Internet of Things (IoT) using LoRa technology

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***Abstract*—LoRa is the new communication technology under the Low Power Wide Area Network (LPWAN). It emphasizes on the long-range communication with the high receiving sensitivity ability which allows it to work under the noise interference or noise floor effectively. The range of communication has become the critical part on most of the IoT system, especially in Wi- Fi and Bluetooth-based IoT system. With the emergence of LoRa technology, further improvements to applications of the Internet of Things (IoT) can be realized. By using a single receiver in the LoRa network, it is able to handle many nodes at multiple locations within the area, unlike Wi-Fi-based system which needs to have many access points to increase the coverage area. The combination of LoRa and Wi-Fi technology reduces the cost of deployment of the IoT system. In this paper, the actual deployment of IoT system using LoRa technology with the combination of Wi-Fi technology. Besides, this paper presents the performance and the actual coverage area of the LoRa network in both the indoor and outdoor condition. For the indoor condition, a different set of LoRa parameter including Spreading Factor and Bandwidth is tested at different locations. As a result, the quality of the LoRa network does not only depend on the distance from the gateway but also the effect of path loss due to the structural element. Moreover, a single LoRa gateway located at the middle floor of the building is able to handle the LoRa end-devices at any location within the campus with Spreading Factor of 9. A better indoor coverage can be improved by adding an additional LoRa gateway in the campus. While for the outdoor condition, the maximum coverage area in the LoRa network for Spreading Factor of 12 is 330 meters with an indoor gateway deployment.**

***Index Terms*—LoRa, Internet of Things, Low-cost LoRa node and gateway, monitoring system**

I. INTRODUCTION

Wi-Fi and Bluetooth are already established wireless technologies for Local Area Network (LAN). Both have well-established standards such as Wi-Fi, Bluetooth 4.0, and Zig- bee. Due to popularity and easy-to-use protocol, those wireless technology has dominated the IoT market. There is a downside or challenge with that technology in IoT which is the transmission range. For the IoT application domains such as smart positioning system, and smart farming requires high energy-efficient sensor nodes that can communicate across a long distance. In the recent studies [1], [2], both the authors had conducted an indoor positioning test based on Wi-Fi and LoRa technology respectively. The coverage area of the Wi-Fi based positioning system in [1] is only 2 meters while the work in [2] can achieved a maximum coverage area of 200 meters and 28.8 meters with high accuracy of positioning result. The result from both the authors show the weakness of Wi-Fi technology in positioning system when comparing with LoRa technology. In addition, the author in [3] stated that the transmission range of Bluetooth is 50 feet (without range extender) while for Wi-Fi is 200 feet. Implementing the solution with Wi-Fi or Bluetooth technology will need a higher cost in order to build a long-range communication network which requires additional range extender. This motivates the development of many Low- Power Wide Area Networks (LPWAN) technologies, such as LoRa, to fulfil these requirements.

LoRa (which stands for long range) is a spread spectrum modulation technique derived from chirp spread spectrum (CSS) technologies. The modulation technique used in LoRa makes it robust to channel noise since the entire allocated bandwidth is used to broadcast a signal (information or data). Furthermore, the security of the LoRa system can be guaranteed as the transmission is spread in a pseudo-random way which presents like a noise, hence the modulation technique had provided the basic security for the LoRa system [4]. Aside from that, LoRa is the best option for IoT solution which required a long range of data communication while keeping very little power usage [5]. In other words, the strong penetration of the LoRa signal makes it able to provide enough coverage in a difficult-to-reach indoor location. When compared to Wi-Fi or Bluetooth based IoT solution which has a short range of data communication and throughput (without adding range extender or repeater), this technology able to provide maximum efficiency in data communication while maintaining low development cost. Based on the study [6], it stated the main targeted deployment of LoRa technology is the smart devices which have limited energy and does not require establishing frequent communication all the time. All these features make LoRa become an interesting candidate for the current Internet of Thing (IoT) market and make it able to compete with other IoT technology such as Wi-Fi and Bluetooth.

In this paper, the focusing point is to conduct several experiments on the LoRa coverage performance and also to implement LoRa-based real-time monitoring which is located at KDU University College.

II. Overview of LoRaWan and LoRa technology

The LoRaWAN is Low Power Wide Area Network (LP- WAN) protocol and system architecture developed by LoRa Alliance while LoRa (developed by Semtech) defines the physical layer of the system. In addition, LoRaWAN is a media access control (MAC) layer protocol which built on top of the LoRa physical layer. It defines the network architecture which operates in a non-licensed band below 1000 MHz. LoRaWAN uses AES-128 encryption for security which is the AppsKEY and NwkKey. There are three frequency bands that are most commonly used which are 433 MHz for Asia, 868 MHz for Europe and 915 MHz for North America [6]. Machine-to-Machine (M2M) and Internet of Thing (IoT) has become the main target of LoRa deployment due to its specification of long-range and low-power communication. Besides, the adaptive data rate algorithm of LoRa technology helps to maximize the node's battery life and network capacity.

LoRa modulation occurs at the physical layer which uses proprietary Chirp Spread Spectrum (CSS) modulation derived from the spread spectrum modulation scheme. The concept of chirp spread spectrum modulation is transforming a single bit of information into another series of the bit and spread it into the entire spectrum. Besides, this type of modulation operates below the noise level which makes it more robust to noise interference and jamming. In other words, the signal or infor- mation is spreading across the wideband. The spread spectrum modulation is an old modulation technique developed in 1940 which was originally used for military communication [7]. The word "chirp" stands for 'Compressed High-Intensity Radar Pulse'. It defines that the increasing and decreasing of the signal frequency with time during the modulation process. There are five important parameters in LoRa physical which are the carrier frequency, transmit power, spreading factor (SF), bandwidth (BW) and code rate (CR). As mention early, there is three main carrier frequency which is 433 MHz, 868 MHz and 915 MHz where the LoRa operate at.

Overall, LoRa is beneficial for IoT system required long-distance communication comparing to short-range protocols like Wi-Fi and Bluetooth though there are some disadvantages on the speed of transmission and limitation on the size of the payload.

III. LORA FREQUENCY BAND IN MALAYSIA

Selection of LoRa frequency bands used is the very first step before designing a LoRa-based IoT network because each country has its own frequency regulation. According to the lat- est regional parameters provided by the LoRa Alliance^{TM} [8], it listed two frequency bands/channels for Malaysia which is 433 – 435 MHz and 919 – 924 MHz (represented by a channel of EU433 and AS923 respectively). LoRa communication de- vice is categorized as a short-range device under the Malaysian Communications and Multimedia Commission (MCMC). It is governed by the Communications and Multimedia ACT 1998 (CMA). In 2015, MCMC allocated 19 of frequency bands for a short-range radio communication device (SRD) in the class assignment (CA) No.2 of 2015 [9]. Although 868 MHz frequency bands are placed under SRD, it has a limited period of usage as stated in the same class assignment.

In 17th April 2015, MCMC had announced that the frequency band of 868 MHz will be taken out for SRD starting on the 1st January of 2018 [10]. In December 2015, MCMC had allocated the new frequency band for the use of SRD as addition to bands 433 MHz, 2.4 GHz and 5.8 GHz that can be used for IoT applications which is 4 MHz of spectrum in the frequency band 919 to 923 MHz as stated in class assignment No.3 of 2015 [11].

A. Equivalent Isotropic Radiated Power limitation

Apart from the frequency band used in Malaysia, another important parameter will be discussed. EIRP refers to the Equivalent Isotropic Radiated Power, which is the radiated output power refer to an isotopic antenna radiating power equally in all directions and whose gain is expressed in dBi.

TABLE I

Frequency bands that are available for SRD and its operating condition (source from class assignment No. 1 of 2017 MCMC)

Frequency Bands	Maximum Power
433 MHz to 435 MHz	100 mW EIRP
919 MHz to 923 MHz	500 mW EIRP

Referring to Table I, the two frequency bands have their own limitation on the maximum power rating listed by MCMC. The maximum of EIRP should be followed when designing the LoRa network. There are three parameters involve in the EIRP which is the output power of the transmitter, cable gain, and the transmitter antenna gain shown in Equation (2).

$$EIRP = P_{out} - C_t + G_t \tag{2}$$

The power and the gain of the antenna must be select accordingly to avoid exceeding the EIRP limitation set by the country.

IV. RELATED WORK

According to (LoRa Alliance, 2018), the latest update on the ISM band for Malaysia is 920 to 923 MHz. But there is no research paper or deployment of LoRa gateway using that frequency band in Malaysia. In [12], [13], [14], the authors tested the performance LoRa using ISM band of 433 MHz (old ISM band) in Malaysia. The authors in [12] presented the performance of LoRa modulation in the outdoor scenario at Johor, Malaysia. The authors focus on the Line-of-sight (LOS) and Non-Line-of-Sight (NLOS) test on the LoRa network. The transmit power used by the authors was 23 dBm with the antenna gain of 3 dBi. Received signal strength indication (RSSI) was used as the measurement parameter in the testing.

Based on the study, the authors concluded that SX1272 is the most power efficiency (used 0.2423W for each transmission) during transmission while SX1278 has the longest coverage of 1 km. While in [14], the authors discussed the performance of the LoRa network in the forested tropical environment. Same as previous works done by other authors, different spreading factor and bandwidth are used to measure the signal strength (RSSI). The authors conducted two tests on a different location (open environment and foliage environment) and compared the obtained result in the graphical method. Based on the result obtained, the authors found out that the LoRa signal experienced much more attenuation in the foliage environment compared with the open environment as the distance between the receiver and transmitter increases.

V. INTEGRATION OF IOT MONITORING SYSTEM IN LORA NETWORK

A. System Architecture

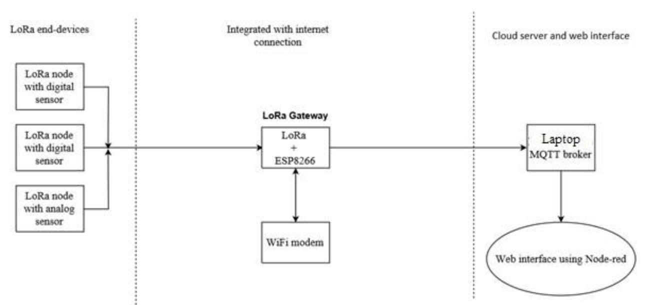

Fig. 1. Connection of LoRa network

Figure 1 shows the basic connection of the LoRa network in the first part of the project. Based on the figure, the LoRa end-devices are communicated to the LoRa single channel gateway in a star topology using LoRa modulation. The spreading factor and bandwidth of the LoRa network will be configured in the coding part before the communication began.

When the LoRa gateway identified the sync word, it will forward the received packet from the end-devices to the local MQTT broker through the ESP8266. The ESP8266 is a Wi-Fi module which will be used to provide an internet interface for the LoRa gateway. The connection between the LoRa gateway and ESP8266 is through SPI communication which is the same as the connection with Arduino. For the web interface part, message query telemetry transport (MQTT) is used. MQTT is a famous machine-to-machine (M2M) communication protocol on the Internet of Thing (IoT). The ESP8266 on the LoRa gateway will publish the data received from those end-devices to the local MQTT broker, while Node-RED will be used to show the receiving packet from the end-devices by subscribing to the same MQTT broker.

B. Hardware setup

In this paper, the LoRa end-devices is the combination of sensor, sx1278 (433 MHz), and Arduino Nano while the LoRa gateway is the combination of sx1278 (433 MHz) and ESP8266 as mention earlier. All the LoRa end-devices will be powered by two 3.7 V lithium rechargeable battery, and the LoRa gateway will be powered by the 5 V DC power source. Three different types of sensor are connected to each of the LoRa end-devices.

C. Network interface

Figure 2 illustrated the web interface of the LoRa network. This is the live dashboard from the Node-Red application which displayed the information obtained from the LoRa end- devices such as SNR, RSSI, and sensor data.

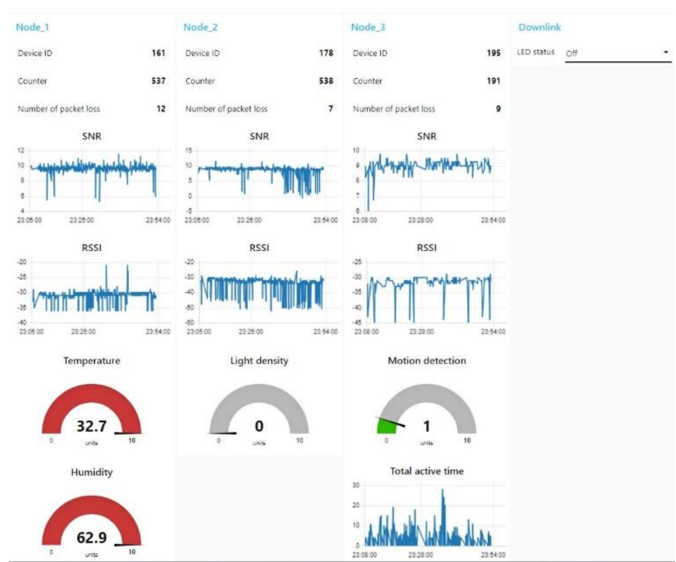

Fig. 2. Graphical User Interface (GUI) of the LoRa system using Node-Red

VI. PARAMETER TESTING FOR INDOOR SCENARIO

The indoor testing is conducted at seven different locations in KDU University College (Table II). During the testing, the LoRa gateway is placed at the Engineering Communication Lab at the second floor while the LoRa end-device is moved from one location to another for each test. The distance between the LoRa transmitter and receiver is measured using the laser distance meter and measuring tape. In this part, only one LoRa end-device and LoRa gateway are used for the testing. There is a total of six modes are used to investigate the indoor performance of the LoRa network. Based on Table III, each mode indicated a different combination of spreading factor and bandwidth while the code rate is constant for all the mode. In the following experiment, each location is tested with six different modes and a total of 20 samples is taken for data analysis.

TABLE II
INDOOR TESTING LOCATION IN KDU UNIVERSITY COLLEGE

Test no.	LoRa transmitter location	LoRa Receiver Location	Distance (meters)	Overall obstacle percentage, %
1	Computer Lab (4th floor)	Engineering Communication lab (2nd floor)	35.00	10
2	School of Communication (3rd floor)		28.00	4
3	Library (1st floor)		55.20	4
4	Cafeteria (Ground floor)		42.80	45
5	Parking area (G level)		40.10	9
6	Parking area (LG level)		45.80	12
7	Parking area (LG1 level)		51.50	16

TABLE III
DIFFERENCE LORA PARAMETER SETUP

	Spreading Factor	Bandwidth, kHz	Code rate
Mode 1	7	125	4/5
Mode 2	7	250	
Mode 3	9	125	
Mode 4	9	250	
Mode 5	12	125	
Mode 6	12	250	

A. Result

At each test location (test no.), the average received signal strength indicator (RSSI), average signal-to-noise ratio (SNR), and packet loss rate of different mode is tabulated in Tables IV, V and VI. The result in the table was converted into different graph format to have better visualization on the result (Figure 3, 4 and 5).

TABLE IV
RESULT OF THE INDOOR TEST AT SEVEN LOCATIONS WITH MODE 1 AND MODE 2

Test No.	Mode 1 Average RSSI (dBm)	Mode 1 Average SNR (dB)	Mode 1 Packet loss rate (%)	Mode 2 Average RSSI (dBm)	Mode 2 Average SNR (dB)	Mode 2 Packet loss rate (%)
1	-109.42	-2.28	0	-105.95	-0.93	0
2	-93.55	8.20	0	-95.20	6.84	0
3	-106.20	0.26	0	-100.65	3.23	0
4	-115.08	-7.13	45	-110.58	-5.11	10
5	-111.95	-4.79	0	-104.35	-0.68	0
6	-109.68	-2.80	0	-103.60	0.10	0
7	-114.05	-5.81	0	-109.30	-4.60	0

TABLE V
RESULT OF THE INDOOR TEST AT SEVEN LOCATIONS WITH MODE 3 AND MODE 4

Test No.	Mode 3 Average RSSI (dBm)	Mode 3 Average SNR (dB)	Mode 3 Packet los rate (%)	Mode 4 Average RSSI (dBm)	Mode 4 Average SNR (dB)	Mode 4 Packet loss rate (%)
1	-111.60	1.61	0	-111.70	-0.98	0
2	-102.25	9.24	0	-98.58	10.24	0
3	-106.05	6.78	0	-106.85	4.53	0
4	-117.50	-3.46	0	-116.35	-4.81	0
5	-110.85	2.08	0	-109.20	1.38	0
6	-110.60	2.18	0	-109.65	0.24	0
7	-119.83	-5.31	0	-118.30	-6.05	0

TABLE VI
RESULT OF THE INDOOR TEST AT SEVEN LOCATIONS WITH MODE 5 AND MODE 6

Test No.	Mode 5 Average RSSI (dBm)	Mode 5 Average SNR (dB)	Mode 5 Packet loss rate (%)	Mode 6 Average RSSI (dBm)	Mode 6 Average SNR	Mode 6 Packet loss rate (%)
1	-110.95	2.33	0	-111.10	0.78	0
2	-104.90	6.76	0	-100.68	7.30	0
3	-106.70	5.68	0	-106.95	4.98	0
4	-113.10	-0.48	0	-120.05	-5.93	0
5	-109.70	3.86	0	-110.55	0.98	0
6	-111.60	1.23	0	-111.95	-0.28	0
7	-115.16	-1.84	0	-120.05	-5.83	0

Fig. 3. Average RSSI at each test location for different mode

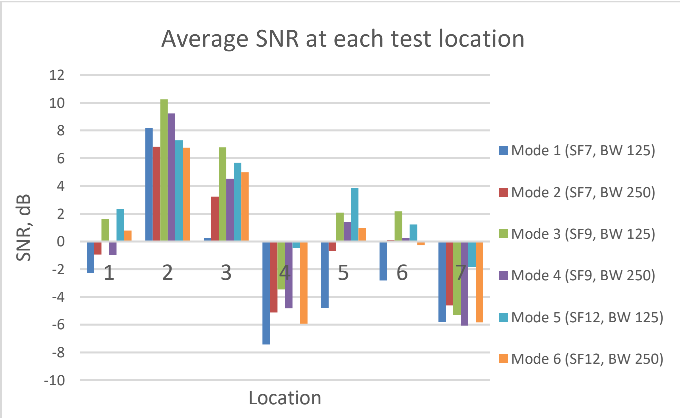

Fig. 4. Average SNR at each test location for different mode

Based on Figure 3, the average RSSI of the entire test result is in between -90 dB and -120 dB. Besides, location 2 which has the shortest distance between the receiver shows the lowest average RSSI value while location 4 and 7 show the highest average RSSI value in each mode. Besides, the average RSSI value decreases when the spreading factor increases at the same bandwidth (Mode 1, Mode 3, and Mode 5 for bandwidth 125 kHz and Mode 2, Mode 4, and Mode 6 for bandwidth 250 kHz).

Figure 4 shows the average SNR collected at each test location. Based on the figure, location 1, 4, and 7 are the area which has higher noise interference compared to location 2, 3, 5 and 6 as lower SNR indicated that more noise was presented in the communication link than signal. Among all the location, location 2 shows the highest average SNR in all the mode while location 7 shows the lowest average SNR in all the mode. Furthermore, increasing the bandwidth from 125 kHz to 250 kHz with the same spreading factor is also reduced the SNR reading (decreasing in receiving sensitivity) except for spreading factor 7 (Mode 1, and

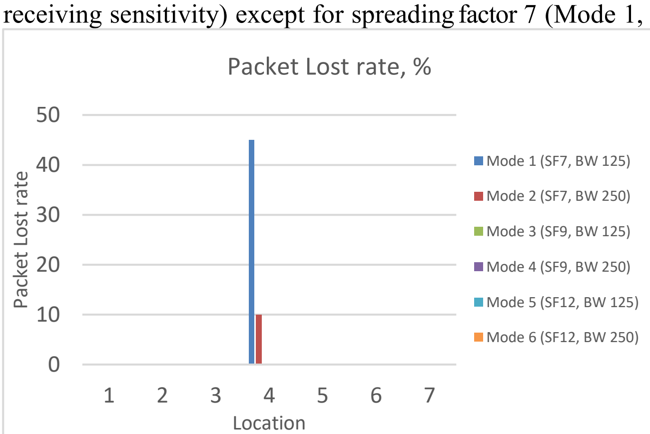

Fig. 5. Overall packet loss rate at each test location

2). In addition, an increase of spreading factor with the same bandwidth (for example from mode 1 to mode 3) increases the SNR of the signal. Based on the observation, the testing location which is closest to the gateway location and lesser obstacle in the transmission path (lower overall obstacle percentage) such as location 2 and 3 shows different result than others when increasing the spreading factor. A significant drop of SNR of the signal is shown when the spreading factor is increased from 9 to 12 at location 2 and 3.

Based on Figure 5, location 4 is the only test site that has packet loss during the testing. In mode 1, location 4 has the highest packet loss rate (45 %), while in mode 2, location 4 shows lesser packet loss (10 %). This shows that increasing the bandwidth can reduce the packet loss rate. In addition, further increasing the spreading factor (Mode 3 to Mode 6) eliminates the chance of the packet loss as a higher spreading factor give better sensitivity in the communication.

B. Discussion

In indoor testing which is non-line-of-sight (NLOS), the distance between the LoRa node and the LoRa gateway does affect the quality of the communication. This is because of the path loss due to the structural element in the campus such as glass, metal, brick wall and more. The different element has a different effect on the level of signal loss as stated in [15]. Under the same environment, further increasing the distance from the LoRa gateway will reduce the quality of the packet (in term of RSSI and SNR). Apart from that, there is another factor that affects the quality of the communication which is the interference of other electronic components or devices around the campus. This effect was present at location 4 which is the only location that is crowded with people during testing and also near to the radio studio in the campus. Even location 4 is located on the same floor with location 5 (but different distance), all the LoRa packet received from location 4 was below the noise floor (negative SNR is shown in Figure 4) especially for mode 1 which reaches the maximum LoRa demodulator sensitivity at that particular spreading factor (-7.5 dB). In addition, this is also affecting on the communication link whereby the packet is not able to transmit in a good condition and more packet loss during the transmission due to the increase of noise floor level at the environment. In general, 2.5 dB of extra link budget is provided in each increment of spreading factor. By increasing the spreading factor can improve the sensitivity of the communication path, therefore reduce the packet loss.

In summary, the deployment of LoRa gateway at the middle of the campus was able to cover the entire building with a minimum spreading factor of SF 9 and above without any packet loss during transmission (minimum SNR of -5 dB for spreading factor 9). The average RSSI value for the entire testing location was in the range between -90 dBm to -120 dBm. Even the SNR of the received packet sometimes reached negative reading, it does not affect the quality of the transmission whereby the packet is able to reach at the receiver side without any losses.

TABLE VII
LORA PARAMETER SOFTWARE AND HARDWARE PARAMETER

Parameter	Value
Spreading Factor	12
Bandwidth, kHz	125
Code Rate	4/5
Transmit Power, dBm	17
Antenna Gain, dBi	2.21

VII. LORA PERFORMANCE TESTING IN OUTDOOR SCENARIO (Partial-NLOS)

Table VII shows the LoRa parameter setup in the outdoor coverage test. In this part, the spreading factor and bandwidth are set to 12 and 125 kHz respectively which can provide maximum coverage distance and increase the sensitivity of the communication. The transmit power and antenna gain is chosen based on the EIRP limitation stated in Section 3.1, Table I.

The LoRa gateway was placed inside the communication laboratory at 2nd floor and the LoRa node (sender) moved away from the LoRa gateway while capturing the data. During the testing, the LoRa node sends a message to the LoRa gateway every 10 seconds and the LoRa gateway will send back a confirmation message to the LoRa node which indicated that the communication is successful (a LED will blink on the LoRa node).

A. Result

Based on Table VIII, the maximum detectable distance of the LoRa communication network is 330 meters which has a signal SNR of -16.75 dB and RSSI of -130 dBm. Furthermore, as the distance from the gateway increases, the quality of the signal reduced. From the result of the testing, at a distance above 120 meters from the gateway, the communication system starts to work below the noise floor (negative SNR value).

B. Discussion

In this part, the maximum communication coverage for an indoor LoRa gateway setup is limited to 330 meters which do not meet the minimum distance of 1 km stated in the datasheet. This is mainly caused by the higher noise interference and path loss occur at inside and outside of the campus. In general, when the LoRa node sends a message to the LoRa gateway, the power of the signal that is radiated in the air will reduce greatly as the distance increases. This is because of the nature of the antenna (omnidirectional) used in the testing. The sender antenna converts the signal into a form of power and sends it through the air in all direction. In other words, the power spread into a different direction and most of the power is lost because it does not flow to the receiver antenna. Furthermore, the penetration of signal power through the obstacle in the sending path will also reduce the power of the sending signal as mention in the indoor test. When the power of the signal from the sender is lower than the maximum receiver sensitivity, the LoRa gateway is not able to detect and pick up the signal. Hence, better coverage of LoRa communication can be achieved when it is conducted in a line-of-sight situation, for example, placed the LoRa gateway near to the window instead of a room.

TABLE VIII
RESULT OF THE LORA OUTDOOR TESTING

Distance, m	SNR, dB	RSSI, dBm
0	10.25	-16
30	8.25	-103
60	5.00	-118
90	2.50	-114
120	-3.25	-118
150	-9.75	-124
180	-10.25	-123
210	-11.50	-125
240	-12.50	-126
270	-13.25	-127
300	-14.75	-128
330	-16.75	-130

VIII. CONCLUSION

LoRa technology has the advantages of working under noise interference and allow long-distance communication thanks to its modulation technique. In this paper, the performance and coverage result of the LoRa indoor and outdoor deployment is presented using a selected combination of Spreading Factor and Bandwidth setting. The LoRa network consists of a low-cost single channel gateway and a private network application. All the measurement was recorded in a real environment at KDU University College campus. In summary, the environment of the deployment of the LoRa network does affect the signal quality especially the high dense of obstruction level in between the transmission path has the most impact on the degradation of the signal quality as seen in the experiment. Spreading factor and Bandwidth were the core factors that influence the performance of the LoRa network. Higher Spreading Factor and lower Bandwidth setting allow a longer range of communication and higher noise immunity. This shows the advantages of LoRa network comparing to others wireless protocol. The LoRa network is able to cover the entire building with one gateway or receiver deployment. At the meantime, the LoRa parameter should be tuned to the optimum setting for each location as different LoRa parameter setting will have different power consumption which will be analyzed in the future. By utilizing the optimum setup, the devices in the LoRa network will be able to work for a few years with the off-grid supply such as a battery.

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REFERENCES

[1] A. Zourmand, N. W. Sheng, A. L. K. Hing, and M. AbdulRehman, "Human Counting and Indoor Positioning System Using WiFi Technology," in *Automatic Control and Intelligent Systems, Shah Alam*. IEEE, October 2018, pp. 142–147. [Online]. Avail- able: https://www.researchgate.net/publication/330253846_Human_Counting_and_Indoor_Positioning_System_Using_WiFi_Technology

[2] C. Wongeun, C. Yoon-Seop, J. Yeonuk, and S. Junkuen, "Low-Power LoRa Signal-Based Outdoor Positioning Using Fingerprint Algorithm," *Goe-Information*, vol. 7, no. 11, pp. 440–455, 2018. [Online]. Available: 10.3390/ijgi7110440;https://www.mdpi.com/2220-9964/7/11/440/pdf

[3] J. Teel, "Bluetooth or WiFi – Which is Best for Your New Wireless Product?" 2018. [Online]. Available: https://predictabledesigns.com/ what-type-of-wireless-is-right-for-your-product-bluetooth-wifi/

[4] E. Notes, "LoRa Physical Layer & RF Interface," 2018. [Online]. Available: https://www.electronics-notes.com/articles/connectivity/lora/radio-rf-interface-physical-layer.php

[5] "Why LoRa?" [Online]. Available: https://www.semtech.com/lora/why-lora

[6] L. Alliance, "White Paper: A Technical Overview of LoRa and Lorawan," 2015. [Online]. Available: https://www.tuv.com/media/corporate/products_1/electronic_components_and_lasers/TUeV_Rheinland_Overview_LoRa_and_LoRaWANtmp.pdf

[7] S. R. Sharan, W. Y. Qiao, and H. Seung-Hoon, "A survey on LPWA technology: LoRa and NB-IoT," *ICT Express*, vol. 3, no. 1, 2017. [Online]. Available: 10.1016/j.icte.2017.03.004

[8] L. A. T. C. R. P. Workgroup, "LoRaWAN^{TM} 1.1 Regional Parameters," January 2018. [Online]. Available: https://lora-alliance.org/resource-hub/lorawantm-regional-parameters-v11rb

[9] M. Communications and M. Commision, "Class Assignment No. 2 of 2015," 2015. [Online]. Available: https://www.mcmc.gov.my/resources/registered-assignments/register-of-class-assignments.aspx

[10] M. Communications and M. C. (MCMC), "Usage of Short Range Device (SRD) and Radio Frequency Identification Device (RFID)," 2015. [Online]. Available: https://www.mcmc.gov.my/skmmgovmy/media/General/pdf/Public-Notice-RFID-SRD.pdf

[11] M. Communications and M. Commision, "Class Assignmnet No. 1 of 2017," 2017. [Online]. Available: https://www.mcmc.gov.my/resources/registered-assignments/register-of-class-assignments.aspx

[12] K. A. Ahmad, J. D. Segaran, F. R. Hashim, and M. T. Jusoh, "LoRa Propagration at 433 MHz in Tropical Climate Environment," *Journal of Fundamental and Applied Sciences*, vol. 9, no. 3S, pp. 384–394, 2017. [Online]. Available: 10.4314/jfas.v9i3s.31;https://www.researchgate.net/publication/322809453_LoRa_propagation_at_433_MHz_in_tropical_climate_environment

[13] S. Daud, T. S. Yang, M. A. Romli, Z. A. Ahmad, N. Mahrom, and R. A. A. Raof, "Performance Evaluation of Low Cost LoRa Modules in IoT Applications ," *IOP Conference Series: Materials Science and Engineering*, vol. 318, no. 1, 2018. [Online]. Available: 10.1088/1757-899X/318/1/012053;https://www.researchgate.net/publication/323860006_Performance_Evaluation_of_Low_Cost_LoRa_Modules_in_IoT_Applications

[14] K. A. Ahmad, M. S. Salleh, J. D. Segaran, and F. R. Hashim, "Impact of foliage on LoRa 433MHz propagation in tropical environment," ser. 1, vol. 1930. AIP, February 2018. [Online]. Available: https://www.researchgate.net/publication/322809453_LoRa_propagation_at_433_MHz_in_tropical_climate_environment

[15] R. Schaupp, "LoRaWAN range, part 1: The most important factors for a good LoRaWAN signal range," October 2018. [Online]. Available: https://smartmakers.io/en/lorawan-range-part-1- the-most-important-factors-for-a-good-lorawan-signal-range/