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LOGIC DESIGN PROJECT - CO2021
SEMESTER 201

INSTRUCTOR: TRAN NGOC THINH

Report:
Simple LoRa Sensor Network used for monitoring enviroment conditions in wide plant field

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1 Introduction

1.1 Problem

In agriculture, the information of the plant field environment is crucial for farmers to analyse and make decision to optimize as well as to grow and protect plants. Therefore, sensors is a reasonable choice for them to get the approximate data about the environment such as temperature, humidity, light,etc.

Moreover, plant field is a wide area of land up to some hundred thousand m^2, so to cover the environment data from far away, one of the choice is to place many sensors far away and send information back to farmer workplace. In order to send data in long range, LoRa is a good choice, a wireless technology that transmit data in long range, low bandwidth with low power consumption.

In this report, a LoRa Node-Gateway sensor network model is presented as one of the solutions.

1.2 Goal

The purpose of this project is to model a simple Node-Gateway sensor network with LoRa devices and evaluate the model in terms of the connection range in different environments.

2 Theory

2.1 LoRa technology

2.1.1 Overview of Internet of Things (IoT) and wireless network technologies

IoT in general refer to circumstances where network connectivity and computing capacities are not just packed in the boundary of human - computer or human - computer - human networks, they extends to the networks of objects, sensors using different communication models that are able to generate, exchange data with each other with minimal human interaction.

This terms is not new, but thanks to the influence of recent markets trend and increasing in demand have bring IoT to the new level and new applications to the world. According to Tech analyst company IDC, there will be approximately 41.6 billion connected IoT devices by 2025, which is much denser than the number of people in the world.

There are many wireless technology used to connect "things" together, such as: Short-range wireless communication, LPWAN[1], Cellular.

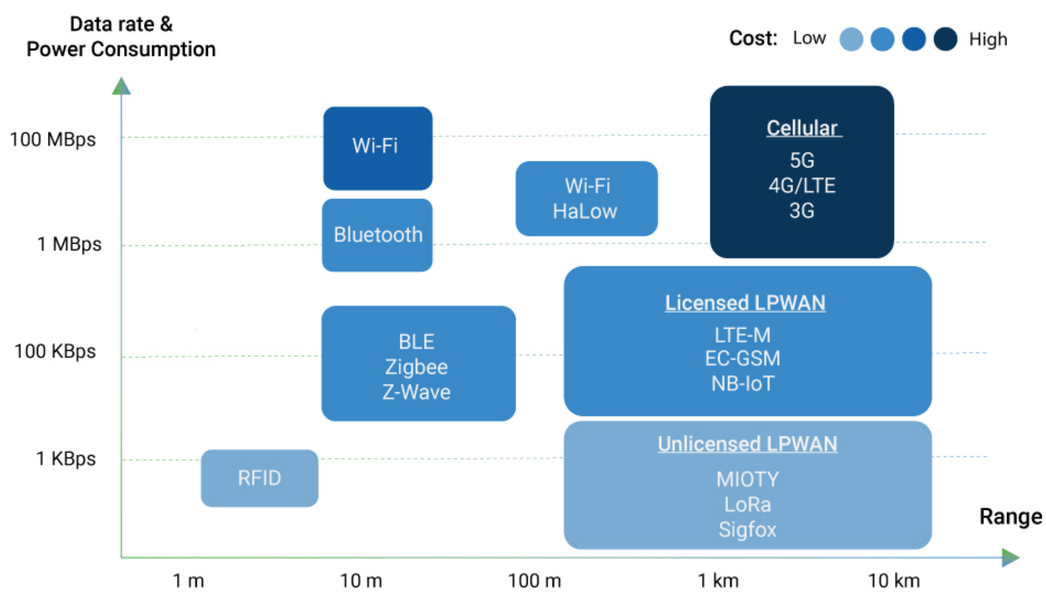

Figure 1: Different wireless technologies are categorized by Data rate, Power Consumption, Range and Cost factors

[1]Low Power Wide Area Network: designed for sending small data packages over long distances

	Communication type	Power Consumption (mW)	Data rate (KB/s)	Range (m)	Cost
Wi-Fi	Short range	~100	~102400	~15	high
Bluetooth	Short range	~20	~1024	~15	low
3G	Cellular	~1000	51200	~5000	very high
LoRa	LPWAN	~20	~0.8	200 - 15000	very low

Figure 2: 3 common-used wireless technologies

It can be seen that LoRa is a good solution for solving long range challenge but low cost, low power consumption. However, LoRa is not good for situations that need transmission with high data rate, Wi-Fi, 3G can solve this problem but there are trade offs of range, power consumption and cost.

There are plenty of applications of LoRa technology. LoRa works well with applications that demand communication within long range but low cost, small data size.

- Safety: Smart lightning, Water level monitoring, earthwake monitoring.
- Efficiency: Asset management: tracking cars, vans, containers.
- Agriculture: Animal monitoring, plant growing conditions monitoring.

2.1.2 What is LoRa?

LoRa - an acronym for **Lo**ng **Ra**nge - is a wireless technology enables extremely long-range data links between a sender and a receiver (or between senders and receivers). A key characteristic of the LoRa-based solutions is ultra-low power requirements, which allows for the creation of battery-operated devices that can last for up to 10 years.

The figure below highlights some important advantages of deploying a LoRaWAN network besides of its low power consumption and long connection range:

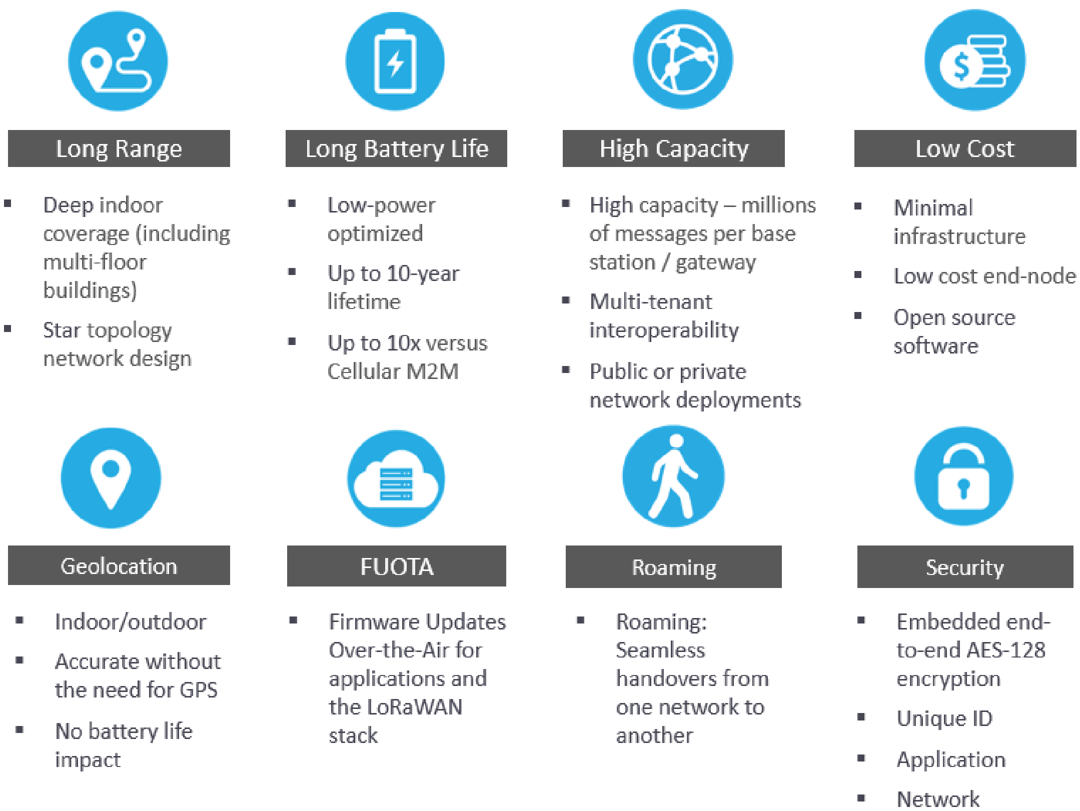

Figure 3: Advantages of deploying a LoRaWAN network

With respect to range, a single LoRa-based device can receive and transmit signals over a distance of more than 10 miles (15 kilometers) in rural areas. Even in dense urban environments, messages are able to travel up to three miles (five kilometers), depending on how deep indoors the receivers are located.

As far as battery life goes, the energy required to transmit a data packet is quite minimal given that the data packets are very small and only transmitted a few times a day.

Furthermore, when the devices are asleep, the power consumption is measured in milliwatts (mW), allowing a device's battery to last for many, many years.

Radio Modulation and LoRa

Modulation will describe how analog or digital information are encoded onto a carrier signal. LoRa is a proprietary spread spectrum modulation scheme that is based on **Chirp Spread Spectrum**[2] modulation (CSS) - a *spread spectrum technique* that uses wideband linear frequency modulated chirp pulses to encode information.

Chirp signals have constant amplitude and pass the whole bandwidth in a linear or non-linear way from one end to another end in a certain time. Chirp spread spectrum uses complete bandwidth to transmit signals. If the frequency changes from lowest to highest, it is call up-chirp and if the frequency changes from highest to lowest, we call it down-chirp. In digital modulation, each chirp represents a certain value of bits. Following is the example of LoRa modulation:

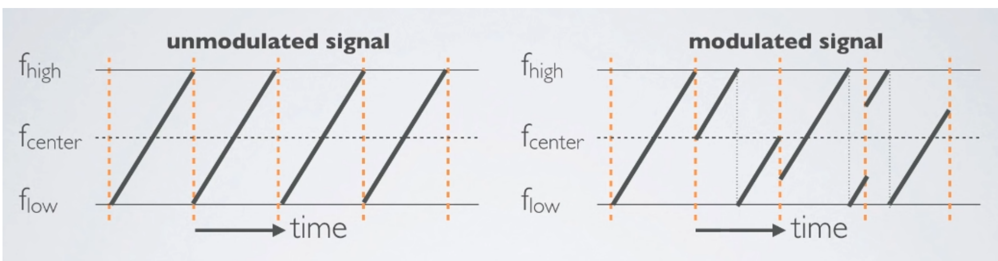

Figure 4: Unmodulated signal and modulate signal (LoRa)

When a node receives the signals, it will do demodultation process which is reverse with modulation.

RSSI in LoRa

The Received Signal Strength Indication (RSSI) is the received signal power in milliwatts and is measured in dBm. This value can be used as as measurement of how well a receiver can "hear" a signal from a sender.

[2]Chirp stands for 'Compressed High Intensity Radar Pulse'.

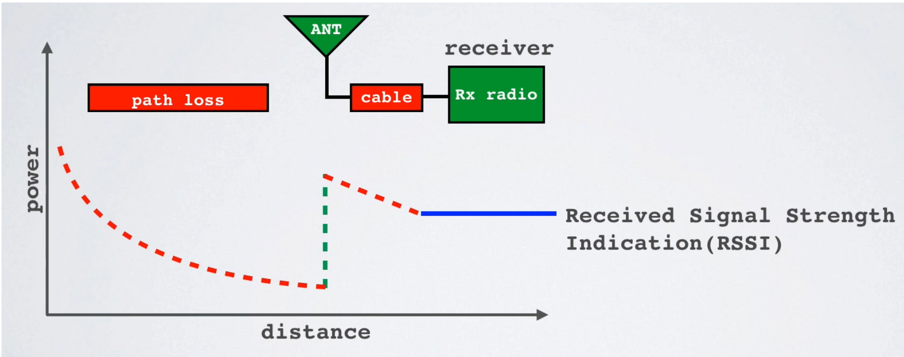

Figure 5: RSSI Graph

The properties of RSSI:

- The RSSI (dBm) is a negative value.
  The closer to 0 the better the signal is.
- Typical LoRa RSSI values are:
  RSSI minimum = -120 dBm
  If RSSI = -30 dBm: signal is strong.
  If RSSI = -120 dBm: signal is weak.

SNR in LoRa
The Signal-to-Noise Ratio (SNR) is the ratio between the received power signal and the noise floor power level. The noise floor is an area of all unwanted interfering signal sources which can corrupt the transmitted signal and therefore re-transmissions will occur.

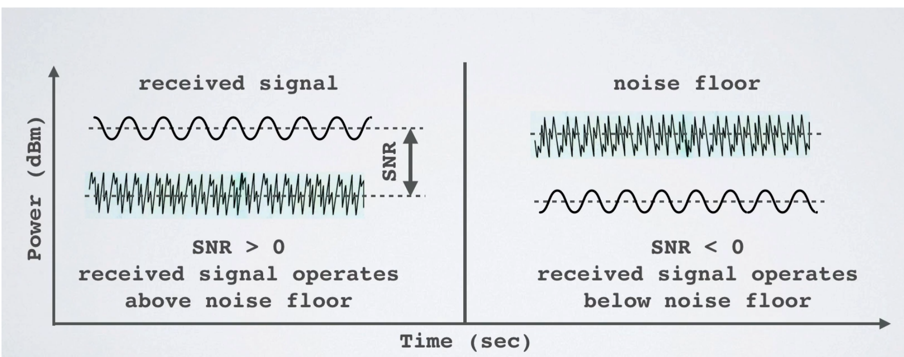

Figure 6: SNR Graph

Normally the noise floor is the physical limit of sensitivity, however LoRa works below the noise level. Typical LoRa SNR values the between: -20dB and +10dB. A value closer to +10dB means the received signal is less corrupted.

2.1.3 What is LoRaWAN?

In LoRa technology, a gateway can handle hundreds of devices at the same time. Specifically, a system of LoRa network contains: gateway (or concentrator) and end node.

Figure 7: The Things gateway

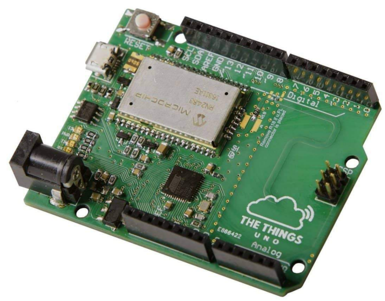

Figure 8: The Things end node

In general, both LoRa end node and gateway consist of 2 parts: a radio module with antenna and microprocessor to process data, e.g: sensor data. End nodes are often battery powered and and can act as a remote sensor. Gateways are connected to the Internet and can listen to multiple frequencies simultaneously. Many gateways can also receive data from the same end node.

LoRaWAN is a network architecture deployed in a star topology. LoRaWAN itself defines an end to end data delivery solution as illustrated in the figure below

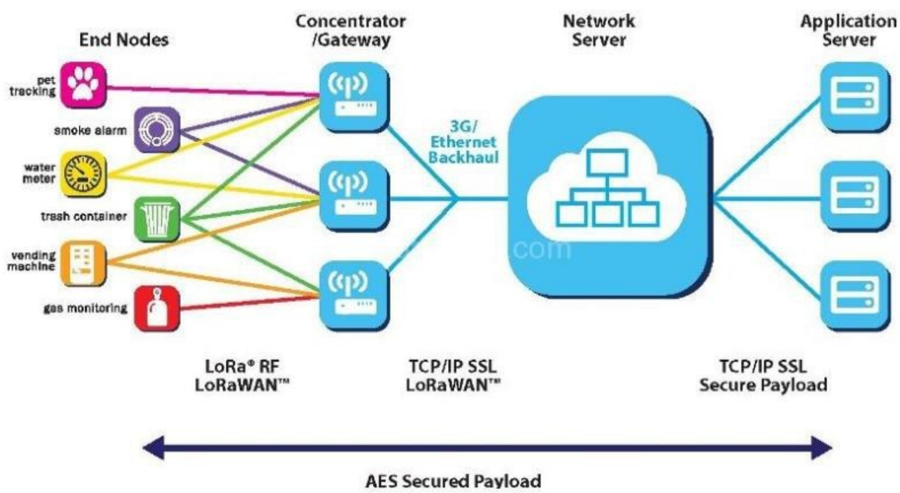

Figure 9: Classic LoRaWAN Architecture

End devices are predominately various types of sensor that broadcast their data to every LoRaWAN gateways in its vicinity. The collected data regarded as packets will be forwarded by the gateways to network server. Afterwards, the network server collects the messages and filter out the duplicate data, then deliver them to the corresponding application server where the user can process/view/analyze the data.

The communication between the end node and gateway in this network is bidirectional which means the end node can both send and receive data from the gateway. When an end node transmits data to the gateway, it is called an uplink. On the contrary, when the gateway transmits data to the end node, it is called a downlink.

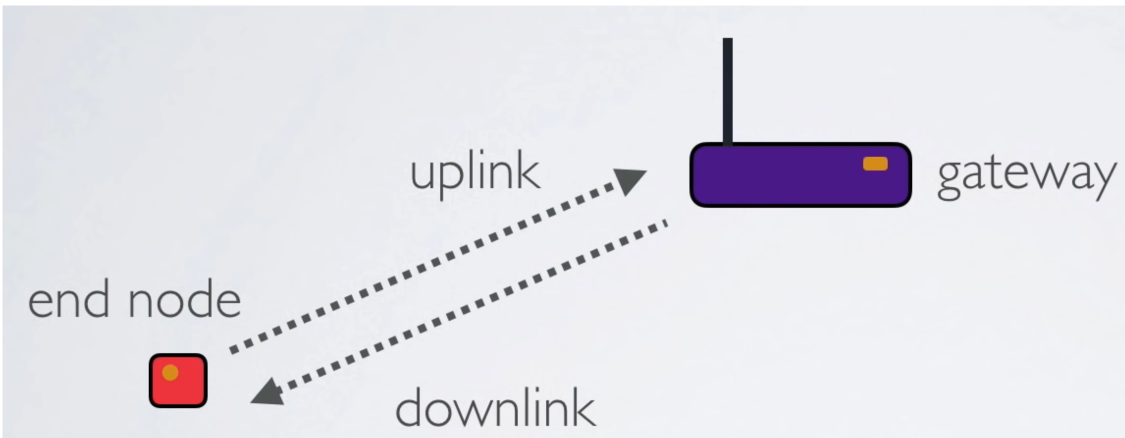

Figure 10: Uplink and Downlink

2.1.4 Rules and regulations

LoRa operates in the unlicensed ISM (Industrial, Scientific and Medical) radio band that are availables worldwide. Example of frequencies by region and country is given below:

Region	Frequency (MHz)
Asia	433
Europe, Russia, India, Africa (parts)	863-870
US	902-928

Region	Frequency (MHz)
Australia	915-928
Canada	779-787
China	779-787, 470-510

According to LoRa Alliance, there are two frequency plans in Vietnam which are **EU433** and **AS923-2**. The regional parameters is specifically given blow:

EU433	433.05 - 434.79 MHz
AS923-2	918 - 923 MHz

2.2 Devices to study

2.2.1 Heltec ESP32 WiFi LoRa 433MHz

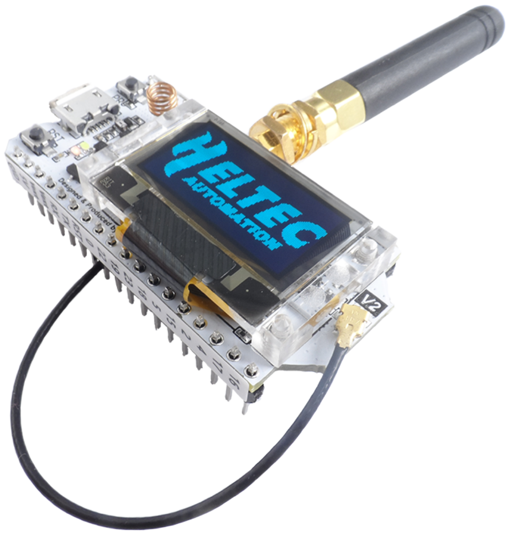

Figure 11: WiFi LoRa 32 433MHz board

WiFi LoRa 32 is an IoT dev-board designed and produced by Heltec Automation(TM), which is integrated with ESP-32 microprocessor, an 0.96" OLED and 3 different wireless communication techonologies: LoRa node chip SX127x from Semtech(TM), Wi-Fi, Bluetooth V4.2.

It can be seen from the pinout diagram of this dev-board that some pins are used to run LoRa chip and OLED, such as pin 19, 18, 5, 26, 27, 14, 32, 33 for LoRa chip for construct SPI protocol and 15, 4, 16 for OLED, which means that if we used LoRa and OLED, these pins cannot be used for other purpose. There is a special point in this board is that it has 18 pins 12-bit ADC input, which allow to read many analog signals compare to ESP-8266 having only 1 10-bit ADC pin. In overall, Heltec ESP-32 have 5 GPIO pins more than ESP-8266 NodeMCU.

LoRa chip of this board supports a frequency of 433MHz for Vietnam (pre-defined in factory), output power goes up to approximately 20dB. Moreover, this board also supports Wi-Fi and Bluetooth. Those factors shows that this board is suitable to act as an gateway in the LoRaWAN network, which has an ability to forward end nodes' data to the Internet via Wi-Fi.

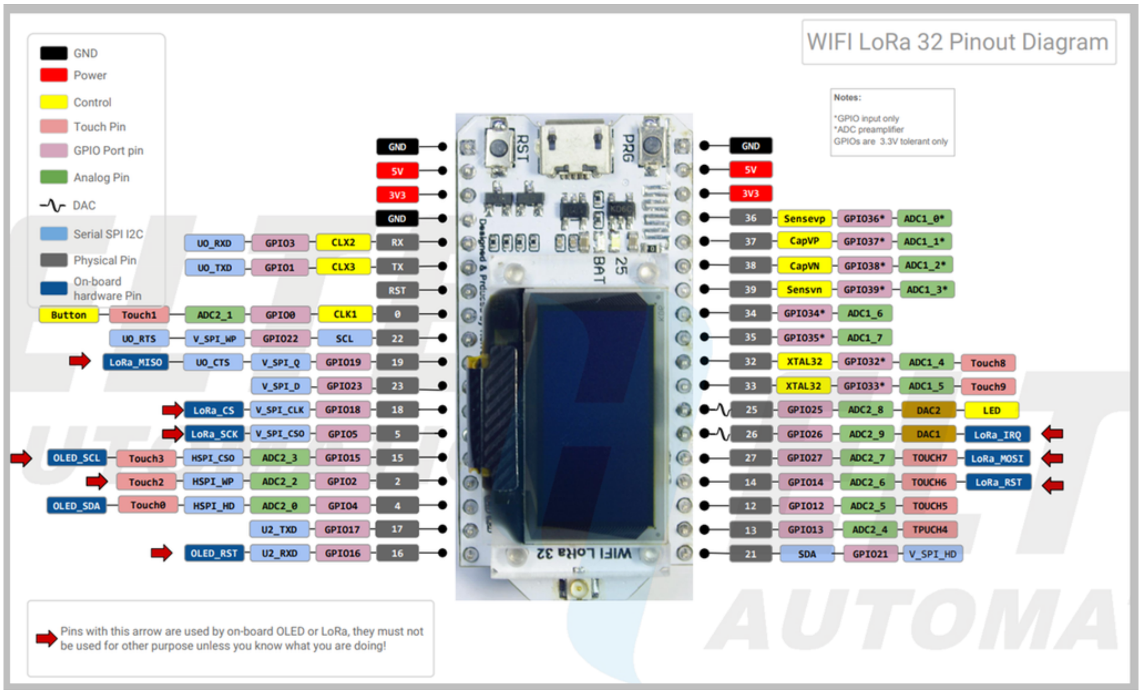

Figure 12: WiFi LoRa 32 433MHz board pin diagram

2.2.2 LoRa Dragino RF98 Shield 433MHz

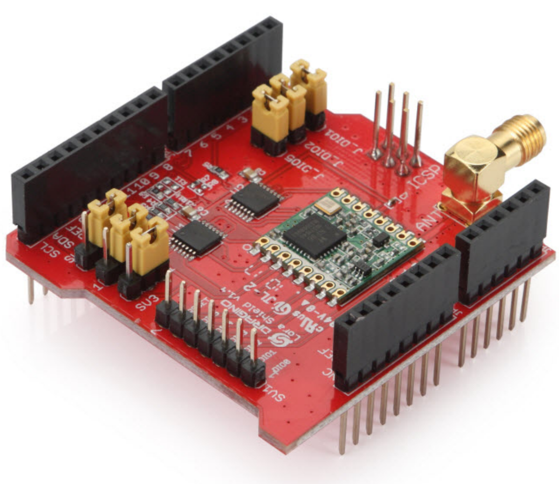

Figure 13: Dragino LoRa RF98 shield

The Dragino LoRa Shield is a long range transceiver on a Arduino shield, integrated with a LoRa chip RF98 which is manufactured by HopeRF(TM).

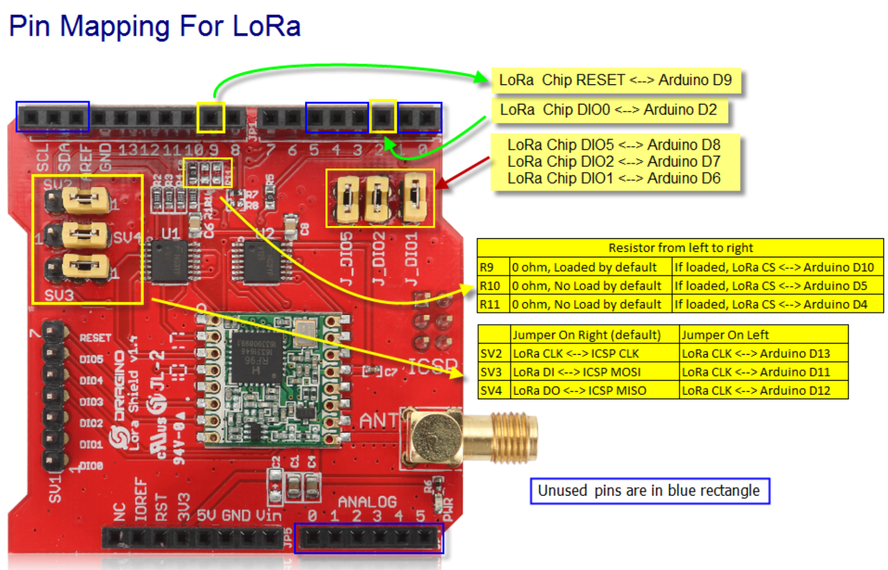

Figure 14: Dragino LoRa RF98 shield pin diagram

It can be seen from the pinout diagram of this shield is that it has 2 way to construct SPI protocol for LoRa chip: the first way is using SPI signals generate from integrated ICSP chip on the shield, the second way is generating SPI signals from Arduino board below. Because it is a shield, so it needs an microprocessor on Arduino to process signals and data. There are 5 unused ADC pins and PWN pins supporting reading and generating multiple analog signals.

RF98 chip on this shield supports a frequency of 433MHz for Vietnam (pre-defined in factory), output power goes up to approximately 20dB. This shield is suitable as an end node or sensor node.

2.2.3 Blynk

Figure 15: Blynk logo

According to Blynk.io "*Blynk is a hardware-agnostic IoT platform with white-label mobile apps, private clouds, device management, data analytics, and machine learning.*". In simple term, Blynk is and application on the mobile phone that provides for users abilities to control dev-boards remotely, collect, store data from hardware at anytime and anywhere provided that users has accessed to the Internet.

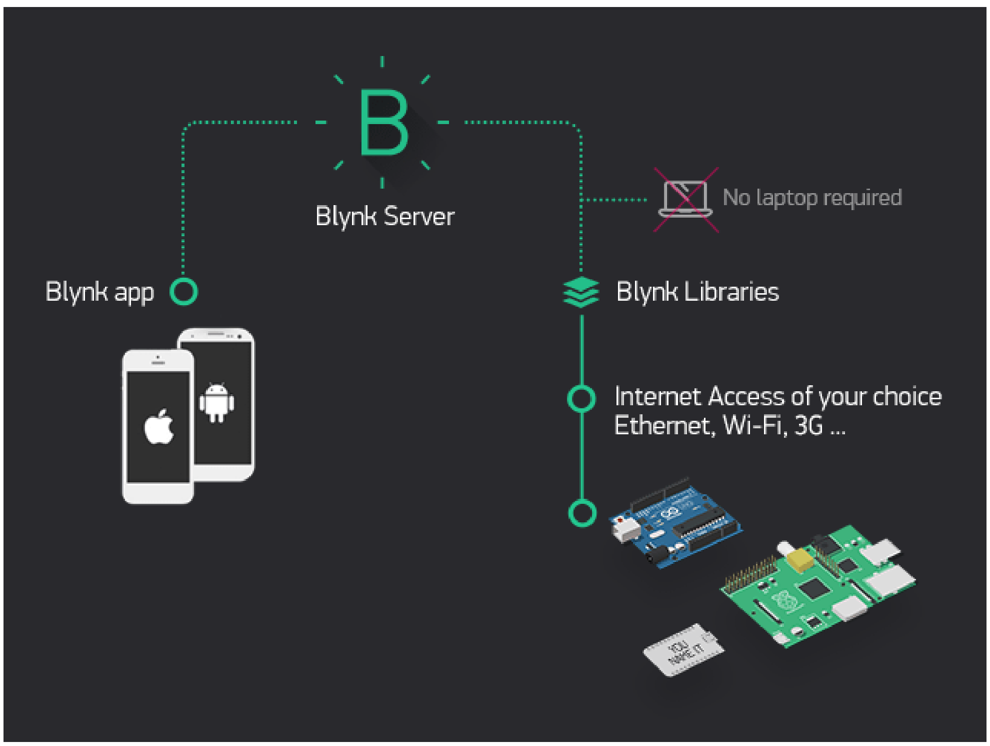

Figure 16: Blynk model

Blynk model have 3 major components:

- Blynk App: provide an environment for users to create and manipulate their own interface with available widgets. Moreover, Blynk provide an unlimited virtual pins for some widgets.

- Blynk server: A middle center to process communication and data between BLynk app and dev-boards. There are 2 options for users: choosing Blynk server or creating their own local Blynk server.
- Blynk libraries: provides many APIs for many dev-board platforms to process incoming and outcoming commands and data.

Overall, Blynk is a good applications to connect users and hardware below.

3 Network model

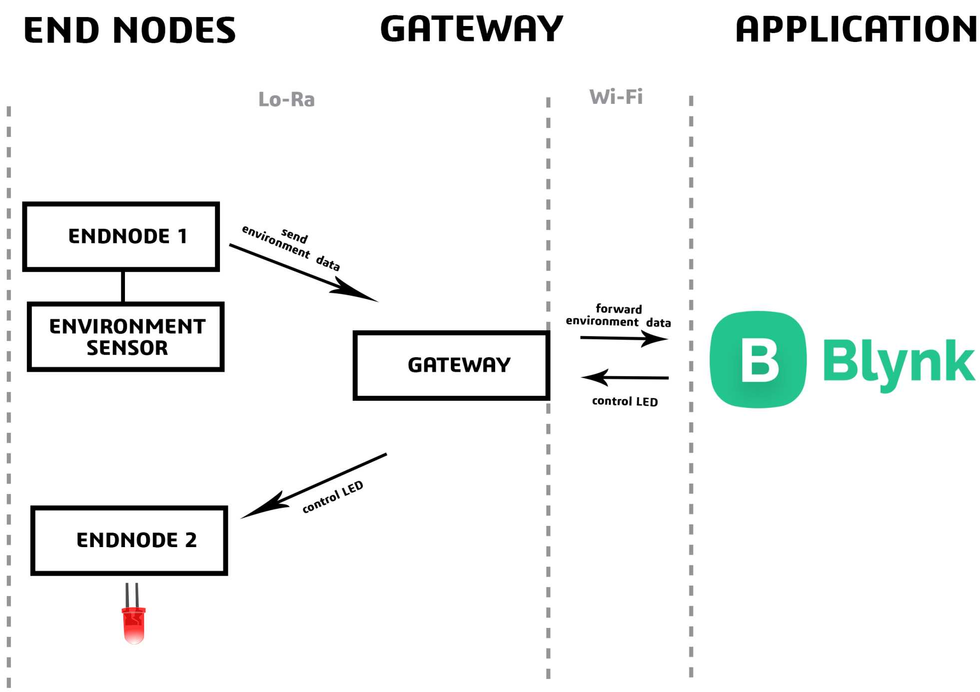

Figure 17: LoRa Node-Gateway sensor network model

The model consists of 3 parts:

- End nodes: There are 2 end nodes. The first one collects environment information, specifically temperature, humidity, pressure, altitude, light intensity from the field and send these data to the gateway. The second one holds the LED, which is controlled remotely by user.
- Gateway: There is one gateway communicating and transferring data between end nodes and the user via 2 different wireless technology. The gateway forwards environment data to the app and receive LED control signal from the app.
- Application: An app which show environment data from the plant field and help user to control the LED to lighten the field. User can access and observe information at anywhere if he can access to Internet.

In order to overcome the long range challenge, LoRa is used to communicate between end nodes and Gateway. Gateway then upload and receive data to and from the application via Wi-Fi.

3.1 Description of 2 test sites

There are 2 test sites used to test the performance of the LoRa in this model:

- HCMC University of Technology, District 10: This place is located in the center of urban area, in which have many obstacles such as tree, buildings; have many noice.
- Street 4, Binh An Ward, District 2: This place is located outside the urban area, one straight street with few obstacles.

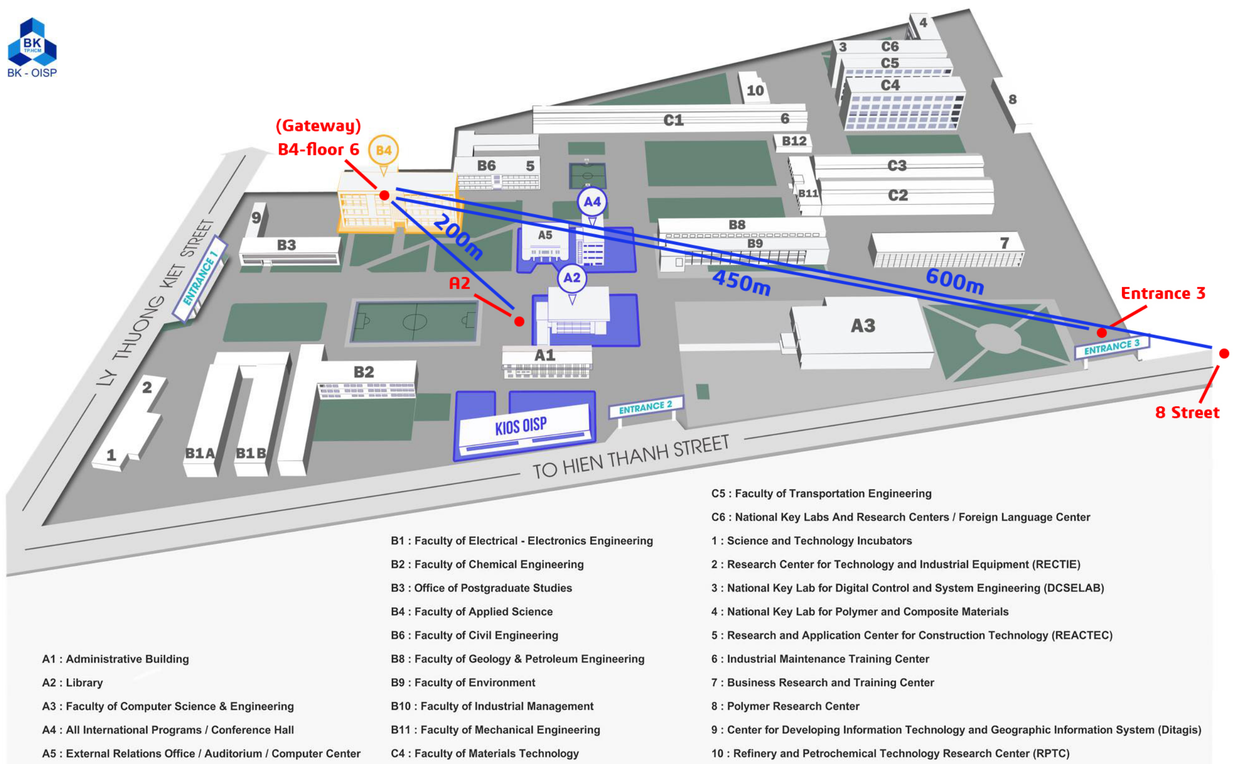

Figure 18: HCMC University of Technology map for testing

The first environment to test this model is the area of HCMC University of Technology. Gateway is placed at B4 - floor 6, environment sensor node is placed at 4 different places to test the range of LoRa transmitting ability. 4 scenarios are:

1. B4-floor 6: 1m
2. B4-floor 6 - A2: 200m
3. B4-floor 6 - Entrance 3: 450m
4. B4-floor 6 - D8 street: 600m

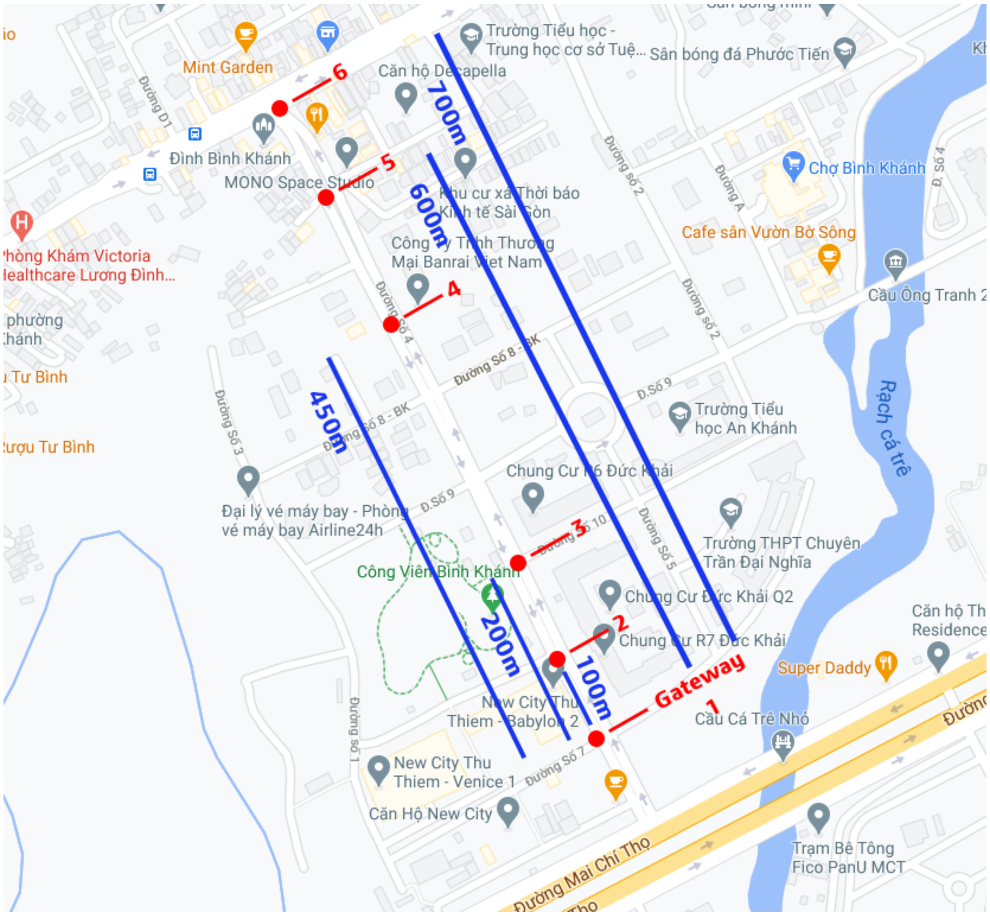

Figure 19: 4 Street map for testing

The second environment to test this model is the straight Street 4, Binh An Ward, District 2. Gateway is placed at Street 7, environment sensor node is placed at 7 different places to test the range of LoRa transmitting ability. 7 scenarios are:

1. 1m
2. 100m
3. 200m
4. 450m
5. 600m
6. 700m
7. 750m

4 Implementation

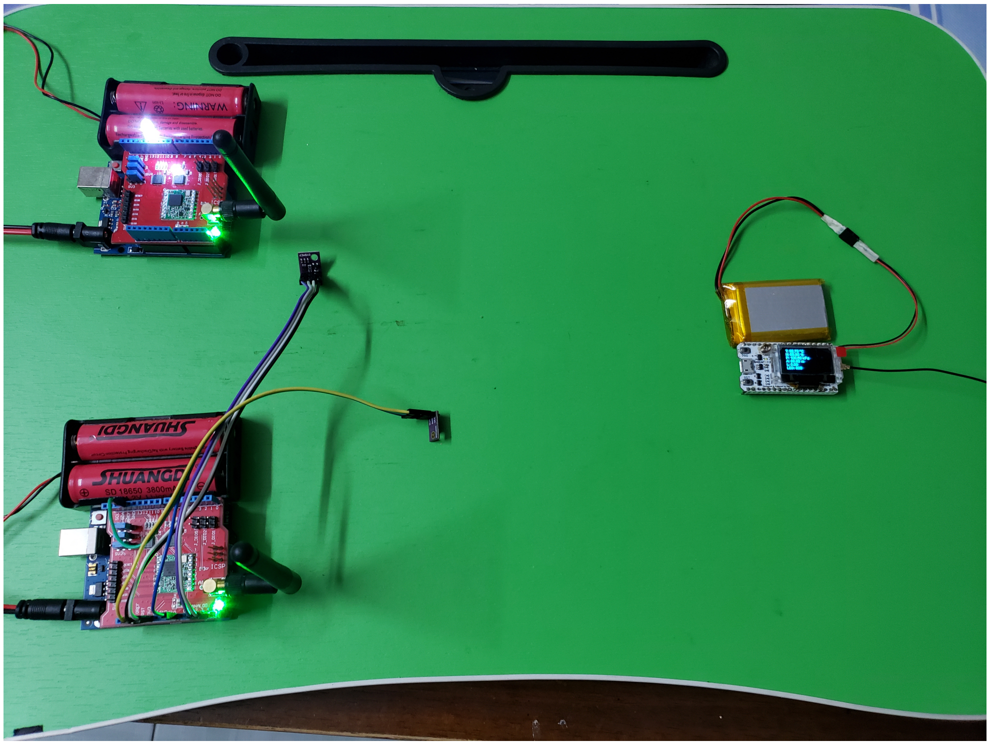

Figure 20: Model is implemented. The 2 left nodes is the 2 end nodes; the right node is the gateway

4.1 Hardware and software

- End node 1: Arduino Uno + LoRa Dragino RF98 Shield 433MHz + BME/BMP280 sensor + TEMT6000 sensor.
- End node 2: Arduino Uno + LoRa Dragino RF98 Shield 433MHz + white LED.
- Gateway: Heltec ESP32 WiFi LoRa 433MHz.
- Application: Blynk server on mobile phone.

4.2 Connection

- LoRa: set on frequency of 433MHz, set sync word 0x29 to avoid signal from outside environment, set TxPower to maximum of 20dB.
- WiFi: connect local WiFi.

4.3 Data package structure

To transfer data between end nodes and gateway, the following sending package format is used:

```
struct info
{
  //data
};

struct package
{
  String src;
  String dst;
  info packageInfo;
};

package dataPackage;
```

Figure 21: Data package format

The data package contains 3 main parts:

- String src: defines the source node.
- String dst: defines the destination node.
- info packageInfo: contains information.

src, dst holds one if the values [NODE0, NODE1, GATEWAY0].

Using ArduinoJson library to serialize and deserialize the data package into String datatype then sending this String via LoRa.

Because the LoRa node will receive every signal with the same frequency and sync word, to define clearly which package to receive from an specific node, String src, dst is used to define clearly where the information need to go, Whenever the receiving node detect the incoming package, if sending dst != receiving src then that node will ignore the package.

Moreover, String length checking method and error checking when deserialize json string is used to detect if the receiving package data is the same as that package data when sending. Gateway additionally check if the incoming package is from the 2 source nodes in the network or not.

4.4 End node 1 (NODE0)

4.4.1 Hardware

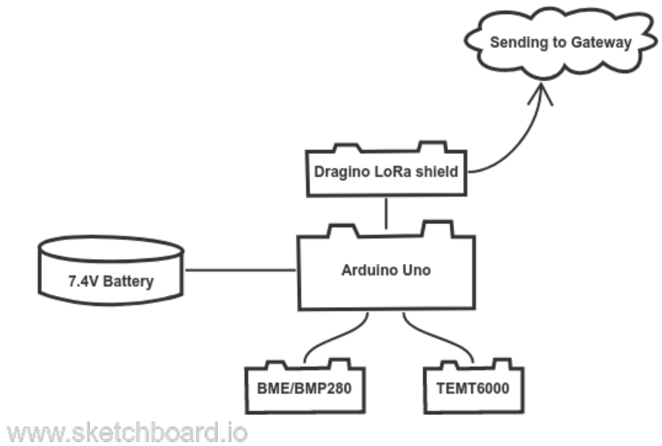

Figure 22: End node 1 hardware connection

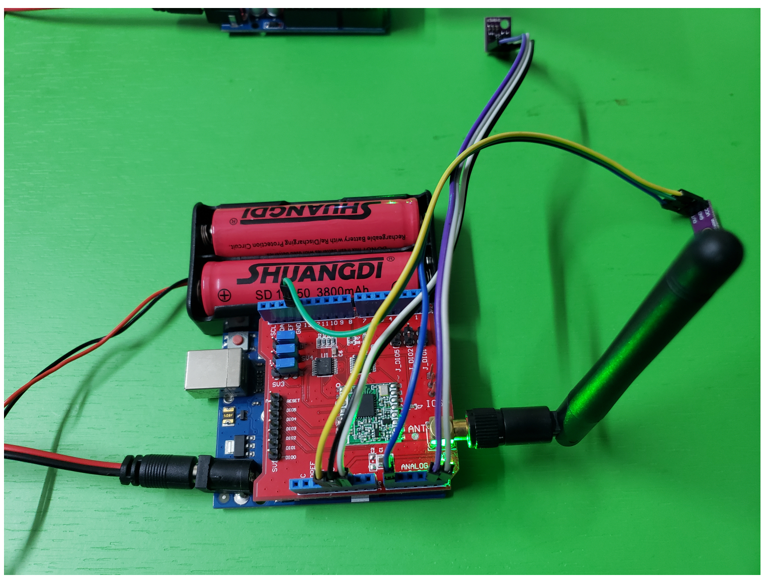

Figure 23: End node 1 is implemented

4.4.2 Code

```
struct info
{
  float tempVal = 0;
  float humidVal = 0;
  float pressVal = 0;
  float altVal = 0;
  int lightVal = 0;
};

struct package
{
  String src = "NODE0";
  String dst "GATEWAY0";
  info packageInfo;
};

package dataPackage;
```

Figure 24: End node 1 data package

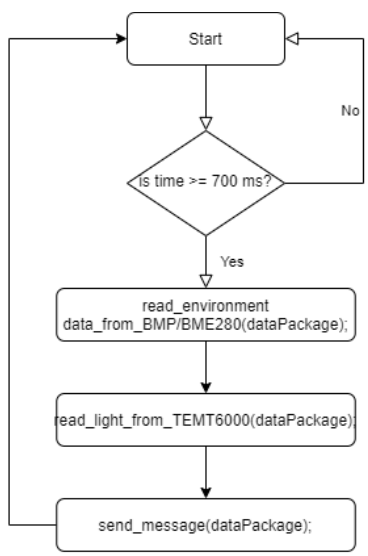

Figure 25: End node 1 pseudo-algorithms flow chart

4.5 End node 2 (NODE1)

4.5.1 Hardware

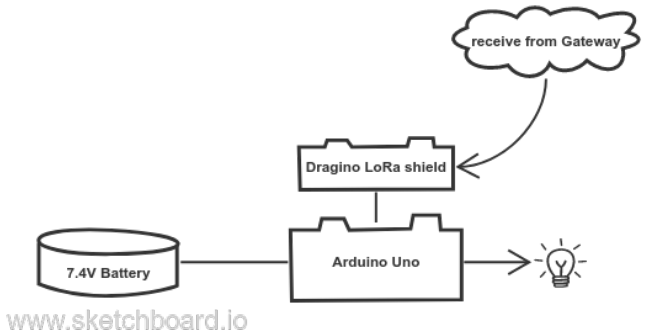

Figure 26: End node 2 hardware connection

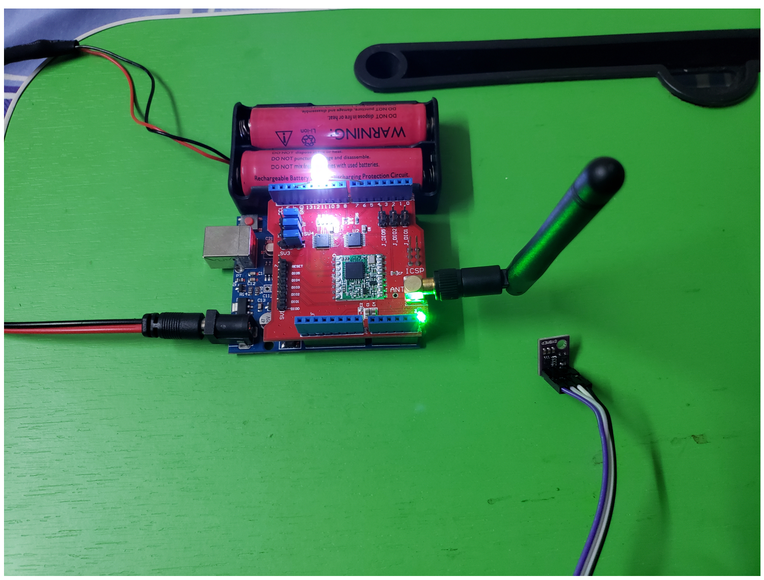

Figure 27: End node 2 is implemented

4.5.2 Code

```
struct info
{
  int ledVal = 0;
};

struct package
{
  String src = "NODE1";
  String dst;
  info packageInfo;
};

package dataPackage;
```

Figure 28: End node 2 data package

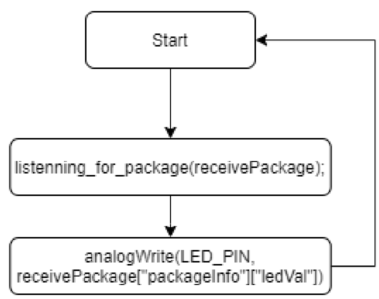

Figure 29: End node 2 pseudo-algorithms flow chart

4.6 Gateway (GATEWAY0)

4.6.1 Hardware

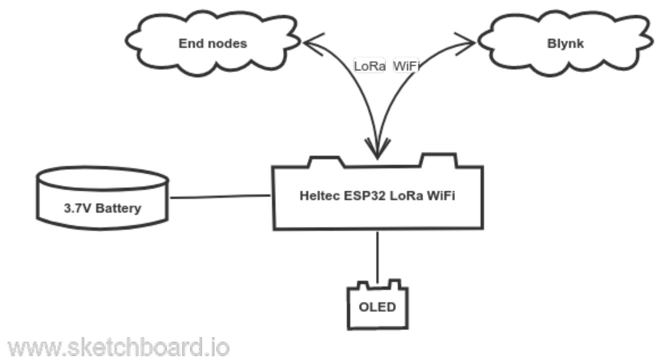

Figure 30: Gateway hardware connection

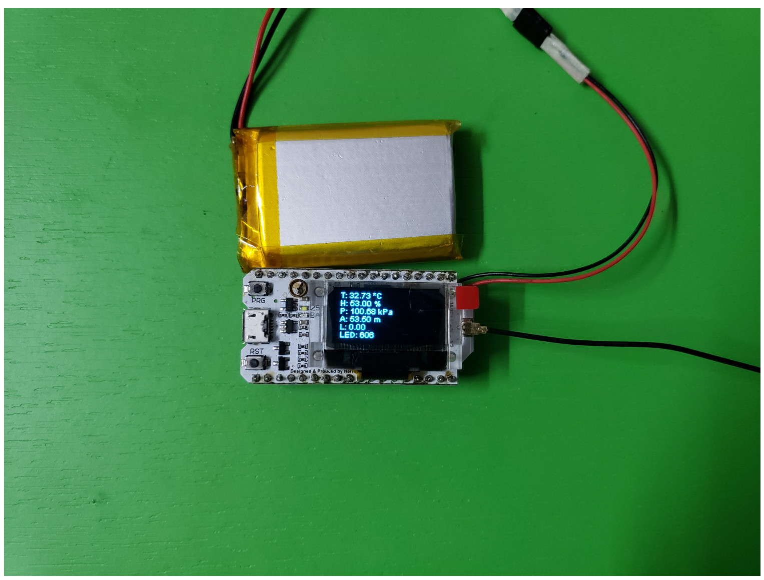

Figure 31: Gateway is implemented

4.6.2 Code

```
struct info
{
  int ledVal = 0;
};

struct package
{
  String src = "GATEWAY0";
  String dst = "NODE1";
  info packageInfo;
};

package dataPackage;
```

Figure 32: Gateway data package

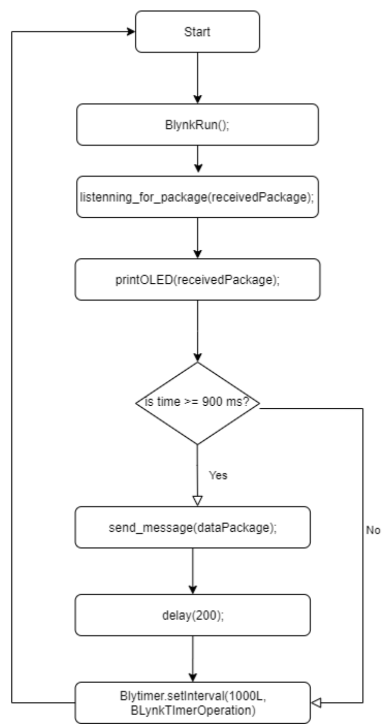

Figure 33: Gateway pseudo-algorithms flow chart

The purpose of delay(200); after sending and before receiving message is to avoid receive its own sending message due to reflection.

The gateway will send data for every 1100ms (900ms + 200ms delay), different from

700ms of the end node 1 in order to reduce the time when 2 message will be sent at the same time and be mixed together.

4.7 Blynk

Figure 34: Blynk app user interface

Gateway will forward data to Blynk for every 1 second. However, the upload speed to Blynk always has a delay of 10 - 15 seconds, but the download speed is faster, delay of 1 - 2 seconds, using virtual pins.

The interface shows 3 main segments:

- ISCONNECT LED: If the LED is blinking, the gateway is successfully connect to Blynk, else, it will stop Blinking.
- Environment Data Diagram and numbers: shows the value of environment pa-

rameters: temperature, humidity, pressure, altitude, light intensity at the specific times, usually for every 15 seconds. Because the diagram has the ability to convert data to .csv file, user can request and receive the files via email.

- Slider: controlling the LED at end node 2 with different light value, the larger the number, the more intense the light.

5 Performance evaluation

5.1 Testing metrics

- receiving/sending rate
- packet RSSI (dBm)
- SNR (dB)
- packet Frequency Error (Hz)

These metrics' values are recorded by the Gateway only in the case the packets are received correctly, which means passing all the signal checking methods such as length checking, json deserialization checking.

5.2 Testing parameters

- Frequency
- Spreading Factor (SF)
- TxPower

All nodes have an additional antenna.

5.3 HCMC Univesity of Technology, District 10 scenario

Set testing parameters' values:

- frequency = 433MHz
- SF = 7
- TxPower = 17dB

We intends to test the performance of this LoRa network model as sending/receiving packages rate and RSSI (Received signal strength indication, always negative, the closer to 0, the better the signal) of the gateway receive information from end node 1 wirelessly when end node 1 is placed at different places. The rate are taken into account only when

	average receiving/sending rate	average RSSI(dBm)
1 m	0.5312	-47.8723
200 m	0.3118	-103.6071
450 m	0.1029	-110.6277
600 m	N/A	N/A

Figure 35: Average Receiving/Sending package rate and average RSSI of the connection between Gateway - End node 1 collected by Gateway in 4 different places

the gateway detect no error in the incoming message, which means the message still remains intact over airtime. After going through 4 different range situations, the result is:

It can be seen that the longer the connection line, the more drop in the Average Receiving/Sending package rate and average RSSI, which means the sensitivity of the gateway "hearing" from the end node decrease. When the connection range is over 500m, no message is successfully received.

In the range of 450m, the RSSI reach approximately -110/-120dBm, 2.3 times smaller than the case of 1m (the minimum RSSI the gateway can handle); average receiving/sending rate reduces approximately 5 times compares to the case of 1m.

5.4 Street 4, Binh An Ward, District 2, HCMC scenario

Set testing parameters' values:

- frequency = 433MHz
- SF = 7
- TxPower = 20dB

The TxPower in this scenario is improved by increasing by 3dB compares to the previous scenario. The testing method is the same as the last scenario, but there are 2 additional performance metrics to be tested, SNR and Frequency Error. After going through 7 different range situations, the result is:

	average receiving/sending rate	average RSSI (dBm)	average SNR (dB)	average frequency error (Hz)
1m	0.5705	-51.6848	9.9511	5137.2717
100m	0.5899	-96.3171	7.8902	5571.6829
200m	0.5211	-104.3222	0.8472	5853.2222
450m	0.2872	-107.1412	-3.2824	5527.2941
600m	0.3090	-109.8966	-4.4253	5627.1379
700m*	0.2337	-106.1786	-6.4821	6399.5000
750m	N/A	N/A	N/A	N/A
*the time successfully receiving between 2 packets is very long				

Figure 36: 4 performance metrics of the connection between Gateway - End node 1 collected by Gateway in 7 different places

Overall, It can be seen that the longer the connection range, the more drop in the Average Receiving/Sending package rate, average RSSI, average SNR but the average Frequency Error increase, which mean the "weaker" the transmission strength of signal. The transmission strength in this case is stronger than the previous scenario, which has an ability to transmit signals up to 700m, longer than the previous scenario by approxlimate 200m. When the connection range is over 750m, no message is successfully received.

the average SNR saw a decrease when the range is longer. The range from 1m to 200m, the average SNR is positive, which means the receiving signal is above the noise level. The range from 450m to 700m saw a contradictory trend, the average SNR is negative, which means the receiving signal is below the noise level. The average frequency error increases with range, but not much significant in terms of MHz.

6 Future plan

We are planning to improve the quality of the connection line by increasing the Average Receiving/Sending package rate by increasing Spreading Factor. Secondly, we will do some experiments on power consumption and try to reduce the power consumption because the gateway is the most power-consumed hardware due to the use of LoRa as well as Wi-Fi.

7 Conclusion

Agriculture is an interesting subject which has many potentials go along with challenges. In this report, we are focus on solving the long range challenge of many plant fields that farmers face: how to cover the information of the surrounding environment of the large field. To solve the problem, using LoRa technology is a reasonable choice due to its ability to transmit data in long range, low bandwidth with low power consumption.

The Node-Gateway model is implemented help farmers to observe the environment information and control the light system of their plant field at anytime and anywhere via Blynk app on mobile phone whenever the phone connect to the Internet.

This LoRa network model can transmit signal in the radius of approximately 500m in the HCMC University of Technology environment and up to 700m in a plain sight of Street 4. The information on Blynk will be updated for every 10 - 15 seconds, depends on the quality of Wi-Fi and the transmission line to Blynk server.

In the future, we are looking forward to improve the connection strength of LoRa specifically to increase the transmission range and reduce power consumption of the Gateway.

We would like to send our thank and appreciation to lecturers from CE lab for providing us an interesting topic and equipment to conduct this research. Hopefully we can embrace many more projects to enhance our ability and widen the knowledge that not only in IoT but also in other aspects of our major field.

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