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Developing an Approach to Improve the Performance of a Linear Wireless Sensor Network

A Thesis

Submitted to the Council of the College of Information Technology at University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master in Information Technology/Information Networks

By

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بسم الله الرحمن الرحيم

فَبَدَأَ بِأَوْعِيَتِهِمْ قَبْلَ وِعَاءِ أَخِيهِ ثُمَّ اسْتَخْرَجَهَا مِن
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سورة يوسف الآية 76

Declaration

I hereby declare that this thesis, submitted to the University of Babylon in partial fulfillment of the requirement for the degree of Master in Information Technology \ network, has not been submitted as an exercise for a similar degree at any other University. I also certify that this work described here is entirely my own except for experts and summaries whose source is appropriately cited in the references.

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In view of the available recommendation, we forward this thesis for debate by the examining committee.

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Date: / / 2022

Dedications

This work is dedicated to…

To the rest of God
on his land and his proof against his servants, the awaited
Imam Mahdi (God hasten his reappearance)

To the one who taught me the first letter

To those who stayed up for me and gave their lives for the sake of my education, they gave me everything to keep my education confident and encouraged me to continue until I reached where I am

Father and mother

To my support and my second half to those who supported and encouraged me step by step to those who were with me in my difficult days
To my husband

To my soul and the source of my strength,
To My daughter

To my other family, to those who supported me, to my husband's tender mother, and to my dear sister-in-law
(The second mother of my daughter)

Researcher

Acknowledgements

Foremost, I am highly grateful to Allah (God) for His unlimited blessings that continue to flow into my life.

I feel highly indebted to my supervisor, **Prof. Dr. Saad Talib Hasson,** whom I am deeply grateful for his suggestions on this topic, and without his support, comments, and guidance, it would be difficult to finish this work.

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I would like to express my gratitude to my close friends for believing in me, and for their constant support, encouragement, and cooperation at all times and apologize to them for not being able to mention them by name here, though they are in my heart.

Zainab Salam Abd Alshaheed

Abstract

Wireless sensor network (WSN) is one of the main technology trends that used in several different applications for collecting, processing, and distributing a vast range of data. It becomes an essential core technology for many applications related to sense surrounding environment.it is a group of sensor devices that communicates monitoring and recording at diverse locations through wireless sink. A special case of the WSNs is the Linear Wireless Sensor Network (LWSN). It can be used to monitor pipelines, railways, gas, oil, and highways either over ground or underground. These structures, can range in length from a few hundred meters to hundreds of kilometers.

This thesis adopts the backbone approach, which is the selection of a specific set of sensors to serve as a backbone node of the network. The proposed method suggests two sinks or more (depending on the length of the area and the application type) at the beginning and the end of the network. The created backbone is started from the first sink and ended in the second sink. This thesis assigns the deployed sensors to play the role of the backbone nodes. The discovered backbone is used for routing purpose later. The goal of the discovery process is to improve the communication efficiency, scalability, reliability, and fault tolerant.

Since the linear network is a special case state characterized by a linear structure, one of the most important challenges of this network are a suitable number of sensors are deployed to take the shape of this linear area and ensuring the end -to-end delivery and successful data transmission to the base station.

A model is developed to estimate the required number of sensors to each area in a random deployment. According to randomness in deployment, some number (tolerances fraction) is suggested to be added to the number of deployed nodes to improve the sensors distribution and ensure the network connectivity. This added number is suggested based on certain proposed Uniform probability distribution function. Simulation results are analyzed and evaluated based on different metrics. Simulation results are used in a comparison between the approach of using two sinks with the results of using one sink only. The superiority is to the proposed approach in all the used metrics.

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List of Abbreviation

AC	Alternating current
GPS	Global positioning system
LBD	Linear backbone discovery
LBDX	Linear backbone discovery for X- backbone number
LWSN	Linear wireless sensor network
RFID	Radio Frequency Identification
WSN	Wireless sensor network

CHAPTER ONE

Introduction

CHAPTER ONE

Introduction

1.1 Over View

The Individual nodes in WSNs networks are able to monitor physical environment. In comparison to sensors, these sensors are small in size, they have limited computational capacity and processing and low cost. These sensors can measure, detect, and sense data from the round world, then its direct that sensing data to do data processes. Since the power of sensors is taken from the batteries, Making the most of their resources is important to prolong the network's life. Transferring the data sensed by the sensor consumes the most sensor power. Therefore, the process of determining the transmission line is significant. The algorithm produces shortest route in single hope or multi hope in order to be used for fault-tolerance or load-balancing [1].

The energy consumption, performance, routing efficiency and reliability of the network and routing protocols that are used to transfer data in LWSNs can all be enhanced by taking benefit of the linearity Property of the network [2].

In order to monitor specific types of infrastructures, one of the WSNs applications are arranging the nodes in a linear form, defined a special case of WSNs which are Linear wireless Sensor Networks (LWSNs). The Monitor of pipelines, gas, oil, and highways are a few examples of these uses (over and underground). These structures, can range in length from a few hundred meters to hundreds of kilometers [3].

LWSNs is a one-dimensional network in which the sensors are deployed in a narrow rectangular area between two parallel lines with a certain number of sensors that is calculated by a proposed model according to the length and width of the distance to obtain the best coverage of the area. To achieve this task, a suitable number of sensors are deployed to take the shape of this linear area. Base on the length and the width of the linear area (bridges, pipelines, highways, borders etc.), the deployment approach, number of sensors, sinks must be selected carefully [4].

LWSNs is a network in which the sensors are deployed in a narrow rectangular area between two parallel lines with a certain number of sensors that is calculated by a proposed model according to the length and width of the distance to obtain the best coverage of the area [5].

The linearity of the network structure must be exploited by new frameworks and protocols for the best network performance, efficiency and dependability. There are different approaches to achieve this purpose of improving the performance of the LWSNs. some of them based on clustering while in certain approach, a leaky shift register is utilized, another approach is backbone discovery method where a small portion of the deployed sensors are select to create a backbone [6].

In some published works, they suggested that backbone nodes are more capable and high-quality, resulting in improved availability and reliability (longer transmission range, more energy resources). To achieve these applications, other sensors type with high capability, more costly and complicated structure were utilized [4].

This thesis adopts the backbone approach, which is the selection of a specific set of sensors to serve as a backbone of the network to which the neighboring nodes are connected and send data to the base station (sink). Certain assumptions are made to let all the backbone nodes equivalent to the standard sensor nodes in terms of capabilities and usage. These sensor nodes are less complexity and economical. The proposed backbone will be tested and evaluated to ensure its effective behavior in routing purposes. The goal of this proposed process is to improve communication efficiency, scalability, reliability, and fault tolerant.

To improve the reliability of LWSNs, a proposed topology has been suggested in this thesis which is represented by assuming that there are two sinks or more sinks at the terminates (ends) of the network.

1.2 Problem Statement

One of the important and recent WSN applications is the LWSN. LWSNs are useful in utilizing their sensors to monitor, track or detect any physical events in a narrow long area (Linear area). To achieve this task, a suitable number of sensors are deployed to take the shape of this linear area. Depending on the linear area length and width, the deployment approach, number of sensors, sinks must be selected carefully.

Ensuring the end-to-end delivery relaying and successful data transmission to the base station represent the essential goal in such networks. A transmission process must be efficient and reliable based on a shortest path approach or a backbone to prolong the network lifetime and improve its performance. The main problem in such networks is that the sensors closer to the sink end up forwarding or relaying more packets than other distinct sensors.

1.3 Thesis Aim

The main aim of this thesis is to study, analyze and proposed a way to improve the performance of a linear wireless sensor network. This aim can be achieved by the following objectives:

1. Select the optimal number of deployed sensors and their deployment approach using a proposed model to ensure cover the certain linear area.

2. Create and implement a suitable linear wireless sensor network topology and propose two sinks (or more) depends on the selected application.
3. Select suitable approaches for data transmission and evaluate the performance of the LWSN.

1.4 Literature Review

- In 2011 Imad Jawhar defined for the first-time linear sensor network (LWSN) as a sub-class from WSN. The idea of LWSNs is developed in this paper, along with a list of applications that this kind of network is suitable for. Additionally, inspiration for creating specific protocols is offered, exploring the network's linearity to improve communication effectiveness, reliability, fault tolerance, energy conservation, and network longevity. Additionally, a taxonomy of LWSNs from both topological and hierarchical perspectives is offered, along with a discussion of their numerous traits, research problems, and underlying prospects. To examine the effectiveness and dependability of LWSNs, simulation experiments with serial data were provided [5].
- Researchers presented the issues and solutions required for LWSNs, the applications of LWSN, significant problems associated with LWSN, and significant trends in this field of research have all been outlined in the current exposition [3].
- The idea of backbone in LWSN was introduced and a “graph-search based topology” discovery approach for LWSNs was presented. A proposed definitions for LWSN structure and its design parameters were presented. According to the proposed protocol, nodes can choose which nodes to include in a backbone, which the other nodes can use to transfer data to the sink at the end of an LWSN or LWSN segment. Additionally, by "jumping" over failed nodes by extending the range, the linearity of the structure and the discovered backbone can improve the reliability of the routing. Their protocol does not

mandate that the nodes have The Global Positioning System (GPS) location detecting capabilities, which would necessitate a more intricate architecture and more expensive sensor nodes [7].

- A proposed WSN was suggested to protect and monitor water, gas and oil pipelines. This study considered three layers; the pipeline, the surface, and the subsurface layer. This paper also provided a “Leach Based Hierarchical Routing Protocol” with a linear structure WSN [8].

- The performance of a LWSN system with backbone nodes was presented and evaluated using an analytical method based on “multivalued decision diagrams”. They estimated and examined the likelihood of the hybrid LWSN performance level, which is determined by the number of sensors that have an ability to connect to the sink. This study used a case study to support the suggested approach for creating the best backbone node allocation plan to ensure the dependability requirement [9].
- Researcher defined a strategy has been put up for the best linear positioning of sensors and base stations to monitor the numerous pipelines utilized in big structures. The proposed method, which makes use of the Lion Optimization Algorithm (LOA), has been evaluated in terms of end-to-end delay lifetime and throughput, and against three other methods: “Ant Colony Optimization (ACO)”, “Genetic Algorithm (GA)”, and Greedy Approach. recommended strategy, especially when the pipeline's length is of medium size, which makes the suggested plan appropriate for energy-efficient buildings [10].

- The adaptive clustering technique presented in this research can be used to group and place numerous sensors along the pipeline. By employing this process, every sensor group choose a cluster head in a flexible manner. The cluster head then aggregated the incoming traffic from its members and sends it to the following cluster head, and so on, until it reaches the base station. When compared to current methods, the simulation and prototype-based investigations' results indicated a significant energy saving [6].

- Another researcher in 2019 proposed a new approach, in the network where each virtual node is connected to a specific geographic region. The network traffic per virtual node is modeled analytically. Using a greedy method to determine how many sensors are needed. That ought to make up each virtual node are shown. Performance Evaluation demonstrates that the avaricious placement can enhance the compared to the uniform network, network lifetime could increase by up to 40%. deployment. Additionally, the suggested strategy outperforms the when used with a scheduling technique, related work it lessens the messages being heard twice. Also demonstrated is that if the network's lifespan is greatly increased, each sensor's battery capacity is measured while taking into consideration the data it transmits or relays [11].

- Researchers presented the implementation of an effective radio communication interference control strategy that takes into account environment change and node activity was one of the biggest issues faced by linear sensor networks. This called for the regulation of propagation circumstances, nodes with effective data frame reception units, and a MAC protocol that makes use of the topology's linearity. The simulation results demonstrated that for all three parameters, the proposed scheme performs better than the other three techniques that were taken into consideration. The suggested method's most noticeable characteristic is that, in terms of end-to-end delay, optimization performs better the longer the pipeline is. The suggested method considerably extends the network's lifespan, especially when the pipeline's length is of a medium size, making it appropriate for energy-efficient structures [2].

- “The linear backbone discovery algorithm (LBD)” and the linear backbone discovery method with x backbone pathways as two distributed topology discovery strategies for thick LWSNs (LBDx). They both attempt to build a linear backbone for effective LWSN routing. The LBD method, aims to reduce the volume of messages used during the fundamental method of discovery. The LBDx algorithm, concentrates on lowering the hops number required to send a message from a node to a sink. LBD and LBDx display good qualities and effective performance are demonstrated via thorough simulations [4].

Author & year	Problem	Tools	Results
Imad Jawhar, Jie Wu, Nader Mohamed and Sheng Zhang in 2011	Specialized Protocols needed to take advantage of the linearity of the network to enhance the LWSN perform-ance.	Simulation	The resulting backbone can be used for efficient routing of the data collected by the other nodes in the network. The routing strategy can then take advantage of the linearity of the network and discovered backbone in order to enhance the

			robustness and fault tolerance of the network.
Yuchang Mo ,, Liudong Xing and Jianhui Jiang in 2018.	Network creation, leak interrupt detection, and reliable routing of high-priority messages.	A multivalued decision diagram (MDD).	The suggest MDD method is more efficient than the traditional exhaustive enumeration methods. A case study is also presented to substantiate the application of the proposed MDD approach for developing the optimal strategy on backbone node allocation.
Rodrigue Domga Komguem, Razvan Stanica, Maurice Tchuenté, Fabrice Valois in 2019.	There is a high traffic accumulation in the neighborhood of the sink. This area constitutes the bottle-neck of the network since the sensors deployed within git rapidly exhaust their batteries.	A greedy algorithm and scheduling algorithm.	a simple greedy deployment can improve the network lifetime by up to 40%, when compared to the uniform deployment. A framework which allows to compare the virtual node-based
Imad Jawhar , Sheng Zhang , Jie Wu , Nader Mohamed and	Minimizing the number of messages used during	Simulation	Reduction in the number of communication hops leads to smaller energy consumption by the individual sensor nodes

Mohammad M. Masud in 2021.	the backbone discovery process		that are involved in the forwarding process, which causes lower battery consumption and increases the average network lifetime.

1.5 Thesis layout

Additional for this chapter, thesis contains four chapters layout as following:

Chapter two: Represent Theoretical Background for LWSN.

Chapter three: displays how simulate LWSN in different cases analysis process in wireless sensor networks using Netlogo.

Chapter four: holds result of the proposed system and its evaluation.

Chapter five: displays the results conclusions and the future works.

CHAPTER TWO

Theoretical Background

CHAPTER TWO

Theoretical Background

2.1 Introduction

This chapter present definitions and principles for Wireless Sensor Networks (WSNs) and their applications. Sensor nodes operation are described with their basic components. Definition of Linear wireless sensor networks, their applications, their architecture, classification and some of their operation algorithms.

2.2 Wireless Networks Types

Infrastructure-based networks and Ad-hoc networks are two types of wireless networks that vary in their connection methods [12].

Infrastructure-Based Networks represent a set of devices that are linked wirelessly by connecting directly to one or more access points that serve as a hub for all nodes. The design of this form of network, such as the Campus network, is carefully controlled by humans [13].

To verify the connection between two nodes, the traffic must be relayed by the access point, which is in charge of transmitting the messages to the correct destination. For all hosts linked to it, the access point serves as a router.

Ad-hoc Networks, also known as peer-to-peer networks it is a form of wireless network that does not rely on infrastructure such as access points or routers, allowing connected devices (computers and mobile phones) to communicate directly with one another [14]. Figure (2.1) presents a sample of these networks.

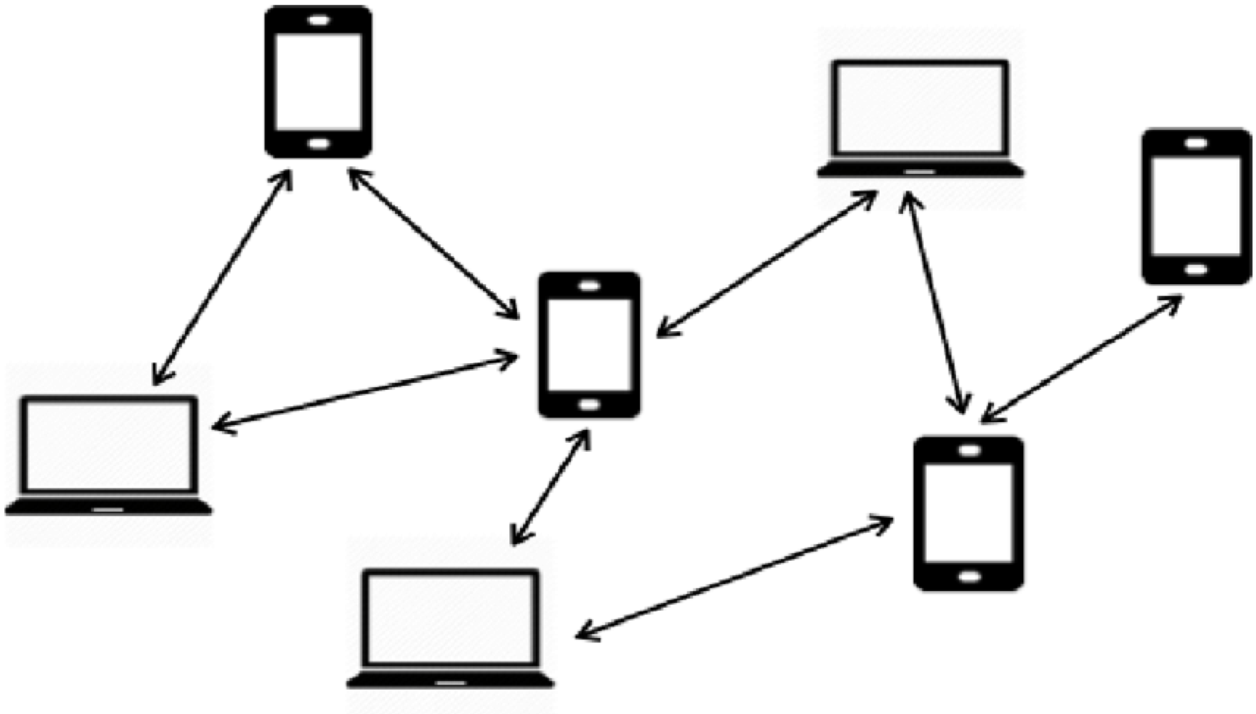


Figure (2.1) ad hoc network [15]

2.3 Wireless Sensor Networks

Wireless sensor networks (WSNs) usually made up of spatially distributed deployed separated and self-contained system units. WSNs are involving of big number of randomly deployed sensor nodes in certain areas. Sensors are small in size with restricted battery power, limited computational and processing resources [15] the sensors are mostly used to keep track of physical and environmental variables, collect data such as temperature, humidity, pressure and so on. The gathered data must be transferred to a base station or a sink. The main challenges in WSNs are the network scalability, fault tolerances, security, reliability, data transmission, robustness and need for efficient energy [16].

WSNs must have an ability to work in environments without any human access to perform a direct monitoring. In most of the WSNs applications, their sensor nodes are often randomly deployed. The sensor nodes are deployed by throwing them in from an unmanned aerial vehicle (UAV) along a thick formation between two parallel lines [3].

2.4 Sensor Node

Sensor network contains many sensor nodes, each of them has the ability to execute some processing, gathering information from its surroundings and share with other linked nodes in the network. Figure (2.2) shows the component of the sensor node.

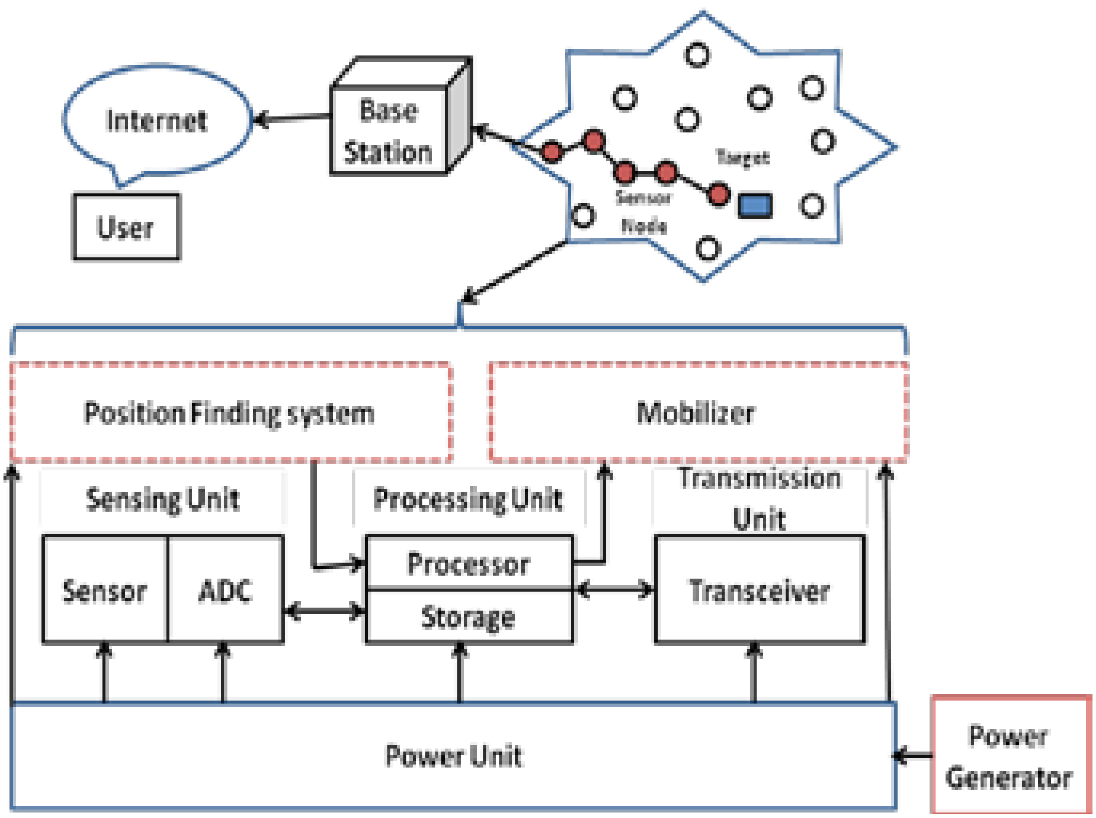


Figure (2.2) the sensor node component [17].

Four components located mainly in the sensor node; a sensing unit, power unit, transceiver unit and a processing unit. The sensor node may also contain other components for position recognition unit such as a Global Positioning System (GPS) and a mobilizer. The following statements presents the sensor components [18].

2.4.1 Sensing Unit

Temperature, pressure, light is information collected from the environment by sensing unit. Then, sensing unit create electrical or optical signal as output. The output signals of sensor are transformed from analog signals to digital signals.

2.4.2 Processing Unit

Sensor node needs distinct small size processors and have low processing power of reduction. The controller responsible for functionality of control and data processing. A micro controller like: ATMEL, ATMEGA, 128L and MSP430 using commonly as sensor controller. The most important feature of the micro controllers is Power saving ability.

2.4.3 Transceiver

Transmitter and receiver in transceiver unit to share the same electric circuit on a single board. It passes instructions to other nodes in the network after receiving it from the processing unit. Through communication channel the communication is implemented.

2.4.4 Power Supply Unit

To observe the environment at low-cost and time, The energy of the sensor node giving by power block. Power generator provides power block by the energy then the energy passes to another component of the node. Another significant component that must be distributed correctly is the battery, because the sensor life depends on it. It provides stability of voltage, long life, ability to recharge under low current.

2.5 Application of WSN

There is a wide range of fields the sensor networks are utilized in, such as military applications, medical, environmental monitoring. Sensor networks support the interaction between humans and material science. To get a lot of applications to explore new applications in the real-world, sensor nodes are widely applied in uncontrolled environments. Deployment tightly sensing node with the ability to remote sensing, wireless communications and processing ability in uncontrolled environment can helps in measuring the ambient conditions. Such networks can collect the important activities surrounding the sensor node, transforming sensed and collected data into electronic signals to be processed [19].

Sensor networks play an important role in the following applications [20].

- Environmental applications
- Health care applications
- Agricultural applications
- Structural monitoring
- Intelligent home monitoring
- Military applications
- Industrial applications
- Vehicle detection
- Congestion control
- Radio Frequency Identification (RFID) indoor tracking system

2.6 Linear Wireless Sensor Network

The linear wireless sensor network is simple linear network, chain type network or one-dimensional network, it is required in specific applications. These applications include oil/gas pipeline monitoring, sea/river beach monitoring, alternating current (AC) lines monitoring and border monitoring. Area in one dimension is a shared feature of these applications. A new sub-class of WSNs named as LWSN has been defined in previous studies. In LWSN, the sensors are located in a semi-linear or linear structure [5]. Figure (2.3) shows the main LWSN classifications,

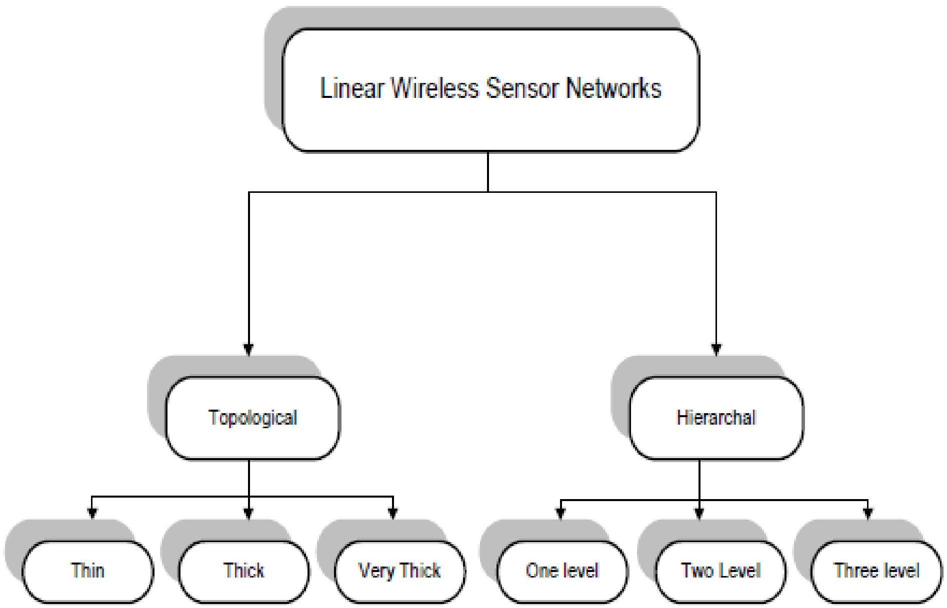


Figure (2.3) the LWSN classifications [21].

2.7 LWSN Classification

LWSN can be sorted according to its topology depending on the sensor's density [21]:

A. Thin LWSN: where all sensors are deployed in line physically like bridge monitoring application.

B. Thick LWSN: some of sensors are placed at a line statically, other nodes random deployment is used, in order to increase the reliability, provides flexibility, prolong network lifetime, additional routing policies and reduce latency in network, The geometric distribution is used like railway monitoring application.

C. Very thick LWSN: in this type of networks all sensors are deployed randomly in narrow and long area. This classification is used in harsh environments and applications that covered large area. This type of LWSN is commonly used in LWSN applications that Which extends for very long distances, such as pipelines, international borders, and the borders of seas and rivers.

Also, LWSN can be classified based on hierarchy [5]:

1 **One-level LWSN**: it's a simplest form. In this type of network all the sensors perform the same functions and have the same capabilities, and these sensors are known as basic sensors. Each sensor can do all functions such as sensing, aggregation routing, relay, etc. This type of LWSN is suitable for application that using in small-scale because of its simple structure and low cost.

2 **Two-level LWSN:** This type of network uses two types of sensors; the data rely sensor in addition to the basic sensor. The data relay sensors do aggregation, routing, and forwarding the data to the sink. The basic sensors communicate with the data relay sensors, which prolongs the network lifetime and decreases the energy consumption. This type of LWSN suitable for medium network size and higher reliability than level one.

3 **Three-level LWSN:** In this type of network, a third type of sensor is used in addition to the previous two types that are the data dissemination sensors. The data dissemination sensors connect with the data relay sensors. The data dissemination sensors are responsible for passing the data to sink. Execution cost and the network complexity is highest from one-level and two-level networks. The performance of this type of network is very high and reliability

is better, it is suitable for application in the large area. Figure (2.4) and figure (2.5) represent the three-levels hierarchy classification of LWSN.

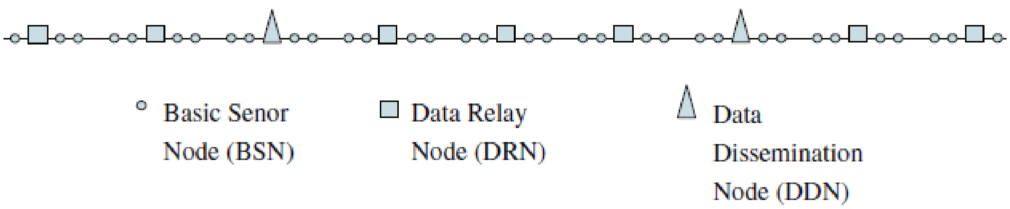


Figure (2.4). A generic representation of a LWSN with three-levels hierarchy LWSN [5]

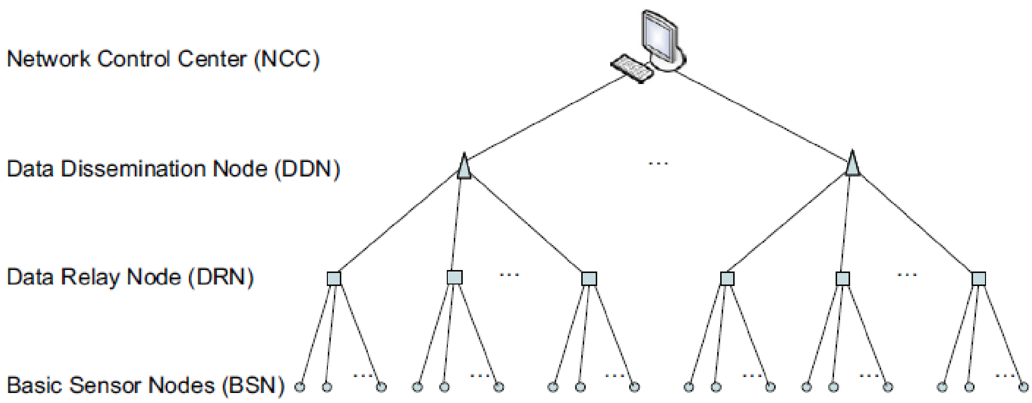


Figure (2.5) A hierarchical representation of LWSN [5]

2.8 LWSN Topology

LWSNs are not always strictly linear. In WSNs cases, topology is dependent on the constancy of the wireless links and on propagation environments. LWSNs networks are classified as low density, where the node on the right contains one neighbor called the right neighbor and on the left one neighbor called the left neighbor. To improve the robustness, the neighbor's number can be more than one in the network deployment as shown in figure (2.6). If a sensor has more than one neighbors, failure can be reduced [21].

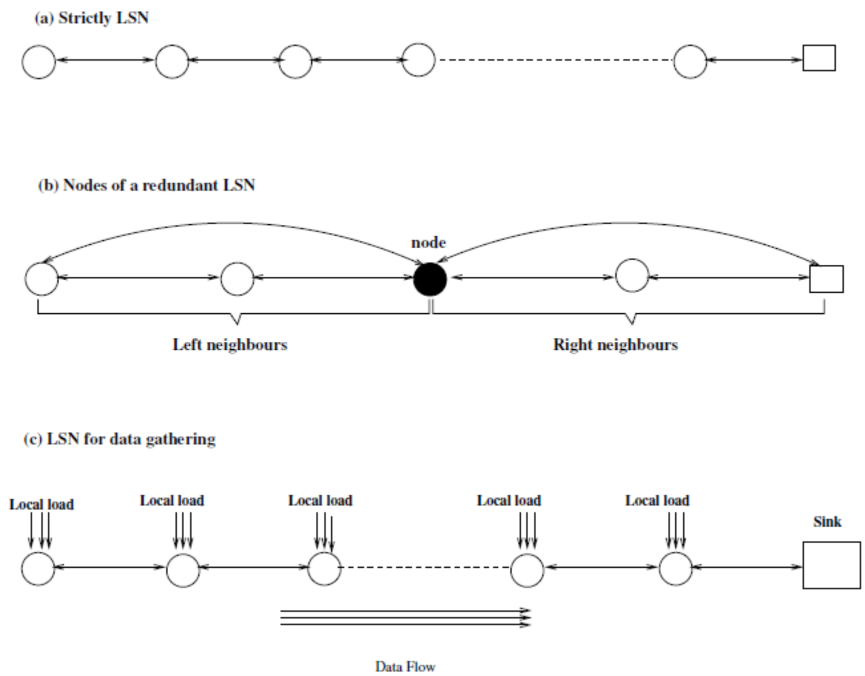


Figure (2.6) LWSNs examples [21].

2.9 LWSN Applications:

WSN applications include monitoring of inaccessible by human installation due to natural, military reasons and political reasons. They also include river and sea monitoring and the areas around linear structures in case of natural or man-made such as water, Alternating current (AC) lines, oil, and gas pipelines, subways and railroads. LWSNs length can be several or hundreds of kilometers. It is obvious that the number of applications requiring LWSN is continuously increasing. That is why a growing number of researchers are turning to investigate the specifics of these networks and proposing new, more tailored solutions to increase their efficiency and performance [3]. Figure (2.7) shows some of LWSN applications.

Figure (2.7) LWSNs applications

2.10 Linear Backbone Discovery

In an LWSN, the sensors are settled in a line. The sensing data are forwarded to the sink when any event occurs. A backbone node is provided communication path for nodes to reach base station (sink). The Backbone receives the data sensing by sensors in backbone or around it and then forward this sensing data along the backbone path to the sink.

2.11 Linearity

Due to a vast number of linear structures that are monitored such as borders, water, oil and gas pipelines, rivers and roads, using WSNs to monitor them, linear topology was created. WSNs topology is not useful in LWSNs; nodes that deployed in linear shape between parallel lines or carves in order to covered linear area. The algorithms and protocols take advantage of the linear network priori knowledge, this property lower the overhead and enhance the efficiency of the exchanged messages process [4].

2.12 Shortest Path Algorithm

The Individual nodes in WSNs networks are able to monitor physical environment. These sensors are small in size, they have limited computational capacity and processing and low cost. These sensors can measure, detect, and sense data from the round world, then it is directed this sensing data in order to do data processing. Since the power of sensors is taken from the batteries, making the most of their resources is important to prolong the network's life. Sensing data transferring by the sensor consumes the most sensor power. Therefore, the process of determining the transmission line is significant [1].

The algorithm produces shortest braided hop multi path in order to be usedfor fault-tolerance or load-balancing [15].

One of the greatest widely used approaches for the transmission of messages in a diversity of networks is the path with the fewest hops or the shortest distance. In terms of energy and time, it offers an effective message transmission to the destination [1].

2.13 Discovered Backbone Caching

The shortest path or the fewest hops is a very commonly used approaches for the message’s transmission in a different type of networks, it provides an effective message transmission in terms of time and energy [15].

After the backbone nodes are discovered, a special message is passed containing list of each backbone nodes IDs. These lists are kept in other nodes to reach the backbone and are also used in the routing process later.

- **Partial Backbone Caching:** “k-neighborhood caching” is another name of this cashing type. The sensors caches k neighbor sensors IDs in the forward and backward directions. This information can be used for route data to the next hop neighbor. For example, if sensor ‘A’ receives a data from sensor A − 1 it will route this data packet to sensor A + 1, which is located in forward direction. Figure (2.8) represented node neighborhood and next-hop.

- **Full Backbone Caching**: All backbone node caches the list of backbone nodes IDs; this technique is advanced and can be more useful for routing process later. In this method a node can forward packet in any direction in order to reach the base station (sink). Storing all the nodes is useful in cases where the node is required to know the path in all directions, for example in the case of avoiding failure and in cases of measuring network performance such as end-to-end delay or load balancing [7].

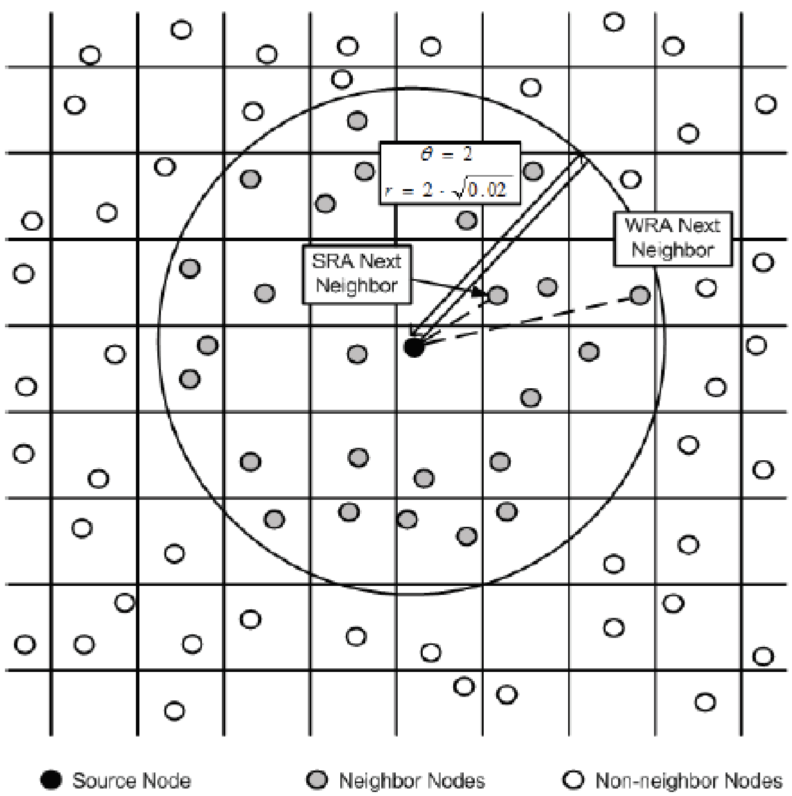


Figure (2.8) Node neighborhood and next-hop selection

[7].

2.14 Netlogo Simulation

Network is a programmable modeling environment for simulating natural and social phenomena. It was authored by Uri Wilensky in 1999 and has been in continuous development ever since at the Center for Connected Learning and Computer-Based Modeling. Netlogo is the next generation of the series of multi-agent modeling languages. Netlogo runs on the Java Virtual Machine, so it works on all major platforms (Mac, Windows, Linux, et al). It is run as a desktop application. Command line operation is also supported. Netlogo is characterized by a graphical interface that allows a better view of the network structure, and this feature is considered one of the most important features on which it was chosen.

2.15 Dijkstra's algorithm

Finding the shortest route from a point in a graph (the source) to a destination is solved using Dijkstra's algorithm, which was named after its inventor, E.W. Dijkstra. It turns out that the single-source shortest pathways issue may be solved by simultaneously determining the shortest routes from a particular source to each and every point in a graph. Figure (2.9) shows example to explain the algorithm [22].

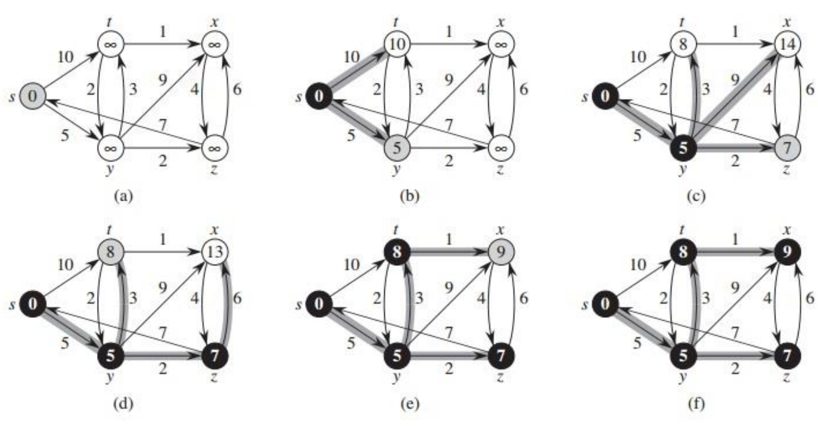


Figure (2.9) An example of Dijkstra's Algorithm [22]

CHAPTER THREE
Proposed System

CHAPTER THREE
Proposed System

3.1 Introduction

This chapter describes the proposed model as well as analyze the Linear wireless sensor network (LWSN) behavior. The first part of the proposed model in this thesis is to proposed backbone nodes discovery process between two designated sinks. The second part of the proposed model is to send the sensing data from nodes inside and outside the backbone.

3.2 Research Methodology

Special kind of WSNs can be utilized in real useful applications by aligning the deployed sensors in a linear form. LWSN can be used different real tracking and monitoring applications like monitoring the Railway lines, tunnels and bridges, monitoring and tracking Border lines and monitoring long Gas, water and oil pipelines. The required solutions for the LWSN are dissimilar to the WSN solutions. Figure (3.1) illustrate the steps of the research methodology of this thesis. In the next statements, each step is explained in details:

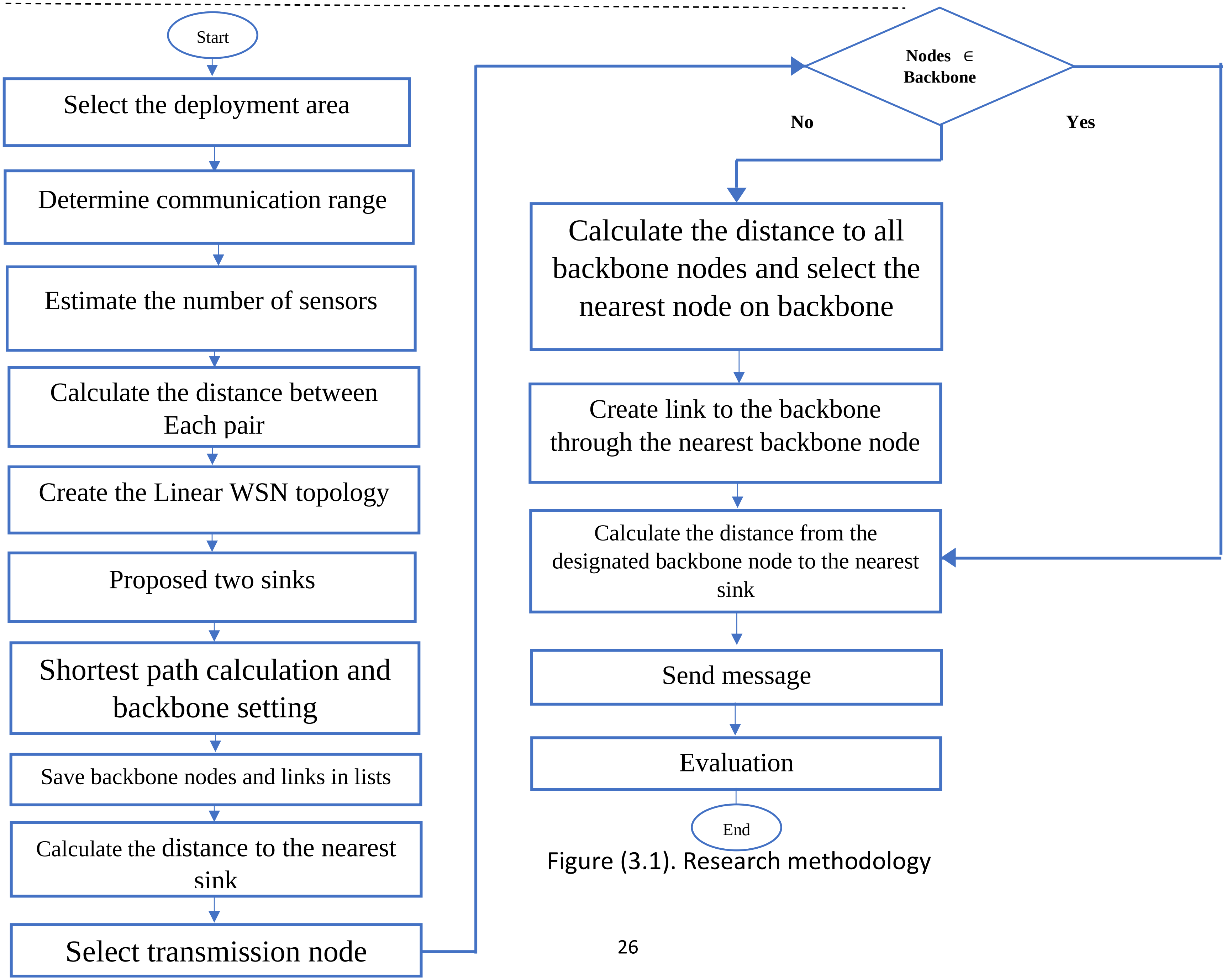


Figure (3.1). Research methodology

3.2.1 Select the Deployment Area

Special kind of WSNs can be utilized in real useful applications by aligning the deployed sensors in a linear form. LWSN can be used different real tracking and monitoring applications like monitoring the railway lines, tunnels and bridges, monitoring and tracking Border lines and monitoring long Gas, water and oil pipelines. The required solutions for the LWSN are dissimilar to the WSN solutions.

In this thesis, a selected area is proposed with a length of L and a width of W. The area size in such applications is like a rectangular with area of Z value as in equation 3.1.

$$Z = L * W \quad \text{……………………..……….(3.1)}$$

3.2.2 Estimate the Number of Sensors

In the linear network applications, the random deployment method was widely considered due to the long line distance and the difficulties of human accessing. The unmanned aerial vehicle (UAV) can be used to deploy the sensors along its flight line. The deployment process is usually controlled by the proposed area width between two parallel lines.

In this thesis, a new proposed model is created to estimate the suitable number of the require sensors to cover certain linear area. The number of the deployed sensors is estimated based on the area size and the used sensors communication range.

The expected number (N) of the required sensors to cover certain area is:

$$N = \frac{(L*W)}{R^2} \quad \text{………………..…………………(3.2)}$$

Where:

R is the sensor communication range.

According to randomness in deployment, some number (tolerances fraction) is suggested to be added to N to improve the sensors distribution and ensure the network connectivity. This added number is suggested in this thesis based on certain proposed mathematical formula. A Uniform probability distribution (equation (3.2)) can be utilized in predicting the optimal tolerances fraction.

As show in figure 3.2, the maximum length (end) coordinate value is Y_1 and the start coordinate value is Y_0 (can be represented as 0). The maximum width (end) coordinate value is X_1 and the start coordinate value is X_0 (can be represented as 0).

$$P(i) = \frac{1}{(Y_1 - Y_0)} \qquad (3.3)$$

Equation 3.3 is valid for a line only, equation 3.4 will be valid for a rectangle area:

$$P(i) = \frac{1}{(Y_1 - Y_0)} * (X_1 - X_0) \qquad (3.4)$$

$$P(i) = \frac{X_1}{Y_1}\ ; \quad Y_0 = 0;\ \ X_0 = 0 \qquad (3.5)$$

$$N = \frac{L*W}{R^2} = \frac{Z}{R^2} \qquad (3.6)$$

$$N_r = \frac{Z}{R^2} + int \left|\frac{x*N}{Y}\right| \qquad (3.7)$$

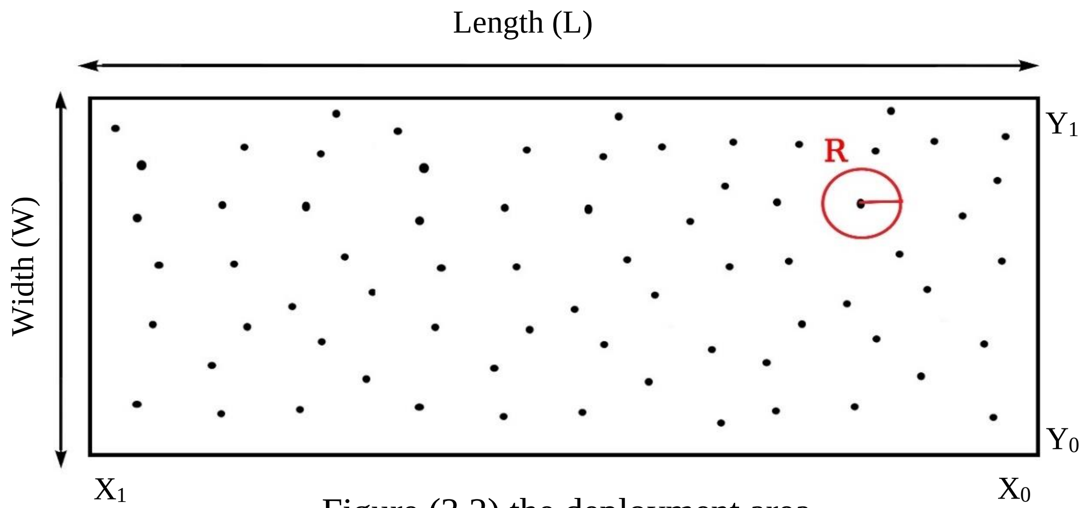


Figure (3.2) the deployment area

Example 3.1:

Let L=1000m, W= 50m, R=10m

$N = \frac{1000*50}{100} = 500$

$N_r = 500 + int\ (\frac{500*50}{1000})$

N_r = 500 + 25 = 525 sensor nodes are needed.

3.2.3 Calculate the Distance Between Each Pair

After randomly deploying the sensor nodes, the coordinates (x, y) for each sensor location are collected. The distance between each two sensors can be calculated based on their ground (2D) locations using the Euclidean distance equation.

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \quad \text{.....................(3.8)}$$

where:

- d: the Euclidean distance.

- (X_1, Y_1): the first sensor coordinate.
- (X_2, Y_2): the second sensor coordinate.

3.2.4 Create the Linear WSN Topology

After deploying the number of sensor nodes, the communication range (R) is settled, and the distance (d) between each pair of the sensor nodes positions is calculated using equation (3.8) If $R \geq d$ then a link is created between this pair. Searching all the sensor nodes will resulted in a connected graph. The number of the links and their lengths can be calculated. The indication of the colors and shapes in the following figures illustrated in table (3.1). Figure (3.4) shows a created connected graph sample for a linear wireless sensor network (LWSN).

Table (3.1) shapes sign in figures

Shapes	Sign
Blue circle	Nodes
Yellow circle	- Sinks before backbone discovery - External source
Red circle	First sink after backbone discovery
Pink circle	Second sink after backbone discovery
Green circle	Choosing sink
White lines	Links between nodes
Red line	Backbone
Green lines	All possible path
Blue line	Selected path
Yellow arrow	Backbone node
Green arrow	Selected backbone node
Red arrow	Message passed through it

Closed letter	Sending message
Opened letter	received message

3.2.5 Propose Two Sinks

Due to the nature of the linear network extended longitudinally, in most of the previous research in the field of LWSN, one sink is adopted in the network at one end of the network. the location of the sink demands several problems:

1- Possibility of losing data on the way to the sink due to the long linear path.
2- Data traffic increased around the sink and the nearby nodes, which causes the Riley Braden problem.
3- More energy consumption in the sink.
4- Delaying the arrival of data to the sink due to the long distance traveled.

In the model proposed in this thesis, two or more sink are approved according to the length of the network and the suitability of the area in which it extends. In view of the applications of the linear WSN in railways or oil pipelines and others, it is assumed that there are stations at the beginning and end of the pipe or railway, it was to be a city, a base or a station, and these places are suitable for the establishment of sink. Figure (3.3) presents the created network topology.

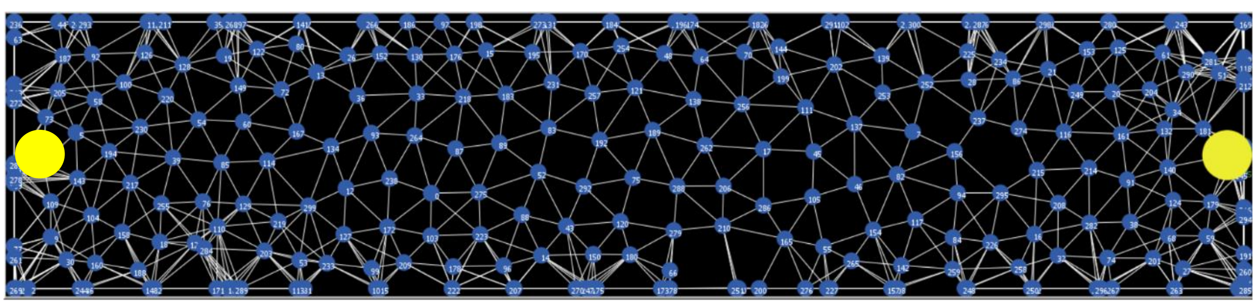


Figure (3.3) the network topology

3.2.6 Shortest Path Calculation and Backbone Setting

Distances are measured between directly and indirectly connected nodes. In Netlogo program interface, these distances are used in different useful calculations such as links creation, calculating the shortest path, calculating the alternate path, and calculating the nearest sink. Figure (3.4) shows a Netlogo interface sample to present the process of calculating and indicating the distances between each nodes pair (Links length).

```
Links Info
----------
End1 (node 147), End2 (node 277) Link Length= 0.6508525956121969
(node 277)
End1 (node 190), End2 (node 277) Link Length= 3.643584542435505
(node 277)
End1 (node 185), End2 (node 277) Link Length= 3.6771686521368636
(node 277)
End1 (node 167), End2 (node 277) Link Length= 3.1420181478653877
(node 277)
End1 (node 34), End2 (node 277) Link Length= 3.1363596028950376
(node 277)
End1 (node 230), End2 (node 277) Link Length= 2.6040294307265035
(node 277)
End1 (node 229), End2 (node 277) Link Length= 1.233060139614219
(node 277)
End1 (node 277), End2 (node 287) Link Length= 2.9518772844960965
(node 277)
End1 (node 155), End2 (node 278) Link Length= 2.4374624990223244
(node 155)
End1 (node 155), End2 (node 205) Link Length= 2.455404336216285
(node 155)
End1 (node 155), End2 (node 279) Link Length= 1.7815925592625719
(node 155)
End1 (node 3), End2 (node 155) Link Length= 3.925131696428726
(node 155)
End1 (node 145), End2 (node 155) Link Length= 2.815292298686965
(node 155)
End1 (node 44), End2 (node 155) Link Length= 3.7821204471592162
```

Figure (3.4) the links length calculations

After calculating the length of the links, the shortest path between the first and second sink can be calculated as shown in figure (3.5). Shortest path between the proposed two sinks is calculated by calculating the lengths of all possible paths to link between these two sinks and then comparing the length of these paths and choosing the shortest length. The Shortest hop multipath algorithm is applied to estimate the shortest path between a sink. Arrange the numbers resulting from the program's arithmetic and mathematical operations into matrices consisting of columns and rows that correspond to the number of deployed sensors.

```
Shortest Path Info
----------
(node 275): " # of nodes   : 3"
(node 275): " Nodes of Shortest Path : [(node 275) (node 207) (node 132) (sink 302)]"
(node 275): " Shortest Path : [(link 275 207) (link 207 132) (link 132 302)]"
(node 275): " Shortest Path length: 8.2045281948048"
 ====================
(node 101): " # of nodes   : 2"
(node 101): " Nodes of Shortest Path : [(node 101) (node 265) (node 27) (sink 302)]"
(node 101): " Shortest Path : [(link 101 265) (link 265 27) (link 27 302)]"
(node 101): " Shortest Path length: 6.008306081619063"
 ====================
(node 90): " # of nodes   : 19"
(node 90): " Nodes of Shortest Path : [(node 90) (node 288) (node 114) (node 199) (node 59) (r
(node 90): " Shortest Path : [(link 90 288) (link 288 114) (link 114 199) (link 199 59) (link
(node 90): " Shortest Path length: 60.07814066792579"
 ====================
(node 175): " # of nodes   : 2"
(node 175): " Nodes of Shortest Path : [(node 175) (node 132) (sink 302)]"
(node 175): " Shortest Path : [(link 175 132) (link 132 302)]"
(node 175): " Shortest Path length: 6.337590618756488"
 ====================
(node 240): " # of nodes   : 8"
(node 240): " Nodes of Shortest Path : [(node 240) (node 128) (node 79) (node 131) (node 66) (
(node 240): " Shortest Path : [(link 240 128) (link 128 79) (link 79 131) (link 131 66) (link
(node 240): " Shortest Path length: 26.20924446387476"
 ====================
(node 199): " # of nodes   : 16"
(node 199): " Nodes of Shortest Path : [(node 199) (node 59) (node 126) (node 209) (node 179)
(node 199): " Shortest Path : [(link 199 59) (link 59 126) (link 126 209) (link 209 179) (linl
(node 199): " Shortest Path length: 49.883146474210584"
```

Figure (3.5) the shortest path calculation

The backbone represents the shortest path from the source node to the sink node in a linear WSN. In this thesis the shortest path connecting the two ends sink nodes is indicated and utilized as a network backbone. All the messages will pass through this backbone from any node on the backbone to the nearest sink node. If a message is available in other node (not on the backbone), this node will send its message to the nearest node on the backbone and to the nearest sink node.

3.2.7 **Save the Backbone Nodes and Links in Lists**

Calculating the length of the path represented by the backbone by calculating the length between each pair of points considered by the length of the link and keeping these lengths with the number of hops for using it later in calculating the path length for the sink when linking to the external points. which is indicated in Table (3.2). Table (3.2) is a matrix of 22 * 22 nodes. Each cell shows the path between two directly connected nodes (A_i and B_j). This table data is collected based on the deployed topology. Figure (3.6) represented the selected backbone.

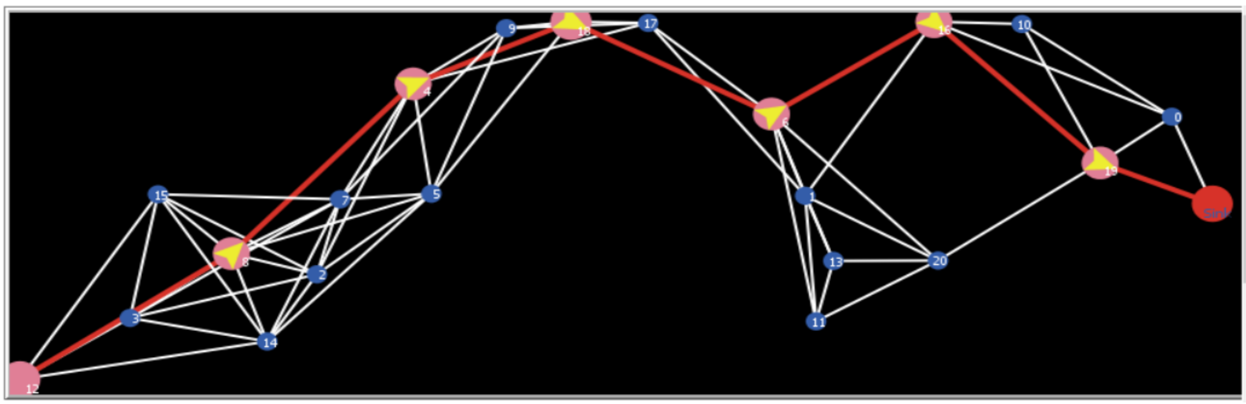


Figure (3.6) Backbone setting

Table (3.2) Saving links nodes and links in list

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0	0																					
1	-	0	-																			
2	-		0																			
3	-	-	9.40	0																		
4	-	-	11.45	-	0																	
5	-	-	7.11	-	6.09	0																
6	-	4.77	-	-	-	-	0															
7	-	-	4.27	12.12	7.26	4.44	-	0														
8	-	-	4.31	6.06	12.84	10.27	-	6.07	0													
9	-	-	-	-	5.46	9.79	-	12.39	-	0												
10	-	-	-	-	-	-	-	-	-	-	0											
11	-	6.91	-	-	-	-	11.58	-	-	-	-	0										
12	-	-	-	6.32	-	-	-	-	12.38	-	-	-	0									
13	-	3.83	-	-	-	-	8.60	-	-	-	-	3.42	-	0								
14	-	-	4.41	6.79	-	11.39	-	-	5.13	-	8.58	-	12.20	-	0							
15	-	-	8.89	6.93	-	-	-	8.86	4.83	-	-	-	12.18	-	9.67	0						
16	12.69	11.43	-	-	-	-	9.38	-	-	-	4.27	-	-	-	-	-	0					
17	-	12.18	-	-	11.91	-	7.81	-	-	6.90	-	-	-	-	-	-	-	0				
18	-	-	-	-	8.40	11.63	10.99	-	-	3.16	-	-	-	-	-	-	-	3.75	0			
19	4.31	-	-	-	-	-	-	-	-	-	8.52	-	-	-	-	-	11.20	-	-	0		
20	-	7.37	-	-	-	-	11.41	-	-	-	-	-	-	5.08	-	-	-	-	-	9.53	0	
21	5.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.90	-	0

3.2.8 Calculate the Distance to the Nearest Sink

In the case that the sensor node is one of the backbone nodes, the node calculates the distance between it and the first sink and between it and the second sink, then chooses the closest sink and thus directs all the message sent from it or through it to this selected sink. The choosing of nearest sink for backbone nodes is shows in the next steps:

1. Calculate the distance between the backbone node and sink 1
2. Calculate the distance between the backbone node and sink 2
3. Compare two distances.
4. Choosing nearest sink.
5. Send data to the choosing sink.
6. Save the path and sink as a cash in the node for future using.

3.2.9 Calculate the distance to all backbone nodes and Select the Nearest Node on Backbone

External node will calculate possible paths connecting it with all backbone nodes in order to create shortest path that can connect this external node with nearest node in backbone using shortest path algorithm. External node saving this length in list for Compare between them. As shown in figure (3.7). Each packet can be sent in the network through this backbone nodes and links. In this thesis two sink nodes are utilized to work as two base stations.

Packets can be sent from each node on the backbone to the nearest base station instead of the base station at the end of the area as in most related works. Each intermediate node on the backbone between the source node and the designated base station is function as relay node.

In most times one of the nodes not on the backbone has sensed information and want to send it to a base station. The developed algorithm in this thesis solved this problem by the following steps:

- Select certain node out of the backbone nodes list.
- Indicate the possible paths from this node to all the backbone nodes.
- Count the lengths of all these paths.
- Select the shortest one.
- Indicate the nearest node on the backbone to the source node.
- Calculate the distance from this backbone node to the two base stations.
- Select the nearest base station.
- Indicate a path from the source node to the designated base station.
- Test the sending process.

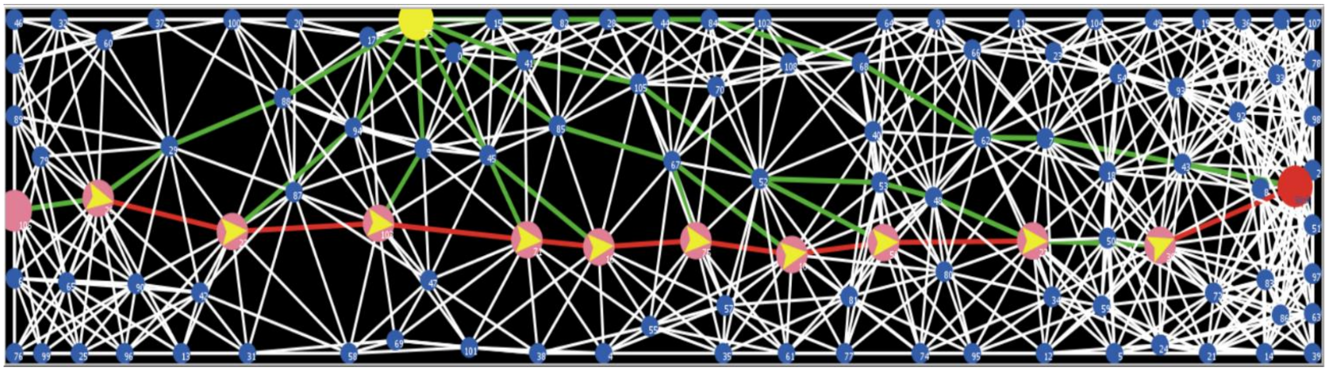


Figure (3.7). All possible path

3.2.10 Create Link to the Backbone Through the Nearest Backbone Node

Then calculate the shortest path between the peer (External node and nearest backbone node). This link is the shortest path between the external node and nearest backbone node (connection node). After compare all possible path, the shortest path chosen. as shown in figure (3.8).

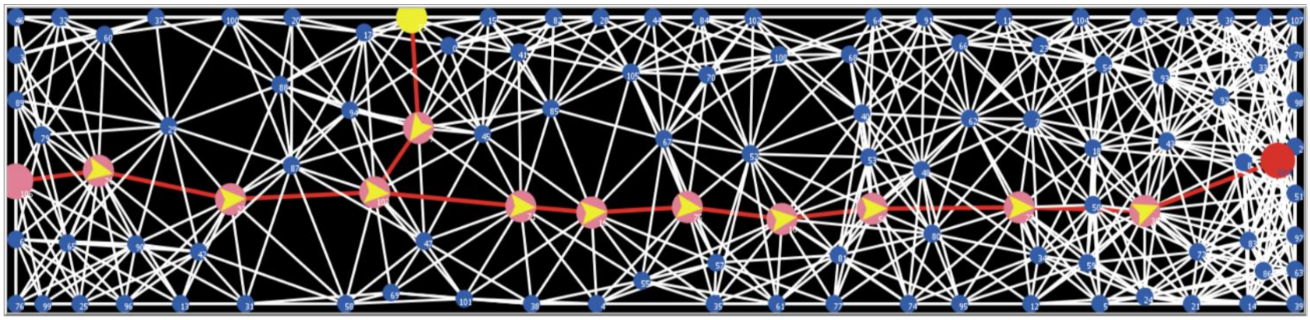


Figure (3.8) Shortest path

3.2.11 Send Message

After creating the LWSN and selecting the primary node, messages from the sensors will be sent to the sinks. A number of messages are generated, sent and received during a specified time to evaluate network metrics. In this section, the arrival time is specified, messages are generated and reserved at this time. This process is repeated several times in different parameters (number of nodes, connection range, different random propagation).

3.2.12 Evaluation:

After sending and receiving messages, certain and specific criteria are used to evaluate the performance of the network. The criteria used in this thesis are the number of messages sent, the number of messages received, delivery ratio and throughput**.**

The number of messages sent is changed every time the transmission process is repeated to evaluate the network in different cases and when different numbers of messages are sent.

Received messages is one of the important criteria to calculate in order to know the number of lost messages and the accuracy of data arrival.

The message delivery ratio can be calculated by dividing the total number of messages that have reached their destinations by the total number of messages that have been delivered from sources. The ratio of the number of messages received at the destination (RM) to the total number of send messages (SM) is known as delivery ratio (R).

$$\boldsymbol{R = \frac{RM}{SM}} \ldots\ldots\ldots\ldots\ldots\ldots(3.9)$$

Throughput is the number of messages successfully transmitted per unit time. Throughput is measured by tabulating the amount of message transferred between multiple locations during a specific period of time.

Throughput can be calculated using the following formula:

$$\mathbf{TH = \frac{RM}{T}} \ldots\ldots\ldots(3.10)$$

where:

- TH = Throughput
- RM = The number of messages received at the destination
- T = The time from start to finish.

CHAPTER FOUR
Simulation
Results and Analysis

Chapter Four
Simulation results and analysis

4.1 Introduction

This chapter presents the use of the NetLogo simulator to implement the specified simulation experiments. The presentation begins with setting up the LWSN, then generates potential links based on the node's coverage area, creates a potential backbone from the first sink node to the second sink node, suggests using multiple sending nodes simultaneously, generates messages, and proposes a sampling approach to analyze these data. Models are used to simulate the effects of many factors, including the number of nodes, the coverage area, the number of sending nodes, common nodes, and alternate pathways.

4.2 Simulation Setup

Simulation scenarios are performed to implement and evaluate a Linear wireless sensor network with different variables as indicated in table (4.1).

Table (4.1) the simulation setup.

Parameter	Value
The simulator	Net Logo 6.1.1
Communication radius	Variable
Number of sensors	Variable
Routing protocol	Shortest path
MAC protocol	CSMA-802.11-DCF
Deployment	Random

4.3 Simulation Results

Variable number of nodes are deployed randomly. Two sink nodes are located at the beginning and the end of the linear area (sink one and sink two). Figure (4.1) shows a Netlogo snapshot for deploying 20 sensors in an area of 370 m * 8 m. The communication range is set to be 13 m. After deploying, links are created among nodes in range to compose a connected graph.

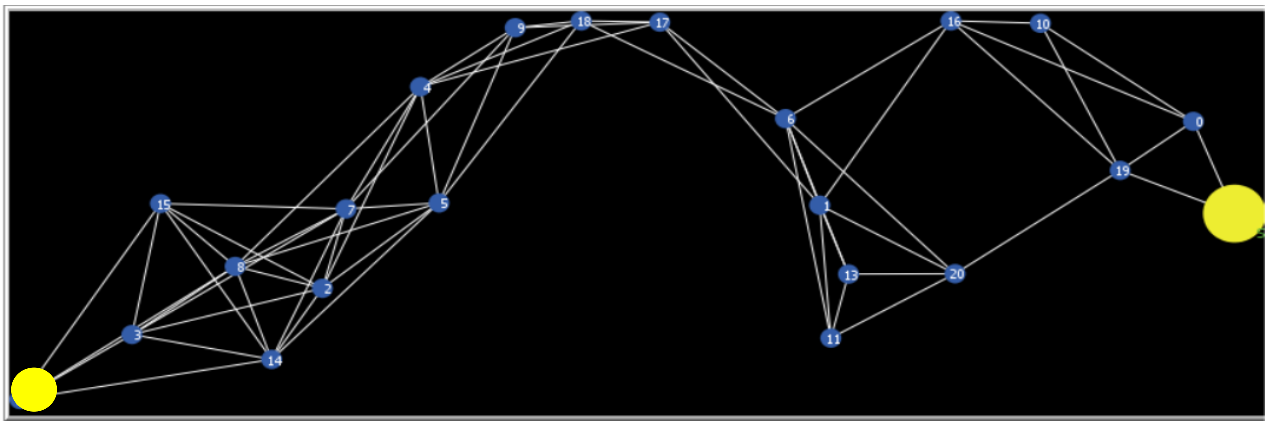


Figure (4.1). Connected graph snapshot

Table (4.1) represent a matrix of 22 * 22. Each cell shows the path between two nodes A_i and B_j. This matrix contains 20 nodes distributed randomly in the area of 370m * 8m on the NetLogo interface. The length between the directly connected nodes are fixed in the matrix. As for the indirectly connected nodes, their length is calculated by summing the lengths between each two nodes inside the path. Example (4.1) illustrates this:

Example (4.1):

The number (2.1) represents the path length between node 1 and node 2, which are directly connected nodes, as shown in figure (4.1)

If the two nodes are not directly connected, then the distance between these two nodes is represented by the cumulative distances between all the intermediate

Nodes. As an example, the distance between Node 3 and Node 7, which are nodes that are not directly connected, rather, Node 3 is connected to Node 8 and Node 8 is connected to Node 7, so the path length is the sum of the distance between Node 3 and Node 8 with Node 7

A to C = A to B + B to C

3 to 7 = 3 to 8 + 8 to 7

3 to 7 = 6.06 + 6.07 =12.13

Table (4.2). The path length between direct connection node

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0	0																					
1	-	0	-																			
2	-		0																			
3	-	-	9.40	0																		
4	-	-	11.45	-	0																	
5	-	-	7.11	-	6.09	0																
6	-	4.77	-	-	-	-	0															
7	-	-	4.27	12.12	7.26	4.44	-	0														
8	-	-	4.31	6.06	12.84	10.27	-	6.07	0													
9	-	-	-	-	5.46	9.79	-	12.39	-	0												
10	-	-	-	-	-	-	-	-	-	-	0											
11	-	6.91	-	-	-	-	11.58	-	-	-	-	0										
12	-	-	-	6.32	-	-	-	-	12.38	-	-	-	0									
13	-	3.83	-	-	-	-	8.60	-	-	-	-	3.42	-	0								
14	-	-	4.41	6.79	-	11.39	-	-	5.13	-	8.58	-	12.20	-	0							
15	-	-	8.89	6.93	-	-	-	8.86	4.83	-	-	-	12.18	-	9.67	0						
16	12.69	11.43	-	-	-	-	9.38	-	-	-	4.27	-	-	-	-	-	0					
17	-	12.18	-	-	11.91	-	7.81	-	-	6.90	-	-	-	-	-	-	-	0				
18	-	-	-	-	8.40	11.63	10.99	-	-	3.16	-	-	-	-	-	-	-	3.75	0			
19	4.31	-	-	-	-	-	-	-	-	-	8.52	-	-	-	-	-	11.20	-	-	0		
20	-	7.37	-	-	-	-	11.41	-	-	-	-	-	-	5.08	-	-	-	-	-	9.53	0	
21	5.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.90	-	0

From the data in table (4.2), the backbone can be selected and indicated. The backbone is considered with the shortest path from sink 1 and sink 2 which is indicated in Table (4.3).The shortest path can be selected by calculating the paths between each pair of nodes. In Table (4.3) highlighted cells represent backbone paths length. Sink1 is connected to the backbone by one link, as well as sink 2. All the intermediate nodes are connected by two links with the other nodes.

Table (4.3). backbone links and nodes indication

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0	0																					
1	-	0	-																			
2	-		0																			
3	-	-	9.40	0																		
4	-	-	11.45	-	0																	
5	-	-	7.11	-	6.09	0																
6	-	4.77	-	-	-	-	0															
7	-	-	4.27	12.12	7.26	4.44	-	0														
8	-	-	4.31	6.06	12.84	10.27	-	6.07	0													
9	-	-	-	-	5.46	9.79	-	12.39	-	0												
10	-	-	-	-	-	-	-	-	-	-	0											
11	-	6.91	-	-	-	-	11.58	-	-	-	-	0										
12	-	-	-	6.32	-	-	-	-	12.38	-	-	-	0									
13	-	3.83	-	-	-	-	8.60	-	-	-	-	3.42	-	0								
14	-	-	4.41	6.79	-	11.39	-	-	5.13	-	8.58	-	12.20	-	0							
15	-	-	8.89	6.93	-	-	-	8.86	4.83	-	-	-	12.18	-	9.67	0						
16	12.69	11.43	-	-	-	-	9.38	-	-	-	4.27	-	-	-	-	-	0					
17	-	12.18	-	-	11.91	-	7.81	-	-	6.90	-	-	-	-	-	-	-	0				
18	-	-	-	-	8.40	11.63	10.99	-	-	3.16	-	-	-	-	-	-	-	3.75	0			
19	4.31	-	-	-	-	-	-	-	-	-	8.52	-	-	-	-	-	11.20	-	-	0		
20	-	7.37	-	-	-	-	11.41	-	-	-	-	-	-	5.08	-	-	-	-	-	9.53	0	
21	5.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.90	-	0

All possible path between sink 1 and sink 2 are tested and the shortest path based on the suggested approach in this thesis is indicated to be a backbone for this network. The highlighted number represented the path from one backbone node to other. Figure (4.2) shows backbone graphical representation based on the data in table (4.3) and (4.2) using the Netlogo user interface.

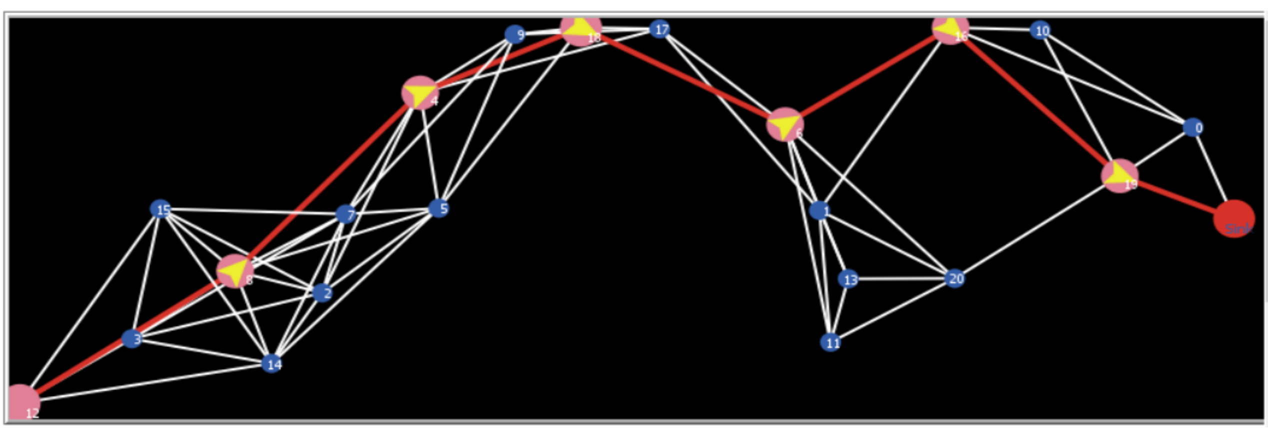


Figure (4.2). backbone representation

Figure (4.3) shows an example of selecting external node and their possible paths to the backbone nodes.

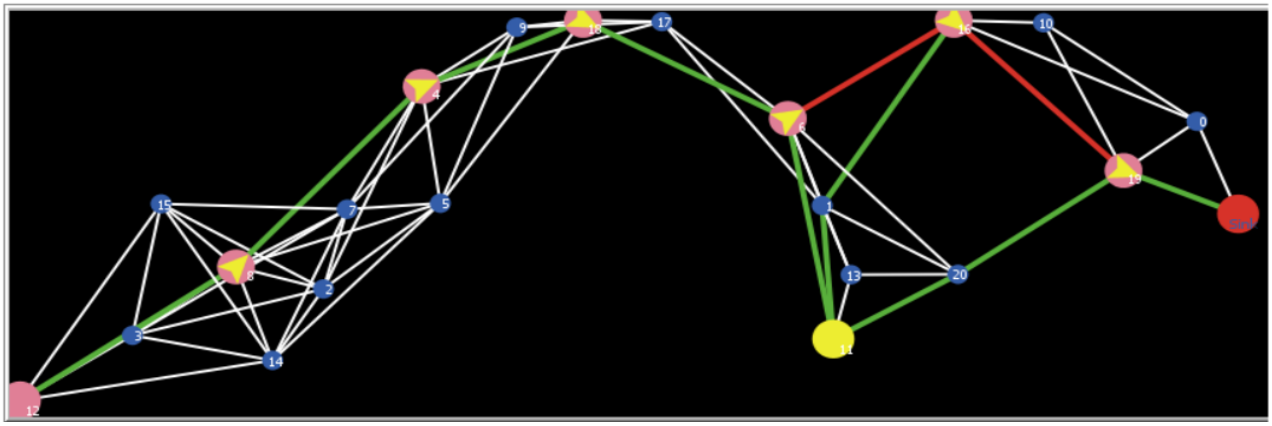


Figure (4.3). External node with all possible path to backbone example

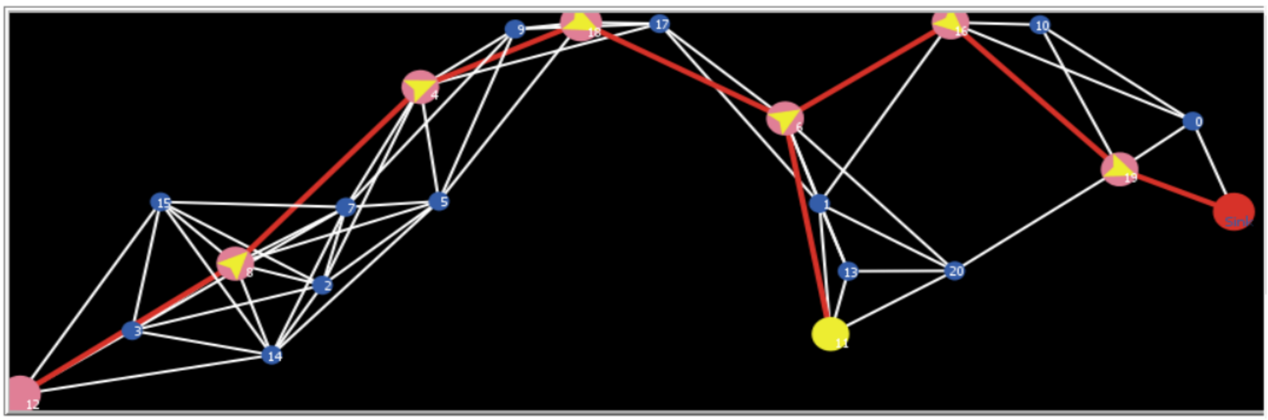


Figure (4.4) the resulted path from source node to the nearest node on the backbone.

Figure (4.5) is composed base on the results in table (4.3). Table (4.3) data is calculated based on the developed program algorithms.

Table (4.4). Sortest path from external node to the nearest backbone node

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0	0																					
1	-	0	-																			
2	-		0																			
3	-	-	9.40	0																		
4	-	-	11.45	-	0																	
5	-	-	7.11	-	6.09	0																
6	-	4.77	-	-	-	-	0															
7	-	-	4.27	12.12	7.26	4.44	-	0														
8	-	-	4.31	6.06	12.84	10.27	-	6.07	0													
9	-	-	-	-	5.46	9.79	-	12.39	-	0												
10	-	-	-	-	-	-	-	-	-	-	0											
11	-	6.91	-	-	-	-	11.58	-	-	-	-	0										
12	-	-	-	6.32	-	-	-	-	12.38	-	-	-	0									
13	-	3.83	-	-	-	-	8.60	-	-	-	-	3.42	-	0								
14	-	-	4.41	6.79	-	11.39	-	-	5.13	-	8.58	-	12.20	-	0							
15	-	-	8.89	6.93	-	-	-	8.86	4.83	-	-	-	12.18	-	9.67	0						
16	12.69	11.43	-	-	-	-	9.38	-	-	-	4.27	-	-	-	-	-	0					
17	-	12.18	-	-	11.91	-	7.81	-	-	6.90	-	-	-	-	-	-	-	0				
18	-	-	-	-	8.40	11.63	10.99	-	-	3.16	-	-	-	-	-	-	-	3.75	0			
19	4.31	-	-	-	-	-	-	-	-	-	8.52	-	-	-	-	-	11.20	-	-	0		
20	-	7.37	-	-	-	-	11.41	-	-	-	-	-	-	5.08	-	-	-	-	-	9.53	0	
21	5.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.90	-	0

Figure (4.5) shows path to nearest sink selected from external node.Blue path represent selected path to nearest sink (sink2).

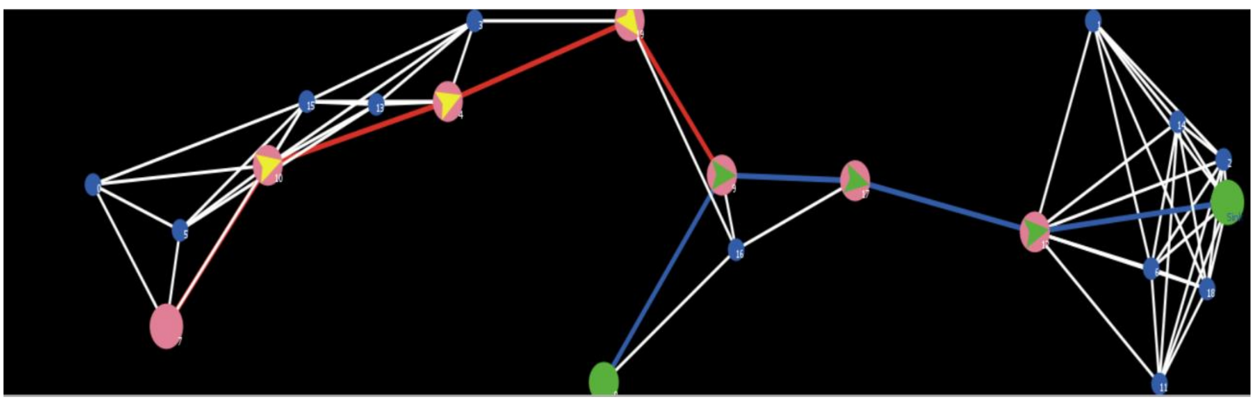


Figure (4.5) selected sink.

4.4 Sending Process Results

Different simulation runs are performed to test the sensing and transmitting packets from different nodes (either on the backbone or not) and selected the shortest path to the nearest base station.

A. Sending from backbone nodes

If any node on the backbone sensed certain activity or event, it will be indicated as a source node and it will transmit the collected data on the backbone through the backbone intermediate nodes to the sink. The nearest sink is selected and the message will send.

B. Sending from external nodes

If any external node (not on the backbone) sensed certain activity or event, it will be indicated as a source node. The possible paths from this node to all the backbone nodes

Will be calculated and shortest one selected to indicate the nearest backbone node and it will transmit the collected data on the backbone through the backbone intermediate nodes to the sink. The nearest sink is selected and the message will send. Figure (4.7) represent the sending process.

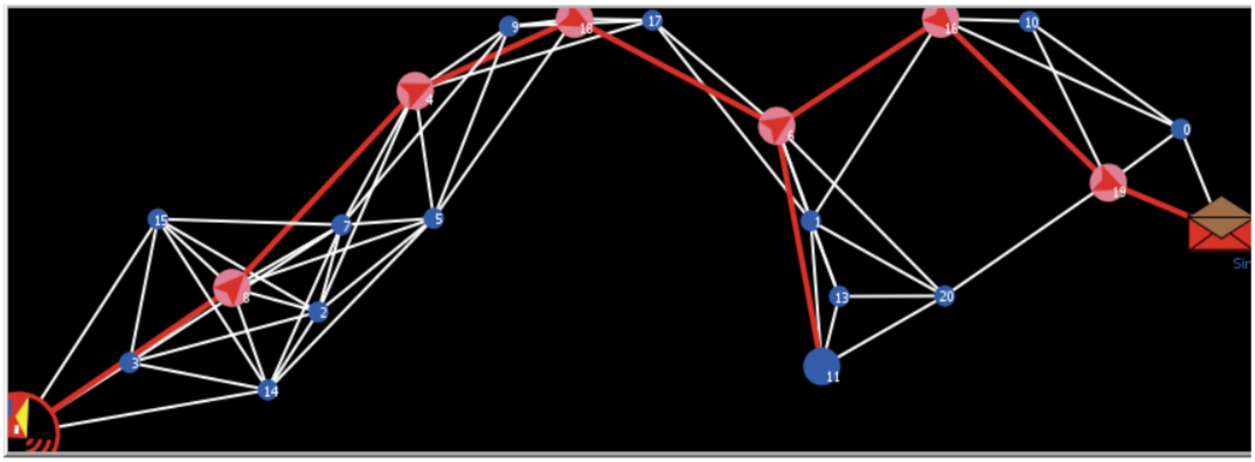


Figure (4.6) sending process

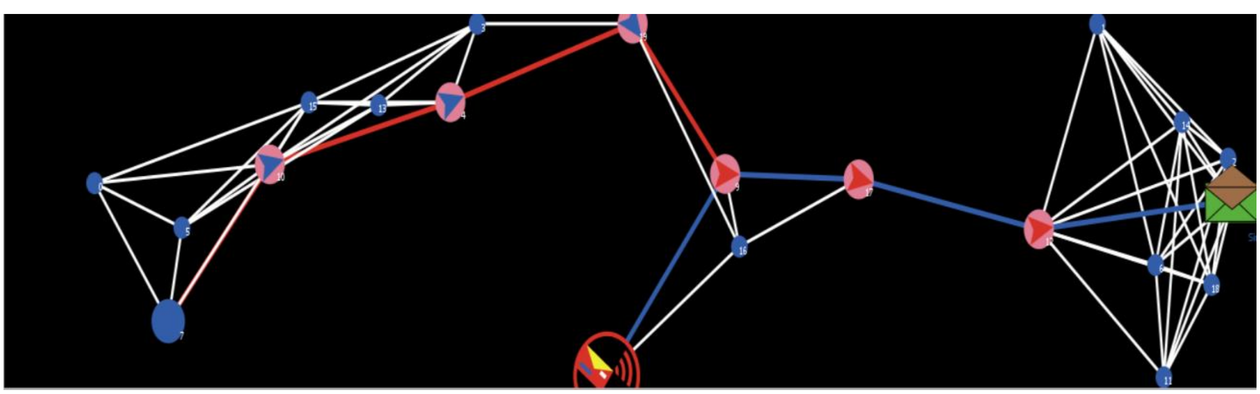


Figure (4.7) External node sending process

Table (4.5) shows several network cases with different number of nodes in the same area size and represent the selected backbone node list, length of backbone and the number of hubs from two sinks. Table (4.4) will describe each column in tablse (4.5), table (3.7) will show cases tables columns meaning.

Table (4.5). Description for Table (4.6) and Table (4.7)

Column	Description
Num	The sequence of case.
Total nodes	The number of random deployed sensor nodes.
Communication range	The amount of distance between one nodes and others nodes that allows a link to be established between them.
Backbone length	backbone length measured in NetLogo interface
Backbone hubs	Number of hubs between sink one and sink 2
Nodes	The list of backbone nodes number
Area	The linear area size (width * length) in Netlogo program.
External node	Nodes not belong to the backbone nodes.
Connection node	Nearest backbone node to the external node.
No. hubs to the backbone	Number of hubs between the external node and the connection node.
No. hubs to sink1	Number of hubs between the external node and the sink1.
Number of hubs to sink2	Number of hubs between the external node and the sink2.
Selected path Nodes	Nodes number from the external node to the sink node in list

Table (4.6) network cases

Num.	Total Nodes	Communication range	Backbone length	No. backbone hubs	Nodes	Area (X . Y)
1	20	16	73.760	6	[sink1, 6, 10, 16,2,14, sink2]	370* 8
2	40	13	77.190	8	9sink1,36,34,28,23,6,33,17,16, sink2]	370 * 8
3	60	12	73.687	7	[sink1,11,43,42,7,41,38, sink2]	370 * 8
4	100	9	74.714	12	[sink 1,78,91 ,40,86,11, 81,24,92,45, 38, sink 2]	370 * 8
5	525	10	203.298	49	[(sink1,106,148,39,493,326,197,425,479,118,468, 274, 460, 439, 406, 518, 147, 370, 322, 85 , 254, 74 , 123 ,429 ,42) , 512, 310, 10, 421, 193 , 330, 236, 94, 407, 297, 408, 427, 4, 438, 108, 171, 176, 275 203 , 161, 67, 233, 440, 331, 511, 255, 308, 48, 212, 508, sink 2]	1000 * 50

Case 1:

In case 1, deployed a number of nodes (20 nodes) in and connection range between links is 13 as show in table (4.10). Figure (4.8) shows the deployed nodes. Each state takes different external node position:

- State (1) select node in the left nearest sink 1. Figure (4.10) ,(4.11) shows state (1).
- State (2) select external node in the center. Figure (4.12), (4,13) show state (2).

- State (3) select node in the right near sink 2. Figure (4.14), (4,15) show state (3).

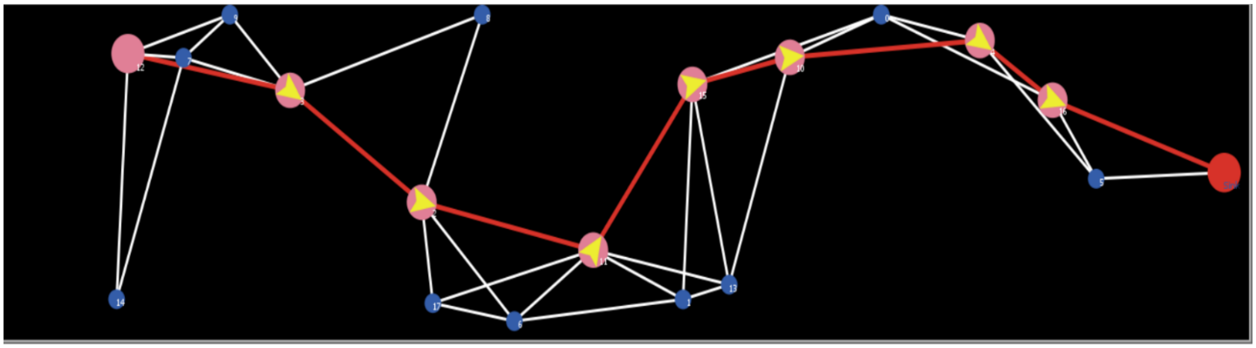


Figure (4.8) 20 nodes deployed case

Table (4.7). Shows three external nodes and their links. Case (1)

Num.	Total Nodes	communication range	External node	Connection node	No. hubs to backbone	No. path hubs to sink1	No. path hubs to sink2	Selected path Nodes
1	20	16	9	6	1	2	6	[(node 9) (node 6) (sink 1)
2	20	16	4	16	1	4	4	[(node 4) (node 16) (node 2) (node 14) (sink 2)]
3	20	16	5	20	1	7	1	[(node 5) (sink 2)]

(Case 1)

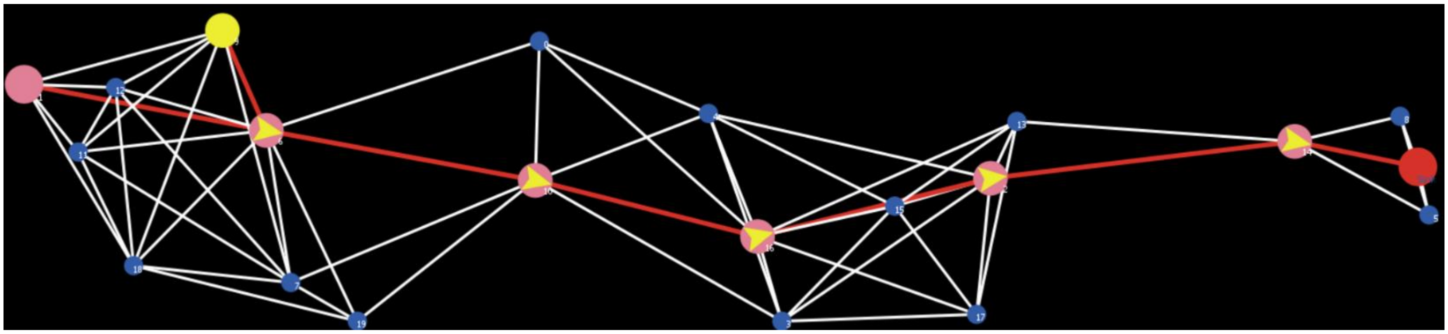


Figure (4.10). External node (state 1)

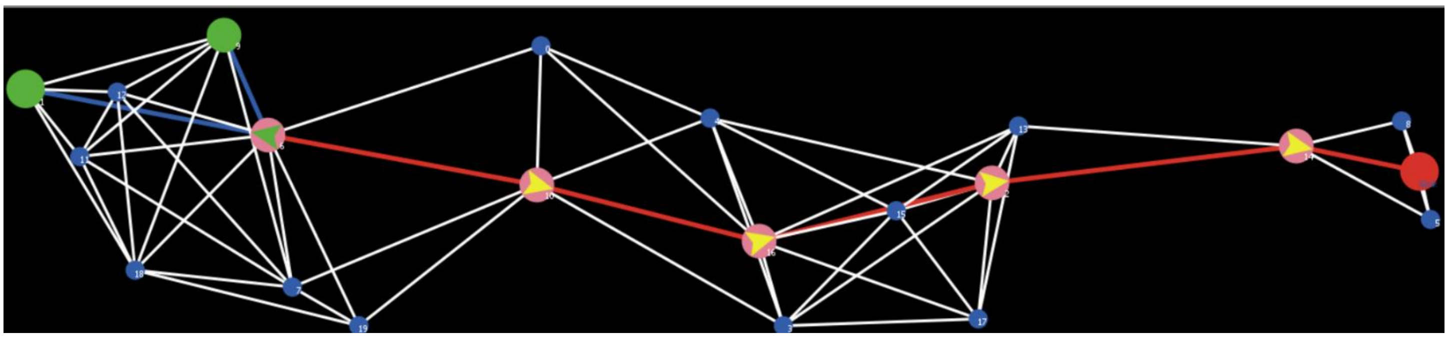


Figure (4.11). External node selects nearest sink (state 1)

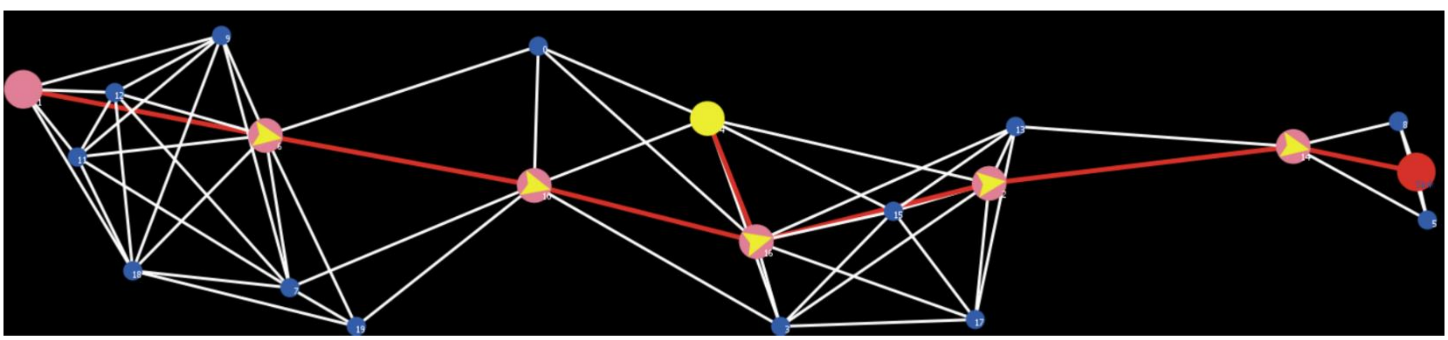


Figure (4.12). External node (state 2)

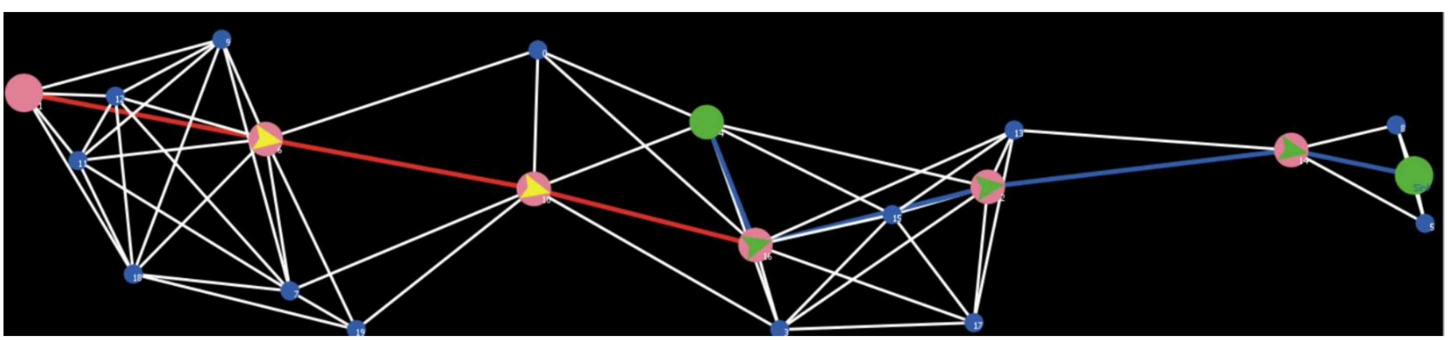


Figure (4.13). External node selects nearest sink (state 2)

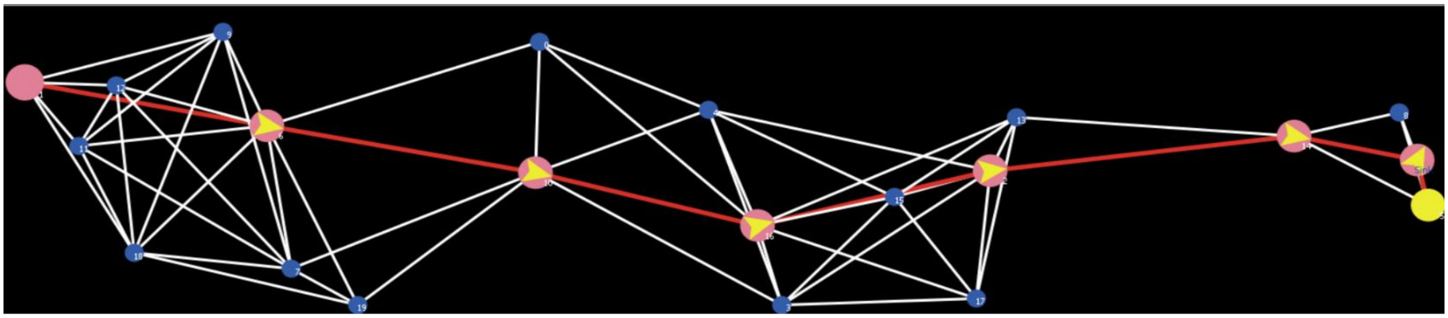


Figure (4.14). External node (state 3)

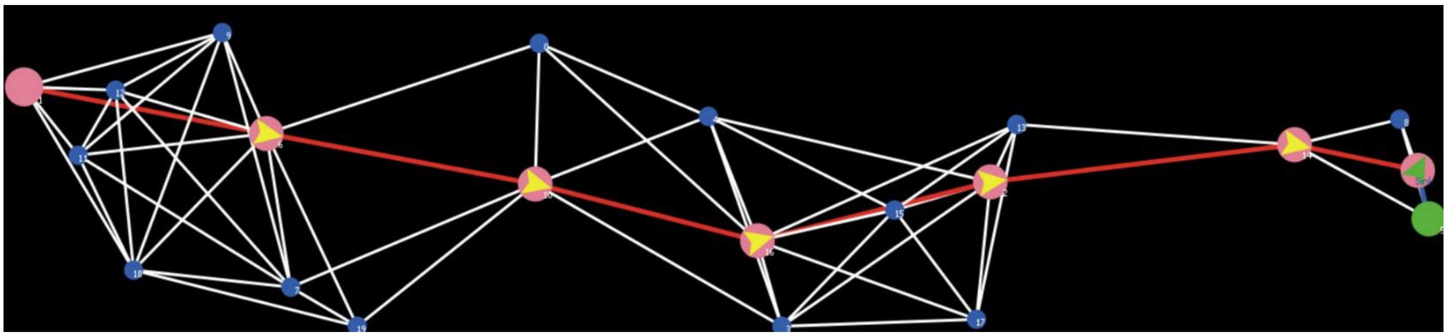
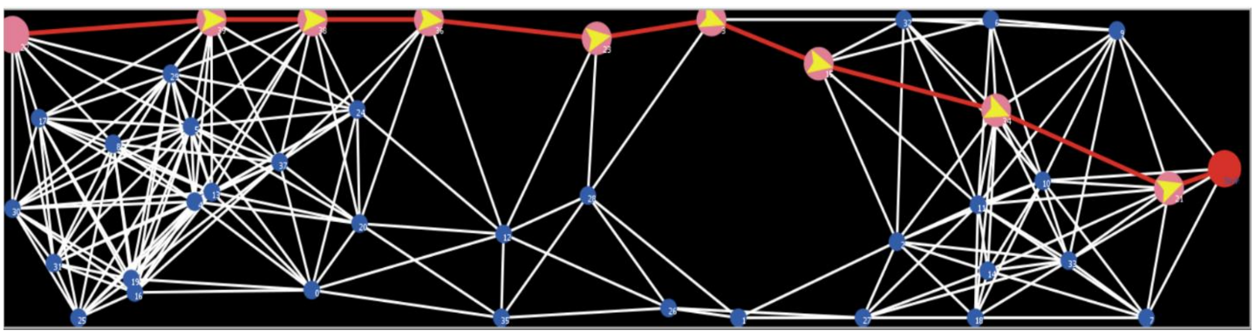


Figure (4.15). External node selects nearest sink (state 3)

Case 2:

In case 2, deployed a larger number of nodes (40 nodes) in the area (width = 8, Length 370) and change range of links between nodes to 13 as show in table (10). Figure (4.16) shows the deployed nodes. Each state takes different external node position:

- State (1) select node in the left nearest sink 1. Figure (4.17) ,(4.18) shows state (1).
- State (2) select external node in the center. Figure (4.19), (4,20) show state (2).
- State (3) select node in the right near sink 2. Figure (4.21), (4,22) show state (3).



(Figure 4.16) 40 nodes deployed case

Table (4.8). Shows three external nodes and their links. Case (2)

Num.	Total Nodes	Sensor range	External node	Connection node	No hubs to backbone	No. hubs to sink 1	No. hubs to sink 2	Selected path Nodes
1	40	13	25	22	2	2	11	[(node 25) (node 17) (sink 1)]
2	40	13	35	23	2	6	6	[(node 35) (node 12) (node 23) (node 36) (node 38) (node 39) (sink 1)]
3	40	13	18	34	1	3	8	[(node 18) (node 21) (sink 2)]

(Case 2)

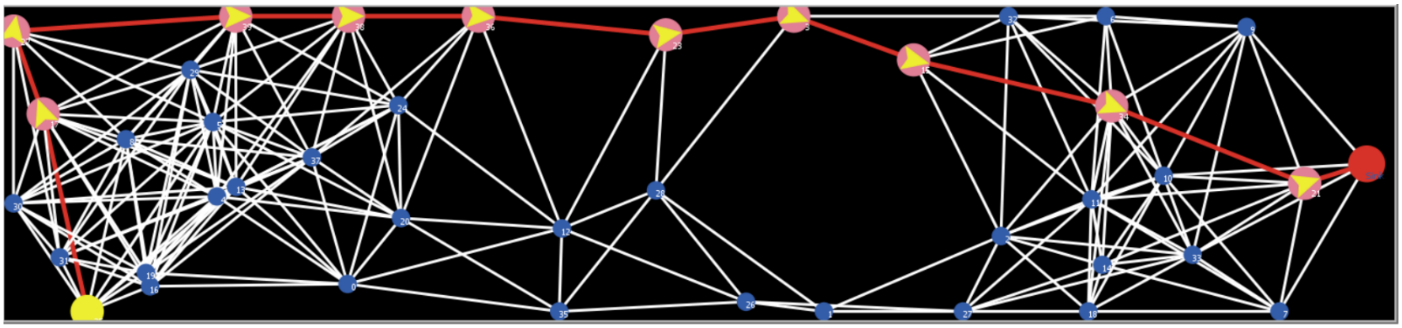


Figure (4.17). External node (state 1)

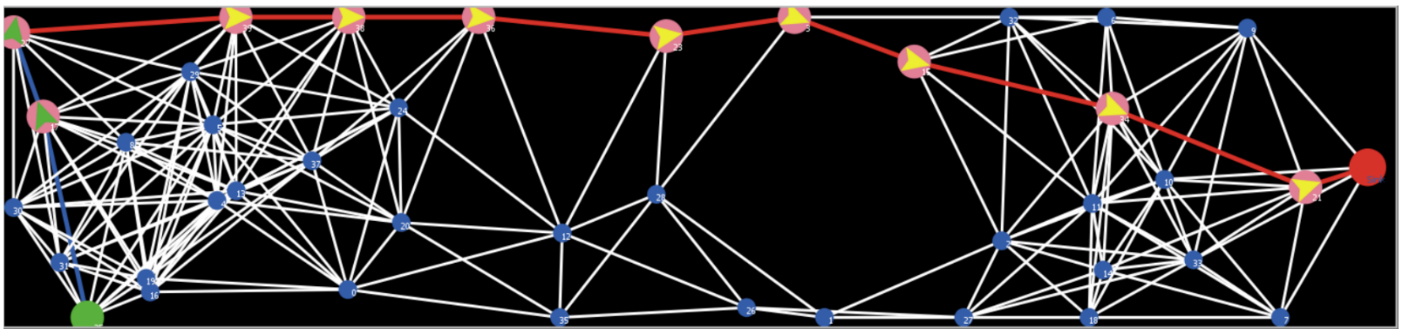


Figure (4.18). External node selects nearest sink (state 1)

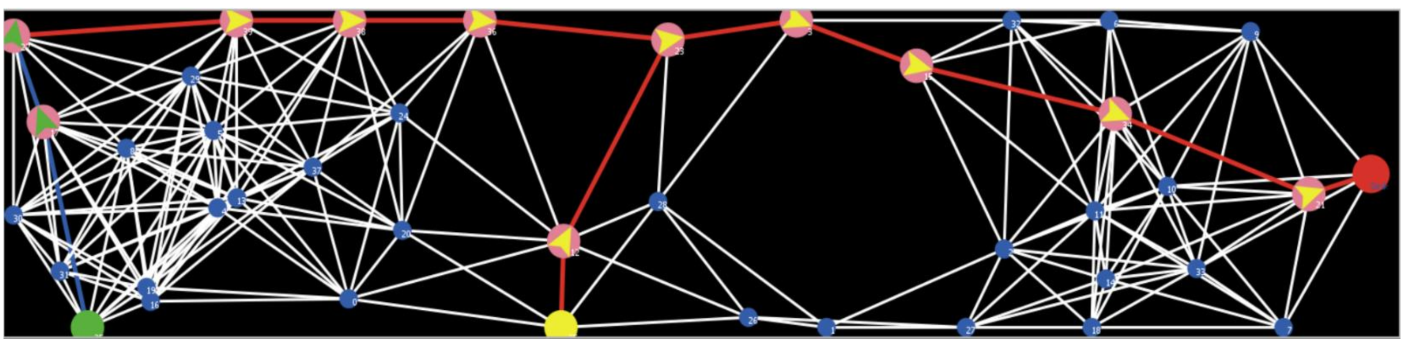


Figure (4.19). External node (state 2)

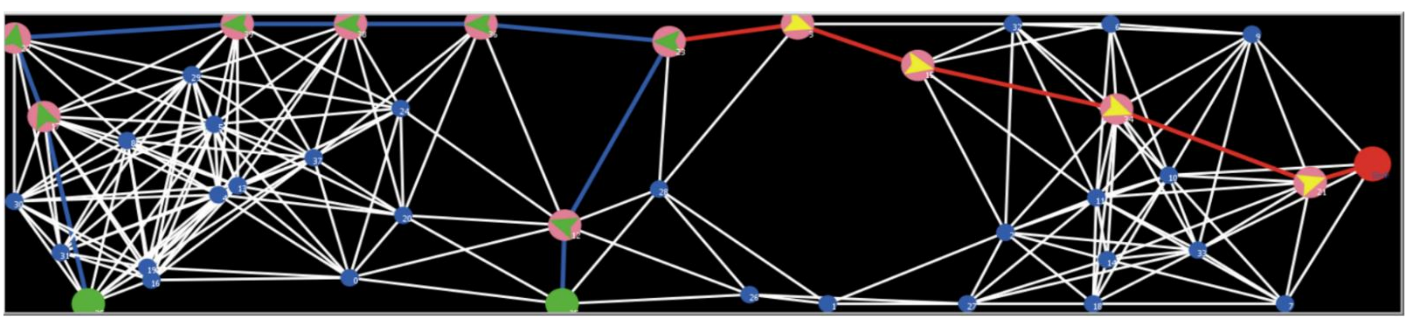


Figure (4.20). External node selects nearest sink (state 2)

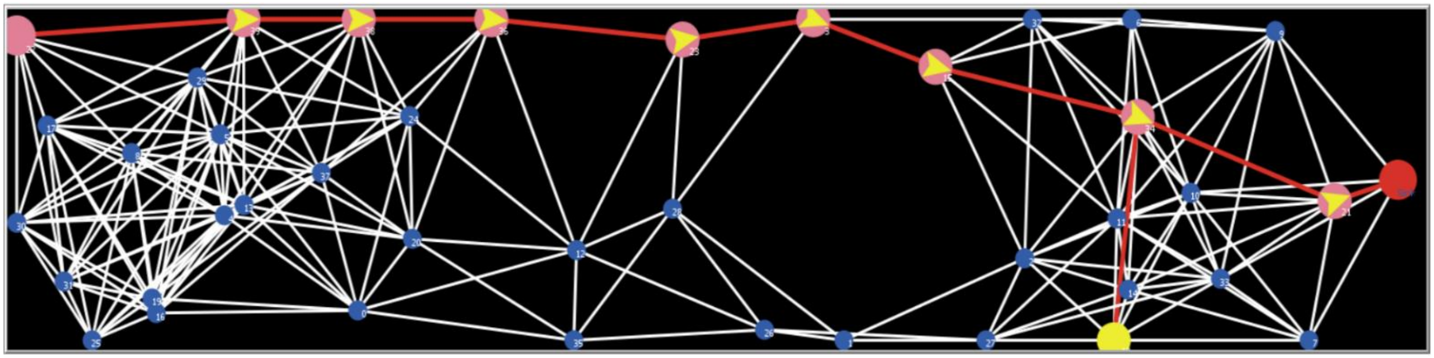


Figure (4.21). External node (state 3)

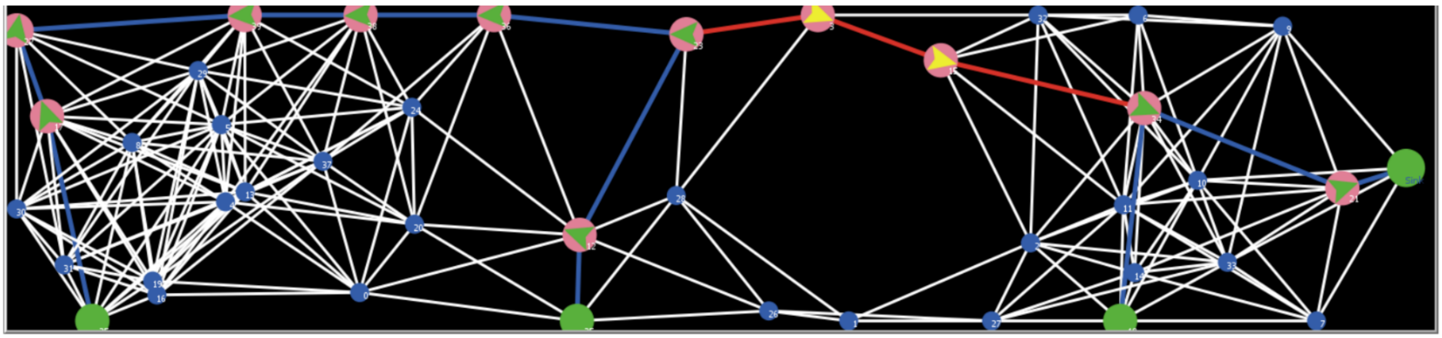


Figure (4.22). External node selects nearest sink (state 3)

Case 3:

In case 3, deployed a larger number of nodes (60 nodes) in the area (width = 8, Length 370) and change range of links between nodes to 12 as show in table (4.9). Figure (4.22) shows the deployed nodes. Each state takes different external node position:

- State (1) select node in the left nearest sink 1. Figure (4.24) ,(4.25) shows state (1).
- State (2) select external node in the center. Figure (4.26), (4,27) show state (2).
- State (3) select node in the right near sink 2. Figure (4.28), (4,29) show state (3).

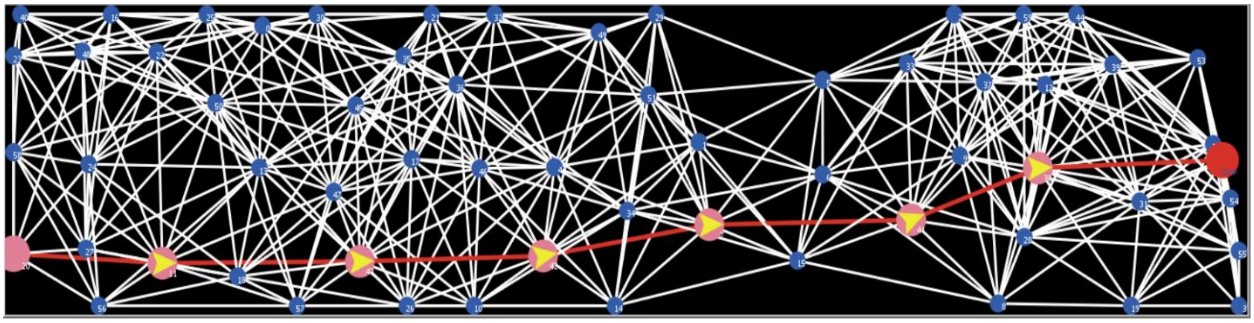


Figure (4.23). 60 nodes deployment

Table (4.9). case (3)

Num.	Total Nodes	Sensor range	External node	Connection node	No hubs to backbone	No. hubs to sink 1	No. hubs to sink 2	Selected path Nodes
1	60	12	40	20	2	2	9	[(node 40) (node 58) (sink 1)]
2	60	12	54	7	1	5	4	[(node 54) (node 7) (node 41) (node 38) (sink 2)]
3	60	12	44	38	1	7	2	[(node 44) (node 38) (sink 2)]

(Case 3)

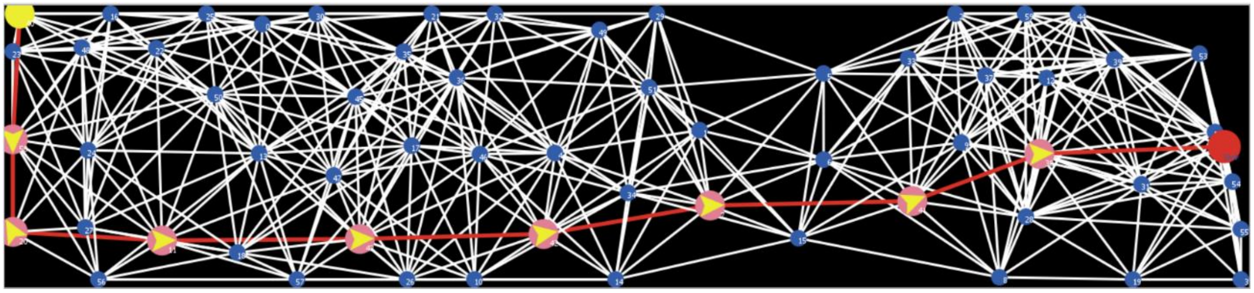


Figure (4.24). External node (state 1)

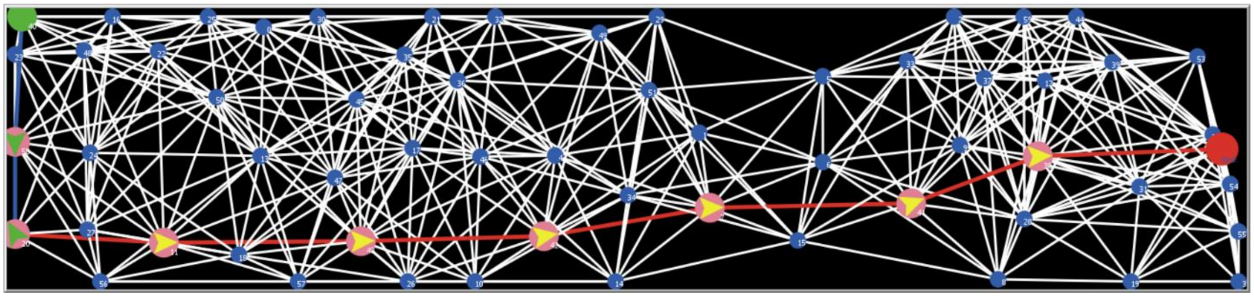


Figure (4.25). External node selects nearest sink (state 1)

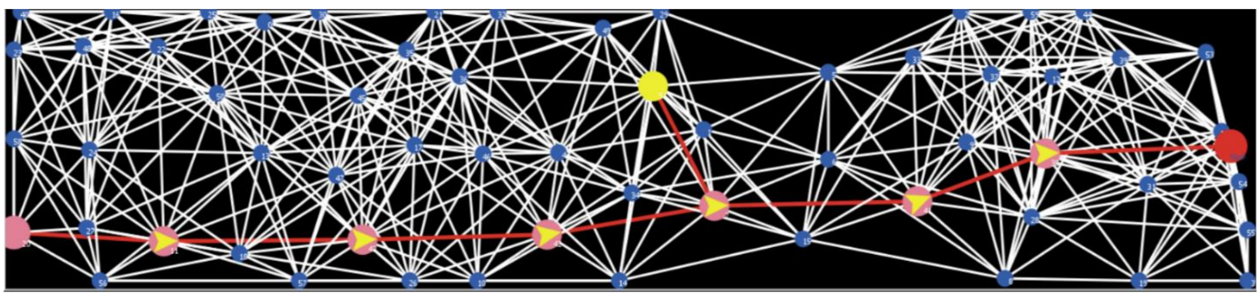


Figure (4.26). External node (state 2)

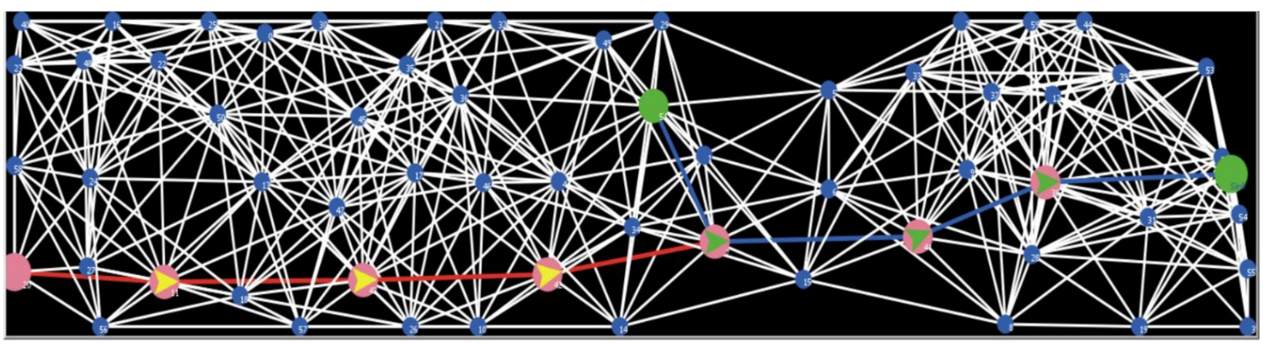


Figure (4.27). External node selects nearest sink (state 2)

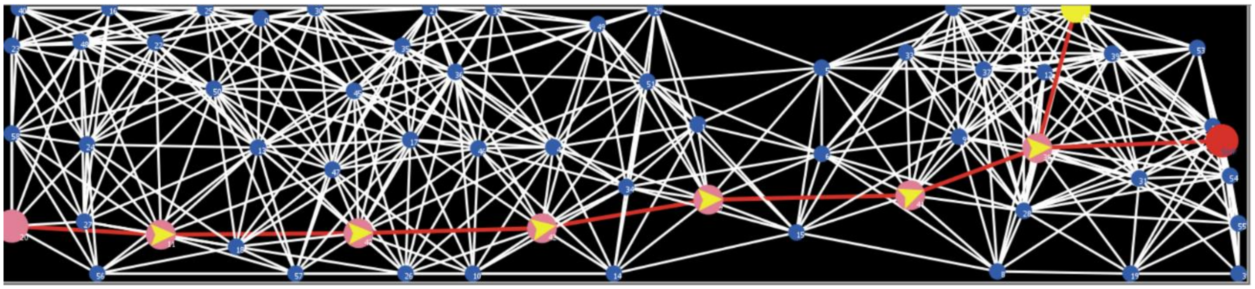


Figure (4.28). External node (state 3)

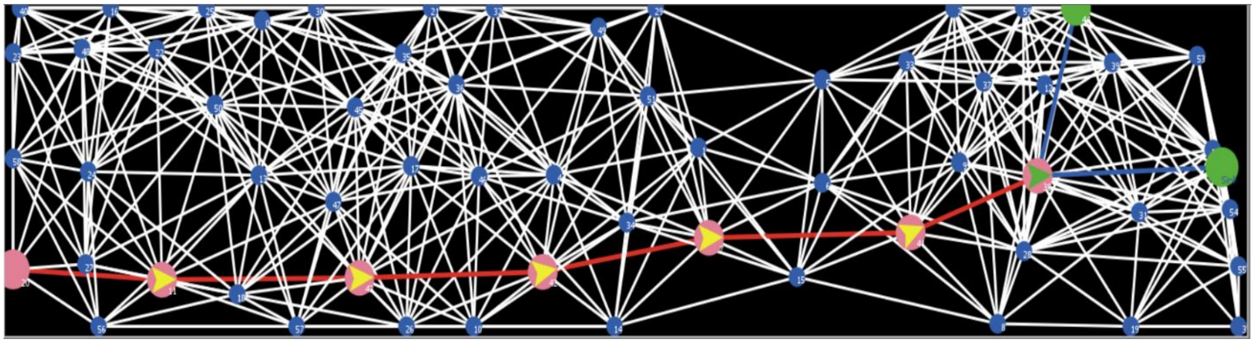


Figure (4.29). External node selects nearest sink (state 3)

Case 4:

In case 4, deployed a larger number of nodes (100 nodes) in the area (width = 8 Length 370) and change range of links between nodes to 10 as show in table (4.10). Figure (4.30) shows the deployed nodes. Each state takes different external node position:

- State (1) select node in the left nearest sink 1. Figure (4.31),(4.32) shows state (1).
- State (2) select external node in the center. Figure (4.33), (4,34) show state (2).
- State (3) select node in the right near sink 2. Figure (4.35), (4,36) show state (3).

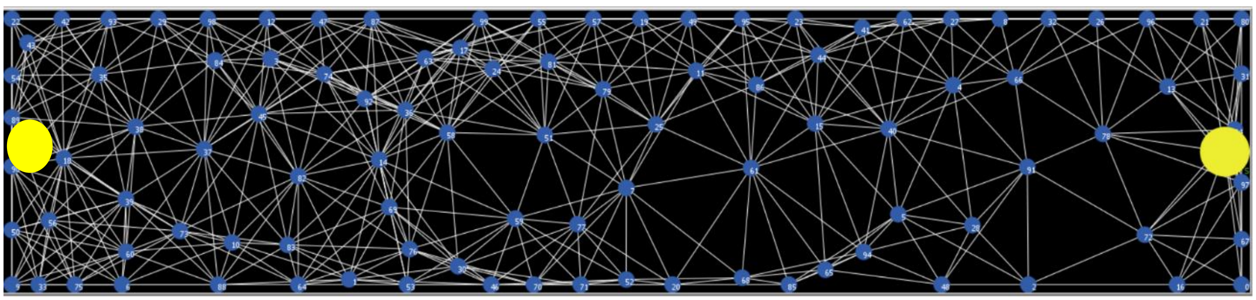


Figure (4.30). 100 nodes deployment

Table (4.10). case (4)

Num.	Total Nodes	Sensor range	External node	Connection node	No hubs to backbone	No. hubs to sink 1	No. hubs to sink 2	Selected path Nodes
1	100	10	6	38	2	3	12	[(node 6) (node 60) (node 38) (sink 1)]
2	100	10	76	81	3	8	9	[(node 76) (node 58) (node 51) (node 81) (node 24) (node 92) (node 45) (node 38) (sink 1)]
3	100	10	98	78	1	11	1	[(node 98) (node 78) (sink 2]

(Case 4)

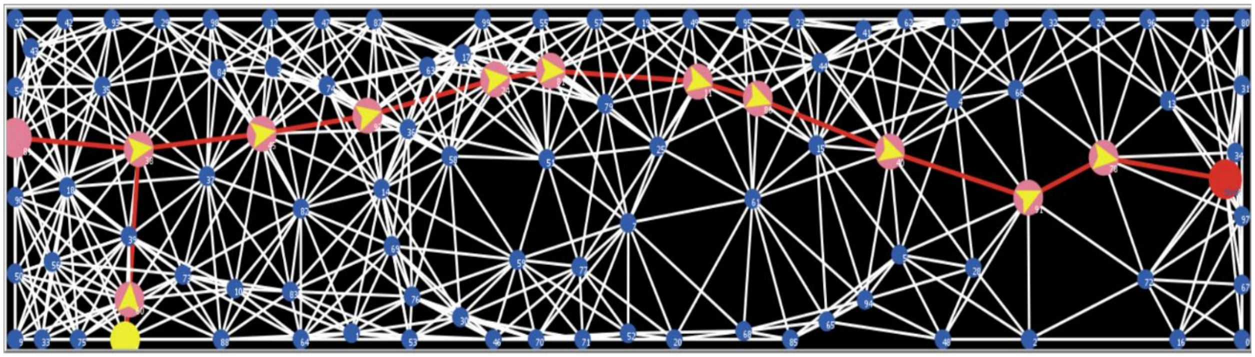


Figure (4.31). External node (state 1)

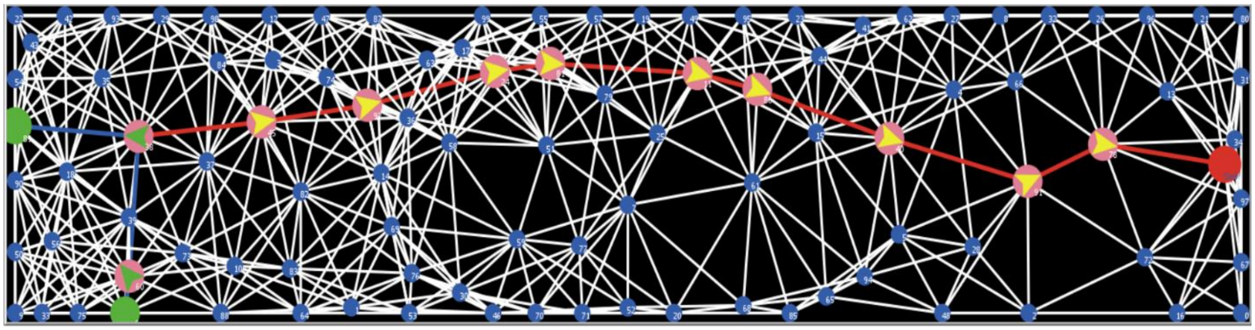


Figure (4.32). External node selects nearest sink (state 1)

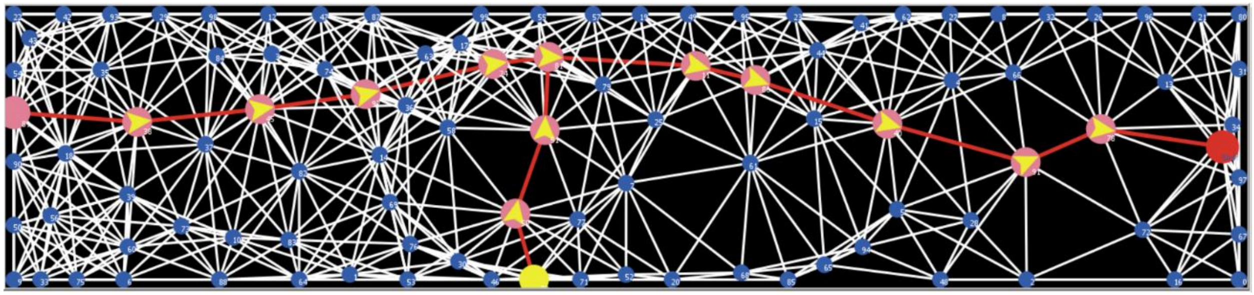


Figure (4.33). External node (state 2)

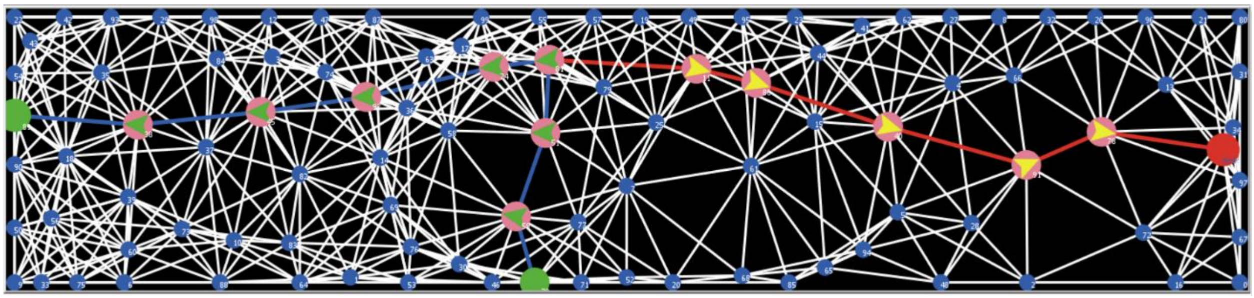


Figure (4.34). External node selects nearest sink (state 2)

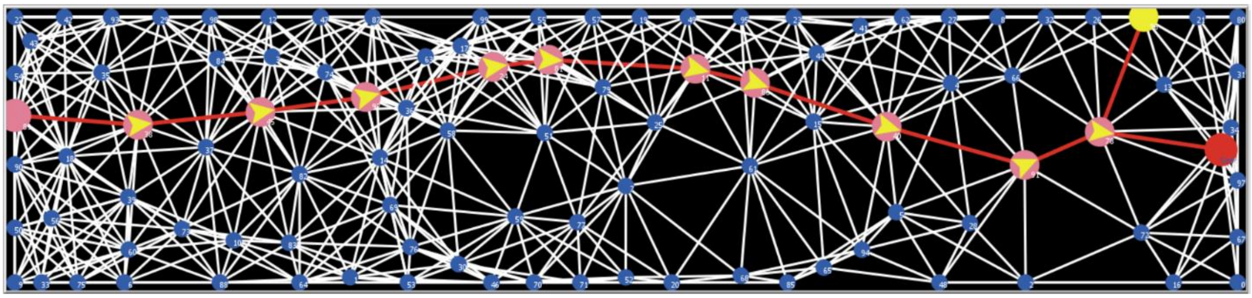


Figure (4.35). External node (state 3)

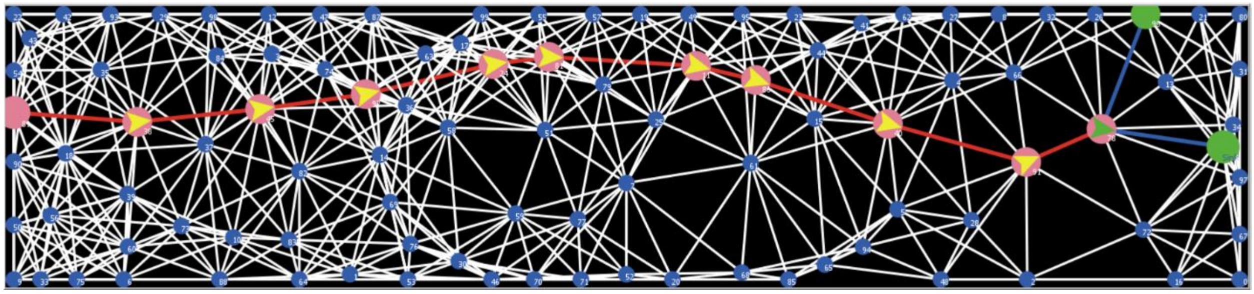


Figure (4.36). External node selects nearest sink (state 3)

Case 5:

In case 5, deployed a number of nodes calculated by proposed model in example (3.1). This model calculates the most appropriate number of sensors published in the area (width = 50, Length 1000) that ensures better communication between the sensor nodes, taking into account the communication range and the dimensions of the area. (525 nodes) is the perfect number of nodes for this area and change range of links between nodes to 10 as show in table (4.11). Figure (4.37) shows the first part of WLSN and Figure (4.38) shows the second part of WLSN. Figure (4.39) is a left part of the backbone and figure (4.40) is a right part of the backbone. Each state takes different external node position:

- State (1) select node in the left nearest sink 1. Figure (4.41), (4.42) shows state (1).
- State (2) select external node in the center. Figure (4.43), (4,44) show state (2).
- State (3) select node in the right near sink 2. Figure (4.45), (4,46) show state (3).

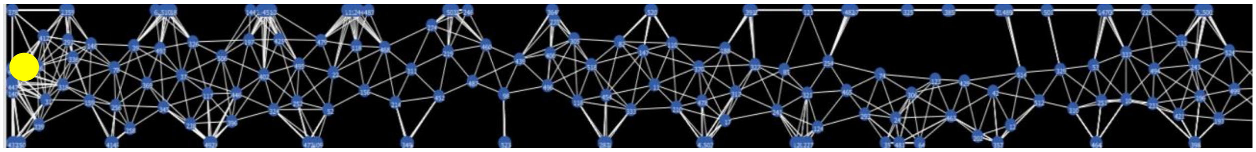


Figure (4.37) left part of deployment sensors area

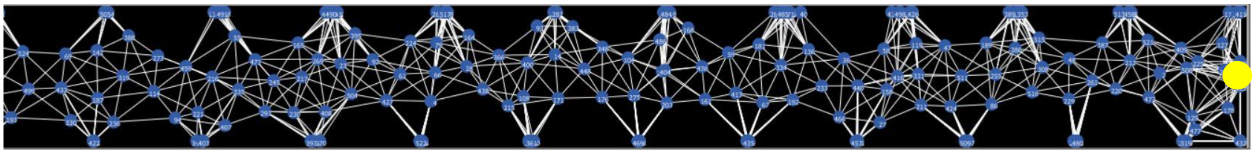


Figure (4.38) right part of deployment sensors area

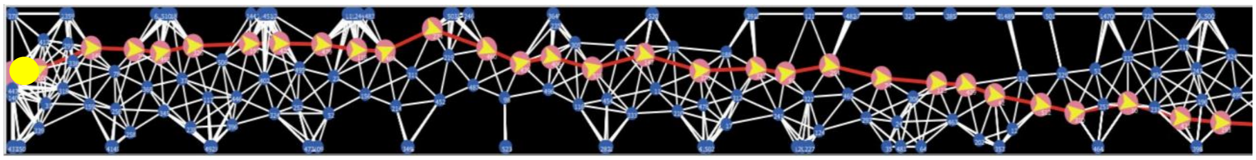


Figure (4.39) left part of backbone

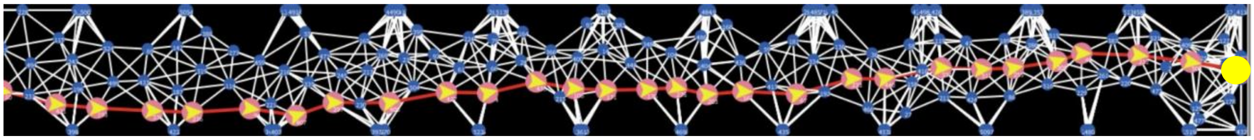


Figure (4.40) Right part of backbone

Table (4.11). case (5)

Num.	Total Nodes	Sensor range	External node	Connection node	No hubs to backbone	No. hubs to sink 1	No. hubs to sink 2	Selected path Nodes
1	525	10	446	197	1	7	50	[(node 446) (node 197) (node 326) (node 493) (node 39) (node 148) (node 106) (sink 1)]
2	525	10	24	74	22	25	10	[(node 24) (node 74) (node 254) (node 85) (node 322) (node 370) (node 147) (node 518) (node 406) (node 439) (node 460) (node 274) (node 468) (node 118) (node 479) (node 425) (node 197) (node 326) (node 493) (node 39) (node 148) (node 106) (sink 1)]
3	525	10	232	Sink 2	2	57	2	[(node 432) (node 462) (sink 2)]

(Case 5)

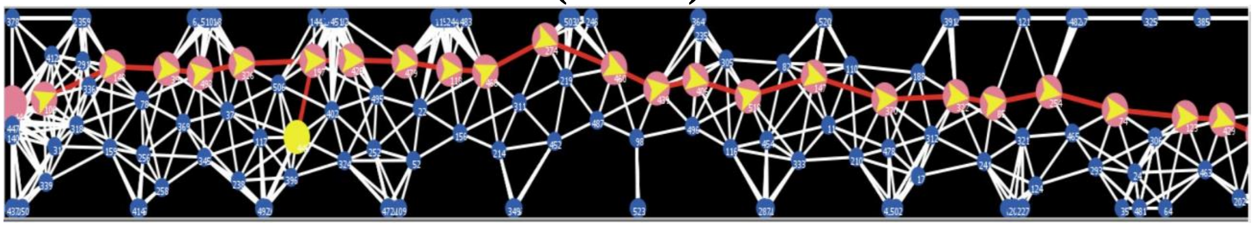


Figure (4.41). External node (state 1)

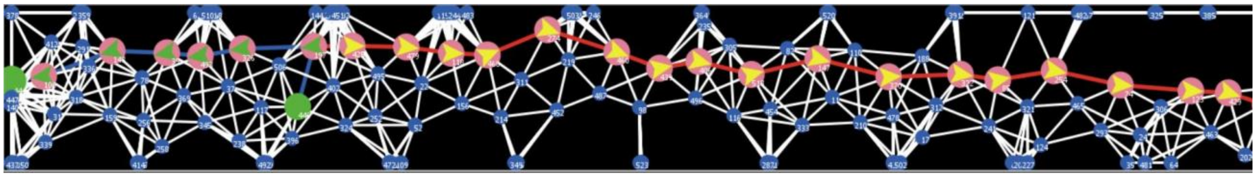


Figure (4.42). External node selects nearest sink (state 1)

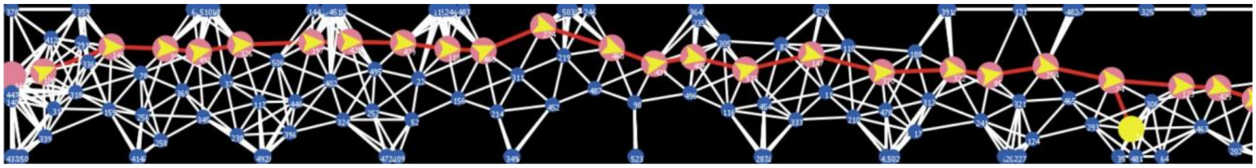


Figure (4.43). External node (state 2)

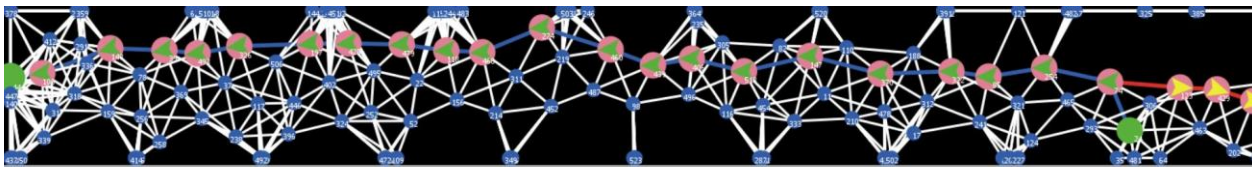


Figure (4.44). External node selects nearest sink (state 2)

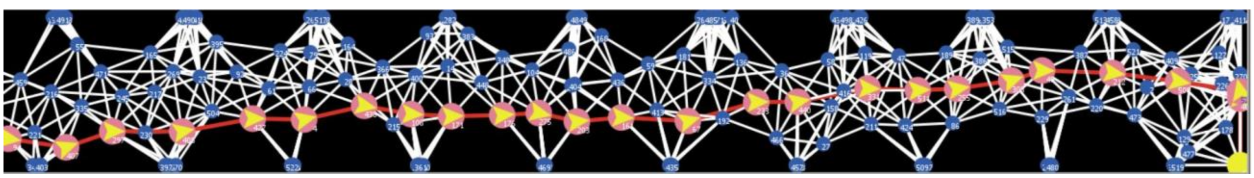


Figure (4.45). External node (state 3)

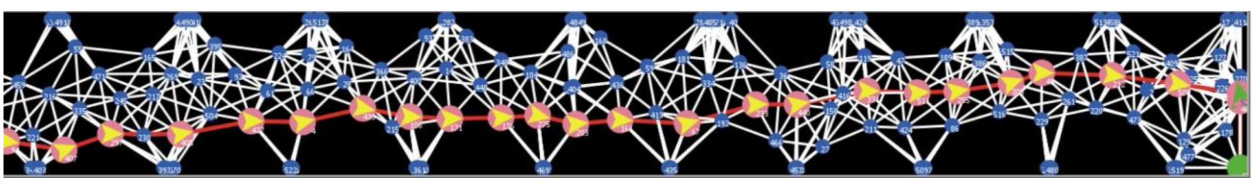


Figure (4.46). External node selects nearest sink (state 3)

4.5 Failure Case

Alter path is proposed in the case of backbone (first shortest path) failure or break. The second possible shortest path is selected as a backbone with avoiding common nodes. In LWSN, the number of alternative paths is limited due to the narrowness of the area. Figure (4.47) represent alter backbone example.

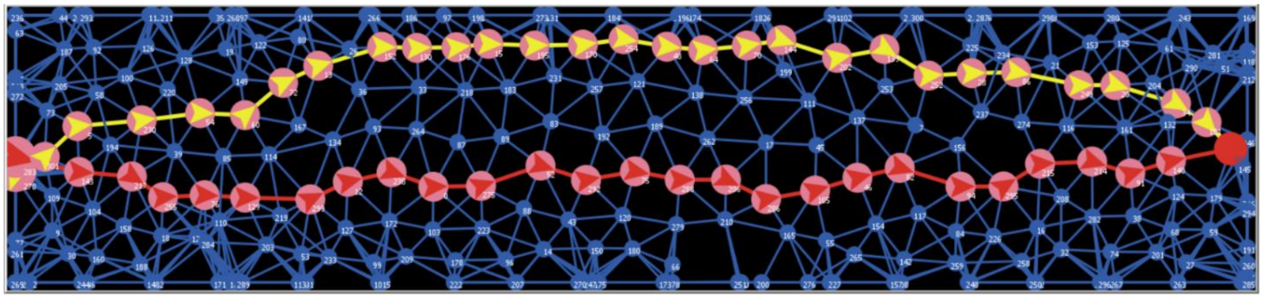


Figure (4.47). Shows an alter path example

4.6 Performance Metrics Results

Table (4.12) shows the network Performance metrics results for different simulation runs. Two cases taken, the first case with one sink and the second case with two sinks.

Table (4.12) Performance metrics results in case of one sink

Number of deployed nodes	Number of. send message	Number of received message	Delivery ratio	Throughput
20	5	5	100%	1.43
40	30	30	100%	3.16
60	66	57	86%	2.59
80	36	34	94%	1.36
100	50	46	92%	1.73
525	289	265	91.6%	6.4

Table (4.13) Performance metrics results in case of two sink

Number of deployed nodes	Number of. send message	Number of received message	Delivery ratio	Throughput
20	6	6	100%	1.76
40	25	24	96%	2.55
60	70	70	100%	3.18
80	78	77	98.7%	3.08
100	102	98	96%	3.84
525	325	320	98.4%	7.76

4.7 Single Sink vs Two Sinks Performance Difference

Table (4.14) represent single sink case when the source is backbone nodes or out of backbone. The data send to sink 2 regardless of which sink is nearest to it.

Table (4.14) single sink

	Node	Nearest sink	Selected sink	Number of hubs to rich sink	Path nodes
From backbone nodes	54	Sink 1	Sink 2	23	(Node 54) (node 63) (node 219) (node 284) (node 78) (node 286) (node 119) (node 161) (node 246) (node 52) (node 156) (node 157) (node 225) (node 282) (node 4) (node 273) (node 116) (node 100) (node 266) (node 80) (node 240) (node 145) (node 130) (sink 2)]
	78	Sink 1	Sink 2	19	node 78) (node 286) (node 119) (node 161) (node 246) (node 52) (node 156) (node 157) (node 225) (node 282) (node 4) (node 273) (node 116) (node 100) (node 266) (node 80) (node 240) (node 145) (node 130) (sink 2)]
	225	Sink2	Sink 2	11	[(node 225) (node 282) (node 4) (node 273) (node 116) (node 100) (node 266) (node 80) (node 240) (node 145) (node 130) (sink 2)]

	80	Sink2	Sink 2	4	[(node 80) (node 240) (node 145) (node 130) (sink 2)]
From External nodes	90	Sink 1	Sink 2	27	[(node 94) (node 214) (node 176) (node 192) (node 63) (node 219) (node 284) (node 78) (node 286) (node 119) (node 161) (node 246) (node 52) (node 156) (node 157) (node 225) (node 282) (node 4) (node 273) (node 116) (node 100) (node 266) (node 80) (node 240) (node 145) (node 130) (sink 2)]
	262	Sink1	Sink 2	27	[(node 262) (node 293) (node 289) (node 115)] [(node 262) (node 293) (node 85) (node 54) (node 63) (node 219) (node 284) (node 78) (node 286) (node 119) (node 161) (node 246) (node 52) (node 156) (node 157) (node 225) (node 282) (node 4) (node 273) (node 116) (node 100) (node 266) (node 80) (node 240) (node 145) (node 130) (sink 2)]
	71	Sink2	Sink 2	5	[(node 71) (node 240) (node 145) (node 130) (sink 2)]
	194	Sink2	Sink 2	3	[(node 194) (node 205) (node 243) (sink 2)]

- Two sink case

Table (4.15) shows different nodes as a source node from backbone and out of the backbone. In this case nearest sink is selected, the selected path is shortest than the first sink.

Table (4.15) show two sinks case

	Node	Nearest sink	Selected sink	Number of hubs to rich sink	Path nodes
From backbone nodes	242	Sink 1	Sink 1	4	[(node 242) (node 227) (node 282) (node 192) (sink 1)]
	150	Sink 1	Sink 1	10	[(node 150) (node 130) (node 121) (node 183) (node 143) (node 41) (node 242) (node 227) (node 282) (node 192) (sink 1)]
	263	Sink 2	Sink 1	10	[[(node 263) (node 289) (node 192) (node 282) (node 227) (node 242) (node 41) (node 143) (node 183) (node 121) (node 130) (node 150) (node 12) (node 270) (node 228) (node 99) (node 175) (node 173) (sink 1)]
	151	Sink 2	Sink 2	5	[(node 151) (node 78) (node 193) (node 166) (sink 2)]
From External nodes	41	Sink 1	Sink 1	8	[(node 41) (node 219) (node 152) (node 266) (node 32) (node 263) (node 72) (sink 1)]
	296	Sink1	Sink 1	14	[(node 296) (node 203) (node 204) (node 142) (node 235) (node 273) (node 185) (node 219) (node 152) (node 266) (node 32) (node 263) (node 72) (sink 1)]
	221	Sink 2	Sink 2	12	[(node 221) (node 193) (node 22) (node 261) (node 283) (node 259) (node 121) (node 176) (node 197) (node 108) (node 211) (sink 2)]
	79	Sink 2	Sink 2	5	[(node 79) (node 111) (node 100) (node 211) (sink 2)]

CHAPTER FIVE
Conclusions and Future Works

CHAPTER FIVE
Conclusions and Future Work

5.1 Conclusions

This thesis applied the simulation approach to test and evaluate the behavior of linear wireless sensor network (LWSN). Different parameters such as: nodes number, shortest paths, backbone discovery, alternative backbone, nearest sink selection approaches are utilized. The focus is made on proposed two sinks and the process of choosing nearest sink by the backbone nodes.

1. Proposing two terminated sinks represent a proposed valid alternative approach in LWSNs.
2. Proposed a model to estimate the best number of deployed nodes to ensure the best coverage in a designated area will reduce the total network cost and improve its efficiency.
3. When the number of nodes increase and the sensors coverage area increases the number of links in a network will increase and vice versa.
4. The process of selecting the backbone depends on the calculations of the shortest path from the first sink to the second sink.
5. The existence of two terminated sinks improves the performance of the network and reduces the load on the sink to its half, which leads to prolong the network lifetime and reducing data loss.
6. Keeping the shortest path from the outgoing node to the nearest backbone node, as well as the nearest sink in the cache of node, speeds up the transmission process and reduces processing in the node each time it is sent.
7. Selecting alternate backbone will ensure the reliable transmission and avoid the delay and losses.

5.2 Future Works

1. Apply this thesis approach on large scale WSNs.
2. Switching between the first and second backbone at each specified period of time in order to reduce the energy consumption of the nodes in one backbone.
3. Suggest a clustering approach in selecting the backbone.
4. Replacing the failure node in the backbone with one of the nodes close to it to avoid network failure.

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المستخلص

تعد شبكة المستشعرات اللاسلكية أحد اتجاهات التكنولوجيا الحديثة والمهمة حيث تستخدم في العديد من التطبيقات المختلفة لجمع ومعالجة وتوزيع مجموعة واسعة من البيانات. أصبحت تقنية المستشعرات تقنية أساسية للعديد من التطبيقات المتعلقة بالإحساس بالبيئة المحيطة. هذه المستشعرات الصغيرة رخيصة الثمن، وتستهلك طاقة أقل، وبسيطة النشر، وتنظيمها ذاتيًا. أجهزة الاستشعار سهلة الاستخدام والنشر في مجموعة متنوعة من البيئات التي يكون فيها الوصول البشري صعبًا ولا تتوفر مراقبة للشبكة. من أجل تتبع منطقة معينة أو مراقبتها، يمكن استخدام شبكات الاستشعار اللاسلكية لأداء واجبات معينة. عرفت مؤخرا حالة خاصة من شبكات المستشعرات اللاسلكية عرفت باسم شبكة المستشعرات اللاسلكية الخطية. يمكن استخدامه لمراقبة خطوط الأنابيب والسكك الحديدية والغاز والنفط والطرق السريعة سواء فوق الأرض أو تحت الأرض. يمكن أن يتراوح طول هذه الهياكل من بضع مئات من الأمتار إلى مئات الكيلومترات.

تتبنى هذه الأطروحة نهج العمود الفقري للشبكة، وهو اختيار مجموعة معينة من أجهزة الاستشعار لتكون بمثابة عقد أساسية للنقل داخل الشبكة. تقترح الاطروحة وضع محطتين اساسيتين أو أكثر (حسب طول المنطقة ونوع التطبيق) في بداية ونهاية الشبكة. يبدأ العمود الفقري للشبكة الذي تم إنشاؤه من المحطة الأساسية الأولى وينتهي في المحطة الأساسية الثانية. تحدد هذه الأطروحة أجهزة الاستشعار المنتشرة لتلعب دور العقد الأساسية. يتم استخدام العمود الفقري للشبكة المكتشف لغرض التوجيه لاحقًا. الهدف من عملية الاكتشاف هو تحسين كفاءة الاتصال وقابلية التوسع والموثوقية وتجنب الأخطاء.

تم تطوير نموذج لتقدير العدد المطلوب من أجهزة الاستشعار لكل منطقة في نشر عشوائي. وفقًا للعشوائية في النشر، يُقترح إضافة بعض الأرقام (جزء التفاوتات) إلى عدد العقد المنشورة لتحسين توزيع أجهزة الاستشعار وضمان اتصال الشبكة. تم اقتراح هذا الرقم الإضافي بناءً على دالة توزيع احتمالية موحدة مقترحة. يتم تحليل نتائج المحاكاة وتقييمها بناءً على مقاييس مختلفة. تستخدم نتائج المحاكاة في المقارنة بين طريقة استخدام محطتين اساسيتين مع نتائج استخدام محطة أساسية واحدة فقط. التفوق النهج المقترح في جميع المقاييس المستخدمة..

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Title	Only the chairs can edit	*Modeling the Behavior of the Linear Wireless Sensor Networks*
Abstract	Only the chairs can edit	Wireless Sensor Network (WSN) represents one of the considerably advanced technology trends. It was used in different applications for collecting, processing, and distributing a vast range of data. In order to monitor a specific type of infrastructure, a special type of WSN can be created by deploying or arranging a big number of sensors in a linear form, narrow curves, or sometimes in narrow rectangles and in thin circles. Such network topology is known as Linear Wireless Sensor Networks (LWSNs). The significant application of such networks is in monitoring different above and underground Pipelines, Railway lines, Bridges, Tunnels, Borderlines, and Highways. To ensure end-to-end packet delivery relying on a number of relay nodes, a transmission process must be efficient and reliable based on the shortest path approach or a backbone to prolong the network lifetime and improve its performance. In such networks, the sensors closer to the sink end up forwarding or relaying more packets than other distinct sensors. In this paper, a backbone is selected and a transmission process is performed by a simulation approach from the backbone nodes and other nodes. Any node outside the backbone selects the nearest backbone node and transmits to it. Different metrics were measured and analyzed.
Keywords	Only the chairs can edit	LWSN; Simulation; Linearity; Shortest Path; Backbone
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طريقة مطورة لتحسين أداء شبكة المستشعرات اللاسلكية الخطية

رسالة مقدمة إلى
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من قبل

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باشراف

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