Faculty of Computer Science and Information Technology

AN EXPERIMENTAL PERFORMANCE EVALUATION OF LORA NETWORK

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Bachelor of Computer Science with Honours

(Software Engineering)

2023

UNIVERSITI MALAYSIA SARAWAK

THESIS STATUS ENDORSEMENT FORM

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ACADEMIC SESSION: 2022/2023

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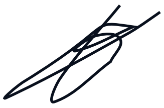

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Acknowledgement

In this project, I would like to express my gratitude toward my supervisor, Dr. Lau Sei Ping who gave me a golden opportunity to involved in this project as my Final Year Project on the topic of an experimental Performance evaluation of LoRa Network. I am sincerely appreciating to Dr. Lau regarding his patience, knowledge, and guidance throughout the project.

Apart of that, I would like to thank the faculty of Computer Science and Information Technology for providing me a location to carry out my Final Year project measurement.

Lastly, I would like to thank my friend who kept helping me, provided me with spiritual support and guidance throughout the journey to complete my Final year Project within the time given.

Abstract

Internet of Things (IoT) is rapidly becoming a part of our life and several company. We are expected to see several IoT device to grow in the future. The verticals within IoT paradigm such as smart cities, smart farming or goods monitoring remand a string requirement to the Radio Access Network (RAN). Recently, LoRaWAn has emerged as a promising technology for IoT, claiming its ability to have a high coverage for transmission data while consume low energy. In this report, the experimental performance (time required to sent certain amount of packet) evaluation of LoRa device over real-life scenario will be carried out. In the end of Final Year Project 1, the idea and method to carry out the experiment have been identified. The significance of this project can assist UNIMAS or any other sector that going to apply IoT able to identify and understand the performance of LoRa device and increase the productivity.

Abstrak

Internet of Things (IoT) semakinpantasmenjadisebahagiandaripadakehidupankita dan beberapasyarikat.Kami dijangkamelihatbeberapaperanti IoT akanberkembang pada masa hadapan.Penegak dalam paradigma IoT seperti bandar pintar, pertanianpintarataupemantauanbaranganmemerlukanrentetankeperluan kepada Rangkaian Akses Radio (RAN).Baru-baru ini, LoRaWAntelahmunculsebagaiteknologi yang menjanjikan untuk IoT, mendakwakeupayaannya untuk mempunyailiputan yang tinggi untuk data penghantaransambilmenggunakantenaga yang rendah.Dalam laporan ini, penilaianprestasipercubaanperanti LoRa berbandingsenariokehidupansebenarakandijalankan.Pada akhirProjekTahun Akhir 1, idea dan kaedah untuk menjalankaneksperimentelahdikenalpasti.Kepentinganprojek ini boleh membantu UNIMAS atau mana-mana sektor lain yang akanmenggunakan IoT dapatmengenalpasti dan memahamiprestasiperanti LoRa dan meningkatkanproduktiviti.

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CHAPTER 1: INTRODUCTION

1.1 An experimental Performance evaluation of LoRa Network

The Internet of Thing (IoT), mainly refer to the network of interconnected things, that is the device such as sensors and actuators, equipped with a telecommunication interface and processing and storage unit. This telecommunication interface should enable seamless integration of potentially any object with the internet and forming a new form of interaction between human and devices.

In general, the communication needs of such scenarios differ from the classic high throughput and low delay requirement that is mainly design of traditional communication system. For example, monitoring of solar panels, smart panel can be installed on the roofs of several buildings to optimize their collective efficiency. As the number of sensors in the IoT system grow, comes the issue on how to transfer data among those devices become extremely complex, and the data transmit needed to be balanced with operating considerations and infrastructure costs. LoRa is one of the technologies proposed to be embedded in those IoT sensor, due to its long-range transmission and low energy consumption. Some experiment had shown that a LoRa devices can transmit data over 15km in an open area, which is suffice for most of the data transferring IoT sensors. However, LoRa device is unable to communicate wirelessly with nearby GW while used indoor, due to obstacle between sensors, which will affect the wireless signal strength and results in package losses and communication errors.

In this research, we will need to investigate the percentage of packages losses in different scenario, be in indoor or outdoor. For urban area, there might be some obstacle between sensors and the frequency might be disrupted by different kind of signal existing in the urban area. Rural area on the other hand, will experience shown that the data transmission range can hit over 15km, we can’t make sure that there is no package loss during the process of transmitting data.

1.2 Research Problem

In this industry revolution era, IoT device plays an important role in connecting human being and sensory device. But, due to the immature yet technologies, a lot of error is found during implementing the IoT device. For example, heat sensor device, which is used in industry to detect the temperature of the machine, confirming in condition, either working normally or overheating. Due to IoT device immatureness, some incorrect or missing data might be sent to the received end and wrong measurement, or decision might be made. Theres a lot of IoT device on the market, we have to identify the benefit and flaws of them, so we can implement them in different type of situations.

1.3 Project aim

The project aim is to evaluate the network coverage of LoRa Device in real deployment scenario and evaluate the energy consumption of LoRa Device under different transmission rates and network coverage, and to determine the reliability and robustness of LoRa device.

1.4 Scope

The scope of this project is focusing on:

LoRa device:

1. LoRa is a proprietary modulation scheme derived from the Chirp Spread Spectrum modulation (CSS).
2. The LoRa device is to improve the sensitivity at the cost of a reduction in the data rate for a given bandwidth.

1.5 Objective

1. To design and develop Arduino for Liligo LoRa32 T3 v1.6.1 board.

2. To evaluate the network coverage of LoRa Device in real deployment scenario

3.To determine the reliability and robustness of LoRa device

1.6 Methodology

LoRa performance will be tested in different scenario, such as urban area, rural area on data transmission distance and data transmission efficiency.

1.6.1 Phase 1: Problem statement and analysis

In this phase, collecting and analysis the problem that is faced by LoRa device user through online. The data is collected through article and some feedback from the user. During observing the article, the performance, and the data of LoRa device efficiency will be recorded.

1.6.2 Phase 2: LoRa design

In this phase, the system design of the application will be developed using data flow diagram, entity relationship diagram. Data flow diagram will include and illustrate the flow of the data transmission from sending end to received end of the LoRa device. The requirements that collected in previous phase will be referred in this phase for parameter purposes.

1.6.3 Phase 3: Implementation and testing of LoRa device.

After the development of the device, the prototype will be implemented and deployed into different scenario for testing purposes. The proposed scenario will be including the data transmission rate of LoRa device in urban area, rural area, and open space. The energy consumption of LoRa device will be recorded in the meantime.

1.6.4 Phase 4: Documentation

For the data recorded from the previous phase, data will be processed and plotted into graphs. Graph such as packet loss for each measurement location, SNR value for each point with spreading factor, PDR evolution with the distance for each DR for each scenario.

1.7 Significant of the Project

The significance of this project is to design and testing a device that is suitable to be deployed into IoT section. The proposed experiment will be able to assist industries or user in choosing which type of data transmission device that is suitable for the sensory device. Through this experiment, user will increase the understanding of the importance of data transmission in IoT sector.

1.8 Expected Outcome

At the end of this project, we are expected to determine and identify on the efficiency of the LoRa device and determine which IoT situation is suitable for LoRa device.

The output of this project will benefit those industry that is transforming into Industry 4.0 direction. Instead of trial and error, management team can decide on the data provided, and choose the suitable data transmission device for their machine. Furthermore, the huge coverage of the data transmission will benefit those control unit such as streetlight, they might just be able to control and adjusted the reading or those devices.

CHAPTER 2: BACKGROUND & LITERATURE REVIEW

This chapter presents the current available article regarding LoRa device and the literature review for this project. In order to carry out the proposed experiment, which to determine the performance of the LoRa device, a research have to be carried out on the existing article and understand the manipulating factor of this experiment (Ana E et al., 2020; Christos B et al., 2022; Nuttakit et al., 2017)

In the end of this chapter, the strength and weakness of LoRa device will be discussed to support the result of the experimental phase of LoRa device.

2.1 Current ecosystem of IoT

The ecosystem for IoT is broad, containing several devices with data rates ranging from a few bps to Mbps. Coverage also variable from a few centimetres to several kilometres. LPWAN is responsible for covering the new application that arise daily. Even though these network must cover different needs, there are common requirement in designing a LPWAN network. The main characteristics of an LPWAN network is:

1. Require minimum energy consumption during operation.
2. Low-cost compared to another device.
3. The network infrastructure is easy to assemble.
4. The transferred information between the node and final user must be safe.

Currently, LoRaWAN is one of the most deployed LPWAN access networks for IoT. Signal propagation is important in IoT as this will affects the network performance in terms of coverage, reliability and data-rate. LoRa is a proprietary modulation scheme derived from the Chirp Spread Spectrum modulation (CSS). The main goal of LoRa is to improve the sensitivity of the device at the cost of reduction in the data rate for a given bandwidth. LoRa is physical layer implementation and does not depend on higher layer implementation. This make LoRa device able to coexist with different network architectures.

2.2 Study of the performance of LoRa device in different scenario

In this section, a study of three reviewed system will be conducted in detail and used as reference purpose for the proposed experiment. The first reviewed is the study of the LoRa signal propagation in forest, urban, and suburban environments by Ana Elise Ferreira, Fernando M. Ortiz, Luis Henrique M. K. Costa, et al. This review will be analysed based on the performance and the reading recorded. The experiment carried out in the forest using short-term static scenario and long-term static scenario is being reviewed.

2.2.1 A study of the LoRa signal propagation in forest, urban, and suburban environments

The study regarding the signal propagation in the forest, urban, and suburban environment is being proposed by Ana Elise Ferreira, Fernando M. Ortiz, Luis Henrique M. K. Costa, et al. The study included 4 kind of scenario which is conducted in the forest, which is short-term static scenario, long-term static scenario, one-mobile node scenario and two-mobile scenario. The metrics used to evaluate the LoRa technology are radio range, RSSI, SNR, PDR, PIR time and mobility. The experiment in forest is carried out using the prototypes as shown below.

Figure 2.1. Pole-mounted nodes

Figure 2.2. Tree-mounted node

Short-term static scenario is to measure the maximum coverage in the forest and trace the behaviour of the signal by analysing the main parameters concerning the distance as shown in Figure 2.1. For each experiment, 200 packets are transmitted and ten run are performed for each distance.

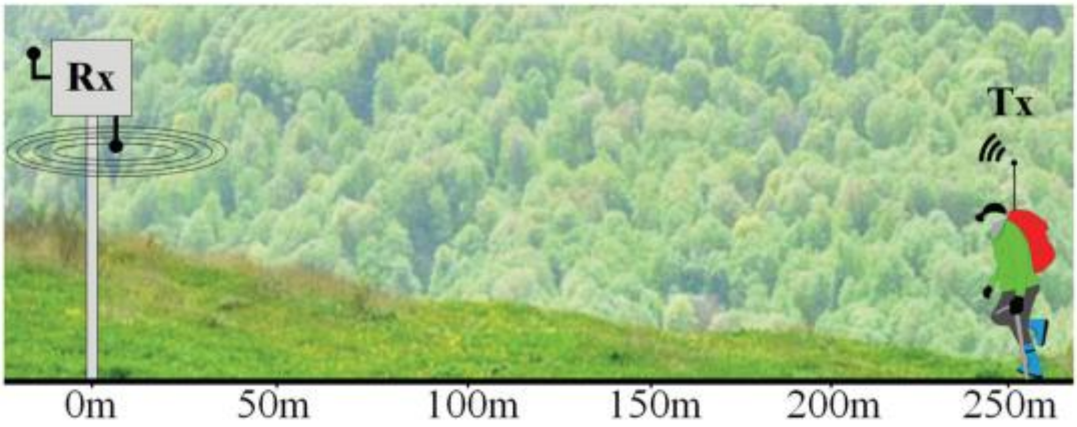

Figure 2.3. short-term static scenario

Long-term static scenario on the other hand Is to analyse the behaviour of the signal over a longer measurement interval and to identify recurring variations and disruptions. The finding indicates that connectivity in the forest environment may behave inconstantly, leading to intermittent connection and opportunistic communication.

2.2.1.1 Result finding

In this section discussed about the finding regarding the 4 methods used in the experiment. RSSI, SNR, PDR and PIR is observed and record.

Short-term static scenario

The scenario is mainly used to identify the range of the LoRa device in the forest. PDR, RSSI and SNR are evaluated as the distance increases.

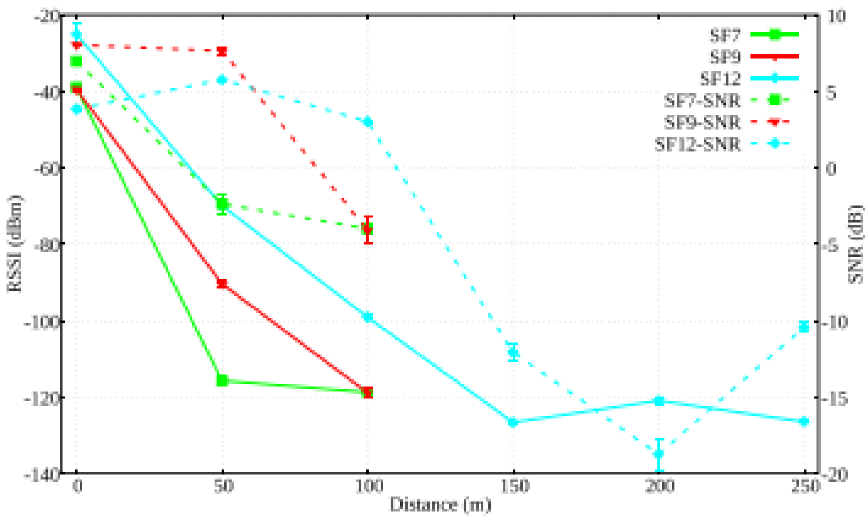

Figure 2.4. RSSI and SNR at the receiver for each distance

The power measurement is obtained from the RSSI information. Due to the degradation of the vegetation, string attenuation is observed.

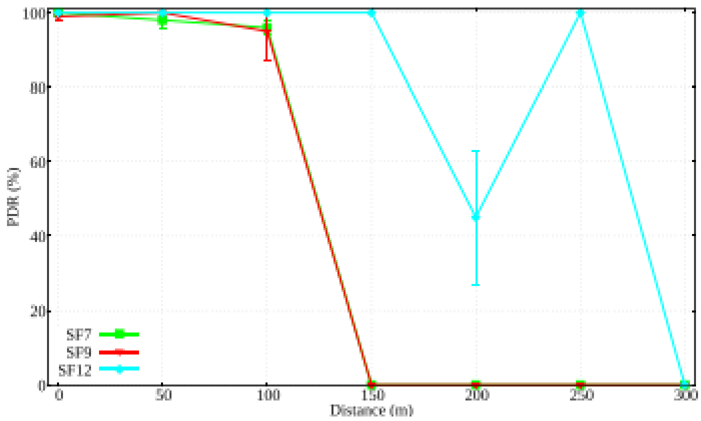

Figure 2.5. PDR measured for each distance.

This figure shows the packet delivery ratio of the link. We can see the link is inversely proportional to the distance, where the packet delivery ratio of the link is decreasing with the distance.

Long term static scenario

This scenario is carried out to evaluate the signal variation for a longer time for the characterization.

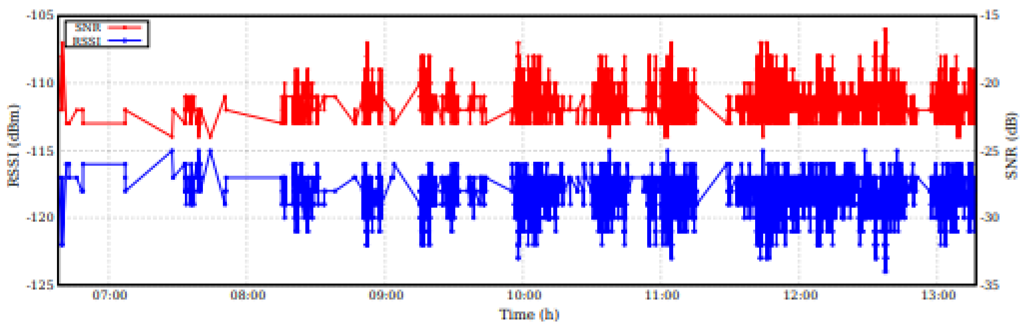

Figure 2.6. SF12 long-term test at 250m

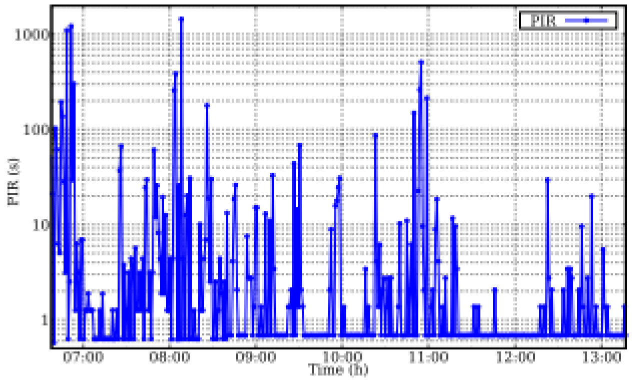

Figure 2.7. PIR time at 250m

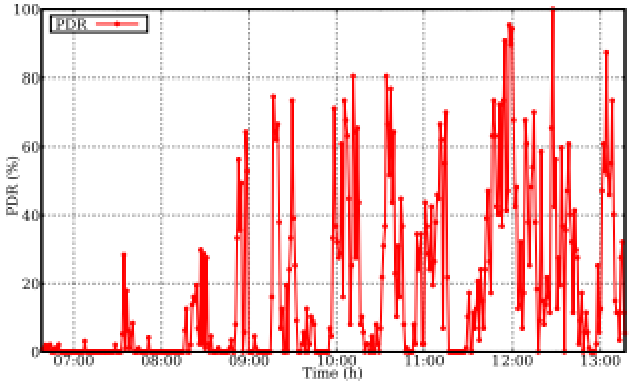

Figure 2.8. PDR measured for each distance.

Using long-term scenario together with short-term one, allows them to study the communication between fixed nodes inserted in the vegetation. These scenarios make it possible to assess the range and performance of the link between fixed points, as well as their temporal variability.

2.2.2 Performance evaluation of monitoring IoT systems using LoRaWan.

This research is a study of LoRaWAN and the performance as well as the application development that can be used as rescue monitor system. For this reason, the study start by describing LoRa as an ideal low power and long-distance communication protocol to IoT devices compared to the Wi-Fi network. Various simulations in term of time on air transmission, bit error rate by changing important metrics is performed to study the behaviour of the whole mechanisms.

2.2.2.1 Architecture

LoRa refers to the protocol an architecture of the general communication, while LoRa refers to the physical layer. LoraWan uses a mechanism to filter multiple copies of the same packets from the available GWs. The equation beneath refers to the mathematical relation of symbol and data rate:

$$R_b = SF * \frac{1}{\left[\frac{2^{SF}}{BW}\right]} bits/s$$

Figure 2.9. relation of symbol and date rate formula

Where SF refers to the used spreading factor and variable BW to the bandwidth in Hz.

The SF value used in the scenario are used to adapt the radio signal speed having in mind the range between the GWs and the end-nodes. BW remains one of the most significant metric of the LoRa study.

Bit Error Rate (BER) or in other term, package loss in comparison to energy per bit to Noise density ratio is being studied in this section. From theoretical point of view the mathematical relation is shown below:

$$E_b/N_0(dB) = SNR(dB) + 10\log\frac{BW}{R_b}(dB)$$

Figure 2.10. Bit Error Rate formula

LoRa utilizes three distinctive BW values, 125kHz, 250kHz and 500kHz. The first use case is usage of 125kHz BW and SF alteration from 7 to 12. The result are shown below:

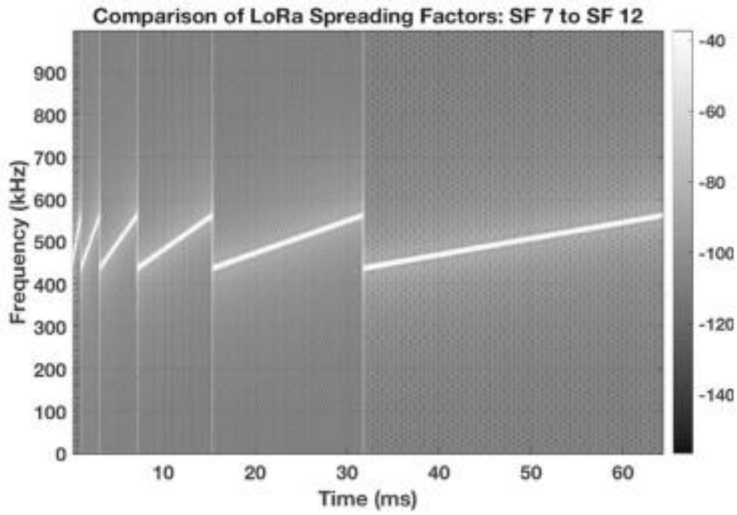

Figure 2.11. SF generation using 125kHz BW.

From the diagram we are able to notice the distinction on over the air transmission time and data rate in case of 125kHz. From figure 2.11, as spreading factor (SF) changes on the testbed 7 to 12, the over tie airtime increases significantly.

By increasing BW from 125kHz to 250kHz and 500kHz, the data rate seems to expand as the bandwidth changes. One the other hand, transmission time is being decrease evetime the bandwidth is increased.

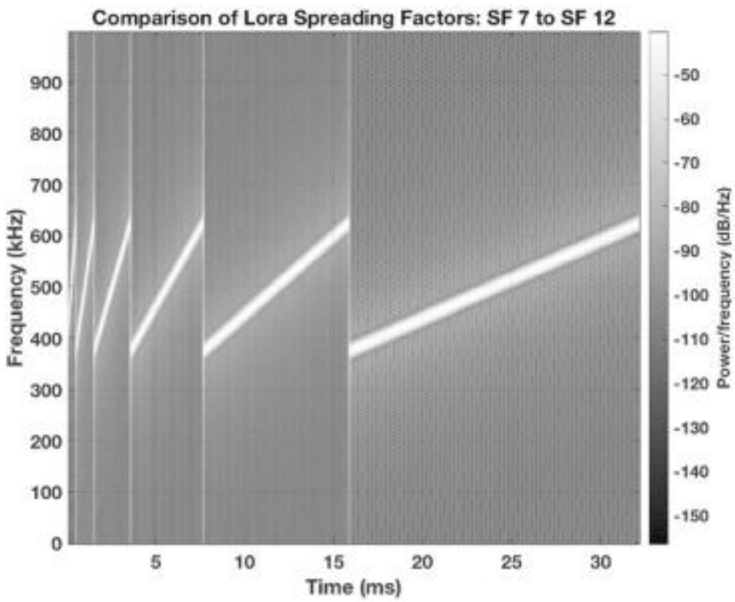

Figure 2.12. SF generation using 250kHz BW

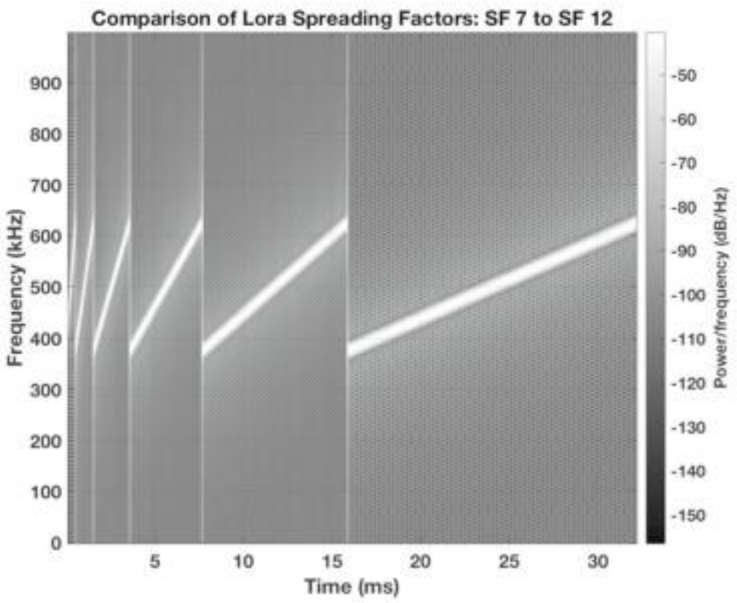

Figure 2.13. SF generation using 500kHz BW.

Local Area Network (LAN) have well established standards such as Wi-Fi, Bluetooth, Zigbee and Z-Wave. But in term of IoT application, the biggest obstacle being the energy consumption as well as the transmission coverage. In this study, it proves that LoRa and Wi-Fi technology were studied as network candidates for IoT monitor application. LoRaWAN is perfect for long-range utilizing in low energy consumption yet additional bandwidth communication.

2.2.3 Experimental Performance Evaluation of LoRaWAN: A Case Study in Bangkok

This section discusses about the case study made in Bangkok regarding performance evaluation of LoRaWAN to explore the limit of communication ranges in both outdoor and indoor environment.

Performance Evaluation

The study focuses on the performance evaluation in both indoor and outdoor environment where the experiment is composed of one end-device, one gateway and one servicer with MQTT protocol. The end device is composed of Arduino connected to Libelium LoRa module via the UART interface which periodically send command to LoRa module.

Time on air

Time on air, on the other word is packet transmission time. Each of the packet or data is transmitted with a specific spreading factor (SF) with a formula $SF = \log_2(Rc/Rs)$ where Rc is the ship rate and Rs, the symbol rate.

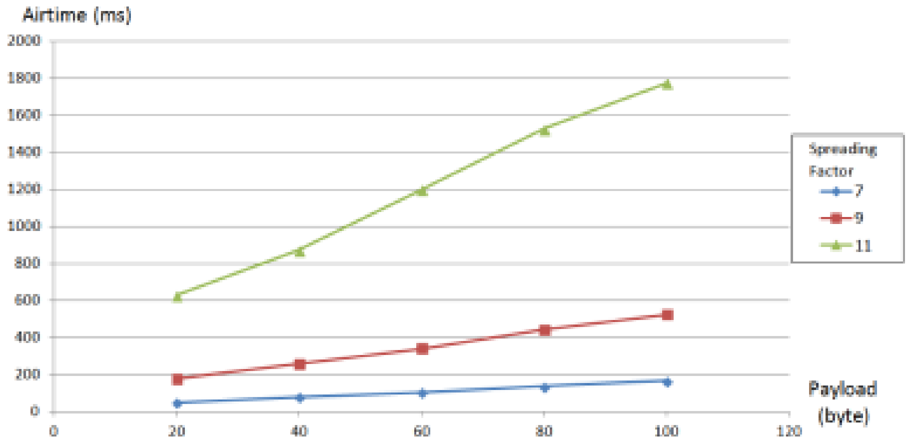

Figure 2.14. Time on air with coding rate 4/5 over a 125kHz bandwidth

Figure above shows the time on air with bandwidth channel of 125kHz. However, with larger spreading factor also increase the time on air.

SNR (Signal to Noise ratio) and Packet Loss

This scenario is taken outdoor with the clear line of sight between the receiver and transmitter. 60 packet per second is send using the transmitter and the SNR value for each point is measured. The experiment is repeated with increasing in the distance between both points, with initially 0.5km and increase 0.5km per experiment, ending up to 2km. Unfortunately, the gateway cannot receive all packet from end device at the distance more than 2km.

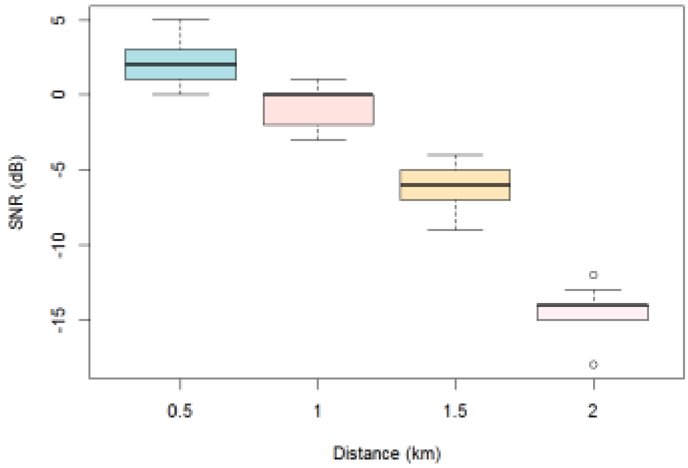

Figure 2.15. SNR value at different distance with spreading factor 11 and 125kHz BW

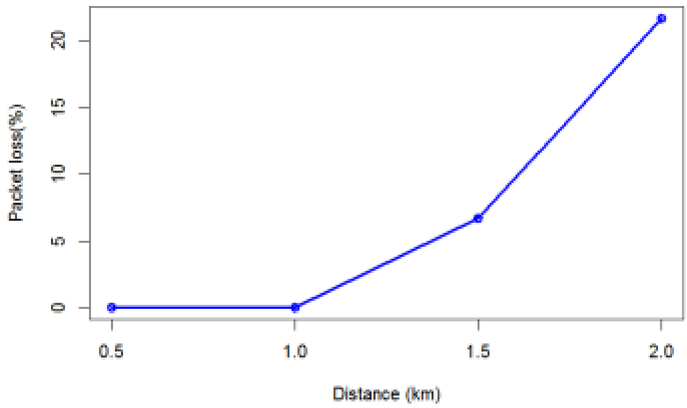

Figure 2.16. Packet loss for each measurement location

After experiment for outdoor, the experiment is relocated into indoor measurement spot, where the measurement spot is 55m, 95m, 120m and 150m. The result is recorded and are shown below. The gateway can only receive packet at only 2 locations at 55m and 120m with packet loss of 56% and 94% respectively.

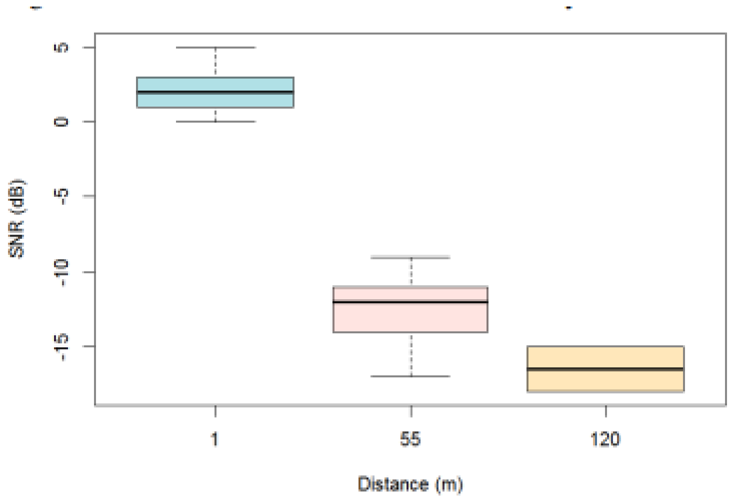

Figure 2.17. SNR values for each point with spreading factor 11 and 125kHz

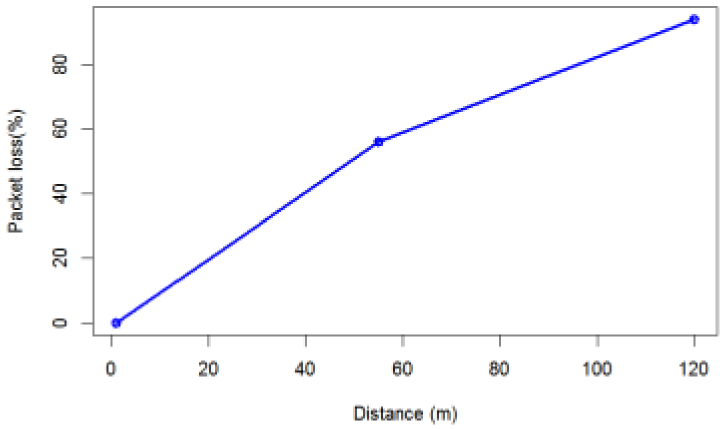

Figure 2.18. Packet loss for each measurement location

For specification of LoRaWAN, it features long range communication that is said to be 2-5km in urban and 15km in rural area. Unfortunately, in this study, the reading shows that the range are only up to 2km in outdoor rural area and 55-100 meter in indoor urban environment. The factor affecting the reading might be the properties of antennas such as antenna gain, direction and antenna hights.

2.3 Direction of proposed experiment

Based on the study reviewed previously, there are several drawbacks existing in the system. The first reviewed article shows thatstudy of the LoRa signal propagation in forest, urban, and suburban environments with 4 scenario, short-term static scenario, long-term static scenario, one-mobile node scenario and two-mobile node scenario. The study covers the performance in term of Received signal strength indication (RSSI), Signal-to-noise ratio (SNR), Passive Infra-Red (PIR) and Packet Delivery Ratio (PDR). Conversely, the study did not include the package loss rate due to any outside disturbance, such as wind, obstacle, and even other type of signal waves. Also, the study did not include the consistency of the LoRa device, which mean how long the LoRa device able to transmit data while on battery.

The second study however, Performance evaluation of monitoring IoT systems using LoRaWan. In this study, the research includes the formula for calculating the relation of symbol and data rate, as well as the formula for Bit Error Rate. However, the study did not actually include the usage of the LoRa device in all kinds of scenario, only mentioned it is suitable for application on the rescue monitor system. There is no case study regarding the device being used in different kind of area, such as open area, rural area, urban area, and even forest.

Lastly on the third study, the experiment only covers the experiment over scenario, which is outdoor rural area and indoor urban area. Factor such as power consumption is not recorded in the experiment. Making it unable to determine the statement of low energy consumption of LoRa device.

In the proposed experiment, the experimental Performance evaluation of LoRa Network is to evaluate the network coverage of LoRa device in real-life deployment scenario, to evaluate the energy consumption of LoRa device under different transmission rates and network coverage, and lastly determine the reliability and robustness of LoRa device. This study will allow any field that is implementing IoT device to take into consideration of the choices available on the market, for example, Wi-Fi, Bluetooth 4.0. Zigbee and Z-Wave and LoRaWAN.

CHAPTER 3: METHODOLOGY

In the previous chapter, three existing study regarding LoRa device had been reviewed. Those studies are a study of the LoRa signal propagation in forest, urban, and suburban environments, performance evaluation of monitoring IoT systems using LoRaWan, and experimental Performance Evaluation of LoRaWAN: A Case Study in Bangkok. After reviewed, the

This chapter will present the methodology about the researching on the experimental Performance evaluation of LoRa Network. The significance of the chapter is to elicit the performance of the LoRa device in different real-life scenario.

3.1 Equipment and Configuration

This proposed experiment will be emphasis on the evaluation of network coverage of LoRa device in real deployment scenario, as well as the energy consumption of LoRa device under different transmission rate and network coverage. While the back end of the LoRa device will be coded using Arduino. The gateway which will be UNIMAS Server will be connected to SX1278 LoRa module, via UART interface, and forward packet through the standard IPv4/TCP stack via Wi-Fi. The receiving end device which will be composed using Arduino also connected to another SX1278 LoRa module via UART interface which will sends command to the LoRa module.

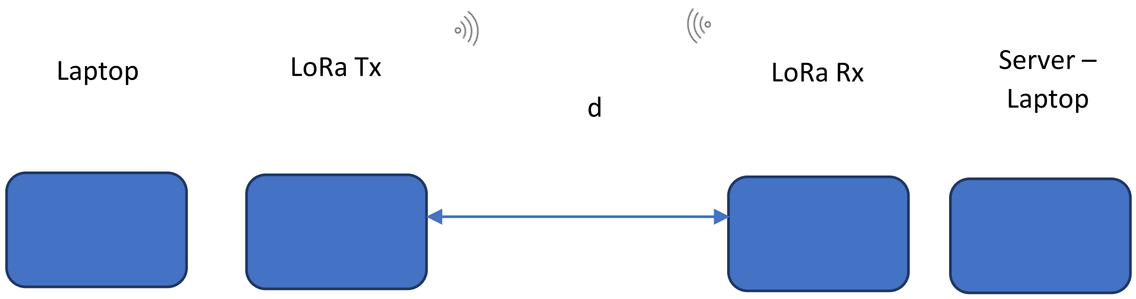

Figure 3.1. Equipment physical configuration

Parameter	Value/Description
Transmitter	SX1276
Receiver	SX1276
Modulation	LoRa

Bandwidth	125khz
Code Rate	5
Spreading Factor	7

Table 3.1. Equipment and Parameters of Transmission

3.2 Environment and Measurement Procedure

In this proposed experiment, most of the test will be carried out in the UNIMAS campus. The surrounding will be adjusted to resemble the requirement of the scenario. The 3 experimental scenario is defined as such:

3.2.1 Rural Area Line of Sight

The objective of this scenario is to measure the maximum communication range, coverage of the LoRa device behaving in rural area. The behaviour of the signal will be traced and analyse. The scenario is illustrated in figure 3.2.

Figure 3.2. Rural area line of sight

The transmitter will be placed at the UNIMAS stadium (mark as yellow) and the receiver along the road (marked as red). The distance between transmitter and receiver will initially be 500m approximately and will be increasing with another 500m up to 1500m. The experiment will be carrying out using by sending 100 packets using a delay function in Arduino coding. The delay will then be increase by 50 after the first 100 package been sent.

3.2.2 Urban Outdoor

In this scenario, it is to identify the behaviour of the signal over several obstacle, either physical obstacle or waves from surrounding. The aim is to identify the transmission rate of LoRa device under variation of disruption. The scenario is being illustrated on figure 3.3

Figure 3.3. Urban outdoor

For the scenario will include 2 distanced variables, which is 200m and 300m respectively. The transmitter (marked or yellow) will be placed at the floor at centre of the urban area and the receiver (marked as red). The scenario will be carried out by sending 100 packets of data to the receiver end by using a delay function in Arduino coding. The delay will then be increase by 50 after the first 100 package been sent.

3.2.3 Urban Indoor to Outdoor

This scenario is to determine the reliability and robustness of LoRa device under real-life application scenario. The illustration of the scenario is illustrated in figure 3.4.

Figure 3.4. Urban indoor to outdoor and vice versa

In this scenario, the transmitter (marked as yellow) will be placed on the highest floor of the FIT building, as the receiver (marked as red) at the car park at sea level. The estimated distance between the transmitter and the receiver will be approximately 50m with using a delay function in Arduino coding. The delay will then be increase by 50 after the first 100 package been sent. The scenario will be repeated by changing the location of the receiver, which is approximately 100m, 150, and 200m respectively.

3.3 Statistical analysis and fitting

The reading for all the scenarios will be recorded and processed into a graphical display. The rate of transmission will be calculated using the formular:

$$R_b = SF * \frac{\left[\frac{4}{4+CR}\right]}{\left[\frac{2^{SF}}{BW}\right]} * 1000$$

Equation 3.1: Rate of transmission.

SF = Spreading Factor (7)

CR = Code Rate (5)

BW = Bandwidth in kHz (125kHz)

Rb = Data rate or Bit Rate in bps

The rate of error / package loss will be calculate using the formular:

Package loss = 1 – package receive/ package sent

3.4 Summary

In this chapter, will be covering the planning of evaluation of LoRa board in different scenario. All of the scenarios will be carried out using different packet / second, to determine the effect of the rate of packet in performance of LoRa network. The result will be recorded and analyse. The result of the evaluation will be display in graphical for easier understanding.

CHAPTER 4 IMPLEMENTATION

In the previous chapter discussed about the planning of the experimental evaluation of the LoRa network. Based on the methodology, implementation phase will be confirming the variables stated in methodology phase and the actual Arduino code that is upload and used throughout the scenario.

Moreover, the detail of the LoRa module used throughout the scenario will be briefly explain in this chapter.

4.1 Lilygo LoRa32 T3 v1.6.1

The LoRa device used throughout the experimental evaluation will be the Liligo LoRa32 T3 v1.6.1. The device is an ESP32 based microcontroller board with a built-In SX1276 LoRa chip and a 0.96-inch OLED display. The board can be programmed through the USB to serial converter and can be used as an Arduino. The board also have a micro-USB connector for programming and power supply purposes. The specification of the LoRa board is stated in table 4.1.

Figure 4.1: Lilygo LoRa32 T3 v1.6.1

Chip	ESP32 (240Mhz dual core processor)
Flash memory	4MB
Wi-Fi	Built-in Wi-Fi
Bluetooth	Built-in Bluetooth
LoRa Chip	SX1276
USB to serial converter	CP2102 or CH9102F (drivers)
Built-in Li-on battery charging circuit	TP4054 chip can charge up to 500mA
Battery converter	2p Molex Picoblade

Table 4.1: Specification of Liligo LoRa32 board

4.2 Arduino coding

4.2.1 Determine the limit of the module.

As the performance evaluation is being determine by the packet / second sending to the receiving end, the following Arduino code is used to determine the lowest delay possible for the said LoRa module. The minimum millisecond gets from sending 100 packet is 0.046ms. Thus, the initial value of the scenario will be starting with 0.05ms or delay (50), with increasing 0.05ms for the sequential scenario up to 0.15ms or delay (150).

```
voidloop() {
  floatstart_time;
  floatduration;
  start_time = millis();
  for (inti = 0; i<100; i++){
    Serial.print("Sending packet: ");
  Serial.println(counter);

  //Send LoRa packet to receiver
  LoRa.beginPacket();
  LoRa.print("hello ");
  LoRa.print(counter);
  LoRa.endPacket();

  display.clearDisplay();
  display.setCursor(0,0);
  display.println("LORA SENDER");
  display.setCursor(0,20);
  display.setTextSize(1);
  display.print("LoRa packet sent.");
  display.setCursor(0,30);
  display.print("Counter:");
  display.setCursor(50,30);
  display.print(counter);
  display.display();

  counter++;

  duration = millis() - start_time;
  }

}
```

Figure 4.2: Code used for determining the minimum delay

4.2.2 LoRa sender

After the minimum packet per millisecond is determine using the previous coding, the actual coding for LoRa sender is being upload into the board. The Arduino coding is being include below.

```
#include<SPI.h>
#include<LoRa.h>

//Libraries for OLED Display
#include<Wire.h>
#include<Adafruit_GFX.h>
#include<Adafruit_SSD1306.h>


#defineSCK5
#defineMISO19
#defineMOSI27
#defineSS18
#defineRST14
#defineDIO026

#defineBAND433E6


#defineOLED_SDA4
#defineOLED_SCL15
#defineOLED_RST16
#defineSCREEN_WIDTH128
#defineSCREEN_HEIGHT64

int counter = 0;

Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RST);

voidsetup() {

  //reset OLED display via software
  pinMode(OLED_RST, OUTPUT);
  digitalWrite(OLED_RST, LOW);
  delay(20);
  digitalWrite(OLED_RST, HIGH);

  //initialize OLED
  Wire.begin(OLED_SDA, OLED_SCL);
  if(!display.begin(SSD1306_SWITCHCAPVCC, 0x3c, false, false)) {
    Serial.println(F("SSD1306 allocation failed"));
    for(;;);
```

```
  }

  display.clearDisplay();
  display.setTextColor(WHITE);
  display.setTextSize(1);
  display.setCursor(0,0);
  display.print("LORA SENDER ");
  display.display();

  //initialize Serial Monitor
  Serial.begin(115200);

  Serial.println("LoRa Sender Test");

  //SPI LoRa pins
  SPI.begin(SCK, MISO, MOSI, SS);
  //setup LoRa transceiver module
  LoRa.setPins(SS, RST, DIO0);

  if(!LoRa.begin(BAND)) {
    Serial.println("Starting LoRa failed!");
    while (1);
  }
  Serial.println("LoRa Initializing OK!");
  display.setCursor(0,10);
  display.print("LoRa Initializing OK!");
  display.display();
  delay(2000);
}

voidloop() {
  for (inti = 0; i<100; i++){
  Serial.print("Sending packet: ");
  Serial.println(counter);

  //Send LoRa packet to receiver
  LoRa.beginPacket();
  LoRa.print("hello ");
  LoRa.print(counter);
  LoRa.endPacket();

  display.clearDisplay();
  display.setCursor(0,0);
  display.println("LORA SENDER");
  display.setCursor(0,20);
  display.setTextSize(1);
  display.print("LoRa packet sent.");
  display.setCursor(0,30);
```

```
  display.print("Counter:");
  display.setCursor(50,30);
  display.print(counter);
  display.display();

  counter++;
  }


  delay(50);

}
```

Figure 4.3: Arduino code for LoRa Sender.

The code used to initiate the display of the LoRa board is included in setup(). The ESP32 sketch initializes the LCD display.

```
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire, OLED_RST);
```

Figure 4.4: Arduino code for initializing LCD display.

There are two functions used to reset the display. The sketch sends a low signal to reset pin and an high value to reset it.

```
  pinMode(OLED_RST, OUTPUT);
  digitalWrite(OLED_RST, LOW);
  delay(20);
  digitalWrite(OLED_RST, HIGH);
```

Figure 4.5: Arduino code for resetting display

After this, the code will be initializing the LoRa module SX1276. As the module is using SPI protocol, thus we need to define the following PINS as shown in figure 4.6.

```
#defineSCK5
#defineMISO19
#defineMOSI27
#defineSS18
#defineRST14
#defineDIO026

#defineBAND433E6
```

Figure 4.6: Arduino code for initializing LoRa module.

After that, the code shown in figure 4.7 will be initiating the sending process of the LoRa board. 100 packets will be sent to the receiver. Each packet will be sent every 0.05 seconds, and the sent packet will be recorded in the counter.

```
for (inti = 0; i<100; i++){
Serial.print("Sending packet: ");
Serial.println(counter);

//Send LoRa packet to receiver
LoRa.beginPacket();
LoRa.print("hello ");
LoRa.print(counter);
LoRa.endPacket();

display.clearDisplay();
display.setCursor(0,0);
display.println("LORA SENDER");
display.setCursor(0,20);
display.setTextSize(1);
display.print("LoRa packet sent.");
display.setCursor(0,30);
display.print("Counter:");
display.setCursor(50,30);
display.print(counter);
display.display();

counter++;
}


delay(50);
```

Figure 4.7: Arduino code for sending packet.

4.2.3 LoRa Receiver

On this subtopic, Arduino code for LoRa receiver will be included and explain. The complete code for LoRa receiver is included in figure 4.8.

```
#include<Arduino.h>


#include<SPI.h>
#include<LoRa.h>

// display include
#include<Wire.h>
#include<Adafruit_GFX.h>
#include<Adafruit_SSD1306.h>

// Define OLED PIN
#defineOLED_SDA4
#defineOLED_SCL15
#defineOLED_RST16

// LoRa pins
#defineLORA_MISO19
#defineLORA_CS18
#defineLORA_MOSI27
#defineLORA_SCK5
#defineLORA_RST14
#defineLORA_IRQ26


#defineLORA_BAND433E3


int counter = 0;

String data;

Adafruit_SSD1306 display(128, 32, &Wire, OLED_RST);

voidresetDisplay() {
 digitalWrite(OLED_RST, LOW);
 delay(25);
 digitalWrite(OLED_RST, HIGH);
}

voidinitializeDisplay() {
 Serial.println("Initializing display...");

  Wire.begin(OLED_SDA, OLED_SCL);
```

```
 if(!display.begin(SSD1306_SWITCHCAPVCC, 0x3c)) {
  Serial.println("Failed to initialize the dispaly");
  for(;;);
 }
 Serial.println("Display initialized");
 display.clearDisplay();

 display.setTextColor(WHITE);
 display.setTextSize(1);
 display.setCursor(0,0);
 display.println("Welcome to LORA");

 display.setTextSize(1);
 display.println("Lora receiver");
 display.display();
}
voidonReceive(intpacketSize) {
 Serial.println("Packet received");

 if (packetSize) {
  while (LoRa.available()) {
   data = LoRa.readString();
   Serial.println("Data:" + data);
  }
 }
 display.setCursor(0,20);
 display.println(data);
 display.display();
}

voidinitLoRa() {
 Serial.println("Initializing LoRa....");
 SPI.begin(LORA_SCK, LORA_MISO, LORA_MOSI, LORA_CS);
 LoRa.setPins(LORA_CS, LORA_RST, LORA_IRQ);

 int result = LoRa.begin(LORA_BAND);
 if (result != 1) {
  display.setCursor(0,10);
  display.println("Failed to start LoRa network!");
  for(;;);
 }
 Serial.println("LoRa initialized");
 display.setCursor(0,15);
 display.println("LoRa network OK!");
 display.display();
 delay(2000);
}
```

```
voidsetup() {
 Serial.begin(9600);
 Serial.println("Setup LoRa Sender....");
 resetDisplay();
 initializeDisplay();
 initLoRa();
}

voidloop() {

 //try to parse packet
 intpacketSize = LoRa.parsePacket();
 if (packetSize) {
  //received a packet
  Serial.print("Received packet ");

  //read packet
  while (LoRa.available()) {
   data = LoRa.readString();
   Serial.print(data);
  }

  display.clearDisplay();
  display.setCursor(0,2);
  display.println(data);
  display.display();
 }
}
```

Figure 4.8: Arduino code for LoRa Receiver

The method used in this LoRa evaluation will be callback function.

```
voidonReceive(intpacketSize) {
 Serial.println("Packet received");

 if (packetSize) {
  while (LoRa.available()) {
   data = LoRa.readString();
   Serial.println("Data:" + data);
  }
 }
```

Figure 4.9: Arduino Code for callback function

In figure 4.9, the sketch will check if the packet size is greater than zero, if yes, the board will read the data packet using LoRa.ReadString();

CHAPTER 5: RESULT AND ANALYSIS

Chapter 5 discuss and shows the measurement result of LoRa transmission on different rate of transmission in different situations. Firstly, numeric result will be shown for 3 scenarios, and then the graph of relation and finally the analysis.

5.1 Previous measurements

To find the best number of packets receive at every scenario, the whole process is being repeated for 10 time, and the average of the reading is calculated to reduce the random error.

5.1.1 Result finding

In this section, will include the graph of relation for all of the scenario mentioned above, rural line of sight, urban outdoor. Urban indoor to outdoor.

a. Rural line of sight

In this rural line of sight environment, the impact of noise and obstacle to the packet loss of the LoRa device. Figure 5.1 shows the packet delivery rate over distance. It is noticeable that the delay in sending packet had a minimum effect on the packet delivery rate. The packet loss is mainly due to signal attenuation, which the radio signals weaken due the increasing in distance between LoRa transmitter and receiver. Attenuation can occur as signals travels through air and encounter various obstacle, such as buildings, trees and even terrain. The weaker signal may result in some packet being loss or corrupted during the transmission.

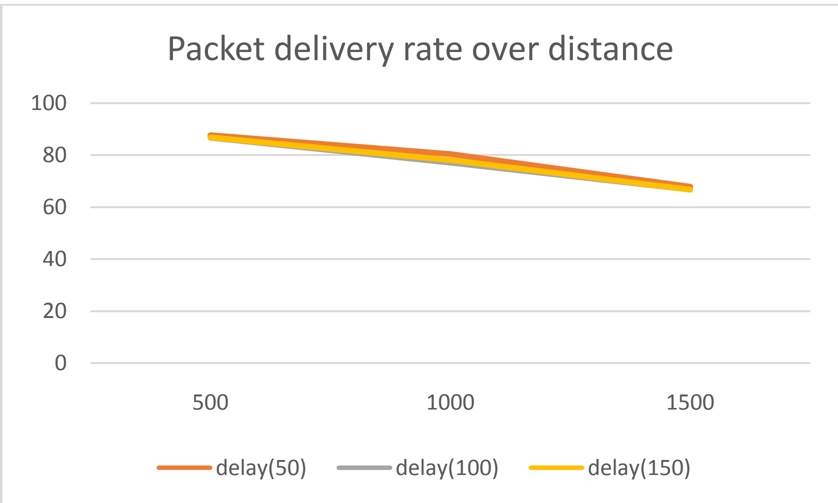

Figure 5.1: Paccket delivery rate over delay

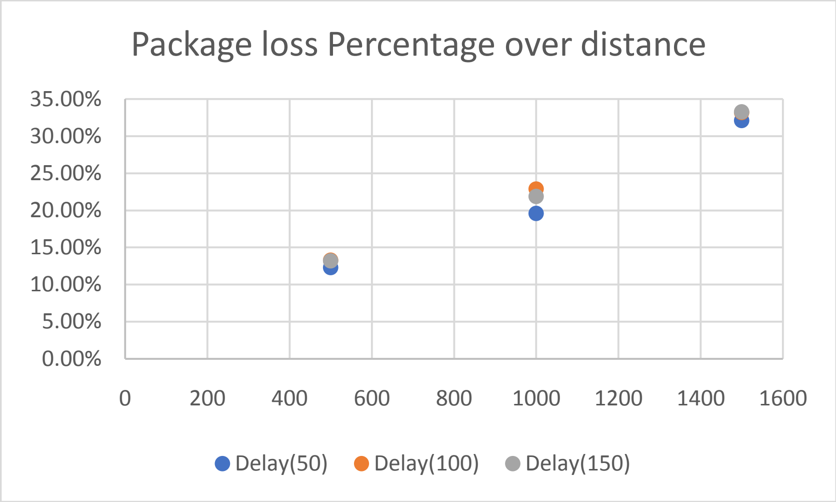

Figure 5.2: Package Loss Percentage over distance

b. Urban outdoor

In this environment, the packet is being sent through a crowded area, in this case, a residential area, where a lot of signal interference such as Wi-Fi signal, Bluetooth signal, etc. From the graph, it is noticeable that the packet loss percentage spiked up a lot when the distance is being changed from 200m to 300m. This might be due to the interference between the transmitter and receiver. As the distance increase, the chance off encountering interference from another device or environmental factor also rise. Interference can come from other device operating in the same frequency, Wi-Fi networks, Bluetooth device, and even other radio frequency (RF) source. These sources can interfere and disrupt the received signal, causing packet loss.

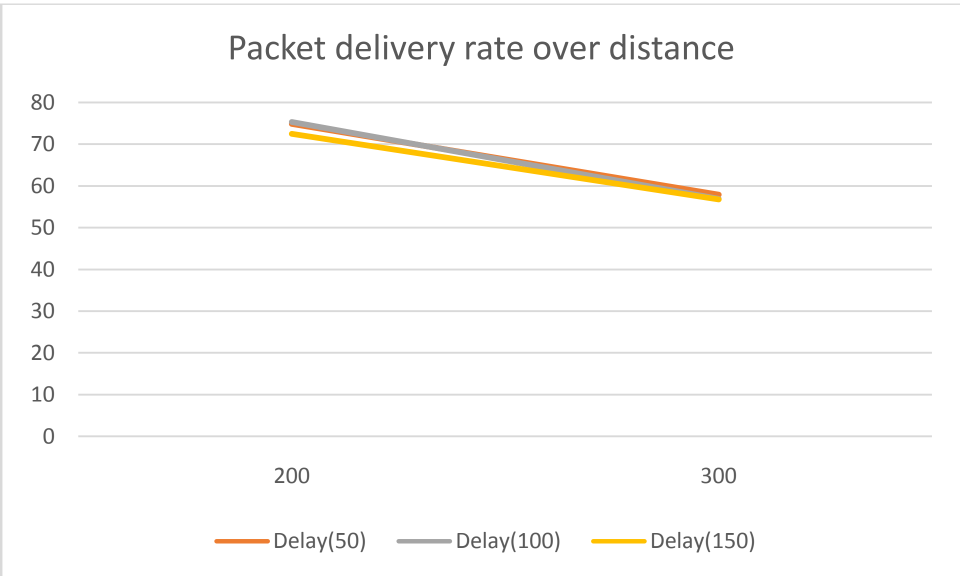

Figure 5.3: Packet delivery rate over distance

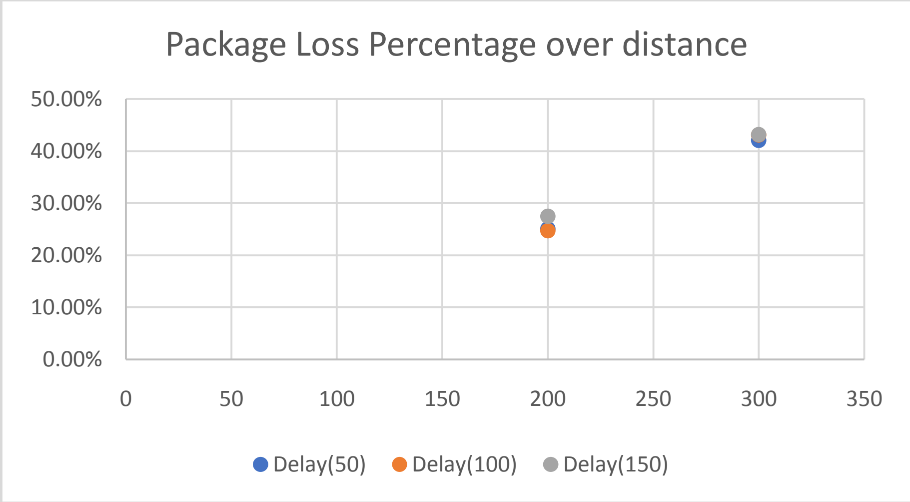

Figure 5.4: Package Loss Percentage over distance

c. Urban Indoor to Outdoor

In this scenario, the packet is being sent through a crowded area too, but with levitation between transmitter and receiver. From figure 5.5 and 5.6, it is noticeable that there is very less package being loss due in this transmission. As this scenario take places in Faculty of Computer Science & Information Technology, UNIMAS, there are a lot of atmospheric conditions or electromagnetic interference that might interfere with the received signal. As the distance increases, the signal strength diminishes, which the noise level remains relatively constant. This leads to a lower SNR, making it more difficult for the receiver to distinguish the transmitted signal from the noise, resulting in package loss.

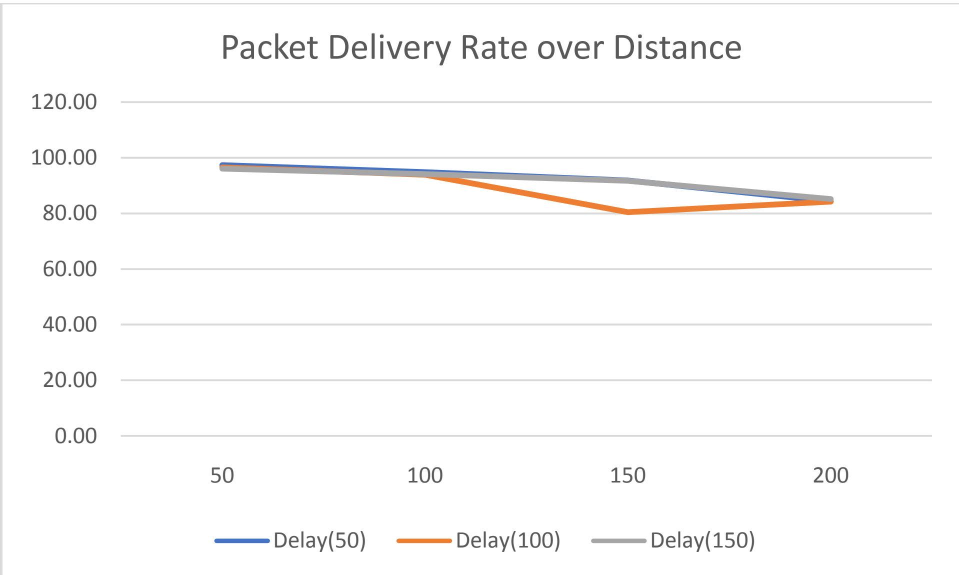

Figure 5.5: Packet Delivery Rate over Distance

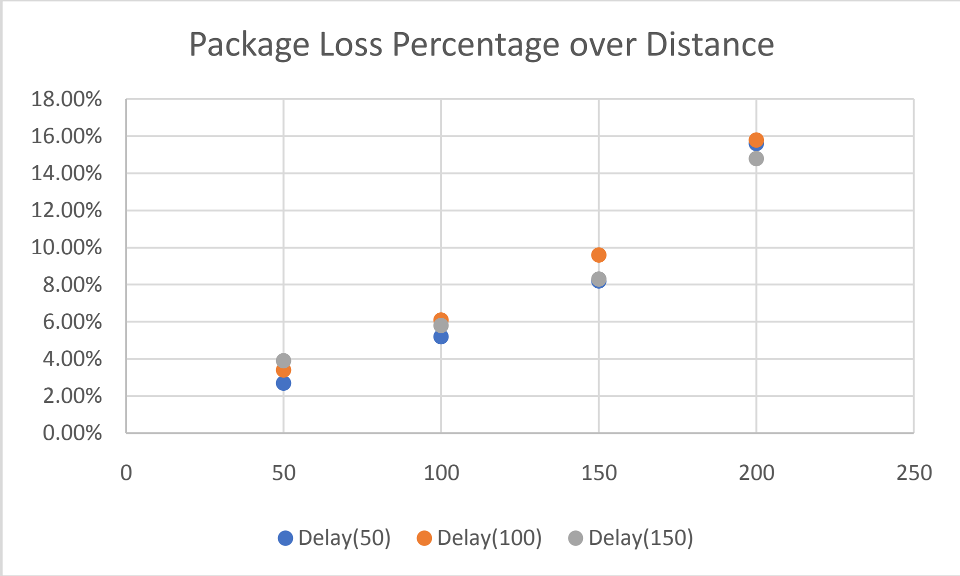

Figure 5.6: Package Loss Percentage over Distance

The rate of transmission for LoRa packet for all of the scenario is being calculated using the formula stated in chapter 3. The rate of transmission throughout the whole experimental evaluation is approximately 3.038kbps.

5.2 Discussion

As shown in the previous section, the package loss percentage in urban area is considerably higher compared to rural area due to several reason, such as signal attenuation, path loss, interference and noise and signal-to-noise. To mitigate the packet loss in LoRa transmission, there are several techniques that can be employed:

a. Optimize antenna placement and orientation.

   Ensure that both the LoRa transmitter and receiver have properly positioned and well-orientated antennas. Proper antenna placement can enhance the signal strength and reduce interference, leading to improved reception and reduced packet loss.

b. Use error Correction Code

   Implementing error correction code (ECC) can help in detecting and correcting error in receiving packets. Adding forward error correction (FEC) techniques, such as Reed-Solomon codes, can enhance the reliability of the transmitted data and mitigate the impact of packet loss.

c. Avoid Channel Congestion

In a LoRa network, multiple devices may share the same frequency channel. Channel congestion can lead to increased interference and packet collisions, resulting in higher packet loss. To minimize congestion, we can use techniques such as adaptive channel hopping or frequency diversity to dynamically select less congest channels.

d. Increase Gateway Density

Deploying more LoRa gateways or repeated within the network can enhance coverage and improve the chances of successful packet reception, especially in area with challenging propagation conditions. Increasing gateway density helps in reducing the distance between the devices and the gateways, thus reducing the impact of signal attenuation and improving overall network performance.

e. Optimize Data Rate

Choosing an appropriate data rate based on the distance and required reliability can help minimize packet loss. Higher data rates are more susceptible to attenuation and interference, while lower data rats provide better resilience but sacrifice overall throughput.

5.3 Summary

This chapter has well-defined the result and discussion of the LoRa deployment in different scenario. The main reason of causing the packet loss is as signal attenuation, path loss, interference and noise and signal-to-noise. However, there are several steps that can be carry out to mitigate the flawless in this experimental evaluation, such as optimize antenna placement and orientation, use error correction code, avoid channel congestion, increase gateway density, and optimize data rate.

CHAPTER 6 CONCLUSION AND FUTURE WORKS

Chapter 6 described the overall achievement of the proposed experimental evaluation and some potential future work to enhance the performance of the LoRa module. A comparison table of project objective and achievement of project is made with explanation. The project limitation will be outline and discussed in detail. Finally, some potential improvement will be mentioned in the future work of the project.

6.1 Project Achievement

LoRa (Long Range) is a low-power, wide-area network (LPWAN) technology developed to enable long -range wireless communication with low data rates and extended battery life. It is designed to address the requirements of Internet of Things (IoT) applications that need to transmit small amounts of data over long distances while operating on low power. In this paper, the efficiency of data transmission of LoRa module is being tested and recorded. The achievements for the project objective for an experimental Performance evaluation of LoRa Network are indicated in table 6.1,

Objective	Achievement
To design and develop Arduino for Liligo LoRa32 T3 v1.6.1 board.	Arduino code for both sending and receiving is being developed and allow the LoRa module to transmit and receive data
To evaluate the network coverage of LoRa Device in real deployment scenario	The performance of Lora board is being tested in a different environment. The result is being recorded and analyse for in different scenario. The LoRa will be able to transmit data in real life deployment as long as the application require to transmit small amounts of data over long distances.
To determine the reliability and robustness of LoRa device	The package loss and the rate of transmission of the LoRa board is being calculated. Reliability of the LoRa device defers for different situation, such as rural or urban area. The Lora device is reliable in urban area with closer range, due to its less interference.

Table 6.1 Achievements of project objective in experimental Performance evaluation of LoRa Network

6.2 Project Limitation

There is no perfect test in the world, although several objectives have been achieved by this experimental evaluation, there ought to be something that can be included into the evaluation to make the result more reliable. For this case, the Lilygo LoRa32 t3 v1.6.1 board, have a fixed spreading factor and bandwidth, causing the evaluation not to be able to cover for LoRa network for another bandwidth other than bandwidth of 125kHz and spreading factor of 7.

The other limitation would be the lack of manpower in carrying out this evaluation. More manpower would be needed to speed up the experiment. It would be efficiency to repeat the scenario more than 10 time and obtain the average reading to reduce the random error.

6.3 Future Works

There is some possible future enhancement can be improved the performance tested of the LoRa device. The proposed improvements are being stated below:

1. Having a newer version of LoRa board

   Lilygo LoRa32 T3 v1.6.1 is being published on 11 March 2022. The accuracy of the evaluation would be increase if the bandwidth and spreading factor of the LoRa board can be configured.

2. Having multiple transmitter

   The relationship of transmitter and receiver can be changed to many to one. For that, packet collision in air could be tested and increase the accuracy of real-life deployments of LoRa module.

6.4 Conclusion

Compared with the specification of LoRa module, it features of long-range communication are 2-5 km in urban and 15km in rural areas. Unfortunately, the result of the experiments shows that the range of the LoRa module will reach up to estimated 800m outdoor urban area and estimated 4km outdoor rural area. According to the result, the communication range is being influenced by the properties of antennas, signal attenuation and different interference from different sources. Last but not least, this proposed evaluation has achieved the objectives that are mentioned in Chapter 1. However, there is still some possible improvement that can enhance the performance of LoRa board.

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