LOW POWER LORA SENSOR NETWORK FOR FLOOD OBSERVATORY SYSTEM

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronics and Computer Technology and Engineering
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DEDICATION

I extend my heartfelt dedication of this thesis to my parents, Nahar Khairudin and Aliza, for being my endless source of inspiration and unwavering support. Special gratitude to En Mazran and Dr Siva Kumar for instilling in me the drive and discipline essential to approach my research with fervour and determination. Their love and encouragement have been indispensable, and without them, the fruition of this study would not have been attainable.

ABSTRACT

Flood is a natural disaster that causes significant damage to infrastructure, property, and human life. Existing monitoring systems has a lack of timely information for public safety, high power consumption, and costly data transmission, making implementing them in remote and flood-prone areas challenging. This thesis proposes the development of a Flood Observatory System (FOS) using Low Power Wide Area Network (LPWAN) technology, specifically LoRa, to address the limitations of traditional flood monitoring systems. The FOS consists of a multipoint sensor network that utilises LoRa for long-range, low-power communication to monitor water levels in flood-prone areas. The system aims to provide a low-power, contactless solution that can operate continuously in remote areas. The project includes PCB fabrication, prototype enclosure procurement, IoT dashboard creation, and mobile/browser-based data access. By utilising LPWAN technology and LoRa specifically, the FOS achieves extended battery-powered operation, enabling accurate flood monitoring and real-time data transmission for timely evacuation and mitigation measures. The system also has applications in agriculture, facilitating efficient irrigation and preventing crop damage. This thesis presents a comprehensive solution for flood detection and monitoring, contributing to enhanced disaster management efforts.

ABSTRAK

Banjir adalah bencana alam yang menyebabkan kerosakan besar kepada infrastruktur, harta benda, dan kehidupan manusia. Sistem pemantauan sedia ada selalunya mempunyai kekurangan maklumat untuk keselamatan awam, penggunaan kuasa yang tinggi dan penghantaran data yang mahal, menjadikan pelaksanaannya agak mencabar terutamanya di kawasan terpencil. Tesis ini mencadangkan pembangunan Sistem Pemantau Banjir (FOS) menggunakan teknologi Rangkaian Kawasan Luas Kuasa Rendah (LPWAN), khususnya LoRa, untuk menangani kekurangan sistem pemantauan banjir sedia ada. FOS terdiri daripada rangkaian penderia berbilang penjuru yang menggunakan LoRa untuk komunikasi jarak jauh dan berkuasa rendah untuk memantau paras air di kawasan yang terdedah kepada banjir. Sistem ini bertujuan untuk menyediakan penyelesaian tanpa wayar berkuasa rendah yang boleh beroperasi secara berterusan. Dengan menggunakan teknologi LPWAN dan LoRa secara khususnya, FOS mencapai operasi berkuasa bateri yang lebih tahan lama, membolehkan pemantauan kejadian banjir yang tepat dan penghantaran data masa yang pantas untuk langkah pemindahan dan mitigasi. Tesis ini membentangkan penyelesaian komprehensif untuk pengesanan dan pemantauan banjir, menyumbang kepada usaha pengurusan bencana yang dipertingkatkan.

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LIST OF SYMBOLS AND ABBREVIATIONS

LPWAN	:	Low-Power Wide-Area Network
FOS	:	Flood Observatory System
IoT	:	Internet of Things
NB-IoT	:	Narrowband Internet of Things
CSS	:	Chirp Spread Spectrum
CR	:	Coding Rate
RSSI	:	Received Signal Strength Indicator
SNR	:	Signal-to-Noise Ratio
LoRaWAN	:	Long-Range Wide Area Network
WSN	:	Wireless Sensor Network
SMT	:	Surface Mount Technology
PWM	:	Pulse Width Modulation
PCB	:	Printed Circuit Board
MQTT	:	Message Queuing Telemetry Transport
QoS	:	Quality of Service
MS	:	Missing Sequence
LoRa	:	Long Range

CHAPTER 1

INTRODUCTION

A quick overview of the project will be given in this section. To familiarise readers with the system, explanations of the LoRa sensor network's evolution will be covered. This chapter provides a thorough explanation of the problem overview, objectives, scopes, and project overview for the whole project.

1.1 Background of Project

In recent years, Low-Power Wide-Area Network (LPWAN) technologies have emerged as a promising solution for remote and low-power applications [1]. LPWANs, such as Sigfox, NB-IoT, and LoRa, offer unique advantages and limitations for different applications [2]. This project focuses on utilising LoRa technology for the development of a flood observatory system in remote areas.

LoRa-LPWAN, in particular, has gained recognition for its efficient combination of optimized battery lifetime, long communication range, and affordability, making it ideal for applications like flood monitoring systems [3]. Several studies have compared different LPWAN technologies, consistently demonstrating LoRa's superior performance in terms of range, battery life, and interference resistance [3].

However, there is a research gap when it comes to the implementation of LoRa-based sensor networks for flood monitoring systems in remote areas. Existing flood observatory systems primarily rely on remote sensing, hydrological modelling, or in-situ monitoring techniques [4]. While these systems provide valuable data for flood prediction and management, they often face limitations such as high costs, technical complexity, and a limited ability to monitor remote areas effectively.

The aim of this research project is to explore the potential of LoRa technology in developing a flood observatory system specifically designed for remote areas. By leveraging LoRa's long-range communication, low power consumption, and interference resistance, the proposed system aims to provide reliable and accurate data for flood monitoring. This research will contribute to filling the gap in the implementation of LoRa-based sensor networks for flood monitoring systems and address the challenges faced in monitoring floods in remote areas.

1.2 Problem Statement

A Flood Observatory System (FOS) that can monitor water levels is crucial in flood-prone areas, as floods have a significant impact on infrastructure, property, and human life, affecting millions of people worldwide. However, existing monitoring systems has a lack of timely information for public safety, high power consumption, and costly data transmission, making it challenging to implement them in remote areas. Several existing flood observatory systems rely on wired communication or cellular networks for data transmission, making them costly and unreliable in remote areas. These systems are also limited in coverage and power consumption, making them unsuitable for long-term monitoring. Additionally, traditional flood monitoring systems using satellite technology are expensive and not ideal for remote areas, as they require high-power consumption and infrastructure. Other monitoring systems, such as pressure sensors, can provide accurate water level data. However, they require frequent maintenance and calibration, which can be costly and time-consuming. Moreover, such systems may not be robust enough to withstand harsh environmental conditions making them unsuitable for monitoring water levels in remote areas prone to flooding.

Therefore, there is a need for a low-power, and long-range wireless sensor network that can efficiently monitor flood-prone areas. The proposed Low Power LoRa Sensor Network for Flood Observatory System using LPWAN technology aims to provide an efficient solution for monitoring water levels in remote areas. This system will allow for accurate and reliable flood predictions, providing timely evacuation and mitigation measures.

1.3 Objectives

i. To analyse the reception performance and power consumption of LoRa-based sensor network nodes.

ii. To develop a battery powered LoRa sensor node for a flood observatory system.

iii. To design a multipoint sensor network that connects to central gateway for real-time data collection of water level information.

1.4 Scope of Project

The work scope of this project is to design a multipoint sensor network using LoRa technology for flood detection. The system will consist of an Arduino Pro Mini Microcontroller board, Ultrasonic Sensor, Temperature and Humidity Sensor, Rain Sensor, and an RFM95 LoRa transceiver module for wireless communication. The project aims to develop a contactless and energy-efficient system that will hang above the water and enter sleep mode between measurements to conserve power. The system will be designed to monitor water levels at multiple points in flood-prone areas, providing a comprehensive view of the flood situation. The system will utilise LoRa technology for wireless communication between the sensor nodes and the gateway, enabling real-time monitoring and data analysis. The project's scope also includes the development of a user-friendly IoT dashboard for visualising and analysing the collected data, as well as demonstrating the system's commercialisation potential for various applications and industries.

1.5 Chapter Outline

All the details about this project were defined in every chapter of this report as shown below.

Chapter 1: In this section, a brief introduction of the project will be provided. Explanations regarding the development of the low power LoRa sensor network will be discussed to familiarise readers with the system. The problem statement, objectives, scopes, and project outline for the entire project are clearly explained in this chapter.

Chapter 2: This chapter will discuss the sources or articles that are relevant to the project. Numerous prior sources and research have been conducted, providing detailed information about this project, and enabling a comprehensive understanding of its key aspects.

Chapter 3: This chapter will discuss the steps involved in completing the project. There are several steps that need to be followed in designing the low power LoRa sensor network. This section provides the project flowchart, the methodology being used, and an explanation of the hardware used for this project.

Chapter 4: This section will present the results obtained throughout the semester. It will also discuss the project's outcomes based on simulation testing and the final completed project.

Chapter 5: This chapter will provide a description of the conclusion and recommendations for the low power LoRa sensor network. It will include a project summary, project findings, and further recommendations to enhance the project.

CHAPTER 2

BACKGROUND STUDY

The sources and publications relevant to the project will be covered in this chapter. It will include a thorough analysis of the body of knowledge and earlier studies carried out in the area. A deeper comprehension of the setting and essential elements of the project will be obtained by looking through these sources. This chapter will specifically offer an overview of prior research, a theoretical foundation, and summaries of relevant investigations.

2.1 Types of Flood Disaster

In Malaysia, floods are among the most frequent natural disasters. They fall into two primary categories, flash floods, and seasonal floods [5, 6, 7, 8].

2.1.1 Flash Flood

Flash floods are a perfect example of nature's unanticipated violence. These phenomena are characterized by severe and unexpected episodes of heavy rainfall that cause them to develop quickly, often in less than six hours [6]. The main issue is that there are too many drainage systems, which causes water to build up quickly. The risk is increased when there is no prior notice since communities can be unprepared and unable to take preventative action. Flash floods have the power to seriously damage infrastructure and property in addition to being unpredictable as shown in Figure 2.1 [6, 9]. This emphasizes how crucial it is to have a flood observatory system that can react quickly and monitor in real time in order to lessen the effects of these unexpected disasters.

Figure 2.1: Flash Floods at Alor Gajah, Melaka, in Kampung Pengkalan

2.1.2 Seasonal Flood

Seasonal floods, on the other hand, follow a more obvious pattern. These floods, which usually occur from November to March during the monsoon season, are caused by extended periods of intense rainfall as shown in Figure 2.2 [7, 10]. River overflows eventually become a regular occurrence, flooding surrounding regions. Seasonal floods are predictable enough to allow communities to prepare to some extent, but the damage is still significant because they occur every year. Even with this predictability, the difficulty comes in handling the danger to certain areas. As a result, even if the yearly flood rhythm is more harmonic, a strong flood observatory system is still required to guarantee the efficient monitoring and control of these recurring occurrences.

Figure 2.2: Flood-hit homes in Kampung Paris Penghulu Benteng, Jasin

2.2 Low-Power Wide-Area Network (LPWAN) Technologies

The Low-Power Wide-Area Network (LPWAN) as shown in Figure 2.3, is a kind of wireless wide-area network that is intended to provide low-bit-rate, long-range communication between Internet of Things (IoT) devices, such battery-operated sensors [11]. Often, LPWANs are utilised to cover devices in difficult-to-reach areas [11]. They can transfer a certain amount of data each day, have longer operational ranges, and use less power overall.

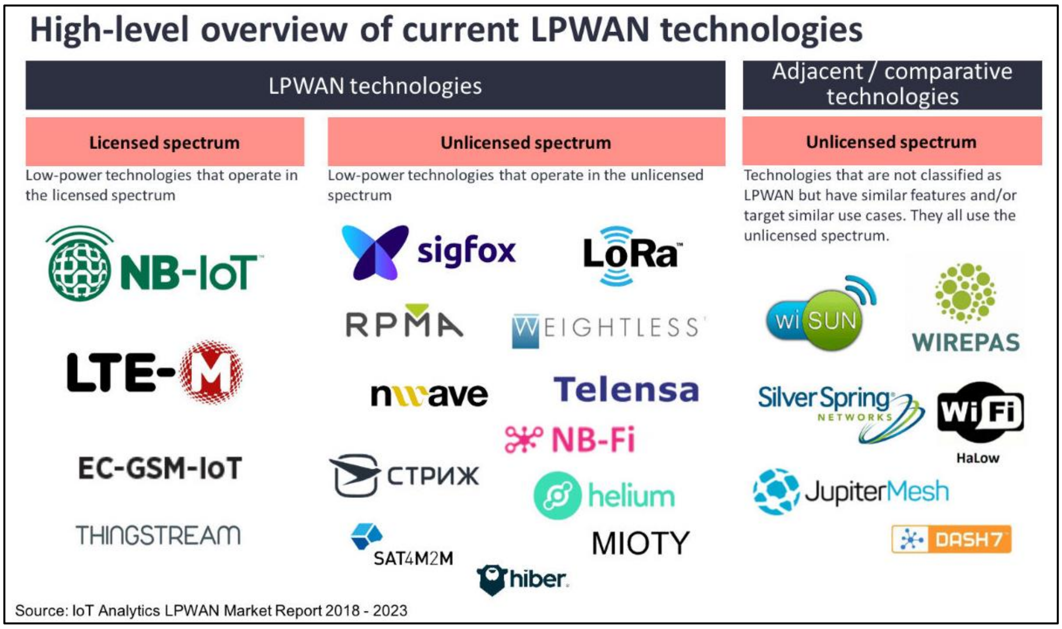

Figure 2.3: Current LPWAN Technologies [11]

2.2.1 Sigfox

A French global network operator called Sigfox created wireless networks to link low-power devices like smartwatches and electricity meters that must always be on and producing little quantities of data [12]. Sigfox uses Gaussian Frequency Shift Keying (GFSK) and Differential Binary Phase-Shift Keying (DBPSK) to facilitate communication in the Industrial, Scientific, and Medical radio band (902 MHz in the US) and the short-range device band (868 MHz in Europe).

2.2.2 NB-IoT

The 3GPP established the low-power wide-area network (LPWAN) radio technology standard known as Narrowband Internet of Things (NB-IoT) for cellular network devices and services [13]. Particularly in deep coverage, NB-IoT greatly increases system capacity, spectrum efficiency, and user device power consumption. Many different use cases may be handled by batteries with a lifespan of over ten years.

2.2.3 LoRa

Long Range, or LoRa, is the name of a proprietary wireless communication technology that combines an effective long range with extremely low power consumption [14]. The Internet of Things (IoT) and machine-to-machine (M2M) networks are the primary uses for this wireless technology. Multiple devices operating on the same network can be connected with this technology in public or multi-tenant networks [14].

2.3 LoRa Technology

The Chirp Spread Spectrum (CSS) technology is the source of the LoRa wireless modulation system. It uses chirp pulses to encode information on radio waves as shown in Figure 2.4, just like bats and dolphins do [15]. Long-range reception of LoRa modulated transmission is possible, and it is resistant to disruptions.

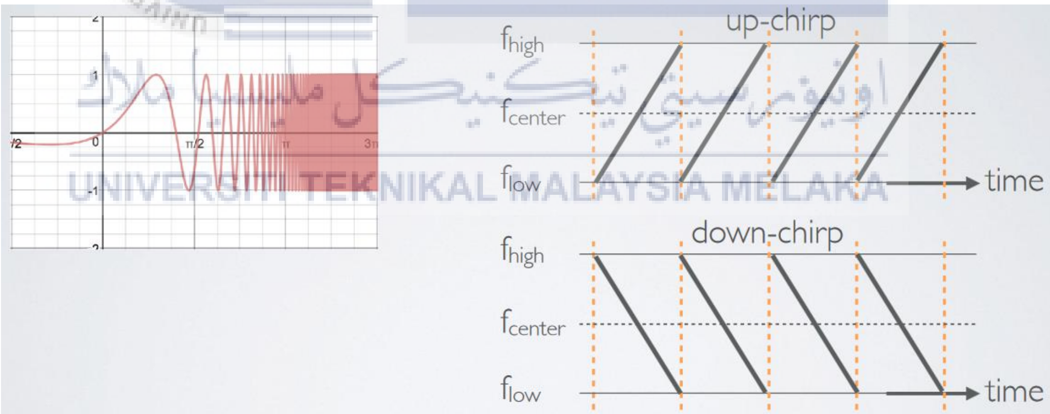

Figure 2.4: Chirp Spread Spectrum [15]

Applications that transfer little amounts of data at low bit rates are best suited for LoRa. It is possible to send data over a greater distance than using WiFi, Bluetooth, or ZigBee technologies. LoRa is a good fit for low power mode sensors and actuators because of these properties.

The license-free sub-gigahertz bands, such as 915 MHz, 868 MHz, and 433 MHz, are suitable for LoRa operation. At the expense of range, it may also be used at 2.4 GHz to reach faster data speeds than sub-gigahertz bands [16]. These frequencies are part of the International Spectrum Management (ISM) bands, which are set aside for use in industry, science, and medicine.

LoRaWAN endpoints are built to operate in low power mode and can last up to 10 years on a single coin cell battery. LoRaWAN gateways can broadcast and receive signals up to 3 kilometers in heavily populated areas and more than 10 kilometers in isolated locales as shown in Table 2.1 [17]. Deep interior coverage and easy coverage of multi-floor buildings are features of LoRaWAN networks.

Table 2.1: Range and Power of Various Wireless Technology

Technology	Wireless Communication	Range	Tx Power
Bluetooth	Short Range	10 m	2.5 mW
Wi-Fi	Short Range	50 m	80 mW
3G/4G	Cellular	5 km	5000 mW
LoRa	LPWAN	2-5 km (urban) 5-15 km (rural) >15km (LOS)	20 mW

2.3.1 LoRa Parameters

Different spreading factors, bandwidth configurations, coding rates, and transmission strengths can be used with LoRa devices [18, 19, 20]. The performance of LoRa is influenced by these key parameters, which are discussed in the following sections.

2.3.1.1 Bandwidth

One important component of LoRa technology is bandwidth. The frequency range that the signal is propagated over is referred to. For example, evaluating various bandwidth settings may be used to assess how well LoRa transmission performs in situations with and without construction impediments obstructing or distorting the wireless signals. The data rate and range of LoRa communication can be greatly impacted by the bandwidth selection. LoRa works in Malaysia at the sub-GHz frequency range of 919MHz to 923MHz [21].

2.3.1.2 Spreading Factor

The performance of LoRa transmission is significantly impacted by the spreading factor choice. With LoRa, the spreading factor is modifiable and situation specific. As seen in Table 2.2 [22], it spans from SF7 to SF12, with SF7 offering the maximum data rate and the shortest airtime and SF12 offering the lowest data rate and the longest airtime. The choice of spreading factor has a direct impact on LoRa devices' communication dependability and energy usage.

Table 2.2: Data Rate, Sensitivity, and Time on Air [22]

Spreading Factor	Sensitivity (dBm)	Time on Air (ms)
SF7	-123.0	41
SF8	-126.0	72
SF9	-129.0	144
SF10	-132.0	288
SF11	-134.5	577
SF12	-137.0	991

2.3.1.3 Coding Rate

By adding redundancy to the data to be sent, the LoRa Coding Rate (CR) acts as a type of Forward Error Correction (FEC), strengthening the connection between nodes in the network against interference. The performance of LoRa transmission is significantly impacted by the choice of coding rate. LoRa has four different coding rates: 4/5, 4/6, 4/7, and 4/84 [23]. More redundancy and a lower data flow are the results of a greater coding rate, but the robustness against errors is enhanced.

2.3.1.4 Lora Performance

The performance of LoRa technology can be evaluated using two key metrics: Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR).

A relative measurement called RSSI (Received Signal Strength Indicator) may be used to assess if the received signal is strong enough to establish a reliable wireless connection with the transmitter. The RSSI has a negative value and is expressed in dBm. The strength of the received signal increases as the RSSI number approaches zero. In addition to the transmitter's output power, path loss, antenna gain, and cable/connector loss are the key determinants of RSSI.

Path loss is one of the main variables affecting RSSI. The signal is attenuated when it passes past barriers in its path through the environment. A thorough grasp of route loss is necessary to maximize RSSI and guarantee reliable communication in difficult environments. Antenna gain is a key factor in determining RSSI pattern. The ability to successfully concentrate and collect signals is determined by the antenna gain. Antenna location and design optimization help to maximize RSSI values, which improves the overall performance of LoRa networks. Losses in signals can also occur from cables and connections. These losses affect RSSI and should be carefully considered while designing the system. Reliable communication depends on maintaining strong RSSI values, which is facilitated by minimizing cable and connection losses.

The study, according to Ousmane et al., shows that RSSI is a useful metric for estimating distance in LoRa networks [24]. With the use of a log-distance path-loss model, real-time modification, and the suggested dynamic and continuous RSSI-distance mapping mechanism, collar localization is made more precise even in the absence of GPS. The findings indicate that there is a strong link between RSSI and distance, and that RSSI is quasi-linear with respect to distance as shown in Figure 2.5. The suggested method works better for lengths above 100 meters, but the log-distance path-loss model's accuracy is restricted for shorter distances.

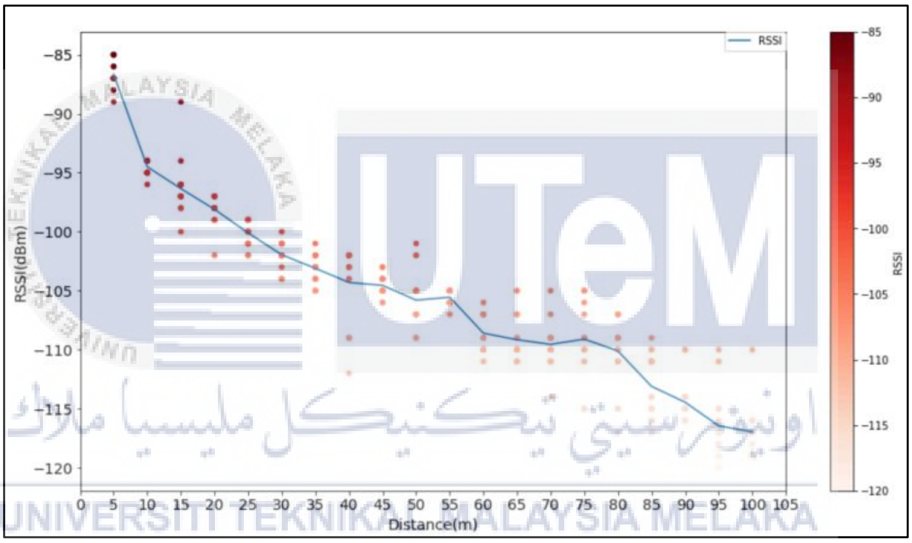

Figure 2.5: Variations in RSSI Values Relative to Distance [24]

A key indicator in LoRa networks is the Signal-to-Noise Ratio (SNR), which offers a numerical assessment of the quality of the received signal. SNR is the comparison of the received signal strength and the background noise floor, expressed as a ratio. This ratio plays a crucial role in determining how well the signal can be separated from background noise, which in turn affects the communication link's dependability and quality. This method provides a consistent measure for assessing signal quality across many contexts by expressing SNR in decibels (dB).

$$SNR(dB) = 10\log\frac{Signal\ Power}{Noise\ Power}$$

The strength of the received signal is one of the key components of SNR. Higher SNRs indicate better signal quality as they are correlated with stronger signal [25]. Increasing signal strength becomes essential in LoRa networks to achieve stable communication.

For campus-scale IoT connection, a research by Universiti Teknologi Mara (UiTM) demonstrates a strong correlation between Signal-to-Noise Ratio (SNR) and distance in the context of outdoor signal performance of LoRaWAN technology [26]. As the distance from the gateway grows, the study findings demonstrate that the SNR values drop, illustrating the effect of distance on the received signal quality as seen in Figure 2.6. Understanding this connection is essential to comprehending the dependability and performance of LoRaWAN networks in outdoor situations, especially on campuses. The study's conclusions offer helpful advice for arranging and configuring LoRaWAN gateways optimally to guarantee dependable and efficient IoT connection throughout campus areas.

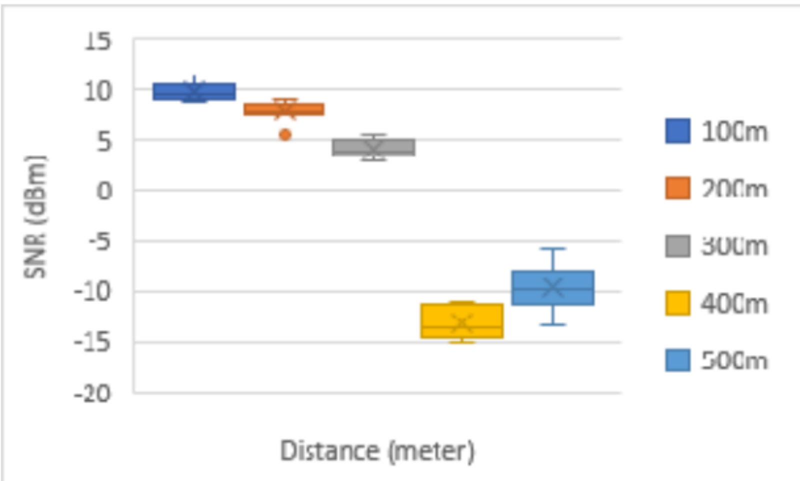

Figure 2.6: SNR Measured at Various Distances [26]

2.4 Flood Monitoring Systems

Flood monitoring systems are essential for controlling and reducing the effects of floods in Malaysia. For example, the Public Infobanjir system gathers data on water level and rainfall in real time from about 200 hydrological sites throughout the nation. The Telemetry Database and servers in each state receive this data after which it is sent to Infobanjir [27, 28]. Designing a flood observatory system that is suited to the unique requirements of the region requires a grasp of remote sensing, satellite technology, hydrological modelling, and in-situ monitoring, all of which are critical given Malaysia's ongoing struggle with flooding.

2.4.1 Remote Sensing in Flood Observatories

In Malaysia, flood observatories rely heavily on remote sensing data. This method gathers important information on river dynamics, flood extents, and water levels using airborne-based sensors. A Flood Information System based on GIS and remote sensing has been created and put into service by the Malaysian Remote Sensing Agency (MRSA) [29]. Data entry, data analysis, information retrieval, and report production are the four main parts of this system. Users may utilise it to obtain data, analyse it, and produce reports that can be used as decision-making tools for damage assessment, mitigation, rehabilitation, and search and rescue.

Remote sensing technology has been employed in building a number of flood observatory systems that track flood incidents. The University of Colorado built the Dartmouth Flood Observatory (DFO) in 1993 [30], making it one of the most well-known flood observatories. The DFO maps and tracks worldwide flood occurrences almost instantly using satellite data. The system creates flood maps with a 250-meter spatial resolution by utilising data from many sources, such as the Advanced

Microwave Scanning Radiometer (AMSR-E) and the Moderate Resolution Imaging Spectroradiometer (MODIS).

2.4.2 Satellite Technology in Flood Monitoring

Satellite technology provides a wide-angle perspective of environmental changes, which greatly aids in flood monitoring. In Malaysia, the use of satellite technology for flood monitoring is growing. In order to help with post-flood monitoring and recovery, the Malaysian Space Agency (MYSA), which is a division of the Science, Technology, and Innovation Ministry (Mosti), offers satellite and drone photos in flood-affected regions [31]. Organizations tasked with overseeing floods in the nation have access to these photos via a number of current tools.

According to research by Nur Atirah et al. [32], image segmentation techniques are crucial for flood monitoring systems. A comparative analysis of image segmentation methods for obtaining water information from digital photos is presented in this work. When it came to extracting water characteristics from digital photos, the hybrid strategy proved to be a promising segmentation method when compared to other approaches.

The potential and cooperative application of multisource satellite observations for flood forecasting and monitoring is demonstrated in another work by Jinyang Du et al [33]. The study created a machine learning-based method for mapping and downscaling 30-meter waves as well as daily forecasting of fractional water cover. The temporal dynamics of the floods from the Idai catastrophe were reflected by the forecast findings.

Although satellite technology is useful for monitoring floods, there are considerable obstacles for deploying it in remote regions like Malaysia, which frequently experiences flooding. According to the studies, satellite technology is expensive to adopt in areas with limited resources because of its significant expenditures. Taking this cost into account is essential to creating flood monitoring systems that are both practical and profitable.

2.4.3 Hydrological Modelling for Flood Prediction

In Malaysia, hydrological models are crucial planning and management tools for water resources and the environment. The models used to assess the compatibility of model outputs with streamflow observations include conceptual, empirical, and physically based models. For example, the Damansara watershed has been used as a case study for the High-Resolution Hydrological-Hydraulic Modelling of Urban Floods using InfoWorks ICM [34].

According to research by J. H. Abdulkareem, B. Pradhan, W. N. A. Sulaiman, and N. R. Jamil [35], hydrological models are essential for managing water resources and the environment in Malaysia. The study assessed the hydrological models applied in Malaysia, established the extent to which the models covered the main river basins, and pinpointed the employed methodology. According to the findings, physical-based models were employed in 65% of the research, empirical models in 37%, and conceptual models in 6% of the investigations.

Hydrology and hydraulic models were merged in an additional study by Hasrul Hazman Hasan et al [36]. to simulate urban flood occurrences in the Aur River watershed. Using XPSWMM software, the main goal was to estimate peak flow and predict water level based on hydrological evaluation of the drainage system.

Complexity and data-intensiveness are two significant drawbacks of hydrological modelling. A large number of datasets, including topographical, meteorological, and land use data, are frequently needed to implement these models. Acquiring such precise data might be difficult in remote places, which compromises the models' dependability and accuracy. Hydrological model deployment requires technical know-how and funding. The absence of qualified staff and infrastructure in remote places might be a challenge for the implementation and upkeep of advanced modelling systems. This restriction emphasizes how crucial it is to take the region's technological capability into account when choosing hydrological modelling techniques.

2.4.4 In-Situ Monitoring Techniques in Flood Observatories

In Malaysia, real-time data is collected through the use of in-situ monitoring techniques, which entail the placement of sensors directly in flood-prone areas. For industrial sites or facilities, for example, the Department of Environment sets rules for the installation and upkeep of Continuous Emission Monitoring Systems (CEMS) [37]. These recommendations address a number of topics, such as data gathering systems, CEMS analyser types, and sampling procedures (both extrinsic and in-situ). This method has limits in terms of coverage and accessibility even if it offers precise information.

The significance of both in-situ and mobile crowdsourcing (MCS) monitoring systems for effective real-time flow measurement in ephemeral streams is demonstrated by a study done by Cecilia et al [38]. Against the backdrop of the environmental disaster plaguing the Mar Menor watershed (Murcia, SE Spain), the system is implemented in what is believed to be the first legally recognized ecosystem in Europe.

Avanzato et al. [39] have proposed a method for sub-block image processing-based river flood detection in another work. Experiments conducted using the suggested approach have demonstrated that the system can accurately and quickly anticipate the flooding event.

Although precise data is provided via in-situ monitoring, its accessibility and coverage are limited. These difficulties get worse in distant locations, thus great care must be taken to make sure that the monitoring network sufficiently covers the targeted areas while taking logistical and physical limitations into account. With its ability to provide accurate and up-to-date data, in-situ monitoring techniques play a crucial role in Malaysian flood observatories. Even in areas with little data and remote locations, in-situ monitoring is a useful tool for disaster planning and mitigation because of its benefits in customisation, cost-effectiveness, and interaction with complementary technology.

2.5 Previous Research in Low-Power LoRa Sensor Networks

Numerous environmental monitoring systems have included LoRa technology. For example, a large-scale campus with a high population density has an intelligent environmental monitoring system built that is based on low-power LoRa transmission technology [26]. Smart agriculture is another use of LoRa in environmental monitoring, where the technology is utilised to track soil pH, moisture content, temperature, and humidity [40]. Numerous tests comparing various LPWAN technologies have repeatedly shown that LoRa performs better in terms of interference resistance, range, and battery life.

.

In a research, Muhammad Ihsanuddin Haji Md Yassin et al. [41] investigate the use of LoRa-based sensors in Brunei Darussalam for real-time flood monitoring and detection. The study presents the Remote Flood Monitoring System (FDMS), which uses LoRa and web technologies to provide lightweight, real-time sensor-to-backend server connectivity. The suggested system successfully detects and shows real-time water levels. It consists of roadside IoT flood detectors and a Node.js-powered backend with components for InfluxDB and Grafana. The FDMS has the potential to improve flood management skills for responsible authorities, as demonstrated by the Pushbullet API interface that guarantees prompt alarm messages. The study provides insightful information about how LoRa technology may be integrated for flood monitoring, paving the way for future developments in disaster planning and mitigation initiatives.

A research employing LoRa technology provides a Fuzzy Logic-Based Flood Detection System by Choo Kam Khuen and Alireza Zourmand at the School of Engineering, KDU University College, Malaysia [42]. The Fuzzy Logic System (FLS) tackles the intricacy of flood detection, which is impacted by factors such as runoff, soil moisture, and rainfall, by offering a reliable method for making decisions. All offsite sensor nodes can communicate wirelessly across long distances with minimal power consumption thanks to LoRa technology, which uses the Semtech SX1278 chip. The study effectively illustrated the system's dependability by generating various flood danger ratings according to the positioning of sensors at various altitudes.

Researchers from the Indian Institute of Technology Delhi [43] have developed a unique method for monitoring the water quality of lakes and reservoirs by utilising a communication system based on the Long-Range Wide Area Network (LoRaWAN).

The study addresses the drawbacks of conventional water quality monitoring techniques and emphasizes the benefits of LoRaWAN, highlighting its broad coverage, low power consumption, and applicability for rural areas. The system's intriguing properties are demonstrated by the proof-of-concept, which involves monitoring the temperature of lake water in real-time. Its range is 150-2,500 meters, depending on barriers and antenna positioning. The authors support LoRaWAN's affordability, scalability, and security, and they anticipate using it in extensive lake monitoring systems that incorporate more water quality metrics and create forecasting models to help decision-makers make well-informed choices.

A notable use of Low Power Wide Area Network (LPWAN) technology is shown in a paper by Ragnoli et al. [44] that centres on a LoRa-based Wireless Sensor Network (WSN) for flood and environmental monitoring. In order to connect to a LoRaWAN network structure, the system makes use of a microcontroller-based sensory device with a LoRa radio interface for communication. Waterproof temperature sensors and a MEMS accelerometer are features of the modular design that monitor the environment and trigger an alarm in the event of structural activity or damage. The benefits of LoRa modulation are highlighted in the report, along with its potential for long-distance, energy-efficient communication for environmental monitoring. The suggested architecture shows encouraging results in temperature sensing and water level monitoring when tested in a real-world setting close to the Vetoio river in L'Aquila, Italy.

CHAPTER 3

METHODOLOGY

This chapter describes the methodical approaches used to create the Flood Observatory System (FOS). It covers the strategic design methods, component integration, and tool selection in an organised way. A flowchart that shows the project's sequential steps is included in this chapter. This chapter seeks to provide a concise, yet thorough, understanding of the organised process used to implement the Low Power LoRa Sensor Network for Flood Observatory System by introducing these approaches.

3.1 Overview of Project Implementation

The flowchart in Figure 3.1 outlines the systematic process of developing a flood observatory system using LoRa technology. The methodology is divided into hardware and software processes and documentation, which are further divided into several sub-processes.

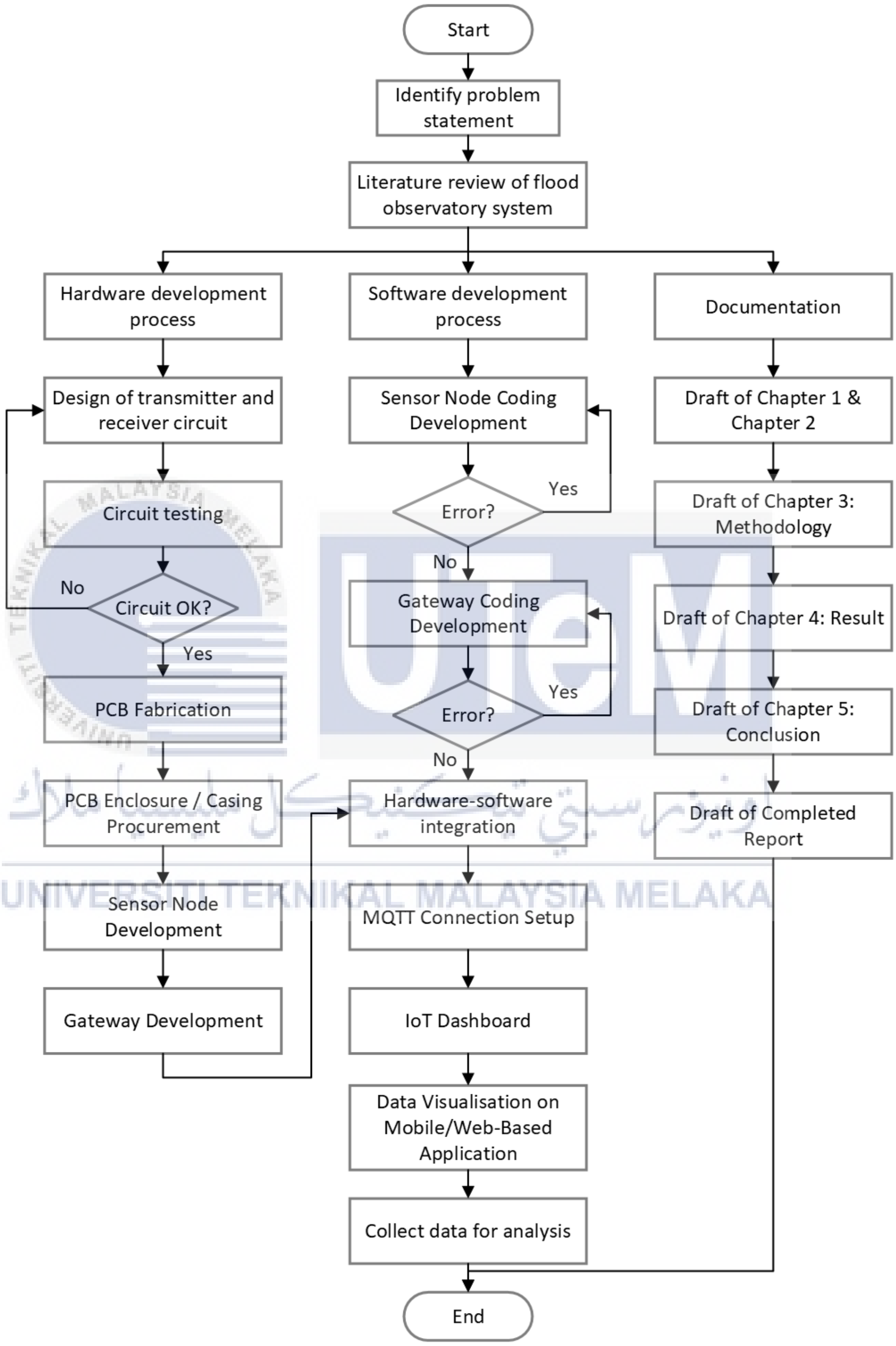

Figure 3.1: Research Methodology Flowchart

The first step in the methodology is to identify the problem statement and conduct a literature review of flood observatory systems. The problem statement should be clear and concise, and it should define the scope of the project. The literature review should cover various aspects of flood observatory systems, such as hardware, software, communication protocols, and data visualization.

The hardware development process initiates with designing the transmitter and receiver circuit, followed by circuit testing. If the circuit is okay, it proceeds to PCB fabrication and then to PCB enclosure or casing procurement. The final steps involve sensor node development and gateway development. The software development process starts with sensor node coding development. If no errors are found, it advances to gateway coding development. After successful coding, hardware-software integration takes place. Both processes converge at MQTT connection setup leading to IoT Dashboard creation for data visualization on mobile/web-based applications. Finally, data is collected for analysis. MQTT is a lightweight messaging protocol that is ideal for IoT applications. The IoT dashboard should be easy to use and should provide real-time data visualization. The data can be analysed using various data analysis tools such as Python, MATLAB, or Excel.

The flowchart provides a systematic approach to developing a flood observatory system using LoRa technology. The methodology is divided into hardware and software processes, which are further divided into several sub-processes. The project is designed to be energy-efficient and contactless, making it ideal for flood-prone areas. The system is designed to monitor water levels at multiple points, providing a comprehensive view of the flood situation. The system has the potential to be commercialized for various applications and industries.

3.2 Project Planning

The Gantt chart in Table 3.1 helps to visualize the progress, status, and deadlines of the project, as well as to identify potential issues and bottlenecks. It shows the main activities, phases, and deliverables of the project, as well as the estimated duration and start and end dates of each task. The Gantt chart also indicates the critical path of the project, which is the sequence of tasks that determines the minimum time required to complete the project.

Table 3.1: Gantt Chart

PROJECT PLANNING (GANTT CHART)

Project Activities	SEM I																			SEM BREAK					SEM II															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Identifying Problem																																								
Literature Review																																								
Writing of Project Proposal																																								
Proposal Defence																																								
Draft of Chapter 1 & Chapter 2																																								
Transmitter and Receiver Circuit Development										X																														
Circuit Troubleshooting																																								
PCB Fabrication											SEMINAR PSM I																											SEMINAR PSM II		
PCB Enclosure / Casing Procurement																																								
Sensor Node Development																																								
Sensor Node Coding Development																																								
Gateway Development																																								
Gateway Coding Development																																								
Hardware-Software Integration																					X																			
Draft of Chapter 3: Methodology																																								

MQTT Connection Setup	
IoT Dashboard Development	
Data Visualisation on Mobile/ Web-Based Application	
Data Collection for Analysis	X
Draft of Chapter 4: Results	
Draft of Chapter 5: Conclusion	
Draft of Completed Report	
Completed PSM Report	

3.3 Overall System Design

The system's block diagram in Figure 3.2 shows a thorough architecture intended for efficient flood monitoring.

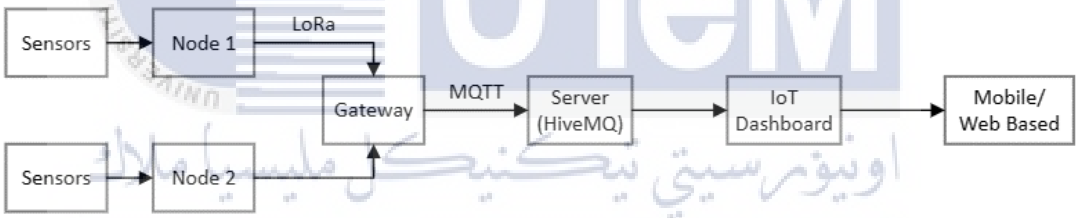

Figure 3.2: Block Diagram of System

The system consists of two sensor nodes that are placed strategically along the riverbank. These nodes act as the front-line data collectors, monitoring water levels accurately by placing them at particular places above the water's surface.

LoRa technology, which demonstrates its effectiveness in long-range communication, is used to wirelessly transfer the data gathered by the sensor nodes to the gateway. The gateway is essential for gathering, compiling, and sending data to a centralised server. The data is processed and stored on this HiveMQ-powered server, which guarantees a reliable and expandable backend architecture.

An IoT (Internet of Things) dashboard is part of the system to provide end users with real-time analytics. A platform for data visualisation, this intuitive interface lets interested parties keep an eye on water levels and other relevant information. Additionally, a mobile/web app makes the gathered data available, guaranteeing people have quick and easy access to the information and improving their readiness for future flooding incidents. This block diagram represents a well-coordinated system that makes optimal use of cutting-edge technologies to tackle the difficulties associated with flood monitoring.

3.4 Sensor Node

The sensor node, a key component of the Flood Observatory System, combines a temperature and humidity sensor, a rain sensor, and an ultrasonic sensor shown in Figure 3.3. An Arduino Pro Mini microcontroller, which controls data processing and gathering, is interfaced with these sensors. An antenna facilitates connection between the Arduino Pro Mini and a LoRa transceiver module, which allows for long-range communication. This arrangement, which serves as the foundation for the flood monitoring system along the riverside, guarantees accurate and timely data collecting.

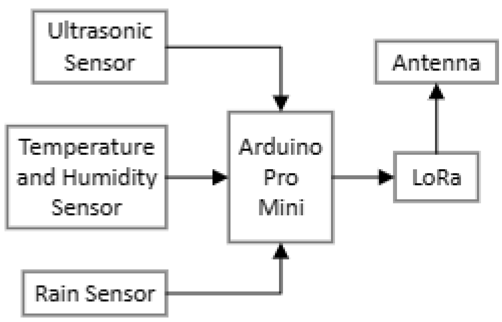

Figure 3.3: Sensor Node Hardware Architecture

3.4.1 Ultrasonic Sensor

The weather-resistant ultrasonic distance sensor shown in Figure 3.4, model number HRXL-MAXSONAR MB7386, has a reading rate of 6Hz and a range of 500mm to 9999mm [45]. This reliable, ultrasonic sensor component module has a small, sturdy PVC housing and offers extremely short- to long-range detection and ranging. The sensor is perfect for outdoor uses, including measuring the level of a bin or a water tank. Applications needing accurate range finding, low voltage operation, space savings, low cost, and IP67 weather protection will benefit from the cost-effective HRXL-MaxSonar-WR sensor line. There are three different output choices available for the ULTRASONIC SENSOR HRXL-MAXSONAR MB7386, TTL serial, analog voltage, and pulse-width. It can identify objects with a tiny beam angle and reports the range to the nearest target. The ultrasonic sensor operates by generating ultrasonic waves, which are then reflected by an object and picked up by the sensor. The distance between the sensor and the object may be determined by timing the intervals between sound wave transmission and reception.

Figure 3.4: MaxBotix MB7386 Ultrasonic Sensor

3.4.2 Temperature and Humidity Sensor

The SHT31 is a weather-resistant sensor that measures temperature and humidity with high precision, internal auto-calibration, and digital output as shown in Figure

3.5 [46]. It responds quickly, uses little power, and has potent anti-interference properties. With an accuracy of ±2% throughout the range of 20% to 80% RH (0.01% RH resolution), the SHT31 can measure humidity over the whole range of 0 to 100% RH. The SHT31 can measure temperatures up to 125°C, and its usual accuracy at 25°C (0.015°C resolution) is ±0.3°C. With the help of the Adafruit SHT31 library, Arduino boards may be interfaced with the SHT31 sensor. The library supports many communication protocols, including I2C, and offers routines to read temperature and humidity information from the sensor.

Figure 3.5: SHT31 Temperature & Humidity Sensor

3.4.3 Rain Sensor

A rain sensor is a switch that turns on when it starts to rain. The detecting pad of the rain sensor module consists of two nickel-coated series copper tracks as shown in Figure 3.6 [47]. Two header pins on this pad are attached to the copper tracks of the pad internally. These two header pins serve the primary purpose of using two wires to link the rain sensor module and the sensing pad. The Adafruit Rain Sensor library may be used to interface the rain sensor module with Arduino boards, which are compatible with it. The library supports many communication protocols, including SPI 3 and I2C, and offers routines to read the sensor's digital output.

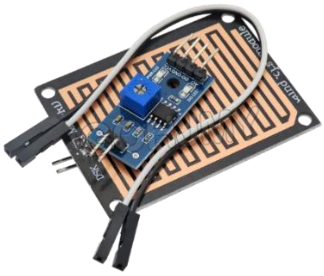

Figure 3.6: Rain Sensor Module

3.4.4 Arduino Pro Mini

Based on the Atmega328 microprocessor, the Arduino Pro Mini is a small and inexpensive microcontroller board as shown in Figure 3.7. It includes six analog inputs, six PWM (Pulse Width Modulation) pins, and fourteen digital input/output pins [48]. There are two versions of the board available: the one used for the project runs at 3.3V and works at 8MHz, and the other operates at 5V and runs at 16MHz. Because it doesn't have a USB connector or an integrated programmer, the Arduino Pro Mini is perfect for embedded applications. An FTDI cable or an external USB-to-serial adapter can be used to program the board. The rain sensor and ultrasonic sensor utilised in the project are two examples of the sensors and modules that can be interfaced with the Arduino Pro Mini.

Figure 3.7: Arduino Pro Mini

3.4.5 LoRa Module

Sensor nodes and gateways communicate wirelessly with each other with the RFM95 LoRa transceiver module as shown in Figure 3.8. A long-range, low-power radio transceiver module operating in the 915 MHz frequency region is called the RFM95 [49, 50]. It minimizes current consumption and offers ultra-long-range spread spectrum communication with superior interference immunity through the use of the unique LoRa modulation method. The sensitivity of the RFM95 is more than -148dBm. The RadioHead library may be used to interface the RFM95 module with Arduino boards, as it is compatible with such boards. Sending and receiving data packets between the RFM95 module and other RFM95 modules or gateways is made possible by the library's functionalities. Wireless sensor networks, telemetry, and remote control are just a few of the uses for the RFM95 module.

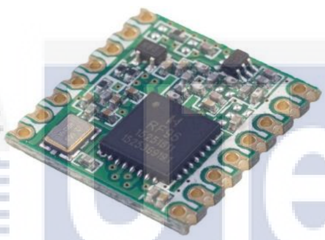

Figure 3.8: RFM95 LoRa Module

3.4.6 SMA Port

Designed as a basic connector interface for coaxial cable with a screw-type coupling mechanism, SMA connectors as shown in Figure 3.9, are semi-precision coaxial RF connectors that date back to the 1960s [51]. The SMA connection can operate from DC (0 Hz) to 12 GHz with an impedance of 50 Ω, however, variations that can reach 18 GHz and 26.5 GHz are also available. Microwave systems, Wi-Fi antenna systems, USB software-defined radio dongles, and handheld radio and mobile phone antennas are the devices that use the SMA connection the most. A 1/4-inch diameter, 36-thread-per-inch threaded barrel is used in the SMA connection. Standard SMA female connectors have a centre sleeve surrounded by a barrel with outside threads, while standard-polarity SMA male connectors have a 0.9mm diameter centre pin surrounded by a barrel with inside threads.

Figure 3.9: Right Angle SMA Port

3.4.7 Switch

An electrical switch intended for use in damp or wet conditions is the waterproof round rocker switch as shown in Figure 3.10 [52]. This particular kind of rocker switch is rounded in shape and sealed to keep water out of the switch. The switch is commonly utilised in maritime, automotive, and industrial settings where resistance to water is crucial.

Figure 3.10: Waterproof Round Rocker Switch

3.4.8 Voltage Regulator

A low-dropout voltage regulator having a set output voltage of 3.3V and a maximum output current of 800mA is the LM1117GS-3.3V as shown in Figure 3.11 [53]. It is a great option for usage in SCSI bus active terminators, portable computers, and battery-powered applications. Additionally, it can control the output voltage even when the input voltage is just marginally greater than the output voltage because to its low dropout voltage of 1.2V at 800mA output current. The Texas Instruments datasheet states that the maximum line regulation and maximum load regulation for the LM1117GS-3.3V are 0.2% and 0.4%, respectively. Moreover, a thermal shutdown mechanism guards against overheating-related harm to the device.

Figure 3.11: LM1117GS-3.3V Voltage Regulator

3.4.9 Rectifier Diode

Diodes Incorporated produces the fast/ultra-fast rectifier diode component RS1G-13F as shown in Figure 3.12, which is intended to offer overcurrent safety [54]. The part works with electronics assemblies that are produced in large quantities. Its maximum rating for reverse voltage is 400V, its highest rating for forward current is 1A, and its maximum forward voltage drop at 1A is 1.3V. The component has a maximum total capacitance of 15pF and a maximum reverse current rating of 5μA at 400V. 150 ns is a quick recovery time for the RS1G-13F. The component has a tiny footprint, low resistance, and a wide variety of resettable devices available in the industry.

Figure 3.12: RS1G-13F Rectifier Diode

3.4.10 Capacitor

An electrolyte is used by electrolytic capacitors as shown in Figure 3.13, a kind of polarized capacitor, to produce high capacitance values. They are often utilised in electronic circuits for energy storage, signal coupling between amplifier stages, noise filtering, and decoupling power supply [55]. They are also utilised in DC link circuits for variable-frequency drives. Because of their asymmetrical design, electrolytic capacitors are polarized parts that require constant operation with a higher voltage on the anode than on the cathode.

Figure 3.13: Electrolytic Capacitor

3.4.11 Resistor

Surface mount technology (SMT) is a type of resistor that is used to install resistors on the surface of a printed circuit board (PCB) as shown in Figure 3.14 [56]. They serve a number of functions in electrical circuits, such as the construction of voltage dividers. A voltage divider, which is a circuit that splits a voltage into smaller halves, is frequently used to measure a battery's voltage. An SMD resistor's purpose in a voltage divider circuit is to split the input voltage by offering a known resistance value. The input voltage and the resistor's resistance value define the current that flows through the resistor and, in turn, the voltage across it. To create a voltage divider circuit that produces the required output voltage, the resistor values can be chosen carefully.

Figure 3.14: SMD Resistor

3.4.12 Connectors

Electrical connectors known as JST connectors as shown in Figure 3.15,are produced in accordance with the original design specifications created by J.S.T. Mfg. Co. (Japan Solderless Terminal) [57]. They serve as the link between the PCB board and sensors. It is made up of metal pins that are crimped onto the wires and a plastic casing. To create an electrical connection, the pins are placed into holes on the PCB board and the housing is made to fit into a matching socket on the board. The purpose of the JST connector header component is to link the sensor and PCB board in a safe and dependable manner.

Figure 3.15: 3-pin Connector

3.4.13 Resettable Fuse

The Littelfuse SMD250F-2 resettable fuse component is intended to offer overcurrent protection in applications where space is limited and resettable protection is preferred [58]. The component is the recommended circuit protection technique for computer, consumer, multimedia, portable, and automotive electronics applications. It is also suitable with high-volume electronics assemblies. Its maximum voltage rating is 15V, and its hold and trip currents are 2.5A and 5A, respectively. The component can dissipate up to 1.9W of electricity and has a maximum fault current rating of 40A. Its resistance ranges from 0.035 Ohms at the least to 0.085 Ohms at the greatest.

Figure 3.16: SMD250F-2 Resettable Fuse

3.4.14 Battery

Batteries of the 18650 lithium-ion kind are frequently found in electronic equipment including electric cars, computers, and flashlights. The term "18650" comes from its cylindrical form, which measures 18 mm in diameter and 65 mm in length [59]. The 18650 lithium-ion battery has the capacity to both store and discharge electrical energy. Lithium ions are transported by the electrolyte from the cathode to the anode during battery charging, where they are stored. The lithium ions return to the cathode as the battery is depleted, releasing energy in the process.

Figure 3.17: 18650 Lithium Ion Battery

3.5 Gateway

The gateway is an essential part of the IoT that gathers and processes data from different sensor nodes before sending it to the server as shown in Figure 3.18. An antenna is the first component of the gateway setup, it acts as the data reception entry point. The LoRa transceiver module then connects to an ESP32 microcontroller to receive data wirelessly from the sensor nodes. The gateway's processing centre, the ESP32, oversees data aggregation and transmission readiness. A GSM modem communicates with the ESP32 to increase the reach and provide dependable data transfer. After then, another antenna transmits the data for long-distance communication. The setting of this gateway creates a strong connection inside the system, guaranteeing effective data flow from the riverside to the central server for additional processing and storage.

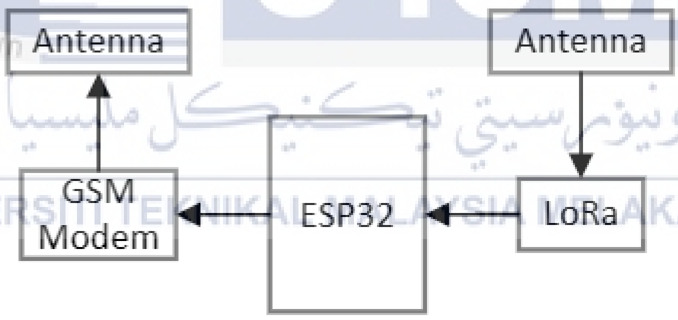

Figure 3.18: Gateway Hardware Architecture

3.5.1 ESP32

An essential component of this system is the ESP32, which is in charge of gathering data from sensors and wirelessly sending it to the central hub. For Internet of Things applications, the low-cost, low-power ESP32 microcontroller is perfect. Its dual-core processor, several input/output connectors, Bluetooth, Wi-Fi, and other features make it an adaptable platform for sensor networks [60]. The LoRa wireless protocol, which is perfect for low-power, long-range communication, is also compatible with the ESP32. The ESP32 in the gateway performs data preprocessing and aggregation before to sending the data to the central server. Incoming data streams from diverse sensors are arranged in this way, data integrity is maintained, and the data is ready for effective transmission via the GSM modem. The Flood Observatory System's real-time and precise monitoring goals are largely dependent on the ESP32's powerful processing capabilities.

Figure 3.19: ESP32

3.5.2 GSM Modem

An essential component of this system is the SIM900A GSM Modem, which is in charge of wirelessly relaying data to the central hub. The GSM modem SIM900A is a dual-band device that operates on DCS1800MHz and EGSM 900MHZ frequencies [61]. It is an inexpensive, low-power gadget that is perfect for Internet of Things uses. With a mobile sim, the module provides GPRS/GSM technology for communication. Additionally, the SIM900A GSM Modem has GPIO pins, status pins, I2C pins, display interface pins, and a keypad interface. The SIM900A GSM Modem component of the project will be in charge of wirelessly sending data to the central hub. Through the usage of a mobile sim, it will communicate using GPRS/GSM technology.

Figure 3.20: SIM900A GSM Modem

3.5.3 MQTT Broker

A lightweight messaging protocol called MQTT (Message Queuing Telemetry Transport) was created specifically for use in Internet of Things (IoT) settings. It is used to link gadgets and sensors to the internet so they can communicate to other systems and with each other. A server called MQTT Broker serves as the focal point for all MQTT messages as shown in Figure 3.21. It forwards communications to subscribers after receiving them from publishers. Any MQTT-based solution must include MQTT Broker as it offers the infrastructure required for message delivery and routing [62].

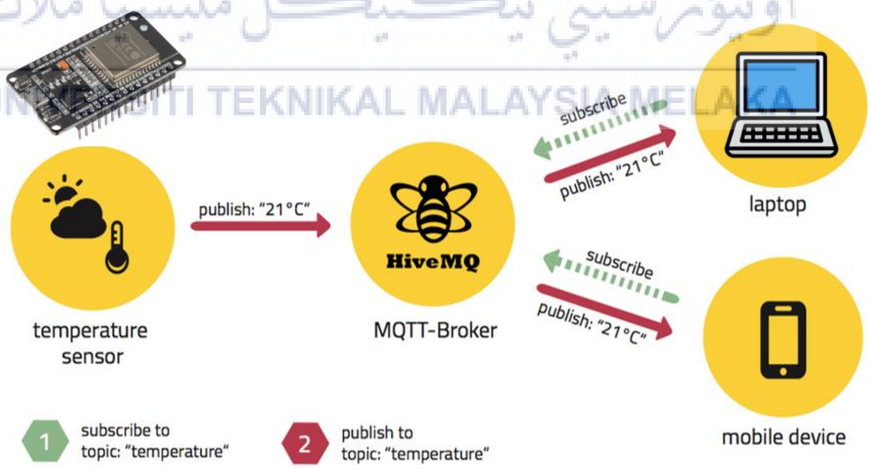

Figure 3.21: Example of Flow Data from Sensor to Device via MQTT-Broker

Among the many MQTT brokers used in Internet of Things applications is HIVEMQ. Large-scale IoT installations can benefit greatly from its extremely scalable and stable architecture. Numerous functionalities are supported by HIVEMQ, such as message routing, message persistence, and QoS (quality of service) levels. Additionally, it offers an online administration portal that lets administrators keep an eye on and control their MQTT Broker instance.

3.6 Analysis of LoRa Reception

The LoRa reception testing procedure flowchart shown in Figure 3.22 is a visual representation of the steps involved in testing the reception of the LoRa wireless communication technology for the flood observatory system project.

To analyse the LoRa reception, a testing was done at Persiaran Bukit Tambun Perdana, Durian Tunggal, Melaka. The antenna gain used are 2dbi and 5dbi antenna. The parameters measured are RSSI, SNR, and missing sequence. The testing ranges from 0 to 700 meters with a 100 meters increment.

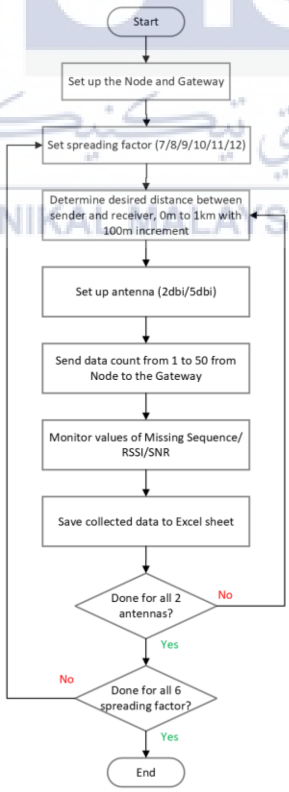

Figure 3.22: LoRa Reception Testing Procedure Flowchart

The procedure begins with setting up both the node, which is equipped with sensors and a LoRa transceiver, and the gateway that receives data from nodes. This setup is crucial for establishing a communication link. Following this initial setup, the spreading factor is set, ranging from 7 to 12 to test different ranges and data rates. A comprehensive test involving all spreading factors ensures that we identify an optimal balance between these variables.

Subsequently, the desired distance between sender (Node) and receiver (Gateway) is determined, ranging from 0m to 1km with increments of 100m. This step allows to assess how distance affects signal strength and data transmission quality. The next step involves setting up antennas with two different gains, 2dbi and 5dbi to evaluate their impact on signal reception under various environmental conditions. Data counts from 1 to 50 are then sent from Node to Gateway, this repetitive process ensures that we gather sufficient data for a reliable analysis.

Then the parameters of Missing Sequence/RSSI/SNR are observed meticulously. These parameters provide insights into packet loss, received signal strength indication, and signal-to-noise ratio respectively which are key metrics for evaluating wireless communication performance. All collected data are saved into an Excel sheet for further analysis, this structured storage facilitates easy retrieval and detailed examination of data patterns and anomalies.

The process iterates through all combinations of antenna types and spreading factors ensuring a comprehensive evaluation as shown in Figure 3.23. Once tests for both antenna types are complete, we proceed to check if all six spreading factors have been evaluated. If not, we loop back to set a new spreading factor until all have been assessed thoroughly. The data collected during testing is recorded systematically for detailed analysis later on.

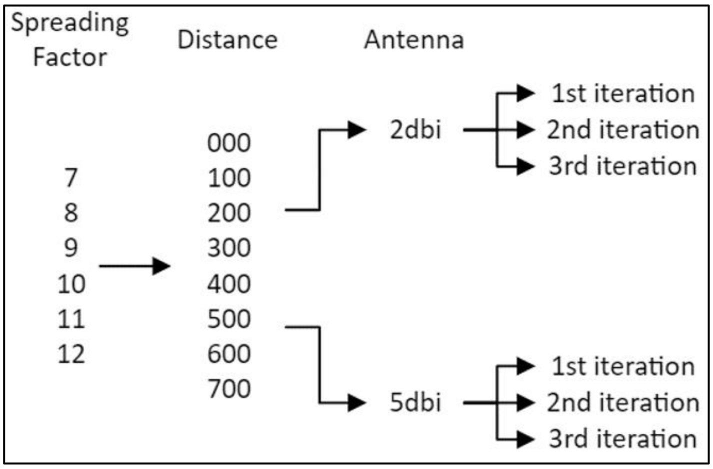

Figure 3.23: Spreading Factor, Distance, and Antenna Iterations

3.7 Sensor Node Operation

Figure 3.24 shows the operational flow of a sensor node for the project, Low Power LoRa Sensor Network for Flood Observatory System.

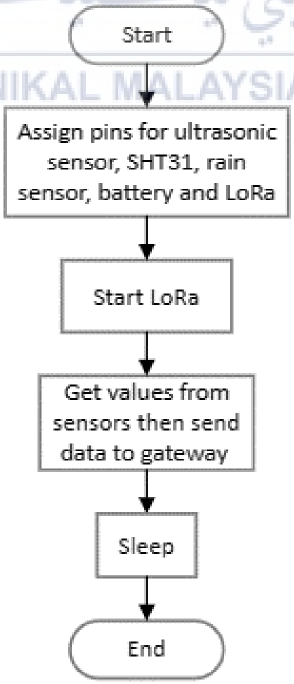

Figure 3.24: Sensor Node Operation

The process begins with initialization, where pins for the ultrasonic sensor, temperature and humidity sensor, rain sensor, battery, and LoRa are assigned. Following this setup, the LoRa communication is started to establish a connection for data transmission. The node then enters a data collection phase where it retrieves values from all connected sensors. This data is subsequently sent to the gateway for processing and analysis through LoRa. After completing data transmission, to conserve energy as per the project’s objective of being low-power, the sensor node enters sleep mode for one hour for the next round of measurements. Whenever it is raining during the sleep mode, the system will wake up instantly, retrieves sensor values, then transmit them to the gateway. Figure 3.25 shows the serial monitor from the sensor node operation.

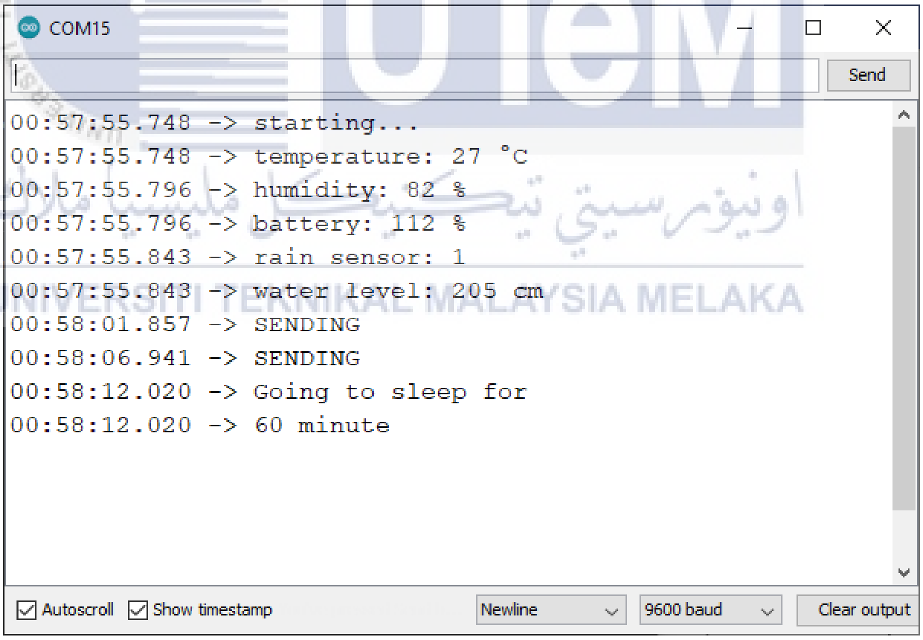

Figure 3.25: Sensor Node Output on Serial Monitor

3.8 Gateway Operation

Figure 3.26 shows the operational flow of the gateway for the project, Low Power LoRa Sensor Network for Flood Observatory System.

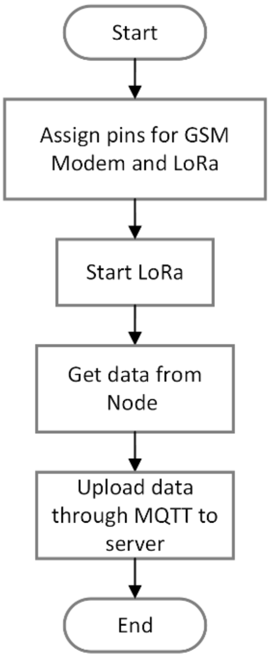

Figure 3.26: Gateway Operation

The gateway's initialization, which signifies the start of its data gathering and transmission procedures, starts the operating cycle. Critical components, such as the GSM modem for cellular communication and the LoRa module for wireless communication with sensor nodes, have pins allocated within the ESP32 microcontroller. After initialization, a communication link is established between the sensor nodes and the LoRa module. In order to receive data transmitted by the nodes, a dependable connection is ensured by this phase. Using the LoRa module, the gateway actively gathers data from the sensor nodes. Measurements of the water level, temperature, humidity, and rain status are all included in this data. The gateway then uses the Message Queuing Telemetry Transport (MQTT) protocol to transfer the gathered data to HiveMQ, a centralized server. The efficient and dependable transport of data to the server for additional processing and storing is ensured by this protocol. The gateway's current iteration comes to an end when the operating cycle ends. The gateway keeps up a steady and responsive data flow, prepared to start the next operational cycle. Figure 3.27 shows the output shows the serial monitor from the gateway operation while Figure 3.28 shows the output sent to HiveMQ.

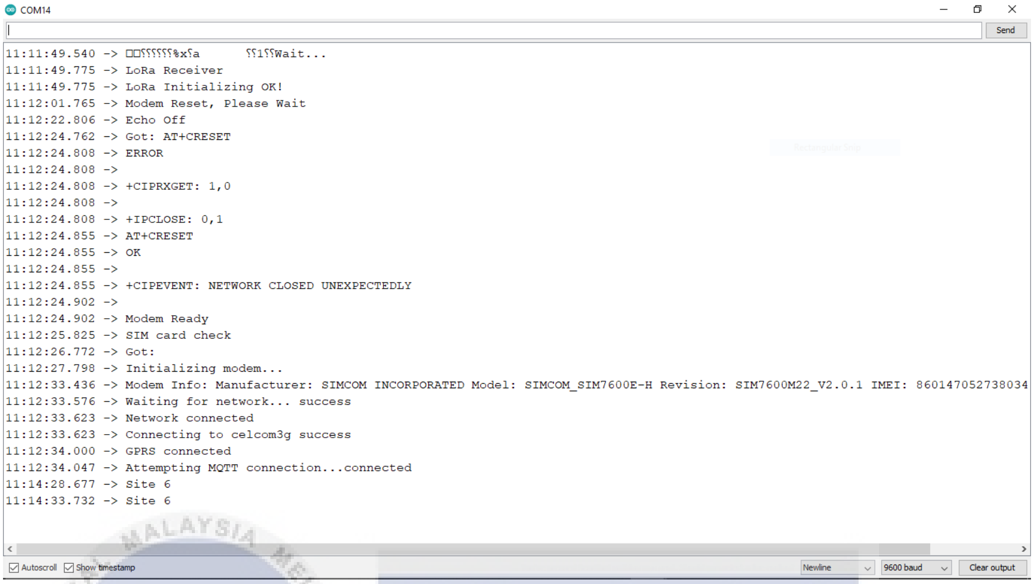

Figure 3.27: Gateway Output on Serial Monitor

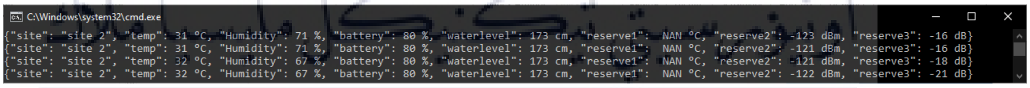

Figure 3.28: Gateway Output on Serial Monitor

CHAPTER 4

RESULTS AND DISCUSSION

This chapter dives into the outcomes and discussions stemming from the real-world implementation of the Flood Observatory System. This section unveils the concrete results obtained from testing the sensor nodes, gateway, and the overall system. This chapter is a crucial checkpoint, where the theoretical concepts transform into practical insights, offering a thorough analysis of how well our system works, its limitations, and possible improvements.

4.1 LoRa Reception Analysis

The testing was successfully done at Persiaran Bukit Tambun Perdana, Durian Tunggal, Melaka to analyse the LoRa reception. The antenna gain used are 2dbi and 5dbi antenna. The parameters measured are RSSI, SNR, and missing sequence. The testing ranges from 0 to 700 meters with 100 meters increment as shown in Figure 4.1.

Figure 4.1: Persiaran Bukit Tambun Perdana, Durian Tunggal, Melaka

4.1.1 Received Signal Strength (RSSI)

The test results, measuring Received Signal Strength (RSSI) for line-of-sight LoRa reception with a spreading factor of 7 and using 2dBi and 5dBi antennas, are illustrated in Figure 4.2.

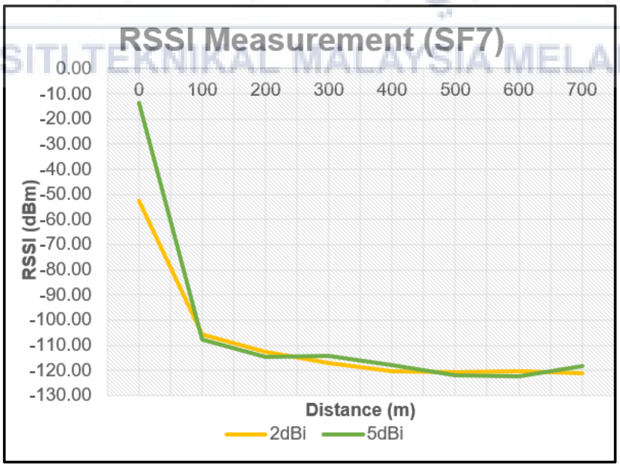

Figure 4.2: RSSI Measurement for Spreading Factor of 7

The graph titled "RSSI Measurement (SF7)" plots RSSI (dBm) on the y-axis ranging from 0 to -130 dBm and Distance (m) on the x-axis ranging from 0 to 700 meters. Two lines represent measurements using antennas with gains of 2dBi (yellow line) and 5dBi (green line). Both lines start at approximately -30 dBm at zero distance. The green line representing the 5dBi antenna remains above the yellow line throughout, indicating better signal strength at all distances measured. Signal strength decreases as distance increases for both antennas but is more noticeable with the 2dBi antenna. The RSSI Measurement graph for SF7 shows that the 5dBi antenna performs significantly better in terms of signal strength compared to the 2dBi antenna over a line-of-sight distance. The 5dBi antenna maintains a higher RSSI value across all distances, indicating stronger signal reception and potentially more reliable data transmission for the system. This could lead to enhanced performance in real-time monitoring and data analysis, especially in challenging environmental conditions during floods.

4.1.2 Signal-to-Noise (SNR) Ratio

Figure 4.3 depicts the test outcomes, which assess the Signal-to-Noise Ratio (SNR) for LoRa reception in line-of-sight conditions, employing spreading factor 7 and utilising antennas with gains of 2dBi and 5dBi.

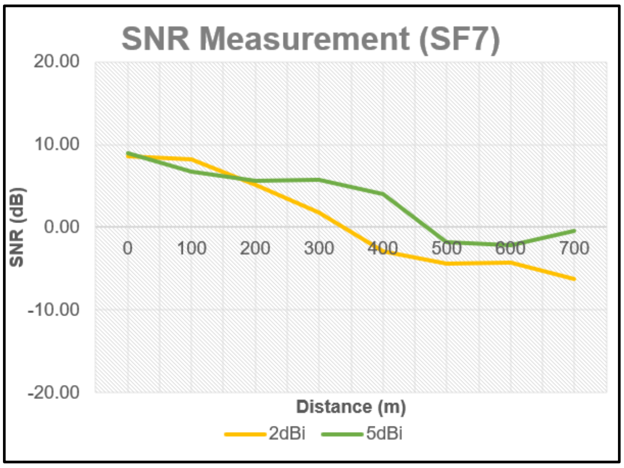

Figure 4.3: SNR Measurement for Spreading Factor of 7

The SNR Measurement graph for SF7 shows that both 2dBi and 5dBi antennas exhibit a decrease in signal-to-noise ratio (SNR) as the distance increases. However, the 5dBi antenna maintains a higher SNR compared to the 2dBi antenna across all distances. This discovery highlights an important realization, using a 5dBi antenna is more beneficial when attempting to maintain connection quality over long distances. The 5dBi antenna is a more dependable option for sustaining strong communication links in situations when distance is a crucial element, as seen by the greater SNR it maintains, which also suggests a better signal quality. The comprehensive SNR analysis offers helpful advice for choosing an antenna by giving a realistic grasp of how various antennas function in various scenarios.

4.1.3 Missing Sequence (MS)

Figure 4.4 illustrates the test results evaluating the Missing Sequence (MS) for LoRa reception in optimal line-of-sight conditions, utilising a spreading factor of 7 and antennas with gains of 2dBi and 5dBi.

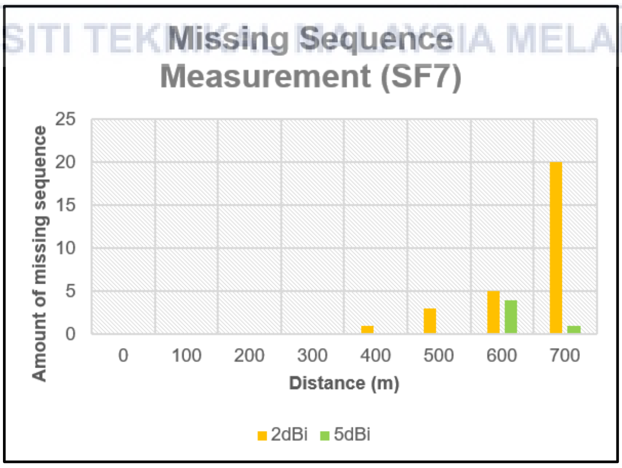

Figure 4.4: Missing Sequence Measurement for Spreading Factor of 7

By analysing the testing results, it is observed that the missing sequence increases with distance for both 2dBi and 5dBi antennas. However, the 5dBi antenna performs significantly better at longer distances. The x-axis represents distance in meters ranging from 0 to 700m. The y-axis represents the amount of missing sequence ranging from 0 to above 20. For both antennas, as distance increases, the amount of missing sequence increases at varying rates. At shorter distances (up to around 500m), there are minimal differences between both antennas' performance. However, at longer distances (600m and especially at 700m), there is a significant increase in missing sequences for the 2dBi antenna indicating poor reception quality while the increase is moderate for the 5dbi antenna. This data is crucial for the project as it helps in optimising the placement of sensor nodes and selecting appropriate antennas to ensure reliable data transmission over long distances.

4.1.4 Changing Spreading Factor

There are discernible trends in the Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), and Missing Sequence (MS) data when the spreading factor is changed to 10 as shown in Figure 4.5, Figure 4.6, and Figure 4.7 respectively.

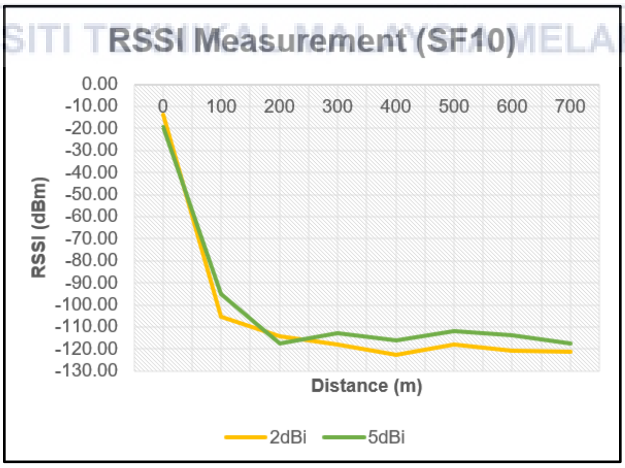

Figure 4.5: RSSI Measurement for Spreading Factor of 10

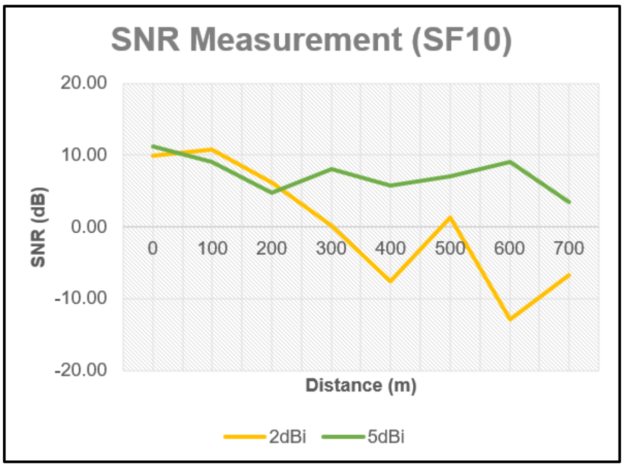

Figure 4.6: SNR Measurement for Spreading Factor of 10

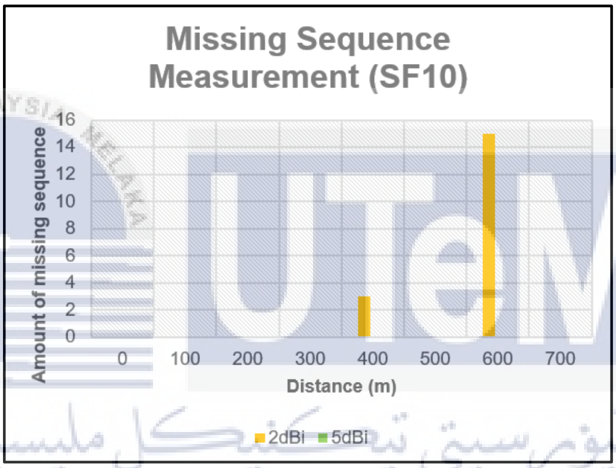

Figure 4.7: Missing Sequence Measurement for Spreading Factor of 10

The higher spreading factor is the cause of these variances. Generally, higher spreading factors lead to lower data rate but better signal resilience. As a result, greater RSSI values, which suggest stronger signal reception, is expected. Concurrently, the improved signal quality may lead to an improvement in the SNR, which would be a benefit of a larger spreading factor. It is important to remember, too, that a greater spreading factor may result in higher latency and perhaps an increase in the number of missing sequences since the system requires more time to analyse and send data. The interaction of these variables highlights the trade-offs related to spreading factor modifications, impacting the effectiveness and quality of communication in LoRa networks. This information can be useful for designing the “Low Power LoRa Sensor Network for Flood Observatory System” and selecting the appropriate antenna for the system.

4.2 Project Deployment and Infrastructure Setup

The Flood Observatory System (FOS) is deployed at Jalan Pulau Nibong, Melaka, shown in Figure 4.8. It also includes building a robust infrastructure in addition to the careful design of sensor nodes and gateways. The thoughtful arrangement of these elements in relation to Jalan Pulau Nibong, Melaka, highlights the critical role that geographical considerations play in the realization of an effective flood monitoring system.

Figure 4.8: Jalan Pulau Nibong, Melaka

4.2.1 Sensor Node

The completed sensor node for measuring river water levels is shown in Figure 4.9. The sensor node is carefully built on an acrylic sheet and enclosed in a robust metal housing for stability and accuracy. This arrangement is purposefully designed to endure environmental challenges while precisely gathering water level data. The sensor node is prepared to record the data required for efficient flood monitoring.

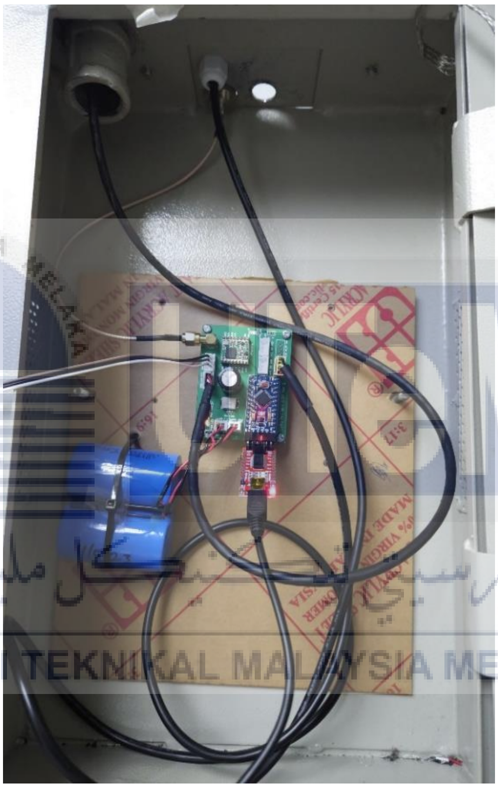

Figure 4.9: Sensor Node Casing

The sensor node's adaptable placement for measuring river water level is shown in Figure 4.10. The sensor node on the left was positioned strategically atop a bridge to highlight its adaptability to work at high elevations. The sensor node near the riverside on the right illustrates how it may be installed at ground level. This provides an overview of the many ways in which the sensor node intended for river water level measurement may be deployed.

Figure 4.10: Location of Site 1 on the Left and Site 2 on the Right

The operating distances, which are essential for dependable LoRa data transfer, between the sensor nodes and the gateway are shown in Figure 4.11. The first image shows that, despite being 473 meters away from the gateway, Sensor Node at Site 1 can sustain a strong connection. The second picture shows Sensor Node at Site 2 taken closer to the gateway, 193 meters away. These images highlight the system's capacity to guarantee smooth data reception and demonstrate how well it can sustain communication across a range of distances.

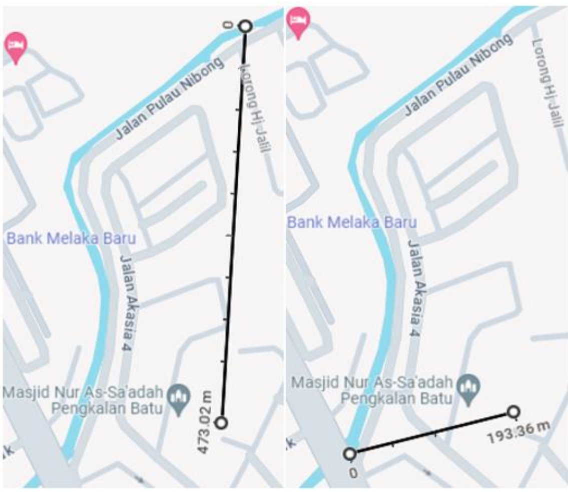

Figure 4.11: Distance of Site 1 on the Left to Gateway and Site 2 on the Right

4.2.2 Gateway

The completed gateway is shown in Figure 4.12, carefully put together inside a protective case, ready to accept critical data from sensor nodes. In addition to providing protection from the weather, the casing strengthens the structural integrity of the gateway and ensures long-term operating effectiveness.

Figure 4.12: Gateway Node Casing

Figure 4.13 captures the gateway strategically positioned at Masjid Nur As-Sa'adah, signifying a key deployment site for the flood monitoring system. This location holds strategic importance as a central hub for the flood monitoring system, positioned to receive and process crucial data transmitted by sensor nodes.

Figure 4.13: Gateway Located at Masjid Nur As-Sa'adah

4.3 IoT Dashboard

The IoT Dashboard displayed in Figure 4.14, Figure 4.15, Figure 4.16, and Figure 4.17 is a user interface for real-time monitoring and data analysis of the flood situation.

Figure 4.14: Front Page of the Dashboard

The dashboard provides a visual representation of the sensor network and also includes textual information on the right side, explaining the Flood Observatory System's objectives and functionalities. The system is designed to capture real-time water level trends in flood-prone areas, offering accurate and timely information for making informed decisions, improving emergency management, and mitigating the impact of floods on communities and infrastructure as well as demonstrating the system's commercialisation potential for various applications and industries.

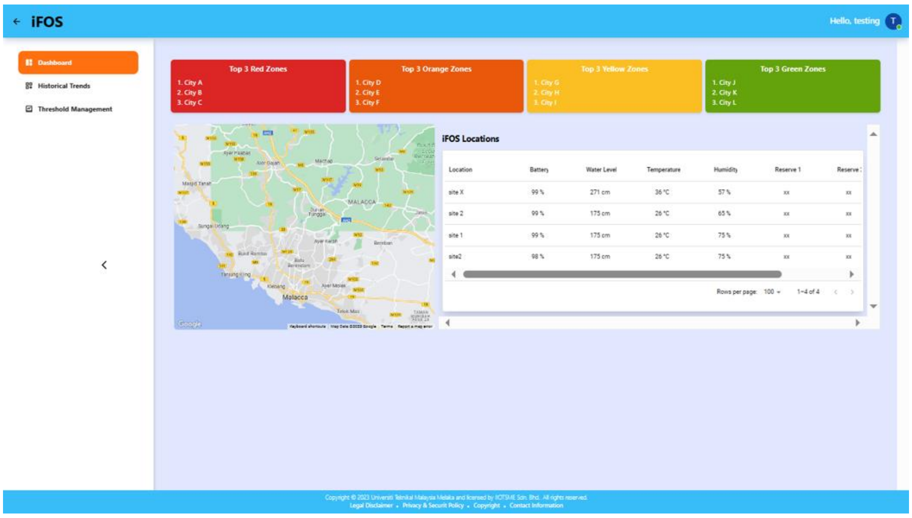

Figure 4.15: Main Page of the Dashboard

On the left side, there are options to view the dashboard, historical trends, and threshold management. At the top, there are sections displaying information about top safe zones, danger zones, medium zones, and green zones based on the data collected. In the centre is a map displaying sensor locations. It helps in visualizing geographical distribution of sensors and their readings. Beside the map is a table that lists each sensor's location with corresponding data like battery level, water level, temperature and humidity. This allows users to quickly assess each sensor's status and readings.

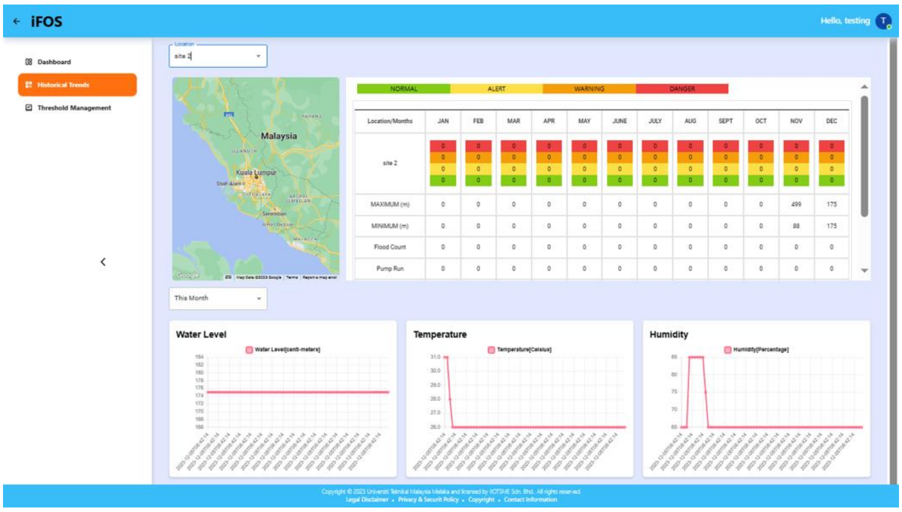

Figure 4.16: Historical Trends of the Dashboard

It features a map on the left side, showing the geographical location of Malaysia, indicating sensor locations. On the right, there's a table with monthly data for different locations, color-coded to represent various states like normal, alert, warning, and danger based on water levels or other parameters. Below this table are three graphs displaying water level, temperature, and humidity over time.

Figure 4.17: Threshold Management of the Dashboard

The IoT Dashboard displayed in the figure is a user interface for managing and monitoring the thresholds of various sensors deployed in the "Low Power LoRa Sensor Network for Flood Observatory System. The dashboard provides a clear and concise table, "Threshold Table", where users can view and manage threshold values for different locations or sensor nodes. The main area displays a table with columns for “Location”, “Normal Threshold”, “Alert Threshold”, “Warning Threshold”, and “Danger Threshold”. Each row corresponds to a specific sensor node identified by its location. The table allows users to set distinct threshold values for normal operation, alert situations, warnings, and danger levels. These thresholds are crucial for real-time monitoring and early warning systems in flood-prone areas.

4.4 Battery Life of Sensor Nodes

This section assesses the flood observatory system's sensor nodes' battery life, paying particular attention to the effects of employing a spreading factor of 12. The study takes into account the important criteria listed in Table 4.1, such as battery capacity, the length of the active and sleep modes, and the current consumed in each case.

Table 4.1: Sensor Node Parameters

Parameters	**Value**
Battery Capacity	19000 mAh
Active Duration	20 seconds
Active Mode Current	11 mA
Sleep Mode Current	5.6 mA
Sleep Duration	1 hour

$$Hourly\ Current\ Consumption \approx \frac{11mA \times 20}{3600} + 5.6mA$$

$$\approx 5.66mA$$

$$Battery\ Life \approx \frac{19000mAh}{5.66mA}$$

$$\approx 3356.89\ Hours$$

$$\approx 140\ Days$$

$$\approx 0.38\ Years$$

With a spreading factor of 12 and the above values, the estimated battery life is 3356.89 hours, or around 140 days or 0.38 years. This evaluation is based on the hourly current consumption calculation, which takes the length of sleep and the duration of activity into account.

In this case, a shorter battery life is correlated with a larger spreading factor. This discovery is consistent with results from M. S. Philip and P. Singh's publication "Energy Consumption Evaluation of LoRa Sensor Nodes in Wireless Sensor Network" [62]. According to the research, there is a proportional increase in energy consumption when the spreading factor rises, as seen in Figure 4.18, which influences the LoRa sensor nodes' total battery life. In sensor network design and optimization, the inverse connection between spreading factor and battery life is crucial to consider.

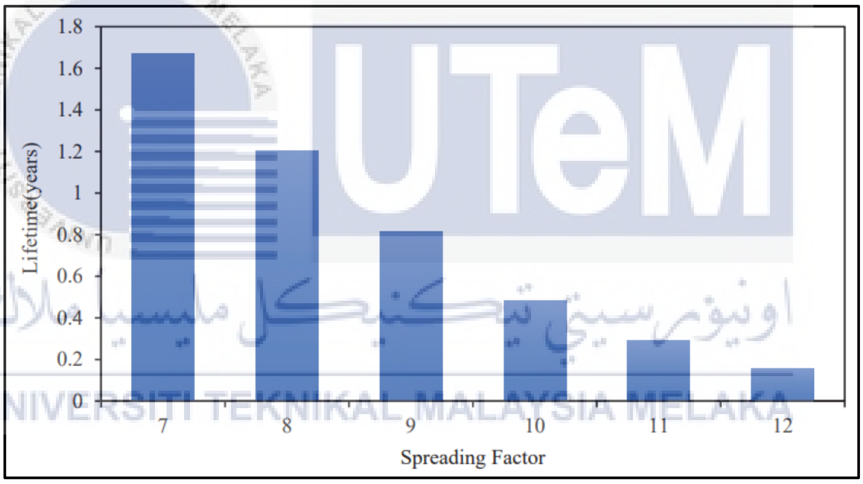

Figure 4.18: Relationship between Lifetime and Spreading Factor [63]

This research emphasizes how crucial it is to choose a spreading factor that balances communication range and energy efficiency in LoRa-based systems. Higher spreading factors have the potential to expand communication range, but they also increase energy consumption, thus they must be carefully considered and optimized depending on the particular needs of the application.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

The Flood Observatory System's creation, deployment, and analysis process have yielded significant insights about the efficacy and potential of the deployed technology.

The analysis of LoRa reception that was done showed that the implementation employing a 5dBi antenna consistently performed better than the 2dBi antenna, with an emphasis on RSSI, SNR, and Missing Sequence metrics. This is in direct line with the objective of evaluating system performance in practical situations. This explores the effects of spreading factor fluctuations as well, providing insight into the complex trade-off between energy efficiency and signal durability.

The implementation of the project in Jalan Pulau Nibong, Melaka, demonstrated the flexibility of the sensor nodes and the resilience of the infrastructure. The gateway's critical role in data processing and receiving was highlighted by its strategic placement, which enhanced the Flood Observatory System's overall effectiveness.

The analysis of the battery life of the sensor nodes highlighted the crucial connection between energy efficiency, communication range, and spreading factor. This is in line with the primary objective of making the system as efficient and long-lasting as possible.

The Flood Observatory System supports international efforts for innovation and climate action by being in line with Sustainable Development Goals (SDGs) 9 and 13. Specifically, SDG 9, which emphasizes technical solutions to social challenges, is directly addressed by the creation of an inventive, low-power LoRa sensor network for flood observatory systems. The project supports efforts to manage and avoid disasters by offering a dependable and effective flood detection technology, which is in line with the larger goals of SDG 9.

Additionally, by reducing the damage caused by floods, especially in vulnerable developing nations, the system contributes to SDG 13. The LoRa-based sensor network's low power consumption allows for prolonged operation in remote locations without the need for regular maintenance or battery changes. This lessens the system's impact on the environment while simultaneously improving the system's sustainability and dependability. The initiative supports international efforts for a sustainable and resilient future by demonstrating an intentional effort to incorporate environmental issues into technical solutions.

In summary, the study not only achieved its goals but also created new opportunities for investigation. The study's conclusions have a big impact on the field of flood monitoring systems as well as more general uses of LoRa and other Low Power Wide Area Networks (LPWANs).

5.2 Future Works

Even though the Flood Observatory System has shown encouraging results, there are still a number of areas that might use further investigation and development.

5.2.1 Enhanced Antenna Technology

Examining and using cutting-edge antenna technology may improve the system's functionality even more. Even more dependable and strong communication lines could be achieved by investigating directional antennas or adaptive antenna systems, particularly in demanding and dynamic environments.

5.2.2 Machine Learning Integration

The system's predictive powers could be improved by incorporating machine learning algorithms to analyse and forecast flood patterns based on the gathered data. More proactive approaches to flood response and preparedness may be made possible by this integration.

5.2.3 Scalability and Network Optimization

As the Flood Observatory System expands, optimising the network architecture and communication protocols will become paramount. Addressing challenges related to scalability, data management, and network congestion will be crucial for ensuring seamless operation in larger geographic areas.

5.2.4 Community Engagement and User Interface Refinement

Optimising the network architecture and communication protocols will become critical as the Flood Observatory System grows. It would be essential to tackle issues pertaining to scalability, data management, and network congestion to guarantee uninterrupted functioning across extended geographical regions.

5.2.5 Integration with Existing Warning Systems

Cooperation with current emergency response plans and flood warning systems could increase the overall resilience of areas that are vulnerable to flooding. Having a smooth integration with current systems guarantees a thorough approach to flood control.

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