NINEVAH UNIVERSITY
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COMMUNICATION ENGINEERING DEPARTMENT

Designing LoRa WAN Network for Public Services in Mosul City

By

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M.Sc. Thesis

In

Communication Engineering

Supervised by

Dr. Ali Othman Al Janaby

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By

Amina Abd Almunim Al-Rawy

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Supervisor's Certification

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Report of Linguistic Reviewer

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Report of the Head of Department

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Publications: -

Some of the important results obtained in this work have appeared in the following publication**: -**

[1] Amina A. Fadhil, and Ali O. Al Janaby, have participated “Evaluation of LoRa WAN network performance for a water level sensing and monitoring scenario in Mosul Dam,” at the 1st International Conference on Sustainable Development Techniques (ICSDT2022), Northern Technical University, Mosul, Iraq for the period from 29th – 30th June 2022.

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[3] Amina A. Fadhil, and Ali O. Al Janaby, “Simulation of Connecting The Smart Energy Meters of The Residential Houses to Reduce The Load on Electrical Distribution Transformers Using LoRa Technology Based on IoT,” Journal of Engineering Science and Technology (JESTEC), indexed by Scopus.

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Abstract

LoRa (Long Range) technology is one of the Low Power Wide Area Network (LPWAN) technologies, characterized by features of Low energy consumption, expanded coverage, low cost, and higher capacity. Many applications need a technology that achieves successful data transmission at a low data rate, low consumption of energy, and low cost. Therefore, LoRa technology was used to avoid high costs by sending a small amount of data across long distances and over short intervals.

In this thesis, LoRa-WAN modeling and simulation of two important applications in Mosul city are studied using the LoRa technology in the simulation OMNET++ program to monitor the performance of electrical power distribution transformers and monitor the water level in Mosul Dam to obtain the best performance of the network. Scalability in the simulations has been analyzed by administering (100) sensor nodes by one gateway, and different coverage areas (1km2, 25km2, 100km2) and (3500x1000) m. The study's findings demonstrated the possibility of modeling and simulating different environments by setting appropriate parameter values of LoRa technology for the coding rate (4/5, 4/8), carrier frequency(868MHz), bandwidth(125KHz), spreading factor (7-12), and transmitted power (2-14) dBm. The LoRa-WAN technology introduced good performance in the major simulation scenarios by enhancing network performance across reduce the network energy consumption, minimizing the number of collisions at the LoRa gateway, increasing the total received packets in the network server, and increasing the packets delivery ratio. These are achieved by reducing the number of sensor nodes to 25 nodes, increasing transmission packets' time interval to exp (3600) s, and placing the gateway at the center of all the networks.

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LIST OF ABBREVIATIONS

Abbreviation	Name
2G	2nd Generation
3G	3rd Generation
4G	4th Generation
5G	5rd Generation
ADR	Adaptive Data Rate
BW	Bandwidth
BLE	Bluetooth Low Energy
C	Channel capacity
CR	Code Rate
CSS	Chirp Spreading Spectrum
DER	Data Extraction Rate
DSSS	Direct Sequence Spread Spectrum
ETSI	European Telecommunications Standards Institute

FC	Carrier Frequency
Flora	Framework LoRa
FSPL	Free Space Path Loss
FEC	Forward Error Correction
GP	Processing Gain
GSM	Global System for Mobile
GW	Gateway
IP	Internet Protocol
ISM	Industrial Scientific and Medical
LoRa	Long Range
LoRa-WAN	Long Range- Wide Area Network.
LoS	Line of Sight
LPWAN	Low Power Wide Area Network
MAC	Media Access Control
NB-IoT	Narrow Band- Internet of Things
NEC	Network Energy Consumption
P_T	Transmitted Power
PL	path-loss
PHY	Physical
PDR	packet delivery ratio
QoS	Quality of Service
R_b	Bit Rate
R_c	Chip Rate
RF	Radio Frequency
RSSI	Received Signal Strength Indicator
S	Sensitivity
SF	Spreading Factor
SNR	Signal to Noise Ratio
SU	sub-urban

ToA	Time on Air
T_s	Symbol Duration
TTN	The Things Network
U	urban
WSN	Wireless Sensor Network

Chapter One
Introduction

1.1 Overview

Some applications need particular requirements to transmit data with low data rate, long-range, low cost, and low power consumption. The technologies of radio short-range like ZigBee and Bluetooth, are not used for long-range transmission [1].

Cellular networks that include 2G, 3G, and 4G are quite popular and widely used. These were designed to handle greater data throughput, but they do not optimize power consumption. These technologies consume a large amount of power and aren't a good solution when it sends a small amount of data less frequently. Additionally, the whole cost is high [1] [2]. Accordingly, these requirements led to the use of new technology for wireless communication called LPWAN (Low Power Wide Area Network). LPWAN has large popularity in the industrial field due to its long-range, low-cost, and low-power consumption features of communication. LPWAN enables communication with long-range up to 1–5 km in an urban area and 10 – 40 km in rural areas [1].

The sensor nodes can be connected to LPWAN technologies to interact, respond, sense their environment, and turn on at any place and at any time to upload data to the cloud [3]. The aim of using LPWAN technology is to resolve many problems of short-range technologies and cellular communication [4]. LPWAN technology has high efficiency in using energy for up to 10 years from the lifetime of the battery. It's suitable to transmit a little amount of data across a long distance. Some technologies of LPWAN work in a licensed frequency bandwidth as NB-IoT and LTE-M, and others in the unlicensed band as Sigfox and LoRa. These technologies have different technical features. Figure 1.2 displays the wanted data rate vs. range capacity for these technologies [1].

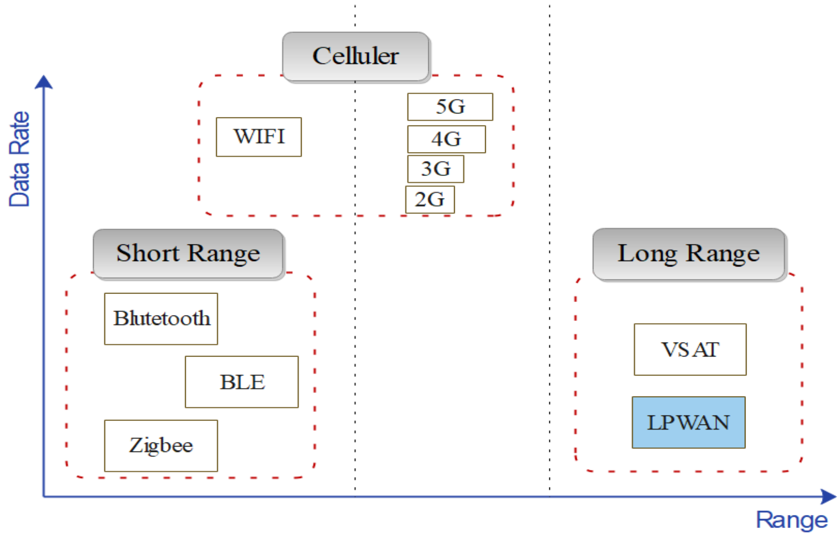

Figure 1.1 Desired data rate versus radio range capacity [1].

LoRa (Long Range) technology is a modern wireless sensor network. It's a part of LoRa-WAN technology [5]. LoRa technology has features of low cost, lower energy consumption, and long-range [6]. These features are useful to create a new intelligent system for controlling and monitoring sensor nodes [7].

LoRa-WAN is a technology with an open source with low cost that can create a private network without the need for infrastructure [4]. The architecture of LoRa-WAN is a star topology in which sensor nodes with a single channel communicate directly with any gateway with multiple channels [8]. The network of LoRa-WAN contains several sensor nodes linked wirelessly with gateways (one at less). This gateway work as a translucent bridge to communicate with the network server [9].

1.2 Literature Review

In 2017, Georgiou and Raza exposed the scalability of several gateways of LoRa-WAN simulation in interference conditions. They explored the occurrence of interference when two or more signals of the same frequency or same spreading factor (SF) collide or arrive at the same time. They suggested a solution to the disconnected of communication by increasing the number of LoRa-WAN gateways placed at suitable distances (2km) to prevent the increase of interference in a deployment area of radius R=12km using different number of end devices (500-2000) with step 500 [10].

In 2017, Frederic Chaxel et al. illustrated the advantage of LPWAN technology in energy consumption of other cellular techniques like 2G, 3G, or 4G. They presented the LoRa technology as a suitable technology in smart farming for testing humidity, water levels, and temperatures. Then they concluded that LoRa technology is very appropriate to use low-cost sensor nodes with the longest battery life [1].

In 2017, Jean Schwoerer and Nadége Varsier analyzed the ability of scalability of LoRa-WAN in a real region in central Paris, France to achieve capacity boundary at the intelligent metering application. They do not apply retransmission, enabled the Adaptive Data Rate (ADR) mechanism, and used the specification of the LoRa Semtech to set the best values of LoRa parameters. They employed 1000 nodes per gateway and used 19 gateways to achieve a cover of 17 km2 area through 24h of the real experiment. They concluded the value of QoS for uplink message is 98% for 1000 node and 96.3% for 2000 node. they showed employing retransmission in experiments will improve the results [11].

In 2018, Chiara Buratti et al. highlighted the intelligent lighting technology in two realistic urban scenarios of smart cities of Italy using the LoRa technology. They researched the technical specifics and the economic interest of about 3000 light poles across measurement as well as simulations. They achieved experimentally the boundary maximal coverage of the dense urban area is 1-2 km. After setting the suitable parameters properly, they achieved a packet success rate of 100% with the presence of the lowest number of buildings (250) and the lowest Packet Success Rate of 20% with the presence of a larger number of buildings (1750) [12].

In 2018, Ivo Sousa et al. showed that can improve cities' efficiency by presenting high-quality services in case use of LoRa-WAN technology. They presented the project “Smart City Abrantes” in Portugal, which incorporates fixed and mobile sensors, they concluded some sensors were not working properly by using one gateway, which led to the use of a second gateway. The first gateway received the signals coming from 25 sensor nodes placed at varying distances from the gateway with ranging from 500 m to 1200 m, to calculate the margin. The results showed that the margin values ranged from (10 to 38) dB, while the margin value increased from (18 to 67) dB when adding a second gateway [13].

In 2018, Sergey Mosin demonstrated that energy consumption is an important factor to design reliable and economical systems. Mosin compares the distinguishing characteristics of low-power communication technologies such as SigFox, ZigBee, and LoRa-WAN. This comparison gives an estimate of the current average consumption and evaluates the lifetime of sensor nodes for each technique. She achieved the best evaluation of the lifetime of sensor nodes and the perfect communication between the network server and sensor nodes when using LoRa WAN technology. she evaluated the lifetime of the end device from calculating the total capacity of the end device (2200) mAh divided by the current consumed for the end device, Mosin concluded the current consumed was decrease from (2.5-0.25) mA at fixed payload =10B and different data rate when increase the duration of notification period from 1 to 1000 minute [14].

In 2018, Michele Luvisotto et al. investigated the worthiness of the LoRa-WAN in the industrial monitoring applications for IoT service. They run the experiment through the Network simulation (NS3) program. They used different scenarios where the number of sensor nodes (10-1000), coverage radius is 200m, SF (7-12), message length 50 Bytes. They conclude probability of success is up to 97% when SF7 for all numbers of end devices, while the probability of success decrease from 97% to 83% when SF12 with an increase of end devices from (10- 1000). They showed that LoRa-WAN has a higher performance in energy consumption and reliability in industrial monitoring scenarios [15].

In 2018, Ruki Harwahyu et al. highlighted the LoRa-WAN technology specification which serves IoT applications. The real scenario contained ten sensor nodes and one gateway. They studied the impact of three parameters on LoRa network performance: coding rate, spreading factor, and carrier frequency. They referred to that the received power should be greater than the sensitivity (S) of the receiver. They produced a performance evaluation of the LoRa-WAN network via measuring energy consumption, the packet delivery ratio (PDR), and wasted energy of the sensor nodes due to a collision of packets transmitted. They conclude the packet delivery ratio decreased from 70% to 10%, increase average energy Consumption for each successful transmission from 0 to 5 J, and increase the average amount of energy wasted in collided transmissions from 400 to 1200J when an increasing number of nodes from (100- 1000) [16].

In 2018, Mariusz Slabicki et al. showed the achievement of deployments that required wireless long-range communication such as LoRa technology. They assigned LoRa parameters in the OMNeT++ simulation program to cover two deployment areas urban area (480x480) m and sub-urban area (9800x 9800) m. They evaluated the performance of LoRa networks through measured Packet delivery ratio and energy consumption for (100-700) sensor nodes in two cases enabling and disabling of ADR mechanism. They conclude the packet delivery ratio decreased from 65% to 58% for urban and increased from 21% to 25% for sub-urban, and increasing the energy consumption in networks from 170 to 220mJ for urban and from 400 to 450mJ for sub urban at enabling ADR-NET when an increasing number of nodes from (100- 700) at moderate variability channel conditions. They showed that enabling ADR that managed the values PT and SF of the sensor nodes improve the performance of the network by reducing energy consumption and incrementing the reliability [17].

In 2018, Sai Srikar Sedola et al. explained the essential requirements to ensure dam is safe against natural disasters. They suggested managing water levels by IoT based on cloud computing through automating dams using LoRa technology to a reduction of costs, lower manual labor, and avoidance of flooding. They showed the significance of connecting Ultrasonic worked sensor nodes on both sides of the dam's gate to obtain the current water level, then transmitted the data to a local base station that exists in the dam then and upload data to the cloud. They concluded the possibility of management of dams’ water efficiently by minimizing manual labor as well as control over cloud data access from any location and on any device [18].

In 2019, Toni Mastelić et al. displayed the types of LPWAN technologies Sigfox, NB-IoT, and LoRa-WAN, and studied the data rate, cost, and battery lifetime. Then they highlighted NB-IoT disadvantages from as high energy consumption and large costs. They described LoRa-WAN advantages as where wide coverage with low energy consumption, as well as possible the determining the capacity by the number of sensor nodes to each gateway in the LoRa-WAN network [19].

In 2019, Setiawan et al. proposed the study for a ship's electrical system monitor by using LoRa technology. Three classes of electrical systems are tracked: generator, power distribution, as well as navigation. They dedicated the use of LoRa technology to record and transmit the electric variables to the network server like the voltage, current, and power due to feature the lower consumed energy in LoRa technology. They showed at increasing the distance between nodes and gateway from 25m to 200m must increase of spreading factor from 6 to 12. They conclude the value of RSSI increasing from (-70) dB to zero at SF6, SF7 while decreasing from (-70) to (-100) dB at SF12. They finished with the possibility of controlling the power of the ship in real time and the possibility achieve successful data transmission by using three spreading factors (SF) are 6, 7, and 12 to distance maximal [20].

In 2019, Yoshitaka Shibata et al. suggested the possibility of benefits from LoRa technology during catastrophes. They showed that the LoRa wireless network can be installed easily in a high place like a helium balloon or drone to make emergency networks most factual in the case of a catastrophe without the need for necessary install high structures. They benefited from the feature of low energy consumption and low weight of LoRa devices and they suggested working for 72 hours after the catastrophe Happen. They recorded the results when using SF8 at an observation point far of 3500m distance between nodes and the gateway. They recorded of the value of packet loss rate is 2% for 500KHz with a data rate of 3467 bps, and 0% for 250KHz with a data rate of 2358 bps, and 0% for 125KHz with a data rate of 916 bps [21].

In 2019, Gan Kok Beng et al. suggested the collection of patients' physical health information and then its analysis by using LoRa technology based on IoT with sensors integrated via the My Signals platform developed for Arduino UNO. The platform My Signals can collect data from several sensors to measure oxygen saturation, temperature, and pulse rate then monitor and transmit the data to the electronic cloud. They showed the normal percentages for blood oxygen are around 96% to 99%, any lower than 90% could be an indication of disease. The results shown was 35^{o}C where normal body temperature would 37^{o}C. They conclude the ability to decrement healthcare expenses by improving the possibility of treatment in certain circumstances [22].

In 2020, Laura García et al. decided to employ LoRa-WAN technology in a real environment, to detect the happen fire risk by using sensor nodes to sense wind speed, humidity, and temperature. They successfully measured the Indicator of received signal strength (RSSI) and the signal-to-noise ratio (SNR) in the area of Motril of Spain. the RSSI value was -75dBm when was the distance between nodes and gateway a few meters while the RSSI value decreased up to -115dBm when increase the distance to 4000m, also they observed the value of SNR that decreased from 10dBm to -4dBm for the same range of distance. The experiment was continued for 20 hours and the measurements were recorded approximately every 28 mins. They achieved the best performance by covering a 4-kilometer radius area with just one gateway [23].

In 2020, Akash Verma et al. stressed that the increased demand for sensor nodes that usually be energy-finite devices required a wireless network to accommodate them in the IoT network. For this reason, LoRa technology, which aimed to save energy, and high efficiency of data transmission long-range, was used to solve the problem of network expansion, that can be used in many IoT applications. They concluded with the possibility of using the LoRa technology in the maintenance predictive domain and monitor and maintain the case of machines even in remote places. They used a sensor node of temperature to send this data to LoRa gateways and then to the cloud using the Arduino interface [6].

In 2021, Aikaterini Griva et al. exploited the features of low power and transmission of long-range for LoRa technology to convert conventional agriculture into the smart cultivation concept using the OMNeT++ simulation program. they used three deployment areas (300m by 300m), (500m by 500m), and (1000m by 1000m). They evaluated the performance of LoRa networks through measured data extraction rate and energy consumption using 1000 nodes and 4 gateways. They concluded the data extraction rate at the deployment area (300m by 300m) decreased from 90% at 10 nodes to 30% at 1000 nodes while increasing at 100 nodes from 89% at one gateway to 95% for 4 gateways, they also recorded increasing the network energy consumption from 90mJ at 10 nodes to 230mJ at 1000 nodes while decreasing at 100 nodes from 89mJ at one gateway to 83mJ for 4 gateway. They concluded the possibility optimize the network's performance by 28.6% through the number of gateways is incremented from one to four. While the network's performance is reduced when incremented the size of the deployment region [24].

In 2021, Mohammad Al Mojamed employed LoRa-WAN technology for the deployment of the IoT as a part of LPWAN technologies due to its features. He researched the scalability of the Mina area of Makkah city based on the application of fire detection. Mohammad used the program OMNeT++ simulator via the Framework LoRa (Flora) model. He introduced of evaluated the performance of the network through the computation of the Packet Delivery Ratio (PDR), consumed energy by sensor nodes, and the collision metrics. He deployed 100 sensor nodes in a (2600 × 4100) m area with one gateway placed at (800x1500) m. He achieved a high success ratio for LoRa-WAN performance for each SF. He recorded a decrease in success ratio from 100% for 1000 end devices to 50% for 10000 end devices at (1800 s) transmission time interval, while recorded an increase in average collisions from 55 for 5000 end devices to 215 for 10000 end devices at the same time interval [25].

1.3 Aim of Thesis

The following are the most important goals of this research:

1- One of the goals of this research is decrement consumed energy for the sensor nodes as well as to enhance the performance of the LoRa-WAN network and increment coverage area.

2- Investigate the employed LoRa physical layer parameters values and evaluate its influence on the LoRa-WAN network to achieve the optimum network performance.

3- Simulate the possibility of connecting the sensor nodes to the LoRa gateway using LoRa technology. The LoRa gateway redirects and uploads the data of readings to the network server via cloud computing, to get control and monitor easily from any location in the world.

1.4 Research Objectives

The following are the most important objectives of this research:

Achieve communication with low cost, long range, and investigate LPWAN scalability using LoRa technology.

Employ the OMNET++ simulation software to test LoRa-WAN performance, to investigate and analyze the system's behavior in a simulation environment like simulating the electric distribution transformers by modeling urban, and sub-urban.

Simulate another application to monitor the water level of the Mosul Dam to achieve the rate of successful transmission and low energy consumption.

1.5 Thesis Layout

The following chapters are included in this thesis:

Chapter two illustrates the theoretical background of presenting a helpful explanation of the LPWAN, properties of LoRa parameters, LoRa modulation, and LoRa WAN features.

Chapter three presents a simulation of the control and monitoring of electrical distribution transformers in Mosul city. To attain the possibility of implementing the simulating of several propagation regions in factual life by using LoRa technology which is implemented by the simulation OMNET++ program.

Chapter four offers the representative section to simulate monitoring water levels of Mosul Dam to avoid its collapse by using ultrasonic sensors and a single gateway implemented with LoRa technology in the simulation OMNET++ program.

Chapter five displays conclusions and several suggestions for future works.

Chapter Two

LoRa Technology

2.1 Overview of LPWAN

There are multiple technologies employed for the service of applications, each technology has its characteristics, benefits, and drawbacks. A single technology cannot even support all applications. We have ZigBee, WiFi, Bluetooth, etc. for short-distance that can be utilized in a variety of applications [2].

lately, a term appeared that is called the Low Power Wide Area Networks (LPWAN), created to connect devices that consumed low-power, long-range, and low-cost. The LoRa technology is a type of LPWAN which is employed for long-range applications [26].

However, the battery is considered the main concern. The LoRa technology is used in the applications of smart cities, and industrial applications. The LoRa technology is gaining large popularity due to features of high capacity, long range, bi-directional, long battery life, cheap cost, interference immunity, and efficient network [2]. LoRa enables transmission over long ranges and uses modulation of the chirp spread spectrum and it is also resistant to fading effects and multipath [27].

2.1.1 Low Power Wide Area Networks (LPWAN) Technology

LPWAN are networks that collect technologies to accomplish robust, long-distance, and low-bitrate communication, with battery-operated sensor nodes dispersed across a wide region. There are three major LPWAN technologies Narrowband IoT, SigFox, and LoRa-WAN [28]. LPWAN uses sensor nodes that connect to the internet without using cellular networks or WiFi [26].

LPWAN work with low-power, long-range, and low data rate. Therefore, these technologies are not suitable for applications requiring high throughput, but they required a very short latency. However, some applications prefer to choose LPWAN for smart metering, smart cities, environmental monitoring, home automation, etc. [29]. LoRa-WAN is one of the best-known LPWAN technologies and is considered more popular due to their support of an open work model to be their hardware cheap and publicly available [29].

2.1.2 Low Power Wide Area Networks (LPWAN) Technology's Importance

The major feature of LPWAN approach is the capability to cover a wide region without having to forward messages through the wireless network by using LoRa or Sigfox technologies. These technologies use unlicensed frequencies lower than 1 GHz and narrow frequency bandwidth to allow a high coverage. This feature of LPWAN is to reduce the bandwidth to allow lower the amount of noise that the receiver collects to perform the improvement of the sensitivity and achieve a long range of a few kilometers [30].

2.1.3 Objectives of LPWAN Technology

1. Long Range: LPWANs are based on designing wireless links with a long range up in urban areas 1-5 kilometers and in rural areas of ten of kilometers. This provides the devices a lot of flexibility to spread across wide geographical areas [29].

2. Energy Efficiency: LPWANs aim to operate at low power to enable linked devices with networks to operate with up to ten years of battery. This removes the requirement to exchange the device’s battery to solve the

device's problems that will be deployed in inaccessible or distant locations such as areas of glaciers, volcanoes, and so on. These techniques operate in a star-topology network; devices communicate with gateways directly to energy-saving without the use of repeaters. Thus, other devices spend more of their time sleeping, to achieve the lowest energy consumption [29].

3. Low Cost: One of the major design aims of LPWANs is to keep low cost. This is achieved by using unlicensed fees and designing star typology networks that do not need repeaters, thus reducing the cost of the network device deployment [29].

4. Scalability: The LPWAN technologies are built with scalability. Scalability refers to the number of devices that a single gateway can manage depending on the requirements of deployment [29].

2.2 LoRa Technology

LoRa (Long Range) is one of the new wireless connectivity that has rapidly improved and has the most popularity in embedded systems that operate with low power and low data rate, and it sends a little amount of data over great distances at short intervals [2]. LoRa technology is a promising technology that operates at a frequency of 868 MHz in the ISM band of European permitting a range up to 25 km [26].

LoRa is composed of two different layers: (1) The physical layer that uses the technique of CSS modulation, and (2) The protocol of the MAC layer (LoRa-WAN) [31]. The LoRa sensor nodes send data to the network server across one gateway but can add one more gateway to improve the QoS [32]. Figure 2.1 shows the LoRa frame structure for the physical, MAC, and application layers [33].

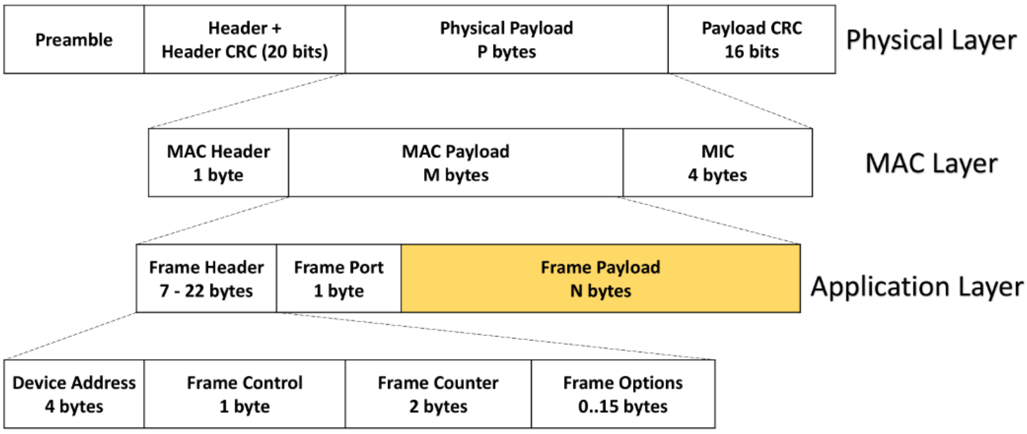

Figure 2.1 LoRa frame format [33].

The most important feature of LoRa is no constraint on the amount of data that can be transmitted or received, that it has low cost, integrated circuits are manufactured by Semtech company, and hence modify the characteristics of the modulation to get suitable values of power consumption, data rate, and range [34]. LoRa-WAN is an open source protocol of network based on the LoRa modulation scheme [35].

LoRa contains a physical layer, but LoRa-WAN contains the protocol of the MAC layer above the physical layer of LoRa [36]. Figure 2.2 below draws the appropriate concept for LoRa-WAN protocol (mac layer) above LoRa (Physical layer) [37].

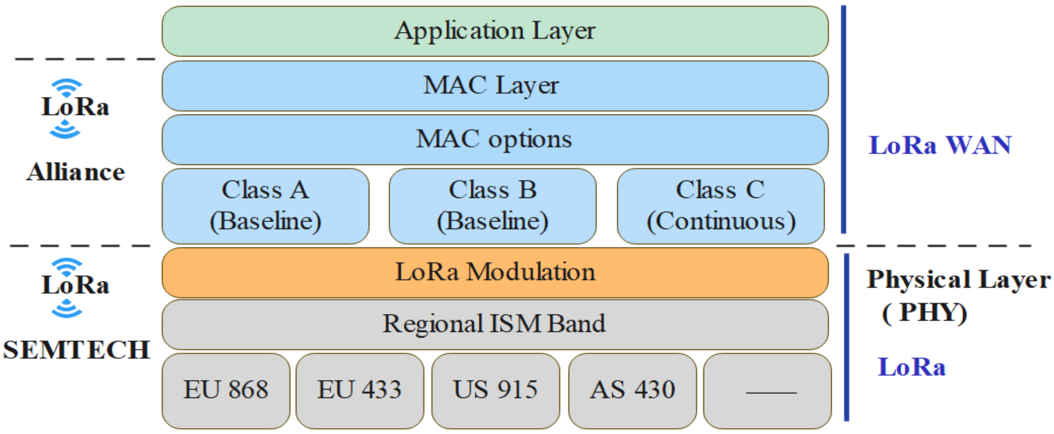

Figure 2.2 LoRa and LoRa-WAN scheme [37].

2.2.1 Comparison between Bluetooth, WiFi, and LoRa Technologies

LoRa technology is a radio spectrum technology that runs in an unlicensed band. That enables transmitting across these frequencies without paying fees, unlike the Wi-Fi network, in which a fee is required for its use [34]. Table 2.1 shows a comparison of WiFi, Bluetooth, and LoRa technologies [31].

Table 2.1 Comparing WiFi, Bluetooth, and LoRa technologies [31].

Features	WiFi	Bluetooth	LoRa
Frequency	2.4 and 5GHz	2.4GHz	EU(868MHz),US(915MHz), AS(430MHz)…
Data rate	0.1-54 Mbps	1,2,3 Mbps	<50 Kbps
Range	100 m	10-100 m	Up to 20km
Transmitted Power	80 mw	2.5mw	25mw
Modulation	Frequency hopping spread spectrum	Frequency hopping spread spectrum	Chirp spread spectrum

2.2.2 LoRa Rules

LoRa modulation is governed by a set of rules during its usage. At the European level, the general regulatory standard was defined by the European Telecommunications Standards Institute (ETSI). The radio waves used in the 25–1000 MHz carrier frequency will be set to use LoRa technology. It is used across the European region in the unlicensed 868 MHz band. The LoRa document used in Europe has been created by the

LoRa Alliance. These documents are called LoRa-WAN Regional Parameters which describe LoRa and LoRa-WAN specified standards [34].

There are five parameters in LoRa devices. It is programmable by Semtech's definition like the following: carrier frequency, spreading factor, transmitted power, coding rate, and bandwidth. To scale a LoRa-WAN network successfully, there are large effects of LoRa settings on the performance of the LoRa network [38].

LoRa technology allows for several bandwidths to be used which are 125, 250, or 500 kHz. LoRa technology supports data rates ranging from 0.3 kbps to 37.5 kbps. The Media Access Control (MAC) layer protocol LoRa-WAN was advanced by the LoRa Alliance. The topology of this network is star-of-stars, which allows different sensor nodes in the network to communicate with LoRa gateways using the scheme of LoRa modulation [31]. Figure 2.3 shows an ideal LoRa-WAN architecture [31].

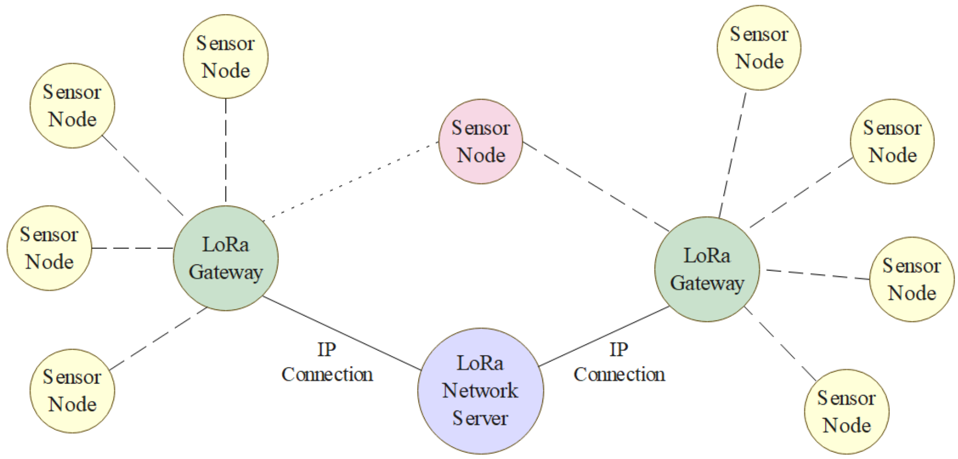

Figure 2.3 Traditional LoRa-WAN architecture [31].

2.3 LoRa-WAN Network Topology

The LoRa-WAN architecture composed of sensor nodes, gateways, the network server, the application server.

2.3.1 LoRa-WAN Sensor Nodes

The sensor nodes send the data and try to consume the least amount of energy feasible [39]. The sensor nodes characteristics by small size, low power consumption, and low cost, sending the data via LoRa protocols, and must contain on LoRa Radio [37]. Each sensor node carries information about transmission parameters such as PT, SF, and the channel [40]. The Flowchart of each LoRa sensor node as shown in Fig. 2.4 [41].

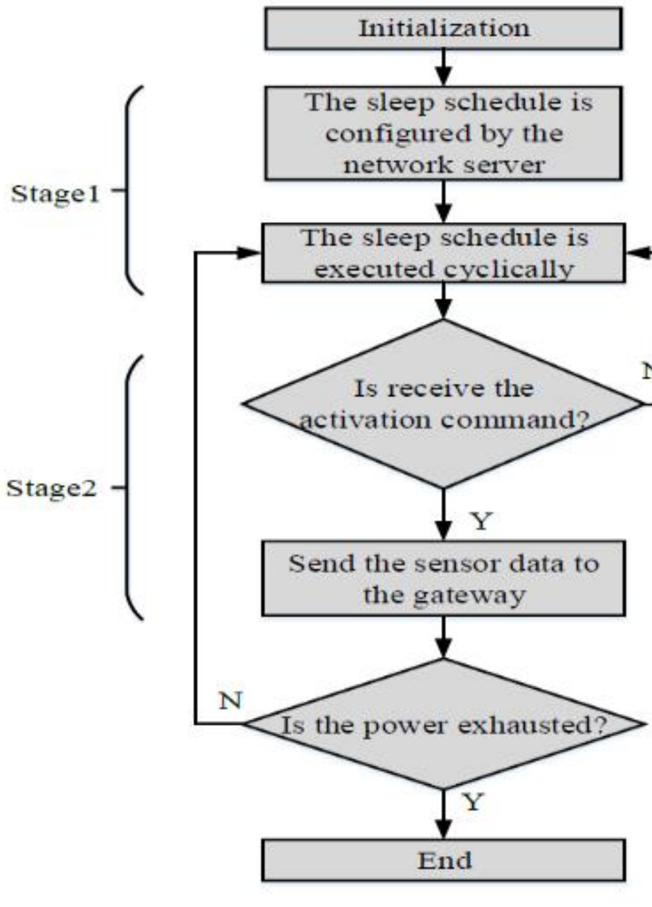

Figure 2.4 Flowchart of each LoRa sensor node [41].

Due to batteries being used to power LoRa devices, the sensor nodes are active only when sending or receiving the ack from the gateway, and then they go into sleep mode [42].

The sensor nodes have three modes for operation depending on energy consumption represented into three operational classes: all (Class A), beacon (Class B), and continuously listening (Class C) as shown in Fig. 2.5 [43].

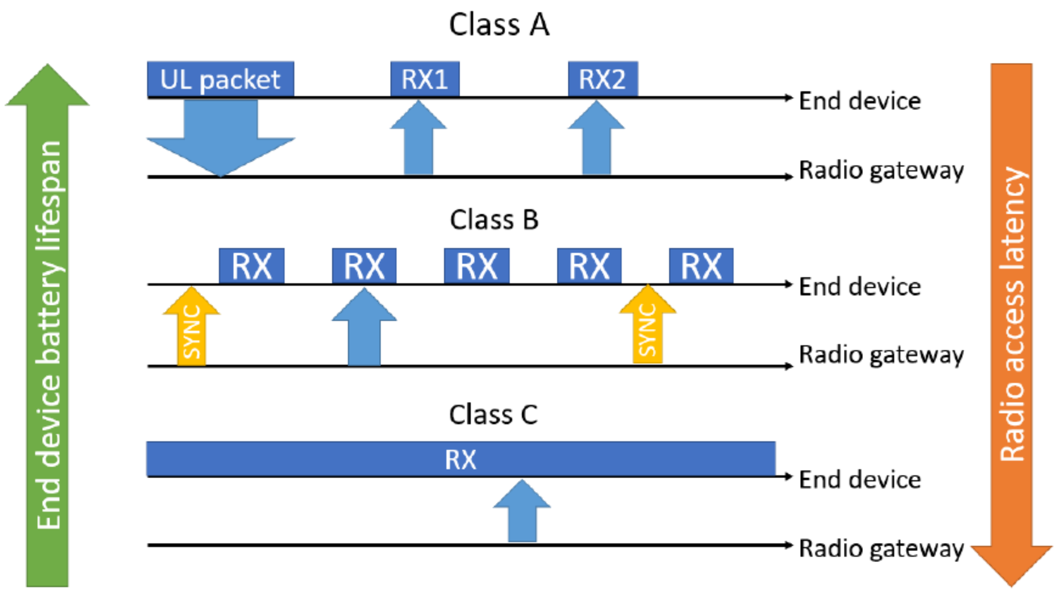

Figure 2.5 Graphical description of the three LoRaWAN classes [43].

Class-A: The up-time is minimized because the sensor node is in listening mode only after an asynchronous uplink transmission.

Class-B: The gateways' radio sends periodic beacons to synchronize the sensor nodes and make them open receive windows at specific time instants within the radio frame.

Class-C: The sensor node is always listening to the downlink channel when it is not transmitting in the uplink.

2.3.2 LoRa-WAN Gateways

The gateway's function according to LoRa-WAN specification is a forwarder between sensor nodes and the network's server [44]. The gateway could receive several signals at the same time with a condition that SF or channels are different, whereas the commercial gateways can synchronize and demodulate up to 8 channels [45].

The physical layer's parameters implementation for sensor nodes and gateways are almost similar except for receiving function. LoRa gateway maintains a menu of all LoRa signals received and computes the bit errors. Although uses of different spreading factors, each signal caused a noise floor to other existing signals. Because of restrictions on devices, LoRa-WAN uses the same channels for uplink and downlink by using the same modulation [40]. The flowchart of gateway shown in Fig. 2.6 [46].

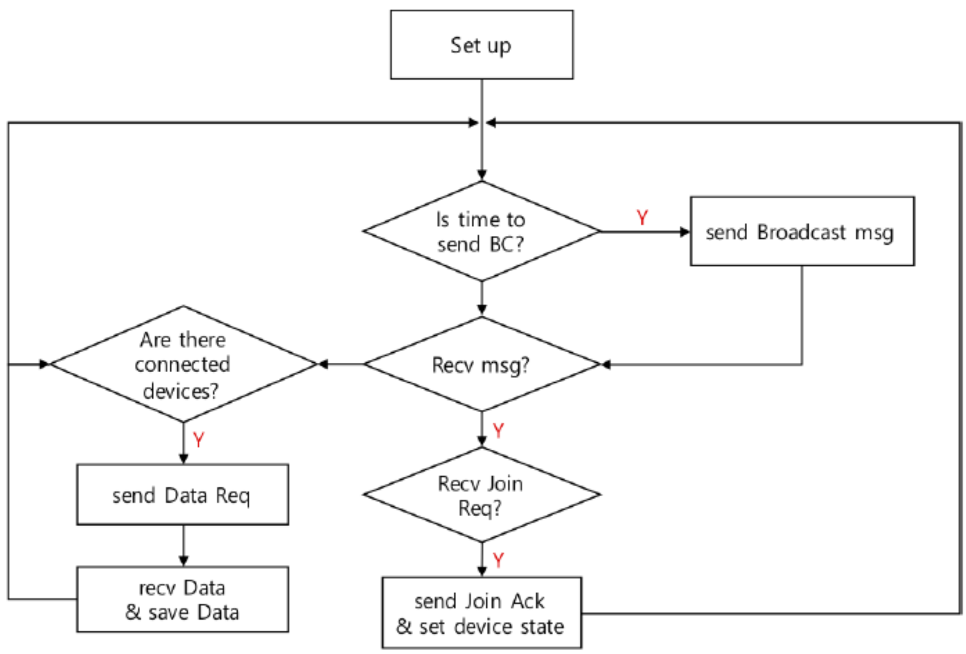

Figure 2.6 Flow chart of gateway [46]

2.3.3 The Network Server

The network server is accountable for adapting the data rate and administering ADR [39]. The network server links the gateways to the application servers. The network server consists of a router, processor, and moderator that is based on the cloud. The function of the network server is to guarantee no duplication of packets by scheduling varied acknowledgments [42]. The network server is accountable for de-duplicating packets as well as the packets' decoding [47]. The Flowchart of network server as shown in Fig. 2.7 [41].

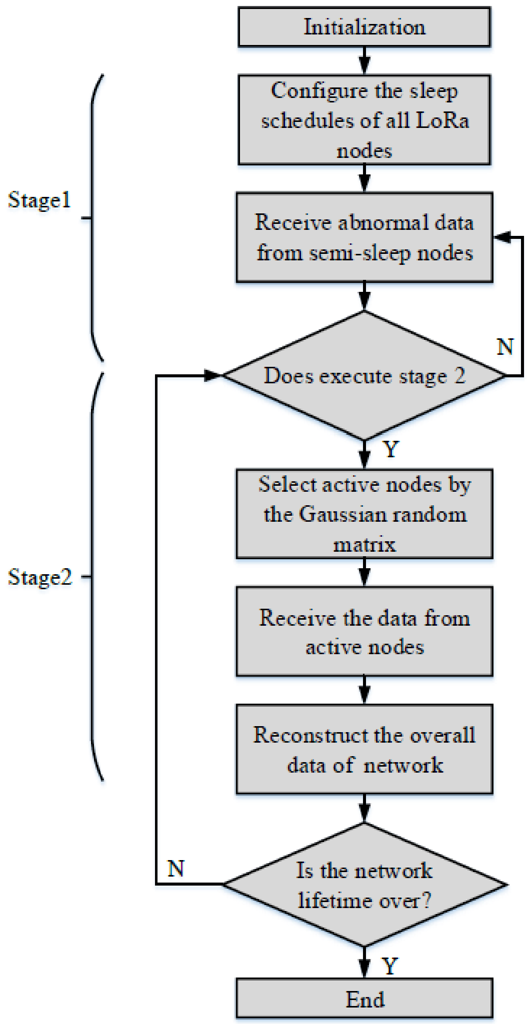

Figure 2.7 Flowchart of the network server [41].

2.3.4 The Application Server

The application server with the network server contributes to managing sensor nodes. The application server provides interfaces to make the data of the devices accessible to users carrying suitable credentials [7].

2.4 LoRa-WAN Protocol

LoRa-WAN is the bidirectional communications protocol, that sends data with long-range, low power, but low data rate [35]. LoRa-WAN is a protocol developed via LoRa Alliance. LoRa-WAN sends data from sensor nodes of the communication network to gateways across a single hop. LoRa-WAN contains three various components: sensor nodes, gateways, and network servers to form a star-of-stars topology. The network server is accountable for information storage received from sensor nodes across the gateway using Internet Protocol (IP). This network employs a mechanism of Adaptive Data Rates (ADR) to manage battery life [31]. The structure of LoRa packet can be seen in Fig. 2.8 [48].

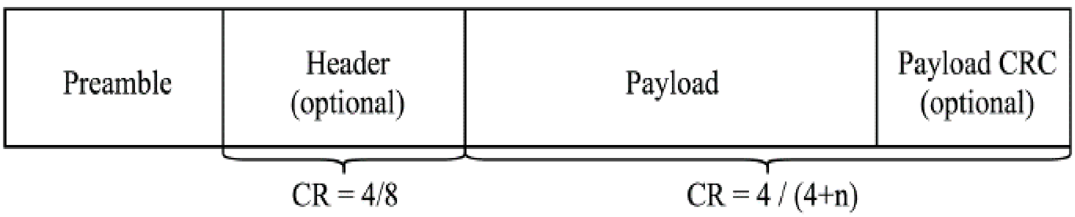

Figure 2.8 LoRa packet structure [48].

2.5 ISM Band Restrictions

Europe works within Industrial Scientific and Medical (ISM) band 863-870MHz to regulate nodes operating and the use of offered channels. This band of frequency enforced restrictions on the duty cycle of sensor nodes to control the number of times the device is allowed to transmit to avoid LoRa-

WAN network congestion. Therefore, restricting the duty cycle in Europe at 0.1%, 1%, and 10%, depends on the channel on which the sensor nodes run [38].

Rules must be followed to avoid congestion and interference in using the band. Therefore, two restrictions are followed in LoRa-WAN which are [37]:
(a) In sub-Bands standard, the Duty Cycle is 1%

(b) In Europe, the EIRP must be 14dBm (25mw).

ISM bands must be specified where operating frequency changes in each area in the world as in Table 2.2 [39]. In this thesis, the European frequency band to control the LoRa-WAN network's performance is discussed [36].

Table 2.2 Running frequency of various countries [39].

Country	Running frequency band in MHz	Common Name
North America	902-928	US915
Europe	863-870	EU868
India	865-867	IN865
Japan	920-925	AS923
Korea	920-925	KR920
China	470-510	CN470
Australia	915-928	AU915
Rusia	864-870	RU864

2.6 The Modulation Parameters of LoRa Technology

The physical layer of LoRa communication describes different parameters such as Bandwidth (BW), Spreading Factor (SF), and Code Rate (CR) in addition to modulation technique [31].

The LoRa modulation's properties are influenced by five parameters:

- Transmitted Power (PT): The transmitted power can be changed for a (4-20) dBm, and (4-14) dBm for European area parameters depending on data rate and channel conditions [42]. A device's power can be traded with the distance to improve the performance of LoRa-WAN. In addition, this parameter contributes to adding important relation called the capture effect where the more powerful of two colliding signals could be decoded at the gateway if the power difference between them was 6dB [38].
- Spreading Factor (SF): LoRa specifies several spreading factors from 7 to 12. The spreading factor enables a trade-off between transmit range and data rate. Choosing a larger spreading factor will increment the transmit range and the sensitivity, but decrement the data rate, so increment the airtime for a packet [47]. It could be noticed that an increment in the SF by one becomes the time of the symbol twice. At the symbol duration increment, each symbol supplies more ability to enable the signal to reach far distances with a robust signal against noise and interference [38].
- Bandwidth (BW): Three bandwidths available with LoRa are 125kHz, 250kHz, and 500kHz. The use of a wider band increments data rates but lowers the sensitivity of the signal at the receiver, which perform more difficult to decode the messages [47].
- Carrier frequency (Fc): Presents the modulation frequency of the message. The LoRa technology uses the 868MHz frequency in the European region. It is possible to divide the frequency band 868MHz into sub-band of frequencies like 868.1MHz or 868.3MHz, to permit multiple messages that will be received by the gateway at the same time and the same SF and via various sub-bands [47].

- Coding Rate(CR): The coding rate is a factor that increases the number of bits added to the transmitted bits for the detection and correction of error. Adding FEC bits by LoRa modulation at each symbol transmission will increase the signal resistance against noise. It also increments the transmission time [37]. The forwarded error correction way permits to recover bits when caused due to interference [49]. The code rate is 4/ (4 + n), where n is one of the numbers (1, 2, 3, 4) [47].

2.6.1 The Significance of the Spreading Factor

The parameter of the spreading factor is very important in the transmission of LoRa communication. As the increment SF by one every time will perform to add a bit of data in the chirp, but it will dual the number of chips encoded and the symbol time. This leads to double the Time on Air (ToA) of the chirp with every increment of the value of SF by one. In LoRa devices, the change of ToA has two major influences; (1) Signals became orthogonal to one another because of the various chirp lengths. (2) The time required for a chirp to be transmitted which is specified by the SF, will influence SNR. It can be concluded when using a higher SF for sending, additional signals could be produced for every chirp that will improve SNR [38]. On the other hand, the increment in SF will perform taller messages and more energy consumption. As a result, it must achieve a balance between energy consumption and reliability [40].

The chirp (symbol) duration of LoRa technology can be computed according to the following equation [36]:

$$T_s(sec) = \frac{2^{SF}}{Bw} \tag{2.1}$$

Where T_S: Time to send one symbol, SF: Spreading Factor (7-12), and BW: Bandwidth in (Hz)

Equation 2.1 displays the computation of the time of symbol (TS). The symbol 2^{SF} means the number of chips required to send one bit for a specific spreading factor. This equation shows the influence of the BW and SF at symbol time that has more effect on the control of the Time on Air (ToA) of the LoRa-WAN messages [37].

2.6.2 Spreading Factor Orthogonality

This parameter permits LoRa gateways to receive packets transmitted on the same channel [38]. The reason why the SF parameter is possible to make transmission orthogonal is the way it encodes bits in a symbol. A chirp consists of several chips. The bit can be encoded by using multiple chips. This means that a chirp can be used to represent one or more bits. The spreading factor influences the number of bits a chirp contains. The number of bits that represents a chirp depends on the SF. As an example, the SF8 will encode eight bits in a chirp. Equation 2.2 offers the relation between many bits, the number of chips, and the spreading factor to compute how many chirps are needed to encode (n) from bits. This equation shows the influence of SF to encode the bit by the number of chips. To explain, one bit at SF8 required 256 chips [38].

$$R_c = 2^{SF} R_b \tag{2.2}$$

Where R_c: number of chips, SF: Spreading Factor (7-12), and R_b: number of bits.

2.6.3 The Bit Rate and Symbol Coding

The bit rate of LoRa technology ranges from (0.3 to 37.5) kbps, based on the spreading factor number. Each one of SF has a set of orthogonal codes associated with it. This enables simultaneous communication at various data rates. In LoRa technology, the symbol has been encrypted for increment robustness [50].

Further coding gain is provided through the Forward Error Correction, which will perform to lower the total bit rate [7].

Thus, the bitrate of each spreading factor as in the equation (2.3) can be calculated as [37].

$$R_b\left(\frac{\text{bit}}{sec}\right) = SF \times \frac{BW}{2^{SF}} \times \frac{4}{(4+CR)} \quad (2.3)$$

Where SF: Spreading Factor is (7-12), BW: Bandwidth(Hz) or Chip/Sec, and CR: Code Rate is (1- 4)

Characteristics of alteration of LoRa communication with different SF are showed in Table 2.3 at BW=125 kHz [31].

Table 2.3 Spreading factor at BW=125 kHz in LoRa technology [31].

Spreading Factor	SNR	Symbols/sec	Bit rate (bit/s)
7	-7.5	976	5468
8	-10	488	3125
9	-12.5	244	1757
10	-15	122	976
11	-17.5	61	537
12	-20	30	293

2.6.4 Relation of the Sensitivity with Spreading Factor

From previous equations, one could say that an increment of just one in the spreading factor value will perform to a dual symbol duration. But when the bandwidth doubles, the bitrate value will double. When the increment ToA for a chirp or so-called symbol gives resistance against noise and interference, it will increment the energy consumption. Therefore, it can be observed that the SF has a great influence on the receiver sensitivity as shown in equation (2.4) as [36].

$$S = -174 + 10\log_{10}(\mathrm{Bw}) + \mathrm{NF} + \mathrm{SNR} \quad [\mathrm{dB}] \tag{2.4}$$

Where:

S (dB): Sensitivity is the needed link budget for decoding a transmission [38].

- 174 (dB): The thermal noise at ambient temperature [38].

BW (MHz): Bandwidth of transmission [38].

NF (dB): Noise due to the receiver hardware implementation [38].

SNR (dB): Is the basic modulation scheme's minimal signal-to-noise ratio required to demodulate correctly [36].

Due to the work in the simulation environment, the typical choice of the value of parameter Noise Figure (NF) in the LoRa-WAN application is 6dB. According to LoRa parameters SF and BW, the sensitivity of the receiver is represented in Table 2.4 [51]:

Table 2.4 Receiver Sensitivity in accordance with various values of spreading factor and bandwidth [51].

The values of sensitivity			
Spreading Factor	BW=125KHz	BW=250KHz	BW=500KHz
7	-123	-120	-117
8	-126	-123	-120
9	-129	-126	-123
10	-132	-129	-126
11	-134.5	-131.5	-128.5
12	-137	-134	-131

2.7 Direct Sequence Spread Spectrum (DSSS)

The multiplying process of the data signal original with the sequence of pseudo-random, is called spreading code. The DSSS is the conventional spread spectrum technology. It multiplies the data bits' sequence with a spreading code as in Fig. 2.9. When the sent signal reaches the Radio Frequency (RF) receiver, multiplied with the same spreading code employed in the RF transmitter to produce an authentic copy of the data signal original [52].

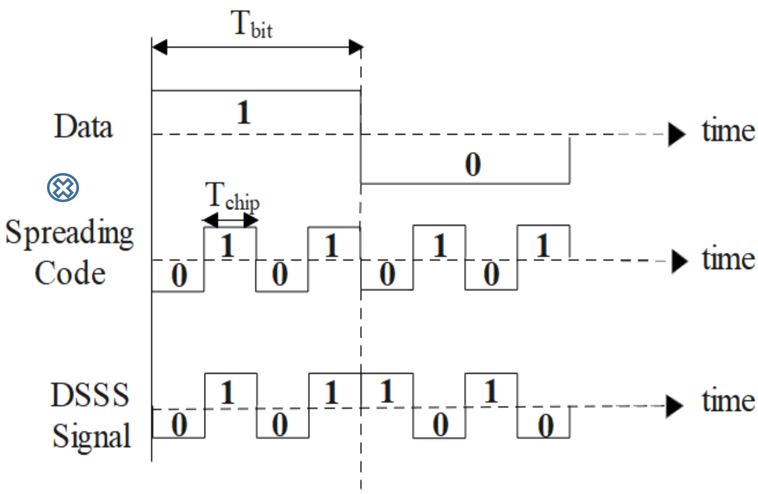

Figure 2.9 Signal of data, spreading code, and DSSS signal [52].

DSSS has limitations of constraints for low-power or low-cost sensor nodes that required high accuracy. The long spreading code is required more time to produce a correlation across the whole code sequence length of the receiver. This is a challenge for sensor nodes that can't be active constantly, because of a limited source of energy and are required to synchronize repeatedly and quickly [52].

2.7.1 The Chirp signal

Chirp is the signal that spreads across the entire bandwidth transmission. The chirp may be an Up-Chirp or even a Down-Chirp. Figure 2.10 displays the chirp signals with an increment or decrement frequency being created with an amplitude change of 1 to -1. This frequency with amplitude oscillation represents the transmitted signal. Thus LoRa generated linear chirps by an increment or decrement frequency of the signal at a linear rate [38].

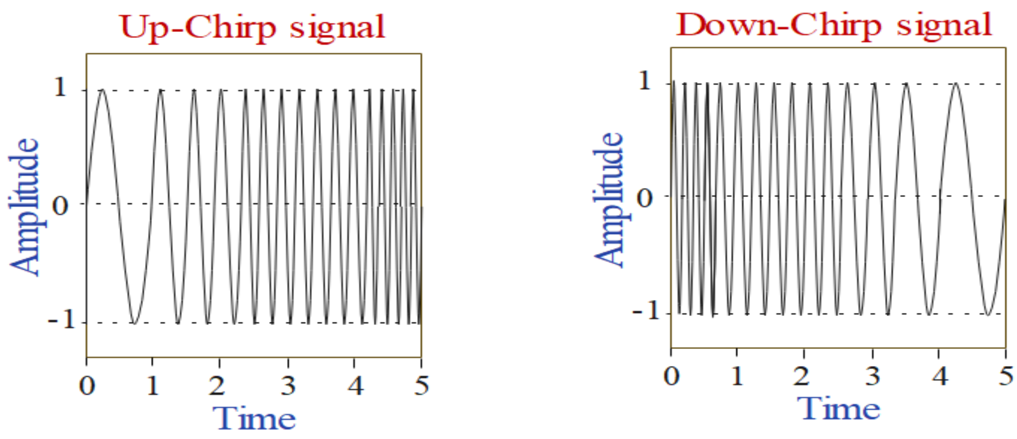

Figure 2.10 Up-chirp and down-chirp waveform [38].

2.7.2 Chirp spread spectrum modulation

The basic idea behind Chirp spread spectrum (CSS) is that a linearly, sinusoidal signal that has a linearly varying frequency and limited duration is called a chirp [32].

The modulation of the CSS is a type of modulation of the spread spectrum. It is used to encode a signal across a wider frequency range. This method achieves in LoRa by using a direct sequence over a wide band of frequency [38].

By relying on the SF, a LoRa symbol (chirp) can contain many bits equivalent to the SF. For example, when the SF=7 then the LoRa chirp contains 7 raw bits, 0011010. The chirp can be encoded with 128 chips [37]. For clarity, Figure 2.11 (a) displays LoRa Up-chirp signal while Figure 2.11 (b) displays an Up-chirp that is modulated by 2 bits which must create a symbol that contains four chips. The minimal LoRa raw bits that a symbol can reserve is 7 and the maximal is 12 [37].

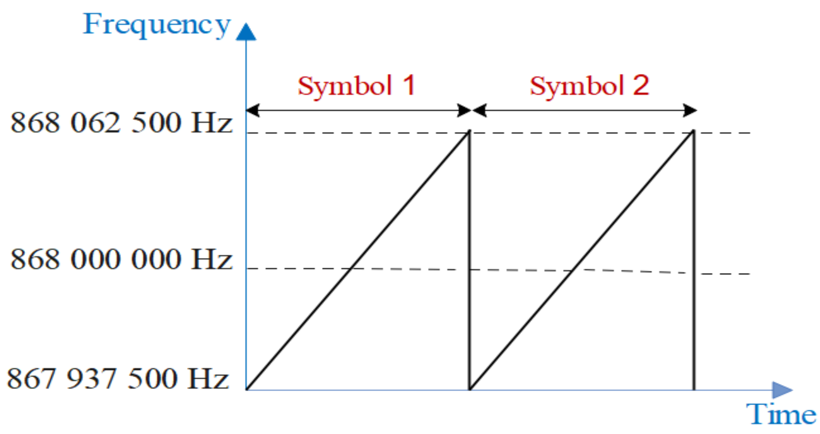

Figure 2.11 (a) LoRa up-chirp at BW= 125KHz [37].

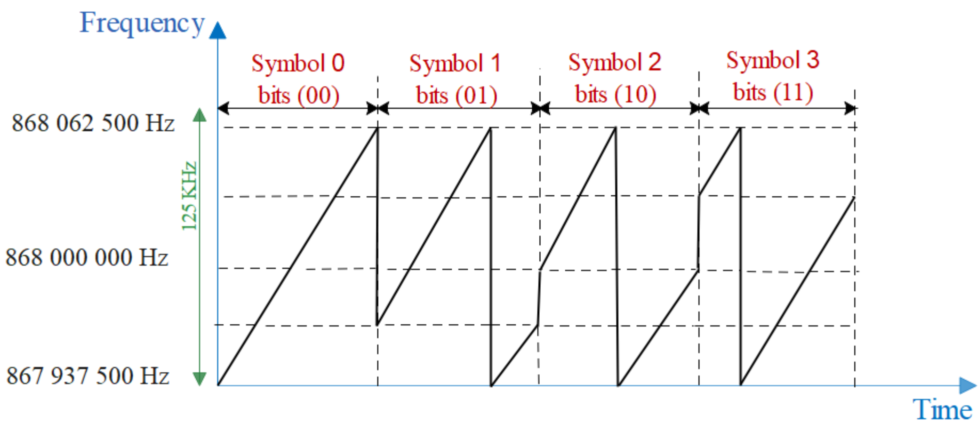

Figure 2.11 (b) Each chirp is split into 2^2 chips [37].

Figure 2.11 (b) shows several linear chirps with a variation in frequency that is either positive or negative across time. Changing the positive in frequency across time will represent an up chirp whereas the reverse represents a down chirp. Due to the linear chirp employing whole bandwidth that has a linear nature, this became easier to distinguish from background noise. Until in case, a signal is weak due to the actuality that noise is non-linear [38].

The CSS of LoRa modulation makes packet receptions possible, even if the signal power is lower than the actual noise floor [45]. Whereas the LoRa chirp occupied the whole bandwidth, this gives the modulation robust for channel noise and makes it not sensitive to frequency shifts [29].

2.8 Adaptive Data Rate (ADR)

The Adaptive Data Rate (ADR) is a mechanism that improves the equilibrium between the maximal communication range and the data rate to maintain a constant output power level. Due to an electromagnetic wave during travel losing power, the energy of a bit at the receiver is lower than the energy at the transmitter. The transfer of data between the transmitter and the receiver is suffering from interruption if the signal's power at the receiver is less than the receiver's sensitivity threshold. To increment the transmitter's communication range, either the energy per bit is raised or the data rate must be decremented. So, the ADR mechanism reduces the data rate, according to the need to extend the communication range [53].

The benefits of the ADR mechanism are represented in incrementing battery life, the capacity of the overall network, and managing the data rate and channel settings to determine the appropriate combination based on the existing link budget and channel that has been used for communication [39].

2.8.1 Adaptive Data Rate Assign Mechanism

The ADR mechanism is the LoRa-WAN algorithm that dynamically assigns the SF and TP of each device. There are two main components to

ADR: (1) ADR-NODE works on the sensor nodes that permit the change value of their SF or PT to recover connection to a gateway. It is enabled usually in case of employing multi-channel. ADR-NODE is described in Algorithm 1 [17]. (2) ADR-NET that works at the network server, the network server preserves the last twenty frames of SNR lists values received from every gateway. Then it computes the maximal SNR among the frames that have been received previously. ADR-NET computes SNR margin to estimate the channel's quality depending on the minimal SNR needed for the frames of the devices that are received with a specifically chosen SF and P_T [54]. ADR would only be utilized in steady RF environments with stationary sensor nodes [52]. ADR-NET is described in Algorithm 2 [17].

Algorithm 1 ADR-NODE

$ADR\_ACK\_LIMIT \leftarrow 64$
$ADR\_ACK\_DELAY \leftarrow 32$
$ADR\_ACK\_CNT \leftarrow 0$
if uplink transmission **then**
    $ADR\_ACK\_CNT \leftarrow ADR\_ACK\_CNT + 1$
if $ADR\_ACK\_CNT == ADR\_ACK\_LIMIT$ **then**
    Request response from network server
if $ADR\_ACK\_CNT \geq ADR\_ACK\_LIMIT + ADR\_ACK\_DELAY$ **then**
    increase SF
if downlink transmission received **then**
    $ADR\_ACK\_CNT \leftarrow 0$

Algorithm 2 ADR-NET

$SNR_m \leftarrow max$(SNR of last 20 frames)
$SNR_{req} \leftarrow$ demodulation floor(current data rate)
$deviceMargin \leftarrow 10$
$SNR_{margin} \leftarrow (SNR_m - SNR_{req} - deviceMargin)$
$steps \leftarrow floor(SNR_{margin}/3)$
while steps $>$ 0 **and** SF $>$ SF_{min} **do**
    $SF \leftarrow SF - 1$
    $steps \leftarrow steps - 1$
while steps $>$ 0 **and** TP $>$ TP_{min} **do**
    $TP \leftarrow TP - 3$
    $steps \leftarrow steps - 1$
while steps $<$ 0 **and** TP $<$ TP_{max} **do**
    $TP \leftarrow TP + 3$
    $steps \leftarrow steps + 1$
end

2.9 The Link Budget for LoRa Technology

A link budget in the LoRa technology is higher than the link budget in any other technology due to the use of CSS modulation [2]. The benefit of computing the link budget between sensor nodes and the gateway is that it can be compared with the transmission sensitivity to estimate whether or not the transmission can be decrypted at receiver devices [38].

To know if a connection between the sensor node and gateway is possible, a mathematical equation to compute the link budget is used [47].

Computation of the link budget in equation (2.5) enables to expect the received power of transmission at the receiver side [38].

$$P_{Rx} = P_{Tx} + G_{Tx} + G_{Rx} - L_{System} - L_{channel} - M \qquad (2.5)$$

Where:

- P_{Rx}: Expectant the received power (dBm).
- P_{Tx}: Transmitted power (dBm).
- G_{Tx}: Gain of transmitter antenna (dB).
- G_{Rx}: Gain of receiver antenna (dB).
- L_{System}: Losses of system (dB).
- $L_{channel}$: Losses of the channel (dB).
- M: link margin.

2.9.1 Free-Space Path Loss Estimation

Free-Space Path Loss (FSPL) is the loss that an electromagnetic wave suffers from attenuation during the spread in a straight line in a space without energy absorbing, its dissipation, or reflection from near objects. Its mathematical formula is [47]:

$$FSPL = 32.45 + 20 \log F_{MHz} + 20 \log D_{Km} \qquad (2.6)$$

Where the FSPL is expressed in dB, the frequencies (F) are expressed in MHz, and the distance (D) in km [47].

2.10 Energy Consumption for LoRa-WAN Network

The power unit was chosen as the sample to evaluate energy consumption [55]. The average energy consumption is dependent on the energy consumption for each sensor node powered by a battery. It is possible to reduce energy consumption by the sensor nodes going to sleep mode for most of the time [30]. There are many parameters, which can be modulated to get reliable energy consumption estimations of LoRa-WAN [53]. These factors are [37]:

1- The amount of data that will be sent

2- The Spreading Factor (SF).

3- Retransmission due to collisions

4- The acknowledgment request for the frames sent.

5- A Duty-Cycle.

6- The transceiver's transmitted power

7- The power consumed between two transmits in standby.

2.11 Packets Collision in LoRa-WAN

The collision refers to the overall number of packets that arrived at the gateway but were destroyed because of interference with other packets. A collision happens when two non-orthogonal transmissions using similar spreading factors interfere at the gateway [25]. The model of packet collision happens when several LoRa transmissions reach the gateway at the same bandwidth and same spreading factor at the same time and on the same channel [56]. The transmission is considered successful when the transmitted signal power at the receiver device is larger than the receiver sensitivity [57].

Chapter Three

Modeling and Simulating Monitoring Transformers of Electrical Distribution

3.1 Environment Modelling

The application has been simulated by LoRa technology, using the OMNET++ program to model and simulate the monitoring and control of the greatest number of distribution electrical transformers in Mosul city. The transformer's performance requires receiving data and monitoring significant parameters like temperature, voltage, current, and oil pressure. This information is transmitted across the LoRa gateway to the network server and then to the application server that communicates with the user to monitor and control of LoRa-WAN network. As a result, it will allow the life of transformers to be extended, reducing maintenance costs, reducing the number of unexpected failures, preserving grid stability, and using smart monitoring instead of traditional monitoring.

3.2 Simulation Framework

FLoRa is the Framework LoRa could be employed to simulate the LoRa-WAN network. FLoRa (version 1) is based on the OMNeT++ (version 6 Preview 12) simulator program and the Inetmanet (version 4) framework on the windows operating system. The FLoRa framework presents a complete LoRa-WAN network architectural implementation and exact modeling of the elements of the LoRa radio network physical layer and dedicated a module to describe the network's energy consumption. FLoRa allows for end-to-end simulations to model LoRa devices that are the sensor nodes, gateways as well as network servers.

3.3 Simulation Setup to LoRa-WAN Network Performance Evaluation

The study has employed a square grid of the urban region with coverage areas 1km2 and 25km2, and the sub-urban region with a coverage area of 100km2. Each network contains sensor nodes of 25–100 sensor nodes with a step 25, one gateway placed at the center of networks, and the network server. A packet was released by the sensor nodes every 10 minutes. Most of the sensor nodes in the urban region were relatively near to one another to simulate regions with dense deployments as depicted in Figure 3.1.

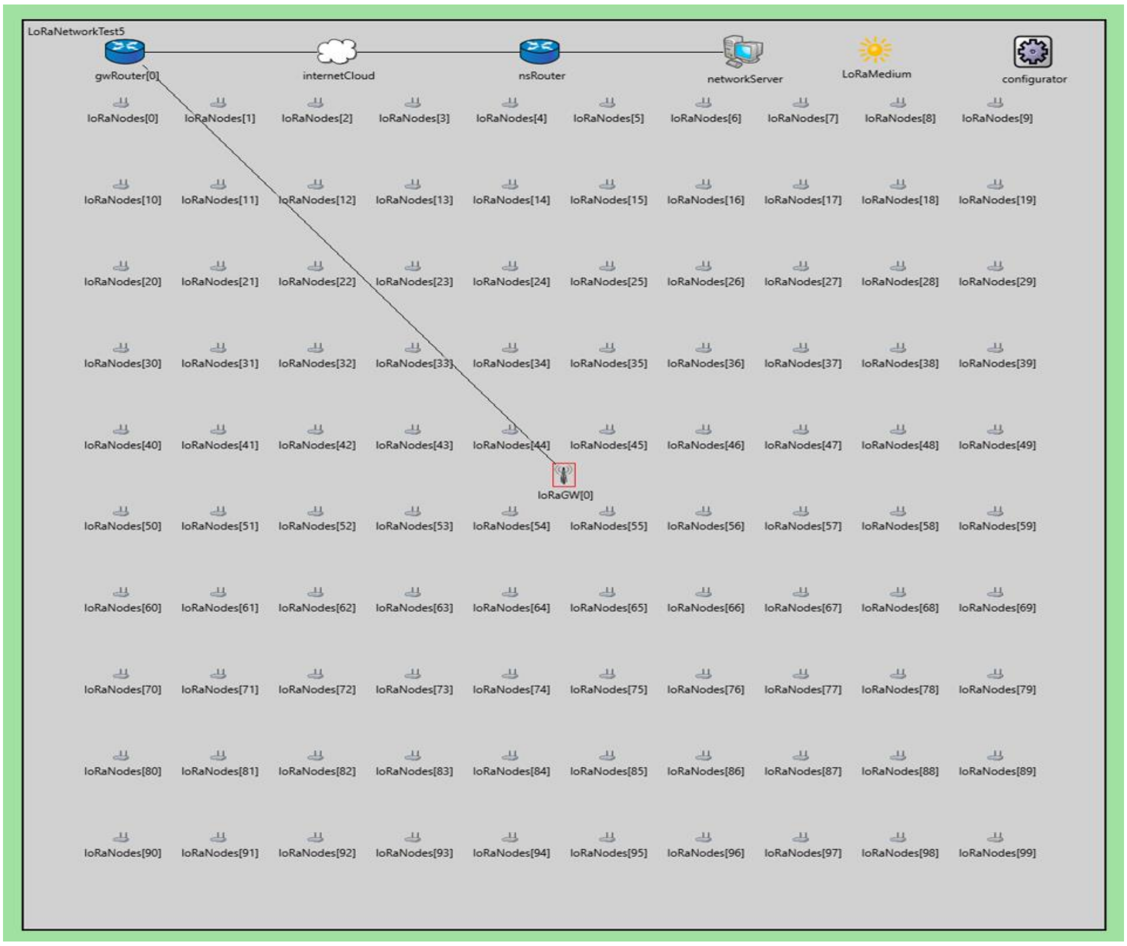

Figure 3.1 Network layout simulation of the Flora window with 100 sensor nodes and LoRa gateway communicated with the network server.

All scenarios of the simulation were executed in one day. The performance of the network was evaluated in the average energy consumption at the network server, the delivery ratio of packets, the number of collisions at the gateway, the total number of the sent message from all sensor nodes, and a total number of the received packet at the network server.

The ADR has been enabled to assign the value of the SF and PT as appropriate. the network server combines statistics from all sensor nodes to assess the performance of the network.

The Packet Delivery Ratio (PDR) was computed as the percentage of all packets received correctly by the network server to the whole number of packets transmitted over the network from all the sensor nodes [24] [58].

The Average Energy Consumption is the sum of the consumed energy for all sensor nodes in the network divided by the total received packets at the network server in the unit (mJ) [24] [58].

Table 3.1 displays the simulation experiments' configuration parameters.

Parameter	Value
Simulator Platform	OMNET++
Simulation model	Inetmanet and FLORA
Coverage area	$1km^2$, $25km^2$, $100km^2$
Simulation time	1 day
Number of GWs	(1)
Number of sensor nodes	25 - 100 step 25
Transmitted Power	(2-14) dBm
Carrier Frequency	868 MHz
Spreading Factor	7 to 12
Bandwidth	125 kHz
Code Rate	4/5, 4/8
Time of the first packet	Exp (600s)
The time interval of transmitted packets	Exp (600s-3600s step 600s)

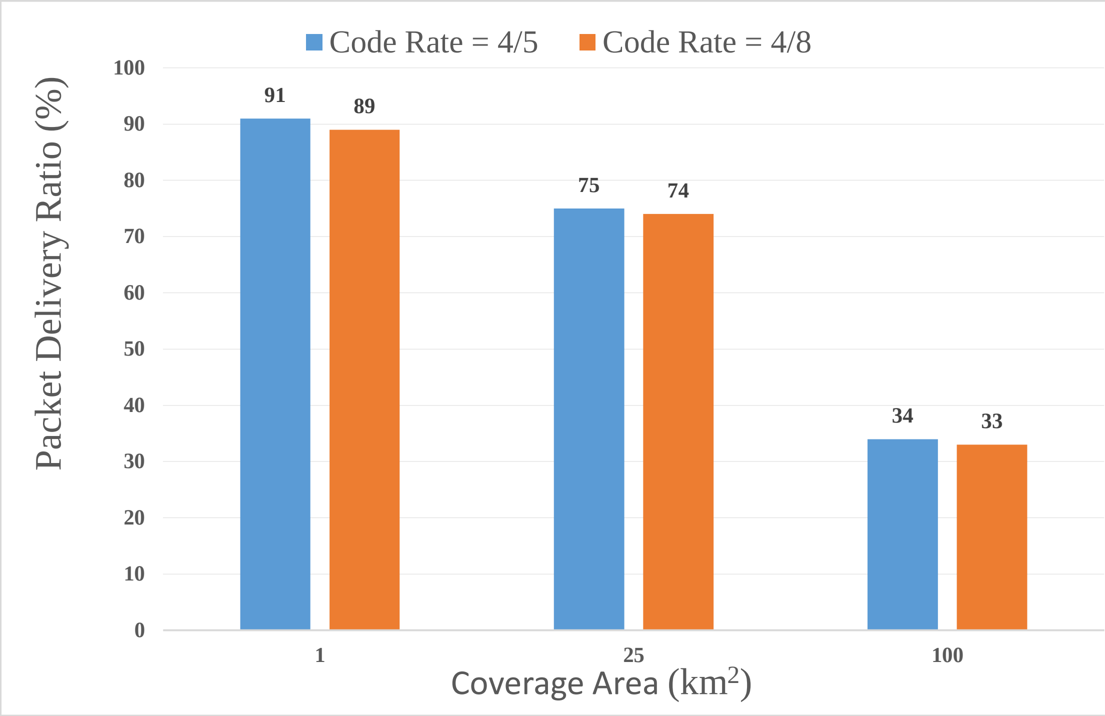

Figure 3.2 The Packet Delivery Ratio vs. the coverage areas at code rates 4/5 and 4/8, using 100 of the sensor nodes with one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

The results proved the increase in coverage areas from $1km^2$ to $100km^2$ decreases the packet delivery ratio from 91% to 34% for a code rate of 4/5 and from 89% to 33% for a code rate of 4/8, due to an increase in the distance between the gateway and sensor nodes in large networks that led to decrease in the packet delivery ratio.

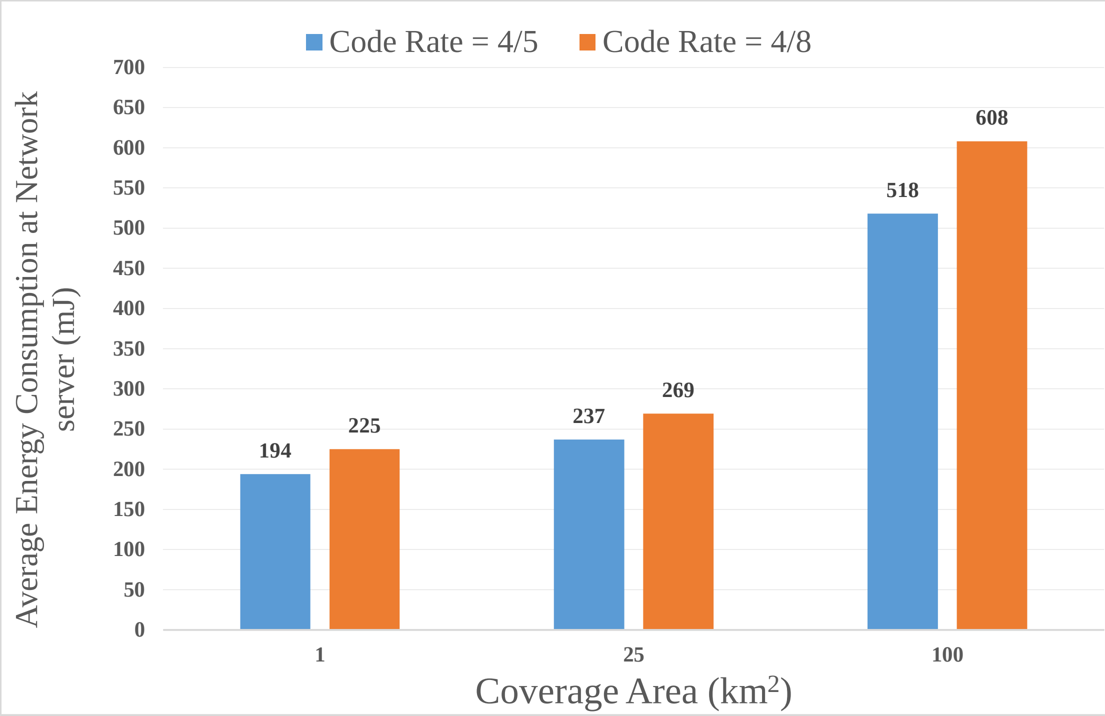

Figure 3.3 The average energy consumption at network server vs. the coverage area at code rates 4/5 and 4/8, using 100 of the sensor nodes with one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

The simulation outcomes in Figure 3.3 revealed the lowest average energy consumption is 194 mJ for a 1 km2 coverage area for a code rate of 4/5, Then the increase in average energy consumption has been recorded at the same coverage area to 225 mJ for a code rate of 4/8. Therefore, we notice the results of a code rate of 4/5 are better than the results of a code rate of 4/8.

using a code rate (4/8) will allow sending a lower signal-to-noise ratio with more redundant bits in chirp, which leads to an increase in the time on air and an increase in the energy consumption for the message.

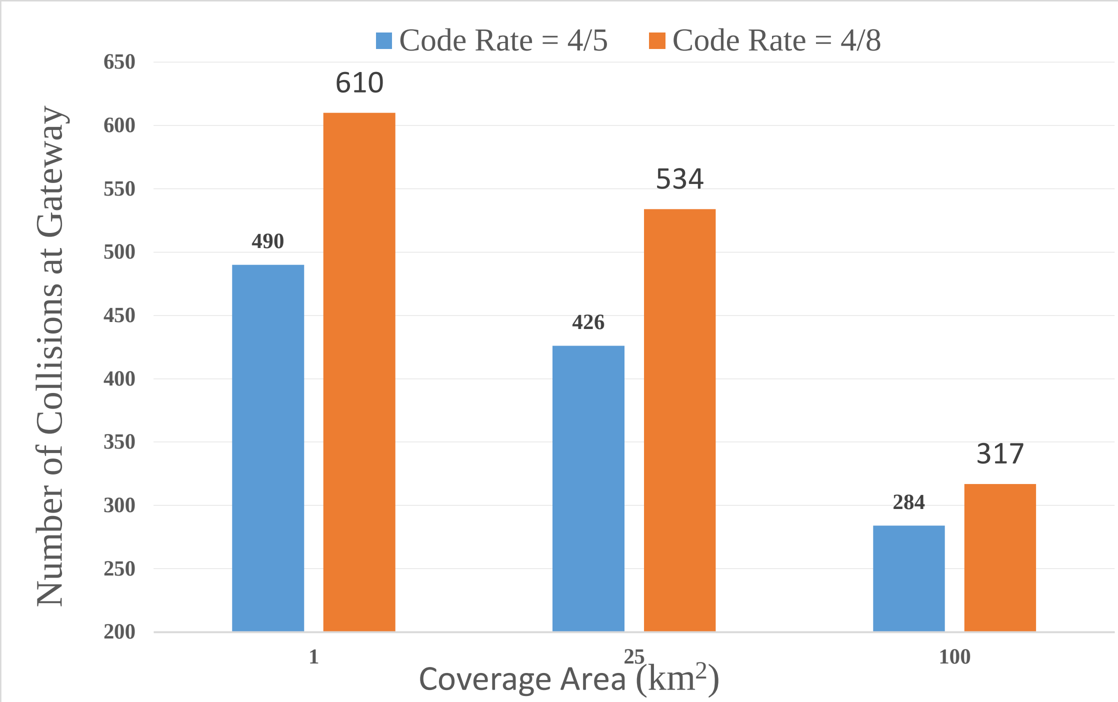

Figure 3.4 The number of collisions at the LoRa gateway vs. the coverage area at code rates 4/5 and 4/8, using 100 of the sensor nodes with one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

The results proved the increase in coverage areas from 1km^2 to 100km^2 decreases the number of collisions at the gateway from 490 to 284 for a code rate of 4/5 and from 610 to 317 for a code rate of 4/8.

Therefore, we notice the number of collisions at a code rate of 4/5 is less than the code rate of 4/8, due to a low code rate (4/5) will lead to a decrease in the Bit Error Rate as possible.

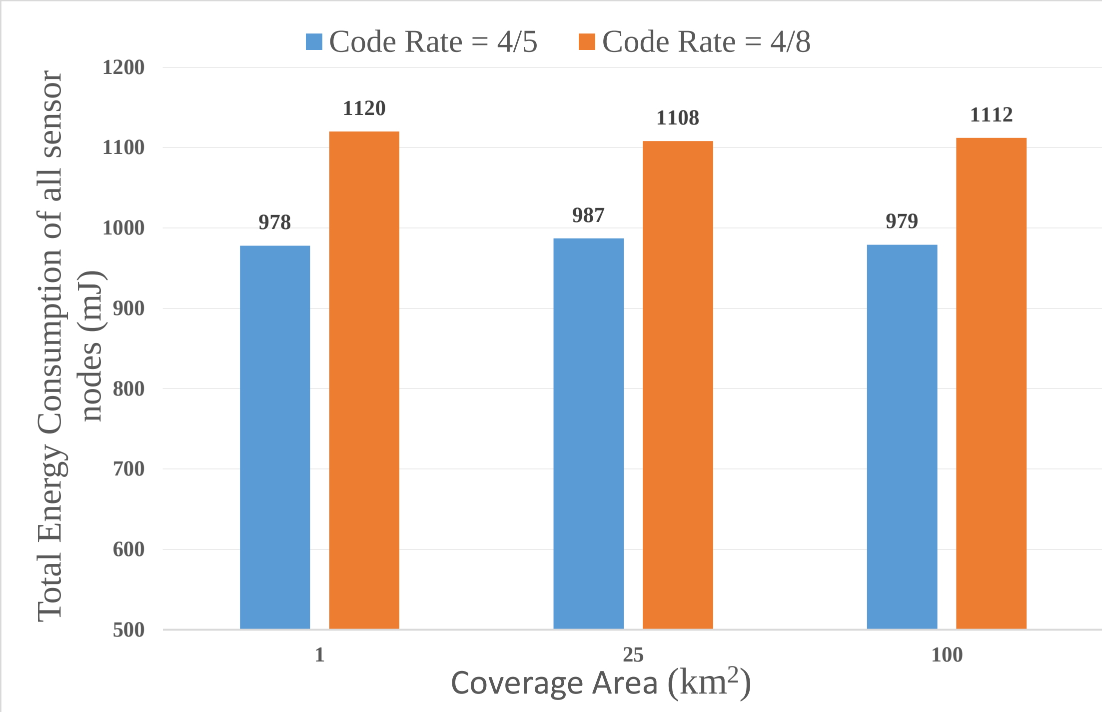

Figure 3.5 The total energy consumption of all sensor nodes vs. the coverage areas at code rates 4/5 and 4/8, using 100 of the sensor nodes with one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

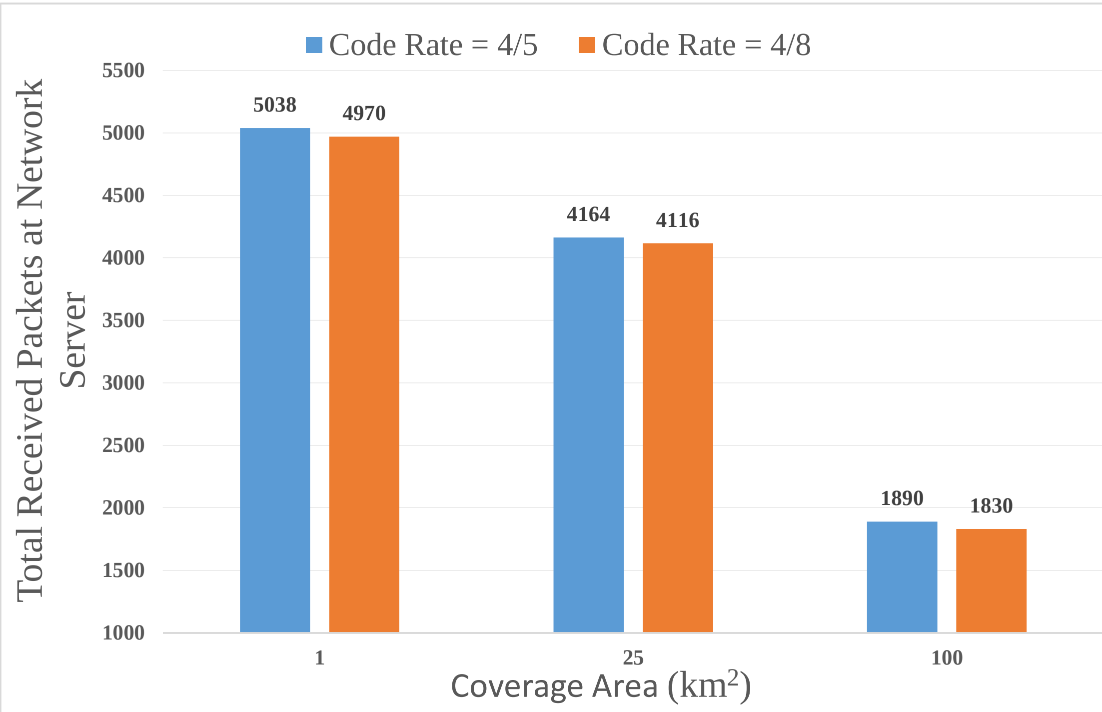

Figure 3.6 The total received packets at the network server vs. the coverage area at code rates 4/5 and 4/8, using 100 of the sensor nodes with

one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

When expanding the coverage areas from 1km2 to 100km2, then the total number of packets received at the network server decrement from 5038 to 1890 for code rate 4/5 and 4970 to 1830 for code rate 4/8, due to the network server can receive the packet for a CR=4/5 which have less number of bits and short time on air than CR=4/8 as shown in Figure 3.6.

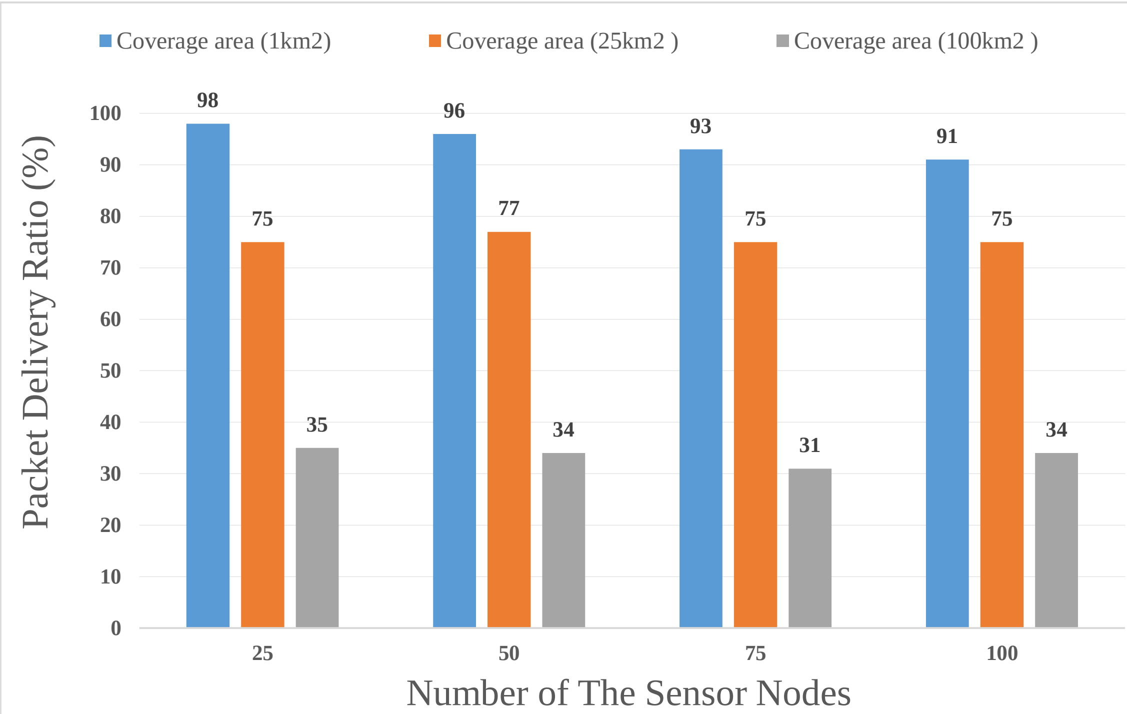

Figure 3.7 The packet delivery ratio vs. the number of the sensor nodes in the coverage areas ($1km^2$, $25km^2$, $100km^2$), using 4/5 code rate, one gateway placed at center of networks, and exp (600)s of the transmission time interval of packets.

the performance of the network of PDR has been assessed with the number of sensor nodes (25,50,75,100) increment that is distributed in the coverage areas 1km2, 25km2, and 100km2 uniformly. This figure shows the best results attained for packet delivery ratio is 98% for the coverage area1km2 when the number of the sensor nodes was 25. Then we witness a gradual decrease in the PDR ratio as an increase in the number of sensor nodes and an increase in the coverage area, due to an increase in the number of collisions as an increase in the number of sensor nodes.

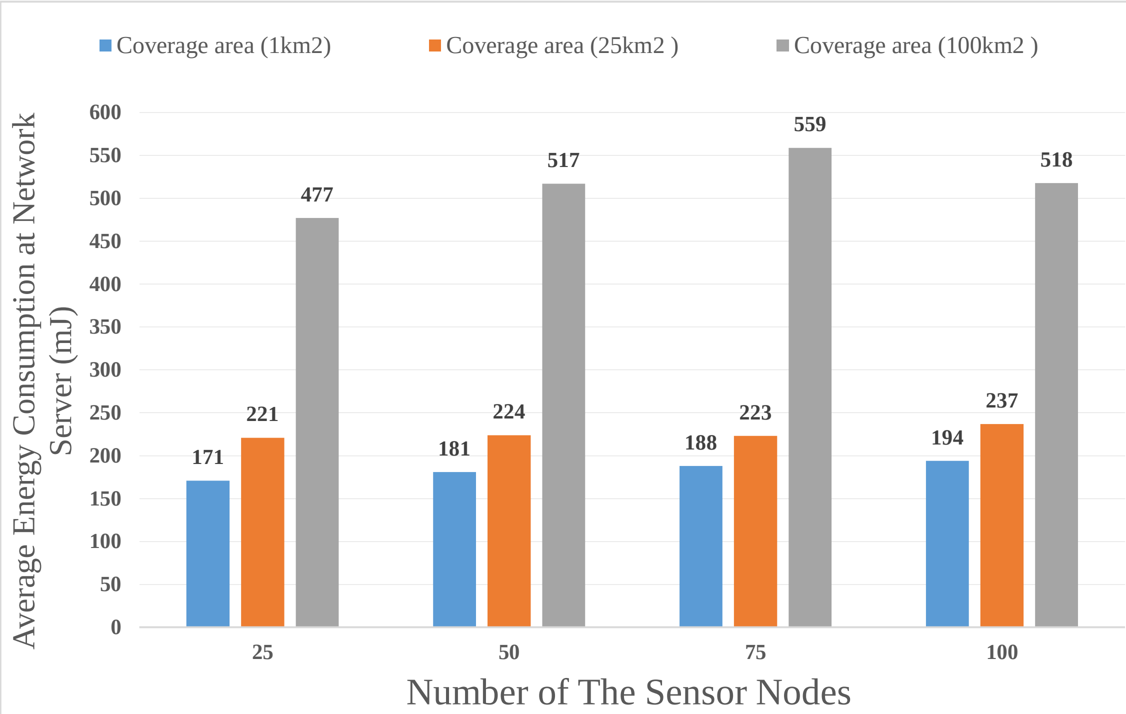

Figure 3.8 The Average energy consumption at the network server vs. the number of the sensor nodes in the coverage areas ($1km^2$, $25km^2$, $100km^2$), using a 4/5 code rate, one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

The simulation included the many coverage areas using varying sensor node densities by altering the deployment area's number of nodes from 25 to 100. This figure introduces the influence of the average energy consumption at the network server with the number of sensor nodes in our simulation. Figure 3.8 illustrates the reduction in network performance due to an increment of the energy consumption from 171 to 194 at an increment in the number of sensor nodes for the 1km2 network from 25 nodes to 100 nodes.

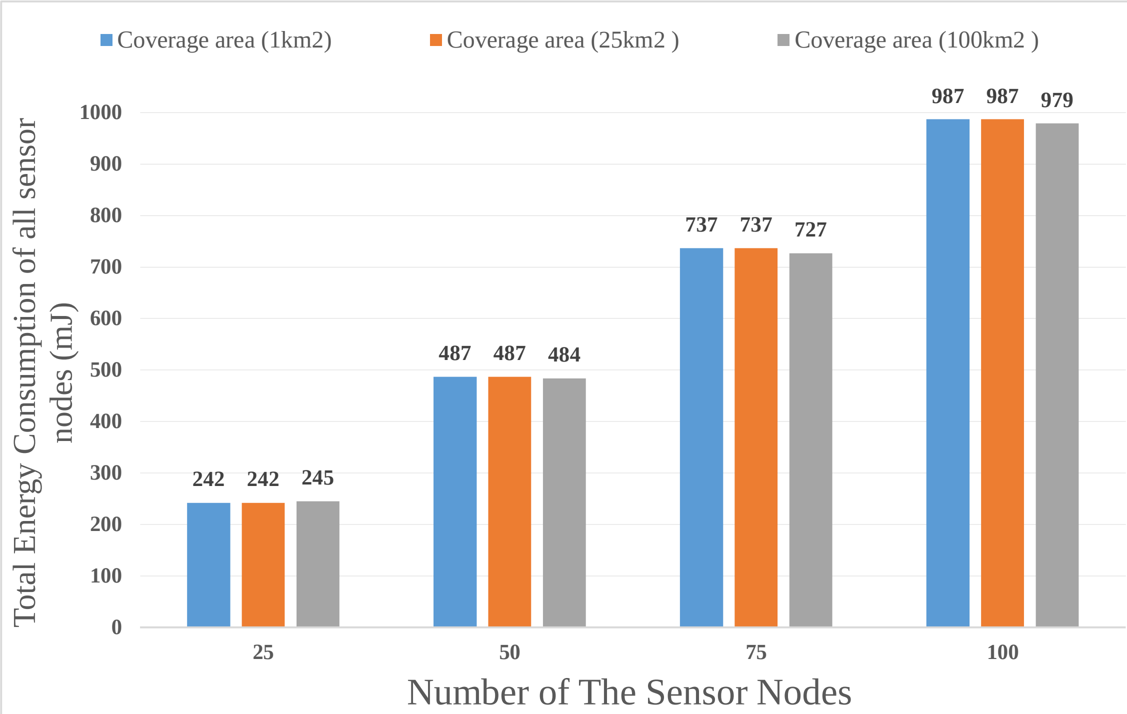

Figure 3.9 The total energy consumption of all sensor nodes vs. the number of the sensor nodes in the coverage areas (1km^2, 25km^2, 100km^2), using 4/5 code rate, one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

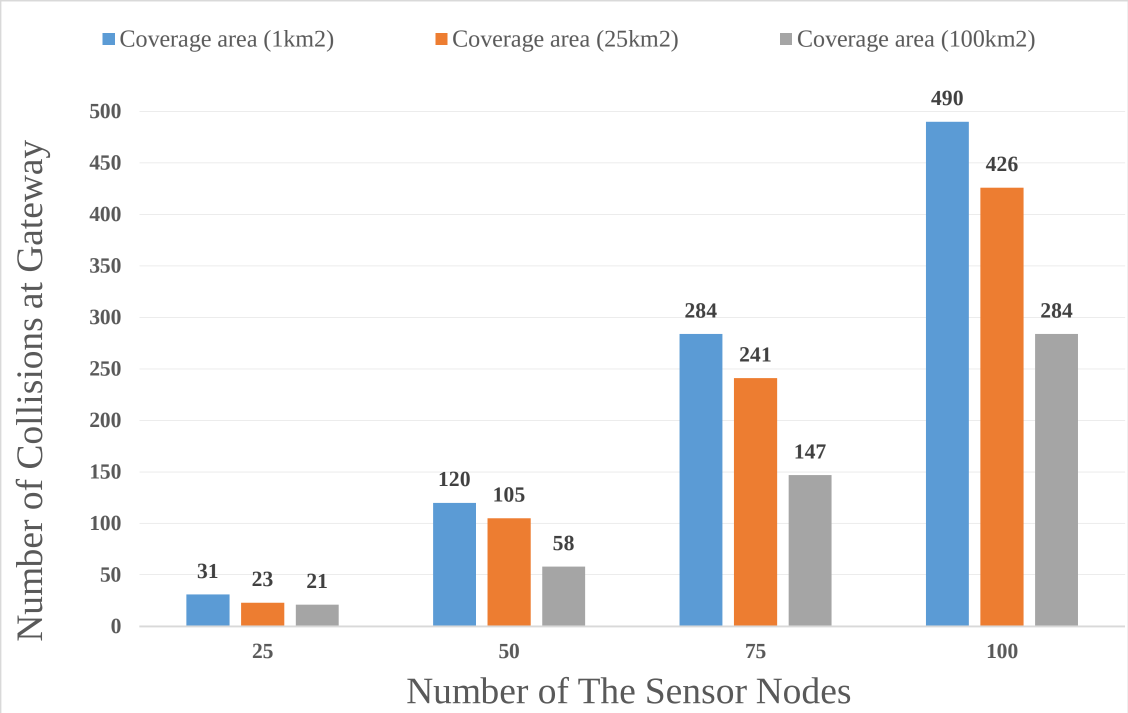

Figure 3.10 The number of collisions at the LoRa gateway vs. the number of the sensor nodes in the coverage areas (1km^2, 25km^2, 100km^2), using 4/5 code rate, one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

The figure above shows the number of collisions at the LoRa gateway for the coverage areas 1 km2, 25 km2, and 100 km2. When incrementing the number of sensor nodes, the network's performance deteriorates since the number of packet collision accidents increases. When the number of sensor nodes increases from 25 to 100, the number of collisions will increment from 31 to 490 for a network of 1 km2. Also, the number of collisions increments from 21 to 284 for a network of 100 km2 for the same number of sensor nodes, whereas drops in the number of collisions were noticed considerably when the distance between nodes and gateway widens in large networks compared with small networks.

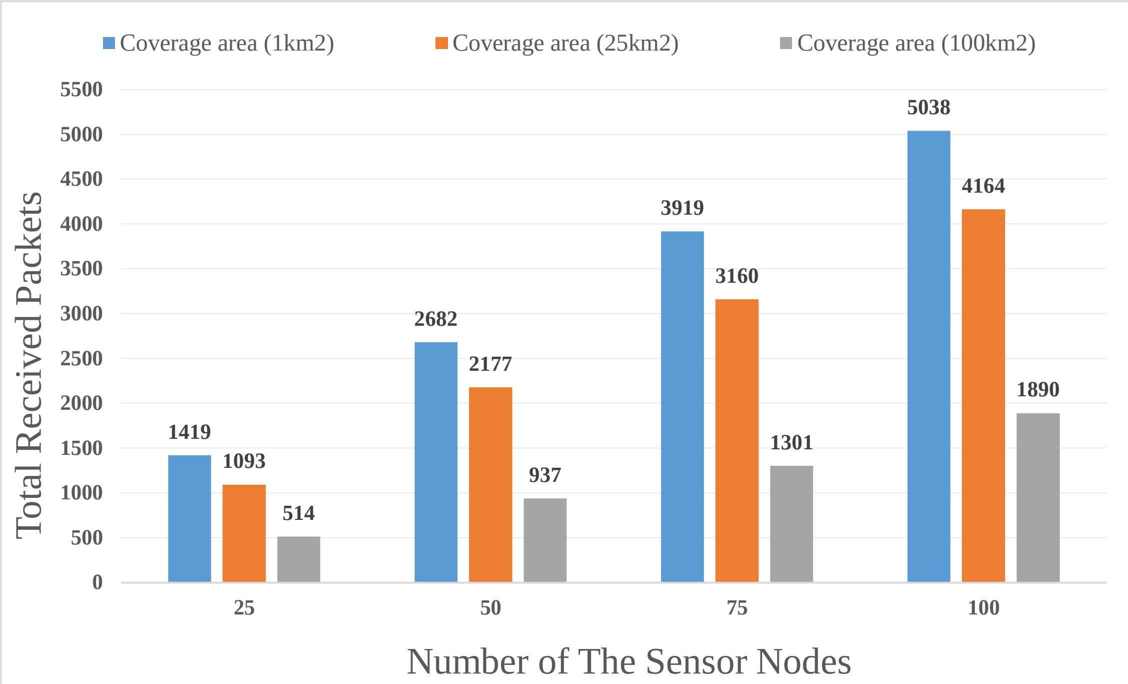

Figure 3.11 The total received packets at the network server vs. the number of the sensor nodes in the coverage areas ($1km^2$, $25km^2$, $100km^2$), using 4/5 code rate, one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

The system scalability has been observed through simulation with different numbers of sensor nodes for varying network sizes while leaving the rest of the parameters and settings untouched. From the figure above, the number of sensor nodes in the deployment region varied from 25 to 100 in steps of 25 nodes, whereas the network areas changed from 1km2 to 100km2, to register the total received packets by the network server. We notice the total received packets increased by increasing the number of nodes and decreased by increasing the network areas.

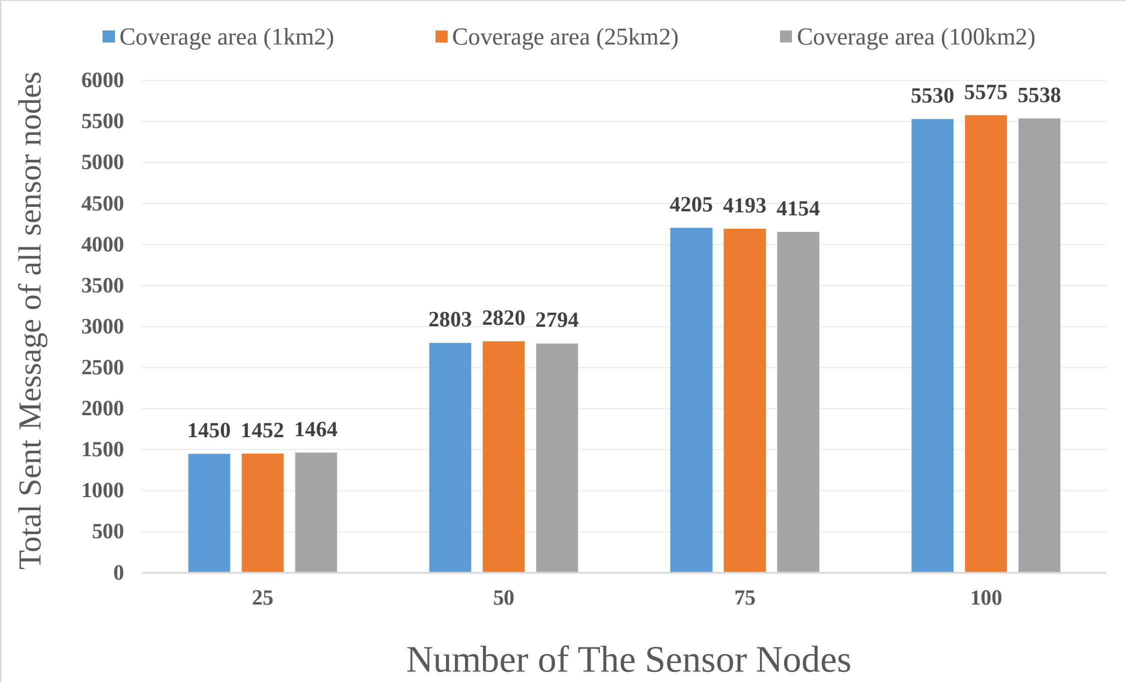

Figure 3.12 The total sent message of all sensor nodes vs. the number of the sensor nodes in the coverage areas ($1km^2$, $25km^2$, $100km^2$), using 4/5 code rate, one gateway placed at the center of networks, and exp (600)s of the transmission time interval of packets.

The total sent message of all sensor nodes has been observed through simulation with different numbers of sensor nodes for varying coverage areas. From the figure above, the number of sensor nodes in the coverage area varied from 25 to 100 in steps of 25 nodes, whereas the coverage areas changed from 1km2 to 100km2. We notice the total sent message increased by increasing the number of nodes and increased by increasing the coverage areas.

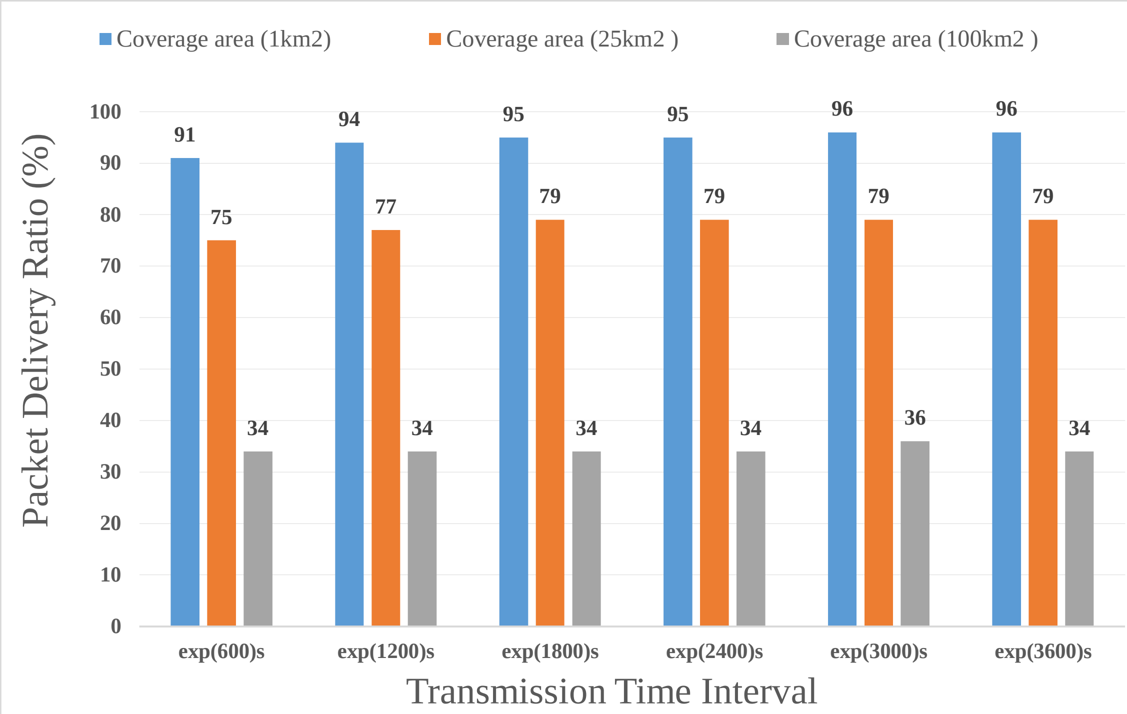

Figure 3.13 The packet delivery ratio vs. the transmission time interval in the coverage areas ($1km^2$, $25km^2$, $100km^2$), using a 4/5 code rate, 100 sensor nodes, and one gateway placed at the center of networks.

Figure 3.13 demonstrated the Packet Delivery Ratio (PDR) for various coverage areas (1km2,25km2,100km2) with a 100 number of nodes. The simulation was implemented via exp(600, 1200, 1800, 2400, 3000, 3600) sec the time interval of transmitting packets. The Packet Delivery Ratio increases gradually at an increase in the time interval of transmitting packets while PDR decreases at an increase in the coverage areas.

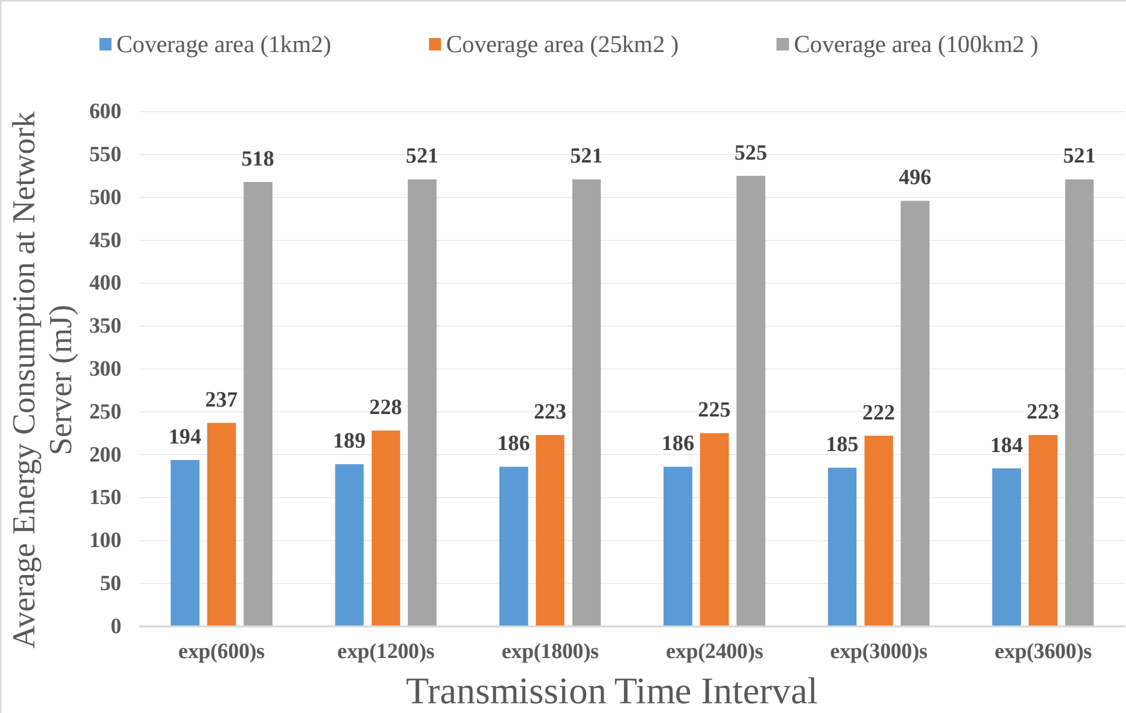

Figure 3.14 The Average energy consumption at the network server vs. the transmission time interval in the coverage areas (1km^2, 25km^2, 100km^2), using a 4/5 code rate, 100 sensor nodes, and one gateway placed at the center of networks.

The average energy consumption at the network server has been chosen as the first metric of benefit to assess the performance of the network for different coverage areas when 100 numbers of sensor nodes. As shown in Figure 3.14, the increment in the time interval of transmitting packets will perform to decrease the average energy consumption for different coverage areas.

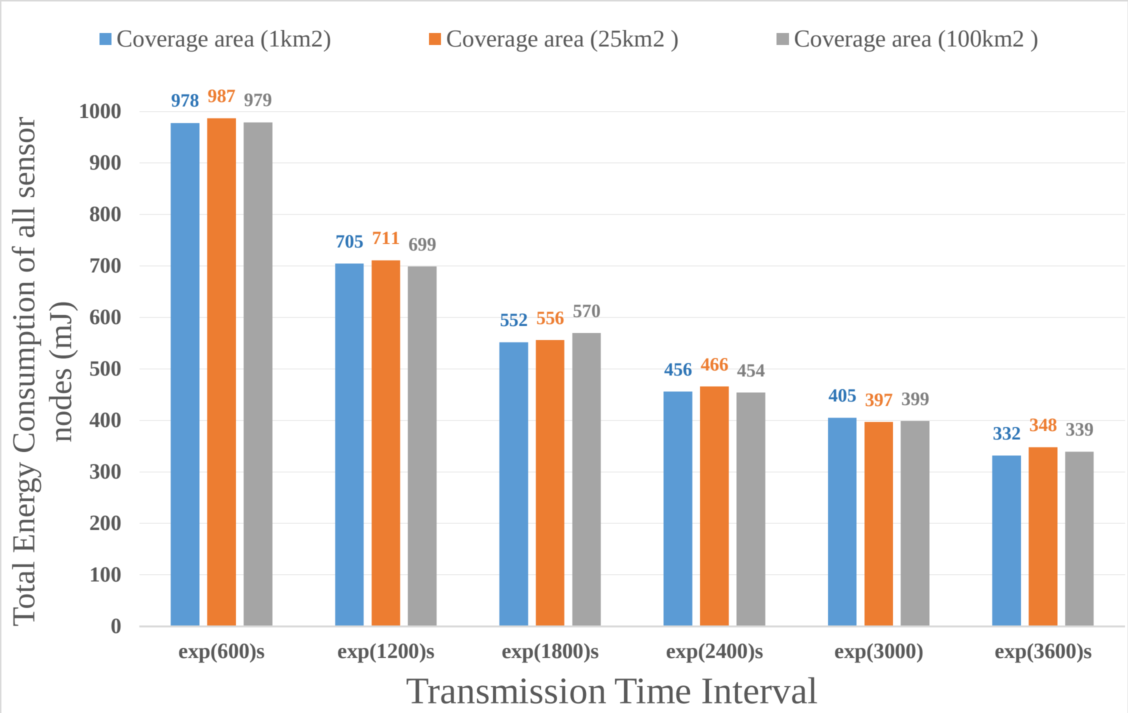

Figure 3.15 The total energy consumption of all sensor nodes vs. the transmission time interval in the coverage areas (1km^2, 25km^2, 100km^2), using 4/5 code rate, 100 sensor nodes, one gateway placed at center of networks.

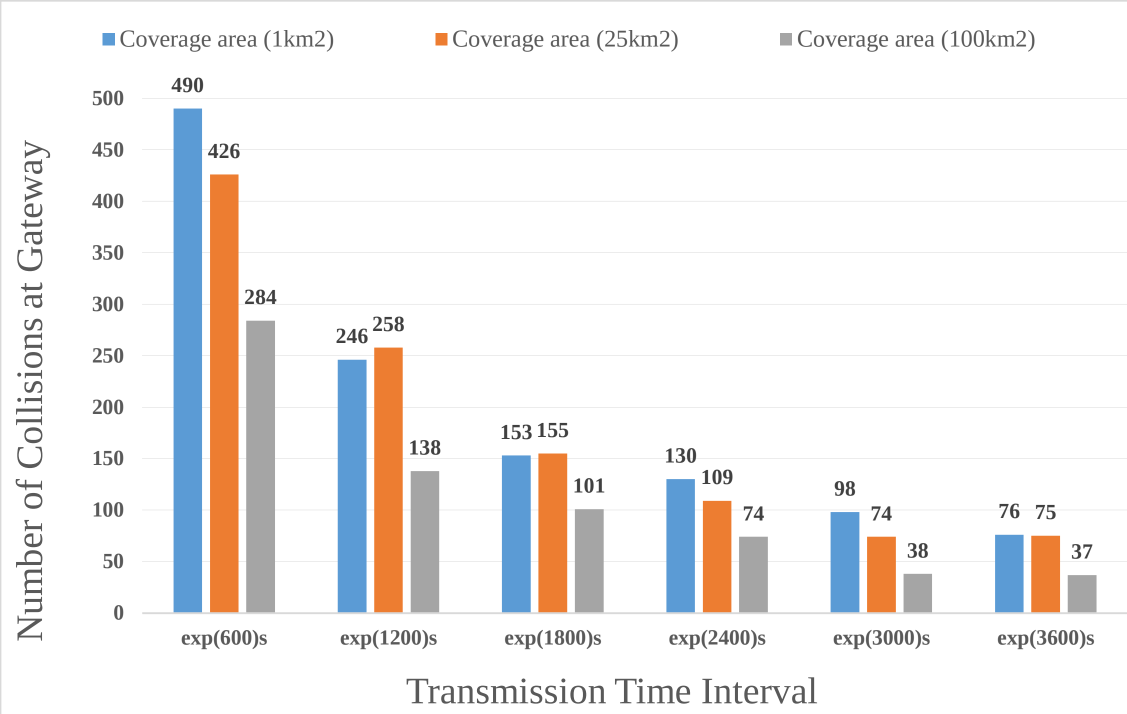

Figure 3.16 The number of collisions at the LoRa gateway vs. the transmission time interval in the coverage areas (1km^2, 25km^2, 100km^2), using 4/5 code rate, 100 sensor nodes, one gateway placed at center of networks.

For the same alternating a time interval of transmitting packets for the sensor nodes across 1km^2, 25km^2, and 100km^2 coverage areas. The number of collisions illustrates decreasing at an increase in both the time interval of transmitting packets and the coverage areas.

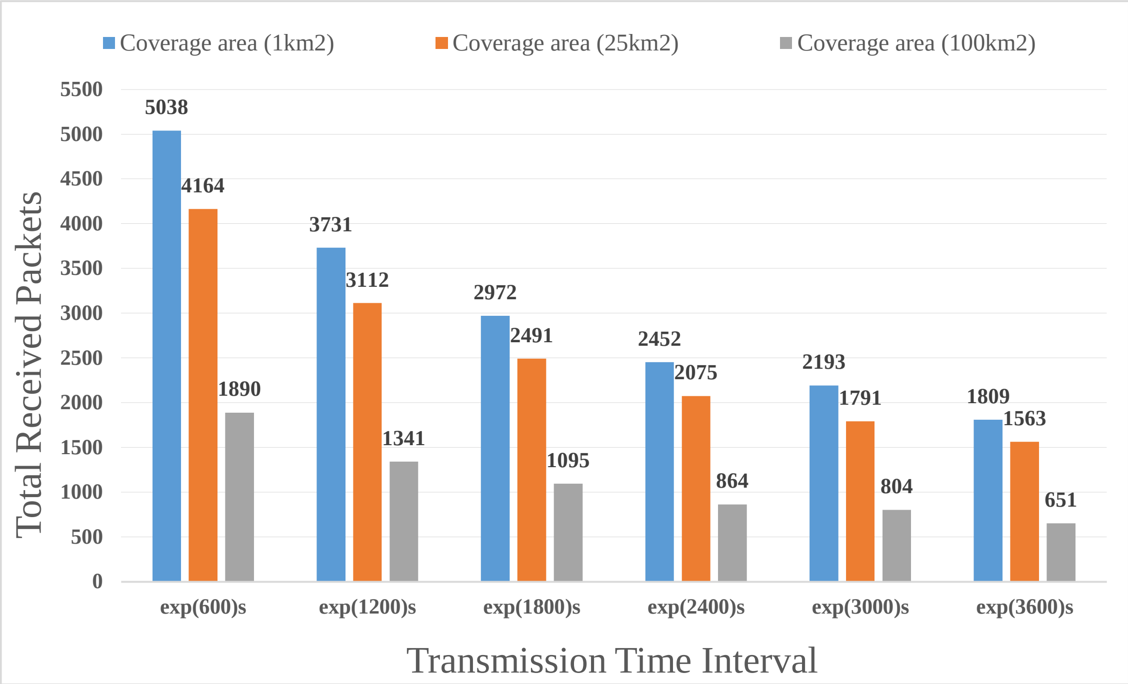

Figure 3.17 The total received packets at the server network vs. the transmission time interval in the coverage areas (1km^2, 25km^2, 100km^2), using 4/5 code rate, 100 sensor nodes, one gateway placed at center of networks.

As in previous coverage areas of 1km2,25km2, and 100km2, we use the same transmission time intervals for sensor nodes and the 100 number of sensor nodes. It has been observed with each increment in the coverage area and increment in transmission time intervals, the total received packets at the server network will decrease.

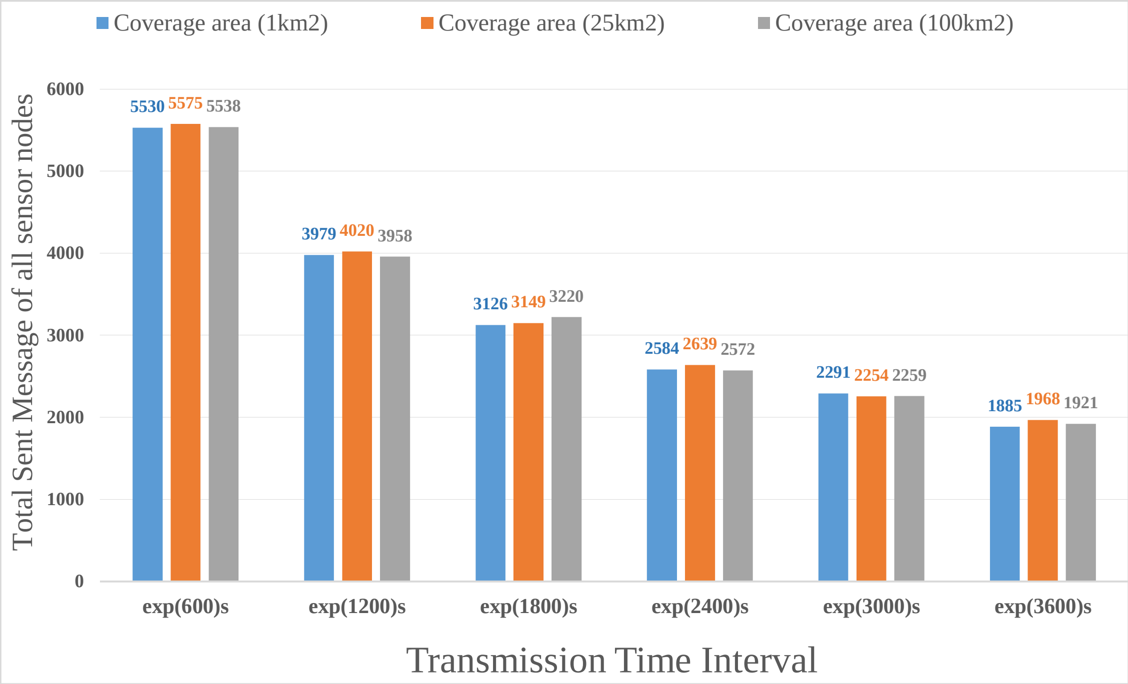

Figure 3.18 The total sent message of all sensor nodes vs. the transmission time interval in the coverage areas (1km^2, 25km^2, 100km^2), using 4/5 code rate, 100 sensor nodes, one gateway placed at center of networks.

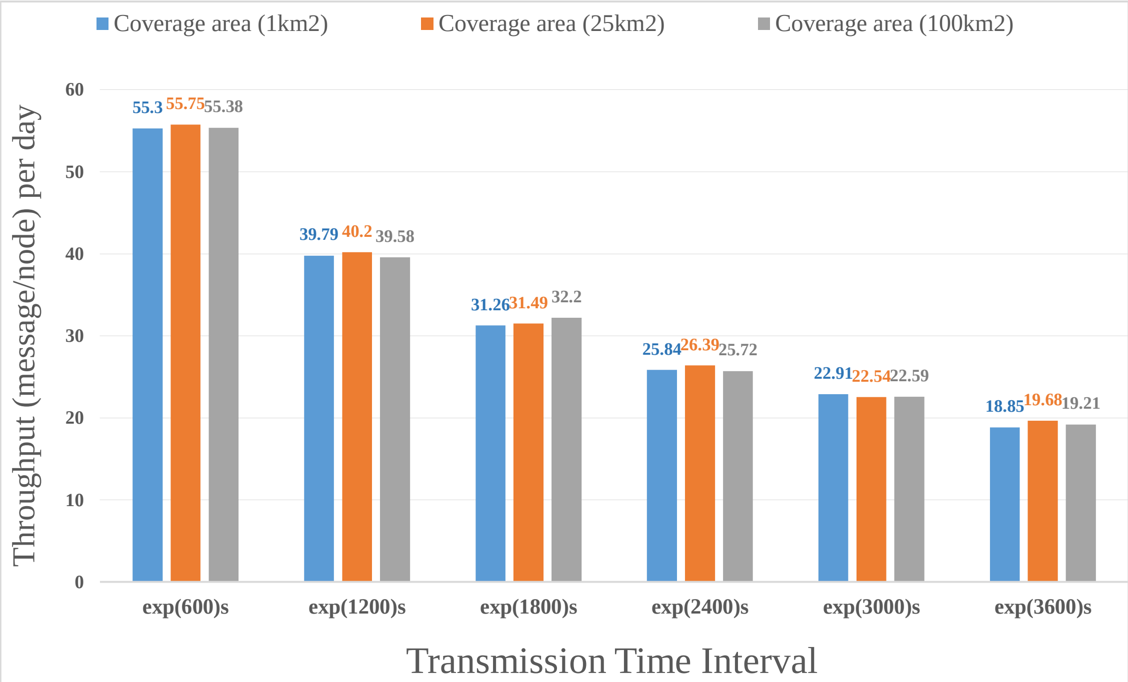

Figure 3.19 The throughput is the total number of sent messages divided by the total sensor nodes during the day vs. the transmission time interval in the coverage areas ($1km^2$, $25km^2$, $100km^2$), using 4/5 code rate, 100 sensor nodes, one gateway placed at center of networks.

Chapter Four

Modeling LoRa WAN Network to Assess Performance for a Water Level Monitoring Simulation

4.1 Modeling of the Environment

The application shows a model simulating monitoring the water level in Mosul Dam using Long Range Wide Area Network (LoRa-WAN) technology. This research simulates using sensor nodes that work ultrasonic, which are placed as floating objects to the water column altimeter to get data on monitoring water levels. If the water level passes the permitted level, the network will take appropriate action and send alerts and these readings across a LoRa gateway.

4.2 LoRa Simulation Scheme

In this scenario, the sensor nodes deployed across a rectangular area of (3500 x 1000) m. the number of LoRa sensor nodes varied from 25 to 100 in step 25, and one LoRa gateway placed at (1750x1000) m, as depicted in Figure 4.1.

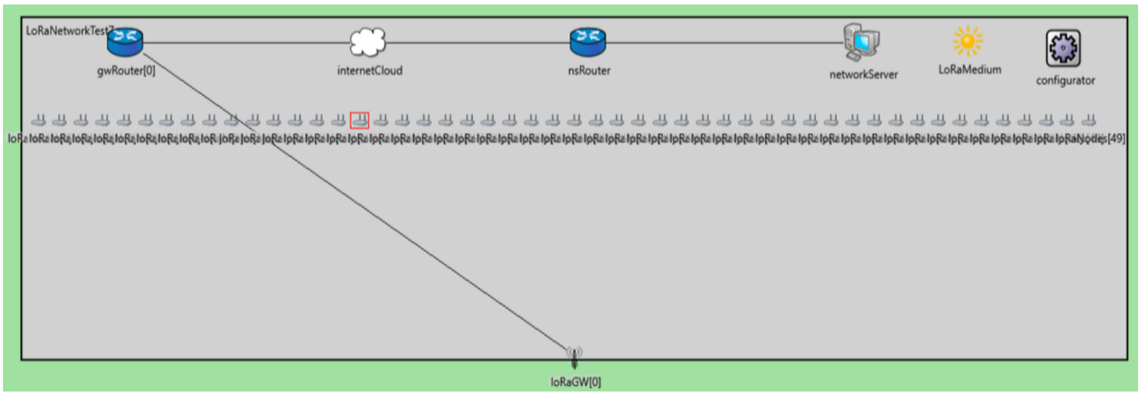

Figure 4.1 Screenshot of a Flora window simulation with 50 sensor nodes and one LoRa gateway communicated with a cloud of the things network (TTN).

The parameters of European regions have been employed to describe the physical layer of LoRa characteristics that are set in Table 4.1.

Table 4.1 Simulating parameters characteristic.

Parameter	Value
Simulator platform	OMNET++
Simulation model	Inetmanet and FLORA
coverage area	3500m x 1000 m
Simulation time	1 days
Number of GWs	(1)
Number of sensor nodes	25 - 100 step 25
Transmitted Power	(2-14) dBm
Carrier frequency	868 MHz
Spreading factor	7 to 12
Bandwidth (BW)	125 kHz
Code rate	4/5
Time to the first packet	exp (600s)
The time interval of transmitted packets	exp (600s-3600s step 600s)

The Transmitted Power

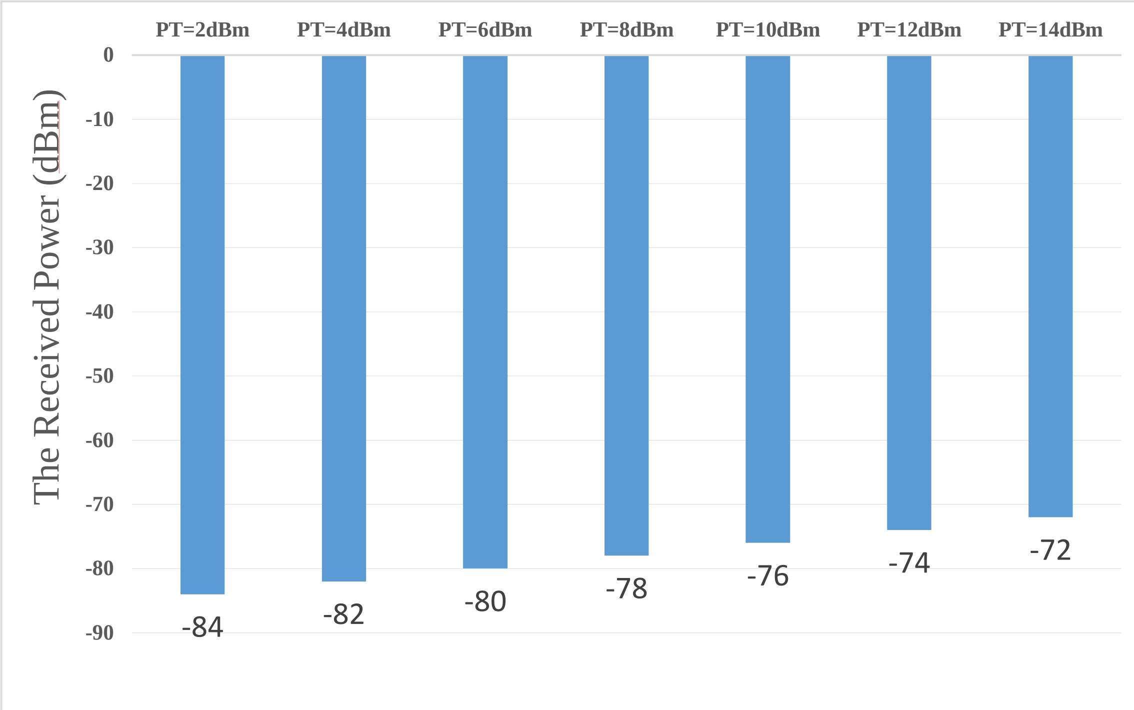

Figure 4.2 The received power vs. transmitted power according to the received power equation.

According to the received power equation, where the sum of antenna gain for transmitter and receiver is 4 dB, while the sum of cable losses for transmitter and receiver is 2dB, the free space path loss is (88dB) according to free space path loss equation at (700m) the distance between LoRa gateway and the sensor nodes.

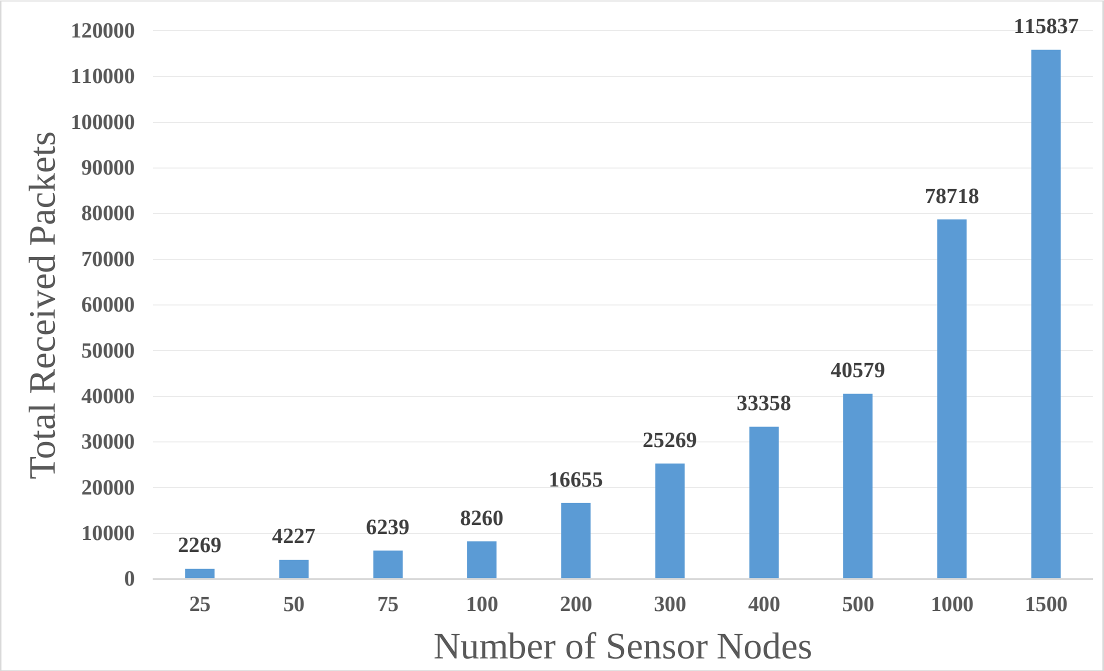

Figure 4.3 The total received packets at the network server vs. the number of sensor nodes, the time interval of transmitting packets exp (600s), one LoRa gateway is placed at (1750x 1000) m.

The total received packets at the network server have been observed through simulation with different numbers of sensor nodes from 25 to 100 in steps of 25 nodes. We notice the total received packets increased by increasing the number of nodes from 2269 to 115837.

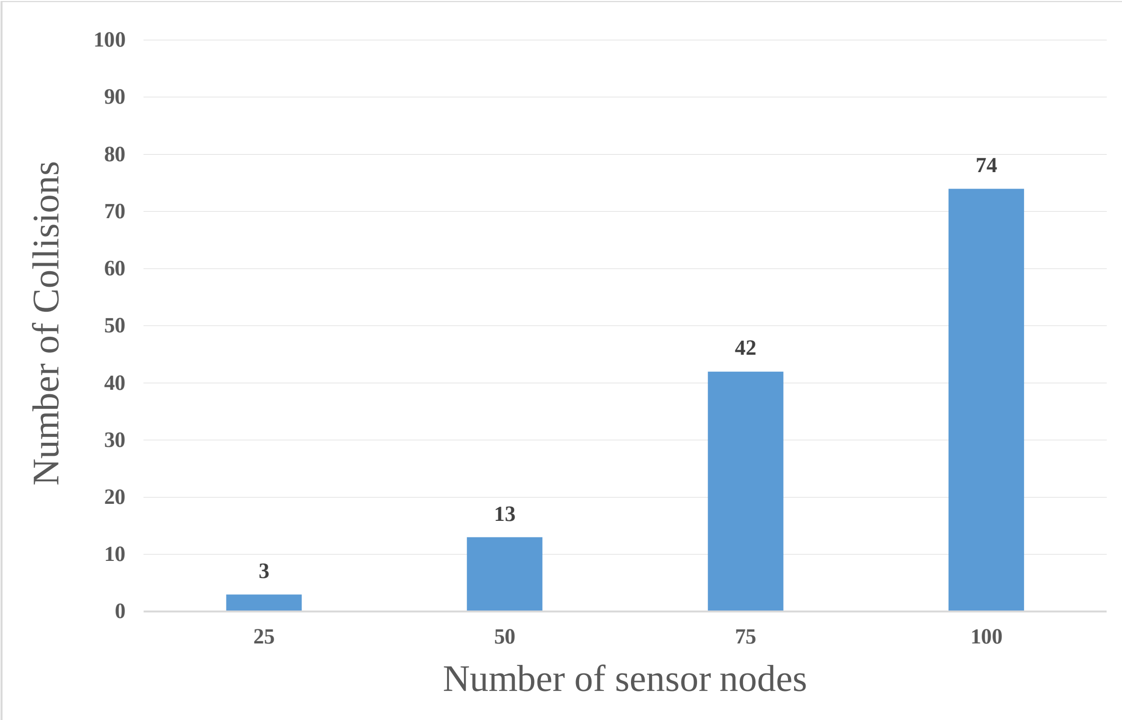

Figure 4.4 The number of collisions at the LoRa gateway vs. the number of sensor nodes, the time interval of transmitting packets exp(600s), one LoRa gateway is placed at (1750x 1000) m.

The figure above shows the number of collisions at the LoRa gateway when incrementing the number of sensor nodes, the network's performance deteriorates as the number of packet collisions increases. When the number of sensor nodes increases from 25 to 100, the number of collisions will increment from 3 to 74 at the LoRa gateway.

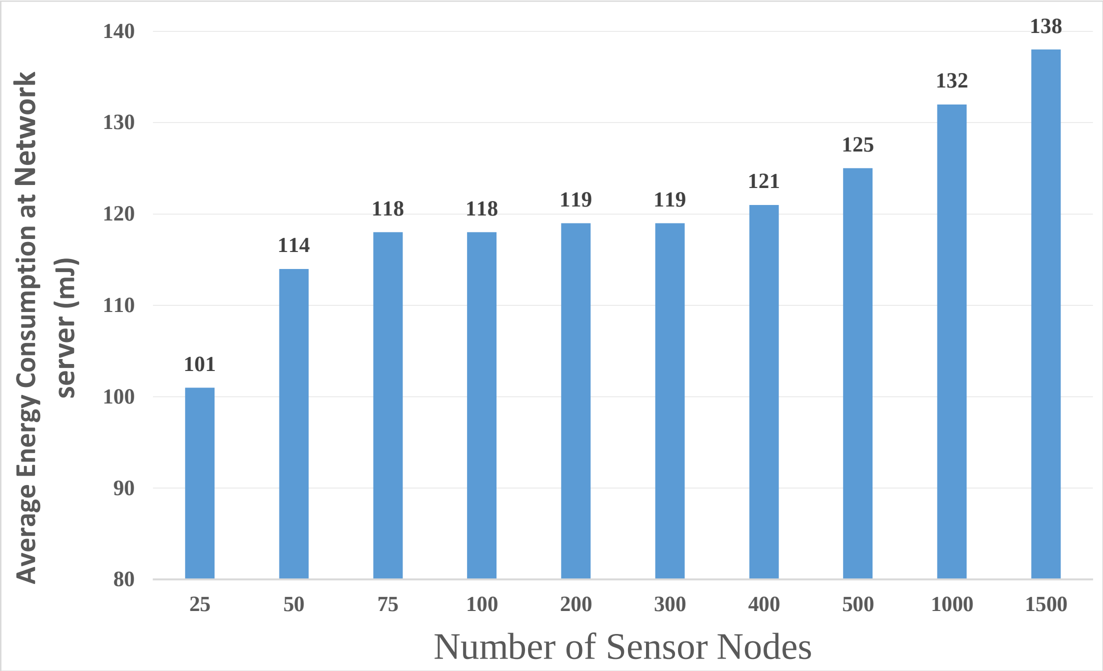

Figure 4.5 The average energy consumption at the network server vs. the number of sensor nodes, the time interval of transmitting packets exp (600s), one LoRa gateway is placed at (1750x 1000) m.

The simulation included the average energy consumption at the network server using varying sensor node densities from 25 to 100 with step 25. This figure shows the reduction in network performance due to an increment of the average energy consumption from 101 to 138 at an increment in the number of sensor nodes from 25 nodes to 100 nodes.

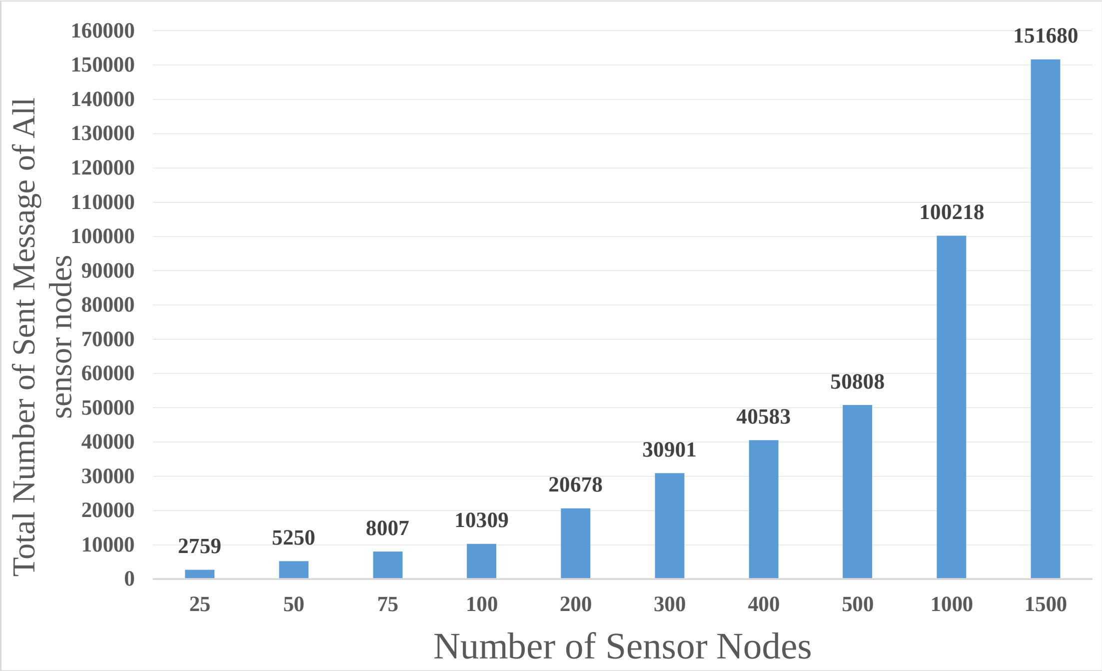

Figure 4.6 The total number of the sent message of all sensor nodes vs. the number of sensor nodes, the time interval of transmitting packets exp(600s), one LoRa gateway is placed at (1750x 1000) m.

The total sent message of all sensor nodes has been observed through simulation with different numbers of sensor nodes. From the figure above, the number of sensor nodes in the coverage area varied from 25 to 100 in steps of 25 nodes. We notice the total sent message increased from 2759 at 25 to 10309 at 100 sensor nodes.

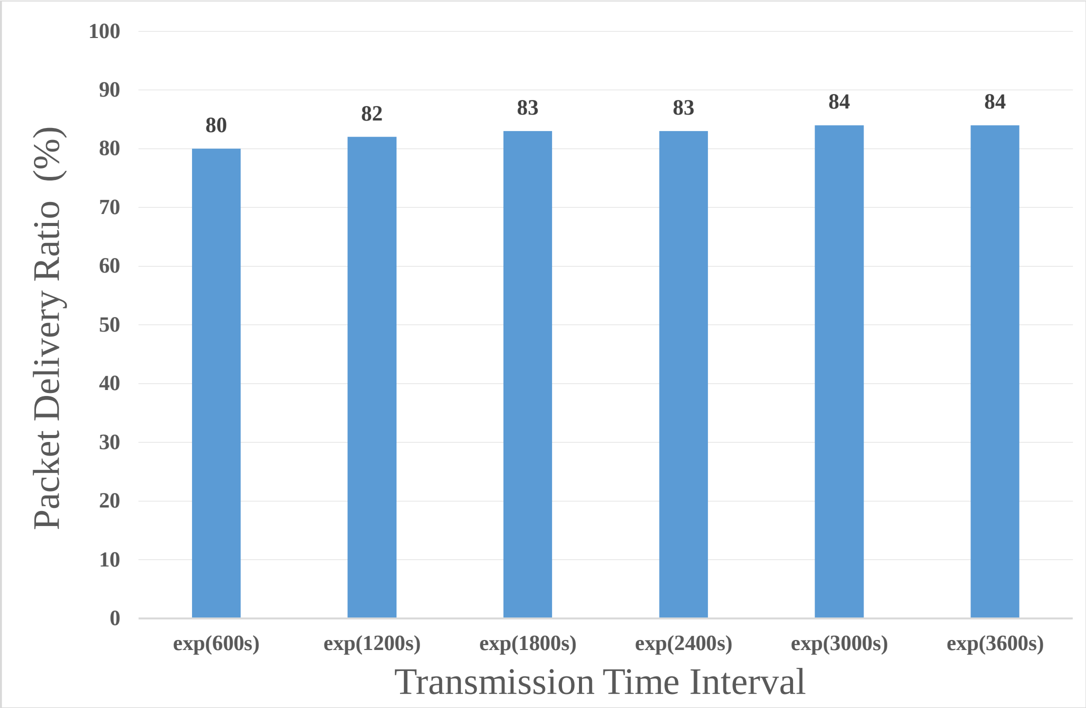

Figure 4.7 The packet delivery ratio vs. transmission time interval, the number of sensor nodes (100), and one LoRa gateway are placed at (1750x 1000) m.

Figure 4.7 demonstrated the Packet Delivery Ratio (PDR) for various transmission time intervals exp(600, 1200, 1800, 2400, 3000, 3600) sec. the network performance enhancement has been observed by an increase gradually in the value of PDR from 80% to 84% at an increase in the transmission time intervals.

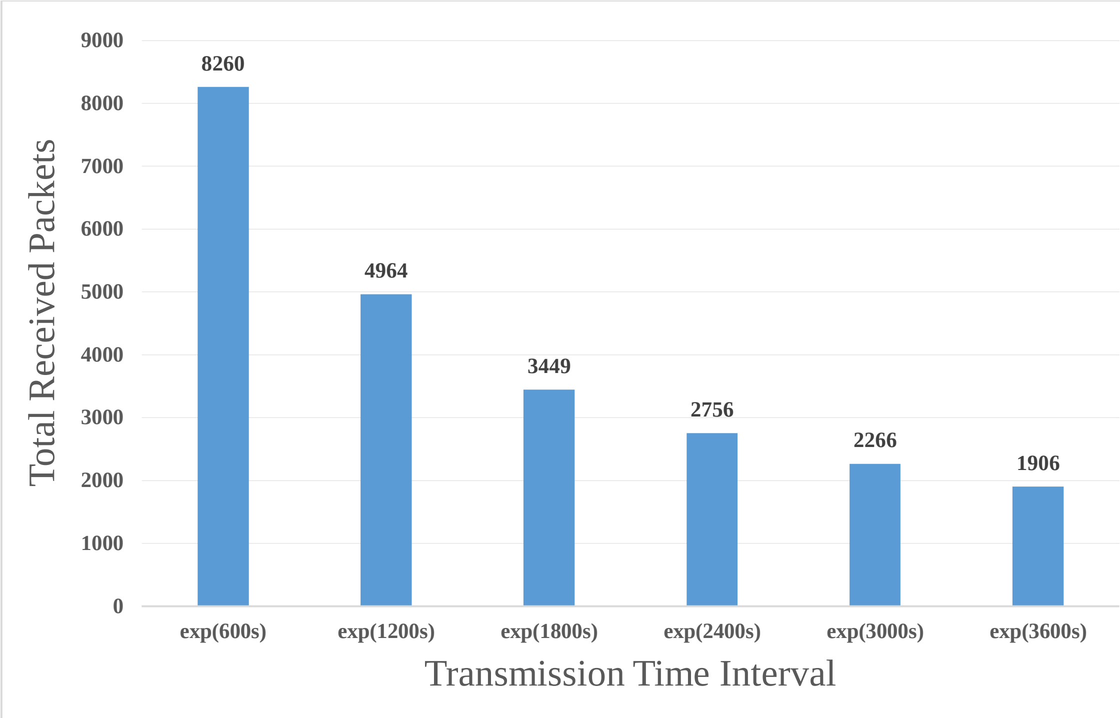

Figure 4.8 The total received packets at the server network vs. transmission time interval, the number of nodes (100), and one LoRa gateway placed at (1750x 1000) m.

This figure used the same transmission time intervals for sensor nodes and the 100 number of sensor nodes. It has been observed with an increase in the transmission time intervals, the total received packets at the network server will decrease from 8260 to 1906.

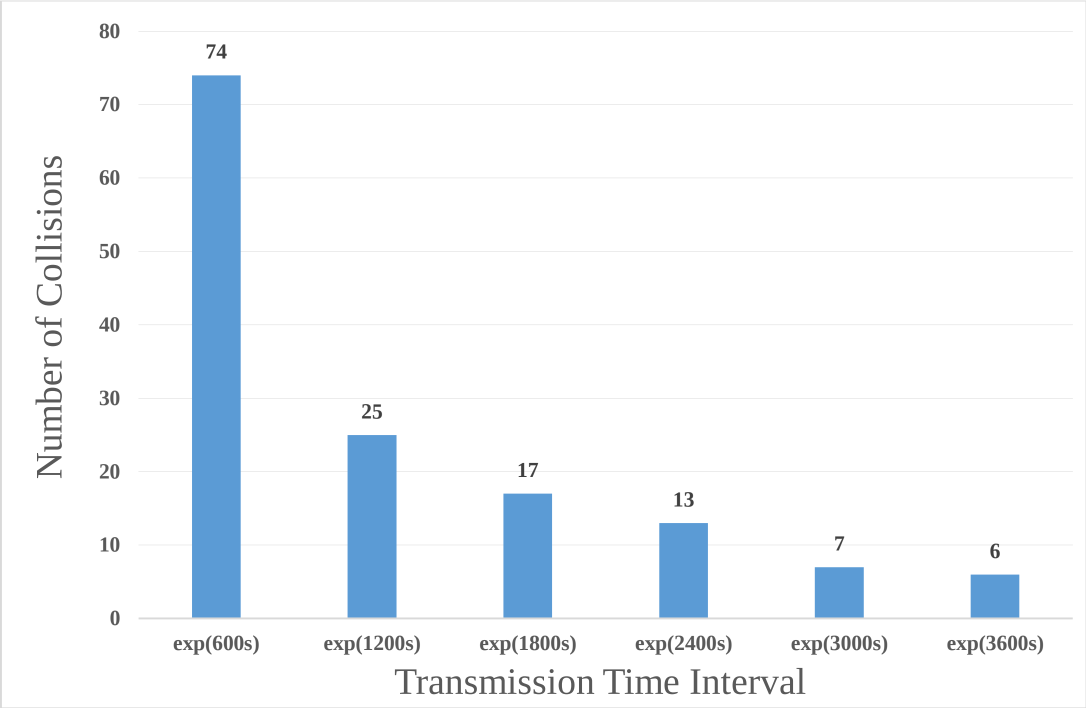

Figure 4.9 The number of collisions at the LoRa gateway vs. transmission time interval, the number of sensor nodes (100), and one LoRa gateway are placed at (1750x 1000) m.

For the same alternating time interval of transmitting packets for the 100 sensor nodes. The number of collisions observed in this figure enhancement in network performance, the number of collisions decreases from 74 to 6 at an increase in the time interval of transmitting packets from exp(600)s to exp(3600)s.

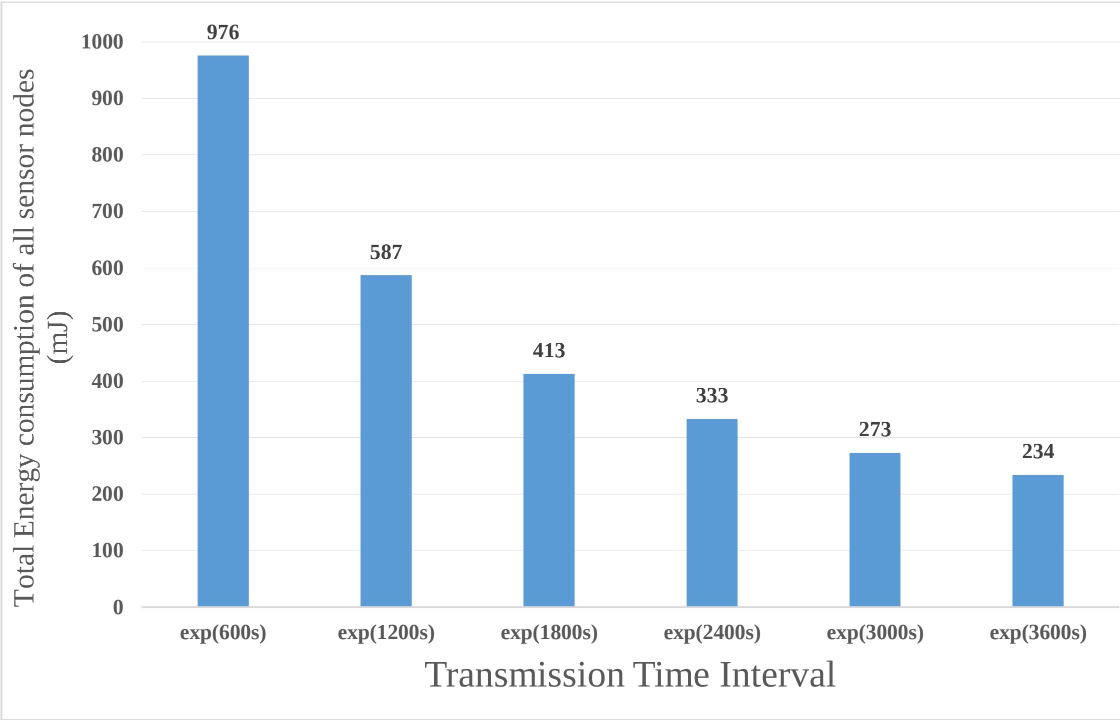

Figure 4.10 The total energy consumption of all sensor nodes vs. transmission time interval. The number of nodes (100), and one LoRa gateway is placed at (1750x 1000) m.

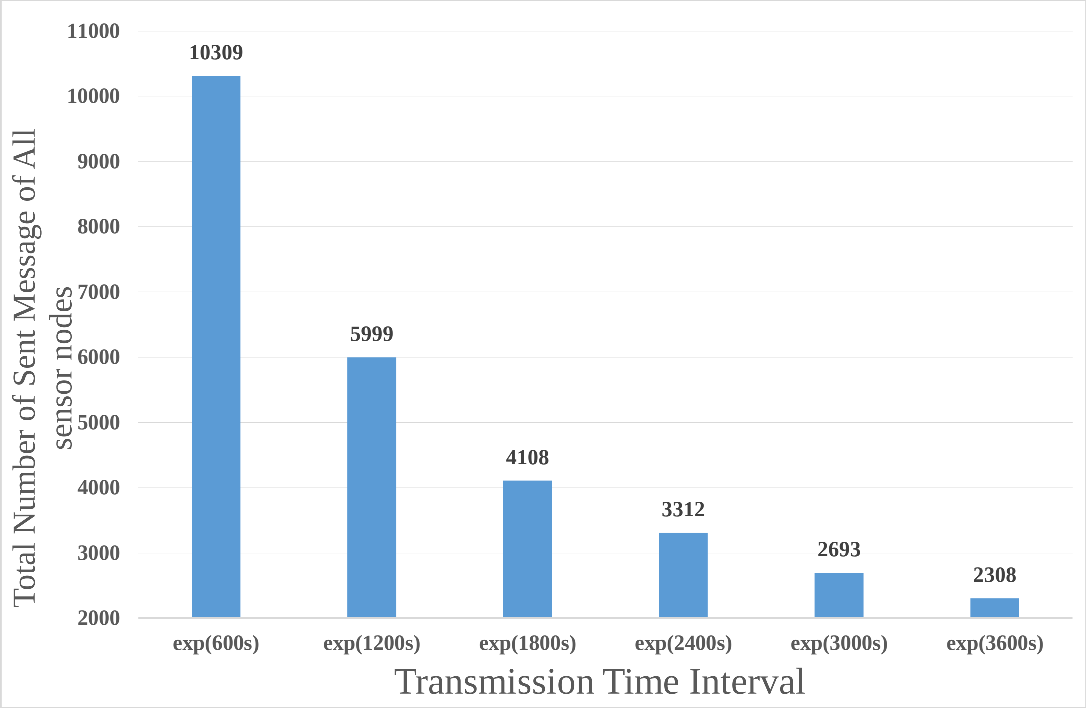

Figure 4.11 The total number of sent message of all sensor nodes vs. transmission time interval, the number of sensor nodes (100), and one LoRa gateway are placed at (1750x 1000) m.

As in the previous figures, the transmission time interval varied exp(600, 1200, 1800, 2400, 3000, 3600) sec. It has been observed with each increase in the transmission time interval, the total number of sent messages of all sensor nodes decreases from 10309 to 2308.

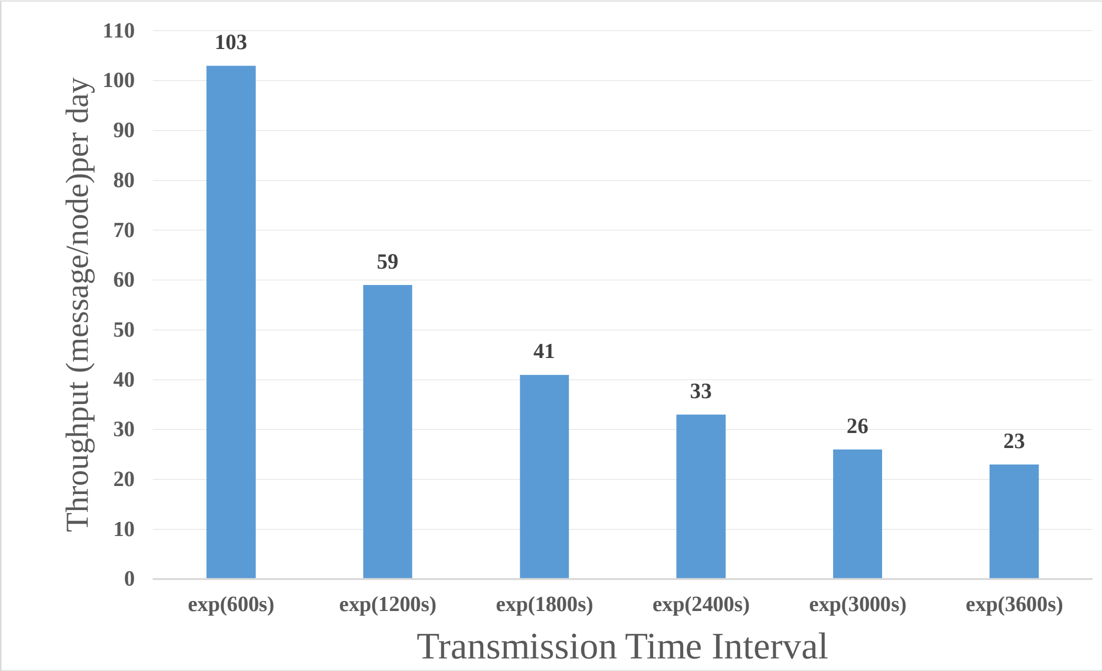

Figure 4.12 The throughput is the total number of sent messages divided by the total of sensor nodes during the day vs. the transmission time interval. The time interval of transmitting packets exp (600s), one LoRa gateway is placed at (1750x 1000) m.

Finally, it must be mentioned the throughput and affected by the transmission time interval varied exp(600, 1200, 1800, 2400, 3000, 3600) sec. It has been observed with each increase in the transmission time interval, the throughput decreased from 103 at exp(600)s to 23 at exp(3600)s.

Chapter Five

Conclusions and Future Work

5.1 Conclusions

In this thesis, a variety of simulation scenarios have been taken into consideration, and the analysis of the experiments was executed through Framework LoRa (FLoRa) in combination with the INET framework, depending on the program OMNET++ simulator to investigate LoRa-WAN performance for 1 days of simulation time.

In the first Scenario: The simulation was offered to analysis the system's behavior in the simulation environment by modeling urban, and suburban regions to simulate electrical distribution transformers in the city of Mosul.

This scenario used 100 sensor nodes, one gateway placed at the center of networks, and multiple coverage areas (1km^2, 25km^2, 100km^2) to make a comparison between code rates 4/5 and 4/8. The simulation results presented the best values when using CR=4/5 in packet delivery ratio 91% at 1km^2 and 34% at 100km^2, average energy consumption at the network server 194mJ at 1km^2 and 518mJ at 100km^2, decrement in the number of collisions from 490 at 1km^2 to 284 at 100km^2.

The networks performance has been tested with different numbers of sensor nodes (25,50,75,100) for different coverage areas (1km^2, 25km^2, 100km^2), the simulation presented the best result at 25 sensor nodes and 1km^2 coverage area in maximum PDR 98%, less Average energy consumption 171mJ, the number of collisions 31.

Then the effect of the transmission time interval of packets on networks performance was tested at {exp(600)s, exp(1200)s,…., exp(3600)s} for different coverage areas (1km^2, 25km^2, 100km^2), using a 4/5 code rate, one gateway, and 100 sensor nodes. The simulation results showed best values at 1km2 coverage area and exp(3600)s transmission time interval of packets, it presented PDR 96%, Average energy consumption 184mJ, and the number of collisions 76.

In the second Scenario: The simulation included administering the sensor nodes through a LoRa gateway based on the cloud to manage the system from any place and access cloud data easily. This simulation employs a (3500x1000) m coverage area, using a 4/5 code rate, and one LoRa gateway placed at (1750x1000) m to simulate a monitoring water level in Mosul Dam and protect low-lying regions from floods.

The network performance has been examined with different numbers of sensor nodes (25,50,75,100), the simulation presented the best result at 25 sensor nodes, it achieved less average energy consumption (101) mJ and the number of collisions at the LoRa gateway (3).

Then the impact of the transmission time interval of packets {exp(600)s, exp(1200)s,…., exp(3600)s}on network performance was tested, using 100 sensor nodes. The simulation results presented the best values when using exp(3600)s transmission time interval of packets, in PDR 84%, The total Energy consumption of all sensor nodes 234mJ, and the number of collisions 6.

In conclusion, all simulation processes proved the possibility of improving networks' performance to reduce the consumed energy by setting the best choice of the LoRa physical layer parameters and choosing the best coverage area and the number of sensor nodes to achieve optimal simulation network performance.

5.2 Future Work

The study that was conducted and addressed in this thesis covers several facets of performance for LoRa-WAN. The performed work can be improved and developed, leaving the possibility for more suggestions and improvements for future research by taking into account the following:

1- Studying and executing the reduction of network energy consumption for LoRa technology and the ability to collect data from the mobile sensor nodes as vehicles and airplanes.

2- The ability of coverage of LoRa gateways prior to deployment, using the right channel model. As signal attenuation is not well captured by popular channel models, intend using Okumura-Hata empirical model.

3- We intend design LoRa-WAN with mobile gateways (GWs) installed on Low Earth Orbit (LEO) satellites to address synchronization issues due to intermittent link availability between the End Devices (EDs) and the GW. And presented a Scheduling Algorithm for LoRa to LEO Satellites (SALSA). SALSA ensures reliable communication, avoiding packet drops and packet collisions, by using a Time Division Multiple Access (TDMA) approach, rather than classic ALOHA-based LoRa.

4- We intend improve the multiple access performance of LoRa satellite, based on the orthogonality of LoRa symbols using the Orthogonal LoRa Multiple Access (OLMA) algorithm for multiple LoRa users occupying the same frequency bandwidth.

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الخلاصـة

تقنية(LoRa طويلة المدى) هي إحدى تقنيات شبكة المنطقة الواسعة منخفضة الطاقة ((LPWAN، والتي تتميز بخصائص الاستهلاك المنخفض للطاقة والتغطية الموسعة والتكلفة المنخفضة والقدرة العالية. تحتاج العديد من التطبيقات إلى تقنية تحقق نقلًا ناجحًا للبيانات بمعدل بيانات منخفض واستهلاك منخفض للطاقة وتكلفة منخفضة. لذلك ، تم استخدام تقنية LoRa لتجنب التكاليف المرتفعة عن طريق إرسال كمية صغيرة من البيانات عبر مسافات طويلة وعلى فترات قصيرة .في هذه الرسالة، تمت دراسة نمذجة LoRa–WAN ومحاكاة تطبيقين مهمين في مدينة الموصل باستخدام تقنية LoRa في برنامج المحاكاة ++ OMNET لمراقبة أداء محولات توزيع الطاقة الكهربائية ومراقبة منسوب المياه في سد الموصل للحصول على أفضل أداء للشبكة.

تم تحليل قابلية التوسع في عمليات المحاكاة من خلال إدارة (100) عقدة أستشعار بواسطة بوابة واحدة، ومناطق تغطية مختلفة (1 كم2، 25 كم2، 100 كم2) و (3500 × 1000) م. أظهرت نتائج الدراسة إمكانية نمذجة ومحاكاة بيئات مختلفة من خلال تحديد قيم المعلمات المناسبة لتقنية LoRa لمعدل الترميز (4/5، 4/8) ، تردد الموجة الحاملة (868 ميجاهرتز) ، عرض النطاق الترددي (125 كيلو هرتز) ، عامل الانتشار (7– 12) ، والقدرة المرسلة (2–14) ديسيبل.

قدمت تقنية LoRa–WAN أداءً جيدًا في سيناريوهات المحاكاة الرئيسية من خلال تحسين أداء الشبكة عبر تقليل استهلاك طاقة الشبكة، وتقليل عدد التصادمات في بوابة LoRa ، وزيادة إجمالي الحزم المستلمة في خادم الشبكة ، وزيادة نسبة تسليم الحزم . يتم تحقيق ذلك عن طريق تقليل عدد عقد الاستشعار إلى 25 عقدة، وزيادة الفاصل الزمني لحزم الإرسال إلى (3600) expثانية، ووضع البوابة في وسط جميع الشبكات.

إقرار المشرف

نشهد بأن هذه الرسالة الموسومة **(تصميم شبكة لورا- وان (LoRa WAN) لخدمات الإنترنت العامة للأشياء في مدينة الموصل)** تم اعدادها من قبل الطالبة **(آمنة عبد المنعم الراوي)** تحت اشرافنا في قسم هندسة الاتصالات / كلية هندسة الالكترونيات / جامعة نينوى، وهي جزء من متطلبات نيل شهادة الماجستير/علوم في اختصاص هندسة الاتصالات.

التوقيع:

الاسم: أ.م.د. علي عثمان الجنابي

التاريخ: / /2022

إقرار المقوم اللغوي

اشهد بأنه قد تمت مراجعة هذه الرسالة من الناحية اللغوية وتصحيح ما ورد فيها من أخطاء لغوية وتعبيرية وبذلك أصبحت الرسالة مؤهلة للمناقشة بقدر تعلق الأمر بسلامة الأسلوب أو صحة التعبير.

التوقيع:

الاسم:

التاريخ: / /2022

إقرار رئيس لجنة الدراسات العليا

بناءً على التوصيات المقدمة من قبل المشرف والمقوم اللغوي أرشح هذه الرسالة للمناقشة.

التوقيع:

الاسم: أ.م.د

التاريخ: / /2022

إقرار رئيس القسم

بناءً على التوصيات المقدمة من قبل المشرف والمقوم اللغوي ورئيس لجنة الدراسات العليا أرشح هذه الرسالة للمناقشة.

التوقيع:

الاسم: أ.م.د

التاريخ: / /2202

إقرار لجنة المناقشة

نشهد بأننا أعضاء لجنة التقويم والمناقشة قد اطلعنا على هذه الرسالة الموسومة **(تصميم شبكة لورا- وان (LoRa WAN) لخدمات الإنترنت العامة للأشياء في مدينة الموصل)** وناقشنا الطالبة **(آمنة عبد المنعم الراوي)** في محتوياتها وفيما له علاقة بها بتاريخ / /2022 وقد وجدناها جديرة بنيل شهادة الماجستير/علوم في اختصاص هندسة الاتصالات.

التوقيع:	**التوقيع:**
رئيس اللجنة: أ.م.د.	**عضو اللجنة:** أ.م.د.
التاريخ: / /2022	**التاريخ:** / /2022
التوقيع:	**التوقيع:**
عضو اللجنة: أ.م.د.	**عضو اللجنة (المشرف):** أ.م.د علي عثمان الجنابي
التاريخ: / /2022	**التاريخ:** / /2022

قرار مجلس الكلية

اجتمع مجلس كلية هندسة الالكترونيات بجلسته المنعقدة بتاريخ: / / 2022

وقرر المجلس منح الطالبة شهادة الماجستير علوم في اختصاص هندسة الاتصالات

مقرر المجلس: د. صدقي بكر ذنون	**رئيس مجلس الكلية:** أ.د. خالد خليل محمد
التاريخ: / / 2022	**التاريخ:** / /2022

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

نَرْفَعُ دَرَجَاتٍ مَنْ نَشَاءُ وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ

صَدَقَ اللَّهُ العَظِيمُ

سورة يوسف

الآية (76)

تصميم شبكة لورا– وان (LoRa WAN) لخدمات الإنترنت العامة للأشياء في مدينة الموصل

رسالة تقدمت بها

آمنة عبد المنعم الراوي

إلى

مجلس كلية هندسة الالكترونيات

جامعة نينوى

كجزء من متطلبات نيل شهادة الماجستير

في

هندسة الاتصالات

بإشراف

أ.م.د. علي عثمان الجنابي

1444 هـ

2022م

جامعة نينوى

كلية هندسة الالكترونيات

قسم هندسة الاتصالات

تصميم شبكة لورا- وان (LoRa WAN) لخدمات الإنترنت العامة للأشياء في مدينة الموصل

آمنة عبد المنعم الراوي

رسالة ماجستير علوم في هندسة الاتصالات

بإشراف

أ.م.د. علي عثمان الجنابي

1444 هـ

2022 م