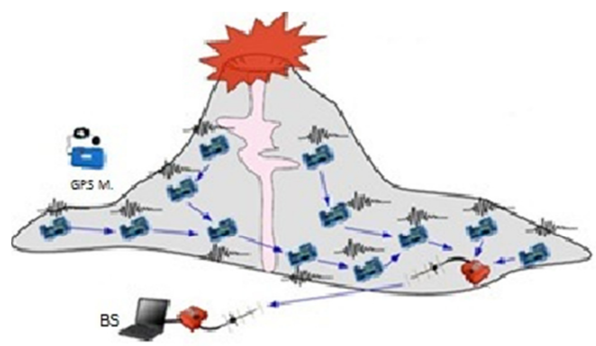


Figure 1.7 An example of volcanic or earthquake monitoring systems (Mainwaring et. al., 2002).

1.8.3 Habitat Monitoring Application

Habitat monitoring is a scientific application that has profited importantly from the deployment of WSNs. In these systems, it is necessary to monitor a variety of environmental characteristics, such as temperature, humidity, barometric pressure and other physical parameters (Mainwaring et. al., 2002). Structural Health Monitoring-Structural health monitoring refers to the continual or periodic monitoring of the health of large structures such as bridges, buildings or ships. The vibration data from bridges can be used to detect the health of bridges.

1.8.4 Home Control Application

Home control applications provide preservation, comfort, control and safety, as follows:

- May use intelligence system to optimize consumption of natural resources.

- Installation, upgrading and networking is easily.
- Sensing applications enable one to configure and run multiple systems from a single remote control.
- Automation control to improve preservation, comfort and safety and flexible management them.
- Sensing applications support the straightforward installation of sensor nodes to monitoring in different situations.
- Sensing applications facilitate the reception of automatic notification upon detection of unusual events.

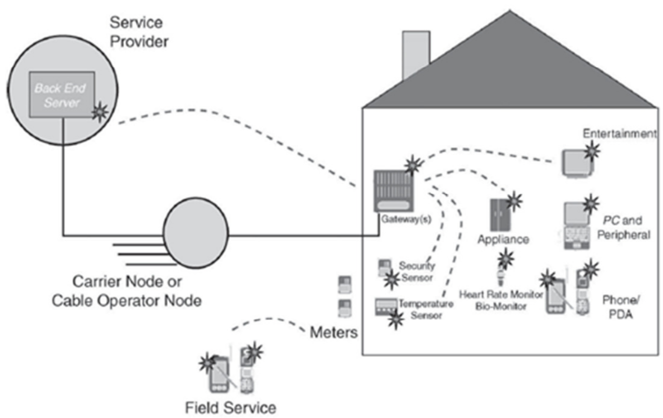


Figure 1.8 Control applications in home system (Mainwaring et. al., 2002).

1.8.5 Prediction of Forest Fires Risk or Humidity Forecast

One of the important applications in WSNs is fire detection and humidity forecast. The accuracy of the monitoring is depending on the sensitivity and importance of incoming data and application. The data is collected by sensor nodes in a WSN. Almost applications are discussed in the two groups. One of them is Phenomena Detection (PD) and other is Spatial Flow Assessment (SFA) (Buratti et. al., 2009). In first case, sensors are deployed to detect phenomena such as fire location in a forest. In second case, estimate a given physical phenomenon such as the humidity forecast in a wide area. Typical sensor measurement parameters are described in (Shastry et. al., 2005; Toriumi et. al., 2008).

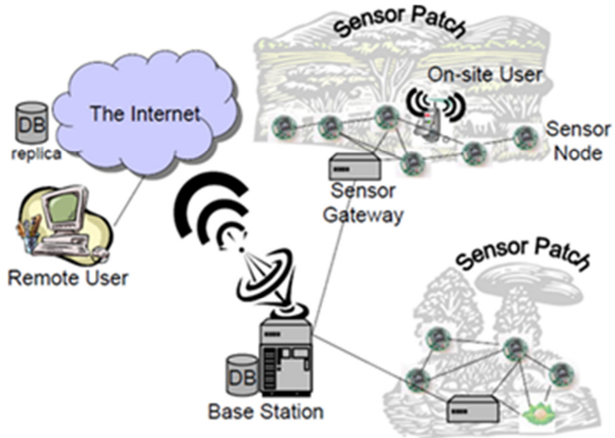


Figure 1.9 A model for habitat monitoring in forest (Toriumi et. al., 2008).

1.8.6 Flood and Water Level Monitoring System

This system is used to control water levels and prevent flooding probability. Suppose the system is installed in a dam. In this case, the sensor nodes in a general network work together and sense phenomenon such as rising water level and send it or faulting a part of system report to BS/sink. An example of the system is shown in the Figure 1.10.

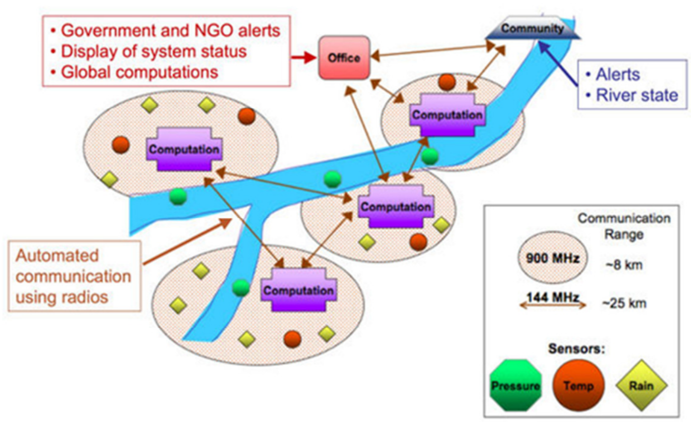


Figure 1.10 An example of flood and water level monitoring systems (Mainwaring et. al., 2002).

1.8.7 Underground Structure Application

An example of the systems is underground mines monitoring. In this case, system do monitor location of workers for protect them. However, it may be extent it to security issues within the mining. For example, if a sensor node senses carbon dioxide gas then security doors in the mine part close or open automatically. This system can use different types of sensors such as temporary, Oxygen, carbon monoxide and humidity. A radio device capable of communicating with other nodes is carried by the miner. The location is determined by identifying the node with which the mine able to communicate (Mo et. al., 2007).

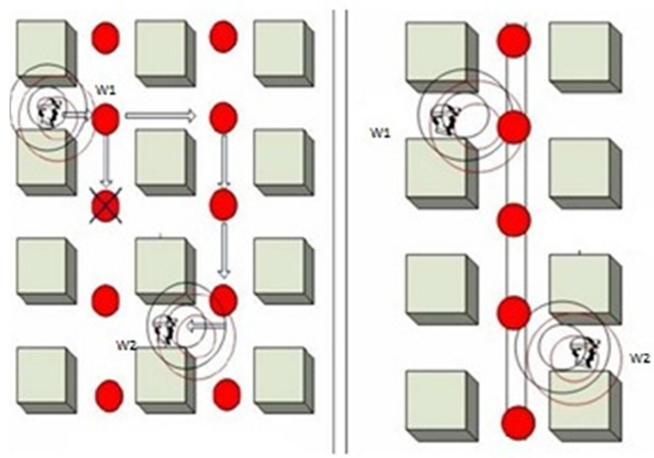


Figure 1.11 A snapshot of underground mine workers equipment sensor nodes (Mo et. al., 2007).

1.9 The Necessity to Focus on Energy Issue

As mentioned, WSNs are consisting of large number of sensor nodes which the nodes sense data. The data is different due to variant applications and environments. These nodes process and store self-data to memory part after convert sensed physical phenomena to digital signals. Then they send them to the BS/sink via direct or with the aid of other sensor nodes. The scenario is seems perfect but it is not easy according to small size and limited battery of nodes. The nodes are failure prone in real applications. Therefore, management and design of networks is different from other networks. In this mode, lifetime of network will deplete as soon as before correct and complete tasks. It seems that this problem is solved by charge of sensor nodes but charging is difficult or impractical according to concept of WSNs and their applications such as spy network in enemy environment and earthquake or fire prevent networks. Also, energy issue and energy efficiency is very important.

The major goal of some methods is reach to energy efficiency. These methods are based on different approaches such as energy-aware routing protocols or energy efficiency MAC protocols, aggregation of data, sleep/wake up nodes, topology control methods etc. It should be noted that output parameters implementation of applications are trade off one another. For example, focus on energy parameter can be cause increasing latency or decreasing system reliability. Therefore, always relative balancing should be between parameters. Due to the above reasons, the thesis concerns with the energy issue with respect to balancing reasons. The thesis is based on increasing lifetime of network by energy-efficiency routing algorithms and energy conservations realize by topology control, data aggregation and sleep/weak up of nodes. These topics will be discussed in the next chapters. This thesis focuses on network layer. Hence it will be discussed on data link layer and MAC shortly and use of current techniques with some modifications.

Given the importance of energy, many researchers focus on the issue in recent years. They proposed many approaches that acceptable results can be presented in two categories. The first category is routing protocols such that they should be energy efficient. Hence they proposed new model of routing algorithms instead flat based approaches. The new approach divides network to sub-networks and manages it. The sub networks are connected with node agent of any subnet. The node is called Cluster Head (CH). In this case, sensed data of sensor nodes are sent to CH node and CH aggregates it and sends it to the other CH nodes or BS/sink. In fact, this model is a hierarchical model for the network.

In the following years we can see the continuity in researching the hierarchical based protocols. Proposed protocols despite their advantages had some problems.

The thesis proposes new optimized algorithms of the category which can solve some of the problems and has a more performance.

As mentioned, energy is one of the important issues in WSNs and it is consumed and wasted as soon as by nodes. But its consumption can be reduced by different energy efficient techniques such as power management by MAC protocols, topology control, data aggregation and learning based approaches. The overall look will be on the methods used to provide energy efficient in WSNs in chapter 3. The routing protocols which will be presented in this thesis will base on those different methods.

1.10 Outline Thesis

This thesis consists of 7 chapters which their main aim is energy efficiency. In Chapter 2, we investigate to routing protocols and review on the related works. In this chapter, we classify routing protocols. We discuss advantages and problems of their algorithms. In chapter 3, we describe energy efficiency methods and introduce a category of the approaches. We show that increasing lifetime of network is possible by power management and topology control techniques and there is no need to the data-driven approaches. In the chapters 2 and 3, we compare them in energy optimality factor. In fact, these two chapters are an introduction to the main chapter of the thesis. In the main chapters (chapter 4, 5 and 6), we describe new routing algorithms with conservation energy consumption. In the chapter 4, we propose a new algorithm that it is based on dynamic clustering and spanning tree and uses data aggregation and sleep/wake up methods to energy conservation. In chapter 5, we introduce a new approach for energy efficiency in wireless sensor networks that is based on intelligent routing protocol and uses data aggregation and learning base techniques to energy efficiency. In chapter 6, we propose another new routing protocol that uses topology control and sleep/wake up methods to energy efficiency. In chapter 7, we consider conclusion and future work in the wireless sensor network area. The final section of thesis is references.

CHAPTER TWO
ROUTING ON WIRELESS SENSOR NETWORKS

2.1 Motivation and Challenges

As mentioned in the first chapter of thesis, advances in the development of WSN in various applications has been occurred (Akyildiz, 2004; Tilak, 2002). In the networks, the sensor nodes sense phenomenon and collect their and then process and transmit them to BS/sink. One of the important goals in routing algorithms is energy efficiency that the selective paths can increase network lifetime. This chapter focuses on routing protocols and their advantages and disadvantages. Each of these protocols may have a good performance for certain applications of WSNs but they can't have an appropriate performance for the other applications. Many factors can affect the routing of WSNs as environmental conditions and goal of application. Therefore, many routing protocols can perform well only under certain conditions (Hu & Kumar, 2003). In this chapter, we will present different classifications of routing protocols that they are success in some of the parameters. WSNs have limitations in terms of energy, memory and bandwidth (Batra, 2004). In contrast to such restrictions in WSN structure with redundant distribution of nodes in sensing area make a big difference in the design and management of these networks. Especially, energy is an important issue in the design of routing protocols.

The other challenges in designing the routing protocols are location of the sensor nodes, network topology and reliability rate of system. For example, location the nodes may be managed by GPS and network topology may be managed by controlling and adaptability in against deletion, addition or changing routing strategies. Reliability management needs to maintain network connectivity and the ability to reach the sink (Batra, 2004). From this point of view we can say that density of nodes in a network area is important and must be managed by routing protocols. Therefore transmission data packets are one of the important tasks of routing protocols. A sample method for data transmission is directly approach so connections between the sensor nodes and BS/sink are single-hop. This schema causes to increasing energy consumption and then generally reduction network lifetime. Another model of data transmission is based on multi-hop approach. It works over short communication radius. Figure 2.1 shows a view of data transferring in WSNs.

In the most applications, sensor nodes can aggregate data and send reached packets to the BS/sink. In multi-hop network, some of the sensor nodes collaborate between source and destination nodes for data transferring. These collaborators nodes are called intermediate nodes. The method of finding optimized paths and selection of the intermediate nodes are the major tasks of routing protocols.

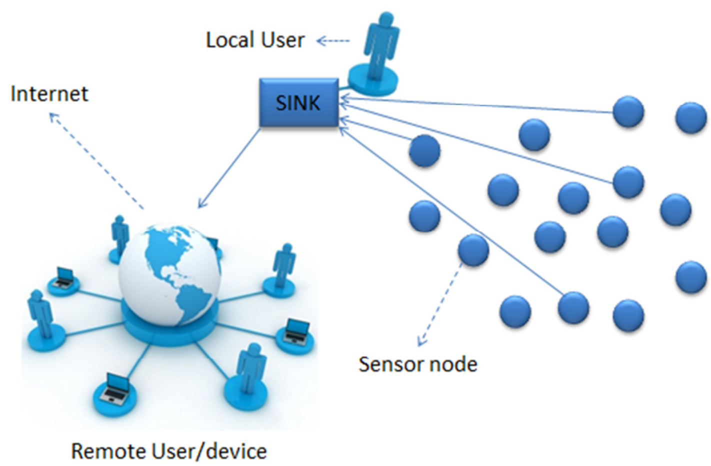


Figure 2.1 A multi-hop and single-hop data forwarding view in WSN (Akyildiz et. al., 2002).

Classification of routing protocols in WSNs is useful for a designer to select the routing method in according with his fashion application. Next section describes the classification of routing protocols and their advantages and disadvantages.

2.2 Classification of Routing Protocols

Routing protocols in WSNs may be concern with various parameters such as QoS, high-speed data transferring, reliable data transferring, reducing packet loss and packet delay, increase network lifetime and optimizing overhead of network by consider the energy and resource limitations. Many current algorithms and routing protocols can be classified in one of the following groups.

One class of routing protocols is Flat architecture. Flat based network architecture has several advantages, including minimal overhead to maintain the infrastructure and support reliable system by multiple paths between nodes. Some of the routing protocols use a data-centric method to distribute interest within the network. The method uses attribute or query based naming, whereby a source node queries an attribute for the phenomenon rather than an individual sensor node. The interest dissemination is achieved by assigning tasks to sensor nodes and expressing queries to relative to specific attributes. Different strategies can be used to communicate interests to the sensor nodes, including broadcasting, attribute-based multicasting and any casting. In this case, sensor nodes energy which is closed to its BS/sink is depleted earlier. In the some of the literature this method is a separate group of classification but in some others it belongs to flat category. We use the second idea for our classification schema.

The second classes of routing protocols have some of the special properties such as energy efficiency, stability and scalability. This category is called Hierarchical approach. In this case, network divides to several parts which each part is named cluster. Each cluster is consisting of many sensor nodes. Any sensor node communicates with other nodes that they belong to the same cluster. The cluster base network has an interface between cluster`s nodes and sink. This task is for a sensor node in any cluster that is named Cluster Head (CH). The CH node receives transmitted data from self-group sensors and aggregates them within the cluster and transfer information to the other clusters or BS/sink. Clustering system can decrease energy consumption and increase network lifetime because any node doesn't participate in transmission routes and routes length shorter than the flat category.

The third classes of routing protocols are based on location architecture. They are useful in applications where the position of the node within the geographical coverage of the network is relevant to the query distributed by the source node. Such a query may determine a specific region where a phenomenon of interest may occur or the nearby area to a specific point in the network.

It should be noted that routing protocols can be proactive, reactive and hybrid protocols. They focus on path finding between source and destination nodes. In proactive protocols, all paths are computed offline. They are good in the energy issue but have problem in memory limitation. In reactive protocols, routes are computed on demand. Their properties are exactly the opposite of the previous method. Hybrid protocols use a combination of these two methods. In general cases second or third approaches are usable.

In the following sections, different current routing algorithms are described so each of them has various performances in WSNs applications. The classification is shown in Figure 2.2.

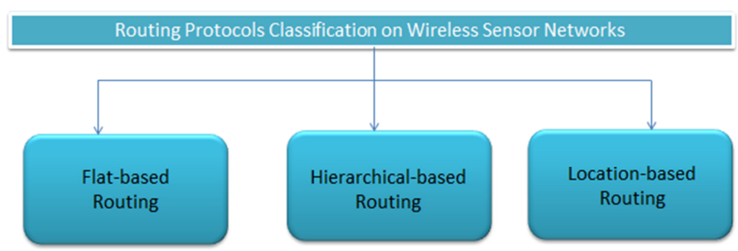


Figure 2.2 A classification of routing protocols for WSNs (Jamal et. al., 2004).

2.2.1 Flat-Based Routing

In the flat based routing, sensor nodes send self-data to the other nodes or BS/sink by single or multi-hop method (although most of multi-hop used). Each sensor node has same role in the network. As mentioned, in WSNs there is no ID for any sensor node due to the large number of nodes. Therefore BS/sink sends queries to certain regions and waits for data from the sensors located in the selected regions (Morati, 2004). Sending data to sink will realize upon sensing phenomena by nodes of its region. Accordingly, redundancy in the whole network is high which it is a problem due to the energy limitation issue. This problem can be solved by data aggregation that will be described in the next section. The flat-based routing study case is proposed in many protocols such as SPIN (Martorosyan et. al., 2008; Jamal et. al., 2004) and Directed Diffusion (DD) (Intanagonwiwat et. al., 2000; Morati, 2004), EAD (Shah & Rabaey, 2002), RUMOR (Braginsky & Estrin, 2002), GBR (Sohrabi et. al., 2005; Schurgers & Srivastava, 2001) and ACQUIRE (Sadagopan et. al., 2003). SPIN and DD have basic role in designing the other protocols. We summarize some of the flat-based routing protocols and express their advantages/disadvantages and their performance briefly.

2.2.1.1 Data Aggregation

Redundancy in the data routing is not affordable for energy efficiency in the WSNs. The routing protocols may have Implosion and Overlap problems (Figure 2.3). In the implosion problem, destination node receives repeated data packet from two neighbors' node. In the overlap problem, radius sensing of some of the sensors has overlap and therefore they sense same phenomenon in its region. These problems could solve by the data aggregation technique (Lu et. al., 2004).

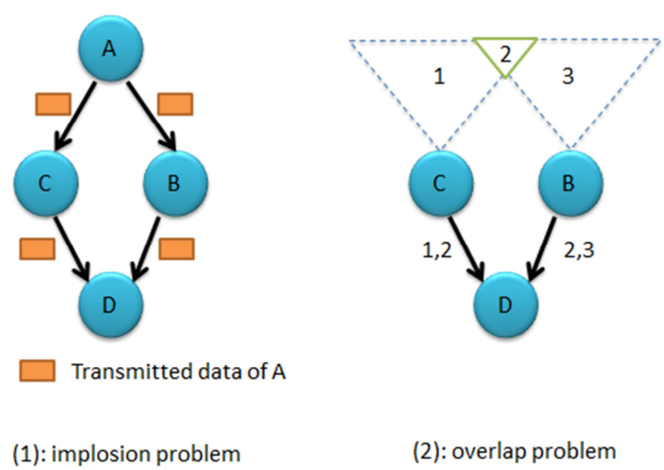


Figure 2.3 Implosion and overlap problems in data centric technique (Lu et. al., 2004).

The data aggregation technique is concerned about combining data packets into a more summarized form and then forwarded on to the BS/sink. The study of aggregation techniques involves optimizing a combination technique and or a schedule for prolonging network lifetime. Decrease energy consumption is possible by mixing data and reduces numbers of data packets. Another of advantages of data aggregation is decrease the number of collisions as the network is not as overcrowded. Meanwhile sink don't need to filtering received duplicate data of the sensor nodes. Therefore on one hand sink can work freedom and even can do other things via sink like data mining. Data aggregation is realized by some functions as suppression for remove duplicates data and etc. (Krishnamachari et. al., 2002; Yao & Gehrke, 2002; Lindsey & Raghavendra, 2002). In the Figure 2.4, transmitted data from H and J received via A, B and C, F. If each of the four nodes sends received data to G then we see the problems again but they aggregate your data and send an aggregated data packet to E and D nodes. Therefore, data aggregation could solve the implosion and overlap problems. It cause decrease energy consumption via sensor nodes.

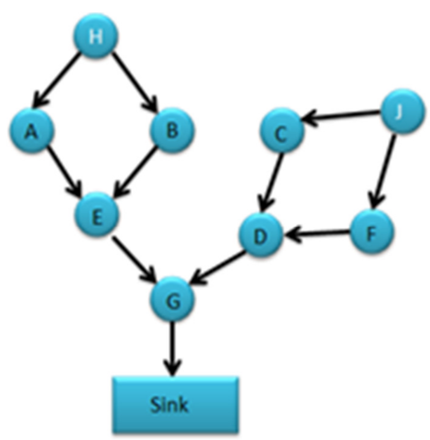


Figure 2.4 An example of data aggregation (Lindsey & Raghavendra, 2002).

2.2.1.2 Flooding and Gossiping

In the flood routing strategy, a node sends a copy of self-data to each of its neighbors. When a node receives a new data, the node will copy it and send it to the neighbor node. When the all nodes have received a copy of the data, the algorithm converges (Morati, 2004). Therefore a packet can be send from all paths and system will be reliable. If network topology changes then data transmission will be done through new paths. It should be noted that the data is transmitted while network is connected. Figure 2.5 illustrates an overview of the flooding protocol concept.

Flooding algorithm avoids rotation of packet due to using hop count variable. The value of hop variable is zero and value of a unit is increased with each send. Requirement time for data transmission is one round. The algorithm converges in O(d) time that d is the diameter of the network or hop count. The algorithm uses a TTL variable for checking the packet lifetime. Indeed, it uses the variable to keep the package away from being in a vicious circle. Flooding has several disadvantages in WSNs. These problems are implosion and overlap which these are soluble with data aggregation technique. The cases are described in the last section. The other problems of the flood are waste of bandwidth and weakness against harmful attacks.

The gossiping approach is improved flooding method (Hedetniemi & Liestman, 1998). In fact, it is an alternative approach to traditional flooding method. Gossiping uses the stochastic process for saving energy. It uses spreading rumors nodes to random sending to one of its neighbors instead of sending data to the all neighbors` node. Therefore the cost of broadcasting reduces and it uses the network bandwidth well than the flooding method (Fang et. al., 2003) but packet delivery is not guaranteed.

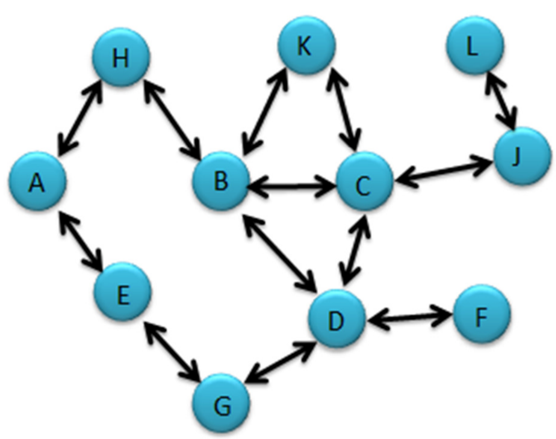


Figure 2.5 Flooding in data communications.

2.2.1.3 Sensor Protocols for Information via Negotiation (SPIN)

SPIN algorithm is a flat-based protocol that can transmit data between sensor nodes effectively (Kulik et. al., 2002, Heinzelman et. al., 1999). The main objective of SPIN is compensation the weaknesses of other methods that are based on data-centric routing protocols as flooding and gossiping protocols. The SPIN protocol focuses on optimal use of resources and therefore doesn't waste the network resource. In this SPIN, the sensor nodes` packet is called meta-data. Also, the nodes use meta-data negotiation to remove the extra data in the network (Heinzelman et. al., 1999). The nodes can decide for their communications that can be based on information about the application and related to their available resources. As a result, the sensor nodes can send their data efficiently by knowing their own limited resources. SPIN uses two key techniques, which are the negotiation and its adaptability to network resources, to optimize the gossiping and flooding algorithms. For example, in SPIN, the nodes use the negotiation with each other before sending data to solve the implosion and overlap problems. Also, they assess theirs resources before sending data and use resource-adaption variable for energy control before transmission. Each node has its own resource manager that keeps the track of its energy consumption. Meta-data is used as representative data and is smaller than real data. Also, if a data packet separates into two pieces then its meta-data must be two pieces. Data exchanging in SPIN is done by three messages. The first message is ADV that nodes use to introduce new data to others so they declare that they have a data packet for sending. The second type is REQ that is requesting the specific data and the third message is DATA that is sent to the nodes which had sent REQ message. Figure 2.6 illustrates an example of SPIN working in a small schema. In step 1, node A advertises its data to its neighbors` nodes by ADV message. In this case, sensor node B is A`s neighbor. In step 2, node B decides to take this data and therefore send REQ message to A. In step 3, node A receive REQ message from B and then send real data to B. This process is continues during the life of the network by all nodes (Intanagonwiwat et. al., 2002).

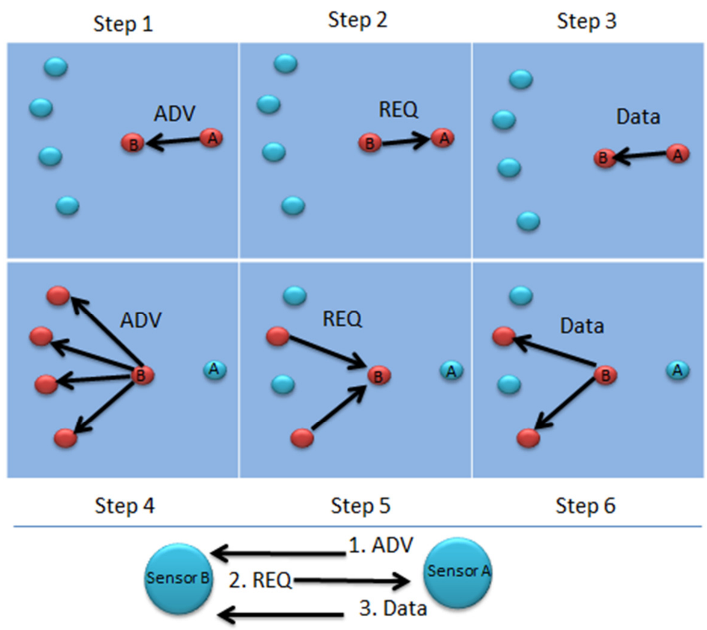


Figure 2.6 SPIN protocol steps (Intanagonwiwat et. al., 2002).

SPIN doesn't guarantee the data delivery therefore it isn't suitable for some applications such as intrusion detection, which require reliable delivery of data packets over regular intervals. Mobility of nodes and reducing of energy consumption are advantages of the protocol. This mobility is due to change topology of network regularly (Martorosyan et. al., 2008).

2.2.1.4 Directed Diffusion (DD)

DD is a significant method in the flat-based routing researches. It uses a naming schema for data diffusion by nodes. The main using reason of the schema is not using the inessential operations in the network layer routing. DD extends the network lifetime by data aggregation and reducing number of transmissions (Jamal & Kamal, 2004).

Basic of DD is on-demand method and its goal is to find an efficient multi-sides route between the transmitter and the receiver. In this method, each task is reflected as an interest that each request is a collection of attribute-value pairs. They are used for the data and query packets and they can be the duration, the name of objects, the interval, the geographical area and etc. In this protocol, each node remembers the node that receives the information from it and creates a gradient for the node. The gradient is to determine the direction of data flow and request status. The status is active, passive or has needed to be update. Generally, the interest message is sent by BS/sink to the network nodes and the gradient message is response message to the interest message. In fact, path of gradient is sent from nodes to BS/sink. Various routes are chosen by reinforcement. If a node predicts the next route from previous gradient or geographic information then the request message will be sent to the neighbors only related to the message. Otherwise, the request will be sent to all adjacent neighbors. If a node receives a request message which is accordance with the expected message then the node will be activated itself to collect the data.

Also, DD supports data aggregation and reliability (Intanagonwiwat et. al., 2002). When a new node is added to the network, DD reinforces again and finds alternative routes for it. Therefore DD is scalable too. On the other hand, alternative routes increase system overhead. One of the important advantages of this method is the fault tolerance and reliability. It has several routes between source node and sink. Therefore, if a node loses the path or dies the other nodes can find new paths to the BS/sink. Therefore, the packet delivery is guaranteed because the protocol uses the link state model routing which that model is based on Dijkstra algorithm.

The major difference between DD and SPIN is in two items. The first, DD is on-demand approach but SPIN uses meta-data schema to transmission and communication between nodes. The second, the communications in DD are hop by hop and neighbor-to-neighbor and each node can aggregate data and doesn’t need to maintain general topology of network. DD is suitable to high-rate packet delivery application such as environmental monitoring.

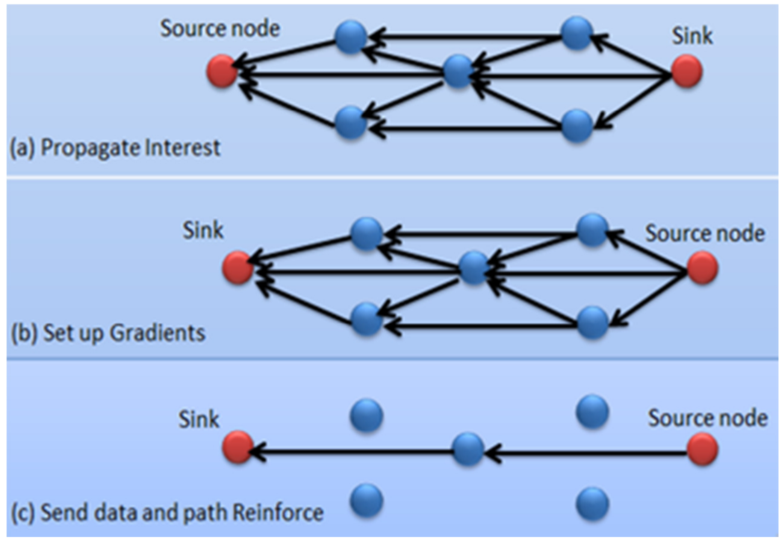


Figure 2.7 An example of interest diffusion in network (Intanagonwiwat et. al., 2002).

```
Setup Phase
The base station broadcasts its set of interest
Do
        For each network node N receiving an interest from node M
                N forwards the received interest to its neighbors
                N set up a gradient with M
        End for
        Until all gradients are set up
          Check for loops in the paths and remove them
Operating Phase
    For each node
        Collect sensor data
        Receive message containing sensor data reading
        Aggregate and correlate (if necessary)
        If data matches an interest
          Forward the data according to the gradient associated with the interest
        End if
    End for
```

Figure 2.8 A pseudo code of Direct Diffusion (Intanagonwiwat et. al., 2002).

2.2.1.5 RUMOR

RUMOR routing (Braginsky & Estrin, 2002) is one of the revision of DD method. It is used in some fields that geographic routing is impossible method. In some applications of DD, only a little amount of data can be requested from the BS/sink or nodes. Indeed, the number of queries is large and the events number is small. In this case, RUMOR is better method than DD.

Simulation result shows that rumor routing protocol is reliable in terms of delivering queries to events in the large network, handle the node failure very smoothly and degrading its delivery rate linearly with the number of failure nodes (Braginsky & Estrin, 2002). It also achieves significant energy saving over event flooding.

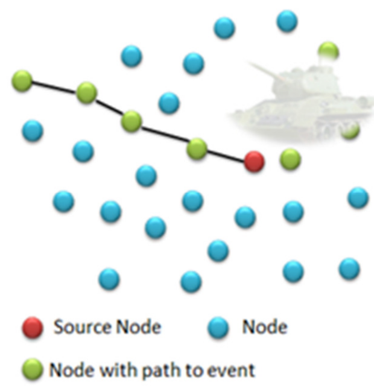


Figure 2.9 Query is originated from the query source and search for a path to the event. As soon as it finds a node on the path, it's routed directly to the event (Braginsky & Estrin, 2002).

2.2.1.6 Gradient-Based Routing (GBR)

GBR is an improvement version of DD (Sohrabi et. al., 2005). When request of the BS/sink is broadcast the entire network, each node calculates the number of hops needed to reach the BS/sink. Therefore the node can gain the minimum number of hop to reach the BS/sink that it is called the height sensor. The main difference between neighboring sensors can be considered as a gradient path between them. Data packets of each node are sent to BS/sink by paths that have the highest gradient. In fact, this method attempts to send data packets to BS/sink with minimum hop count. The protocol uses data aggregation and broadcasting traffic for a uniform distribution of traffic on the network. If the sensor nodes receive data packets from multiple paths then they can use data aggregation technique. Broadcast traffic technique is done by three methods that they are random technique, data flow technique and energy technique. If there are two or more paths with the same gradient, the protocol selects one of them randomly. In energy technique, when the energy of a sensor are lower than a certain threshold then its height will increase. Therefore it advertises to the other nodes that the sensor is less available to data transmission. In data flow technique, existing routes will not be used for the new routes. The simulation results indicate that GBR is more efficient than the DD especially in packet delivery case.

2.2.2 Hierarchical-Based Routing

The flat routing protocols are most suitable for specific applications such as event detections. If this type of routing protocols is applied in monitoring applications then the accuracy of the data is somewhat doubtful and it doesn't represent a real condition of the environment in transmission data packets. This problem or transmission delays for large scale networks are not acceptable. Hence, the flat based routing protocols consume significant energy due to the many number of nodes are participant in transmission information to BS/sink and any node has same role in the network. In Figure 2.10 is shown three models of routing techniques. In the model A, each node sends sensed data to sink directly and without intermediate nodes. This position causes wasting energy in the whole network. The model is initial status of flat approaches. The model B is the improvement of flat based routing techniques that uses multi-hop method for sending data or responding requested queries. This model reduces energy consumption significantly but in the general case, it can't reach to energy efficiently yet. The researchers continue work on energy efficiency factor in routing algorithms due to the weakness and the reasons that has mentioned before. They offered a new model for network configuration and named it as hierarchical based routing algorithms. The basis of the approach is clustering and using Cluster Head (CH) nodes as the interface between clusters. CH nodes can communicate with other CHs or sink except the nodes that are in the same cluster with it. Hence, sensor nodes are not involved in retention of routes between source nodes and sink. As a result, the network lifetime is increased and the routing protocols are converted to energy efficiency methods in WSNs. Many protocols are proposed in the category such as LEACH (Heinzelman et. al., 2000), PEGASIS (Lindsey & Raghavendra, 2002), TEEN (Manjeshwar & Agrawal, 2001), EAD (Shah & Rabaey, 2002), HEED (Younis & Sonia, 2004), HEED-NPF (Taheri et. al., 2010), EECS (Mao et. al., 2005), DSCE (Kiyani et. al., 2010), ECRA(Youssef et. al., 2002), VGA (Jamal et. al., 2004), EESR (Hussain & Islam, 2007), HEAP (Moazeni & Vahdatpour, 2007), Improved-LEACH (Xiangning & Yulin, 2007), New-LEACH (Arbab et. al., 2012) and EE-LEACH (Sharma & Verma, 2013). We describe some of the protocols in this section.

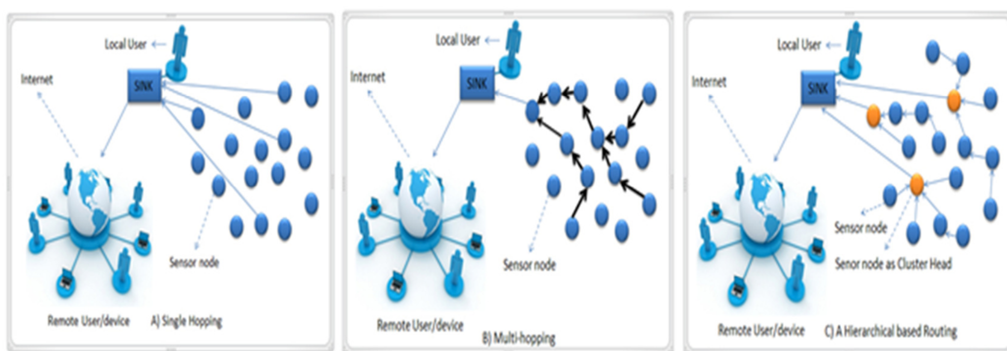


Figure 2.10 Models of routing and data transmission protocols.

Overall the hierarchical based protocols support scalability and energy efficiency better than the flat based protocols. They use CH nodes that these CHs reduce overhead in any cluster and energy consumption of any sensor nodes. CH node is a sensor node so that is selected from the all nodes of that cluster. CH node can change and also the other nodes can be CH node in the network lifetime. This case is depending on CH selection policy of any protocols. CH node performs data aggregation and fusion in multi-hop based communication models therefore reduces energy consumption within any cluster.

In this regard, many approaches have suggested until now that we will describe some of them here. The basic idea of this thesis is based on clustering technique and our approaches are compared with them by simulation. We will discuss on our approaches in the next chapters.

2.2.2.1 Low-Energy Adaptive Clustering Hierarchy (LEACH)

As mentioned, the flat based routing is not very suitable for energy saving in the whole network. LEACH is an approach based on hierarchical protocol that can reduce energy consumption with the idea of clustering (Heinzelman et. al., 2000). In the LEACH, the CH nodes aggregates receiving data from self-group sensor nodes and transfer it to BS/sink. In this protocol, network is divided to several clusters of sensor nodes. If the node is far from the distention or the data packet size is big then energy consumption is increased. LEACH attempts to reduce number of the transmission operations and uses the short-distance spreading method. LEACH selects a CH node to any cluster. If the CH node in each cluster is stable in the whole network lifetime then its tasks and energy consumption multiplies as soon as. Therefore, LEACH uses a formula and gives a chance to all nodes of per cluster to be a CH. The operation of LEACH is divided into rounds that per round have set-up and steady-state phases. In the set-up phase clustering operations is created, CH nodes are selected and are managed inter-cluster. The data transmission is realized in the steady-state phase.

Initially, when clusters are formed, each node decides to whether be or not be the CH node in this round. This decision has a direct relationship with the percentage recommended for the number of CH in the protocol. Also, number of times that a node has been selected as CH is effective in this decision. Node N selects a random number between zero and one to the decision. The decision is independent from other operations or other nodes` behavior. If the selected number is less than threshold value then it will be CH node to current round. If sensor is not CH node in the round then its chance to CH selection in next round will increase. This process continues until the last round so its value will be 1. This means that if the node still is not the CH node then it will be the CH node in the last round.

In CH election formula of LEACH protocol, P is equal to the percentage of CH in current round. G is the set of sensors that have not become CHs in the past 1/P rounds. If the number of CHs is T (n), a sensor n becomes a CH for the current round, where T (n) is a threshold given by:

$$T(n) = P/1\text{-}P\,(r \bmod (1/p)),\ \text{if } n \in G \qquad (2.1)$$
$$T(n) = 0,\ \text{otherwise}$$

The selected node as CH broadcasts a message to other nodes. At this stage, CHs use a CSMA MAC method (Heinzelman et. al., 2000). After this step, each node chooses a cluster to which it will belong that it is calculated based on the received signal strength or its distance to the CH node. Under the same conditions, a node randomly selects a CH node and cluster. For transmission data inter clusters, CH node computes a TDMA schedule so that each node can send its data by using it. The schedule is broadcast to the all nodes in the cluster except CH node.

When clusters are formed and TDMA schedule is allocated, data transferring can start in the protocol. The nodes can send data to the CH in the time allocated to them. As mentioned, this connection requires the least energy. LEACH uses data aggregation method for energy saving in the network. Also this protocol uses CDMA technique for neighbor nodes to avoid creating interference between transmitted signals in each communications` clusters.

The Figure 2.11 shows a pseudo code of LEACH algorithm. In recent years, many of researchers have worked on hierarchical protocols and the most researchers have used LEACH to compare with self-protocol.

```
Setup Phase
          In this phase clusters are created---cluster heads (CH) are chosen
While (node N)
N selects a random number r between 0 and 1
          If (r < Threshold value)
           N become a CH
           N broadcast the message advertising its CH status
          Else
           N becomes a regular node
           N listens to the advertising message of the CHs
           N chooses the CH with the strongest signal as its CH
          End if
   For each CH
    CH creates a TDMA Schedule for each node to transmit data
   CH communicates the TDMA Schedule to each node in the cluster
  End for
Steady state Phase
          For each regular node
           N collected sensed data
           N transmit the sensed data to each in the corresponding TDMA slot time
          End for
          For each CH
           CH received data from its nodes
           CH aggregate the data
           CH transmit the data to the base station
          End for
```

Figure 2.11 A pseudo code of LEACH (Heinzelman et. al., 2000).

2.2.2.2 Power-Efficient Gathering in Sensor Information Systems

This method (PEGASIS) is an improved LEACH method. PEGASIS uses chains of sensor nodes for clusters formation so that each node receives data from one neighbor and sends data to one neighbor only. Therefore, each node as a chain member sends data to the sink. The data packets are aggregated like LEACH. Structuring chain rings are created by a greedy method as each node chooses closer neighbor to itself (Lindsey & Raghavendra, 2002). The goals of PEGASIS are prolonging network lifetime by creating balance in energy consumption of sensor nodes and also reducing packet delays. PEGASIS assumes a homogeneous set of nodes deployed across a geographical area (Lindsey & Raghavendra, 2002). Also, it uses CDMA like LEACH (Lindsey & Raghavendra, 2002; Fang et. al., 2003).

Chain structure data begins with the farthest node from the sink. The network nodes are added neighbor to neighbor to chain structure. Each node uses a signal to measure the distance from its neighbors. Therefore, it can find the nearest neighbor.

So each node hears the nearest neighbor with using the signal only. A node is selected as chain head in the chain length. Chain task is transmitting aggregated data to BS/sink. Each time a unit will shift the position of the chain and it is causing balance on energy consumption of network nodes. The balance rate will be increased when it uses CDMA technique.

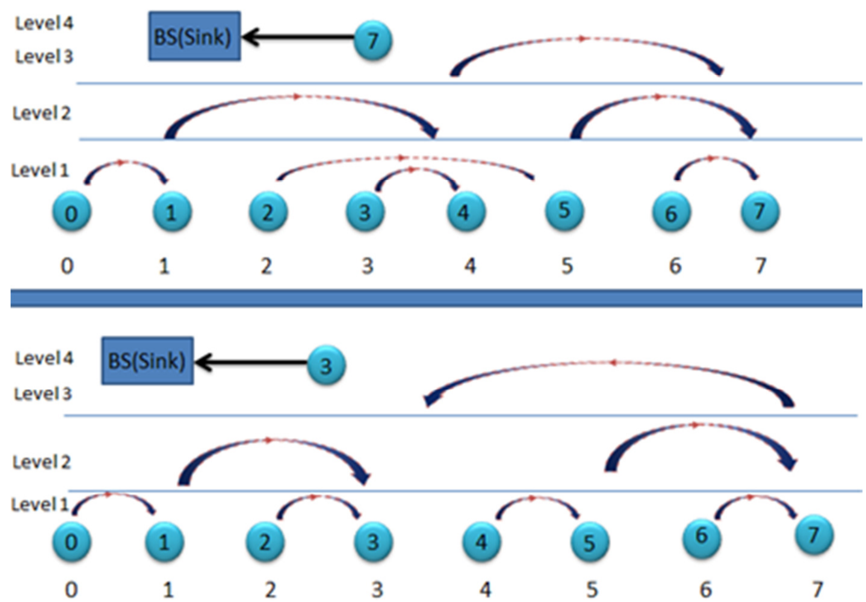


Figure 2.12 PEGASIS scheme in two different examples (Lindsey & Raghavendra, 2002).

2.2.2.3 TEEN and APTEEN

Threshold sensitive Energy Efficient sensor Network protocol (TEEN) is introduced to respond to sudden changes sensed data such as humidity and etc. (Manjeshwar & Agrawal, 2001). In these applications, the network is not continually active and when the desired change is achieved, it will be reported to the BS/sink. TEEN is based on hierarchical protocol but uses data-centric protocols too. Sensors close together form a cluster and then CH nodes send two threshold values to the other nodes. The threshold values are soft and hard thresholds. The hard threshold is value of the parameter which is measured. If the value of the sensor is greater than the threshold value then the value will report, otherwise it will not happen again. The value is for the sensed phenomenon and when the value is sensed by any node, it must active its transmitter and must report it to CH node absolutely. Therefore, the nodes transmit only when the sensed attribute is in the range of interest and the volume of transmitted data is reduced markedly. In soft threshold, data will transmit when the value is less than the value of threshold hard. If a small change is occurred in the value sensed attribute then the node actives its transmitter and report it. Therefore, the transmitted data is reduced by soft threshold. It can control the volume of transmitted data to the BS/sink by setting the soft and hard threshold levels. In transmission phase, node send its data to 1^{th} level CH and then it send the packet to 2^{th}level CH node and finally the data packet reach to the BS/sink. Therefore, TEEN is two level protocol as is shown in the Figure 2.13.

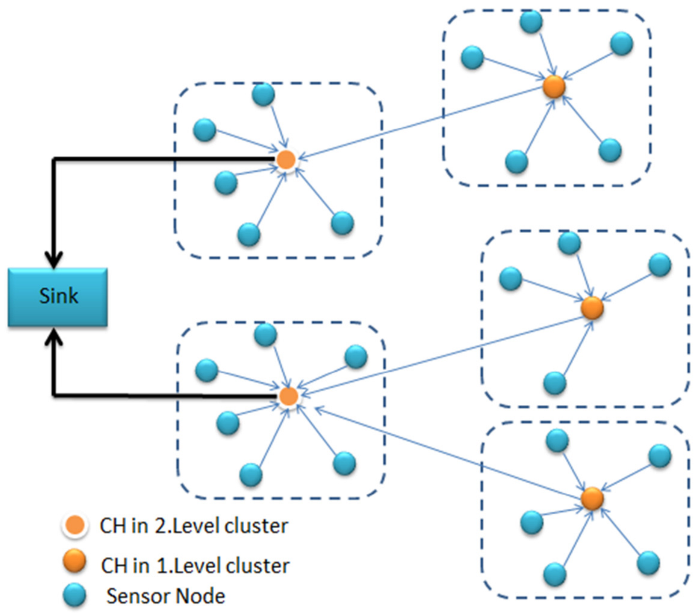


Figure 2.13 A schema of TEEN and APTEEN protocols (Luo et. al., 2005).

TEEN is not good for applications that need to periodic reports whenever the user can't reach to data due to inability to use the threshold values. Pressure is imposed on the CH nodes in TEEN protocol. Also, The Far distance between CH nodes is problematic. However, TEEN is very useful to dynamically control for applications in which users can manage differentiate between energy efficiency, data accuracy, response time. An important feature of this protocol is suitable response time in crisis situation. Also, the data transmission needs to consume more energy than data sensing.

The simulation show that TEEN performs much better than LEACH. Furthermore, TEEN using a soft threshold outperforms TEEN with a hard threshold as expected (Lou, 2005).

APTEEN is the improvement of TEEN protocol. In addition to reporting of important events, it is able to take sensor data periodically. In this protocol, after the formation of clusters, CH nodes send parameters, threshold values and send schedule sensors to them. Data aggregation is done for energy saving in network nodes. APTEEN sends three different requests to the network. The first is history of the analysis of past data. The second is a time that collects network information at the moment. The third is to monitor events for a period of time and is constantly unlike the previous two cases.

Summary of advantages and disadvantages of LEACH, TEEN and APTEEN is shown in Figure 2.14. In additional, comparison of some of the hierarchical based protocols is shown in Figure 2.15.

	Advantages	Disadvantage
LEACH	1- Completely distributed 2- No global knowledge of the network 3- Increases the lifetime of the network	1- Uses single-hop routing within cluster 2- Dynamic clustering brings extra overhead (advertisements, etc.)
TEEN & APTEEN	1- Outperform LEACH in terms of energy dissipation and total lifetime of the network	1- Overhead and complexity of forming multiple level clusters, Implementing threshold-based functions, dealing with attribute-based naming of queries. 2- Not good for applications that need periodic reports 3-based on threshold values

Figure 2.14 Some of specific properties of LEACH, TEEN and APTEEN (Lou, 2005).

Performance parameter	LEACH	PEGASIS	TEEN	APTEEN
Energy Efficiency	Poor	Good	Moderate	Moderate
Network Lifetime	Low	high	moderate	Moderate
Self-organization capability	High	High	High	Low
Network Quality Maintenance	Poor	Good	Moderate	Moderate
Throughput	Low	Low	Low	High
Latency	High	High	Low	Moderate
Transmission	Multi-hop	Multi-hop	Multi-hop	Multi-hop
Data Aggregation	CH-Centralize	CH-Centralize	CH-Centralize	Distribute
Critical Event Detection Capability	No	Yes	Yes	Yes

Figure 2.15 Performance evaluations of LEACH, TEEN, APTEEN and PEGASIS (Jamal et. al., 2004)

2.2.2.4 Hierarchical Energy Aware Protocol (HEAP)

HEAP (Moazeni & Vahdatpour, 2007) is a hierarchical based routing protocol which it is energy efficient and fault tolerance approach. The protocol is used in two model applications. The first is real time applications which must be guarantee packet delivery and fault tolerance in the whole network. The second model is for applications that time are not important. In the case, goal of the protocol will be network lifetime. Main idea of the protocol is building a hierarchical tree which used of interest messages for creating tree. It should be noted that the sink is root of tree. Each node is place in per level of tree and depth of the nodes reachable of it. Continuously changing of tree structure is reasonable but its costs are more than the data transmission. Therefore the build of tree of protocol must be efficient.

Each node only has information about its neighbors in its radio. The network is run by broadcasted interest message from sink to its neighbors. Each node has as least one path to BS/sink and also has one parent. Some of the protocols have a route between a node and BS/sink and therefore they are inefficient (Heinzelman et. al., 1999). In addition to, each node maintains a list of its possible parents and selects one of them in different topologies dynamically. The data structure consists of two tables that are hierarchical and subscript tables. The hierarchical table maintains the identity of BS/sink, the node level and a list of its parents. The subscript table is to save received subscriptions in association with the BS/sink. When a node receives an interest message, it knows itself level and sink-ID and saves in parent list. If a node receives a message with the same number of previous level number then it adds to parent list. If the level of received message has larger than current level then it ignores the message. In otherwise, the level number of sensor node will updated in hierarchical table and message transmitter will be added to the list of parents. In the end of configuration step, one of the parents optionally is selected from the list. Figure 2.16 illustrates a sample of the configuration tree structure.

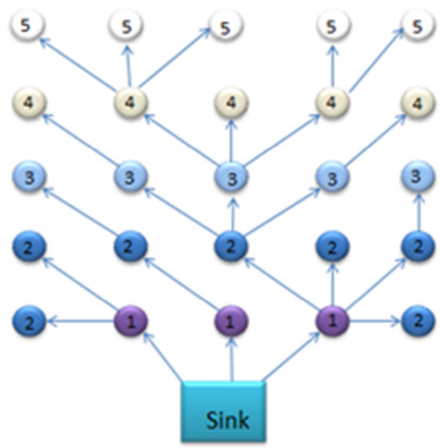


Figure 2.16 A constructed schema in hierarchical tree structure (Moazeni & Vahdatpour, 2007).

Restructuring of hierarchical tree is causing increasing energy consumption. Therefore it must is managed well. In this algorithm, each parent checks itself energy level periodically. If the energy is below a certain level then it broadcasts a CHANGE-PARENT message to its neighbors and informs them that change self-parent. Hence, the nodes change its parent after receiving the notify message. If a node doesn't any other parent then it can't change its parent and therefore it continues to work with the current parent. It should be noted that frequent changes of parent may be inefficient to network lifetime so the choice of remaining energy level is an important factor. Figure 2.17 shows a hierarchical tree which has been restructured.

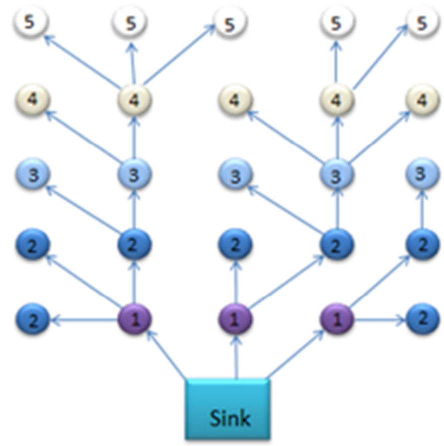


Figure 2.17 An example of restructured schema in HEAP (Moazeni & Vahdatpour, 2007).

Furthermore, In LEACH some nodes may remain out of clusters, which do not occur in HEAP. Moreover, because the aggregators are selected randomly in LEACH they will not necessarily be selected in a proper location relative to other aggregators in the network. In addition, in the approach there is no extra waiting time necessary for the cluster to be set up since each node will independently select its aggregator, which is the same as the selected parent.

2.2.2.5 Energy Efficient Spanning Tree Routing (EESR)

Multiple routes can be avoid and balance of waste of energy in network and increase network lifetime (Hussain & Islam, 2007). EESR uses a minimum spanning tree structure with multi-hopping method that all nodes are same and location of sink and them is fixed. The major goals of EESR are prolonging network lifetime, increasing packet delivery and network balance. It uses data aggregation as an energy efficiency method. The spanning tree is configured by greedy algorithm that it is Kruskal (Ronald, 2002) method. The data collection and aggregation by nodes is based on the Kruskal algorithm. Network runtime is split into several rounds and restructuring tree that need to be done in each round.

The tree configuration algorithm starts with assigning link weight among nodes and forms a spanning tree. The weight assignment is calculated as follow formulate for transmit a k-bit packet from node i to node j as follows (Hussain & Islam, 2007):

$$W_{ij}(k) = \min (E_i - T_{ij}(k), E_j - R_j(k)) \quad (2.2)$$

In the formula, E_i is energy rate so that it is the current energy of the sensor node i and T_{ij} (k) is the energy required to k bit packet transferring from node i to node j. R_j (k) denotes energy consumed to k bit packet receiving for node j. A node calculates the weight of all neighbors when it wants transmit a data packet. In this case, it selects the link with the largest weight for data transmission to BS/sink. The simulation results show that EESR has a good performance in network lifetime, packet delivery and especially network balance in compared to other tree-based methods.

2.2.3 Location-Based Routing

In WSNs, most of routing protocols need to location information of sensor nodes. It is calculable from the distance between two special nodes so that energy consumption can be estimated. Coordinates of neighboring nodes can be reached by exchanging such information between neighbors. If addressing scheme for sensor network is not known then routing protocol can be reach to energy efficiency. This condition is true because WSNs don't use of IP-addressing so their addressing schema is not known. For instance, if the region to be sensed is known, using the location of sensors, the query can be diffused only to that particular region which will eliminate the number of transmission significantly. Some of the protocols discussed here are designed primarily for MANET (Xu et. al., 2001; Li & Halpern, 2001). However, they are also well applicable to WSNs where there is less or no mobility. Many of location-based routing protocols in MANET are usable to WSNs too. The location of nodes may be available directly by communicating with a satellite, using GPS, if nodes are equipped with a small low power GPS receiver (Xu et. al., 2001). To save energy, some location based schemes demand that nodes should go to sleep if there is no activity. More energy savings can be obtained by having as many sleeping nodes in the network as possible. The problem of designing sleep period schedules for each node in a localized manner was addressed in (Xu et. al., 2001; Chen et. al., 2002). In the rest of this section, we review most of the location or geographic based routing protocols.

2.2.3.1 Minimum Energy Communication Network (MECN)

MECN has been developed to achieve the minimum energy in WSNs. It attempts generate and maintenance a network with minimum energy with mobile sensor nodes. They use low-power GPS devices. Nevertheless Motion Sensors, it maintains communications of network and set them automatically. Optimal spanning tree is calculated in root node as BS/sink which is known to be minimal topology. They contains are the minimum energy path from the sensor to the sink only. The major objective of MECN is increasing network lifetime (Li & Halpern, 2001). In first phase of static network, scatter diagram (that is called graph area) is made based on the required locations of sensors. This diagram is a directed graph that includes all the sensors and its vertices are sensor nodes and its edges are connections between nodes. In second phase, the non-optimal links are removed from graph and the resulting graph is a minimum energy topology. It is the most cost-effective route in entire network to each node. Each sensor broadcast its costs to neighbors` nodes where the cost of a sensor node is the minimum energy required to create a route to the sink. MECN is a self-configurable and fault tolerance protocol. It divides a network into several subnets and has high and dynamically adaptability within subnets. However, it has an extreme battery drain problem when it is used in the static network. A sensor always uses the same neighborhood to transmit sensed data to the BS/sink. Therefore, the neighbor dies too fast and as a result, the network is disconnected over time. Topology should operate with minimum power based on residual energy of sensors dynamically to solve the problem.

2.2.3.2 Small Minimum Energy Communication Network (SMECN)

In MECN, if there is an obstacle between two nodes then the node can’t transmit data to other. SMECN is proposed to cope with obstacles. SMECN uses full connective graph and divide the network into several subnets like MECN. But the subnets are smaller in terms of the number of edges compared with the one in MECH if broadcasts are able to reach all nodes in a circular region around the broadcaster. Therefore number of hops of SMECN is less than MECN and the network lifetime is more efficient. Also, the cost of maintaining links is less than MECN (Li & Halpern, 2001). Figure 2.18 shows pseudo codes` MECN and SMECN.

```
Algorithm MECN
p = p0;
A = ∅;
NonNbrs = ∅;
η = F(u, p_max);
while F(u, p) ⊉ η do
    p = Increase(p);
    Broadcast NDM with power p and gather responses;
    M = {v|Loc(v) ∈ F(u, p), v ∉ A, v ≠ u};
    A = A ⋃ M;
    NonNbrs = NonNbrs ⋃ M;
    for each v ∈ M do Flip(v);
    η = ⋂_{v∈(A−NonNbrs)} (F(u, p_max) − R_{u→v});
N(u) = A − NonNbrs;
p(u) = min{p : F(u, p) ⊇ η}

Procedure Flip(v)
    if v ∉ NonNbrs then
        NonNbrs = NonNbrs ⋃ {v};
        for each w ∈ A such that Loc(w) ∈ R_{u→v} do
            Flip(w);
    else if Loc(v) ∉ ∪_{w∈A−NonNbrs} R_{u→w} then
        NonNbrs = NonNbrs − {v};
        for each w ∈ A such that Loc(w) ∈ R_{u→v} do
            Flip(w);
```

```
Algorithm SMECN
p = p0;
A = ∅;
NonNbrs = ∅;
η = F(u, p_max);
while F(u, p) ⊉ η do
    p = Increase(p);
    Broadcast NDM with power p and gather responses;
    M = {v|Loc(v) ∈ F(u, p), v ∉ A, v ≠ u};
    A = A ⋃ M;
    for each v ∈ M do
        for each w ∈ A do
            if Loc(v) ∈ R_{u→w} then
                NonNbrs = NonNbrs ⋃ {v};
            else if Loc(w) ∈ R_{u→v} then
                NonNbrs = NonNbrs ⋃ {w};
    η = η ∩ ⋂_{v∈M} (F(u, p_max) − R_{u→v});
N(u) = A − NonNbrs;
p(u) = min{p : F(u, p) ⊇ η}
```

Figure 2.18 MECN and SMECN algorithms at node u (Li & Halpern, 2001).

2.2.3.3 Geographic Adaptive Fidelity (GAF)

GAF is a protocol for MANET but it is usable in WSNs due to it protects the existing energy. This approach is one of the best location based algorithms and it is one the important reference for researches (Roychowdhury & Patra, 2010). GAF investigates energy consumption that it is achieved by the use of sending and receiving packets and latency. GAF is based on a mechanism that turns off unnecessary sensors, while it maintains a constant level of routing in network. In other word, connectivity between all nodes is stable and don't damage to routing fidelity. Nodes are placed according to itself geographical location and radio range in a square shape as virtual grid. Each pair of nodes only can connect to the adjacent grid. Width of each grid must be is less than half the radius of the radio coverage at each node. Each node uses its GPS-indicated location to associate itself with a point in the virtual grid. Each node in the piece is able to communicate with all nodes adjacent grid. The nodes that are located together in a same grid considered to be equal in terms of costs of packets routing. The set of nodes are called equivalent nodes. One node is active at the moment to maintain communications in different parts of the network in the each set. It is causing increasing network lifetime.

Active node selection is done by grid`s nodes. These nodes have three modes that are active, discovery and sleep. A sample situation is depicted in Figure 2.19, which is redrawn from (Baranidharan & Shanthi, 2010). In this figure, node 1 can reach any of 2, 3 and 4 and nodes 2, 3, and 4 can reach 5. Therefore nodes 2, 3 and 4 are equivalent and two of them can sleep. The default status of each node is discovery mode and changes it to active mode after send discovery message (T_d). Each of the nodes in discovery or active mode can route with finding of equivalent nodes. After this step, the node goes to sleep mode. Then sleep nodes return to discovery mode after the sleep time (T_s). The transition process is shown in Figure 2.20. In usually, the active node in per grid is leader of the grid. This case is similar to CH node in hierarchical based routing protocols.

GAF acts independently for many routing approaches and as a topology control protocol does not affect the performance of the routing protocol. GAF uses half the radius of the radio in the most the communications so it is a problem to it. It should be noted that GAF is implemented both for non-mobility (GAF-basic) and mobility (GAF-mobility adaptation) of nodes. Obviously, the performance of GAF-basic is better than other in many parameters such as network lifetime.

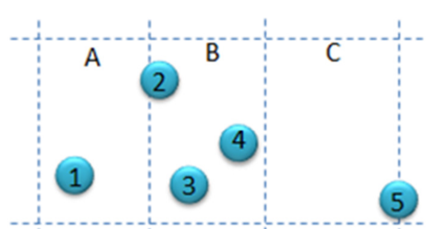


Figure 2.19 Example of virtual grid in GAF (Roychowdhury & Patra, 2010).

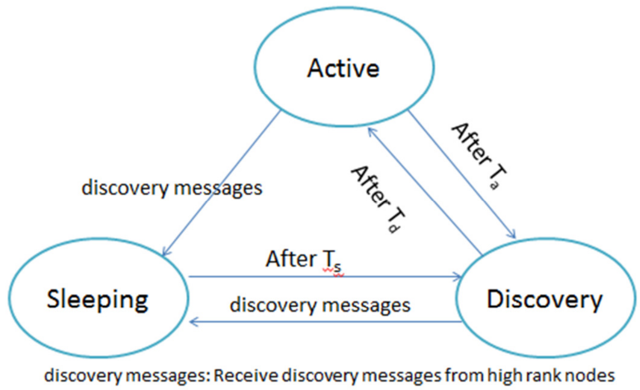


Figure 2.20 Three states in GAF and transitions among them (Baranidharan & Shanthi, 2010).

2.2.3.4 Geographic and Energy-Aware Routing (GEAR)

GEAR is energy efficient and location based routing protocol (Yu et. al., 2001). Given that there are requests for a specific location in the network, in this protocol has been tried to be used location of sensor nodes for sending the request to the desired location. In fact, each node that receives a request, it will try to send it to its neighbor sensor. The node chooses a neighbor that is closer to destination. Indeed, in this protocol doesn't broadcast a request to the entire network as DD protocol. It sends the request to the certain location. Therefore GEAR can save energy in network.

In GEAR, each node has the estimated cost to destination and learned cost to destination. The estimated cost is the combination of residual energy and distance to the destination. The learned cost is the corrected values estimated cost is around holes. If a sensor doesn't have any neighbor closer to the destination than itself and also it doesn't have access to the destination then a hole in the network will occur. If there isn't any hole in the network then the estimated cost to destination and learned cost values will be same. If data is received by destination node then learned cost value will be updated and the value is sent back to updating by all nodes in the path. Thus routes information is corrected for the other data packets.

Generally, the protocol is consisting of two parts. First part is data transmission to specific region and second is data transmission to destination in the specific region and the main goal of GEAR is energy efficiency by geographic and location information. In first part, protocol uses learned and estimated parameters so If a sensor doesn't have any neighbor closer to the destination than itself and also it doesn't have access to the destination then a hole in the network will occur. If there isn't any hole in the network then the estimated cost to destination and learned cost values will be same. In this case, GEAR selects a neighbor that has a minimum learned cost.

In second part, GEAR uses a recursive location algorithm or limited-flooding technique to transmission the packet in specific region. If density of nodes is high in the region then limited-flooding will use. Otherwise, recursive algorithm will apply in transmission data packets. In this case, the target region is split into four sub regions and the current sensor creates four copies of the packet to be unicast to those sub regions (Baranidharan & Shanthi, 2010). This division will continue as far as the whole area is transformed into single sensor regions and data is received by BS/sink.

Figure 2.21 shows a sample of recursive algorithm in GEAR. Also, Figure 2.22 illustrates protocol performance upon occurrence of holes.

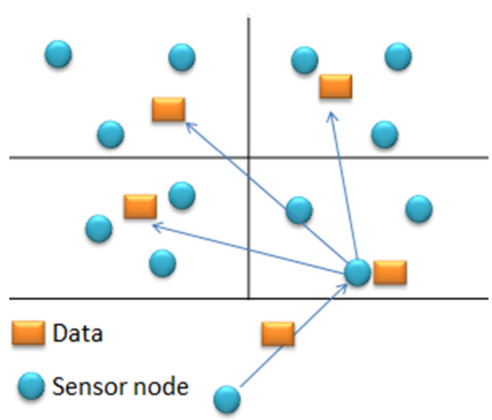


Figure 2.21 Recursive geographic forwarding in GEAR (Yu et. al., 2001).

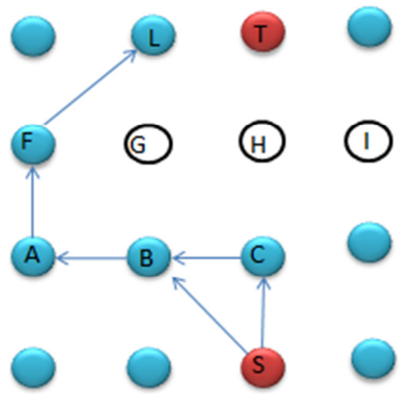


Figure 2.22 Routing while avoiding holes (Yu et. al., 2001).

2.2.3.5 SPAN

In SPAN (Chen et. al., 2002), the sensor nodes decide stay in sleep mode or are connected to backbone coordinators so they try to maintain routing correction. The coordinators stay awake continuously but the nodes stay in reserve power mode and periodically receive and send HELLO messages to find time to change self-status to coordinator. HELLO message is consist of the nodes` advertisements that the sensor nodes told each other are coordinator or not. If two of the neighbors of a node can't communicate with each other either directly or via two coordinators then the node is the coordinator.

The main goal of SPAN is optimization of energy consumption in network. It uses a connective based method that it is based on duty cycle and topology control schema. Sleep/wake up method is causing increasing energy saving (Chen et. al., 2002).

2.3 Comparison of Routing Protocols

Routing protocols are different performance in various applications. Also, they have many advantages and disadvantages and are similar to/different from each other. Therefore, they are placed in three categories as hierarchical, flat and location based protocols. It should be noted that data transmission between the sensor nodes and BS/sink is based on continuous, on-demand, query-based and hybrid. An example of continuously model is temperature monitoring systems that sensed information always must transmit to BS/sink. The all methods described in the previous sections.

Three groups of routing protocols were studies and some of parameters of the protocols have been compared in Figure 2.23. We believe that composite any protocol with a cluster or tree based approach can be energy efficient.

	Classification	Power Usage	Data Aggregate	Scalability	Query-based	Mobility
SPIN	Flat	Limited	Yes	Limited	Yes	possible
Direct Diffusion	Flat	Limited	Yes	Limited	Yes	Limited
ACQUIRE	Flat	Low	Yes	Limited	Yes	No
GBR	Flat	Low	Yes	Limited	Yes	Limited
EAR	Flat	Low	Yes	Limited	Yes	Limited
SAR	Flat	Low	Yes	Limited	Yes	No
RUMOR	Flat	Low	Yes	Good	Yes	Very Limit.
LEACH	Hierarchical	High	Yes	Good	No	Fixed sink
PEGASIS	Hierarchical	High	No	Good	No	Fixed sink
TEEN & APTEEN	Hierarchical	High	Yes	Good	No	Fixed sink
VGA	Hierarchical	High	Yes	Good	No	Possible
ECRA	Hierarchical	High	Yes	Good	No	
HEAP	Hierarchical	Limited	Yes	Good	No	
MECN & SMECN	Location	Low	No	Low	No	No
GAF	Location	Limited	No	Good	No	Limited
GEAR	Location	Limited	No	Limited	No	Limited

Figure 2.23 Comparison of some of the routing protocols (Jamal et. al., 2004).

2.4 Summary and Conclusion

As mentioned at the last section, one of the most important problems in the WSN is optimal using of resources in the network. Because usually in such networks when the energy of one node has finished, it disport from the network cycle and generally replacing the energy source and reusing a node which its energy has finished is not affordable or in some cases is not possible. In that case the new nodes replace in the network. The maintenance cost of network reduces by saving energy in each node. As we know, most of energy consumption in nodes is related to communication between themselves. The energy required to one signal bit transmission is nearly the same as that needed to process several hundred operations in a sensor node. Therefore network traffic, information compression issues are very important for researches in recent year specially. On the other hand, routing protocols that were originally developed for wireless networks such as DSR, AODV proactively and reactive, are not applicable for WSNs. These IP-based protocols require a global addressing scheme and a high overhead. Providing unique ID for a large number of sensor nodes and the high maintenance required is not feasible for WSNs. Furthermore, for the sink the data is more important than identifying the source. IP-based protocols are also not suitable for WSNs due to resource limitation (e.g., energy, memory). Hence, routing technique is an essential approach for reach to this major. The recent years focus on routing protocol in particular energy efficient routing protocols. Routing is new filed in researches of WSNs and almost researchers focus on it to reach energy efficiency in data transmission and increasing packet delivery rates. The goals of routing protocols are different and they usually depend to the required applications. Routing in sensor networks is a new area of research, with a limited, but rapidly growing set of research results.

In this chapter, routing protocols are discussed based on three categories that are flat hierarchical and Location based routing protocols. Almost, they have the common goal and it is prolonging network lifetime. Flooding was the simplest of flat based routing protocols. Each node broadcasted its data packet to its neighbors. It used hop counter and TTL variable to management the packet lifetime and avoidance of rotations in network. However, this protocol was easy and usable but it had implosion and overlap problems. These problems resolve with data aggregation technique. In the general case, this protocol is not very suitable for sensor networks which are often used in extensive environment and consume very battery via nodes. This algorithm was based on flat based routing protocol. Also, some of the other flat based routing protocols described which the most important were SPIN and Direct Diffusion. They are of basic algorithms in the category and are used in most flat based routing techniques. In SPIN, if node S wants send data to node T, then it will send an advertisement message (ADV) containing meta-data first to B. The sensor node B, which is interested in this packet, sends a request message (REQ) to A. Then, the node A sends the data to B. Although the SPIN approach can avoid the problem of the flooding technique, it suffers from finding an intermediate node to forward the packet to the sink when this intermediate sensor node is not interested in the data and the sink is far away from the source sensor node.

The disadvantage of SPIN protocol is that it is not sure about the data will certainly reach the target or not and it is also not good for high-density distribution of nodes. Also, it is possible that the interested message doesn't reach to destination node. For example, the intermediate nodes may be fault in the path. In fact, SPIN algorithm allows sensors to advertise the availability of data and the nodes which are interested query that data but in Directed Diffusion the interest message is broadcasted by sink to all nodes. DD is consisting of several members as interest message, gradients and data packet. DD is on-demand approach and also, communications in DD is hop by hop and neighbor-to-neighbor and each node can aggregate data and doesn't need to maintain general topology of network. DD isn't suitable to high-rate packet delivery application such as environmental monitoring. Despite of its advantages, it is not a good choice for the application such as environmental monitoring because it require continuous data delivery to the sink will not work efficiently with a query-driven on demand data model. In the general case, flat-based routing protocols are not efficient on energy saving than other category protocols.

In the following, new group of routing protocols introduced. They were hierarchical based protocols. The most well-known protocol in the category is LEACH. It is one of the first hierarchical protocols and is self-organize. In the LEACH, sensor nodes will organize themselves into local clusters and cluster members. Then is selected a cluster head (CH) to each cluster to avoid additional energy consumption. Also, it uses data aggregation to reduction of the number of sent messages to sink. Therefore this algorithm has an effect on energy saving. The

CH node selection in LEACH is done periodically and each period contains two steps. The first step is configuration of clusters and the second step is data transferring. Despite the best aspects, it has a basic problem. This problem is much focus on CHs because LEACH is only depend on probability model, some CHs may be very close to each other and can be located in the edge of the WSN. These in-efficient cluster heads could not maximize energy efficiency. These are described in the section with details. Some of the other algorithms were discussed such as PEGASIS, TEEN, APTEEN, HEAP and etc. Overall, the Hierarchical-based routing protocols are energy efficient as well as flat based protocols. Meanwhile, the protocols could composite with other techniques or approaches but the best answer is often combined a protocol with cluster-based approaches. The aim of best answer is energy efficiency.

The third category is location based protocols. They are based on geographical location of sensor nodes. The routing protocols in this category have good performance on network lifetime in generally. The most of the current routing protocols described in this chapter such as GAF MECN, SMECN and GEAR. The GAF is more important than most category methods. GAF is based on a mechanism that turns off unnecessary sensors, while it maintains a constant level of routing in network. In other word, connectivity between all nodes is stable and don't damage to routing fidelity. Nodes are placed according to itself geographical location and radio range in a square shape as virtual grid. Each node uses its GPS-indicated location to associate itself with a point in the virtual grid. However, this case is a problem due to expensive the GPS based devices. GAF uses half the radius of the radio in the most the communications so it is a problem to it. GEAR can save energy in network. In GEAR, each node has the estimated cost to destination and learned cost to destination. The protocol is consisting of two parts. First part is data transmission to specific region and second is data transmission to destination in the specific region and the main goal of GEAR is energy efficiency by geographic and location information. In first part, protocol uses learned and estimated parameters so If a sensor doesn't have any neighbor closer to the destination than itself and also it doesn't have access to the destination then a hole in the network will occur. If there isn't any hole in the network then the estimated cost to destination and learned cost values will be same. In this case, GEAR selects a neighbor that has a minimum learned cost. In second part, GEAR uses a recursive location algorithm or limited-flooding technique to transmission the packet in specific region. If density of nodes is high in the region then limited-flooding will use. Otherwise, recursive algorithm will apply in transmission data packets.

As mentioned, in WSNs, energy efficiency plays a major role to determine the lifetime of the network. The network is usually powered by a battery which is hard to recharge. Hence, one major challenge in WSNs is the issue of how to extend the lifetime of sensors to improve the efficiency. In order to reduce the rate at which the network consumes energy, researchers have come up with energy conservation techniques, schemes and protocols to solve the problem. In the next chapter we will describe the techniques and in the next chapters will use of their in routing algorithms and will present three new algorithms for energy saving in sensor nodes and prolonging lifetime of WSNs.

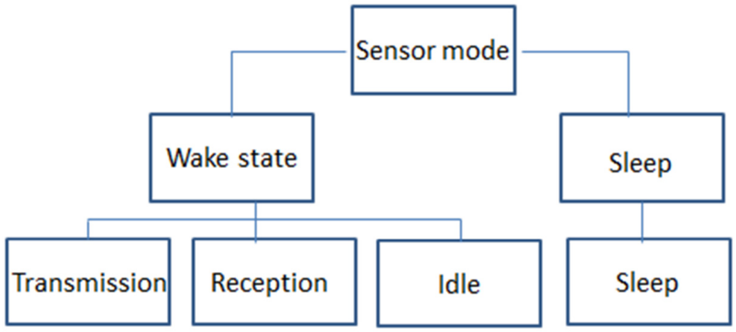
CHAPTER THREE
ENERGY EFFICIENCY IN WIRELESS SENSOR NETWORKS

3.1 Motivation and Challenges

As mentioned, energy is one of the important parameters in the design of WSNs. Sensor nodes have limited energy and memory but their small size and cheap prices are causing to expand their usability in various applications. Energy problem create many new challenges in design and development of hardware and software sensors and belonging network. Therefore proposed protocols must be energy efficient as possible. Energy saving may be has trade off with some of other output parameters in some of the WSNs applications. But energy efficiency is an important issue in the networks due to reasons as mentioned previously. Given that recharging battery is usually impossible, one of the primary design goals is to use this limited amount of energy as efficiently as possible.

Researchers in WSNs field referred several methods for energy saving in whole networks such as data aggregation via sensor nodes or CH nodes, changing sensor mode to sleep/wake up, maintenance network in connective state, learning methods for finding paths and data transferring steps and MAC protocols (e.g. when use of collision management in network). We will describe some of these methods in the form of the proposed scheme.

A sensor node has two modes in operation environment. First is wake state and the other is sleep state. Sleep/wake up modes addition to power consumption of a node is shown in the Figure 3.1.



State		Idle	Sleep	Transmit	Receive
Processor	Active	X		X	X
	Sleep		X		
Radio Board	Transmit			X	
	Receive				X
	Sleep	X	X		

Figure 3.1 A view of states node and power consumption (Lumtan et. al., 2012).

As mentioned, energy efficiency is converted to popular issue and many of researchers focus on it. Energy efficiency is debatable in all layers of protocol stack. For example, in (Niewiadomska et. al., 2009) collision, packet overhead, latency, overhearing and idle listening are discussed and focus on their management to reach energy efficiency. Collisions must be control because they cause unnecessary receive costs at the destination sensor node and also cause undue send costs at the source sensor node. The collisions can are managed in the design phase by TDMA and so on protocols and also, in after the design by avoidance protocols.

In overhearing case is inevitable item in WSNs because the networks have many sensor nodes in an environment and broadcast data transferring is a widespread method. Therefore possibility of overhearing the nodes within the network is perfectly normal but it is causing increasing energy consumption in the network. Hence, it must be control by some of the approaches as management of nodes density (Lumtan et. al., 2012; Niewiadomska et. al., 2009). Latency is gained by delays of transmitted packets in the network. The rate is high in the multi-hop routing protocols.

In idle listening is one of the significant reasons increasing energy consumption in the network. When node is active but doesn't receive any packet or sense any event, it wastes the self-energy extremely. This problem is solvable by different methods as sleep/ wake up and MAC protocols. The sleep/wake up scheduling is important case in the protocols. For example, in some of the approaches, the nodes are in sleep mode and upon sense or receive data are changed to active position. In another approaches, the modes changing of each node are depend to time. In methods based on MAC, it is managed by TDMA, contention based and hybrid schemas. In TDMA-based methods, each node has a time slot and uses it to switching modes. Each of the approaches is discussed in the following in classification of energy efficiency format. We do not discussed much on the energy-aware data link layer (MAC) protocols. We can say only that MAC protocols are based on content-free and content-based approaches. Content-based approaches have competition for share channel such as MACA and MACAW. In content-free approaches the channel divides to some sections and each sensor node uses of self-bandwidth without competition. As mentioned in chapter one, some of the content-free approaches are were expressed.

The sensor nodes consume a lot of the energy when they use the control packets. Therefore the packets number must be managed and the nodes shouldn't use the packets as possible. The packets generally are used in the systems which its goal is reliability. ACK and NACK packets are the samples of the control packets.

According to what was said, energy is one of the most critical resources for WSNs but one problem common to most of them is lack of reliable power for each sensor node in the network. Essentially, data transmission consumes much more energy than data processing. However the energy consumed by the sensing subsystem varies depending on each node. In some cases, sensing consumes less energy than the one required for data processing while in other cases, it even consumes more than the energy needed for data transmission. In view of the above, several research works has been carried out to solve the energy problem which results in different schemes and protocols. Most energy conservation techniques target the networking subsystem and sensing subsystem thus, both energy efficient protocols to minimize energy consumption during network activities and power management schemes for switching off idle node components are necessary for maximum energy conservation in wireless sensor networks.

We focus on energy efficiency issue in the thesis and one of the main our goals is energy saving and prolonging network lifetime. For example, chapter four will propose a new routing algorithm with rely on data-driven and sleep/weak up of nodes techniques. The chapter five will explain a new routing protocol base on machine learning technique which use of data-driven technique of energy efficiency schemas. The chapter six will introduce a novel routing algorithm based on topology control technique. All the techniques are discussed in this chapter completely.

3.2 Classification of Energy Efficiency Schemas

We can classify energy efficient schemes and protocols in WSNs. They are into three classifications so duty-cycling, data-driven and mobility-based methods. Duty cycle schema focuses on subsystem networks and radio transmission switching. Main work of duty-cycle base approaches is maintenance radio transceiver in low power state by sleep mode and it is realizable whenever a sensor node doesn’t communicate with other nodes. If a node is idle and doesn’t senses/sends/receives then the radio mode of the node will wake up to energy consumption management.

Process unit of sensor node do exchanging sleep to wake up mode or vice versa in special and defined periods. This task is done a sleep/wake up scheduling algorithm within any protocol based on duty cycle schema. It is typically a distributed algorithm based on which sensor nodes decide when to transition from active to sleep and back. It allows neighboring nodes to be active at the same time, thus making packet exchange feasible even when nodes operate with a low duty cycle (i.e., they sleep for most of the time). Duty-cycling schemes are typically oblivious to data that are sampled by sensor nodes. On one hand, data-driven approaches are the other method of energy efficiency that can be used to improve the energy saving even more. Data sensing impacts on sensor nodes' energy consumption are in two topics. Sampled data generally has strong spatial and/or temporal correlation (Li & Mohapatra, 2007), so there is no need to communicate the redundant information to the sink. In fact, they are unnecessary samples. Reducing communication is not enough when the power of self-sensor is low. This issue arises whenever the consumption of the sensing subsystem is not insignificant. Data driven techniques presented in the following are designed to reduce the amount of sampled data by keeping the sensing accuracy within an acceptable level for the application. In case some of the sensor nodes are mobile, mobility can finally be used as a tool for reducing energy consumption (beyond duty cycling and data-driven techniques). In a static sensor network packets coming from sensor nodes follow a multi-hop path towards the sink(s). Thus, a few paths can be more loaded than others, and nodes closer to the sink have to relay more packets so that they are more subject to premature energy depletion (funneling effect) (Vuran et. al., 2004).

If some of the nodes (including, possibly, the sink) are mobile, the traffic flow can be altered if mobile devices are responsible for data collection directly from static nodes. Ordinary nodes wait for the passage of the mobile device and route messages towards it, so that the communications take place in proximity (directly or at most with a limited multi-hop traversal). As a consequence, ordinary nodes can save energy because path length, contention and forwarding overheads are reduced as well. In addition, the mobile device can visit the network in order to spread more uniformly the energy consumption due to communications. When the cost of mobilizing sensor nodes is prohibitive, the usual approach is to "attach" sensor nodes to entities that will be roaming in the sensing field anyway, such as buses or animals. The classification is shown in Figure 3.2 with detailing of subgroups. The schema inspired of (Akilandeswari et. al., 2013).

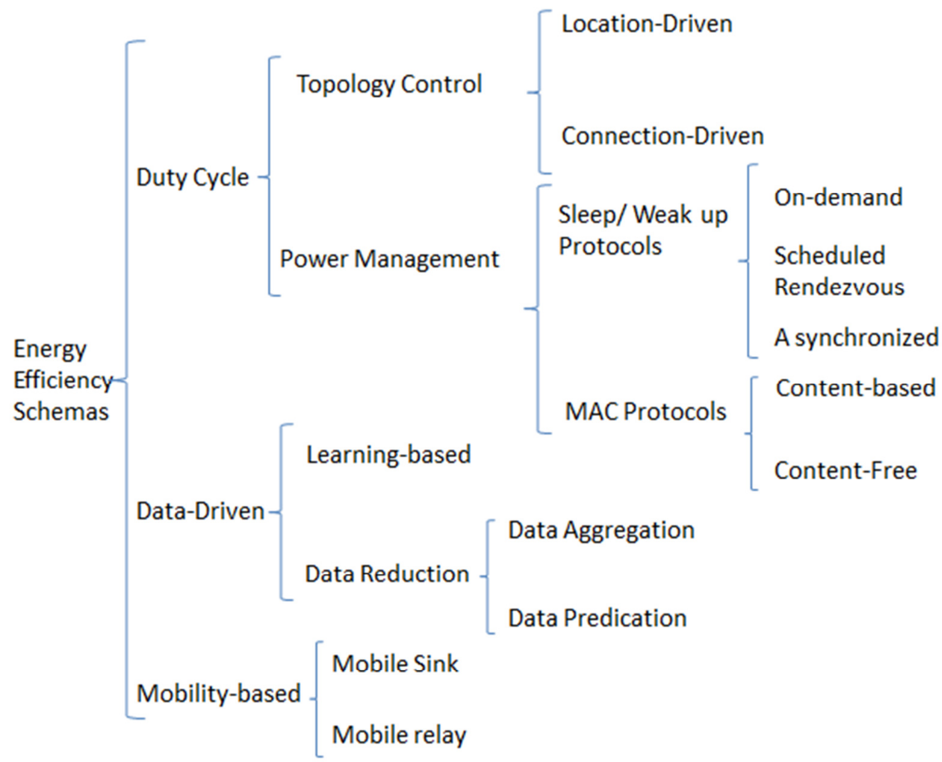


Figure 3.2 Classification of energy efficiency schemas in WSNs (Anastasi et. al., 2009).

3.2.1 Duty Cycle Schema

Duty cycle methods focus on processing subsystem cost and control it but data-driven methods improve communication and sensing subsystem cost. Duty cycling can be achieved through two different and complementary approaches. From one side it is possible to exploit node redundancy, which is typical in sensor networks, and adaptively select only a minimum subset of nodes to remain active for maintaining connectivity. Nodes that are not currently needed for ensuring connectivity can go to sleep and save energy. Duty cycle is into two categories. They are topology control and power management. Then There are different modes in sensor nodes radio operation: active and sleep modes. Nodes switches between both modes based on the activities of the network and this behavior is known as duty cycling (Lai, 2010). During the idle mode, it has been discovered that idle energy is very significant in saving energy in wireless sensor networks. Duty cycle can thus be defined as the percentage of time a node is active during its lifetime.

3.2.1.1 Topology Control Method

Topology control finds the optimal subset of nodes that guarantee connectivity. It should say topology control is not same with power control. Power control refers to techniques that adapt the transmission power level to optimize a single wireless transmission. But topology control is used to reduction of energy consumption (Godfrey & Ratajczak, 2004). Therefore, the basic idea behind topology control is to exploit the network redundancy to prolong the network longevity, typically increasing the network lifetime (Ganesan et. al., 2004; Warrier et. al., 2007). The concept of topology control is strictly associated with that of network redundancy. Dense sensor networks typically have some degree of redundancy. In many cases network deployment is done at random, e.g., by dropping a large number of sensor nodes from an airplane. Therefore, it may be convenient to deploy a number of nodes greater than necessary to cope with possible node failures occurring during or after the deployment. In many contexts it is much easier to deploy initially a greater number of nodes than re-deploying additional nodes when needed. For the same reason, a redundant deployment may be convenient even when nodes are placed by hand (Ganesan et. al., 2004). Topology control protocols are thus aimed at dynamically adapting the network topology, based on the application needs, so as to allow network operations while minimizing the number of active nodes (and, hence, prolonging the network lifetime). Topology control protocols can be broadly classified in the following two categories. Location driven protocols define which node to turn on and when, based on the location of sensor nodes which is assumed to be known. Connectivity driven protocols dynamically activate/deactivate sensor nodes so that network connectivity, or complete sensing coverage (Kong & Yeh, 2007), is fulfilled. A detailed survey on topology control in wireless ad hoc and sensor networks is available in (Karl & Willig, 2005; Rhee et. al., 2008). We continue to our debate with review several existing methods and without getting into details.

GAF is a protocol for MANET but it is usable in WSNs due to it protects the existing energy. This approach is one of the best location based algorithms and it is one the important reference for researches (Roychowdhury & Patra, 2010). GAF investigates energy consumption that it is achieved by the use of sending and receiving packets and latency. GAF is based on a mechanism that turns off unnecessary sensors, while it maintains a constant level of routing in network. In other word, connectivity between all nodes is stable and don't damage to routing fidelity. Nodes are placed according to itself geographical location and radio range in a square shape as virtual grid. Each pair of nodes only can connect to the adjacent grid. Width of each grid must be is less than half the radius of the radio coverage at each node. Each node uses its GPS-indicated location to associate itself with a point in the virtual grid. Each node in the piece is able to communicate with all nodes adjacent grid. The nodes that are located together in a same grid considered to be equal in terms of costs of packets routing. The set of nodes are called equivalent nodes. One node is active at the moment to maintain communications in different parts of the network in the each set. It is causing increasing network lifetime.

Active node selection is done by grid`s nodes. These nodes have three modes that are active, discovery and sleep (Baranidharan & Shanthi, 2010). The default status of each node is discovery mode and changes it to active mode after send discovery message (T_d). Each of the nodes in discovery or active mode can route with finding of equivalent nodes. After this step, the node goes to sleep mode. Then sleep nodes return to discovery mode after the sleep time (T_s). In usually, the active node in per grid is leader of the grid. This case is similar to CH node in hierarchical based routing protocols.

GAF has two assumptions: (a) node's communication range is deterministic. (b) Exact node position is known, which requires the availability of GPS at each node, or at some nodes and the rest perform some kind of localization. GAF is independent of the routing protocol, so that it can be used along with any existing solution of that kind. In addition, GAF does not significantly affect the performance of the routing protocol in terms of packet loss and message latency. The main problem of GAF is need to GPS and is not affordable regarding cost of any nodes. GAF acts independently for many routing approaches and as a topology control protocol does not affect the performance of the routing protocol. GAF uses half the radius of the radio in the most the communications so it is a problem to it.

Naps protocol is a topology control based protocol that it is connectivity driven. It attempts to keep the network connected by keeping enough number of representative nodes in active mode. These representative nodes undertake communication duty of other a sleep neighbor nodes in the same layer. For this purpose we use two parameters T and C. T represents duty cycling period time and C determines the degree of internal communications. Each node with C active neighbors in the same layer, in own radio radius devolve its communication duty to those active nodes and goes to sleep state. Any node is waiting during t_v times and it is in sleep mode in this time. The t_v is distributed uniform and tis value is into the range [0, T). After this time, node convert to active mode and send HELLO message to self-neighbors that they are in range of its RF. It goes into sleep mode again upon receiving the responses from the neighbors. The responses are based on C value. This time is different to nodes and C and T parameters guarantee connectivity of network. Then, it listen HELLO messages sent by other nodes.

```
Naps (Neighbor threshold c ε Z+, time period T ε R+)
  Wait random time tv chosen uniformly from [0,T)
 While true do
        Broadcast HELLO message
        Start timer t
        i ← 0
        While t < T and i < c do
          Increment i for each HELLO message received
        Nap until t=T
```

Figure 3.3 The Naps algorithm, executed at each node v in the network (Godfrey & Ratajczak, 2004).

ASCENT is a connective driven method and its goal is optimizing energy consumption. In this method, many nodes are sleep and a few numbers of nodes are active. The passive or sleep nodes collect the network position information only and don't play a role on transmission issue. The nodes are active by BS/sink that it is unlike SPAN and Naps.

Sink uses a variable with a constant value to lost packet control. Indeed, the maximum number of lost packets can be equal to the variable value. As a result, ASCENT has a constant level of lost packets and increases packet delivery in the network. Also, it is scalable because new added nodes are sleep in start.

3.2.1.2 Power Management Method

Power management techniques can be further subdivided into two broad categories depending on the layer of the network architecture they are implemented at. They can be implemented either as independent sleep/wake up protocols running on top of a MAC protocol (typically at the network or application layer), or strictly integrated with the MAC protocol itself. Sleep/wakeup schemes can be defined for a given component (i.e. the radio subsystem) of the sensor node, without relying on topology or connectivity aspects. In this section we will survey the main sleep/wakeup schemes implemented as independent protocols on top of the MAC protocol (i.e. at the network or the application layer). Independent sleep/wakeup protocols can be further subdivided into three main categories: on-demand, scheduled rendezvous, and asynchronous schemes.

On-demand protocols take the most intuitive approach to power management. The basic idea is that a node should wakeup only when another node wants to communicate with it. The main problem associated with on-demand schemes is how to inform the sleeping node that some other node is willing to communicate with it. To this end, such schemes typically use multiple radios with different energy/performance tradeoffs (i.e. a low-rate and low-power radio for signaling, and a high rate but more power hungry radio for data communication). On-demand schemes are based on the idea that a node should be awaken just when it has to receive a packet from a neighboring node. This minimizes the energy consumption and, thus, makes on-demand schemes particularly suitable for sensor network applications with a very low duty cycle (e.g., fire detection, surveillance of machine failures and, more generally, all event-driven scenarios). In such scenarios sensor nodes are in the monitoring state (i.e., they only sense the environment) for most of the time. As soon as an event is detected, nodes transit to the transfer state. On-demand sleep/wakeup schemes are aimed at reducing energy consumption in the monitoring state while ensuring a limited latency for transitioning in the transfer state. Power consuming is low that it is an advantage for this schema but also additional delay when a node has to wait for its next hop node to wake up is an important disadvantage. For the schema was been introduced some of approaches such as STEM (Schurgers et. al., 2002), STEM-B (Schurgers et. al., 2003) and PTW (Yang & Vaidya, 2004).

The basic idea behind scheduled rendezvous schemes is that each node should wake up at the same time as its neighbors. Typically, nodes wake up according to a wakeup schedule, and remain active for a short time interval to communicate with their neighbors. Then, they go to sleep until the next rendezvous time. Scheduled rendezvous schemes require that all neighboring nodes wake up at the same time. Typically, nodes wake up periodically to check for potential communications. Then, they return to sleep until the next rendezvous time. The major advantage of such schemes is that when a node is awake it is guaranteed that all its neighbors are awake as well. This allows sending broadcast messages to all neighbors. On the other side, scheduled rendezvous schemes require nodes be synchronized in order to wake up at the same time. Clock synchronization in wireless sensor networks is a relevant research topic. However, it is beyond the scope of the present section. The reader can refer to (Keshavarzian et. al., 2006) for detailed surveys on time synchronization techniques. Different scheduled rendezvous protocols differ in the way network nodes sleep and wake up during their lifetime. The simplest way is using a Fully Synchronized Pattern (Deshpande & Madden, 2006). In this case all nodes in the network wake up at the same time according to a periodic pattern. More precisely, all nodes wake up periodically every T_{weakup}, and remain active for a fixed time T_{active}. Then, they return to sleep until the next wakeup instant. A fully synchronized wakeup scheme is also used in MAC protocols such as S-MAC and T-MAC. Even if simple, this scheme allows a low duty cycle provided that the active time (T_{active}) is significantly smaller than the wakeup period (T_{wakeup}). A further improvement can be achieved by allowing nodes to switch off their radio when no activity is detected for at least a timeout value (Dam & Langendoen, 2003). In addition, due to the large size of the active and sleeping part, it does not require very precise time synchronization (Malesci & Madden, 2006). The main drawback is that all nodes become active at the same time after a long sleep period. Therefore, nodes try to transmit simultaneously, thus causing a large number of collisions. In addition, the scheme is not very flexible since the size of wakeup and active periods is fixed and does not adapt to variations in the traffic pattern and/or network topology. As the Figure 3.6 shows, all sensors wake at the same time that this is an advantage but also all sensors should be synchronized in order to wake and work in the same time is disadvantage. The other some of the approaches based on the schema are available in (Li et. al., 2005; Mirza et. al., 2005; Solis et. al., 2004).

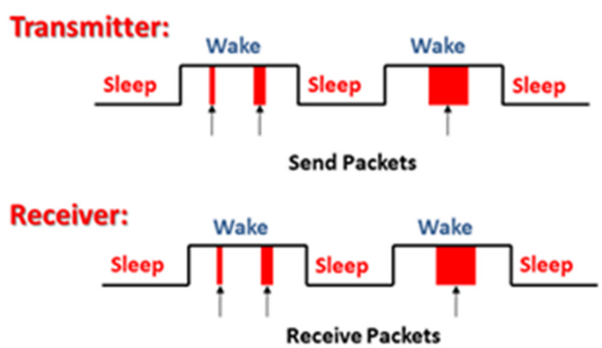


Figure 3.4 Wake up time in scheduled rendezvoused (Dam & Langendoen, 2003).

Finally, an asynchronous sleep/wakeup protocol can be used. With asynchronous protocols, a node can wake up when it wants and still be able to communicate with its neighbors. This goal is achieved by properties implied in the sleep/wakeup scheme, thus no explicit information exchange is needed among nodes. Indeed, Asynchronous schemes allow each node to wake up independently of the others by guaranteeing that neighbors always have overlapped active periods within a specified number of cycles. Figure 3.7 shows that all neighbors should have an overlapping between their wake periods. In this case, the sensors don’t have to be synchronized together and this timer is independent for each node. Therefore contention is reduced. These are advantages of the schema. Many approaches are proposed in the category such as RAW (Paruchuri et. al., 2004) and AWAHN (Zheng et. al., 2003).

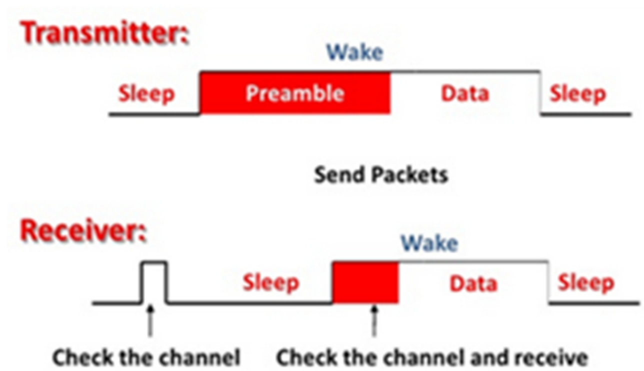


Figure 3.5 Wake up state in a synchronize schema (Dam & Langendoen, 2003).

Several MAC protocols for WSNs have been proposed, and many surveys and introductory papers on MAC protocols are available in the literature and we review and introduce some of the protocols in the before discusses. In summary, actually, the approach taken by on-demand protocols is the ideal one, because it maximizes energy saving as nodes remain active only for the minimum time required for communication. In addition, there is only a very limited impact on latency, because the target node wakes up immediately as soon as it realizes that there is a pending message. Unfortunately, the adoption of a radio triggered wake up scheme is almost always impractical, because it can be only applied when the distance between nodes is very short indeed (a few meters). Introducing an additional wakeup radio is a more promising direction, especially suitable to event detection applications. However, the wakeup radio is costly and generally it is not shipped with commonly used sensor platforms. So, when a second radio is not available or convenient, other solutions such as the scheduled rendezvous and the asynchronous wakeup schemes can be used. Both of them trade energy savings for an increased latency experienced by messages to travel through several hops. The scheduled rendezvous approach is convenient, because it is suitable to data aggregation and supports broadcast traffic. Unfortunately, it requires nodes to be synchronized, which in some cases can be difficult to achieve or expensive, in terms of additional protocol overhead for synchronization. On the other side, asynchronous wakeup protocols don't need a tight synchronization among network nodes. In addition, asynchronous schemes are generally easier to implement and can ensure network connectivity even in highly dynamic scenarios where synchronous (i.e., scheduled rendezvous) schemes become inadequate. This greater flexibility is compensated by lower energy efficiency. In the asynchronous schemes nodes need to wake up more frequently than in scheduled rendezvous protocols. Therefore, asynchronous protocols usually result in a higher duty cycle for network nodes than their synchronous counterparts. In addition, the support to broadcast traffic is problematic. Due to their wider applicability and their properties, scheduled rendezvous and asynchronous approaches seem to be the most promising solutions in the class of sleep/wakeup protocols. However, there is still room for improvements over the techniques discussed above. For instance, scheduled rendezvous protocols should relax the assumptions of clock synchronization among nodes, so that a coarse-grained time reference should be sufficient. Alternatively, they could embed a time synchronization solution as well, so that their timing requirements can be guaranteed without requiring a separate protocol. On the other side, exploiting cross-layer information seems to be a factor often neglected in the design of asynchronous protocols.

3.2.2 Data-Driven Schema

There are two ways by which data driven approach affects energy consumption (Arun-raja & Malathi, 2012): First it sorts out unneeded samples which results in useless energy consumption and stops them from being transmitted to the sink. Secondly, it minimizes the power consumption of the sensing subsystem by keeping the accuracy of the sensor at a reasonable level. Data driven approaches are categorized according to the problem they address into data-reduction schemes and learning based sampling schemes (Anastasi et. al., 2009). The former solved the problem of unneeded samples while the latter reduces the energy spent on the sensing subsystem.

3.2.2.1 Data Reduction Method

In-network processing performs data aggregation at intermediate nodes to reduce the amount of data that is transmitted from the source to the sink. It should be noted that, this scheme is good where readings accuracy is not important and the sensors readings are static (Zhang, 2012). Data compression encodes information at the source nodes and decodes it at the sink in order to reduce the amount of data transmitted. Data reduction by prediction scheme uses adaptive filters to predict data both at the source node and the sink nodes.

Data prediction techniques build a model describing the sensed phenomenon, so that queries can be answered using the model instead of the actually sensed data. There are two instances of a model in the network, one residing at the sink and the other at source nodes (so that there are as many pairs of models as sources). The model at the sink can be used to answer queries without requiring any communication, thus reducing the energy consumption. Clearly, this operation can be performed only if the model is a valid representation of the phenomenon at a given instant. Here comes into play the model residing at source nodes, which is used to ensure the model effectiveness. To this end, sensor nodes just sample data as usual and compare the actual data against the prediction. If the sensed value falls within an application-dependent tolerance, then the model is considered valid. Otherwise, the source node may transmit the sampled data and/or start a model update procedure involving the sink as well. The features of a specific data prediction technique depend on the way the model is built. Details of the different algorithms of this schema are available in (Chu et. al., 2006; Goel et. al., 2006; Tulone & Madden, 2007; Tulone & Madden, 2006).

3.2.2.2 Learning-based Sampling Method

Learning-based data-driven is an emerging class of applications which is actually sensing-constrained. This has three schemas generally: Adaptive sampling, hierarchical sampling and model sampling. This class is in contrast with the general assumption that sensing in not relevant from energy-consumption standpoint. In fact, the energy consumption of the sensing subsystem not only may be relevant, but it can also be greater than the energy consumption of the radio or even greater than the energy consumption of the rest of the sensor node (Alippi et. al., 2007).

The hierarchical sampling approach requires that nodes are equipped with different types of sensors. Each sensor is characterized by its own accuracy and its associated energy consumption. This technique dynamically determines which class to activate, in order to get a trade-off between accuracy and energy conservation (Schott et. al., 2005; Prati et. al., 2005).

Adaptive sampling techniques exploit similarities among the sensed data with respect to the available energy to reduce the amount of data to be acquired from the transducer (Rahimi et. al., 2005; Tseng et. al., 2007).

Model-based active sampling builds a model of the sensed phenomenon on a sample data so that next data can be forecasted. This technique exploits the obtained model to reduce the number of data samples thereby reducing the amount of data to be communicated to the sink (Zhou & Roure, 2007; Padhy et. al., 2006; Deshpande et. al., 2004).

3.2.3 Mobility-based Schema

In this scenario, nodes are assumed to be static, and their density is expected to be large enough to allow communication between any two nodes, eventually by using a multi-hop path. More recently, however, mobility has been considered as an alternative solution for energy-efficient data collection in wireless sensor networks. Mobility of sensor nodes is actually feasible, and it can be accomplished in different ways (Akyildiz et. al., 2004). For example, sensors can be equipped with mobilizers for changing their location. As mobilizers are generally quite expensive from the energy consumption standpoint, adding mobility to sensor nodes may be not convenient. In fact, the resulting energy consumption may be greater than the energy gain due to mobility itself. So, instead of making each sensor node mobile, mobility can be limited to special nodes which are less energy constrained than the ordinary ones. In this case, mobility is strictly tied to the heterogeneity of sensor nodes. On the other side, instead of providing mobilizers, sensors can be placed on elements which are mobile of their own (e.g. animals, cars and so on). There are two different options in this case. First, all sensors are put onto mobile elements, so that all nodes in the network are mobile. Alternatively, only a limited number of special nodes can be placed on mobile elements, while the other sensors are stationary. Anyway, in both cases there is no additional energy consumption overhead due to mobility, but the mobility pattern of mobile elements has to be taken into account during the network design phase. By introducing mobility in wireless sensor networks, several issues regarding connectivity can be afforded. First, during sensor network design, a sparse architecture may be considered as an option, when the application requirements may be satisfied all the same. In this case, it is not required to deploy a large number of nodes, as the constraint of connectivity is relaxed because mobile elements can reach eventual isolated nodes in the network. A different situation happens when a network, assumed to be dense by design, actually turns out to be sparse after the deployment. For example, nodes involved in a random deployment might be not sufficient to cover a given area as expected, due to physical obstacles or damages during placement. In this context, solutions exploiting Unmanned Aircrafts as mobile collectors (Hansen et. al., 2005; Jun et. al., 2005) can be successfully used. In addition, an initially connected network can turn into a set of disconnected sub networks due to hardware failures or energy depletion. In these cases, nodes can exploit mobility in order to remove partitions and reorganize the network so that all nodes are connected again (Venkitasubramaniam et. al., 2004). In this case, the sensor network lifetime can be extended as well. Mobility is also useful for reducing energy consumption. Packets coming from sensor nodes traverse the network towards the sink by following a multi-hop path. When the sink is static, a few paths can be more loaded than others, depending on the network topology and packet generation rates at sources. Generally, nodes closer to the sink also have to relay more packets so that they are subject to premature energy depletion, even when techniques for energy conservation are applied.

On the other hand, the traffic flow can be altered if a designated mobile device makes itself responsible for data collection (mobile data collector). Ordinary nodes wait for the passage of the mobile device and route messages towards it, so that the communication with mobile data collector takes place in proximity (directly or at most with a limited multi-hop traversal). As a consequence, ordinary nodes can save energy thanks to reduced link errors, contention overhead and forwarding. In addition, the mobile device can visit the network in order to spread more uniformly the energy consumption due to data communication. For more information on mobility in sink or relay (or target) issue the following references can be studied. (Wang et. al., 2008; Basagni et. al., 2008; Luo et. al., 2002; Kim et. al., 2003; Martinez & Bullo, 2006; Sadaphal & Jain, 2007; Juang et. al., 2002).

3.3 Summary and Conclusion

In many applications of WSNs energy issue is an important factor. A power source supplies the energy needed by the device to perform the programmed task. This power source often consists of a battery with a limited energy budget. In addition, it could be impossible or inconvenient to recharge the battery, because nodes may be deployed in a hostile or unpractical environment. On the other hand, the sensor network should have a lifetime long enough to fulfill the application requirements. To prolong the operational lifetime of a sensor network, energy efficiency should be considered in every aspect of sensor network design, not only hardware and software, but also network architectures and protocols. Reducing node energy consumption is important in WSNs.

In this chapter we have reviewed the main approaches to energy efficiency in WSNs. This is a very wide topic since energy as one of the most critical resources in WSNs needs to be greatly managed in order to prolong the lifetime of the network. Several research works have been carried out to address this issue which results in different schemes as well as protocols. We did not limit our discussion to topics that have received wide interest in the past, but we have also stressed the importance of different approaches such as data-driven and mobility-based schemes. It is worth noting that the considered approaches should not be considered as alternatives, they should rather be exploited together.

In summary, some of these schemes are discussed in of this chapter are duty cycling, data driven and mobility based. However, it should be noted that most of them sacrificed one or more things in order to save energy. Duty cycle schema has focus on sub network and on/off radio frequency. It don't concern on communication issue. This is schema is called duty cycle due to switching state of node to sleep or wake up. If our aim realizing connectivity in network with minimum wake sensor node then it uses of topology control method and management of the nodes and switching they with sleeping mode nodes are tasks of power management method. Some researchers believe that the two methods are complementary together. Basic idea behind topology control is to exploit the network redundancy to prolong the network longevity, typically increasing the network lifetime. Topology control protocols can be broadly classified in the following two categories. Location driven protocols define which node to turn on and when, based on the location of sensor nodes which is assumed to be known. Connectivity driven protocols dynamically activate/deactivate sensor nodes so that network connectivity or complete sensing coverage is performed. Location-driven topology control protocols obviously require that sensor nodes can somewhat know their position. This is generally achieved by providing sensors with a GPS unit. As the GPS is quite expensive and energy consuming, it is often unfeasible to install it on all nodes. In this case, it would be enough to equip only a limited subset of nodes with a GPS, and then derive the location of the other ones by means of other techniques. From the above discussion it emerges that connectivity-driven protocols are generally preferable, since they only require information which can be derived from local measurements. In any case, as the energy efficiency of topology control protocols is tightly related to the nodes density, also the achievable gain in terms of network lifetime depends on the actual density. We described some of the protocols such as GAF, SPAN and ASCENT. Power management is another method in the duty cycle schema. They can be implemented in two models. One of them is independent sleep/wakeup protocols that running on top of a MAC protocol (typically at the network or application layer), or strictly integrated with the MAC protocol itself and another method is MAC protocols with low duty cycle such as content-free and content-based techniques. Sleep/wake up methods reviewed in on-demand, scheduled rendezvous and asynchronies approaches. In on-demand, nodes are awake when need to reception data. This approach is used in fire detection or event-based applications. Indeed, the nodes are monitoring state in environment and the state convert to transfer state once an event has occurred. In scheduled rendezvous approach, all nodes wake up in the special periodic times and are online for some time and then go into sleep mode. In the synchronization approach the nodes sleep/wake up in the different times and each node is independent of the others.

Duty-cycling schemes are typically oblivious to data that are sampled by sensor nodes. Hence, data-driven approaches can be used to improve the energy efficiency even more. Data driven techniques presented in the following are designed to reduce the amount of sampled data by keeping the sensing accuracy within an acceptable level for the application. Data driven approaches are categorized according to the problem they address into data-reduction schemes and learning based sampling schemes. Data reduction by prediction scheme uses adaptive filters to predict data both at the source node and the sink nodes. Data-reduction had two subsets. First, In-network processing performs data aggregation at intermediate nodes to reduce the amount of data that is transmitted from the source to the sink Data compression encodes information at the source nodes and decodes it at the sink in order to reduce the amount of data transmitted too. In second, data prediction techniques build a model describing the sensed phenomenon, so that queries can be answered using the model instead of the actually sensed data. Learning-based data-driven is an emerging class of applications which is actually sensing-constrained. This has three schemas generally: Adaptive sampling, hierarchical sampling and model sampling. They described in within text completely.

In case some of the sensor nodes are mobile, mobility can finally be used as a tool for reducing energy consumption (beyond duty cycling and data-driven techniques). In a static sensor network packets coming from sensor nodes follow a multi-hop path towards the sink(s). Thus, a few paths can be more loaded than others, and nodes closer to the sink have to relay more packets so that they are more subject to premature energy depletion. In the schema divide to two subsections which in the first method sink could be mobile and in the second method, target could be mobile in the environment (mobile relay). The mobile relay case is custom than mobile sink in the real applications such as obtain secret information the security and spyware.

Overall, we discussed on energy issue in the chapter and focus on energy efficient approaches in WSNs because of its high importance. All schemas and methods presented have advantages and disadvantages normally and when to use them depend to applications. We will propose a new routing algorithm with rely on data-driven and sleep/wake up of nodes techniques in the fourth chapter. In the fifth chapter we will explain a new routing protocol base on learning technique which use of data-driven technique of energy efficiency schemas. Finally, in the sixth chapter we will introduce a novel routing algorithm based on topology control technique and connectivity-driven method.

CHAPTER FOUR
ENERGY EFFICIENT ROUTING PROTOCOL BASED ON SPANNING TREE AND DYNAMIC CLUSTERING STRUCTURE

4.1 Introduction and Motivation

As mentioned in the previous chapters, energy issue is an important parameter in the WSNs and should be managed in the different applications. Routing algorithms can reduce energy consumption in the sensor nodes by finding optimum routes from source nodes to sink and also between all nodes. Significant approaches for realizing energy efficiency are hierarchical based routing algorithms. The most applications can use them to reach the goal but they have some of the problems such as finding optimal network lifetime, overhead over CH nodes, packet delays and etc. This category had been described from 2002 to now. Each of the methods has some of the advantages and disadvantages as they are usable in special applications only. Also, they have unavoidable trade-off between parameters in the any applications such as network lifetime and packet delays.

We propose a new routing algorithm to optimize energy consumption in the WSNs. The protocol is based on hierarchical approach and it uses tree structure for deploying network and routing on it. We show that our algorithm has the improvement rather to some of the current methods such as LEACH (Heinzelman et. al., 2000), Improved-LEACH (Xiangning & Yulin, 2007), EESR (Hussain & Islam, 2007) and HEED (Younis & Sonia, 2004) in similar fields. Our protocol has two main phases. First phase is consisting of steady cluster, CH election and creation spanning tree in the each cluster and the second phase is data routing. Our protocol is based on dynamical model in CH selections, changing topologies structures in any round of running network. This can reduce overhead and improves resources consumption in the whole system.

Structure of communications between sensor nodes in the clusters is based on spanning tree. This part of algorithm is similar to EESR partially because EESR used of spanning plan too. Tree structure is one of the appropriate architectures to data collection in the WSNs. A spanning tree is a graph that spans all the nodes as vertices and contains no cycles. The tree is structured in the way that the node with the smallest identifier is chosen as the root. All other nodes are connecting to this selected root via the shortest-path route. The protocol requires each node to exchange configuration messages in a format that contains its own identifier, its selected root, and the distance (in hops) to this selected root. Each node updates its configuration message upon identifying a root with a smaller identifier or the shortest-path neighbor. Furthermore, the neighbor for which the shortest-path configuration message comes from is chosen as the parent of a node whenever it is detected. Node identifier is used to break ties if necessary.

CH election is based on specific method that uses the residual energy parameter. In the method, overhead over a CH node will be reduced because CH nodes are changed in per round. This case is one of the advantages rather to LEACH. In this step, not selected nodes as CH can play in CH elections process. In this case, some of the parameters are impact such as residual energy of any nodes.

One the other hand, one of the specific characteristics in our protocol is using of sleep/wake up method. This is an energy efficiency method. As mentioned in the third chapter, this case belongs to the data-cycle category. Also, our protocol uses the data-driven schema to energy saving in the network. Those approaches will explain in the next sections of the thesis. The energy management is an important part of our approach which many of the current approaches have not concern on it.

Routing phase in our algorithm is based on spanning tree algorithm. In fact, it uses a new approach for data transferring from BS/sink to other sensor nodes or vice versa. It should be noted that this phase once simulate with SPIN and DD but we saw spanning tree based algorithm is better of SPIN and DD in this protocol.

We will explain all phases of our algorithm in the next section. Also, we will describe the algorithm operation by pseudo code and flow chart. In the end of chapter, we will show simulation results of the algorithm and compare them with some of the current protocols.

4.2 EESTDC Algorithm Description

Energy Efficient routing protocol based on Spanning Tree and Dynamic Clustering structure (EESTDC) is based on hierarchical routing protocols. It is inspired like many of protocols from the LEACH protocol but it has major changes and improvements in energy saving parameter. The EESTDC has two phases. The first, deployment of clusters and determination CH for every cluster and create communication model between nodes by a dynamic spanning tree schema. The second phase is data transmission between sensor nodes and BS/sink by spanning tree. In the first step of the protocol, network is divided to several clusters. Then election CH node method is applied to every cluster. This method is applied for all rounds of running network and therefore CH node is changed in every round. In fact, network divides to several executive rounds and the both phases are applied in any round. All the sensor nodes belong to clusters that can collaborate in the CH election its cluster. Since CH nodes discharge their energy faster than other sensor nodes in that cluster, we must apply special measures to CH selection nodes in our network. CH node must be replaced regularly to avoid overuse a node as the CH node. In the first round, all sensor nodes within each cluster can are selected as CH node but in the next rounds, the CH re-selection is applicable to nodes that have already been chosen previously. Moreover, residual energy of nodes is effective in the CH elections. This CH election method is shown in the following formula. The first part of this formula is similar to CH election in the LEACH protocol. Heavy duty imposed on a CH node is an important weakness in the LEACH and also it does not change CH node in the whole network lifetime. These problems are solved by added parts to formula in this case.

$$\begin{aligned} &T(i) = P(i) / 1 - P(i)\,(r \,\%\, (1/P(i)) \\ &CH(i) = T(i) / E(i) \\ &CH(R) = \min(CH(i)) \end{aligned} \tag{4.1}$$

In this case, P is a random number that identifies percent of CH node possibility. r show current round and T (i) is a threshold that its value is between zero and one. This value calculates for all sensor nodes in every cluster. i is number of each sensor. E (i) is residual energy of i^{th} node. In finally, a node is selected as CH node that has minimum value among CH (i). This model will cause to reduction energy consumption on CH nodes, energy balance of the whole network and prolonging lifetime of network. Figure 4.1 shows an example of clusters formation and selected CH node to every cluster.

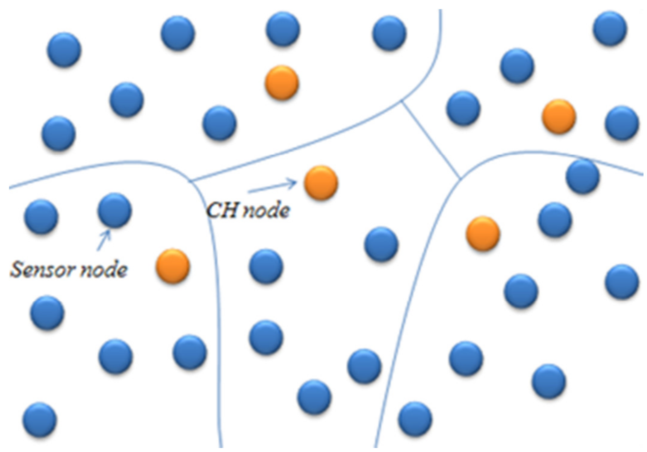


Figure 4.1 An example of network after selection CH nodes.

After election CH node process, selected CH node broadcast an announcement message to neighbors` nodes which it had selected as CH node. Selected node is a CH node for one round only. After receiving message by the each sensor node, it decides be a member of a cluster so it will transmit its data to CH node of the cluster. If a sensor node has same distance from two or more CH node then it selects a cluster by random. This issue is shown in Figure 4.2. In fact, a node may place in the neighbor cluster and therefore it is a new member to the cluster. This case indicates that our clustering scheme is dynamic. Relations between all nodes (new or old) within every cluster are based on spanning tree schema.

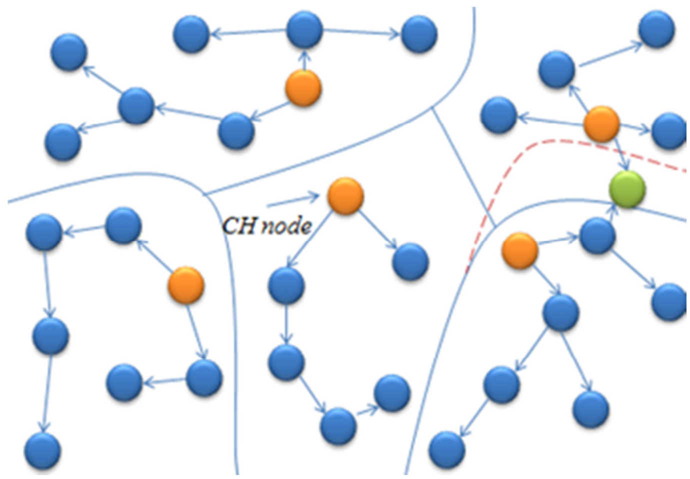


Figure 4.2 A case of changing membership by sensor nodes between clusters.

Tree structure is applied to every cluster after determination CH nodes. This architecture helps data aggregation in each layer. Therefore, data aggregation task doesn't impose on the CH nodes only. This will cause to reduction of system overhead and increasing network lifetime. Data aggregation technique is an approach for energy saving in nodes and prolonging lifetime of the network. It should be noted that, CH nodes are root of tree in each cluster. The architecture has variable topology due to changing in CH nodes in each round. The nodes must be configured in the range new CH nodes for reach to acceptable level in the re-organization of tree in the each round. Hence, all structure of the tree doesn't change in different rounds of running network. Set-up tree structure is explained in the next section.

The creation of tree is an iterative procedure. Every sensor node is located within a cluster and has a relation with its CH node. This case is done by tree spanning model. Indeed, all communications between nodes and nodes-CH nodes are made by this model. Each node selects its children and this case is iterative to end. In the end, all sensor nodes are within a tree structure so this structure is based on spanning tree algorithm. An example state of our protocol in the end of tree structure creation is presented in the Figure 4.3.

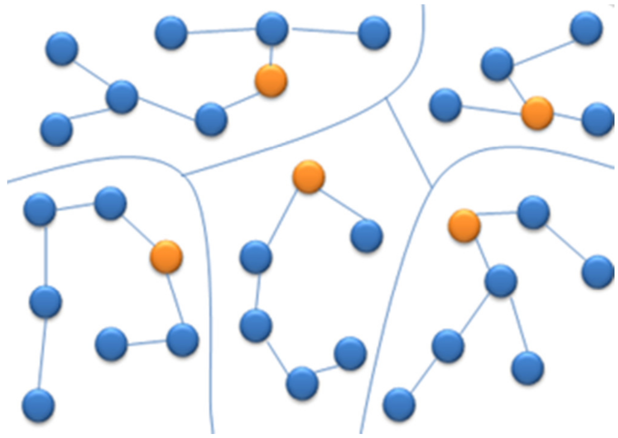


Figure 4.3 An example of network after creation spanning tree.

After the determination of communication channel of each node, every one of them is active for a few seconds and then is changed to sleep mode. This is a method for energy efficiency in the WSNs that it can avoid unnecessary consumption of energy in each node and this will cause to prolonging lifetime of the network. As described earlier, a sensor node has three main parts as sensing unit (S.U), processing unit (P.U) and transmission unit (T.U). Generally, T.U and S.U can sleep but P.U is always on in the all conditions. When S.U goes to sleep mode, it buffers sensed data so it can send them after changing mode to wake up. The waking of the S.U is task of the P.U. For example, sensor is activated once every ten seconds by the P.U. In the sleep mode, memory part of P.U may be in sleep mode for more energy saving but it must wakes up after activation of S.U. Table 4.1 present a schema of the sleep/wake up power management model without involving with turn on/off rapidly. This case is called Dynamic Power Management (DPM).

Table 4.1 A schema of dynamic sleep/wake up model (DPM)

States	State node	Memory	ADC	State transmitter
S0	Active	Active	On	TX, RX
S1	Idle	Sleep	On	RX
S2	Sleep	Sleep	On	RX
S3	Sleep	Sleep	On	Off
S4	Sleep	Sleep	Off	Off

On the other hand, T.U can't send or receive any data packet of its neighbors or BS/sink in sleep mode. After activation of node`s RF, it can send the buffered data to its neighbors. The crucial point is that while T.U is sleep mode, node never can't receive or send data and this case is problematic especially in the target tracking applications. One of the good transmitter modules for short-range schemas is TR1000 module. It has a short range but energy consumption in receiving part is quarter of send part. Indeed, we can hold off the portion of the reception to receive possible message packets of neighbors. Therefore, they can receive wake up or target tracking messages of neighbors. This case is semi-sleep model and can active reception part of T.U. Our protocol uses the module because it is suitable in target tracking applications such as possible prosecution of enemy tanks.

In our protocol waking time is limited for maintaining energy in the nodes. Therefore the nodes must be efficient and sense the target and announce to its neighbors in the short time. A path is created from source node to CH node upon finding a target via the source node. At this time, data transferring is done by new routing protocol that is based on spanning tree structure. In our algorithm, some of the nodes are sleep which they are unrelated to the target. This case will cause to extra energy saving in the whole network. The problem of data redundancy will not in the protocol because it uses the data aggregation technique. In this case, all parent nodes aggregate their data packets. The turn on/off nodes approach and spanning tree structure are combined together and are used within a clustering system in our protocol. Communications between nodes within each cluster are hierarchical-based and transmissions are from down (child node) to up (parent node). The data packets are aggregate by each the receiver nodes. Hence, CH node will receive low volume data packet of children and this will cause to prolonging the survival rate of the network. In fact, our protocol increases network lifetime and is energy efficient in three visions. The CH nodes will be available more time and they will have long-lifetime in the network. This is the result of two reasons. First, reduction tasks over CH node by data aggregation technique in per nodes. The second is repeated changes in clusters of heads task. Second vision is sleep/wake up approach that uses a specific module for our application types. Third vision is sleep mode in some nodes that they are unrelated to the target.

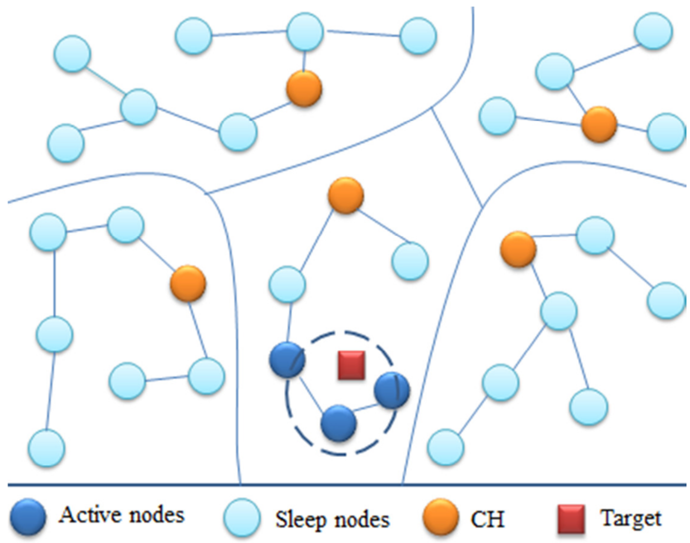


Figure 4.4 EESTDC operation in target tracking application (CH node is active mode).

The first phase is terminated after completion of the build tree. Afterwards, the protocol arrives into second phase. The second phase is data transferring that the sensor nodes can send/receive their data packets to/from other nodes by paths that are created in the first phase. This phase is divided into time frames. A transmission gaps is assigned to each sensor node in each frame. A time variable is assigned to the gaps so it is constant and depends to depth of tree and number of nodes in a cluster (Pei & Chien, 2003). This uses a scheduling algorithm awakening that is suitable for tree structure approaches so many of researchers use it for their works. This algorithm is described in (Lu et. al., 2004). In fact, it uses the TDMA method in data transferring phase. For example, we suppose a cluster has 10 sensor nodes (9 nodes and one CH node). In this case, CH node cuts bandwidth between 9 the sensor nodes by the TDMA.

The CH nodes receive the information from their children nodes and then send them to BS/sink. In this phase, CH node doesn't have to aggregate all data because the other nodes can do it themselves. Therefore, CH node aggregate received low-volume data of neighbors' nodes only. This will cause to reduction overhead over CH node and prolonging lifetime of CH nodes. During the data receiving, paths may change due to fault a sensor node or changing CH node task in a cluster. A sensor is fault when the some of the sensor nodes in the path is dead or its hardware is damaged. In this case, the protocol must find a new route by routing algorithm immediately for avoidance packet losses.

In this phase, a sensor node can be in receiving, transmitting or sleeping state. In the receive state, nodes are waiting to receive packets from the sender and send ACK packet to sender upon reception a packet. In the sender state, nodes send data packets to neighbors and receive ACK packets. ACK packet management can be based on sliding window and selective repeat. In the sleep state, the sensor node saves its energy and changes its position when it receives a wake up message from any neighbors' nodes or P.U. Periods of the sending and the receiving is constant and short that is enough for the operations. In this structure, the data receiving is performed in one directory template to root only (Lu et. al., 2004).

In summary, we used data aggregation method of data-driven category and sleep/wake-up and MAC protocol methods of duty-cycle category in the EESTDC protocol. Also, the protocol selects a CH node to each cluster and then nodes decide be a member of each cluster. This decision can be based on different factors as remaining energy, distance to other nodes, distance to BS/sink and etc. The EESTDC is based on spanning tree and built data transfer routes based on it. The network is run in some of the period times that are called rounds. In per round, CH nodes are changed and hence tree structures are reorganized. Numbers of clusters are constant but their size can be variable.

Actually, our protocol can increase network lifetime and support energy efficiency. CH nodes will be available longer period of times and they will have long-lifetime in network. In another view, this has fourth reasons that the first reason is reduction tasks over CH node by data aggregation technique in each node. The second of reason is repeated changes in the clusters of heads task. Third reason is sleep/wake up approach and use a specific module for our application types that it uses TR1000 module for low power consumption when data reception is efficient in the mobile applications. Fourth reason is sleeping mode some nodes so that unrelated nodes to the target is not need to be idle state so the nodes are not on the sensing range of target. Figure 4.5 represents a snapshot of our protocol in during of the simulation. In fact, the routing and data transferring approach in our protocol is based on spanning tree. We present a snapshot of Improved-LEACH and EESR in two next figures. All three snapshots have been taken in the same conditions as the initial energy, the nodes number, the interval and the duration of phenomenon, the simulation test and etc. They will explain in the simulation section with details.

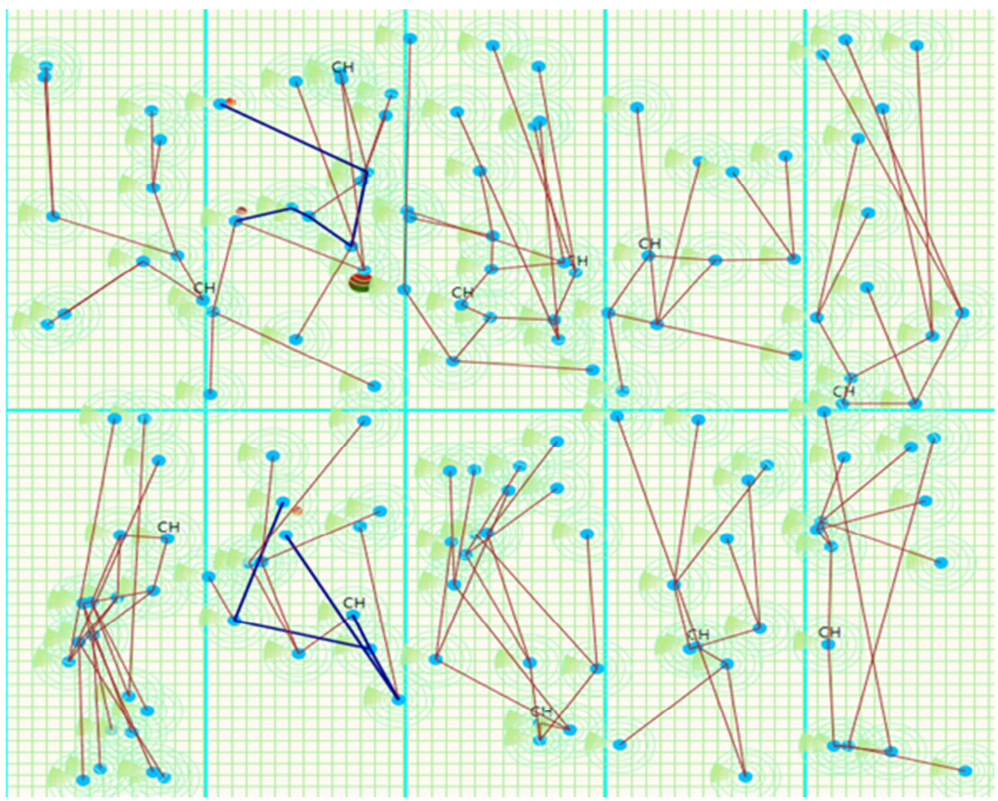


Figure 4.5 A snapshot of basic network topology in EESTDC protocol.

Figure 4.6 and 4.7 represent a snapshot of basic topology of EESR and Improved-LEACH. We will explain and compare them in simulation and comparison sections.

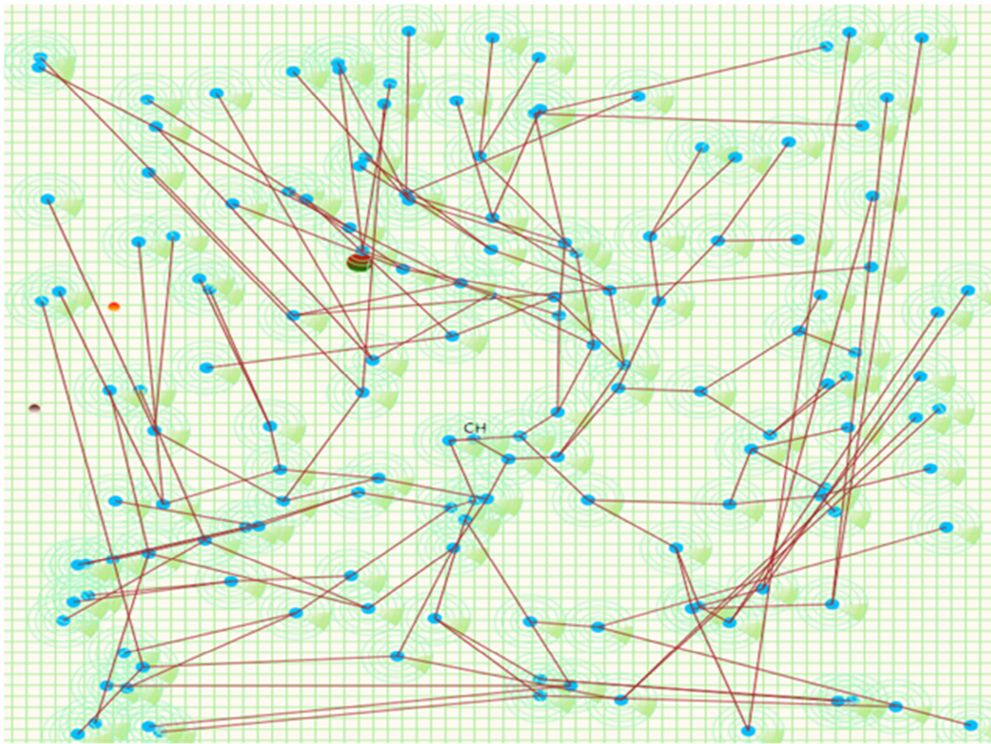


Figure 4.6 A snapshot of basic network topology in EESR protocol.

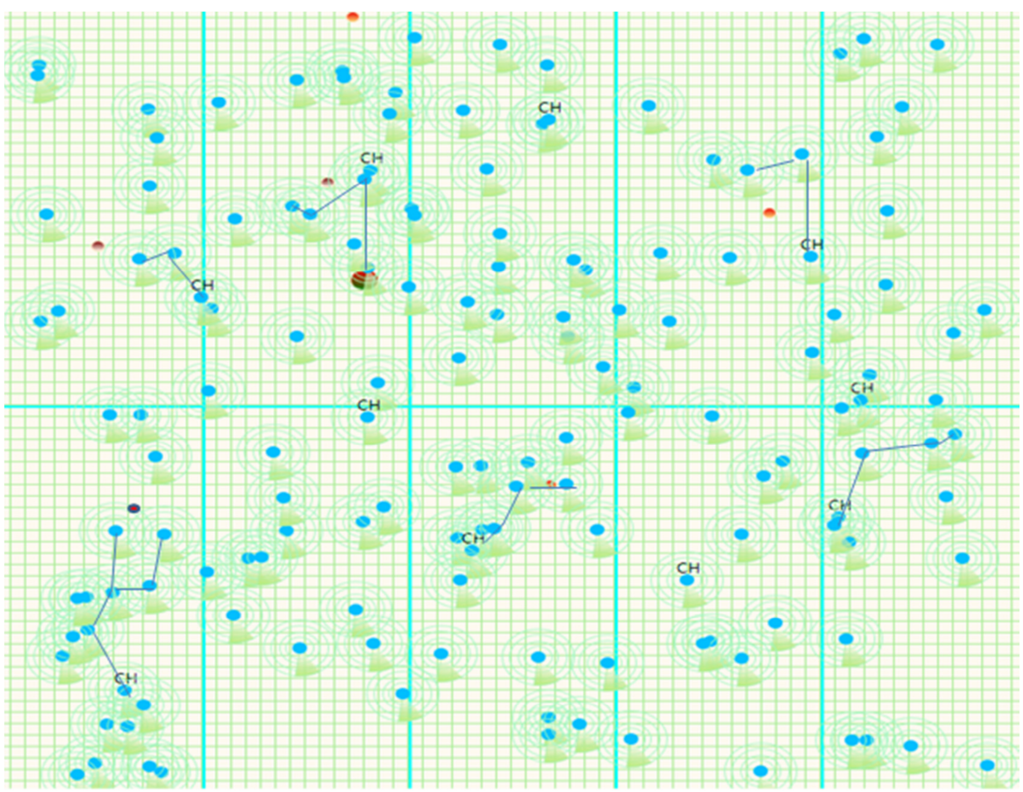


Figure 4.7 A snapshot of basic network topology in Improved-LEACH.

In the section, we explain EESTDC protocol again with using flow chart and pseudo code. As mentioned, the EESTDC has two phases. In first phase, network is divided to several clusters and into equal periods of time known as rounds. The protocol selects a CH node for each cluster and builds or reorganizes a spanning tree in per round. We use an optimized method for energy management of each CH node. The method is based on residual energy of each node for CH election. The Figure 4.8 represents a pseudo code for set-up phase of EESTDC.

```
SETUP PHASE
//Variables
T is threshold value, r is round of network, i is number of node, E is energy of a node, P is random number between 0, 1
//Clustering and Election of CH nodes
   Network is divided to several clusters
   While (r is true)
      Select CH node to each cluster
       T (i) = P (i) / 1-P (i)*(r mod (1/P (i))
      CH (i) = T (i) / E (i)
      CH (r) = Min (CH (i))
//Broadcasting by selected CH node
       CH node broadcast his success in the CH election message
//To recruits members' nodes to clusters
Each message receiver node chooses to be a member of cluster. This decision is apply by some parameters such as
distance it to CH node.
 In fact, node chooses the nearest CH node.
If distance of two or more CH node to a node is same
Then a CH node will select randomly
//Building spanning tree
      Stack= number nodes of a cluster
      M=1, N=1, CH= root
While (cluster number >0)
 List-level 1= neighbors CH
 Queue (M) = list-level 1
 M= M +1, S= S-1
 While (S>1)
List-level (N+1) = neighbors (list level (N)
Queue (M) = list-level (N +1)
M= M +1, S= S-1
End while
End while
End while
```

Figure 4.8 Overview of pseudo code for setup phase of EESTDC.

In the second phase, data routing and transferring is done. In this case, the protocol uses paths which are gained by spanning tree structure. In the EESTDC, the new algorithm is a link state and dynamic routing approach. In fact, the routes are created in organization of spanning tree step so the structure is used in data transferring phase. Pseudo code of the phase is shown in the Figure 4.9. It is briefly described of flow chart of EESTDC in Figure 4.10 too.

```
DATA TRANFERRING  PHASE
// Start
CH node broadcast its set of interest messages
Sensed data by sensors send to self-neighbors via one of the created
routes that is gained by spanning tree structure.
//Routing
Spanning tree is to finding shortest route from CH node to all nodes of it cluster
While (CH node receive all INFO)
Nodes aggregate self-data and send INFO to self-neighbors nodes
End while
CH node send gathered data to other cluster members or BS/sink
.
```

Figure 4.9 Overview of pseudo code for data transferring phase of EESTDC.

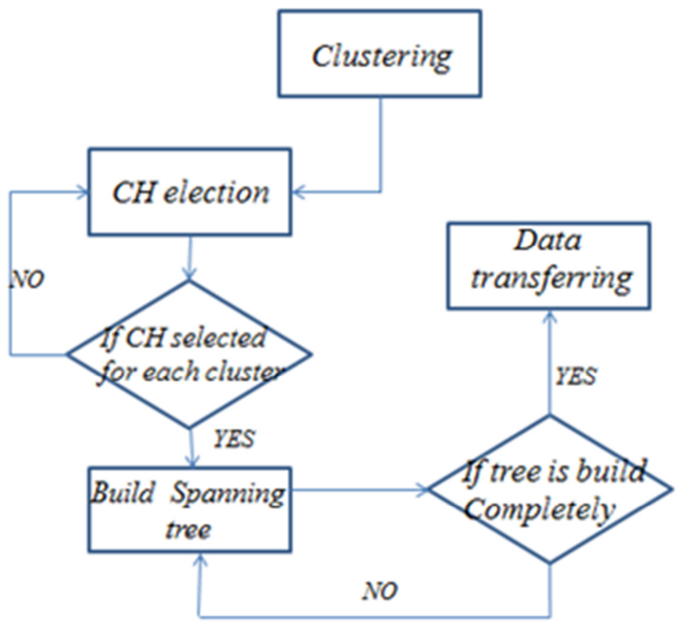


Figure 4.10 A general view from EESTDC operations by simple flow chart.

We will explain EESTDC with simulation results in next section. We will show that it has better performance as compare to Improve-LEACH, HEED and EESR protocols too.

4.3 Simulation

We made a WSN simulation tool in C# program that use it for all simulations in our thesis. The tool is applied on four protocols in the same conditions and the input parameters in this chapter. The tool allows us have results documentation or simulation charts in network lifetime, packet delivery and packet delay parameters at the moment or end. In this case study, we simulate all protocols with same outputs parameters too such as network lifetime, packet delivery, packet delay and network balance. Also, we use original simulation charts of Improved-LEACH, HEED and EESR to demonstrate the correctness of our protocol. We apply their input parameters for EESTDC to comparison and then will use our tools for further simulations.

The input parameters are initial energy of each sensor nodes, radio and sensor energy consumption, transmit, receive and sense process cost, send/receive buffer size. All four protocols are performed as parallel and have same values for the parameters. Therefore simulation results will have a high degree of confidence.

The tool uses same node count and location of sink to increase the accuracy of simulations. Table 4.2 shows an example of input parameters values that they are constant and same for three protocols in a simulation. It should be noted that following values have been used to several examples of protocols and we can use arbitrary values for simulations. In this case, we suppose have information of sensor locations therefore we don't consider to location of nodes and time synchronization in three protocols. Also, the current protocols didn't consider to these issues. In this case, number of clusters in hierarchical based approaches is constant and its value is 10.

We consider that many of input parameters are same in three algorithms. The first simulation applies following table values to illustrate comparison results of network lifetime, packet delivery and packet delay. Deployment of sensor nodes is random and the nodes are distributed in a two-dimensional space. The BS/sink can be in any arbitrary position inter or out of network and doesn't have limitation battery or computing power. Locations of nodes and sink are fixed after the establishment.

Table 4.2 Values of input parameters for EESTDC protocol.

Initial (max) energy	1 J/bit	Receive buffer size	1000 bytes
Radio/ Sensor energy consumption	40 n J/bit	Send buffer size	1000 bytes
Transmit process cost	40 n J/bit	Deployment area size	(1000 x 1000) m
Receive/sense process cost	10 n J/bit	Send/receive buffer counts	20
Data packet size	500 bytes	Sink position	(310 x 310) m
Sensing Radius	6 m	Transmission Radius	10 m

We use spanning tree structure to avoid distant communications between nodes and high consumption of energy. This has been considered in EESR too but it doesn't have suitable in clustering system. The sensor nodes sense phenomena and then send to CH nodes from a path that this route is gained by spanning tree structure. Meanwhile, EESTDC applies a new method to CH nodes selection with the aim of reducing overhead over CH nodes, the packet lost numbers and prolonging network lifetime.

We illustrate performance of EESTDC in four models. In fact, they are our output parameters of simulation tool. They are network lifetime, packet delivery, packet delays and network balance rate. Figure 4.11 shows a case of network lifetime with using of 100, 200, 300 and 400 nodes. Network is active until death the last sensor. In some of the literature, network is alive as long as there is at least one connection between sensor and sink. Assumption of our simulation tool is first case. It should be noted that the input parameters in all cases of the chapter simulation are according with the Table 4.2 values. Also, we present an example of energy consumption in our network for 100 nodes case. It is shown in the Figure 4.12. As know that energy unit is joules. We illustrate packet delivery and packet loss performance in EESTDC with same values in Figure 4.13 and 4.14. The number of successfully transmitted packets from a node to sink and also their reception by sink is concept of packet delivery. Also, packet loss is gained from subtraction of all sensed data packets and number of delivered packets. Despite the fact that our method doesn't focus on packet delivery and reliability factor accurately and completely but it is relatively good with compared to the same protocols due to it has long lifetime and is energy efficient approach. Figure 4.13 illustrates packet delivery rate of EESTDC with using of different number of nodes.

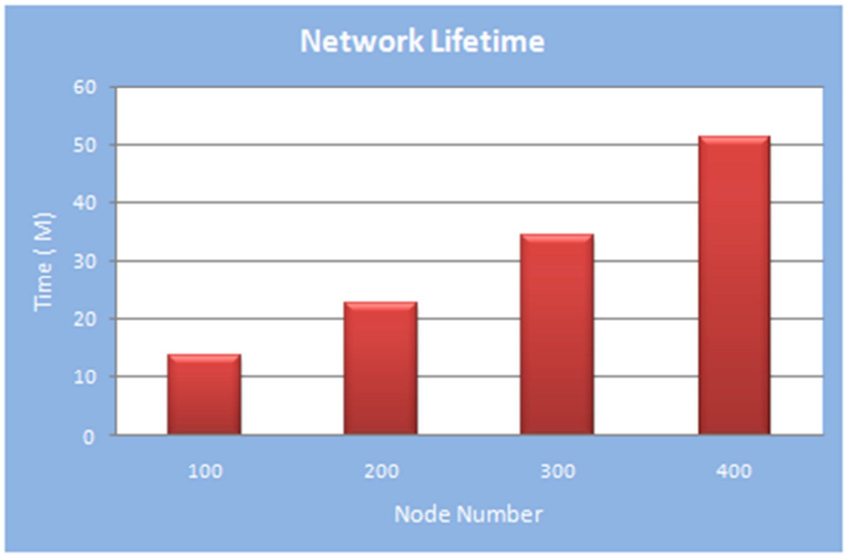


Figure 4.11 A performance from EESTDC in lifetime case with different node numbers.

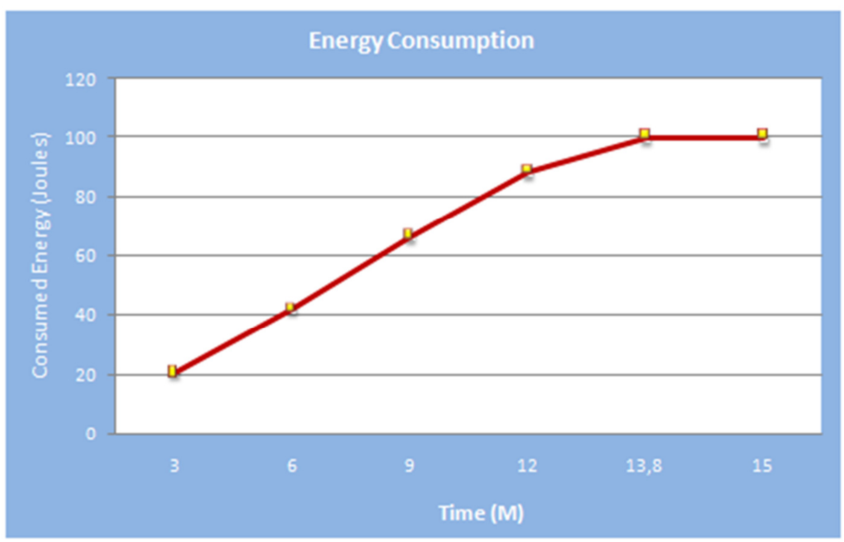


Figure 4.12 Energy consumption of EESTDC in different times for 100 nodes.

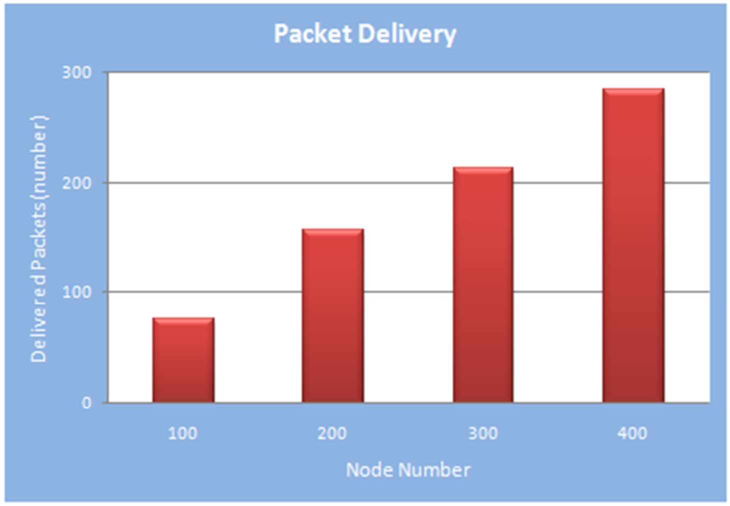


Figure 4.13 A performance from EESTDC in packet delivery case with different nodes number.

The third case of output parameters is packet delay. Packet delay is a period time that a transmitted packet will reach to sink in certain time. In fact, a transmitted packet will consume sometimes for reach to sink. This time is a delay for every data packet. Figure 4.14 illustrates the average packets delays so we have different number of nodes.

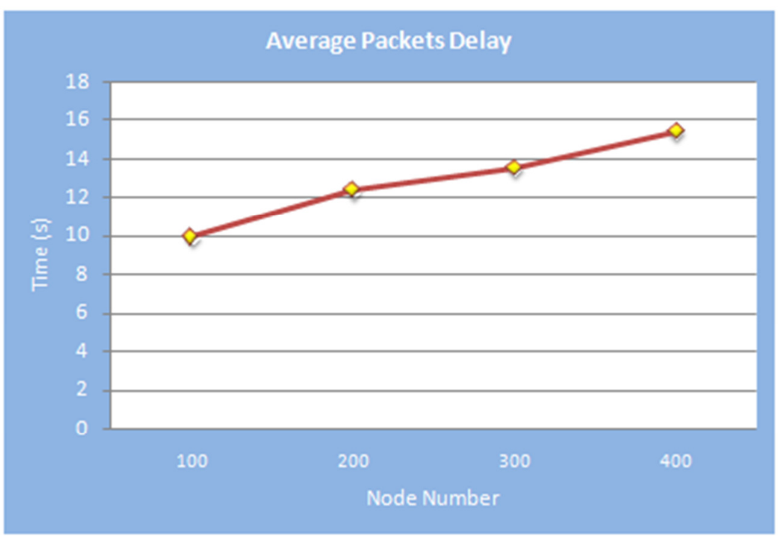


Figure 4.14 A performance from EESTDC in average packet delay case with different nodes number.

Network balance is another measure to simulation of our protocol. As mentioned in previous chapters, some of output parameters aren't in the same direction. An example, if main goal of network design is reduction overhead then network lifetime will reduce automatically. With this description, if a protocol can make a balance between output parameters then it would have a good performance in general views. The measure can gain from different methods such as percent of packets delay to network lifetime, percent of packet delivery to network lifetime and etc. Figure 4.15 illustrates network balance rate with relation between packet delivery and network lifetime. Balance factor of our protocol is tangible after 300 nodes in this sample case so it can be a suitable balance with employing more than 300 nodes.

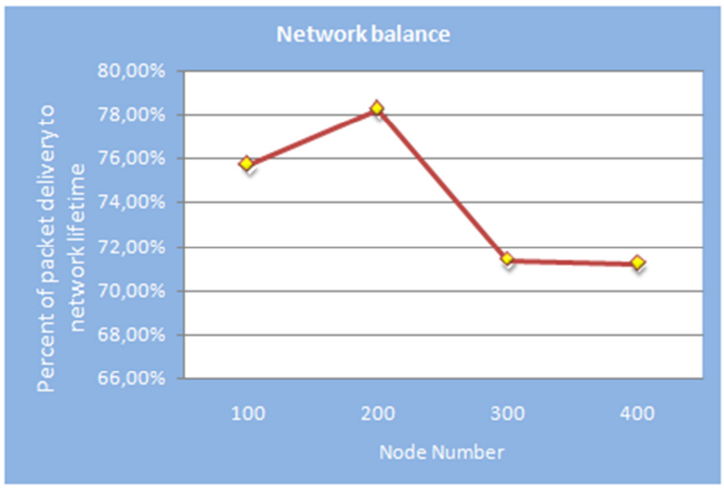


Figure 4.15 An example view from balance rate EESTDC.

As it appears, great advantage of our protocol is energy saving in whole network. Packet delay and packet delivery rates are good too but they aren't suitable in data-oriented applications or real-time systems. In the next section, we will use main results simulation of LEACH, HEED and EESR protocols. Then we will compare our protocol with them.

4.4 Comparison and Results

As mentioned, we made a WSN simulation tool in C# program and used it for all simulations in our thesis. In this section, the tool is applied for Improved-LEACH, HEED, EESR and EESTDC protocols in same conditions and input parameters. The tool allows us have results documentation or simulation charts in network lifetime, packet delivery and energy consumption parameters at the moment or end. In this case study, we simulate all protocols with same outputs parameters such as network lifetime, packet delivery, energy consumption and network balance and use the original simulation values of Improved-LEACH, HEED and EESR to demonstrate the correctness of our protocol results. We apply their input parameters in EESTDC to comparison and then we will use our tool to further simulations. The input parameters are initial energy of each sensor nodes, radio and sensor energy consumption, transmit, receive and sense process cost, send/receive buffer size. All protocols are performed as parallel and with same values for the parameters. Therefore simulation results will have a high degree of confidence.

We use the simulation of main results of each protocol that they will be compared with our protocol. For this work, we must use similar input parameters. The parameters use in our tool and the results illustrate that our protocol have a good performance with regard to Improved-LEACH, HEED and EESR. The values of the input parameters of the protocols aren't same together. Hence we simulate our protocol separately with each protocol and use same value of their input parameters.

In the first, we simulate EESTDC with following input parameters (Table 4.3) and compare with EESR. Number of clusters are 10. Also, we simulate our protocol and three above protocol parallel by our tool and evaluate their results on graphic charts in the next section.

Table 4.3 Input parameters values for EESR and EESTDC simulations (Hussain & Islam, 2007).

Initial (max) energy	10 J/bit	receive buffer size	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	Send buffer size	1500 bytes
Transmit process cost	50 n J/bit	Deployment area size	(100 x 100) m
Receive/Sense process cost	50 n J/bit	Nodes count	50, 70, 90, 100
Data packet size	250 bytes	Sink position	(50 x 50) m

The results illustrate that our protocol has good lifetime and is energy efficient than to EESR. Also, it is better than EESR in packet delivery but EESTDC is weaker than EESR in average packet delivery because it doesn't have alternative paths to data transferring and uses the spanning tree only. It should be noted that the issue isn't a problem and many of researchers don't focus on it. EESTDC is much better than the most protocols that don't have relaying on to packet deliveries and even it can compete with their family protocols. The EESR is tree based approach that is based on reliability and maximizing lifetime.

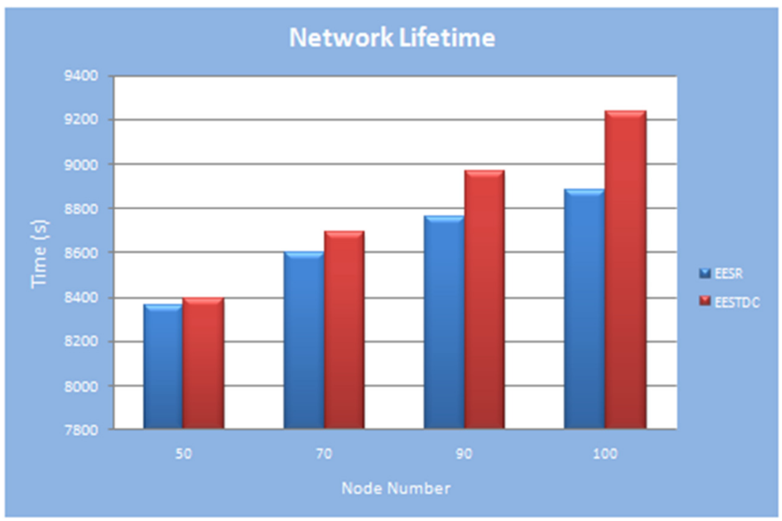


Figure 4.16 Comparison of EESTDC and EESR in network lifetime field with considering to EESR input parameters values absolutely.

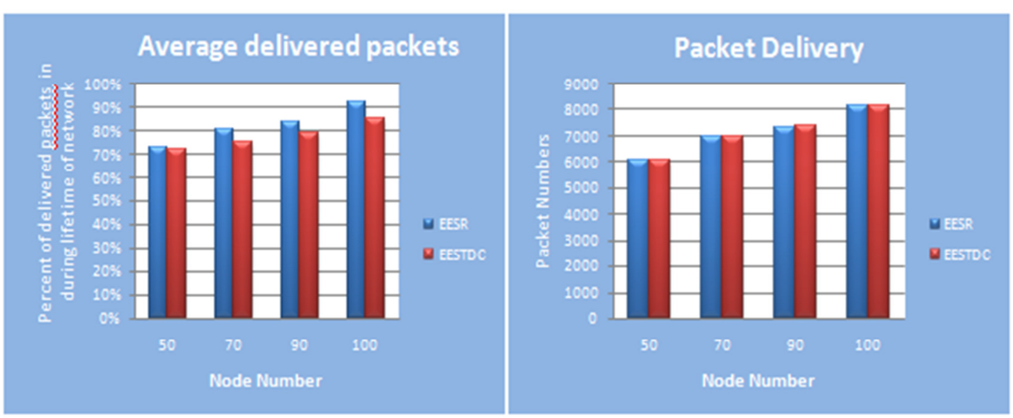


Figure 4.17 Comparison of EESTDC and EESR in percent of successful in transmission data to sink with considering to EESR input parameters values absolutely.

We apply the same process for the next protocol. In this section, we simulate our protocol, LEACH and HEED based on the Table 4.4. Cluster numbers in this case are 8. Simulation result is shown in Figure 4.18. As appears, EESTDC has better lifetime than HEED and LEACH. We will simulate Improved-LEACH protocol by our tool. In fact, we don't use ready result of Improved-LEACH for comparison because this approach doesn't have any constant and standard simulation in literature. Therefore, we implement and simulate this protocol with using the pseudo code and algorithm that is written by the paper authors (Xiangning &Yulin, 2007).

Table 4.4 Input parameters values for LEACH, HEED and one of the EESTDC simulations (Younis & Sonia, 2004).

Initial (max) energy	2 J/bit	receive buffer size	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	Send buffer size	1500 bytes
Transmit process cost	50 n J/bit	Deployment area size	(100 x 100) m
Receive/sense process cost	50 n J/bit	Nodes count	300, 380, 460, 540, 620, 700
Data packet size	150 bytes	Sink position	(50 x 175) m

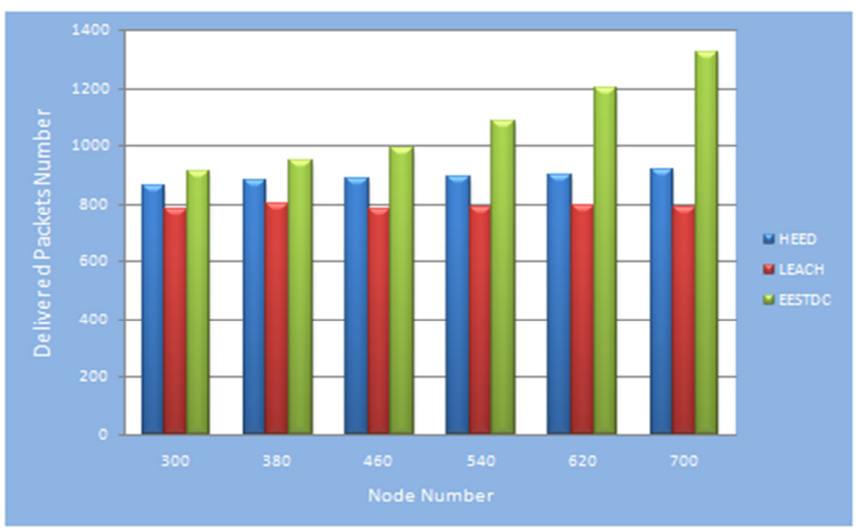


Figure 4.18 Comparison of EESTDC with EESR and LEACH in percent of successful in transmission data to sink with considering to EESR input parameters values absolutely.

In this section, we simulate all protocols by our tool in different cases so we will apply different input parameters and analyze performance of each protocol. We assume the input parameters values have listed in Table 4.5. We ran each of protocols in seven cases with different node numbers. As it seems, EESTDC has a good performance in network lifetime and can increase this factor by methods such as sleep/wake up, data aggregation, applying new approach in CH node election and spanning tree methods. Figure 4.19 illustrates results all four protocols in terms of network lifetime. EESTDC has a good performance than other protocols. The EESTDC improvement is about 6 percent higher than Improved-LEACH, 21.5 percent higher than EESR and 26.5 percent higher than HEED.

Table 4.5 Values of input parameters for EESTDC, Improved-LEACH, EESR and HEED protocols.

Initial (max) energy	0.1 J/bit	Receive buffer size	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	Send buffer size	1500 bytes
Transmit process cost	40 n J/bit	Deployment area size	(600 x 600) m
Receive/sense process cost	10 n J/bit	Send/receive buffer counts	10
Data packet size	150 bytes	Sink position	(310 x 310) m
Sensing Radius	4.5m	Transmission Radius	9m

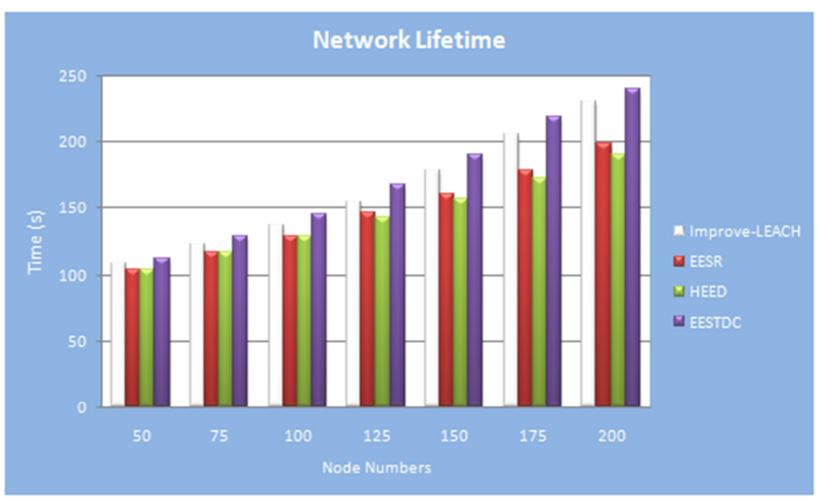


Figure 4.19 Network lifetime simulations with different node numbers in Improved-LEACH, HEED, EESR and EESTDC protocols.

The Figure 4.20 is another presentation of the protocols. As it appears, network lifetime in all protocols have shortest lifetime in a small node number case but it rises with the increasing number of sensors. In the Figure 4.20, lifetime of network is written in each case. For example, when protocols ran with 50 nodes, network lifetime of Improved-LEACH is 108 seconds, 103 seconds to EESR, 104 seconds to HEED and 112 seconds to EESTDC.

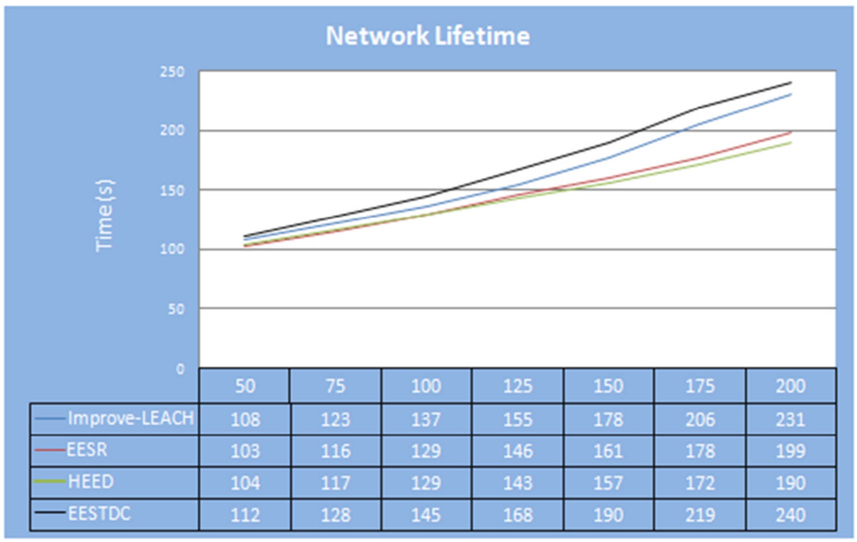


Figure 4.20 Another chart of lifetime simulation for Improved-LEACH, HEED, EESR and EESTDC.

The second case of comparison is packet delivery. As mentioned, the number of successfully transmitted packets from a node to sink and also their reception by sink is concept of packet delivery. Also, packet loss is gained from subtraction of all sensed data packets and number of delivered packets. Our protocol has low optimization in packet delivery than Improved-LEACH, HEED and EESR unlike its improvement in the network lifetime. The improvement is about 3.5 percent higher than Improved-LEACH, 6.5 percent higher than EESR and 17.5 percent higher than HEED.

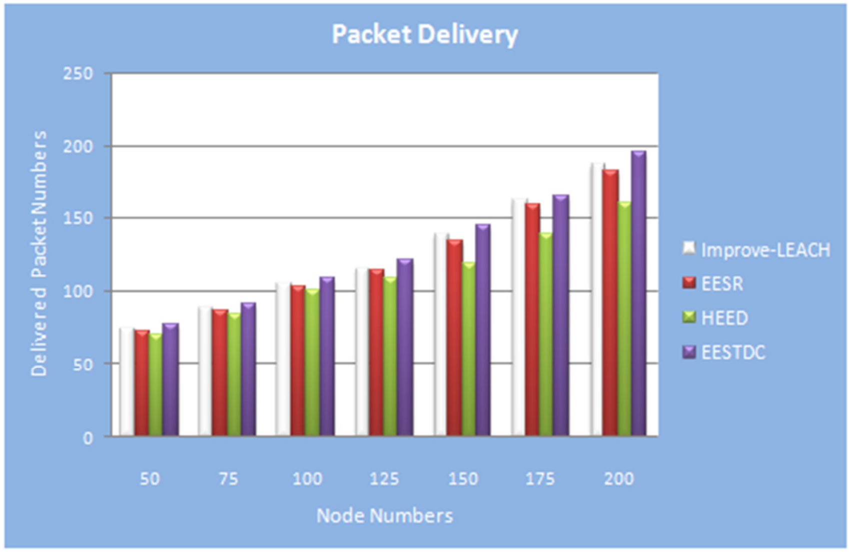


Figure 4.21 Network lifetime simulations with different node numbers in Improved-LEACH, HEED, EESR and EESTDC protocols.

Figures 4.22 and 4.23 illustrate packet delivery values in different times of network running for cases with 50 and 200 nodes. As it seems, our protocol isn't good enough in 50 nodes case but it is optimized more and more. Also, EESR performs a good performance with increasing node numbers but its lifetime is low.

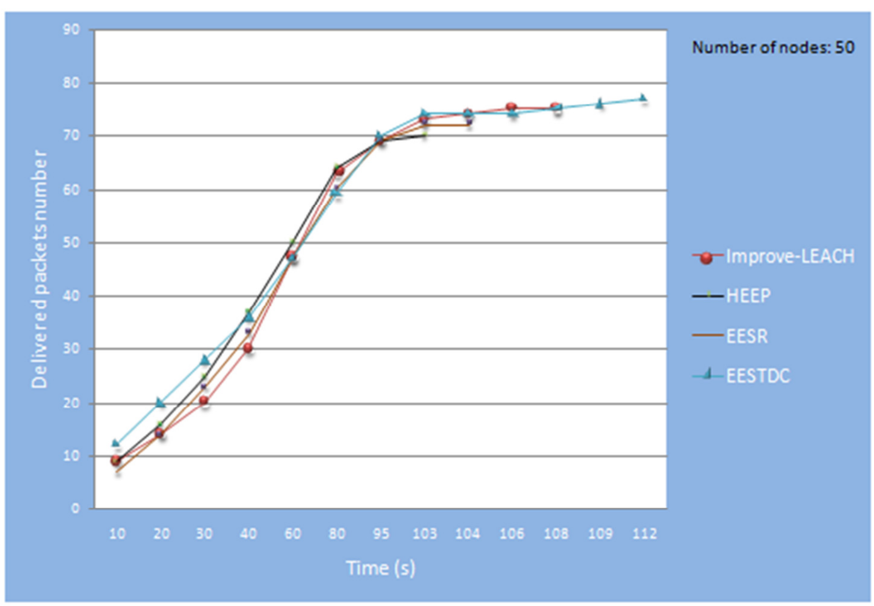


Figure 4.22 Packets delivery in different times of network rounds with 50 nodes for Improved-LEACH, HEED, EESR and EESTDC.

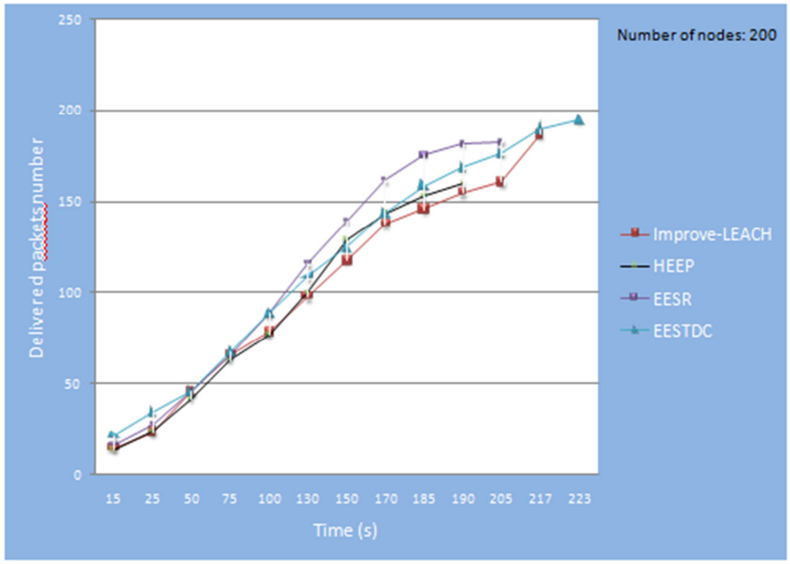


Figure 4.23 Packets delivery in different times of network rounds with 200 nodes for Improved-LEACH, HEED, EESR and EESTDC.

The third case of comparison is packet delay. As mentioned, packet delay is a period time that a transmitted packet will reach to BS/sink in this time. In fact, a transmitted packet will consume some times for reach to BS/sink. This time is a delay for every data packet. Figure 4.24 illustrates simulation results for all fours protocols. As it seems, EESTDC is second suitable approach after Improved-LEACH protocol. Increasing delay rate in EESTDC has balance.

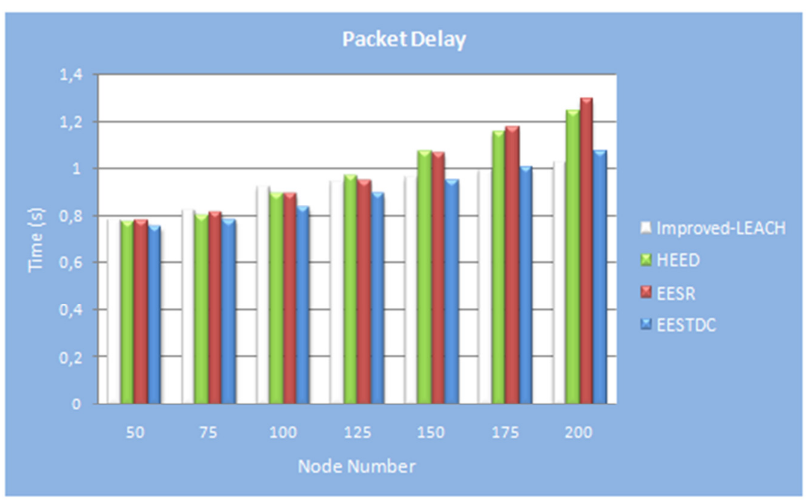


Figure 4.24 Packet delay simulations in different node numbers cases for Improved-LEACH, HEED, EESR and EESTDC.

The last simulation parameter is network balance. As mentioned, network balance is another measure to simulation of four protocols. If main goal of network design is increasing reliability then network lifetime will reduce automatically. With this description, if a protocol can make a balance between output parameters then it would have a good performance in general views. It can gain from different methods such as percent of packets delay to network lifetime, percent of packet delivery to network lifetime and etc. Figure 4.25 shows a case of network balancing comparison that it is calculated based on relation between delivered packets numbers and network lifetime. Our expectation from EESTDC isn't very good performance because reach to ideal network balance is actually impossible. EESTDC has an acceptable balance level.

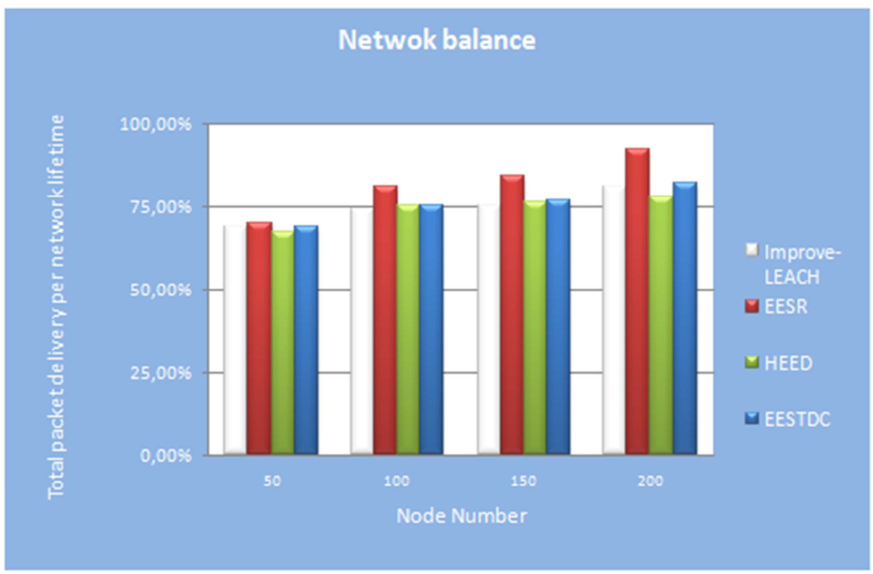


Figure 4.25 A specific view from performance of Improve-LEACH, HEED, EESR and EESTDC in network balance.

The main focus of our protocol is energy saving and prolonging lifetime. Therefore, the parameter has priority than other output factors such as packet delivery and packet delay. Nevertheless, EESTDC has suitable performance in the packet delivery parameter. But levels of network balance and packet delay of EESTDC are medium. The other of the main shortcomings of our protocol is lack of focus on relationships between the nodes of different clusters. Meanwhile it is seems that CH node election and restructuring tree in per round of running network has extra overhead over system. Also, it is seems that an intelligent approach can solve the disadvantages automatically and it tries to keep a balance in whole of the network. We propose a similar approach to WSNs in next chapter.

4.5 Summary and Conclusion

Energy is an important parameter in the WSNs and our protocols must manage it in the different applications. Routing algorithms can reduce energy consumption in sensor nodes by finding optimum routes from source nodes to sink and between all nodes too. Significant approaches for realizing energy efficiency are hierarchical based routing algorithms that the most applications can use them to reach the goal but they have some of the problems such as doesn’t have an optimal network lifetime continually or have overhead over CH nodes. This category has been described from 2002 to now. Each the methods had some of the advantages and disadvantages as they were usable in special applications only.

Also, they had unavoidable trades-off between parameters in the any applications. We proposed a new routing algorithm for optimizing energy consumption in this chapter. It was based on hierarchical based protocol. In the protocol, the network has divided to several clusters and then selects CH node to every cluster. After CH node elections, other sensor nodes decided that be a member of which cluster. Our protocol used the tree structure for deploying network so each node of cluster had a parent node. In fact, the tree structure was based on spanning tree and routing of data packets are realized by this structure. The spanning tree structure in our protocol was similar to EESR protocol. Tree structure was one of the appropriate architectures to data collection in the WSNs. Our routing mechanism was a greedy approach thus it often can transmit the packets from optimal paths.

Generally, our protocol had two main phases. First phase was consisting of steady cluster, CH election and creation of spanning tree in the each cluster. The second phase was data transferring and routing. Our protocol was based on dynamical model to CH selections and changed topology of network in any round of network. This helped reduction overhead and improvement of resources consumption in the whole of the system.

CH election was based on a specific method that used the residual energy parameter. In the method, overhead over a CH node is reduced because CH nodes are changed in per round. CH nodes were available more time and they have long-lifetime in network. One the other hand, one of the specific characteristics in our protocol was using the sleep/wake-up method. This was an energy efficiency method that was based on duty-cycle schema. In this case, idle nodes placed to sleep and wake up mode periodically. If the target is sensed by the node and its neighbor nodes are in sleep mode then the node will active its neighbors by wake up message packet. This approach was cause saving energy in network. It used TR1000 module for this case.

Routing phase in our algorithm was based on spanning tree algorithm. In fact, it used a new approach to data transferring from BS/sink to other sensor nodes or vice versa. Tree structure is applied to every cluster after determination CH nodes. This architecture helped data aggregation in each layer. Therefore data aggregation task didn't impose on the CH nodes. Also, it used the TDMA technique in data transferring phase. For example, if a cluster is consisting of 10 sensor nodes (9 nodes and one CH node) then CH will cut bandwidth between 9 nodes by the TDMA.

In fact, our protocol could increase the network lifetime and support the energy efficient in three visions. CH nodes would be available more time and they had long-lifetime in network. This had some visions. The first was reduction tasks over CH node by data aggregation technique in each node. The second of reason was repeated changes in clusters of heads task. The second vision was sleep/wake up approach and used specific module for our application types. The third vision was sleeping mode some nodes that unrelated to the target nodes hence the nodes that are not on the path of target.

In simulation section, we presented performance of our protocol and compared their results with some of the protocols as Improved-LEACH, HEED and EESR. We applied some of the input parameters to simulation of EESTDC and other protocols and compared their results together. The input parameters were initial energy of each sensor nodes, radio and sensor energy consumption, transmit, receive and sense process cost, send/receive buffer size. Our output parameters in simulation were network lifetime, packet delivery and packet delay.

Also, first dead node, half dead node, minimum and maximum packet delay in network, lost packet numbers can be included in the list of output parameters. These external parameters are shown in our simulation tool. The results presented our protocol has first good performance in network lifetime, energy saving and packet delivery. Also, it has second place in packet delay and network balance. It should be noted, our protocol appears to be more balanced with the increasing number of nodes so that it can be in better place.

EESTDC improvement in network lifetime was about 6 percent higher than Improved-LEACH, 21.5 percent higher than EESR and 26.5 percent higher than HEED. The improvement of packet delivery was about 3.5 percent higher than Improved-LEACH, 6.5 percent higher than EESR and 17.5 percent higher than HEED. Improvement of packet delay parameter was about 17 percent higher than EESR and 13.5 percent higher than HEED but Improved-LEACH had a good performance than our protocol about 4.5 percent.

Our protocol could realize energy saving and prolonging lifetime factors. Because energy parameter had priority than other output factors such as packet delivery, lost and packet delay. Nevertheless, EESTDC has suitable performance in the packet delivery parameter. But levels of network balance and packet delay of EESTDC are medium. The other of the main shortcomings of our protocol is lack of focus on relationships between the nodes of different clusters. Meanwhile it is seems that CH node election and restructuring tree in per round of running network has extra overhead over system. Also, it is seems that an intelligent approach can solve the disadvantages automatically and it tries to keep a balance in whole of the network. We propose a similar approach to WSNs in next chapter.

CHAPTER FIVE
FAULT TOLERANCE AND INTELLIGENT ENERGY EFFICIENT ROUTING PROTOCOL BASED ON CLUSTERING STRUCTURE

5.1 Introduction and Motivation

As was discussed in the previous chapters repeatedly, energy is a significant factor in the WSNs. Therefore the most researchers concern with routing protocols and energy efficiency factor. In initially, more attention of the current protocols were on QoS, bandwidth and packet delivery or reliability factors and their attention to the energy issue was less. The researchers focused on energy factor gradually when they understood that the energy is an important parameter in the WSNs. The sensor nodes are small size devices and have very low battery and their charging in the most applications is impossible. Therefore, the engineers found that energy saving is very important issue in the most applications. Despite energy saving has trade-off with some of the design factors as reliability or system overhead, they must create a balance between the factors. The hierarchical based routing protocols have a good performance in the energy efficiency issue among the routing methods. We know that the cluster based protocols may be appropriate for some of the applications. In fact, the network protocols are depended to special applications. If the algorithms have integrity and ability then techniques are generalizable to more applications.

Energy efficiency schemas are methods for energy saving and prolonging network lifetime. These approaches are different in the WSNs as duty cycle or data driven methods. They have been described in the third chapter. We used data aggregation method of data-driven category and sleep/wake-up method of duty-cycle category in the EESTDC protocol in the previous chapter. The protocol of this chapter uses data aggregation and learning based methods that they are subset of the data-driven category.

As it was mentioned, the hierarchical based protocols are suitable to energy saving issue. In these protocols, networks are divided to some clusters and have a CH node for each cluster. The CH nodes are intermediaries between the sensors in its cluster and other clusters or BS/sink. Clustering models are different in the researches. For example, in some of the protocols are selected CH nodes to each cluster and then nodes decides be a member of cluster. This decision can be based on different parameters such as residual energy, distance to other nodes, distance to BS/sink and etc. In other some, in the beginning, each node knows that to which cluster it belongs and then is selected a CH node to each cluster. The new protocol is based on the second category so the nodes are placed in a cluster and then select a CH node to their cluster but EESTDC protocol was based on the first category. In both protocol, the main aim is selection of optimal CH node. Selection of CH nodes imposes control overhead in the network. This case is not considered in many hierarchical based protocols. For example, in EESTDC, CH nodes in each cluster are changed in per round. Therefore we propose other new routing protocol for our network. Meanwhile, EESTDC has to re-organize tree structure in per round and this cause to increase system overhead. As mentioned absolute energy saving has trade-off with some parameters as reliability and system overhead. The new protocol creates a balance between them and therefore, we don't consider energy efficiency absolutely. This does not mean that we haven't attention to energy issue and our main goal is energy efficiency still.

On the other hand, the new protocol has fault tolerant ability so failure of a path is not caused loss data packet. Therefore, this approach is reliable and fault tolerance. Fault management doesn't consider in many protocols and EESTDC. In these protocols, when a failure occurs in the network, the nodes send special data packets to fixing the problem but it would cause significant overhead in system that led to increased latency and packet loss of real data packets in the network. Also, preference of the other some is retransmission. The proposed protocol in this chapter solves these problems.

Routing phase in new protocol is novel approach like EESTDC. The EESTDC was based on spanning tree and built data transfer routes based on it. The network was run in some of the period times that are called rounds. In per round, CH nodes are changed and hence tree structures are reorganized. The modifications are cause overhead on the whole network. We propose a routing algorithm based on intelligent approach in this chapter so that learning and routing phases are realized in same time. This strategy avoids to waste energy in learning phase and reduces overhead of system. The phase will be described in next sections like other phases of the protocol.

We will describe operation of proposed protocol and then explain it by help pseudo code and flow chart methods. Thereinafter simulation of the protocol is done and is shown it results in the graph charts. In the end, we will compare it with some of the current protocols such as LEACH, HEED-NPF and EECS.

5.2 FTIEE Algorithm Description

Clustering is a process in the WSNs that the network is divided to several clusters. Each cluster has a CH node that this node send collected data from its group`s nodes to BS/sink. As mentioned, selection CH node is an important issue in the hierarchical based protocols and it increase overhead of system. If CH node is crash then the network will generate considerable overhead in the network.

Our goal is proposing an energy efficiency protocol that reduces system overhead and increases reliability as possible. In this protocol, all nodes within a cluster can be CH node and clusters don't have to be a CH node and this election is done by learning machine. In fact, we want increase network lifetime by reduction energy consumption which the energy is wasted in repeated elections of CH nodes. All process of the protocol will be described in the next section.

The learning machine techniques are categorized into several methods such as reinforcement learning approach (Sutton & Barto, 2005) and genetic algorithms (Russell & Norvig, 2003). Reinforcement learning is studying on computer algorithms that the routes are optimized by their own experiences and automatically (Sutton & Barto, 2005). The basic issue in the reinforcement learning is learning an agent from self-environment method. In the most methods, learning actions are done in periodic times and selection an action is based on a special policy at that moment. The agent receives a reward value for every selection action. Goal of learning algorithms is maximizing the values to faster learning. FTIEE uses the reinforcement learning approach to data routing. Some of the terms are in reinforcement learning techniques as action, agent, state, reward, episode and policy. Agent is a learner that optimizes its behavior over time learning process. Action is series of activities that an agent can do them. Reward is a value that agent receives from the environment for every action and it can be positive or negative. State shows the agent mode. Episode is set of states that an agent passes to reach the goal. Policy is concerned with choice of an action by the Agent. Policies are defined in the different models as greedy and ε-greedy policies (Forster, 2007). The greedy policies choose the best action at the moment. They aren't good policy because they may be fall into the traps. ε-greedy policies are similar to greedy approaches but they choose best action with an epsilon small possibility. This case cause to the algorithm doesn't fall into traps or doesn't reach to local optimal answers. A WSN is based on reinforcement learning with multiple agents. In the networks, agent is a sensor node, action is next hop of each node and agent state is routing cost of a node to BS/sink via their neighbors. Indeed, it indicates multi-hopping communication system that it is more common in hierarchical based protocols. A success and energy efficient data transferring in the algorithm gives a positive reward to a node and otherwise it gives a negative reward. These rewards help to find correct (energy efficient or reliable) routes to any node.

FTIEE is based on the hierarchical-based protocol. Numbers of clusters are constant as like EESTDC protocol but unlike it, the shapes of clusters are square. The forms of clusters in EESTDC were arbitrary and could be in any form. Size of clusters is variable in FTIEE. It is same with EESTDC but the models are different. In the first approach, we don't have any rule to it and cluster sizes can be variable and different from each other but second approach (FTIEE) is based on a rule. Clusters that are close to BS/sink are smaller than to clusters that are located farther toward the BS/sink. In fact, the size of the clusters increases with increasing distance to the BS/sink. This is one of the methods that the clusters formed in initial and then is selected CH node for them.

The nodes work together for data transmission to the BS/sink thus the nodes that closer to the BS/sink will consume more energy than to other nodes. Therefore it is possible that the clusters close to the BS/sink convert to non-connect status. Hence the sensed data doesn't reach to the BS/sink. For solve this problem, the clusters near the BS/sink have smaller sizes. Therefore some energy for data transmission will be saved. Figure 5.1 represents an example state of clustering and their sizes.

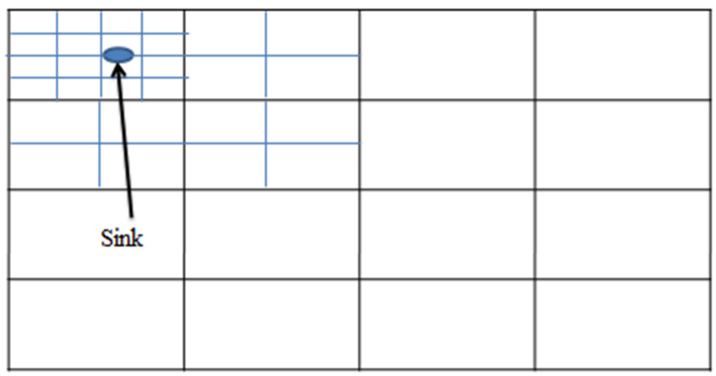


Figure 5.1 Clusters size in FTIEE protocol.

We use some of the parameters as coordinates of the BS/sink, the maximum and minimum size of the clusters and growth rate for having clusters in the different sizes. The sensors must use of its cluster-ID for coordination intra clusters. For this purpose, the network is divided into clusters with a maximum size and then is assigned a unique identify number to each of the clusters. The ID-numbers will be used in routing and CH node selection. For example, if deployment area network is 2000*2000 and maximum cluster size is 500*500 then network will be divided to 16 clusters and their ID will be from 1 to 16 according with the Figure 5.2.

ID=1	ID=2	ID=3	ID=4
ID=5	ID=6	ID=7	ID=8
ID=9	ID=10	ID=11	ID=12
ID=13	ID=14	ID=15	ID=16

Figure 5.2 ID number assignation to each cluster.

In the first, we divide the network into several clusters with maximum sizes and then calculate size of the cluster that BS is placed within it. In this case, it will be divided into minimum size as possible. After this work, adjacent clusters sizes are calculated from one of the following formulas.

Grow-rate= log 2 (cluster-numbers)

Main cluster that BS is within it and Min-size = Max-size * (1/Grow-rate)

Grow-rate=1

Adjacent cluster size= Min size * (Grow-rate+1)

Other cluster size= Max-size If Adjacent cluster size >= Max size (5.1)

Grow-rate = log 2 (cluster-numbers)

Main cluster that BS is within it and Min-size = Max-size * (1/Grow-rate)

Adjacent cluster size= Min size * [log (Grow-rate)]

Other cluster size= Max-size If grow-rate value is 1 for next step (5.2)

If growth rate is much small then the size of the clusters will grow slowly. Value of grow rate parameter will be updated with each moving away from the BS/sink. Figure 5.1 indicates one of the dividing of network into different clusters with different size. In Figure 5.1, maximum size is 500 and minimum size is 125 and growth rate is 2. It should be noted that if value of growth rate is one then the clusters size will be same.

Stability of clusters is another important issue in the hierarchical based protocols. In some of the current approaches, number of clusters is less over the passage of time but number of clusters in this approach is always stable and fixes as like the first our approach. One other point is that CH nodes have multi-hop communications to the BS/sink as like EESTDC. It should be noted that some of the protocols don't focus to this case or use directly link between CH nodes and the BS/sink. The next issue in FTIEE protocol is connectivity. It is based on full connectivity and graph theory but EESTDC was based on spanning tree.

In our protocol, sensor nodes don't need to identify the CH node. A sensor node sends its data to the BS/sink with using its cluster ID and basic information about its neighbors that have one hop distance with it. Our protocol is a distributed and local approach that finds the optimal CH nodes to each cluster by learning system. In this case, each node can be CH node or selects a best path to data transmission. Therefore, the algorithm has good flexibility rate so the sensor nodes don't involve to CH election and therefore, energy consumption and system overhead is reduced. The main criterion in CH nodes selection is depending to current state of the node and their neighbors. FFIEE uses a reinforcement learning approach that is called Q-learning technique. This algorithm is able to learn the optimal CH node and manage some of the problems as node failure. Optimal CH node is a node that has shortest cost to the BS/sink. Each of the sensor nodes is an independent learning agent and chooses its actions for data transferring to a neighbor or selects own as CH node. As mentioned, an action is the next hop of the node. If the next hop is own node then it will buffer receiving packets for determined period of time and send them to the BS/sink after this time. Rewarding system in our protocol is indicated by Q-value variable. It is calculated by two parameters. The first is based on a value that is depending to distance between a node and the BS/sink. It is suitable to reduction overhead. The second is based on residual energy of a node. It is appropriate for delay control in the whole network. Indeed, these parameters are cost functions of FFIEE protocol. In summary, main Q-value is relation of Q-value of a node and Q-value of its actions. This is shown in the Figure 5.3 to better understanding of the issue. This value is changed by actions selection of agents and it is calculated by bellow formula.

$$Q_{new}(a_{ni}) = Q_{old}(a_{ni}) + \alpha (R(a_{ni}) - Q_{old}(a_{ni})) \quad (5.3)$$

R (a_{ni}) is reward value and α is learning rate. If value of α is one then learning speed will increase and the formula will change to the following mode. In fact, reward value determines action of a node to find optimal route to send data to BS/sink. The policy of actions selection is based on ε-greedy approach.

$$Q_{new}(a_{ni}) = R(a_{ni}) \quad (5.4)$$

Q-value $_i$ = A_i x B_i

A_i= (Q-value of node $_i$):

α_i= Cost of sink x (1-1/ (n-1)) + 1/distance $_{sink,\ i}$

α_k= α_i * (1-(1/(n-1))) + 1/distance $_{k,\ i}$ // k ε {neighbors of node i}

B_i= (Q-value of action $_i$):

If B>=50 Q(a $_i$)= 1/3 B_i + 2/3 α_i //B is Battery of a node

else Q(a $_i$)= 2/3 B_i + 1/3 α_i

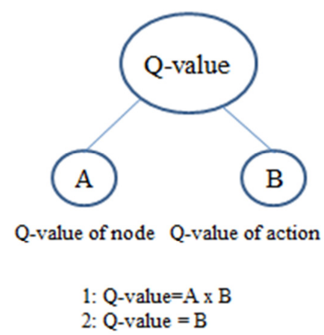


Figure 5.3 A general view of Q-values calculation.

The pseudo codes of A and B parts of Q-value calculation is represented in the Figure 5.4 and 5.5. The algorithm computes the value of each node (A part) with using distance between nodes and the BS/sink. Values nodes that are farthest relative to the BS/sink are lower than to near nodes. The algorithm computes the value of each action (B part) by considering the battery level in each node so if battery is high then the calculated A value will impact more intervening to main Q-value and will reduce packet delay in network. Otherwise, B value will impact more intervening to main Q-value and will reach to balance in energy consumption in whole network. The Q-value is gained two methods that it is shown in the Figure 5.3.

```
// Computing cost of each node
// n: number of nodes
// α: cost of each node
// d x,y : distance between node X and Y
    1. Cost of BS = n
    2. For each neighbors of BS, for example X, αx is computed
       as follow:
       αx = cost of BS * (1- (1/ (n-1))) + 1/d BS, X
       BS sends αx to node X
    3. Each neighbor such as K receives α of itself and
       then compute new α for each neighbor as follow:
       αi = αk + (1- (1/ (n-1))) + 1/d k, i
    4. Repeat step 3 even all nodes receive α
```

Figure 5.4 Pseudo code for Q-value of each node calculation.

```
// Computing Q-value of each action
// We define a possible action as with i { N , self}
// N: number of neighbors of node i
// Q ( a oi) = Q-value for an action
// B i = battery level of node i
// α i = cost of node i
   If (B i >= 50)
        Q ( a oi) = 1/3 * B i + 2/3 * α i
   Else
        Q ( a oi) = 2/3 * B i + 1/3 * α i
```

Figure 5.5 Pseudo code for Q-value of each node action calculation.

In general case, our protocol learns finding optimal CH nodes and paths at the moment of network rounds. In other words, when the optimal CH nodes are learned, paths within a cluster will learned automatically. Therefore, finding paths in our protocol doesn't have extra overhead over system. The Figure 5.6 represents learning optimal CH node and paths intra network. As previously mentioned, the topology of network is based on connected graph. In fact, the path from each node to other nodes may be present and this is done in routing phase. As we remember, the EESTDC was based on spanning tree and communication paths are determined before sending the packets between nodes. But, in the FTIEE, data transferring and routes detection are done parallel and are on-demand. This technique is one of the special properties of the FTIEE.

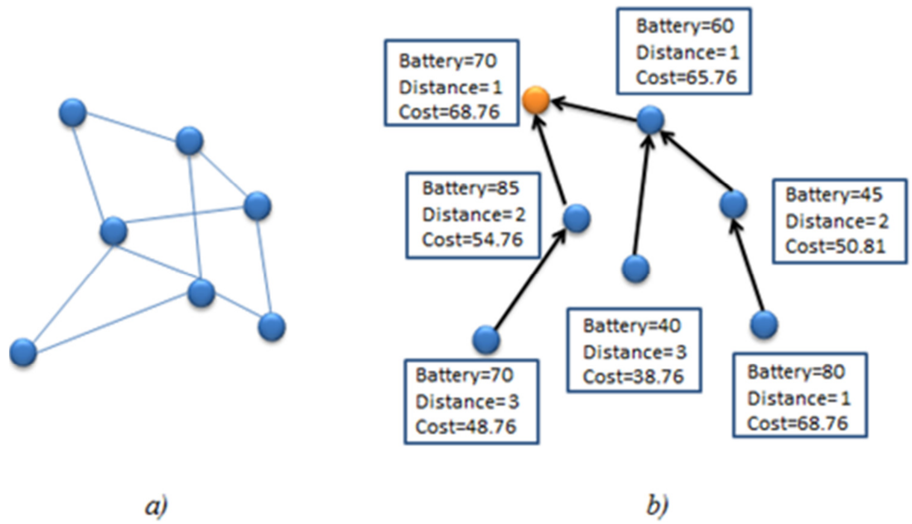


Figure 5.6 Communication form a connected cluster sample a) before running b) after running the algorithm.

In the figure, all nodes will send their data to the node that has maximum Q-value. In other words, the nodes will learn by repetition of the learning process. The CH node can change over time due to updating Q-values. We have two problematic issues in this case of our algorithm. The first is possibility of non-connected graph in the network or any cluster. Another is time learning. In the first case, the algorithm can be automatically identifies the two CH node for each non-connected parts. This concept is illustrated in the Figure 5.7.

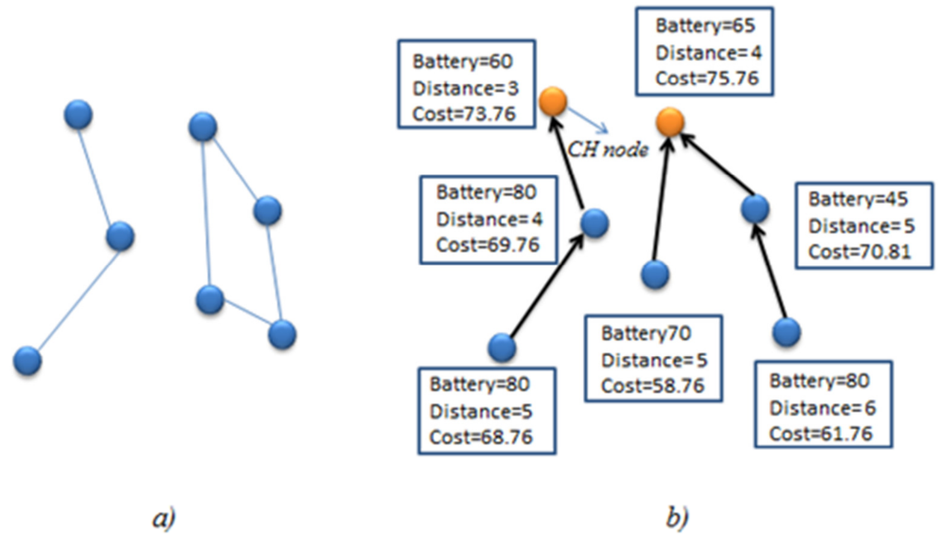


Figure 5.7 Communication form a non-connected cluster sample a) before running b) after running the algorithm.

As was explained, routing phase in our protocol is based on an intelligent approach so doesn't has to CH election in per rounds because it can select optimal CH nodes in different periodic times of network rounds by learning mechanism. It doesn't have one CH node at the each cluster and number of CH node can be more. If learning time is much then the algorithm operates well. One of the significant notes this algorithm is paralleling schema in finding optimal paths and data transferring. This is a very good ability that has a good performance to an intelligent based approach. In the general case, priority data transferring in FTIEE as follows:

Data is sent to a node that has a more Q-value. If Q-value two nodes are same then data will send to one of them randomly regardless their cluster numbers. Meanwhile, the order of maximum Q-value is the value that is chosen by ε-greedy approach. This cause doesn't fall into traps or the local optimal solutions.

The concept of effective energy is observed in the protocol too. It saves the energy with using data-driven schema only. In fact, FTIEE uses the learning based and the data aggregation methods to energy consuming management. The protocol doesn't use the sleep/wake up method to energy saving in the network. Management of shared channel is realized by the TDMA and on-demand approaches.

Reliability and fault tolerance ability is one of the strengths of the protocol. This will cause increasing packet delivery and reduction of packet loss. Also, the network is connected for a long time because it finds new routes in case of deterioration of the path or node failure. In the Figure 5.8, node B is failure and node A can't send data to node C. This problem is a serious problem. In our protocol, node A waits short time and then chooses itself as CH node. During the waiting period, it aggregates received data from other nodes and then sends them to the BS/sink with using other its neighbors of close cluster.

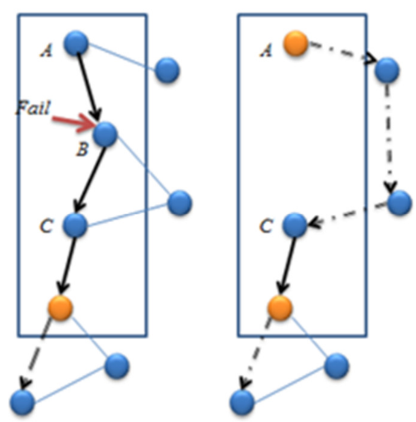


Figure 5.8 An example of fault tolerance in FTIEE protocol.

Our protocol doesn't consume energy to learning in passive or idle of network. It saves energy in the whole network. It should be pointed out that the learning part of routing protocol is done on active sections because learning phase is parallel with routes detection data transferring. As mentioned, available parameters to routing in FTIEE are Q-values and batteries of each node and ID-cluster that each node is member of it. In general case, FTIEE focuses on three important parameters that are network lifetime, packet delay and delivery. It seems that FTIEE has optimal performance for some of applications. It will describe in the next sections. Also, FTIEE algorithm is represented by pseudo code and flow chart in Figure 5.9 and 5.10.

```
//Routing algorithm
1.  Each node sends a message to all its neighbors to receive their costs.
    When a node runs out of energy, α value corresponding to that node
    becomes zero.
2.  When a node such as K wants to send a packet, it chooses the next node
    as described below:
2.1. for all neighbors of the same Id with its Id:
2.1.1. if (cost of neighbor > its cost)
•   Then compute Q-value of it.
•   Sends the packet to the neighbor with the highest Q-value.
•   if some of neighbors have same Q-value, chose one of them randomly.
2.1.2. else if (any neighbors has not the same Id with its Id OR cost of
neighbors with the same Id <= its Id)
•   Go to step 2.2.
2.2. for all neighbors in adjacent clusters:
2.2.1. if (cost of neighbor > its cost)
•   Compute Q-value of it.
•   Sends the packet to the neighbor with the highest Q-value.
•   if some of neighbors have same Q-value, chose one of them randomly.
2.2.2. else chose one of neighbors randomly.
// in this case the node K is cluster head
```

Figure 5.9 Pseudo code of routing algorithm for a cluster in FTIEE.

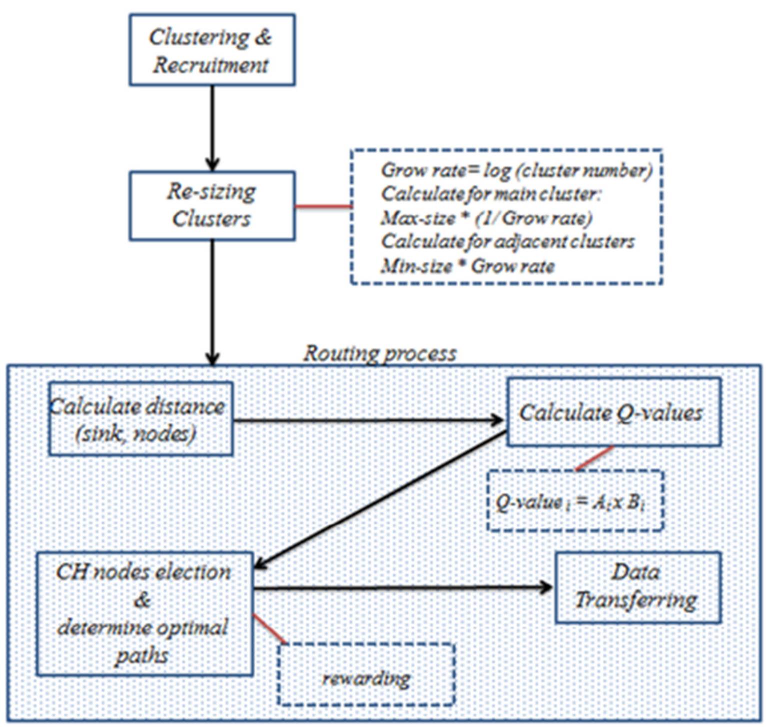


Figure 5.10 General views of FTIEE protocol.

The Figure 5.11 represents a snapshot of our protocol in during the simulation. In fact, the routing and data transferring approach in our protocol is based on intelligent routing. As mentioned, our protocol could have several CH nod in each cluster. Also, it is reliable against faults as explained in the previous section. Figure 5.11 is an example state of FTIEE operation so we suppose that protocol has 100 nodes, one phenomenon in per second and ten clusters in initial. These conditions are same for FTIEE and HEED, EESC. All snapshots are one minute of running of network. All three snapshots have been taken in the same conditions as initial energy, node numbers, interval and duration of phenomenon, simulation test and etc. They will explain in the simulation section with details.

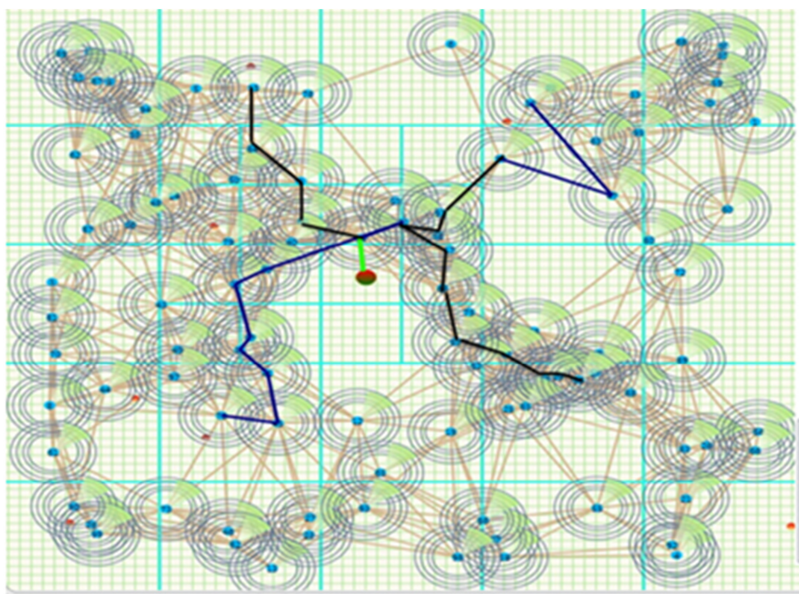


Figure 5.11 A snapshot of basic network topology in FTIEE protocol.

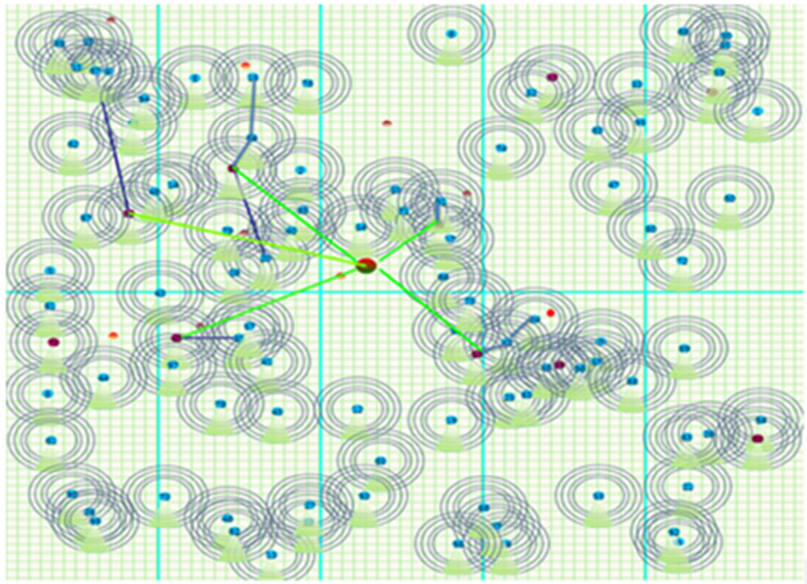


Figure 5.12 A snapshot of basic network topology in HEED-NPF protocol.

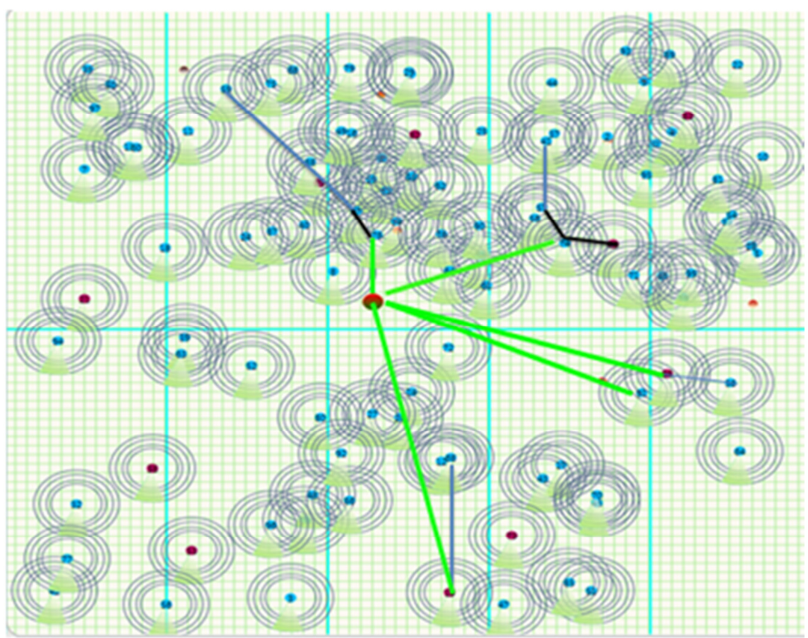


Figure 5.13 A snapshot of basic network topology in EECS protocol.

We will explain FTIEE in simulation section by its gained results from simulator tool. The other protocols as HEED-NPF, LEACH and EECS will be evaluated and will compare with our protocol results. We use the same conditions to increase the precision and validity of simulation results.

5.3 Simulation

We made a WSN simulation tool in C# program and used it for all simulations in our thesis. The tool is applied on four protocols in same conditions and input parameters in this chapter. The tool allows us have results documentation or simulation charts in network lifetime, packet delivery and packet delay parameters at the moment or end. In this case study, we simulate all protocols with same outputs parameters too such as network lifetime, packet delivery, packet delay and network balance. Also, we use original simulation charts and parameters of HEED-NPF, LEACH and EECS to demonstrate the correctness of our protocol. We apply their input parameters for FTIEE to comparison and then will use of our tools for further simulations. The input parameters are initial energy of each sensor nodes, radio and sensor energy consumption, transmit, receive and sense process cost and send/receive buffer size. All four protocols are performed as parallel and have same values for the parameters. Simulation results will have a high degree of confidence.

The tool uses same nodes count and location of sink to increase the accuracy of simulations. Table 5.1 shows an example of input parameters value that they are constant and same for all protocols in a simulation. It should be noted that bellow values have been used to several examples of protocols and we can use arbitrary values for simulations. In this case, we suppose information of sensor locations is available therefore we don't consider to location of nodes and time synchronization in four protocols. Also, the current protocols didn't consider to these issues. Number of clusters in cluster based approaches is constant and its value is 10. It should be noted that clusters are resizing in FTIEE and thus number of cluster can increase. We consider that input parameters are same in four algorithms. The first simulation applies following table values to illustrate comparison results of network lifetime, packet delivery and packet delay. Deployment of sensor nodes is random and the nodes are distributed in a two-dimensional space. The BS/sink can be in any arbitrary position inter or out of network and doesn't have limitation battery or computing power. Locations of nodes and sink are fixed after the establishment.

We can say that with the increasing number of nodes, number of received packets is increased but packet delivery rate almost is reduced because some of factors such as increasing density of nodes, hop count and node failure probability are affective. Also, with the increasing number of nodes, the network lifetime will be increased and also, packet delays in network are increased due to different reasons such as increasing hop counts.

Table 5.1 Values of input parameters for FTIEE protocol.

Initial (max) energy	1 J/bit	Receive buffer size	10000 bytes
Radio/ Sensor energy consumption	40 n J/bit	Send buffer size	10000 bytes
Transmit process cost	40 n J/bit	Deployment area size	(1000 x 1000) m
Receive/sense process cost	10 n J/bit	Send/receive buffer counts	20
Data packet size	500 bytes	Sink position	(310 x 310) m
Sensing Radius	6 m	Transmission Radius	10 m

We illustrate performance of FTIEE in four models. In fact, the four models are our output parameters of simulation tool. They are network lifetime, packet delivery, pocket lost and network balance. Figure 5.14 shows a case of network lifetime with using of 100, 200, 300 and 400 nodes. Network is active to death last sensor. In some of the literature, network is alive as long as there is at least one connection between sensor and sink. Assumption of our simulation tool is first case. It should be noted that input parameters in this case and all cases of simulation section accordance with the Table 5.1 values. As know that energy unit is joules.

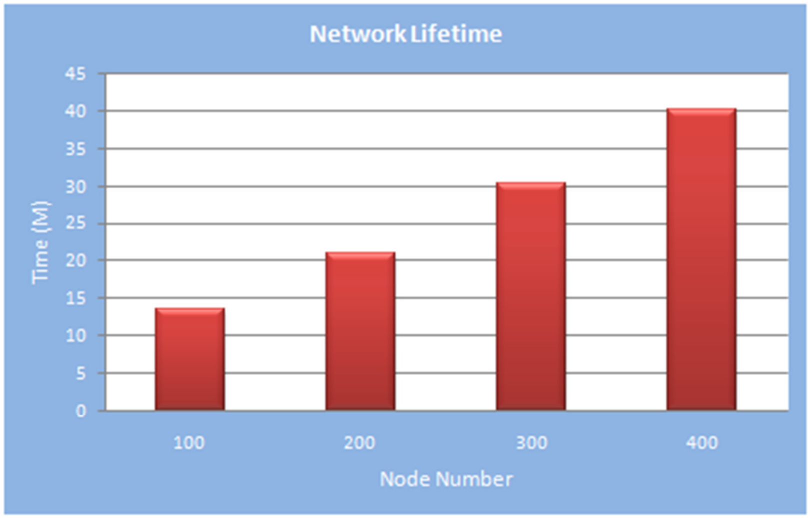


Figure 5.14 The network lifetimes in FTIEE protocol with 100, 200, 300 and 400 nodes.

We illustrate delivery and loss packets performance in the FTIEE with the same values in Figure 5.15 and 5.16. The number of successfully transmitted packets from a node to sink and also their reception via sink is concept of packet delivery. Also, packet loss is gained from subtraction of all sensed data packets and number of delivered packets. In this chapter, our protocol focuses on packet delivery, reliability and network lifetime factors and tries create a balance between the parameters. The results of simulations present that it has a better operation than EESTDC in system network balance, reliability and packet delivery.

It is relatively good with compared to the same protocols because it has good lifetime, packet delivery rate and network balance. In fact, it is an appropriate energy efficient approach. The Figure 5.15 illustrates packet delivery rate of FTIEE with using different number of nodes. The Figure 5.16 shows number of loss packet in the network when FTIEE works with 100, 200, 300 and 400 sensor nodes.

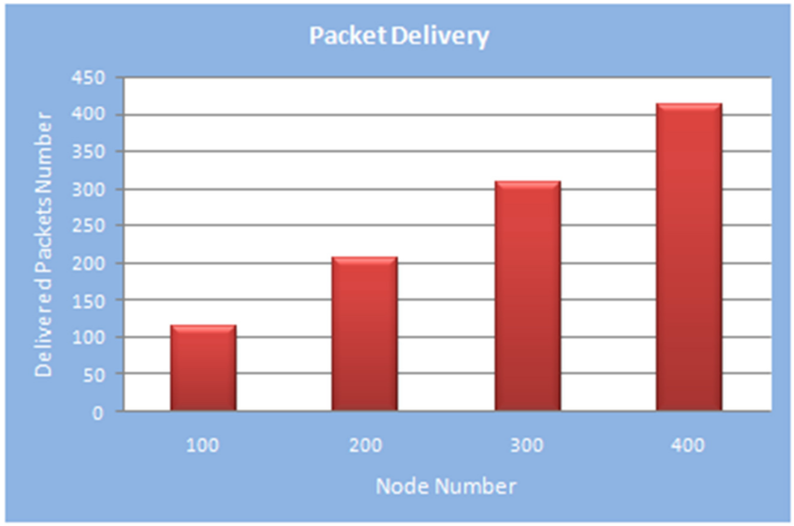


Figure 5.15 Number of delivered packets in FTIEE protocol with 100, 200, 300 and 400 nodes.

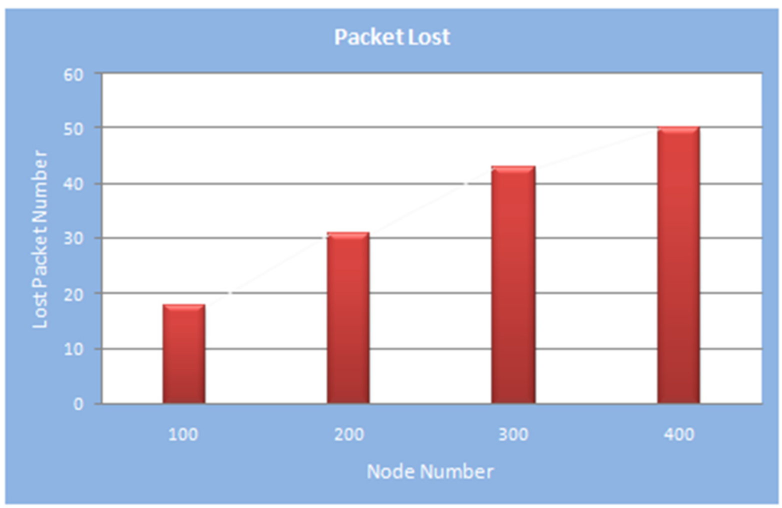


Figure 5.16 Number of lost packets in FTIEE protocol with 100, 200, 300 and 400 nodes.

The Figure 5.17 explains relation between lost and delivery packets in our protocol. Low rates of lost packets and high or appropriate rates of delivery packets are ensuring to good system reliability. This is due to fault tolerance capability of our approach. When a node on path is dead, our algorithm selects its previous node and introduces the node as CH node and also uses the other nodes that are members of adjacent cluster. Packet delivery rate rises with increasing number of sensor nodes in our simulation area. This issue has direct relation to the low rate of lost packets.

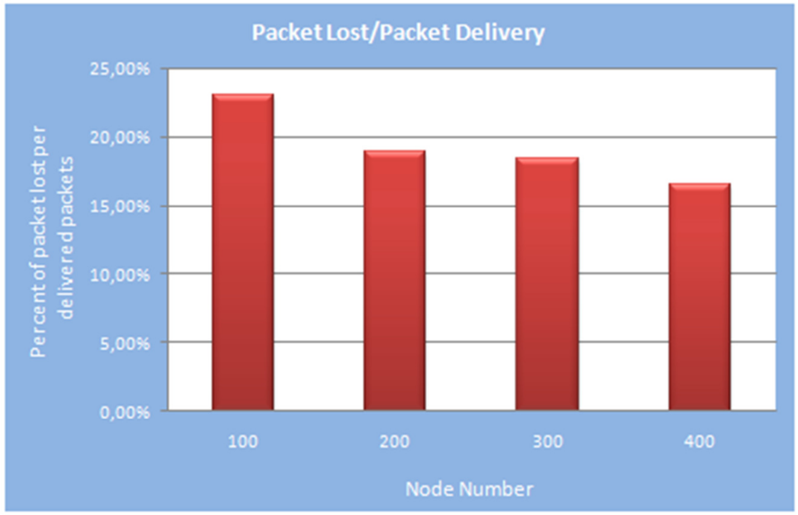


Figure 5.17 Relationship between lost and delivered packets in FTIEE protocol with 100, 200, 300 and 400 nodes.

Also, Figure 5.18 present relation between network lifetime and packet delivery in the case that network works with 100 nodes. With the passage of time, nodes begin to die or fault, therefore packet delivery rate will decrease. Our assumption is which new node can’t add to network.

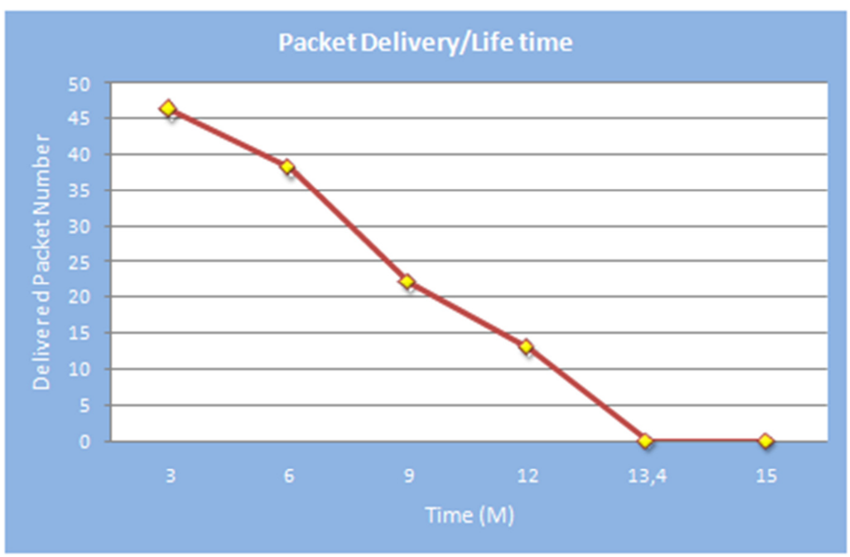


Figure 5.18 Relationship between delivered packets and network lifetime in FTIEE protocol with 100 nodes.

Network balance is another measure to simulation of our protocol. As mentioned in previous chapters, some of the output parameters aren't in the same direction. An example, if main goal of network design is increasing packet delivery then network lifetime will reduce automatically. With this description, if a protocol can make a balance between output parameters then it would have a good performance in general view. It can gain from different methods such as percent of packets delay to network lifetime, percent of packet delivery to network lifetime and etc.

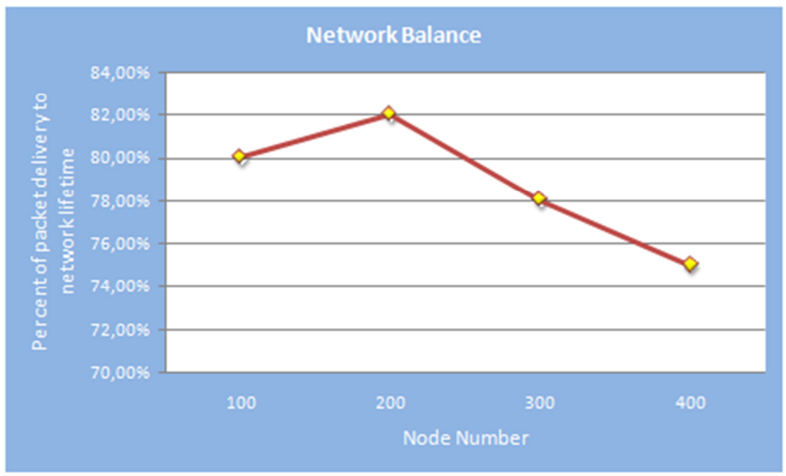


Figure 5.19 An example view from network balance rate in FTIEE protocol.

It seems great advantage of our protocol is balance in the whole network so increase the lifetime and the packet deliveries in the normal form. Packet delay in the protocol can be high because the algorithm selects alternative paths for successful transmission so the alternative routes create delay and rate of energy saving than the EESTDC is not very good. But the algorithm has good performance in packet delivery rates so it can suitable in data-oriented applications or real-time systems. In the next section, we will use main results simulation of LEACH, HEED-NPF and EECS protocols. Then we will compare our protocol with them.

5.4 Comparison and Results

As mentioned, we made a WSN simulation tool in C# program and used it for all simulations in our thesis. In this section, the tool is applied on four protocols

(LEACH, HEED-NPF, EECS and FTIEE) in same conditions and input parameters. The tool allows us have results documentation or simulation charts in network lifetime, packet delivery and energy consumption parameters at the moment or end. In this case study, we simulate all protocols with same outputs parameters too such as network lifetime, packet delivery, energy consumption and network balance and use original simulation values of LEACH, HEED-NPF and EECS to demonstrate the correctness of our protocol results. We apply their input parameters to FTIEE to comparison and then we will use our tools to further simulations. The input parameters are initial energy of each sensor nodes, radio and sensor energy consumption, transmit, receive and sense process cost, send/receive buffer size. All protocols are performed as parallel and same values for the parameters. Therefore simulation results will have a high degree of confidence.

We use main results simulation of each protocol that they will be compared with our protocol. For this work, we must use similar input parameters with them. These parameters are used in our tool and the gain results illustrate that our protocol have optimizing than LEACH, HEED-NPF and EECS. The values of the input parameters of the protocols aren't same together. Hence we simulate our protocol separately with each protocol and use same values in their input parameters.

We can say that with the increasing number of nodes, number of received packets is increased but packet delivery rate almost is reduced because some of factors such as increasing density of nodes, hop count and node failure probability are affective. Also, with the increasing number of nodes, the network lifetime will be increased and also, packet delays in network are increased due to different reasons such as increasing hop counts. In the first, we simulate FTIEE with values of input parameters in the Table 5.2 and compare with EECS and LEACH. Number of clusters are 10. We simulate our protocol and two above protocols parallel by our tool and evaluate their results on graphic charts. In this case, simulation is done on the first, half and last nodes times of death. The Figures of 5.20, 5.21 and 5.22 present each of conditions with 400, 600 and 1000 nodes. In the reference EECS is compared with LEACH. Therefore we use from both results to our simulations and results.

Table 5.2 Values of input parameters in original reference of EECS protocol.

Initial (max) energy	5 J/bit	Receive buffer size	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	Send buffer size	1500 bytes
Transmit process cost	50 n J/bit	Deployment area size	(100 x 100) m
Receive/sense process cost	10 n J/bit	Send/receive buffer counts	20
Data packet size	500 bytes	Sink position	(350 x 200) m
Sensing Radius	4.5m	Transmission Radius	9m

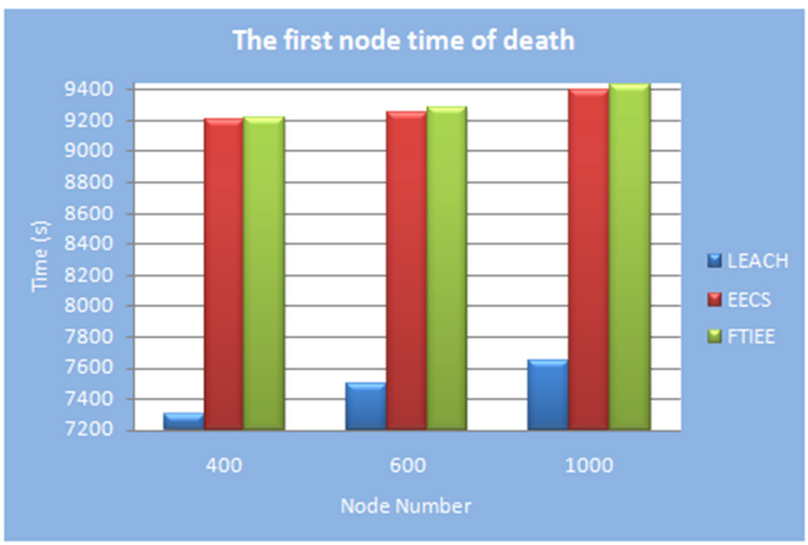


Figure 5.20 The first node time of death in LEACH, EECS and FTIEE with 400, 600 and 1000 nodes.

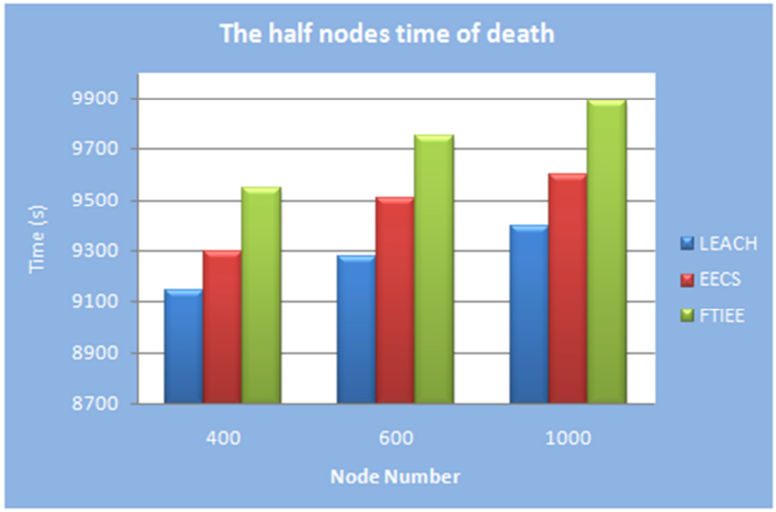


Figure 5.21 The half nodes time of death in LEACH, EECS and FTIEE with 400, 600 and 1000 nodes.

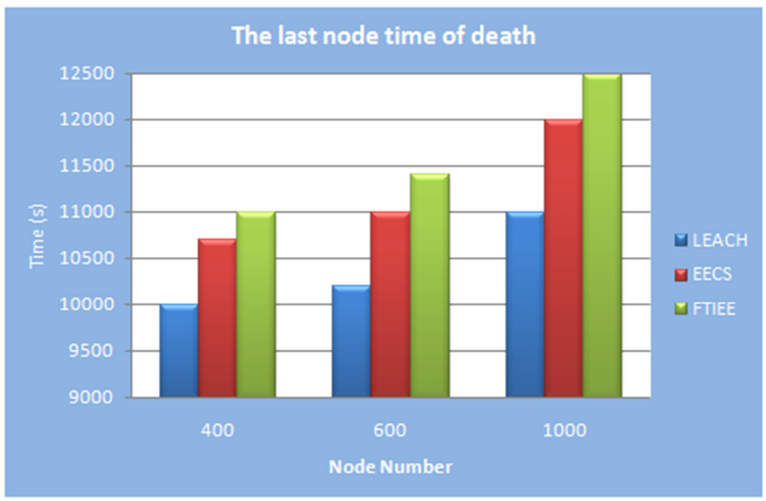


Figure 5.22 The last node time of death in LEACH, EECS and FTIEE with 400, 600 and 1000 nodes.

We will simulate Improved-LEACH protocol by our tool. In fact, we don't use ready result of Improved-LEACH for comparison because this approach doesn't have standard simulation with any current network simulation programs in the literature. Therefore, we will implement and simulate this protocol by its pseudo code and algorithm that are written by the authors (Taheri et. al., 2010).

In this section, we simulate all protocols by our tool in different cases so we will apply different input parameters and analyze performance of each protocol. We assume the input parameters values are listed in the Table 5.3 that will use them to all protocols in the simulation processes. We ran each of protocols in seven cases with different node numbers. In another part of simulation process, we will present offline running of our algorithm with same input parameters values to increasing learning rate and reach to optimizing factor. As mentioned, offline running of our protocol would be more desirable results. The HEED-NPF is similar to our protocol partly because it uses an expert approach in routing process. As it seems, FTIEE has a good performance in the network lifetime and can increase this factor by methods as data aggregation and applying the new intelligent approach as CH node election mechanism and on-demand routing.

As mentioned, FTIEE finds routes when it needs to send data unlike EESTDC. This method is somewhat similar to the HEED-NPF method. The Figure 5.23 illustrates results all four protocols in terms of network lifetime. Our protocol has a good performance than other protocols and its improvement is about 2.5 percent higher than HEED-NPF, 6.5 percent higher than EECS and 16 percent higher than LEACH.

Table 5.3 Values of input parameters for FTIEE, LEACH, HEED-NPF and EECS protocols.

Initial (max) energy	0.1 J/bit	Receive buffer size	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	Send buffer size	1500 bytes
Transmit process cost	40 n J/bit	Deployment area size	(600 x 600) m
Receive/sense process cost	10 n J/bit	Send/receive buffer counts	10
Data packet size	150 bytes	Sink position	(310 x 310) m
Sensing Radius	4.5m	Transmission Radius	9m

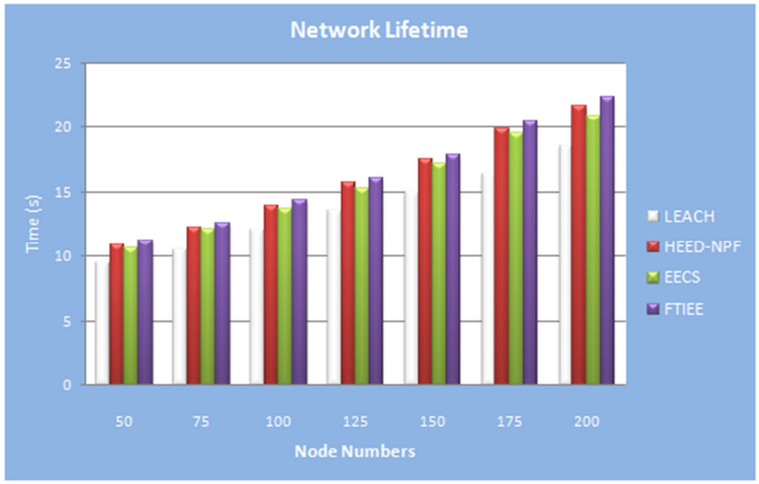


Figure 5.23 Simulation results based on network lifetime parameter in different node numbers cases for FTIEE, EECS, LEACH and HEED-NPF protocols.

The second case for comparison is packet delivery. As mentioned, the number of successfully transmitted packets from a node to the BS/sink and also, their reception via sink is concept of packet delivery. Also, packet loss is gained from subtraction of all sensed data packets and number of delivered packets. Our protocol has acceptable optimization performance in packet delivery than LEACH, HEED-NPF and EECS. The improvement is about 4.5 percent higher than HEED-NPF, 5.5 percent higher than EECS and 44 percent higher than LEACH. The Figure 5.24 shows simulation results four protocols in same conditions.

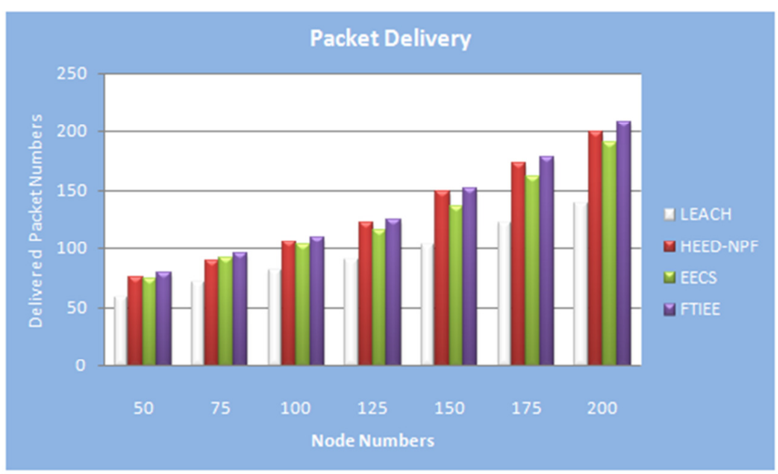


Figure 5.24 Simulation results based on packet delivery parameter in different node numbers for FTIEE, EECS, LEACH and HEED-NPF protocols.

On the other hand, we ran our protocol in simulation area after 100 rounds offline running. It should be noted that HEED-NPF ran with the same number of rounds in offline mode. The results show our protocol has been progress than HEED-NPF indeed its rate growth is good. Based on the results, FTIEE improvement in packet delivery factor is about 5.5 percent higher than HEED-NPF, 9 percent higher than EECS and 47 percent higher than LEACH. Also, its improvement in network lifetime factor is about 4 percent higher than HEED-NPF, 9.5 percent higher than EECS and 20.5 percent higher than LEACH.

In this section, we present another simulation results in four protocols. That is first node die (FND), half node die (HND) and last node die (LND). It should be noted that LND is selfsame the network lifetime. This measure can be an indicator to evaluation clustering model and determination of amount to avoid the bottleneck via algorithms. The Figure 5.25 shows the results of four protocols.

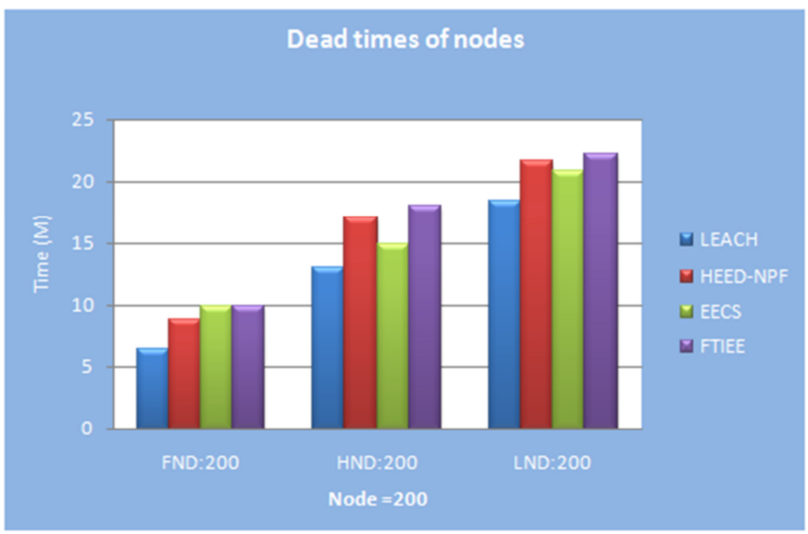


Figure 5.25 Simulation results for first, half and last nodes times of death packet in FTIEE, EECS, LEACH and HEED-NPF protocols with 200 nodes.

Last simulation parameter is network balance. As mentioned, network balance is another measure to simulation of four protocols. If main goal of network design is increasing reliability then network lifetime will reduce automatically. With this description, if a protocol can make a balance between output parameters then it would have a good performance in general views. The Figure 5.26 shows a case of network balancing comparison that it is calculates based on relations between the delivered packet numbers and the network lifetime.

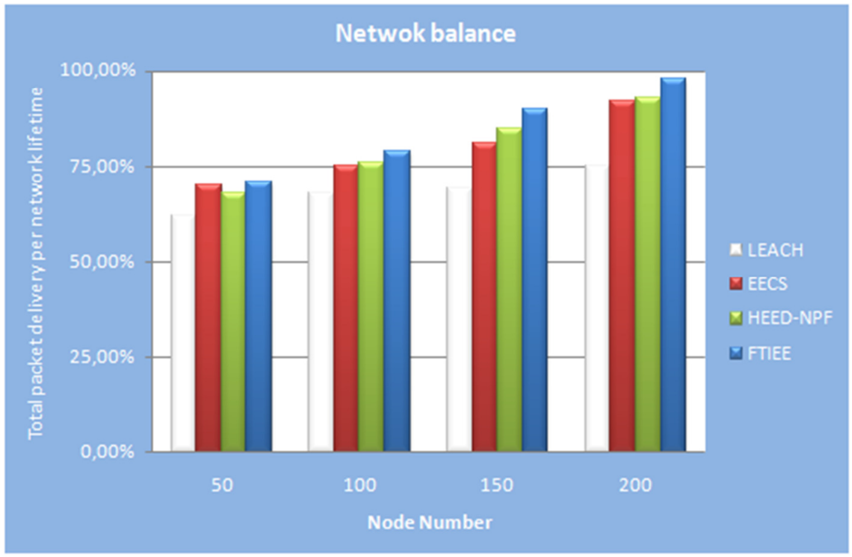


Figure 5.26 A specific view from performance of LEACH, HEED-NPF, EECS and FTIEE in network balance.

The main focus of our protocol is energy saving and increasing packet delivery with maintaining network balance. All goals are available simultaneously and are depend on usage environment. Hence, the algorithm can more focus on one of the parameters. For example, the lifetime parameter has priority than other output factors such as packet delivery and packet delay when energy saving to be an important aim in our application. In fact, this protocol is a general algorithm for different applications in the WSNs. But the protocol has some shortages such as need to offline working to reach good performance.

5.5 Summary and Conclusion

Unlike other networks, WSNs are designed for specific applications so characteristics and requirements for each of these applications are different. Therefore they need to the new communication protocols, algorithms and designs. Moreover, factors related to network design must also be considered to achieve the expected performance in the WSNs. The most important constraint in the WSN is energy. Hence, it must is managed by approaches or techniques as algorithms. In the chapter, we focus on energy problem from the perspective of algorithmic to have an energy-efficient and longer life network. The most researches in recent years in relation to energy-efficient wireless sensor network are done and one of the strategies in this regard is using a communication protocol based on clustering. The protocols based on clustering or hierarchical systems have a CH node to creation connection between nodes and BS/sink. The selection CH nodes have control overhead in the network. Sometimes it is too much overhead. In this chapter, we proposed a new routing algorithm to energy management and increasing network performance by an intelligent algorithm. It manages system overhead by the CH selection. In the proposed method, all the sensor nodes can be CHs node. They are chosen by machine learning technique. This method saves energy in the whole network. The most important feature of the algorithm is that the routing mechanism and the paths detection are applied as soon as and are based on on-demand.

Another important feature of FTIEE is fault tolerance. In the first our protocol when a failure occurs in the network, it prefers to retransmit the packet instead of repairing or preventing faults. This has an overhead over system but is better than other current protocols. The most other protocols send special data packets to repair faults. Reliability and fault tolerance feature is one of the strengths of the protocol. This will cause to increase packet delivery rate and reduction of packet loss. Also, the network is connected for a long time because it finds new routes in case of deterioration of the path or node failure.

The concept of effective energy is observed in the protocol too. It saves energy with using data-driven schema only. FTIEE uses learning based and data aggregation methods to this aim. The methods are subset of data-driven schema. The protocol doesn’t use the sleep/wake up method to energy saving the network. It should be noted that shared channel management is realized by the TDMA and on-demand approaches.

According to the simulation results, our protocol has a good performance in delivered and lost packet numbers and network lifetime, generally. Our output parameters are network lifetime, packet delivery and lost rate, the first, half and last node death time and energy consumption rate. We simulated our protocol with concurrent and offline running methods. FTIEE had a better performance in the offline method. Based on the results, FTIEE improvement in the packet delivery factor was about 5.5 percent higher than HEED-NPF, 9 percent higher than EECS and 47 percent higher than LEACH. Also, its improvement in the network lifetime factor was about 4 percent higher than HEED-NPF, 9.5 percent higher than EECS and 20.5 percent higher than LEACH. In the concurrent simulation method its performance in the delivered packet rate was about 4.5 percent higher than HEED-NPF, 5.5 percent higher than EECS and 44 percent higher than LEACH. Also, FTIEE improvement in the network lifetime was about 2.5 percent higher than HEED-NPF, 6.5 percent higher than EECS and 16 percent higher than LEACH.

CHAPTER SIX
ENERGY EFFICIENT ROUTING PROTOCOL BASED ON TOPOLOGY CONTROL SCHEMA

6.1 Introduction and Motivation

Routing is one of the important issues in the WSNs. It has more significant due to the energy constraints of these networks. Therefore, the routing algorithms must focus on efficient energy consumption in the network to reach a good performance. Structures of routing algorithms are static and dynamic. Static algorithms do not pay attention to traffic and topological conditions of network. They usually use from routing tables that are assigned in set-up phase of the network and are constant over time. If topology of the network infrastructure is changed then these tables will be reset manually by the network operator. Although they are fast approaches but don't suitable to the WSNs because don't find the best paths for data transferring. Also, changing in the network topology is main problem in the network and their applications. In dynamic algorithms, routing is based on last topological statues and traffic of network. Routing tables in the method are updated in a few second or when they sense an event. These algorithms are usually used in the WSNs.

Data collection in the WSNs is decentralized, global or semi-centralized algorithms. In global algorithms each node must have complete information of the network communications infrastructure. In this case, form of nodes is a graph and task of routing algorithm is finding optimal paths. The routing algorithms are named Link State (LS). For example, Dijkstra is based on LS. In decentralized method, each node doesn't have complete information of the network infrastructure. In this case, a node can calculate cost of its neighbors only. The name of this type is the Distance Vector (DV). The semi-decentralized methods are amongst the two previous methods.

As mentioned in throughout thesis, energy is one of the important issues in the WSNs. The sensor nodes are placed in inaccessible environments in many applications. Therefore, their charge is impossible and they will be useless with the depletion their energy. Radio is one of the most widely used components of the hardware sensor networks. But we can reduce energy consumption with an energy-aware algorithm. If the algorithm need to less communication then energy saving will be possible. The algorithms are based on energy efficiency schemas so had described in third chapter of the thesis.

Since the network topology is constantly changing, control of this topology can be useful to energy saving in the network. The topology control methods are based on connection-oriented and location-based approaches. The location-based approaches need to information about the status of their own explicitly. It is gained via the GPS devices. Since these devices are expensive therefore they are used on some sensor nodes in best case. They are used in some of special applications as home monitoring applications. According to the above description, connection-oriented approaches can be suitable for topology control because it need to reduction communication between nodes and full connectivity structure. It can provide with an algorithm and without need to other hardware. But it should be noted that, the algorithm must be energy efficient really. Our protocol in this chapter is focused on connection-oriented of topology control schema. Additionally, it saves energy by data aggregation and sleep/wake up methods. Goals of our protocol are reduction of packet delays, increasing packet delivery numbers and prolonging network lifetime.

Our protocol uses from Dijkstra algorithm to data transferring and focuses on topology control to reach energy efficiency and doesn’t need to location of sensor nodes or environment. In fact, our protocol more focuses on energy efficiency methods to increase network lifetime and reliability. We will illustrate that the protocol has better performance than to other protocols even our two previous methods in energy saving field. Our new protocol creates virtual communication layers to the BS/sink and puts some nodes in sleep mode with respect to maintaining communication between layers. These layers are our clusters in this protocol and active nodes in each layer are CH nodes. This method has appropriate performance because is usable on many of routing protocols that their goal is energy saving. We also apply it on two approaches in future works. The new protocol is emphasis on constant level fidelity. It will explain in the next section.

On the other hand, new protocol has fault tolerance feature so failure of a path is not cause lost data packets. Therefore, this approach is reliable and fault tolerance. The fault management doesn't consider in the many protocols. In these protocols, when a failure occurs in the network, they send special data packets to fixing the problem but it has significant overhead on system that is lead to increase latency and packet loss of real data packets in the network. The proposed protocol solves these problems.

We will describe the operations of proposed protocol and then explain it with using pseudo code and flow chart methods. Thereinafter, simulation of the protocol is done and is shown its results in graphs charts. In the end, we will compare it with some of the current protocols such as GAF, GBR and Naps. These methods have been described in previous chapters.

6.2 EETC Algorithm Description

In this chapter, Energy Efficient routing protocol based on Topology Control (EETC) is protocol is suggested for the WSNs that is based on energy efficiency. EETC can conserve energy by detection and turning on/off radio frequency. In fact, it uses a topology control method and keeps the network in the connected statues. Also, routing of the protocol is based on data-center gradient diffusion. EETC is inspired from combining Gradient-Based Routing (GBR) to find routes and Naps protocol to topology management so that it applies the both protocols advantages, and keeps nearly constant level of routing accuracy without need to geographic location information. After establishing communicative layers towards the sink to keep inter-layer communications, this protocol puts extra nodes in sleeping state. In fact, in each layer, a node can go to sleep state by detection of some other nodes that can do communication duty on behalf of that node. Despite conformity with all data delivery models, EETC produces considerable results continuous and event-driven models towards query-driven model.

In the EETC protocol, the sensor nodes have fixed positions and all nodes have same architecture and have collaboration with together for sending data to the BS/sink. The EETC increases network lifetime by keep a sufficient number of sensor nodes in active mode in every virtual layer for maintaining network connectivity. The sink/BS broadcast interest message to all nodes of the network and the virtual layers is created based on the nodes distance hops to the BS/sink. It is shown in the Figure 6.1. In the protocol, active nodes in every layer are responsible to sleep nodes' communications that the sleep nodes are their neighbors.

The EETC protocol has two phases. In the first phase, sink broadcast interest message to the sensor nodes after deployment of the sensor nodes in the environment. This packet is containing the interest hop that its default value is zero. The sensor nodes wait for receiving the packet. Each node adds one unit to interest hop value as received packet and saves this value as self-interest hop rate. Broadcasting packet by sink is only received by sink's neighbors and then the neighbors broadcast to their neighbors. This process will continue to the farthest layer's nodes. If nodes that have been set their interest hop values receive this packet again then they will remove the interest packet. All sensor nodes receive an interest packet after finishing of the broadcasting process. The Figure 6.1 shows the first of phase of EETC. As can be seen in the Figure, the nodes placement in the virtual layers is based on the closeness and number of hops to the sink. The first phase is finished in step d so in this step all layers are created for the network.

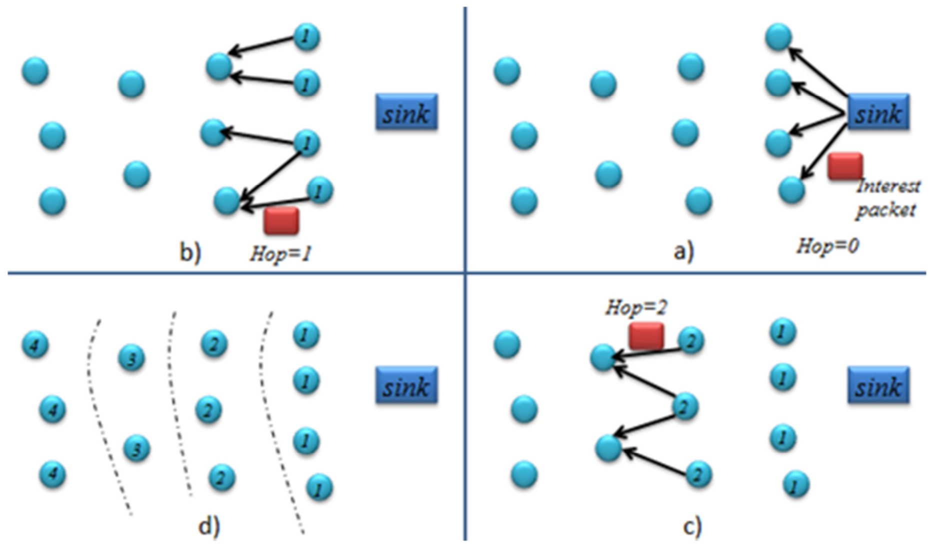


Figure 6.1 The first phase steps in EETC protocol.

The second phase, all nodes of each layer can be modeled as a random graph and then begin to doing duty cycle method. Concept of the duty cycle is maintenance minimum active nodes to energy efficiency. In fact, Duty cycling is mainly focused on the networking subsystem. The most effective energy conserving operation is putting the radio transceiver in the (low-power) sleep mode whenever communication is not required. Our algorithm creates a full connection state for each of active nodes in every layer.

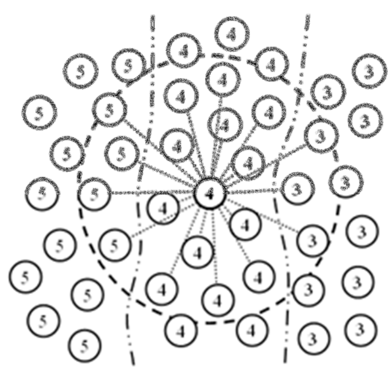


Figure 6.2 Radio radius of a specific sensor node.

In this phase, EETC attempts to keep the network connection by maintaining enough number of representative nodes in active mode in each virtual layer. These representative nodes undertake communication duty with other sleep neighbor nodes in the same layer. For this purpose, we use two parameters T and C. T represents duty cycling period time and C determines the degree of internal communications. Each node with C active neighbors in the same layer, in own radio radius devolve its communication duty to those active nodes and goes to sleep state. Number of active nodes and communications in the network can increase with increasing C value. To do so, each node spots considers time periods with duration T. Any node is waiting during t_v times and it is in sleep mode in this time. The t_v is distributed uniform and tis value is into the range [0, T). After this time, node converts to active mode and sends HELLO message to self-neighbor that they are in range of its RF. It goes into sleep mode again upon receiving the responses from the neighbors. The responses are based on C value. This time is different to nodes. The C and T parameters guarantee connectivity of network. The Figure 6.3 shows selected same layer neighbors by a typical node to send HELLO packets. Then, it listen HELLO messages sent by other nodes. Assuming that value of C parameter is three, we illustrate operating style of the algorithm in the Figure 6.4. In fact, a node will be at the sleep mode after receiving answer from the three neighboring nodes in the same layer.

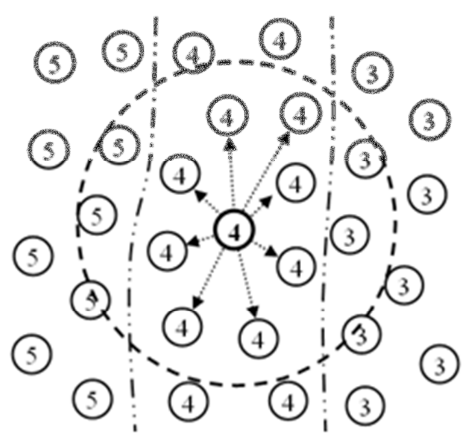


Figure 6.3 The selected neighbors by a typical node to send HELLO packets.

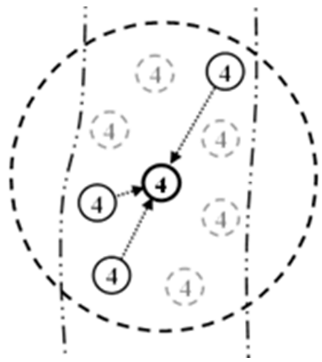


Figure 6.4 The received HELLO packets illustrate an activation of other nodes.

During node operations over T, node can change its mode to sleep mode if it receives C activation HELLO messages from its neighbors in the same layer. Otherwise, it doesn't change its mode in all the periods. For example, as shown in Figure 6.5, if at a typical network, C is equal to 3; each node after publishing its activity, sends its own HELLO packet and upon receiving 3 HELLO messages goes to sleep state until beginning of the next period.

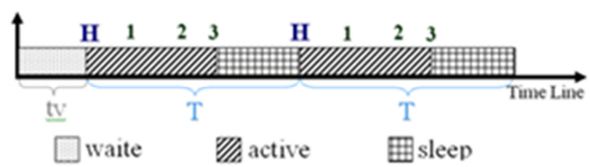


Figure 6.5 Activation time line for a typical node.

We show a snapshot of our topology schema of this phase in the Figure 6.6. Red sensors are active nodes and yellow sensors are passive (sleep mode) nodes. The virtual layers creation and their connections are used for sending data and maintenance stability of the network. Each active node transmits data toward sink via one of the self-neighbor that it has minimum interest hop value. In fact, the sensors closer to the sink have minimum interest value. In the same way, all sensors send data to sink by multi-hop transmission method without having to discover paths. The sleeping nodes can send their buffered data to one of the active nodes that are their neighbors. This case reduces packet delay in whole network. In fact, our sleep/wake up method is different from traditionally approaches because sleeping nodes can send data by activation of their radios for sometimes.

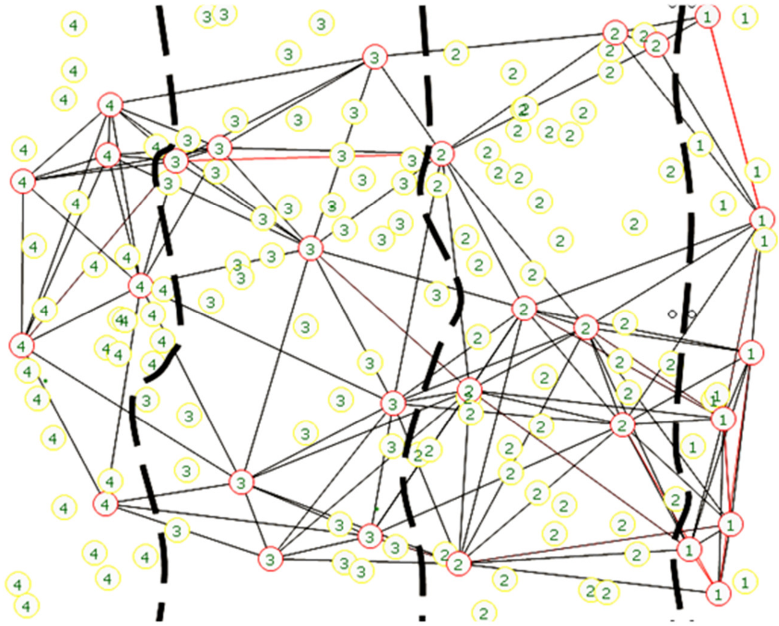


Figure 6.6 An example of communications and topology schema in EETC.

The EETC uses data-centric routing schema to flow data packets through multiple layers to the sink without route discovery. It is based on Dijkstra algorithm. Each node in active state sends its own packet to at least one of its active neighbors in next layer that have the less interest hop. Next, the node in the lower layer takes the responsibility and sends the packet to the next lower layer to near the sink, after some steps without the need to end path, the packet will reach to the sink (Figure 6.7). In this method, nodes aggregate packets as receiving them from our neighbors. Hence the algorithm doesn’t have redundant data and this case is causes prolonging network lifetime.

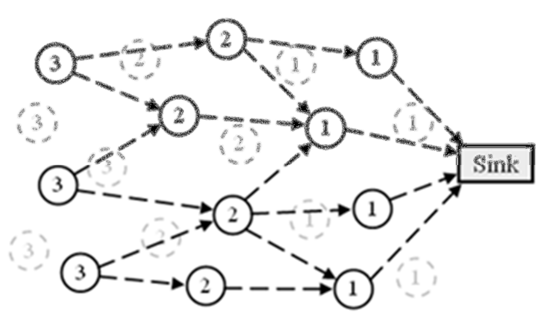


Figure 6.7 Packet routing in active nodes.

The sensor nodes, which are in the sleep state, may want to send packet in this case they can send the packet to one of their adjacent active nodes. This leads to considerable decline in packet sending delay. In fact, sleep state approach in this protocol is different from traditional approaches. Available nodes in sleeping state (whose radios are inactive) can activate their radio components for a moment by conserving state title (sleeping state) to send packets to one of active neighbors in same layer (Figure 6.8).

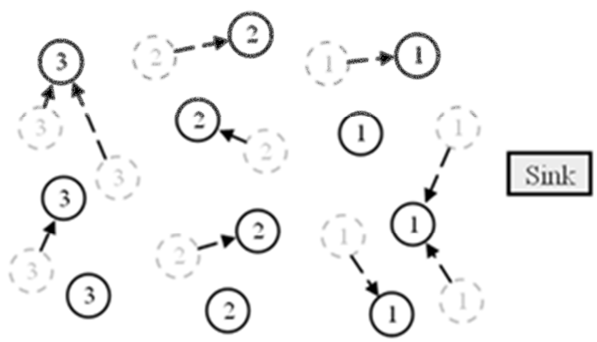


Figure 6.8 Packet routing in sleeping nodes.

There is no stable path to forward packets in EETC. This means that, paths that a packet will get through from a particular node to the sink will change in different times. Path instability in some cases is desirable due to the increased reliability. Some exceptions could be occurring in terms of routing that we investigate some of them. An active node might not found active neighbor with less interest step in own radio range, therefore it can send data packet to one of neighbors in same layer or buffer the packet until a node with that situation is appear.

On the other hand, for each sleeping node, it is assured that there exist one or more active nodes around it. If any sleeping node could not find active node in its neighborhood, means that some of active neighbors active nodes have been broken or their energy have ended, so sleeping node get awaken, and takes the responsibility of its own communication duty.

EETC is a reliable approach too. When a node breaks down or its energy is over, alike to the Figure 6.9, other nodes on the same layer undertake its packet delivery duty. It should be noted that, existence of several routes, as a result of path instability, causes a non-stop transmission of packets to the sink. On the other hand by completion of the adjacent sleeping nodes time-cycle, they wake up and we achieve former connectivity degree.

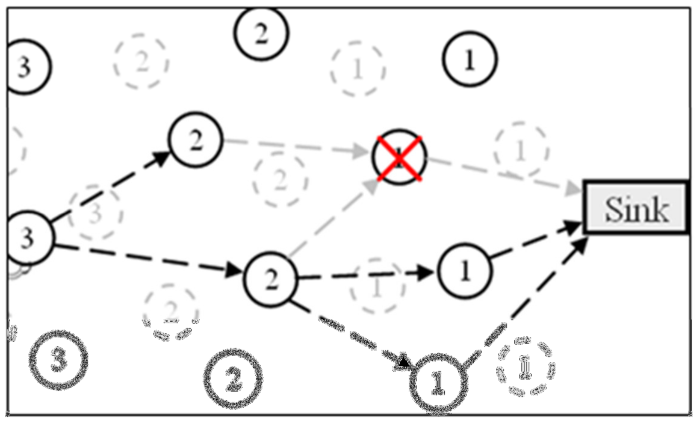


Figure 6.9 Sensor network continues to forward packets when some nodes fail.

Routing in EETC is based on energy saving and prolonging network lifetime so energy conservation is realized by topology control, data aggregation and sleep/wake up methods. This is one of the main properties of the protocol. Despite this, our protocol is reliable and has tolerance against faults of nodes, physical damage inflicted on the environment and etc. The best method to show the transfer of data to the sink is virtual layer because passing through each layer represents one step in the data transferring toward server or sink. Numbers of nodes in each layer are placed in sleep mode for maintaining communication between the layers and act based on duty cycle method periodically. In this cycle, each of nodes has undertaking communications creation between layers for sometimes and then changes their states to sleep until the beginning of the next period and with ensure the existence of other active nodes. Flexibility of virtual layers in finding optimal paths on our protocol is shown in the Figure 6.10 that is compared with another topology control methods that they are based on location-driven approaches.

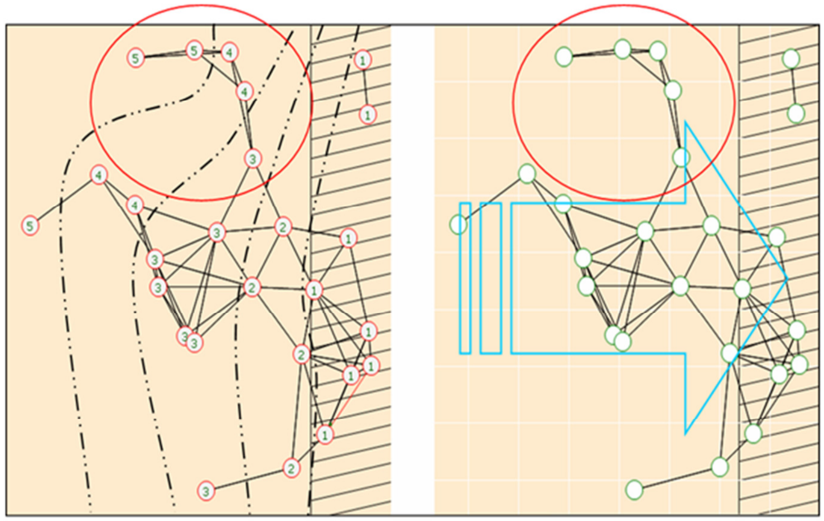


Figure 6.10 Performance comparisons between EETC and location driven methods in heterogeneous topologies.

In summary, our protocol is an energy-aware connection-based routing protocol for WSNs. It uses the gradient routing and connectivity driven topology control schema at the same time, and gains the benefits of both to keep routing fidelity and increasing network lifetime. It should be noted that communication subsystem has energy consumption rate in subsystems are different so energy consumption in communication sets are much higher than the computation sets. Also, energy consumption of radio is consisting of sensing phenomena, data transmission and idle time. The radio should be in sleep mode as possible because it is causing energy saving in nodes. In fact, our protocol focuses on energy efficiency issue and uses data aggregation and topology control methods to reach it.

As mentioned, duty-cycle schema exploits node redundancy, which is typical in WSNs and selects only a minimum optimal subset of nodes to remain active for maintaining connectivity is referred to as topology control. It is realized by connectivity-driven topology management with no need to geographic location information.

Also, our routing method is based on Dijkstra algorithm. Every node detects optimal paths to data transmission with using of Dijkstra algorithm. In fact, all communications are neighbor-to-neighbor with no need to a global addressing mechanism. A packet is forwarded on a link with the largest gradient.

Our protocol is consisting of three phases that they are virtual layer creation, connective duty-cycle and data transmission. In the first phase, the sink starts to broadcast interest packet. Packet includes interest hop that the sink set it to zero. All nodes are waiting for receiving interest packet. Each node increases one unit to interest hop rate after getting the packet and conserves it as its interest hop rate then rebroadcast interest packet to its neighbors. Those nodes, that determined their interest hop, drop interest packet if they re-receive it. Completing first phase, virtual interest layers among network nodes is provided. After generating virtual layers, at the second phase, all nodes in each layer are modeled as a random graph. Each node waits for a random amount of time t_v, uniformly distributed into the range [0, T). After t_v, a node operates on the basis of T. At first, a node broadcasts a HELLO message to advertise its activation its neighbor nodes in the same layer. The node can go to sleep until the next time period as soon as it receives C messages from its neighbors. C is connectivity degree and T is duty cycling period. The third phase is routing and data transferring. Active nodes send its own packets to one of its neighbors that have the less interest step rate. Sleeping nodes activate their radios for a while and send their packet to one of their adjunct active nodes.

EETC doesn’t have routing table. Also, it doesn’t discover routes in data transferring times. This case is similar to EESTDC. However, the second method is different. Our protocol doesn’t have a stable path to transmission data and it can send to sink via different routes. The method increases reliability feature in the EETC. In this case, nodes relay data between hops for delivering it to the sink. We can reinforce some hops to achieve better path steps by adding some another parameters. The reinforced step uses more than other ones. When a node breaks down, other nodes on its layer undertake its packet forwarding duty. We achieve former connectivity degree by ending sleep nodes time cycle.

In this section, we present snapshots of our protocol and some of the protocols that will compare with EETC. The Figure 6.11 shows a snapshot of EETC topology. In this sample, C value is 3 and T is 500 seconds. Also, Figure 6.12 shows topology of GAF protocol at the moment of running network. Active time is 250 seconds and sleep time is 100 seconds. In other cases, Figure 6.14 shows snapshot of Naps protocol with connectivity value 3 and time period 500 seconds and Figure 6.15 shows a snapshot of GBR topology. In the all cases, node numbers are 50 and initial energy of each node is 10 joules.

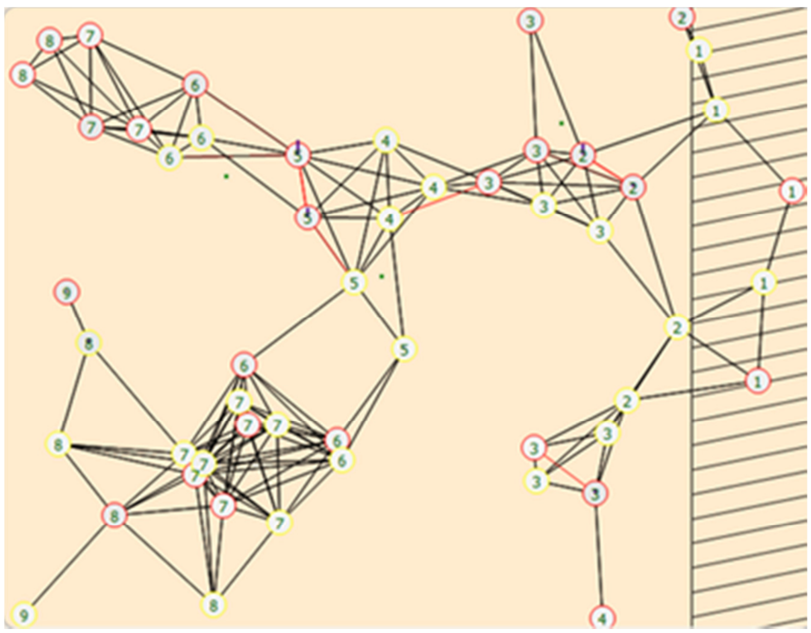


Figure 6.11 A snapshot of basic network topology in EETC protocol.

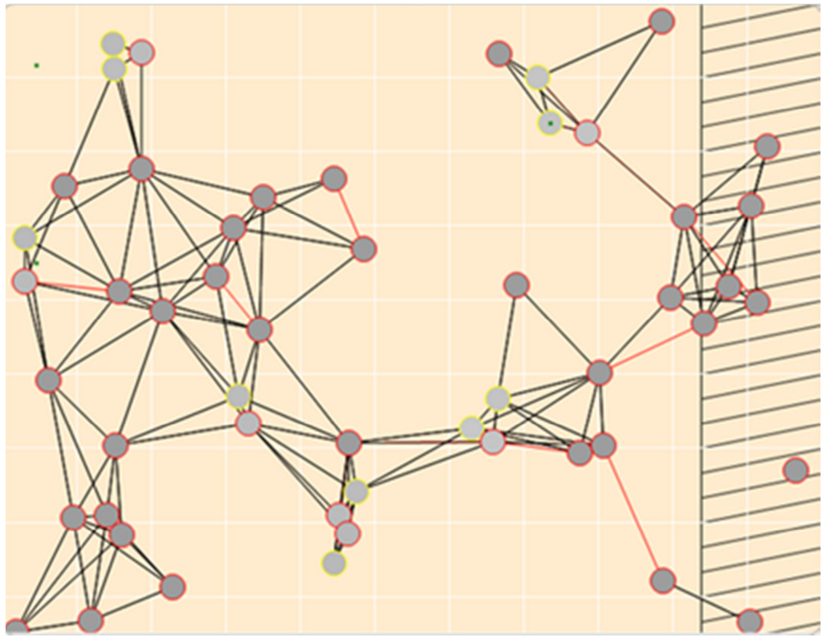


Figure 6.12 A snapshot of basic network topology in GAF protocol.

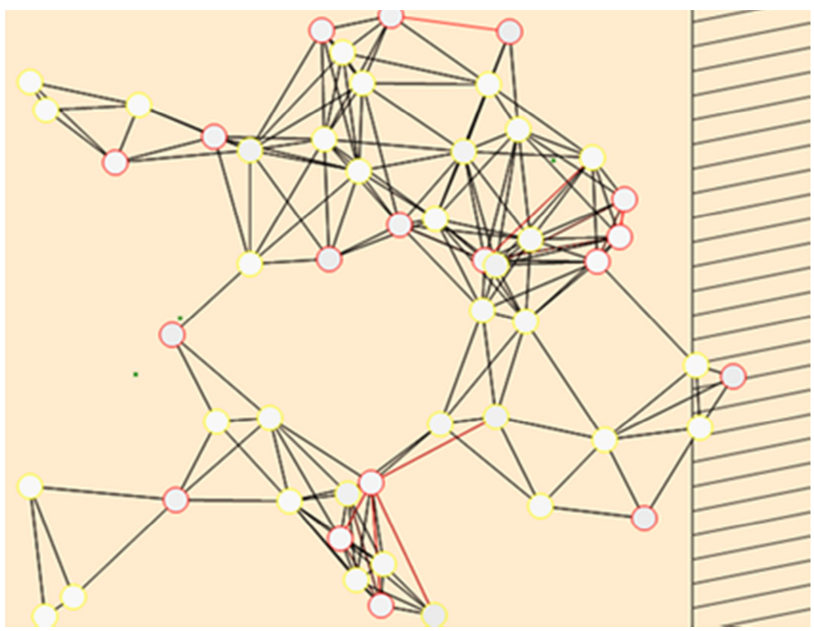


Figure 6.13 A snapshot of basic network topology in Naps protocol.

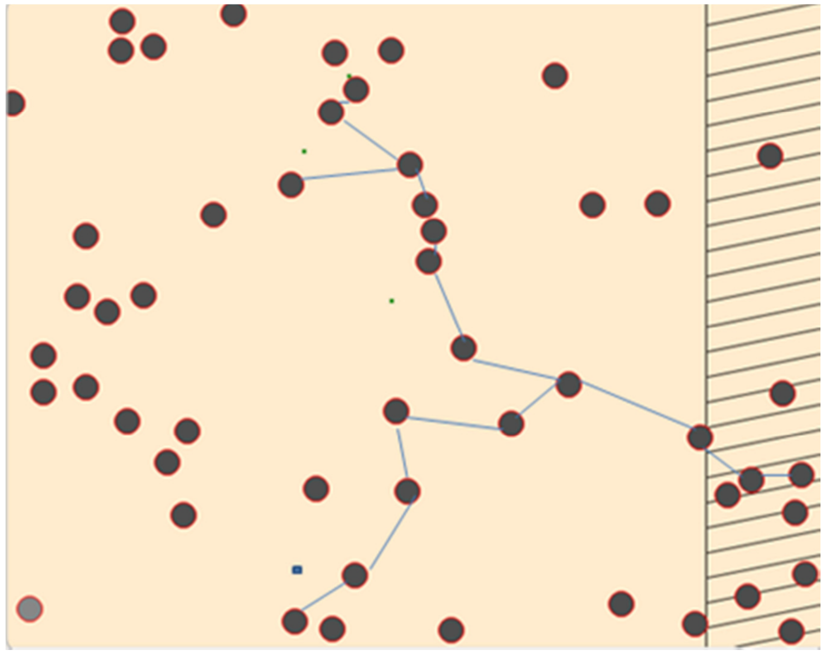


Figure 6.14 A snapshot of basic network topology in GBR protocol.

The main reason for choosing these three protocols to compare our method is their similarity in some parts to EETC. GBR is used to comparison packet delivery rate because it has a good performance in this case. All nodes are active in the GBR protocol and therefore its packet delivery rate is high. Our protocol uses a method to topology control that it is similar to Naps protocol. GAF uses a method of topology control and it is based on location-driven but topology control of our protocol is connection-based approach. EETC is based on an event-driven data delivery model and uses aggregation or fusion on active nodes to reach efficient results with continuous and query-driven models. Therefore, it seems that EETC can be a good choice as a routing protocol for the applications such as environmental monitoring.

The operations of our phases in the EETC are illustrated by flow chart and pseudo code. They are shown in the Figures 6.15 and 6.16.

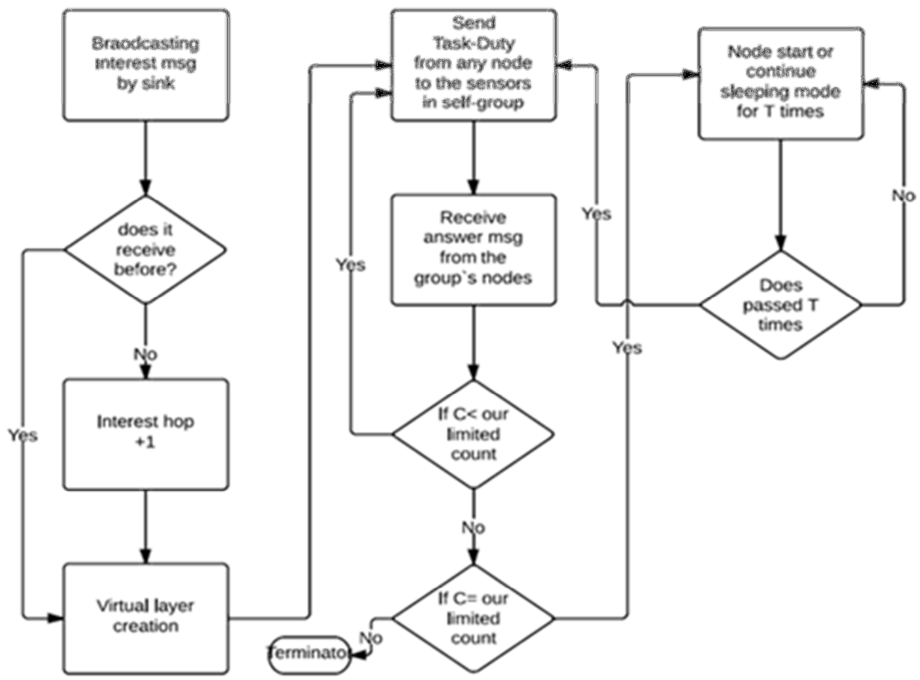


Figure 6.15 A general view of phases of EETC by flow chart.

1. Sink broadcast interest message to all nodes
2. The nodes receive the message
3. For all nodes
4. If message = not repeat
5. Interest hop = interest hop + 1
6. Else go to 7
7. For all nodes
8. If interest hop's nodes are same
9. They are in a same layer
10. For all layer
11. While (duty-task-message <= our limited number)
12. Send duty-task-message from any node to its neighbors
13. If receive-answer-count = our limited number
14. While (time is true)
15. Node is sleep mode
16. Go to 12

Figure 6.16 Pseudo code for EETC phases.

In the next section, we will explain EETC with simulation results. We will show that it has better performance as compare to Naps, GAF and GBR protocols, generally. We use the same conditions to increase the precision and validity of simulation results.

6.3 Simulation

As mentioned, we made a WSN simulation tool in C# program and used it for all simulations in our thesis. The tool is applied on four protocols in same conditions and input parameters in this chapter. The tool allows us have results documentation or simulation charts in network lifetime, packet delivery and packet delay parameters at the moment or end. In this case study, we simulate all protocols with same outputs parameters too that they are network lifetime, packet delivery, packet delay and network balance. Also, we use the original simulation results and charts of Naps, GAF and GBR to demonstrate the correctness of our protocol. We apply their input parameters for EETC to comparison and then will use of our tools for further simulations. The input parameters are initial energy of each sensor nodes, radio and sensor energy consumption, transmit, receive and sense process cost and send/receive buffer size. All four protocols are performed as parallel and have same values for the parameters. Therefore simulation results will have a high degree of confidence.

We consider a network of static (e.g. immobile) with energy constrained sensors nodes that redundantly deployed over a flat region. All nodes in the network have the same architecture and design fundamental and they are participating in the network and forward the given data to a command center. These sensor nodes have limited processing power, storage and energy. Our protocol is consisting of three phases that they are virtual layer creation, connective duty-cycle and data transmission. They described in before section.

The tool uses same nodes count and location of sink to increase the accuracy of simulations. Table 6.1 shows an example of input parameters values that they are constant and common for all protocols in our simulations. It should be noted that the values have been used to several examples of protocols and we can use arbitrary values for simulations. We consider that many of input parameters are same in the all algorithms. The first simulation applies following table values to illustrate comparison results of network lifetime, packet delivery and packet delay. We can say that with the increasing number of nodes, number of received packets is increased but packet delivery rate almost is reduced because some of factors such as increasing density of nodes, hop count and node failure probability are affective. Also, with the increasing number of nodes, the network lifetime will be increased and also, packet delays in network are increased due to different reasons such as increasing hop counts. Deployment of the sensor nodes is random and the nodes are distributed in a two-dimensional space. The BS/sink can be in any arbitrary position inter or out of network and doesn't have limitation battery or computing power. Locations of nodes and sink are fixing after the establishment.

GBR is a flat based routing algorithm that isn't energy-aware approach. In the GBR, all nodes are active and so its packet delivery rate is high. Therefore, we select GBR to comparison packet delivery rate with our protocol. EETC uses a method to topology control that it is similar to Naps protocol. GAF uses a method of topology control and it is based on location-driven but topology control of our protocol is connection-based approach.

Table 6.1 Values of input parameters for EETC protocol.

Initial (max) energy	0.7 J/bit	Receive buffer size	10000 bytes
Radio/ Sensor energy consumption	40 n J/bit	Send buffer size	10000 bytes
Transmit process cost	40 n J/bit	Deployment area size	(600 x 600) m
Receive/sense process cost	10 n J/bit	Send/receive buffer counts	20
Data packet size	500 bytes	Sink position	(600 x 300) m
Sensing Radius	7.5 m	Transmission Radius	15 m

The Figure 6.17 shows network lifetime of EETC protocol in four different node numbers cases. As it appears network lifetime is directly related to the number of nodes. In other words, with the increasing number of nodes, the network lifetime will be increased. The Figure 6.18 shows delivered packet numbers of network in four different node numbers cases. We can say that with the increasing number of nodes, number of received packets is increased but packet delivery rate almost is reduced because some of factors such as increasing density of nodes, hop count and node failure probability are affective. Also, with the increasing number of nodes, the network lifetime will be increased and also, packet delays in network are increased due to different reasons such as increasing hop counts.

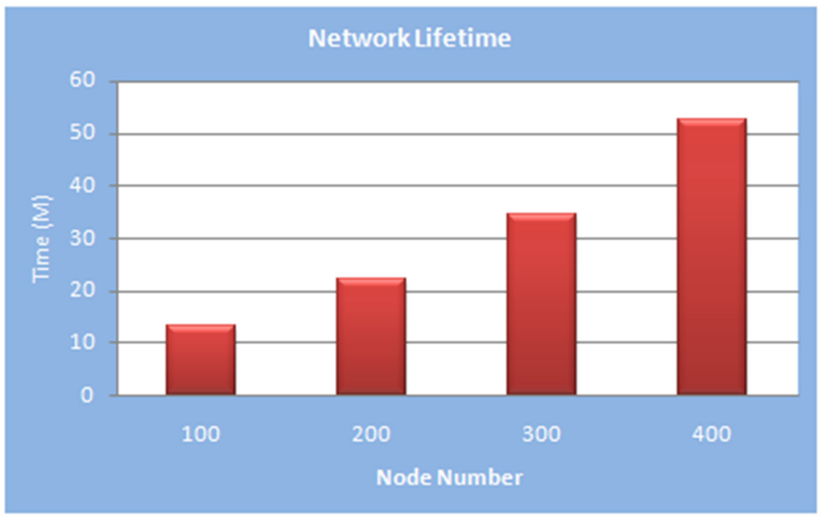


Figure 6.17 Lifetimes of network in EETC protocol with different node numbers.

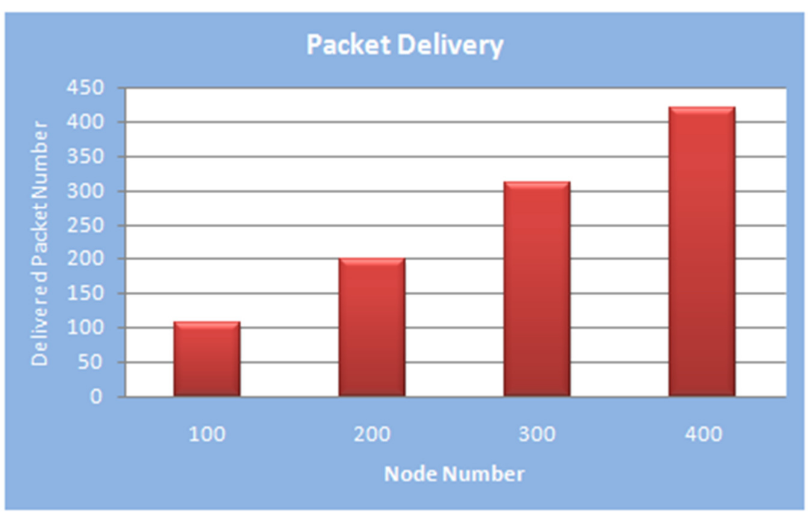


Figure 6.18 Delivered packet numbers in EETC protocol with different node numbers.

The Figure 6.19 shows average energy consumption with 100 nodes in lifetime of network. The network worked 13.1 minutes with 100 nodes. The Figure illustrates energy consumption in different times of running network.

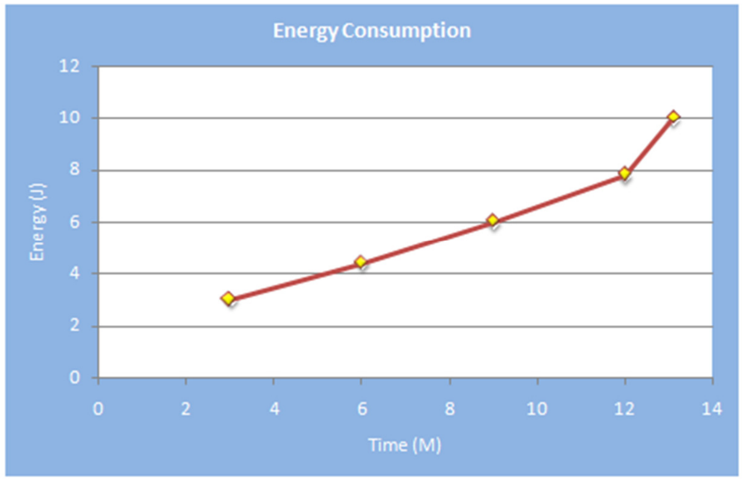


Figure 6.19 Average energy consumption of network with 100 nodes.

Packet delay is a period time that in this period, a transmitted packet will reach to sink. In fact, a transmitted packet will consume some times for reach to sink. This time is a delay for every data packets. The Figure 6.20 shows average packet delay in the network with different node numbers. With the increasing node numbers, packet delays in network increases due to different reasons such as increasing hop numbers.

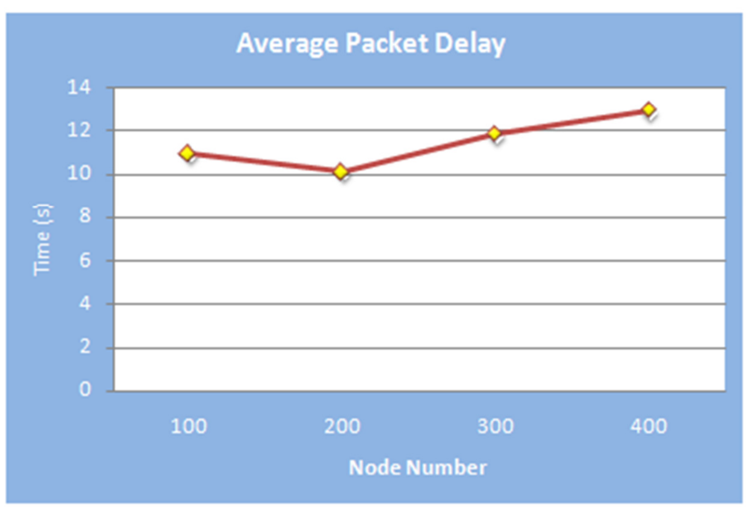


Figure 6.20 Average packet delay of network with different node numbers in EETC protocol.

Network balance is another measure to simulation of our protocol. As mentioned in previous chapters, some of output parameters aren't in the same direction. An example, if main goal of network design is reduction overhead then network lifetime will reduce automatically. With this description, if a protocol can make a balance between output parameters then it would have a good performance in general view. It can gain from different methods such as percent of packets delay to network lifetime, percent of packet delivery to network lifetime and etc. The Figure 6.21 illustrates the network balance rate by relation between packet delivery and network lifetime.

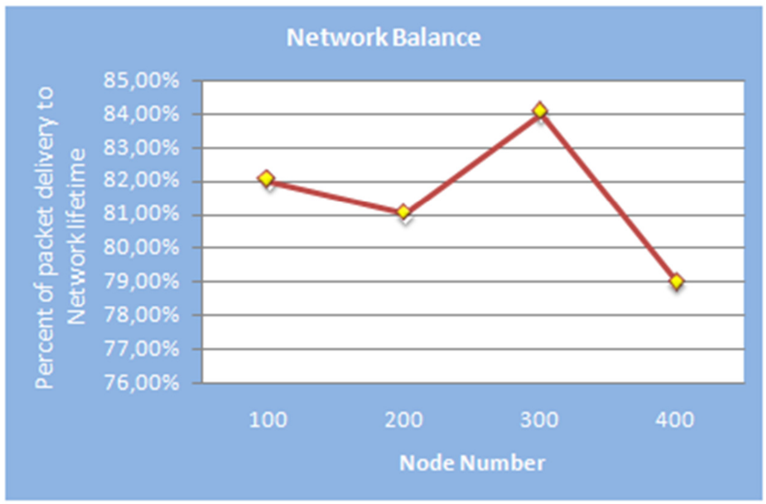


Figure 6.21 A view of network balance in EETC with different node numbers.

In the next section, we will use main results simulation of GAF, GBR and Naps protocols. Then we will compare our protocol with them.

6.4 Comparison and Results

As mentioned, we made a WSN simulation tool in C# program and used it for all simulations in our thesis. In this section, the tool is applied on four protocols (GAF, GBR, Naps and EETC) in the same conditions and the input parameters. The tool allows us have results documentation or simulation charts in network lifetime, packet delivery and average packet delay parameters at the moment or end. In this case study, we simulate all protocols with same outputs parameters too. As mentioned, they are network lifetime, packet delivery, energy consumption and network balance. Also, we use the original simulation values of GAF, GBR and Naps to demonstrate the correctness of our protocol results. We apply their input parameters to EETC to comparison and then we will use our tools to further simulations. The input parameters are initial energy of each sensor nodes, radio and sensor energy consumption, transmit, receive and sense process cost, send/receive buffer size and packet time to life.

In the first, we simulate EETC with values of input parameters in the Table 6.2 and compare with EETC and LEACH. We simulate our protocol and GAF protocol parallel with using original GAF parameters and then evaluate their results on graphic charts. In this case, output parameters of simulation are network lifetime, packet delivery rate and average of packet delay. We suppose that GAF is without mobility capability in the simulations because our protocol is described without mobility feature. This case can be one of the future works.

Table 6.2 Values of input parameters in GAF.

Initial (max) energy	1.4 J/bit	Receive buffer size	2200 bytes
Radio/ Sensor energy consumption	40 n J/bit	Send buffer size	2200 bytes
Transmit process cost	40 n J/bit	Deployment area size	(600 x 600) m
Receive/sense process cost	10 n J/bit	Send/receive buffer counts	20
Data packet size	100 bytes	Sink position	(600 x 300) m
Sensing Radius	8 m	Transmission Radius	15 m

The Figure 6.22 shows numbers of living node in 900 seconds of network running for EETC and GAF protocols. The number is a measure to reach the network lifetime evaluation. Results of simulation explain performance of each protocol so they work with 100 nodes. Also, the packet delivery ratio and comparison between both protocols with 100 nodes is shown in the Figure 6.23. The ratio is gained from division the number of successfully delivered packets to total sent packets. The ratio between both is near due to GAF can keep alive all sensors throughout 400 seconds but after this time, distance between them rises so performance of EETC is better than GAF.

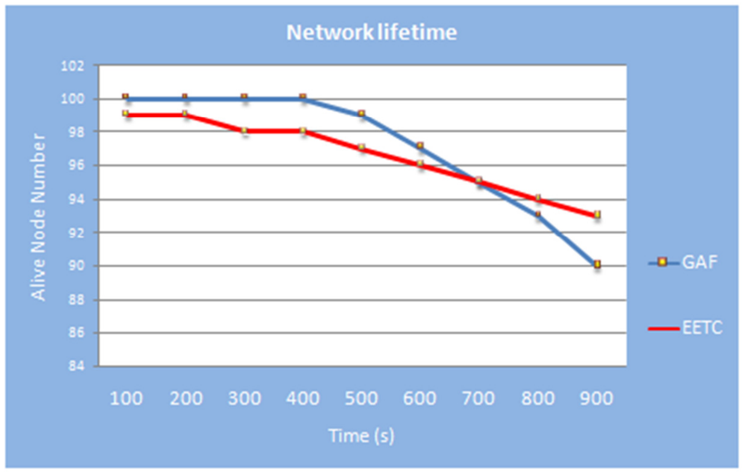


Figure 6.22 The alive node numbers in 900 seconds of network running with 100 nodes.

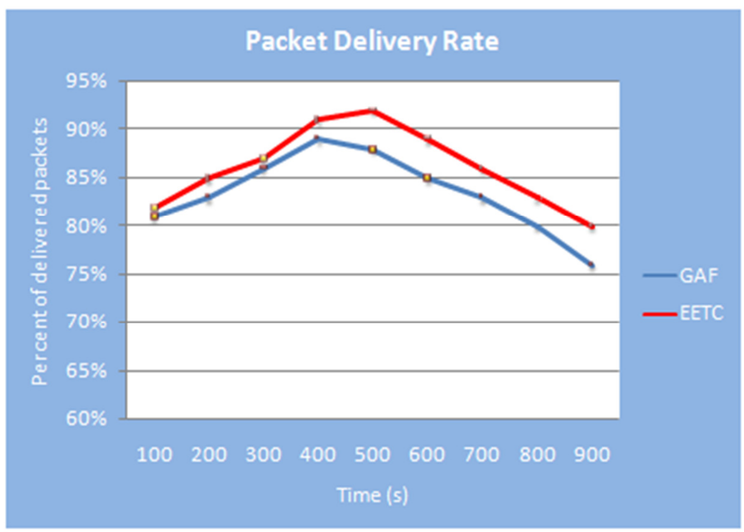


Figure 6.23 The packet delivery rate in 900 seconds of network running with 100 nodes.

Average packet delay is another comparison case. It is calculated in several times of network running with 100 nodes. Results illustrate a good performance of our protocol. It should be noted that both protocols will be a little bit more packet delay due to using of sleep wake up method. Moreover, our protocol has bad performance than GAF in first 100 seconds. Because of this happen is using C and T parameters. It should be noted that value of C in GAF is constant value and it is 1. In EETC, we assume value of C is 3 and T is 500 seconds.

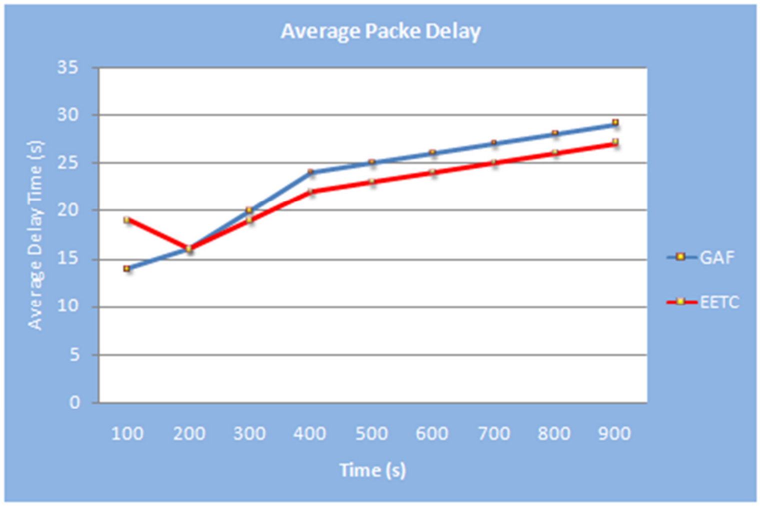


Figure 6.24 Average packet delay time in 900 seconds of network running with 100 nodes.

In this section, we simulate our protocol and Naps with using of input parameters` values of Naps paper. Input parameters values in EETC and Naps are based on the Table 6.3. The values have been used in Naps original paper. They are compared in packet delivery and network lifetime factors. Packet delivery of Naps isn't good and EETC is better than it with noticeable difference. This case is illustrated in the Figure 6.25.

Table 6.3 Values of input parameters in Naps.

Initial (max) energy	0.1 J/bit	Receive buffer size	10000 bytes
Radio/ Sensor energy consumption	20 n J/bit	Send buffer size	10000 bytes
Transmit process cost	20 n J/bit	Deployment area size	(600 x 600) m
Receive/sense process cost	10 n J/bit	Send/receive buffer counts	20
Data packet size	500 bytes	Sink position	(600 x 300) m
Sensing Radius	6 m	Transmission Radius	12 m

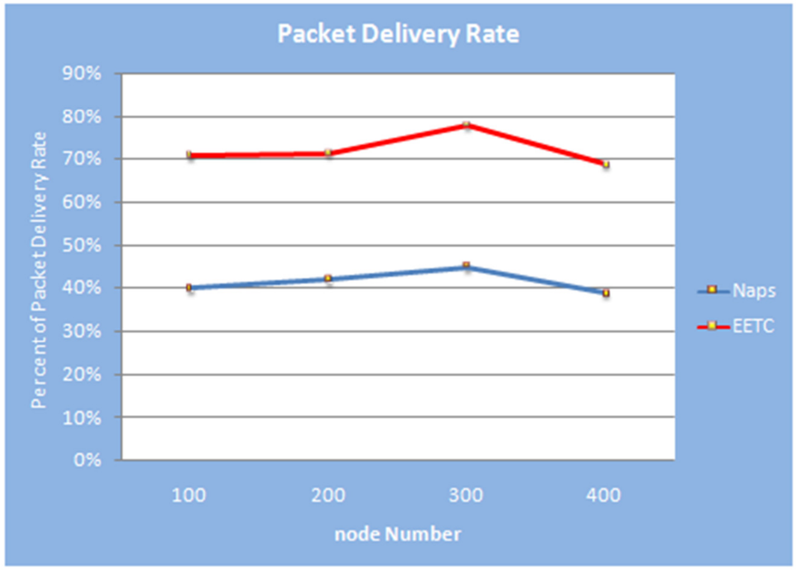


Figure 6.25 Ratio of packet delivery time in EETC and Naps with different node numbers.

In the Figure 6.26, performance of network lifetime in EETC and Naps is shown so they have closer together results with increasing node numbers. For example, EETC improvement with 400 nodes is about 2.5 percent higher than Naps and with 100 nodes is about 4.8 percent higher than Naps.

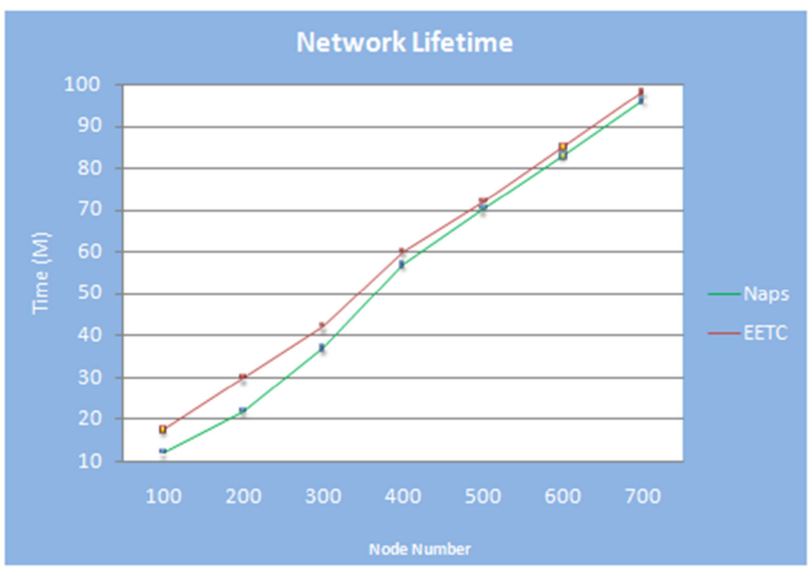


Figure 6.26 The network lifetimes of EETC and Naps with different node numbers.

In the next section, we simulate our protocol with other input parameters values to comparison with GBR protocol. The values of parameters are given GBR protocol. We use some of the common input parameters that it based on the Table 6.4.

Table 6.4 Values of input parameters in GBR.

Initial (max) energy	1 J/bit	Receive buffer size	2400 bytes
Radio/ Sensor energy consumption	20 n J/bit	Send buffer size	2400 bytes
Transmit process cost	20 n J/bit	Deployment area size	(100 x 100) m
Receive/sense process cost	10 n J/bit	Send/receive buffer counts	20
Data packet size	110 bytes	Sink position	(0 x 0) m
Sensing Radius	9 m	Transmission Radius	18 m

Simulation results are based on network lifetime and packet delivery rate. These parameters are to comparison between GBR and EETC protocols. GBR has a good performance in packet delivery rate and delivered packets number than EETC because it doesn't have sleep/wake up method. In fact, all nodes are active in GBR and therefore network lifetime is short. Figure 6.27 illustrates network lifetimes of GBR and EETC. It shows EETC is better than GBR. On other the hand, Figure 6.29 shows packet delivery rate so GBR has a good performance in this case.

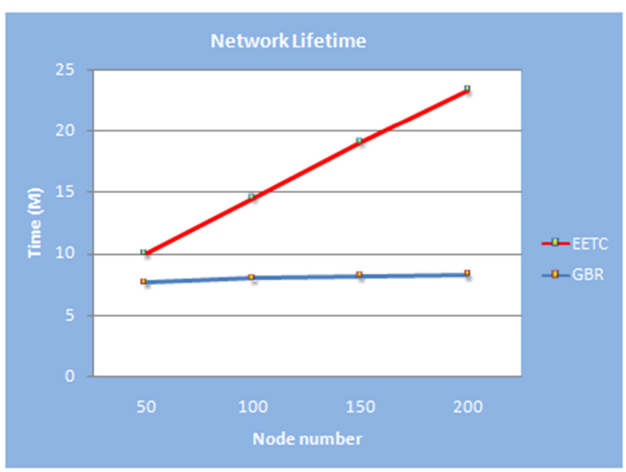


Figure 6.27 Network lifetimes of EETC and GBR with different node numbers.

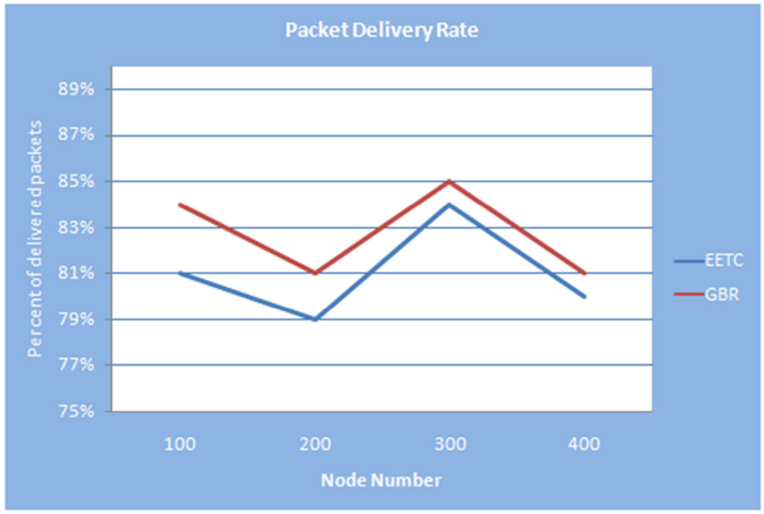


Figure 6.28 Packet delivery rates of EETC and GBR with different node numbers.

In this section, we simulate all protocols by our tool in different cases so we will apply different input parameters and analyze performance of each protocol. We assume input parameters values are listed in the Table 6.5 that will use them to all protocols in the simulation processes. We ran each of protocols in some cases with different node numbers. As it seems, EETC has a good performance in network lifetime and can increase this factor with using data aggregation, topology control and sleep/wake up methods. The topology control and wake up/sleep methods are almost like to the Naps method. Also, EETC is like to GBR method of routing technique.

The Figure 6.29 illustrates results all four protocols in terms of network lifetime. Our protocol has a good performance than other protocols and its improvement is about 2.5 percent higher than GAF, 13.5 percent higher than Naps and 70 percent higher than GBR. Also, the Figure 6.30 shows simulation results of four protocols in packet delivery ratio scope. This ratio is packet delivery numbers than the number of nodes on the network. Its improvement is about 10.5 percent higher than GAF and 72 percent higher than Naps, but GBR is better than our protocol in this case and it is about 3 percent higher than EETC. The all nodes are active in GBR protocol. On the other hand, direct based routing approaches are fast and can transmit many packets to sink generally. Obviously, if routes are without siphoning then the amounts of lost packets reduces and data are transferred rapidly to sink.

Table 6.5 Values of input parameters for EETC, GBR, GAF and Naps protocols.

Initial (max) energy	1.1 J/bit	Receive buffer size	13000 bytes
Radio/ Sensor energy consumption	40 n J/bit	Send buffer size	13000 bytes
Transmit process cost	40 n J/bit	Deployment area size	(600 x 600) m
Receive/sense process cost	15 n J/bit	Send/receive buffer counts	25
Data packet size	250 bytes	Sink position	(600 x 350) m
Sensing Radius	6 m	Transmission Radius	12 m

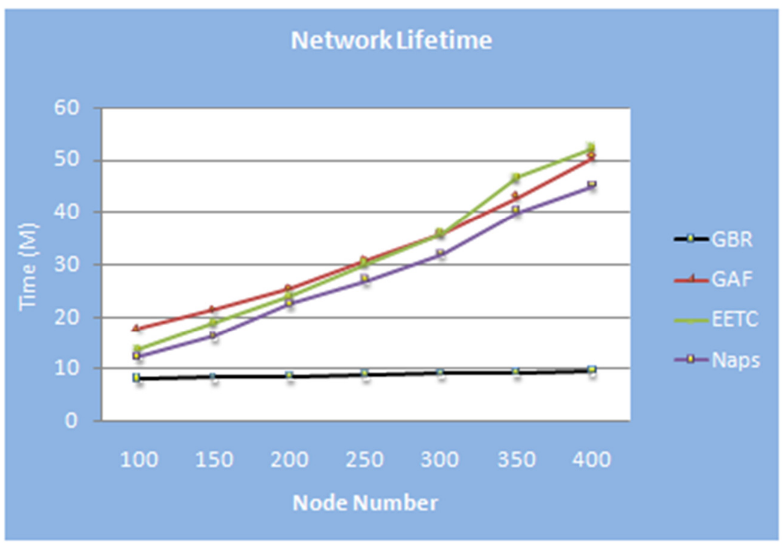


Figure 6.29 Network lifetimes in EETC, Naps, GBR and GAF four protocols with different node numbers.

The third case for comparison is packet delay. As mentioned, packet delay is a period time that in this period, a transmitted packet will reach to sink. In fact, a transmitted packet will consume some times to reach to sink. This time is a delay for every data packets. The Figure 6.31 illustrates simulation results for all four protocols. As it seems, EETC is suitable approach among other protocols. Average delays imposed on the nodes in the structure of our protocol have little relationship with the number of nodes on the network unlike many other methods. In the many protocols, with increasing node numbers, density of nodes rises and communication channels are also more likely to sink and packet buffering is low. But EETC controls the density by topology control schema so that it uses C parameter to it. This is also true for Naps. In summary, packet transmission is performed with a delay of almost constant with maintaining a certain number of connections in the network. However, it should also bear in mind that we can be consistent of value of C to avoid delays caused by the sudden increase depending on specific times. On the other hand, direct routing methods are affective on reduction of delays. In the Figure 6.31, our protocol has a constant delay rate relatively.

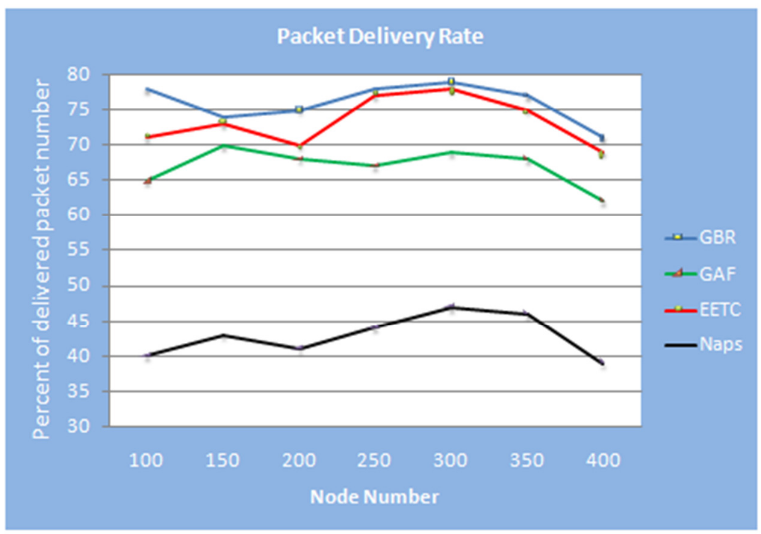


Figure 6.30 Packet delivery rates in EETC, Naps, GBR and GAF four protocols with different node numbers.

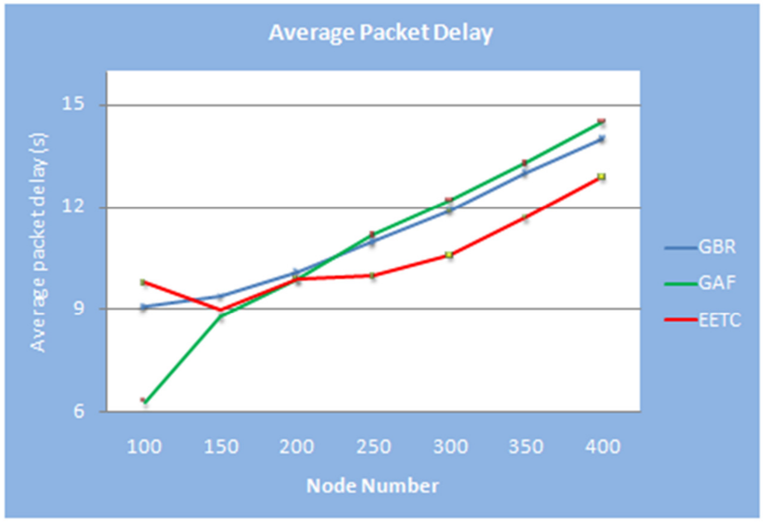


Figure 6.31 Average packet delays in EETC, Naps, GBR and GAF four protocols with different node numbers.

The main focus of our protocol is energy management and increasing reliability. Energy saving is realized by topology control and sleep/wake up methods. Also, it uses data aggregation technique to prolonging network lifetime. EETC uses a routing algorithm that is based on link state categories. It detects paths with using Dijkstra algorithm.

EETC is connectivity-driven protocol and works without need to geographic location information. Another type of topology management protocols are location-based protocols. In location-driven protocols, sensors nodes require know somewhat about their position by certain tools like the GPS (global positioning system) unit. The GPS is quite expensive and energy consuming so it is often unfeasible to install it on all nodes. The most of sensor platforms lack the hardware suitable to acquire location information. Therefore, connectivity-driven protocols are preferable generally.

6.5 Summary and Conclusion

EETC protocol is an energy efficient approach so its major object is reach to energy efficiency with using some of the methods such as topology control, sleep/wake up and data aggregation schemas. The protocol has three phases. In the first phase, sink broadcast an interest message to all sensor nodes. The nodes increase one unit to interest hop variable with receiving the message and its value is registered to node as ID-layer. If the message duplicate to a node then the node doesn't change interest hop value. In end of the phase, the sensors with the same identifier will be into a virtual layer. Also, a node knows its distance to sink via its ID-layer. For example, if ID-layer a node is five then it will be at least four-hop path to the sink. The second phase start after finishing the first phase.

In the second phase, all nodes in each layer can be modeled as a random graph and then begin to doing duty cycle method. Concept of the duty cycle is maintenance minimum active nodes to energy efficiency. In fact, Duty cycling is mainly focused on the networking subsystem. The most effective energy conserving operation is putting the radio transceiver in the (low-power) sleep mode whenever communication isn't required. Our algorithm creates a full connection state for each of active nodes in every layer. In fact, any node is waiting during t_v times and it is in sleep mode in this time. After this time, node convert to active mode and send HELLO message to self-neighbors that they are in range of its RF. It goes into sleep mode again upon receiving the responses from the neighbors. The responses are based on C value. This time is different to nodes and C and T parameters guarantee connectivity of network.

The third phase is routing and data transferring. Our routing protocol is based on direct and LS method and uses Dijkstra algorithm to find optimal paths. In fact, the routes are created before data sensing of nodes so that they select an optimal route to send it to sink. This method is similar to EESTDC and is opposite FTIEE. Our method is different from conventional routing and this different is sleep nodes routing. When a sleep node actives self-RF and senses a phenomenon, it send the data to nearest active neighbors. If any neighbor node doesn't receive then it changes its position to active mode. Also, in our protocol doesn't exist a fixed route from a node to sink and it can send its data to sink via several paths. This case guarantees reliability and tolerance against faults.

Activation of sleep nodes is done by wake up nodes. However, it is done by sink in almost current protocols. This case guarantees energy saving in our network. Moreover, if number of lost packets rise and or an error has occurred in the network then sink send HELP message to sleep nodes to activation of them. Also, if a new node adds to the network then it goes to sleep mode and therefore it is managed by the proposed approach. Hence, the method is stable.

Also, the protocol can be introduced as hierarchical based method so that the virtual layers can be our clusters and active nodes in every layer can be our CH nodes. Also, data aggregation is realized by active nodes and therefore we don't extra overhead over a node of layer or cluster.

Our protocol is based on energy management field and uses duty-cycle schema to it. Therefore it pays less attention to communication and data transferring issues. The protocol relies on connectivity issue so it creates a reliable and connective structure. In this protocol, the sleep nodes are placed in the graph structure after changing to active mode so the switching states don't damage to the network performance.

We simulated our protocol in different cases and compared it with Naps, GBR and GAF. GAF is one of the best of energy efficient routing protocols in topology control based schema. GBR is a direct-based routing protocol that it has a good performance in packet delivery factor. Because it doesn't use sleep/wake up modes and all nodes are active in the GBR. Naps protocol is a strong connectivity based topology control method but it doesn't attention to optimal routing. We simulated all protocols in some of the output parameters such as network lifetime, packet delivery/lost ratio and packet delays. The results showed that the EETC has a best performance in the network lifetime parameter so its improvement is about 2.5 percent higher than GAF, 13.5 percent higher than Naps and 70 percent higher than GBR. Also, its performance in the packet delivery rate is about 10.5 percent higher than GAF, 72 percent higher than Naps, but GBR is better than our protocol in this case and it is about 3 percent higher than EETC. Average delays imposed on the nodes in the structure of our protocol have little relationship with the number of nodes on the network unlike many other methods. In the many protocols, with increasing node numbers, density of nodes rises and communication channels are also more likely to sink and packet buffering is low. But EETC controls the density by topology control schema so that it uses C parameter to it. This is also true for Naps. In summary, packet transmission is performed with a delay of almost constant with maintaining a certain number of connections in the network. However, it should also bear in mind that we can be consistent of value of C to avoid delays caused by the sudden increase depending on specific times. On the other hand, direct routing methods are affective on reduction of delays.

CHAPTER SEVEN
CONCLUSIONS AND FUTURE WORK

Wireless Sensor Network (WSN) is combining of large number of mini size sensor nodes and a few Base Stations (BS) or sink. The nodes have low battery and limited memory. In this structure, the sensor nodes work together so they sense phenomenon and then collect and process data and send to the BS/sink in the end. The WSNs can be used in the many applications as civil, medical, military, governmental and probability-based application as volcano. Although, researchers focused on service quality and creation new applications but they attend to energy issue in these networks gradually. The researchers propose different approaches for this goal such as energy efficiency by routing techniques, data aggregation, duty-cycle techniques, medium-access decision and etc. Energy efficiency is posed primarily on communications, data transferring and power management techniques. Routing methods are one of these methods that use the techniques. They are classified in three groups.

In fact, the WSNs are designed for specific applications so characteristics and requirements for each of these applications are different. Therefore, they need to the new communication protocols, algorithms and designs. Moreover, factors related to network design must also be considered to achieve the expected performance in the WSNs. The most important constraint in the WSN is energy. Hence, it must is managed by approaches or techniques as algorithms. In the chapter, we focus on energy problem from the perspective of algorithmic to have an energy-efficient and longer life network.

The first group is flat based protocols. Flat based network architecture has several advantages, including minimal overhead to maintain the infrastructure and support reliable system by multiple paths between nodes. Some of the routing protocols use a data-centric method to distribute interest within the network. The method uses attribute or query based naming, whereby a source node queries an attribute for the phenomenon rather than an individual sensor node. The interest dissemination is achieved by assigning tasks to sensor nodes and expressing queries to relative to specific attributes. Different strategies can be used to communicate interests to the sensor nodes, including broadcasting, attribute-based multicasting and any casting. In this case, sensor nodes energy which is closed to its BS/sink is depleted earlier. In the some of the literature this method is a separate group of classification but in some others it belongs to flat category. We use the second idea for our classification schema.

The second classes of routing protocols have some of the special properties such as energy efficiency, stability and scalability. This category is called Hierarchical approach. In this case, network divides to several parts which each part is named cluster. Each cluster is consisting of many sensor nodes. Any sensor node communicates with other nodes that they belong to the same cluster. The cluster base network has an interface between cluster`s nodes and sink. This task is for a sensor node in any cluster that is named Cluster Head (CH). The CH node receives transmitted data from self-group sensors and aggregates them within the cluster and transfer information to the other clusters or BS/sink. Clustering system can decrease energy consumption and increase network lifetime because any node doesn't participate in transmission routes and routes length shorter than the flat category.

The third classes of routing protocols are based on location architecture. They are useful in applications where the position of the node within the geographical coverage of the network is relevant to the query distributed by the source node. Such a query may determine a specific region where a phenomenon of interest may occur or the nearby area to a specific point in the network.

Different protocols have been presented in the three categories. Each of these methods was pursuing specific goals. For example, some of them were working to prolonging lifetime; the others were working to increasing data delivery and or reliability but common goal most of them were reach to improvement the energy consumption.

The other category of energy efficiency approaches is energy management. Duty cycling is mainly focused on the networking subsystem. Main work of duty-cycle based approaches is maintenance radio transceiver in low power state by sleep mode and it is realizable whenever a sensor node doesn't communicate with other nodes. Ideally, the radio should be switched off as soon as there is no more data to send/receive, and should be resumed as soon as a new data packet becomes ready. In this way nodes alternate between active and sleep periods depending on network activity. Process unit of sensor node do exchanging sleep to wake up mode or vice versa in special and defined periods. This task is done a sleep/wake up scheduling algorithm within any protocol based on duty cycle schema. It is typically a distributed algorithm based on which sensor nodes decide when to transition from active to sleep and back. It allows neighboring nodes to be active at the same time, thus making packet exchange feasible even when nodes operate with a low duty cycle (i.e., they sleep for most of the time). Duty-cycling schemes are typically oblivious to data that are sampled by sensor nodes.

In this thesis, we proposed three new algorithms to optimizing energy consumption in WSNs. In the first work (EESTDC), we suggested an energy efficient routing algorithm that it was based on spanning tree structure and dynamic clustering. These two ideas together could increase lifetime of network and had some other advantages as increase delivered packets number. It was based on hierarchical based protocols. The EESTDC had two phases. The first, deployed clusters and determined CH for every cluster and created communication model between nodes by a dynamic spanning tree schema. The second phase was data transmission between sensor nodes and the BS/sink. In fact, the first step in this protocol was dividing network to several clusters. Then election CH node method has applied to every cluster. This method has applied for all running rounds of network and therefore, CH node has changed in every round. In fact, the network has divided to several executive rounds and has applied both phases in any round. All sensor nodes belong to per cluster can be in this CH election self-cluster. Since CH nodes discharge their energy faster than other sensor nodes in that cluster, we must apply special measures to CH selection nodes in our network. CH node must be replaced regularly to avoid overuse of a node as the CH node. One the other hand, one of the specific characteristics in our protocol was using sleep/wake-up method. This was an energy efficiency method that was based on duty-cycle schema. Our protocol could realize energy saving and prolonging lifetime factor. Because energy parameter had priority than other output factors such as packet delivery, lost and packet delay. Nevertheless, it had suitable performance in the parameters.

The second protocol (FTIEE) was an intelligent routing protocol to creation balance between network output parameters as network lifetime and reliability. Therefore, except the energy concept, it focused on fault tolerance too. It was based on hierarchical protocols. Our protocol used the reinforcement learning approach to data routing. The terms used in this technique were action, agent, state, reward, episode and policy. Agent was a learner that optimizes its behavior over time learning process. Action was series of activities that an agent can do them. Reward was a value that agent received from the environment for every action and it could be positive or negative. State showed the agent mode. Episode was set of states that an agent passed to reach the goal. Policy was concerned with choice of an action by the Agent. Policies were defined in different models as greedy and ε-greedy policies. Also, in this protocol, all nodes within a cluster could be CH node and clusters didn't have to be a CH node and this election is done by learning machine. In fact, one of our goals was increasing network lifetime by reduction energy consumption obtained of repeated elections of CH nodes. In our protocol, numbers of clusters were constant as like EESTDC protocol but unlike it the shaped of clusters are square. The forms of clusters in EESTDC were arbitrary and could be in any form. Size of the clusters was variable in FTIEE. It is same with EESTDC but the models are different. In first approach didn't exist any rule to it and cluster sizes can be variable and different from each other but second approach (FTIEE) was based on a rule. Clusters that are close to BS/sink were smaller than to clusters that are located farther toward the BS/sink. In fact, the size of the clusters increased with increasing distance to the BS/sink. In generally case, it could create almost good balance between packet delivery and network lifetime.

EETC protocol was an energy efficient approach so its major object was reach to energy efficiency with using some of the methods such as topology control, sleep/wake up and data aggregation schemas. In first phase, the sensors have placed into virtual layers. The second phase, all nodes in each layer could be modeled as a random graph and then began to management by duty cycle method. Concept of the duty cycle was maintenance minimum active nodes to energy efficiency. Our algorithm created a full connection state for each of active nodes in every layer. It could increase network lifetime and reliability by C and T parameters into its structure. The third phase was routing and data transferring. Our routing protocol was based on direct and LS method and uses Dijkstra algorithm to find optimal paths. In fact, the routes have created before data sensing of nodes so that they selected an optimal route to send it to sink. This method is similar to EESTDC and is opposite FTIEE. Our protocol was based on energy management field and uses duty-cycle schema to it. Therefore it paid less attention to communication and data transferring issues. The protocol relied on connectivity issue so it created a reliable and connective structure. In this protocol, the sleep nodes was placed in the graph structure after changing to active mode so the switching states didn't damage to the network performance. Also, this protocol can be introduced as hierarchical based method so that the virtual layers can be our clusters and active nodes in every layer can be our CH nodes. Also data aggregation is realized by active nodes and therefore we don't extra overhead over a node of layer or cluster.

In the end of thesis, we offer some of the future works in the fields. Our suggestions on first protocol are:

1- Focus on communications between CH nodes in intra-network and optimize their relations.
2- Use intelligent routing techniques like FTIEE and its combining with dynamic clustering and spanning tree structures.
3- Use Fuzzy Logic and so on in EESTDC to create optimal communication paths and activation of nodes.
4- Transfer CH tasks to adjacent nodes in the cluster. It was applied in FTIEE.

5- Use topology control methods to improve the lifetime of sensor networks. It was applied in EETC.

Our suggestions on second protocol are:

1- Use intelligent part of this method on our other two protocols.
2- Deployment of static applications based on intelligent protocol.
3- Study performance of other intelligent methods with using the general policy of FTIEE.

Our suggestions on third protocol are:

1- Extend to mobile wireless sensor networks.
2- Apply EESTDC or FTIEE protocols on the data transferring phase of EETC.
3- Apply in the real hierarchical based structure.
4- Increase adaptively with consistency between communication parameters and the number of packets in the environment. Also, we can be prevented from delays caused by the sudden increase of packet with this consistency.

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APPENDICES

Appendix A- EESTDC performance by different data sets

First input parameters table

Initial (max) energy	0.1 J/bit	**Receive buffer size**	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	**Send buffer size**	1500 bytes
Transmit process cost	40 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	10 n J/bit	**Send/receive buffer counts**	10
Data packet size	150 bytes	**Sink position**	(310 x 310) m
Sensing Radius	4.5m	**Transmission Radius**	9m

A: Output: Network Lifetime by different nodes number: It is evident that network lifetime will increase with increasing the node numbers (s=second).

	50	75	100	125	150	175	200	225	250
EESTDC	112s	128s	145s	163s	190s	219s	240s	263s	286s
Improved-LEACH	108s	123s	137s	155s	178s	206s	231s	253s	274s
EESR	103s	116s	129s	146s	161s	178s	199s	220s	242s
HEED	104s	117s	129s	143s	157s	172s	190s	209s	230s

B: Output: Packet delivery by different nodes number: It is evident that packet delivery will increase with increasing the node numbers but rate of it can decrease or increase.

	50	75	100	125	150	175	200	225	250
EESTDC	77	91	109	122	145	165	195	219	248
Improved-LEACH	75	89	105	116	139	162	187	213	239
EESR	72	86	103	115	135	159	183	208	232
HEED	70	84	100	109	119	139	160	181	204

Second input parameters table

Initial (max) energy	0.1 J/bit	**Receive buffer size**	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	**Send buffer size**	1500 bytes
***Transmit process cost**	30 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	10 n J/bit	**Send/receive buffer counts**	10
Data packet size	150 bytes	**Sink position**	(310 x 310) m
Sensing Radius	4.5m	**Transmission Radius**	9m

A: Output: Network Lifetime by different nodes number (s=second).

	50	75	100	125	150	175	200	225	250
EESTDC	113s	130s	148s	166s	193s	222s	245s	268s	292s
Improved-LEACH	112s	126s	141s	160s	182s	211s	237s	259s	281s
EESR	106s	119s	134s	151s	165s	184s	205s	227s	249s
HEED	108s	121s	133s	148s	161s	177s	195s	215s	236s

B: Output: Packet delivery by different nodes number.

	50	75	100	125	150	175	200	225	250
EESTDC	78	92	111	124	148	169	200	225	255
Improved-LEACH	77	91	108	120	141	166	192	220	245
EESR	74	88	106	119	139	164	189	215	239
HEED	71	85	101	111	121	142	163	185	210

Third input parameters table

*** Initial (max) energy**	0.2 J/bit	**Receive buffer size**	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	**Send buffer size**	1500 bytes
Transmit process cost	30 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	10 n J/bit	**Send/receive buffer counts**	10
Data packet size	150 bytes	**Sink position**	(310 x 310) m
Sensing Radius	4.5m	**Transmission Radius**	9m

A: Output: Network Lifetime by different nodes number.

	50	75	100	125	150	175	200	225	250
EESTDC	123s	141s	164s	184s	211s	244s	265s	292s	318s
Improved-LEACH	122s	136s	154s	173s	198s	211s	237s	259s	281s
EESR	115s	129s	143s	159s	173s	184s	205s	227s	249s
HEED	117s	130s	144s	155s	170s	177s	195s	215s	236s

B: Output: Packet delivery by different nodes number.

	50	75	100	125	150	175	200	225	250
EESTDC	81	97	116	130	154	175	206	230	261
Improved-LEACH	78	94	113	126	150	172	198	223	250
EESR	75	90	109	121	142	166	192	217	242
HEED	73	86	103	115	127	148	168	190	214

Fourth input parameters table

Initial (max) energy	0.1 J/bit	**Receive buffer size**	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	**Send buffer size**	1500 bytes
Transmit process cost	30 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	10 n J/bit	**Send/receive buffer counts**	10
Data packet size	150 bytes	**Sink position**	(310 x 310) m
Sensing Radius	4.5m	*** Transmission Radius**	11m

A: Output: Network Lifetime by different nodes number.

	50	75	100	125	150	175	200	225	250
EESTDC	115s	132s	150s	169s	199s	229s	252s	276s	301s
Improved-LEACH	111s	126s	141s	160s	185s	213s	240s	263s	285s
EESR	105s	119s	134s	152s	167s	185s	208s	229s	256s
HEED	106s	121s	134s	150s	162s	179s	199s	217s	244s

B: Output: Packet delivery by different nodes number.

	50	75	100	125	150	175	200	225	250
EESTDC	78	93	111	125	149	169	202	225	255
Improved-LEACH	77	91	109	122	145	167	193	220	246
EESR	74	89	106	120	140	163	189	215	239
HEED	72	87	103	113	125	146	167	188	213

Fifth input parameters table

Initial (max) energy	0.1 J/bit	**Receive buffer size**	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	**Send buffer size**	1500 bytes
Transmit process cost	30 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	10 n J/bit	**Send/receive buffer counts**	10
Data packet size	150 bytes	*** Sink position**	(650 x 650) m
Sensing Radius	4.5m	**Transmission Radius**	11m

A: Output: Network Lifetime by different nodes number.

	50	75	100	125	150	175	200	225	250
EESTDC	109s	124s	141s	159s	185s	213s	232s	255s	278s
Improved-LEACH	107s	122s	136s	154s	177s	205s	230s	251s	273s
EESR	101s	114s	126s	143s	157s	174s	194s	215s	237s
HEED	104s	117s	128s	142s	156s	171s	190s	209s	230s

B: Output: Packet delivery by different nodes number.

	50	75	100	125	150	175	200	225	250
EESTDC	73	86	104	116	145	160	189	209	238
Improved-LEACH	73	86	103	113	137	158	184	208	234
EESR	69	83	100	110	130	155	179	201	227
HEED	70	83	99	109	118	138	160	180	203

EESTDC has better performance than EESR, Improved-LEACH and HEED in network lifetime parameter, when:

1- Transmit process cost / sense process cost >=4
2- Node number >=150
3- Initial energy of each node / energy consumptions >=20
4- Buffer size / data packet size >=10
5- Transmission radius / sensing radius >=2
6- Sink position is within environment and near center.

EESTDC has better performance than EESR, Improved-LEACH and HEED in packet delivery parameter, when:

1- Transmit process cost / sense process cost >=4
2- Node number >=175
3- Initial energy of each node / energy consumptions >=20
4- Buffer size / data packet size >=15
5- Transmission radius / sensing radius >=2.5
6- Sink position is within environment and near center.

Appendix B- FTIEE performance by different data sets

First input parameters table

Initial (max) energy	0.1 J/bit	**Receive buffer size**	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	**Send buffer size**	1500 bytes
Transmit process cost	40 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	10 n J/bit	**Send/receive buffer counts**	10
Data packet size	150 bytes	**Sink position**	(310 x 310) m
Sensing Radius	4.5m	**Transmission Radius**	9m

A: Output: Network Lifetime by different nodes number: It is evident that network lifetime will increase with increasing the node numbers (s=second).

	50	75	100	125	150	175	200	225	250
FTIEE	112s	126s	144s	160s	178s	204s	223s	245s	267s
HEED-NPF	109s	122s	139s	157s	175s	199s	217s	236s	253s
EECS	106s	121s	137s	153s	171s	195s	209s	225s	242s
LEACH	95s	105s	121s	135s	150s	164s	185s	197s	210s

B: Output: Packet delivery by different nodes number: It is evident that packet delivery will increase with increasing the node numbers but rate of it can decrease or increase.

	50	75	100	125	150	175	200	225	250
FTIEE	79	96	110	125	152	178	209	246	290
HEED-NPF	75	90	106	122	149	173	200	232	275
EECS	72	86	103	115	135	159	183	208	232
LEACH	70	84	100	109	119	139	160	181	204

Second input parameters table

*** Initial (max) energy**	0.2 J/bit	**Receive buffer size**	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	**Send buffer size**	1500 bytes
Transmit process cost	30 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	10 n J/bit	**Send/receive buffer counts**	10
Data packet size	150 bytes	**Sink position**	(310 x 310) m
Sensing Radius	4.5m	**Transmission Radius**	9m

A: Output: Network Lifetime by different nodes number.

	50	75	100	125	150	175	200	225	250
FTIEE	123s	141s	160s	177s	195s	222s	241s	257s	273s
HEED-NPF	120s	138s	157s	173s	190s	217s	236s	248s	263s
EECS	116s	136s	155s	171s	189s	216s	235s	248s	262s
LEACH	103s	119s	140s	158s	170s	193s	210s	221s	239s

B: Output: Packet delivery by different nodes number.

	50	75	100	125	150	175	200	225	250
FTIEE	86	102	122	141	165	189	224	260	317
HEED-NPF	82	98	118	135	159	180	213	242	294
EECS	79	96	115	131	150	172	199	229	243
LEACH	70	84	100	109	119	139	160	181	204

Third input parameters table

Initial (max) energy	0.1 J/bit	**Receive buffer size**	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	**Send buffer size**	1500 bytes
Transmit process cost	30 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	10 n J/bit	**Send/receive buffer counts**	10
Data packet size	150 bytes	**Sink position**	(310 x 310) m
Sensing Radius	4.5m	*** Transmission Radius**	11m

A: Output: Network Lifetime by different nodes number.

	50	75	100	125	150	175	200	225	250
FTIEE	115s	129s	148s	166s	184s	213s	232s	256s	279s
HEED-NPF	114s	128s	146s	164s	180s	207s	227s	250s	272s
EECS	110s	122s	142s	160s	177s	202s	219s	238s	260s
LEACH	100s	112s	126s	142s	160s	179s	199s	218s	239s

B: Output: Packet delivery by different nodes number.

	50	75	100	125	150	175	200	225	250
FTIEE	86	105	120	135	163	192	227	270	321
HEED-NPF	80	99	111	128	157	182	222	246	293
EECS	74	93	108	123	150	172	190	218	248
LEACH	73	89	105	113	129	152	179	205	221

Fourth input parameters table

Initial (max) energy	0.1 J/bit	**Receive buffer size**	1500 bytes
Radio/ Sensor energy consumption	50 n J/bit	**Send buffer size**	1500 bytes
Transmit process cost	30 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	10 n J/bit	**Send/receive buffer counts**	10
Data packet size	150 bytes	*** Sink position**	(650 x 650) m
Sensing Radius	4.5m	**Transmission Radius**	11m

A: Output: Network Lifetime by different nodes number.

	50	75	100	125	150	175	200	225	250
FTIEE	93s	116s	134s	150s	168s	192s	210s	232s	252s
HEED-NPF	92s	111s	130s	149s	160s	186s	201s	223s	240s
EECS	90s	104s	127s	140s	157s	183s	197s	219s	235s
LEACH	89s	102s	118s	133s	148s	162s	183s	194s	206s

B: Output: Packet delivery by different nodes number.

	50	75	100	125	150	175	200	225	250
FTIEE	72	86	105	118	150	166	195	223	272
HEED-NPF	70	83	100	110	144	160	182	213	249
EECS	67	80	97	105	130	152	177	201	219
LEACH	65	78	95	100	119	130	166	187	208

FTIEE has best performance in network lifetime parameter, when:

Node number <=200

Initial energy of each node / energy consumptions >=30

Buffer size / data packet size >=5

Transmission radius / sensing radius >=2

Sink position is within environment and near center.

FTIEE has best performance in packet delivery parameter, when:

Node number >=150

Initial energy of each node / energy consumptions >=30

Buffer size / data packet size >=10

Transmission radius / sensing radius >=2.5

Sink position is within environment and near center.

Appendix C- EETC performance by different data sets

First input parameters table

Initial (max) energy	1.1 J/bit	**Receive buffer size**	13000 bytes
Radio/ Sensor energy consumption	40 n J/bit	**Send buffer size**	13000 bytes
Transmit process cost	40 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	15 n J/bit	**Send/receive buffer counts**	25
Data packet size	250 bytes	**Sink position**	(600 x 350) m
Sensing Radius	6 m	**Transmission Radius**	12 m

A: Output: Network Lifetime by different nodes number: It is evident that network lifetime will increase with increasing the node numbers (M=minute).

	100	150	200	250	300	350	400	450	500
EETC	14 M	19 M	24 M	30.3 M	36 M	46.5 M	52 M	59 M	67.3 M
GAF	18 M	21.5 M	25.5 M	31 M	36 M	43 M	50.5 M	55.1 M	62.8 M
Naps	12.4 M	16.3 M	22.5 M	27 M	32 M	40 M	45 M	52 M	59.2 M
GBR	8.2 M	8.4 M	8.6 M	8.8 M	9.1 M	9.3 M	9.5 M	9.7 M	9.9 M

B: Output: Packet delivery rate by different nodes number. Its rate may be decrease or increase with increasing node number because some of the parameters effect on it such as high volume of node density.

	100	150	200	250	300	350	400	450	500
EETC	71%	73%	70%	77%	78%	75%	69%	65%	63%
GAF	65%	70%	68%	67%	69%	68%	62%	60%	58%
Naps	40%	43%	41%	44%	47%	46%	39%	36%	33%
GBR	78%	74%	75%	78%	79%	77%	71%	68%	65%

Second input parameters table

***Initial (max) energy**	1.5 J/bit	**Receive buffer size**	13000 bytes
Radio/ Sensor energy consumption	40 n J/bit	**Send buffer size**	13000 bytes
Transmit process cost	40 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	15 n J/bit	**Send/receive buffer counts**	25
Data packet size	250 bytes	**Sink position**	(600 x 350) m
Sensing Radius	6 m	**Transmission Radius**	12 m

A: Output: Network Lifetime by different nodes number.

	100	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
EETC	15 M	20.2 M	25.3 M	32 M	37.2 M	48.1 M	53.3 M	60.4 M	68.9 M
GAF	18.6 M	22.4 M	26.5 M	32.3 M	37 M	44.7 M	52.1 M	56.6 M	64.3 M
Naps	12.9 M	17.1 M	23.2 M	28.3 M	33.7 M	41.4 M	46.8 M	53.8 M	60.7 M
GBR	8.4 M	8.6 M	8.8 M	9.1 M	9.3 M	9.6 M	9.9 M	10.1 M	10.3 M

B: Output: Packet delivery by different nodes number.

	100	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
EETC	71%	73.3%	70.4%	77.5%	78.5%	76.3%	69.4%	65.8%	63.3%
GAF	65.3%	71%	69%	68%	69.9%	68.5%	62.7%	60.4%	58.9%
Naps	40.8%	43.9%	41.5%	45%	48%	47%	39.8%	36.9%	34%
GBR	79.3%	75.3%	76.2%	78.9%	79.9%	77.4%	72%	68.8%	65.5%

Third input parameters table

Initial (max) energy	1.5 J/bit	**Receive buffer size**	13000 bytes
Radio/ Sensor energy consumption	40 n J/bit	**Send buffer size**	13000 bytes
Transmit process cost	40 n J/bit	**Deployment area size**	(600 x 600) m
Receive/sense process cost	15 n J/bit	**Send/receive buffer counts**	25
Data packet size	250 bytes	**Sink position**	(600 x 350) m
Sensing Radius	6 m	***Transmission Radius**	12 m

A: Output: Network Lifetime by different nodes number: It is evident that network lifetime will increase with increasing the node numbers (M=minute).

	100	150	200	250	300	350	400	450	500
EETC	14.4 M	19.5 M	24.5 M	30.7 M	36.7 M	47.5 M	53 M	60.1 M	68.4 M
GAF	18.1 M	21.6 M	25.7 M	31.2 M	36.2 M	43.3 M	50.8 M	55.5 M	63.4 M
Naps	12.7 M	16.9 M	23.2 M	27.6 M	32.8 M	40.9 M	45.9 M	53.1 M	60.9 M
GBR	8.3 M	8.5 M	8.8 M	9 M	9.3 M	9.6 M	9.9 M	10.2 M	10.4 M

B: Output: Packet delivery rate by different nodes number.

	100	150	200	250	300	350	400	450	500
EETC	71%	73.1%	70.2%	77.2%	78.2%	75.3%	69.3%	65.3%	63.3%
GAF	65%	70%	68.1%	67.1%	69.1%	68.2%	62.2%	60.2%	58.3%
Naps	40.1%	43.2%	41.2%	44.2%	47.3%	46.3%	39.3%	36.3%	33.4%
GBR	78.2%	74.2%	75.3%	78.3%	79.4%	77.3%	71.5%	68.3%	65.4%

EETC has best performance in network lifetime parameter, when:

Node number >=300

Buffer size / data packet size >=25

Transmission radius / sensing radius >=2

EETC has best performance in packet delivery rate parameter, when:

Node number =300

Buffer size / data packet size >=25

Transmission radius / sensing radius >=2