東海大學

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碩士論文

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運用 LoRa 網路建立校園空氣監測系統
The Implementation of a Campus Air Monitoring System Using LoRa Network

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經本委員會審查，符合碩士學位論文標準。

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摘要

我們都知道電力與通訊網路的距離會影響監測站部署的速度，本論文的終端感測器透過 LoRa 低功耗網路傳輸資料，提供我們快速部署的監測站，讓我們容易的收集詳細的資料，LoRa 低功耗網路適合在空曠地區與多建築物的區域中使用且蒐集資料傳輸穩定可靠。實驗規劃於學校設置六個監測位置分布室內與室外，使用 PM2.5 感測器、二氧化碳濃度感測器與溫度濕度感測器，每分鐘回傳資料到系統資料庫透過 OSM 地圖 (Open Street Map) 的顯示方式可以讓我們即時的監控東海大學校園內的監測站與周邊地區的監測站的空氣品質的狀況，我們同時也收集行政院環境保護署的開放資料，提供校園生活圈空氣品質資料完整性，歷史資料將會收集建置呈現在 ELK Stack 的 Kibana 繪製視覺化圖形提供分析與區域比較，最後結合互動式介面，提供給決策者參考運用。也進行校園內 LoRa 性能的實驗與評估，這一套 LoRa 低功耗網路與即時監測系統容易套用到其他相關環境數據收集的系統與即時的分析與評估。

關鍵字: LoRa，物聯網，低功耗網路，環境監控，空氣汙染.

Abstract

We all know that the distance between the power and communication network will affect the speed of the monitoring station deployment. The terminal sensor of this paper transmits data through Laura low power network and provides our rapid deployment monitoring station so that we can easily collect detailed Data, LORA low-power network suitable for use in the open area and multi-building area and to collect data transmission is stable and reliable. The experiment is planned to set up six monitoring locations in the school. Indoor and outdoor use, using PM2.5 sensor, CO2 concentration sensor and temperature and humidity sensor, every minute back to the system database through the OSM map (Open Street Map) Shows how we can monitor the air quality of the monitoring stations in the Donghai University campus and the surrounding areas. We also collect open information from the Environmental Protection Department of the Executive Yuan to provide information on the integrity of the air quality of the campus life , Historical data will be collected and created in ELK Stack. Kibana Draw Visual Graphics provides analysis with regional comparisons, and finally combines interactive interfaces for use by decision makers. Also conducted on the campus LORA performance of the experiment and evaluation, this set of LORA low-power network and real-time monitoring system is easy to apply to other related environmental data collection system and real-time analysis and evaluation.

Keywords: LoRa, Internet of Things, Low Power Network, Environmental Monitoring, Air Pollution.

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這兩年在東海大學的研究生活讓我受益良多，在研究所的教授教導下，讓我對於研究的領域更加精進，能實際將這些技術應用於生活當中，並完成一篇論文與系統。

能完成這篇論文必須感謝很多人，首先，非常感謝我的共同指導教授楊朝棟教授，我從修平科技大學電機工程系畢業後，來到東海資工所成為我的共同指導教授，除了研究的方面的教導，楊老師提供了一個很好的學習環境讓我學習與提供實驗所需要的設備，有了這些資源才能讓我完成這篇論文，謝謝老師這幾年的鼓勵與幫忙，使我能找到解決的辦法繼續作下去。此外，還要感謝我的指導教授劉榮春教授，提供了一個很好的實驗室讓我學習，對我的論文提供了很多建議與幫忙，讓我的論文更加完整。

特別感謝口試委員姜自強教授、張玉山教授以及時文中教授特地撥空前來參加我的論文口試，在論文口試時提出很多論文的盲點和非常多寶貴的意見，讓我能將論文修改得更加完整，學生衷心感謝。我也要感謝我實驗室的學長姐、學弟妹以及最重要的同學們，這兩年的生活一路走來，如果不是大家互相幫忙，要完成這麼多事情是不太可能的，因為有大家的陪伴，讓我在這兩年的生活中，增添許多快樂。

最後要感謝我的父母，如果沒有他們的支持與支助我沒辦法完研究所的學業，因為有父母對我的關心與幫助，讓我的研究得以成功，由衷感謝一路陪伴的所有人。

東海大學資訊工程學系 HPC 高效能計算實驗室　林育陞 106 年 07 月

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Chapter 1

Introduction

1.1 Motivation

We all know that haze is harmful to our health, Taiwan's air pollution comes from domestic thermal power plants and industrial production of pollutants, as well as neighboring industrial production and dust diffusion [1], which power communication network will affect the construction of the monitoring station Speed, we use a low-power LoRa network with long-distance transmission function [2], power supply using solar charging equipment, to achieve self-contained erection sites without power constraints, today's low-power wide area network technology to solve the power problem We can use the low-power LoRa network to quickly set up monitoring stations, and can be transmitted remotely. Usually we can observe the government air monitoring station is not intensive, and in order to be able to immediately monitor the campus air data, we set up a number of monitoring stations.

1.2 Contributions

This article through the LoRa transmission of information per minute by monitoring the status of aviation products for the East China Sea students to provide air quality and weather conditions, our monitoring station rapid deployment of details, LoRa signal affected by the building less [3] , The signal transmission distance is suitable for the East China Sea University of open expansion of the campus to use, and LoRa itself is the use of star network architecture Figure 1.1, each node linked to each other, a single node failure will not lead To network interruption, transmission quality is stable and reliable, together with our established monitoring station Can be quickly to build In different locations, the monitoring station itself is maintained on the low cost, in the future when the expansion, at any time to increase the different sensors can be customized according to different needs of the type.

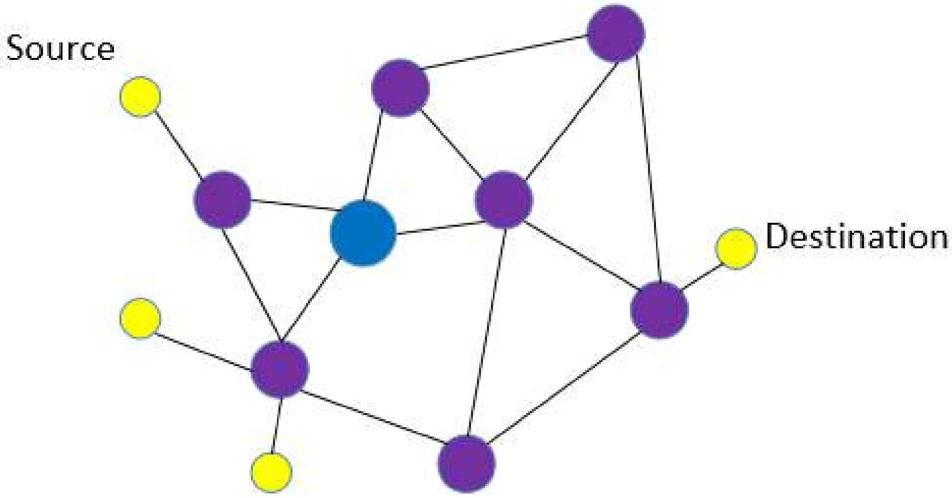


FIGURE 1.1: LoRa star network

1.3 Thesis Organization

In Chapter 2, we will introduce some background and related works, including real-time display, large data, IoT, ThingSpeak, Open Street Map and Highcharts data charts. Chapter 3 shows the system architecture and how to collect airborne data. Chapter 4 has experimental results and experimental results. Finally, in Chapter 5, we will discuss and summarize future work.

Chapter 2

Backgroud Review and Related Works

2.1 LoRa Low Power Consumption Network and Real-Time Display System

2.1.1 LoRa Low Power Consumption Network

LoRa means ”remote” meaning, is extended by the LoRa Union remote wireless communication system. The system is designed for long-life battery-powered equipment that is critical to energy consumption. LoRa basic star network topology, each node directly with the base station communication. The communication link is highly asymmetric between the uplink and the downlink connection. The uplink is using a significant amount of data to send the measurement data, while the downlink is primarily used for acknowledgment in many applications.

2.1.2 LoRa Network Architecture

The commonly used LoRa network is a ”star-like network”, which consists of at least three different types of devices. The basic architecture of the LoRaWAN network is that the terminal uses LoRa and LoRaWAN to communicate with the gateway. The gateway forwards the data of the terminal device from the device to the web server through a high throughput interface (mostly 4G, 3G or Ethernet). The gateway acts only as a two-way relay or protocol converter, and the network server is responsible for decoding the packets by the terminal and generating packets that should be sent back to the terminal.

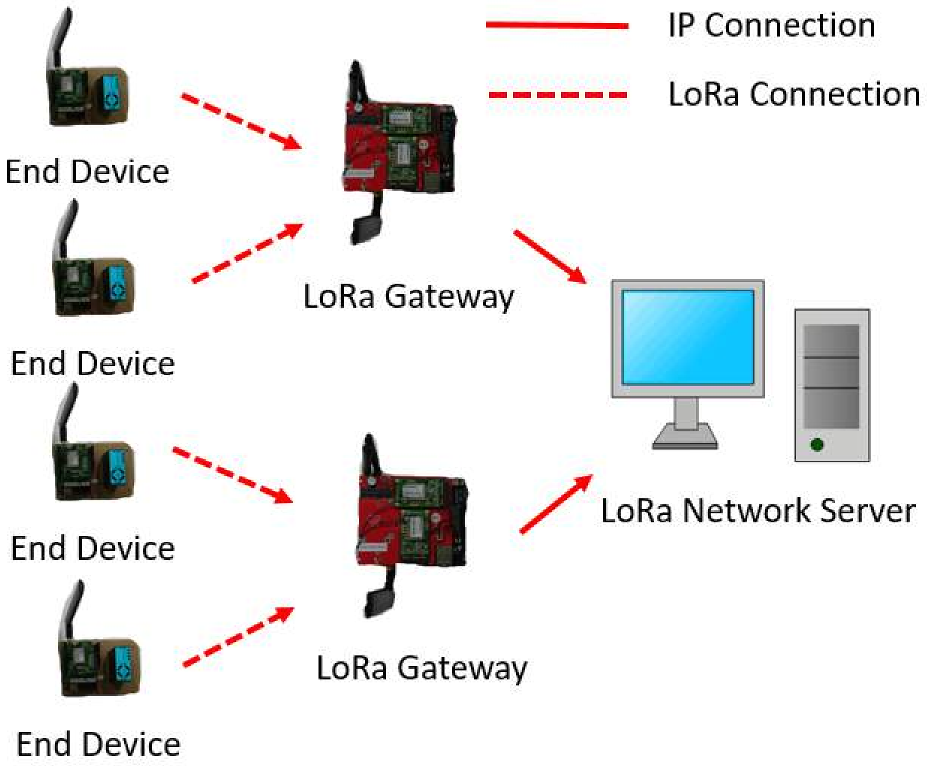


FIGURE 2.1: Composed of LoRa Network Three Different Types of Equipment

2.1.3 Real-Time Display System

Our real-time display system is through the OSM map (Open Street Map), select the OSM map, because the OSM map in the application than Google Map flexible, you can display a variety of information. OSM map (Open Street Map) location pin, as shown 2.2:

FIGURE 2.2: Use the OSM map (Open Street Map) to place a pushpin on the map

2.2 Arduino Development Board and sensor

2.2.1 Arduino Development

Arduino's appearance was due to the fact that students of a teacher at a high-tech design school in Italy often complained that a cheap and easy-to-use microprocessor controller could not be found. The teacher named Massimo Banzi worked with another David Cuartielles Spanish chip engineer Discuss and decide to design their own circuit boards, and introduce students David Mellis for the circuit board design and development language, then they will this circuit board named ”Arduino”.

Arduino is an open hardware platform based on the open-source spirit, which uses Atmel AVR (Note 1) single-chip, its language similar to Java, C / C + + language development environment.

AN OPEN PROJECT WRITTEN, DEBUGGED, AND SUPPORTED BY ARDUINO.CC AND THE ARDUINO COMMUNITY WORLDWIDE

LEARN MORE ABOUT THE CONTRIBUTORS OF ARDUINO.CC on arduino.cc/credits

FIGURE 2.3: Arduino Logo

2.2.2 PM2.5 temperature and humidity sensor

PMS5003T is a 3 in 1 sensor Figure 2.4, the use of laser digital particle concentration sensor to determine the level of particulate matter, the number of particles, the sensor is quite accurate, and support the monitoring of temperature and humidity.

FIGURE 2.4: Platower PMS5003T PM2.5 temperature and humidity sensor

2.3 ELK Stack (Elasticsearch + Logstash + Kibana)

2.3.1 Elasticsearch

Elasticsearch is a very useful information search engine. As long as the data can be fed to him (no limit is logstash), you can the next parameter to search for the required information. And he will spit out the relevant JSON reply, if the information has been fed to him, it can be used as a database.

Elasticsearch comes from the first open source project Compass library by author ShayBanon, and the original purpose of the Java library was simply to make a recipe search engine for Shay's chef's wife. 2010, Elasticsearch officially released. Has become the most popular Java project on GitHub. At the beginning of 2015, Elasticsearch held its first global user conference, Elastic ON 15. Many IT giants have sponsored the participants, speech. After the meeting, Elasticsearch announced the renaming of Elastic, the company's official website has become http: This means that Elasticsearch development direction, no longer limited to the search business, that is, ELKstack and other machine materials and IT services to become the official pay more attention to the field.

2.3.2 Logstash

Logstash is a lightweight log collection and processing framework that allows you to easily collect and diversify your logs and customize them, then transfer them to a specific location, such as a server or file. Of course it can appear alone, as a log collection software, you can collect logs to a variety of storage systems or temporary transit systems such as MySQL, redis, kakfa, HDFS, lucene, solr, etc. are not necessarily ElasticSearch.

The Logstash project was born on August 2, 2009. Its author is the world's leading operation and maintenance engineers Jordan Xisai (JordanSissel), Logstash also from the beginning of 2011 to enter the intensive period and continue to this day. As a well-known product, Logstash's presence has appeared on Sysadmin-Weekly many times, and it has become an open source project for comparison with its Elasticsearch and Kibana directly to the commercial product Splunk. In 2013, Logstash was acquired by Elasticsearch, and ELKstack officially became the official language (although not officially named). This book is also one of the most talked about in the past two years, with three financing more than $100 million. With the joint efforts of Elasticsearch developers, Logstash's release mechanism, plug-in architecture is more scientific and reasonable.

2.3.3 Kibana

Kibana provides the log-friendly web interface for Logstash and ElasticSearch to help you aggregate, analyze and search important data logs.

Logstash used to bring a particularly simple Logstash-web to view the data in the ES. It's function is too simple, so RashidKhan wrote a better use of PHP web, called Kibana. Soon RashidKhan rewritten Kibana with Ruby, also known as Kibana2. Because Logstash is also written in Ruby, so Kibana can replace the original that simple Logstash-web page. At present we see the angularjs version of Kibana, in fact, the original name is Elasticsearch-dashboard, but with the Kibana2 author is the same person, in other words, Kibana than Logstash has long been into the Elasticsearch name. This project was renamed Kibana in February 2014, also known as Kibana3. The new design all of a sudden swept DevOps sector.

2.4 Related Works

The remote and low-power network of Internet of Things is an important subject of future urban development. Augustine et al. [2]were analyzed and evaluated in 2016, providing an overview of LoRa and an in-depth analysis of its functional components. Physical and data link layer performance is evaluated by field testing and simulation. Based on analysis and evaluation, some possible solutions for performance enhancement are proposed.

Juha Petäjäjärvi et al. [3]Tested the performance of the LoRa interior in 2016 at the University of Oulu, where there were more than 570 meters north-east of the East Asia 320 meters west of the main area of the main area using 14 dBm of transmit power and 868 MHz ISM band 12 Of the maximum spreading factor, the entire campus area can be covered. The measured packet delivery rate was 96.7%, with no acknowledgment and retransmission.

Andrea Zanella et al. [4]Published the Smart City website in 2014, focusing on the City Internet Internet of Things system, which is a comprehensive survey of urban Internet technologies, protocols and architectures, providing technical solutions and best practice guidelines.

Pitarma, Rui et al. [5]In 2017 study pointed out the impact of indoor air quality on the pathogenesis of many nonspecific symptoms, characterized by ”sick building syndrome” involving skin, upper and lower respiratory tracts, eyes and nervous system, and many building-related disease. Indoor air quality (IAQ) is considered an important factor in passenger health and comfort. Most of the monitoring systems currently available are very expensive and only allow random samples to be collected. This work describes the low cost indoor air quality monitoring wireless sensor network system (IAQ) developed using Arduino, XBee modules and micro sensors for real-time storage and provision of monitoring data on the portal.

M. Lauridsen et al. [6] Published in March 2017, Interference Measurements in the European 868 MHz ISM Band with Focus on LoRa and SigFox, which referred to the LoRa868 MHz ISM band interference test, with five different locations; shopping, commercial Parks, hospital complexes, industrial areas and residential areas, where the 865-868 MHz band is occupied by strong RFID interrogator signals, which may prevent LoRa and SigFox deployments and need to switch channels to avoid this problem.

D. M. Hernandez et al. [7]Published the Energy and coverage study of LPWAS schemes for Industry 4.0 in May 2017, which mentions that low-power broadband networks (LPWAN) are becoming one of the major components of the Industrial Internet of Things (IIoT). According to their experimental results, the combined network topology can cover relatively large urban areas as well as the indoor environment, using energy-efficient transmission. In the IoT sensor 1 hour to pass a data can run independently for a long period of time, can reach 4 years.

T. Peter et al. [8]Published a paper on the performance and analysis of LoRa in Sept. 2016, where the experiments were performed and analyzed. LoRa technology offers excellent outdoor coverage results in urban or rural areas, with very low frame losses (about 3%) under optimal conditions.

Chapter 3

System Design and Implementation

This section describes LoRa system architecture and implementation of low power networks, campus air pollution monitoring system is established. And low power consumption of the system is based on sensor network architecture, beginning with environmental sensors to collect data, and then returns the data processing and rendering, efficient access to real-time air quality information and real-time display.In addition, the system supports historical data query and analysis. For your convenience, we chose the campus of Tunghai University in the lab environment, a series of environmental experiments. Finally, the proposed system with a user-friendly graphical interface.

3.1 System Design

We refer to [4] plan to set up six monitoring locations in the school (Table 3.1) overall structure Figure 3.1, the sensor distribution indoor and outdoor, outdoor deployment of temperature and humidity sensors and PM2.5, indoor and outdoor temperature and humidity Measuring device with carbon dioxide sensor. Outdoor air quality is mainly collected in the city of outdoor temperature and humidity as well as the concentration of PM2.5 in the air to observe the source of health hazards [5], indoor air quality to collect temperature and humidity and carbon dioxide concentration. in-stalled in the top floor of the location and indoor, monitoring stations using Arduino integrated sensors and modules with solar charge and discharge control panel, outdoor collection environment temperature and humidity, PM2.5, Outdoor environment, the temperature and humidity, carbon dioxide, by LoRa will be the value of the frequency per minute upload ThingSpeak website Figure 3.2, and then by the JSOUP ThingSpeak in the information into the database, the use of Open Street Map presentation of real-time data , Many of the information will be collected and built on the web page as well as ELK Stack's Kibana drawing visualization graphics to complete the LoRa low-power network to build a campus air pollution monitoring system.

Table 3.1: The monitoring station places the position

ID	location	Description
A	Technology building	Monitor road air quality
B	Library	Monitor the library room learning room air quality
C	Language Hall	Monitor air quality on campus
D	Restaurant	Monitor the air quality of the sports area on campus
E	School gate	Monitor road air quality
F	Pasture	Monitor the air quality of industrial areas

3.2 System Services

Based on the architecture in the proposed system, this section describes the main services such as data collection, data real-time monitoring and data analysis. The details of these services are described below:

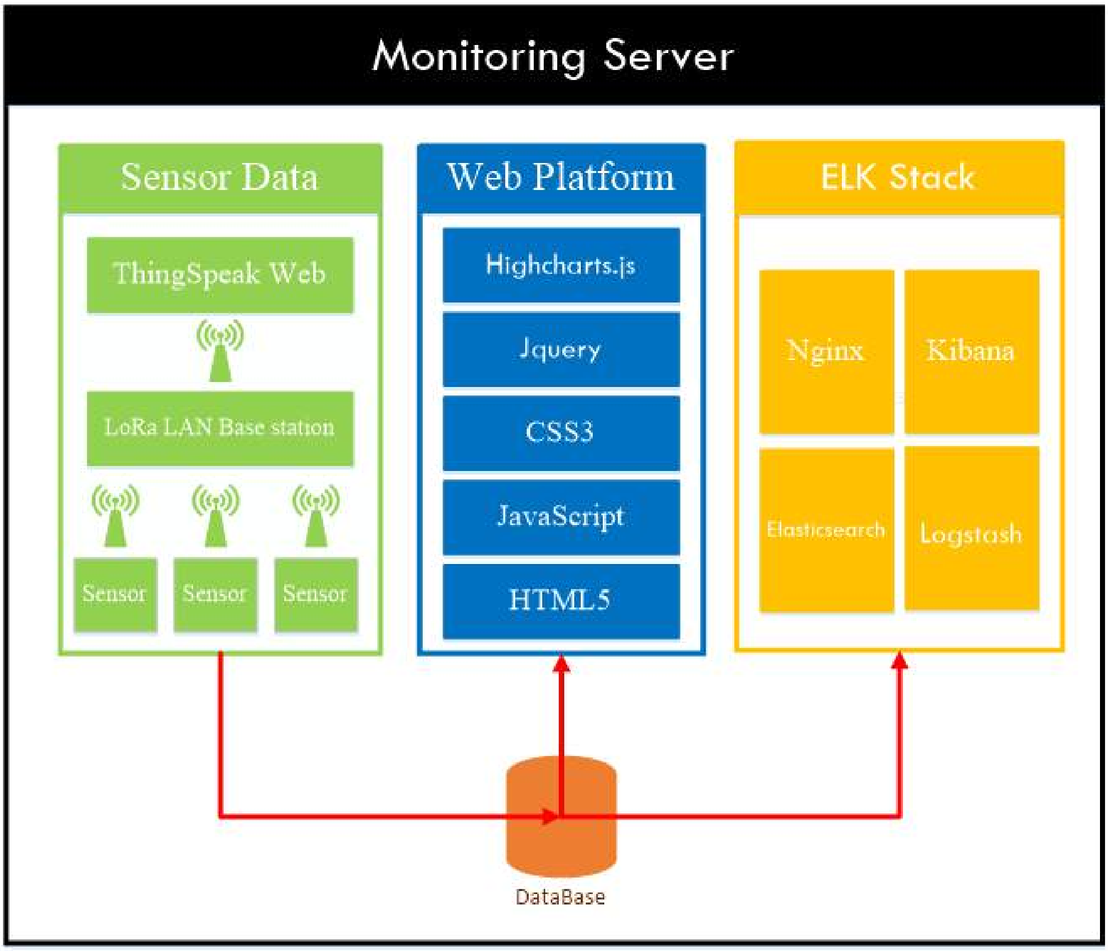


FIGURE 3.1: System architecture

3.2.1 Air Data Collection Service

In the data collection service through the LoRa node to the gateway, the gateway upload to ThingSpeak, low-level data on ThingSpeak using Java programs to crawl and store the database. In addition, the use of Java programs to filter these data into valid data into the database provided to the real-time system as a user.

3.2.2 Real Time Data Collection Service

Real-time data is important for the assessment of school air environmental conditions. We use Java programs to capture these real-time data from the environment sensor, and then store the data in the MySQL database by the Open street map and ELK Stack to extract the MySQL database data to do.

FIGURE 3.2: Monitoring station deployment location map

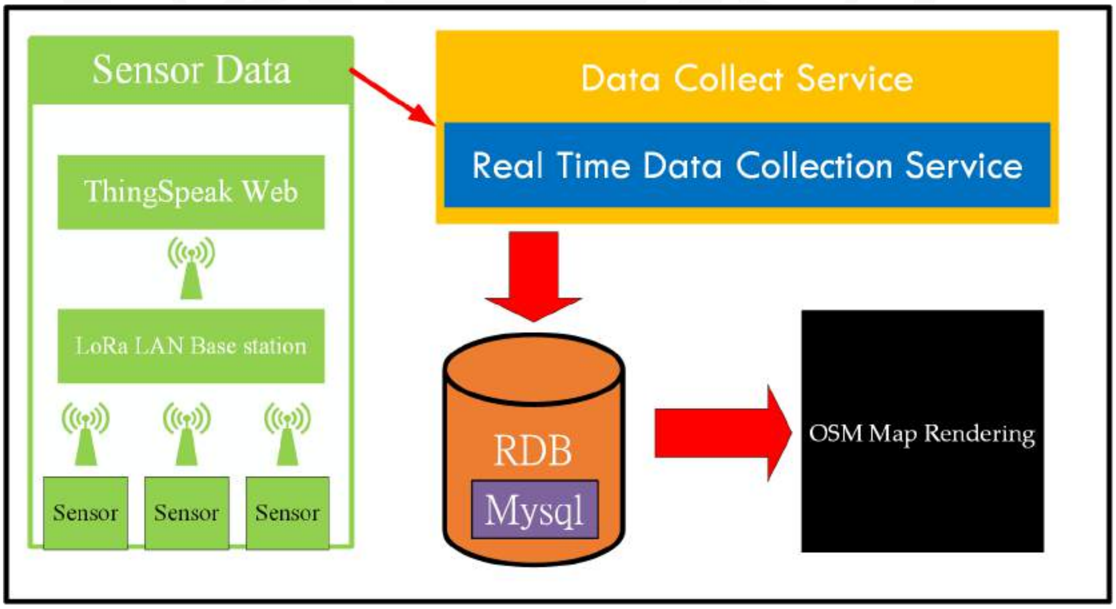


FIGURE 3.3: Data Collection Service

3.2.3 Historical Data Collection Service

Air Quality Analysis Using historical data, we have outside the campus station we also extract government open data to increase our historical data to enable us to use Highcharts data charts for analysis.Figure **??** shows the Historical Data Collection Service.

3.2.4 Real-Time Processing of Services and Data Analysis Services

The service is responsible for using OpenStreetMap to render the collected data in real time. Real-time functions include data observation, basic activity recommendations, and ELK Stack systems provide data comparison and data evaluation. Figure **??** shows the Real Time Process Service.

FIGURE 3.4: ELK stacking system architecture

```
February 29th 2016, 02:24:15.606  message: Feb 29 02:24:07 elkslave su[41435]: + /dev/pts/1 root:root @version: 1 @timestamp: February 29th 2016, 02:24:15.606 beat.hostname: elkslave beat.name: elkslave count: 1
                                  fields: - input_type: log offset: 38,248 source: /var/log/auth.log type: syslog host: elkslave tags: beats_input_codec_plain_applied _id: AVMpH7yzN6YdPQ-yGtum _type: syslog
                                  _index: filebeat-2016.02.28 _score: -

February 29th 2016, 02:24:15.606  message: Feb 29 02:24:10 elkslave sudo: pam_unix(sudo:session): session opened for user root by hpcslave(uid=0) @version: 1 @timestamp: February 29th 2016, 02:24:15.606
                                  beat.hostname: elkslave beat.name: elkslave count: 1 fields: - input_type: log offset: 38,975 source: /var/log/auth.log type: syslog host: elkslave tags: beats_input_codec_p
                                  ain_applied _id: AVMpH7yzN6YdPQ-yGtuu _type: syslog _index: filebeat-2016.02.28 _score: -

February 29th 2016, 02:24:15.606  message: Feb 29 02:24:09 elkslave su[41447]: + /dev/pts/1 root:hpcslave @version: 1 @timestamp: February 29th 2016, 02:24:15.606 beat.hostname: elkslave beat.name: elkslave
                                  count: 1 fields: - input_type: log offset: 38,699 source: /var/log/auth.log type: syslog host: elkslave tags: beats_input_codec_plain_applied _id: AVMpH7yzN6YdPQ-yGtur
                                  _type: syslog _index: filebeat-2016.02.28 _score: -

February 29th 2016, 02:24:15.606  message: Feb 29 02:24:09 elkslave su[41447]: pam_unix(su:session): session opened for user hpcslave by hpcslave(uid=0) @version: 1 @timestamp: February 29th 2016, 02:24:15.606
                                  beat.hostname: elkslave beat.name: elkslave count: 1 fields: - input_type: log offset: 38,762 source: /var/log/auth.log type: syslog host: elkslave tags: beats_input_codec_p
                                  ain_applied _id: AVMpH7yzN6YdPQ-yGtus _type: syslog _index: filebeat-2016.02.28 _score: -
```

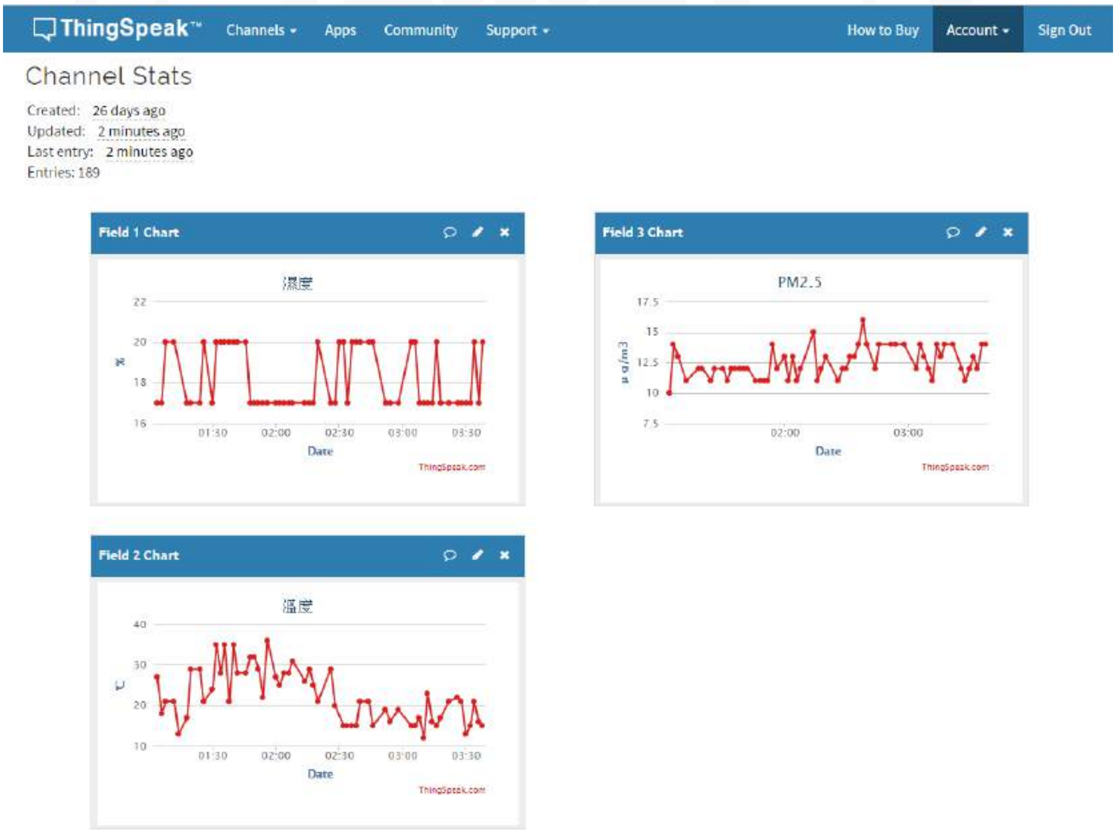
FIGURE 3.5: Kibana shows a bar graph

3.3 System Implementation

In this work, we have created a collection of data using multiple LoRa terminals, using the NMS as a node, using the Jsoup Java Web Reptile Kit to store data into MySQL, providing OSM maps (Open Street Map) with ELK Stack Analysis using.

3.3.1 Thingspeak System Implementation

Figure 3.6 Displays the data status and history of the currently running terminal nodes.



Channel Stats

Created: 26 days ago
Updated: 2 minutes ago
Last entry: 2 minutes ago
Entries: 189

FIGURE 3.6: The gateway uploads data to the Thingspeak website

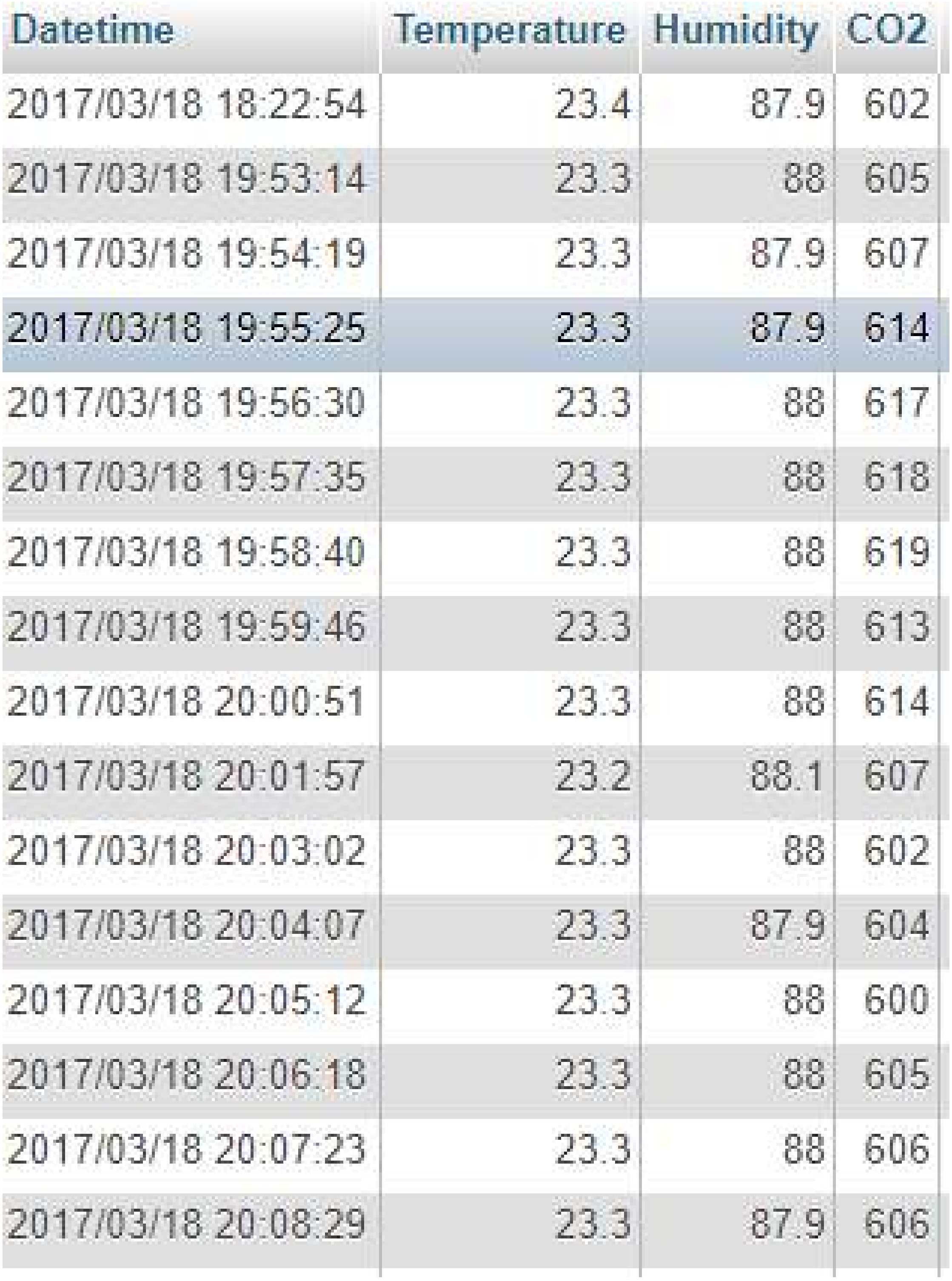
Figure 3.7 3.8 shows the outdoor time data storage format in the MySql database.

Datetime	Temperature	Humidity	Particulate_matter
2017/05/01 08:37:20	28.1	62.6	17.09
2017/05/01 08:36:15	28.1	62.6	17.09
2017/05/01 08:35:11	28.1	62.6	17.09
2017/05/01 08:34:05	28.1	62.7	17.09
2017/05/01 08:33:00	28.1	62.7	20.51
2017/05/01 08:31:55	28.1	62.7	23.93
2017/05/01 08:30:48	28.1	62.8	20.51
2017/05/01 08:29:43	28.1	62.8	17.09
2017/05/01 08:28:38	28.1	62.8	20.51
2017/05/01 08:27:33	28	62.9	20.51
2017/05/01 08:26:28	28.1	63	17.09
2017/05/01 08:25:21	28	63	20.51
2017/05/01 08:24:16	28	63.1	20.51
2017/05/01 08:23:11	28	63.1	20.51
2017/05/01 08:22:05	28	63.2	20.51
2017/05/01 08:21:00	28	63.2	20.51

Figure 3.7: Create Database and Data Presentation(Outdoor)

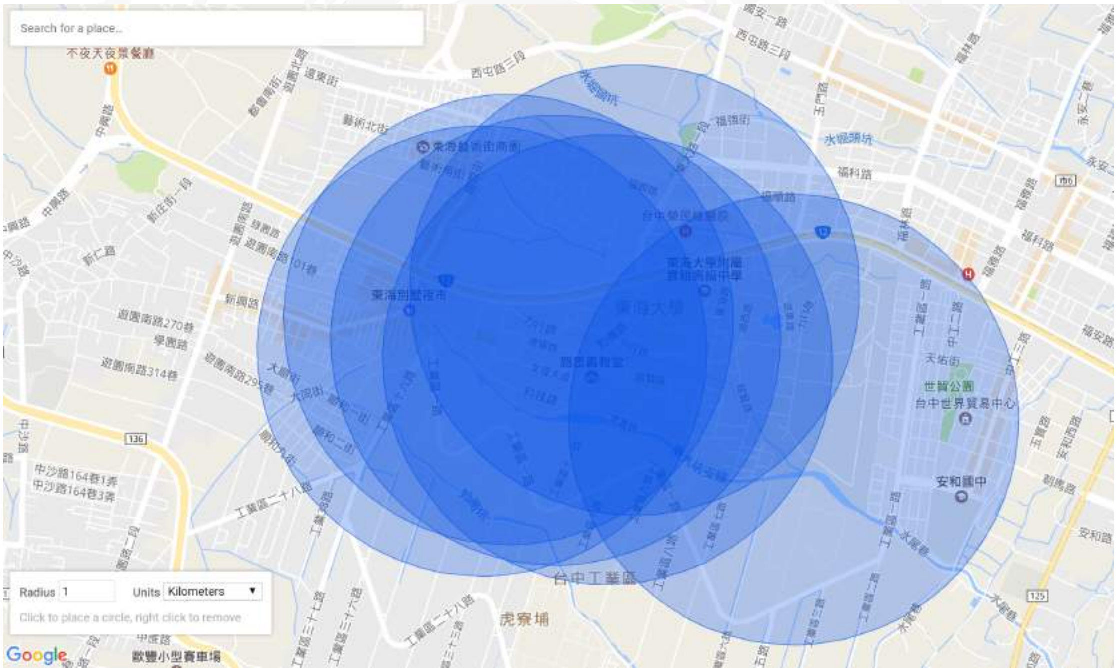
3.3.2 LoRa Terminal Deployment

Figure 3.9 shows the location and scope of the deployment station at the campus LoRa monitoring station.



Datetime	Temperature	Humidity	CO2
2017/03/18 18:22:54	23.4	87.9	602
2017/03/18 19:53:14	23.3	88	605
2017/03/18 19:54:19	23.3	87.9	607
2017/03/18 19:55:25	23.3	87.9	614
2017/03/18 19:56:30	23.3	88	617
2017/03/18 19:57:35	23.3	88	618
2017/03/18 19:58:40	23.3	88	619
2017/03/18 19:59:46	23.3	88	613
2017/03/18 20:00:51	23.3	88	614
2017/03/18 20:01:57	23.2	88.1	607
2017/03/18 20:03:02	23.3	88	602
2017/03/18 20:04:07	23.3	87.9	604
2017/03/18 20:05:12	23.3	88	600
2017/03/18 20:06:18	23.3	88	605
2017/03/18 20:07:23	23.3	88	606
2017/03/18 20:08:29	23.3	87.9	606

Figure 3.8: Create Database and Data Presentation (Indoor)


Search for a place...

Radius 1 Units Kilometers

Click to place a circle, right click to remove

FIGURE 3.9: LoRa Monitoring Station Coverage Map

Chapter 4

Experimental Results

This paper introduces the experimental environment and the results of the LoRa low power network to establish the campus air pollution monitoring system. In Section 4.1, the system design architecture is described. Section 4.2 lists the aeronautical data collection services and real-time processing services and data analysis services, Section 4.3 is the presentation of ELK historical data, and the performance evaluation and results presented in the LoRa campus in Section 4.4.

4.1 Experimental Environment

In this section, we introduce our system environment, including hardware and software. On the hardware, the hardware of the monitoring station terminal (Table 4.1) Arduino UNO, temperature and humidity sensor (PMS5003T), LoRa module, Gateway, solar panel, charge and discharge control board Figure 4.1, The sys-tem server Figure 4.2 and (Table 4.2) Citrix: IBM AMD Opteron (tm) Processor 6172 x24 cores, RAM: 40GB, HDD: RAID10 / 300GB / SAS * 4. In the software, using the Ubuntu 14.04 LTS 64 bit. Install Open Street Map, JAVA, ELK (Elasticsearch, Logstash, Kibana) to form the system.

Table 4.1: Monitoring Station Experimental Equipment

ID	Name	Quantity
1	Arduino UNO	6
2	PMS5003T	5
3	GE T6603-5 CO2	1
4	LoRa Node	6
5	Gateway	1
6	Solar panels	5
7	Charge and discharge control board	5

Table 4.2: System Service Equipment

ID	CPU	RAM	HDD	NIC
1	AMD® Opteron™ Processor 6172@2.1GHz x24	40GB DDR3	1TB	4Gb Ethernet

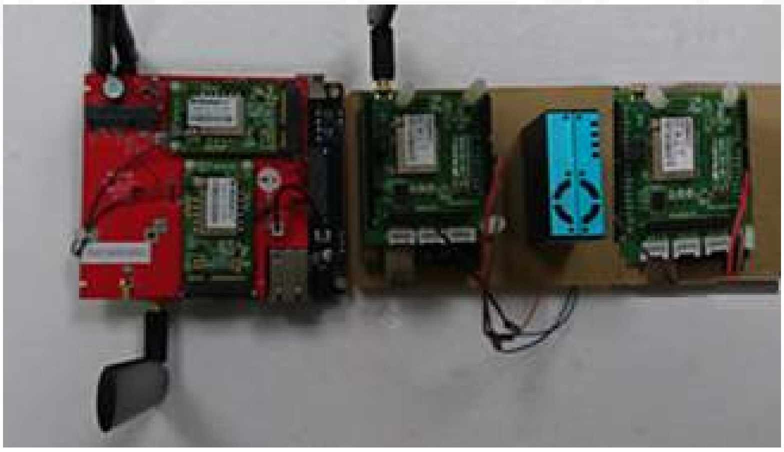


Figure 4.1: Monitoring Station Experimental Environment(LoRa module, Gateway)

4.2 Air Quality Monitoring System

In this study, we have implemented the six low-power campus air quality monitoring network system. In the initial phase, we installed six monitoring stations on campus. Experimental results showed that monitoring data into outdoor and indoor. Unlike the PM2.5 suspended particles and collect the carbon dioxide. Home is based on OSM map, shows the location of monitoring stations within the

FIGURE 4.2: System Server Device

campus. We also collect information on Government and private, provide information about the integrity of the campus life, and provide more information. As in Figure 3.2 shows, we can see our six prevention in school establishments, outdoor technical architecture, language center, restaurant, school, farm and network information Figure 4.3. PM2.5 effects on the human body are divided into low, medium, high, text color for differentiation and activity suggestions.

花園餐廳：詳細資料

細懸浮微粒:13.67 (μg/m³) 低 (建議:正常戶外活動)

溫度:25.4 (°C)，濕度:62.2 (%) 舒適

PM2.5 :

FIGURE 4.3: Live information on campus activities(Outdoor)

Our six low-power network is implemented air quality monitoring system in a test lab environment on campus locations in the Interior, main monitor CO2, and LoRa Interior pass the packet drop rate data collected, sensor installed on the ground floor in the library study room on the first floor, mainly to provide study hall real-time CO2 concentration in ppm unit Figure 4.4 also provide activity recommendations.

圖書館：

二氧化碳:518 (ppm) 中 (呼吸順暢)

溫度:25 (°C) , 濕度:68.1 (%)

THI:19 稍寒(多添加衣物)。建議適合洋蔥式穿法。

CO2 :

FIGURE 4.4: Live information on campus activities(Indoor)

We have joined 25 monitoring stations in Taichung City area Figure 4.5, collecting government public messages, we can view the above chart Figure 4.6, 15 minutes to update once.

FIGURE 4.5: Taichung City, 25 monitoring station location

4.3 Historical Data ELK Stack Results

In addition to the real-time map, the system provides detailed information on PM2.5, temperature, and humidity in recent hours, as well as providing historical data for analysis.

4.4 Performance Evaluation

In order to verify the LoRa specified performance of the receiver, LoRa testing is established. GlobalSat LM-130 AEB and the Arduino UNO R3 Development Board as a Terminal and use LG-S201H as a gateway. Gateway through the WiFi 2.4G Thingspeak (https://thingspeak. com/) provides a Web server so that it can monitor the server receives the packet, and write data to the database using the crawler.

In the figure, the distance and the plane position of the distance gateway are set for each site in the campus.

西屯監測站

提醒: 寒冷

建議多穿厚暖衣物並待在家裡保暖。

THI: 8

溫度: 25.7 (°C) , 濕度: 80 (%)

風向: 南南西

風力: 1.3 (m/s)

當日累積雨量: 0 (mm)

更新時間: 2017/04/10 00:00:00

FIGURE 4.6: Details of the government monitoring station

4.4.1 Receive Transmission Packet Loss Rate

Figure 4.8 packet loss rate equipment from LoRa device approximately 1500 to 2000 sent to the gateway package and the GPS coordinates, and recorded in the campus of received packet data and mobile device coordinates.

Figure 4.9 campus measuring point return packets and GPS coordinates to a record.

In 915kHz band and 868kHz band measuring results in the we using different of band for received transfer of lost package rate test of results, we validation of gateway is erection in indoor Windows next using 2 only 3dBi antenna, received transfer back of lost package rate not contains (Ranch) can has must of level, if to avoid more far locations of lost rate cover high, need increased gateway number or is for theFor more dBi antenna would be able to reduce the packet rate.

Can be seen in 868kHz band can deliver packets reduced to 1500 but passing distance 1 2%, sent 51 bytes is the minimum unit, in fact, the transmission we

Table 4.3: 915 kHz Channel Measurements at Different Locations

Location	Distanceto the Gateway	Tx	Rx	Success ratio
Technology building	10±5m	2000	1995	99.7%
Library	150±5m	2000	1989	99.4%
Language Hall	230±5m	2000	1981	99.0%
Restaurant	500±10m	2000	1966	98.3%
School Gate	1000±10m	2000	1764	88.2%
Pasture	1400±15m	2000	0	0%
Total (no Pasture)	-	10000	9695	96.6%

Table 4.4: 868 kHz Channel Measurements at Different Locations

Location	Distanceto the Gateway	Tx	Rx	Success ratio
Technology building	10±5m	1500	1498	99.8%
Library	150±5m	1500	1493	99.5%
Language Hall	230±5m	1500	1490	99.3%
Restaurant	500±10m	1500	1475	98.3%
School Gate	1000±10m	1500	1339	89.3%
Pasture	1400±15m	1500	247	16.4%
Total (no Pasture)	-	7500	7295	97.6%

need does not need such a big packet of data, packets will be passed down to 25 bytes of the packet reduces packet loss rate.

4.4.2 Gateway Receiving Sensitivity

Figure 4.13 recorded from the device side, LoRa device approximately 1500 to 2000 packets sent to the gateway, and group records received data with mobile devices coordinate with received signal strength indicator (RSSI).

Figure 4.14 actual results in the measurement result is slightly lower than the specified value, measured a minimum RSSI group may be due to the gateway in the Interior, cause signal additional shadow in front of unable to adjust the angle of the antenna with the best location, at 1400m station is not functioning and follow-up needs to be adjusted.

4.4.3 Single Device Maximum Throughput

The objective of the experiment was to assess the maximum throughput of a single device can be achieved. According to the physical layer instead of a MAC Protocol using 125 kHz using the six channel 7 to 12 test spreading factor, to make use of orthogonal spreading factor (base station to each channel receives multiple transfers), the node must be minimum air time for spreading factor.In order to test the accuracy, cancel the sending MAC command, so the MAC head about 13 bytes in size. Results depend on payload size, as shown in the figure, measuring about 100 packets sent in each test. 51 bytes maximum payload size is allowed to perform the test.

4.4.4 Total Capacity and Channel Load

Found total network capacity is greater than the payload size. Because at the same frequency, can simultaneously decode two transmission spreading factor, next, logical channel consists of a pair (bands, spreading factor).LoRaWAN the transmission capacity of the network is the sum of all logical channels and volume. 125 kHz frequency range, there are 6 possible expansion factor (from 7 to 12), with a total capacity of up to 125 kHz channel 12, 025 bps.Because the transmission bit rate depends on the spreading factor, so not all logical channels have the same capacity to present number 6 stations and transmission of data, the single devices transfer data at one time will not exceed 51bytes size, for a total capacity of channels and channel capacity is enough to load.

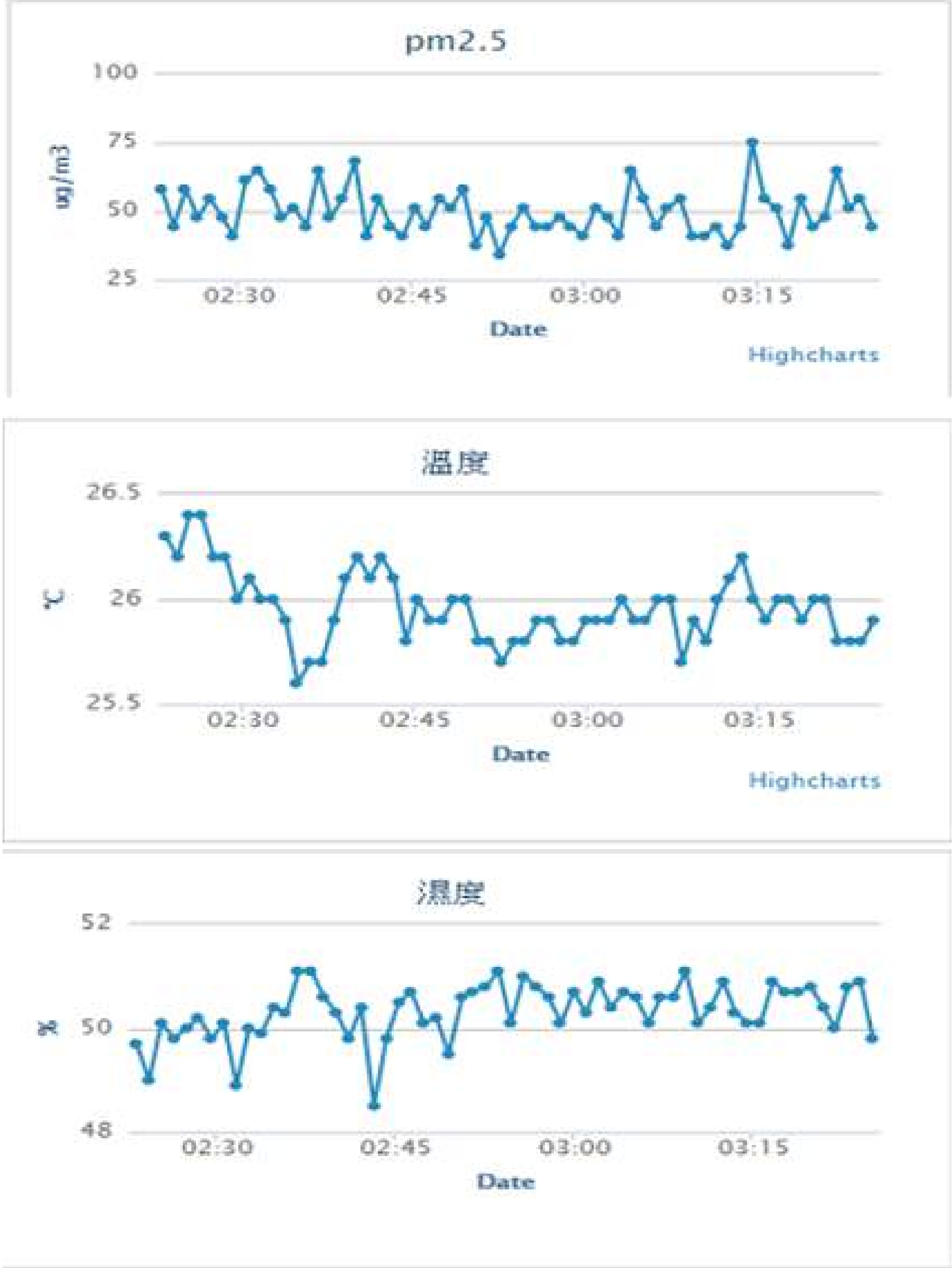


FIGURE 4.7: Hourly time axis to observe changes in the data

Figure 4.8: LoRa Campus Test Chart

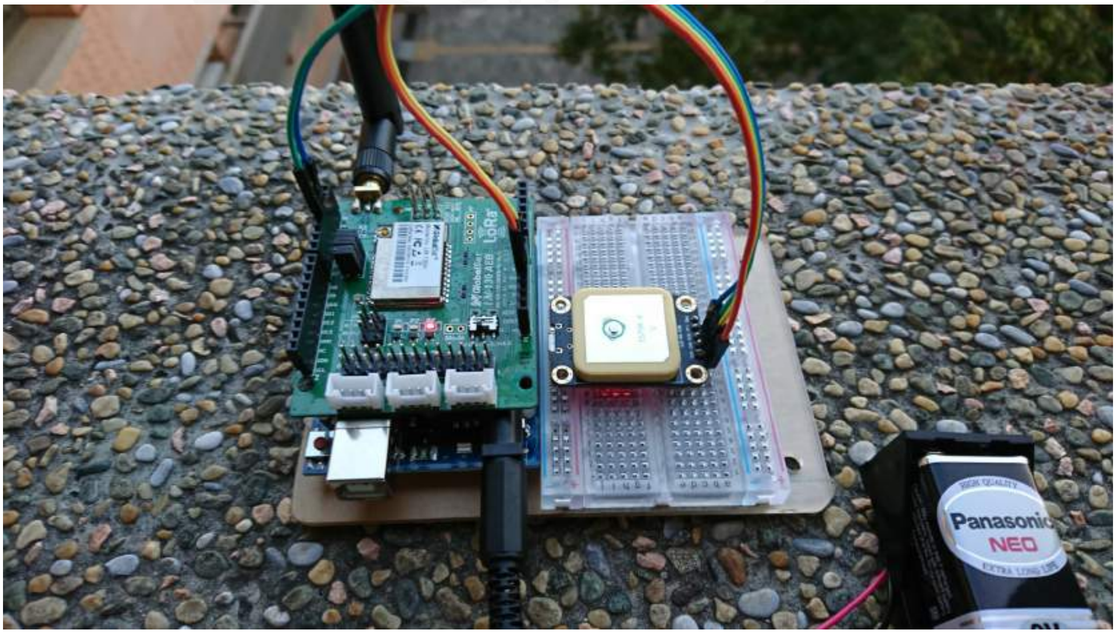


Figure 4.9: Packet Loss Rate Test Equipment

Figure 4.10: Packet Loss Rate Test

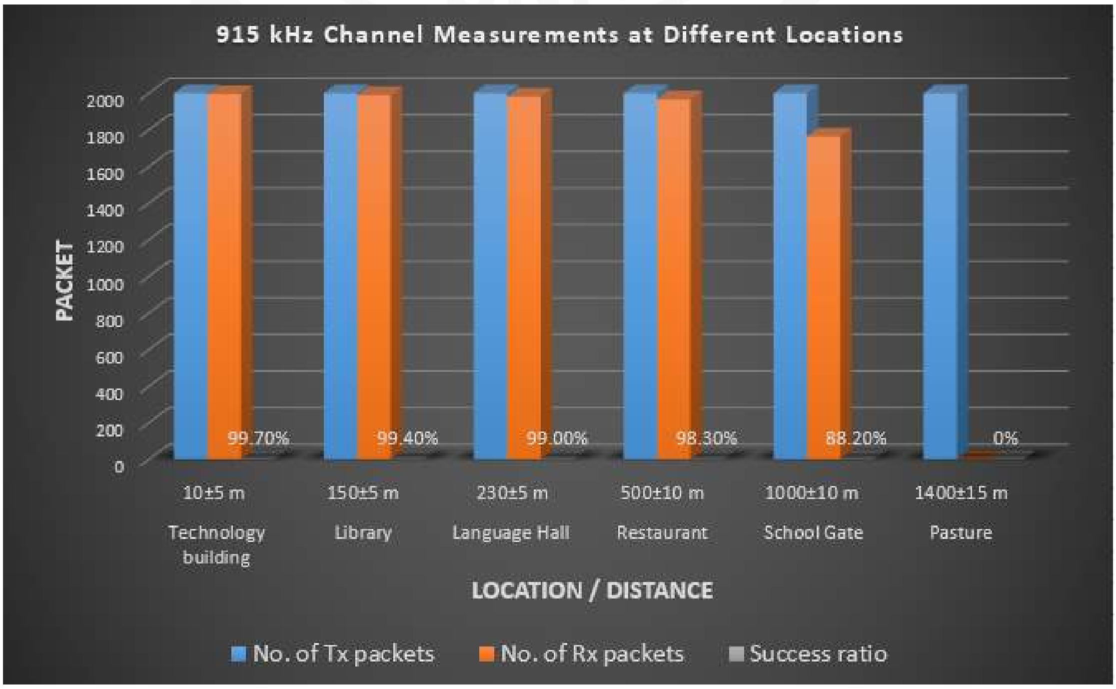


Figure 4.11: Receiver sensitivity data collection

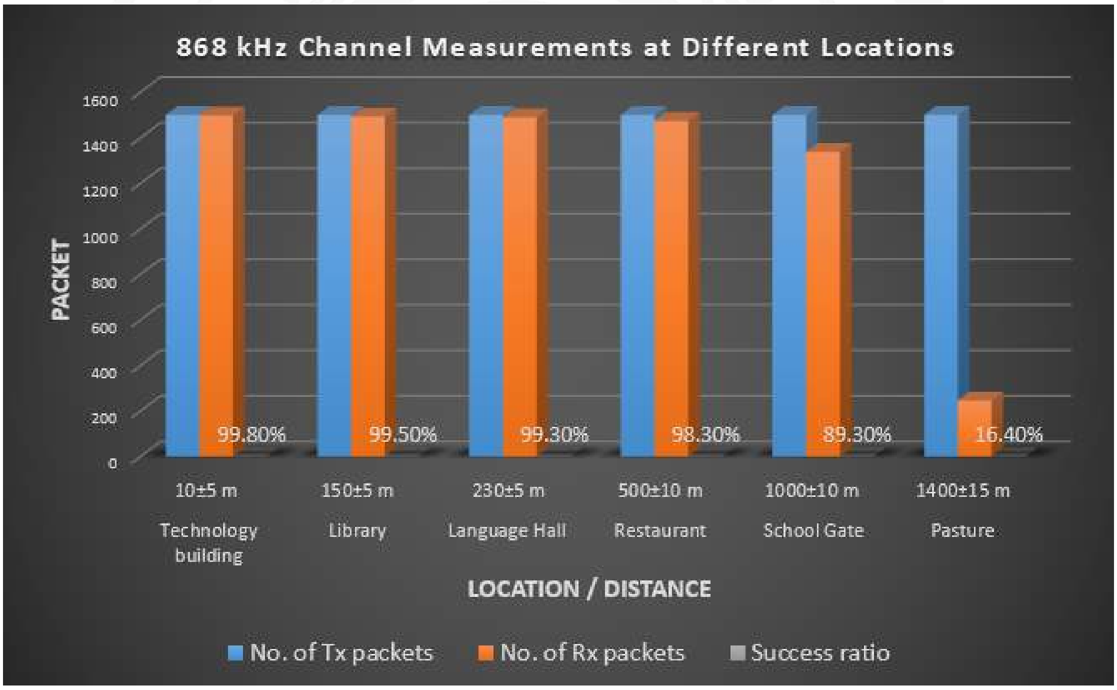
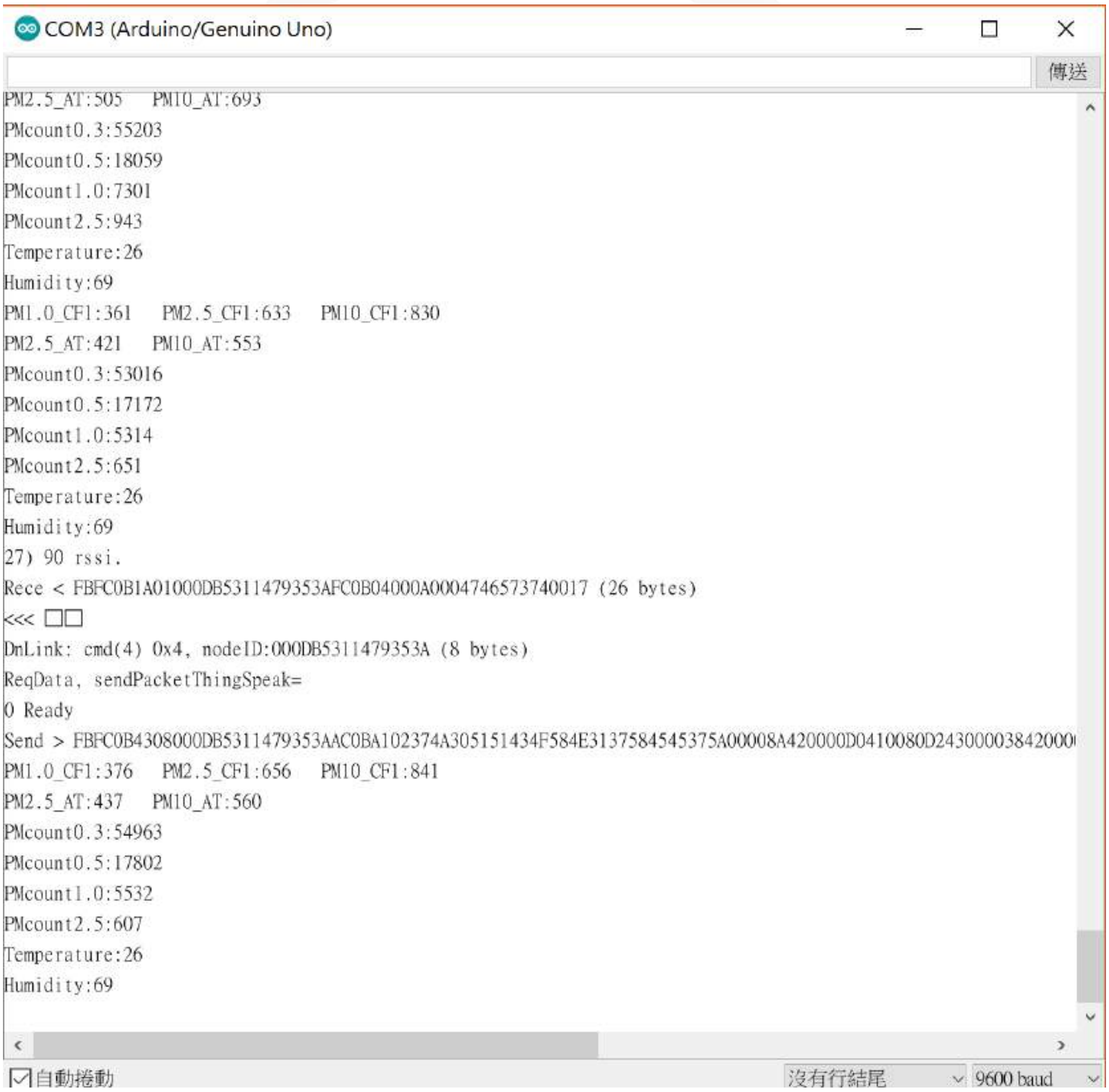


FIGURE 4.12: Receiver sensitivity data collection



```
PM2.5_AT:505    PM10_AT:693
PMcount0.3:55203
PMcount0.5:18059
PMcount1.0:7301
PMcount2.5:943
Temperature:26
Humidity:69
PM1.0_CF1:361    PM2.5_CF1:633    PM10_CF1:830
PM2.5_AT:421    PM10_AT:553
PMcount0.3:53016
PMcount0.5:17172
PMcount1.0:5314
PMcount2.5:651
Temperature:26
Humidity:69
27) 90 rssi.
Rece < FBFC0B1A01000DB5311479353AFC0B04000A0004746573740017 (26 bytes)
<<< □□
DnLink: cmd(4) 0x4, nodeID:000DB5311479353A (8 bytes)
ReqData, sendPacketThingSpeak=
0 Ready
Send > FBFC0B4308000DB5311479353AAC0BA102374A305151434F584E3137584545375A00008A420000D0410080D24300003842000
PM1.0_CF1:376    PM2.5_CF1:656    PM10_CF1:841
PM2.5_AT:437    PM10_AT:560
PMcount0.3:54963
PMcount0.5:17802
PMcount1.0:5532
PMcount2.5:607
Temperature:26
Humidity:69
```

FIGURE 4.13: Receiver sensitivity data collection

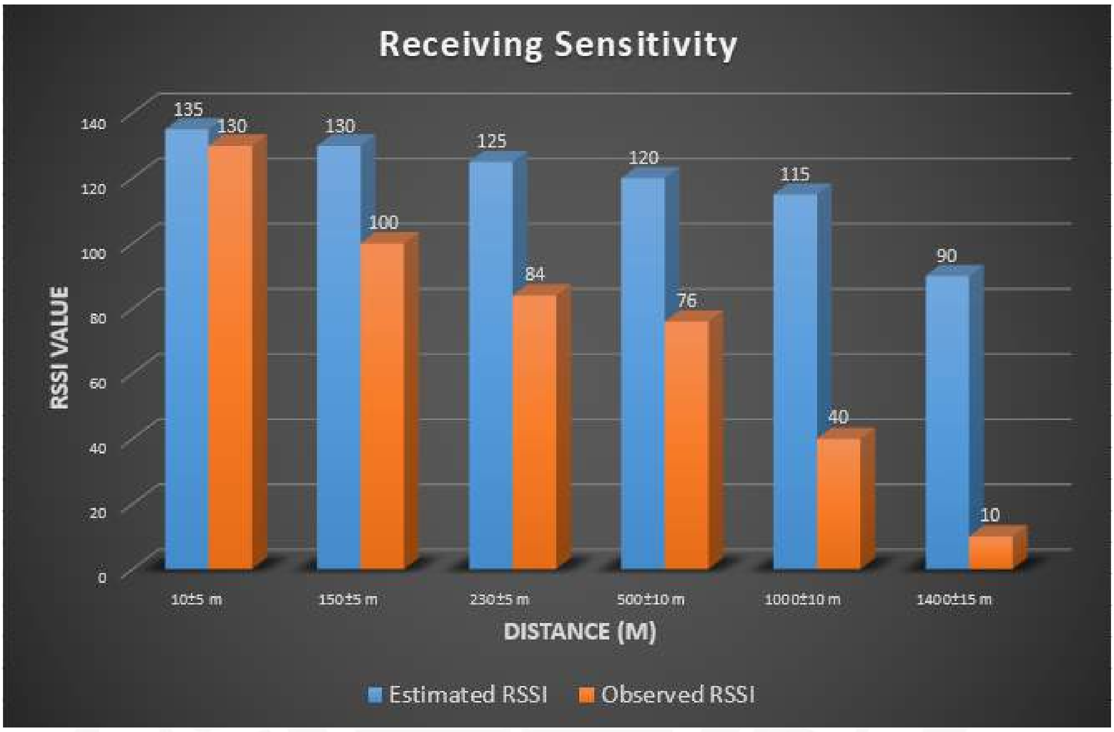


Figure 4.14: Receive the Actual Results of Sensitivity

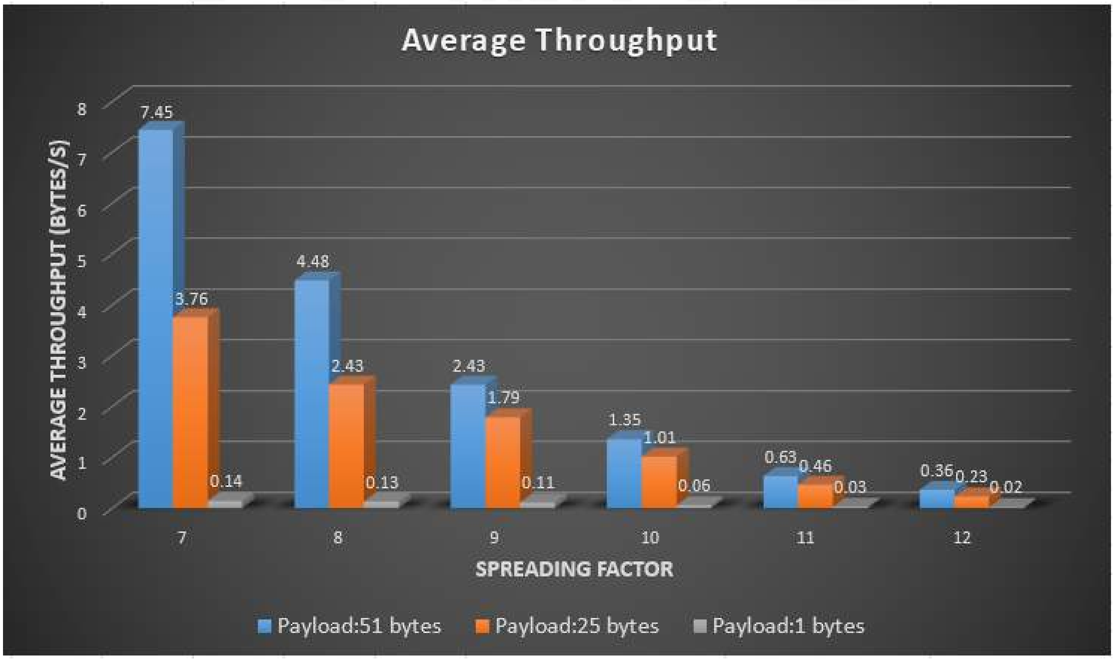


Figure 4.15: Average Throughput

Chapter 5

Conclusions and Future Works

5.1 Concluding Remarks

In this work, through the construction of Laura air monitoring system, rapid deployment of monitoring stations, low maintenance costs, rapid installation of the station, you can not plug the fixed power and the previous generation Wifi communication network deployment monitoring site fast, low energy consumption, Benchmark CO2 concentration data changes, drawing bar graphs, observing changes in carbon dioxide and time, with temperature and humidity and PM2.5 can also maintain data accuracy, the use of ELK stack is data acquisition, data filtering to achieve intelligent performance, and visualization The result is not a simple analysis tool, in an open campus, after a number of experiments to find the best solution, in this campus using the packet format and frequency band, to provide data to verify the actual value of low-power network equipment to do the adjustment and planning.

5.2 Future Works

Through the introduction of the whole system, the paper uses LoRa low-power network to establish a real-time analysis system in the campus. In order to make the data more efficient and more expansion and multiple demonstrations, more nodes will be set up with new small gateways To ensure the stability of the system, is currently showing the environmental conditions of schools and Taichung City, the future system can be extended to the city and the country and other more applications.

To conduct the campus air monitoring the stability of the system and more detailed data collection, we are expected to add 4 to 8 sites, will move to the Gateway Center on campus, within a radius of 1 km can be established at the gateway stations to ensure all points can be collected on the campus records data.

References

[1] Xue Yang, Shaojian Wang, Wenzhong Zhang, Dongsheng Zhan, and Jiaming Li. The impact of anthropogenic emissions and meteorological conditions on the spatial variation of ambient SO2 concentrations: A panel study of 113 chinese cities. *Science of The Total Environment*, 584–585:318 – 328, 2017.

[2] Aloÿs Augustin, Jiazi Yi, Thomas Clausen, and William Mark Townsley. A study of lora: Long range & low power networks for the internet of things. *Sensors*, 16(9), 2016.

[3] J. Petäjäjärvi, K. Mikhaylov, M. Hämäläinen, and J. Iinatti. Evaluation of lora lpwan technology for remote health and wellbeing monitoring. In *2016 10th International Symposium on Medical Information and Communication Technology (ISMICT)*, pages 1–5, March 2016.

[4] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi. Internet of things for smart cities. *IEEE Internet of Things Journal*, 1(1):22–32, Feb 2014.

[5] Rui Pitarma, Goncalo Marques, and Barbara Roque Ferreira. Monitoring Indoor Air Quality for Enhanced Occupational Health. *JOURNAL OF MEDICAL SYSTEMS*, 41(2), FEB 2017.

[6] M. Lauridsen, B. Vejlgaard, I. Z. Kovacs, H. Nguyen, and P. Mogensen. Interference measurements in the european 868 mhz ism band with focus on lora and sigfox. In *2017 IEEE Wireless Communications and Networking Conference (WCNC)*, pages 1–6, March 2017.

[7] D. M. Hernandez, G. Peralta, L. Manero, R. Gomez, J. Bilbao, and C. Zubia. Energy and coverage study of lpwan schemes for industry 4.0. In *2017 IEEE International Workshop of Electronics, Control, Measurement, Signals and their Application to Mechatronics (ECMSM)*, pages 1–6, May 2017.

[8] T. Petrić, M. Goessens, L. Nuaymi, L. Toutain, and A. Pelov. Measurements, performance and analysis of lora fabian, a real-world implementation of lpwan. In *2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, pages 1–7, Sept 2016.

[9] R. K. Jain, J. M. F. Moura, and C. E. Kontokosta. Big data /+ big cities: Graph signals of urban air pollution [exploratory sp]. *IEEE Signal Processing Magazine*, 31(5):130–136, Sept 2014.

[10] Shancang Li, Li Da Xu, and Shanshan Zhao. The internet of things: a survey. *Information Systems Frontiers*, 17(2):243–259, 2015.

[11] Hans Schaffers, Nicos Komninos, Marc Pallot, Brigitte Trousse, Michael Nilsson, and Alvaro Oliveira. *Smart Cities and the Future Internet: Towards Co-operation Frameworks for Open Innovation*, pages 431–446. Springer Berlin Heidelberg, Berlin, Heidelberg, 2011.

[12] S. Lee, D. Yoon, and A. Ghosh. Intelligent parking lot application using wireless sensor networks. In *2008 International Symposium on Collaborative Technologies and Systems*, pages 48–57, May 2008.

[13] N. Bressan, L. Bazzaco, N. Bui, P. Casari, L. Vangelista, and M. Zorzi. The deployment of a smart monitoring system using wireless sensor and actuator networks. In *2010 First IEEE International Conference on Smart Grid Communications*, pages 49–54, Oct 2010.

[14] R. Bonetto, N. Bui, V. Lakkundi, A. Olivereau, A. Serbanati, and M. Rossi. Secure communication for smart iot objects: Protocol stacks, use cases and practical examples. In *2012 IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, pages 1–7, June 2012.

[15] K. Zheng, S. Zhao, Z. Yang, X. Xiong, and W. Xiang. Design and implementation of lpwa-based air quality monitoring system. *IEEE Access*, 4:3238–3245, 2016.

[16] D. H. Kim, J. Y. Lim, and J. D. Kim. Low-power, long-range, high-data transmission using wi-fi and lora. In *2016 6th International Conference on IT Convergence and Security (ICITCS)*, pages 1–3, Sept 2016.

[17] K. H. Ke, Q. W. Liang, G. J. Zeng, J. H. Lin, and H. C. Lee. Demo abstract: A lora wireless mesh networking module for campus-scale monitoring. In *2017 16th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN)*, pages 259–260, April 2017.

[18] M. Werme, T. Eriksson, and T. Righard. Maintenance concept optimization — a new approach to lora. In *2017 Annual Reliability and Maintainability Symposium (RAMS)*, pages 1–6, Jan 2017.

[19] L. Gregora, L. Vojtech, and M. Neruda. Indoor signal propagation of lora technology. In *2016 17th International Conference on Mechatronics - Mechatronika (ME)*, pages 1–4, Dec 2016.

[20] G. S. Ramachandran, F. Yang, P. Lawrence, S. Michiels, W. Joosen, and D. Hughes. µPnP-WAN: Experiences with LoRa and its deployment in DR Congo. In *2017 9th International Conference on Communication Systems and Networks (COMSNETS)*, pages 63–70, Jan 2017.

[21] V. Gokul and S. Tadepalli. Implementation of a wifi based plug and sense device for dedicated air pollution monitoring using iot. In *2016 Online International Conference on Green Engineering and Technologies (IC-GET)*, pages 1–7, Nov 2016.

[22] P. Neumann, J. Montavont, and T. Noël. Indoor deployment of low-power wide area networks (lpwan): A lorawan case study. In *2016 IEEE 12th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, pages 1–8, Oct 2016.

[23] C. Pham, A. Rahim, and P. Cousin. Low-cost, long-range open iot for smarter rural african villages. In *2016 IEEE International Smart Cities Conference (ISC2)*, pages 1–6, Sept 2016.

[24] K. Mikhaylov, .. Juha Petaejaejaervi, and T. Haenninen. Analysis of capacity and scalability of the lora low power wide area network technology. In *European Wireless 2016; 22th European Wireless Conference*, pages 1–6, May 2016.

[25] J. P. Bardyn, T. Melly, O. Seller, and N. Sornin. Iot: The era of lpwan is starting now. In *ESSCIRC Conference 2016: 42nd European Solid-State Circuits Conference*, pages 25–30, Sept 2016.

Appendix A

ELK Stack Environment Construction and Installation

I. Update the system

```
# sudo apt-get update
```

II. Modify hostname

```
# sudo vim /etc/hosts
```

III. Install Java JDK

```
# sudo apt-get -y install openjdk-7-jdk
# sudo ln -s /usr/lib/jvm/java-7-openjdk-amd64 /usr/lib/jvm/jdk
```

IV. Added JAVA function

```
 # sudo add-apt-repository -y ppa:webupd8team/java
 # sudo apt-get update
 # sudo apt-get -y install oracle-java8-installer
```

V. Installation Elasticsearch

```
# wget -qO - https://packages.elastic.co/GPG-KEY-elasticsearch | sudo apt-key add -
# echo "deb http://packages.elastic.co/elasticsearch/2.x/debian stable main" | sudo
tee -a /etc/apt/sources.list.d/elasticsearch-2.x.list
# sudo apt-get update
# sudo apt-get -y install elasticsearch
# sudo vi /etc/elasticsearch/elasticsearch.yml
# sudo service elasticsearch restart
```

VI. Set up Elasticsearch as a service

```
# sudo update-rc.d elasticsearch defaults 95 10
# curl -X GET  ‘http://<IP Address>:9200
```

VII. Installed Kibana

```
# wget https://download.elastic.co/kibana/kibana/kibana-4.4.1-linux-x64.tar.gz
# tar xvf kibana-*.tar.gz
# sudo vim ~/kibana-4*/config/kibana.yml
# vim core-site.xml
        server.port             : 5601
        server.host             : "<IP Address>"
        elasticsearch.url       : http://192.168.244.131:9200
# sudo mkdir -p /opt/kibana/
# sudo cp -R ~/kibana-4*/* /opt/kibana/
# sudo chown -R hpcmaster: /opt/kibana
# cd /etc/init.d && sudo wget
```

X. Open Kibana admin permissions

```
# sudo chmod +x /etc/init.d/kibana4
# sudo update-rc.d kibana4 defaults 96 9
# sudo service kibana4 start
# sudo chown -R hpcmaster: /opt/kibana
```

XI. Install the NGINX service

```
# sudo apt-get install nginx apache2-utils
```

XII. Modify the NGINX service code

```
# sudo vi /etc/nginx/sites-available/default
```

XIII. Reboot the nginx service

```
# sudo service nginx restart
```

XIV. Install Logstash

```
# echo 'deb http://packages.elastic.co/logstash/2.2/debian stable main' | sudo tee
/etc/apt/sources.list.d/logstash-2.2.x.list
# sudo apt-get update
# sudo apt-get install logstash
# sudo service logstash start
```

XV. Generate SSL credentials and set the Logstash Configuration file

```
# sudo mkdir -p /etc/certs/
```

XVI. Open the OpenSSL file

```
# sudo vim /etc/ssl/openssl.cnf/
# subjectAltName = IP: logstash_server_private_ip
# cd /etc/certs
# sudo openssl req -config /etc/ssl/openssl.cnf -x509 -days 3650 -batch -nodes -newkey
rsa:2048 -keyout server.key -out server.crt
```

XVII. Test the Logstash service status

```
# sudo service logstash configtest
# sudo service logstash restart
```