ENHANCED TECHNIQUE FOR MAXIMIZING WIRELESS SENSOR NETWORKS LIFETIME BASED ON UTILIZING THE PHENOMENA OF OVERLAPPING NODES AND DATA TRANSMISSION

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by

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With the name of Allah, Most Gracious, Most Merciful

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LIST OF ABBREVIATIONS

BA	Blind Area
BS	Base Station
CE	Consumed Energy
CH	Cluster Head
D	Density of Nodes
GA	Genetic Algorithm
LNS	Normal Sensors Lifetime
LOS	Overlapping Sensors Lifetime
NS	Normal Sensors
OA	Overlapping Area
OEMCM	Overlapping Effect Minimization Clustering Mechanism
OEMM	Overlapping Effect Minimization Mechanism
OMPFM	Optimal Multi-hop Path Finding Mechanism
OS	Overlapping Sensors
SR	Sensing Range
SVR	Sensing Volume Ratio
TR	Transmission Range
WSN	Wireless Sensor Network

LIST OF SYMBOLS

alpha	Overlapping Factor
AVG_{CER}	Average of Consumed Energy Required for Data Receiving
AVG_{CET}	Average of Consumed Energy Required for Data Transmit
AVG_{RE}	Average of the Residual Energy
CTd	Critical Overlapping Threshold
E_{CHs}	Average Residual Energy of All CHs in the Transmission Path
F(i)	Fitness Function
Iterations	Number of Iterations in GA
L_{CH}	Ratio of Any CH's Remaining Lifetime
L_{NS}	Ratio of Any Normal Sensor Node's Remaining Lifetime
L_{NW}	Remaining Lifetime of the Whole Network
L_{OS}	Ratio of Any Overlapping Sensor Node's Remaining Lifetime
Mr	Mutation Rate
Cr	Crossover Rate
NoOfPart	Number of Participations of Any CH in the Transmission Path
Pop-Size	Size of Population
Rmax	Maximum Number of Rounds
Td	Overlapping Threshold

TEKNIK DIPERTINGKAT UNTUK MEMAKSIMUM TEMPOH HAYAT RANGKAIAN SENSOR WAYARLES BERASASKAN PENGGUNAAN FENOMENA NOD-NOD BERTINDIH DAN PENGHANTARAN DATA

ABSTRAK

Rangkaian Sensor Wayarles (WSN) telah menarik perhatian ramai penyelidik dalam tempoh beberapa dekad yang lalu kerana penggunaan yang meluas dalam banyak aplikasi seperti pemantauan persekitaran, penjejakan api, dan pemantauan jagaan kesihatan. Dalam WSN, nod-nod sensor diletak atur dalam kawasan sasaran untuk mengesan peristiwa-peristiwa yang dikehendaki. Letak atur nod-nod boleh dibuat secara formal (lokasi spesifik) atau secara rawak (lokasi rawak). Bagi WSN yang diletak atur secara rawak, salah satu masalah yang selalu dihadapi apabila kedudukan sensor berada berdekatan antara satu sama lain, adalah pertindihan antara mereka. Pertindihan ini menyebabkan pengesanan data yang lebih kurang sama oleh nod-nod yang berbeza dan seterusnya penghantaran data duplikasi ke kepala gugusan (CH), yang mengakibatkan penggunaan lebih banyak tenaga. Masalah lain dalam WSN adalah penghantaran data secara terus dari CH ke Stesen Utama (BS), yang turut mempengaruhi keseluruhan tempoh hayat rangkaian secara negatif. Tambahan lagi, kerawakan kaedah pemilihan CH menyebabkan nod yang mempunyai tenaga yang rendah terpilih menjadi CH yang akan mengurangkan tempoh hayat rangkaian. Tesis ini bertujuan untuk menyelesaikan masalah pertindihan antara nod-nod dan penghantaran data secara terus dengan menggunakan mekanisma-mekanisma yang berbeza. Dalam tesis ini, satu mekanisma untuk memanjangkan tempoh hayat rangkaian dicadangkan dengan mengurangkan kesan negatif masalah pertindihan dan disesuaikan dengan nod-nod yang bertindih untuk memaksimumkan kecekapan rangkaian dari segi tempoh hayat rangkaian dan penggu-

naan tenaga. Mekanisma ini mengambil kira jarak antara nod-nod secara efisien untuk mengenalpasti pertindihan antara mereka berasaskan tabiat aplikasi dengan mengambil kira kawasan buta nod-nod bertindih. Seterusnya, proses pengesanan berselang-seli digunakan pada nod-nod bertindih secara efisien untuk memaksimumkan tempoh hayat mereka. Tambahan lagi, kes-kes kritikal seperti pertindihan lebih daripada dua nod dan urusan dengan nod-nod bertindih apabila salah satu daripadanya tamat tempoh hayat turut diambil pertimbangan dalam tesis ini. Dua lagi mekanisma dicadangkan dalam tesis ini untuk memanjangkan tempoh hayat rangkaian dengan menyelesaikan masalah penghantaran data secara terus dari CH ke BS, dan dengan menyelesaikan masalah kerawakan dalam pemilihan CH. Mekanisma-mekanisma ini memadankan Algoritma Genetik (GA) sebagai teknik pengoptimuman untuk mencari laluan multi-hop optimal dari CH sumber ke BS. Satu praproses dilaksanakan untuk mempertingkatkan teknik GA dan meningkatkan lagi kecekapannya. Tambahan lagi, parameter-parameter yang sesuai turut dicadangkan untuk merumus fungsi kesesuaian (fitness function). Ini akan memaksimumkan tempoh hayat rangkaian dengan pengurangan penggunaan tenaga oleh CH. Keputusan eksperimen menggunakan data simulasi menunjukkan teknik yang dicadangkan berupaya memperbaiki prestasi keseluruhan rangkaian dari segi tempoh hayat rangkaian dengan peningkatan bilangan kitaran sebanyak kira-kira 2,709 kitaran secara purata (kira-kira 180.3%) berbanding beberapa protokol yang berkaitan, dan dari segi bilangan paket yang dihantar ke stesen utama dengan peningkatan jumlah bilangan paket kira-kira 6,821 paket secara purata (kira-kira 77.5%) berbanding beberapa protokol yang berkaitan.

ENHANCED TECHNIQUE FOR MAXIMIZING WIRELESS SENSOR NETWORKS LIFETIME BASED ON UTILIZING THE PHENOMENA OF OVERLAPPING NODES AND DATA TRANSMISSION

ABSTRACT

Wireless Sensor Networks (WSNs) have attracted the attention of the researchers in the last few decades due to their involvement in many applications such as monitoring environment, fire tracking, and health care monitoring. In WSN, sensor nodes are deployed on the target area to sense the required events. The deployment of nodes can be formal (in specific locations) or random (in random locations). In the WSN that uses the random deployment of nodes, one of the common problems, when the sensors are close to each other, is the overlapping between them. This overlapping causes sensing approximately the same data by different nodes and also the transmission of duplicate data to the Cluster Head (CH), which leads to more energy consumption. Another problem in WSNs is the direct transmission of data from a CH to the Base Station (BS), which also negatively influences the overall network lifetime. Moreover, the random selection of the CHs leads to select nodes with low energy to be CHs which reduces the network lifetime. This thesis intends to solve the overlapping between nodes and the direct data transmission using different mechanisms. In this thesis, a mechanism is proposed to prolong the network lifetime by reducing the negative effect of the overlapping problem and utilizing the overlapping nodes to maximize the efficiency of the network in terms of network lifetime and energy consumption. This mechanism considers the distance between nodes in an efficient way in order to identify the overlapping between them based on the nature of the application with considering the blind area of the overlapping nodes. Moreover, the alternating sensing process should be applied on the overlapping nodes in an efficient way to maximize their lifetime. In addition, the critical cases such as the overlapping among more than two nodes and the dealing with the overlapping nodes when one of them dies are to be taken into consideration. Other mechanisms are proposed to prolong the network lifetime by solving the problem of the direct data transmission from the CHs to the BS, and by solving the randomness in the CHs selection. These mechanisms adapt the Genetic Algorithm (GA) as an optimization technique to find the optimal multi-hop path from a source CH to the BS. A pre-processing technique is implemented to enhance the GA and to increase the efficiency of it. Furthermore, suitable parameters are proposed to formulate the fitness function. These processes maximize the network lifetime by reducing the consumed power in the CHs. The experimental results using the simulated data show that the proposed technique improves the overall performance of a network in terms of the network lifetime by increasing the number of rounds by approximately 2709 rounds in average (with approximately 180.3%) compared to several related protocols, and in terms of the number of transmitted packets to the BS by increasing the total number of these packets by approximately 6821 packets in average (with approximately 77.5%) compared to several related protocols.

CHAPTER 1

INTRODUCTION

1.1 Overview

Wireless Sensor Network (WSN) is a type of networks which is used in wide range areas to monitor several attributes that the human being cannot do due to the large size of the monitored area; therefore, the WSN is a good solution to be used in many applications for monitoring. WSN consists of large number of sensor nodes which are either formally or randomly deployed in the sensed area in order to sense specific events and send data to the basic device called Base Station (BS) for further analysis (Tiwari *et al.*, 2015).

The main problem in WSN is the limitations of the sensor nodes due to their limited power supply which causes these nodes to get down in a short time, and then negatively affects the lifetime of the WSN.

According to ONWorld reports (Hatler *et al.*, 2017) number of wireless devices that installed to be used in industrial fields increased by 553% between 2011 and 2016 and reached 24 million sensors deployed worldwide. In 2014, the percentage of wireless devices was 15% of the control equipment sensing point, and in 2016 was 33%. In 2018, the shipments of WSN components will reach one billion and in 2022 will reach three billion.

Based on the above statistics, it is clearly evident that the usage of WSNs is dramatically increased in the recent years and it will be continually increased in the coming years. Hence, it is important to find significant solutions to prolong the lifetime of WSN due to its significant influence on the overall network performance.

1.2 Background

In this section, a comprehensive overview of WSNs is explained, including the definition and usage of WSN, the structure of WSN and sensor nodes, and the challenges in WSN.

1.2.1 Wireless Sensor Networks (WSNs)

WSNs are type of networks used to monitor an area which is large and difficult to monitor by human beings. This type of networks is used in some applications which require continuous monitoring such as Fire sensing, Healthcare applications, and Environmental monitoring applications (HolgerKarl and Willig, 2006; Kumar and Chauhan, 2011; ChiaraBuratti *et al.*, 2009). Figure 1.1 shows the structure of the WSN. In order to do its function, WSN consists of a number of nodes which have the ability of sensing, monitoring, and transmitting data. These nodes are small in size, limited in power. Therefore, the main challenge in WSNs is how to extend the lifetime of the network with these constraints (Tiwari *et al.*, 2015). Figure 1.2 shows the components of a sensor node.

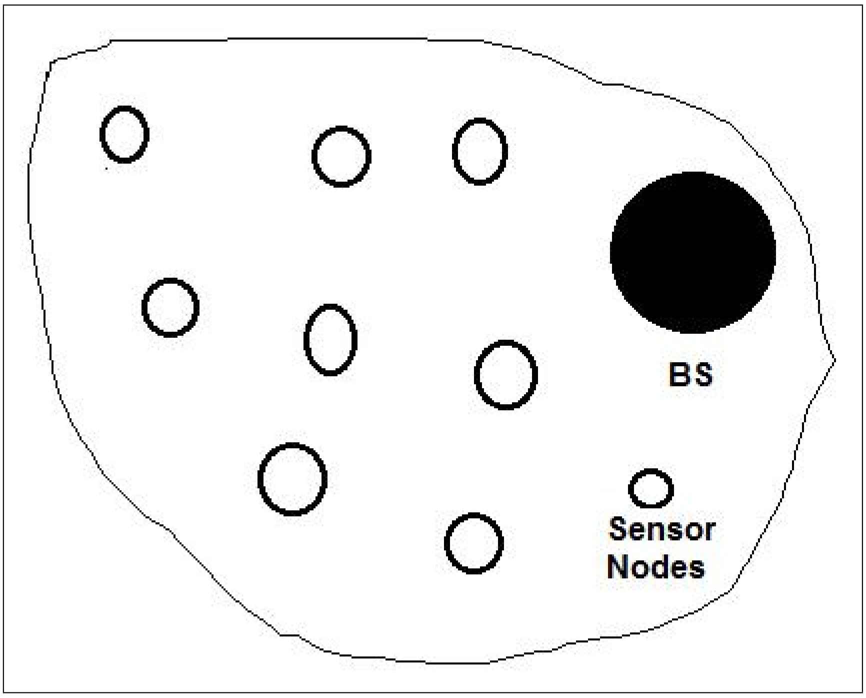

Figure 1.1: The Structure of the WSN

As it is noticed from Figure 1.1, the sensor nodes are randomly deployed in a sensing area in order to collect a specific data and send these data directly to the BS for further processing and analysis operations.

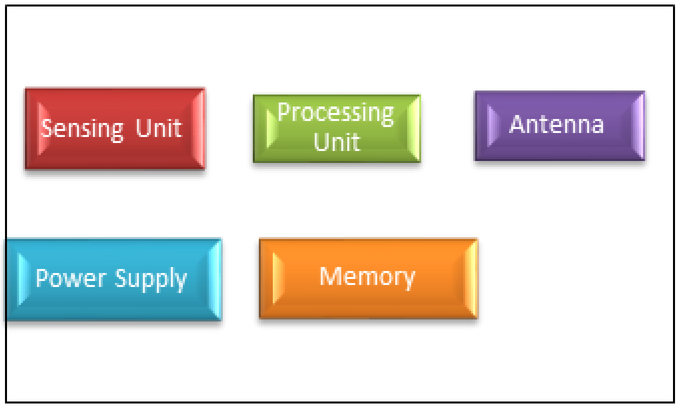

Figure 1.2: Components of the Sensor Nodes

Based on Figure 1.2, a sensor node consists of a sensing unit for sensing a specific event from sensing area according to the application. Also, it consists of a processing unit and small memory. The antenna is used to send data to other nodes or to receive data from other nodes. A small power supply is responsible for supplying the power to the sensor node; it is like a small battery which is limited in power. This limitation in power supply causes a fast drain of power in a sensor which leads to its death and then disconnect from a network (Lee *et al.*, 2012; Aliouat, 2012).

Unlike the traditional networks, WSNs are designed in a specific way according to the applications that use this type of networks, and these applications usually require a long time monitoring to collect data and make an analysis. However, WSNs have many drawbacks in terms of power and transmissions in order to keep these networks working properly without disconnecting (Singha *et al.*, 2015; Yick *et al.*, 2008).

Network lifetime is one of the most important issues in WSN field, which indicates the time of a network that it can be used without problems (Kewei and Weisong, 2005).

The lifetime of a network depends on many factors such as the number of active nodes and the connectivity. When the time of the last dead node increases, this leads to increase the lifetime of a network. This issue is considered very essential in WSN with sensor nodes that are randomly deployed in a large area, and the human beings cannot easily reach them; therefore, if the power of a node finishes, it is difficult to replace it and this negatively affects the functionality of a network (Tiwari *et al.*, 2015). In order to cope with this challenge, the network lifetime should be maximized.

Maximizing the lifetime of WSN is a very important issue to keep the network running for a long period of time in order to achieve its goal. This important issue in WSN is not appropriately solved yet. However, many protocols are proposed to address this problem, but still gaps in these protocols that should be considered to enhance the network lifetime.

1.2.2 WSN Structure

As discussed in subsection 1.2.1, WSNs have many sensor nodes which are deployed in a specific area for sensing a specific phenomenon such as the temperature, humidity, etc (Abed *et al.*, 2012). Many routing protocols are proposed to control the sensing operation and send the data to the BS. The proposed protocols are based on the structure of the WSN, and they are classified into three classes: Flat routing protocols, Location-based routing protocols, and Hierarchal-based routing protocols (Wu *et al.*, 2011).

In the Flat routing protocols, data are sent from each node to the BS. In the second category, the Location-based routing protocols, the data are sent from the source node to the BS based on the location information for the other nodes to decide which one is the next node in the transmission process. Finally, the Hierarchal-based routing protocols, the sensor nodes are divided into two types; sensing nodes and forwarding nodes, the data are sent from the sensing node to the BS via a forwarding node (Aetesam and Snigdh, 2017)

The Flat routing protocols have a negative impact on the network lifetime because each node in the network senses the data and transmits them to the BS, and all the nodes have the same roles for sensing and transmitting data. The Location-based routing protocols require location information of the nodes to be involved in the transmission process, and this decreases the lifetime of the network due to the extra consumption in the energy for sending the location information. The Hierarchical-based routing protocols are considered in this research due to their advantages in prolonging the network lifetime by distributing the roles among nodes (Cao *et al.*, 2017).

1.2.3 Challenges in WSN

WSNs have major issues that affect the performance of them especially in terms of a lifetime; the most critical issues that negatively affect the lifetime of WSNs and are considered in this thesis are summarized as follows:

1. **Energy:** WSN consists of small sensor nodes, and these nodes are limited in power supply. Sensor nodes consume power during many operations such as sensing events, collecting and processing data and transmitting data. Therefore, these sensor nodes die after a short period of time, and the power supplies in them need to be recharged or replaced by new ones, which is difficult in the real world due to the nature of the WSNs. These limitations lead to decrease the lifetime of sensor nodes which results in decreasing the overall network lifetime. For these reasons, the challenge for the researchers in the WSNs field is how to design an effective protocol to save the energy in the sensor nodes as much as possible to increase the lifetime of the network (Sharma *et al.*, 2013; Wang *et al.*, 2010).

2. **Distance:** Sensor nodes in WSN are randomly distributed and deployed in a wide range area, and the nodes need more power to transmit their data to the Cluster Head (CH) or to the BS due to the long distance among them, this makes a sensor node consumes its energy quickly which gives rise to minimize the lifetime of the network (Singh *et al.*, 2013; Nakamura *et al.*, 2007).

3. **Deployment:** Implementing the WSNs in real areas considers a big challenge especially if the targeted area is difficult to reach such as a big forest, which requires a tool such as a helicopter to drop the sensor nodes in this large area. The randomness of deploying the sensor nodes may result in overlapping nodes where the nodes share the same sensing area, and the data which are sensed and transmitted by them are redundant, which in turns causes wasted consume of energy in these sensor nodes. Therefore, developing efficient techniques to deal with the phenomenon of the overlapping nodes is highly required to prolong the lifetime of the network (Sharma *et al.*, 2013).

4. **Density of nodes:** Number of deployed nodes in an area plays a significant role in causing the phenomenon of the overlapping nodes. If there are many sensor nodes to be deployed in a small area, then the possibility of some of them to be overlapping increases. Implementing suitable techniques to deal with this phenomenon and utilize it to prolong the network lifetime is required (Pacharaney *et al.*, 2017).

1.3 Problem Statement

Many researches are conducted in the last years to increase the lifetime of a network depending on many factors such as the topology of a network and the path establishment between a node and the BS. Based on the network structure, dividing a network to many groups called clusters is considered an efficient way to balance the energy distribution among nodes (Suri *et al.*, 2015; Akkaya and Younis, 2005; Liu, 2012), and there are many protocols are suggested for clustering and selecting a CH in an efficient way such as the protocol that is proposed by (Heinzelman *et al.*, 2000). On the other hand, the way of transmitting data from a sensor node or a CH to the BS is also considered an important factor in increasing the networks' lifetime. The default way is to send data directly to the BS, but this way is inefficient especially if a node or a CH is far enough from the BS because the direct transmission in this case consumes a lot of node's energy and then it causes the death of the node quickly.

Based on the network structure, there are many protocols that concentrate on the hierarchy of the network due to its advantages in prolonging the network lifetime by fairly distributed the energy among nodes as described in subsection 1.2.2. The main hierarchical protocol that is proposed by (Heinzelman *et al.*, 2000) is Low Energy Adaptive Cluster Hierarchy (LEACH) protocol. This protocol increases the network lifetime by applying the clustering on the nodes and distributing the energy among them (Barai and Gaikwad, 2014; Singh, 2015).

In spite of its advantages, the LEACH protocol suffers from many limitations such as disregarding the overlapping between nodes which results in minimizing the network lifetime due to the sensing and transmitting redundant data which leads to wasting consume of energy. Many variants of LEACH protocol are proposed in the recent years to deal with the phenomenon of the overlapping clusters rather than the overlapping nodes, such as (Amirul *et al.*, 2010; Mrinmoy and Gupta, 2014; Devendra *et al.*, 2016; Pacharaney *et al.*, 2017). The phenomenon of the overlapping clusters considers just the nodes in the common area between the clusters without considering the overlapping between the nodes in the overall network, and this not efficiently utilize the phenomena of the overlapping. Other variants, that are proposed and considered the overlapping nodes, used different mechanisms for utilizing this phenomenon. However, there are still gaps in these variants in terms of identifying the overlapping nodes, considering the blind areas of the overlapping nodes, dealing with the overlapping node when its adjacent node dies, and dealing with the overlapping among more than two nodes (Dahiya and Kaushik, 2014).

Another problem in the LEACH protocol is the way of data transmission from the CHs to the BS, which is done directly because it significantly affects the lifetime of the network. In multi-hop transmission, data are sent from a CH to the BS via another node or set of nodes (or intermediate CHs) instead of direct transmission (Al-Karaki and Kamal, 2004). Moreover, The LEACH protocol suffers from the random selection of the CHs which leads to reducing the network lifetime due to the probability of nodes with low energy to be CHs after some rounds, and this affects the transmission process when the source CH has low energy and it is far from the BS (Seifemichael *et al.*, 2016).

Many protocols are proposed to increase the lifetime of the network by selecting intermediate nodes for data transmission such as (Baranidharan and Santhi, 2015; Kansal, 2015; Yao *et al.*, 2015). These protocols concentrate on the concept of intermediate CH or intermediate node to transmit data to the BS without taking into account the optimal multi-hop path from the source CH to the BS in order to minimize power consumption.

Other protocols are proposed to select suitable CHs in an efficient manner to solve the random selection of them in order to increase the network lifetime such as (Heinzelman *et al.*, 2002; Zhang *et al.*, 2010; Naregal and Gudnavar, 2012). These protocols deal with either one parameter or some parameters to select the CHs, but also still gaps exist in these protocols in terms of ignoring some important factors when selecting the CHs, which are considered in this thesis.

In summary, the problem gaps in the hierarchical-based WSNs, where the LEACH protocol and its variants did not comprehensively consider them, can be identified as follows:

1. **The phenomenon of the overlapping nodes:** When some of the deployed nodes sharing the same sensing area and sense the same data, which results in transmitting redundant data to the CHs and then rapid wasting consume of their energy.

2. **CH selection:** Random selection of the CHs leads to reduce the network lifetime due to the possibility of the low energy nodes to be CHs.

3. **Direct data transmission:** Direct transmission of data from a source CH to the BS causes a fast drain of its energy, especially if the distance between them is far. Moreover, the process of CH selection plays a significant role in the data transmission because if a node with low energy is selected to be a CH, and it is far from the BS, then it is not able to transmit the data to the BS.

1.4 Research Motivation

In WSNs where nodes are randomly distributed in a large area to collect data and transmit them to the BS, the energy consumption is the most important factor that affects the lifetime of the entire network (Jamalipour and Zheng, 2009). Developing an efficient mechanism to utilize the phenomenon of the overlapping nodes in the network as well as developing a mechanism to efficiently transmit the data from a CH to the BS lead to prolonging the lifetime of the network.

As discussed before, the main clustered protocol in WSNs is the LEACH protocol, and there are many variants of it in order to increase the network's lifetime. However, some of the proposed protocols focused on the residual energy in individual nodes to select a CH without considering the distance to the BS and the locations of nodes in the network. Other protocols consider the distance from each node to the BS when selecting the CHs, but the locations of nodes in each cluster are still not considered.

The location of nodes in the network is important to find the overlapping between them according to their sensing area because some nodes may share the same sensing area and then they sense almost the same data, this causes wasted energy and send redundant data to the BS.

If two nodes in a network share the same sensing area, then there is an overlapping between them. These two nodes sense the same events in this area, and then send the same data to the BS. This case leads to data redundancy and makes these nodes consume insufficient energy due to sensing the same events at the same time.

The number of these overlapping nodes increases when the density of nodes in a network increases. Hence, the density is a critical issue that should be considered when designing an efficient technique in WSNs.

In the LEACH protocol and its variants, the concentration is on how to prolong the WSNs without considering the amount of consuming energy when the overlap exists between nodes, and without considering the density of nodes in a network. Hence, this thesis considers enhancing the LEACH protocol in order to reduce the negative effect of the phenomenon of the overlapping nodes by utilizing it to decrease the wasted consume of energy in the overlapping nodes and then increase the lifetime of the network.

Moreover, data transmission is a very important issue in WSNs. The CH after collecting the data from other sensor nodes in a cluster, it transmits these data to the BS. As discussed above, many protocols attempted to improve the way of data transmission in WSNs. These protocols are not efficient enough in terms of energy consumption due to the selection of just one intermediate node or two intermediate nodes and without finding the optimal multi-hop path that considers many factors rather than just the distance or just the energy (Sergiou *et al.*, 2014).

All of these problems are critical in the hierarchical-based WSNs. If there are no efficient and comprehensive solutions to solve them, then the lifetime of the network still drain quickly. Especially, if the network has all of these problems together, then the solving of one problem not comprehensively increases the efficiency of the network.

Now, how to develop a mechanism to minimize the negative effect of the overlapping between nodes in the network, and a mechanism to select suitable CHs and to efficiently transmit the data from these CHs to the BS? How to develop an efficient mechanism to utilize the overlapping between nodes in the network? How to join the proposed mechanisms together to enhance the LEACH protocol and the hierarchical-based WSNs in terms of maximizing the network lifetime? There is no LEACH based enhancement mechanism deals with the phenomenon of the overlapping nodes, and also no such mechanism solves the direct transmission in the LEACH protocol by finding an optimal multi-hop path between the source CH and the BS, and selects suitable CHs by using proper factors. Moreover, there is no combined technique that solves the overlapping problem, the CH selection problem and the direct transmission problem together to enhance the LEACH protocol and the hierarchical-based WSNs in general.

1.5 Research Objectives

The main goal of this research is to propose an enhanced technique for maximizing the Wireless Sensor Networks lifetime based on adapting the phenomenon of the overlapping nodes and solving the direct data transmission problem.

The following objectives are formulated to achieve the main goal of this research:

1. To propose an adaptive mechanism that utilizes the phenomenon of the overlapping nodes to maximize the network lifetime and to maintain the network coverage stable as much as possible.
2. To propose a mechanism that selects the CHs in an efficient way to maximize the network lifetime and to increase the efficiency of data transmission from these CHs to the BS.

3. To propose a transmission mechanism that handles the transmission of packets from a CH to the BS with minimal power consumption using a multi-hop approach.

1.6 Contributions

The main contribution of this research is proposing an enhanced technique for maximizing Wireless Sensor Networks lifetime, which is designed for adapting the phenomenon of the overlapping nodes and solving the direct data transmission problem. The following are the sub contributions:

- An adaptive mechanism that utilizes the phenomenon of the overlapping nodes to maximize the network lifetime and to maintain the network coverage as stable as possible.
- A mechanism that selects the CHs in an efficient way to maximize the network lifetime and to increase the efficiency of data transmission from these CHs to the BS.
- A transmission mechanism that handles transmission of packets from a CH to the BS with minimal power consumption using a multi-hop approach.

1.7 Scope and Limitations

The research presented in this thesis considers the hierarchical WSN which consists of a number of nodes with radius r. The sensing and transmission processes as the same as in the LEACH. Other scopes in this research are as follows:

- The BS is fixed and located at the center of a network.
- The BS has no energy limitation.
- All sensors in the network are homogeneous and energy constrained.
- All nodes have the same sensing range.
- Nodes are deployed randomly in the area.
- Nodes are in fixed positions.
- Applications that do not require continues sensing such as monitoring applications are considered in this research.

Table 1.1 shows the mapping among the objectives, contributions and problem gaps in this research:

Table 1.1: Mapping Among the Objectives, Contributions and Gaps

Research Objectives	**Research Contributions**	**Problem Gaps**
Objective 1	Contribution 1	Gap1
Objective 2	Contribution 2	Gap2
Objective 3	Contribution 3	Gap3

1.8 Organization of The Thesis

This thesis is organized as follows:

Chapter One introduces the background principles of WSNs and their challenges, and the problems of WSNs along with the research objectives, contribution, and limitations.

Chapter Two provides the literature review and the related works in the past three years that address the challenges in WSNs field and some earlier researches that used a genetic algorithm in addressing these challenges.

Chapter Three presents the methodologies used to deal with the shared sensing areas and the transmission problems. The chapter also describes the procedure used for analyzing the proposed mechanisms.

Chapter Four presents the mathematical modeling of the proposed clustering mechanism in addition to the proposed transmission mechanism, with the verification of models of the proposed mechanisms.

Chapter Five presents the implementation of the proposed mechanisms using the simulation tool and also discusses the simulation results comparing to some of the existing protocols.

Chapter Six concludes the results of the proposed mechanisms and gives suggestions for future researches.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a background of the WSNs and the related protocols that are conducted to enhance the LEACH protocol in the hierarchical-based WSN and highlights the limitations of each protocol, which provide the motivation to this research. The related protocols that are conducted to deal with the overlapping problem, the cluster head selection, and the direct transmission problem are also highlighted.

This chapter is organized as follows: Section 2.1 provides an introduction of the WSNs, Section 2.2 presents an overview of the routing protocols in WSN, Section 2.3 investigates the cluster head selection and the transmission protocols in WSN which based on the evolutionary algorithms, Section 2.4 provides a critical review of the related works, and finally, the chapter is summarized in Section 2.5.

2.1 Introduction

A Wireless Sensor Network is a special kind of networks that are utilized according to a specific application. This type of networks consists of a large number of small sensor units called nodes, these nodes are randomly distributed in a specific region, the aim of these nodes is to monitor the region and sense the required events. A node is a small unit which consists of small power supply, small processor, and small memory. Due to its small power supply, if the power is fully consumed, it is difficult or impossible for humans to change the dead node or recharge its power supply. Thus, the energy consumption plays a critical role in WSNs (Akyildiz *et al.*, 2002).

In the environments where the nodes are randomly distributed, and the locations of them are not considered, the overlapping among sensors may occur, and if the network is highly dense, the probability of the overlapping between nodes increases due to the increased number of nodes in a small region. This negatively affects the performance of the network when many sensors sense approximately the same events at the same time due to the sharing of their sensing area. Hence, reducing the negative effect of the overlapping as much as possible is very important in the WSN in order to maximize its lifetime.

Another important issue in the WSN is the data transmission between the CH and the BS. This issue negatively affects the efficiency of the network in terms of its lifetime especially if the distance between them is far. To reduce the negative effect of this issue, an optimal multi-hop path between a CH and the BS should be found. Furthermore, the CH selection is very important in WSN due to its important role in aggregating data and sending them to the BS. Therefore, an efficient way to select proper nodes as CHs should be conducted.

This chapter provides a comprehensive review of the related protocols in the WSNs that enhance the LEACH protocol and the hierarchical-based WSNs in terms of maximizing the network's lifetime and also provides a comprehensive review of the CH selection and the transmission protocols in the WSNs. These issues define the scope of this research. In addition, this chapter presents the evaluation of the protocols that are proposed to enhance the hierarchical-based WSNs in the last few years. Moreover, this chapter conducts a comparison between these protocols and highlights the gaps in them.

2.2 Routing Protocols for WSN

In the WSNs, there are a lot of sensor nodes which they are randomly distributed over a large area, and the role of these nodes is to sense a specific event and send the sensed data to the main device which is called Base Station (BS) for further analysis (Abed *et al.*, 2012; Pantazis *et al.*, 2013; García *et al.*, 2009). Due to the large number of nodes, the wide area of sensing, and to the limitation of nodes in terms of power, it is difficult to send data from nodes to the BS directly. Thus, data should be sent via some intermediate nodes, this is called a route from a source node to the destination (BS) (Pino-Povedano *et al.*, 2014).

To deal with this issue, many routing protocols are proposed in WSNs to find an efficient route between a sensor node and the BS. These routing protocols are divided into three classes based on the network structure, which are Flat routing, Hierarchical-Based routing, and Location-Based routing (Wu *et al.*, 2011; Chitrapriya *et al.*, 2017), as shown in Figure 2.1.

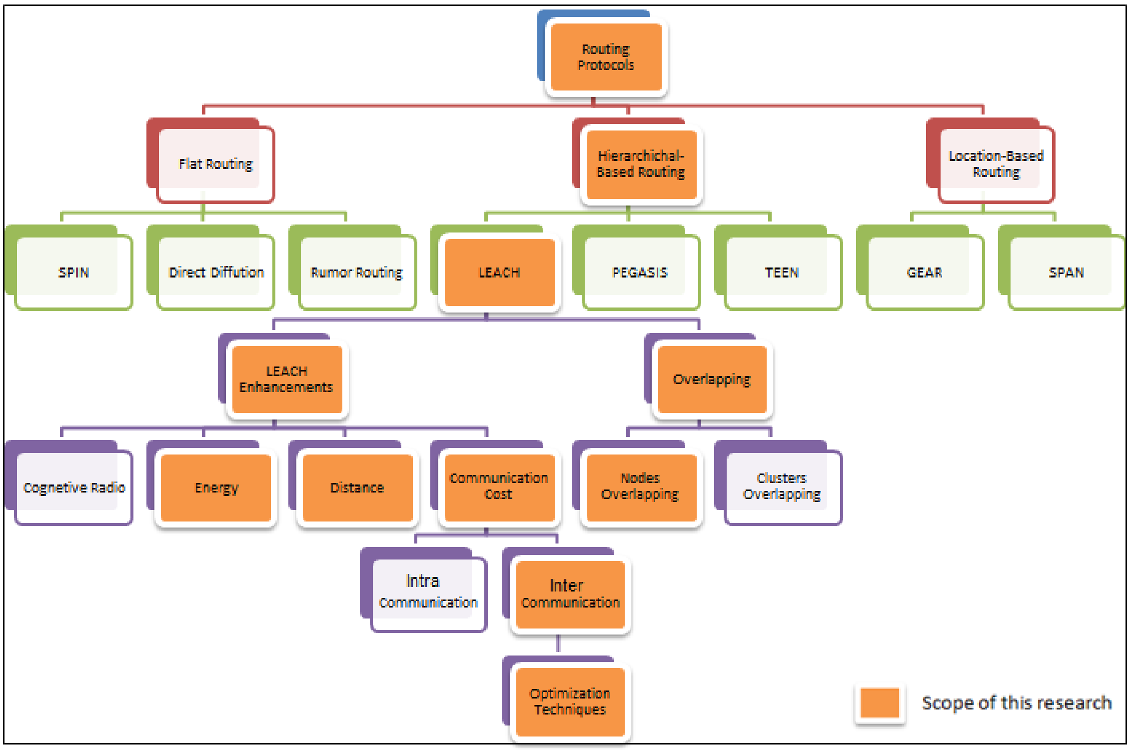

Figure 2.1: Routing Protocols for the WSN

In flat routing, all nodes have the same role for sensing and transmitting data, which negatively influence the lifetime of the network because each node in the network senses the data and transmits them to the BS, and this consumes a lot of their energies. On the other hand, the location-based protocols require the location information of the nodes to be involved in the data transmission process which decreases the lifetime of the network because sending the location information consumes more energy.

In contrast, the hierarchical-based protocols distribute the roles of sensing and transmitting data between the nodes by classifying them as sensors and CHs, where the sensors sense the data and the CHs aggregate and transmit these data to the BS (Jeny and Ananth, 2013). The hierarchical-based protocols are considered in this research due to their advantages over other types of routing protocols in terms of power consumption, network lifetime and scalability.

In the following sub subsections, the Hierarchical-Based Routing protocols will be described in details. Sub subsection 2.2.1 presents the LEACH protocol and its latest variants, while sub subsection 2.2.2 discusses the protocols that are proposed to deal with the overlapping problem, which they are related to the first proposed mechanism in this research.

2.2.1 Hierarchical-Based Routing Protocols

The purpose of these protocols is to increase the lifetime of networks by dividing the network into a set of clusters, and each cluster consists of a number of nodes (Munir *et al.*, 2015; Goyal and Tripathy, 2012). This technique leads to reduce the number of data transmissions which send to the BS by using the data aggregation in a single node inside a cluster called a CH instead of transmitting the data directly from each node to the BS (Lotf *et al.*, 2010). Another purpose is that the task of a CH is distributed among sensor nodes in the network to minimize the energy consumption. Figure 2.1 shows the structure of hierarchical protocols.

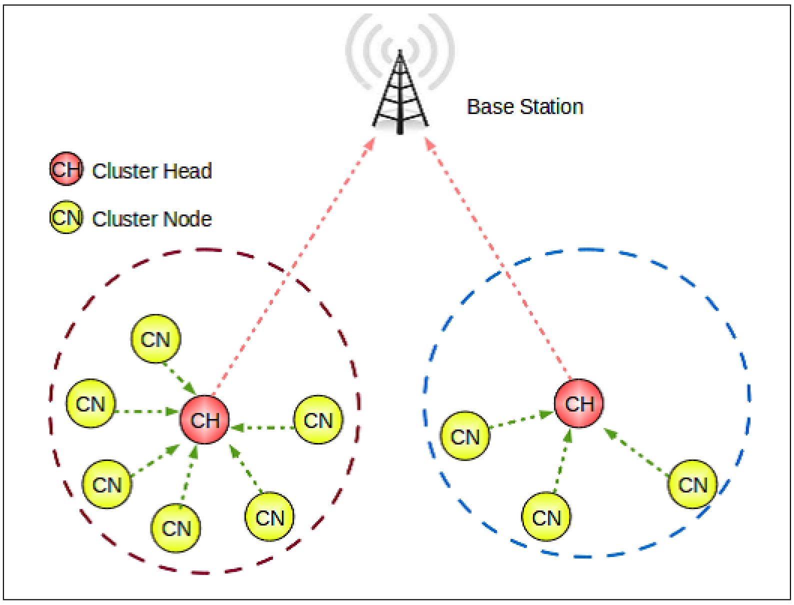

Figure 2.2: Hierarchical-Based Routing (Kole *et al.*, 2014)

Some of the hierarchical protocols which are proposed for the sensor networks are the Low-Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman *et al.*, 2000), Power-Efficient Gathering in Sensor Information Systems (PEGASIS) (Lindsey and Raghavendra, 2002), Threshold-Sensitive Energy-Efficient Sensor Network (TEEN) (Manjeshwar and Agrawal, 2001), and Adaptive Threshold-sensitive Energy-Efficient sensor Network (APTEEN) (Manjeshwar and Agrawal, 2002), in addition to many variants of LEACH protocol. In the following sub subsections, the LEACH protocol and some of its variants protocols will be described in details due to the important of the LEACH protocol in the hierarchical-based WSNs and the proposed mechanism is inspired by it.

2.2.1.1 Low-Energy Adaptive Clustering Protocol (LEACH)

LEACH protocol is the first energy efficient routing protocol that is proposed by (Heinzelman *et al.*, 2000) to improve the efficiency of WSNs by increasing their lifetime. The

LEACH protocol operates in many rounds (Peng and LI, 2010; Ihsan *et al.*, 2015) and each of them comprises two stages, which are the set-up and the steady-state. A CH is selected during the first stage, and the cluster (a collection of nodes) is formed. Afterward, a CH announces itself to the cluster members and assigns a time division multiple access (TDMA) table to each member in a cluster (Masdari *et al.*, 2013). Figure 2.3 shows the structure of the LEACH protocol.

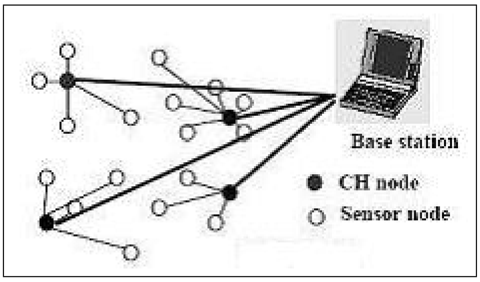

Figure 2.3: Structure of the LEACH Protocol (Yadav *et al.*, 2014)

To select a CH (Xiangning and Yulin, 2007), nodes create random numbers between 0 and 1 in each round. A reference number *T(n)* is predefined to compare with the created numbers. In which the value of the reference number is greater than the value of the randomly created number, then the node that created the random number becomes the CH. Equation 2.1 is used to determine the value of the reference number *T(n)* (Heinzelman *et al.*, 2000).

$$T(n) = \begin{cases} \frac{P}{1-P*(r mod 1/9))} & : if n \in G \\ 0 & : if n \notin G \end{cases} \tag{2.1}$$

where P is the percentage of CHs, r is the existing round, and G is a group of nodes that did not become CH in the prior *1/P* rounds. In this manner, the energy is distributed among all nodes in the network. After CHs are chosen, a decision is taken by each normal node to decide which CH is suitable to join with to form clusters (Xiangning and Yulin, 2007). CH sends an advertisement message to all other nodes. After that, each node selects the appropriate CH to connect with it depending on the strength of a signal. If the advertising CH is close to a node, then the signal has high strength and vice versa. When a node selects its potential CH, it transmits a message to it to be a member of a cluster. Then, the CH sends a timetable to other member nodes in its cluster. The table is used to avoid data collision during transmission (Chauhan and Nayyer, 2016). During the steady-state stage, each CH collects data, which are sent by sensor nodes in its relative cluster, and transmits them to the BS (Fu *et al.*, 2013).

The LEACH protocol has many advantages (Li *et al.*, 2011). It balances power consumption among all nodes in a network due to the rotation of the CH selection process. This procedure can increase the network's lifetime. Furthermore, using the TDMA table allows nodes to be in sleep mode while waiting for their turn to send their data; this condition also increases network lifetime. In contrast, several disadvantages exist. For example, LEACH does not take into account the residual energy of a node in the selection process of a CH. According to Equation 2.1, the possibility of a node becoming a CH is not fixed. After several rounds, all nodes have the same probability to become CHs. Thus, nodes with a high amount of energy and nodes with a low amount of energy have equal chance to become a CH. Another problem is the direct transmission from a CH to the BS using single-hop communication. This situation would be a serious issue if the CH and the BS are located in far positions because it uses more energy than a CH that is close to the BS, resulting in energy holes in which isolated nodes are unable to transmit their data. This situation considerably affects the performance of the network (XingGuo *et al.*, 2016; Li *et al.*, 2015). To overcome these disadvantages of LEACH, many improvements are proposed by modifying LEACH to increase efficiency, as presented in the following paragraphs.

2.2.1.2 LEACH-SAGA (LEACH-Simulated Annealing and Genetic Algorithm)

A new routing protocol based on annealing and genetic algorithms called LEACH simulated annealing and genetic algorithm (LEACH-SAGA) is proposed by (Zhang *et al.*, 2014) to enhance energy distribution among nodes in the network. In LEACH-SAGA, clusters are formed by using genetic and annealing algorithms. Afterward, the BS finds center point in each cluster, and then, it considers the energy level and the distance from each node to the center of each cluster. Average energy in each cluster is calculated and the remaining energy in each member node will be compared with the average. All nodes that have energy more than the average will be nominated as CHs of that cluster. Then, the final decision of selecting the potential CH is taken by the BS depending on the distance from the center. Therefore, the distance plays a major role in this protocol (Zhang *et al.*, 2014).

LEACH-SAGA protocol is better than LEACH protocol based on network lifetime. Moreover, this protocol solves the randomization problem in the LEACH protocol, which is discussed before, by using the distance factor. The main disadvantage of this protocol is the complexity due to the use of a genetic algorithm.

2.2.1.3 P-LEACH (Partition LEACH)

To equally split the energy among nodes in wide area networks, and to increase the