



UNIVERSITI PUTRA MALAYSIA

***DEVELOPMENT OF LORAWAN COMMUNICATION SYSTEM
TO MONITOR SOIL ELECTRICAL CONDUCTIVITY AND PH
IN OIL PALM NURSERY***

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**DEVELOPMENT OF LORAWAN COMMUNICATION SYSTEM
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IN OIL PALM NURSERY**

GOH YEE NIE

189679

**A project report submitted in partial fulfilment of the requirements for the degree
of Bachelor of Agricultural and Biosystems Engineering with Honours**

**Faculty of Engineering
Universiti Putra Malaysia
Serdang, Selangor**

JUNE 2019

Approval Sheet

This final year research project entitled “**Development of LoRaWAN Communication System to Monitor Soil Electrical Conductivity and pH in Oil Palm Nursery**”, prepared and submitted by Goh Yee Nie in partial fulfilment of the requirements for the degree of Bachelor of Agricultural and Biosystems Engineering with Honours has been examined and is recommended for approval and acceptance.

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Abstract

As Malaysia's agricultural sector gradually move towards industry 4.0, the implementation of the Internet of Things (IoT) in precision agriculture allows farmers to improve the overall management with real-time monitoring. However, IoT implementations are very much restricted in oil palm nurseries as they are vast and usually located in rural areas with limited internet access. This study aims to propose a system design based on Long Range Wide Area Network (LoRaWAN) protocol to monitor soil electrical conductivity (EC) and pH in oil palm nurseries. This network protocol is promising because the technology is suitably developed for outlying regions without cellular network coverage, or for establishing private networks covering long distances with minimum power consumption and maintenance. In this study, a comparison of LoRa communication performance in young oil palm plantation, oil palm nursery, urban area and greenhouse shows that strong LoRa transmission is achievable with higher gateway elevation and clear line of sight. LoRa transmission successfully covered the entire oil palm nursery area of 6 ha and reaches up to more than 1 km distance in urban area. From this study, the feasibility of LoRaWAN as a communication protocol to be used in oil palm nurseries for soil EC and pH monitoring is proven to be successful.

Keywords: LoRaWAN, LPWAN, IoT, Arduino, Raspberry Pi, Oil Palm, Agriculture

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Chapter 1

Introduction

1.1 General Overview

As Malaysia's agricultural sector gradually move towards industry 4.0, the implementation of the Internet of Things (IoT) in precision agriculture allows farmers to improve the overall management with real-time monitoring. With Wireless Sensor Network (WSN), information regarding variability of soil electrical conductivity (EC) and pH that crucially affect nutrient uptake are easily monitored. However, the challenge of joining these technologies in agriculture is the need for a scalable and wide coverage wireless communication system. IoT implementations are very much restricted in oil palm estates as they are vast and usually located in rural areas with limited internet access. Long Range Wide Area Network (LoRaWAN) is a Low Power Wide Area (LPWA) networking protocol specifically designed for IoT applications with the purpose of connecting thousands of sensors, modules and appliances over a large network. It provides long range communication of small amounts of data and high immunity to interference under low power consumption. These advantages show LoRaWAN as the ideal communication system providing farmers with the luxury of monitoring large scale plantations remotely. In this study, LoRaWAN is implemented as the transmission protocol that meets the need of the IoT services in oil palm nurseries and in this case to monitor soil EC and pH of growing mediums.

1.2 Problem Statement

Current fertigation systems in oil palm nurseries lack real time crop requirement information as systems are monitored and controlled manually. To maximize crop yield, monitoring of EC and pH levels in growing mediums are essential to provide crops with optimum quantity of water and fertilizers based on crop requirement. However, IoT could not be widely implemented for real time crop monitoring in oil palm nurseries because plantations in Malaysia are large and located in rural areas, where internet access is limited and expensive. Thus, making it less feasible for IoT applications. LoRaWAN offers a very compelling combination of long range, low power consumption and secure data transmission, providing the ability to connect to sensors more than 15 km away in rural areas (Adelantado et al., 2017).

1.3 Aim

This research aims to implement LoRaWAN protocol for IoT in agriculture mainly focusing on Malaysia oil palm plantations. LoRaWAN is expected to provide long range communication in large and outskirts oil palm nursery areas. This research also aims to provide real time crop monitoring of EC and pH of growing medium that is accessible through cloud.

1.4 Objectives

- To develop a soil EC and pH monitoring system based on LoRaWAN protocol.
- To test the feasibility of LoRaWAN to transmit data in oil palm plantation, nursery and urban area.
- To monitor and collect EC and pH data in growing medium of oil palm seedlings.

Chapter 2

Literature Review

2.1 Precision Agriculture

The agricultural sector in Malaysia is gradually improving as farmers are encouraged to use modern techniques to increase yield and cut down on input cost. Precision agriculture is a farming management concept that uses technology to provide site specific care by observing, measuring and responding to inter and intra-field variability in crops. This approach applies information technology (IT) to ensure crops and soil receive all they need for optimum health and productivity. Furthermore, the use of modern technology not only increase crop productivity, but also help in saving resources while keeping the environment clean and safe (Pierce and Nowak, 1999). Precision agriculture includes monitoring crops from various sensor nodes placed in agricultural fields using Internet of Things (IoT) and Wireless Sensors Network (WSN) to provide solutions based on collected data (Mohd Kassim et al., 2014)

2.2 Internet of Things in Agriculture

IoT refers to the implementable Machine-to-Machine (M2M) communication which is a crucial component of digital advancement in precision agriculture. An IoT system is comprised of several functional blocks to facilitate various utilities to the system such as, sensing, identification, actuation, communication, and management. Agricultural IoT framework is a six-layered concept which includes hardware facilities, internet and communication technologies, IoT middleware, cloud services, big data analytics, and farmer experience as depicted in Figure 1 (Ray, 2017).

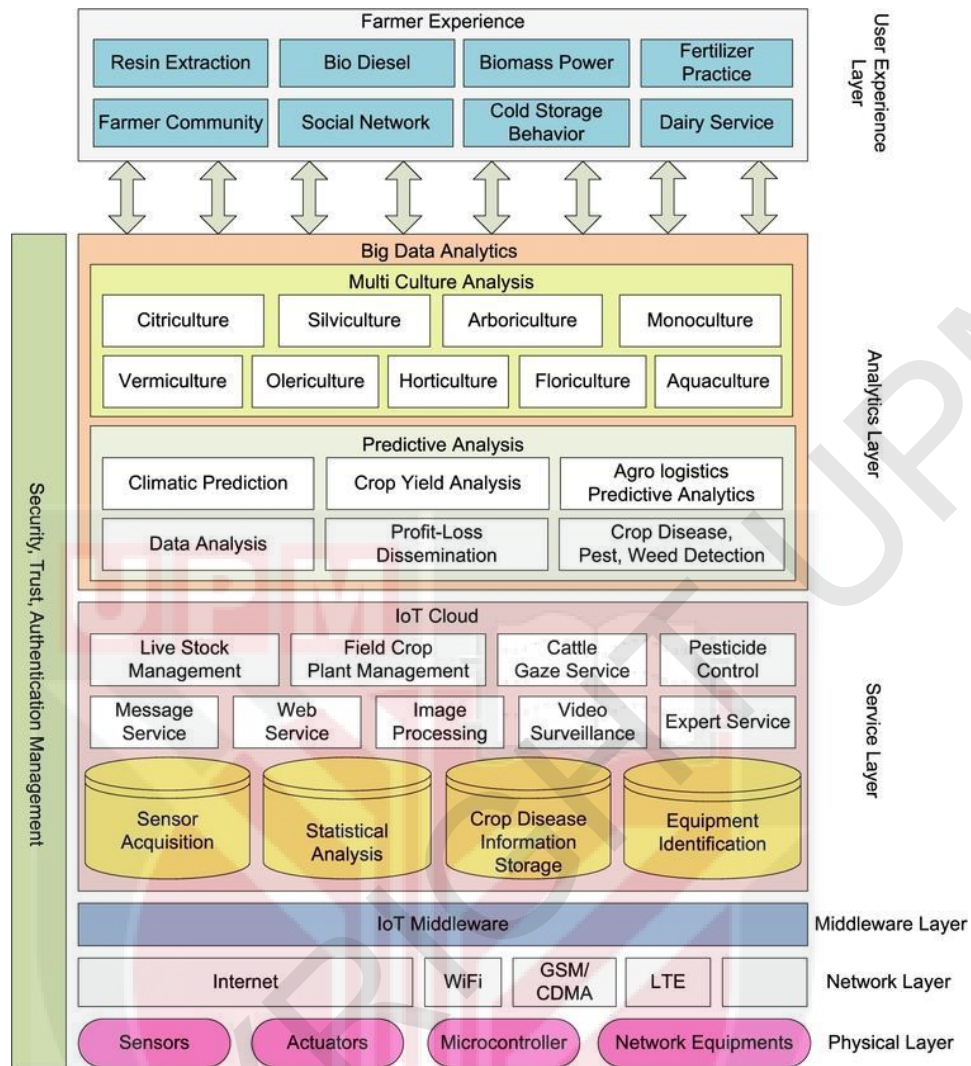


Figure 1: IoT framework (Ray, 2017)

Some of the domains of IoT for agriculture are farm monitoring, irrigation management system, pest and disease control and animal tracking (Ray, 2017). As crop requirement varies throughout the field, real-time ecological information gathered remotely from agricultural surroundings provides precise input of location, timing and amount required. Nevertheless, a suitable wireless communication for data transmission is essential to make sure IoT can be successfully implemented in agriculture.

2.3 Wireless Sensor Network in Agriculture

Wireless Sensor Network (WSN)s are employed as a cost-effective application to increase agricultural yield. Sensor nodes communicate wirelessly through a communication protocol, forwarding data to a base station by communicating with a gateway. As more sensor nodes are added to WSN, parameters of agricultural monitoring and network scalability increases. Communication protocols form the backbone of IoT systems that enable network connectivity and coupling to applications. However, the limitations of most wireless communication technologies are high power consumption and short transmission distance that fail to meet the requirement of WSN applications in agriculture (Brewster et al., 2017).

To overcome this barrier, low-power wide-area network (LPWAN) is the new solution in the communication sector. Three representative technologies of LPWAN that compete for large scale IoT are Long Range (LoRa), Narrow-Band Internet of Things (NB-IoT), and Sigfox. In agriculture, devices only update sensed data a few times per hour as the environment conditions does not radically change. LPWAN do not focus on enabling high data rates per device rather, the key performance metrics defined for LPWAN are energy efficiency, scalability, and coverage where Sigfox and LoRa are ideal for this application. Moreover, many farms do not have LTE cellular coverage thus, NB-IoT is not the best solution to be used in agriculture (Mekki et al., 2019).

Sigfox has a slightly longer network coverage and range than LoRa, however LoRa performs better in battery life and latency (Jawad et al., 2017). Besides, LoRa technology operates in the unlicensed frequency band, where end users are free to

build up LoRa gateways that are similar to house-owned WiFi routers (Alliance, n.d.). Therefore, LoRa technology is perfect for outlying regions without cellular network coverage, or for establishing private networks covering long distances with minimum power consumption and maintenance.

2.4 LoRaWAN

LoRaWAN, an open standard LPWAN protocol based on LoRa technology is designed to wirelessly connect battery operated things to the Internet. LoRaWAN is the medium access control (MAC) layer protocol that provides access to LoRa architecture (Figure 2). LoRa which is the physical layer of LoRaWAN is based on Chirp Spread Spectrum (CSS) modulation, maintains the same low power characteristics as frequency-shift keying (FSK) modulation but significantly increases the communication range (Semtech, n.d.). Transmission range highly depends on the environment and its obstructions, but LoRa and LoRaWAN have a link budget greater than any other standardized communication technology.

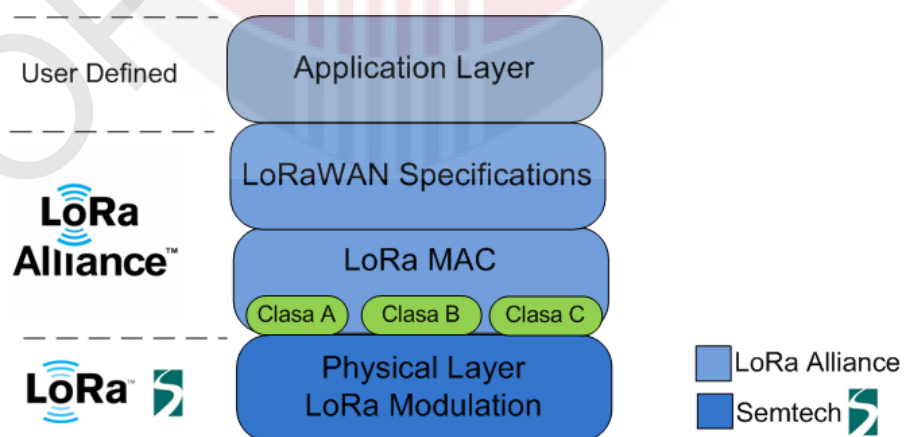


Figure 2: LoRaWAN communication protocol (Lavric and Petrariu, 2018)

Figure 3 presents the LoRaWAN architecture that consists of 4 parts which includes LoRa End Nodes, LoRa Gateway, Network Server and Application Server. A packet sent from the node received by the Gateway module will be retransmitted to the Network Server, where users can access the information hence perform cloud computing and further integrations in the Application Server (Lavric and Petrariu, 2018). The LoRa Gateway can receive packets from thousands of LoRa End Nodes, covering a large geographical area in the line of site with the base station. Moreover, packets sent at different data rates using different spreading factors (SF) will not interfere with each other (Reynders et al., 2016). The sensitivity of the gateway depends on the spreading factor to obtain a longer communication range, however in return compromises the data rate (Lavric and Popa, 2017).

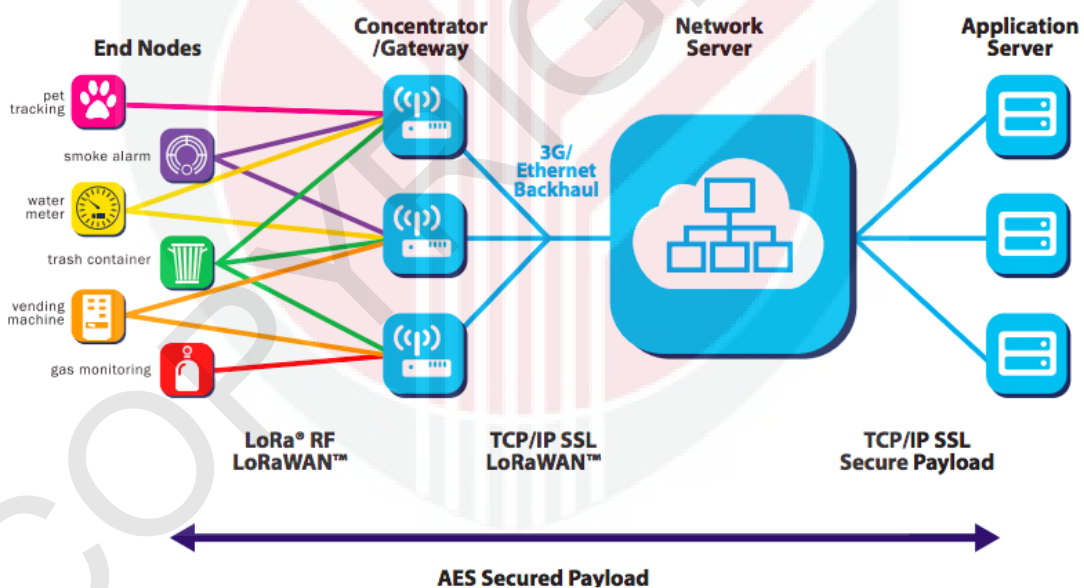


Figure 3: LoRaWAN architecture (Ram, 2018)

LoRaWAN is proven to achieve data transmission range of 2 to 5 km in urban areas and up to 15 km in suburban areas (Adelantado et al., 2017). Besides the long range transmission and the better suited star-of-stars topology for agriculture, LoRaWAN also has low power consumption, making it perfect for battery powered applications

in agriculture (Aziz et al., 2013). Energy used in data transfer is lesser than GSM communication technology while the coverage area of LoRaWAN base station is 50 times more than a GSM base station (Civelek, 2017). However, one disadvantage of LoRaWAN network is its low data rates, that prevents it to be used in high throughput applications such as video transmission (Silva et al., 2017).

LoRaWAN is used widely in renewable energy solutions, big data analytics healthcare solutions and autonomous automobiles for smart city applications (Pal et al., 2018). In agriculture, cattle health, location and real-time body temperature are monitored to aid in animal care and to prevent disease from spreading (Choi et al., 2018). Innovative approaches based on LoRaWAN protocol for measuring environmental and soil parameters such as air temperature, humidity, soil moisture and soil nutrient by Davcev et al. (2018), Ma and Chen (2018) and Tapashetti and Shobha (2018) show feasibility in using LoRaWAN for its long range and low power advantages in agricultural settings.

Only recently, Atilze Digital Sdn Bhd from Malaysia uses LoRaWAN to monitor sensor data of soil EC, moisture, pH, temperature and humidity for smart farming in food crop farms (“Atilze Sensor Hub - Atilze Digital,” n.d.). The agricultural sector can benefit from the combination of LoRa and cloud computing to complement the modern development of agriculture in providing smart solutions to solve issues from a remote location efficiently. This protocol shows great potential for implementations in food production and agricultural applications. Over and above that, LoRa technology has yet to be applied in Malaysia oil palm plantations, thus this study aims to implement LoRaWAN protocol to monitor soil EC and pH in oil palm nurseries.

2.5 Soil Electrical Conductivity (EC) and pH for Oil Palm

Oil palm (*Elaeis guineensis*) is one of the most important crops used for biodiesel production and is a major cash crop income for Malaysia's economy. To ensure optimum growth and high yield of oil palm, balanced and adequate supply of fertilizers are required (Goh et al., 2003). Since fertilizer recommendations are based on calibrated soil and crop requirement, it is essential to monitor the variability of EC and pH level in soil (Behera et al., 2017). Smart fertigation systems provide balanced nutrition level to crop by monitoring and modifying pH and EC level of water mixed fertilizers with respect to soil parameters (Samsuri et al., 2010).

Electrical conductivity (EC) is a measure of the total amount of salts in the growing medium. High soil salinity restrict crop's ability to uptake water from soil while high EC levels has toxic effect on plant's metabolism (Hanlon, 2012). On the other hand, pH is a measure of acidity or alkalinity that affects the availability of macro and micronutrients in the growing medium (Ketterings et al., 2005). Almost all crops prefer a slightly acidic pH between 5.4 to 6.0. Soil EC value less than 1000 mhos/cm and pH value more than 4.0 are categorized in the desirable range of soil properties for oil palms (Applied Agricultural Resources, n.d.). Furthermore, pH values above 5.5 correlate to high soil fertility for oil palm cultivation (Goh, 1997). Thus, regular monitoring of EC and pH of growing medium in oil palm nursery is essential to prevent almost all nutrient-related problems during oil palm growth.

Chapter 3

Materials and Method

3.1 System Design

The template for LoRaWAN network is laid out in four parts; (i) Sensor Node, (ii) Gateway, (iii) Network Server and (iii) Application Server. A soil EC and pH monitoring system was proposed and developed using LoRaWAN protocol. The LoRaWAN architecture is as shown in Figure 4. LoRa end node has sensors that sense changing parameters which sends data to the LoRa gateway via LoRaWAN protocol. The LoRa gateway connects to the internet via the standard IP protocol and transmit data to the Internet, a network server. The network server like The Things Network (TTN) is a cloud-based platform solution which has a router, broker and handler, that processes the data packets from the LoRa gateway. Application server like Node-RED run mostly on a private or public cloud which interfaces with the LoRaWAN network server and does the application-specific processing.

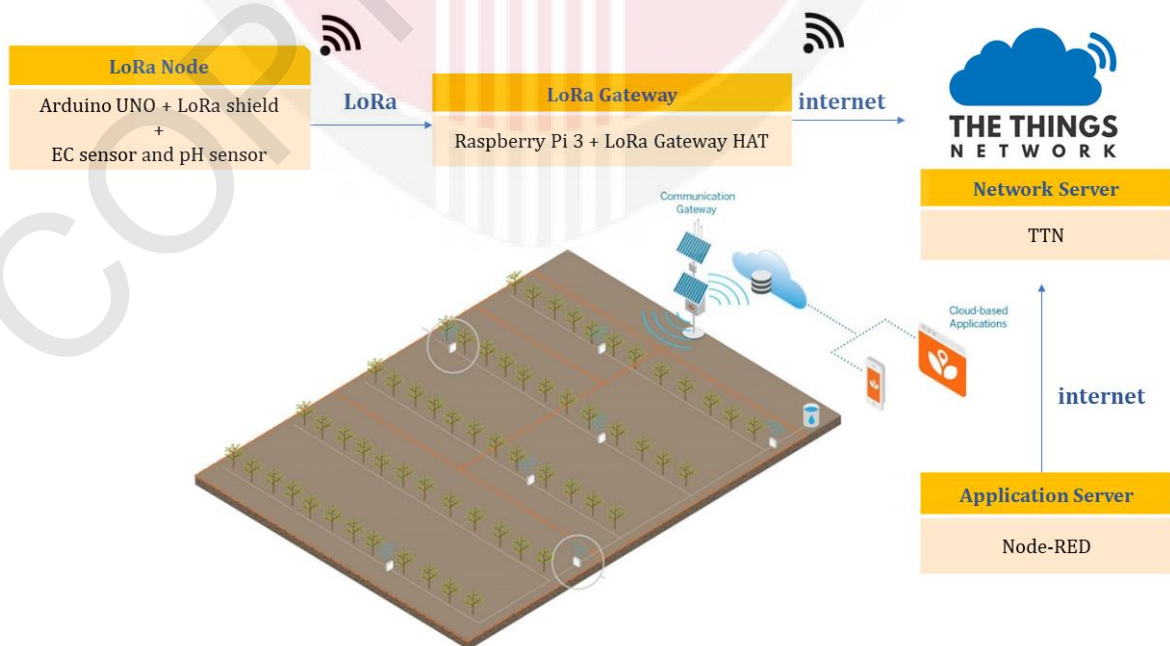


Figure 4: System design based on LoRaWAN architecture

3.1.1 Sensor Node

A LoRaWAN node is an endpoint physical hardware device that contains sensing capabilities, some computing power and a radio module for translating the data into a radio signal. These end devices can send data to the gateway and also receive data via LoRa wireless protocol. The connection between a node and a gateway is bi-directional with very low bandwidth, between 0.3 and 50 kbps. Hardware requirement to setup the sensor node module for soil EC and pH monitoring is as follows:

1. Arduino UNO Rev3
2. Dragino LoRa Shield 915Mhz
3. 915Mhz SMA Antenna (50 Ohm)
4. DFRobot Analog Electrical Conductivity Sensor
5. DFRobot Analog pH Sensor



Figure 5: A LoRa node consist of Arduino UNO as the controller, LoRa shield and sensors

To build the LoRa node, LoRa shield is stacked onto Arduino UNO with the antenna installed (Figure 5). The schematic of the connection circuit is as shown as in Figure 6. The EC sensor is connected at analog pin A1 and pH sensor at analog pin A0 of the LoRa shield. GND and VCC of both sensors are connected to GND and 5V pins respectively. LoRa node firmware is setup by downloading the zip from <https://github.com/orenonline/arduino-lmic-as923.git>. The Arduino LoraMAC-in-C (LMIC) and EC sensor libraries are imported into the complete node sketch (Appendix I) in Arduino IDE software using programming C language.

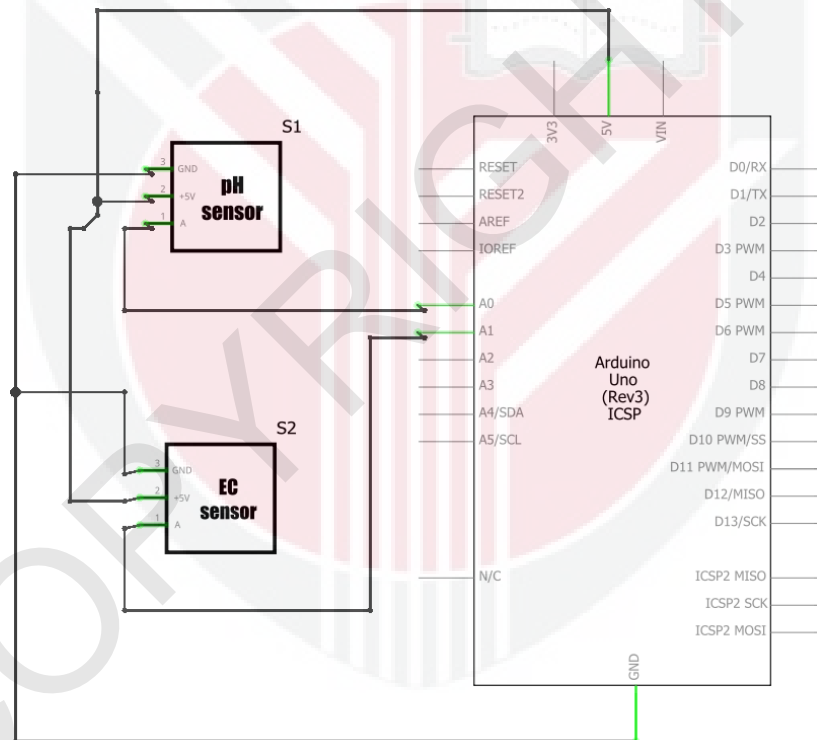


Figure 6: Schematic diagram of sensors connected to the Arduino UNO at the LoRa node

The flow chart in Figure 7 elaborates the programming algorithm to read data from sensor node and send it to the LoRa gateway. Initial settings like pin assignments for both sensors, baud rate and frequency are set according to

requirement. The frequency for this system is set to 921.2Mhz which is within the allowable unlicensed frequency band for LoRa in Malaysia; from the range of 919Mhz to 923Mhz. Since algorithm uses serial communication, availability of serial pin and acknowledgement from gateway is checked to indicate successful communication between the node and the gateway.

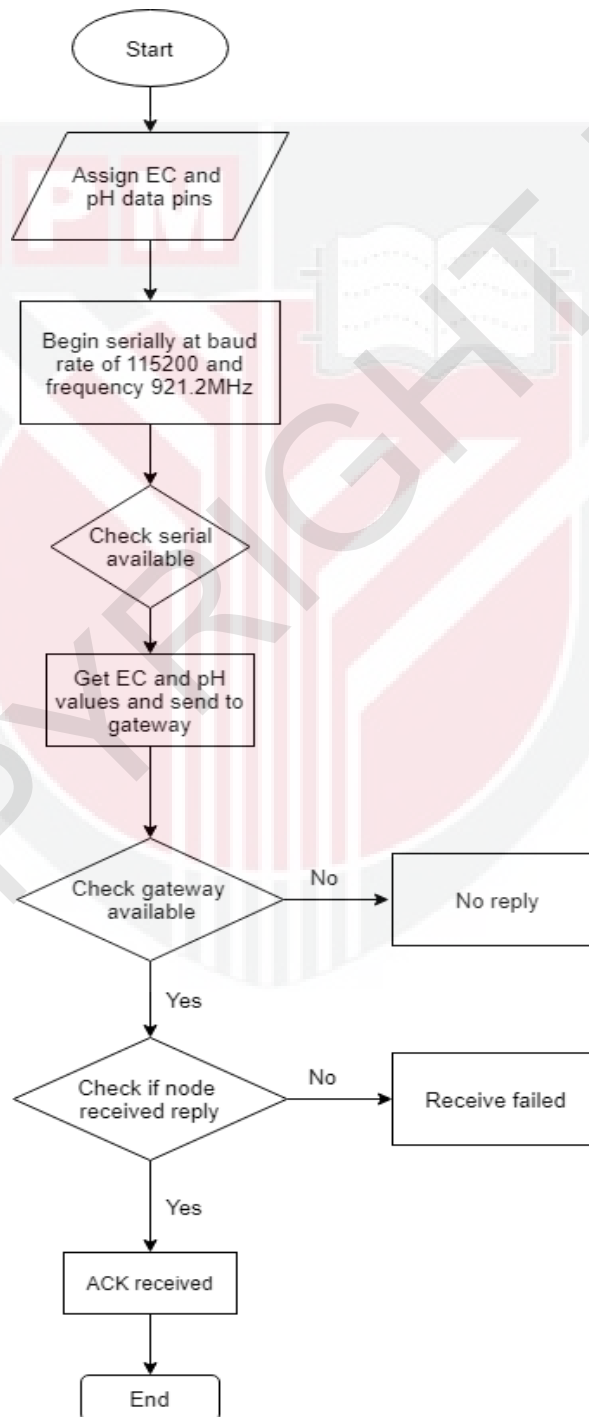


Figure 7: Programming flowchart to send data from sensor node to the LoRa gateway

3.1.1.1 Calibration of Sensors

Pilot calibration of EC and pH sensors are carried out prior to measurement. Errors are estimated during normal operation of a sensor and corrected by suitable feedback mechanism of a calibration code available at <https://wiki.dfrobot.com> for both EC and pH sensor. The sensors are connected to the BNC connector of each respective sensor board that connects to the Arduino analog port. Arduino IDE software is used to upload calibration codes into the Arduino board.

i) EC sensor calibration

A two-point calibration was done using standard buffer solutions of 1413 μ S/cm and 12.88mS/cm. The EC calibration code (Appendix II) is uploaded to the Arduino board and commands are input into the serial monitor to view and calibrate electrical conductivity readings. The sensor probe is washed with distilled water, dried with paper and inserted into the 1413 μ S/cm standard buffer solution (Figure 8). The probe is stirred gently in the solution, until the values are stable as the program automatically identifies buffer solution 1413 μ S/cm. After the first point calibration is completed, relevant parameters are saved and the second point calibration for buffer solution 12.88mS/cm is performed.



Figure 8: EC sensor and conductivity buffer solutions

ii) **pH Sensor Calibration**

Buffer solutions 4.00, 7.00 and 10.00 are used to calibrate for neutral, acidic and alkaline solutions (Figure 9). The buffer solutions are measured with a handheld pH meter to check the accuracy of their pH value before they are used to calibrate the sensor (Figure 10).



Figure 9: pH buffer solutions of 4.00, 7.00 and 10.00



Figure 10: pH measurement of buffer solution

The pH electrode is washed with deionized water and placed into the 7.00 buffer solution (Figure 12). The pH calibration code (Appendix III) is uploaded to the Arduino and the error of the pH value printed on the serial monitor is compared with 7.00. The value difference of 0.11 is input at “#define Offset” of the calibration code. Then the pH electrode is placed into the 4.00 buffer solution and waited for about one minute. Then the potential gain of the sensor board is adjusted until it reaches 4.00 and the readings are allowed to stabilize. After the acidic calibration is completed, alkaline calibration is then performed using 10.00 buffer solution.



Figure 11: pH Sensor used in this study



Figure 12: Apparatus for pH Sensor calibration

3.1.2 Gateway

A gateway is a physical machine which forwards the LoRa packets from nodes to network server via Internet. These messages are converted to an array of bits that can be sent via the traditional IP networks. The gateway is connected to The Things Network (TTN) to which it transmits all the messages. Hardware requirement to setup the gateway module is as follows:

1. Raspberry Pi 3 Model B+
2. Dragino LoRa GPS HAT 915Mhz
3. RP-SMA (Male) Tilt Swivel 1/2 Wave Whip Antenna



Figure 13: A LoRa gateway

To build the LoRa gateway, LoRa HAT is stacked onto the Raspberry Pi with the antenna installed as shown in Figure 13. The Raspberry Pi runs on Raspbian, the free operating system based on Debian optimised for the Raspberry Pi hardware. The software for the single channel LoRa gateway is cloned from GitHub (https://github.com/orenonline/single_chan_pkt_fwd.git). The pin configuration

in globalconf.json file is set as so; "pin_nss": 6, "pin_dio0": 7, "pin_rst": 0. Then, server is defined as 13.66.213.36 (router.us.thethings.network), spreading factor set to SF7 and frequency configured to 921.2MHz in the main.cpp file. After the code is compiled, the gateway is executed to obtain Gateway ID: b8:27:eb:ff:ff:c8:55:a1.

Figure 14 elaborates the algorithm flow at the server side from receiving broadcasted message and sending back acknowledgement to the same LoRa node. The baud rate and frequency is set with the Application Programming Interface (API) key which is exposed by the handler selected; ttn-handler-brazil. Data is checked continuously as it is displayed in the TTN application data window.

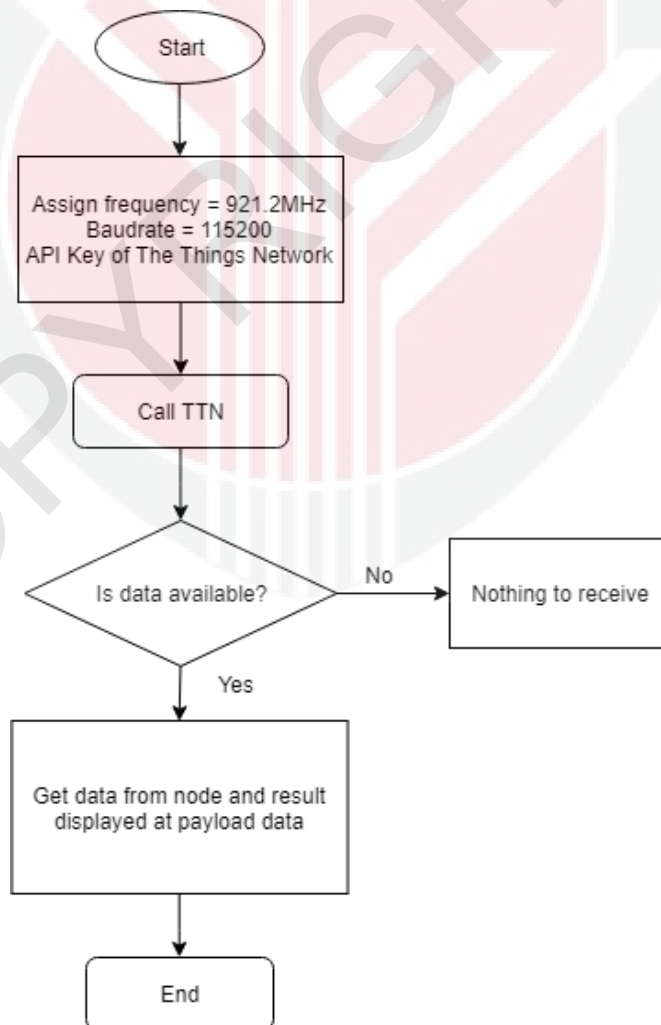


Figure 14: Programming flowchart at LoRa gateway to receive data from sensor node

3.1.3 Network Server

The Things Network (TTN) provides the network for IoT devices based on LoRaWAN standard. It is based on an open community of developers, where LoRa gateways and applications are registered for free. The TTN Server receive data packets from the LoRa Gateway stored temporarily in TTN and reachable via Internet (Figure 16). The network servers can be used for both uplink (i.e. sensor to application) or downlink (i.e. application to sensor) communication.

A user account is registered at <https://www.thethingsnetwork.org>. To setup the node in TTN, an application is created, and the device is registered under Activation by Personalization (ABP). The two session keys generated for this device, Network Session Key and Application Session Key together with the Device Address are then hardcoded into the complete node sketch (Appendix I). To setup the gateway in TTN, the Gateway ID obtained previously from the gateway module is filled at gateway EUI of the new registered gateway. The frequency of 921.2MHz is set and “ttn-router-asia-se” is selected. Upon successful node and gateway registration, TTN data displays received packet from LoRa node in the application data window (Figure 17). The payload shown in raw bytes in the application data window is decoded to display in ASCII format (Figure 15). The raw byte data is taken and then a string that contains all of the characters corresponding to each byte is returned.

```
1 function Decoder(bytes, port) {
2   var decoded = {};
3
4   //decoded.DevAddr = (bytes[4] << 24 | bytes[3] << 16 | bytes[2] << 8 | bytes[1]);
5   decoded.Voltage = (bytes[0] << 8 | bytes[1]) / 1000;
6   decoded.pH = (bytes[2] << 8 | bytes[3]) / 100;
7   decoded.Temperature = (bytes[4] << 8 | bytes[5]) / 100;
8   decoded.EC = (bytes[6] << 8 | bytes[7]) / 100;
9   //decoded.Timestamp = Date();
10
11  return decoded;
12 }
```

Figure 15: Decoder code in TTN

Applications > lora_node_one > Data

Filters: uplink | downlink | activation | ack | error

time	counter	port	dev id	payload	EC	Temperature	Voltage
11:40:27	476	1	ph_sensor	14 46 01 A9 15 08 00 85 00 00	1.33	53.84	5.19
11:40:00	475	1	ph_sensor	14 46 01 AA 15 08 00 94 00 00	1.48	53.84	5.19
11:39:34	474	1	ph_sensor	14 46 01 A3 15 08 00 94 00 00	1.48	53.84	5.19
11:39:08	473	1	ph_sensor	14 46 01 A8 15 08 00 88 00 00	1.36	53.84	5.19
11:38:44	472	1	ph_sensor	14 2E 01 A3 15 08 00 71 00 00	1.13	53.84	5.166
11:38:17	471	1	ph_sensor	14 46 01 A4 15 08 00 97 00 00	1.51	53.84	5.19
11:37:51	470	1	ph_sensor	14 46 01 A6 15 08 00 9D 00 00	1.57	53.84	5.19

Figure 16: TTN payload data

Filters: uplink | downlink | activation | ack | error

time counter port

Uplink

Payload

14 46 01 94 15 08 00 00 00 00

Fields

```
{
  "EC": 0,
  "Temperature": 53.84,
  "Voltage": 5.19,
  "pH": 4.04
}
```

Metadata

```
{
  "time": "2019-05-28T03:40:53.432126704Z",
  "frequency": 921.2,
  "modulation": "LORA",
  "data_rate": "SF7BW125",
  "coding_rate": "4/5",
  "gateways": [
    {
      "gtw_id": "eu1-b027ebffffc855a1",
      "timestamp": 1854322367,
      "time": "",
      "channel": 0,
      "rssi": -30,
      "snr": 10
    }
  ]
}
```

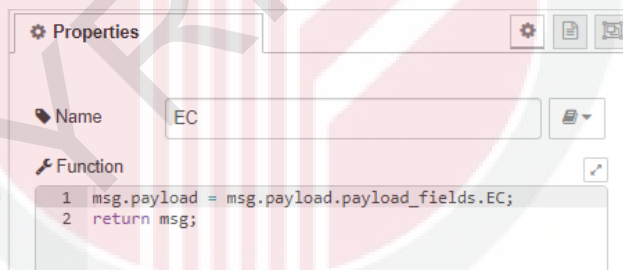
Estimated Airtime

41.216 ms

Figure 17: TTN received packet

3.1.4 Application Server


Application server is where the data collected from the end devices are available to browsers for viewing, manipulated and sent back out to nodes over the network server. Application server performs application-specific processes on cloud which interfaced with the LoRaWAN network server. The last segment of the system is the visualisation of received data using Node-RED, which is a flow-based development tool for visual programming developed originally by IBM for wiring together hardware devices, APIs and online services as part of the Internet of Things. The Node-RED has extensions to get data from TTN and functions for dashboard user interface (UI). The browser-based flow editor wires flows together using the wide range of nodes in the palette (Figure 20). Data from TTN are downloaded, modified into charts and gauges to be displayed in the dashboard UI. Example of some function codes are shown in Figure 18 and Figure 19.



The screenshot shows a Node-RED function block configuration. The 'Name' field is set to 'EC'. The 'Function' field contains the following code:

```
1 msg.payload = msg.payload.payload_fields.EC;
2 return msg;
```

Figure 18: Code for EC function block



The screenshot shows a Node-RED function block configuration. The 'Name' field is set to 'Data Combined'. The 'Function' field contains the following code:

```
1 msg.temperature = msg.payload.payload_fields.Temperature;
2 msg.voltage = msg.payload.payload_fields.Voltage;
3 msg.EC = msg.payload.payload_fields.EC;
4 msg.pH = msg.payload.payload_fields.pH;
5 msg.RSSI = msg.payload.metadata.gateways[0].rssi;
6 msg.SNR = msg.payload.metadata.gateways[0].snr
7
8 msg.data = msg.temperature + "," + msg.voltage + "," + msg.EC + "," + msg.pH + "," + msg.RSSI + "," + msg.SNR;
9 return msg;
```

Figure 19: Code for data combined function block

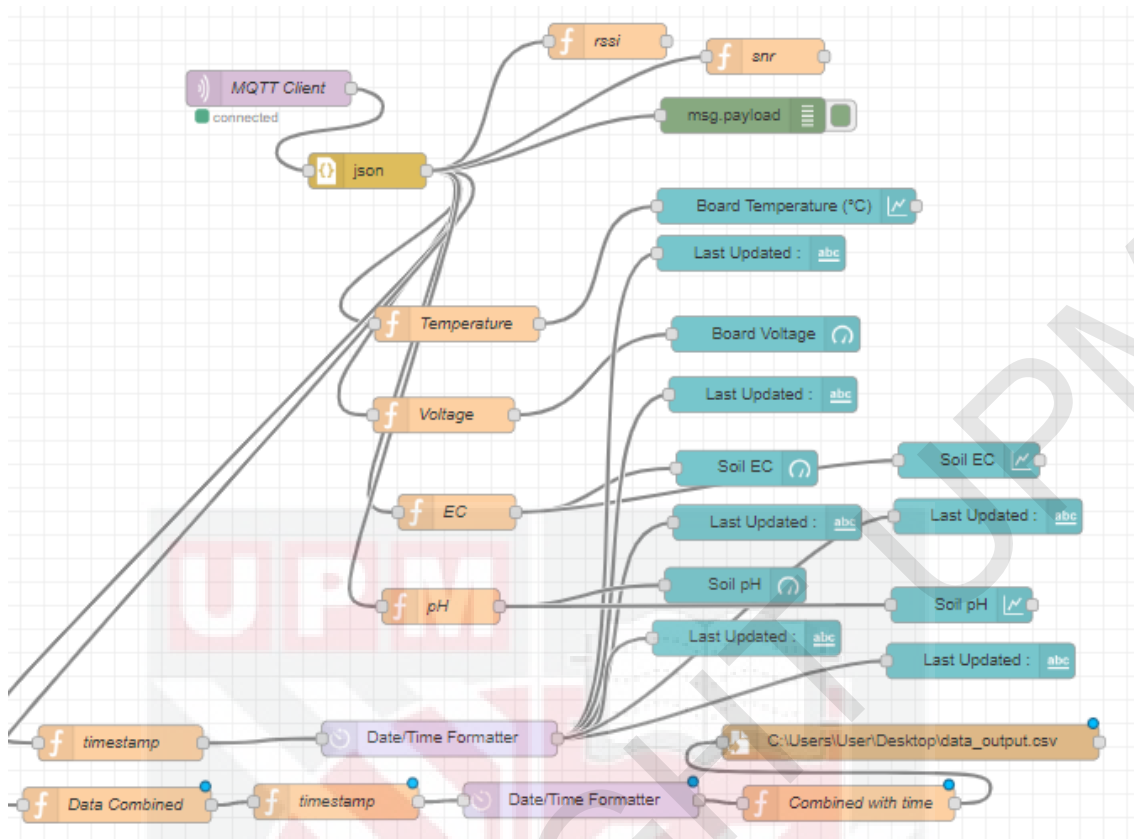


Figure 20: Node-RED browser-based flow editor for board voltage, board temperature, soil EC and soil pH data obtained from TTN

3.2 Experimental Setup

There are two types of experiment conducted in this work, which is (i) signal propagation test and (ii) soil EC and pH measurement test. The first part aims to measure and compare the signal propagation performance through foliage environment; young oil palm plantation (Figure 21), oil palm nursery (Figure 23) and urban area (Figure 25). The second part aims to install the proposed system to monitor and collect soil EC and pH readings of oil palm seedlings in a greenhouse (Figure 27).

3.2.1 Signal Propagation Test

A series of small-scale deployments is carried out to test the feasibility of LoRa transmission as a function of environmental factors. From these experiments, relevant information such as received signal strength indication (RSSI) and signal-to-noise ratio (SNR) measurements together with the distance of each node from gateway are extracted to determine quality of LoRa transmission. All tests are carried out in Selangor area. The gateway and an end-node device hardware of the system built in Chapter 3.1 are battery powered. Thus, this mobile setup allowed the experiment to be tested in various kind of environments.

i) Young Oil Palm Plantation

The test area was at UPM Oil Palm Plantation, Block B with total area of 4 hectares. 850 of 7-year-old 5 metres tall oil palm trees are planted in this block. The gateway is stationary and placed at latitude 2.988439, longitude 101.723713 on a 7m high building. The ground elevation of the building is 81m, thus the total elevation inclusive of building height is 88m. The test is

carried out by positioning the end-node device at different distances to test the maximum range of signal received.



Figure 21: (a) Environment in young oil palm plantation, (b) Gateway placement

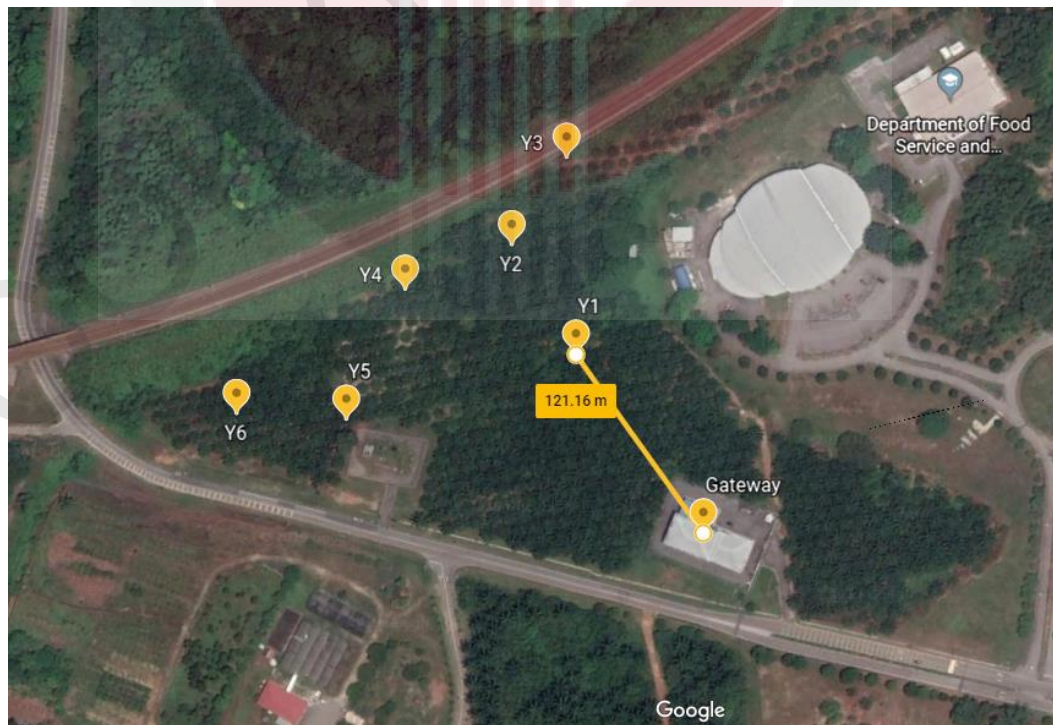


Figure 22: Node and gateway location in young oil palm plantation

ii) **Oil Palm Nursery**

The next test area was at MPOB Nursery, Bangi with total area of 6 hectares. The oil palm seedlings are about 12 to 18 months old, ranging from 1 to 2 metres tall. The gateway is stationary and placed at latitude 2.928454, longitude 101.765041 on a 2.5m high hut. The ground elevation of the hut is 22m, thus the total elevation inclusive of hut height is 24.5m. The test is carried out by positioning the end-node device at different distances to test the maximum range of signal received.



(a)



(b)



(c)

Figure 23: (a)(b) Environment in oil palm nursery, (c) Gateway placement

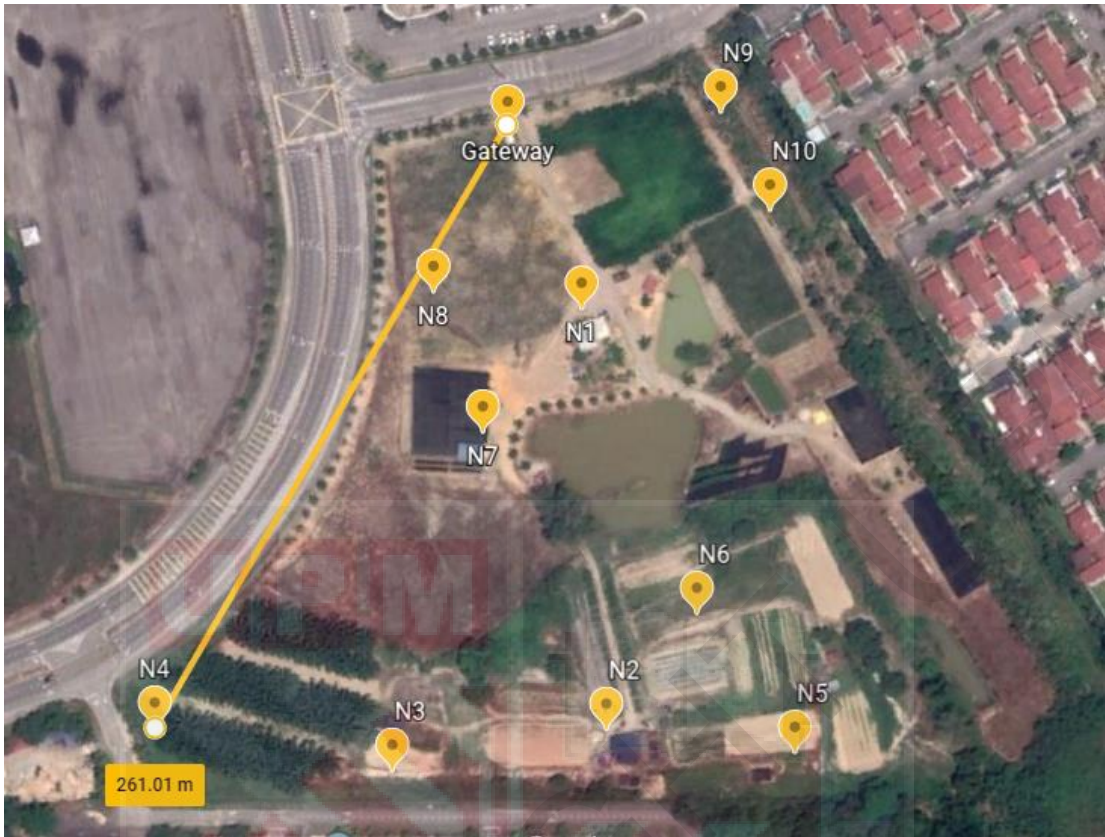


Figure 24: Node and gateway location in oil palm nursery

iii) Urban Area

In this test, the signal propagation performance is carried out in urban area surrounded with tall buildings, houses and trees around UPM and Sri Serdang with an estimated total area of 225 hectares. The gateway is stationary and placed at latitude 3.008647, longitude 101.721345 on a 50m (11 storeys) high building. The ground elevation of the building is 46m, thus the total elevation inclusive of building height is 96m. The test is carried out by positioning the end-node device at different distances to test the maximum range of signal received.



(a)

(b)

Figure 25: (a) Gateway placement, (b) Position of gateway in the building

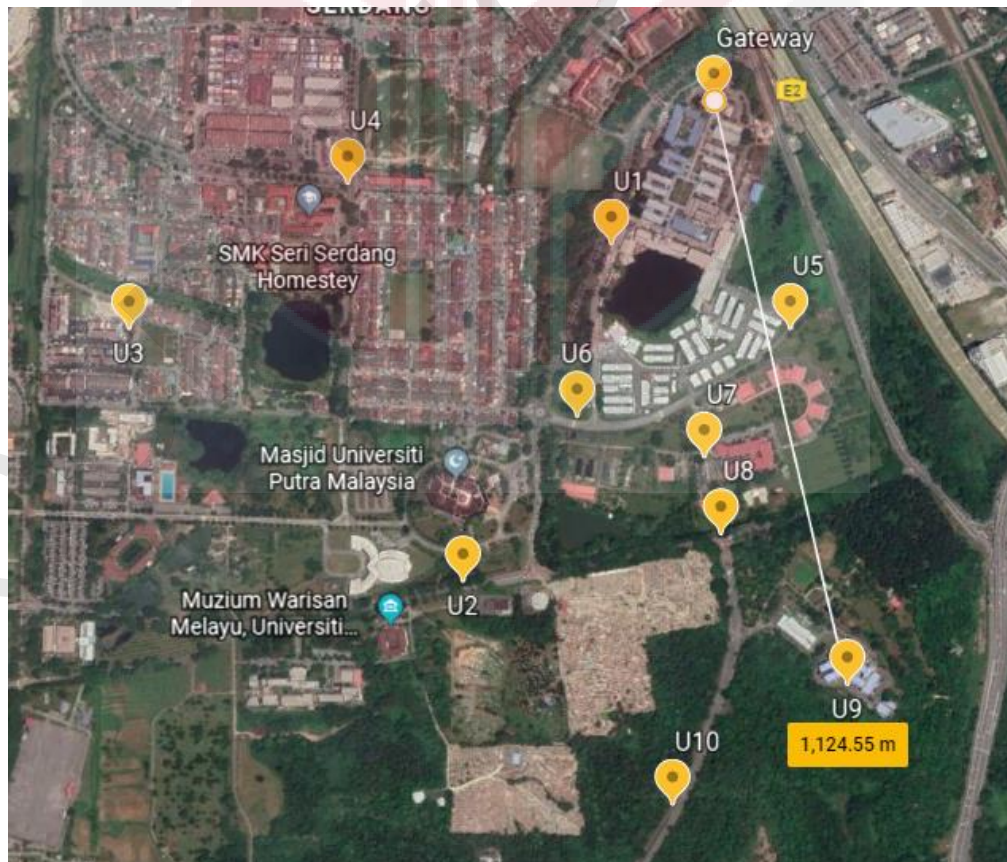


Figure 26: Node and gateway location in urban area

3.2.2 Soil EC and pH Measurement Test

To test the practicality of using this system indoor to monitor soil parameters, a soil EC and pH measurement test is carried out in UPM Transgenic Greenhouse (latitude 2.993361, longitude 101.719596). A total of 60 oil palm seedlings of 9 months old are planted in this 78.04 m² greenhouse. Four different types of treatment are given to the oil palm seedlings in the greenhouse; uninoculated, water deficit; uninoculated, well -watered; inoculated, well -watered; and inoculated, water deficit. In this measurement test, 5 seedlings from each bench are monitored for soil EC and pH readings (Figure 29). The gateway is placed at 5 different points in the greenhouse (Figure 30).



Figure 27: Environment in greenhouse

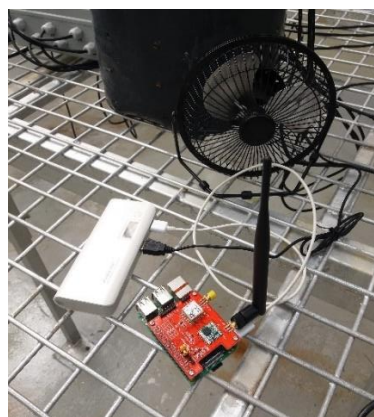


Figure 28: Gateway placement



(a)

(b)

Figure 29: (a) Sensor node, (b) EC and pH sensors placed in soil

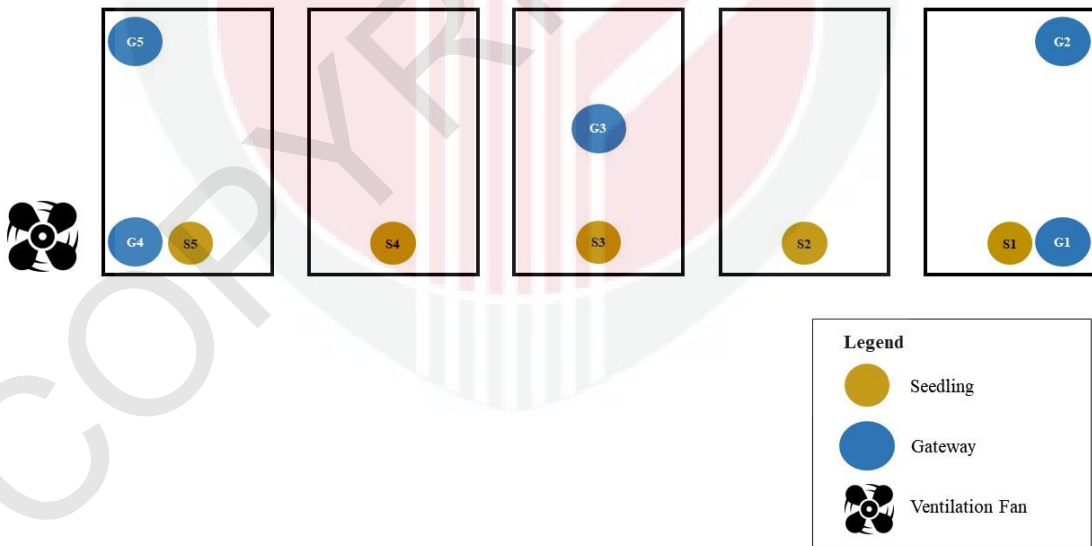


Figure 30: Layout of greenhouse benches, gateway positions and tested seedlings

Chapter 4

Results and Discussion

4.1 Soil EC and pH Monitoring System based on LoRaWAN protocol

This proposed system consists of a sensor node, where soil EC and pH are measured from sensors, a gateway that receives LoRa packets from the node then converting them into IP packets where data is stored in the cloud. Visualisation of the received data sensed by the node module is displayed in the dashboard UI of the application server that is accessible by users. Figure 31 shows the results obtained from the sensor node as EC and pH sensors are placed into the soil. Information of board voltage, board temperature, soil EC and pH readings of growing medium are obtained in real time. From this dashboard, users can easily track and monitor their crop condition to make better decisions for further controls.

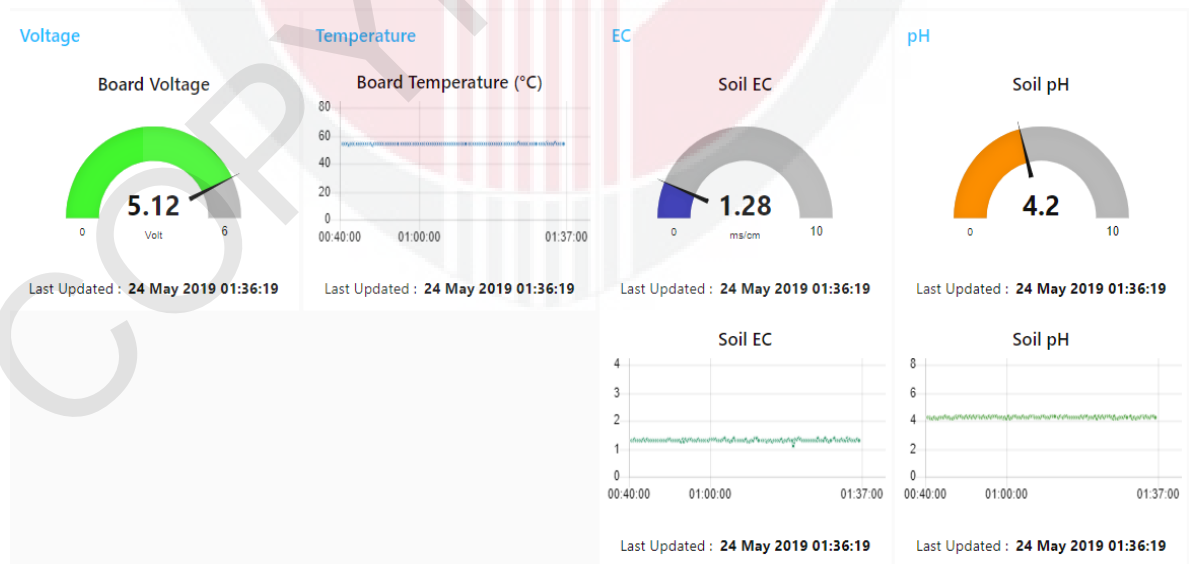


Figure 31: Node-RED Dashboard for Soil EC and pH

4.2 Signal Propagation Evaluation

i) Signal Propagation in Young Oil Palm Plantation

The Received Signal Strength Indication (RSSI) is the received signal power in milliwatts and is measured in decibel-milliwatts (dBm). This value is used as a measurement of how well the receiver (gateway) can “hear” a signal from the sender (node). RSSI values are in negative and the closer it is to zero, the stronger the signal. For LoRa transmission, RSSI values from -30dBm to -120dB are considered strong while values above -120dBm are categorized as weak signals. On the other hand, Signal-to-Noise Ratio (SNR) is the ratio between the received power signal and the noise floor power level measured in decibel (dB). The noise floor is an area of all unwanted interfering signal sources which can corrupt the transmitted signal and therefore retransmission will occur. Normally the noise floor is the physical limit of sensitivity, however LoRa works below the noise level. Typical LoRa SNR values are between -20dB and +10dB. Signals closer to +10dB indicates that the received signal is less corrupted. LoRa can demodulate signals which are -7.5dB to -20dB below the noise floor. In all charts in chapter 4.2, the red colour points at zero does not indicate the value zero but rather an indication of signal loss at that specific point location.

To effectively cover long ranges and achieve a good link budget, it is important to establish a direct line of sight between sender and receiver as often as possible. In radio transmission, specific spatial areas between the line of sight are referred to as Fresnel zones (Figure 32). If there are objects in these zones, they can have a negative influence on the wave propagation, even

when there is visual contact between the transmitting and receiving antennas. For each object located in the Fresnel zone, the signal level is lowered, and the range is reduced.

Based on the results for LoRa transmission in young oil palm plantation, the RSSI values were almost constant as distance increased (Figure 33). Five of the points were in the range of strong LoRa signals except for point Y6 which has packet loss. According to Table 4.2.1, it is observed that there is a large variation in topography as ground elevation ranged from 81m at the gateway to 53m at where point Y6 is located. Since Y6 is at a lower elevation, the signal is disrupted before reaching the gateway as signal must pass through wide canopy and fronds of oil palm trees that were of similar height to the gateway. Thus, there is no clear line of sight between the node and the gateway. The area was secluded and the foliage attenuate LoRa signal propagation quite heavily (Figure 21(a)). Signals that propagate through the oil palm trees are greatly affected by the distributed wide fronds that causes attenuation, scattering, diffraction and absorption of the radiated propagating waves (Ahmad et al., 2018).

In the experiment, the gateway placement was limited to a 7m building which was the tallest building in that area. For LoRa transmission to reach further areas in the young oil palm plantation, the gateway should be placed at a higher elevation for direct line of sight. The furthest point tested that received signal was as far as 223.04m. The SNR values for all five points had negative values showing that noise level is higher than signal level throughout the

transmission but is still within the range of good signal (Figure 34). The transmission is affected by the nature of the plantation environment where large oil palm fronds attenuate LoRa signals.

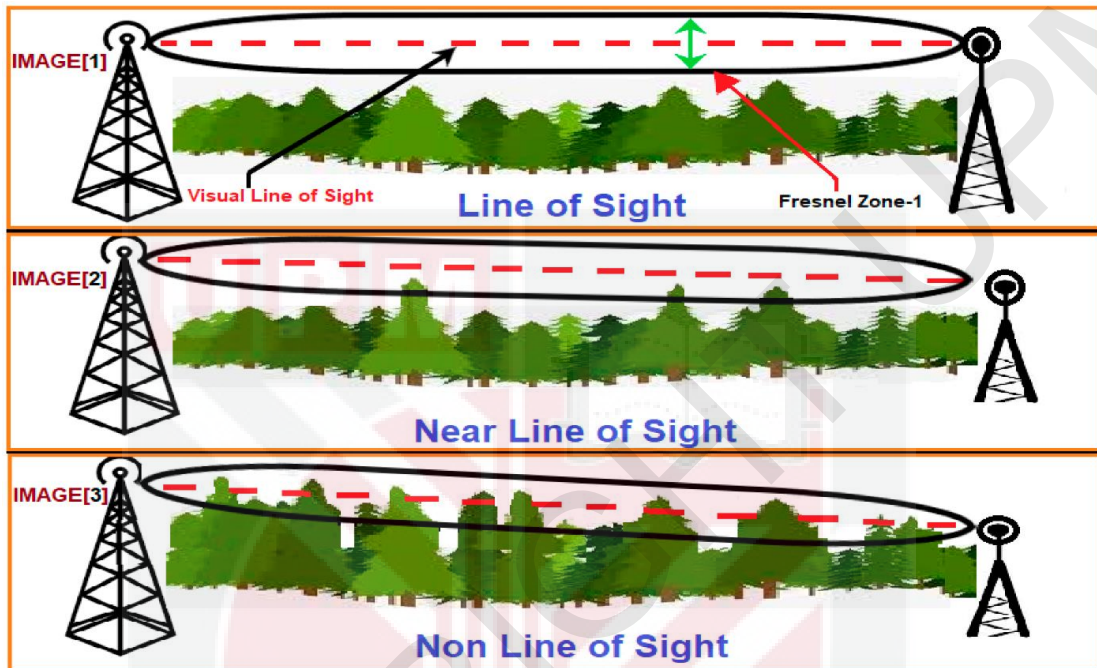


Figure 32: Fresnel zone between sender and receiver (Jebril et al., 2018)

Table 4.2.1: LoRa transmission results in young oil palm plantation

Point	Coordinates	Distance from gateway (m)	Height (m)			RSSI (dBm)	SNR (dB)
			Ground Elevation (m)	Approximate Surrounding Tree Height (m)	Total Height (m)		
Y1	2.989326, 101.723095	121.16	76	5	81	-101	-5
Y2	2.989889, 101.722742	192.58	67	5	72	-101	-4
Y3	2.990331, 101.723019	223.04	66	5	71	-102	-6
Y4	2.989674, 101.722206	217.27	60	5	65	-102	-3
Y5	2.989009, 101.721890	212.98	59	5	64	-102	-5
Y6	2.989030, 101.721305	276.51	53	5	58	-	-

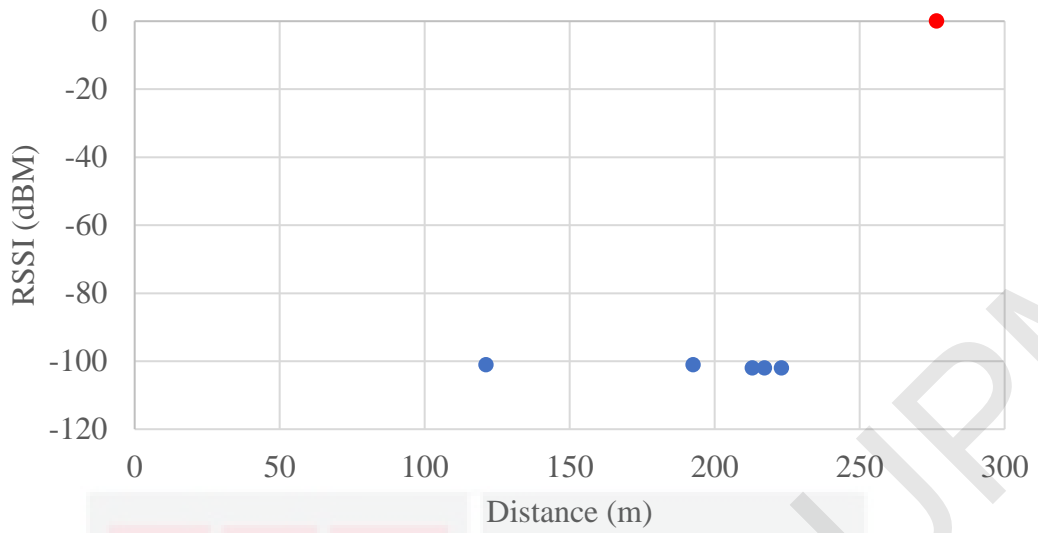


Figure 33: Received Signal Strength Indication (RSSI) across distance in young oil palm plantation

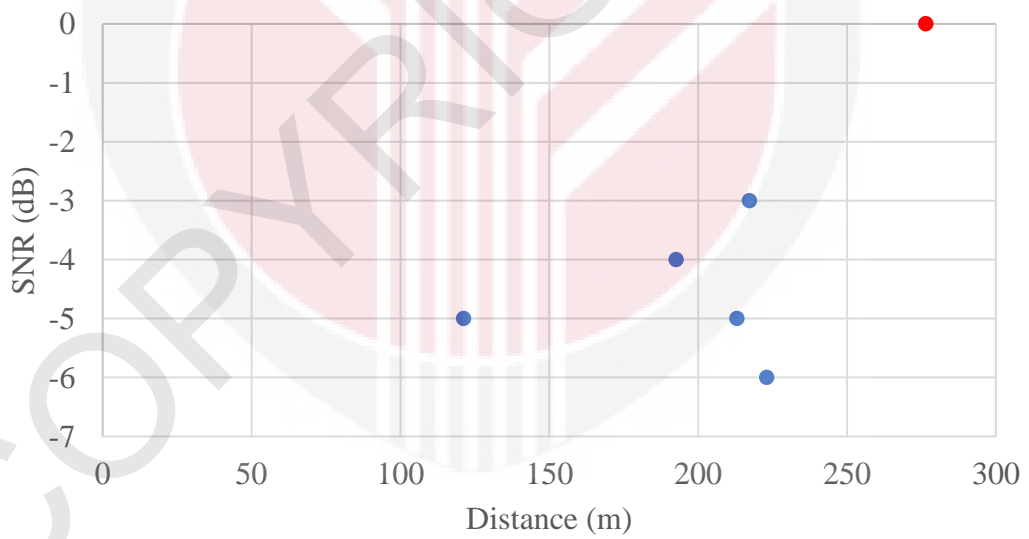


Figure 34: Signal-to-Noise Ratio (SNR) across distance in young oil palm plantation

ii) **Signal Propagation in Oil Palm Nursery**

In the oil palm nursery, typically there were no tall buildings and the seedlings had average height of 1 to 2 metres as shown in Figure 23(b). As there were no attenuation factors, LoRa transmission at every node point was successful without packet loss, covering the whole area of 6 hectares. For these distances, even with small obstacles like small storage buildings and oil palm seedlings, the communication was done with success. In this nursery, communications with distance up to 261.01m can easily be achieved even when the gateway is placed on a 2.5m hut (Table 4.2.2). In contrast, at distance near to 261.01m, however at 276.51m of point Y6 in young oil palm plantation, there were no signal received. This strongly proves that a clear and direct line of sight is required for successful LoRa transmission.

Based on the RSSI vs distance graph in Figure 35, as distance increases, RSSI gradually decreases from -91dBm to -104dBm. All node points have positive SNR with higher received power signal than noise except for point N6 having negative SNR value indicating signal being lower than noise (Figure 36). This probably could be caused by the storage building at N1 which is directly in the line of sight between N6 and the gateway. Even at N4 there were few rows of 7m high oil palm trees, the signal was still good because there is clear line of sight as trees were planted sparsely with ample space for penetration. From this experiment, the feasibility of LoRaWAN as a network protocol is justified as the whole oil palm nursery area was successfully covered with strong LoRa transmission.

Table 4.2.2: LoRa transmission results in oil palm nursery

Point	Coordinates	Distance from gateway (m)	Height (m)			RSSI (dBm)	SNR (dB)
			Ground Elevation (m)	Approximate Surrounding Tree Height (m)	Total Height (m)		
N1	2.9278347, 101.76529435	73.62	22	1	23	-91	8
N2	2.92640933, 101.76537634	227.58	23	1	24	-100	4
N3	2.92627145, 101.76467087	241.57	23	1	24	-96	6
N4	2.92642459, 101.76386446	261.01	21	7	28	-99	4
N5	2.92633962, 101.7660182	256.75	21	1	22	-95	7
N6	2.92681377, 101.76570588	194.66	23	1	24	-104	-3
N7	2.92740759, 101.76496567	115.84	23	1	24	-96	6
N8	2.92789339, 101.76479844	67.68	23	1	24	-93	8
N9	2.92850714, 101.76577265	80.36	20	2	22	-98	5
N10	2.92815334, 101.76593863	103.77	20	1	21	-101	2

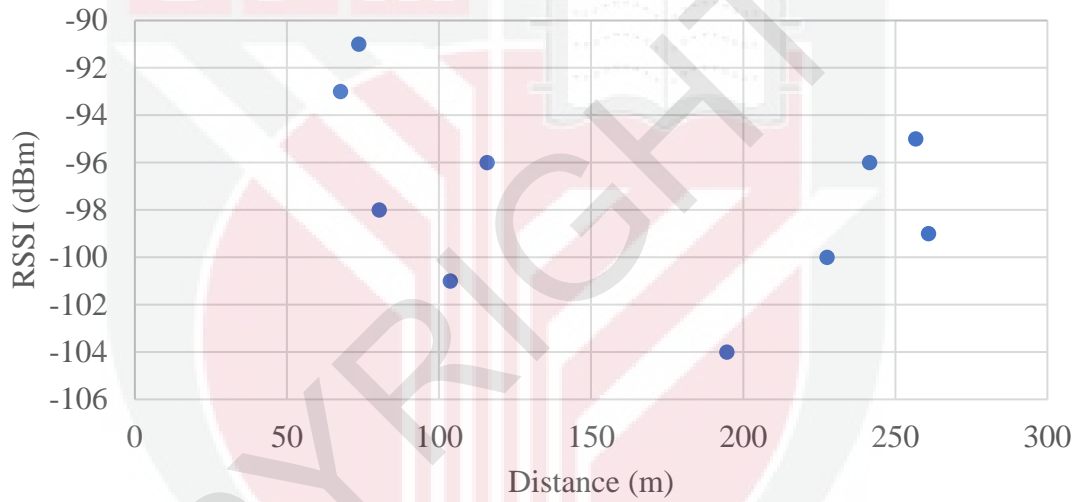


Figure 35: Received Signal Strength Indication (RSSI) across distance in oil palm nursery

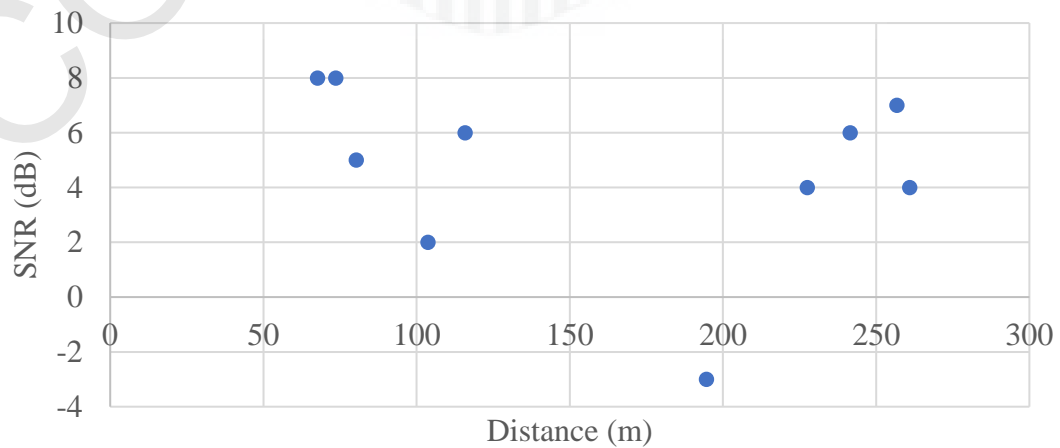


Figure 36: Signal-to-Noise Ratio (SNR) across distance in oil palm nursery

iii) **Signal Propagation in Urban Area**

In urban area, the gateway was placed at a much higher elevation than in both young oil palm plantation and nursery as it was easier to get access to higher buildings. The gateway was placed indoor beside a window on the 11th floor at about 50 metres high. Thus, LoRa transmission successfully reached up to 1.1 km in a city neighbourhood surrounded by trees, houses and some tall buildings that were made of various of materials (Table 4.2.3). In Figure 37, the RSSI values were almost constant as distance increased. At point U6, though it was just 646.66m away from the gateway, signal was blocked by a 7 storey UPM Engineering Faculty building. Point U3 had a similar distance of 1.1km as U9, however had signal loss due to the dense housing area surrounding U3. Furthermore, coverage radius was limited as the gateway is placed indoor.

Almost all points transmitted data at negative SNR indicating there were higher interference in the transmission (Figure 38). The attenuation of signal happens due to it having to pass through or around several materials harder than wood (Rudd et al., 2014). Thus, in an urban environment, there is a heavy dependency on the placement of both gateway and end-node as a single house can have a large effect on the signal quality. A study by Carlsson et al., (2018) stated that the transmission quality is significantly worse in a city environment hardly reaching distance above 350m due to the high amount of noise and quantity of dense materials. In another study, the path with the longest distance achieved was found to be 4.9km which was clear from obstacles. These tests

have also shown that, for distances lower than 1km, communications can be done through small obstacles like trees (Nico, 2017).

It is mentioned that these problems can be mitigated by placing the gateway at higher elevations to reduce path loss by going around objects rather than through them. Height has a great impact on performance when there is free line of sight and the Fresnel zone is clear of obstacles. By applying this elevation in the young oil palm plantation and oil palm nursery, performance would very likely improve drastically.

Table 4.2.3: LoRa transmission results in urban area

Point	Coordinates	Distance from gateway (m)	Height (m)	RSSI (dBm)	SNR (dB)
U1	3.006262, 101.719660	333.51	45	-101	-3
U2	3.000516, 101.717129	1,026.92	54	-102	-6
U3	3.004829, 101.711426	1,194.04	41	-	-
U4	3.007306, 101.715167	712.52	47	-101	-8
U5	3.004845, 101.722722	455.51	46	-104	-1
U6	3.003334, 101.719087	646.66	47	-	-
U7	3.002631, 101.721258	679.38	48	-103	0
U8	3.001333, 101.721528	822.46	58	-104	-3
U9	2.998801, 101.723629	1,124.55	77	-105	-7
U10	2.996780, 101.720701	1,322.66	81	-	-

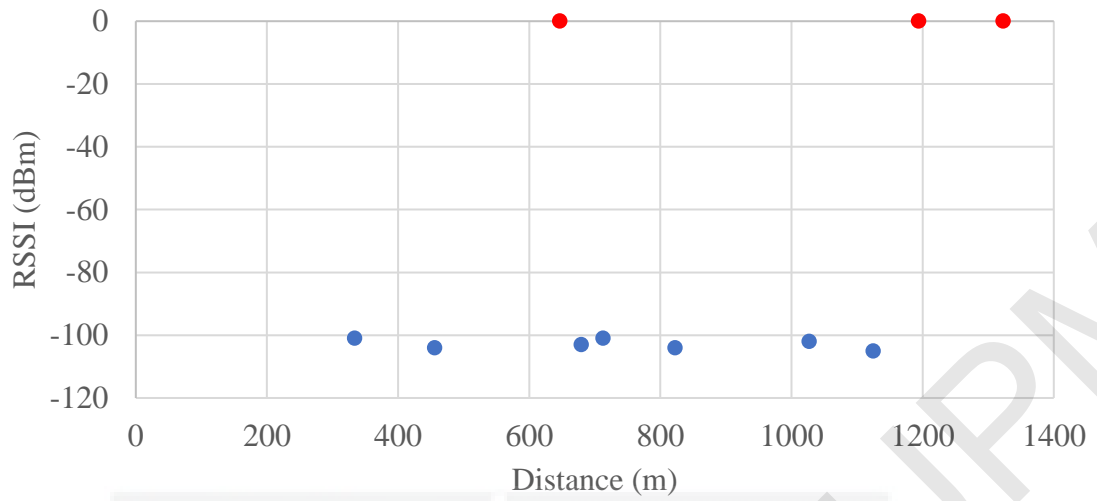


Figure 37: Received Signal Strength Indication (RSSI) across distance in urban area

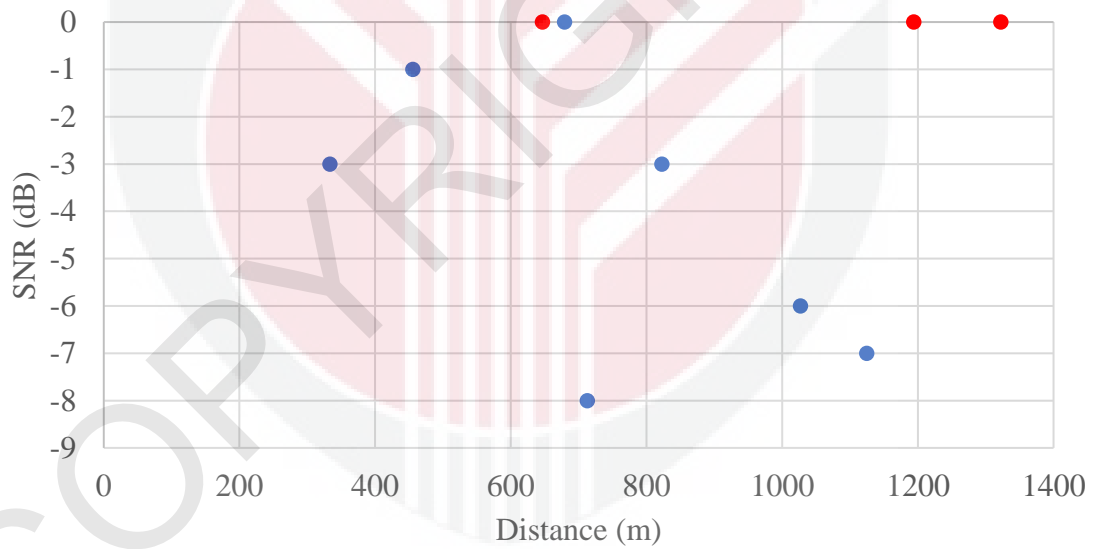


Figure 38: Signal-to-Noise Ratio (SNR) across distance in urban area

4.3 Soil EC and pH Measurements

Both the gateway and the node were placed in the greenhouse to evaluate the RSSI and SNR in an indoor environment while monitoring soil EC and pH of five different oil palm seedlings (Figure 30). According to Table 4.3.1, RSSI decreases as distance between gateway and node increases. Overall, the average RSSI of -63dBm and SNR of 9dB are categorized as strong and good LoRa transmission as seen in Table 4.3.1 and Table 4.3.2. In the greenhouse, the oil palm seedlings were arranged with relatively wide spacing between the seedlings (Figure 27). The transmission did not face much interference as the signals from the node did not need to penetrate any walls to reach the gateway.

Measurements of soil EC in Figure 39 and pH in Figure 40 both show smooth line graph for each seedling indicating accurate sensor measurement and data transmission. Both EC and pH graphs display the differences in soil EC and pH values of seedlings in different growing conditions. Further observations and experiments can be carried out with the data obtained from soil monitoring to conduct plant health analysis. Though S2 and S5 are both uninoculated and well-watered, however their EC value varies. EC of S2 is within 400 ds/cm while S5 is within 100 ds/cm. It could be due to the positions of the seedlings as one of the factors which may affect soil salinity is the evapotranspiration rate.

The uninoculated seedlings S1, S2 and S5 have similar pH values within 5.0. On the other hand, inoculated seedling with water deficit S4 has pH value within 6.0 while inoculated seedling S3 that is well watered have pH value within 4.0. Overall the pH values in all of the seedlings are inclined towards acidity. Based on both charts,

healthy seedling that is uninoculated and well-watered has average EC value of 419.2 ds/cm and average pH value of 5.5.

Table 4.3.1: Node RSSI at various gateway location inside greenhouse

	S1	S2	S3	S4	S5
G1	-37	-59	-65	-65	-76
G2	-56	-68	-75	-64	-68
G3	-65	-80	-57	-60	-66
G4	-66	-60	-54	-51	-55
G5	-75	-67	-64	-65	-62

Average RSSI: -63

Table 4.3.2: Node SNR at various gateway location inside greenhouse

	S1	S2	S3	S4	S5
G1	10	9	9	9	10
G2	10	10	9	9	10
G3	9	9	9	9	10
G4	9	9	9	9	9
G5	9	9	9	10	9

Average SNR: 9

Table 4.3.3: Soil electrical conductivity data in greenhouse

Time	Electrical Conductivity (ds/cm)				
	S1 Uninoculated, water deficit	S2 Uninoculated, well-watered	S3 Inoculated, well-watered	S4 Inoculated, water deficit	S5 Uninoculated, well-watered
10:00	321	427	207	284	110
11:00	318	419	207	282	110
12:00	314	410	204	290	109
13:00	316	418	198	285	109
14:00	321	422	196	288	110

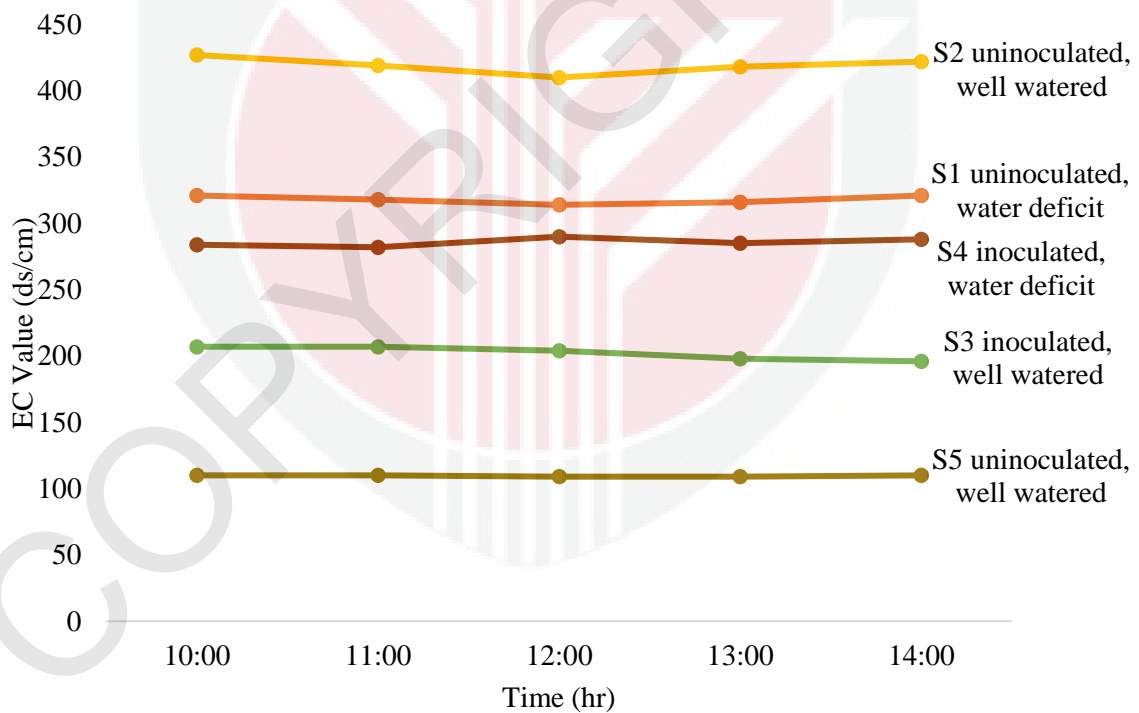


Figure 39: Soil EC data chart

Table 4.3.4: Soil pH data in greenhouse

Time	pH				
	S1 Uninoculated, water deficit	S2 Uninoculated, well-watered	S3 Inoculated, well-watered	S4 Inoculated, water deficit	S5 Uninoculated, well-watered
10:00	5.44	5.61	4.95	5.98	5.60
11:00	5.37	5.57	4.99	5.99	5.59
12:00	5.34	5.43	4.92	5.93	5.55
13:00	5.39	5.47	4.93	5.89	5.59
14:00	5.35	5.45	4.90	5.86	5.52

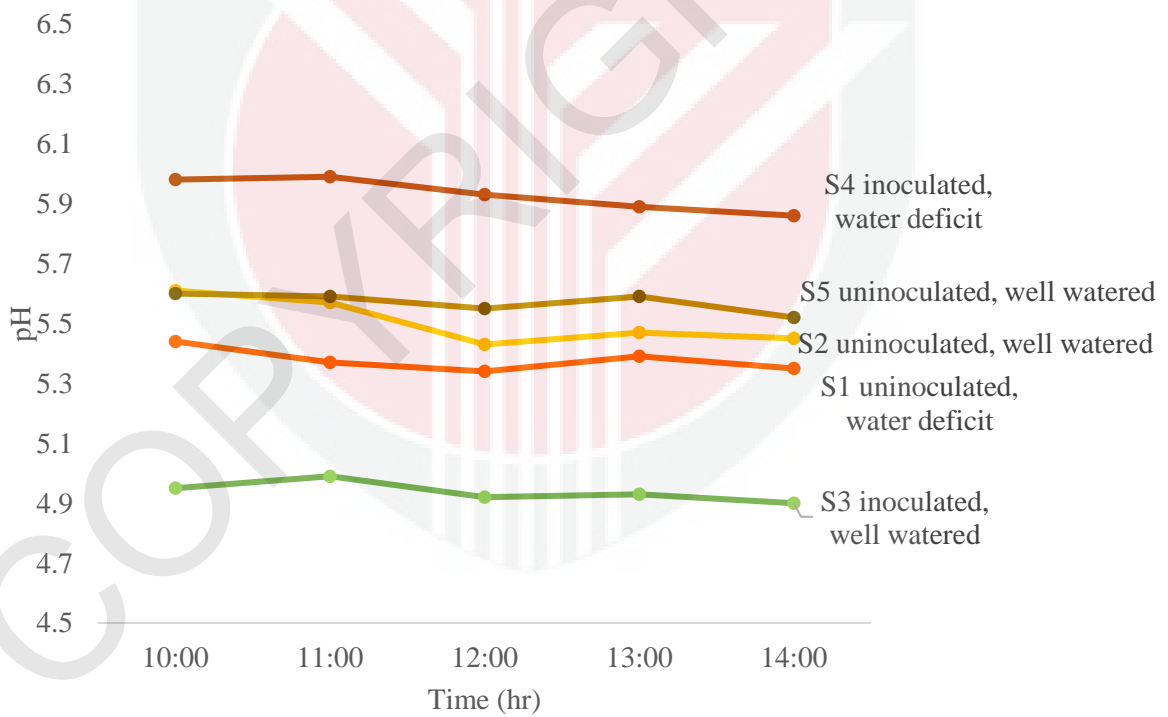


Figure 40: Soil pH data chart

Chapter 5

Conclusion

5.1 Conclusion

A soil EC and pH monitoring system based on LoRaWAN protocol was successfully developed. In this study, a performance evaluation of LoRa network was conducted and from this evaluation, limitations of the performance in different environments were analysed. LoRa transmission was able to cover the entire oil palm nursery area of 6 ha in this study with maximum distance of 261 m. In young oil palm plantation, as the area was secluded with wide canopy and fronds, the signal strength weakened as distance increased therefore achieving only a maximum distance of 223 m. This problem can be circumvented by elevating the gateway or device to the point with free line of sight as proven in urban area achieving up to more than 1 km distance. As for the test in the greenhouse setup (78.04 m²), the transmission did not face much interference and LoRa communication gave stable measurements throughout the experiment (10.00 am until 2.00 pm) with average EC of 419.2 ds/cm and average pH of 5.5 for healthy plant. From this study, the feasibility of LoRaWAN as a network protocol to be used in oil palm nurseries for soil EC and pH monitoring is proven to be successful. The use of LoRaWAN will benefit farmers and overcome the restrictions for the implementation of IoT in Malaysia's agricultural sector.

5.2 Recommendation

The scalability of LoRaWAN can be improved by increasing the spreading factor (SF) values. In this study, SF7 was used throughout the whole experiment. By increasing the SF, the bit rate will be slower but energy per data set becomes higher thus resulting in higher range. Furthermore, there should be optical visibility between the transceiver and receiver antennas by placing the gateway at a higher elevation for clear line of sight. The range can be improved by increasing the height of the antennas to achieve optical visibility between them. Furthermore, a relay can also be added in between the sensor node and gateway to increase transmission distance.

For future investigation into this subject, more case studies are needed as this one is limited to short term tests and conducted under similar weather conditions for all the cases. As to further improve the monitoring system, a fully automated fertigation system can be developed based on the LoRaWAN protocol. Complete data analytics can be performed by incorporating information from weather station and sensor node to send feedback (downlink) to the actuator in fertigation systems. Another improvement could be made for the system is to add additional features such as resistance to the environment with waterproof, surge and lightning protection.

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