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Simulation of Wireless Mesh Network and Links Estimation using Regression Model

A Thesis

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

By:

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Dedications

This work is dedicated to…

My father...

I will always be your daughter,

who is proud of you?

My mother...

I ask Allah to protect you from all evil

you are the best.

My beloved brothers and my beloved sisters,

My close friends who

stand by me when things look very difficult.

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Praise be to Allah, Cherisher and Sustainer of the worlds. I'm intended to His Almighty in helping me to finish what I started, and in presenting this work.

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DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

2021 7th INTERNATIONAL CONFERENCE ON SIGNAL PROCESSING AND COMMUNICATION (ICSC)

CERTIFICATE OF PARTICIPATION

This is to certify that **Zahraa Abdullah Khait** of **University of Babylon, Iraq, Babylon** has presented a paper entitled **An Optimization Technique for Wireless Communication based on Mesh Topology** through virtual mode in 2021 7th International Conference on Signal Processing and Communication (ICSC) held on 25th - 27th November, 2021 at Jaypee Institute of Information Technology, Noida, India.

(Dr. Jitendra Mohan) **Organizing Secretary**	**(Prof. Shweta Srivastava)** **General Chair**	**(Prof. Hari Om Gupta)** **General Chair**

Abstract

A local network topology is called mesh network if their infrastructure nodes are connected directly, and non-hierarchically, and mesh network can be called Wireless Mesh Network (WMN). WMN consisting of mesh routers, mesh clients, and gateways. With the advanced in communication technology and complication of wireless Mesh networks, different factors are being significant in WMN performance. These factors are; load balancing, provision quality of services, reducing end-to-end delay, improving the throughput. Traditional routing methods are unable to achieve the required network performance. Thus, more techniques will be used to improve network performance. In this study, wireless mesh networks are created by deploying different number of nodes in a fixed-area. The shortest path among the available paths is selected. In some times, one or more nodes on the shortest path mayor more nodes on the shortest path may being busy during the transmission from other nodes, an alternative path is suggested as a solution to avoid the packet dropping or message lost. A regression approach is suggested to estimate the number of possible links and their lengths for each suggested network. This estimation approach is based on two factors; the number-of nodes and the node's coverage area. The performance metrics are evaluated and estimated using the Net Logo simulator especially through the Behavior Space tool in the simulator. The WMN performance was compared between the long and short path approaches. An increasing in the throughput by 133% and a decreasing in the end-to-end delay by 50% , but the increasing in the quality of services is observed by 0.004% for variable number of nodes and ranges.

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List of Symbols

a_1 Slope of the regression y on the first independent variable.

a_2 Slope of the regression y on the second independent variable.

b_1 Slope of the regression y on the first independent variable.

b_2 Slope of the regression y on the second independent variable.

x_2 Second independent variable.

a Intercept or constant.

b Slope of the line on the independent variable.

x Independent variable (it is plotted on the x axis).

y Dependent variable (it is the variable that goes on the y axis).

List of Abbreviations

AP	**Access Point**
EM	**Electromagnetic**
E2E DELAY	**End-to-End Delay**
LBE	**Load Balancing Efficiency**
NRL	**Normalize Routing Load**
PDR	**Packet Delivery Ratio**
P2P	**Peer-to-Peer**
QoS	**Quality of Services**
TC	**Target Coverage**
TS	**Tabu Search**
WC	**Wireless Communication**
WMANs	**Wireless Metropolitan Area Networks**
WMN	**Wireless Mesh Network**
WLANs	**Wireless Local Area Networks**
WPANs	**Wireless Personal Area Networks**

CHAPTER ONE

General Overview

Chapter One

General Overview

1.1 Introduction

Wireless communication is one of the important areas of research in the communications field. In wireless communication, information is transmitted from the transmitter to the receiver without the need for a confined medium (e.g., cable). Figure 1.1 shows depicts part of the electromagnetic (EM) spectrum. The wavelength of a signal decreases as the frequency increases and different frequencies across the EM spectrum have different propagation properties (Hamza, et al., 2016).

The mesh network is rank nodes that take shape of a communication network. In mesh network there is no dependent on a single node particularly in the state any node fails. So allows every node in the mesh network to send the information to balance the flow between paths. This network can dynamically self-configure and self-regulating, making installation time to be reduced. The mesh network known as a Wireless Mesh Network (WMN). WMN are a technology which for bring to reality the goal of a world that is seamlessly connected. Making use of Wireless mesh networks, entire cities can be easily, effectively and wirelessly connected using inexpensive, existing technologies. The existing traditional networks depend on a small number of wired access points or wireless hotspots to connect users. Whereas, a wireless mesh network connection spreads out among dozens or even hundreds of wireless mesh nodes that "communicate" with each other to extend the network connection across a very large and wide area. WMNs consisting of routers mesh, clients mesh, and gateways. Client mesh contain a different wireless device such as computers and radio devices. Routers mesh help in load forward from and to gateways (Siemuri, et al., 2019).

WMN provide redundancy. When any node halt, the other nodes hold to work with each other through one or more intermediate nodes. WMN can subjective -heal and subjective -form. WMN can be executed by different wireless technologies IEEE 802.11, IEEE 802.16, and other. The main capable of relaying data packets from characteristics of WMN is the multi-hop technology, this packet transmit from a sender node to receiver node by way multi-hop and using the intermediate nodes of the network for the success of this process. Therefore, in a wireless mesh network, messages routing is not just depending on the sender and receiver points (nodes), but depends to the routing is based on the presence of intermediate points as well for delivers these packets to the destination node (Silva, et al., 2017).

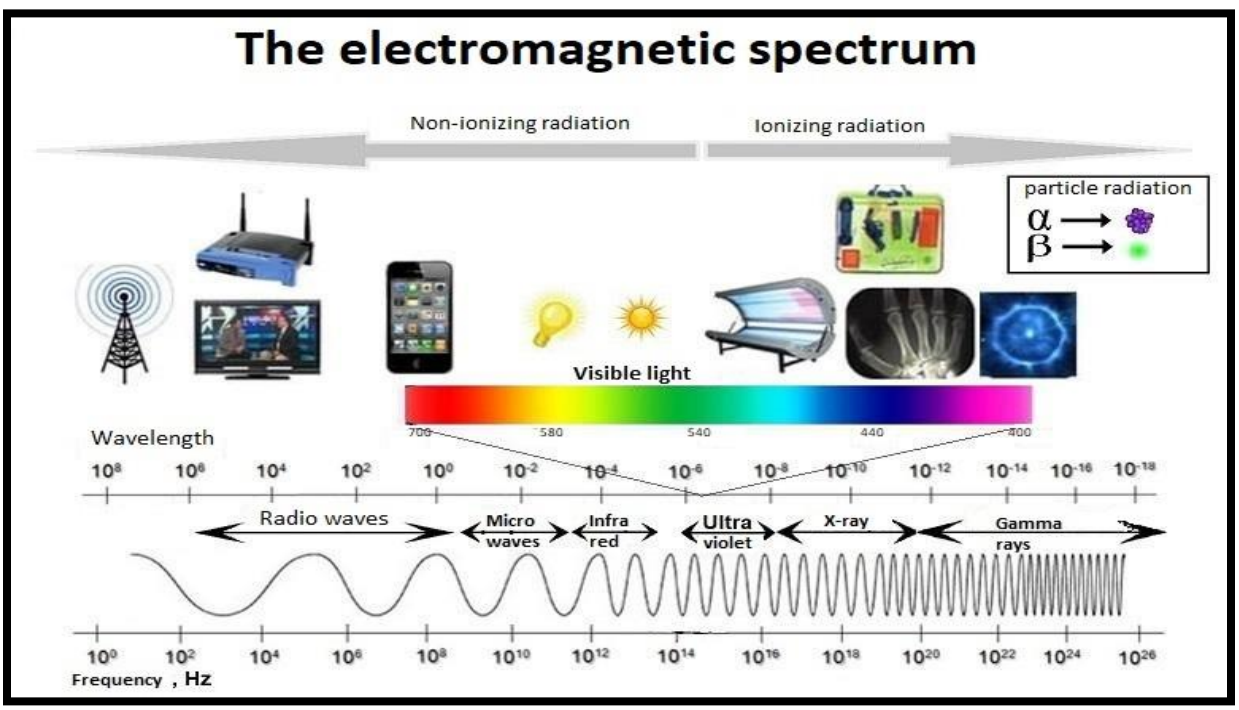

Figure 1.1: The Electromagnetic Spectrum (Hamza, et al., 2016).

1.2 Problem Statement

With the advanced in communication technology and complication of wireless Mesh networks, different factors are being significant in WMN performance. These factors are; load balancing, provision quality of services, reducing end-to-end delay, improving the throughput, increasing the packet delivery and finding the short-path between nodes in a wireless Mesh network have becoming a fundamental issue. Traditional routing methods are unable to achieve the required network performance. Thus, more techniques will be used to improve network performance.

In this study, the focus is on connecting the networks as mesh network, developing an approach to estimate the number of the possible links in each suggested network. Increasing the links will give a chance to find more feasible paths to route the messages. Improving the network performance by decreasing its delay, reduce the lost messages, reduce the congestion and provide an acceptable quality of services are important issues.

1.3 Objectives

The aim of this study is to improve the network performance based on mesh topology. This aim can be achieved by the following objectives:

- To create wireless network based on mesh topology for different number of nodes and ranges in a fixed-area.
- Simulating the wireless mesh network with applying the algorithm of shortest path and an alternative path between the source and destination node to improve the network performance.

- Modeling the number of the available links and their total lengths.
- Evaluating the network performance in terms of the throughput, end-to-end delay, packet delivery ratio, quality of services.

1.4 Related Works

Many literatures have been proposed various techniques improvement performance for WMNs. Most significant related studies are listed in the following statements.

An optimization model to minimize the expected end-to-end delay transmission time in Wireless Mesh Networks was conducted by (Silva, et al., 2017), this paper presented an optimization model to minimize Weighted Cumulative Expected Transmission Time (WCETT) in a WMN, subject to constraints grouped by bandwidth, flow control and power control. As the model includes nonlinear constraints, they propose a heuristic to solve it, which divides the problem in two subproblems. The first subproblem maximizes the network link capacity and a Simulated Annealing algorithm is used to solve it. Considering the link capacities obtained, the second subproblem minimizes the WCETTs, which is formulated as a linear programming model. Some numerical results are presented, based on instances of WMNs randomly generated.

Wireless Mesh Networks based on Modified Binary Particle Swarm Optimization (MBPSO) algorithm to improvement throughput was conducted by (Ameen, et al., 2018), this study summarized is determine the proper methods, approaches or algorithms that should be adapted to improve the throughput. MBPSO approach was adapted to improve the throughput. Finally, the finding shows that throughput increased by 5.79%.

An artificial neural network-based fault detection and diagnosis for Wireless Mesh Network was conducted by (Yaqini, et al., 2018), in this paper they proposed a fault detection and diagnosis approach for enhancing performance of WMN based on Artificial Neural Networks (ANN). The artificial neural network is trained to detect and classify individual or composite faults. They consider node failure, link failure and traffic congestion as the target faults. The approach is implemented in NS3 network simulator and its performance is evaluated considering detection rate, false positive and false negative

A new method for congestion avoidance In Wireless Mesh Networks was conducted by (Pa, et al., 2019), the traffic in this network (WMN) often saturates on certain paths, causing congestion problems to occur. Proposed protocols have been created based on Ant Colony Optimization (ACO) to contribute towards solving this particular problem. Unfortunately, most of these methods disregard the congestion problem after an optimal path is found. this paper, a New Congestion Avoidance Method (NCAM) is proposed. NCAM is designed to improve load balancing by solving congestion problems after the optimal path is found. There are three mechanisms proposed in NCAM: detection of congestion in each optimal node to prepare a suboptimal path, updating of suboptimal pheromone value, and transferring data packets to the suboptimal path. they implemented method in network simulator version 2 and measured its effective performance compared to a family of existing ACO approaches in terms of packet throughput, end-to-end delay, and packet loss. The result demonstrates that NCAM provided better throughput, decreased end-to-end delay, and less packet loss compared to Ant Net and CACO.

Investigation on optimization, prioritizing and weight allocation techniques for load balancing and controlling multimedia traffic in Wireless Mesh Network was conducted by (Raja, et al., 2020), wireless mesh network is a type of wireless ad hoc network where radio nodes are wirelessly connected within sizable geographic area through mesh topology. The best path is identified by routing metrics to ensure efficient data transmission from source node to destination node. The performance of routing is concern with set of routing constraints such as bandwidth, network delay, energy consumption, load balancing and communication cost. The routing constraints are needed to be resolved to improve the WMN performance. In WSN, network load balancing plays a significant role to achieve effective routing without traffic. The energy consumption is an additional factor to provide high-quality data delivery at the destination end. they research work is concentrated on developing the energy efficient and load balanced routing in WMN.

Optimal placement of unmanned aerial vehicles (UAVs) of an aerial mesh network in an emergency situation was conducted by (Gupta, et al., 2021), they proposed UAVs have been used in Aerial Mesh Networks (AMNs) that act as backbone network to support communication in a post-disaster scenario. However, there may be limited available number of UAV nodes that need to be utilized efficiently to improve the performance of such networks. Here, they consider three important objectives of the network i.e., target coverage, Quality of Service and energy consumption by the network that need to be optimized efficiently to improve the performance. Yet, it is a hard task to optimize all of these conflicting objectives at the same time, which is affected by the height of UAVs. To optimize more than one conflicting objectives; they used metaheuristic based multi-objective optimization algorithms, Multi-objective Particle Swarm Optimization (MOPSO), Non-dominated Sorting Genetic Algorithm II (NSGA-II), Strength Pareto Evolutionary Algorithm 2 (SPEA2) and Pareto Envelope-based Selection Algorithm II (PESAII), which suggested the optimal placement of UAVs. These algorithms are compared based on four performance metrics, generational distance, diversification metric, spread of non-dominant solutions and percentage of domination in three different scenarios. The rigorous experiments are performed by each algorithm in small, medium and large-scale scenarios to compare their results. The Analysis of variance (ANOVA) validation test suggests that SPEA2 performs better than others in small-scale scenarios while NSGA-II performs better than others in medium and large-scale scenarios. However, MOPSO has lowest average execution time, after that NSGA-II, then PESA-II and then SPEA2. The related works are summarized in table 1.1.

Table 1.1: Summary of the Related Works.

Proposed	Results	Algorithm	Simulation
An optimization model to minimize the expected End-To-End transmission time in Wireless Mesh Networks (Silva, et al., 2017).	Minimize Weighted Cumulative Expected Transmission Time (WCETT) in a WMN.	Heuristic algorithm	NS2
Wireless Mesh Networks based on MBPSO algorithm to improvement throughput (Ameen, et al., 2018),	The finding shows that throughput increased by 5.79%.	MBPSO algorithm	NS2

An artificial neural network-based fault detection and diagnosis for Wireless Mesh Network (Yaqini, et al., 2018),	The artificial neural network is trained to detect and classify individual or composite faults.	Fed-forward neural network and a back-propagation learning algorithm	NS3
A new method for congestion avoidance In Wireless Mesh Networks (Pa, et al., 2019).	The result demonstrates that NCAM provided better throughput, decreased end-to-end delay, and less packet loss compared to Ant Net and CACO.	NCAM algorithm	NS2
Investigation on optimization, prioritizing and weight allocation techniques for load balancing and controlling multimedia traffic in Wireless Mesh Network (Raja, et al., 2020).	They research work is concentrated on developing the energy efficient and load balanced routing in WMN.	LBR algorithm	NS2

Optimal placement of UAVs of an aerial mesh network in an emergency situation (Gupta, et al., 2021),	Improve the network performance such as target coverage, quality of Service.	SPEA2, NSGA2, PESA2 and MOPSO Algorithm	NS2

1.5 Thesis layout

Chapter one presents the introduction, problem statement, objectives and related works for WMN.

Chapter two presents theoretical background about WMN, its applications, and properties.

Chapter three describes the proposed system.

Chapter four clarifies the system proposal and discuss results analysis.

Chapter five presents the conclusions and gives the suggestion for future works.

CHAPTER TWO

Theoretical Background

Chapter Two

Theoretical Background

2.1 Introduction

Wireless Communication is the fastest increasing technological areas in the communication field. Wireless Communication is a way of transmitting information from one point to other, without using any connection like wires, cables or any physical medium. In general communication system, information is transmitted from source to destination. In wireless communication the source and destination can be placed anywhere over few meters (like a T.V. Remote Control) to few thousand kilometers (Satellite Communication) (Montori, et al., 2018).

In mesh topologies, network nodes are directly and dynamically linked in a non-hierarchical method, so allowing many-to-many communications (among nodes cooperating with each other) to efficiently route data from a source to a destination. The mesh network known as a Wireless Mesh Network (WMN). WMN consist of mesh routers, mesh clients and gateways. Moreover, mesh networks do not require an infrastructure, since they dynamically self-organize and configure themselves, with following advantages, in terms of: (1) easy deployment, installation and maintenance's overhead and cost reduction; (2) dynamic workload distribution; (3) better reaction to node failures; and (4) easy network topology modification. WMN need to definition of a routing among all nodes, to discovering and determining the best routes on the base of different metrics (e.g., throughput, link quality, hops number, etc.) measured on data streams (Cilfone, et al., 2019).

In this study, the focus on explaining the concept of both wireless communication, mesh network, wireless mesh network from where architectural characteristics and applications for both mesh network and wireless mesh node

2.2 Wireless Communication

In communication systems, connection can be wired or wireless and the medium used for communication can be guided or unguided. In wired communication, the medium is a physical path like co-axial cables, twisted pair cables and optical fiber links etc., which guides the signal to propagate from one point to other. Such type of medium is called Guided Medium. On the other side, wireless communication doesn’t require any physical medium but propagates the signal through space. because, space only allows for signal transmission without any guidance, the medium used in wireless communication is called Unguided Medium Antennas are used in wireless communication to transmit and receive signals. Antennas are electrical devices that transform the electrical signals to radio signals in the form of Electromagnetic (EM) Waves and vice versa. These electromagnetic waves propagate through space. Hence, both transmitter and receiver consist of an antenna. in wired communication systems the setup and installation of infrastructure is an expensive and time-consuming job compare the infrastructure for wireless communication can be installed easily and low cost. (Montori, et al., 2018). Figure 2.1 shows the wireless communication systems.

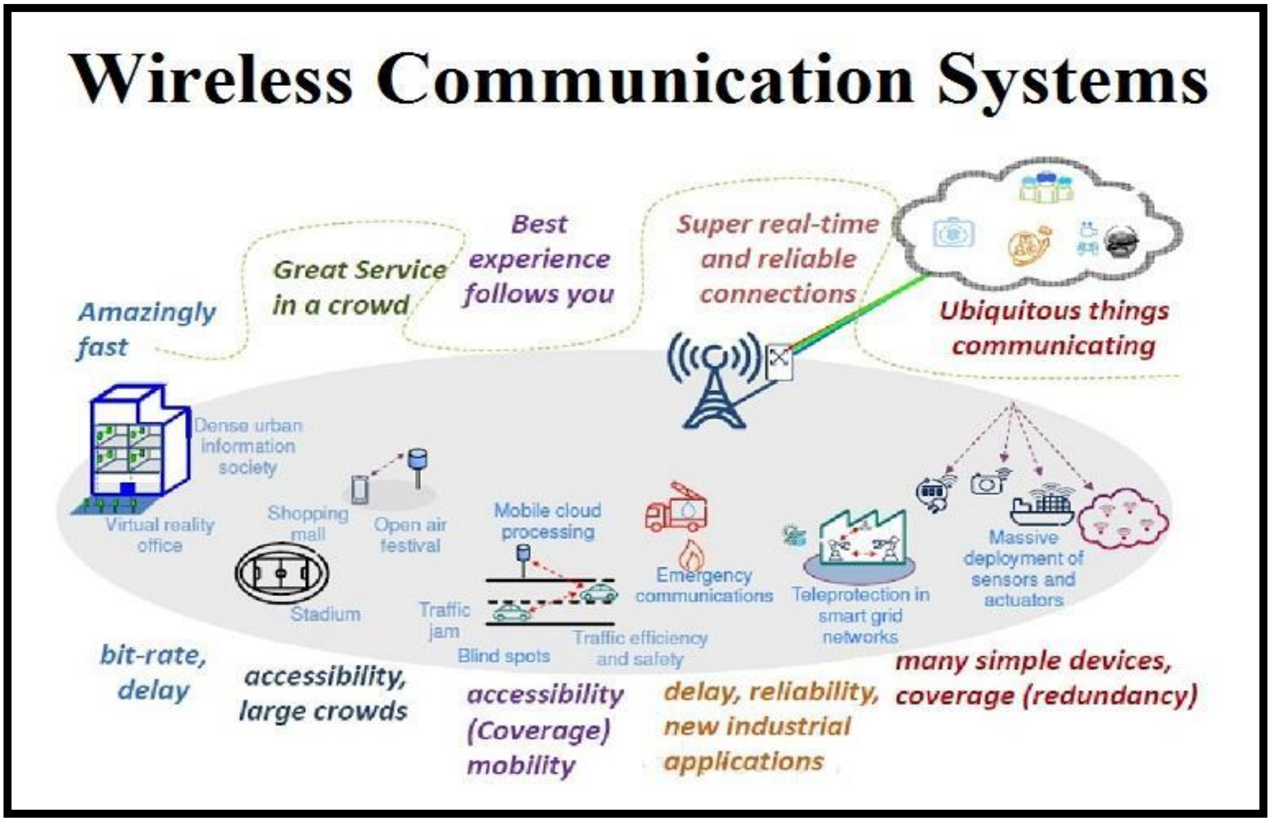

Figure 2.1: Wireless Communication (Montori, et al., 2018).

2.2.1 Advantages of Wireless Communication

There are numerous advantages of wireless communication technology over wired communication (Montori, et al., 2018). Some of the following advantages:

- Low-Cost.
- Ease of Installation.
- High Speed.
- Communication is wireless.

2.2.2 Types of Wireless Communication Systems

Wireless communication systems also provide different services like video conferencing, cellular telephone, TV, Radio etc. Due to the need for variety of communication services (Montori, et al., 2018). Figure 2.2 shows the wireless communication types. Some of the important Wireless Communication Systems available today are:

- Television and Radio Broadcasting.
- Satellite Communication.
- Radar.
- Mobile Telephone System (Cellular Communication).
- Global Positioning System (GPS).
- Infrared Communication.
- WLAN (Wi-Fi).
- Bluetooth.
- ZigBee.
- Cordless Phones.
- Radio Frequency Identification (RFID).

Figure 2.2: Wireless Communication Types (Montori, et al., 2018).

2.3 Network Topology

In computer network, the networks topology is mean how a set of communication system elements is arranged. Contains information about devices / nodes, links / connections, etc. Either topology refers to the actual physical interconnection pattern of network elements or to the logical data flow between the elements (Nedić, et al., 2018). There are common types of network topology that are illustrated as in the Figure 2.3 shows the network topology.

- Ring topology: A ring topology is a closed loop wherein every node has exactly two connections to others.
- Mesh topology: In this type of topology network, every node has a point-to-point (P2P) connection to another node. There are at least two paths between any two nodes.
- Star topology: In this type of topology network, each node is conveyance to a centric node called hub, which is responsible for communication transmissions between peripheral nodes.
- Tree topology: This type of topology network is hierarchical. The node in the root level is connected to nodes in the next level of the hierarchy, and those nodes in return connect to nodes in their next level, and each level fans out further.
- Bus topology: In this type of topology network, all nodes of a network are connected to a single common cable called bus.

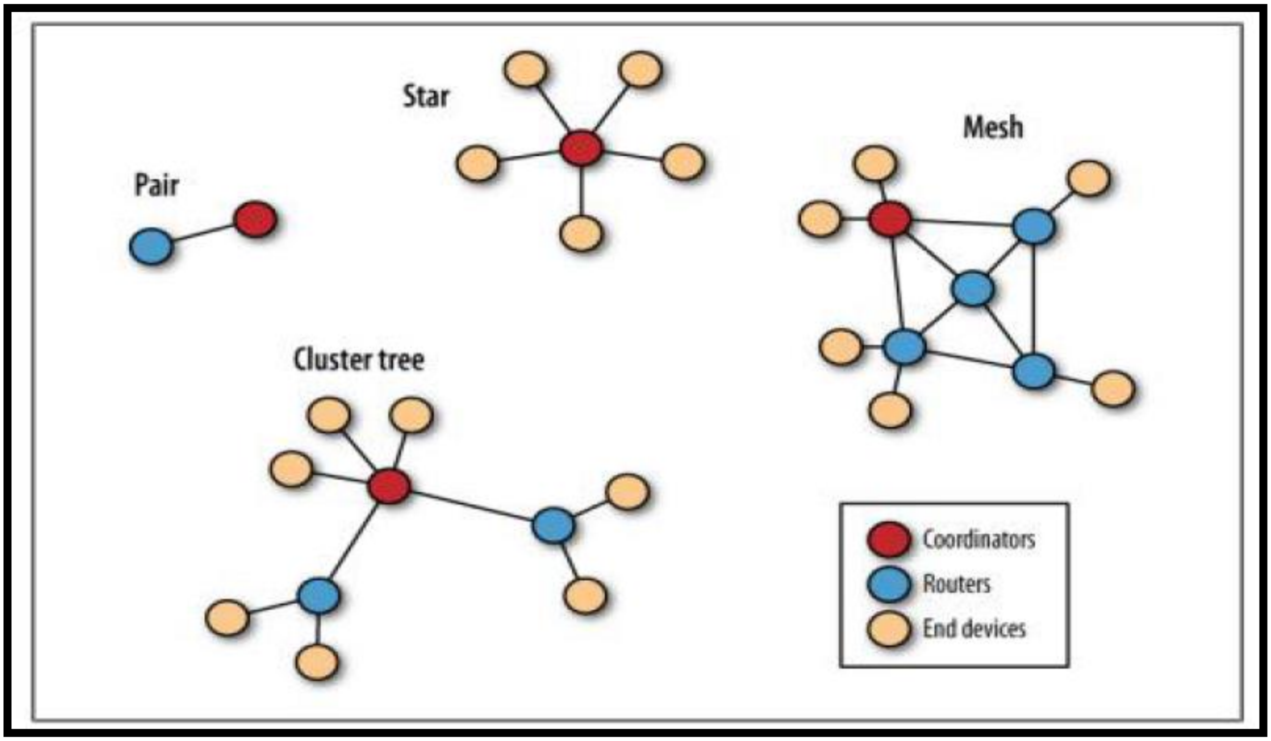

Figure 2.3: Network Topology (Faludi, 2010).

2.4 Mesh Network and Wireless Mesh Network

Mesh network is a network in which devices or nodes are connect together. These networks are set up to efficiently route data between clients (nodes). Mesh topologies can be created multiple paths to information transfer among connected nodes (Lee, et al.,2018). This approach increases the resilience of the network in case of a node or connection failure, so the mesh network does not reliance on one node, but rather each node is allowed to participate in the transfer of data. Mesh topology are dynamic organization and configuration which has the benefit of reducing time. Mesh topology ability to self-configure, dynamic distribution of and balance the congestion. (Siemuri, et al., 2019).

Mesh network topology is the latest form of wireless internet. A mesh or mesh Wi-Fi is a system of several network nodes or access points (which are network delivery or supply devices commonly referred to as nodes, network extenders, satellites, or other designations) that together function as a large home Wi-Fi system. The mesh topology is divided into two types, fully mesh network is where each device is connected to every other device in the network and is used in backbone networks. Partially meshed network, where each device is indirectly connected to other devices, where some stations are fully meshed with each other and some are connected to one or two devices, and this network is less expensive than the fully meshed network and this network is often used in mixed topologies system (κlophaus, 2021). Figure 2.4 shows an example of mesh network types.

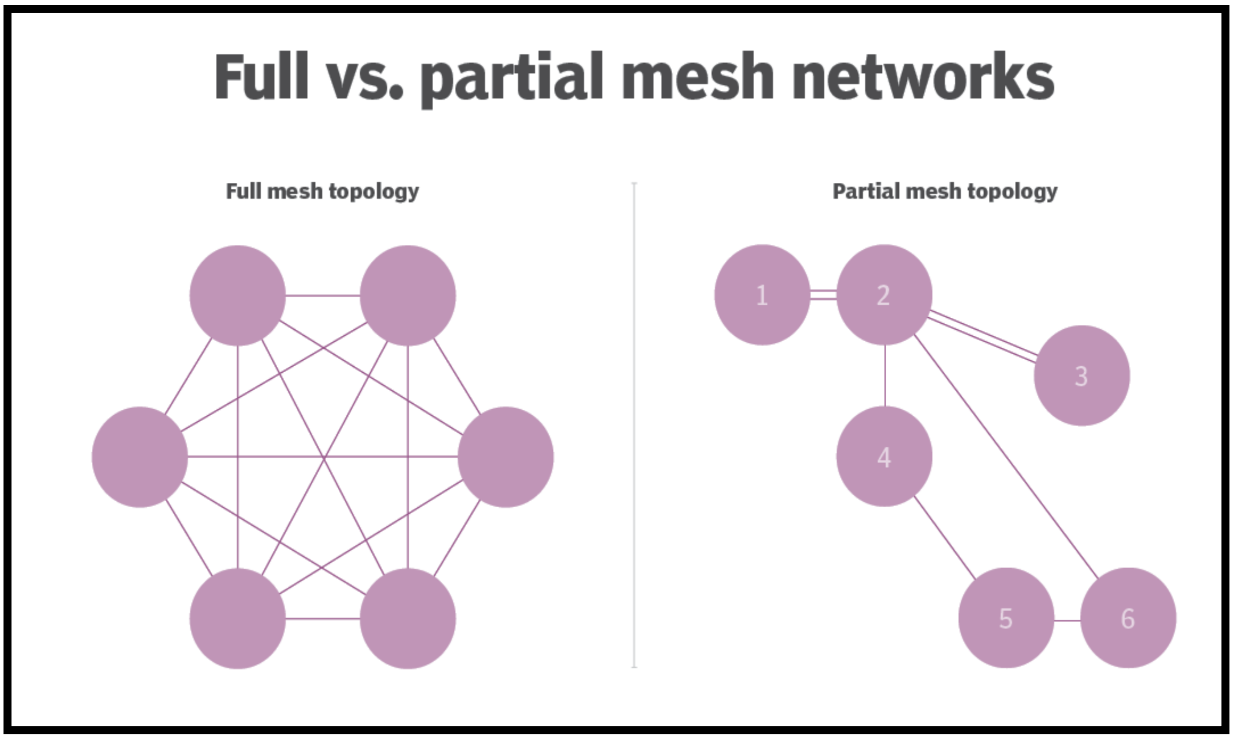

Figure 2.4: Mesh Network Types (Full and Partial Networks) (Lee, et al.,2018).

The mesh network is available and repetition, because when any intermediate node failure, the other nodes complete the work. so, the designer can be using more than one intermediate node to work in WMN and transportation the message to the receiver. Routing mechanism uses propagation right a path through hopping from node to another node until its arrival the target point. It guarantees that each it is available by allowing persistent information and reshape herself concerning cracked path. Mesh networks either be wire or wireless, WMN are usually made up of client's mesh, routers mesh and gateways. Client's mesh could be cellular telephone and different devices. routers mesh for messages to and of the gateways, whose may do or may do not be joint to the Internet. The clients mesh mostly constant and ability be using to inspire a custom mesh connection between themselves and among mesh routers. Gateways are grid devices joint to a foreign fountain, for example the end-user device). WMN are a technology which may bring to reality the goal of a world that is seamlessly connected. Making use of WMN, entire cities can be easily, effectively and wirelessly connected using inexpensive, existing technologies. The existing traditional networks depend on a small number of wired access points or wireless hotspots to connect users. Whereas, a WMN connection spreads out among dozens or even hundreds of wireless mesh nodes that "communicate" with each other to extend the network connection across a very large and wide area (Siemuri, et al., 2019).

WMN can be using to resolving determination as fully as get better the execution of ad hoc networks such as Wireless Local Area Networks (WLANs), Wireless individual Area Networks (WPANs), Wireless Metropolitan Area Networks (WMANs) all of which provides wireless services to a big of implementation of individual, local and campus area. It is not hard to execute and spread a mesh network in order that all the desired components are formerly ready in the shape of dedicated directing protocol. WMN provide redundancy. It is possible to integrate the WMNs with other networks such as the Internet, IEEE 802.11, IEEE 802.15, IEEE 802.16, sensor networks, etc. (Ameen, et al., 2018).

The main characteristics of WMN is using the many jump (multi-hop) technologies. Ability of relaying messages from a sender to a specific receiver via way of the jump on the intermediate devices of the network. WMN architecture provides low-price. WMN infrastructure is a gride of routers without the wire between points compare the traditional Network. Figure 2.5 shows an example of WMN.

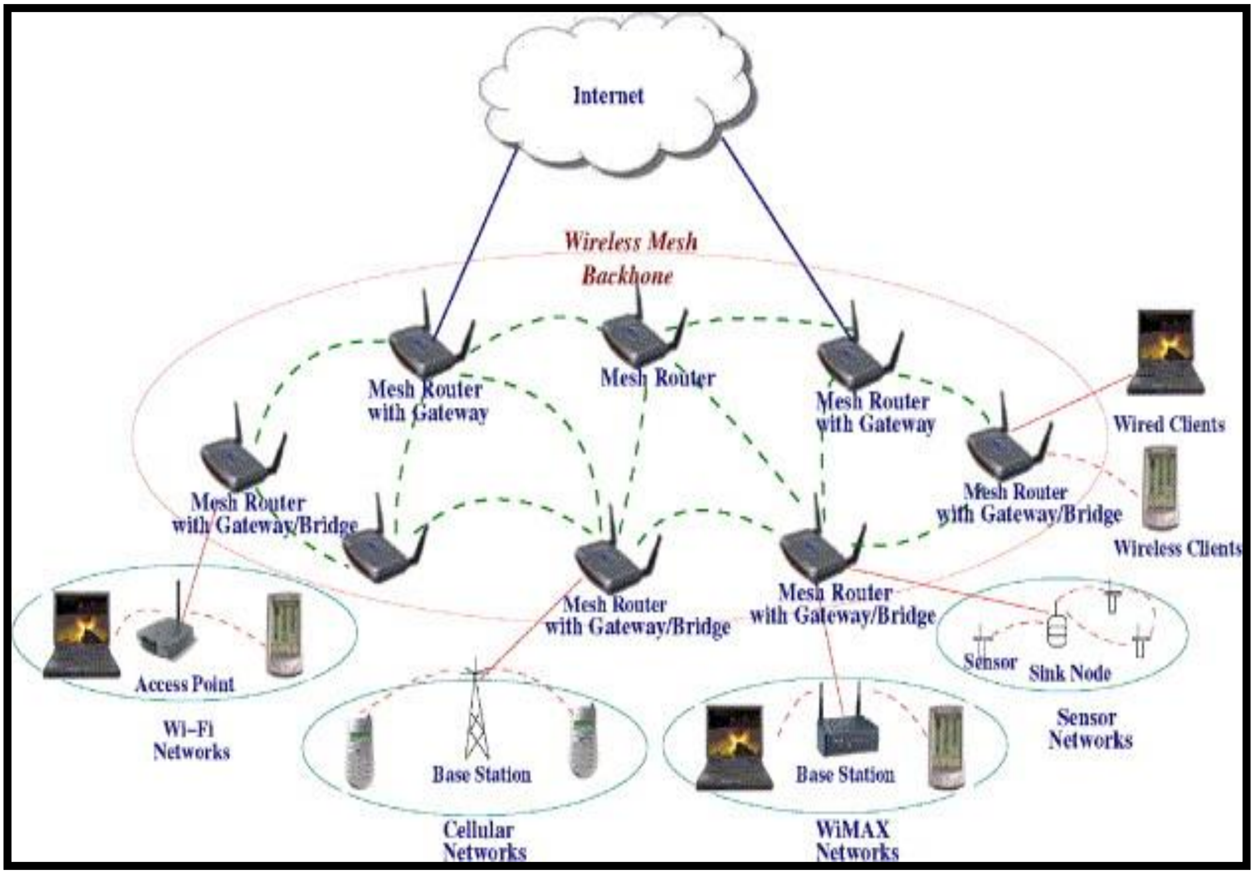

Figure 2.5: Example of Wireless Mesh Network (Siemuri, et al., 2019).

2.5 WMNs Architecture

The WMN Architecture can be categorized into three groups founded on location of the points (nodes) (Siemuri, et al., 2019).

2.5.1 Infrastructure/Backbone WMN

This kind of WMN represents the most used one as integration of WMN technologies to other existing networks is easy and simple. The infrastructure/backbone of WMN as shown in figure 2.6. It consists of mesh routers forming an infrastructure/backbone for mesh client. It is the wireless mesh backbone that can connect to existing wireless networks (Siemuri, et al., 2019).

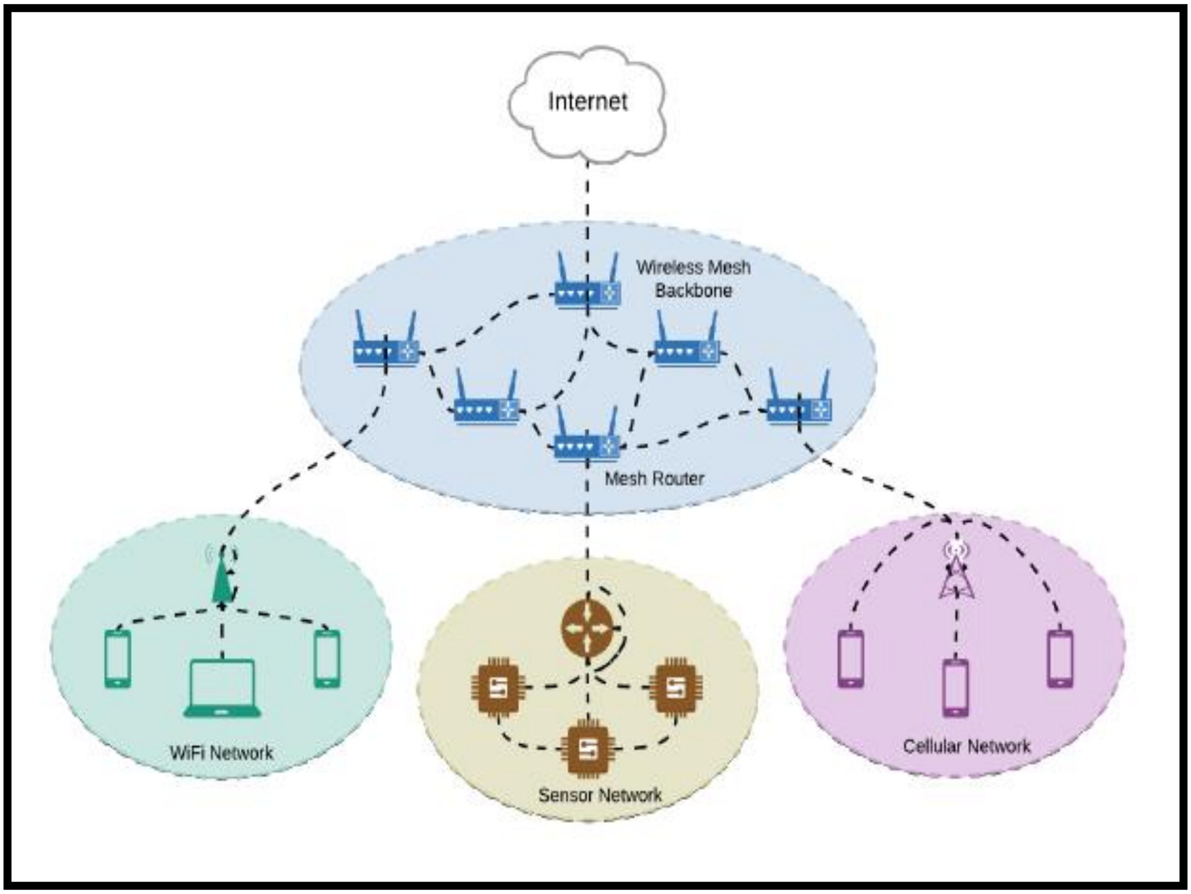

Figure 2.6: Infrastructure/Backbone of WMN (Singh, et al., 2019).

2.5.2 Client WMN

Similar to Peer-to-Peer (P2P) network communication is provided, and routers mesh are not required in this kind of architecture as shown in figure 2.7 client WMN. Mesh clients are able to forward traffic as well so packet can arrive at the destination node through multi-hop communication (Siemuri, et al., 2019).

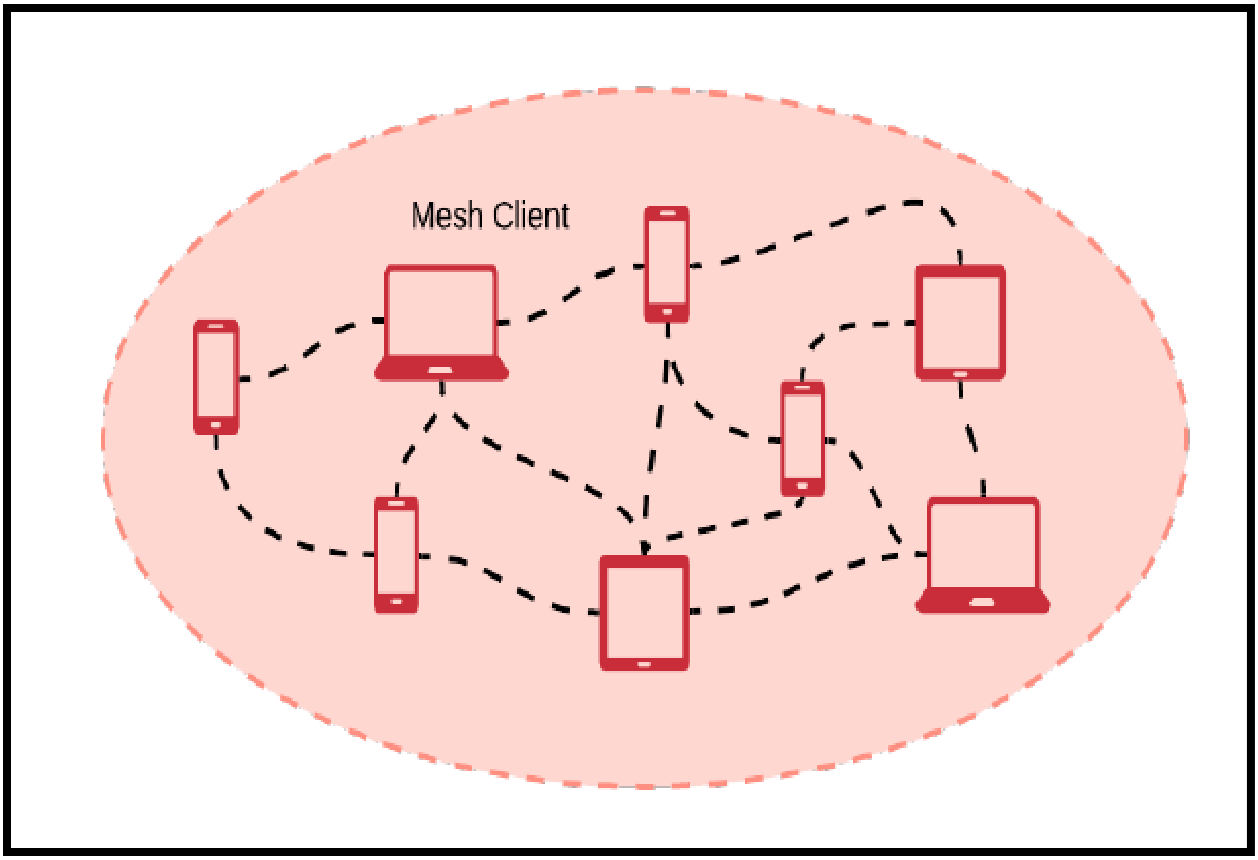

Figure 2.7: Client WMN (Quan, et al., 2019).

2.5.3 Hybrid WMN

This type of WMN hybrid between infrastructure and client WMN is shown in figure 2.8 hybrid WMN. The client mesh can arrival the network other via infrastructure/backbone or directly integrate with other clients (Siemuri, et al., 2019).

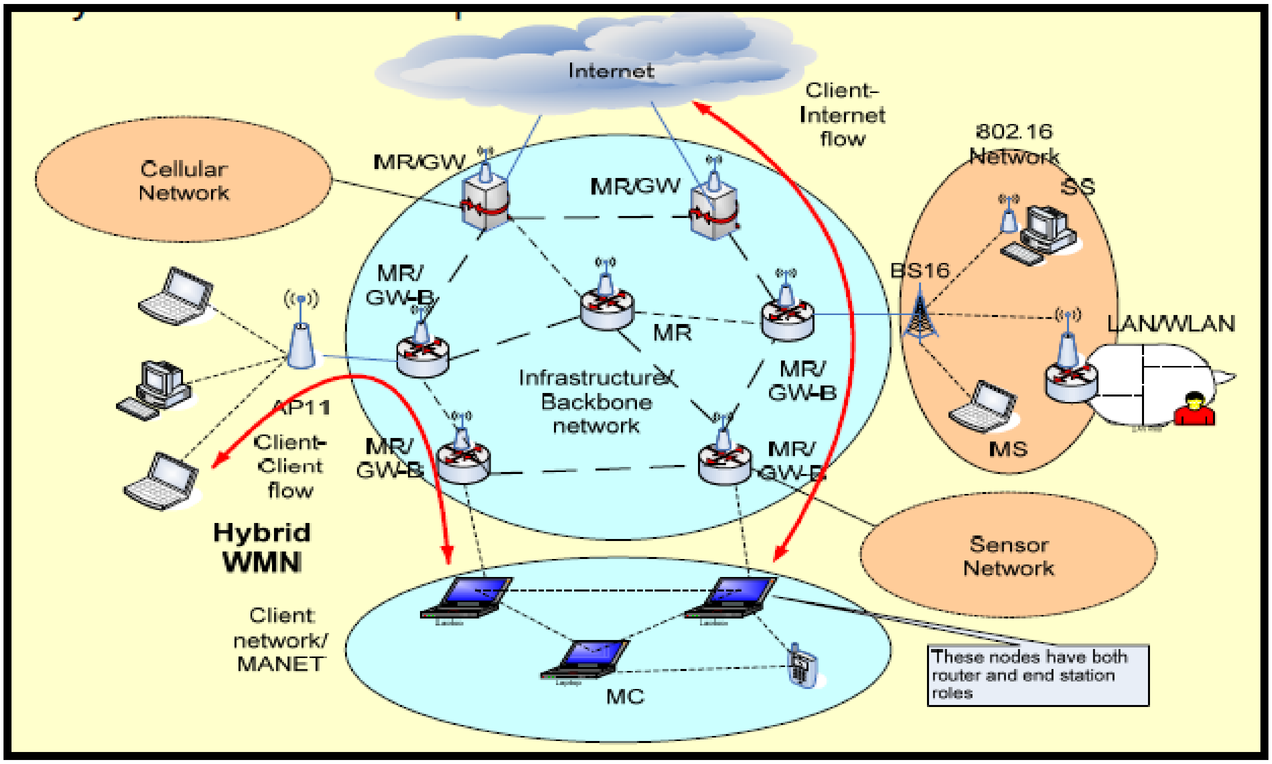

Figure 2.8: Hybrid WMN (Quan, et al., 2019).

2.6 WMNs Characteristics

WMN is an effective and cheap technology. WMN are being installed in companies, vehicles, buildings because of its strength, self-configuration and easy maintenance. WMN is not difficult to execute and spread a mesh network for all the components are already available in the form of guided protocols (Siemuri, et al., 2019).

1. WMN provide Multi-hops (Singh, et al., 2019).
2. Ability of subjective-figuration, subjective-healing, subjective-organization and subjective-configuration (Singh, et al., 2019).
3. Low-cost.
4. Capability employment with existing Wireless Networks.
5. Provide redundancy.

2.7 WMNs Application

Some of the general applications of WMN.

1. Enterprise networking: This can be a small network within an office or a medium-size network for all the offices within an entire building (Siemuri, et al., 2019).

2. Metropolitan area: MAN, network covers greater space than institutions networks. wherefore, these networks need high cost and ability (Siemuri, et al., 2019).

3. Travelling systems: technology such as IEEE 802.11, IEEE 802.16 They have limited access to the stations while network technologies provide unlimited access to buses, trains and ferries, which allows monitoring and ease of transfer of information between passengers (Siemuri, et al., 2019).

4. Premises automation: different electric devices such as energy and light. need monitoring and this job is finished via the cable networks, but it is costly in terms of maintenance and deployment, Therefore, WMN are used instead of wired (Siemuri, et al., 2019).

5. Medicinal systems: control and diagnostic information must be processed in an infirmary and transferred from place to another for many objectives. conventional cable networks can provide restricted network access to medicinal utilities; but WMN provide unlimited access (Siemuri, et al., 2019).

2.9 Tabu-Search Algorithm

Tabu search (TS) is the technique of type Meta-heuristics algorithm, its benefits to avoiding using the same search or path in the solution space by that keep track of the regions of the solution space. It starts from a random initial solution and successively moves to one of the neighbors of the current solution. The difference of tabu search from other Meta-heuristic approaches is based on the notion of tabu list, which is a special short-term memory, it used to store the previously visited solution and avoiding repeating the search near of these areas. The process of TS can be represented as follows: (Said, et al., 2014).

TS Algorithm

Step 1 Generate initial solution x.

Step 2 Initialize the Tabu List.

Step 3 While set of candidate solutions X'' is not complete.

Step 3.1 Generate candidate solution x'' from current solution x

Step 3.2 Add x'' to X'' only if x'' is not tabu or if at least one Aspiration Criterion is satisfied.

Step 4 Select the best candidate solution x^* in X''.

Step 5 If fitness(x^*) > fitness(x) then $x = x^*$.

Step 6 Update Tabu List and Aspiration Criteria

Step 7 If termination condition met finish, otherwise go to Step 3.

2.10 Optimization Techniques

In optimization of a design, the design objective could be simply to minimize the cost of production or to maximize the efficiency of production by using an optimization algorithm. An optimization algorithm is a procedure which is executed iteratively by comparing different solutions till an optimum or a favorable solution is found (Cao, et al., 2019).

2.11 Regression Model

Is using to determine the relationship between one or more variables and a response variable (Reka, et al., 2020). Figure 2.10 shows the types of regression model.

Figure 2.10: Regression Model Types (Reka, et al., 2020).

The types of regression model as the following:

A. Linear Regression

This type represents the simple model, which is used when an explanatory variable and a response variable have a linear relationship (Olive, et al., 2017), it is used to explain the relationship between a dependent variable y and one independent variables x. Figure 2.11 shows linear regression model.

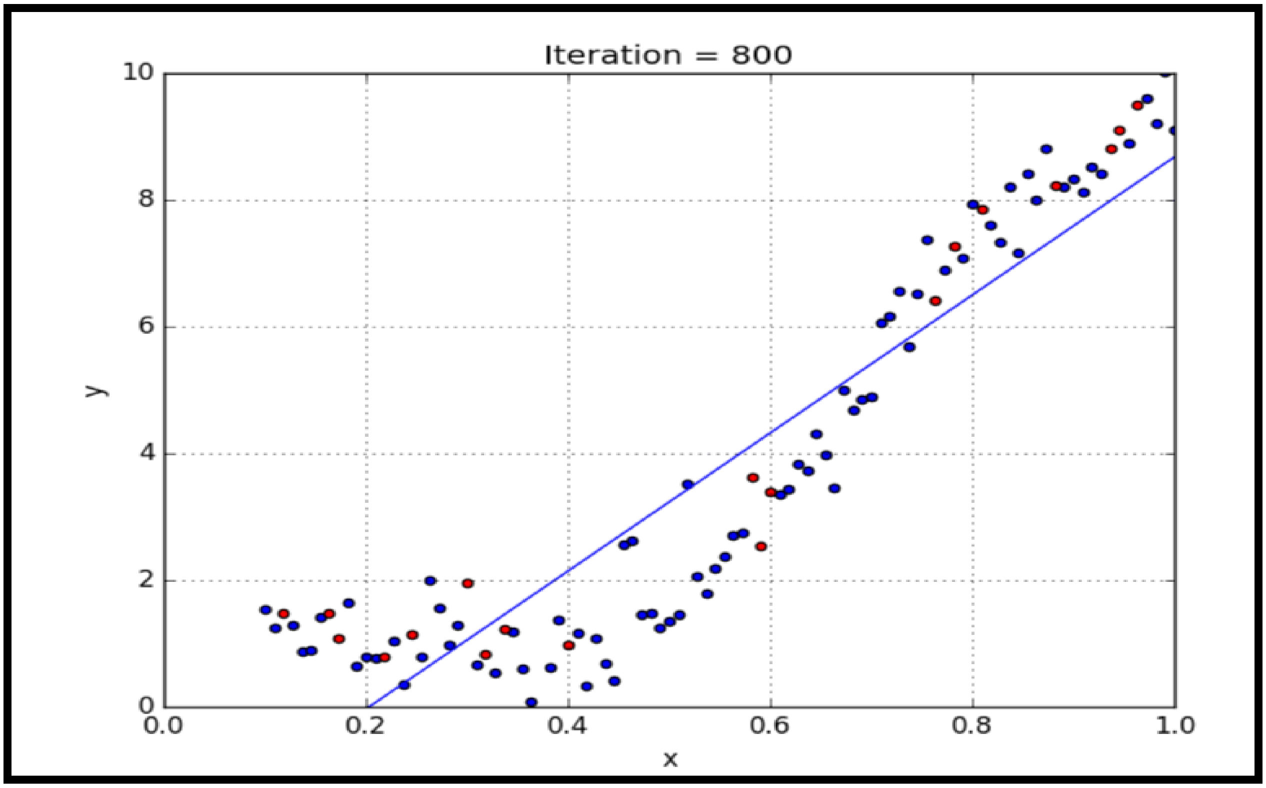

Figure 2.11: Linear Regression (BIOS, et al., 2019).

The linear regression equation can form (Goulet, et al., 2018) as the following:

$$\boldsymbol{y = a + bx} \tag{2.1}$$

Where, y: is Dependent variable (it is the variable that goes on the y axis).

x: is independent variable (it is plotted on the x axis).

a: is the intercept or constant.

b: is the slope of the line on the independent variable.

B. Multiple Linear Regression

This type represents the second type of regression, it is a regression of the dependent variable y on many independent variable x. That is, it is used to explain the relationship between a dependent variable y and two or more independent variables x (Olive, et al., 2017). Figure 2.12 shows multiple linear regression.

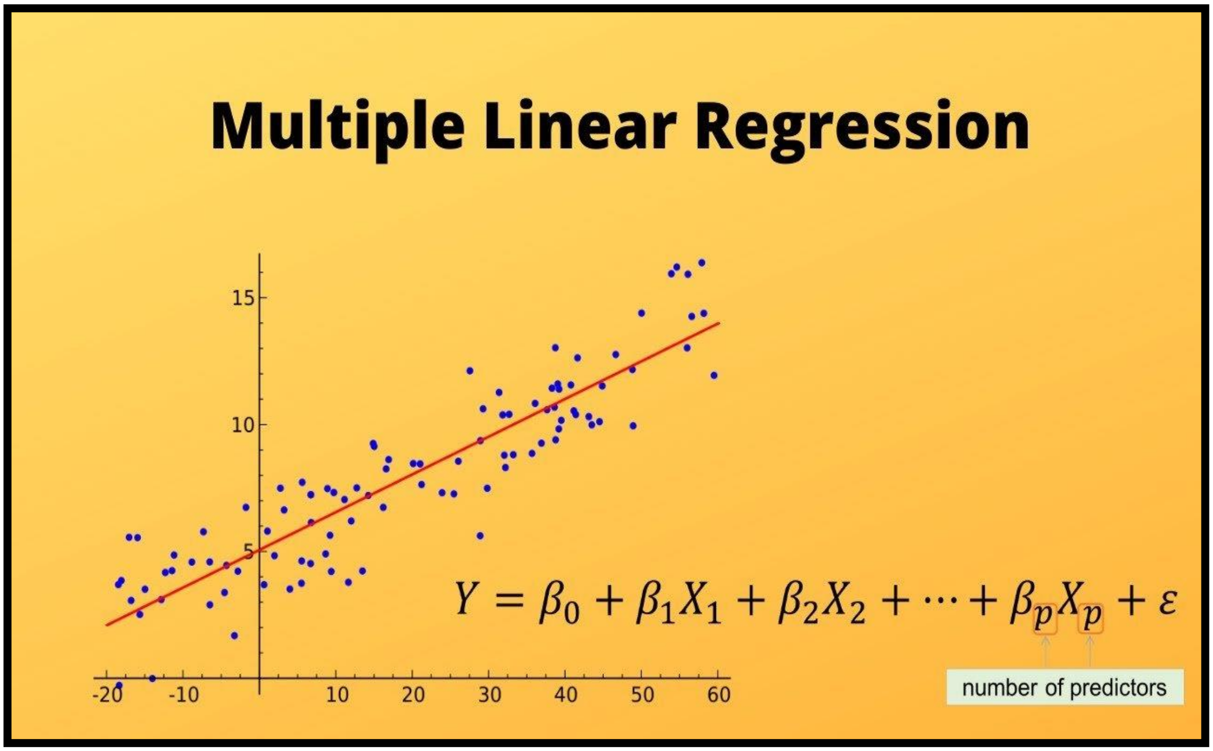

Figure 2.12: Multiple Linear Regression (Olive, et al., 2017)

The multiple linear regression equation can form (Swain, et al., 2017) as the following:

$$\boldsymbol{y = b_0 + b_1 x_1 + b_2 x_2} \qquad \textbf{(2.2)}$$

Where, b_0: is the intercept or constant.

b_1: Slope of the regression y on the first independent variable.

b_2: Slope of the regression y on the second independent variable.

x_1: The first independent variable.

x_2: The second independent variable.

y: is Dependent variable (it is the variable that goes on the y axis).

C. Polynomial Regression

This type represents the third model, which can account for the nonlinear relationship between dependent and independent variables (Gómez-Valent, et al., 2018). Figure 2.13 shows polynomial regression.

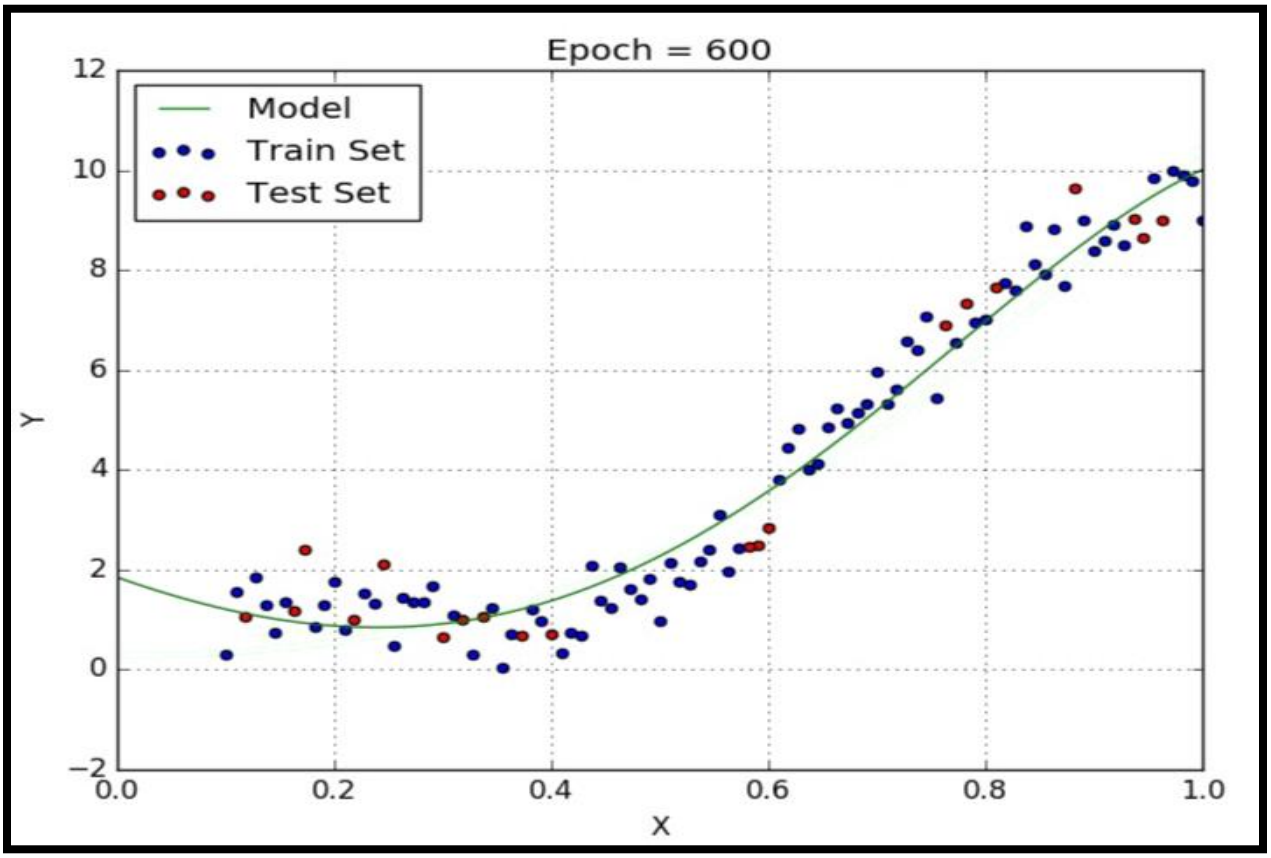

Figure 2.13: Polynomial Regression (Diakonikolas, et al., 2021).

Suppose we have x as independent data and y as dependent data. The equation of polynomial becomes something like this (Diakonikolas, et al., 2021),

$$y = a_0 + a_1x + a_2x^2 \ \dots + \ a_nx^n \qquad (2.3)$$

If $x_j = x^j$, j = 1,2, ……, n, then the model is multiple linear regressions model in (n) explanatory variables $x_1, x_2, \dots, x_n$. So, the linear regression model $y = a + bx$ includes the polynomial regression model. Thus, the techniques for fitting linear regression model can be used for fitting the polynomial regression model. The coefficients a_1 and a_2 are called the linear effect parameter and quadratic effect parameter, respectively (Diakonikolas, et al., 2021)..

2.11.1 Polynomial Regression Model in One Variable

A. One-Order Model (Simple Linear Model)

This type contains one variable of one order (Olive, et al., 2017), it has the equation the following:

$$y = a + bx \qquad (2.4)$$

B. Second-Order Model (Quadratic Model)

This type contains one variable of second order (Gómez-Valent, et al., 2018), it has the equation the following:

$$y = a_0 + a_1x + a_2x^2 \qquad (2.5)$$

C. Third-Order Model (Cubic Model)

This type contains one variable of third order (Gómez-Valent, et al., 2018), it has the equation the following:

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 \qquad (2.6)$$

D. Higher-Order Model

This type contains one variable of higher order such as 6 and (Gómez-Valent, et al., 2018), it has the equation the following:

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6 \qquad (2.7)$$

2.12 Performance Metrics

There are various metrics that can be utilized to analyze the performance of WMN. Some of these metrics are:

2.12.1 The Throughput

It is Known to be the amount of exception data from the receiving nodes during a duration of time. The unit of bytes per second (bytes/sec) is used to measure throughput (Ameen, et al., 2018). The mathematical expression for throughput is writing in the following equation,

$$\textbf{Throughput} = \frac{\sum_{1}^{n} \ \ packet-size\,[i]}{simulation\ time} = \text{(bytes/sec)} \qquad \textbf{(2.8)}$$

2.12.2 End to End Delay (E2E Delay)

The data packet will arrive at the endpoint within the time that is averaged out. For the metric calculation, the arrival time of the first data packet is used to subtract the time at which the first packet was transmitted. The unit of per second (sec) is used to measure end-to-end delay (Ameen, et al., 2018). The mathematical expression for end-to-end is writing in the following equation,

End-to-End Delay = Arrival time – Transmitted time **(2.9)**

2.12.3 Packet Delivery Ratio (PDR)

It represents the proportion of the receipting data packets by the receiver node to the packets sending by sender nodes. The unit percentage (%) is used to measure PDR (Ameen, et al., 2018). The mathematical expression for packet delivery ratio is writing in the following equation,

$$\textbf{PDR} = (\text{Number of received packets/number of sent packets})\,\boldsymbol{*100} \qquad \textbf{(2.10)}$$

2.12.4 Normalize Routing Load (NRL)

NRL represents the number of transmitted, Routing packets to the delivery packets (Lai, et al., 2019). The mathematical expression for normalize routing load is writing in the following equation,

$$\textbf{NRL} = \text{Number of routing packets} \,/\, \text{Number of received packets} \qquad \textbf{(2.11)}$$

2.12.5 Load Balancing Efficiency (LBE)

The load balancing is known as the proportion of volume of nodes specific for sending to the overall volume of nodes. The unit percentage (%) is used to measure LB (Raja, et al., 2020). The mathematical expression for load balancing is writing in the following equation,

$$\textbf{Load Balancing Efficiency}= \frac{\textit{Number of nodes determined for transmission}}{\textit{The total number of nodes}} * 100 \qquad \textbf{(2.12)}$$

2.12.6 Target Coverage (TC)

It is known as the volume of nodes that existing within its coverage radius (Gupta, et al., 2020).

$$\boldsymbol{d}(\boldsymbol{e},\boldsymbol{n}) = = \sqrt{(x2 - x1) \wedge 2 + (y2 - y1) \wedge 2} \qquad \textbf{(2.13)}$$

Variable (x1, y1) that represents the current node n and variable (x2, y2) is represents the node e within the coverage radius of (x1, y1) and closet to it. variable $\boldsymbol{Cen}$ that represents the link connectivity between end node e and current node n. The variable $\boldsymbol{Cen}$ is set to 1 if end node e is closest to the node n and end node e is within the coverage radius of n (Eq. 2.13). Thus, the mathematical formula to calculate TC becomes:

$$\boldsymbol{TC(n)} = \sum_{e\in n} Cen \qquad \textbf{(2.14)}$$

Where,,

$$\boldsymbol{Cen} = \begin{cases} 1 & if\ for\ any\ e \exists n\ such\ that\ min\ e \in n\ d(e,n)\ \& \sqrt{(x2 - x1) \wedge 2 + (y2 - y1) \wedge 2} \\ 0 & else \end{cases}$$

2.12.7 Quality of Services (QoS)

Is the description or measurement of the overall performance of a service, such as a telephony or computer network or a cloud computing service, particularly the performance seen by the users of the network. To quantitatively measure quality of service, several related aspects of the network service are often considered, such as packet loss, bit rate, throughput, transmission delay, availability, jitter (Lai, et al., 2019). In this study focuses on two services that you provide QoS, namely reducing E2E Delay and increase packet delivery rates (PDR) (Gupta, et al., 2020). so, the mathematical formula to calculate QoS becomes:

QoS = Weight * PDR - Weight * E2E Delay **(2.15)**

Variable weight that represents a value.

CHAPTER THREE

Proposed System

Chapter Three

Proposed System

3.1 Introduction

Improving the performance of WMNs can be achieved to transfer the data successfully whoever the source to the received node.

In this chapter different wireless mesh network will be implement and display. Certain research different cases were using for it applying on WMN.

3.2 Research Methodology

The following steps are suggested to explain the process of designing and implementing the proposed wireless mesh network in this thesis.

1. Design the wireless mesh network setup using the Net Logo interface tab and select the suitable method for entering the required data and the process of objects display.
2. Select the environment area shape and size.
3. Create and call the suitable agents (nodes) to represent the sensor nodes in the network and assign their numbers (Node who).
4. The sensor nodes will not be distributed randomly in the area.
5. Create mesh network by define the number-of nodes
6. One of these nodes will be selected (either randomly or by the user) to be the source node (or the node to start transmitting message).
7. Select another node (either randomly or by the user) from the network to represent the destination (or the node to receive transmitting message).

8. At the beginning of the implementation steps, the way of message transmission approaches from the sender to the receiver (or destination node) must be selected (direct and either multi hops or four sectoring approach).

A: If the destination node is within the sending node range the message can be transmitted directly (single hope).

B: If the destination node is Extreme from the source node (out of the source range) then multi hops can be selected to transfer the message from any node to the destination node in five different suggested cases (approaches):

(1): The select transmission approach can be applied. select source and destination nodes by the user. This called (short-path).

(2): The random transmission approach can be applied. select randomly source and destination nodes. This called (short-path with random-source and destination node).

(3): The hybrid transmission approach can be suggested and applied. It can be achieved by selecting one of the nodes (source or destination) randomly and select the other node by the user. This called (short-path with random-source or destination node).

(4): This approach can be improved to avoid the case of busy node at the sending time with constant number both of (source and destination node) called (alternate-path with busy intermediate node approach).

(5): This approach can be improved to avoid the case of busy node at the sending time with select source and destination node randomly by the program called (alternate-path random-source and destination with busy intermediate node approach).

C: Another approach can be followed to improve the transmission process from the source to the destination node by using the four sector techniques. Three four sectoring techniques can be suggested and implemented in messages transmission process. The three proposed four sectoring cases are: -

(1): In the first four sectoring approach, one of nodes can be selected randomly, will be connect all its neighbor nodes within its coverage area.

(2): In the second four sectoring approach, one node can be selected by the user to be the center node, it will be selecting one of the neighbor's nodes within its coverage area.

(3): In the third four sectoring approach, one node can be selected by the user to be the center node, it will be selecting three of the neighbor's nodes within its coverage area.

The following simulation program was designed to achieve the process of messages transmission in WMN. Figure 3.1 presents the general flowchart of the suggested simulation program model.

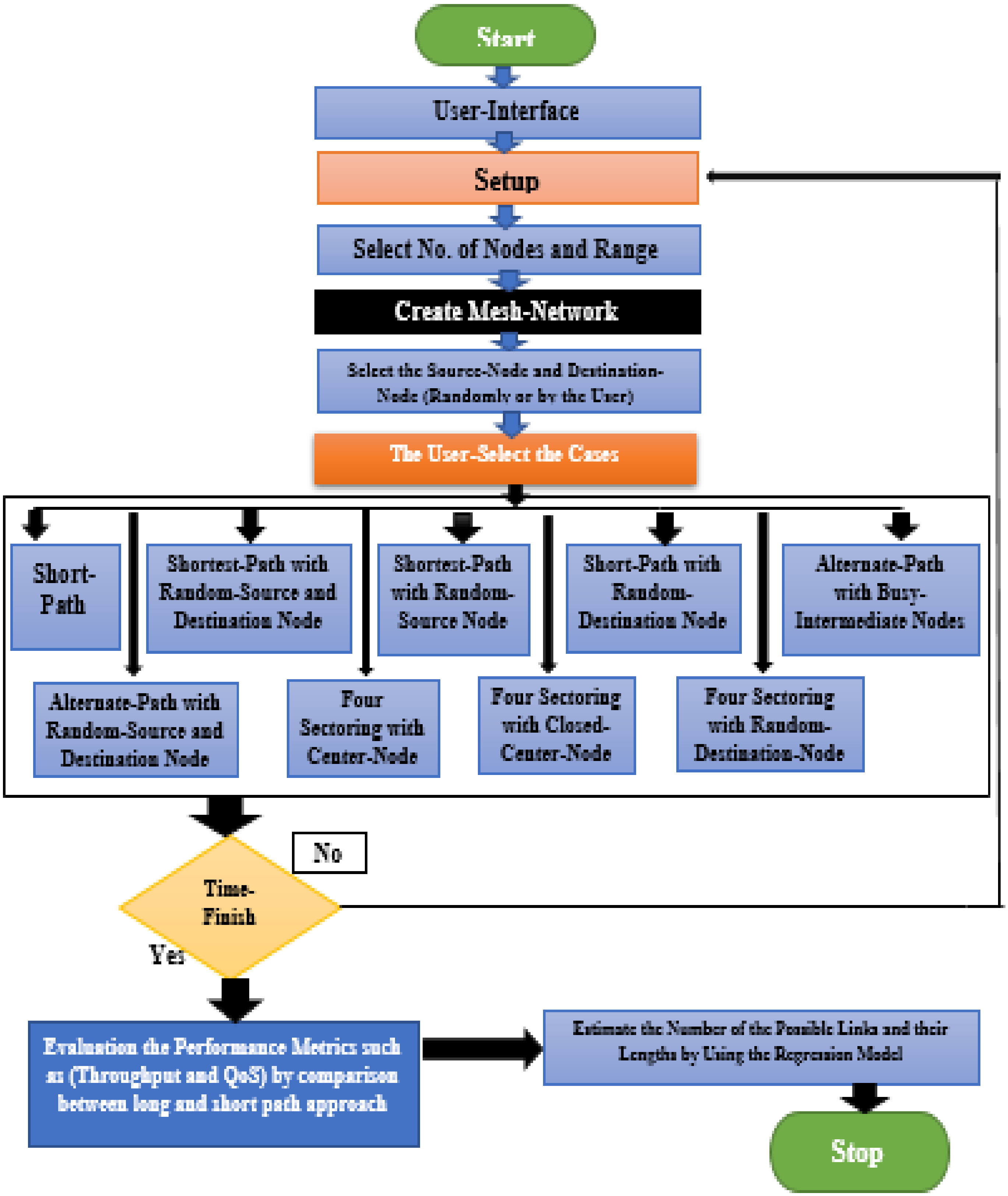

Figure 3.1: Flow Chart of WMN.

3.2.1 Setup Procedure

The setup procedure represents the first step by determine the required sensor nodes. Net Logo commands were used to distribute nodes fixed in these the environment. Each node can be identified by its ID (who) and its position (x, y) coordinates. Certain node will be selected either randomly or by the user to be the source node (its color, shape and size will be changed), and will be select another node either randomly or by the user to be the destination node (its color, shape and size will be changed).

3.2.2 Constant-Nodes Procedure

This procedure can build in net logo program. The user can distribute in the environment constant nodes rather than random.

3.2.3 Create Mesh-Network Procedure

The suggested procedure in this approach is to select number-of sensor nodes by the slider and it's distributed in environment area, and determine transmission range by the slider. To connect these nodes with each other and create mesh network by using undirected links, must be using a certain condition, which is to make the distance of these nodes less or equal to the given transmission range, so we need to determine the number of nodes and the transmission range from their sliders. In the event that the distance of these nodes is greater than the transmission range, a mesh network will not be created

3.2.4 Selection of Source Node Procedure

It is the process of selecting one of the nodes from the surrounding environment in wireless mesh network for sends the message to the next node. Two approaches have been suggesting the first approach is selection by the user and the other is randomly.

A. Random Selection

The suggested procedure in this approach is to select one of the nodes from the built environments randomly and change some of its variable like (colour, size, shape) to distinguish it visually, save its location and its id (the identifier number of node). Then the next step is to create message in the selected node which assumed sense physical effects in the environment of the network in order to send it to destination node

B. User Selection

In this approach, the user can select one of the nodes directly from the environment by specify its number to be the sensing node. The program will respond to this selection by changing some variable like (colour, size, shape).

3.2.5 Selection of Destination Node Procedure

It is the process of selecting one of the nodes from the surrounding environment in wireless mesh network for receive the message from the source node. Two approaches have been suggesting the first approach is selection by the user and the other is randomly.

A. Random Selection

The suggested procedure in this approach is to select one of the nodes from the built environments randomly by the program to be the receiver node.

B. User Selection

In this approach, the user can select one of the nodes directly from the environment by specify its number to be the destination node. The program will respond to this selection by changing some variable like (colour, size).

3.2.6 Shortest-Path Approach

In this approach, a send message is transmitting from the source node will be select by the user to the destination node will be select by the user directly if the sink node is existing in the range of the transmitting node. Otherwise, the sensor node sends its message to the Extreme node in its range and in the direction of the target node (destination). The same process will continue till reaching the target node (sink). To implement this approach will using tabu search algorithm. Tabu search is the technique of type Meta-heuristics algorithm, its benefits to avoiding using the same search or path in the solution space by that keep track of the regions of the solution space. It's using special short-term memory to store the previously visited solution and avoiding repeating the search near of these areas

3.2.7 Shortest-Path with Random-Source and Destination Node Approach

In this approach, a message is transmitting from the source node will be define random by the program to the destination node will be define random by the program also. Called this method shortest path Random if the close node exists in the range of the transmitting node (source node) by creating a direct link between them.

3.2.8 Shortest-Path with Random-Source Node Approach

In this approach, a message is transmitting from the source node will be define random by the program to the destination node will be define by the user. Called this method shortest path with random source if the close node exists in the range of the transmitting node (source node) by creating a direct link between them.

3.2.9 Shortest-Path with Random-Destination Node Approach

In this approach, a message is transmitting from the source node will be define by the user to the destination node will be define random by the program. Called this method shortest path with random source if the close node exists in the range of the transmitting node (source node) by creating a direct link between them.

3.2.10 Alternate-Path with Busy-Intermediate Nodes Approach

This approach was suggested to treat the expected challenges that may appear in applying the alternate-path approach. One of the intermediate nodes may being busy during the same period of receiving another message form the sensing node. In this case the sent message either to wait very short time or it may be dropped. Dropping this message will reduce the system reliability, lost the messages and the route (path) failed. The approach was proposed to be the developed version of short-path approach. The difference with the previous approach is by testing each next node based on variable called capacity before sending a message to it. If it is busy the message must be routed to another node. Another node must be selected carefully; it must be in the sent node transmission range and in the same direction. Its distance may be same or the second greater the previous busy node.

3.2.11 Alternate-Path Random-Source and Destination with Busy-Intermediate Nodes Approach

This approach is similar to alternate-path approach with busy intermediate nodes, but in this approach the source and destination selected by the randomly by the program

3.2.12 Four Sectoring Approaches

Nodes collected as a structure in groups called four sectoring using many algorithms to make high throughput, minimums end-to-end delay and increase packet delivery ratio in WMN.

A. Four Sectoring with Random-Destination-Node Approach

This algorithm was built and simulated using Net Logo in this study. Four sectoring random-destination algorithm based on select random one of nodes as the destination for to receive the message from all its neighbor nodes in its coverage area.

B. Four Sectors with Center-Node Approach

This algorithm was built and simulated using Net Logo. Four sectoring select nodes algorithm based on select center node as the destination for to receive the message from three its neighbor nodes on its different patches.

C. Four Sectoring with Close-Center-Node Approach

This approach was developed in this study to ensure and its simulated using Net Logo. Four sectoring with algorithm based on select one of nodes on a certain patch as the destination for to receive the message from one its neighbor nodes in its coverage area and Its properties such as (color, size, id) will be changed in a simulation program.

3.2.13 Optimization Techniques

Connect the network in a mesh way at first, then calculate the number and length of links with different number of nodes and range.

A. Calculate the Number of Links

Calculate the number of links in mesh network by using the following programmatically equation,

Count Links = count link + set [my-links] of nodes **(3.1)**

B. Calculate the Length of Links

Calculate the length of links in mesh network by using the following programmatically equation,

Count Length-of-Links = count links + sqrt ((x2 – x1) ^ 2 + (y2 – y1) ^ 2) **(3.2)**

3.3 Simulation Cases

To achieve the process of message transfer from sender node (source) to received node (destination) in WMN, we need to apply some cases, each case consists of set of steps, each step represent procedure.

3.3.1 Case 1 (Shortest-Path Approach)

The following steps represent the process of transmitting a message from one source node to the destination node using the developed simulation program in Net Logo.

1. Input the identifier number-of nodes.
2. Input coverage area (range) of the nodes.
3. Press button create-mesh to create wireless mesh network.
4. Press button source-node
5. Press button destination node
6. Press button short-path.

3.3.2 Case 2 (Shortest-Path with Random-Source and Destination Node Approach)

The following steps represent the process of transmitting a message from one source node to the destination node using the developed simulation program in Net Logo.

1. Input the identifier number-of nodes.
2. Input coverage area (range) of the nodes.
3. Press button create-mesh to create wireless mesh network.
4. Press button short-path random.

3.3.3 Case 3 (Shortest-Path with Random-Source Node Approach)

The following steps represent the process of transmitting a message from one source node to the destination node using the developed simulation program in Net Logo.

1. Input the identifier number-of nodes.
2. Input coverage area (range) of the nodes.
3. Press button create-mesh to create wireless mesh network.
4. Press button destination node.
5. Press button shortest-path with random-source.

3.3.4 Case 4 (Shortest-Path with Random-Destination Approach)

The following steps represent the process of transmitting a message from one source node to the destination node using the developed simulation program in Net Logo.

1. Input the identifier number-of nodes.
2. Input coverage area (range) of the nodes.
3. Press button create-mesh to create wireless mesh network.
4. Press button source node.
5. Press button shortest-path with random-destination.

3.3.5 Case 5 (Alternate-Path with Busy-Intermediate Nodes Approach)

The following steps represent the process of transmitting a message from one source node to the destination node using the developed simulation program in Net Logo.

1. Input the identifier number-of nodes.
2. Input coverage area (range) of the nodes.
3. Press button create-mesh to create wireless mesh network.
4. Press button source-node
5. Press button destination node
6. Press button alternate-path.

3.3.6 Case 6 (Alternate-Path Random-Source and Destination with Busy-Intermediate Nodes Approach)

The following steps represent the process of transmitting a message from one source node to the destination node using the developed simulation program in Net Logo.

1. Input the identifier number-of nodes.
2. Input coverage area (range) of the nodes.

3. Press button create-mesh to create wireless mesh network.
4. Press button alternate-path random.

3.3.7 Case 7 (Four Sectoring with Random-Destination-Node Approach)

1. Input the identifier number-of nodes.
2. Input coverage area (range) of the nodes.
3. Press button create-mesh to create wireless mesh network.
4. Press button four sectoring with random- destination-node.

3.3.8 Case 8 (Four Sectoring with Center-Node Approach)

The following steps represent the process of transmitting a message from one source node to the destination node using the developed simulation program in Net Logo.

1. Input the identifier number-of nodes.
2. Input coverage area (range) of the nodes.
3. Press button create-mesh to create wireless mesh network.
4. Press button four sectoring with center-node.

3.3.9 Case 9 (Four Sectoring with Close-Center-Node Approach)

1. Input the identifier number-of nodes.
2. Input coverage area (range) of the nodes.
3. Press button create-mesh to create wireless mesh network.
4. Press button four sectoring with close-center-node.

CHAPTER FOUR

Simulation Results and Analysis

Chapter four

Simulation Results and Analysis

4.1 Introduction

In this chapter, Net logo simulator was used to apply the simulation process in order to implement and evaluate nine approaches to send data from source node to the destination node based on a different performance metrics such as (NRL, PDR, End-to-End Delay, Throughput, LB, TC and QoS). The effect of several parameters such as the number-of-nodes, range (coverage area) on the performance of these approaches was also studied.

4.2 Research Methodology

Net Logo (a multi-agent modeling language) was suggested as a network simulator to be used in building and implementing the suggested wireless mesh networks. It represents an appropriate tool for modeling complex systems developing over time.

There are many parameters effect on implementation of approach or cases in WMN such as: number-of-nodes, range (coverage area of the node). The parameters and their initial values are presented in table 4.1.

Table 4.1: The Simulation Parameters and their Values.

Parameters	**Value**
The Simulator	Net Logo 6.2.0 version (2019)
Number-of-Nodes	Variable (25, 50, 75, 100, 150, 200, 300)
Algorithm	According to the Applied Approach
Transmission Range	(5, 10, 15, 20, 25, 30) m
Simulation Area	Length * Width
Source-Number	According to the Applied Algorithm
Destination-Number	According to the Applied Algorithm
Simulation Time	12 Second
No. of Packet	28
Size of Packet	1500 Byte

4.2.1 Setup Procedure Result

The first state is clear- and -reset all of the nodes, links, ticks, monitors and plots by using setup procedure. In the same procedure will distributed constant nodes in the Net Logo environment. Figure 4.1 shows a program snapshot for a setup procedure.

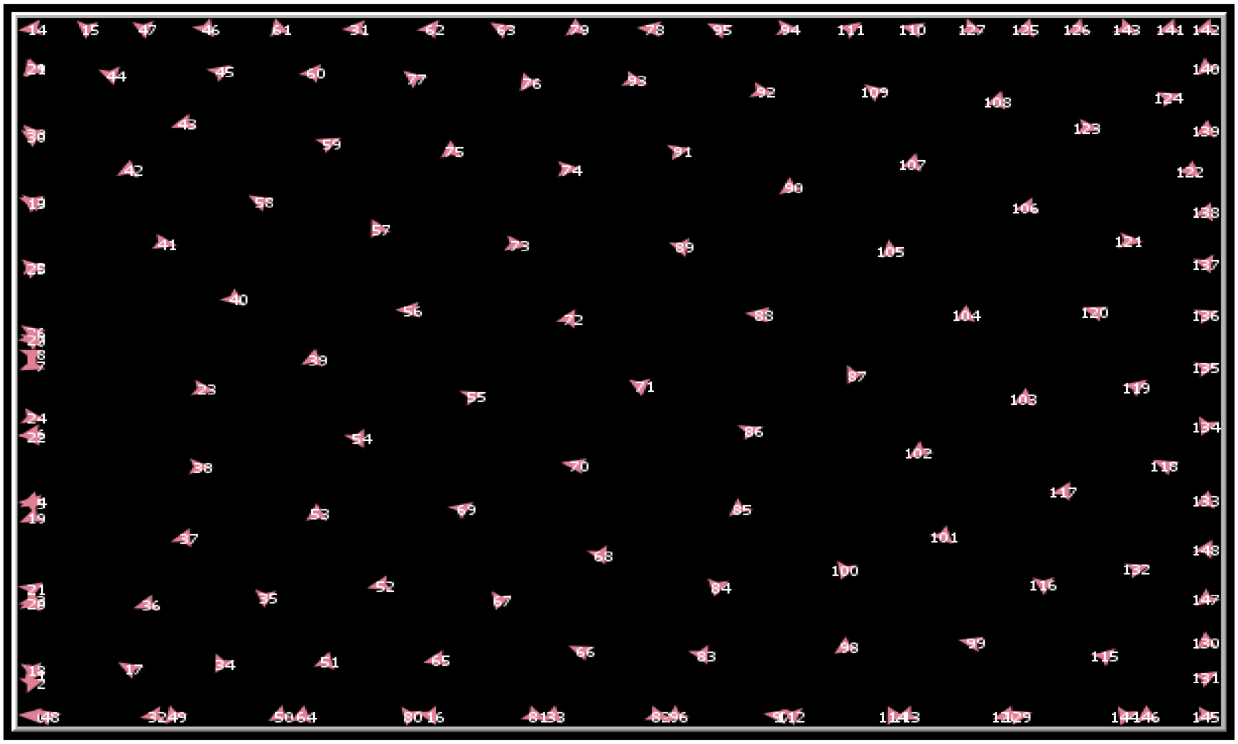

Figure 4.1: Program Snapshot for a Setup Procedure Result.

4.2.2 Create-Mesh Network Procedure Result

The first state is creating wireless mesh topology by define the number-of nodes (by the slider) and determine the transmission range (by the slider). Figure 4.2 shows a program snapshot for a create-mesh network procedure result.

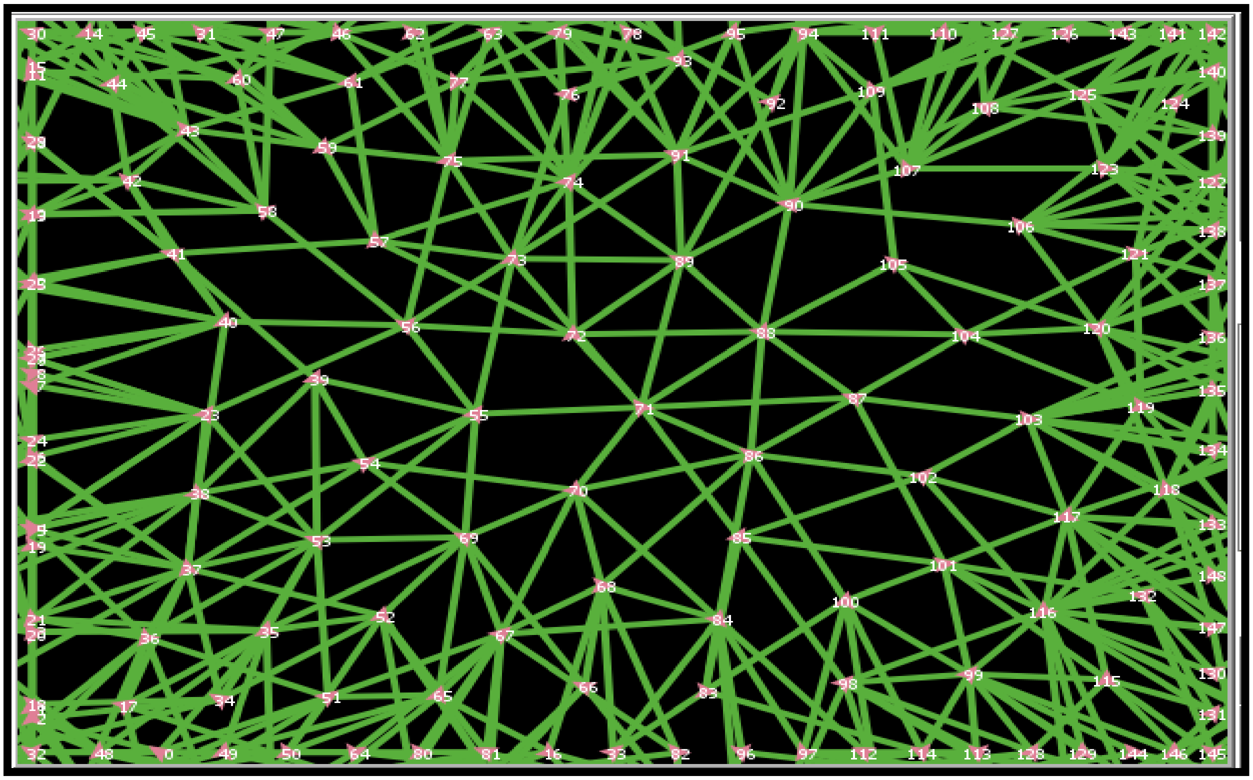

Figure 4.2: Program Snapshot for a Create-Mesh Network Procedure Result.

4.2.3 Case 1 Result; (Shortest-Path Approach)

The table 4.2 specifies the simulated result with varying number of nodes. This table contains the short paths that were obtained when executing the Net Logo simulation program between the source node and the destination in different number of nodes. Using the same variables in table 4.1. The implemented algorithm in this case is called shortest-path approach. In this approach the selected source node number is 73 and the selected destination node number is 102. Figure 4.3 shows a program snapshot number-of-nodes in the short-path approach.

Table 4.2: Simulation Results of Case1, Varying Number of Nodes and Ranges.

Ranges	150 Node	200 Node	300 Node
5	73—72—71—86—102	73—88—87—102	73—88—87—102
10	73—71—102	73—88—102	73—120—117—68—102
15	73—71—102	73—102	73—102
20	73—71—102	73—87—102	73—136—102
25	73—88—85—102	73—103—101—102	73—84—102
30	73—102	73—117—86—102	73—135—102

For example, if the number of nodes is 150 and the range is 5, then the short path is 73—72—71—86—102.

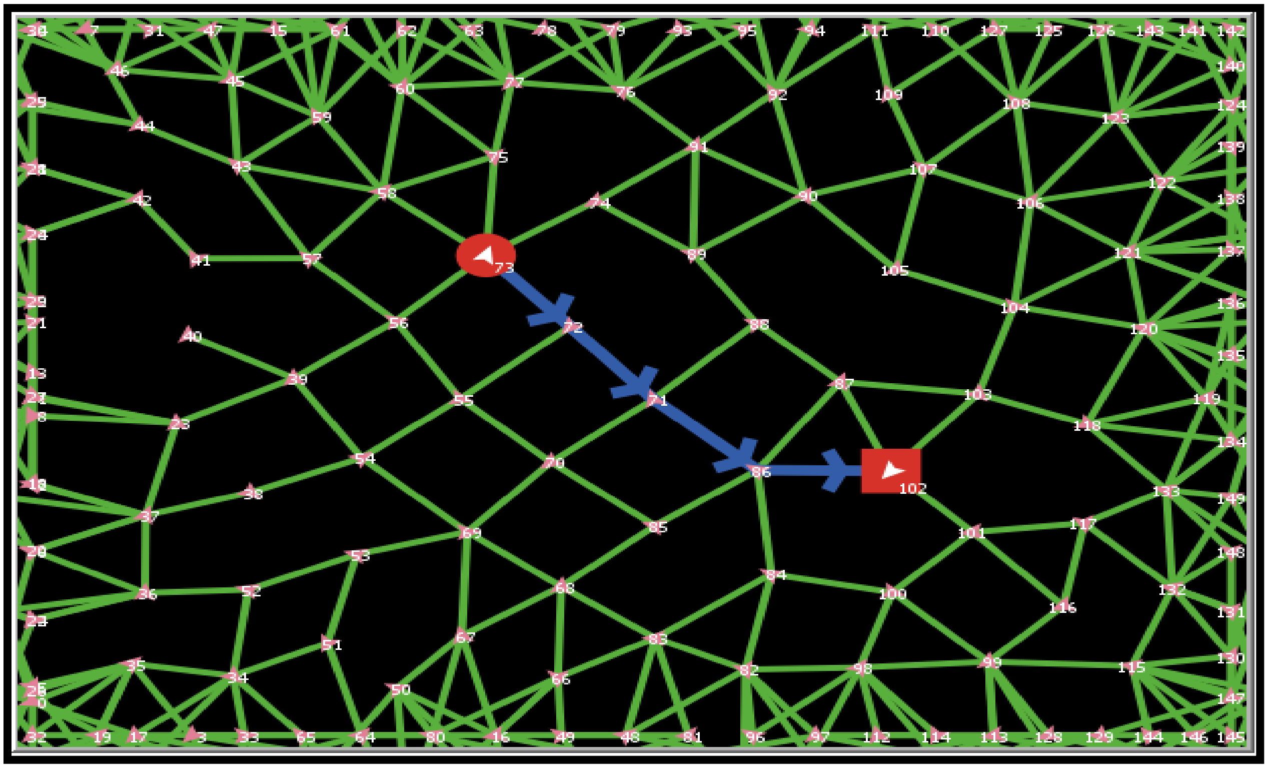

Figure 4. 3: Program Snapshot 150 Number-of-Nodes and 5 Range in the Short-Path Approach.

4.2.4 Case 2 Result; (Shortest-Path with Random-Source and Destination Node Approach)

Using the same table 4.1, but the algorithm in this case called the short path with random-source and destination approach, the number source node is random and the number destination node is random. The table 4.3 specifies the simulated result with varying number of nodes. This table contains the short path with random-source and destination that were obtained when executing the Net Logo simulation program between the source node and the destination in different number of nodes. Figure 4.4 shows a program snapshot number-of-nodes in the short path with random-source and destination approach. This scenario suggest that all parameters are fixed except the number-of-nodes are changeable.

Table 4.3: Simulation Results of Case 2, Varying Number of Nodes and Ranges.

Ranges	150 Nodes	200 Nodes	300 Nodes
5	129--127	105--104--87-- 86--69	268—128-- 211
10	80 – 45—59-- 61	77--64-- 85	125—121—88-- 55
15	75—88--106	27—191-- 116 --160	274-- 205-- 211
20	20—21—1	184-- 55-- 54	104—180—166-- 182
25	71--101	35--87	199-- 135
30	71—74	18—104—87--89	267--149--125

For example, if the number of nodes is 150 and the range is 5, then the short path is 129--127**.**

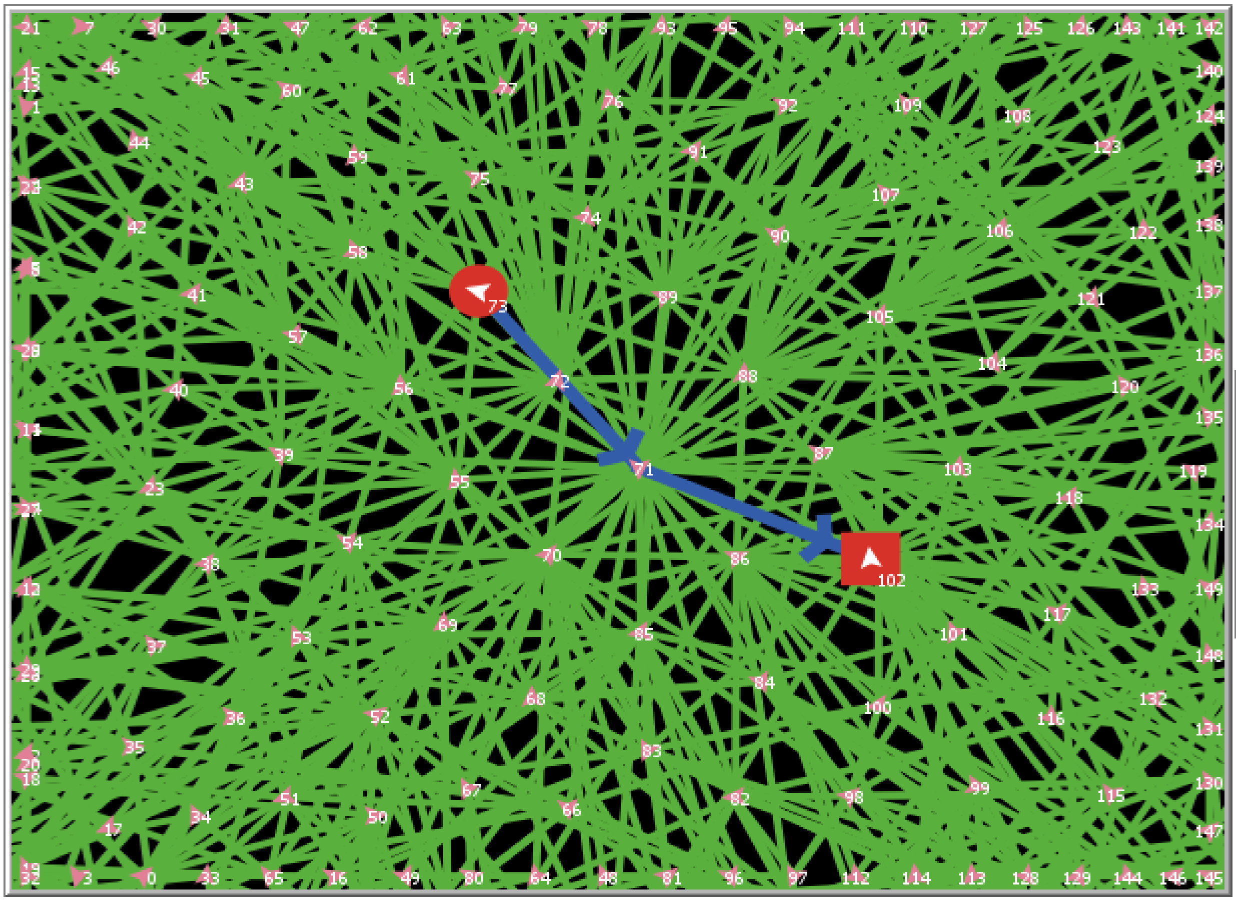

Figure 4.4: Program Snapshot 150 Number-of-Nodes and 15 Range in the Short-Path with Random-Source and Destination Node Approach.

4.2.5 Case 3 Result; (Shortest-Path with Random-Source Approach)

In this case only number-of-nodes states were implemented. The table 4.4 shows specify the simulated result with varying number of nodes. This table contains the short path with random-source and constant destination that were obtained when executing the Net Logo simulation program between the source node and the destination in different number of nodes. Using the same table 4.1, but the algorithm in this case called the short path with random-source and constant destination approach, the number source node is random and the number destination node is 102. Figure 4.5 shows a program snapshot number-of-nodes and range in the short-path with random-source approach. This scenario suggest that all parameters are fixed except the number-of-nodes are changeable

Table 4.4: Simulation Results of Case 3, Varying Number of Nodes and Ranges.

Ranges	150 Nodes	200 Nodes	300 Nodes
5	42—41—40—23—10—7—119—118--103—102	105—104—103--87—102	122—105—120--103—102
10	100—101--86—71—102	57—71--87—102	136—180—132--135—102
15	66—85—71 —102	160—102	1—117--119—102
20	123--71—102	15—120—102	151—102
25	68—87--88—102	1—102	155—102
30	69—85--102	115—102	145—135—102

For example, if the number of nodes is 150 and the range is 5, then the short path is 42—41—40—23—10—7—119—118--103—102.

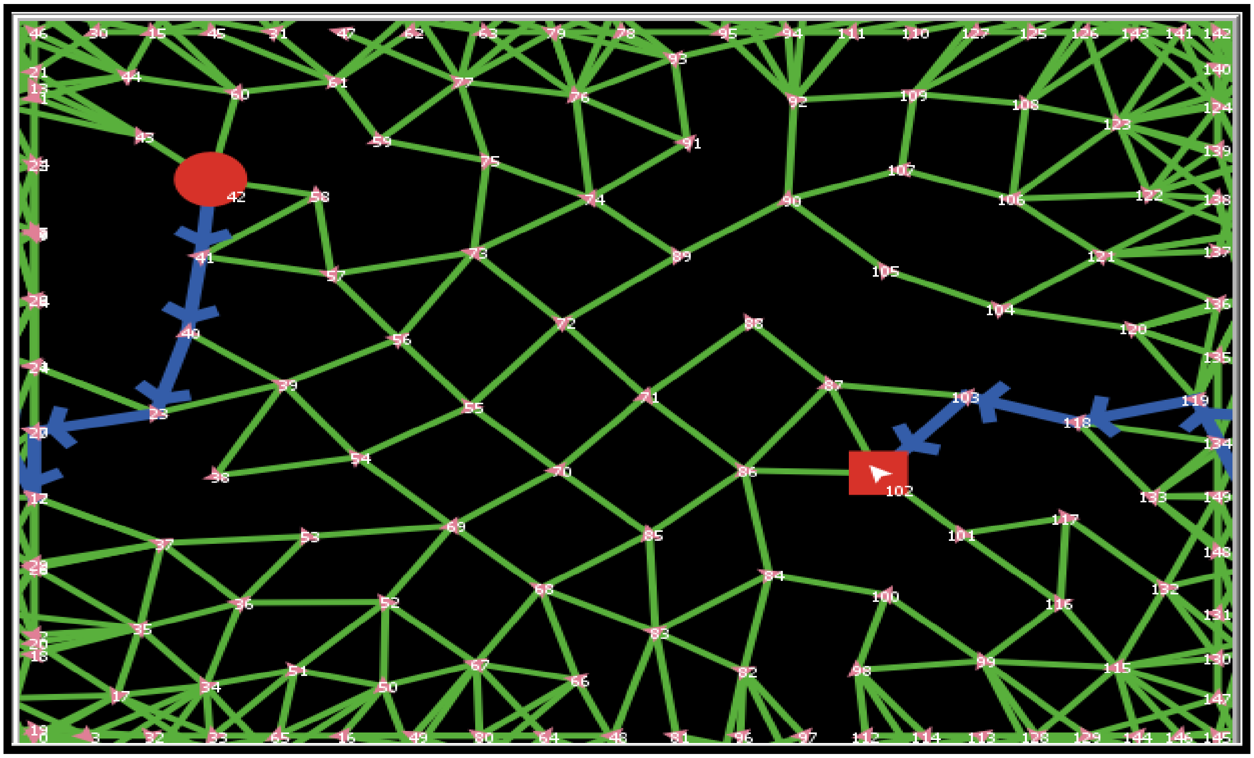

Figure 4.5: Program Snapshot 150 Number-of-Nodes and 5 Range in the Short-Path with Random-Source Approach.

4.2.6 Case 4 Result; (Shortest-Path with Random-Destination Node Approach)

The table 4.5 shows specify the simulated result with Varying number of nodes. This table contains the short path with constant source and random destination that were obtained when executing the Net Logo simulation program between the source node and the destination in different number of nodes. Using the same table 4.1, but the algorithm in this case called the short path with constant source and random destination approach, the number source node is 73 and the number destination node is random. In this case only number-of-nodes states were implemented. Figure 4.6 shows a program snapshot number-of-nodes in the short path with constant source and random destination approach. This scenario suggest that all parameters are fixed except the number-of-nodes are changeable.

Table 4.5: Simulation Results of Case 4, Varying Number of Nodes and Ranges.

Ranges	150 Nodes	200 Nodes	300 Nodes
5	73—57--58	73—89—105--106—123—124--141	73—88—104--119—135—150--166
10	73—71--105—121—103--104	73—24--6	73—264—215--200—197—183—214—199--198
15	73—15	73—48	73—71--101—68
20	73—71-- 86	73—125—158	73—151—150
25	73—120--88—123—103--106	73—88	73—45
30	73—97	73—91	73—151—181

For example, if the number of nodes is 150 and the range is 5, then the short path is 73—57—58.

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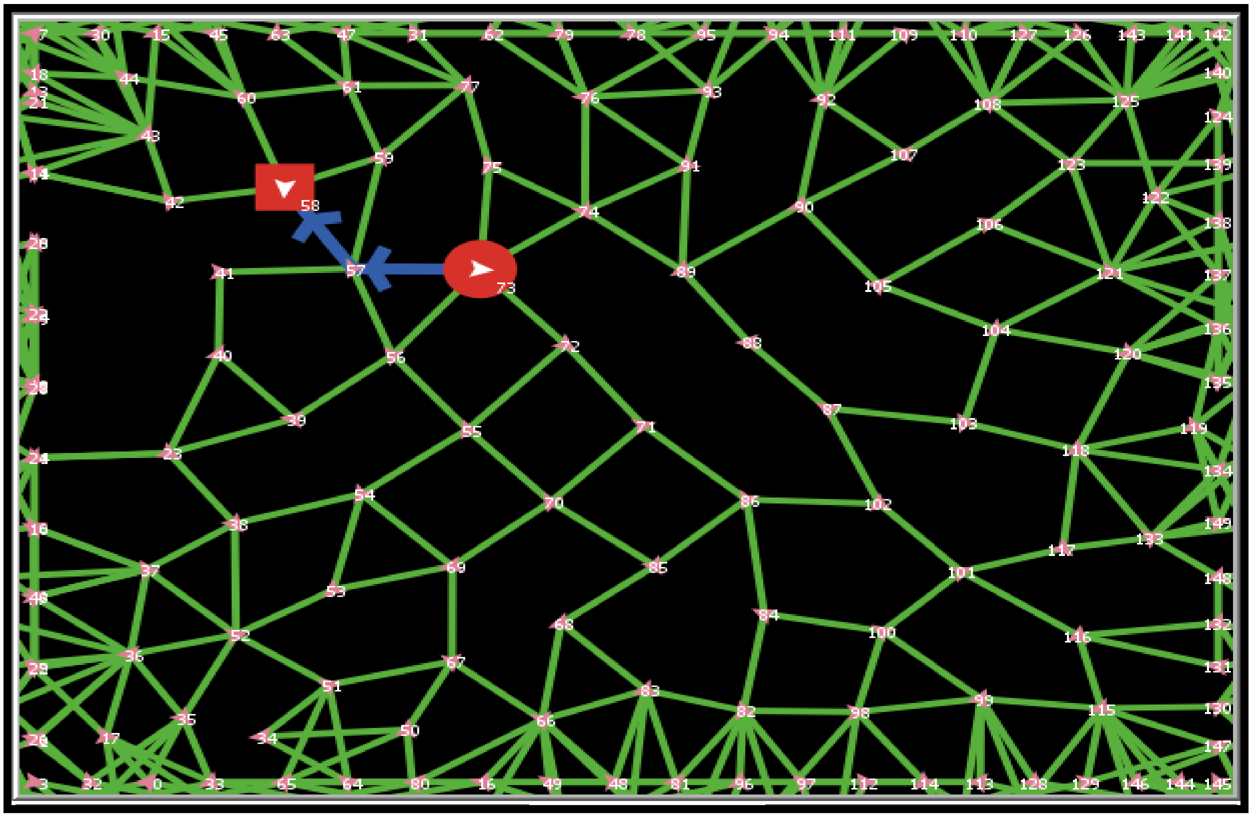

Figure 4.6: Program Snapshot 150 Number-of-Nodes and 5 Range in the Short Path with Constant Source and Random Destination Node Approach.

4.2.7 Case 5 Result; (Alternate-Path with Busy-Intermediate Nodes Approach)

Using the same table 4.1, but the algorithm in this case called the alternate-path with constant source and destination approach, the number source node is 73 and the number destination node is 102. In this case only number-of-nodes states were implemented. The table 4.6 specifies the simulated result with Varying number of ranges. This table contains the alternate-path with constant source and destination that were obtained when executing the Net Logo simulation program between the source node and the destination in different number of nodes. Figure 4.7 shows a program snapshot number-of nodes in the alternate-path with constant source and destination approach. This scenario suggest that all parameters are fixed except the number-of nodes are changeable.

Table 4.6: Simulation Results of Case 5, Varying Number of Nodes and Ranges.

Ranges	150 Nodes	200 Nodes	300 Nodes
5	73—72—71—86—102	73—88—87—102	73—88—103—102
10	73—71—102	73—88—102	73—88—134—102
15	73—87—86 —102	73—103—87--102	73—102
20	73—102	73—87—102	73—83--35—102
25	73—102	73—102	73—135—102
30	73—71—102	73—87—102	73—54—118--86—102

For example, if the number of nodes is 150 and the range is 5, then the short path is 73—72—71—86—102.

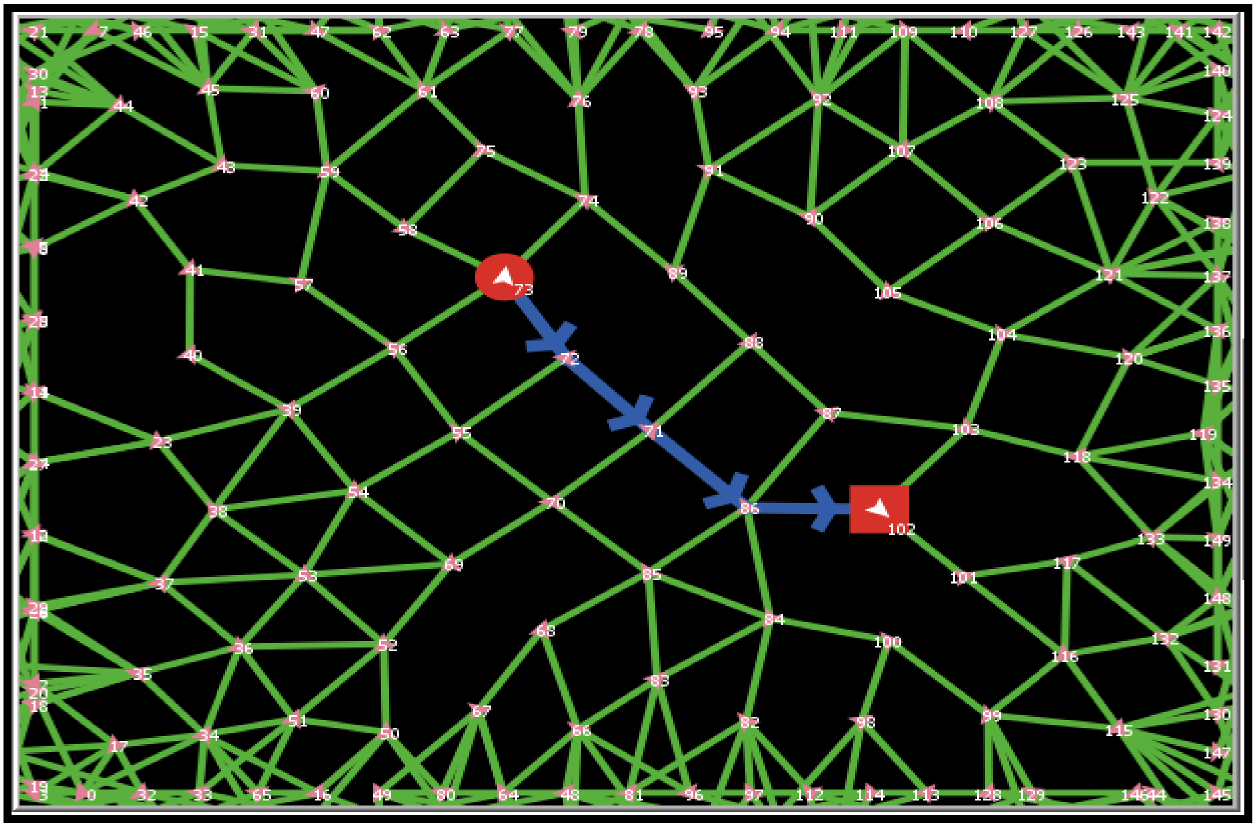

Figure 4.7: Program Snapshot 150 Number-of-Nodes and 5 Range in the Alternate-Path with Constant Source and Destination Approach.

4.2.8 Case 6 Result; (Alternate-Path Random-Source and Destination with Busy-Intermediate Nodes Approach)

The table 4.7 shows specify the simulated result with varying number of ranges. This table contains the alternate-path with random-source and destination that were obtained when executing the Net Logo simulation program between the source node and the destination in different number of nodes. Using the same table 4.1, but the algorithm in this case called the alternate-path with random-source and destination approach, the number source node is random and the number destination node is random. In this case only number-of-nodes states were implemented. Figure 4.8 shows a program snapshot number-of nodes in the alternate-path with random-source and destination approach. This scenario suggest that all parameters are fixed except the number-of nodes are changeable.

Table 4.7: Simulation Results of Case 6, Varying Number of Nodes and Ranges.

Ranges	150 Nodes	200 Nodes	300 Nodes
5	64--49	22 -- 183	268—128-- 211
10	126—100-- 85	77—126—114—166—159	125—121—88-- 55
15	26 -- 69 -- 23	170—73—77—105--109	274-- 205-- 211
20	113 -- 71 -- 68	71--137	104—180—166-- 182
25	71 -- 40	34—76--43	199-- 135
30	54 -- 71 -- 88	196 -- 120 -- 108	267 -- 149 -- 125

For example, if the number of nodes is 150 and the range is 5, then the short path is 64--49.

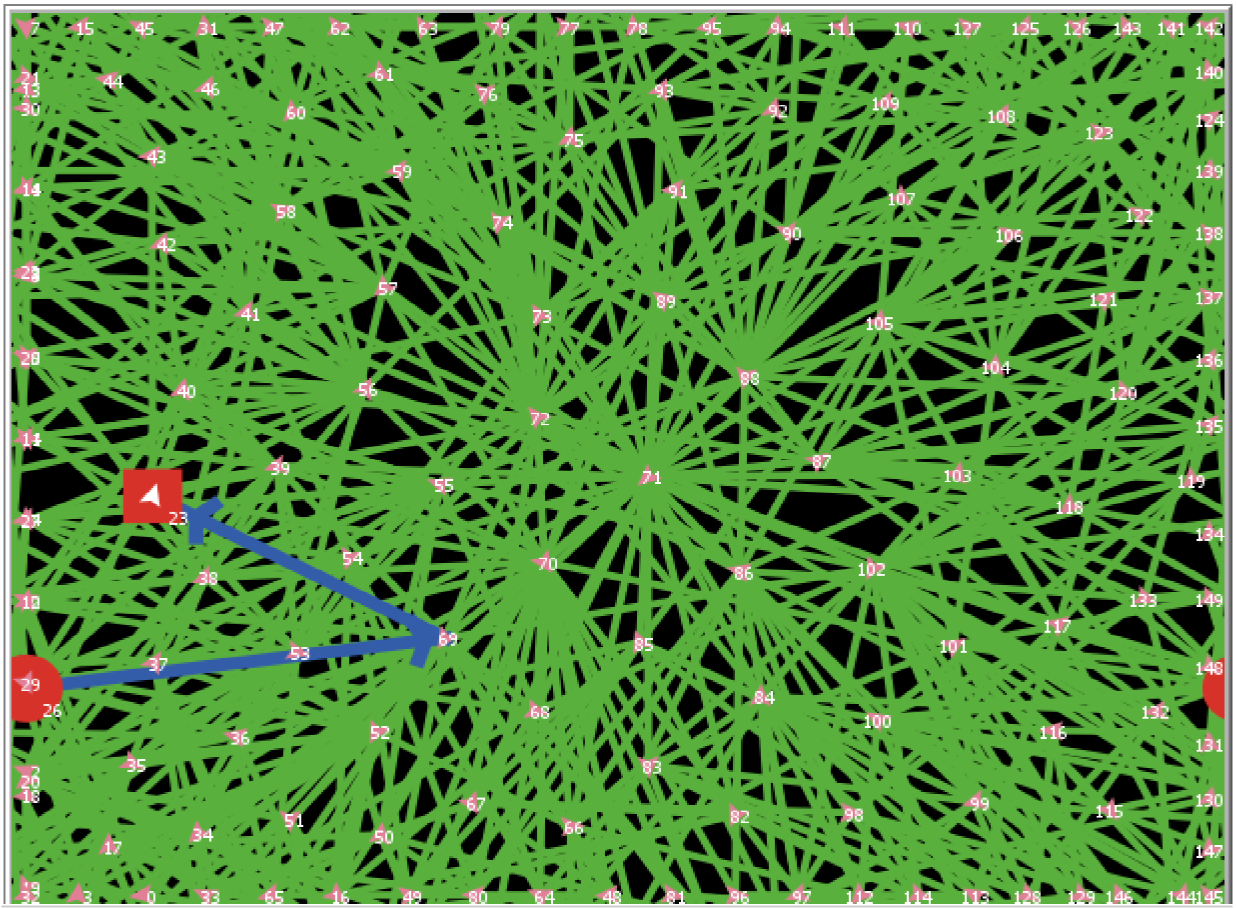

Figure 4.8: Program Snapshot 150 Number-of-Nodes and 15 Range in the Alternate-Path with Random-Source and Destination Approach.

4.2.9 Four Sectoring Approaches

A. Case 7 Result; (Four Sectoring with Random-Destination-Node Approach)

Using the same table 4.1, but the algorithm in this case called the four sectoring with approach, all neighbor nodes in destination coverage area represents the number source node**,** the number destination node is random, the range is 8m and the number of nodes is 149. The first step comprises of 149 number-of-nodes distributed in net logo environment. then select the transmission range is 8m. Press button create-wireless-mesh-network. the last step is press button four sectoring with random- destination-node. Figure 4.9 shows a program snapshot 149 number-of-nodes and 8 range in the four sectoring with random-destination-node approach.

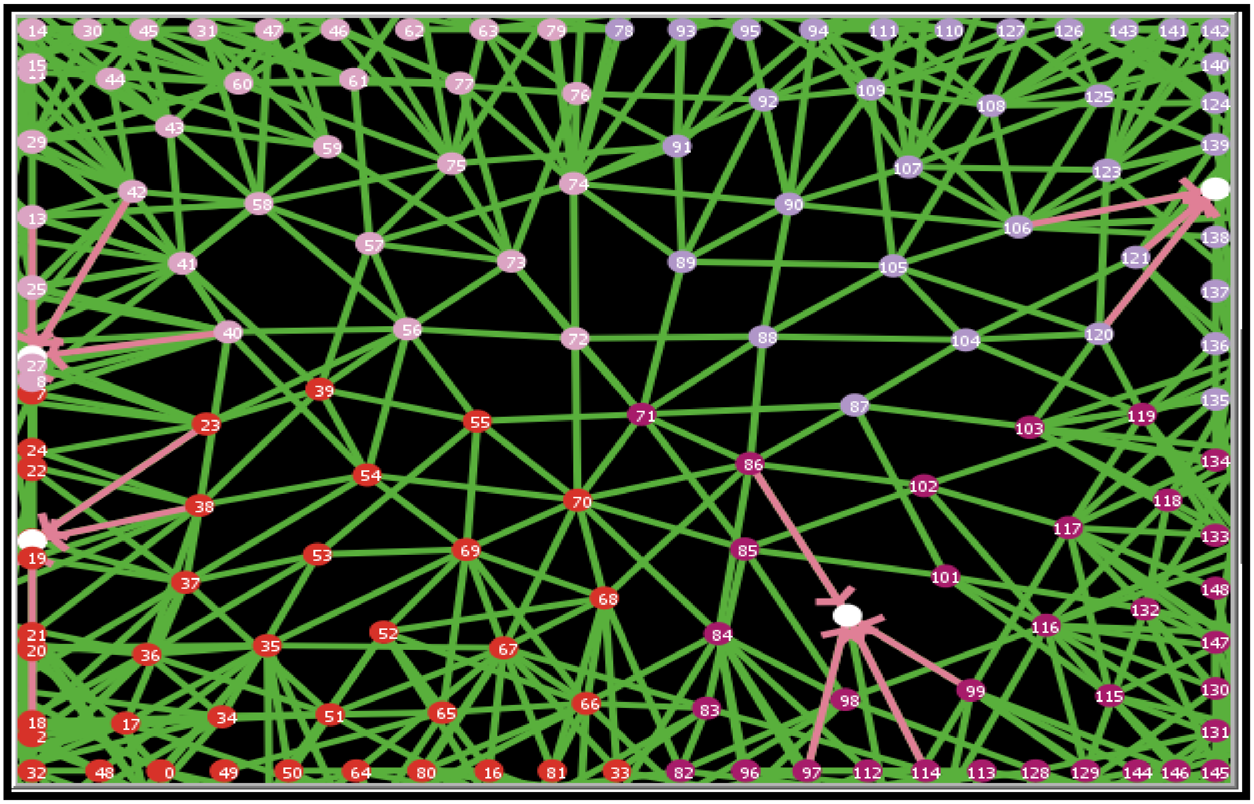

Figure 4.9: Program Snapshot 149 Number-of-Nodes and 8 Range in the Four Sectoring with Random-Destination-Node Approach.

B. Case 8 Result; (Four Sectoring with Center-Node Approach)

The same table 4.1, the algorithm in this case called the four sectoring with center-node approach, three of neighbor nodes in destination coverage area represents the number source node**,** the number destination node is center node (71), the range is 8m and the number of nodes is 149. The first step comprises of 149 number-of-nodes distributed in net logo environment. then select the transmission range is 8m. press button create-wireless-mesh-network. the last step is press button four sectoring with center node. Figure 4.10 shows a program snapshot 149 number-of-nodes and 8 range in the four sectoring with center node approach.

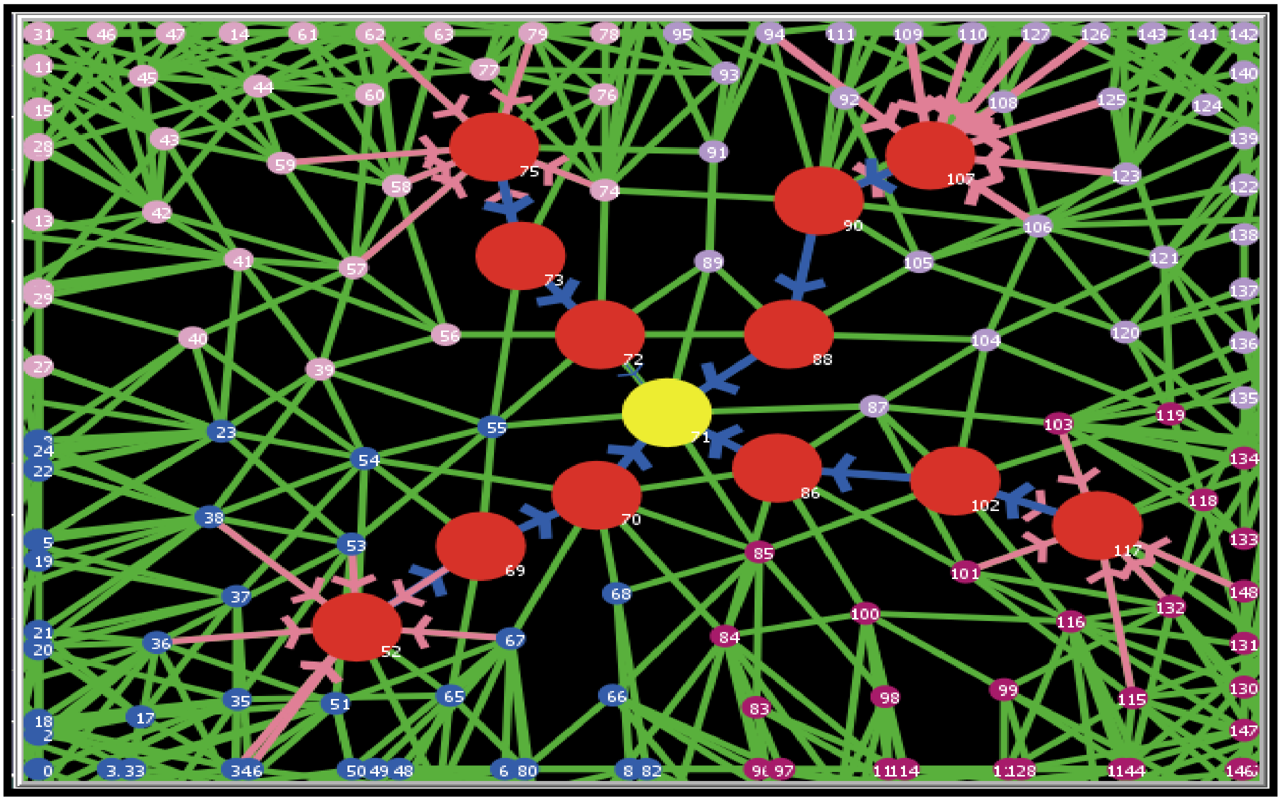

Figure 4.10: Program Snapshot 149 Number-of-Nodes and 8 Range in the Four Sectoring with Center-Node Approach.

C. Case 9 Result; (Four Sectoring with Close-Center-Node Approach)

The first step comprises of 149 number-of-nodes distributed in net logo environment. then select the transmission range is 8m. press button create-wireless-mesh-network. the last step is press button four sectoring with close-center node. Using the same table 4.1, the algorithm in this case called the four sectoring with center-node approach, one of neighbor nodes in destination coverage area represents the number source node**,** the number destination node is center node (71), the range is 8m and the number of nodes is 149. Figure 4.11

shows a program snapshot 149 number-of-nodes and 8 range the four sectoring with close-center-node approach.

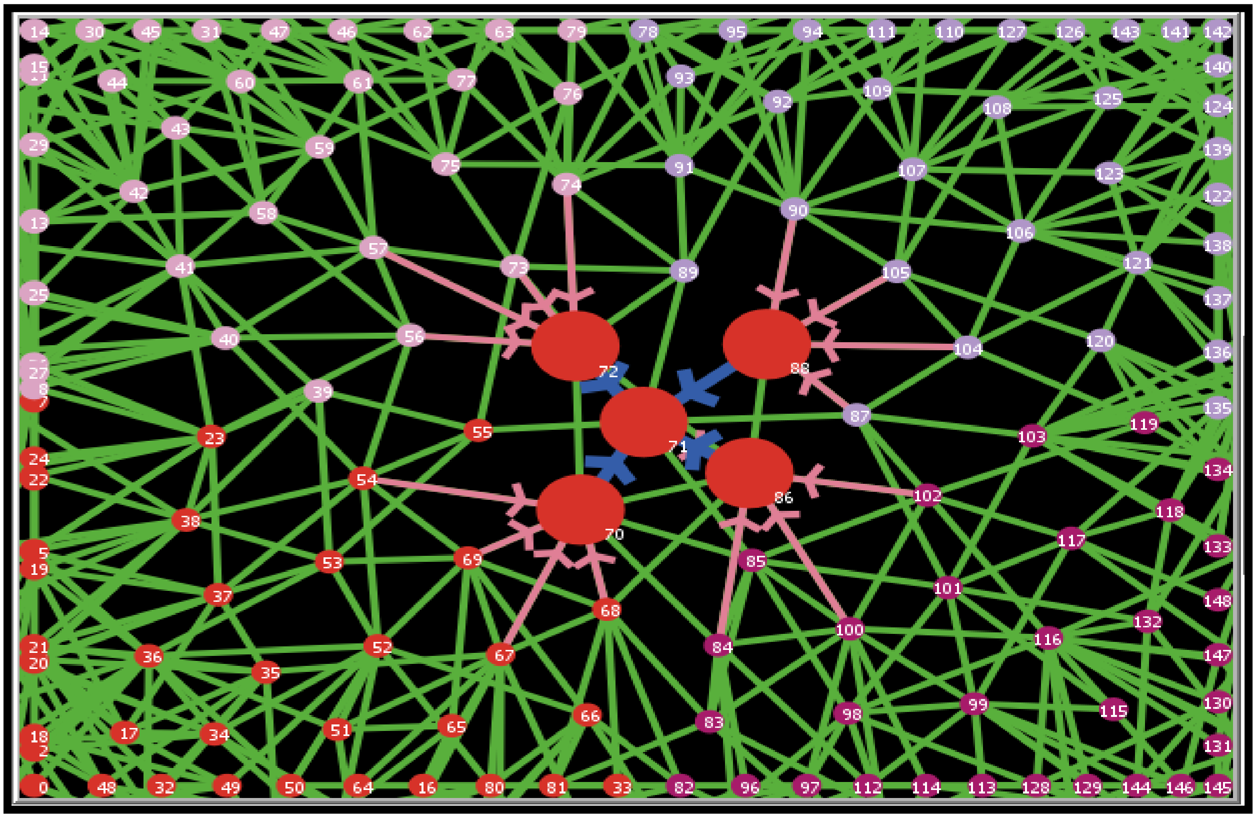

Figure 4.11: Program Snapshot 149 Number-of-Nodes and 8 Range in the Four Sectoring with Close-Center-Node Approach.

Comparison among four sectoring approaches in figure 4.12 shows in A:an example of four sectoring with random-destination-node approach. B: example of four sectoring with center-node approach. C: example of four sectoring with close-center-node approach. The four-sectoring approach is useful in the event that the environment is divided into sections so that each approach has its own work and form. The method of sending messages depends on the approach used.

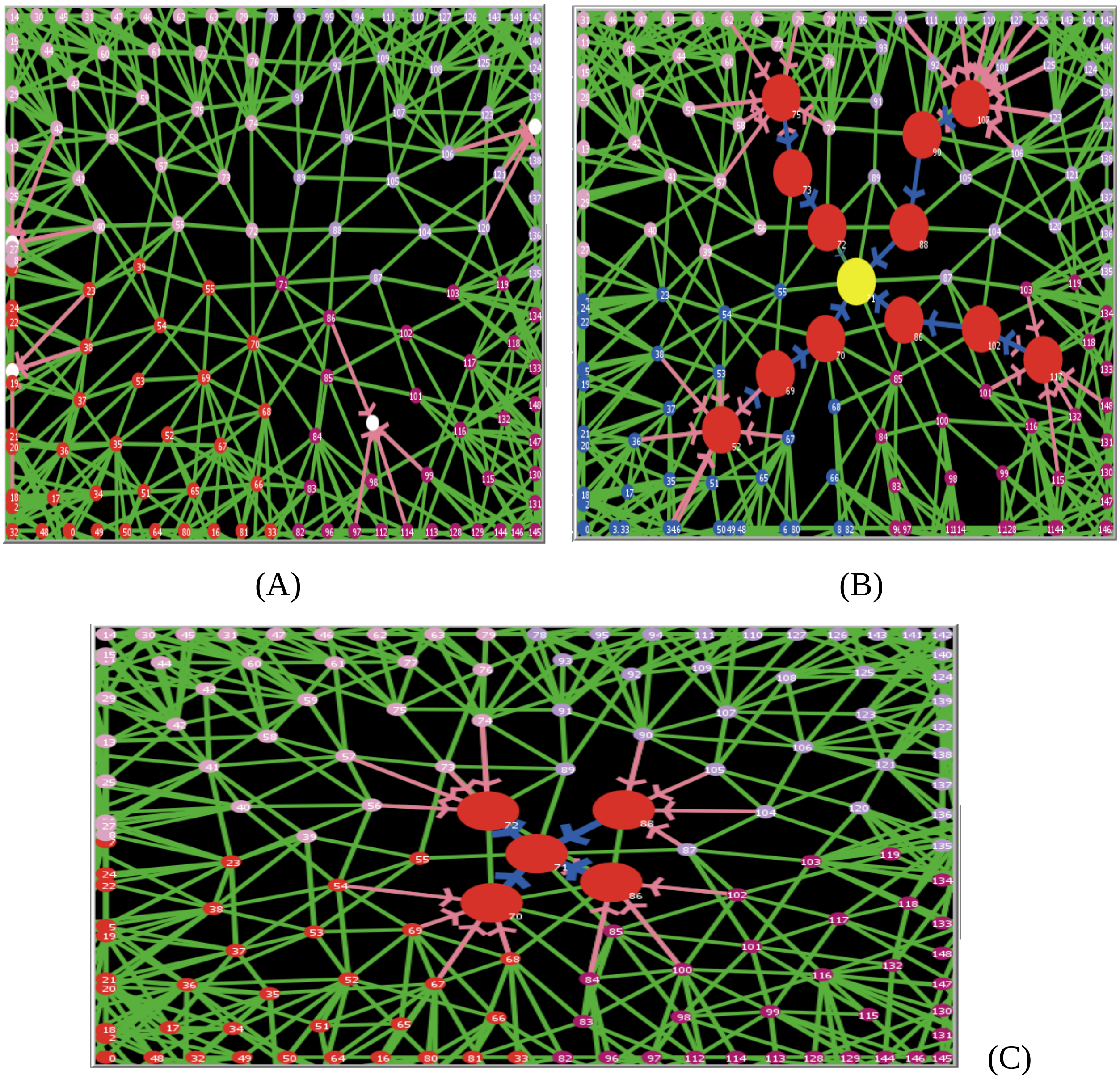

Figure 4.12: Comparison Among Four Sectoring Approaches.

4.3 Performance Metrics Result

For display the information about each metric in state varying number-of-nodes and range, will implement the network metrics in three cases.

4.3.1 Throughput

The table 4.8 show the result of throughput in three cases and number-of-nodes. All the following tables contain the results that were obtained when implementing three of the approaches (short-path approach, short-path with random-destination approach, alternate-path with busy node approach) with different number of nodes in Behavior Space in the simulation program Net-Logo. Figure 4.13 shows the throughput values with different number-of-nodes and ranges in three cases.

Table 4.8: Throughput Values with Different Number-of-Nodes and Ranges.

	Throughput					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	3,500	3,500	3,500	3,500	3,500	3,500
200	3,500	3,500	3,500	3,500	3,500	3,500
300	3,500	3,500	3,500	3,500	3,500	3,500

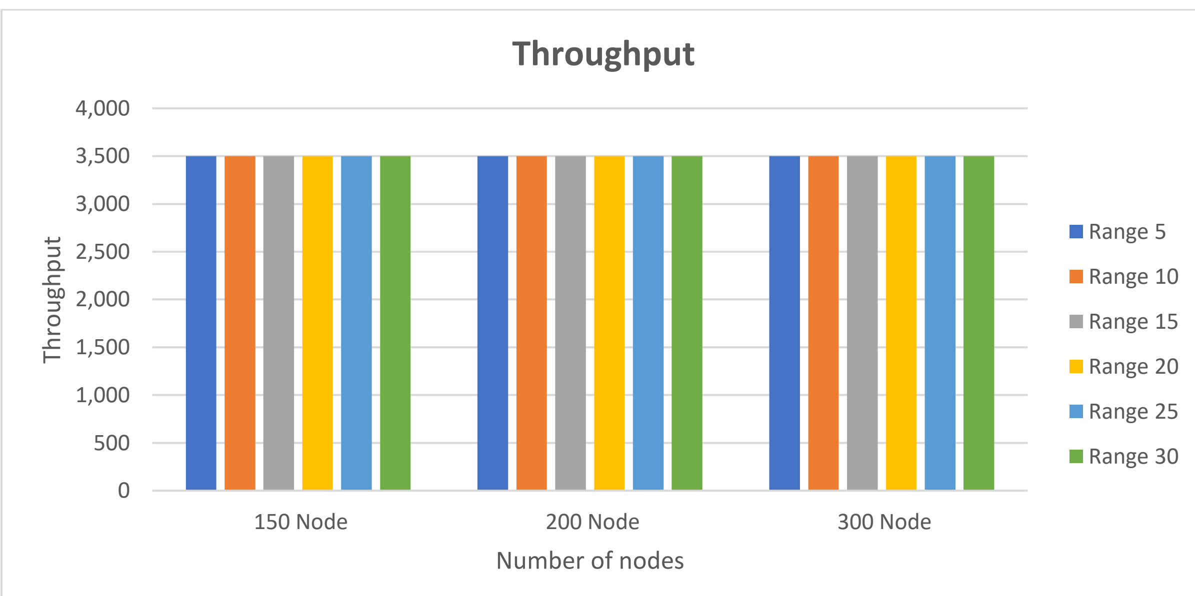

Figure 4.13: Throughput Values with Different Number-of-Nodes and Ranges.

Figure 4.13 displays that the throughput in the best at all nodes. The implement results the throughput in the three cases (short-path approach, short-path with random-destination approach, alternate-path with busy node approach). The figure 4.13 are the result of using the Eq.2.8 in the simulation program net-logo.

4.3.2 End-To-End Delay

The table 4.9 shows the result of end-to-end values with different number-of-nodes and ranges in three cases.

Table 4.9: End-To-End Delay Values with Different Number-of-Nodes and Ranges.

	End-To-End Delay					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	0.004	0.004	0.004	0.004	0.004	0.004
200	0.004	0.004	0.004	0.004	0.004	0.004
300	0.004	0.004	0.004	0.004	0.004	0.004

Table 4.9 displays that the end-to-end delay in all nodes is the best at all ranges. The table 4.9 shows the result of using the Eq.2.9 in the simulation net-logo program.

4.3.3 Packet Delivery Ratio (PDR)

The table 4.10 shows the result of PDR in three cases and number-of-nodes. Figure 4.14 shows the PDR values with different number-of-nodes and ranges in three cases.

Table 4.10: PDR Values with Different Number-of-Nodes and Ranges.

	Packet Delivery Ratio (PDR) %					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	100	100	100	100	100	100
200	100	100	100	100	100	100
300	100	100	100	100	100	100

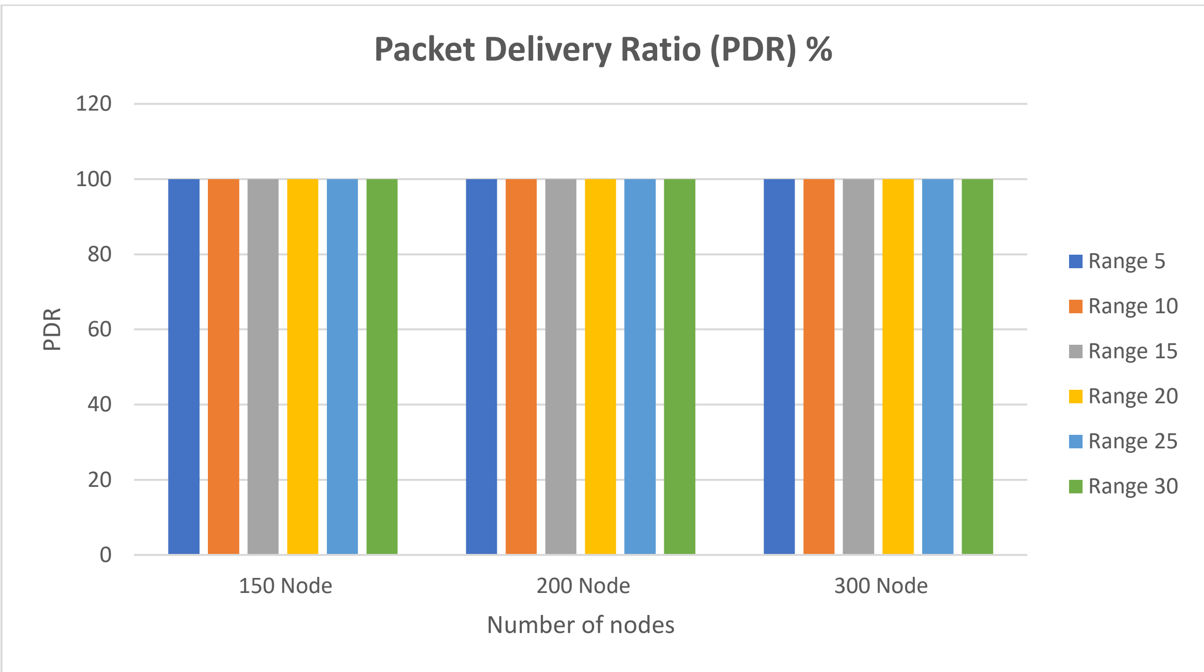

Figure 4.14: PDR in Three Cases and Number-of-Nodes and Ranges.

Figure 4.14 displays that the PDR in all nodes is the best at all ranges. The figure 4.14 shows the results of using the Eq.2.10 in the simulation net-logo program.

4.3.4 Normal Routing Load (NRL)

The table 4.11 shows the result of NRL in three cases and number-of-nodes. Figure 4.15 shows the NRL values with different number-of-nodes and ranges in three cases.

Table 4.11: NRL Values with Different Number-of-Nodes and Ranges.

	Normal Routing Load (NRL)					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	1	1	1	1	1	1
200	1	1	1	1	1	1
300	1	1	1	1	1	1

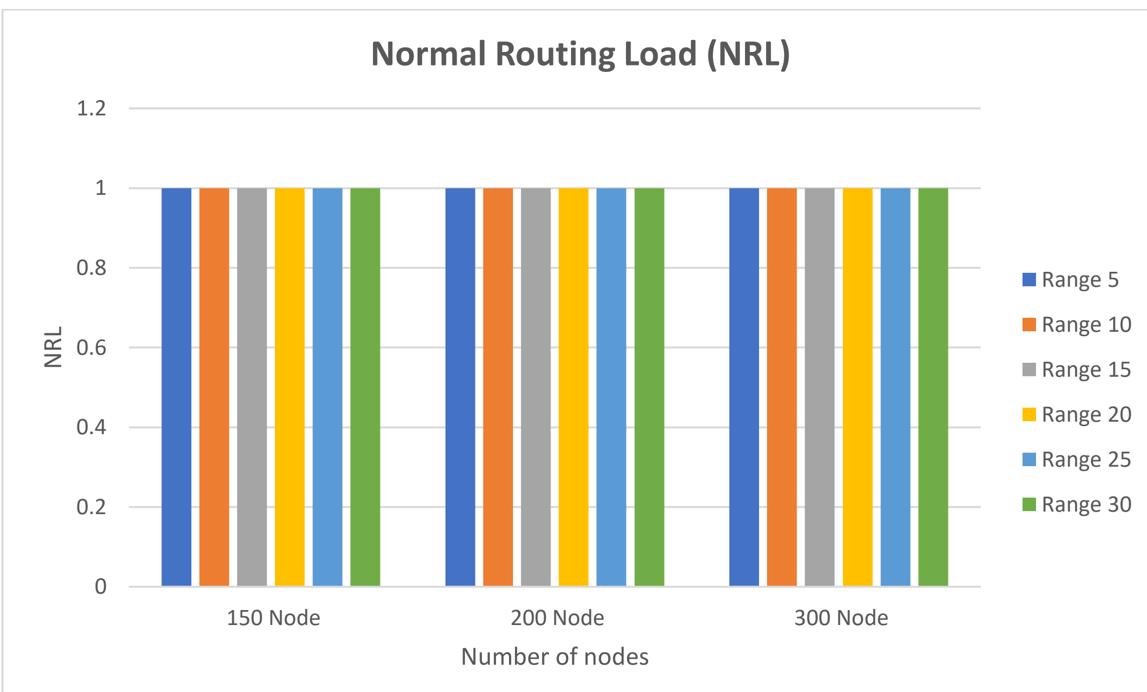

Figure 4.15: NRL in Three Cases and Number-of-Nodes and Ranges.

Figure 4.15 displays that the NRL in all nodes is the best at all ranges. The figure 4.15 shows the results of using the Eq.2.11 in the simulation net-logo program.

4.3.5 Load Balancing Efficiency (LBE)

The table 4.12 shows the result of Load-Balancing in three cases and number-of-nodes. Figure 4.16 shows the Load-Balancing values with different number-of-nodes and ranges in three cases.

Table 4.12: Load-Balancing Values with Different Number-of-Nodes and Ranges.

	Load Balancing Efficiency (LB) %					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	0.5	0.5	0.5	0.5	0.5	0.5
200	0.6	0.6	0.6	0.6	0.6	0.6
300	1	1	1	1	1	1

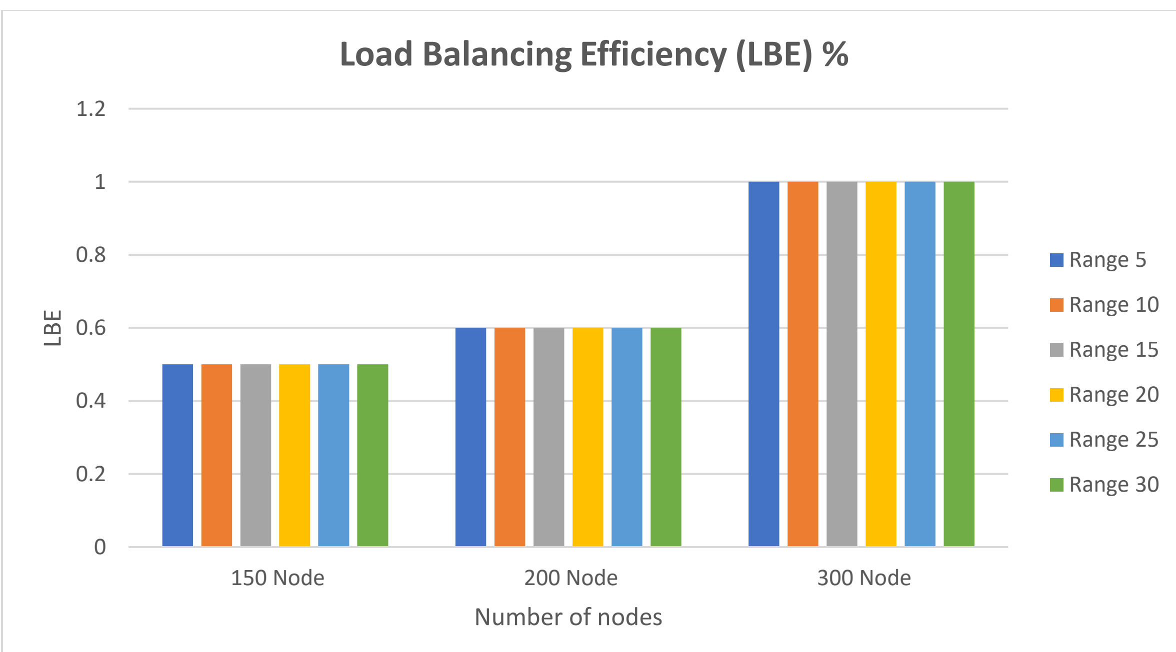

Figure 4.16: Load-Balancing in Three Cases and Number-of-Nodes and Ranges.

Figure 4.16 displays that the Load-Balancing in 300 node is the best at all ranges. The figure 4.16 shows the results of using the Eq.2.12 in the simulation net-logo program.

4.3.6 Quality of Services (QoS)

The table 4.13 shows the result of QoS in three cases and number-of-nodes. Figure 4.17 shows the QoS values with different number-of-nodes and ranges in three cases.

Table 4.13: QoS Values with Different Number-of-Nodes and Ranges.

	Quality of Services (QoS)					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	99.996	99.996	99.996	99.996	99.996	99.996
200	99.996	99.996	99.996	99.996	99.996	99.996
300	99.996	99.996	99.996	99.996	99.996	99.996

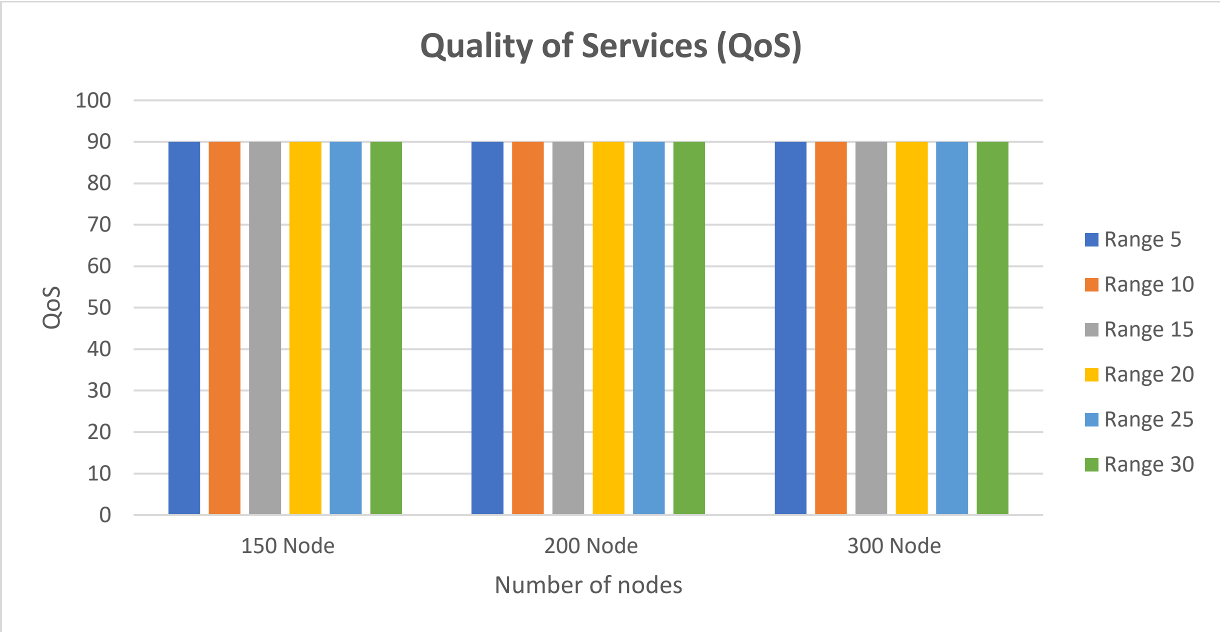

Figure 4.17: QoS in Three Cases and Number-of-Nodes and Ranges.

Figure 4.17 displays that the QoS in 150, 200, 300 node is the best at all ranges. The figure 4.17 shows the results of using the Eq.2.15 in the net-logo program.

4.3.7 Target Coverage (TC)

The table 4.14 shows the result of TC in three cases and number-of-nodes. Figure 4.18 shows the TC values with different number-of-nodes and ranges in three cases.

Table 4.14: TC Values with Different Number-of-Nodes and Ranges.

	Target Coverage (TC)					
No. of Nodes	**Ranges 5**	**Ranges 10**	**Ranges 15**	**Ranges 20**	**Ranges 25**	**Ranges 30**
150	13	13.52	18	23	24	25
200	14	14.61	19	24	25	26
300	15	15.71	20	25	26	27

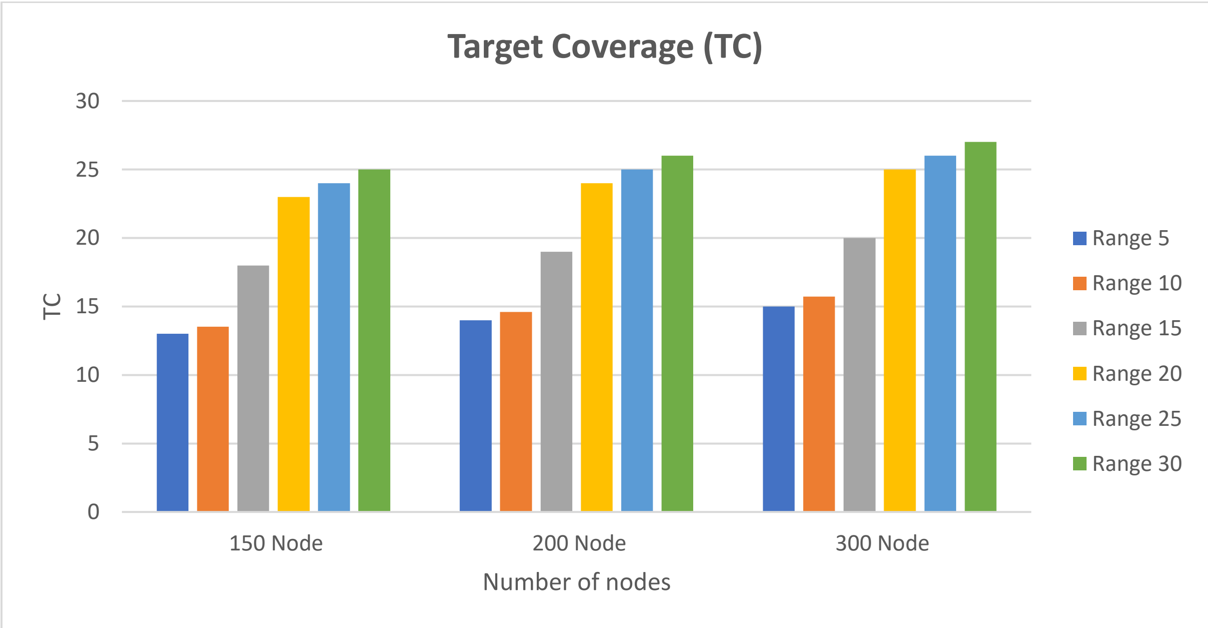

Figure 4.18: TC in Three Cases and Number-of-Nodes and Ranges.

Figure 4.18 displays that the TC in 300 node is the best at range (25, 30). The figure 4.18 shows the results of using the Eq.2.14 in the net-logo program.

4.4 Optimization Techniques

4.4.1 Calculate the Number-of Links Result

Using the same table 4.1, but the algorithm in this case called calculate the number-of links, the number source node is 73 and the number destination node is 102. The table 4.15 shows specify the built environment for varying number of nodes to be simulated result below various parameters. This table contains the results of the number of links obtained when executing a different number of nodes in the Net-Logo program. This table has been implemented in Excel to obtain the following diagrams and also to obtain equations that allow the programmer to know the number of links without using the Net-Logo program. Figure 4.19-4.26 shows number-of-nodes and equation in each range for calculate the number-of links.

Table 4.15: Simulation Result of Calculate the Number-of Links, Varying Number of Nodes and Ranges.

	Calculate the Number-of Links					
No. of Nodes	**5**	**10**	**15**	**20**	**25**	**30**
25	90	140	200	310	410	510
50	221	2012	2299	4888	11811	25062
75	375	3936	13015	60525	90834	99879
100	482	4954	25015	79525	190834	295879
150	582	6954	79737	89525	290834	397879
200	682	7978	89887	190525	490834	597879
300	1867	9978	99897	290735	590954	699899

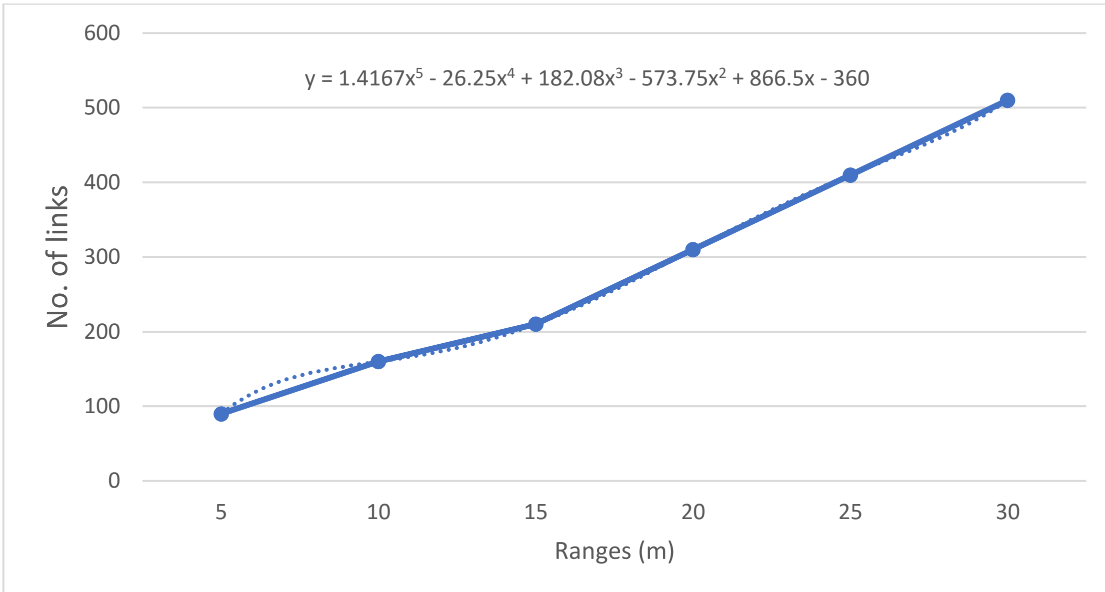

Figure 4.19: Regression model of the Number-of Links with Range for 25 Nodes.

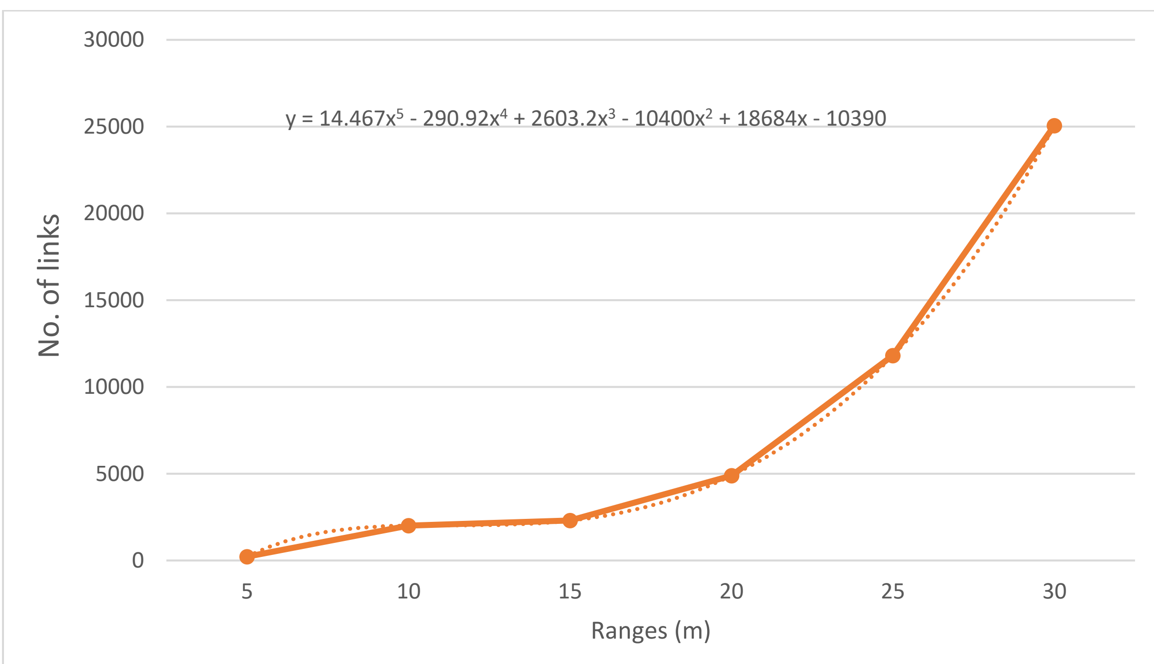

Figure 4.20: Regression model of the Number-of Links with Range for 50 Nodes.

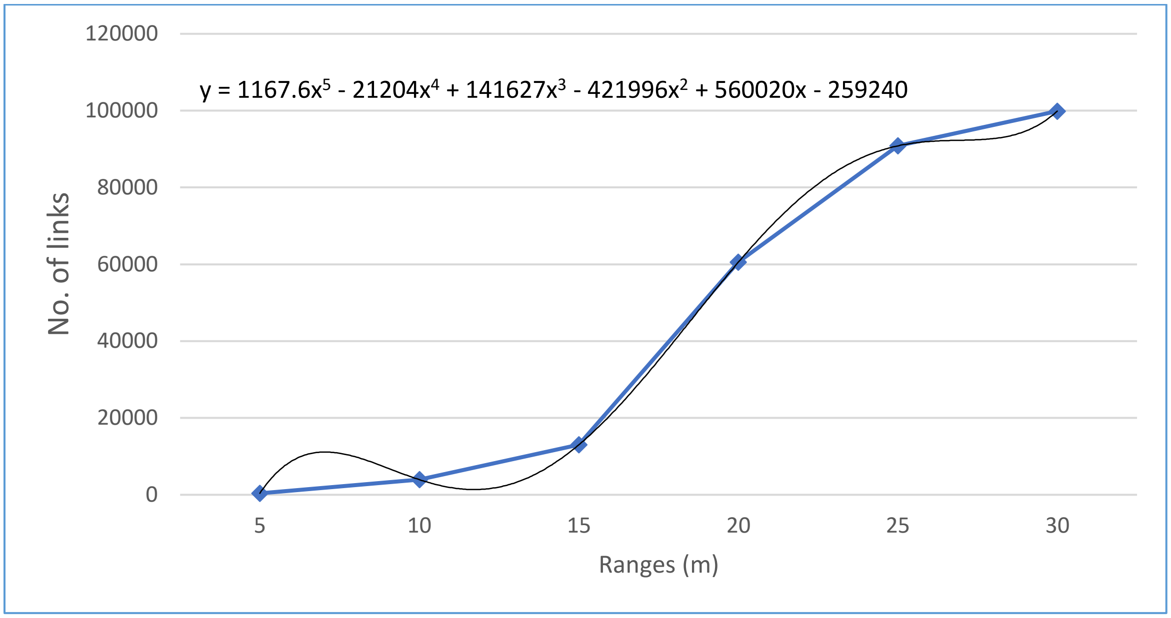

Figure 4.21: Regression model of the Number-of Links with Range for 75 Nodes.

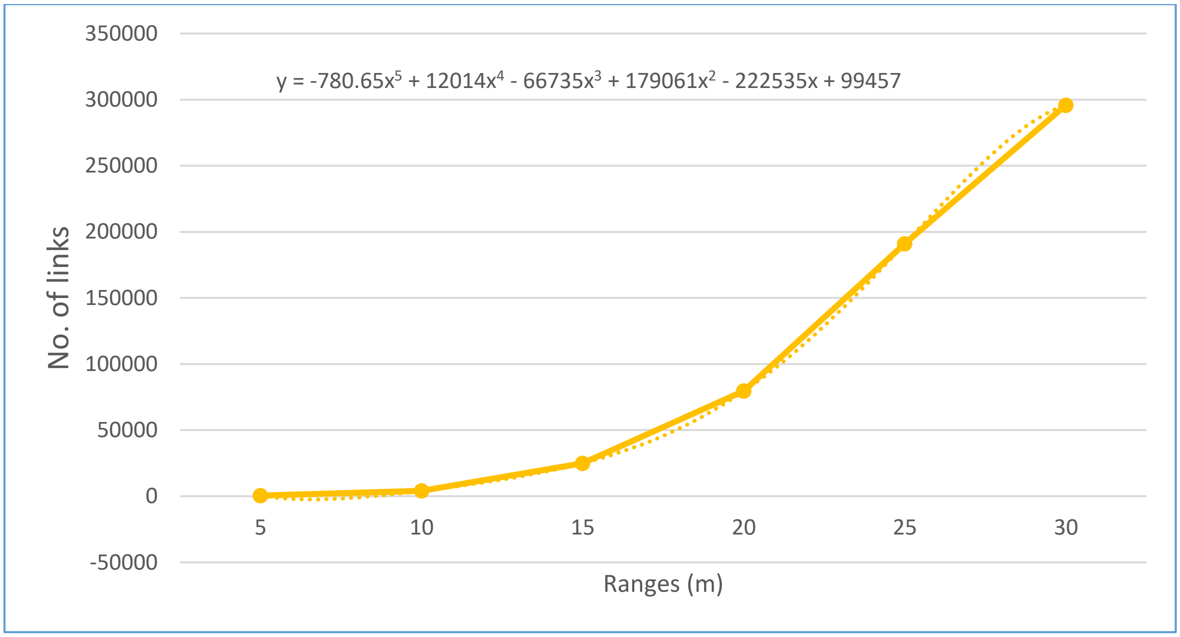

Figure 4.22: Regression model of the Number-of Links with Range for 100 Nodes.

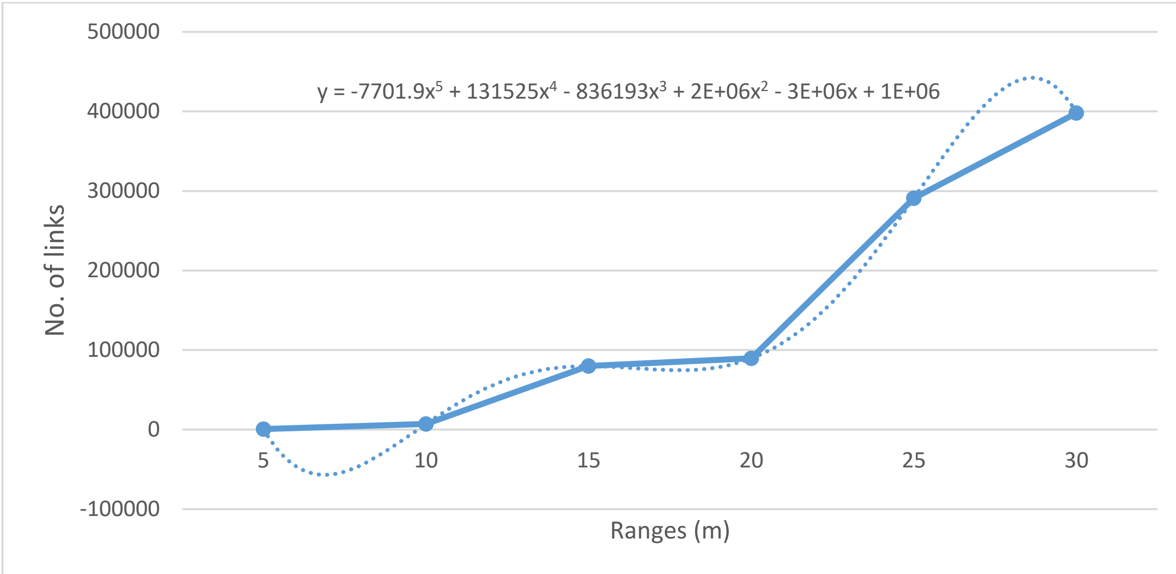

Figure 4.23: Regression model of the Number-of Links with Range for 150 Nodes.

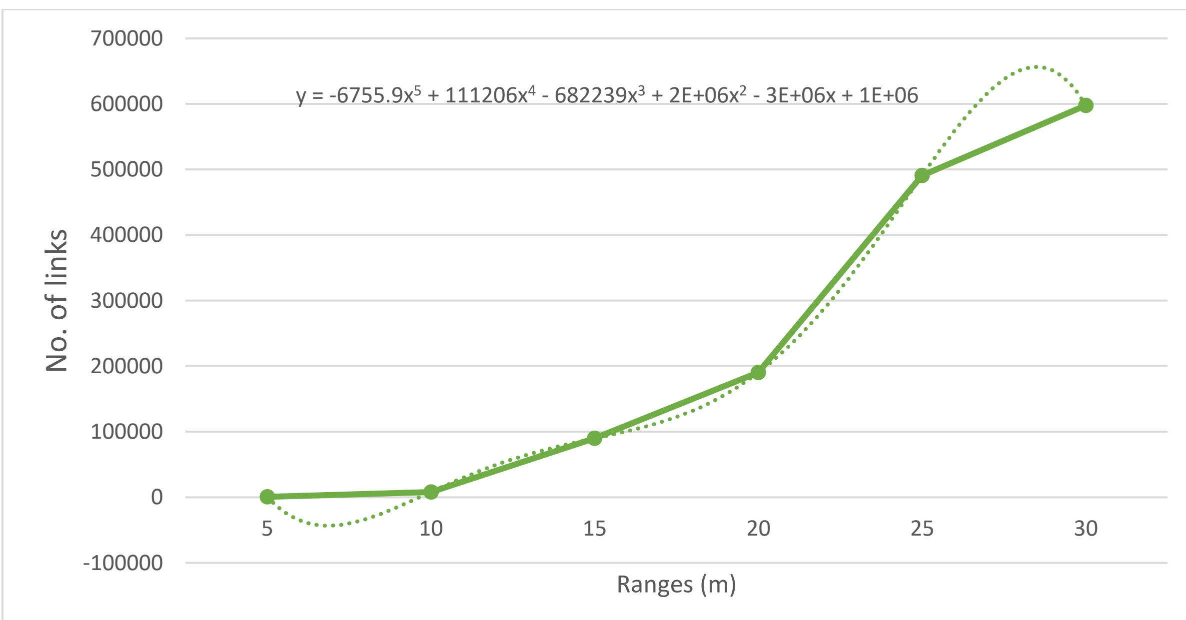

Figure 4.24: Regression model of the Number-of Links with Range for 200 Nodes.

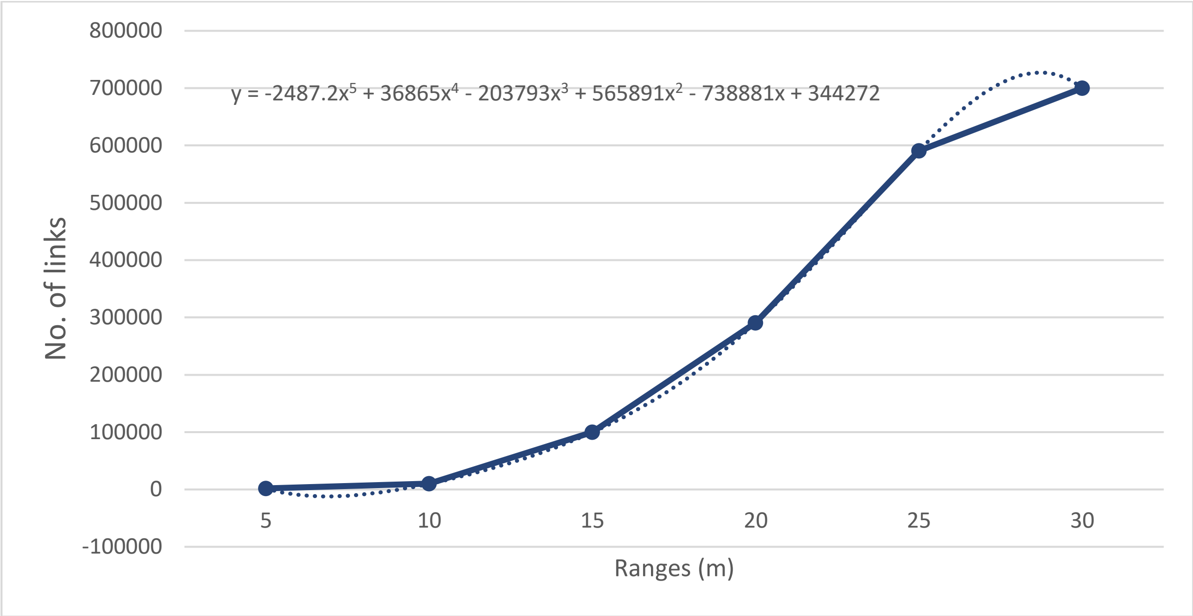

Figure 4.25: Regression model of the Number-of Links with Range for 300 Nodes.

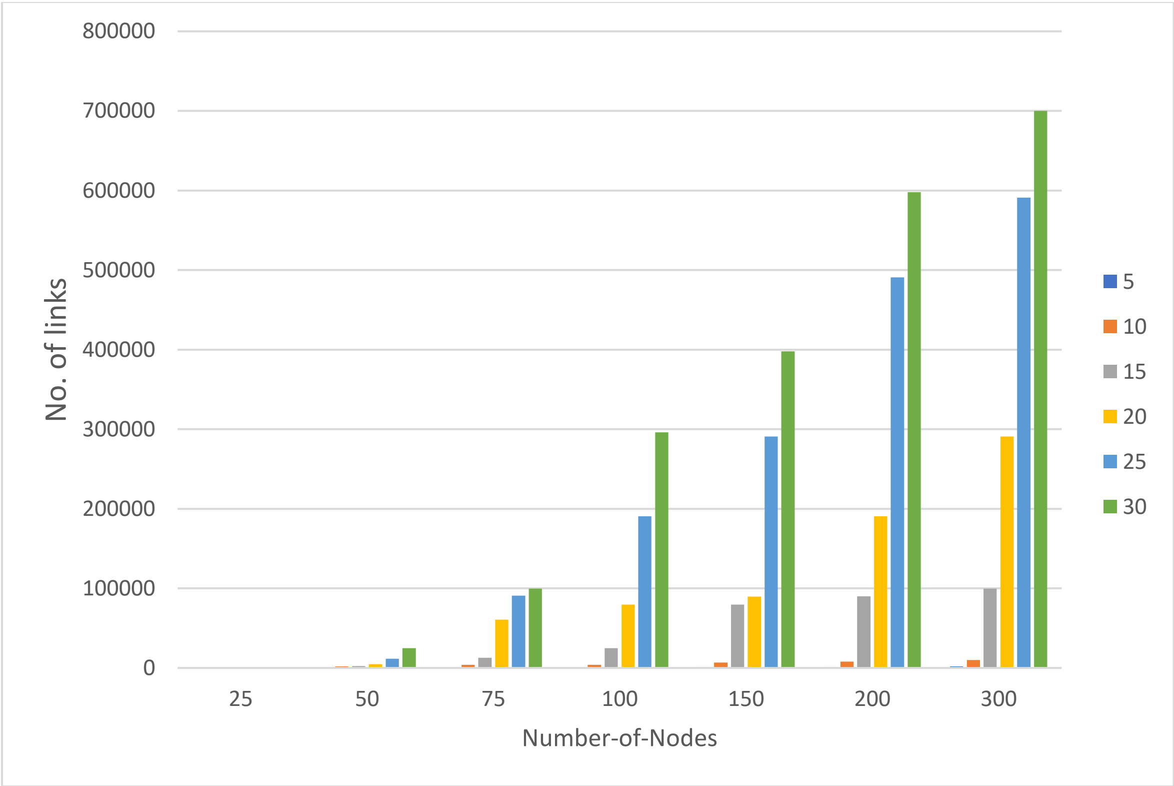

Figure 4.26: Regression model of the Number-of Links with all Ranges and all Nodes.

Figure 4.26 represents the number of links with the different number-of nodes (25, 50, 75, 100, 150, 150, 200, 300).

To apply one of the equations, we will use the equation in the figure 4.26 and substitute the value of one in it,

$$\mathbf{y = -124.4x^5 + 2070.7x^4 - 12588x^3 + 34881x^2 - 42620x + 18468} \qquad \mathbf{(4.1)}$$

y = -124.4 (5) ^5 + 2070.7 (5) ^4 - 12588 (5) ^3 + 34881 (5) ^2 - 42620 (5) ^1 + 18468 = 87

For example, the number 87 in table 4.19 represents the number of links when the number of nodes is 25 and the range is 5.

The table 4.16 shows specify the built environment for varying number-of ranges to be simulated result below various parameters. This table contains the results of the number of links obtained when executing a different number of ranges in the Net-Logo program. This table has been implemented in Excel to obtain the following diagrams and also to obtain equations that allow the programmer to know the number of links without using the Net-Logo program. Figure 4.27-4.33 shows number-of ranges and equation in each number-of nodes for calculate the number-of links.

Table 4.16: Simulation Result of Calculate the Number-of Links, Varying Number-of Ranges.

	Calculate the Number-of Links						
Ranges	**25**	**50**	**75**	**100**	**150**	**200**	**300**
5	90	221	375	482	582	682	1867
10	140	2012	3936	4954	6954	7978	9978
15	200	2299	13015	25015	79737	89887	99897
20	310	4888	60525	79525	89525	190525	290735
25	410	11811	90834	190834	290834	490834	590954
30	510	25062	99879	295879	397879	597879	699899

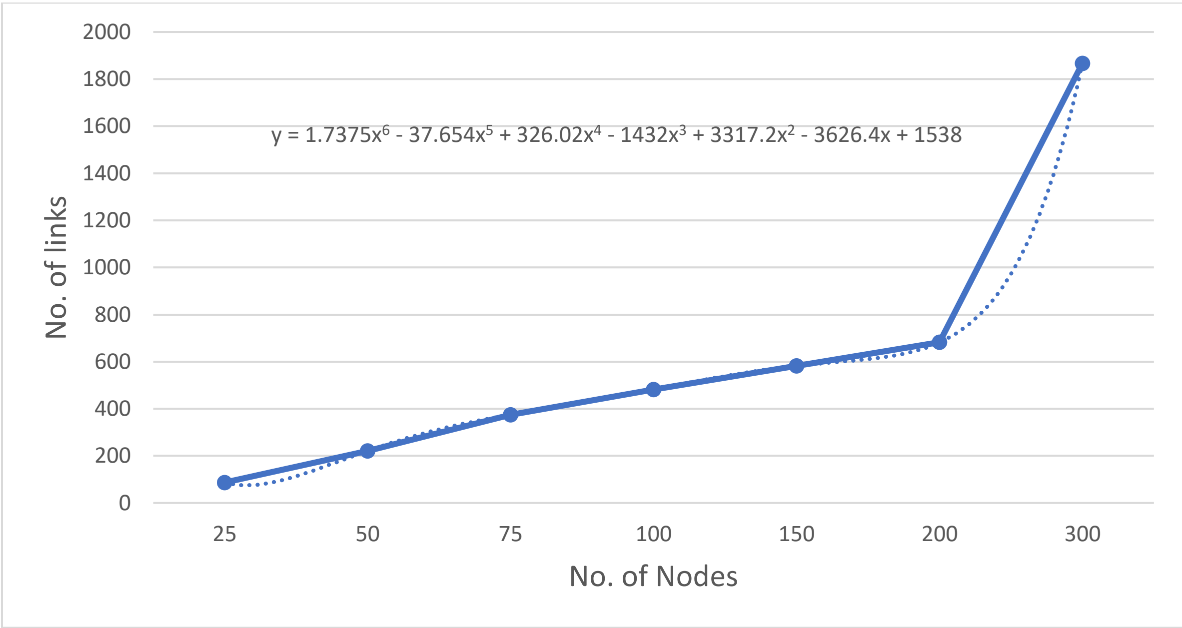

Figure 4.27: Regression model of the Number-of Links with Node for 5 Ranges.

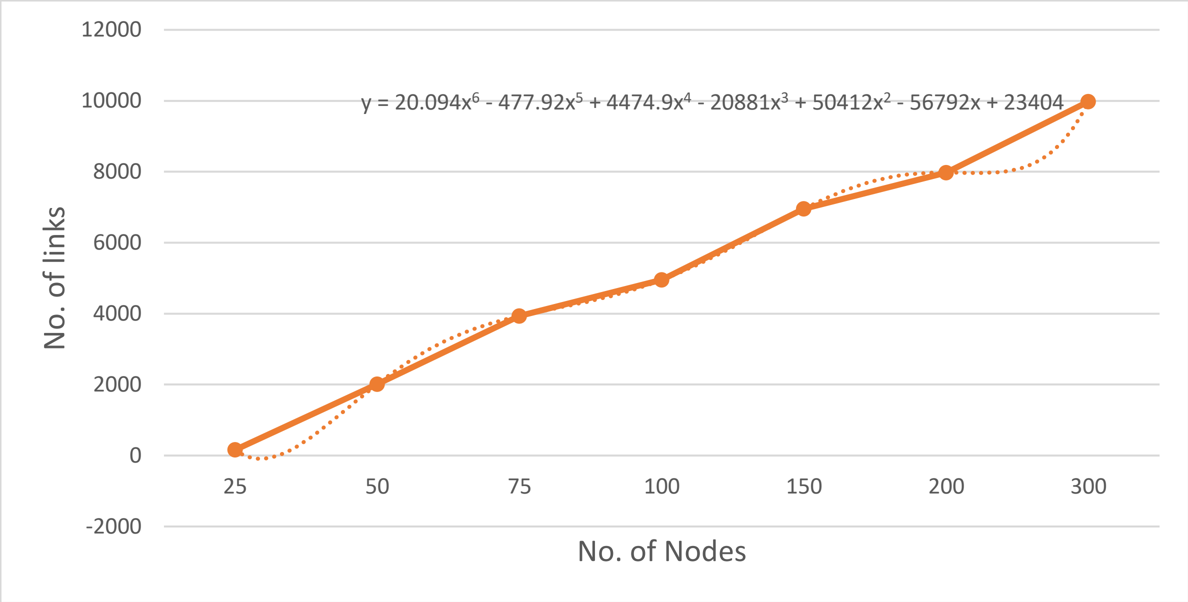

Figure 4.28: Regression model of the Number-of Links with Node for 10 Ranges.

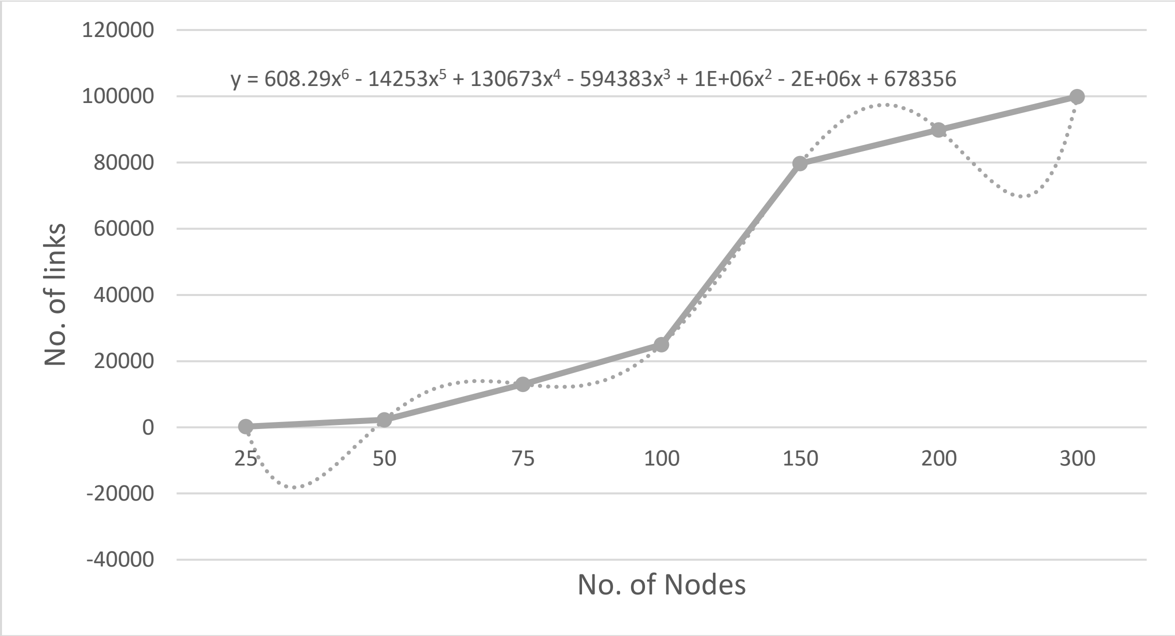

Figure 4.29: Regression model of the Number-of Links with Node for 15 Ranges.

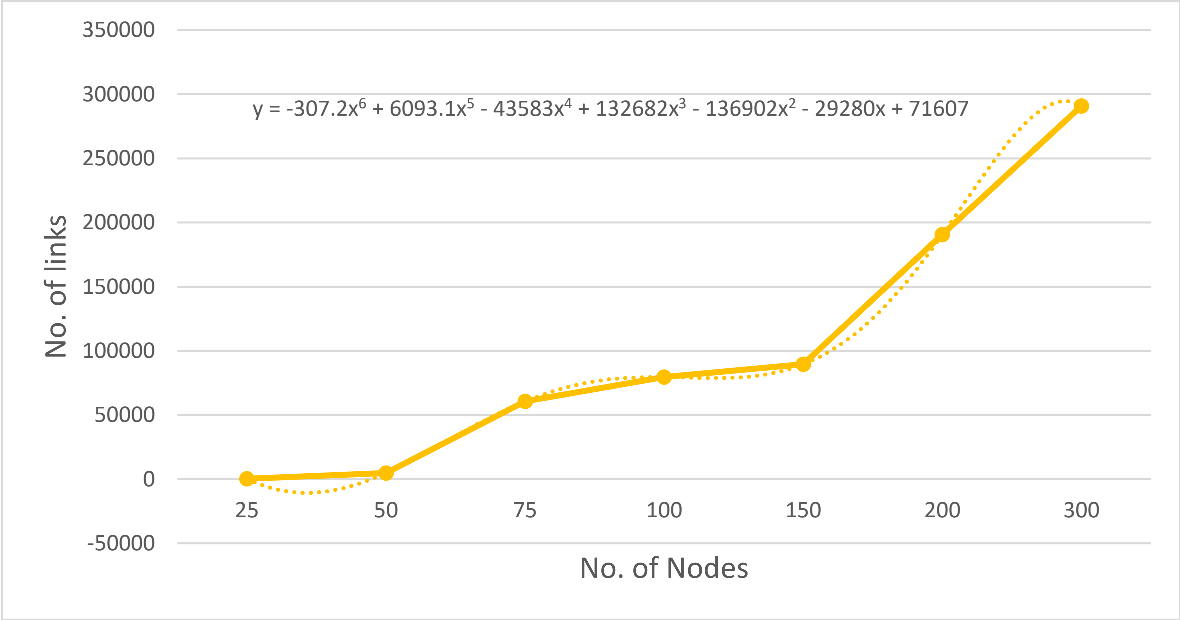

Figure 4.30: Regression model of the Number-of Links with Node for 20 Ranges.

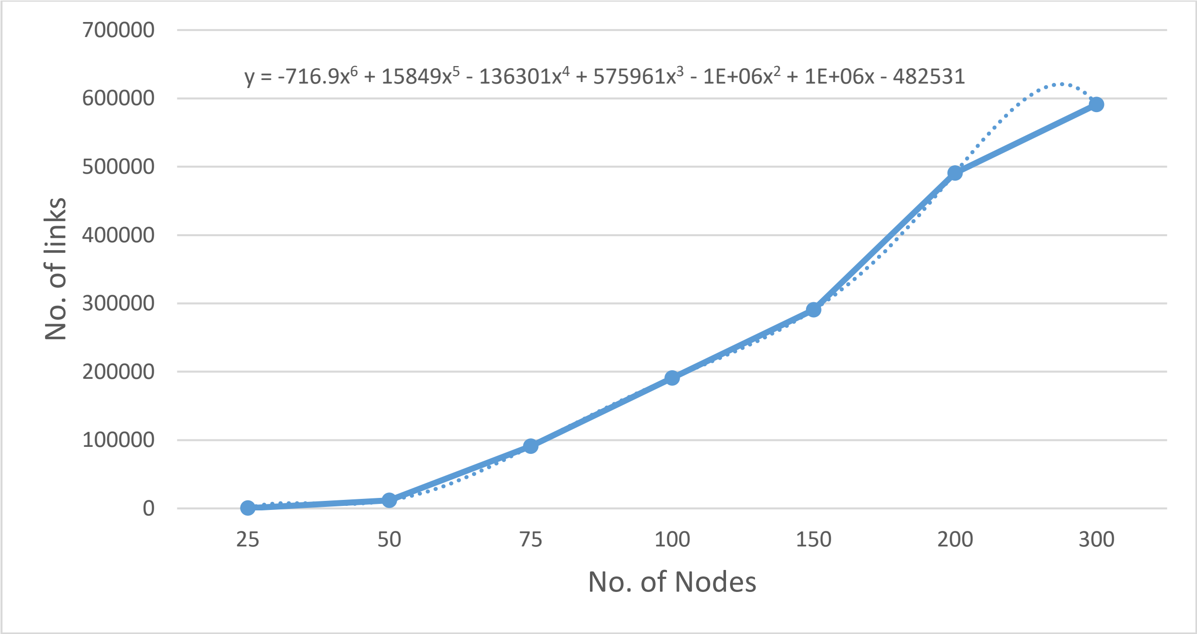

Figure 4.31: Regression model of the Number-of Links with Node for 25 Ranges.

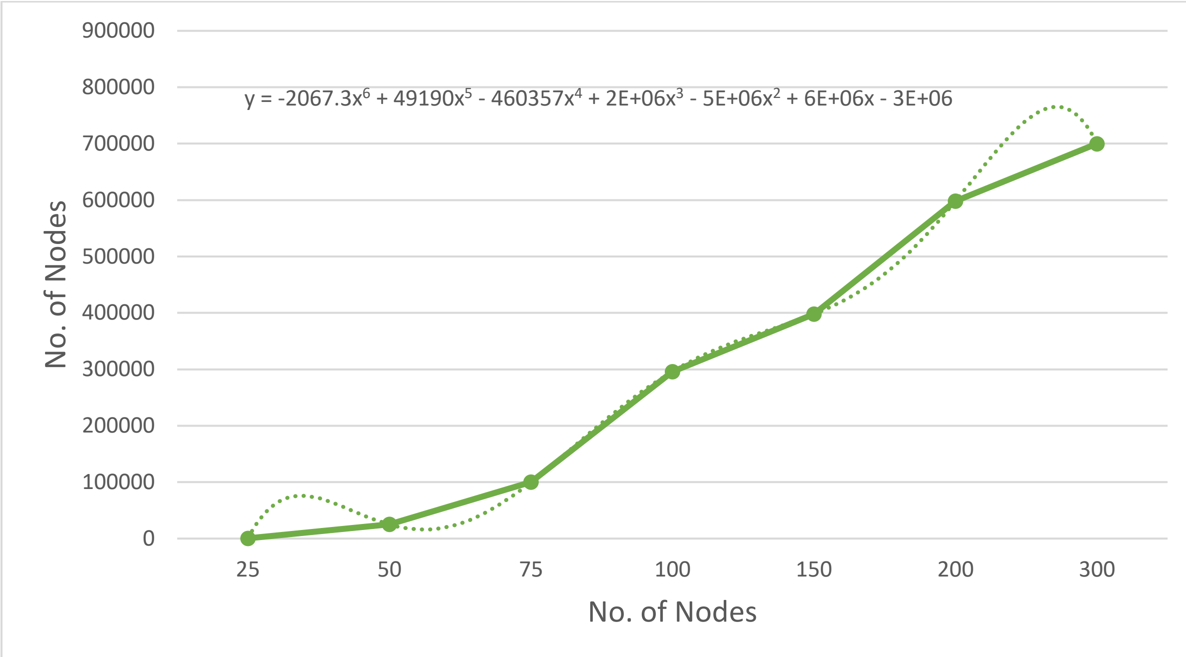

Figure 4.32: Regression model of the Number-of Links with Node for 30 Ranges.

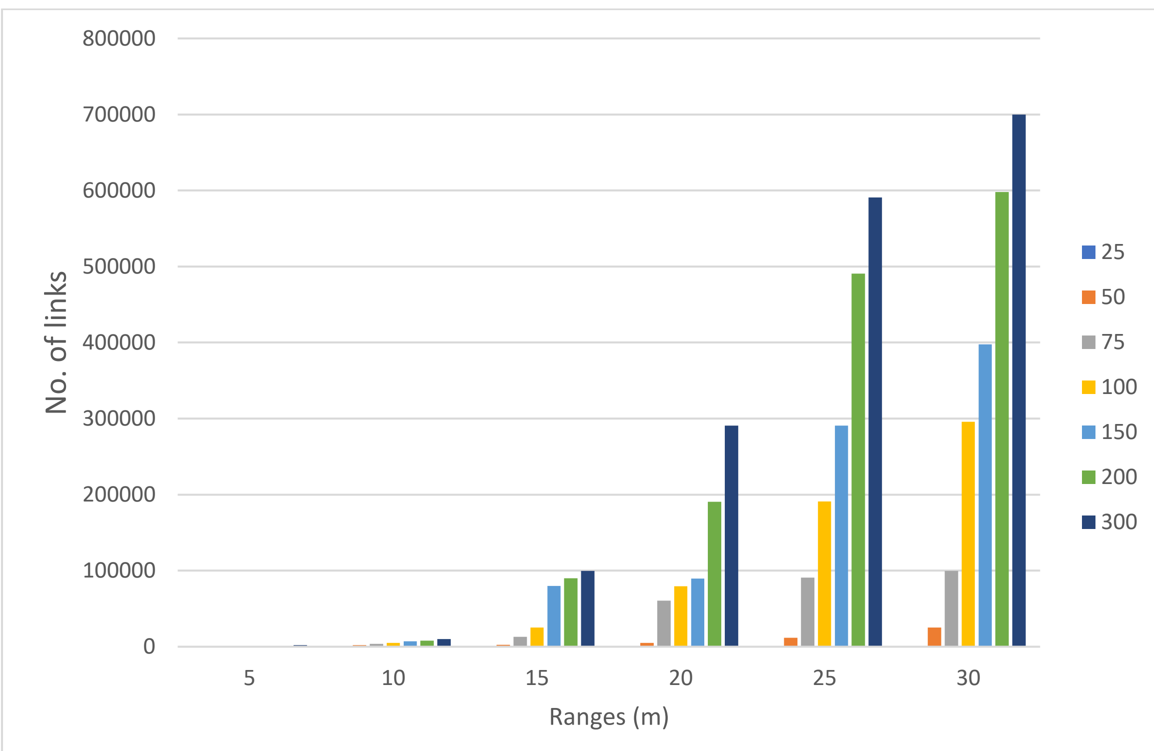

Figure 4.33: Regression model of the Number-of Links with all Nodes and all Ranges.

Figure 4.33 represents the number of links with the different ranges (5, 10, 15, 20, 25, 30).

To apply one of the equations, we will use the equation in the figure 4.33 and substitute the value of one in it,

$$\mathbf{y = 4.0458x^5 - 68.076x^4 + 425.57x^3 - 1224.6x^2 + 1734x - 785.29} \qquad \mathbf{(4.2)}$$

y = 4.0458 (5) ^5 - 68.076 (5) ^4 + 425.57 (1) ^3 - 1224.6 (1) ^2 + 1734 (1) ^1 - 785.29= 87

For example, the number 87 in table 4.20 represents the number of links when the range is 5 and the number of nodes is 25.

4.4.2 Calculate the Length-of Links Result

There are many parameters effect on calculate the length-of links in WMN such as: number-of-nodes, range (coverage area of the node). Using the same table 4.1, but the algorithm in this case called calculate the length-of links, the number source node is 73 and the number destination node is 102. The table 4.17 shows specify the built environment for varying number of nodes to be simulated result below various parameters. This table contains the results of the length of links obtained when executing a different number of nodes in the Net-Logo program. This table has been implemented in Excel to obtain the following diagrams and also to obtain equations that allow the programmer to know the length of links without using the Net-Logo program. Figure 4.34-4.41 shows number-of-nodes and equation in each range for calculate the length-of links.

Table 4.17: Simulation Result of Calculate the Length-of Links, Varying Number-of-Nodes.

	Calculate the Length-of Links					
No. of Nodes	**5**	**10**	**15**	**20**	**25**	**30**
25	199	3139	4698	5899	7980	9980
50	240	4410	5988	6899	8,998	19980
75	377	4814	6988	7999	19999	29990
100	534	5914	28178	34948	49978	59985
150	721	6866	38471	49585	59536	69986
200	1159	7899	89471	99585	169536	269536
300	1867	8999	152690	221820	237797	369536

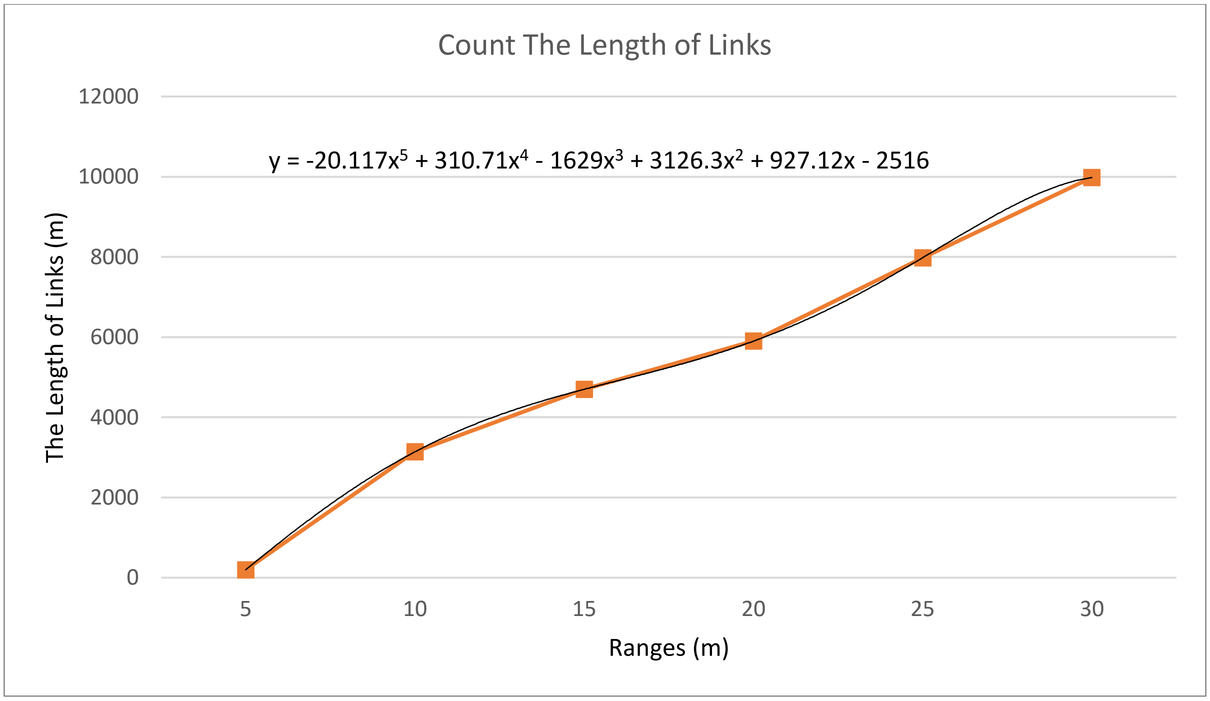

Figure 4.34: Regression model of the Length-of Links with Range for 25 Nodes.

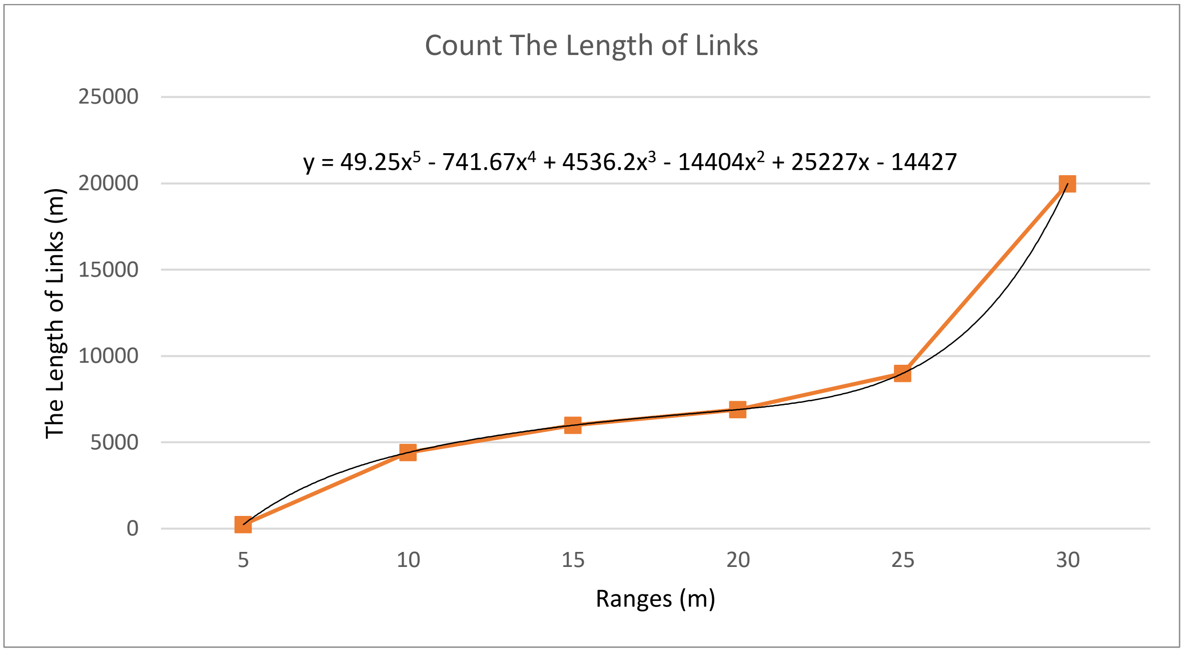

Figure 4.35: Regression model of the Length-of Links with Range for 50 Nodes.

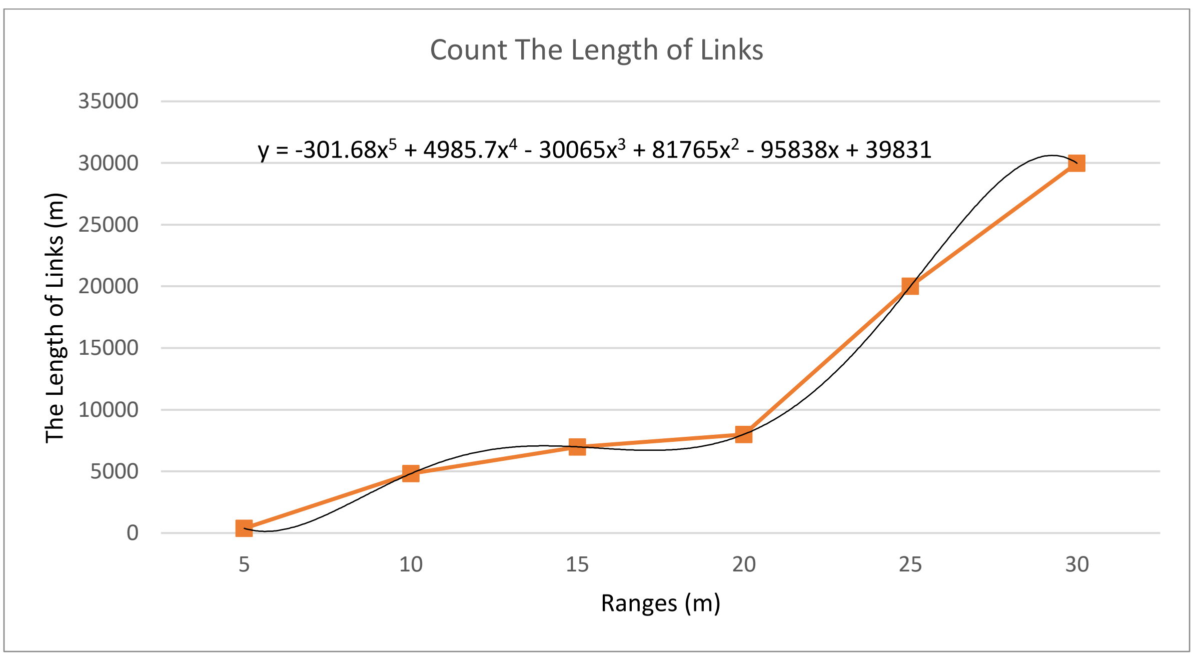

Figure 4.36: Regression model of the Length-of Links with Range for 75 Nodes.

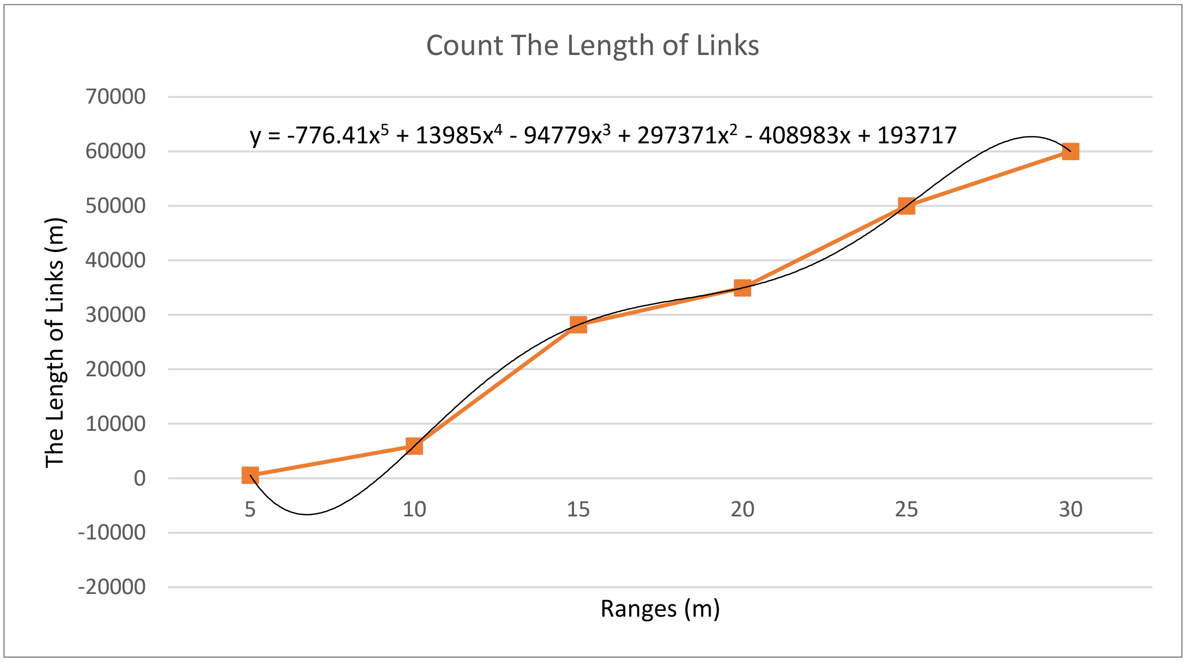

Figure 4.37: Regression model of the Length-of Links with Range for 100 Nodes.

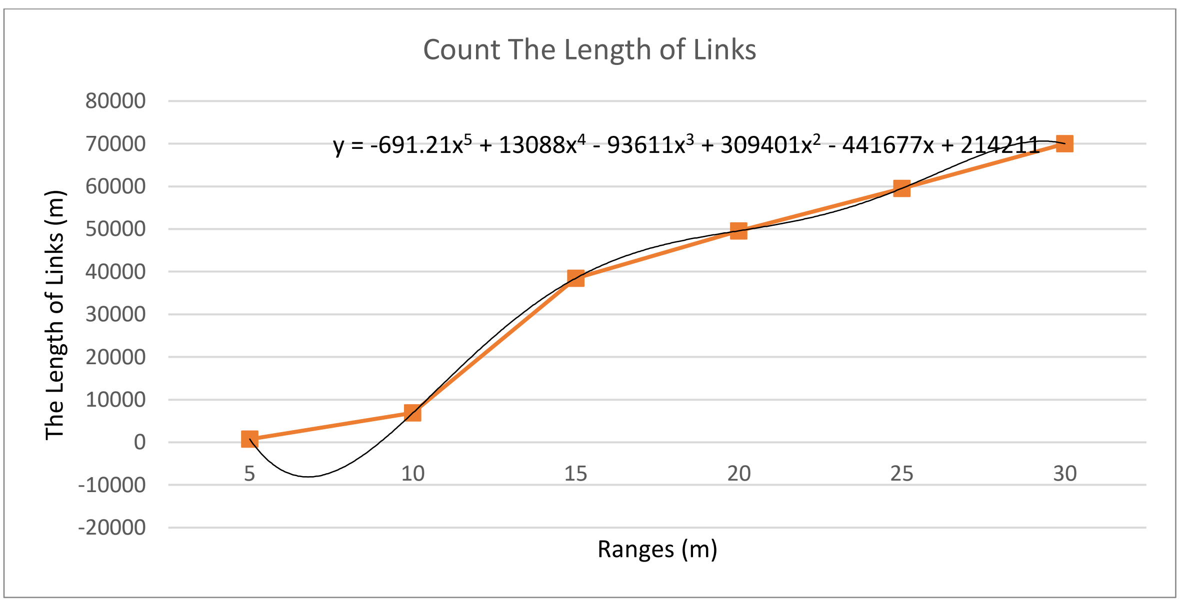

Figure 4.38: Regression model of the Length-of Links with Range for 150 Nodes.

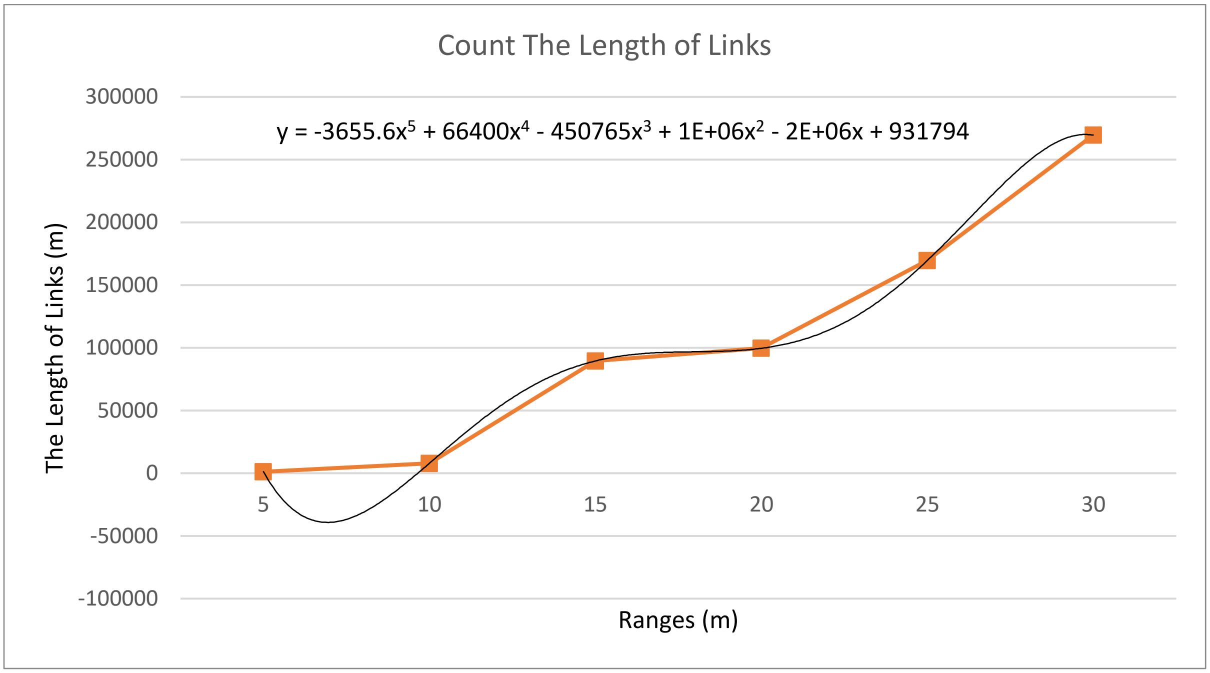

Figure 4.39: Regression model of the Length-of Links with Range for 200 Nodes.

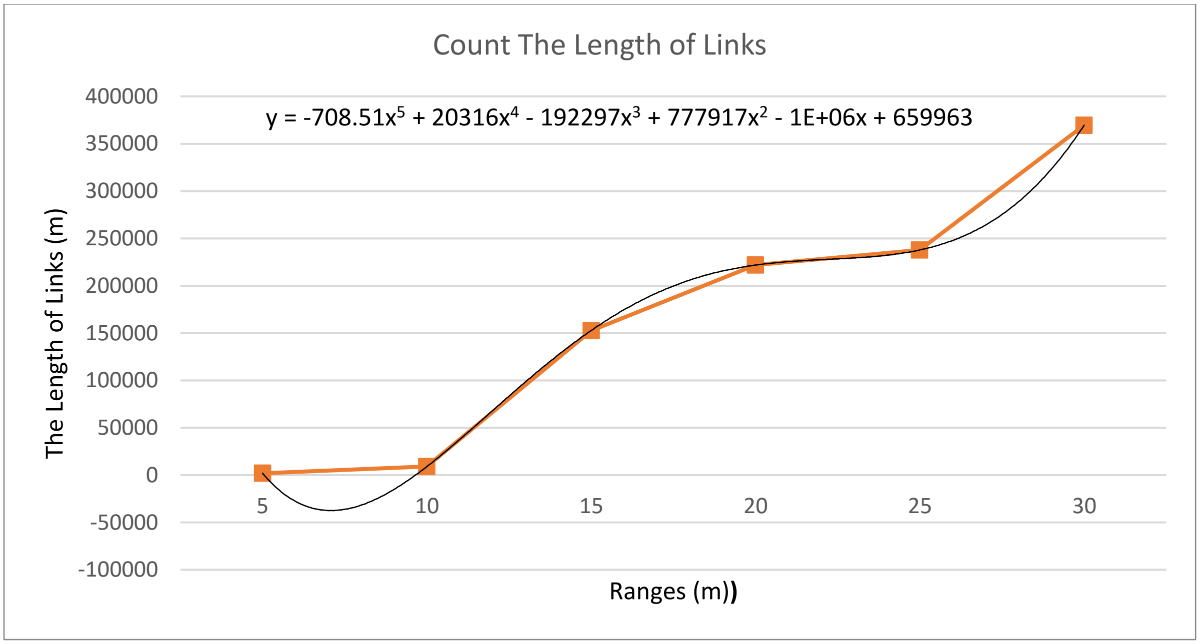

Figure 4.40: Regression model of the Length-of Links with Range for 300 Nodes.

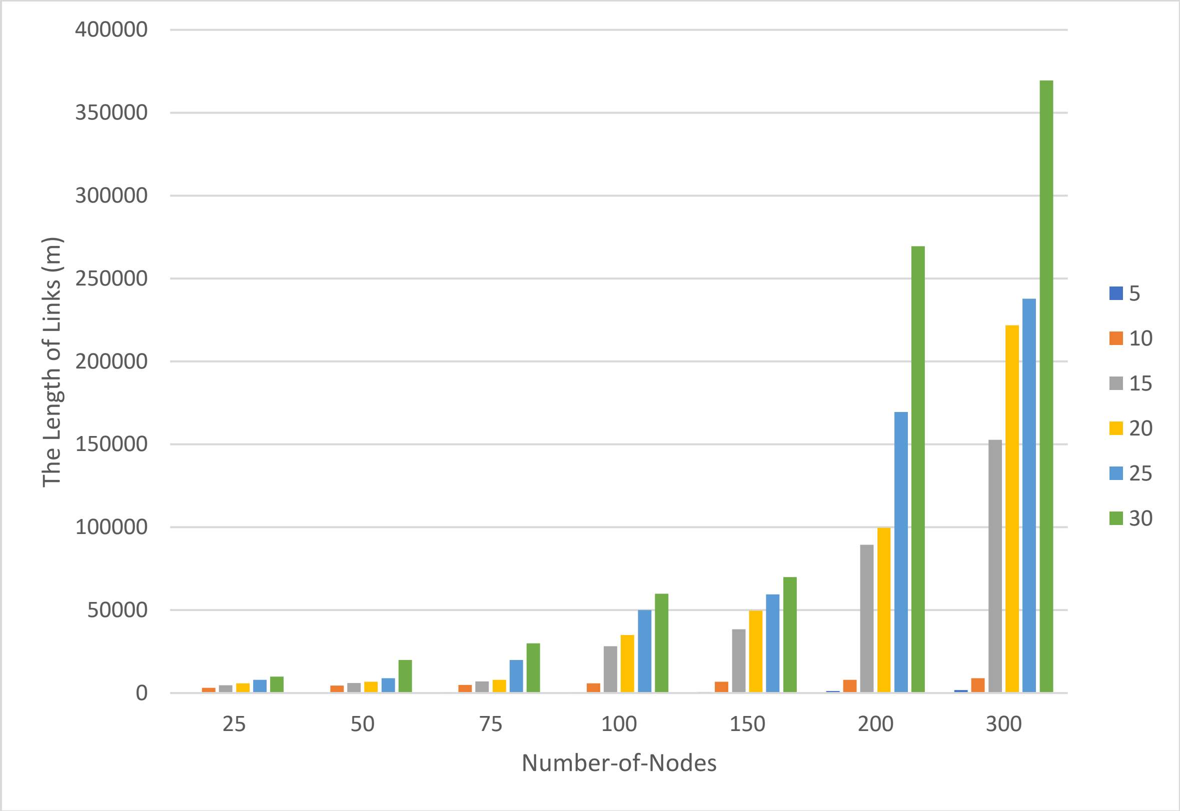

Figure 4.41: Regression model of the Number-of Links with all Ranges and all Nodes.

Figure 4.41 represents the length of links with the different number of nodes (25, 50, 75, 100, 150, 150, 200, 300).

To apply one of the equations, we will use the equation in the figure 4.41 and substitute the value of one in it,

$$\mathbf{y = -20.117x^5 + 310.71x^4 - 1629x^3 + 3126.3x^2 + 927.12x - 2516} \qquad \mathbf{(4.3)}$$

y = -20.117 (5) ^5 + 310.71 (5) ^4 - 1629 (5) ^3 + 3126.3 (5) ^2 + 927.12 (5) ^1 - 2516 = 199

For example, the number 199 in table 4.21 represents the number of links when the number of nodes is 25 and the range is 5.

The table 4.18 shows specify the built environment for varying number of ranges to be simulated result below various parameters. This table contains the results of the length of links obtained when executing a different number of ranges in the Net-Logo program. This table has been implemented in Excel to obtain the following diagrams and also to obtain equations that allow the programmer to know the length of links without using the Net-Logo program. Figure 4.42-4.48 shows number-of ranges and equation in each number-of nodes for calculate the number-of links.

Table 4.18: Simulation Result of Calculate the length -of Links, Varying Number of Ranges.

	Calculate the length -of Links						
Ranges	**25**	**50**	**75**	**100**	**150**	**200**	**300**
5	199	240	377	534	721	1159	1867
10	3139	4410	4814	5914	6866	7899	8999
15	4698	5988	6988	28178	38471	89471	152690
20	5899	6899	7999	34948	49585	99585	221820
25	7980	8998	19999	49978	59536	169536	237797
30	9980	19980	29990	59985	69986	269536	369536

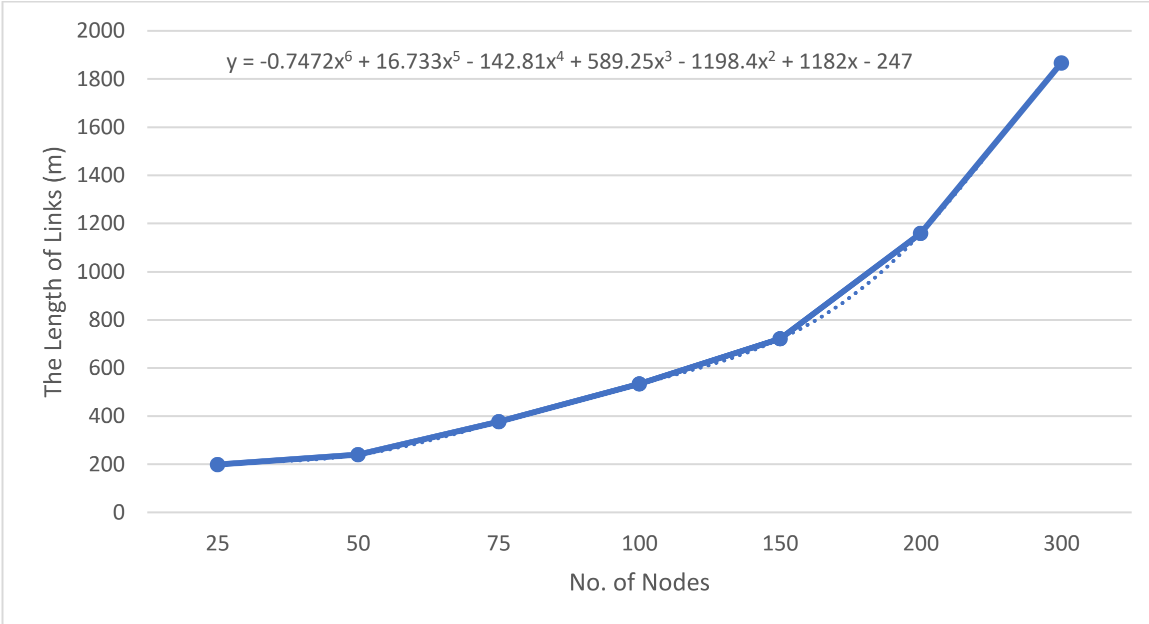

Figure 4.42: Regression model of the Length-of Links with Node for 5 Ranges.

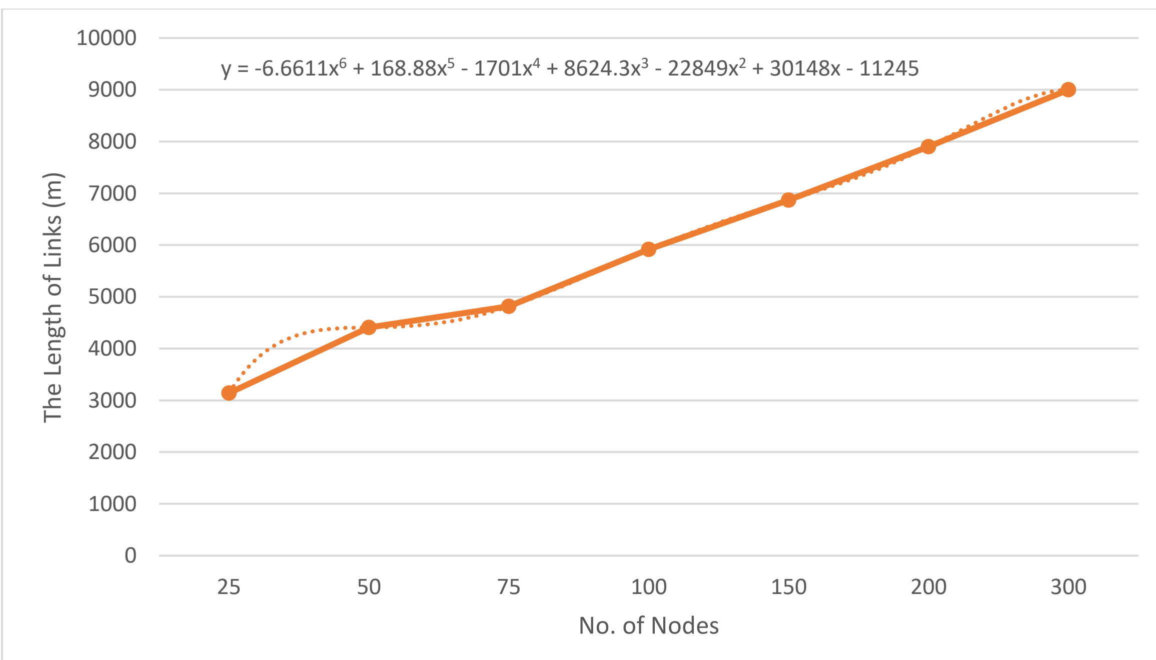

Figure 4.43: Regression model of the Length-of Links with Node for 10 Ranges.

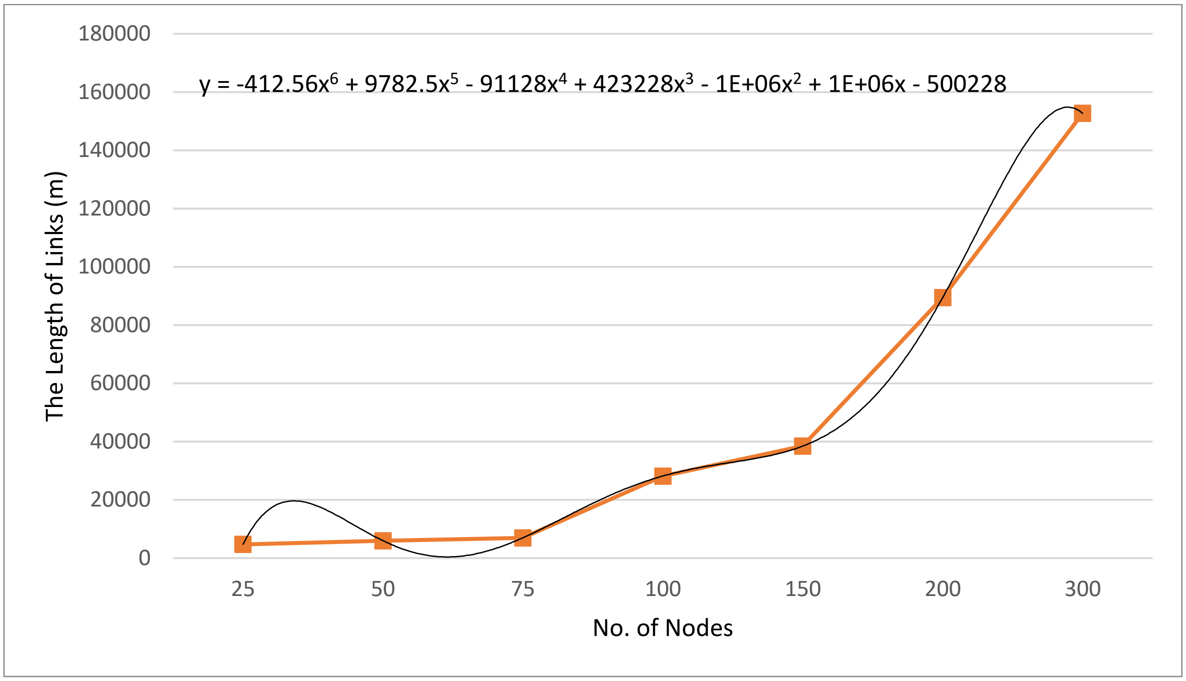

Figure 4.44: Regression model of the Length-of Links with Node for 15 Ranges.

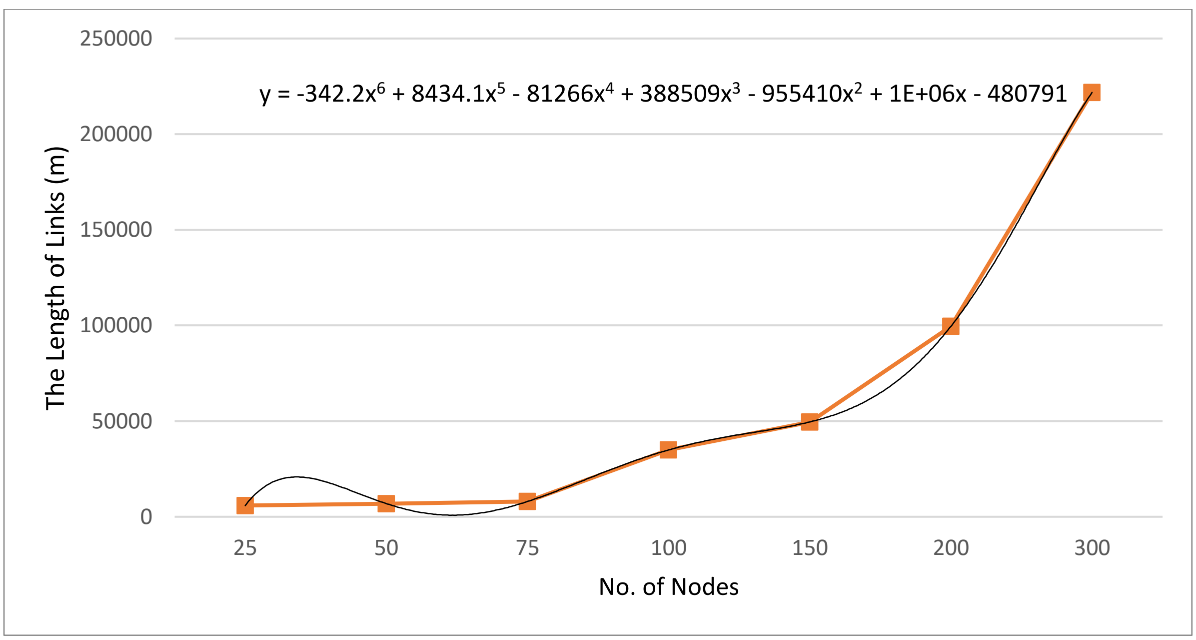

Figure 4.45: Regression model of the Length-of Links with Node for 20 Ranges.

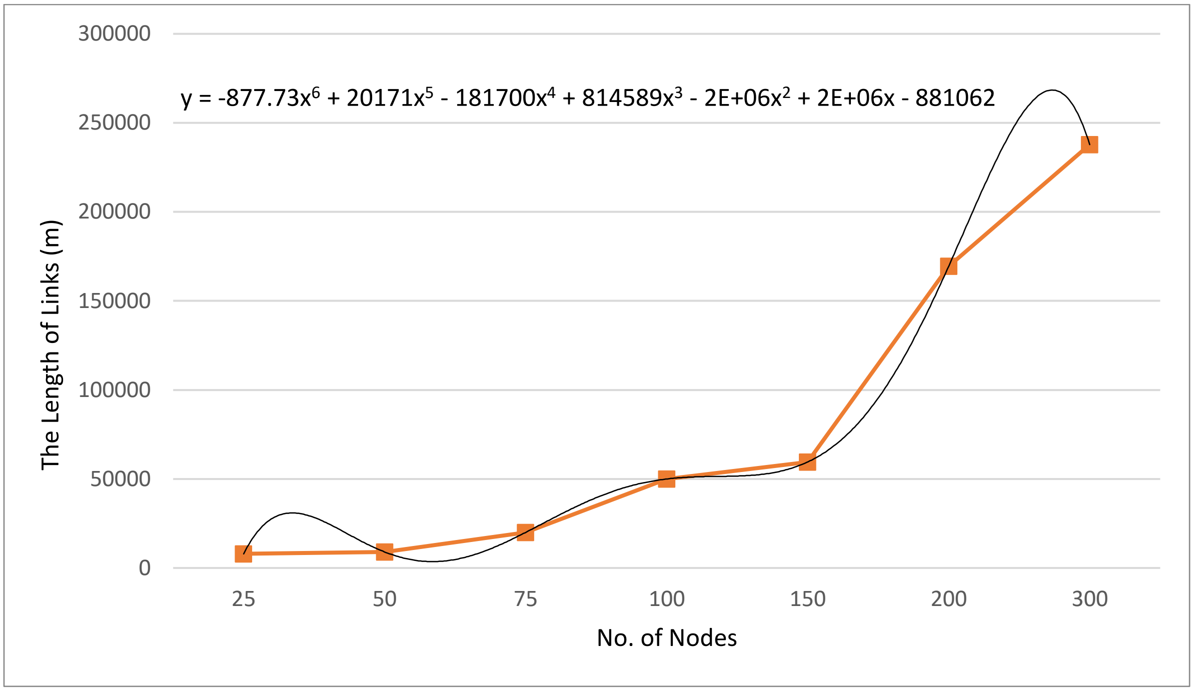

Figure 4.46: Regression model of the length-of Links with Node for 25 Ranges.

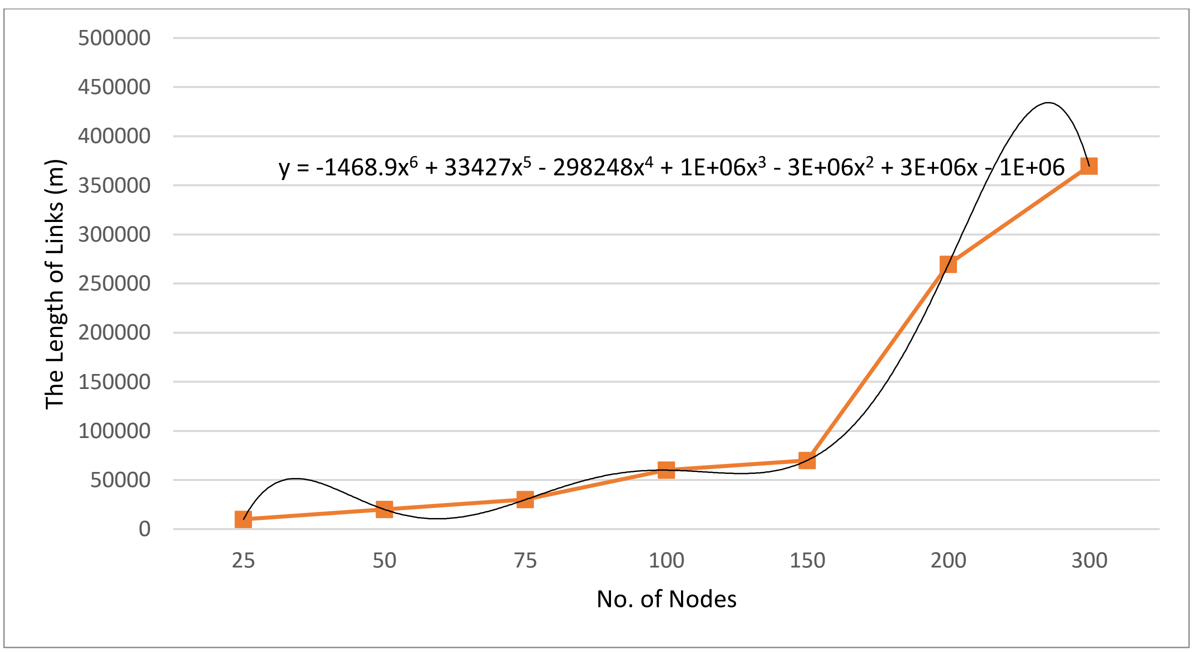

Figure 4.47: Regression model of the length-of Links with Node for 30 Ranges.

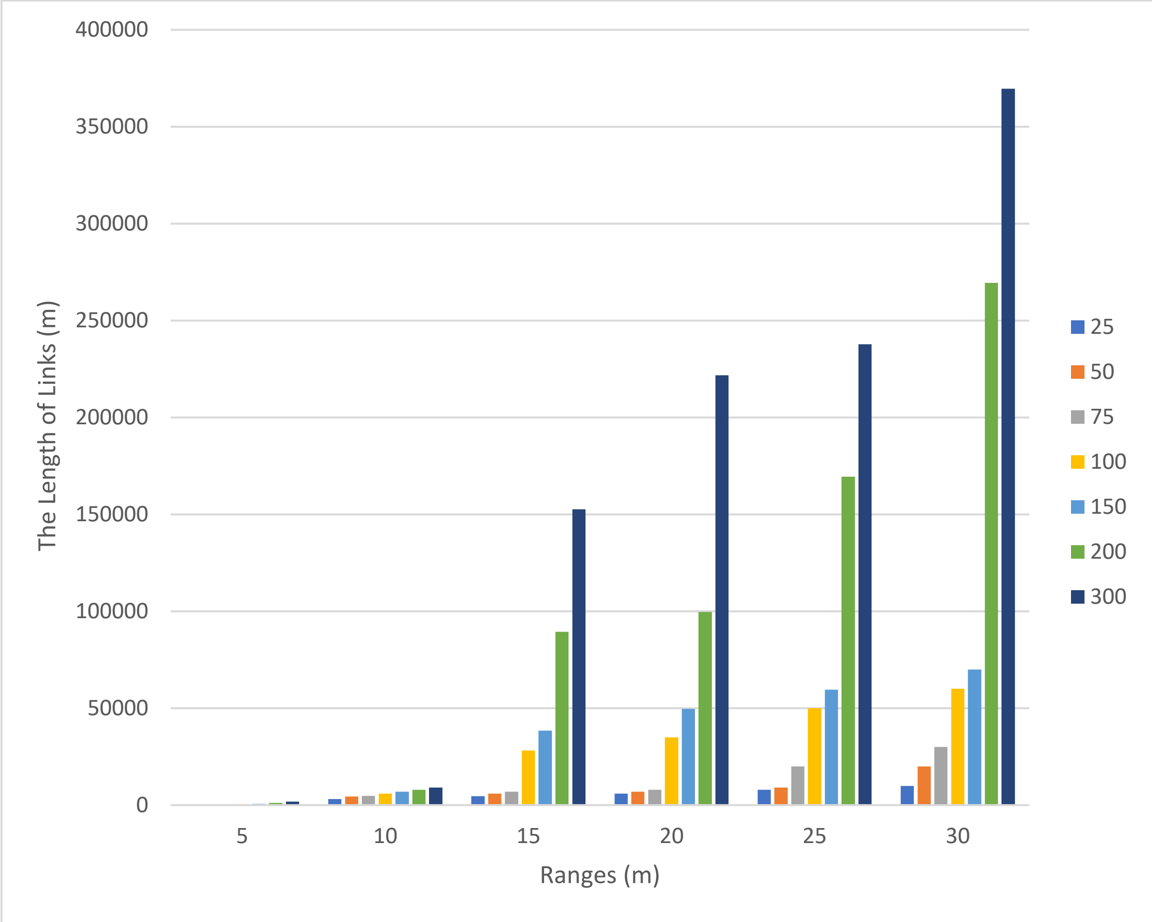

Figure 4.48: Regression model of the length-of Links with all Nodes and all Ranges.

Figure 4.48 represents the length of links with the different number of ranges (5, 10, 15, 20, 25, 30).

To apply one of the equations, we will use the equation in the figure 4.48 and substitute the value of one in it,

$$\mathbf{y = -1.2x^5 + 26.678x^4 - 209.6x^3 + 754.79x^2 - 1123.2x + 752.14} \quad \mathbf{(4.4)}$$

y = -1.2 (5) ^5 + 26.678 (5) ^4 - 209.6 (5) ^3 + 754.7 (5) ^2 - 1123.2 (5) ^1 - 2661.1(5) ^1 + 752.14 = 199

For example, the number 199 in table 4.22 represents the number of links when the range is 5 and the number of nodes is 25.

4.5 Long Path Scenario Results

For comparison purposes the WMN was created and simulated under the case of long path with similar parameters of short path. The results of different metrics for this case are presented in the following tables.

A. Throughput

Table 4. 19: Throughput Results in the Long Path.

	Throughput					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	1500	1500	1500	1500	1500	1500
200	1500	1500	1500	1500	1500	1500
300	1500	1500	1500	1500	1500	1500

B. End-To-End Delay

Table 4. 20: End-To-End Delay Results in the Long Path.

	End-To-End Delay					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	0.008	0.008	0.008	0.008	0.008	0.008
200	0.008	0.008	0.008	0.008	0.008	0.008
300	0.008	0.008	0.008	0.008	0.008	0.008

C. Packet Delivery Ratio

Table 4. 21: Packet Delivery Ratio Results in the Long Path.

	Packet Delivery Ratio (PDR) %					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	100	100	100	100	100	100
200	100	100	100	100	100	100
300	100	100	100	100	100	100

D. Normal Routing Load

Table 4. 22: Normal Routing Load Results in the Long Path.

	Normal Routing Load (NRL)					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	1	1	1	1	1	1
200	1	1	1	1	1	1
300	1	1	1	1	1	1

E. Load Balancing Efficiency

Table 4. 23: Load Balancing Efficiency Results in the Long Path.

	Load Balancing (LB) %					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	0.5	0.5	0.5	0.5	0.5	0.5
200	0.6	0.6	0.6	0.6	0.6	0.6
300	1	1	1	1	1	1

F. Quality of Services

Table 4. 24: Load Balancing Results in the Long Path.

	Quality of Services (QoS)					
No. of Nodes	**Range 5**	**Range 10**	**Range 15**	**Range 20**	**Range 25**	**Range 30**
150	99.992	99.992	99.992	99.992	99.992	99.992
200	99.992	99.992	99.992	99.992	99.992	99.992
300	99.992	99.992	99.992	99.992	99.992	99.992

G. Target Coverage

Table 4. 25: Load Balancing Results in the Long Path.

	Target Coverage (TC)					
No. of Nodes	**Ranges 5**	**Ranges 10**	**Ranges 15**	**Ranges 20**	**Ranges 25**	**Ranges 30**
150	13	13.52	18	23	24	25
200	14	14.61	19	24	25	26
300	15	15.71	20	25	26	27

4.6 Comparison Results

In this study, nodes are deployed and interconnected to form WMN. The results of comparison between the long and short-path approach are illustrated in table 4.26. Clearly, some of the performance metrics represented by the QoS, End to End delay and throughput. The throughput is improved by 133%, End to End delay by 50% and QoS by 0.004% respectively. But the other metrics such as the PDR, load balancing efficiency and target coverage are not altered.

Table 4. 26: Summary of the Comparison.

Metrics	Long-Path Approach Result	Short-Path Approach Result	Improving %
Throughput (Bytes/Second)	1500	3500	133%
QoS	99.992	99.996	0.004%
E2E Delay (Second)	0.008	0.004	50%
NRL	1	1	0
LBE	1	1	0
TC	27	27	0
PDR	100	100	0

CHAPTER FIVE

Conclusion and Future Works

Chapter Five
Conclusion and Future Works

5.1 Conclusions

There are many points that can be concluded from this research as follows:

1. Connecting a wireless mesh network of the second type that contains sensor nodes.

2. Implementation of nine cases for finding paths and sending messages between the source and destination nodes.

3. Calculation the number of the links and their total lengths by using regression model with two Factors, different number-of nodes and ranges. These equations have been tested and proven they are the same values found in the table, or they are close to the real values.

4. After analyzing and evaluating the performance of WMN; there was an increase in the throughput by 40 when increasing the number of nodes and ranges, and increase the QoS are observed by 28 when increasing the number of nodes and ranges.

5.2 Future Works

1. Creating and simulating hybrid network in WMNs.

2. Create a network of routers and find out the best location to put the routers.

REFERENCES

REFERENCES

Ameen, S. Q., & Khaleel, F. L. (2018). Wireless Mesh Networks Based on MBPSO Algorithm to Improvement Throughput. International Journal of Electrical & Computer Engineering (2088-8708), 8(6).

BIOS 9136 - General and Generalized Linear Models Singh, M. (2019). Wireless mesh networks architecture. In *Node-to-node approaching in wireless mesh connectivity* (pp. 11-14). Springer, Singapore.

Cao, K., Zhou, J., Wei, T., Chen, M., Hu, S., & Li, K. (2019). A survey of optimization techniques for thermal-aware 3D processors. *Journal of Systems Architecture*, *97*, 397-415.

Cilfone, A., Davoli, L., Belli, L., & Ferrari, G. (2019). Wireless mesh networking: An IoT-oriented perspective survey on relevant technologies. Future Internet, 11(4), 99.

Diakonikolas, I., Kane, D. M., Pittas, T., & Zarifis, N. (2021, July). The Optimality of Polynomial Regression for Agnostic Learning under Gaussian Marginals in the SQ Model. In *Conference on Learning Theory* (pp. 1552-1584). PMLR.

Faludi, R. (2010). *Building wireless sensor networks: with ZigBee, XBee, arduino, and processing*. " O'Reilly Media, Inc.".

Gómez-Valent, A., & Amendola, L. (2018). H0 from cosmic chronometers and Type Ia supernovae, with Gaussian Processes and the novel Weighted Polynomial Regression method. *Journal of Cosmology and Astroparticle Physics*, *2018*(04), 051.

Goulet, J. A., & Koo, K. (2018). Empirical validation of bayesian dynamic linear models in the context of structural health monitoring. *Journal of Bridge Engineering*, *23*(2), 05017017.

Gupta, M., & Varma, S. (2021). Optimal placement of UAVs of an aerial mesh network in an emergency situation. Journal of Ambient Intelligence and Humanized Computing, 12(1), 343-358.

Hamza, A. S., Deogun, J. S., & Alexander, D. R. (2016). Wireless communication in data centers: A survey. *IEEE communications surveys & tutorials*, *18*(3), 1572-1595.

Klophaus, R., Merkert, R., & Lordan, O. (2021). Mesh network as a competitive advantage for European LCCs: An alternative topology to hub-and-spoke for selling online connections. *Transport Policy*, *106*, 196-204.

Lai, P., He, Q., Cui, G., Xia, X., Abdelrazek, M., Chen, F., ... & Yang, Y. (2019, October). Edge user allocation with dynamic quality of service. In *International Conference on Service-Oriented Computing* (pp. 86-101). Springer, Cham.

Lee, H. C., & Ke, K. H. (2018). Monitoring of large-area IoT sensors using a LoRa wireless mesh network system: Design and evaluation. *IEEE Transactions on Instrumentation and Measurement*, *67*(9), 2177-2187.

Montori, F., Bedogni, L., Di Felice, M., & Bononi, L. (2018). Machine-to-machine wireless communication technologies for the Internet of Things: Taxonomy, comparison and open issues. *Pervasive and Mobile Computing*, *50*, 56-81.

Nedić, A., Olshevsky, A., & Rabbat, M. G. (2018). Network topology and communication-computation tradeoffs in decentralized optimization. *Proceedings of the IEEE*, *106*(5), 953-976.

Olive, D. J. (2017). Multiple linear regression. In *Linear regression* (pp. 17-83). Springer, Cham.

Pa, S., & Mandala, S. (2019, March). A new method for congestion avoidance in wireless mesh networks. In Journal of Physics: Conference Series (Vol. 1192, No. 1, p. 012062). IOP Publishing.

Raja, G. P., & Mangai, S. (2020). Investigation on optimisation, prioritising and weight allocation techniques for load balancing and controlling multimedia traffic in wireless mesh network. International Journal of Business Information Systems, 33(2), 250-266.

Reka, R. (2020, October). Computing dissimilar types of regression analysis models. In *AIP Conference Proceedings* (Vol. 2261, No. 1, p. 030070). AIP Publishing LLC.

Said, G. A. E. N. A., Mahmoud, A. M., & El-Horbaty, E. S. M. (2014). A comparative study of meta-heuristic algorithms for solving quadratic assignment problem. arXiv preprint arXiv:1407.4863.

Siemuri, A. (2019). "Smart Energy Systems Research Platform SESP". *vaasan yliopisto*, 50, 1-50.

Silva, M. D., Senne, E. L., & Vijaykumar, N. L. (2017). An optimization model to minimize the expected end-to-end transmission time in wireless mesh networks. Pesquisa Operacional, 37, 209-227.

Sun, T. P., Huang, C. T., Lui, P. W., Chen, Y. T., & Shieh, H. L. (2019, May). Novel measurement system for linear array type uvc germicidal system. In 2019 IEEE Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability (ECBIOS) (pp. 57-60). IEEE.

Swain, S., Patel, P., & Nandi, S. (2017, April). A multiple linear regression model for precipitation forecasting over Cuttack district, Odisha, India. In *2017 2nd International conference for convergence in technology (I2CT)* (pp. 355-357). IEEE.

Yaqini, A., & Popalyar, F. (2018, April). An artificial neural network based fault detection and diagnosis for wireless mesh networks. *In 2018 Wireless Days (WD)* (pp. 107-109). IEEE.

APPENDIX

1. Code Setup Procedure.

```
Create nodes.
Set default-shape nodes  ←   default
distributed nodes constant
set  xs ys    ←  set-xcor-xs  set-ycor-ys
change some nodes properties
begin
set color   ←  pink
set label  ← who //who represents the identifier number of node
]
END.
```

2. Code Constant-Nodes Procedure.

```
Create nodes.
set xs ← -20   // xs represent x axis
set ys ← -16 // ys represent y axis
set xs1 ← -20
set xs2 ← 20
set ys1 ← -16
set ys2 ←16
let u ← 1 // u represent any number
while [u <= number-of-nodes] // number-of-nodes represent the slider
begin
if ys = ys2 [set  xs  xs + 2  set  ys -16]
create-nodes 1 ← [set  xcor  xs  set  ycor  ys]
set ys ← ys + 2
set u ← u + 1
]
END.
```

3. Code Create Mesh-Network Procedure.

let Cnode self. ← Information for the current node
let CloNode self ← Information for the close node
let IdC who ← id cureent node
let IdCl who ← id close node
let X1 ← xcor
let Y1 ← ycor
set d 1000 ← distance from close node to destination
Ask nodes (distance Cnode <= rang)
begin
if (sqrt (X1 ^ 2 + Y1^ 2) <= d)
set d ← sqrt (X1 ^ 2 + Y1 ^ 2)
set CloNode ← self
let x2 ← xcor
let y2 ← ycor
if (CloNode != Cnode) [
create-friendship-with ← C-Node
set color ← green
set thickness ← 0.3
set dd sqrt ((X2 – x1) ^ 2 + (Y2 – y1) ^ 2) ← distance between two nodes
]
print the number of links
print the length of links
END.

4. Code Source Node Procedure with Random Selection.

select one of nodes from the environment randomly.
change some properties
begin
set shape ← circle
set size ← 2
set color ← red
]
save (ID) and location of the sensor node

begin
set id1 ← who
set x ← xcor
set y   ← ycor
]
create-massage
begin
set color   ← white
set mid ← who //who represents the identifier number of message
]
END.

5. Code Source Node Procedure with User Selection.

select one of nodes in the environment through who of node.
change some properties
begin
set shape ← circle
set size ← 2
set color ← red
]
save (ID) and location of the sensor node
begin
set id1 ← who
set x ← xcor
set y   ← ycor
]
create-massage
begin
set color   ← white
set mid ← who //who represents the identifier number of message
]
END.

6. Code Destination Node Procedure with User Selection.

select one of nodes in the environment through who of node.

change some properties
begin
set shape ← circle
set size ← 2
set color ← red
]
END.

7. Code Shortest-Path Approach.

while (id1 != Destination-number) // (id1) represent id of the source node, (Destination-number) represent id of the receiver node .
begin
ask ← node id1
ask ← one of the nodes to be within the radius of the destination nodes
set jj ← who
if (jj != id1)
begin
ask node id1
create link to node jj
begin
set color ← blue
set thickness ← 0.5
]
]
4. move message to jj
set id1 ← jj
set hop ← hop + 1
]
END.

8. Code Shortest-Path with Random-Source and Destination Node Approach.

while (a != receiver node) // (a) represent id of the source node, (idd3) represent id of the receiver node .
begin
ask ← node a

ask ← one of the nodes to be within the radius of the destination nodes
set jj ← who
if (jj != a)
begin
ask node a
create link to node jj
begin
set color ← blue
set thickness ← 0.5
]
]
move message to jj
set a ← jj
set hop ← hop + 1
END.

9. Code Shortest-Path with Random-Source Node Approach.

while (id1 != Destination-number) // (id1) represent id of the random source node, (id1) represent id of the destination node select by the user.
begin
ask ← node id1
ask ← one of the nodes to be within the radius of the destination nodes
set jj ← who
if (jj != id1)
begin
ask node id1
create link to node jj
begin
set color ← blue
set thickness ← 0.5
]
]
move message to jj
set id1 ← jj

```
set hop ← hop + 1
end
END.
```

10. Code Shortest-Path with Random-Destination Node Approach.

```
while ( id1 != Destination-number) // (idd3) represent id of the one-of nodes .
begin
ask  node id1
ask  ← one of the nodes to be within the radius of the destination nodes
set jj ←  who
if ( jj  != id1)
begin
ask node id1
create link to node jj
begin
set color ←  blue
set thickness ←  0.5
]
]
move message to jj
.set  id1 ←  jj
set hop ← hop + 1
]
END.
```

11. Alternate-Path with Busy-Intermediate Nodes Approach.

```
while ( id1 != Destination-number) //( Destination-number) represent id of the sink node .
begin

ask  node id1

if (who != Destination-number)

ask ← one of the nodes to be within the radius of the destination nodes
set jj ←   who
```

```
set b ← jj
ask node jj
set c ←  random float (1 ) // c:: represent node capacity
if ( c < 0.8)
begin
if (jj !=  id1 )
begin
ask node id1
begin
create-link-to  node jj
begin
set color← blue
set thickness ←0.5
]
]
]
set id1 ←  jj
move message ← jj
]
else
begin
ask ← one of the nodes to be within the radius of the destination nodes
set ii ← who
if (id1 != ii )
begin
ask node id1
begin
create link to node ii
set color ←  blue
set thickness ← 0.5
]
```

]

ask node id1
begin
create link to node b

begin
set color ← white
set thickness ← 0.3
]

]

]

set id1← b

move message ← ii

]
]
]
]
set hop ← hop + 1
2. ask node Destination-number
begin
ask massage mid
set r ← r + 1
set s ← s + 1
]
END.

12. Alternate-Path Random-Source and Destination with Busy-Intermediate Nodes Approach.

while (a2 != idd4) //(a2) represent id of the random source node, (idd4) represent id of the random destination node .
begin

ask ← node id1

```
if (who != Destination-number)
ask ← one of the nodes to be within the radius of the destination nodes
set jj ←   who
set b ← jj
ask node jj
set c ←  random float (1) // c: represent node capacity
if ( c < 0.8)
begin
if (jj !=  id1 )
begin
ask node id1
begin
create-link-to  node jj
begin
set color← blue
set thickness ←0.5
]
]
]
set id1 ←  jj
move message ← jj
]
else
begin
ask ← one of the nodes to be within the radius of the destination nodes
set ii ← who
if (id1 != ii )
begin
ask node id1
begin
create link to node ii
```

```
set color ← blue
set thickness ← 0.5
]

]

ask node id1
begin
create link to node b

begin
set color ← white
set thickness ← 0.3
]

]

]

]

set id1← b

move message ← ii

]
]
]
set hop ← hop + 1
2. ask node Destination-number
begin
ask massage mid
set r r + 1
set s s + 1
]
END.
```

13. Four Sectoring with Random-Destination-Node Approach.

```
ask ← nodes with [ pxcor >= 0 and pxcor <= 40 and pycor >= 0 and pycor <= 20]
```

```
set color ← 117
set shape ← "circle"
begin
ask ← one-of nodes with [ pxcor >= 0 and pxcor <= 40 and pycor >= 0 and pycor
<= 20]
begin
set id4 ←  who  //node marked as destination
set color ←  white
]
ask ←  node id4
begin
ask ← one of the nodes to be within the radius of the destination nodes
[if( pxcor >= 0 and pxcor <= 40  and  pycor >= 0 and pycor <= 20)]
set id5 ← who
set x ← xcor
set y ← ycor
]
if (id5!= id4 and id4 != 0)
begin
create-friend-to node  ← id4
set color pink
set thickness 0.3
]
]
]
ask nodes with [ pxcor > 0 and pxcor <= 40 and pycor >= -20 and pycor < 0]
set color ← 125
set shape ← "circle"
begin
ask ←one-of nodes with [ pxcor > 0 and pxcor <= 40 and pycor >= -20 and pycor
< 0]
begin
set id4 ←  who  //node marked as destination
set color ←  white
```

```
]
ask  ← node id4
begin
ask← one of the nodes to be within the radius of the destination nodes
[if(  pxcor > 0 and pxcor <= 40 and pycor >= -20 and pycor < 0)
set id5 ← who
set x ← xcor
set y ← ycor
]
if  (id5 != id4 and id4 != 0)
begin
create-friend-to node  ← id4
set color pink
set thickness 0.3
]
]
]
ask ←nodes with [ pxcor >= -40 and pxcor <= 0 and pycor >= -20 and pycor <= 0]
set color ← 15
set shape ← "circle"
begin
ask← one-of nodes with [ pxcor >= -40 and pxcor <= 0 and pycor >= -20 and
pycor <= 0]
begin
set id4 ←  who  //node marked as destination
set color ←  white
]
ask   ←node id4
begin
ask ←one of the nodes to be within the radius of the destination nodes
[if (pxcor >= -40 and pxcor <= 0  and pycor >= -20 and pycor <= 0)
set id5 ← who
set x ← xcor
set y ← ycor
```

```
if (id5! = id4 and id4! = 0)
begin
create-friend-to node  ← id4
set color pink
set thickness 0.3
]
]
]
ask ←nodes with [ pxcor >= -40 and pxcor < 0 and pycor > 0 and pycor <= 20]
set color ← 128
set shape ← "circle"
begin
ask ←one-of nodes with [ pxcor >= -40 and pxcor < 0 and pycor > 0 and pycor <=
20]
begin
set id4 ←  who  //node marked as destination
set color ←  white
]
ask  ←node id4
begin
ask← one of the nodes to be within the radius of the destination nodes
[If (pxcor >= -40 and pxcor < 0 and pycor > 0 and pycor <= 20)
set id5 ← who
set x ← xcor
set y ← ycor
if  (id5 != id4 and id4 != 0)
begin
create-friend-to node  ← id4
set color ← pink
set thickness ← 0.3
]
]
END.
```

14. Four Sectors with Center-Node Approach.

```
ask ← nodes with [ pxcor >= 0 and pxcor <= 40 and pycor >= 0 and pycor <= 20]
set color ← 117
set shape ← "circle"
begin
ask ← nodes-on (Patch-set Patch 1 -1 Patch 1 0 Patch 0 -1 Patch 0 0 Patch 1 1
Patch 1 0 Patch -1 0 Patch -1 -1 Patch -1 1 Patch 0 0]
begin
set id4444 ←  who  //node marked as destination
set color ←  yellow
set size ← 3
]
ask ←nodes-on patch 5 3
begin
set id444 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
ask ←nodes-on (patch-set patch 5 9 patch 6 9 patch 6 8)
begin
set id4 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
ask ←nodes-on (Patch -set Patch 10 10 Patch 10 11 Patch 8 12 Patch 9 11 Patch 9
12 Patch 9 10)
begin
set id44 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
ask node id44
begin
if (link-with node id4! = nobody)
create-friend-to node  ← id4
```

```
set color ← blue
set thickness ← 0.4
]
]
]
ask node id4
begin
if (link-with node id444 != nobody)
create-friend-to node  ← id4
set color ← blue
set thickness ← 0.4
]
]
]
ask ←node id44
begin
if (link-with node id4444 != nobody)
create-friend-to node  ← id4
set color ← blue
set thickness ← 0.4
]
]
]
ask ← node id44
ask← one of the nodes to be within the radius of the destination nodes
if( pxcor >= 0 and pxcor <= 40    and pycor >= 0 and pycor <= 20)
begin
set id5 ←who
if (id5 != id44 and id44 != 0 and id44 != id4)
create-friend-to node id44
set color pink
set thickness 0.3
]
]
```

```
]
]
]
ask ← nodes with [pxcor > 0 and pxcor <= 40 and pycor >= -20 and pycor < 0]
set color ← 125
set shape ← "circle"
begin
ask ← nodes-on (Patch -set Patch 1 -1 Patch 1 0 Patch 0 -1 Patch 0 0 Patch 1 1
Patch 1 0 Patch -1 0 Patch -1 -1 Patch -1 1 Patch 0 1]
begin
set id4444 ←  who  //node marked as destination
set color ←  yellow
set size ← 3
]
ask ← nodes-on (Patch -set Patch 4 -3 Patch 4 -2 Patch 4 -3 Patch 5 -3)
begin
set id444 ←  who  //node marked as close to destination
set color ←  red
set size ← 3
]

ask← nodes-on (patch-set patch 10 -4 patch 10 -3 patch 0 -1)
begin
set id4 ←  who  //node marked as close to destination
set color ←  red
set size ← 3
]
ask←  nodes-on (patch-set patch 15 -5 patch 15 -6 )
begin
set id44 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
ask ←node id44
begin
```

```
if (link-with node id4 != nobody)
create-friend-to node  ← id4
set color ← blue
set thickness ← 0.4
]
]
]
ask node id4
begin
if (link-with node id444 != nobody)
create-friend-to node  ← id4
set color ← blue
set thickness ← 0.4
]
]
]
ask node id44
begin
if (link-with node id4444 != nobody)
create-friend-to node  ← id4
set color ← blue
set thickness ← 0.4
]
]
]
ask node id44
ask ←one of the nodes to be within the radius of the destination nodes
[ if(pxcor > 0 and pxcor < 40 and pycor > -20 and pycor < 0)
begin
set id5 ←who
if (id5 != id44 and id44 != 0 and id44 != id4)
create-friend-to node id44
set color pink
```

```
set thickness 0.3
]
]
]
]
]
ask← nodes with [pxcor >= -40 and pxcor <= 0 and pycor >= -20 and pycor <= 0]
set color ← 105
set shape ← "circle"
begin
ask← nodes-on (Patch -set Patch 1 -1 Patch 1 0 Patch 0 -1 Patch 0 0 Patch 1 1
Patch 1 0 Patch -1 0 Patch -1 -1 Patch -1 1 Patch 0 1]
begin
set id4444 ←  who  //node marked as destination
set color ←  yellow
set size ← 3
]
ask← nodes-on (Patch -set Patch -2 -4 Patch -1 -4 Patch -1 -4 Patch -1 -5 Patch -2 -
5 Patch 0 -5 Patch -1 -2 Patch -2 -3 Patch 0 -3 Patch 0 -4)
begin
set id444 ←  who  //node marked as close to destination
set color ←  red
set size ← 3
]
ask ←nodes-on (Patch -set Patch -5 -6 Patch -6 -6 Patch -1 -5 Patch -6 -7 Patch -5 -
7 Patch -5 -5 Patch -5 -8 Patch -6 -5 Patch -4 -7 Patch -4 -6)
begin
set id4 ←  who  //node marked as close to destination
set color ←  red
set size ← 3
]
```

```
ask← nodes-on (Patch -set Patch -10 -10 Patch -8 -10 Patch -8 -9 Patch -9 -10
Patch -10 -9 Patch -8 -8 Patch -9 -9 Patch -8 -11 Patch -7 -10 Patch -9 -11 Patch -9
-8 Patch -7 -9)
begin
set id44 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
ask← node id44
begin
if (link-with node id4 != nobody)
create-friend-to node  ← id4
set color ← blue
set thickness ← 0.4
]

]

]
ask ←node id4
begin
if (link-with node id444 != nobody)
create-friend-to node  ← id4
set color ← blue
set thickness ← 0.4
]
]
]
ask ←node id44
begin
if (link-with node id4444 != nobody)
create-friend-to node  ← id4
set color ← blue
set thickness ← 0.4
]
```

```
]
]
ask← node id44
Ask← one of the nodes to be within the radius of the destination nodes
[ if (pxcor >= -40 and pxcor <= 0 and pycor >= -20 and pycor <= 0)
begin
set id5 ←who
if (id5 != id44 and id44 != 0 and id44 != id4)
create-friend-to node ← id44
set color ← pink
set thickness ← 0.3
]

]

]

]

]
ask← nodes with [pxcor >= -40 and pxcor < 0 and pycor > 0 and pycor <= 20]
set color ← 105
set shape ← "circle"
begin
ask ← nodes-on (Patch -set Patch 1 -1 Patch 1 0 Patch 0 -1 Patch 0 0 Patch 1 1
Patch 1 0 Patch -1 0 Patch -1 -1 Patch -1 1 Patch 0 1]
begin
set id4444 ←  who  //node marked as destination
set color ←  yellow

set size ← 3
]
ask ←nodes-on (Patch -set Patch -2 -4 Patch -1 -4 Patch -1 -4 Patch -1 -5 Patch -2 -
5 Patch 0 -5 Patch -1 -2 Patch -2 -3 Patch 0 -3 Patch 0 -4)
begin
set id444 ←  who  //node marked as close to destination
```

```
set color ← red
set size ← 3
]
ask← nodes-on (Patch -set Patch -5 -6 Patch -6 -6 Patch -1 -5 Patch -6 -7 Patch -5 -
7 Patch -5 -5 Patch -5 -8 Patch -6 -5 Patch -4 -7 Patch -4 -6)
begin
set id4 ← who //node marked as close to destination
set color ← red
set size ← 3
]
ask ←nodes-on (Patch -set Patch -10 -10 Patch -8 -10 Patch -8 -9 Patch -9 -10
Patch -10 -9 Patch -8 -8 Patch -9 -9 Patch -8 -11 Patch -7 -10 Patch -9 -11 Patch -9
-8 Patch -7 -9)
begin
set id44 ← who //node marked as destination
set color ← red
set size ← 3
]
ask ←node id44
begin
if (link-with node id4! = nobody)
create-friend-to node ← id4
set color ← blue
set thickness ← 0.4
]

]

]
ask← node id4
begin
if (link-with node id444! = nobody)
create-friend-to node ← id4
set color ← blue
```

set thickness ← 0.4
]
]
end
ask← node id44
begin
if (link-with node id4444! = nobody)
create-friend-to node ← id4
set color ← blue
set thickness ← 0.4

]
]
]
ask node id44
Ask ←one of the nodes to be within the radius of the destination nodes
if(pxcor >= -40 and pxcor <= 0 and pycor >= -20 and pycor <= 0)
begin
set id5 ←who
if (id5 != id44 and id44 != 0 and id44 != id4)
create-friend-to node ← id44
set color ← pink
set thickness ← 0.3
]
END.

15. Four Sectoring with Close-Center-Node Approach.

ask nodes with [pxcor >= 0 and pxcor <= 40 and pycor >= 0 and pycor <= 20]
set color ← 117
set shape ← "circle"
begin
ask ← nodes-on Patch -set
begin
set id4444 ← who //node marked as destination
set color ← red

```
set size ← 3
]
ask ←nodes-on patch 5 3
begin
set id444 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
ask ←node id4
begin
if (link-with node id44 != nobody)
create-friend-to node  ← id44
set color ← blue
set thickness ← 0.5
]
]
]
. ask ←node id4
Ask← one of the nodes to be within the radius of the destination nodes
[ if ( pxcor >= 0 and pxcor <= 40 and pycor >= 0 and pycor <= 20)
begin
set id5 ← who
if (id5 != id44 and id44 != 0 and id44 != id4)
create-friend-to node ← id4
set color ← pink
set thickness ← 0.3
]

]

]

]

]

ask ←nodes with [ pxcor > 0 and pxcor <= 40 and pycor >= -20 and pycor <0]
```

```
set color ← 117
set shape ← "circle"
begin
1. ask ←nodes-on (Patch -set Patch 1 -1 Patch 1 0 Patch 0 -1 Patch 0 0 Patch 1 1
Patch 1 0 Patch -1 0 Patch -1 -1 Patch -1 1 Patch 0 1]
begin
set id4444 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
2. ask ←nodes-on (Patch -set Patch 4 -3 Patch 4 -2 Patch 4 -3 Patch 5 -3)
begin
set id444 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
3. ask ←node id4
begin
if (link-with node id44! = nobody)
create-friend-to node  ← id44
set color ← blue
set thickness ← 0.5
]
]
]
ask node id4
Ask← one of the nodes to be within the radius of the destination nodes
if( pxcor > 0 and pxcor <= 40 and pycor >= -20 and pycor < 0)
begin
set id5 ← who
if (id5 != id44 and id44 != 0 and id44 != id4)
create-friend-to node ← id4
set color ← pink
set thickness ← 0.3
```

```
]
]
]
]
]
ask ← nodes with [ pxcor >= -40 and pxcor <= 0 and pycor >= -20 and pycor <=
0]
set color ← 117
set shape ← "circle"
begin
ask ←nodes-on (Patch -set Patch 1 -1 Patch 1 0 Patch 0 -1 Patch 0 0 Patch 1 1
Patch 1 0 Patch -1 0 Patch -1 -1 Patch -1 1 Patch 0 1]
begin
set id4444 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
ask← nodes-on (Patch -set Patch -2 -4 Patch -1 -4 Patch -1 -4 Patch -1 -5 Patch -2 -
5 Patch 0 -5 Patch -  1 -2 Patch -2 -3 Patch 0 -3 Patch 0 -4)
begin
set id444 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
ask ←node id4
begin
if (link-with node id44 != nobody)
create-friend-to node  ← id44
set color ← blue
set thickness ← 0.5
]
]
]
```

```
. ask ←node id4
Ask ← one of the nodes to be within the radius of the destination nodes
[ if(pxcor >= -40 and pxcor <= 0 and pycor >= -20 and pycor <= 0)
begin
set id5 ← who
if (id5 != id44 and id44 != 0 and id44 != id4)
create-friend-to node ← id4
set color ← pink
set thickness ← 0.3
]
ask← nodes with [ pxcor >= -40 and pxcor < 0 and pycor > 0 and pycor <= 20]
set color ← 117
set shape ← "circle"
begin
1. ask ← nodes-on (patch-set patch 1 -1 patch 1 0 patch 0 -1 patch 0 0 patch 1 1
patch 1 0 patch -1 0 patch -1 -1 patch -1 1 patch 0 1]
begin
set id4444 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
2. ask ←nodes-on (Patch -set Patch -2 3 Patch -1 3 Patch -1 2 Patch -2 2 Patch -3 2
Patch -3 3 Patch -1 4 Patch -2 4 Patch -4 2 Patch -3 4 Patch -2 1 Patch -3 1)
begin
set id444 ←  who  //node marked as destination
set color ←  red
set size ← 3
]
3. ask ← node id4
begin
if (link-with node id44 != nobody)
create-friend-to node  ← id44
set color ← blue
set thickness ← 0.5
```

]
ask← node id4
Ask← one of the nodes to be within the radius of the destination nodes
if(pxcor >= -40 and pxcor < 0 and pycor > 0 and pycor <= 20)
begin
set id5 ← who
if (id5 != id44 and id44 != 0 and id44 != id4)
create-friend-to node ← id4
set color ← pink
set thickness ← 0.3
]
END.

16. Calculate the Number of Links.

let Cnode self. ← Information for the current node
let CloNode self ← Information for the close node
let IdC who ← id cureent node
let IdCl who ← id close node
let X1 ← xcor
let Y1 ← ycor
set d 1000 ← distance from close node to destination
Ask ←nodes (distance Cnode <= rang)
begin
if (sqrt (X1 ^ 2 + Y1 ^ 2) <= d)
set d ← sqrt (X1 ^ 2 + Y1 ^ 2)
set CloNode ← self
let x2 ← xcor
let y2 ← ycor
if (CloNode! = Cnode) [
create-friendship-with ← C-Node
set color ← green
set thickness ← 0.3
set dd sqrt ((X1 – x2) ^ 2 + (Y1 - y2) ^ 2) ← Distance between two nodes

set Path-Length count link-set [my-links] of nodes ← Calculate the number of links
]
print the number of links
END.

17. Calculate the Length of Links.

let Cnode self. ← Information for the current node
let CloNode self ← Information for the close node
let IdC who ← id cureent node
let IdCl who ← id close node
let X1 ← xcor
let Y1 ← ycor
set d 1000 ← distance from close node to destination
Ask nodes (distance Cnode <= rang)
begin
if (sqrt (X1 ^ 2 + Y1 ^ 2) <= d)
set d ← sqrt (X1 ^ 2 + Y1 ^ 2)
set CloNode ← self
let x2 ← xcor
let y2 ← ycor
if (CloNode! = Cnode) [
create-friendship-with ← C-Node
set color ← green
set thickness ← 0.3
set dd sqrt ((X1 – x2) ^ 2 + (Y1 - y2) ^ 2) ← Distance between two nodes
set Path-Length count link-set [my-links] of nodes ← Calculate the number of links
set path-length2 count links + dd ← Calculate the length of links
]
print the length of links
END.

المستخلص

يُطلق على طوبولوجيا الشبكة المحلية اسم الشبكة المعشقة إذا كانت عُقد البنية التحتية الخاصة بها متصلة بشكل مباشر وغير هرمي ، ويمكن تسمية الشبكة المعشقة بالشبكة اللاسلكية المعشقة. تتكون الشبكة المعشقة اللاسلكية من موجهات شبكية وعملاء شبكيين وبوابات. مع التقدم في تكنولوجيا الاتصال وتعقيد الشبكات اللاسلكية ، هناك عوامل مختلفة لها تاثير في تقليل أداء الشبكة هذه العوامل هي ؛ موازنة الحمل ، توفير جودة الخدمات ، التأخيرمن طرف الى اخر ، تحسين الإنتاجية. طرق التوجيه التقليدية غير قادرة على تحقيق أداء الشبكة المطلوب. وبالتالي ، سيتم استخدام المزيد من التقنيات لتحسين أداء الشبكة .

في هذه الدراسة ، يتم إنشاء الشبكات المعشقة اللاسلكية عن طريق نشر عدد مختلف من العقد في منطقة ثابتة. يتم تحديد أقصر مسار بين المسارات المتاحة. في بعض الأوقات ، قد تكون نقطة واحدة أو أكثر على أقصر مسار مشغولة أثناء الإرسال من العقد الأخرى ، يتم اقتراح مسار بديل كحل لتجنب إسقاط الحزمة أو فقدان الرسالة. تم اقتراح نهج الانحدار لتقدير عدد الروابط الممكنة وأطوالها لكل شبكة مقترحة. يعتمد نهج التقدير هذا على عاملين ؛ عدد العقد ومنطقة تغطية العقدة. يتم تقييم مقاييس الأداء وتقديرها باستخدام محاكي النت لوكو .

بعد تحليل وتقييم أداء الشبكة المعشقة المقترحه لوحظ زيادة الانتاجية بمقدار 133% عند زيادة عدد العقد والنطاقات ، وتقليل التاخير من طرف الى طرف بنسبة 50% عند زيادة عدد العقد والنطاقات بالاضافة الى زيادة في جودة الخدمات بنسبة 0.004% عند زيادة عدد العقد والنطاقات .

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة بابل كلية تكنولوجيا المعلومات

قسم شبكات المعلومات

محاكاة شبكة الميش اللاسلكية وتقدير الروابط باستخدام نموذج الانحدار

رسالة مقدمة إلى
مجلس كلية تكنولوجيا المعلومات - جامعة بابل كجزء من متطلبات
نيل درجة الماجستير في تكنولوجيا المعلومات / شبكات المعلومات

من قبل

زهراء عبدالله كحيط عبدالله

بإشراف

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