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Modeling the Connectivity Probability in Wireless Sensor Networks

A Thesis
Submitted to the Council of the College of Information Technology/University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master in Information Technology/Information networks

By

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بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

وَإِذْ قَالَتِ الْمَلَائِكَةُ يَا مَرْيَمُ إِنَّ اللَّهَ اصْطَفَاكِ وَطَهَّرَكِ وَاصْطَفَاكِ عَلَىٰ نِسَاءِ الْعَالَمِينَ(42)

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[آل عمران: 42–43] 1.1

Supervisor Certification

I certify that this thesis was prepared under my supervision at the Department of network, Collage of Information Technology, University of Babylon, by **Maryam Ayad Gabbar** as a partial fulfillment of the requirements for the degree of **Master in Information Technology.**

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Date: / / 2022

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Declaration

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

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Name: Maryam Ayad

Date: / / 2022

Dedications

This work is dedicated to…

My travelling father,

I will always be your eldest daughter of whom you are proud. You are my first mentor and my support in this life. May Allah protect you for our sakes.

My mother,

I pray that Allah protects you against all evils. You are everything in my life; you are my sister, my friend and the most affectionate mother ever. It is a promise that I keep you in my heart as long as I live.

My beloved brothers Buraq and Mohammed who have always been by my side. May Allah surround you with his merciful mercy and bless you as well.

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Above all, I am so grateful to God (Allah) for His infinite power of blessings that continue to flow into my life to this day and to this point.

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

Maryam Ayad Gabbar

Abstract

The connectivity of a wireless sensor network (WSN) is generally measured by the probability that all the sensors are connected to a sink node (base station) via one or more intermediate nodes. Network connectivity represents a measure of how easily and reliably a packet sent by a node can reach another node in a network. The simulation experiment is investigated by randomly deploying all the nodes in a given area and estimating the connectivity of the whole network. An appropriate connectivity threshold is calculated by a developed modeling and simulation approach and a regression equation is proposed to be used as an estimator to calculate the connectivity threshold for any transmission power or range. Sensors in a WSN can communicate and exchange information with neighbors based on their communication radius. The number of the generated messages are modeled an simulated based on a Poisson and exponential distributions with different rates. The connectivity probability is estimated based on the fundamentals of the Binomial probability distribution. Another approach is used to estimate the network connectivity based on an exact sent messages rate. Different network performance metrics are calculated to evaluate the network behaviors. Various results and solutions are provided and discussed by different simulation experiments. The collected simulation results are utilized mathematically in generating a general regression formula to be used in advance to calculate any required parameter instead of re-running the simulation experiments. These equations are trained with the simulation results to ensure their validity. The equations results are found very accurate and identical to the simulation results. These equations can be easily used to calculate any wanted result without running the simulation experiments. The simulation models are created using Net Logo programming fundamentals.

List of Thesis Related Publications

Conferences > 2022 10th International Confe...

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Maryam Ayad Gabbar ; Saad Talib Hasson All Authors

Abstract

Document Sections

I. Introduction

II. Connectivity in WSN

III. Proposed Simulation Model

IV. Simulation Results

V. Conclusions

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Keywords

Abstract:
Wireless Sensor Networks (WSNs) are utilized to communicate the collected information wirelessly. A wireless network can be represented as a graph composed of nodes and links. Such graph is known as connected graph if it has at least one path from any node to any other nodes, otherwise it will be indicated as a disconnected graph. A graph is considered a connected graph if for any two vertices x1 and x2 belong to a graph, there is a path whose ends at x1 and x2. The connectivity problems in WSNs are representing a crucial issue in all the WSNs applications. The network connectivity is an indication for a connected graph, it can be lost by removing certain number of the nodes from the network. This number of nodes can be used as one of the network connectivity threshold values. Sensors in a WSN can communicate and exchange information with neighbors based on their communication radius. This paper is to model the connectivity and the connectivity probability problems in WSNs. The effects of varying the number of the deployed sensors and their communication radius (range) on the network connectivity are analyzed and evaluated. To evaluate the developed model in this study, different rates are used in transmitting messages during the proposed WSNs. These rates are implemented as random values with different rates to model the connectivity probability. The number of the generated messages are created based on a Poisson distribution with different means. The connectivity probability is estimated based on the binomial probability distribution. Another approach is used to estimate the network connectivity based on an exact sent message rate. Different network performance metrics are calculated to evaluate the network behaviors.

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CERTIFICATE

This certificate is granted to

Maryam Ayad

for his/her active and invaluable participation as a

Presenter

with a paper entitled

Wireless Sensor Networks Connectivity based on Sensors Transmission Power

In the 11th Electrical Power, Electronics, Communications, Control, and Informatics Seminar 2022

held from August 23-25, 2022 at Malang, East Java - Indonesia

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Universitas Brawijaya

Dr. Fakhriy Hario Partiansyah
General Chair of EECCIS 2022

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ACK	acknowledgment
CSMA/CA	carrier sense multiple access collision avoidance
CWmin	contention window minimum
CWmax	contention window maximum
DCF	distributed coordination function
DIFS	distributed inter frame space
GPS	global positioning system
ISM	industrial, scientific, and medical
MAC	media access control
PL	path loss
PLE	path loss exponent
SIFS	short inter frame space
SSO	slap swarm optimizer
Total rx	total received
Total tx	total transmitted
TSO	tunicate swarm optimizer
Tx power	transmission power
WSN	wireless sensor network

CHAPTER ONE

Introduction

CHAPTER ONE
Introduction

1.1 Introduction

Wireless sensor networks WSNs represent a useful and applicable universal technology to collect significant knowledge resulting from utilizing available low-cost units as well as low-power wireless technology (Singh et al., 2018). WSNs are composed of sensor nodes deployed in the form of groups to perform sensing tasks. It can observe, monitor, collect and track environmental parameters automatically and transfer the collected data using wireless networking to a base station (Tripathi et al., 2018). WSNs are commonly used for numerous applications. Several challenges must be addressed and considered before implementing any WSN. These challenges are: connectivity, localization, channel access, coverage, energy, security and scheduling (Potdar et al., 2009).

A network can be considered as a connected network if a communication link is existing between every couple of the nodes, so theses nodes can communicate with each other (Mekikis et al., 2016). Graph representation can be utilized to model the network connectivity. (Y. Li et al., 2020). Radio signal is usually used to achieve the communication between any sensor nodes and the base station either directly (single-hope) or through intermediate nodes (multi-hope).

A sensor node is having an ability to sense, converts the physical value of the sensed quantity into a suitable signal form. One of the important metric to measure the quality of the WSNs, is how to communicate the sensory data of the target to the sink. The deployed sensor nodes can affect the process of sensing or monitoring the given area (Harizan & Kuila, 2019). Sensors are powered by batteries. It is essential to decrease the power consumption of the sensors during their connectivity operation. Deployment approaches and power allocation with the network topologies must be carefully considered (Yang & Chin, 2016).

In this study, WSN connectivity and connectivity probability were considered. The sensors transmission range is modeled based on the transmission power. The Effect of sensors deployment approaches and the sensors transmission ranges on the wireless sensor networks connectivity represents the main focus of this thesis. A simulation approach is utilized in creating the network topology as well as in implementing the proposed scenarios.

1.2 problem Statement

Full connectivity may not be feasible to be achieved in WSNs. A crucial problem in a WSN is its connectivity, it significantly influences the case of sensor communication with one another and the process of transferring data to a sink node. A WSN must have a proper connectivity in order to accomplish reliable and seamless communication. All nodes must be connected to correctly deliver their messages. The major necessary stage in designing any new WSN is the sensors deployment. It is powerfully influences the network performance in its effective communication and precise detection. Modeling and simulation represent the unique tool in proposing, creating, and evaluating the WSNs by offering a platform to implement and operate different scenarios.

1.3 Thesis Aim

The main aim of this thesis is to Model and Simulate the Connectivity and the Connectivity Probability in Wireless Sensor Networks and to analyze the effects of the deployment approach, number of sensors and their transmission ranges on the connectivity issue. This aim can be achieved by the following objectives: -

- Suggesting different simulation scenarios to analyze and evaluate the effects of the deployment approach, number of the deployed sensors, sensors transmission power on a network connectivity within a certain area.
- Proposing generalized mathematical models as estimators to be used for the network connectivity and connectivity probability estimation instead of the simulation experiments.
- Test and evaluate the connectivity proposed models.

1.4 Related Works

Saunhita and Mini at 2018 proposed a wireless sensors situated in certain positions, these sensors can be divided into isolated groups as a result of the failure of one or more sensors. These isolated groups may result in the entire network failure. To guarantee the accuracy of the data gathered by the sink node, the isolated groups connectivity must be restored. By placing relay nodes at certain places throughout the deployment area, they ensure the fully connected network. To create a fully connected WSN, it is necessary to locate the best relay nodes. Their suggestion is implemented by checking the network's connectivity using the heuristic fully connected network. Simulations have been performed in implementing their proposal (Sapre & Mini, 2018).

Hanbing Cong et. al. at 2018 considered that an energy harvesting technique was a good way to give sensors sustained power. The unpredictability of the energy harvesting process, which results in practically random link construction among sensors, makes it difficult to always ensure network connectivity in energy-harvesting wireless sensor networks. Based on the energy harvesting random graph, they examined at the network connection in Energy Harvesting Wireless Sensor Networks. They suggested the Statistical Analysis algorithm and the Path Probability algorithm. To determine the probabilities of network connectivity. As an indicator of the network's connection, the lowest, greatest, and average node connections probabilities as well as the network's maximum connectivity ratio were used. The relationships between connectivity, node density, node usable probability, link customizable probability, communication radius, and the position of the sink node were analyzed using simulation scenarios.(Cong et al., 2018).

Mekikis et al. stated in 2018 that the emergence of Machine-type communication is one of the 5G communication paradigms, would lead to a massive increase in ad hoc applications that needed connectivity across wireless network sensors. They claimed that due to transmission techniques and network topology, It is difficult to maintain a reliable network operation in fading environments. In their work, They found that the performance can be impacted by uniform or clustered deploys. As the quantity of deployed nodes rises, wireless energy harvesting and natural energy sources can reduce the maintenance costs and improving the network lifetime. They achieved a zero-energy wireless-powered sensor networks if green sources are used to power their components. They concluded that it is possible to design accurate mathematical models to represent the network's conduct. This study provided an analytical model for the connectivity in clustered wireless powered sensor networks under unicast and broadcast communications (Mekikis et al., 2018).

Pakpoom and Wiklom, at 2019 stated that a sink is set in the center of a finite rectangular plane, and a finite number of object-detecting sensors are distributed throughout the plane at random locations. Two mathematical approaches were developed by them. The first one is for the estimated detection probability at any particular location, and the second one is for the anticipated level of sink connectivity for any sensor node that cannot directly transmit to the sink. They supposed that the sensing model was Gaussian-like and dependent on the sensor node's distance, and the connection model was a binary disk. Results from simulations in various scenarios are compared showed the formulae's startling accuracy when border effects were taken into account. They utilized their research to make predictions about connectivity and coverage levels. They claimed that their established equations can be used for a variety of tasks, Among them include examining a network's ability to withstand sensor nodes failing randomly and independently and minimizing the deployment cost of diverse groups of homogeneous sensor nodes. (Hoyingcharoen & Teerapabkajorndet, 2019).

Wang et. al. at 2019 proposed the connectivity and energy efficiency algorithm, a particular type of network algorithm. They want to ensure connectivity and connectivity probability with their suggested algorithm. Within a certain communication radius, all the utilized sensors can communicate with one another. They estimated the relation among the communication radius, the connectivity, and the number of sensor nodes.

This paper tried to maximize the connectivity probability and network connectivity by selecting the sleeping and wake up nodes. According to the outcomes of their simulation, their algorithm combines connectivity and energy efficiency to provide a relevant reference value for the typical operation of sensor networks. (Wang et al., 2019).

Yinggao Yue et.al. at 2019, explored the connectivity issue in wireless sensor networks. Instead of the conventional roulette wheel selection model, they took into account the artificial bee colony algorithm with the free search algorithm pheromone sensitivity model. Three different types of WSNs were examined in this paper. Through simulation and experimental verification, coverage and connectivity of algorithm performance are analyzed and compared. Random distribution, genetic algorithms, and the proposed algorithm are compared; the proposed algorithm has a higher degree of coverage and connectivity, which reduces traffic and redundancy, increases network reliability, and extends the lifetime of the network. (Yue et al., 2019).

Orhan Dagdeviren and Vahid Khalilpour Akram at 2019 stated that keeping network connectivity in WSNs is a challenging problem since node failure in some nodes may prevent communication paths in other nodes. Because a k-connected network retains connectivity even in the case that any k-1 nodes fail, the k number can be used as a statistic to evaluate the connectivity robustness of WSNs. This study considered how the k value of WSNs is affected by random node distribution and node transmission range. They generated a total of 1000 random topologies with various node counts and transmission ranges, evaluated the k value of already-existing networks, and investigated the effects of node count and transmission range on k. Their simulation result showed that they needed at least 200 nodes with a minimum transmission range of 80 m in order to predict a network with k ≥ 1 in a field of 1000 m2 with uniform random distribution. Additionally, The simulation results showed that disconnected networks are typically brought about by randomly deploying up to 500 nodes in an area with a transmission range of under 80. (Dagdeviren & Akram, 2019).

Rahul Priyadarshi et. al. at 2020 stated that WSN computing and connection have recently developed. Data extraction and transmission to distant places are the main duties of WSN. placement of nodes, efficiency in power use, distribution of bandwidth, and coverage In a WSN, deployment is a critical issue that impacts many other aspects, including coverage, connectivity, lifetime, and many more. The four key areas of connectivity improvement, coverage maximization, lifetime optimization, and energy efficiency can also be used to categorize deployment issues. In addition to a result-oriented review of alternative deployment schemes, this research addressed the goal, strategy, and constraints connected to the deployment of WSNs. Additionally, the outcomes of various deployment strategies are covered and presented in tabular form. (Priyadarshi et al., 2020b).

Jehan and Navaz at 2020 considered maximizing the connectivity and coverage issues in designing target based WSNs. They have suggested a hybrid optimization-based methodology to address the coverage and connectivity issues. As a result, the target-based WSNs can comprise the sensor nodes that are placed based on identifying a minimal number of selected potential positions. An optimization technique based on a hybrid tunicate swarm optimizer (TSO) and slap swarm optimizer (SSO) is suggested for problems with coverage and connection in WSNs. TSO operators enhance SSO is capacity to utilize its features because they can also function as local search operators. In essence, the fitness function was derived using these hybrid algorithm operators, then the solution representation step. The results of their simulation showed exceptional performance in addressing the coverage and connectivity issues in WSNs. (Chelliah, 2020).

Chaya and Jayasree at 2020, stated that a key factor in target tracking in WSNs can be connectivity and coverage. They showed that the current algorithms could be unable to select the fewest possible nodes. To reduce the drawbacks of the conventional coverage algorithms, they created a hybrid gravitational search algorithm with a social ski-driver based model. This study hybrid approach optimized the coverage and connectivity requirement in target based WSN. Their approach is validated and compared with other optimization algorithms. Their results of the randomly deployed nodes were implemented in the MATLAB simulation tool (Jayasree, 2020).

Rahmati at 2021, implied that long-term routing efficiency for WSNs is possible if uniformly distributed load balancing algorithms are used, which decreases node failures near sink nodes. A WSN was modeled in this work, and the node distribution was depicted utilizing a predetermined total point value. The underlying WSN model was simulated using an algorithm. By randomly searching a small portion of the solution space, near optimum solutions were recovered to prove that it is potential to route quickly uniformly load balanced networks (Rahmati, 2021).

Mahmood et. al. at 2021 stated that node failure causes a breakdown in inter-node connection and may also cause a division of the network. The sensor network's core functionality may be compromised if nodes are able to communicate with one another and the base station. They proposed a technique called smart node relocation. They claimed that their technique can identify and restore connectivity damage brought on by a single or numerous node failures. They demonstrated that smart node relocation beats previous methods in terms of a variety of performance indicators, Including, among other things, the total number of packets sent, the total distance travelled to restore connectivity, and the percentage of the loss in field coverage (ul Hassan et al., 2021).

Table 1.1: A Summarizing of the Relevant Works

Author &year	**Problem**	**Tools**	**Results**
Saunhita Sapre and S. Mini at 2018	Relay nodes positioning to achieve full connectivity.	Moth flame optimizer algorithm, interior search algorithm and bat algorithm.	Number of relay nodes needed for different sensors node counts. Number of required relay nodes versus number of deployed sensor nodes for varying radius.
Hanbing Cong et. al. at 2018	Calculated the connectedness of the network. Network connectivity is affected by node density, sink node location, feasible probability, communication radius, and link failure.	The simulation experiment was created using a control variable approach.	They calculated the relation between node density and connectivity, connectivity and radius, and node workable probability and connectivity.

Prodromos-Vasileios Mekikis et.al. at 2018	Employed a cloud-aware algorithm in order to achieve a high network connectivity without energy interruptions due to energy limitations.	Cloud Cover Aware Algorithm for Energy Allocation.	provided an analytical model for the connectivity in two widely used transmission strategies, namely unicast and broadcast, in a large scale zero energy clustered WPSN.
Pakpoom Hoyingcharoen and Wiklom Teerapabkajornd et at 2019	Deploying sensors in real terrestrial applications.	obtaining a mathematical expression for the connectivity and coverage levels.	Relation between the simulation results and analytical estimations for expected detection probability at each deployment level with average detection probability. The expected degree of sink connectivity for various transmission range values with different values of sink connectivity.
Lijun Wang et. al. at 2019	The energy consumption and connectivity problems in WSN to ensure the connectivity, connectivity probability and to decrease the energy consumption.	Developed energy efficiency and connectivity algorithm.	The relation between the connected probability, node connectivity and node communication range.
Yinggao Yue et.al. at 2019	WSN coverage and connectivity problem.	Developed a hybrid artificial bee Colony algorithm.	The relation between the number of nodes and coverage degree. They observed the network lifetime.
Orhan Dagdeviren and Vahid Khalilpour Akram at 2019	Random deployment and transmission radius effects on network connectivity in WSNs.	Simulation, graph theory fundamentals and random deployment.	Established the suitable k value for a random deployment based on the number of sensors and their transmission radius.

Rahul Priyadarshi et. al. at 2020	The effect of the deployment approach on connectivity, coverage and lifetime.	Simulation	Connectivity and coverage estimation with different diffusion levels at various random deployment approaches.
Jehan Chelliah and Navaz Kader at 2020	Connectivity and coverage problem optimization in WSNs.	Slap swarm and hybrid tunicate swarm optimizer algorithms (Metaheuristic).	The optimal positions using hybrid tunicate swarm optimizer and slap swarm optimizer for different scenarios.
Chaya Shivalingegowda and P. V. Y. Jayasree at 2020	Connectivity and coverage problem optimization in WSNs.	mixed integer linear programming, gravitational search algorithm with k- mean clustering.	Relation between network lifetime, number of active sensors, connectivity with the number of deployed sensors. The relation between transmission radius and network lifetime.
Vahid Rahmati at 2020	Connectivity Matrix and routing optimization problem	Random routing algorithm	The simulation results show that updating the connection matrix after each routing leads to a more balanced network in loading and thus improves the path efficiency.
Mahmood ul Hassan et. al. at 2021	The problem of node failure in wireless sensor networks and disruption of communication between nodes	Technique called smart node relocation.	Detect single and multiple node failures and restore connectivity efficiently by relying on minimal movement of nodes. It also avoids the cascade transfer problem by moving the minimum number of nodes to restore connectivity. Field coverage is improved as it results in a minimal reduction in field coverage compared to other approaches.

1.5 Thesis layout

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

Chapter two talks about the basic and theoretical concepts of connectivity process in "Wireless sensor networks".

Chapter three displays how simulate the connectivity process in wireless sensor networks using Net Logo.

Chapter four contains the results of the proposed system and its evaluation.

Chapter five This chapter presents the conclusion for the thesis as well as some suggestions for future works.

CHAPTER TWO

Connectivity in WSN

CHAPTER TWO

Connectivity in WSN

2.1 Introduction

Determining the best sensor's transmission line to the destination is a critical issue in such networks (Akyildiz et al., 2002). WSNs are typically deployed in different areas based on the required application. Most of their deployment are randomly (Elloumi et al., 2018). In a random topology, if one or more of the nodes fails for whatever reason battery drain, hardware failure, etc. The communication links with other live nodes may be broken. In other words, if a WSN loses some of its nodes, the network can be divided into isolated sub networks (Priyadarshi et al., 2020a). When certain nodes lose their connection, the sink is unable to reach them, wasting a lot of active resources. There may be at least one node (cut vertex) in some types of connected networks that, in the event of failure, would totally disconnect some nodes. Since the connectivity of the whole network depends on a select few nodes operating correctly, such connection types are typically regarded as unstable (Cao et al., 2021). To fail network connectivity in another linked network, at least k nodes must stop operating. A greater k value increases the number of alternate paths and the fault tolerance of WSNs. The location of the nodes and each node's transmission range greatly affect the network connectivity in random deployments (Wang et al., 2019). The influence of random deployment, transmission power, and transmission ranges on network connection is the main topic of this thesis. The analysis and evaluation of the relationship among the number of sensors, transmission power, and transmission range in a defined area size.

2.2 Challenges in WSNs

Data collection from the sensor node members of the WSN, which are spread out over big zones and deployed in great numbers, is one of its distinct characteristics. There will be numerous difficulties with this kind of network that will affect the design, effectiveness, and functionality of the WSNs (Sharma & Kaur, 2021).

- **Power Consumption:** the power management in sensor networks is the main issue. Designing power-conscious algorithms and protocols for WSN is essential (Ibrahim et al., 2021).
- **Production Cost:** the sensor can be considered as disposable devices, due to the several deployment models. Only if the particular sensor node could be made cheaply would sensor networks be able to compete with conventional information gathering techniques. The goal price for a sensor node should ideally be extremely low. The price of a sensor needs to be brought down in order to make a WSN practical. This makes the price of a sensor a very difficult problem (Torres-Ruiz et al., 2018).
- **Computational power and memory size:** Every sensor stores data independently, and oftentimes more than one node saves the same information and transfers it to the sink, wasting power and node storage capacity. Effective strategies are therefore required to reduce redundancy in the WSN (Sharma et al., 2014).
- **Operating environment:** Nodes for sensors may operate in conditions that are very difficult. These nodes could be used for automobile traffic control, at the bottom of the ocean, in a house or other big building, etc. (Rajasekaran & Anandamurugan, 2019).

- **Deployment:** Deployment means placing a network of working sensors in a real world environment. Deployment of nodes is a crucial problem to tackle in WSNs. A suitable node deployment strategy will minimize of WSN issues such as routing, the convergence of data, connectivity, etc. It can also prolong the life of WSNs by energy reduction. WSNs nodes will be deployed in various manners under various situations of application. Techniques of deployment are tightly associated with particular applications, the type of sensors and the environment the network will work in. Deployment is of two types: deterministic deployment and random deployment (Sharma et al., 2014).
- **Connectivity:** Connectivity is also another serious problem in WSN that discusses The transmission of sensed data from the source sensor to the target named sink. Connectivity is often used to define WSN's topological features, which could influence the outcomes of the connection between sensor nodes. Coverage and connectivity are essential for the network to achieve various monitoring tasks. Given the two items are ensured (coverage and connectivity), Lifetime of the network is known as the interval of the network that starts from the network is put up to the network loss able to meet specific coverage and/or connectivity criteria (Sharma & Kaur, 2021).

2.3 Application of WSN

There is a wide range of fields the sensor networks are utilized, such as military applications, medical, environmental monitoring. In general, Due to the fact sensor networks support the interaction between humans and material science to it, it would be all over the place in the near future. To get a lot of applications to explore new applications in the real-world sensor nodes applied in the uncontrolled environment. Deployment tightly sensing node with the ability to remote sensing, wireless communications, and the calculation in the uncontrolled environment, which helps in measuring the ambient conditions, and get the important characteristics surrounding this node, transforming sensed and collected data into electronic signals can be processed, is the idea behind these application (Derakhshan & Yousefi, 2019). Sensor networks play an important role in the following applications (Kandris et al., 2020).

- Environmental applications
- Health care applications
- Agricultural applications
- Structural monitoring
- Intelligent home monitoring
- Military applications
- Industrial applications
- Vehicle detection
- Congestion control

2.4 Sensor Node Component

Sensor network contains many sensor nodes, each of them has the ability to execution some processing, gathering information from its Surroundings, and shared with other linked nodes in the network. Figure (2.1) shows the component sensing node.

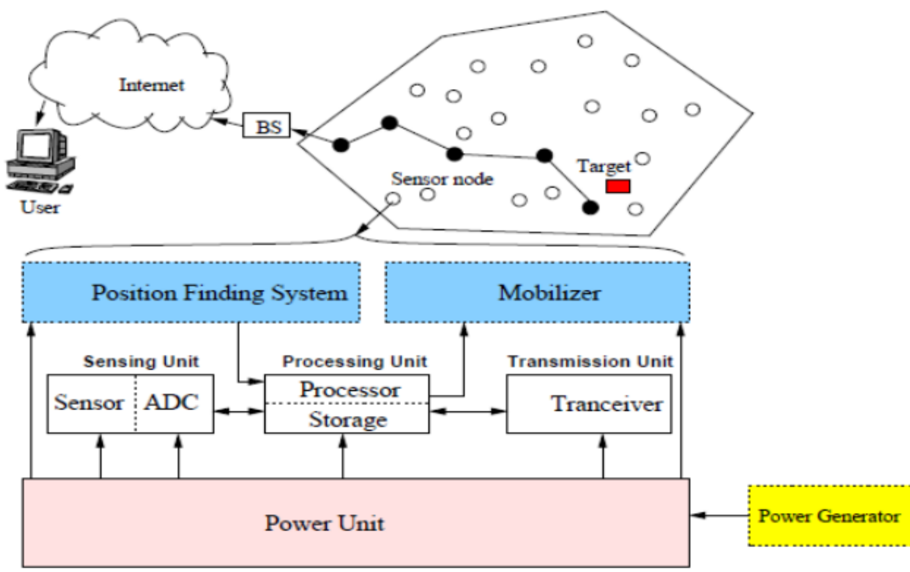


Figure 2.1: Sensor Node Component (Negi et al., 2015)

Four essential elements of the nodes of sensor are: a transceiver unit, a power unit, a processor unit and a sensing unit. The node of sensor may also contain other components for position recognition unit such as a Global Positioning System (GPS), a mobilizer (Negi et al., 2015).

2.5 Transmission

Sensors are transmitting either directly as a single hop or Multi hop Transmission.

2.5.1 Direct Transmission

Messages are transferred directly from the sensing region to the base station in some applications. If the distance to the base station is long, a single node to transmit data become not capable to directly send the data, or too much energy may consume (Hasson & Al-Kadhum, 2017) . Figure (2.4): show the process of direct transmission.

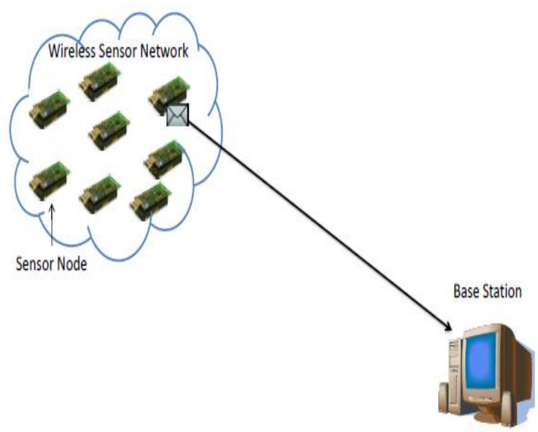


Figure 2.2: Direct Transmission (Hasson & Al-Kadhum, 2017).

2.5.2 Multi hop Transmission

Relay nodes are used to transmit data from the sensing region to the base station. data transmitted through multi hops. The data collected by a sensor node sent to a relay node at first that is nearer to the base station when it is far away from the base station (Hasson & Al-Kadhum, 2017). Then the sensor node (relay) sends the data to the base station. When the distance to the base station is even farther, the data forwarding technique can be extended to more hops. The distance between every two hops when transmitting through multiple hops shorter than that in direct transmission (Al-Shalabi et al., 2019) . Therefore, each relay node consume less energy. When there are no relay nodes available Multi hop transmission fails, such as sending the data that has been gathered from the ground to a satellite. The remaining energy and the power utilized to cover some of the distance traveled are the two parameters used to determine the relay node (Mohanty & Kabat, 2016). Figure (2.3) shows the process of multi hop transmission.

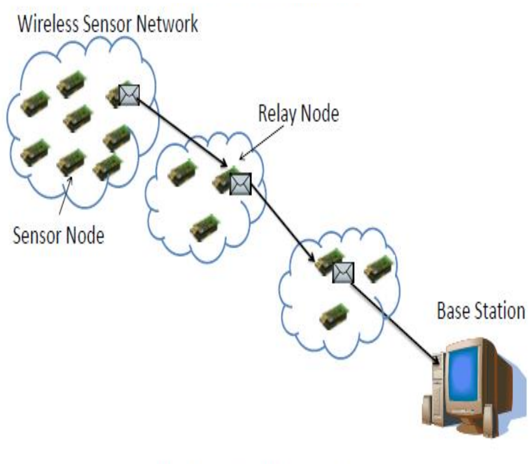


Figure 2.3 : Multi Hop Transmission (Hasson & Al-Kadhum, 2017).

2.6 Connectivity and Probability

WSNs are composed based on either random or predefined deployment approach. Sensors can be failed in all or some of their functions. Such failures are probable. Certain probability distribution can be utilized to model the sensors behavior. Network Connectivity can be modeled as a binomial probability distribution. In this study, a Binomial probability distribution (Wang et al., 2019) is utilized to test the connectivity as indicated in (2.1):

$$B(n,k) = \sum_{k=0}^{n} \binom{n}{k} P^k (1-P)^{n-k} \qquad (2.1)$$

where n is the number of deployed sensors, k is the number of the connected nodes effectively with probability (p) and;

$$\binom{n}{k} = \frac{n!}{k!(n-k)!} \qquad (2.2)$$

The Poisson distribution density function (Wang et al., 2019) is shown in (2.3):

$$\Pr\,(X = k) = \frac{e^{-\lambda}\,\lambda^{k}}{K!} \qquad (2.3)$$

2.7 The Constraints of the Sensor Node Deployment

A WSN's primary restriction is the deployment of sensors. The fundamental attributes of a WSN, such as connection, coverage, cost, and lifetime, are determined by the type of deployment, the number of sensors, and the desired locations of the devices. A wireless sensor node is outfitted with radio transceivers, power supplies, and sensing and processing equipment. A wireless sensor network's individual nodes are fundamentally limited in terms of their computing power, storage space, and communication bandwidth (Priyadarshi et al., 2020b). Figure (2.4) provides an illustration of the deployment approach in order to better comprehend it.

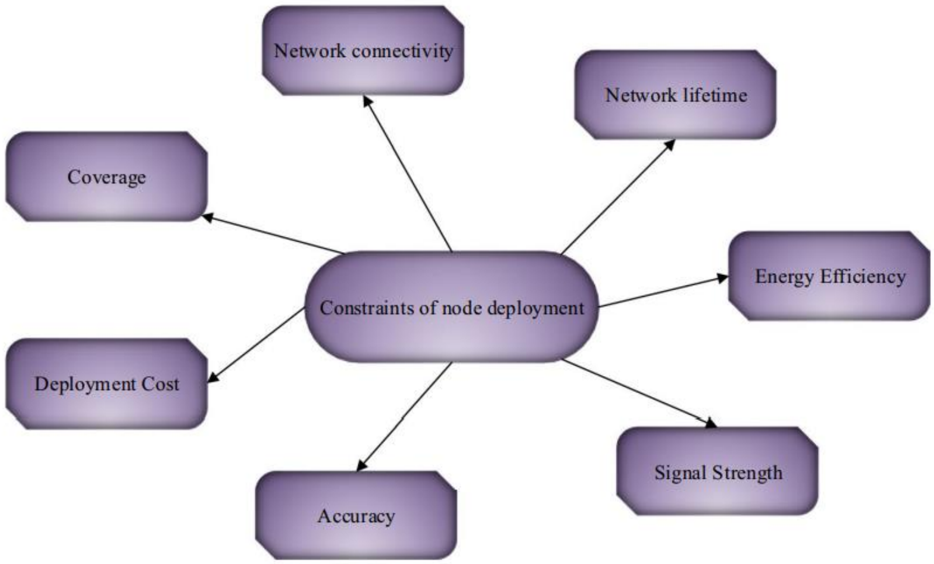


Figure 2.4: Deployment Constraints For The Sensor Nodes (Priyadarshi et al., 2020b).

2.8 Approaches for Deploying WSNs

The deployment of WSNs is typically separated into two categories: the deployment of static sensors and the deployment of dynamic sensors. The type of the region of interest, the type of sensors, and the type of application are just a few of the variables that influence the choice of a suitable method. Static sensor deployment is the process of deploying sensors that do not move once they are in place. The term "dynamic sensor deployment" refers to the deployment of sensors that can change position (Priyadarshi et al., 2020a). There are two different approaches for deploying static sensors:

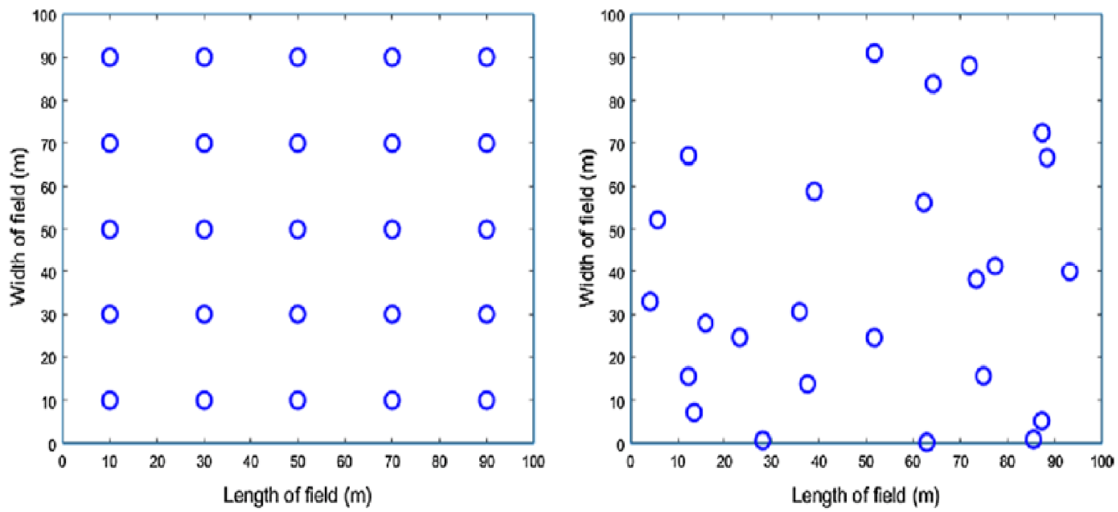
- Random deployment
- predefined deployment

2.8.1 Predefined Sensor Deployment

deployment is occasionally referred to as grid deployment. Prior to the nodes' actual deploy, the coordinates of each node inside the area are established in predefined deployment. The placement of sensor nodes is chosen in a way that maximizes target monitoring, lowers network costs, makes efficient use of energy, and extends the life of the sensor network (Tripathi et al., 2018).

2.8.2 Random Sensor Deployment

Random deployment is often the only option, for example, in WSN applications to detect forest fires, combat reconnaissance missions and disaster management when controlled deployment is very dangerous and sometimes impossible. One of the most common ways to deploy sensors is to drop them from a plane. We can say that distribution in this way leads to the random deployment of the sensors but it is possible to control it and to control to a certain extent the density of these sensors. Although not very practical, many research projects assessed network performance and found a uniform sensor distribution. The reason for this is the expectation of a large sensor population with the continuous reduction of the cost and size of micro sensors, and therefore a uniform distribution becomes a practical approach (Saad et al., 2018). The performance of the WSN with sensor nodes deployed randomly will be worse than that of the sensor node deployed predefined. This creates a challenge to improve network performance while taking the application's various characteristics into account (Feng, 2010). Figure (2.5) shows type of static sensor deployment.



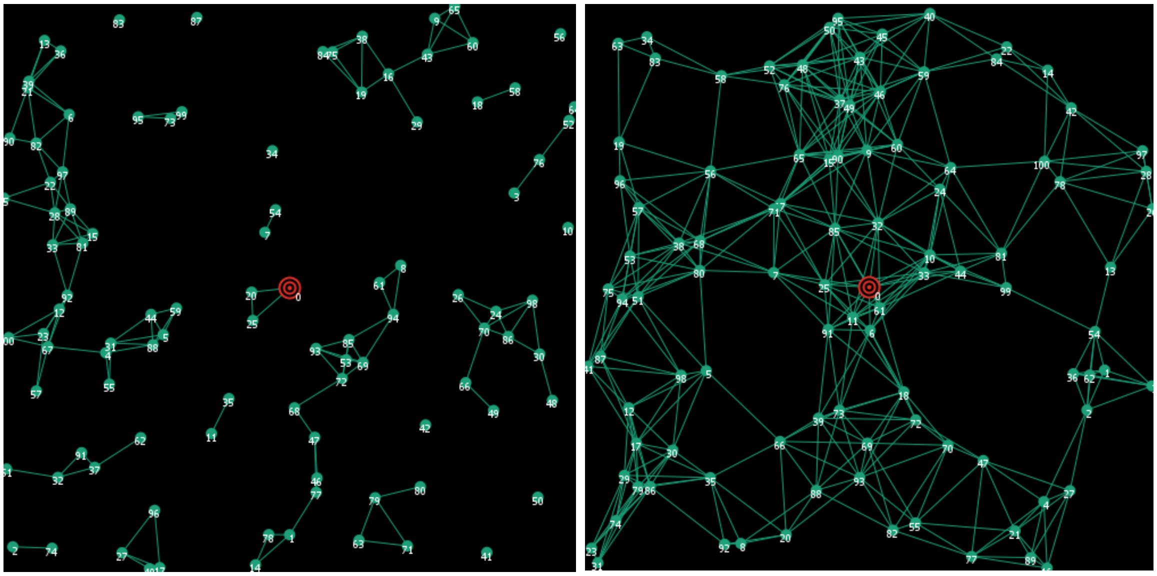
(a) (b)

predefined deployment *random deployment*

Figure 2.5 : Type of Static Sensor Deployment (Bhat, Soumya & Santhosh, K.., 2020).

2.9 Connectivity

A general assumption is that all sensors have the same range of communication. Sensors may vary in age, manufacturer and communication capacity. For this reason, some sensors may have an advanced range of communication than others (Dagdeviren & Akram, 2019). Figure (2.8) represents a sample of this thesis implementation snapshots, in (a) a disconnected topology where some sensors cannot communicate with the base station (unconnected graph). Furthermore, in Figure (2.8 b) all sensors can communicate with base station (connected graph).



(a) disconnected network *(b) connected network*

Figure 2.6 : Connected and Disconnected Topology.

2.10 Radio Transceiver

The radio transceiver utilized in this study is an nRF24L01+ which used as a single chip radio transceiver in Net Logo. In this radio transceiver type, each module is capable of sending and receiving data. It runs between 2.4 and 2.5 GHz in frequency. ISM (Industrial, Scientific, and Medical) band applies to this frequency. It was used in most engineering applications with channel bandwidth of 1 MHz at 250 - 1000 kbps, 2 MHz at 2Mbps. The energy threshold represents the node low battery state value (Mahbub, 2019). This module is a fantastic option for any wireless networks because it can cover a distance of 100 meters. It operates with about 3.3V. The module has a channel capacity of 125, which allows for the establishment of a network of 125 independently operating modems in one location. Each channel can support up to 6 addresses, and each unit is capable of simultaneous communication with up to 6 other units. This module is suitable for Mesh networks topologies. It can transfer data with rates of 250 kbps, 1Mbps and 2Mbps.This radio transceiver module can also supports output power with ranges (-6 dBm, -12 dBm, -18 dBm, or 0 dBm). As an example, for 0 dBm it consumes 11.3 mA (Simicondutor, 2008). For example

Applications

- Connected devices
- Wireless control application
- Mesh networks
- RF remote controllers

As an example, table (2.1) Presents the transmission power consumption against the transmission cost (current) for several device configurations of nRF24L01+ specification. Table (2.2) , presents the bit rate values against the receiving cost (Simicondutor, 2008):

Table 2.1 transmission power consumption.

Tx Power	Tx Cost
-18dBm	7.0mA
-12dBm	7.5mA
-6dBm	9.0mA
0dBm	11.3mA

Table 2.2 bit rate values.

Bit rate	Rx Cost (mA)
250 kbps	12.6
1Mbps	13.1
2Mbps	13.5

2.10.1 Receive Sensibility

The smallest signal strength that a receiver can detect is known as receiver sensitivity. It reveals the least-powerful signal that a receiver will be able to recognize and interpret. In dBm, receiver sensitivity is measured. The lower the power level of the signal, the better because it indicates how weak an input signal must be in order for the receiver to correctly receive it. A receiver with a sensitivity of -90 dBm, for example, is better to one with a sensitivity of -80 dBm because it is more sensitive and able to decode signals at lower power. The usual receiver sensitivity range for different RF modules is between -50 and -100 dBm. Receiver sensitivity specifications differ between standards and technologies. The receiver sensitivity is influenced by a receiver's bandwidth and noise level (Ferrari et al., 2004). In this study, the sensitivity of the receiver equal to -94 was used, depending on the radio used in this model.

2.10 .2 IEEE 802.11

The most used technology for wireless local area networks is the IEEE 802.11 standard. One of the most important elements of 802.11 in terms of performance is the media access control (MAC). Access to the shared medium is primarily controlled by the MAC protocol. The distributed coordination function (DCF) is the main medium access mechanism used by IEEE 802.11 wireless networks. Based on the CSMA/CA (carrier-sensing multiple-access with collision avoidance) protocol, the sender first senses the medium to ascertain whether it is busy or idle. The sender may begin data transmission to access the channel when it is idle in order to access the medium. A sender node waits for a time period called DCF as an inter frame space (DIFS) + a multiply of a slot size by number of slots, when there are different nodes trying to access the same medium, in this case the shorter back-off period will start first. Otherwise, the sender node terminates from transmitting packets if the medium is busy (Eyadeh* et al., 2019).

Example:

Node A waits for DIFS + 4 ∗ slot size, while node B back-off is DIFS + 7 ∗ slot size. Whenever node A starts transmitting, node B freezes its own back off timer and starts it again once node A finishes transmitting plus an additional period of DIFS. Node B may also start its transmission after the back-off timeout has expired. Figure (2.10) shows Mechanisms for MAC access in IEEE 802.11.

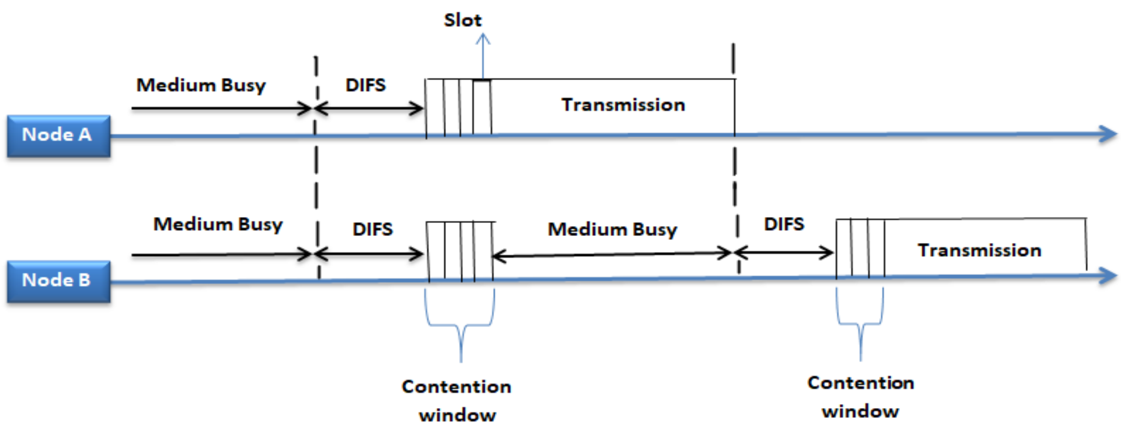


Figure 2.7: Mechanisms for MAC Access in IEEE 802.11(Dargie & Poellabauer, 2010).

2.11 Path loss (PL)

Is used to describe the loss or attenuation an electromagnetic signal (or wave) experiences as it travels from the transmitter to the receiver (Miranda et al., 2013).

2.11.1 Path Loss at a Close-in Reference Distance

Reference distance (d0) is suitable for the propagation environment free space reference distance. Microcellular systems typically employ significantly shorter distances (such 100 m or 1 m), but high coverage cellular systems frequently use 1 km reference lengths. In order to prevent near-field influences from changing the reference path loss, the reference distance should always be in the antenna's far field (Zaarour et al., 2016). In this study, the reference distance d0 was assumed to be 55 meters, and depending on the reference distance, the reference path loss was assumed to be 0.001.

2.11.2 Path Loss Exponent (PLE)

According to the particular propagation environment. PLE is equal to 2 in a free space, but increases in value in the presence of obstructions. Table (2.3), presents the path loss exponent for different environment (Miranda et al., 2013).

Table 2.3 path loss exponent for different environment.

Environment	Path loss exponent e
Free Space	2
Urban Area Cellular Radio	2.7 - 3.5
Shadowed Urban Cellular Radio	3 - 5
Line-of-Sight in Building	1.6 - 1.8
Obstruction in Building	4 - 6
Obstruction in Factories	2 - 3

2.12 Evaluation

Performance metrics include quality of service to the end user in terms of a number of general characteristics. There are a number of parameters that may be used to quantitatively evaluate the perceived quality of a service. Throughput, average latency, packet loss, end-to-end latency, packet delivery fraction, power, Accuracy , Scalability, reliability, Signal strength were considered and other factors were included in the analysis. In this study, we will select the suitable significant metrics to be considered in network performance evaluation (Said, 2015).

2.12.1 Throughput of Sink

The amount of data transferred from one sensor node to a sink during certain period of time is known as the network throughput (Zhang et al., 2020). Network Throughput can be defined as the successful delivery rate of messages through certain link (Almasi & Szilagyi, 2013). It measured by bits per second. The throughput of a sink is calculated based on the sum of the number of the packet data received with in the sink. Throughput can be calculated by equation (2.4):

$$\text{Throughput} = \sum_{i=1}^{n} \frac{\text{totalrx (sink)}}{\text{simulation time}} \qquad (2.4)$$

2.12.2 Transmission Power

Set the transmission power of your radio in dBm. The greater the energy, the greater the distance. Every node when you are transmitting decreases its energy. Transmission Power is defined between -20 to 30. Access point radios have a direct relationship between their transmit power and their usable range. In general, a signal can pass through more obstacles and travel farther with a higher transmit power. Transmitter power output in radio communication refers to the actual quantity of radio frequency energy that a transmitter emits when operating (Miyashita, 2019).

2.12.3 Total Transmitted Messages

The total transmitted messages are calculated based on the number of messages sent form all sensors during the simulation run. Suppose the number of sensors is n, the number of messages sent by the sensor i is T_i and totaltx equal to the total number of messages sent (T) is calculated by equation (2.5).

$$T = \sum_{i=1}^{n} T_i \qquad (2.5)$$

2.12.4 Total Received Messages

The total received messages are calculated based on summing the number of received messages by the sink from each sensor during a simulation run. Suppose the number of sensors is n, the number of messages received by the sensor i is R_i and totalrx is equal to the total number of messages received is R as in equation (2.6).

$$R = \sum_{i=1}^{n} R_i \qquad (2.6)$$

2.12.5 Link Delivery Ratio

The link Delivery Ratio is calculated based on the total number of received messages to the total number of transmitted messages. It is desired to maximize the number of data packets that reached to the destination. The delivery ratio is calculated by (2.7):

$$\text{Delivery ratio} = \frac{\mathbf{R}}{\mathbf{T}} \qquad (2.7)$$

2.12.6 End-to-End Delivery Ratio

End-to-End Delivery Ratio or sometimes called (Sink Delivery Ratio) represent the end-to-end delivery ratio. It can be calculated based on sum of the number of messages received by the sink to the total number of sent messages. Delivery ratio of sink is usually less then delivery ratio of the total sensors because not all messages reaches the sink. The network connectivity is considered good when the delivery ratio of the sink is close to the delivery ratio of the total sensors. The end-to-end delivery ration is calculated based on equation (2.8):

$$\text{Delivery ratio at sink} = \frac{\text{total (sink R)}}{\sum_{i=1}^{n} Ti} \qquad (2.8)$$

2.12.7 Transmitted Messages Failures

Some of the transmitted messages are failed to be received by the sink node. These failed messages are calculated in eq. (2.9):

$$\text{Totaltx failed} = \sum_{i=1}^{n} \text{T} - \sum_{i=1}^{n} \text{R} \qquad (2.9)$$

2.12.8 Residual Energy

The sensors energy is consumed due to transmission and reception process. After each simulation run, a residual energy is calculated. Subtracting the lost energy after each transmission or reception from the total energy. Increasing the transmission distance will increase the consumed energy. Residual energy is calculated by eq. (2.10).

$$\text{Average residual energy} = \frac{\sum_{i=1}^{n}(\text{residual energy})}{(\text{total number of sensors})} \qquad (2.10)$$

2.12.9 Delivery Delay

Delivery delay represent the time for each message to reach from the sensor to the sink. It can be calculated by eq. (2.11):

Delivery delay = message received time – its sent time (2.11)

2.12.10 Average Buffer Size

Buffer is used to get enhanced performance in a WSN. Buffer size is suggested based on the arrival rate (message rate) to reduce the failed or lost packets. It can be used when an arriving packet is reached to a busy node or in the case of many transmissions toward a certain node at the same time. The average buffer size (in Kbytes) is calculated in this study based on the relation between the total number of sent messages and the number of sensors multiplied by the size of the message in bytes. Equation (2.12) is suggested to calculate the average buffer size.

$$\text{Average Buffer Size} = \frac{\sum_{i=0}^{n} \text{sensors buffer}}{total\ sensors} * size\ of\ a\ message(in\ byte)\ /\ 1024 \quad (2.12)$$

2.13 Dijkstra Algorithm

Finding the shortest path from a point in a graph (the source) to a destination is solved by Dijkstra's algorithm, which was named after its inventor, E.W. Dijkstra. This problem is frequently referred to as the single-source shortest routes–problem since it turns out that the shortest pathways from a particular source to all of the points in a graph can be found simultaneously (Javaid, 2013).

2.14 Simulation

Simulating the continuous operation of a system or process in the actual world. The importance of the real system increases as it becomes more challenging and expensive to construct and continually reconfigure. As a result, the simulation can be used as a tool to assess the system's performance under a variety of different constraints and configurations that might exist in real life. The cost, danger, and failure condition associated with the actual system's construction operation can all be reduced by simulation. It may also be viewed as a process of planning a logical or mathematical model that corresponds to the real system and then using the computer to carry out several trials in order to predict and explain how the real system will function. Need a simulator in order to simulate any system. various network simulators have varies property hand-me-down and practical. Several examples of network simulators are Net Logo, OPNET, NS2, and NS3.

2.15 Net Logo

Is a practical programmable modeling platform that simulates and implements WSNs into practice. It was created by Uri Wilensky in 1999, and the Center for Connected Learning and Computer-Based Modeling has been working on it ever since (Wilensky & Rand, 2015). Net Logo is an effective and well-suited tool for simulating intricate communication systems. Many autonomously operating agents can be instructed by modelers using this language. For students to open simulations and "play" by modifying and testing their behavior under various circumstances, Net Logo provides a good laboratory. With Net Logo, educators, teachers, and curriculum designers can precisely build their own models. It is an easy and efficient tool that may be used by researchers in a variety of subjects (Sklar, 2007) (Wilensky & Rand, 2015). Due to the following characteristics, Net Logo was selected as the primary programming and simulation tool in this study.

- Net Logo is compatible with all major platforms (Mac, Windows, Linux, et al).
- Net Logo is entirely open-sourced. Simulators available for free make it easier to measure internal metrics.
- System Dynamics Modeler Net Logo has an understandable syntax.
- A broad vocabulary of built-in language primitives and double precision floating point math are both features of fully programmable systems.
- Each model is viewable in both 2D and 3D, using Net Logo 3D to construct 3D environments.
- With API controls, Net Logo can be included into a script, application, or extensions. API enables Net Logo Language to add additional commands and reports.
- Net Logo is appropriate for complicated system evolution. It runs quickly and requires little technological expertise (Amblard et al., 2015).

CHPTER THREE

The Proposed System

CHAPTER Three

The Proposed System

3.1 Introduction

This chapter explains the simulation steps of implementing the suggested system to simulate, implement and analyze the network connectivity behavior. The first part of the model in this thesis proposes the predefined and random deployment processes of different numbers of sensors to solve the problem of sensors density and locations. The second part of the proposed system is to deal with the communication of sensors with each other by links so that there are no isolated nodes, depending on the communication range and transmitting power. Different scenarios are used as to analyze and investigate performance of the WSN.

3.2 Research Steps

The following sequence of steps is followed in implementing, analyzing and evaluating the connectivity of the suggested wireless sensor networks in this thesis.

1. Select the deployed area shape and size as n*n square meter.
2. Create and deploy variable number of similar (homogenous) static sensor nodes in a suggested area.
3. The sensor nodes are deployed either randomly and in predefined manner in the suggested area. A mathematical model is proposed to select and indicate the sensors locations in the predefined deployment. While the

simulation program will utilized to find the location of each sensor in a random deployment approach.

4. Create a sink node (base station) and select its location in the center.
5. Estimate the sensors transmission radius based on their transmission power using a suggested developed equation.
6. Create communication links among the sensor nodes (based on the transmission radius) and count the number of the created links in the network.
7. Generate and transmit messages in different rates. If the sink node is located within the transmission radius of a sensor node, the message can be transmitted directly in a single hope. If the sink node is not located within the transmission radius of a sensor node, the message will be transmitted in multi hops by shortest path.
8. Estimate the probability and the Connectivity threshold in two ways as a full connectivity and partial connectivity. In full connectivity, all sensors are connected to each other by a link and can reach a base station. In partial connected there are some sensors isolated, not connected with others by a link.
9. In the case of a partial connection, redeployment or changing the transmitter power of the deployed sensors is crucial to ensure the network connectivity.
10. When full connectivity is achieved, a type of message generation rate is selected, either exact or random. In this thesis the used message rate values are (0.05, 0.1, 1) message per sec. The number of sent and received messages are calculated during the simulation run.
11. The time (Tx) required to generate each message in each sensor is created

based on an exponential probability distribution function. Counting these messages will be known as the total generated messages.

a. Generate a random number (0-1) based on the number of deployed sensors.
b. Transform this random number into a random variable based on the following developed equation:

R = Random (Number of deployed sensors)

Tx = (- 1/ message rate)* ln R

12. When the simulation run completed, the performance metrics are calculated as in section (2.12), residual energy for each sensors ,life time , graph the simulation results, and creating a regression equations for all the values in the tables obtained from the simulation experiment.
13. Test and evaluate the validity of the created models.

3.3 Modeling Approach

Modeling is the process of representing the wireless sensor networks systems to promote understanding of the real system behaviors. The following modeling and simulation programs were designed to achieve the process of connectivity in WSNs. Figure (3.1) presents the general steps of The Proposed System Simulation Steps.

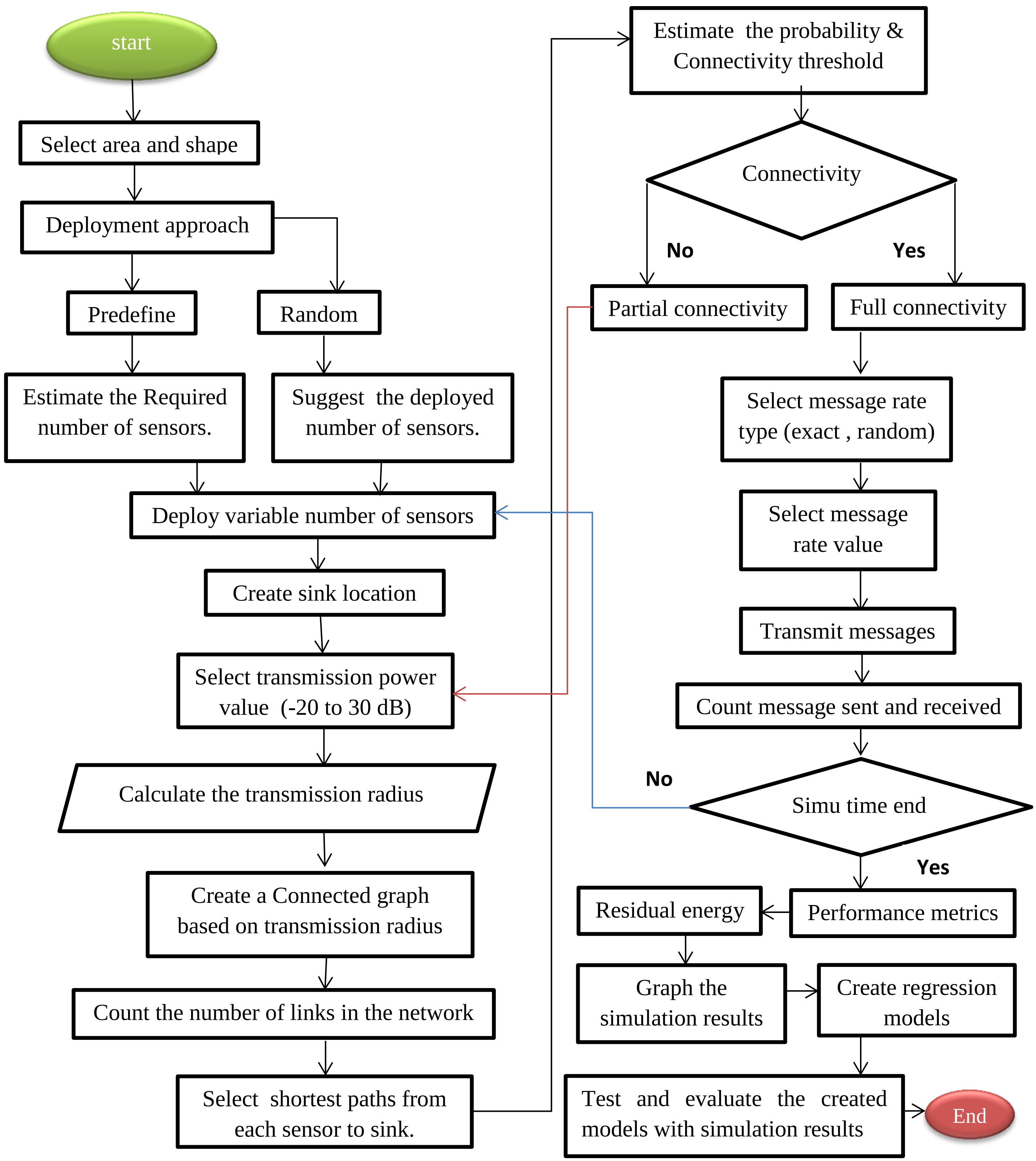


Figure 3.1: The Proposed System Simulation Steps.

3.3.1 Area and Shape

There are different area shapes and sizes in which the sensors can be deployed. The shape may be a rectangular, square, triangle, circle or hexagonal shape, but in this thesis a square shape is proposed and the area size is selected to be 500*500 square meters.

3.3.2 Deployment Approach

In this study, two methods were used for the process of deploying the sensors in the specified area, which are predefined and random.

3.3.2.1 Predefined

Sensors location (position or coordinates) is the most required factor in planning to build or design any new WSN especially in the reached areas. The most important metrics are inter-sensor distances among others. To deploy suitable number of sensors in square area, different number of sensors can be selected. Each selected number must have a square root integer value, for example (25, 49, 64,…., 100). This value of the square root is the distance between each sensor. Figure (3.2) shows the representation behind this selection. Following is the developed model to select the sensors coordinates and to calculate the distance. Algorithm 3.1 shows the Predefined deployment steps.

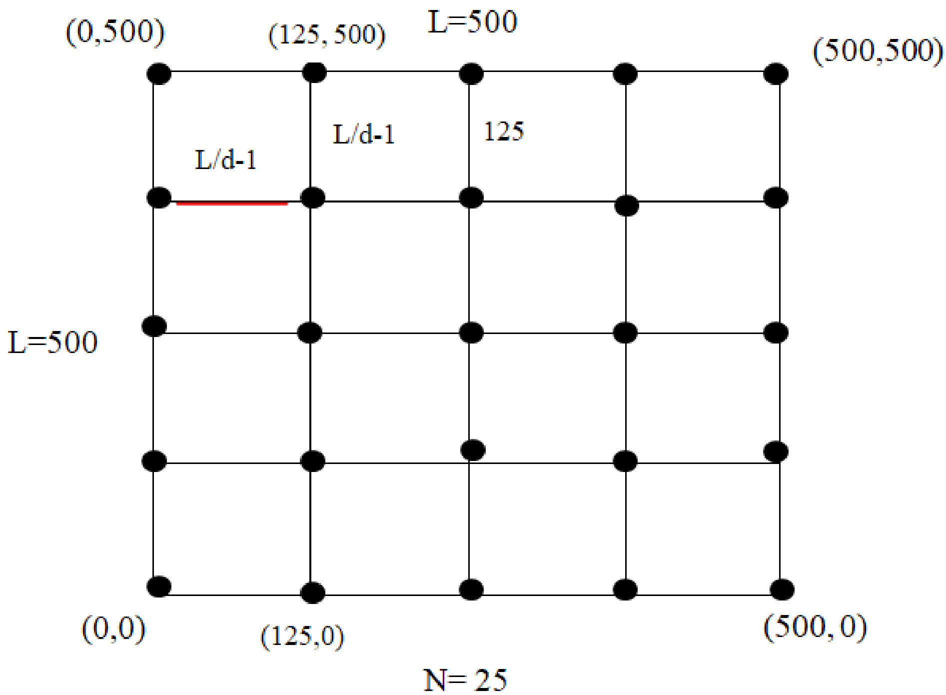


Figure 3.2: Predefined Position.

- ***The proposed model is used in a certain limited area.***

Initialization:

$$\left.\begin{matrix} x_i \\ y_j \end{matrix}\right\} = 0 \qquad i = 0, \qquad j = 0$$

$$X_{i+1} = x_i + (L/(d-1))$$

$$Y_{j+1} = y_j + (L/(d-1))$$

$$C_{ij} = c(x_i, y_j) \qquad coordinates$$

x_i is the x Coordinate

y_j is the y Coordinate

L area size

d distance between two sensor

C Sensor node coordinates

The following example is to show the validity of the proposed model.

Example 3.1:

Let L = 500 m, N = 25

$so, \quad d = \sqrt{N}$ = 5

$X_0 = 0, \qquad Y_0 = 0$

$X_1 = x_0 + 125 = 125$

$Y_1 = y_0 + 125 = 125$

$X_2 = x_1 + 125 = 250$

$(x_0, y_0) = (0,0) \qquad (x_1, y_0) = (125,0)$

$(x_0, y_1) = (0,125) \qquad (x_1, y_1) = (125,125)$

$(x_0, y_2) = (0,250) \qquad (x_1, y_2) = (125,250) \qquad (x_2, y_1) = (250,125)$

Algorithm 3.1 predefined deployment
Input: number of sensor (x), length of Square area (L),communication radius (r).
Output: sensor position and distance between sensors (d).
process:

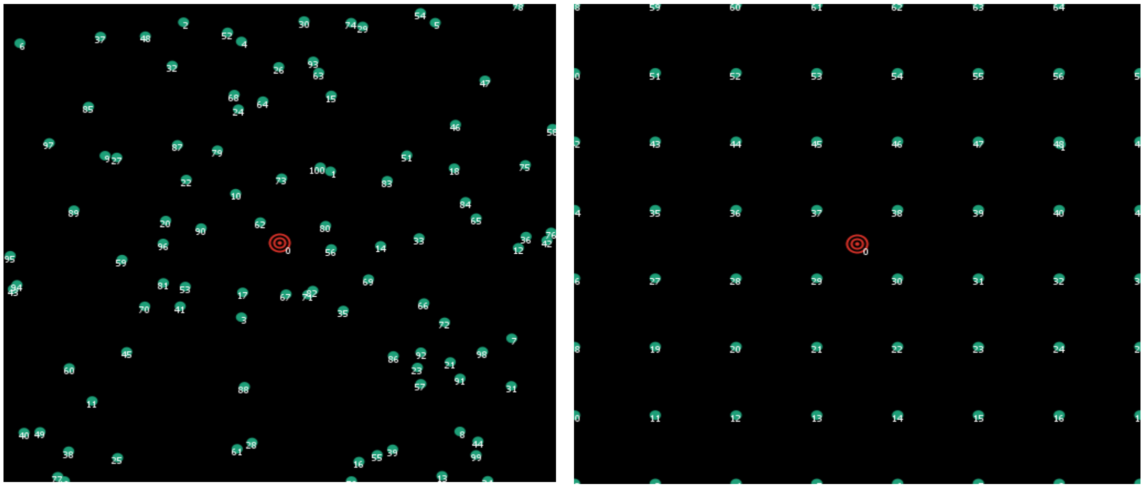
1. X → integer value
2. X^2 → number of deployed sensors
3. d → abs sqr (X^2)
4. 0 → X_{11}
5. 0 → Y_{11}
6. for J=2 to X
7. for I=2 to X
8. X_{ij} → X_{ij} + (L/(d-1))
9. Y_{ij} → Y_{ij} + (L/(d-1))
10. next
11. next
12. End

3.3.2.2 Random Deployment

There are different approaches for the random deployment of sensors in a specified area based on certain probability distributions. Most of these approaches follows the uniform, binomial and Poisson distributions. However, in this thesis, A Net Logo programming function is called and utilized in generating the random deployment.

3.3.3 Number of Sensors

The number of sensors used in this thesis is varied from 1-100 sensors that were deployed in the square area. The user can select the required number of sensors by a created slider in a simulation interface in this thesis scenarios. In a random deployment approach, the number of the deployed sensors are ranged from 10 to 100 with a step of 10. Algorithm 3.2 summarized the simulation setup steps.



(a) *random* *(b) predefined*

Figure 3.3: Deployment Approach (a) Random and (b) Predefined.

Algorithm 3.2 setup procedure

Input: sensors, sink –number (represents the identifier number (ID) for the base station sensor).

Output: wireless sensor network (WSN) initial state.

process:

1. Create n sensors in certain area
2. deploy random or in grid form
3. create and locate the base station
4. create a sensor node inside the base station
5. Calculate the transmission radius according to equation (3.1)
6. create link among sensors according to the radius of the transmission.
7. Estimate the transition matrix.
8. Estimate the required simulation time.
9. End

3.3.4 Transmission Power and Radius

The transmission range is directly proportional with the transmission power. The transmission power values in this thesis simulation scenarios are ranges from (-20 to 30 dB). A programming tool is designed to control these values as a slider in a Net Logo interface menu. Equation (3.1) is developed to estimate the suitable transmission distance at each transmission power value. Another parameters affecting the transmission distance are also included. High transmission power will reduce the sensor live time. A compromise between the transmission power and distance can be considered based on number of hops.

$$\text{Transmission range} = 10^{\frac{1}{10\,PathExpo} * -(rsensibility - Txpower + pathlossdis)} \quad (3.1)$$

PathExpo, r $rsensibility, and\ Pathlossdis$ are discussed in ch. 2.

Txpower is the transmission power value in dB.

3.3.5 Connected Graph Creation

If the Euclidean distance between any two neighbor sensors is less or equal to the sensors transmission range distance, then a communication link will be created to make possible communication between these sensors. A distance between any sensors pair is calculated for all the network sensors. A total number of the possible created links is also computed and compared with the number of sensors. Increasing the number of links will increase the network connectivity. Regression equations are created to estimate the number of links and the connectivity thresholds.

3.3.6 Shortest Path Creation

After composing a connected graph for each proposed network topology, a proposed sink node position is indicated. The next step is to calculate and list all the possible paths from each sensor node to the sink. A shortest path among each list is performed and indicated as a shortest path. Another implemented approach is to utilize the “Dijskstra” method in estimating the shortest path. A connected matrix is proposed to indicate the collected information about each proposed WSN topology. This created matrix is used in selecting the possible and the shortest paths and as an indication about the network connectivity.

3.3.7 Connectivity Threshold Estimation

In this study, a model is developed to propose a way to estimate the threshold value which compromise the transmission power with the connectivity. The following sequence are followed:

1. Deploy number of sensors.
2. Determine the transmission power from (-20 to 30) and monitor the connection (the number of links) and see whether one or more sensors are unconnected. If the answer yes, increase the transmission power and repeat the previous step until we get all the sensors connected and there is no isolated sensor. The higher the transmission power, the stronger the connection.
3. The minimum value that can make a full connectivity (all the nodes in the network are connected by links) is called a connectivity threshold value for a certain area.
4. For example, when 100 sensors are randomly deployed in 500*500 m, the threshold value is 8 dB. This value make all the sensors are connected with each other. When the transmission power is less than 8 dB, number of separated sensors (isolated) are found so, connectivity is not achieved. Isolated nodes that are not connected to other sensors by a link. This prevents data from reaching the sink. This type of connection is called partial connection. As for the full connection, it is achieved when all sensors are connected to each other via a links and the data is transmitted to the sink. Figure (3.4) threshold connectivity.

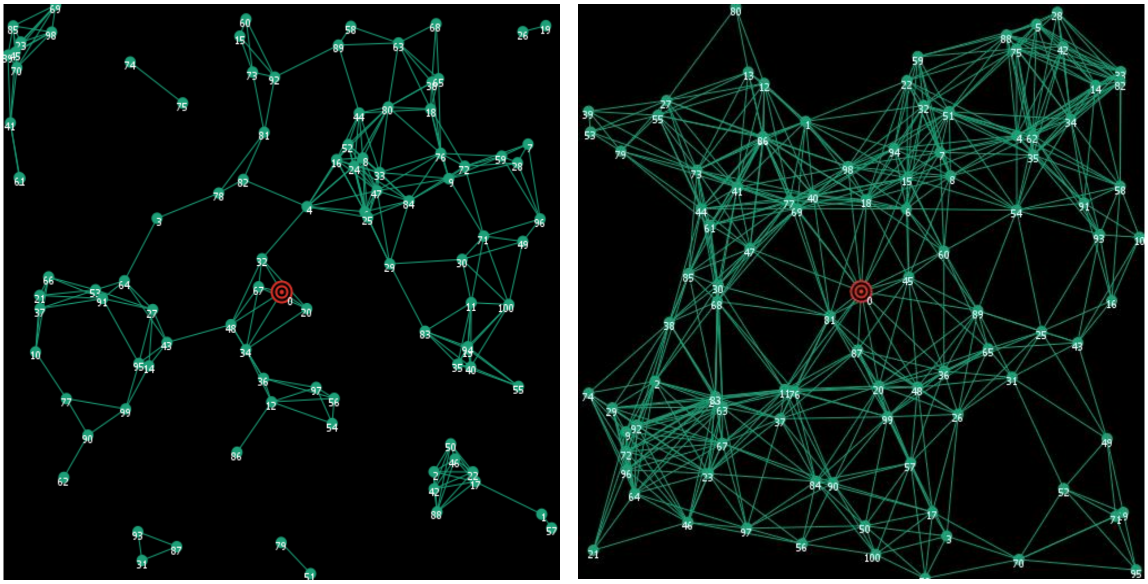


Figure 3.4 : Threshold Connectivity.

3.3.8 Message Generation

The process of generating messages between sensors in two ways:

3.3.8.1 Exact rate

In an exact-rate, the number of the generated message per unit time is fixed. For example 1 message per sec. This means that the simulation program will generate one message from each sensor every sec. From this criterion, the total number of the generated messages can be estimated based on the number of the sensors and the length of the simulation time.

3.3.8.2 Random rate

In a random rate, the number of the generated message per unit time is selected randomly.in this thesis, the message arrival rate is utilized as a mean. The mean value is selected to generate number of messages at any time for each sensor. A developed model is proposed in this thesis to generate the total number of messages. This model is based on an exponential probability distribution. Following are the main assumptions to create the suitable model.

Let $\lambda = B = message\ rate$

$f(x) = Be^{-Bx}$; The general density function for the exponential distribution

$F(x) = 1 - e^{-BX}$; The general cumulative function for the exponential distribution

Replace the F(x) by a random number

$so,\ random = 1 - e^{-BX}$

$x = 1 - \frac{1}{B}\ \ln\ random \Longrightarrow x = -\frac{1}{B}\ \ln\ random$

$$T_i = -\frac{1}{message\ rate} * \ln(random)$$

This time indicates after what time the next message is generated. The number of the generated messages is 1/Ti.

Where:

T_i The number of messages sent by the sensor i

Example:

Let B= 0.1

$T_i = -\frac{1}{0.1} * \ln(0.6)$ = 5.1082 sec

Algorithm 3.3 present the complete setup procedure followed in this thesis.

Algorithm 3.3 WSN simulation

Input: number of sensors (n), energy, message rate

Output: total massages, residual energy, shortest path

process:

For i=1 to n
select the possible paths from node i to the sink
choose the shortest one.
Next
U= rv
If rv ≤ 0.5 then
Msg=1/sec ;msg : message rate
residual energy= e
Msg (i) =0
For j=1 to simulation time
For i=1 to n
Msg (i)= Msg (i)+ Msg
total messages (i) = total messages (i)+ 1
residual energy (i) = residual energy (i) -processing energy
Next i
Next j
Else
Average Msg =0.05/sec
Y = Random
$T_i = -\frac{1}{average\ msg} * \ln(y)$
residual energy = e
Msg (i) =0
For j=1 to simulation time
For i=1 to n
Msg (i)= Msg (i)+ Msg
total messages (i) = total messages (i)+ 1
residual energy (i) = residual energy (i) -processing energy
Next i
Next j
End.

3.4 Regression Models

A regression fundamentals are utilized to predict the uncalculated values in each simulation scenario. A relationship between outcome variables and the predictor variables are presented. Regression model is created by analyzing the correlation and directionality of the data, estimating the model (fitting the curve) and evaluating the validity and usefulness of the model. A scatter plot can be used to analyze the data and check for directionality and correlation of data. Regression can be used to explain how an independent variable is numerically associated with the dependent variable.

Regression equation is proposed for each case based on the behavior of effective variables. The value of these variables are controlled based on the collected simulation results. These equations present the correlation among different variables for each simulation scenario.

CHAPTER FOUR

Simulation Results and Analysis

CHAPTER FOUR

Simulation Results and Analysis

4.1 Introduction

In this chapter, the implementation of the suggested simulation experiments using Net logo simulator are presented. The presentation is started from establishing the WSN, generate the possible links based on the sensors communication range, creating the possible short paths from sensors to a sink node, suggesting more than one sending node at the same time. Net Logo ("a multi-agent modeling language") was suggested as a network simulator to be used in building and implementing the suggested wireless sensor networks.

4.2 Simulation Setup

In this step, a wireless sensor network is created on certain area by generating random sensor nodes and sink node. Table (4.1) presents the simulation setup parameters. Figure (4.1) shows a Net logo snapshot for sensors deployment.

Table 4.1: the simulation setup.

Variable	Value
The simulator	Net Logo 6.1.1
Number of sensors	10, 20, ….. , 100
Area	$500*500\ m^2$
Routing protocol	shortest path
MAC protocol	CSMA-802.11-DCF
Massage rate	Exact , random
Simulation time	Estimated
Deployment	Random, predefined
CWmin	8
CWmax	30
DIFS	0.021
SIFS	0.001

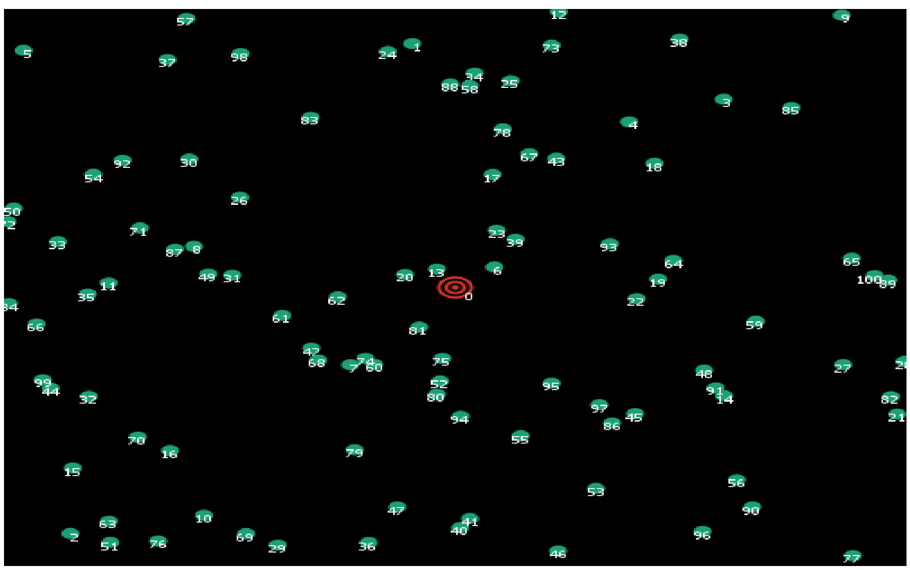


Figure 4.1: 100 sensors random deployment snapshot.

Net logo as an agent based modeling approach is utilized in simulating the suggested scenarios. Figure (4.1) presents a simulation program snapshot for the initial deployment of 100 sensors in an area of 500*500 m. There are many parameters affects the connectivity of the WSNs such as; number of created and deployed sensors, their locations, their transmission radius and transmission power in addition to the sink location as a base station. The deployed sensors are suggested to be homogenous.

4.2.1 Varying Number of Sensors Results

Number of deployed sensor nodes are controlled and varied from 10 to 100 nodes with a step of 10. Figure (4.2) shows a Net logo snapshot for deploying 100 sensors with their links for a transmission power of 8 dB in an area of 500*500 m. Every simulation step is performed to estimate the possible outcomes for each suggested WSN topology. In this step, different transmission power values are suggested starting from (-20 dB with increment of 1). After testing these values, a minimum value which make a fully connected network topology is selected as a transmission power threshold value. A detailed experiment trials are performed as a simulation approach to estimate the sensor transmission radius for each suggested transmission power value. Equation (3.1) is used to estimate the transmission radius.

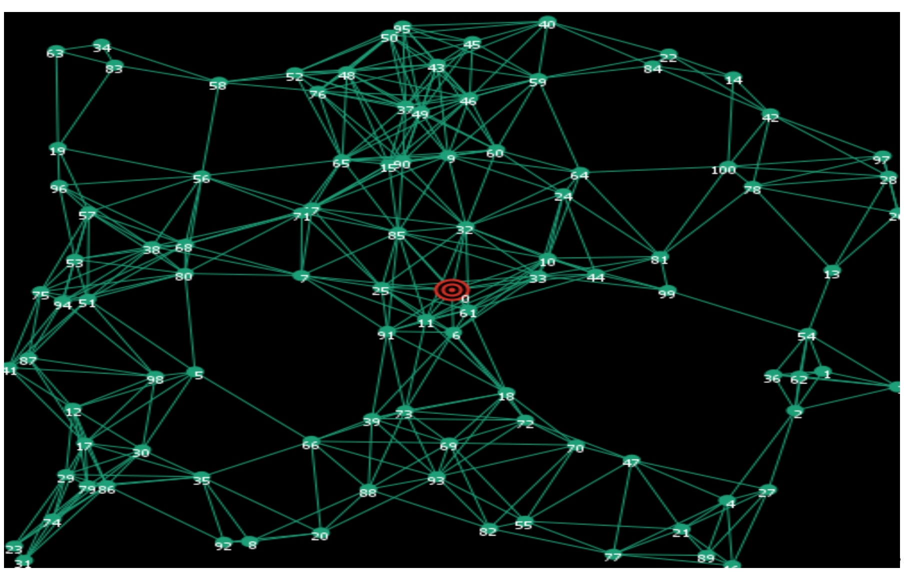


Figure 4.2: 100 sensors with their links for a transmission power of 8 dB.

Table (4.2) represents the relationship between the transmission power and the resulted transmission radius. The sensors transmission power are ranges from (-20 to 30 dB) in this thesis. The sensor's transmission radius is directly proportional with the transmission power. When the transmission power is low the transmission radius will be small which affects the network connectivity when a small number of sensors are deployed in a large area. The probability of connectivity among sensors is increased when the transmission power is increased, this will improve the communication among sensors.

Table 4.2: transmission radius for each transmission power.

Transmission Power (dB)	transmission radius (m)
-20	6.189
-15	10
-10	16.155
-5	26.101
0	42.169
5	68.129
10	110.069
15	177.827
20	287.298
25	464.158
30	749.894

Based on table (4.2), a regression equation can be proposed to be used as an estimator to calculate the transmission radius for each transmission power value in a mathematical manner. Figure (4.3) represents the relationship between transmission power and transmission radius based on table (4.2).

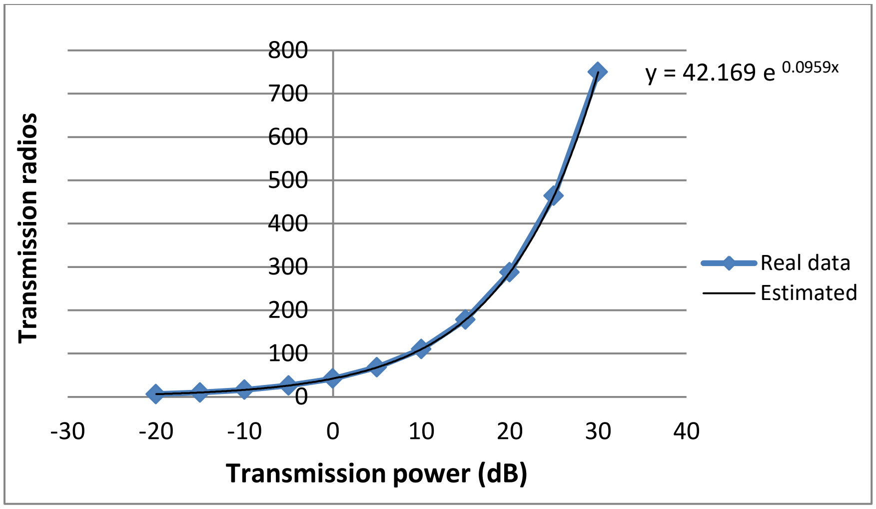


Figure 4.3: transmission radius for each transmission power.

Equation (4.1) represents a regression equation which can be used to estimate the value of the transmission radius based on any suggested transmission power as an input and vice versa. The increased value in a transmission rang is found to be exponentially with the increase in a transmission power value (dB).

$y = 42.169\ e^{0.0959\ x}$ …….(4.1)

Where: y represents the transmission range (radius) and x is the transmission power value. To verify the validity of equation (4.1) the following examples are suggested to train and test this equation. Firstly, two transmission power values (x= -10 and x= 20) are selected randomly from table (4.2) and the resulted transmission radius (y) are calculated:

When x = -10 then y = 16

When x = 20 then y = 287

The resulted transmission radius from the equation are equal to the calculated results from a simulation experiment. To test the validity of this equation, different values for the transmission power not calculated in table (4.2) are proposed to estimate their equivalent transmission radius:

When x = 8 then y = 90

When x =16 then y = 195

Equation (4.1) represents a good estimator to be used instead of the repeated complex simulation experiment runs.

To study the effects of varying the number of the deployed sensors on the required transmission power to make a good connectivity. A good connectivity is achieved by creating links among all nodes (no node is found without link with others). Different simulation runs are performed for each scenario to reach to the connected network. The summary of the simulation results is presented in table (4.3). The minimum value that can make a full connectivity (all the nodes in the network are connected by links) is called a connectivity threshold value for a certain area. For example, when 10 sensors are randomly deployed in n*n mater, the threshold value is 19 dB. This value make all the sensors are connected with each other. When the transmission power is less than 19 dB, number of separated sensors (isolated) are found so, connectivity is not achieved. As a conclusion result, the greater the power will have resulted in an increased number of the created links. This means that the connection will be better with increased number of links. When 20 sensors are deployed, the threshold value is 16, with 30 is 14, and with 100 is 8. As a conclusion, the required transmission power is gradually decreases when the number of sensors increases.

Table 4.3: number of sensors and transmission power (threshold).

Number of sensors	Transmission power (threshold)
10	19
20	16
30	14
40	13
50	12
60	11
70	10
80	9
90	8
100	8

A regression equation can be proposed to be used as an estimator to calculate the transmission power (threshold) for each number of sensors mathematically. Figure (4.4) represents the relationship between number of sensors and the required transmission power (threshold) to make a connected graph. The presented graph is based on the results of table (4.3). These results are graphed to be used in estimating the other information concerning the relation between any number of sensors value and the required transmission power (threshold) based on a proposed regression equation.

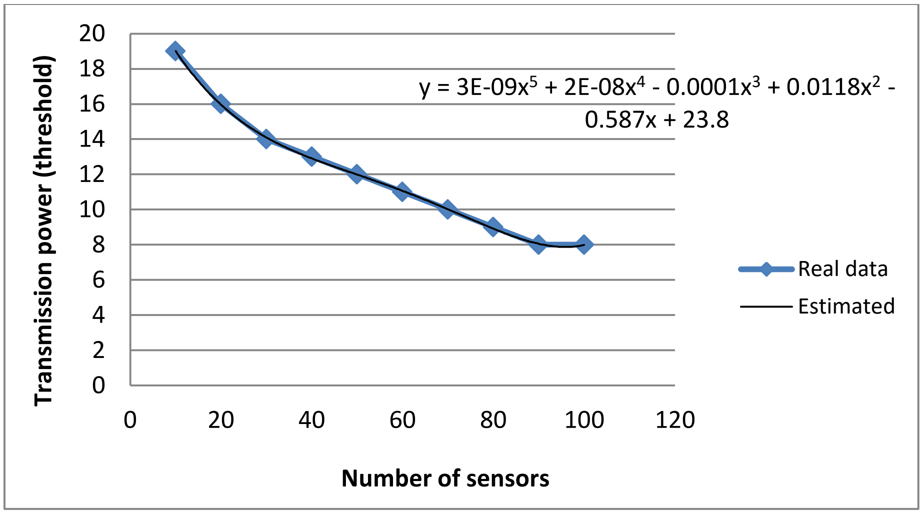


Figure 4.4: transmission power (threshold) for each number of sensors.

Equation (4.2) represents a proposed regression equation using a Microsoft Excel. This proposed equation is used to estimate the value of the required transmission power to make a good connectivity based on the number of sensors as an input value and vice versa.

$$y = 3E\text{-}09x^5 + 2E\text{-}08x^4 - 0.0001x^3 + 0.0118x^2 - 0.587x + 23.8 \quad \ldots..(4.2)$$

Where y is the required transmission power (connectivity threshold value) and x is the number of sensors.

To verify the validity of equation (4.2) the following examples are suggested to train and test this equation. Firstly, two number of nodes (x= 20 and x= 60) are selected randomly from table (4.3) and the resulted required transmission power values (y) are calculated:

When x = 20 then y = 16

When x = 60 then y = 12

The resulted transmission powers from equation (4.2) are approximately equal to the calculated results from a simulation experiment in table (4.3). To test the validity of this equation, different values for the number of sensors that not calculated in table (4.3) are proposed to estimate their equivalent transmission powers:

When x = 25 then y =15

When x = 65 then y =11

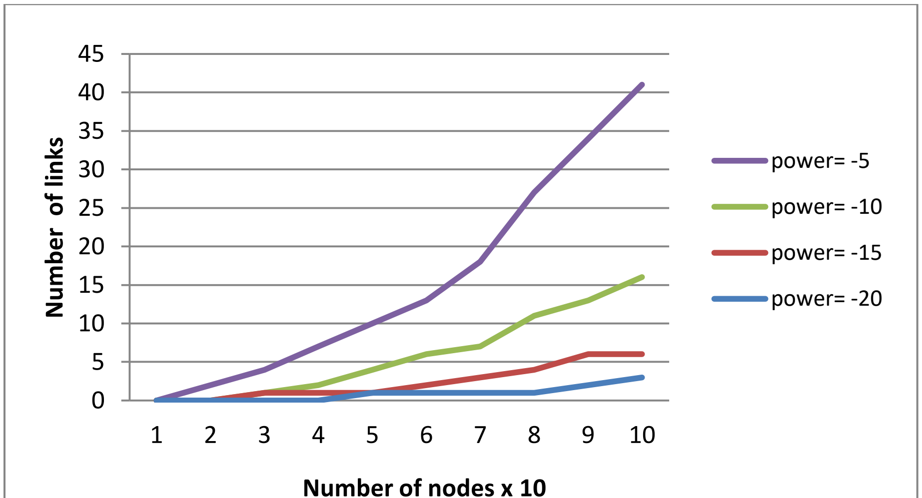
Equation (4.2) represents a good estimator to be used instead of the repeated complex simulation experiment runs to evaluate the relation between the number of the deployed sensors and the required transmission power to make a good connectivity.

Table (4.4) represents the average number of the total created links with different power values in dB and different number of sensors. The average number of the total created links are calculated after repeating each simulation scenario 20 times. It is seen that the average number of links is very few when the power of the sensors is low, while the number of the average links increases as the number of sensors and energy increases.

Table 4.4 number of links with different power values and number of sensors.

	Average Number of Links									
Power (dB)	10 sensors	20 sensors	30 sensors	40 sensors	50 sensors	60 sensors	70 sensors	80 sensors	90 sensors	100 sensors
-20	0	0	0	0	1	1	1	1	2	3
-15	0	0	1	1	1	2	3	4	6	6
-10	0	0	1	2	4	6	7	11	13	16
-5	0	2	4	7	10	13	18	27	34	41
0	1	3	10	18	26	37	51	68	83	108
5	2	10	24	45	66	97	127	173	211	253
10	7	26	60	101	162	231	315	409	512	631
15	16	65	140	239	367	531	710	921	1170	1446
20	36	130	286	490	753	1108	1482	1913	2408	2935
25	53	200	438	778	1215	1734	2360	3074	3885	4770
30	55	210	465	820	1275	1830	2485	3240	4095	5050

Table (4.4) is used to suggest certain regression equations to estimate the number of the possible created links with different power values and different number of sensors node simultaneously.



A: power ranges (from -20 to -5 dB)

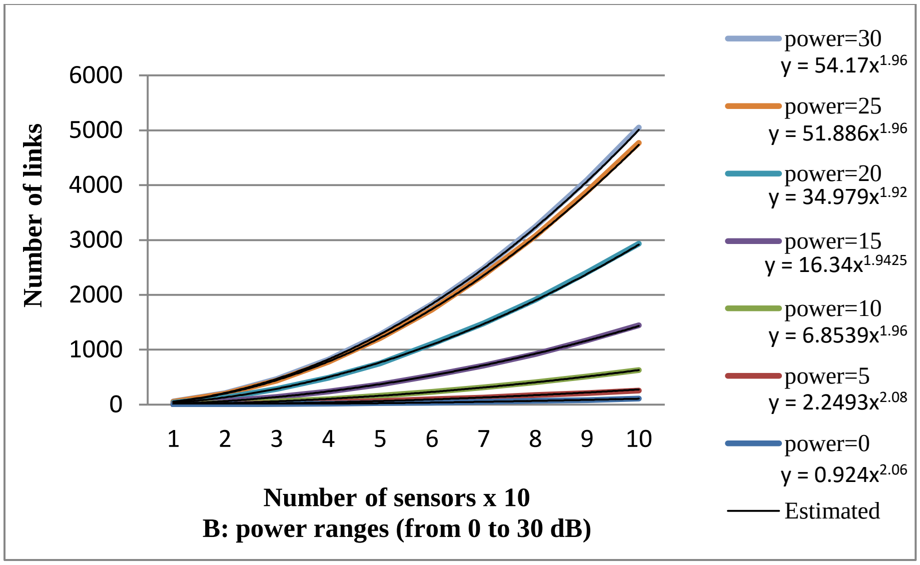


Figure 4.5: Number of Links with Different Power Values and Different Number of Sensors.

From figure (4.5), regression equations are proposed and created for each transmission power value to represent a mathematical estimation for the possible number of links with each number of sensors. The regression equations (4.3-4.9) are created for different cases based on certain suggested power values greater than or equal to 0 dB. When the transmission power is 30 dB then the number of links (y) can be estimated using equation (4.3) with number of sensors= x.

$$y = 54.17x^{1.96} \qquad \ldots\ldots (4.3)$$

Examples 4.1:

When x = 20 then y = 210

When x = 65 then y = 2123

When the transmission power is 25 dB then the number of links (y) can be estimated using equation (4.4) with number of sensors = x.

$y = 51.886x^{1.96}$ ….. (4.4)

Examples 4.2:

When x = 20 then y = 201

When x = 65 then y = 2034

When the transmission power is 20 dB then the number of links (y) can be estimated using equation (4.5) with number of sensors = x.

$y = 34.979x^{1.92}$ ….. (4.5)

When the transmission power is 15 dB then the number of links (y) can be estimated using equation (4.6) with number of sensors = x.

$y = 16.34x^{1.94}$ ….. (4.6)

When the transmission power is 10 dB then the number of links (y) can be estimated using equation (4.7) with number of sensors = x.

$y = 6.8539x^{1.96}$ ….. (4.7)

When the transmission power is 5 dB then the number of links (y) can be estimated using equation (4.8) with number of sensors = x.

$y = 2.2493x^{2.08}$ ….. (4.8)

When the transmission power is 0 dB then the number of links (y) can be estimated using equation (4.9) with number of sensors = x.

$y = 0.924x^{2.06}$ ….. (4.9)

These equations represent an advanced mathematical representation to analyze and evaluate the wireless sensor network topology and performance.

These equations are found to be accurate in calculating the possible created links in each network and a good estimator for the network connectivity.

4.3 Deployment

Two deployment approaches are implemented in this thesis (random and predefined). Different number of sensors are deployed in each deployment approach.

4.3.1 Random Deployment

Different scenarios are proposed to analyze, test and evaluate the network connectivity performance. Certain number of sensors are deployed in each scenario. The number of the deployed sensors in these scenarios are (20, 40, 60, 80 and 100). Making use of table (4.2), equation (4.1) and table (4.3), Connectivity threshold power and the transmission radius are calculated based on the number of sensors. In each simulation scenario the total transmitted messages (totaltx), total received messages (totalrx), failed transmitted messages (failedtx), sensor delivery ratio, sink delivery ratio, data messages generated, throughput and average residual energy are calculated based on section (2.12). Three cases are proposed for the message generation rate (0.05, 0.1 and 1 message per second).

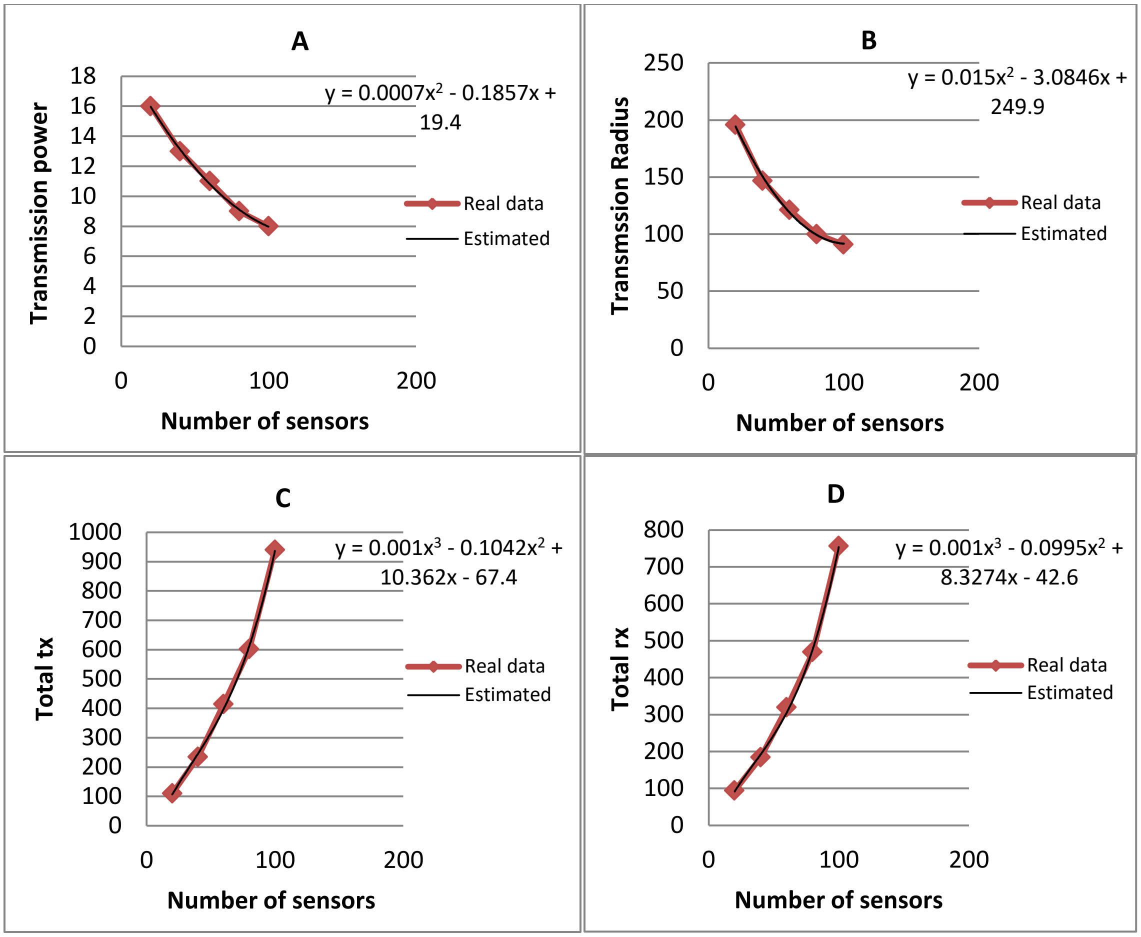
4.3.1.1 Case 1R

In this case, different number of sensors are randomly deployed (20, 40, 60, 80 and 100). The message rate is suggested to be randomly generated with rate of 0.05 message per second. Table (4.5) presents the suggested parameters and the calculated performance metrics results. The results in each row of table (4.5) are calculated as the average value of 5 repeated simulation runs.

Table 4.5 results for case 1R.

Number of sensors	Connectivity threshold Power	Transmission radius	Totaltx	Totalrx	Failedtx	sensors Delivery ratio	sink Delivery ratio	Data generated	throughput	Av.residual energy
20	16	195.73	109	94	15	0.86	0.77	65	1.44	190.47
40	13	146.77	234	184	50	0.78	0.62	136	2.48	195.11
60	11	121.15	414	319	95	0.77	0.54	210	3.33	196.71
80	9	100	601	469	132	0.76	0.52	279	4.28	197.52
100	8	90.85	940	756	184	0.75	0.46	342	4.59	198.01

The results in table (4.5) shows a directly proportional between transmission power and transmission radius while there is an inversely proportional between number of sensors and transmission radius. When the number of sensors increases, the number of the totaltx, totalrx, failedtx, data messages generated, throughput and average residual energy are increased while the sensor delivery ratio and the sink delivery ratio are decreased. To make use of table (4.5), a suggested regression approach is utilized to generalize its benefit. Figure (4.6) presents the regression curves and there suggested equations to show the effect of number of sensors on the network performance metrics.


A
y = 0.0007x² - 0.1857x + 19.4
Transmission power
Real data
Estimated
Number of sensors
B
y = 0.015x² - 3.0846x + 249.9
Transmssion Radius
Real data
Estimated
Number of sensors
C
y = 0.001x³ - 0.1042x² + 10.362x - 67.4
Total tx
Real data
Estimated
Number of sensors
D
y = 0.001x³ - 0.0995x² + 8.3274x - 42.6
Total rx
Real data
Estimated
Number of sensors

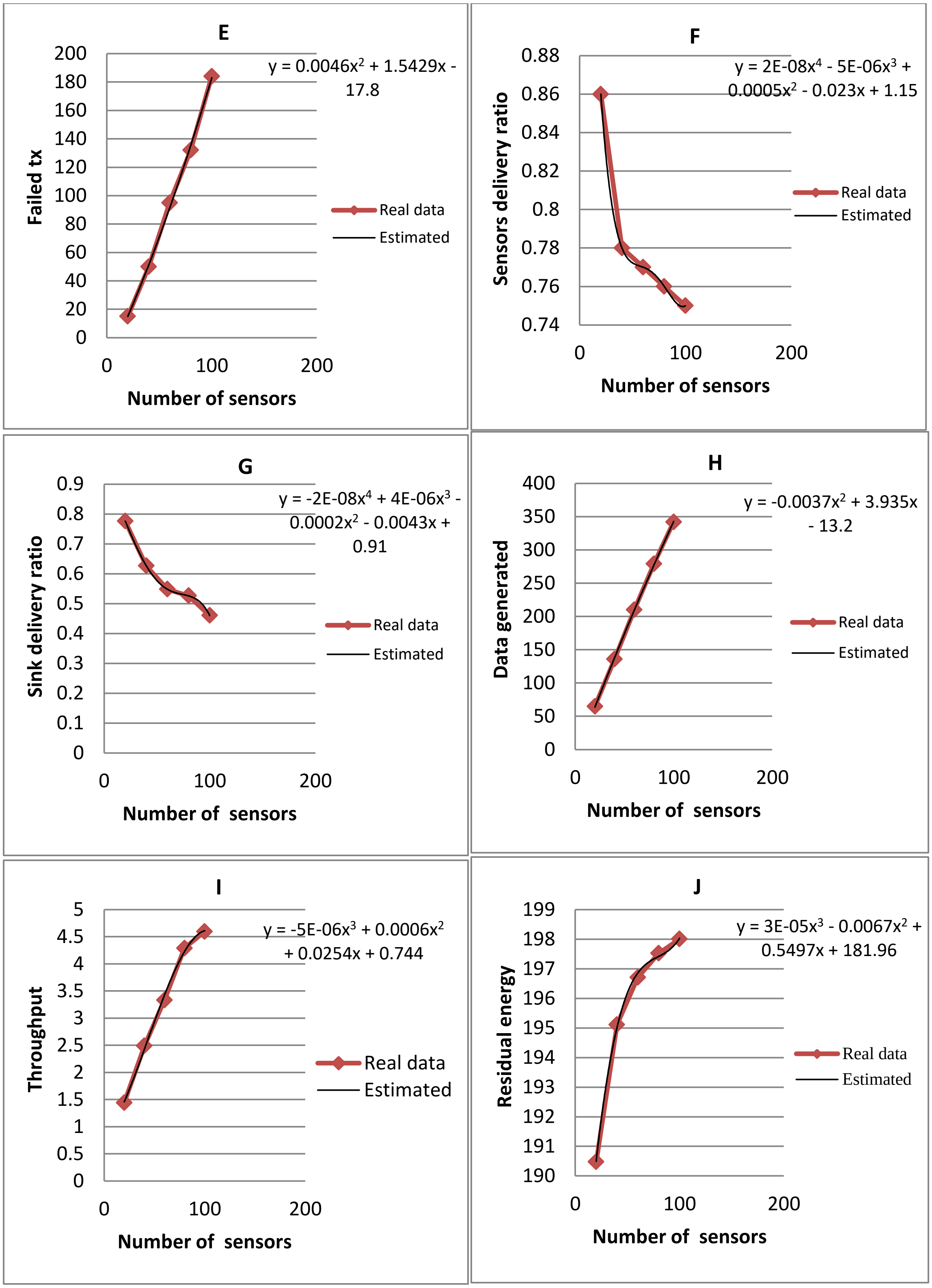


Figure 4.6: Effects of Number of Sensors on WSN Parameters.

Examples 4.3:

A (number of sensors vs transmission power):

When x = 20 then y = 16

When x = 65 then y = 10

B (number of sensors vs transmission radius):

When x = 20 then y = 194

When x = 65 then y = 112

C (number of sensors vs totaltx):

When x = 20 then y =106

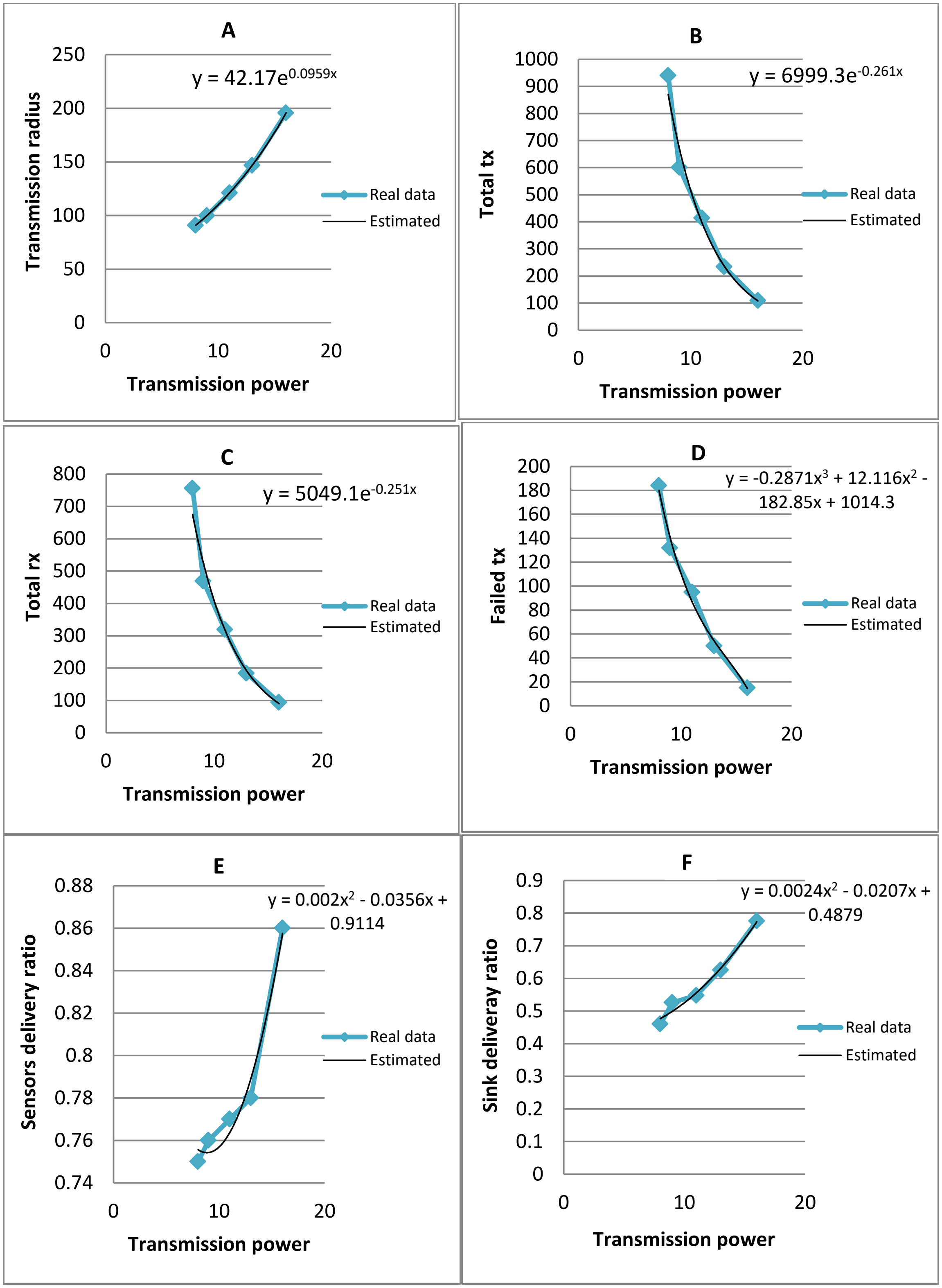
When x = 65 then y = 440

D (number of sensors vs totalrx):

When x = 20 then y = 92

When x = 65 then y = 352

To make another use of table (4.5), a suggested regression approach is utilized to generalize its benefit. Figure (4.7) presents the regression curves and there suggested equations to show the effect of transmission power on the network performance metrics.


A
y = 42.17e^0.0959x
Transmission radius
Transmission power
Real data
Estimated
B
y = 6999.3e^-0.261x
Total tx
Transmission power
Real data
Estimated
C
y = 5049.1e^-0.251x
Total rx
Transmission power
Real data
Estimated
D
y = -0.2871x³ + 12.116x² - 182.85x + 1014.3
Failed tx
Transmission power
Real data
Estimated
E
y = 0.002x² - 0.0356x + 0.9114
Sensors delivery ratio
Transmission power
Real data
Estimated
F
y = 0.0024x² - 0.0207x + 0.4879
Sink deliveray ratio
Transmission power
Real data
Estimated

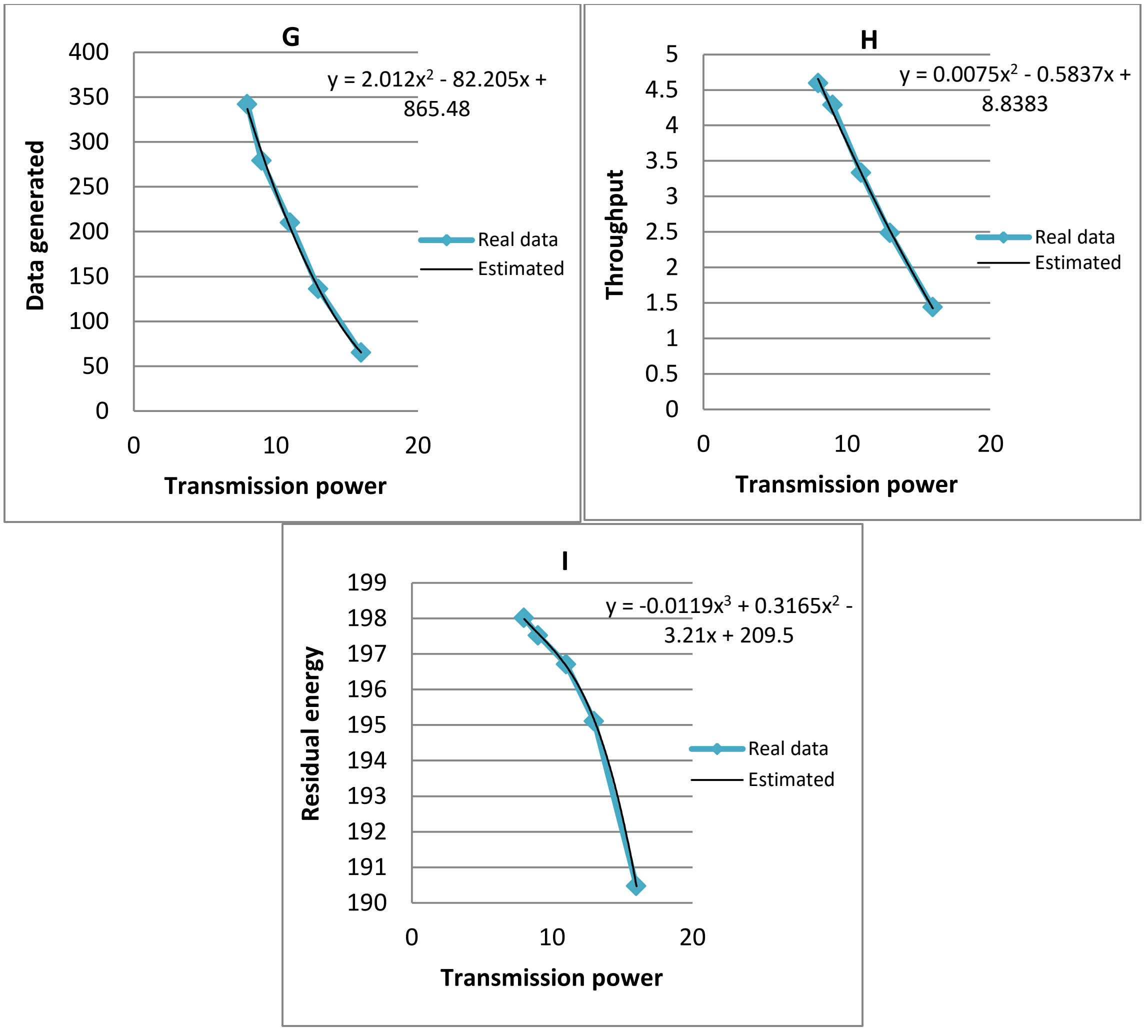


Figure 4.7: Effects of Transmission Power on WSN Parameters.

Examples 4.4:

A (transmission power vs transmission radius):

When x = 16 then y = 195

When x = 10 then y = 110

B (transmission power vs totaltx):

When x = 16 then y = 108

When x = 10 then y = 514

C (transmission power vs totalrx):

When x = 16 then y = 91

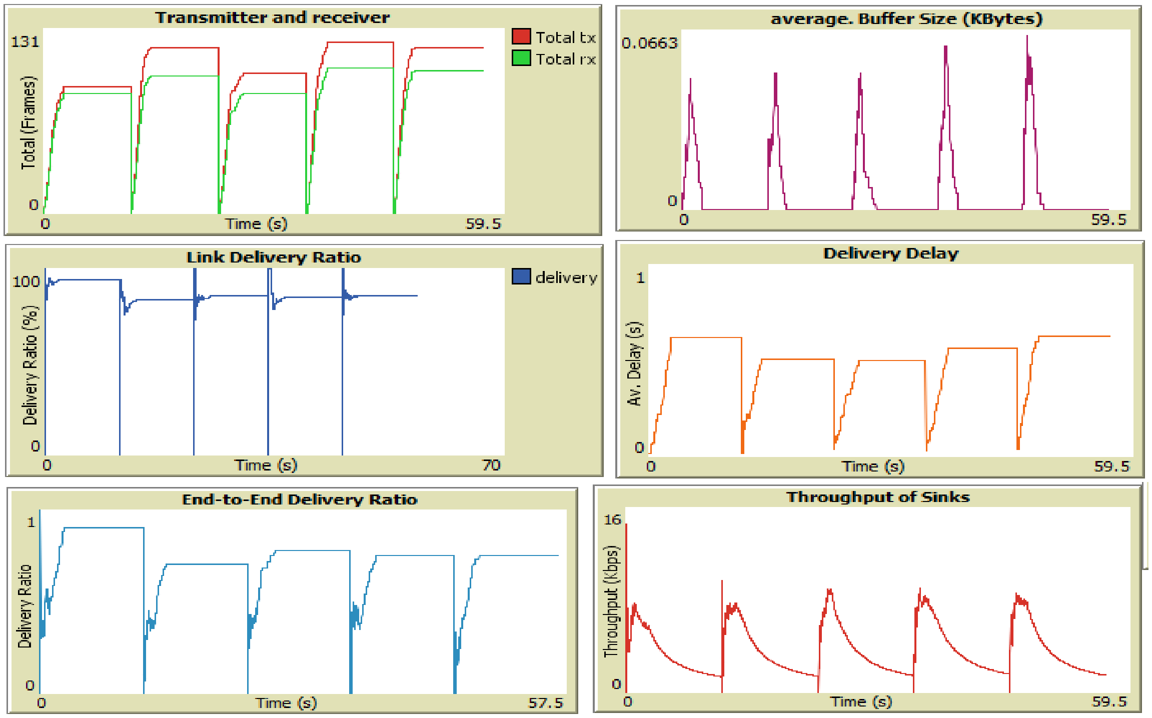
When x = 10 then y = 410

D (transmission power vs failedtx):

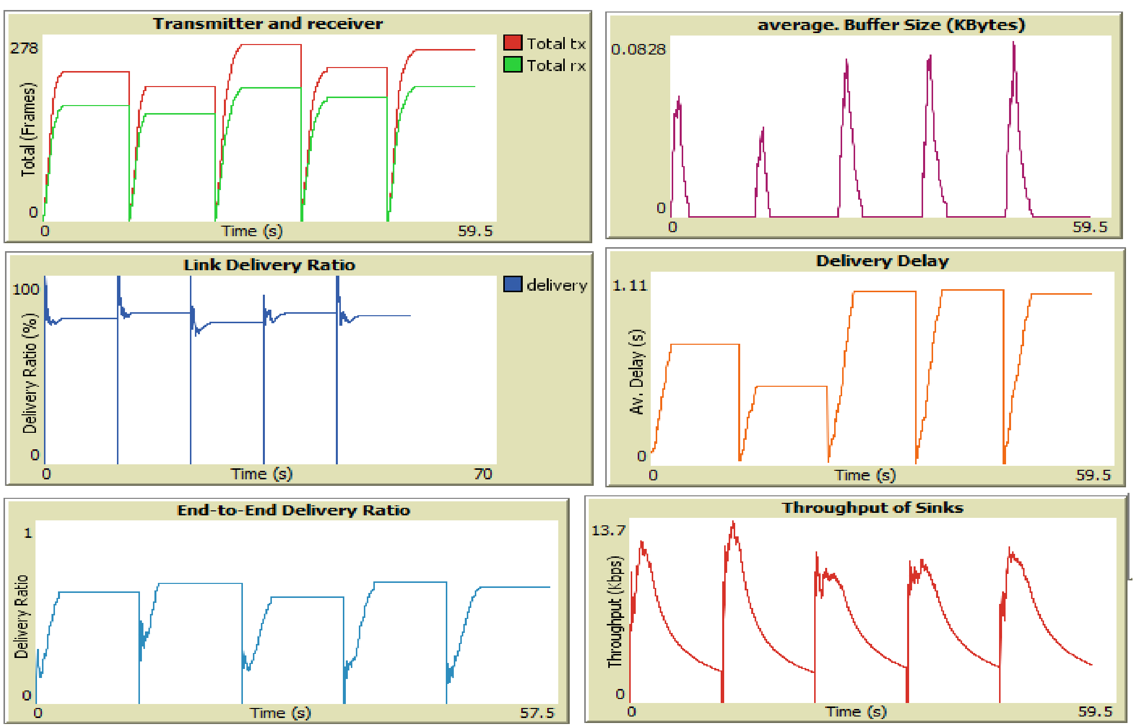
When x = 16 then y = 14

When x = 10 then y = 110

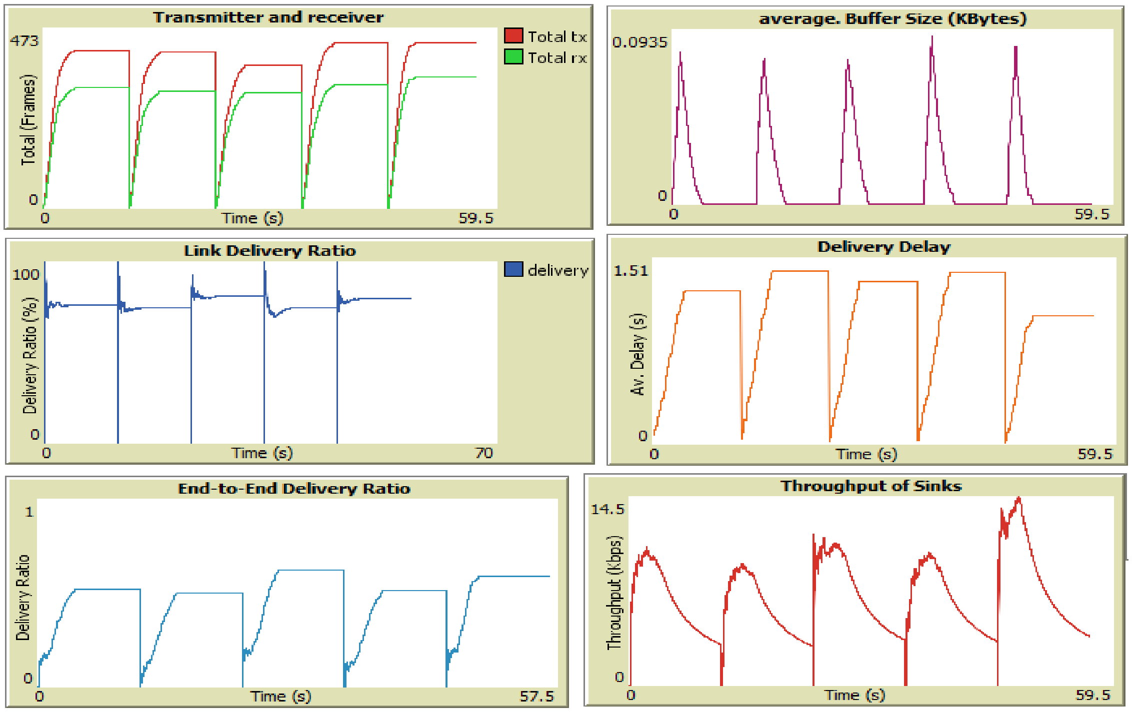
Figure (4.8) presents the transmission process by indicating the way in which a message is sent wirelessly from a source node to another node called a receiver node. A reception process represents the responding activity to the arriving messages. Number of the sent and received messages are used as indications to evaluate the WSNs performance and behavior. Dropped (failed) messages can be identified based on the difference between the sent and received messages. Buffer is crucial in performing a reliable communication in any WSN. Its size also important to improve the efficiency of the network. The links delivery ratio is also stated and indicated along the simulation run. The delivery delay, end-to-end delay and throughput are good metrics for the network behavior. Probability random variables are proposed in this thesis and utilized in simulation experiments for sending, receiving as well as the transmission and reception times. Sending message time and its reception time can be utilized in measuring the delay in the network.



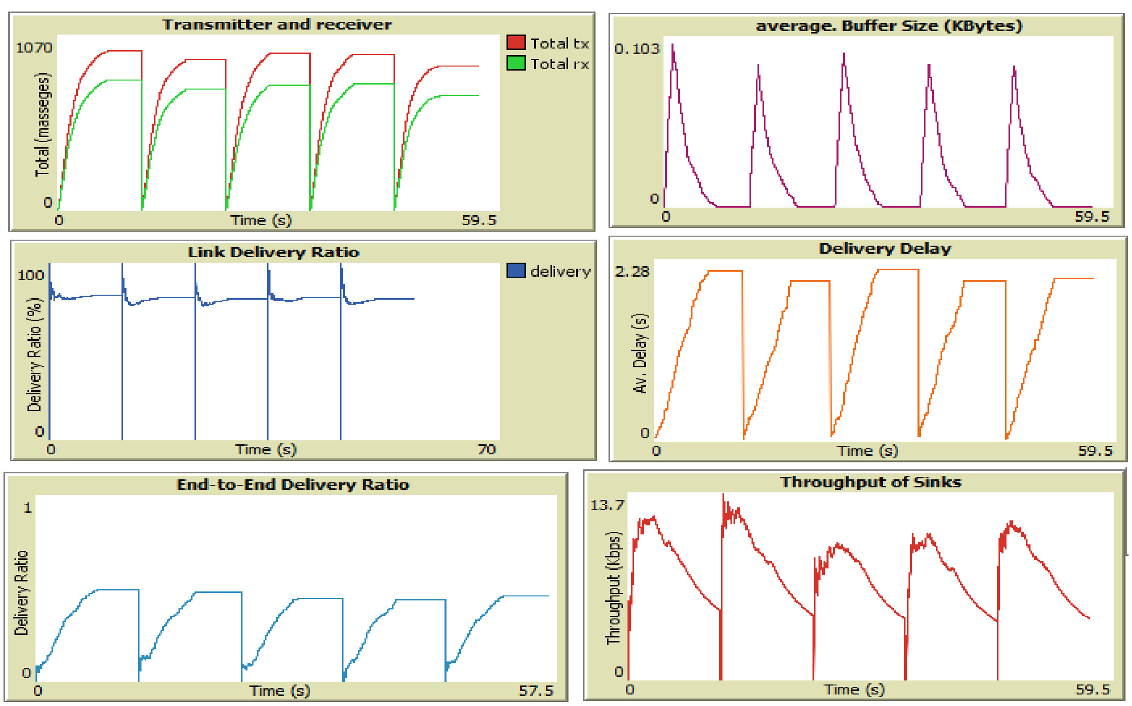
(A) 20 sensor deployment



(B) 40 sensor deployment



(C) 60 sensor deployment



(D) 100 sensor deployment

Figure 4.8: Network Performance Snapshot.

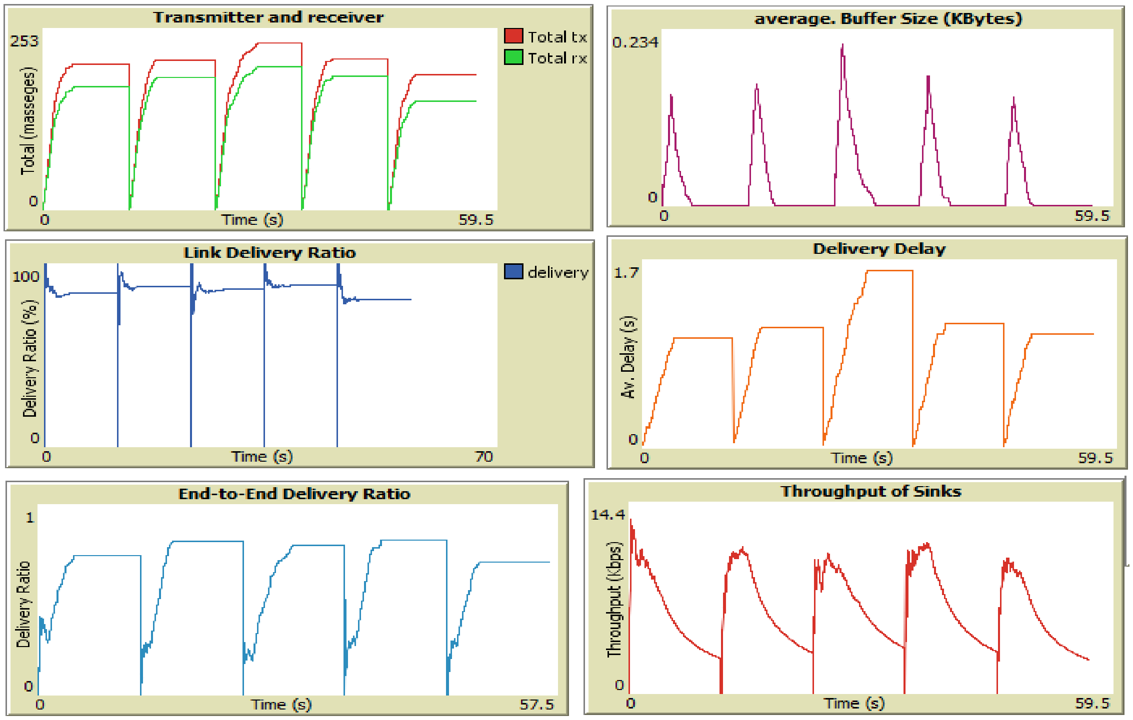
4.3.1.2 Case 2R

In this case, the same different number of sensors are randomly deployed. The message rate is suggested to be randomly generated with rate of 0.1 message per second. Table (4.6) presents the suggested parameters and the calculated performance metrics results. The results in each row of table (4.6) are calculated as the average value of 5 repeated simulation runs.

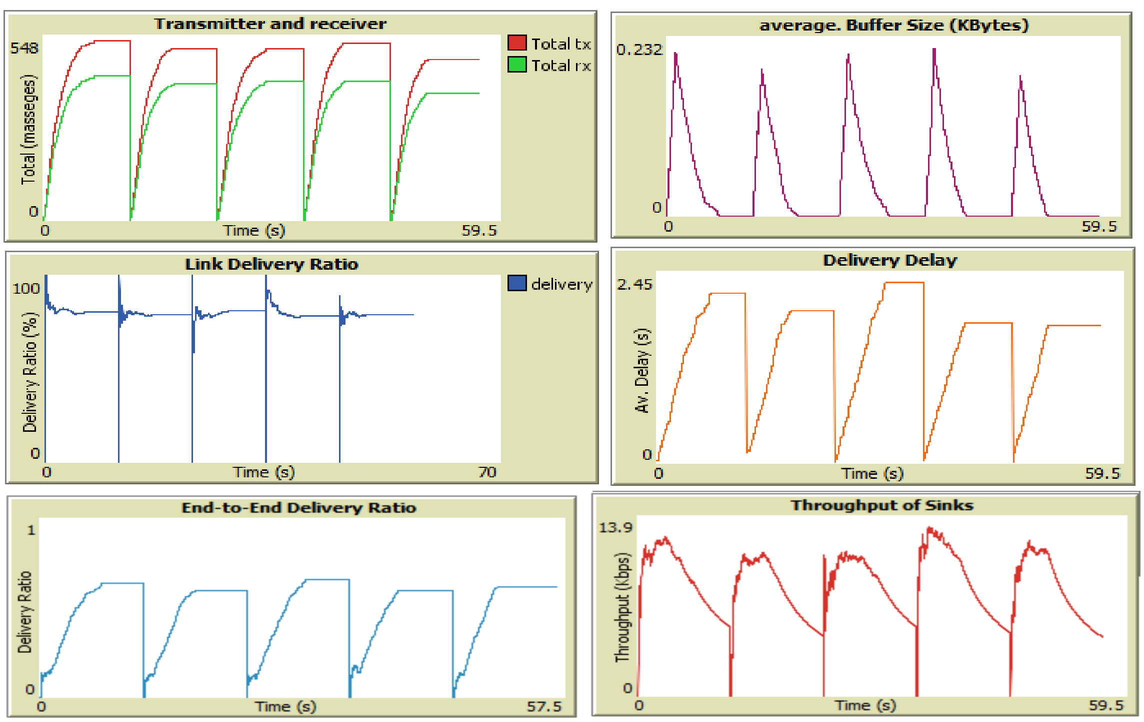
Table 4.6 results for case 2R.

Number of sensors	Connectivity threshold Power	Transmission radius	Totaltx	Totalrx	Failed tx	sensors Delivery ratio	sink Delivery ratio	Data generated	Throughput	Av. residual energy
20	16	195.73	209	178	31	0.85	0.76	132	2.93	190.47
40	13	146.77	510	406	104	0.81	0.61	274	4.92	195.11
60	11	121.15	882	714	168	0.79	0.56	395	6.55	196.71
80	9	100	1054	796	258	0.75	0.49	515	7.46	197.52
100	8	90.85	1391	1020	371	0.73	0.43	665	8.46	198.01

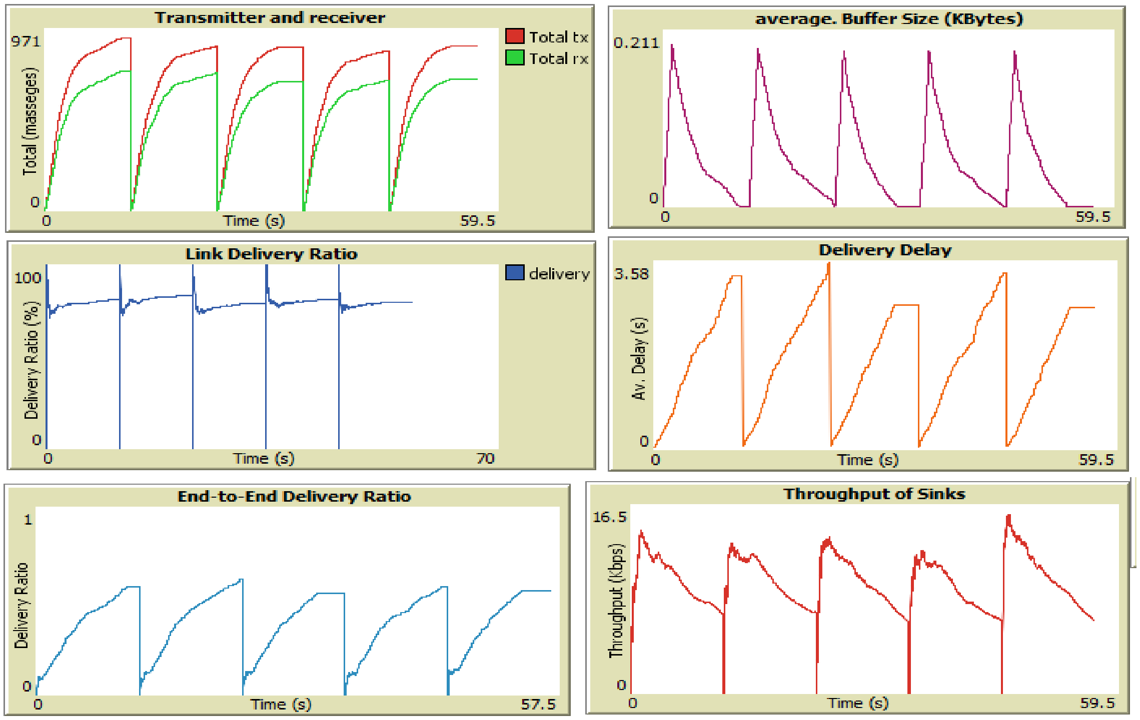
The relationship between the variables as mentioned in case 1R. Figure (4.9) presents the relations between different variables as mentioned in case 1R.



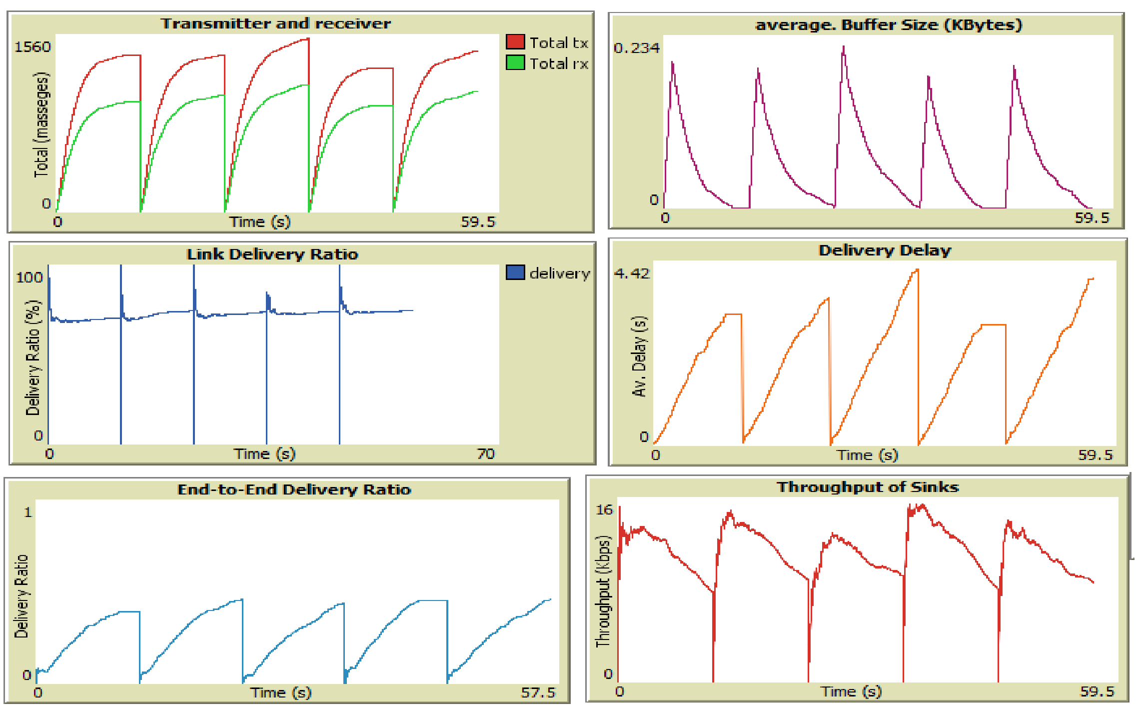
(A) 20 sensor deployment



(B) 40 sensor deployment



(C) 60 sensor deployment



(B)100 sensor deployment

Figure 4.9: Network Performance Snapshot.

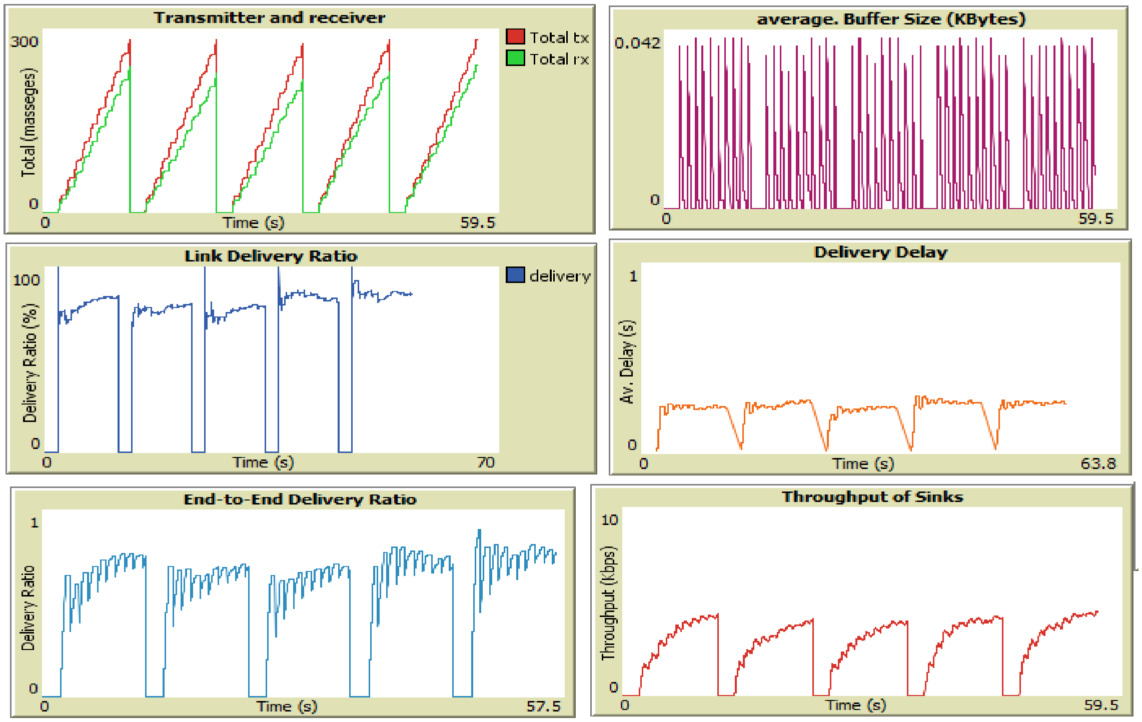
4.3.1.3 Case 3R

In this case, the same different number of sensors are randomly deployed. The message rate is suggested to be exactly generated with 1 message per second. Table (4.7) presents the suggested parameters and the calculated performance metrics results. The results in each row of table (4.7) are calculated as the average value of 5 repeated simulation runs.

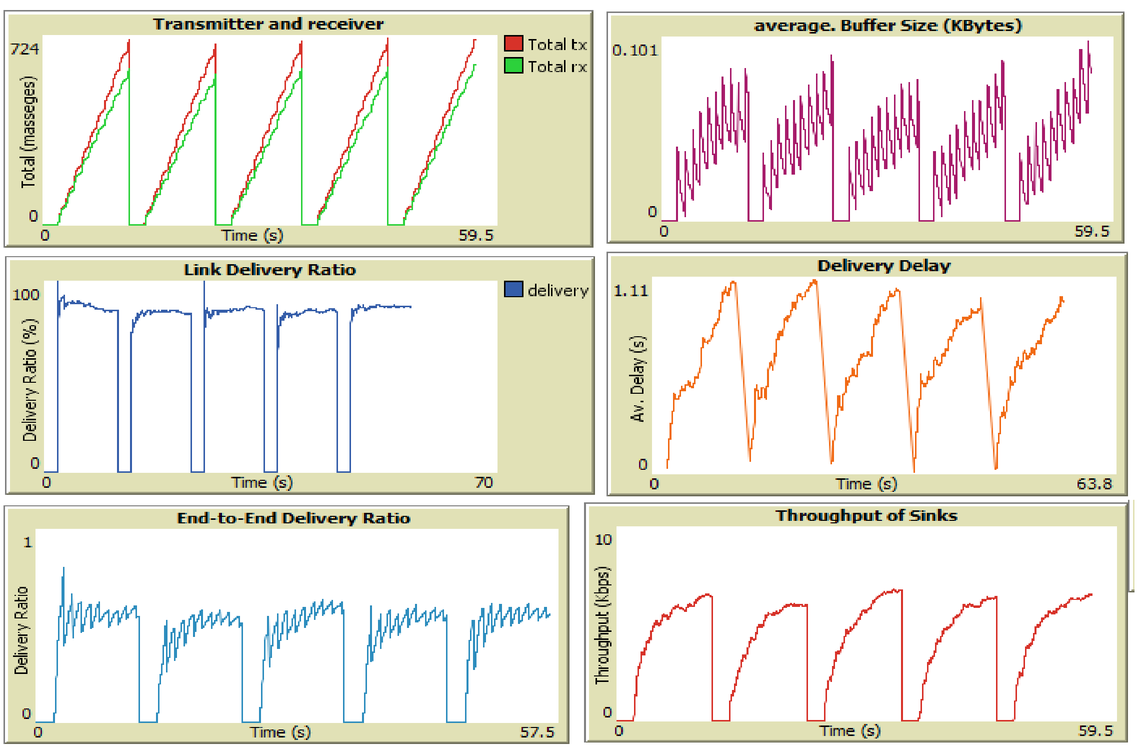
Table 4.7 results for case 3R.

Number of sensors	Connectivity threshold Power	Transmission radius	Totaltx	Totalrx	Failedtx	Sensors delivery ratio	Sink delivery ratio	Data generated	Throughput	Av. residual energy
20	16	195.73	281	231	50	0.84	0.72	200	4.20	190.47
40	13	146.77	705	597	108	0.82	0.55	400	6.39	195.11
60	11	121.15	1142	901	241	0.78	0.46	600	8.10	196.71
80	9	100	1491	1111	380	0.74	0.40	800	9.43	197.52
100	8	90.85	1957	1467	490	0.74	0.31	990	9.17	198.01

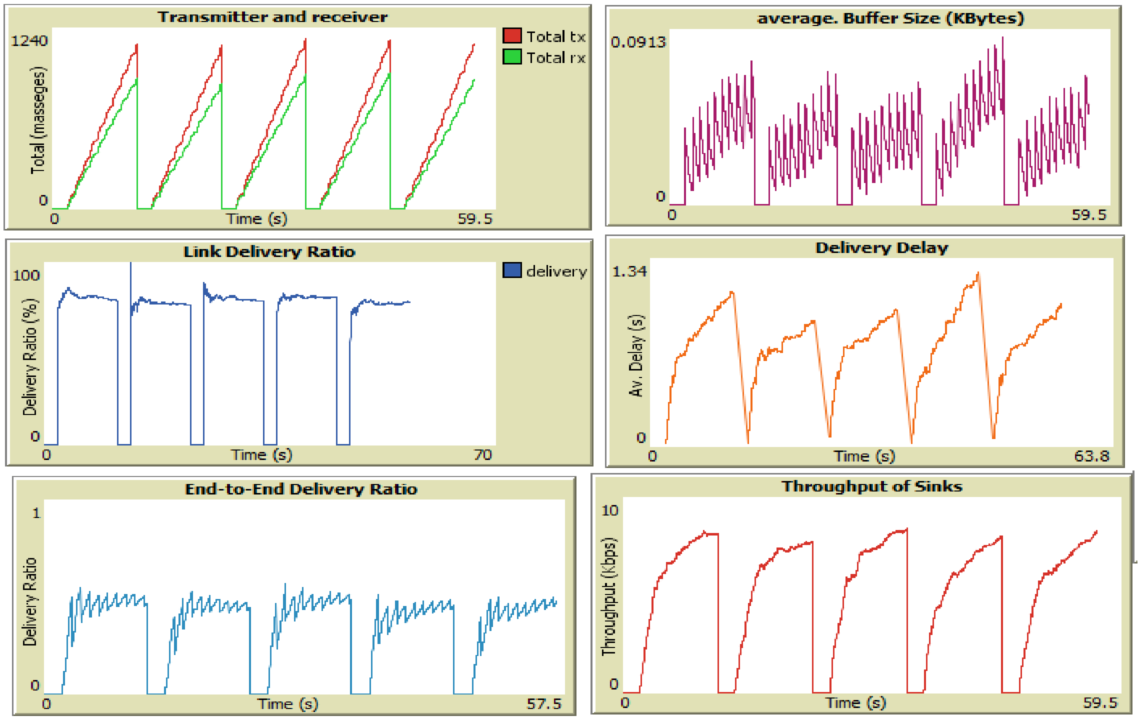
The relationship between the variables as mentioned in case 1R and 2R. Figure (4.10) presents the relations between different variables as mentioned in case 1R.



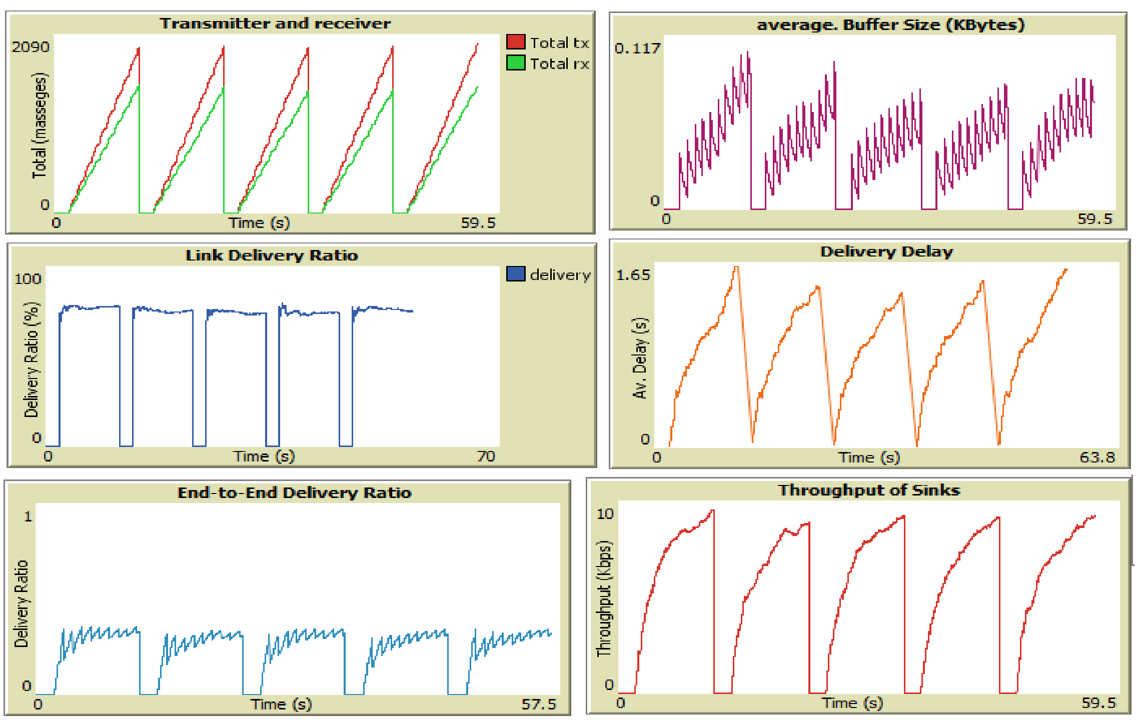
(A) 20 sensor deployment



(B) 40 sensor deployment



(C) 60 sensor deployment



(D) 100 sensor deployment

Figure 4.10: Network Performance Snapshot.

4.3.2 Predefined Deployment

Different scenarios are proposed to analyze, test and evaluate the network connectivity performance. Certain number of sensors are deployed in each scenario. The number of the deployed sensors in these scenarios are (25, 49, 64 and 100). Connectivity threshold power and the transmission radius are calculated based on the number of sensors. In each simulation scenario the total transmitted messages (totaltx), total received messages (totalrx), failed transmitted messages (failedtx), sensor delivery ratio, sink delivery ratio, data messages generated, throughput and average residual energy are calculated based on section (2.12). Three cases are proposed for the message generation rate (0.05, 0.1 and 1 message per second).

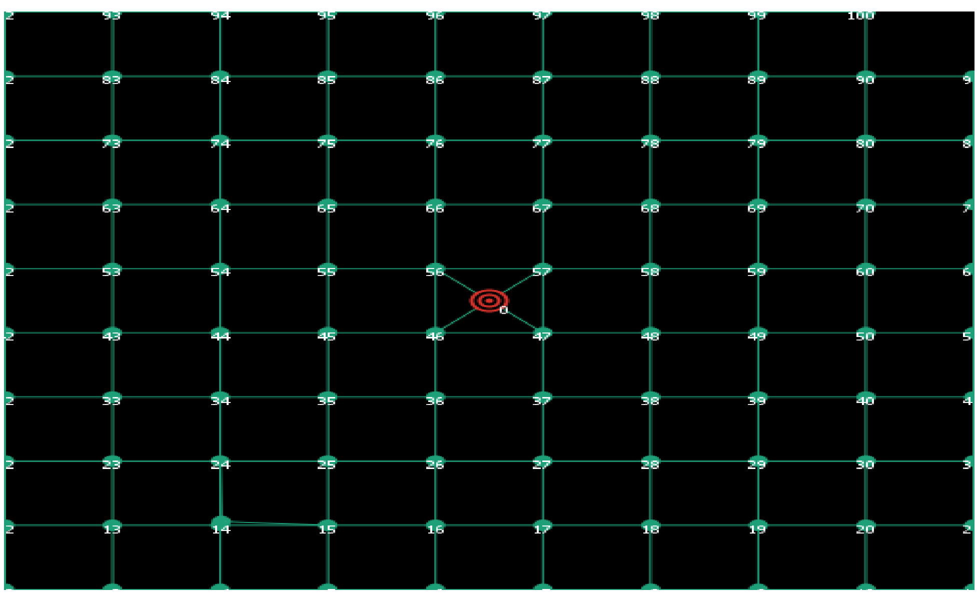


Figure 4.11: Predefined Deployment.

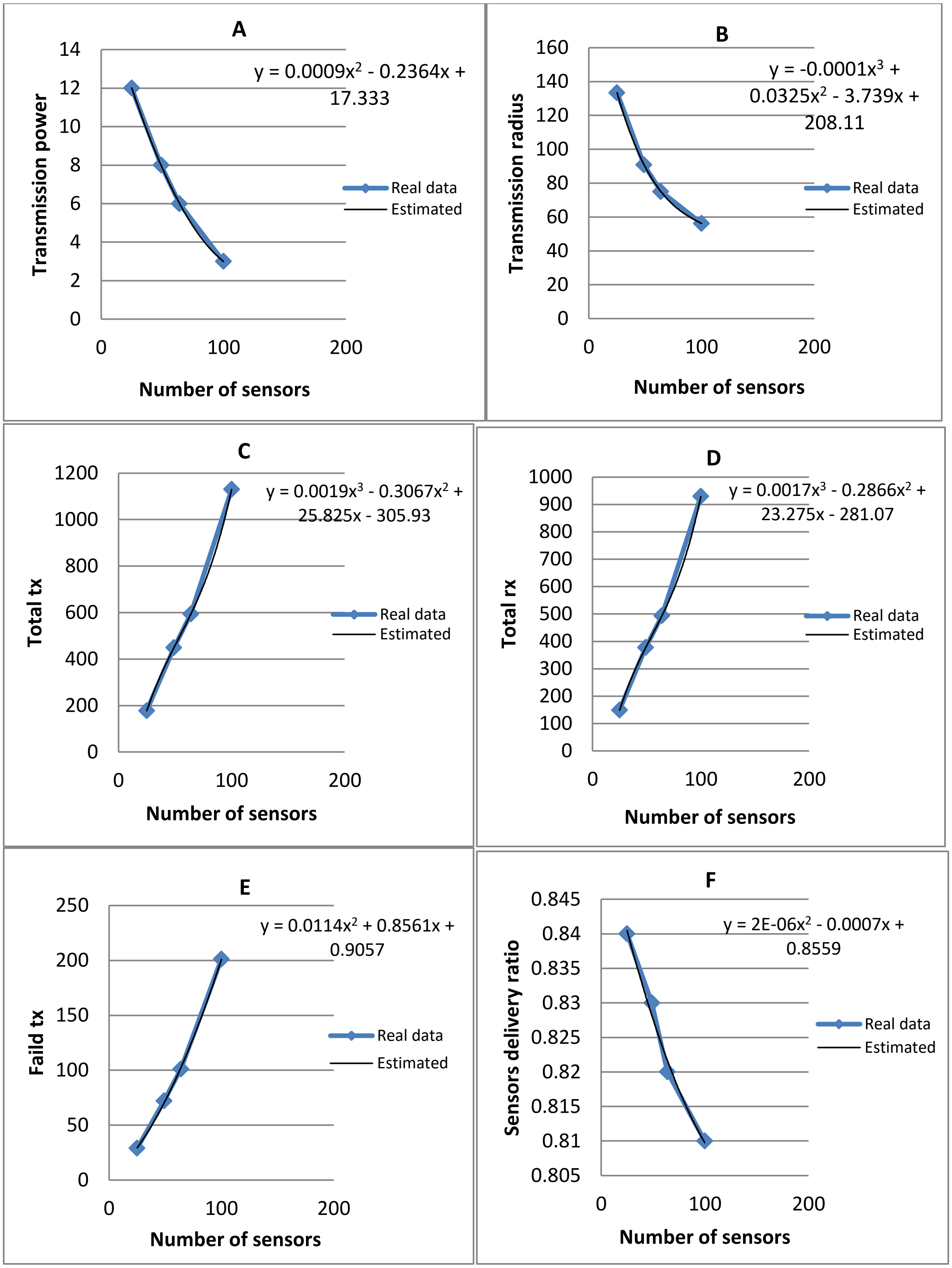
4.3.2.1 Case 1P

In this case, different number of sensors are deployed in a predefined manner (25, 49, 64 and 100). The message rate is suggested to be randomly generated with rate of 0.05 message per second. Table (4.8) presents the suggested parameters and the calculated performance metrics results. The results in each row of table (4.8) are calculated as the average value of 5 repeated simulation runs.

Table 4.8 results for case 1P.

Number of sensors	Connectivity threshold power	Transmission Radius	Totaltx	Totalrx	Failedtx	Sensors delivery ratio	Sink delivery ratio	Data generated	Throughput	Av. residual energy
25	12	133.35	178	149	29	0.84	0.65	85	1.61	192.31
49	8	90.85	449	377	72	0.83	0.55	163	2.62	195.99
64	6	74.98	594	493	101	0.82	0.50	206	3.03	196.91
100	3	56.23	1130	929	201	0.81	0.39	339	3.97	198.01

The relationship between the variables as mentioned previous cases. To make another use of table (4.8), a suggested regression approach is utilized to generalize its benefit. Figure (4.12) presents the regression curves and there suggested equations to show the effect of number of sensors on the network performance metrics.


A
Transmission power
y = 0.0009x² - 0.2364x + 17.333
Real data
Estimated
Number of sensors
B
Transmission radius
y = -0.0001x³ + 0.0325x² - 3.739x + 208.11
Real data
Estimated
Number of sensors
C
Total tx
y = 0.0019x³ - 0.3067x² + 25.825x - 305.93
Real data
Estimated
Number of sensors
D
Total rx
y = 0.0017x³ - 0.2866x² + 23.275x - 281.07
Real data
Estimated
Number of sensors
E
Faild tx
y = 0.0114x² + 0.8561x + 0.9057
Real data
Estimated
Number of sensors
F
Sensors delivery ratio
y = 2E-06x² - 0.0007x + 0.8559
Real data
Estimated
Number of sensors

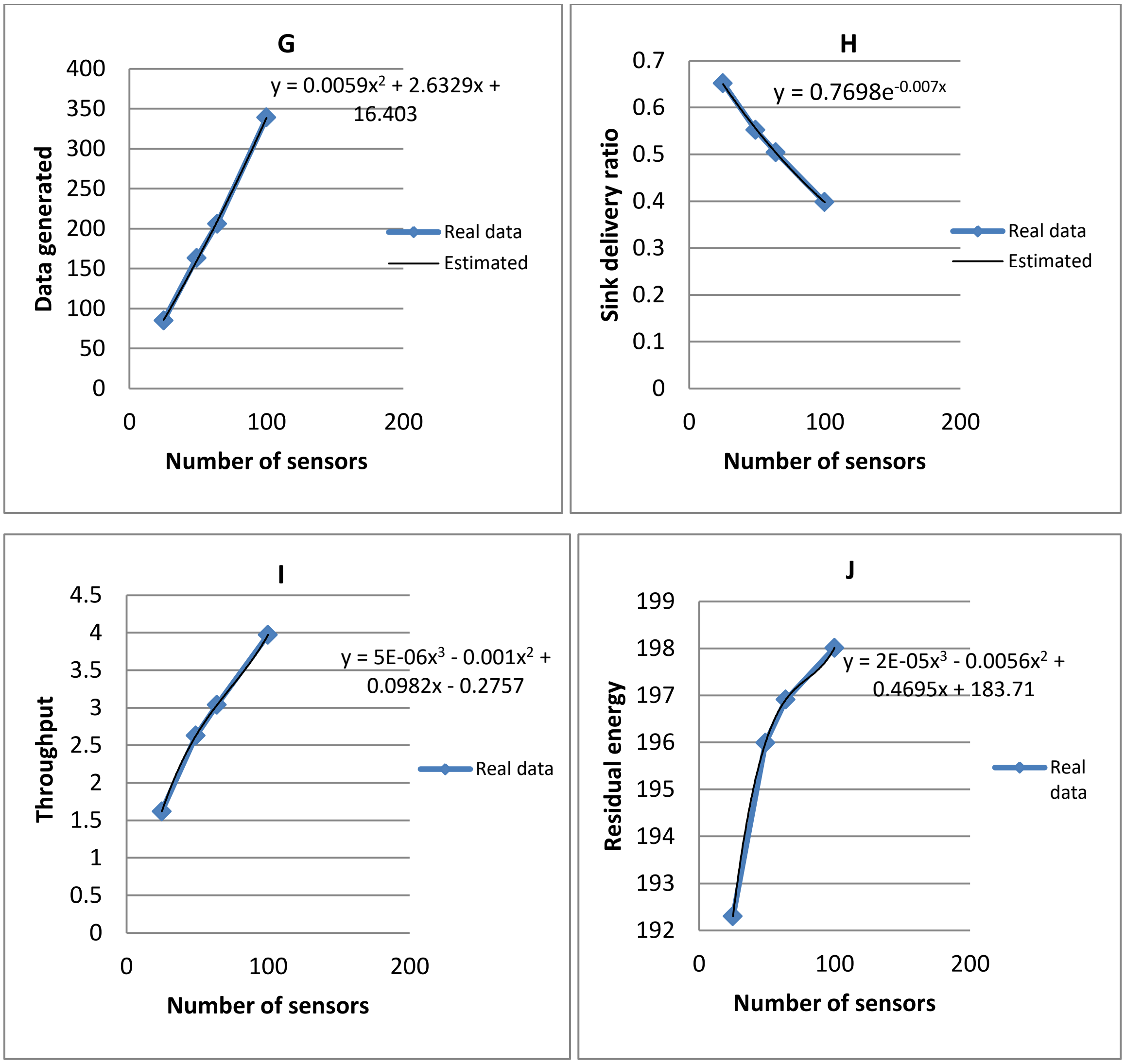


Figure 4.12: Effects of Number of Sensors on WSN Parameters.

Examples 4.5:

A (number of sensors vs transmission power):

When $x = 25$ then $y = 12$

When $x = 81$ then $y = 4$

B (number of sensors vs transmission radius):

When x = 25 then y = 133

When x = 81 then y = 65

C (number of sensors vs totaltx):

When x = 25 then y = 178

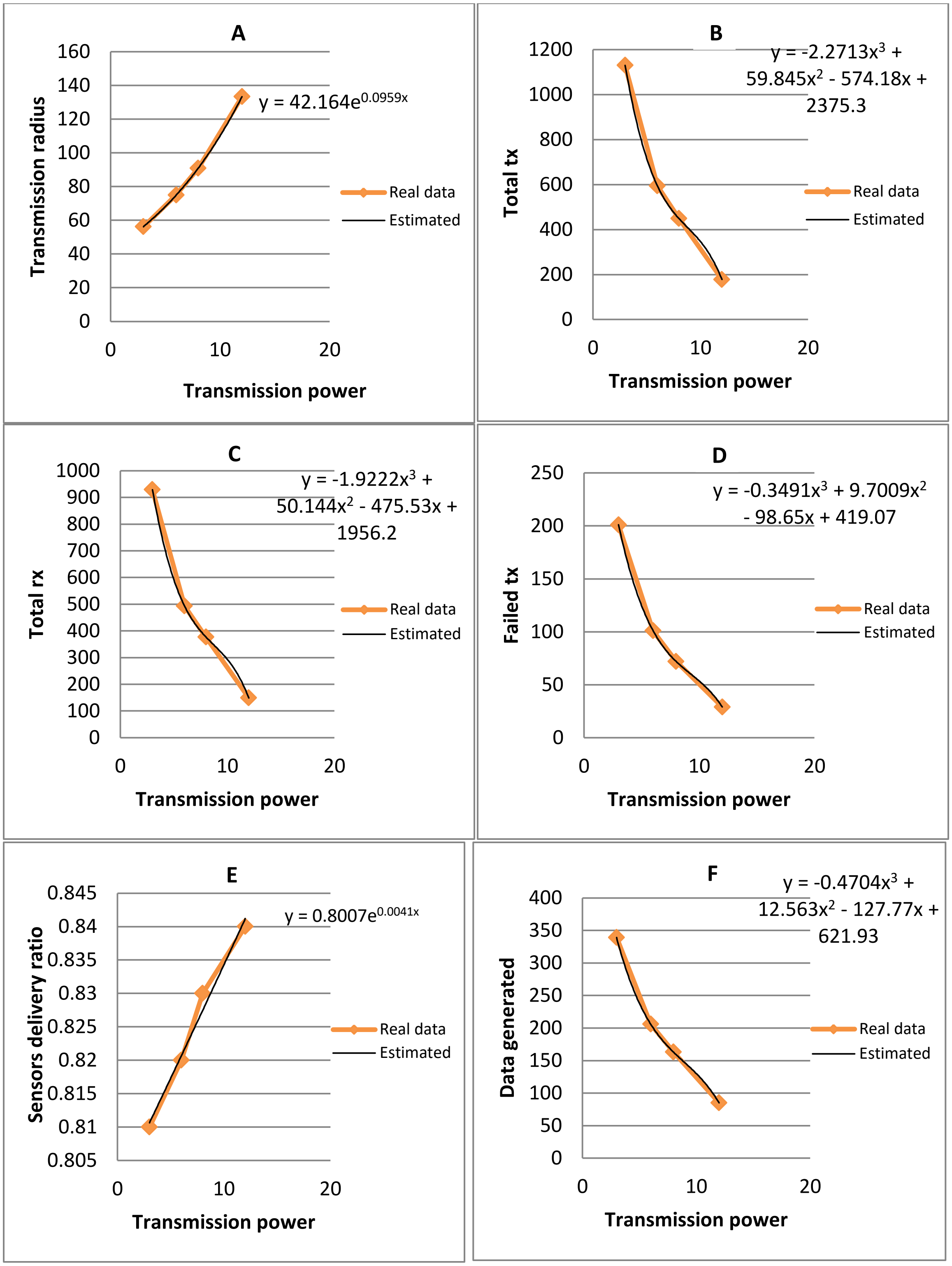
When x = 91 then y = 783

D (number of sensors vs totalrx):

When x = 25 then y = 148

When x = 81 then y = 627

To make another use of table (4.8), a suggested regression approach is utilized to generalize its benefit. Figure (4.13) presents the regression curves and there suggested equations to show the effect of transmission power on the network performance metrics.


A
Transmission radius
Transmission power
y = 42.164e^0.0959x
Real data
Estimated
B
Total tx
Transmission power
y = -2.2713x^3 + 59.845x^2 - 574.18x + 2375.3
Real data
Estimated
C
Total rx
Transmission power
y = -1.9222x^3 + 50.144x^2 - 475.53x + 1956.2
Real data
Estimated
D
Failed tx
Transmission power
y = -0.3491x^3 + 9.7009x^2 - 98.65x + 419.07
Real data
Estimated
E
Sensors delivery ratio
Transmission power
y = 0.8007e^0.0041x
Real data
Estimated
F
Data generated
Transmission power
y = -0.4704x^3 + 12.563x^2 - 127.77x + 621.93
Real data
Estimated

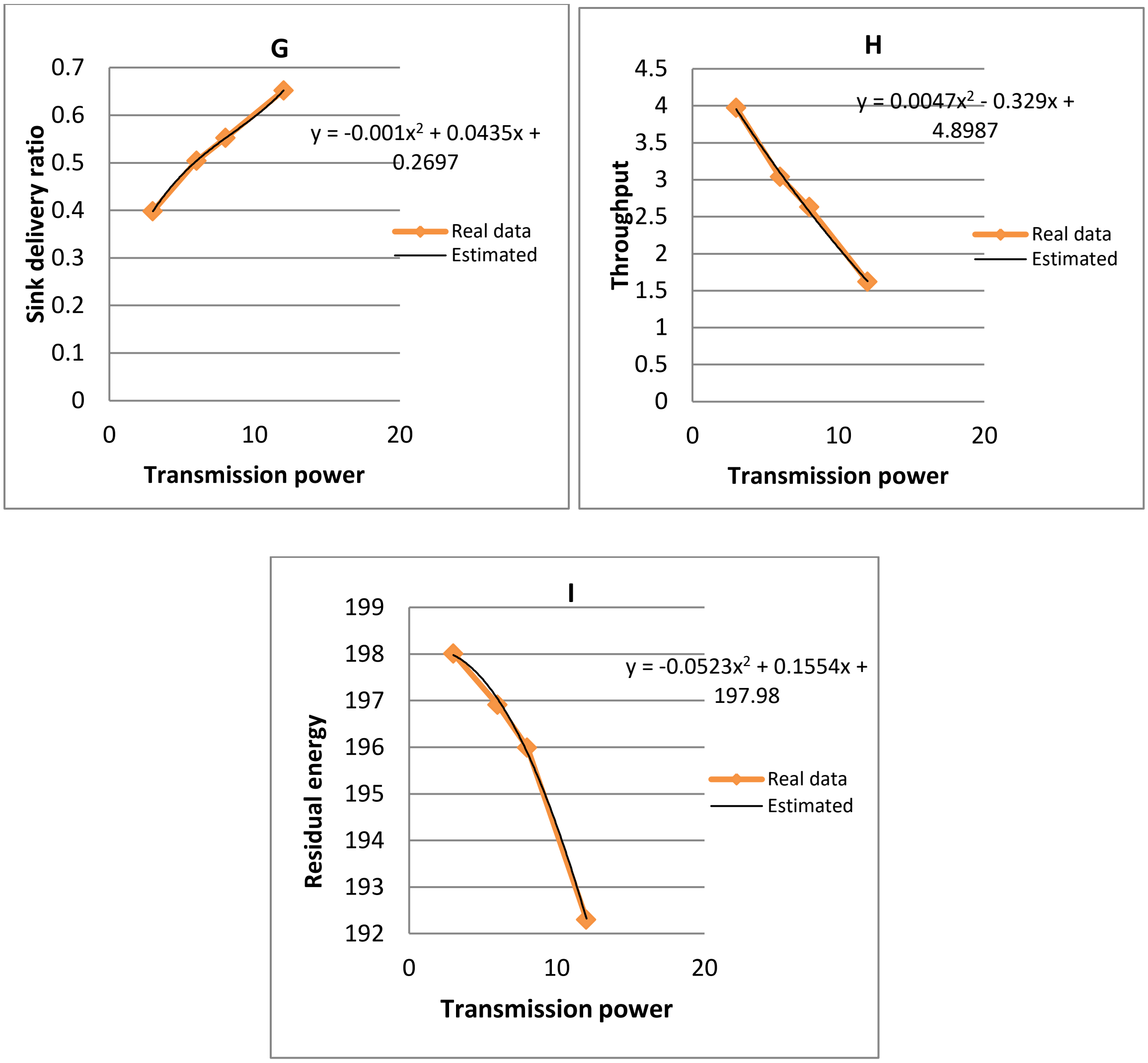


Figure 4.13: Effects of Transmission Power on WSN Parameters.

Examples 4.6:

A (transmission power vs transmission radius):

When x = 12 then y = 133

When x = 4 then y = 61

B (transmission power vs totaltx):

When x = 12 then y = 178

When x = 4 then y = 890

C (transmission power vs totalrx):

When x = 12 then y = 149

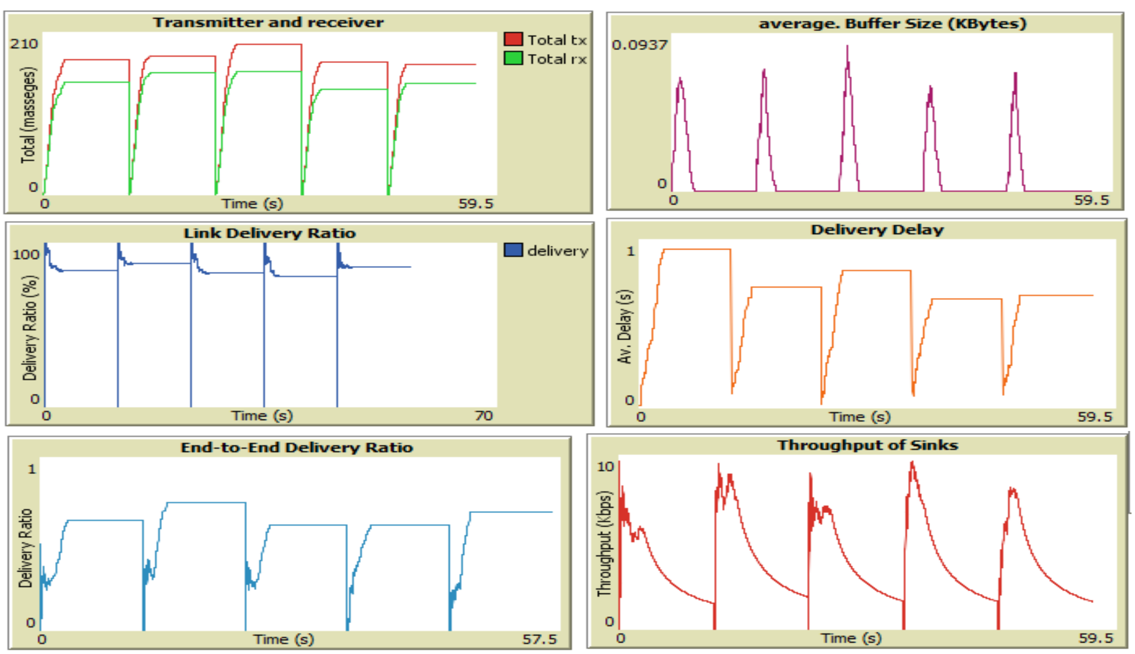
When x = 4 then y = 733

D (transmission power vs failedtx):

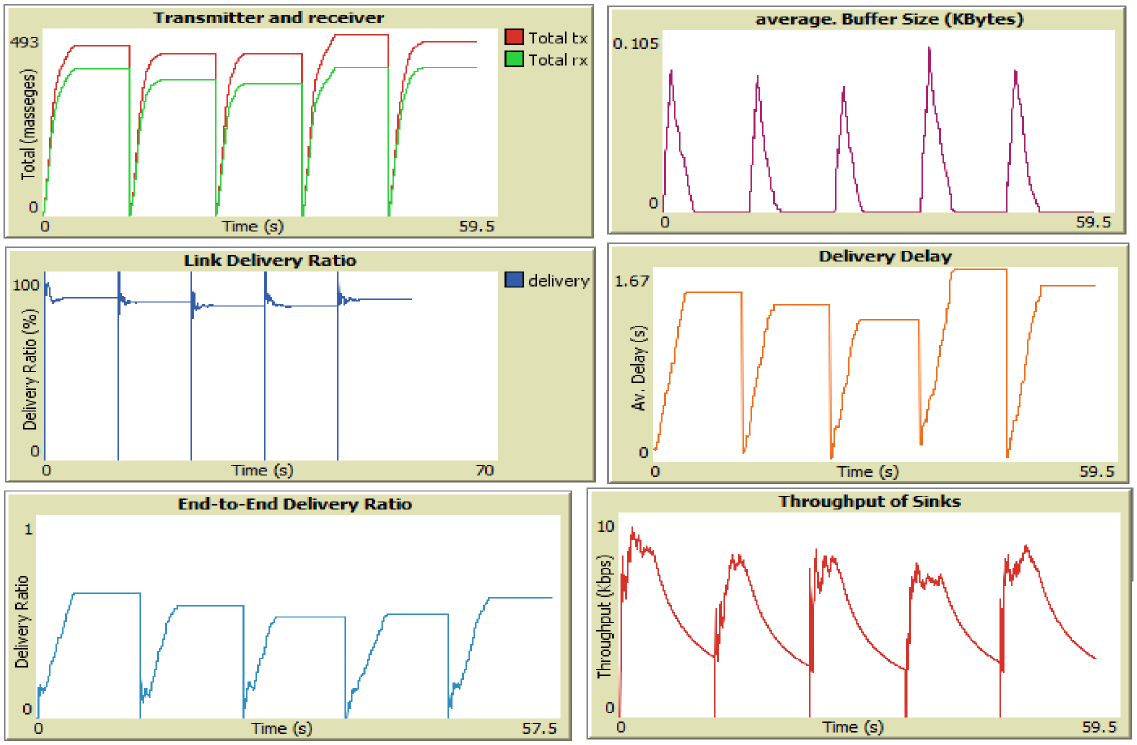
When x = 12 then y = 29

When x = 4 then y = 157

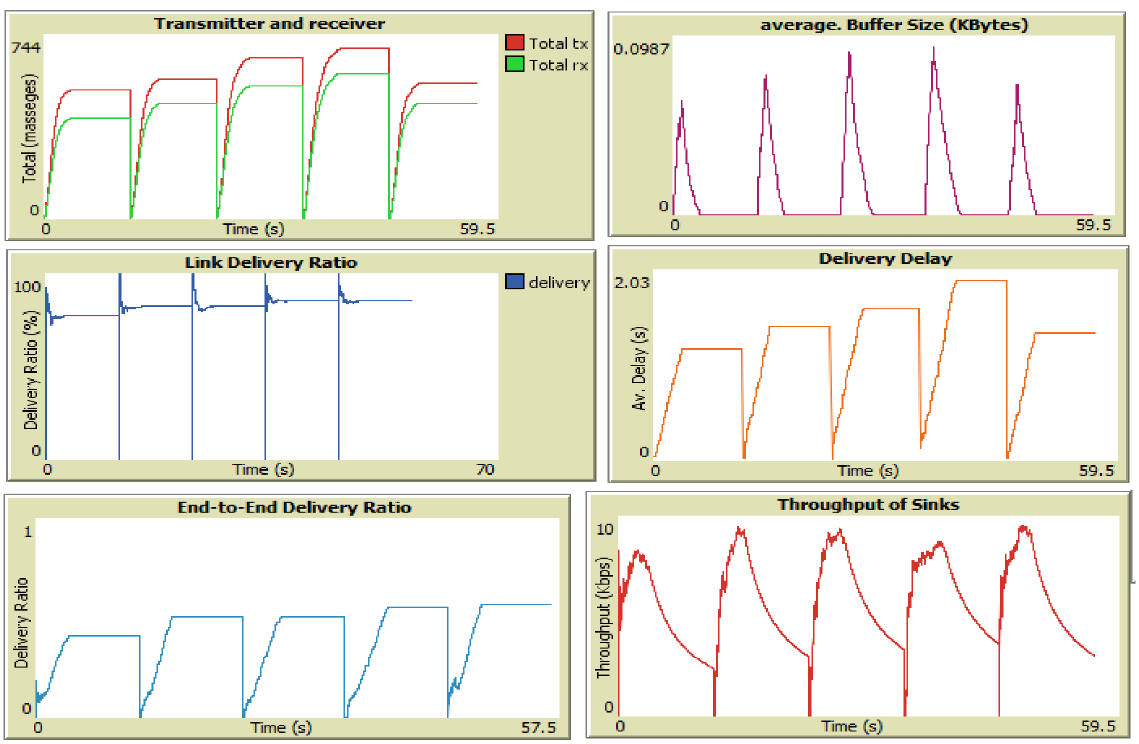
Figure (4.14) presents the relations between different variables as mentioned in previous cases.



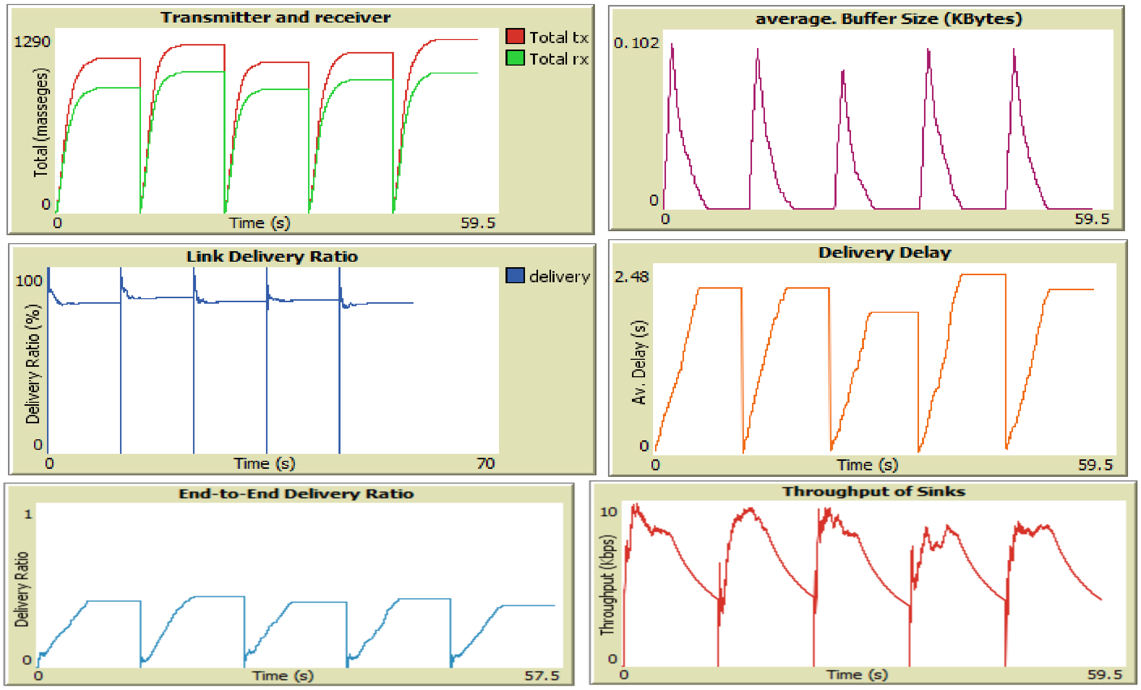
(A) 25 sensor deployment



(B) 49 sensor deployment



(C) 64 sensor deployment



(D)100 sensor deployment

Figure 4.14: Network Performance Snapshot.

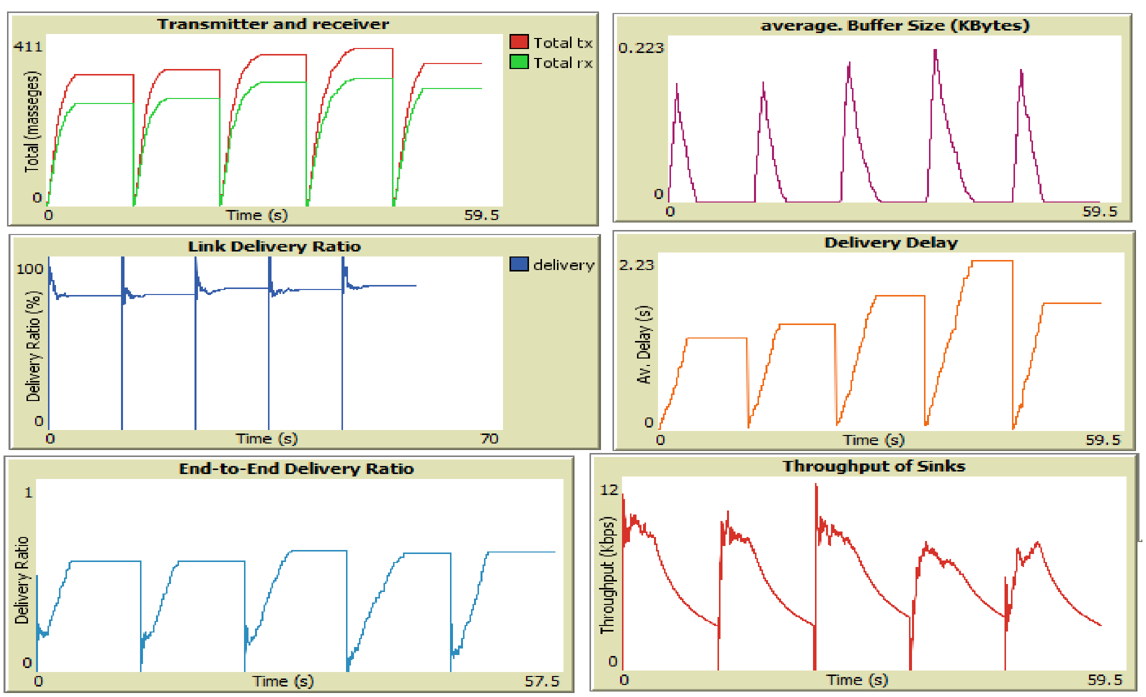
4.3.2.2 Case 2P

In this case different number of sensors are deployed in a predefined manner (25, 49, 64 and 100). The message rate is suggested to be randomly generated with rate of 0.1 message per second. Table (4.9) presents the suggested parameters and the calculated performance metrics results. The results in each row of table (4.8) are calculated as the average value of 5 repeated simulation runs.

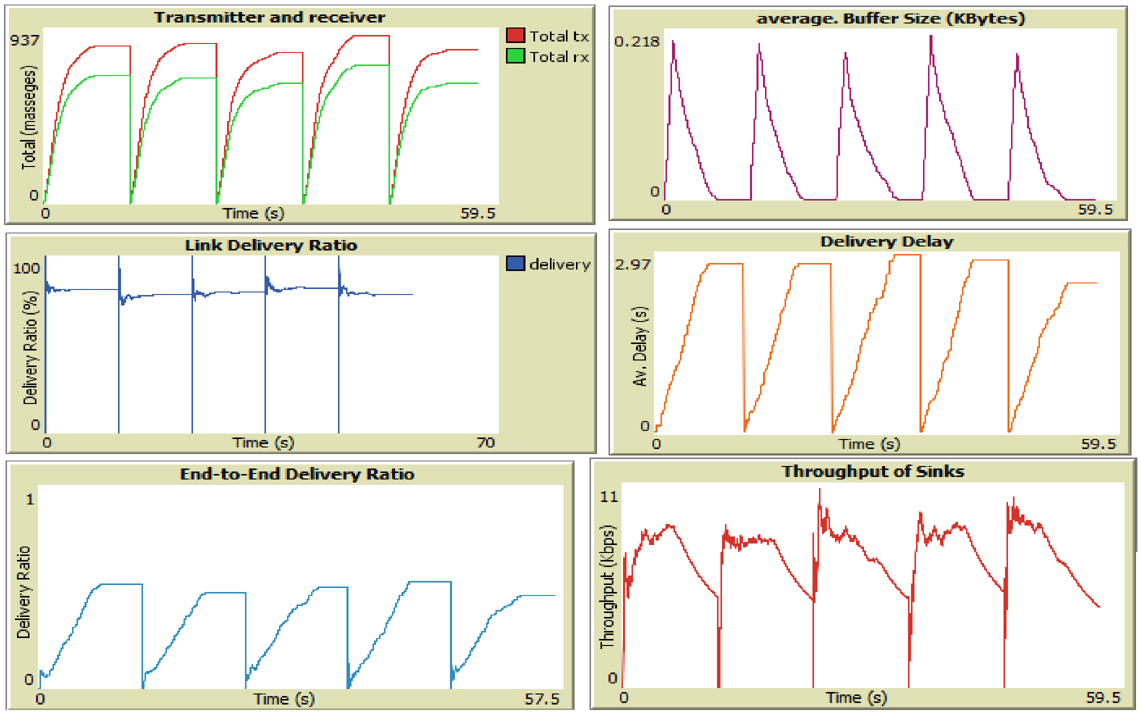
Table 4.9 results for case 2P.

Number of sensors	Connectivity threshold power	Transmission Radius	Totaltx	Totalrx	Failed tx	sensors delivery ratio	sink delivery ratio	Data generated	Throughput	Av. residual energy
25	12	133.35	345	278	67	0.80	0.6	170	2.96	192.3
49	8	90.85	843	675	168	0.80	0.48	332	4.74	195.99
64	6	74.98	1209	977	232	0.80	0.45	429	5.73	196.91
100	3	56.23	2026	1613	413	0.79	0.36	657	7.06	198.01

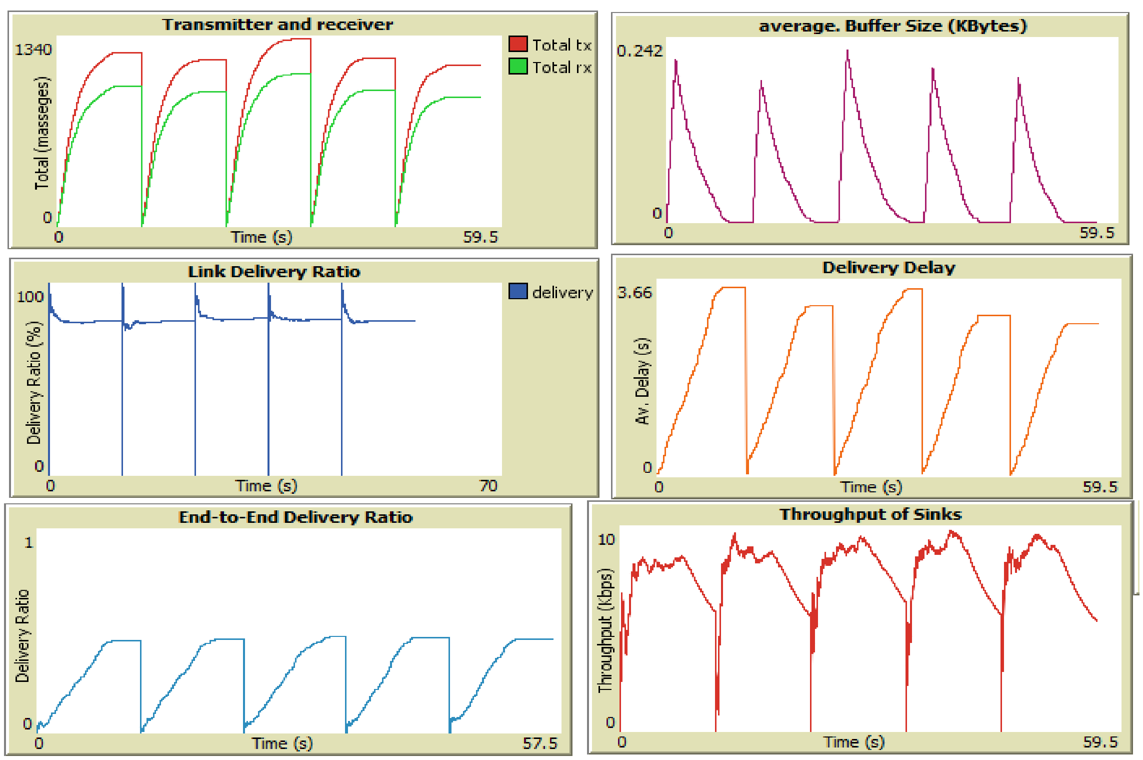
The relationship between the variables as mentioned previous cases. Figure (4.15) presents the relations between different variables as mentioned in previous cases.



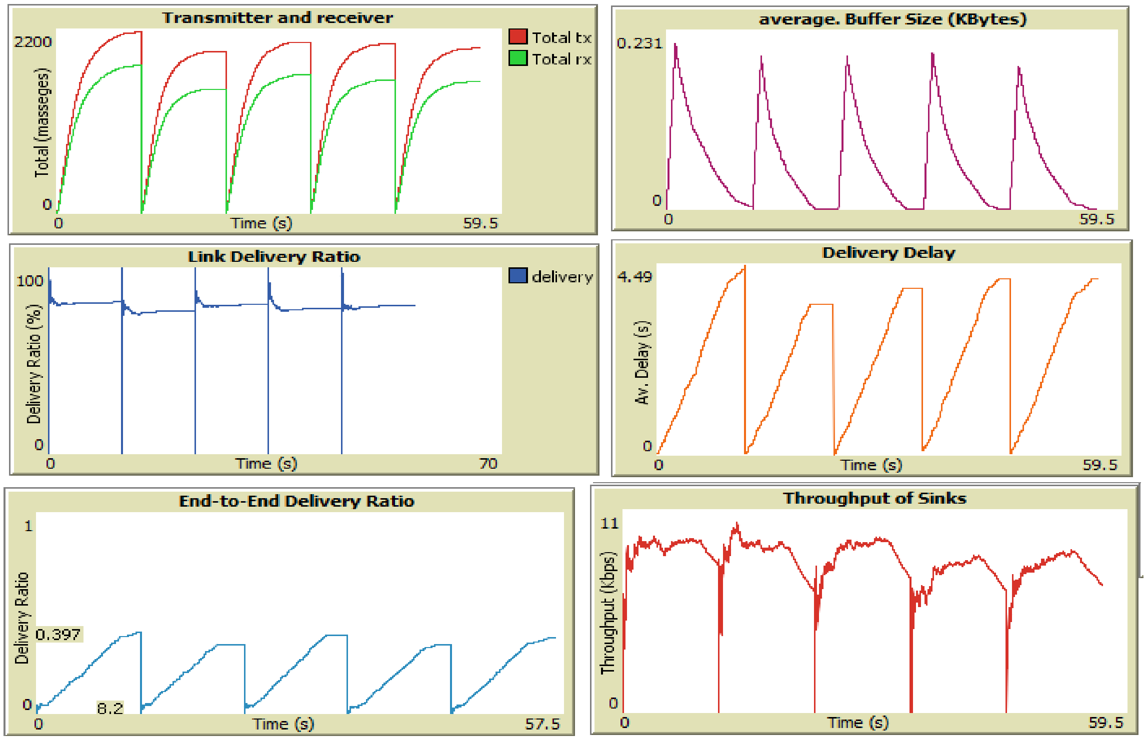
(A) 25 sensors deployment



(B) 49 sensors deployment



(C) 64 sensors deployment



(D) 100 sensors deployment

Figure 4.15: Network Performance Snapshot.

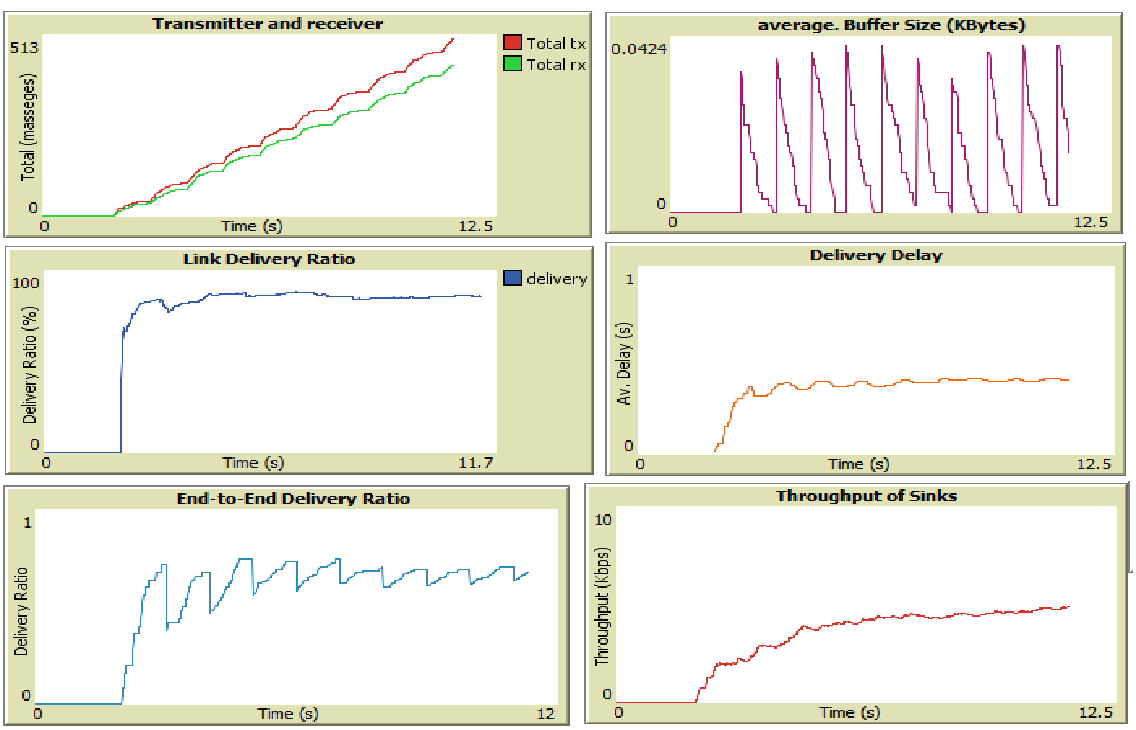
4.3.2.3 Case 3P

In this case different number of sensors are deployed in a predefined manner (25, 49, 64 and 100). The message rate is suggested to be exactly generated with 1 message per second. Table (4.10) presents the suggested parameters and the calculated performance metrics results.

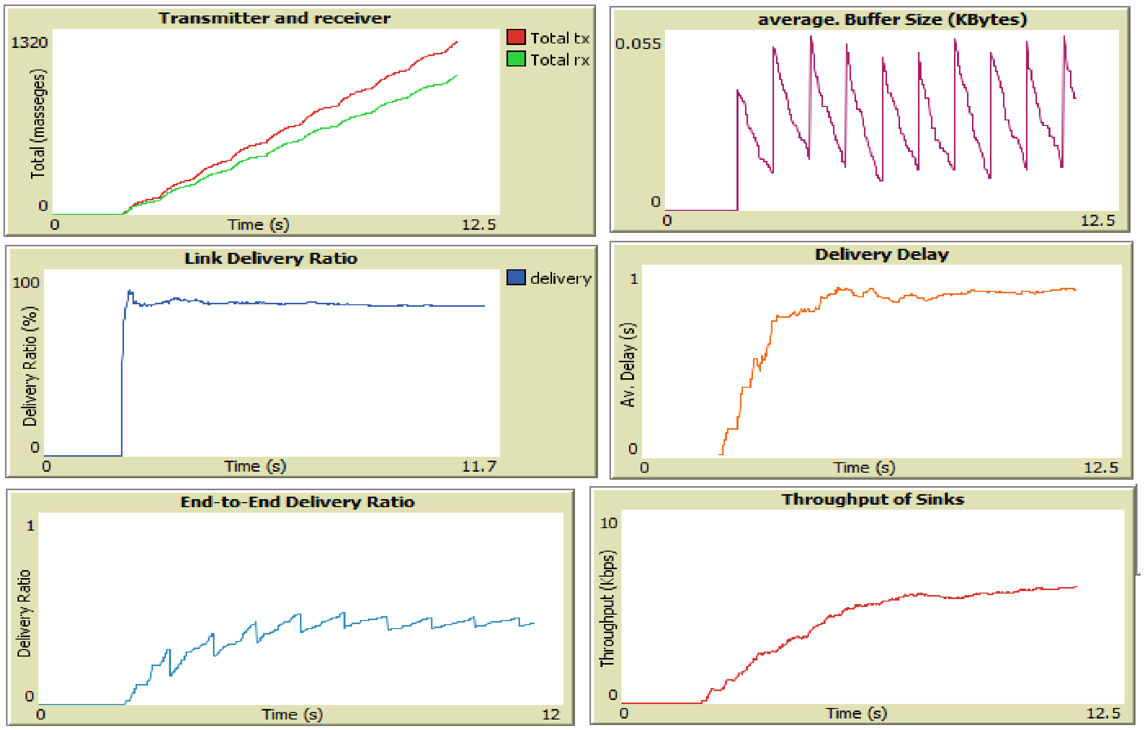
Table 4.10 results for case 3P.

Number of sensors	Connectivity threshold power	Transmission Radius	Totaltx	Totalrx	Failedtx	Sensors delivery ratio	Sink delivery ratio	Data generated	Throughput	Av. residual energy
25	12	133.35	500	428	72	0.85	0.67	250	4.90	192.30
49	8	90.85	1231	991	240	0.83	0.42	490	6.04	195.99
64	6	74.98	1703	1404	299	0.82	0.38	640	7.17	196.91
100	3	56.23	2946	2375	571	0.80	0.26	1000	7.72	198.01

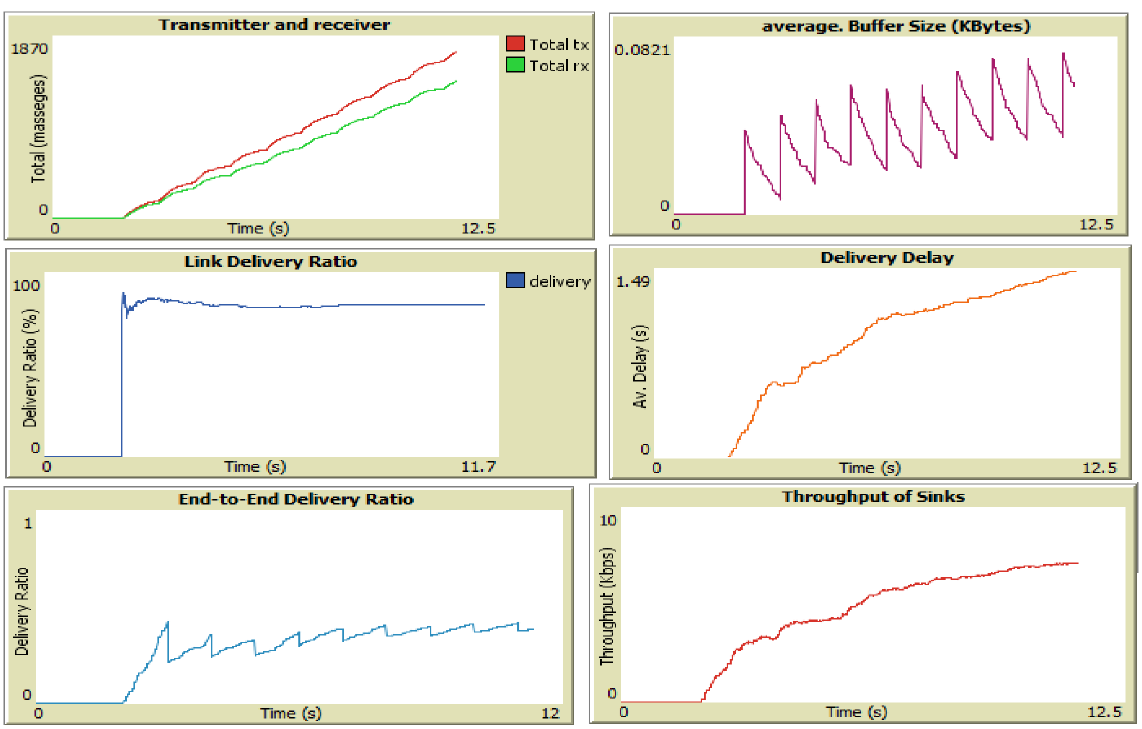
The relationship between the variables as mentioned previous cases. Figure (4.16) presents the relations between different variables as mentioned in previous cases.



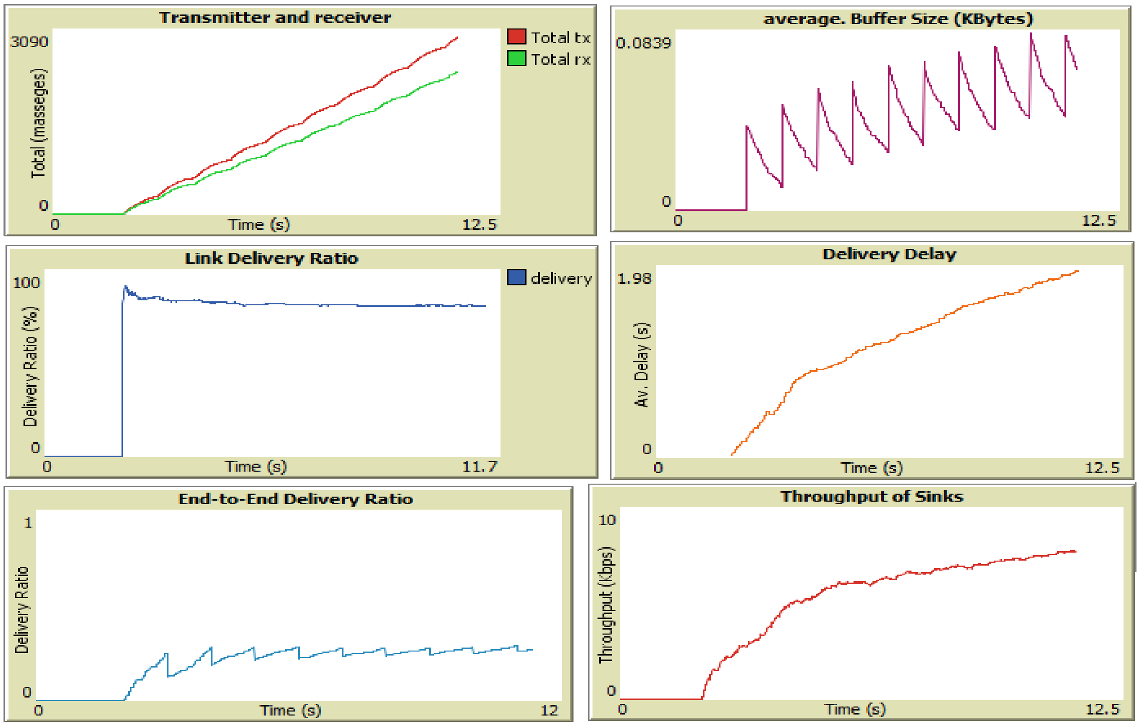
(A) 25 sensors deployment



(B) 49 sensors deployment



(C) 64 sensors deployment



(D) 100 sensors deployment

Figure 4.16: Network Performance Snapshot.

4.4 Connectivity Matrix

The idea of graph theory is utilized in this thesis by presenting the connected graph as nodes and links. Figure (4.17) shows an example of deploying 10 nodes in addition to the sink node. A connection matrix is also developed to represent the connected graph. From this matrix any connected nodes can be observed. Such matrix is easy to be processed as network indications mathematically. Equation (4.10) presents the connectivity graph matrix.

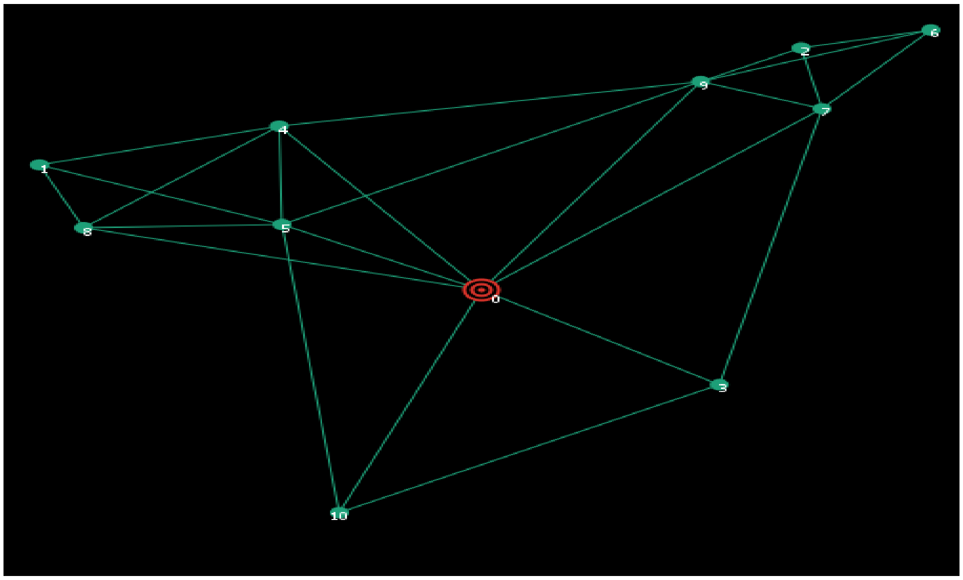


Figure 4.1 7: Network Connections.

$$A_{11*11}=\begin{bmatrix}0&0&0&1&1&1&0&1&1&1&1\\0&0&0&0&1&1&0&0&1&0&0\\0&0&0&0&0&0&1&1&0&1&0\\1&0&0&0&0&0&0&1&0&0&1\\1&1&0&0&0&1&0&0&1&1&0\\1&1&0&0&1&0&0&0&1&1&1\\0&0&1&0&0&0&0&1&0&1&0\\1&0&1&1&0&0&1&0&0&1&0\\1&1&0&0&1&1&0&0&0&0&0\\1&0&1&0&1&1&1&1&0&0&0\\1&0&0&1&0&1&0&0&0&0&0\end{bmatrix} \quad \ldots\ldots(4.10)$$

Equation (4.11) is developed from equation (4.10) by considering the number of nodes and links.

$$\text{Connectivity} = \left(\frac{number\ of\ sensors}{number\ of\ links}\right) * 100\% \quad \ldots\ldots(4.11)$$

$$= \frac{11}{24}$$

$$= 0.458$$

Figure (4.18) shows another example of deploying 20 nodes in addition to the sink node. A connection matrix is also developed to represent the connected graph. From this matrix any connected nodes can be observed. Such matrix is easy to be processed as network indications mathematically. Equation (4.12) presents the connectivity graph matrix.

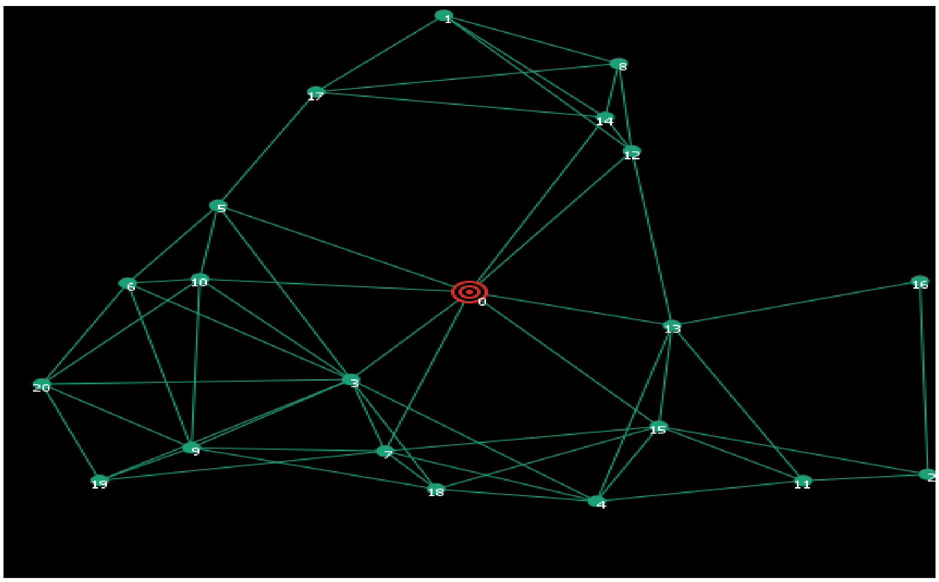


Figure 4.18: Network Connection.

$$A_{21*21}=\begin{bmatrix}
0&0&0&1&0&1&0&1&0&0&1&0&1&1&1&1&0&0&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0&0&1&0&1&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&1&1&0&0&0&0\\
1&0&0&0&1&1&1&1&0&1&1&0&0&0&0&0&0&0&1&1&1\\
0&0&0&1&0&0&0&1&0&0&0&1&0&1&0&1&0&0&1&0&0\\
1&0&0&1&0&0&1&0&0&0&1&0&0&0&0&0&0&1&0&0&0\\
0&0&0&1&0&1&0&0&0&1&1&0&0&0&0&0&0&0&0&0&1\\
1&0&0&1&1&0&0&0&0&1&0&0&0&0&0&1&0&1&1&0&0\\
0&1&0&0&0&0&0&0&0&0&0&0&1&0&1&0&0&1&0&0&0\\
0&0&0&1&0&0&1&1&0&0&1&0&0&0&0&0&0&0&1&1&1\\
1&0&0&1&0&1&1&0&0&1&0&0&0&0&0&0&0&0&0&0&1\\
0&0&1&0&1&0&0&0&0&0&0&0&0&1&0&1&0&0&0&0&0\\
1&1&0&0&0&0&0&0&1&0&0&0&0&1&1&0&0&0&0&0&0\\
1&0&0&0&1&0&0&0&0&0&0&1&1&0&0&1&1&0&0&0&0\\
1&1&0&0&0&0&0&0&1&0&0&0&1&0&0&0&0&1&0&0&0\\
1&0&1&0&1&0&0&1&0&0&0&1&0&1&0&0&0&0&1&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0\\
0&1&0&0&0&1&0&0&1&0&0&0&0&0&1&0&0&0&0&0&0\\
0&0&0&1&1&0&0&1&0&1&0&0&0&0&0&1&0&0&0&0&0\\
0&0&0&1&0&0&0&1&0&1&0&0&0&0&0&0&0&0&0&0&1\\
0&0&0&1&0&0&1&0&0&1&1&0&0&0&0&0&0&0&0&1&0
\end{bmatrix} \quad ...(4.12)$$

Using equation (4.11), the connectivity level is :-

$$\text{Connectivity} = \frac{21}{56}$$

$$= 0.375$$

CHAPTER FIVE

Conclusions and Future Works

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Conclusions and Future Works

5.1 Conclusions

1. Random deployment of sensors resulted in random and unknown places, the distances among nodes and links creation will be unknown. To achieve the network connectivity, certain probability distribution with reliable prediction approach must be developed.

2. Graph theory can be utilized to study and present the connectivity models in WSNs for better concentrating and evaluation.

3. WSN connectivity represents sensors ability to discover a suitable possible path to the base station. The availability of such path is essential for the network reliability, if it is not available, the network is considered as a failure network.

4. Considering the connectivity models in WSNs are having significant effect on the network performance and lifetime.

5. Utilizing the probability distributions in developing the connectivity models improves the WSNs efficiency and performance.

6. Ensuring and maintaining the WSN connectivity is a significant and challenging task to achieve the network creation purposes.

7. A good connected network is a network that have an ability to remain connected after the failure of certain number of its sensors.

8. The messages transmission rate effects can be modeled based on the connectivity probability of the WSN.

9. A threshold value can be estimated for each WSN connectivity to reflect the relation between the transmission range and a transmission power.

10. Regression models can be efficiently utilized to estimate the thresholds, transmission power and transmission ranges for different WSN environments.

11. The created equations in this thesis are suitable to be used in current and future studies for different WSNs applications.

12. Increasing the number of the total links in a WSN will improve its connectivity.

13. The required transmission power is gradually decreases when the number of the deployed sensors are increases.

14. The greater the power will have resulted in an increased number of the network links.

5.2 Future Works

1. Apply the same approaches to evaluate the coverage area in WSN.
2. Propose a WSN with multiple base stations.
3. Consider the connectivity in Wireless linear sensor networks .
4. Mention to the security issues with trust and reputation on the same proposed network.
5. Proposed an optimization approach for the random deployment in WSN by considering the network connectivity.

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المستخلص

بشكل عام باحتمالية توصيل جميع (WSN) يتم قياس اتصال شبكة المستشعرات اللاسلكية المستشعرات بعقدة الحوض (المحطة الأساسية) عبر عقدة وسيطة واحدة أو أكثر. يمثل اتصال الشبكة مقياسًا لمدى سهولة وموثوقية الحزمة المرسلة بواسطة عقدة يمكن أن تصل إلى عقدة أخرى في الشبكة. يتم التحقيق في تجربة المحاكاة عن طريق النشر العشوائي لجميع العقد في منطقة معينة وتقدير اتصال الشبكة بأكملها. يتم حساب عتبة التوصيل المناسبة من خلال نهج نمذجة ومحاكاة مطور ، ويُقترح استخدام معادلة الانحدار كمقدر لحساب عتبة التوصيل لأي قدرة أو نطاق إرسال. الاتصال وتبادل المعلومات مع الجيران بناءً على WSN يمكن لأجهزة الاستشعار الموجودة في نصف قطر الاتصال الخاص بهم. عدد الرسائل التي تم إنشاؤها على غرار محاكاة بناءً على والتوزيعات الأسية بمعدلات مختلفة. يتم تقدير احتمالية الاتصال بناءً على أساسيات Poisson توزيع الاحتمالية ذات الحدين. يتم استخدام طريقة أخرى لتقدير اتصال الشبكة بناءً على معدل الرسائل المرسلة بدقة. يتم حساب مقاييس أداء الشبكة المختلفة لتقييم سلوكيات الشبكة. يتم تقديم نتائج وحلول مختلفة ومناقشتها من خلال تجارب محاكاة مختلفة. يتم استخدام نتائج المحاكاة المجمعة رياضيًا في إنشاء معادلة انحدار عامة لاستخدامها مسبقًا لحساب أي معلمة مطلوبة بدلاً من إعادة تشغيل تجارب المحاكاة. يتم تدريب هذه المعادلات مع نتائج المحاكاة للتأكد من صحتها. تم العثور على نتائج المعادلات دقيقة للغاية ومطابقة لنتائج المحاكاة. يمكن استخدام هذه المعادلات بسهولة لحساب أي نتيجة مطلوبة دون إجراء تجارب المحاكاة. يتم إنشاء نماذج المحاكاة باستخدام أساسيات برمجة Net Logo.

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كلية تكنلوجيا المعلومات- قسم الشبكات

نمذجة احتمالية الاتصال في شبكات الاستشعار اللاسلكية

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

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