MTSFB TR 007: 2019

TECHNICAL REPORT

DEVELOPMENT OF ENERGY-EFFICIENT, LONG-RANGE COMMUNICATION SYSTEM FOR ENVIRONMENTAL MONITORING USING LOW POWER WIDE AREA NETWORKS FOR INTERNET OF THINGS

Preface

Malaysian Technical Standards Forum Bhd (MTSFB) has awarded Universiti Putra Malaysia the Industry Promotion and Development Grant to implement the Proof of Concept (PoC) through the Development of Energy-efficient, Long-range Communication System for Environmental Monitoring using Low Power Wide Area Networks for Internet of Things. The duration of this PoC lasts for a period of 15 months starting January 2018.

The PoC is done at Universiti Malaysia Terengganu Research Station, Bidong Island, Terengganu. The key objective of this PoC is a development of an energy-efficient, long-range communication system for environmental monitoring system using LPWAN technology.

This Technical Report outlines objective, benefit, scope of work, methodology and result analysis.

Prepared by:

Universiti Putra Malaysia

In collaboration with:

School of Ocean Engineering, Universiti Malaysia Terengganu, Department of Communication Engineering, Faculty of Engineering, Universiti Teknologi Malaysia and Luimewah (M) Sdn Bhd, Shah Alam, Malaysia.

Published by:

Malaysian Technical Standards Forum Bhd (MTSFB)
Malaysian Communications and Multimedia Commission (MCMC)
Off Persiaran Multimedia, Jalan Impact, Cyber 6
63000 Cyberjaya, Selangor Darul Ehsan
Tel : (+603) 8320 0300
Fax : (+603) 8322 0115
Email : admin@mtsfb.org.my
Website : www.mtsfb.org.my

Contents

Abbreviations

BW	Bandwidth
CF	Carrier Frequency
CR	Coding Rate
CSS	Chirp Spread Spectrum
FEC	Forward Error Connection
ICE	Integrated Development Environment
ICT	Information, Communication and Technology
IoT	Internet of Things
ISM	Industrial, Scientific and Medical
LPWAN	Low Power Wide Area Network
PHP	Hypertext Preprocessor
RSSI	Received Signal Strength Indicator
SF	Spreading Factor
SNR	Signal to Noise Ratio
TP	Transmission Power
UMT	Universiti Malaysia Terengganu

MTSFB TR 007:2019

DEVELOPMENT OF ENERGY-EFFICIENT, LONG-RANGE COMMUNICATION SYSTEM FOR ENVIRONMENTAL MONITORING USING LOW POWER WIDE AREA NETWORKS USING INTERNET OF THINGS

1. Introduction

This PoC is developed to have an energy-efficient long-range communication system for environmental monitoring by using Low Power Wide Area Network (LPWAN) technology. The LPWAN is the radio communication technology to enable the communication of the sensors and base station or gateway. The LPWAN technology also features a wide coverage, low bandwidth and low power consumption for the operation of low data transmission.

In this PoC, the sensors are located at the area of Bidong Island. The sensors are used to detect and collect information on parameters of temperature, humidity, altitude and pressure. These sensors also called as the end nodes. The data collected are transmitted from the end nodes to the Long-Range (LoRa) transmitter, LoRa receiver till the IoT gateway.

The Internet of Things (IoT) gateway is developed to have a real-time monitoring by using the cloud database. A responsive web also developed for easy data accessed for the monitoring and analysis purpose.

1.1 Low power wide area network

The recent improvement of small, cheap and energy-efficient communication devices has inspired the development of novel communication technologies, Low Power Wide Area Networks (LPWAN). The new technology becomes a complement to the traditional communication technology such as cellular and short-range wireless technologies by augmenting a better functionality and requirement for IoT applications. The special features of LPWAN technology such as wide coverage, low bandwidth and low power consumption for operation are in line with the requirements of IoT applications that only need to transmit a small amount of data in the long-range.

LPWAN is a new type of a wireless communication network which allows long-range communications at a low bit rate. It is designed to cover a large area, extend the battery lifetime and also low operational cost. The LPWAN technologies have proven that the connectivity range of the LPWAN nodes is more than 3 kilometres for the urban area, meanwhile, for the rural area, it is more than 10 kilometres. In the line of sight condition, the communication range is up to 20 kilometres and it is still possible to reach up to 30 kilometres.

Most of LPWAN solutions operate in the unlicensed industrial, scientific and medical (ISM) bands with the frequencies of 433 and 868 MHz for Europe Region while 902 MHz for USA. Currently, there are three most promising solutions for LPWAN which are Sigfox, Ingenu of On-Ramp Wireless, and LoRa by LoRa Alliance. Among these three, the LoRa™ technology is one of the main players in LPWAN and it is developed by LoRa Alliance. The LoRa Alliance introduces LoRaWAN, the communication protocol and system architecture for the network which is designed to optimize the LPWAN for battery lifetime, capacity, range and cost while LoRa™ physical layer enables the long-range communication link.
The low power of the technologies ensures that the energy consumption of the LPWAN radio technologies is relatively low for data transmission. However, the low data rate will limit transmission of large data. Another limitation of LPWAN technologies is the duty-cycle

regulations, which can be 0.1%, 1%, or 10% depending on the frequency band or transmit power of the network. Usually, a 1% duty cycle (36 s/h) is applied for total transmission time with 36 s in one hour. There are three main parameters that affect the performance of LPWAN solutions (e.g. LoRaWAN), known as physical bandwidth (BW) for radio frequency modulation, coding rate (CR) and spreading factor (SF). These parameters are the main aspect to determine the distance between transmitter and receiver, data rate and immunity to interferences.

1.2 Project site

The project was conducted at Universiti Malaysia Terengganu (UMT) research station (*Stesen Penyelidikan Alami Marin*) in Bidong Island, Terengganu. The transmitter node was placed on the hilltop of Bidong Island fixed with a 6-meter height of communication tower while the receiver node located on the rooftop of Central Lectures Complex (*Kompleks Kuliah Pusat*) in UMT Campus, Mengabang Telipot (Figure 1a, 1b and 1c). The communication range between transmitter and receiver is around 23 km from each other with line-of-sight radio link.

Figure 1a. Project location covers with 23 km line-of-sight radio link from Universiti Malaysia Terengganu (UMT) and Bidong Island, Terengganu

Figure 1b. Transmitter node on hilltop of Bidong Island

Figure 1c. Receiver node located on the rooftop of Central Lectures Complex in UMT

Figure 1. Location of transmitter and receiver nodes

1.3 Environmental monitoring system

The environmental monitoring system consists of two nodes which are LoRa transmitter (Figure 2a) and LoRa receiver (Figure 2b) that associate with parts of power management and IoT for cloud computing.

A. LoRa nodes (Transmitter and Receiver)

Figure 2a. LoRa transmitter node

Figure 2b. LoRa receiver node

B. Power management

The system uses 50 W of the solar panels to charge 12 V 20 A solar battery for power supply to the system.

C. Internet of things

The project is completed by implementing IoT for the cloud data storage platform by connecting the LoRa receiver node with Raspberry Pi 3B+ as an Internet gateway device. Then 3G/4G USB Modem Huawei E177 is used for an internet connection to continuously updating real-time data in the server. The website link is:
http://www.bidong-umt.net.

2. Benefits

The environmental monitoring system based on LoRa has benefitted Universiti Malaysia Terengganu in the following items:

a) improve the quality of the environment by providing real-time data monitoring;

b) encourage to widen the field of environmental monitoring for educational and research purposes;

c) enhance agricultural and ocean-related activities to the communities; and

d) provide an efficient data transmission solution for stakeholders in terms of time and cost.

3. Objectives

The objectives of the project are as follows:

a) to develop an energy-efficient, long-range communication system for environmental monitoring system using LPWAN technology;

b) to evaluate the performances of the network system in terms of communication range, packet loss ratio and energy consumptions; and

c) to verify the proposed environmental monitoring system.

4. Scope of work

The scope of work performed for the PoC are as follows:

a) design the circuitry and protocol of the prototype;

b) collection of data of the test bed real time experimental results for the system;

c) analyse on packet received, packet error, PELR, RSSI and etc;

d) comparison of energy consumption on site with the theoretical; and

e) verify the system functions and results.

5. Methodology

5.1 System architecture of environmental monitoring system based on LoRa

An environmental monitoring system based on LoRa is a combination of hardware and software that creates a dedicated computer system that is able to sense environmental parameters using designated sensors, processed the value by the microcontroller and transmit the acquired data to the LoRa receiver and store it in the cloud. All data can be viewed in real-time within 10 minutes interval at the website as stated above.

The hardware involves embedded BME sensors, Arduino Mega as a microcontroller, RFM95W LoRa technology as a signal communication module, and Yagi Antennas for radio waves propagation device. In order to serve the data into IoT gateway, Raspberry Pi 3B+ is used and connected to 3G/4G modem Huawei E177.

The programming language is written in visual studio C# programming in Arduino Integrated Development Environment (IDE) software, while Hypertext Preprocessor (PHP) used in both Raspberry Pi and web page development. The operating system in Raspberry Pi is Linux and MySQL is used for the database. The system architecture of the developed environmental monitoring system can be simplified into three layers which are LoRa transmitter node, LoRa receiver node and IoT gateway as shows in Figure 3.

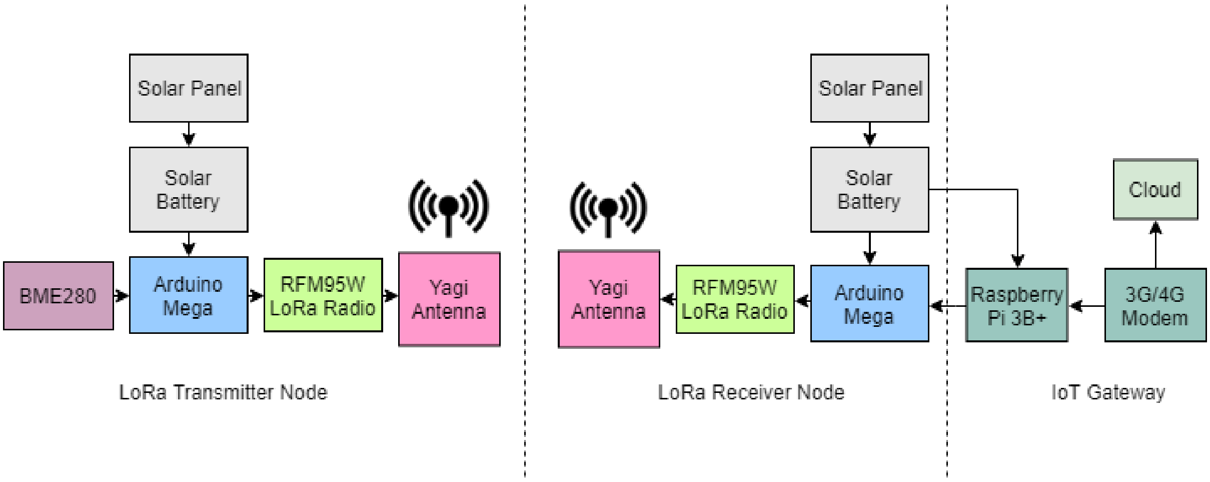

Figure 3. System architecture of environmental monitoring system based on LoRa

5.2 Hardware components

a. BME 280 sensor module

This small precision sensor module comes with LM6206 3.3 V regulator and I2C voltage level translator and compatible with Arduino (Figure 4). It measures ambient temperature range from -40 ˚C to 85 ˚C with ±1.0 ˚C accuracy, humidity from 0 to 100% with ±3% accuracy and pressure from 300 Pa to 1100 hPa with ±1 hPa absolute accuracy. This sensor consumes less than 1 mA of power during measurement and only 3 µA during idle.

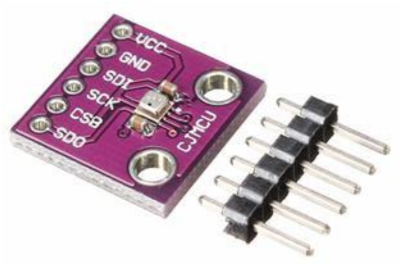

Figure 4. BME 280 temperature, humidity and pressure sensor module

b. Arduino Mega 2540 rev3 microcontroller

This microcontroller board uses ATmega2560 chip which has 256 KB of flash memory storing code, 8 KB of SRAM and 4 KB of EEPROM. Then for pins, this board consists of 54 digital input/output pins to support various types of applications where 14 pins can be used as PWM outputs, 16 for analog inputs and 4 UARTs for hardware serial ports (Figure 5). This board oscillates using a 16 MHz crystal oscillator and can be powered via USB connection or with an external power supply.

Figure 5. Arduino Mega 2540 Rev3 Microcontroller

c. RFM95W LoRa radio module

LoRa module featuring SX1278 transceivers (Figure 6) is used in this project as a communication module and able to operate well with the microcontroller via the Serial Peripheral Interface (SPI). LoRa can reach long-distance communication and the data transmission is robust through their chirp spread spectrum and this module operates in the 915 MHz frequency band and has highly receiver sensitivity down to 148 dBm.

Figure 6. RFM95W LoRa Radio Module

d. Yagi-Uda directional antenna

Powerful high gain directional antennas are installed at LoRa transmitter and LoRa receiver as they are able to create strong focusing signals in one direction for maximum signal strength and performance over long distances. This antenna is located at a built communication tower of 6 meters height as shown in Figure 1b.

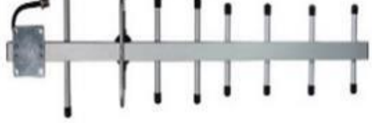

Figure 7. Yagi-Uda Directional Antenna

e. Raspberry Pi 3B+

The Raspberry Pi 3+ used in this project is a small board computer updated with an ARM Cortex-A53 64-bit Quad-Core processor system-on-chip that running at 1.4 GHz with built-in metal heatsink (Figure 8). This board also provides dual-band WiFi 802.11ac that runs at 2.4

GHz and 5 GHz wireless LAN for a better range in wireless communication. For Ethernet port, it comes with 300 Mbit/s and the board has Power-over-Ethernet (PoE) capability via separate PoE that used to maintain necessary electric current to devices using data cables instead of power cords as overheating protection to the processor. The Raspberry Pi 3B+ also provides 4 built-in USB ports with output up to 1.2 A that is enough to power peripherals connection.

Figure 8. Raspberry Pi 3B+

f. 3G/4G Huawei modem E177

This compact Huawei E177 modem (Figure 9) featured with a custom software platform with auto APN and do not require setting. It works excellently with Malaysia and oversea mobile networks including Digi, Celcom, Maxis and etc. It has a built-in slot for standard sim card size 15 x 25 mm and the modem can speed up to 7.2 Mbit/s.

Figure 9. 3G/4G Huawei Modem E177

5.3 Software

A responsive web for the environmental monitoring system based on LoRa technology which reads parameters such as temperature, humidity, altitude and pressure has been developed. The data can be accessed from the website URL: http://www.bidong-umt.net.

Figure 10 shows the screenshot of the website main page and Figure 11 displays the site summary for environmental parameters options.

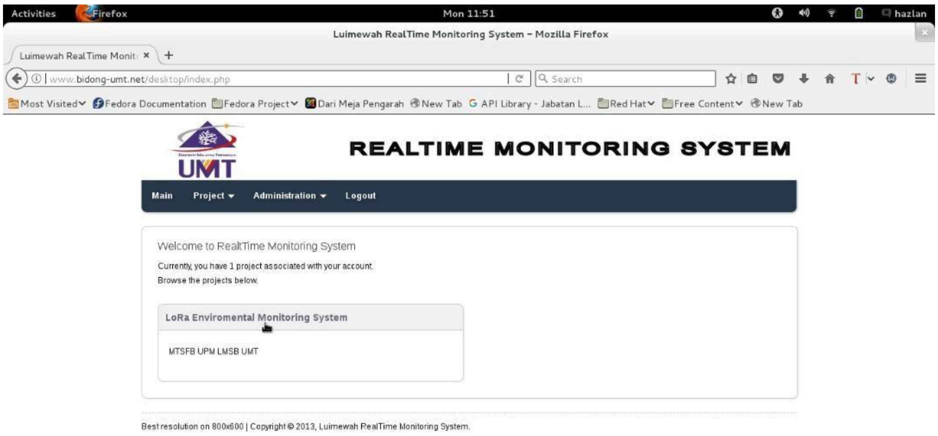

Figure 10. Screenshot of connection health check reading

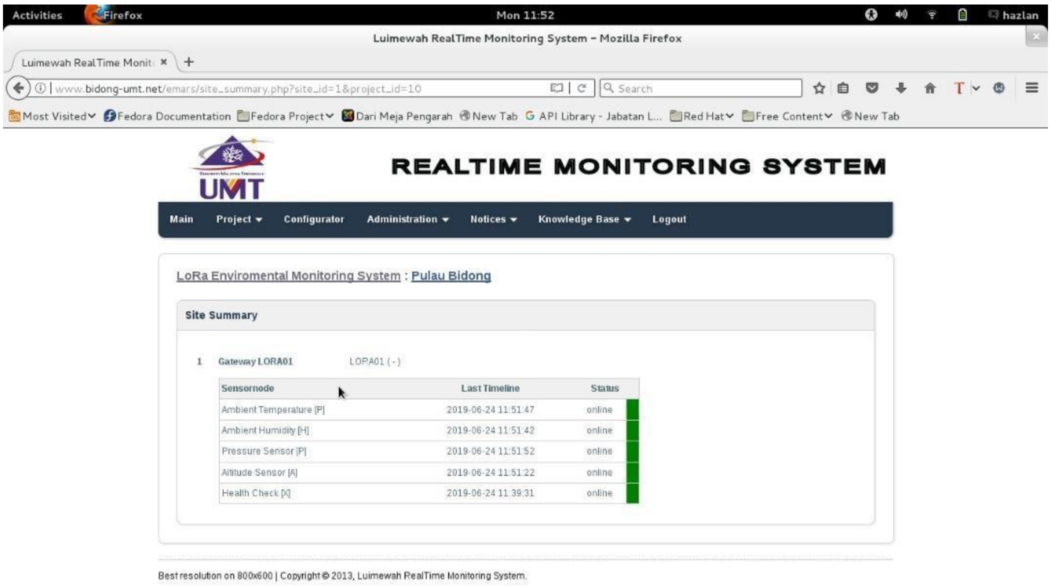

Figure 11. Screenshot of site summary for environmental parameters reading

All readings parameters shown in Figure 11 can be monitored in real-time on a personal computer or mobile phone on the website and it requires username and password. The website is designed to provide a user-friendly interface for the user and available to highlight the data collected from sensors. The development process involved Hypertext Preprocessor (PHP) for backend processes and MySQL for data acquisition from the database. Figures 12- 16 show the screenshots of data reading captured and displayed on the website.

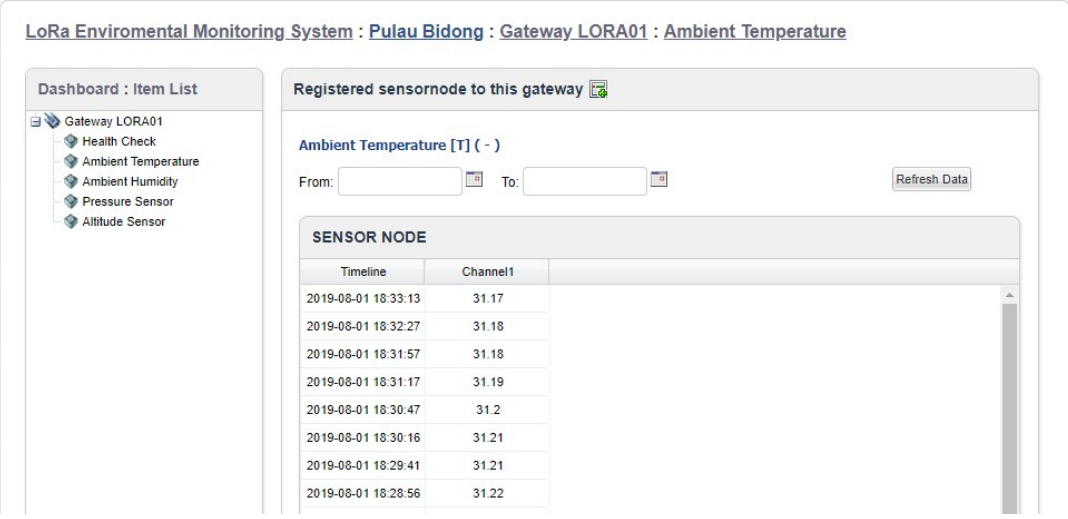

Figure 12. Screenshot of ambient temperature reading

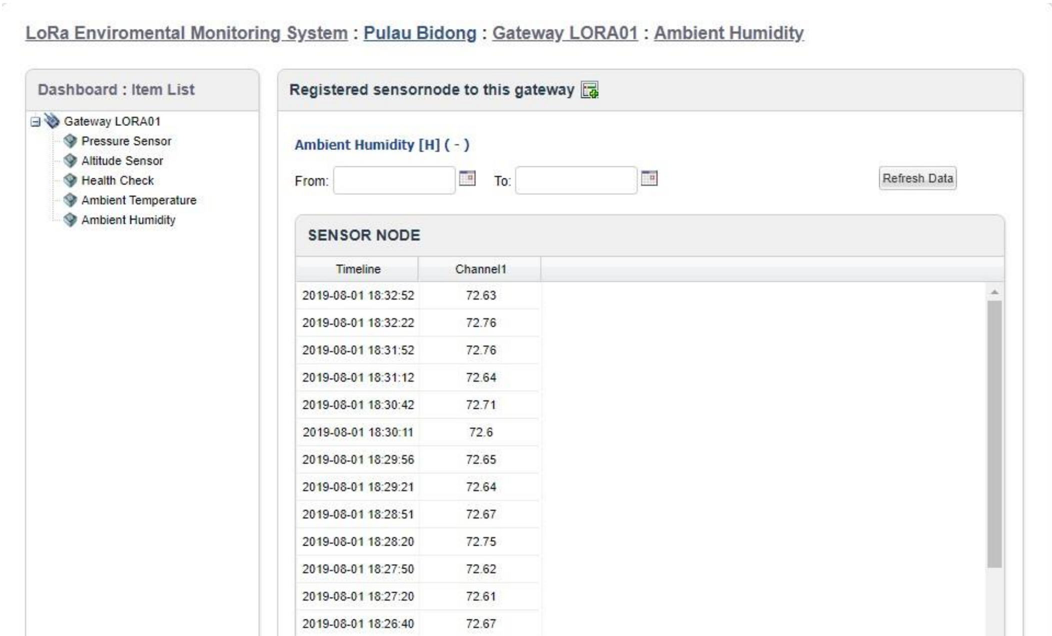

Figure 13. Screenshot of ambient humidity reading

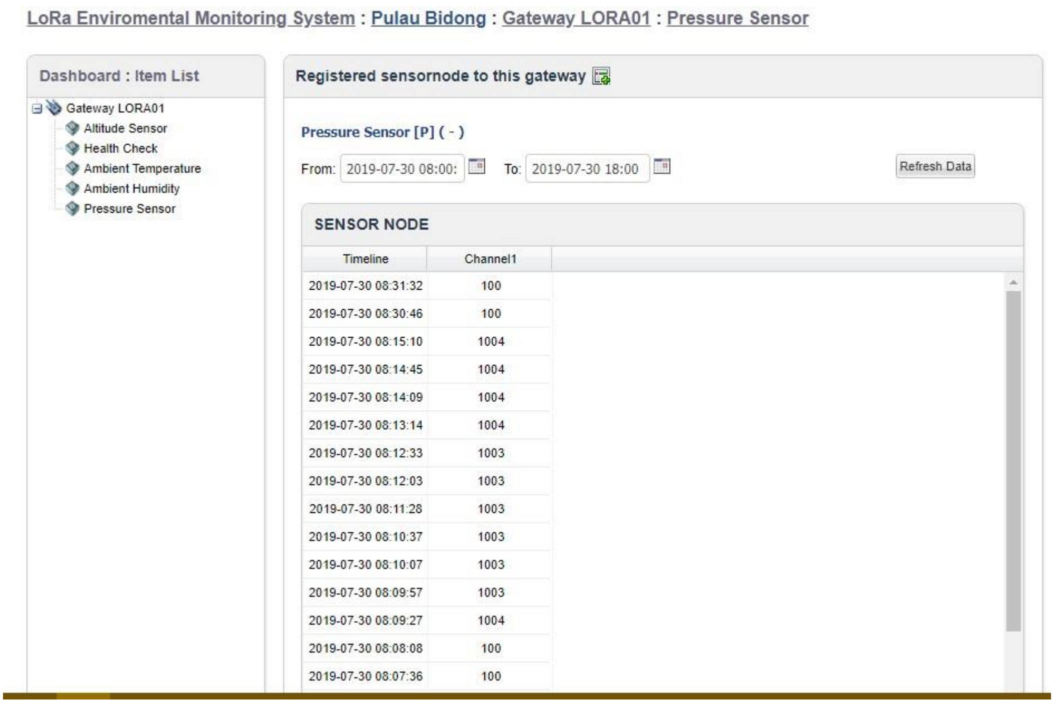

Figure 14. Screenshot of barometric pressure reading

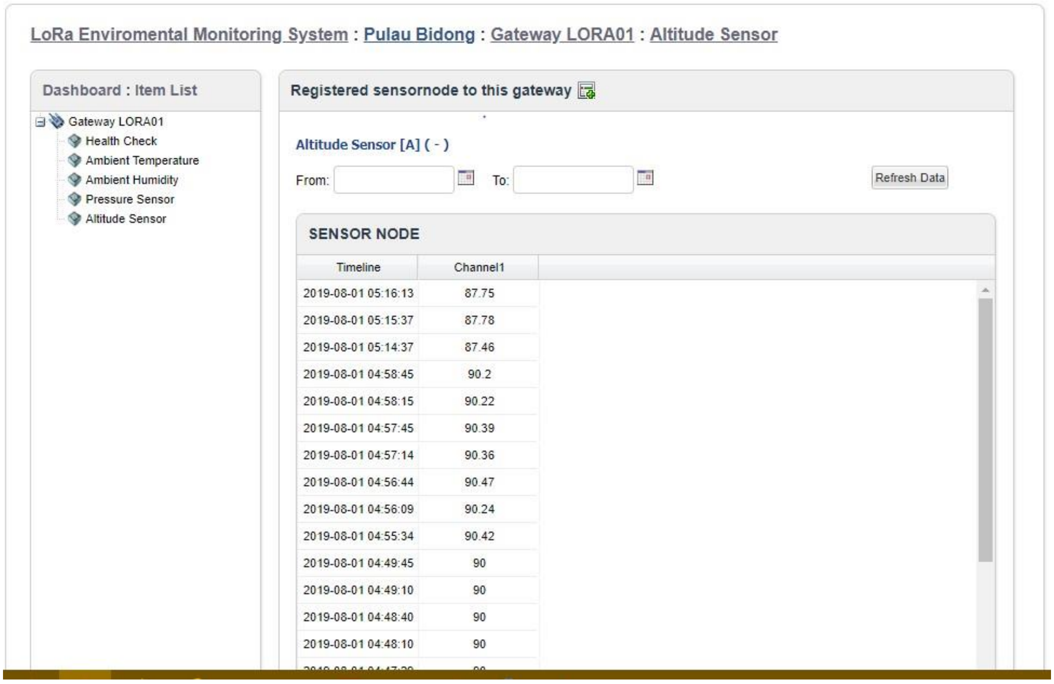

Figure 15. Screenshot of barometric altitude reading

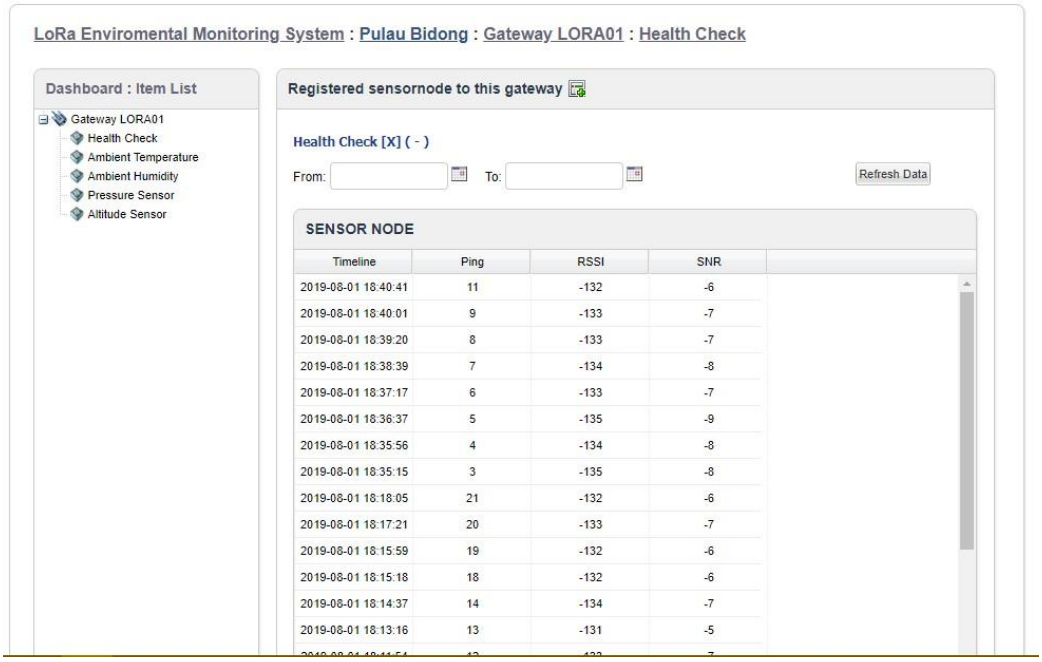

Figure 16. Screenshot of health check for communication signal reading

5.4 LoRa characteristic configuration

"Long-Range" or well known as LoRa is one of LPWAN technology in the wireless communication system proposed by LoRa Alliance and developed by Semtech. It operates in sub-GHz frequency band under unlicensed Industrial, Scientific and Medical (ISM) radio bands. It modulates in the Chirp Spread Spectrum (CSS) scheme where the preferred signal data frequency chipped decreases or increases over a specific time in the form of the chirp signal.

Then, this modulation scheme depends on five main configurable parameters under the LoRa physical layer. These parameters can be tuned into certain values to meet an optimal condition hence give the best data signal transmission and communication performance. The configurable transmission parameters are Transmission Power (TP), Spreading Factor (SF), Coding Rate (CR), Bandwidth (BW) and Carrier Frequency (CF).

- **Transmission Power (TP**) is a power of the propagation signal to transmit a packet in LoRa transceiver and this parameter affects the power expenditure. It can be fine-tuned from 2 dBm to 20 dBm in 1 dB steps depending on hardware limitation while power usage higher than +17 dBm limits for 1% radio duty cycle.

- **Spreading Factor (SF)** is a ratio of symbol rate and chip rate. The chip rate is a multiplication of bit rate and 2^{SF} [23] while varying the SF value from SF7-SF12 can avoid concurrent transmission and does not cause packet collisions because every spreading factors are orthogonal to each other. Higher SFs provide long-range but in trade-off low data rates.

- **Bandwidth (BW)** is the width of a selected frequency used in a transmission band. LoRa network can be operated either in the bandwidth of 125 kHz, 250 kHz, and 500 kHz. Higher BW increases the data rate while shorter the time-on-air but decreases the transmission range and its sensitivity. Meanwhile, the lower BW will be narrowing the bandwidth of the LoRa receiver and enhance the signal-to-noise ratio (SNR).

- **Coding Rate (CR)** is a factor that increases the protection against corrupted bits in a radio link and known as Forward Error Correction (FEC) rate. LoRa radio always used CR 4/8 for the header packet while packet for payload can select either 4/5, 4/6, 4/7 or 4/8.

- **Carrier Frequency (CF)** is a central frequency used in transmission band with a range of 860 – 1020 MHz in ISM bands. Meanwhile, carrier frequency depends on the local regional frequency and in Malaysia, the range frequency is from 919.0 to 923.0 MHz.

Several testing have been done in order to get the optimised values of LoRa characteristics configuration. After completing the test, Table 1 shows the LoRa physical setting used in this project.

Table 1. LoRa physical setting for the project

SF	BW	CR	CF	Payload
11	125 kHz	4/8	921.9 MHz	9 Bytes

5.5 Calculation of EIRP

The Effective Isotropic Radiated Power (EIRP) is given a limit by MCMC. The EIRP is limited to 500 mW, around 27 dBm. The calculation for EIRP is given as below:

$$EIRP = P_T - L_c + G_a$$

For this project, the EIRP is calculated using the spectrum analyser (Figure 17). The EIRP calculation is shown below:

$$Attenuation = +20dBm$$
$$Ref.\ Level = -18.4dBm$$
$$P_T = -18.4 + 20$$
$$= 1.6dBm$$

Figure 17. EIRP measurement using a spectrum analyser

To conclude, the EIRP calculated in this project is within the limit given by MCMC.

6. Results analysis

6.1 Performance analysis of LoRa communication signal

The Received Signal Strength Indicator (RSSI) and Signal to Noise Ratio (SNR) are also measured in this project. Figures 18 shows the average, maximum and minimum of RSSI in one week.

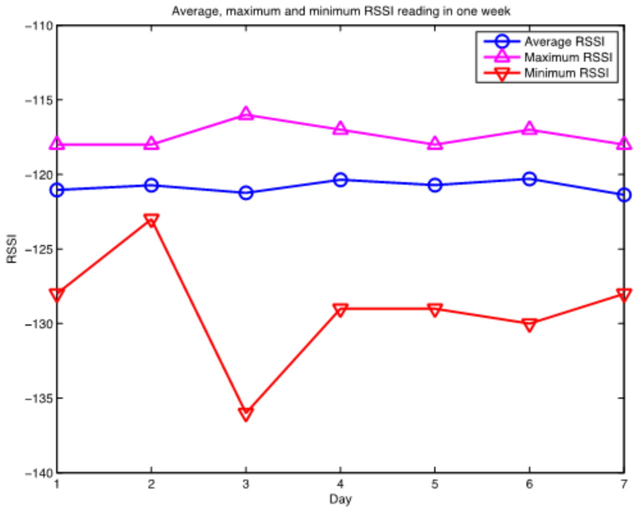

Figure 18. Measurement of RSSI for one week

Figure 19 below shows the average, maximum and minimum of SNR reading in one week.

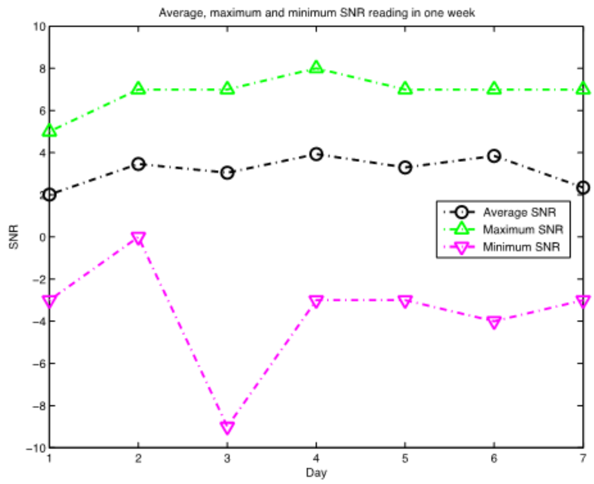

Figure 19. Measurement of SNR for one week

Figure 20 below shows RSSI reading on 25 June 2019 vs time.

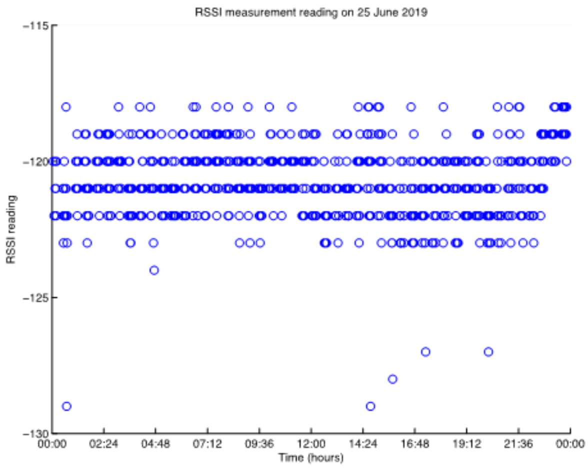

Figure 19. Measurement of RSSI on 25 June 2019

Data from figures 18 and 20 were taken from 21st - 27th June 2019 respectively. It is shown in the graphs above that the average SNR was 3 and the average RSSI was -121 for the week. The SNR reading is good reading as it proves that the signal is strong with very minimal interference. Factors such as Line of Sight (LoS) and the signal was sent above the sea show that there was a minimum interruption from other devices that might use the same channel with our system. As for RSSI, the minimum acceptable value for LoRa is -148 in order to make sure that the receiver receives a signal from the transmitter. In this case, the average reading of RSSI was -121 given that the distance between the transmitter is far (around 23 km) from the receiver. This range of RSSI is suitable to be used with SF of 11 as the value has been chosen to use in this project.

6.2 Result for power consumption consumed by the node

LoRa is an energy-saving network given that it is low power with long-range data transmission. Below is the comparison of power consumption for the actual network versus theoretical from the datasheet. Figure 21 shows the power consumption of the LoRa radio module in terms of current is 120 mA when using the transmit power of 20 dBm.

2.4. Chip Specification

The tables below give the electrical specifications of the transceiver under the following conditions: Supply voltage VDD=3.3 V, temperature = 25 °C, *FXOSC* = 32 MHz, F_{RF} = 169/434/868/915 MHz (see specific indication), Pout = +13dBm, 2-level FSK modulation without pre-filtering, FDA = 5 kHz, Bit Rate = 4.8 kb/s and terminated in a matched 50 Ohm impedance, shared Rx and Tx path matching., unless otherwise specified.

2.4.1. Power Consumption

Table 51 Power Consumption Specification

Symbol	Description	Conditions	Min	Typ	Max	Unit
IDDSL	Supply current in Sleep mode		-	0.2	1	uA
IDDIDLE	Supply current in Idle mode	RC oscillator enabled	-	1.5	-	uA
IDDST	Supply current in Standby mode	Crystal oscillator enabled	-	1.6	1.8	mA
IDDFS	Supply current in Synthesizer mode	FSRx	-	5.8	-	mA
IDDR	Supply current in Receive mode	*LnaBoost* Off, higher bands *LnaBoost* On, higher bands Lower bands	- - -	10.8 11.5 12.1	- - -	mA
IDDT	Supply current in Transmit mode with impedance matching	RFOP = +20 dBm, on PA_BOOST RFOP = +17 dBm, on PA_BOOST RFOP = +13 dBm, on RFO_LF/HF pin RFOP = + 7 dBm, on RFO_LF/HF pin	- - - -	120 87 29 20	- - - -	mA mA mA mA

Figure 21. Excerpt from LoRa transceiver module data sheet

In this project, the power consumption of the system is the sum of power consumption of Arduino Mega, sensor, LoRa radio module and antenna. In the idle state, the power consumption of the system includes only Arduino Mega and sensor. While in transmit mode, the power consumption consists of all the above values.

The power consumption for the whole system is as below:

$$I_{Sys} = I_s + I_A + I_{db} + I_T \qquad (1)$$

Where I_{Sys} is the current consumption for the system, I_T is current consumption of LoRa radio module,
I_s is current for the sensor,
I_A is current for Arduino Mega, and I_{db} is current for 19 dBi antenna with cable.

Meanwhile, in the idle state, the power consumption is as below:

$$I_{Sys\_idle} = I_s + I_A \qquad (2)$$

The measurement for power consumption for the system was done at the station in Bidong Island. Most of the time, the system uses the power consumption in the idle state and only use the power consumption in the transmit mode when the system is the sequel to transmit the data. Figure 22 below shows the setup of the measurement.

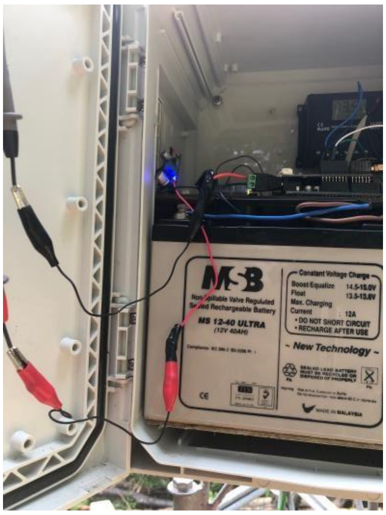

Figure 22. Measurement of power consumption of the system

Figures 23 shows the power consumption of the system while in idle state.

Figure 23. Measurement of power consumption in idle state

While Figure 24 shows the power consumption on the transmit mode.

Figure 24. Measurement of power consumption on the transmit mode

In the idle state, the recorded reading was about 80.9 mA and in transmit mode, the recorded reading was 206.0 mA.

$I_{Sys\_idle} = 80.9mA$

$I_{Sys} = 206.0mA$

From equation (1) and (2), it can be concluded that the power consumption for LoRa radio module with 19 dBi antenna and cable while transmitting the data is 125.1 mA. The calculation is shown below:

$$I_T + I_{db} = I_{Sys} - I_{Sys_{idle}}$$

$= 206.0mA - 80.9mA$
$= 125.1mA$

The theoretical value of power consumption for the LoRa module is 120 mA (Figure 21). Note that the measured value is including the power consumption used by the cable where it is usually small (In the above case it is estimated around 5.1 mA). It is then safe to say that the power consumption for the LoRa radio module is similar to the theoretical value.

7. Conclusion

The Lora systems helped in developing an energy-efficient, long range communication for environmental monitoring. An environmental monitoring system is one of the important systems to monitor the changes in climate continuously such as the changes in ambient temperature, relative humidity, barometric pressure and barometric altitude. This environmental monitoring system provides all the real-time data and has effectively used in remote monitoring purposes from Bidong Island to UMT campus with the distance of 23 km. The results are useful to monitor the environmental changes and at the same time can be used as emergency disaster management in the future.

This effective long-range communication is achieved from the evaluation of the performance of the network systems in terms of communication range from the transmitter and receiver, the packet loss ratio of the data and energy consumption used to achieve energy-efficiency communication.

Furthermore, the analysis of sensed data and performance analysis of the networks are important as this can potentially extending the scope, scale and reliability of data gathering for assessment purposes, as well as developing new model or methodologies. Environmental parameters used in this project can be interrelated with other factors and can be utilised by researchers in developing a new project.

Finally, the system architecture of this project is verified suitable for environmental monitoring at Bidong Island and can be replicate for other remote monitoring applications that require real-time monitoring with IoT features. The potential applications that are suitable for this system are as below:

a) agriculture monitoring;

b) disaster/Landslide monitoring;

c) air quality monitoring;

d) rainfall monitoring; and

e) solar panel performing the monitoring.

References

[1] 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), 2016, pp. 1–3.

[2] D.-Y. Kim and M. Jung, “Data Transmission and Network Architecture in Long Range Low Power Sensor Networks for IoT,” Wirel. Pers. Commun., Jul. 2016.

[3] P. Neumann, J. Montavont, and T. Noel, “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), 2016, pp. 1–8.

[4] M. Centenaro, L. Vangelista, A. Zanella, and M. Zorzi, “Long-range communications in unlicensed bands: the rising stars in the IoT and smart city scenarios,” IEEE Wirel. Commun., vol. 23, no. 5, pp. 60–67, Oct. 2016.

[5] C. Pham, “Low-cost, low-power and long-range image sensor for visual surveillance,” 2nd Work. Exp. Des. Implement. Smart Objects, SmartObjects 2016, vol. 03–07–Octo, pp. 35–40, 2016.

[6] J. Petäjäjärvi, K. Mikhaylov, A. Roivainen, T. Hänninen, and M. Pettissalo, “On the coverage of LPWANs: Range evaluation and channel attenuation model for LoRa technology,” 2015 14th Int. Conf. ITS Telecommun. ITST 2015, pp. 55–59, 2016.

[7] R. Kalfus and T. Hégr, “Ultra Narrow Band Radio Technology in High-Density Built-Up Areas,” in Communications in Computer and Information Science, vol. 319, no. October, 2016, pp. 663–676.

[8] C. Pham, “Building Low-Cost Gateways and Devices for Open LoRa IoT Test-Beds,” vol. 2006, 2017, pp. 70–80.

[9] LoRa Alliance, “A technical overview of LoRa and LoRaWAN,” no. November, pp. 1–20, 2015.

[10] C. Pham, A. Rahim, and P. Cousin, “Low-cost, long-range Open IoT for smarter rural African Villages,” IEEE 2nd Int. Smart Cities Conf. Improv. Citizens Qual. Life, ISC2 2016 - Proc., 2016.

[11] C. PHAM, “QoS for Long-range wireless sensors under duty-cycle regulations with shared activity time usage,” ACM Trans. Sens. Networks, vol. 12, no. 4, pp. 1–31, 2016.

Publication of:

Malaysian Technical Standards Forum Bhd (MTSFB)

Malaysian Communications and Multimedia Commission (MCMC)
Off Persiaran Multimedia, Jalan Impact, Cyber 6
63000 Cyberjaya, Selangor Darul Ehsan
Tel: (+603) 8320 0300
Fax: (+603) 8322 0115
Website: www.mtsfb.org.my

In collaboration with

Malaysian Communications and Multimedia Commission (MCMC)

MCMC Tower 1
Jalan Impact, Cyber 6, 63000 Cyberjaya
Selangor Darul Ehsan
Tel: (+603) 8688 8000
Fax: (+603) 8688 1000
Website: www.mcmc.gov.my