Journal of Computers Vol. 33 No. 5, October 2022, pp. 73-82
doi: 10.53106/199115992022103305007

An Evaluation of Self-Built Low-Power Wide-Area Network Based on LoRa

Sheng-Tao Chen[1*], Chien-Wu Lan[2], Shih-Sung Lin[3], Chia-Te Liao[4]

[1] Department of Avionics Engineering, R.O.C. Air Force Academy, Taiwan
iiccanffly@gmail.com
[2] Department of Electrical and Electronic Engineering of Chung Cheng Institute of Technology, NDU, Taiwan
chienwulan@gmail.com
[3] Department of Computer Science and Information Engineering, Chinese Culture University, Taiwan
shihsunglin@gmail.com
[4] Department of Aviation Communication and Electronics, R.O.C. Air Force Institute of Technology, Taiwan
jiader0502@gmail.com

Received 4 December 2021; Revised: 20 February 2022; Accepted 3 March 2022

Abstract. With the rapid development of applications in Internet of Things (IoT). Low power consumption and wide area is one of the solutions for the development of information transmission. Therefore, Low-Power Wide-Area Network (LPWAN) technology had led to extensive applications and discussions. The Long Range (LoRa) has the characteristics of self-built network and programmable control of communication parameters besides the above features of LPWAN technologies. The LoRa has more flexible application capabilities compared with the LPWAN technology that requires infrastructure provided by Internet Service Providers (ISP). Therefore, this paper describes the evaluation method from the LoRa parameters and the experiment of long-distance transmission. According to the experimental results, the actual effective transmission distance of the lightweight LoRa module from the packet loss rate is 621 meters. Moreover, the phenomena that different types of antennas connected to the transmitter affect the direction of the device are discussed.

Keywords: LoRa, self-built LPWAN network, antenna field

1 Introduction

The IoT allows many devices to be connected through the network [1] can be conceptually divided into the application layer, network layer, and perception layer [2]. Moreover, the network layer provides a network for data exchange of Internet of Things devices so that devices can access data anytime and anywhere [3]. Therefore, the network technology in the network layer is one of the factors that must be considered in the development and application of the IoT system. In the most basic concept of the IoT, the sensors in the perception layer are used to detect information and the application layer collects data deploys data sensed in various areas through the wireless network. The wireless network allows higher mobility between devices and reduces the cost of deploying wired network lines. Therefore, the Wireless Sensor Network (WSN) based on wireless networks is a basic and important capability for IoT devices to transmit and access information with awareness, connectivity, and mobility.

Each wireless network technology has its own advantages and disadvantages and suitable application scenarios. The use of wireless network technology can be basically divided into Wireless Wide Area Network (WWAN), Wireless Local Area Network (WLAN), Wireless Personal Area Network (WPAN) and Near Field Communication (NFC) based on the difference in signal coverage. Among them, WLAN (such as Wi-Fi) and WPAN (such as Bluetooth) can provide higher transmission speed and low latency. However, these wireless technologies require the deployment of many gateways or Access Points (APs) to increase the signal coverage [4], which may affect the application of the Internet of Things. Therefore, a more widely used wireless network technology for the IoT is remain to be found.

In recent years, the LPWAN wireless technology with signal wide area coverage, low power consumption and maintenance cost advantages had been widely discussed [5]. The LPWAN wireless network technology had gradually become one of the wireless network technologies in the network layer during the development of the IoT system. The corresponding characteristics of these LPWAN technologies are shown in Table 1 [4].

* Corresponding Author

Table 1. The LPWAN wireless communication technology [4]

Technology	NB-IoT	SigFox	LoRa
Receiver sensitivity	–137 dBm	–147 dBm	–137 dBm
Frequency band	Licensed	Sub-GHz ISM	Sub-GHz ISM
Minimum transmission bandwidth	3.75 kHz	100 Hz, 600 Hz	125 kHz
Fully bi-directional	Yes	No	Yes
Modulation	p/2 -BPSK, p/4 -QPSK	D-BPSK	LoRa modulation, GFSK
Medium Access Control (MAC)	SC-FDMA	Unslotted ALOHA	Unslotted ALOHA
Data rate	Up to 100 kb/s	100 b/s	0.3-38.4 kb/s
Over the air upgrade	Yes	No	Yes
Roaming	Yes	No	Yes
Standard	LTE (Release 13)	No	LoRaWAN

The SigFox and NB-IoT need to rely on ISPs to provide a large number of network equipment to form a wide coverage in the urban area. However, the development of IoT systems embedded in SigFox and NB-IoT must comply with the ISP's information specifications and bear a certain rental fee. These issues had become factors that must be considered in system development and maintenance. Among them, the advantages of NB-IoT proposed by the 3rd Generation Partnership Project (3GPP) can be developed based on existing the Fourth Generation (4G) cellular base stations are also widely discussed. However, the NB-IoT has certain restrictions on application and development, making the demand for self-built networks lack a certain degree of flexibility. Therefore, the LoRa technology implements self-built low-power networks easily was a suitable solution for improving this shortage. Therefore, the LoRa technology implements self-built low-power networks easily was a suitable solution for improving this shortage. This paper will focus on the LoRa-based LPWAN network performance evaluation method and discuss the phenomenon of experimental results.

2 LoRa Wireless Communication Technology

The LoRa wireless communication technology developed and promoted by the LoRa Alliance [6] use the Long Range Wide Area Network (LoRaWAN) protocol and architecture to extend the network coverage through the gateway deployed in urban area. On the other hand, the LoRa chip [7] produced by Semtech in the physical layer of LoRaWAN network is used to realize the ability of self-built network.

The LoRa in the sub-1Ghz frequency band has better penetration characteristics for obstacles compared with 2.4Ghz frequency band wireless technology [8]. In addition, the advantages of self-built network, wide area and low power consumption make the LoRa is suitable for regional networks in suburban or indoor multi-compartment complex environments that lack a complete network environment.

The definition of the LoRa wireless technology [9] is divided into two parts, as shown in Fig. 1. First, the LoRaWAN network protocol [10] is used to optimize the power limit terminal equipment regulates the protocol of the MAC layer. LoRaWAN belonging to the star topology uses the gateway as a relay station between the end node and the application server, and the TCP/IP protocol is used to provide connection services as shown in Fig. 2. Furthermore, the LoRa applies the frequency bands of 430, 433, 868 and 915 MHz to transmit and receive radio frequency signals in accordance with development regulations in different regions.

Secondly, the LoRa modulation is a Chirp Spread Spectrum (CSS) modulation technology. The CSS modulation formed a broadband linear modulation pulse to change the frequency according to the encoding information [7]. Thus, the transmitted radio frequency pulse signal will linearly change within a range within a period of the radio frequency pulse signal. This modulation technology can provide high-sensitivity signals with a lower transmission rate on a fixed channel. Therefore, LoRa is suitable for long-distance communication transmission and has the advantages of strong anti-interference ability, high sensitivity and low current consumption [11].

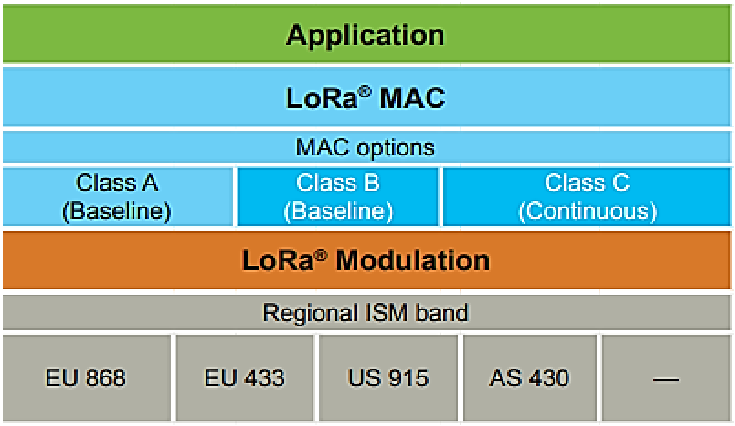


Fig. 1. Definition of the LoRa [9]

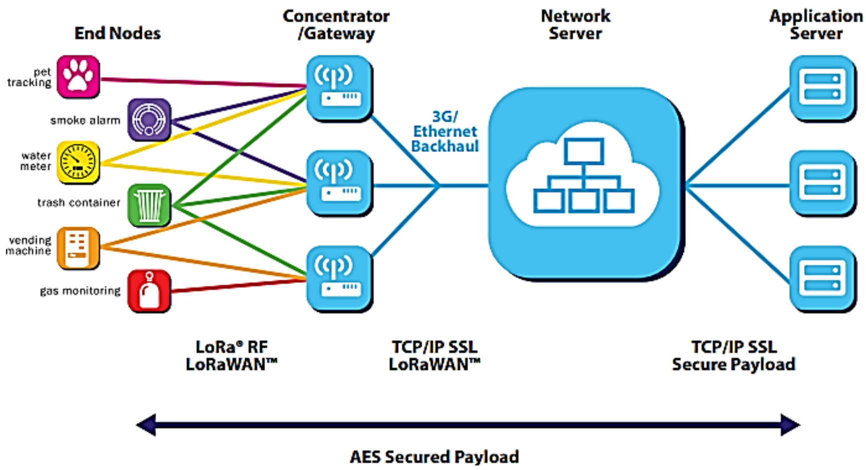


Fig. 2. The LoRaWAN network architecture [9]

2.1 The Evaluation Method of LoRa

The LoRa is an unlicensed frequency band technology that allows the network to be easily deployed within a range of more than a few kilometers and provides network services with less deployment and maintenance costs [5]. In addition, the ability to programmatically control network parameters allows the network to be controlled according to system development requirements based on the LoRa transmission characteristics. This paper evaluates and experiments from the LoRa parameter to the transmission signal and the antenna's influence on the radio frequency signal.

2.2 Evaluation of Parameters

The Self-built network and programmable adjustment of parameters make LoRa have the ability to control the network autonomously. The characteristics of the LoRa network signal can be determined through parameter settings to meet specific low-power and wide-area transmission requirements. The effective bit rate (R_b) be used to evaluate the LoRa transmission speed [12] is given by:

$$R_b = SF \times \frac{BW}{2^{SF}} \times CR \cdot \quad (1)$$

Here, the various parameters will affect the characteristics of the LoRa network in terms of transmission distance, transmission rate and anti-interference ability are described as follows:

1. Spreading Factor (SF):

The SF is used to set the chirp modulation rates of LoRa, which directly affects the transmission distance of the signal. The SF parameter has 6 levels from 7 to 12. The larger the SF, the longer the signal transmission distance but the relatively lower data rate.

2. Bandwidth (BW):

BW is the signal bandwidth representing the data transfer rate of LoRa. Furthermore, the transmission time can be shortened by increasing BW but at the same time the sensitivity will be reduced. 125, 250 and 500kHz are the BW of LoRa in the Industrial, Scientific, and Medical (ISM) frequency bands.

3. Coding Rate (CR):

The parameter CR is the code rate of the modulated signal and defines the ratio of the effective part of the data. The parameters of CR can be set to 4/5, 4/6, 4/7, 4/8, which can be used to improve signal interference and improve signal anti-interference.

On the other hand, the transmission distance is an important advantage for LoRa, which can be evaluated through the formula (2) proposed by [13] are given below:

$$l_{SF} = \left(\frac{P_0 A(f_c)}{\theta_{rx_{SF}}}\right)^{\frac{1}{\alpha}} . \tag{2}$$

Where, l_{SF} is the distance threshold under a specific SF, $A(f_c) = (f_c{}^2 \times 10^{-2.8})^{-1}$ is the deterministic loss in the path loss model, the carrier frequency (f_c) is 430, 433, 868 and 915 MHz frequency band, α is the path loss exponent, and $\theta_{rx_{SF}}$ is the receiving sensitivity corresponding to a specific SF. The corresponding parameters [13] are shown in Table 2.

Table 2. The SF corresponds to the distance threshold value [13]

SF	Bitrate R_m [kb/s]	Receiver sensitivity $\theta_{rx_{SF}}$ [dBm]	Distance threshold l_{SF} [km]
7	5.47	-123	0 ~ 0.453
8	3.13	-126	0.453 ~ 0.538
9	1.76	-129	0.538 ~ 0.639
10	0.98	-132	0.639 ~ 0.760
11	0.54	-134.5	0.760 ~ 0.877
12	0.29	-137	0.877 ~ 1

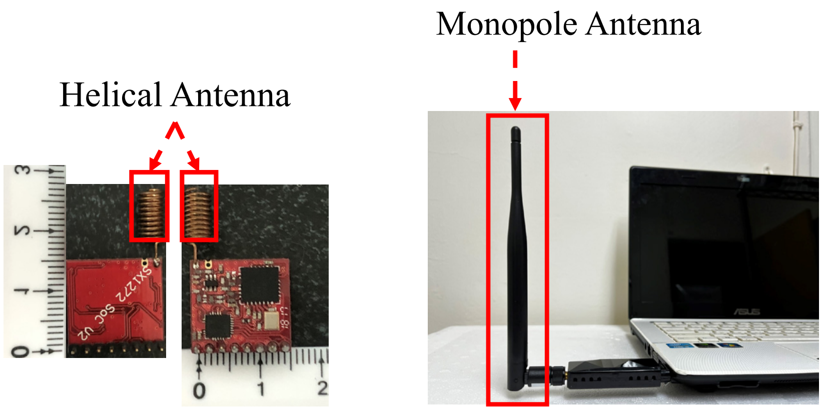
From the above parameters, SF is the main factor that determines the LoRa transmission distance, and BW and CR determine the transmission rate and signal interference capability. The comprehensive indexes R_b and l_{SF} obtained by formulas (1) and (2) can evaluate the effective bit rate and transmission distance of LoRa in the setting conditions of this parameter combination. Furthermore, there are transmission power and frequency that can be set through the Microcontroller Unit (MCU) connected to the LoRa chip to adjust the network characteristics. Therefore, LoRa is a flexible LPWAN technology with development independence.

2.3 Influence of Antenna

For the communication module, the antenna connected to the communication module will radiate a specific field pattern. The radiation pattern of the antenna is a factor that needs to be evaluated for long-distance communication. This paper will experiment with the helical antenna of the iL-LoRa 1272 module [14] and the monopole antenna of the iL-LoRa 1272 dongle. The communication problems caused by the antenna type will be explained in the results and discussion. This conclusion can be used as an evaluation factor that should be paid attention to when developing LoRa networks in the future.

3 Experimental Design

The communication coverage of wireless signals is one of the important evaluation factors of LoRa network technology. Next, this paper will conduct transmission distance experiments for LoRa. The iL-LoRa 1272 module produced by iFrogLab was used for experiments. The iL-LoRa 1272 module connected to the helical antenna for radio frequency signal radiation has a lighter module and antenna size than the general LoRa module, and is suitable for development in a variety of application scenarios. The Fig. 3(a) shows that the iL-LoRa 1272 module used as the transmitter includes an antenna module with a size of 2.8 cm long and 1.5 cm wide and connected to a helical antenna. On the other hand, the iL-LoRa 1272 dongle connected to the monopole antenna was used as the receiver as shown in Fig. 3(b).



(a) iL-LoRa 1272 (b) iL-LoRa 1272 dongle

Fig. 3. The LoRa modules

The Arduino UNO board was used as MCU to conduct experiments by integrating iL-LoRa 1272 module. In addition, the MCU sets the parameters of the iL-LoRa1272 module and transmits signal through the Universal Synchronous Asynchronous Receiver Transmitter (UART) interface.

The experiment set the most important parameter SF that affects the communication distance directly to the level 9 of the middle-level value. The setting is use to avoid extreme result and fixed parameter settings during execution, as shown in Table 3.

Table 3. Experimental parameter setting

Parameters	Setting values
SF	9
BW	500KHz
CR	4/5
Power	17dBm
Frequency	915 KHz

The Fig. 4 shows the scenario of the experiment on campus. In the experiment, a mobile transmitter sends a wireless signal to a fixed-position signal receiver at the test point. Moreover, the antenna of the LoRa transceiver module always maintains a Line of Side (LOS) transmission signal in a direction perpendicular to the ground 90 degrees. During the communication process, the transmitter sends 300 packets to the iL-LoRa 1272 dongle receiver connected via the notebook. Finally, the Packet Loss Rate (PLR) [15] is used to calculate the appropriate transmission distance of the iL-LoRa 1272 wireless communication module through formula (3) according to the packet reception of the fixed position receiver is as follows:

$$\mathrm{PLR} = \frac{Number\ of\ lost\ packets}{Total\ number\ of\ transmitted\ packets} \ . \tag{3}$$

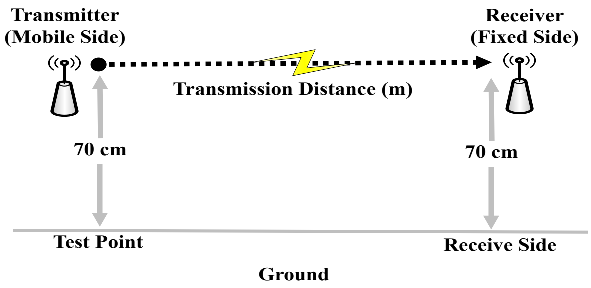


Fig. 4. The scenario of experiment

The Fig. 5 shows the flow of data transmission in the experiment, which was developed by using Unified Modeling Language (UML) modeling. When the experiment starts, the transmitter and receiver set LoRa module to transmit (Tx) and receive (Rx) modes respectively. Moreover the SF, BW, CR, Power, and frequency are set to the same parameters in sequence to conduct the transmission process of 300 packets. Next, The MCU in the transmitter calculates the CRC code of the packet to ensure the correctness of the data and encapsulates the counter variable into the packet payload. Finally, the transmitter sends the packet signal after completing the above process.

On the other hand, the receiver performs a loop to receive the signal continuously. When the signal from the transmitter was be received, the laptop checks the CRC code of the packet and encapsulates the counter variable form the packet payload. After confirming the correctness of the signal, the number of packets is accumulated and used for calculating the PLR of each test point.

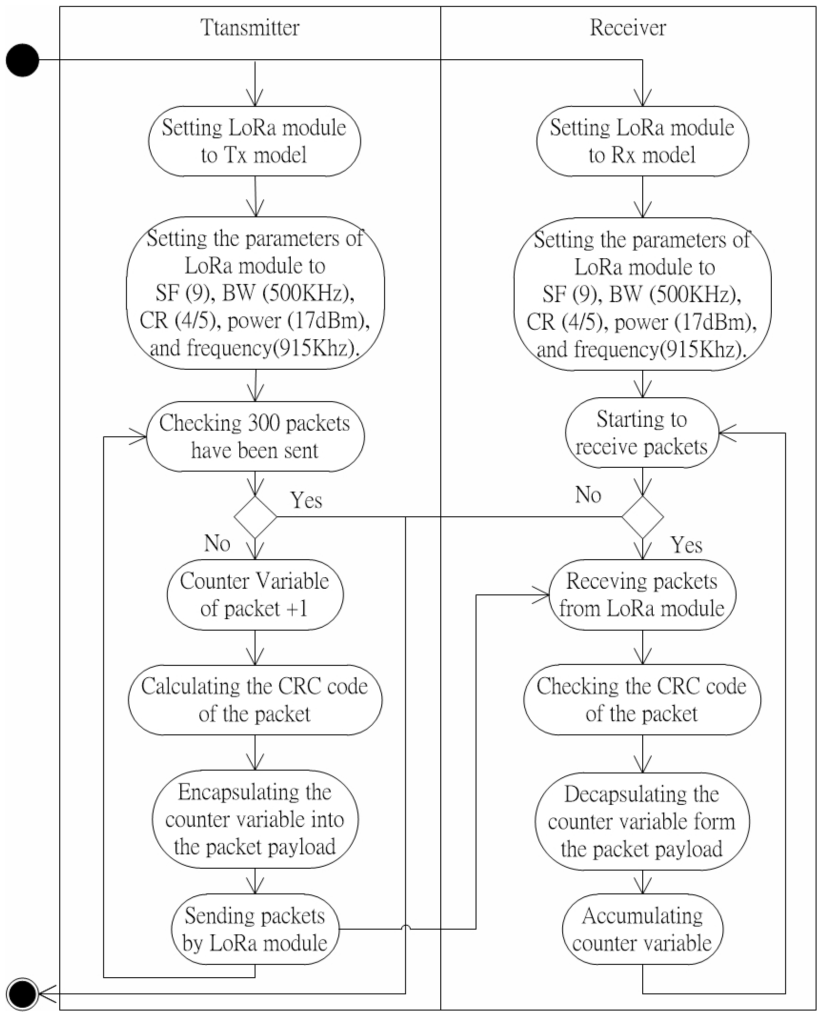


Fig. 5. The flow of data transmission in the experiment

After the experiment starts, transmitter sends signals to the receiver at test points A to D, the distances are 364, 438, 621, and 641 meters respectively. Among them, the signal cannot be received after the distance of the test point D is exceeded. The scenario of experiment in campus is shown in Fig. 6.

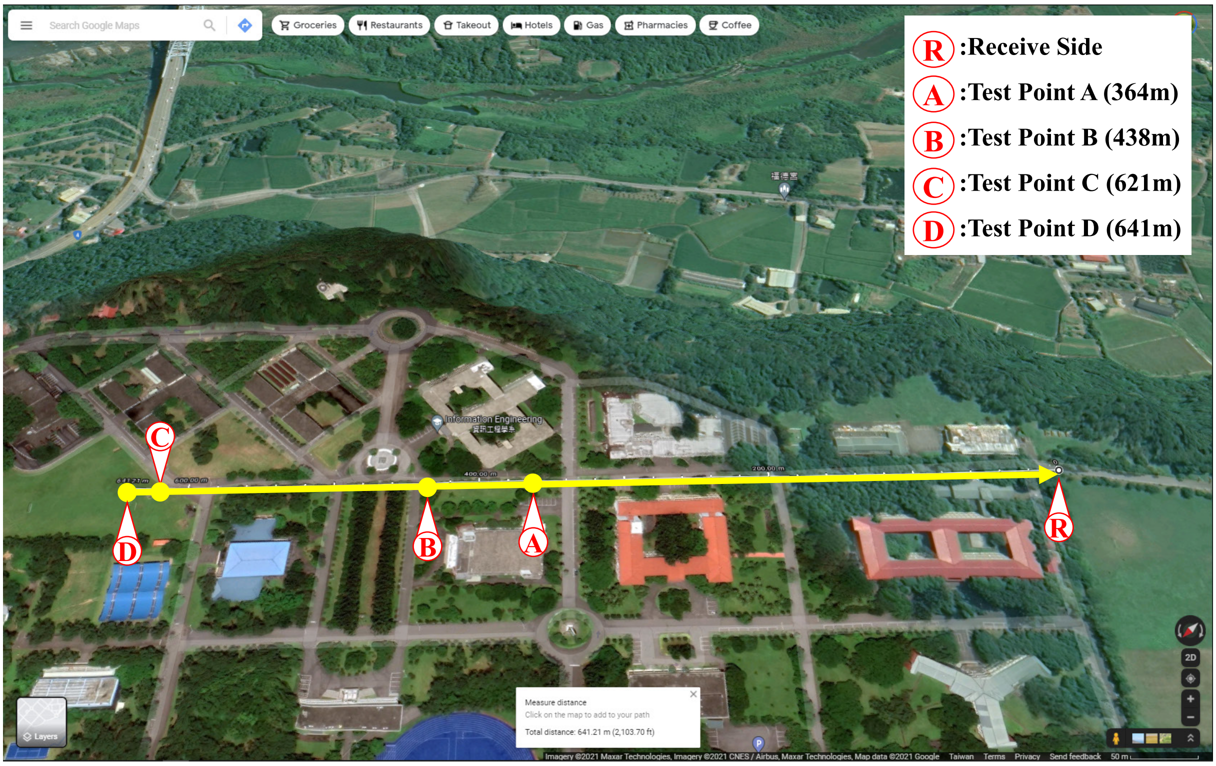


Fig. 6. The scenario of experiment in campus

4 Results and Discussion

The PLR calculated by the experiment is shown in Table 4 [15]. First, no packet loss occurred at test points A and B. Second, when the communication distance is increased to the test point C (621 meters), the signal becomes unstable and the total PLR increases to 1.34%. Third, as the distance increases to the test point D (641 meters), the PLR increases to 6.00%. Finally, the receiver cannot receive the signal when the distance exceeds the test point D.

Table 4. Statistics of PLR at test points A to D

Test points	Distance (m)	300 packets of PLR (%)
A	364m	0.00%
B	438m	0.00%
C	621m	1.34%
D	641m	6.00%

Furthermore, the phenomenon can be observed from the PLR accumulated at each test point during the experiment in Fig. 7. First of all, the test points A and B are the distances for stable transmission of data. Next, a total of 18 packets were significantly lost in the 148th to 206th packet interval at the test point D, resulting in a cumulative PLR of 6.00%. Finally, only 4 packet losses correspond to 1.34% of the cumulative PLR at the test point C.

Therefore, the distance of the test point C (621m) is the result of the longer effective transmission distance and the lower packet loss rate of the iL-LoRa1272 module based on the same LoRa parameter conditions.

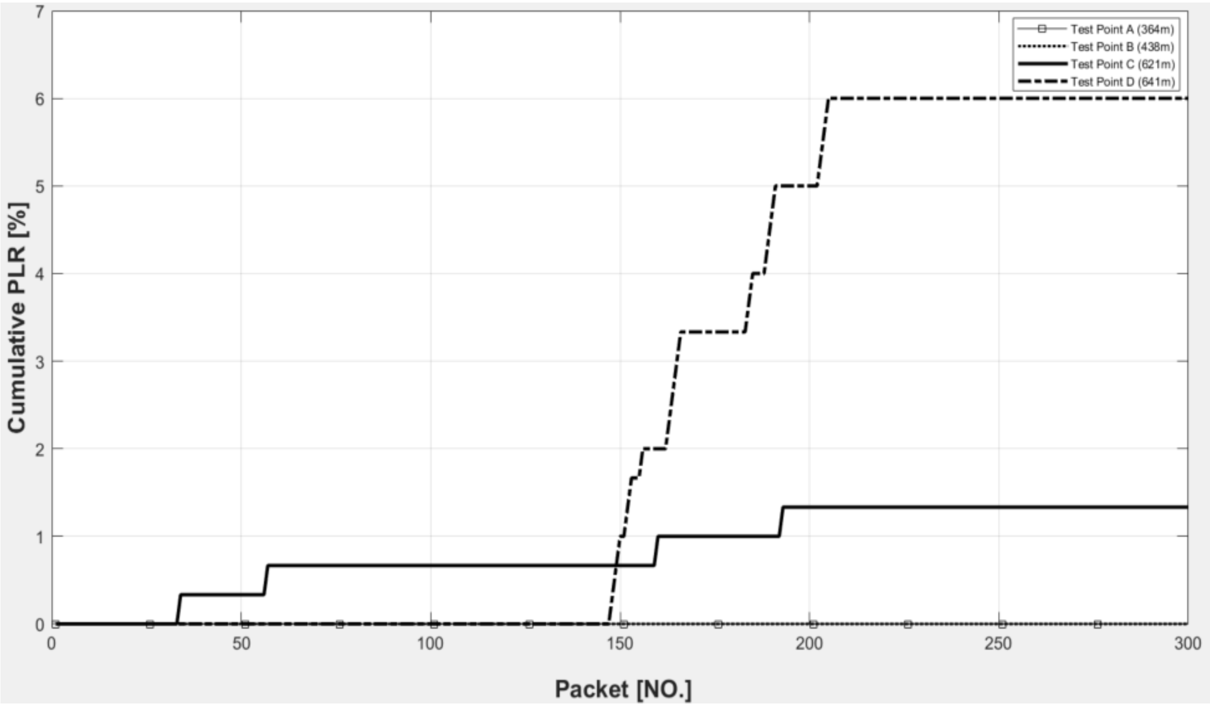


Fig. 7. Statistical results of cumulative PLR

The phenomenon produced by the experimental results will be discussed from the antenna types of the transmitter and receiver. The coordinates between transmitter and receiver was shown in the middle of Fig. 8.

Among the three axes, the Y axis is the horizontal direction indicating the distance between the transmitter and the receiver. Next, the Z axis is the vertical direction and the pointing direction of the antenna. Third, the X axis is used to evaluate whether the transmitter and receiver are in the same straight line for LOS transmission. Moreover, the coordinates define that θ is the angle between the X and Z axes, and Φ is the angle between the X and Y axes.

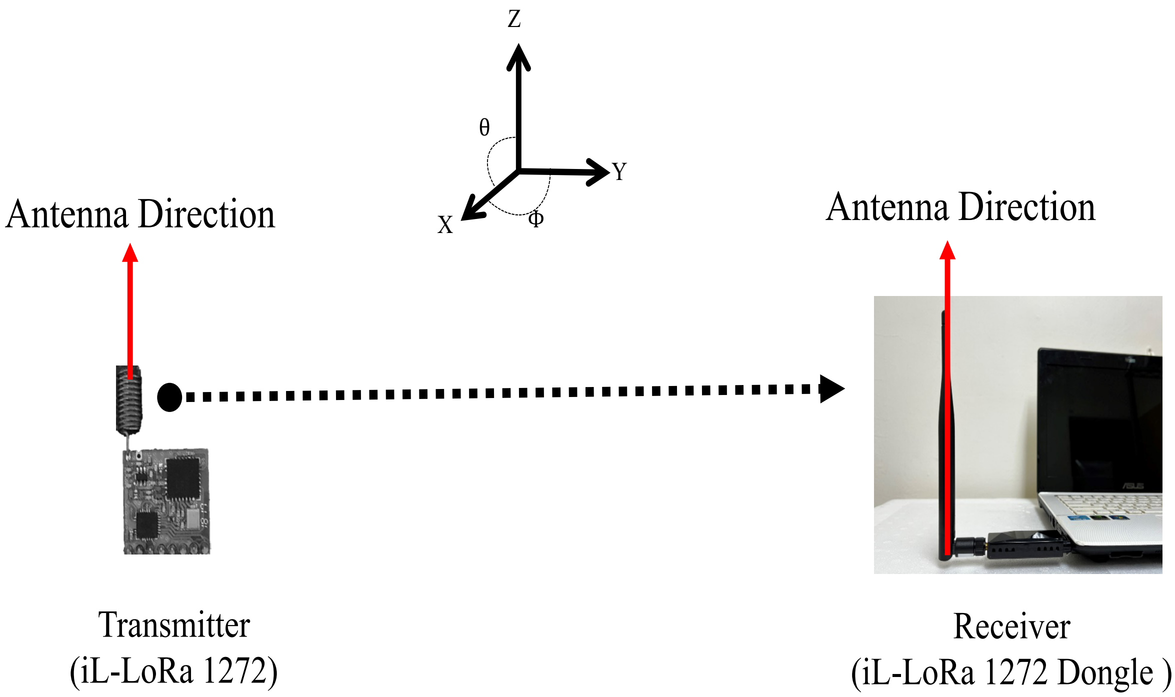


Fig. 8. The coordinate corresponding to the experiment

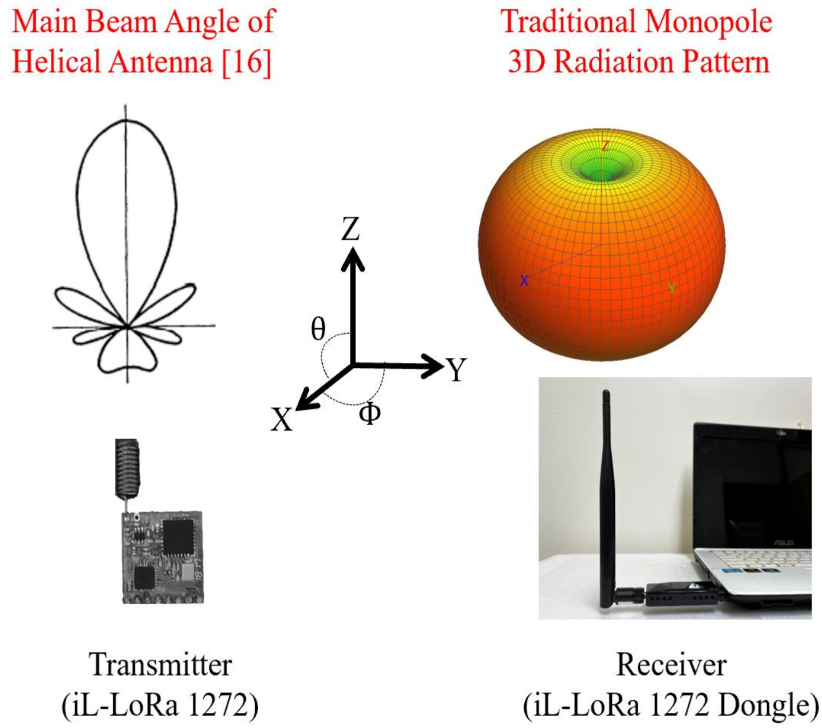


Fig. 9. Radiation pattern of antenna

It can be seen on the left side of Fig. 9. The main beam direction of the helical antenna embedded in the transmitter is the +Z axis direction [16] in Fig. 9 (corresponding to $\theta = 0°$ and $\Phi = 180°$). However, the radiation signal strength on both sides of the helical antenna (corresponding to $\theta = 0°$ and $\Phi = 0°\sim360°$) is obviously weaker than the main beam.

On the other hand, the iL-LoRa 1272 dongle receiver uses a monopole antenna and its radiation pattern simulated by the software [17] was shown on the right side of the Fig. 9. Compared with the helical antenna, the monopole antenna had a stronger radiation pattern on both sides (corresponding to $\theta = 0°$ and $\Phi = 0°\sim360°$) and the radiation pattern of the +Z axis is the zero point of no radiation energy. The difference in field characteristics between the iL-LoRa 1272 module and the iL-LoRa 1272 dongle antenna made the actual transmission distance unable to reach the officially declared long distance and had a considerable drop. Therefore, besides the factors of LoRa parameters, the radiation characteristic of the antenna is also a factor that must be considered in the evaluation of LoRa network transmission.

In this experiment, the SF was set to 9 can achieve a better balance between the transmission distance and the transmission rate, which was a suitable parameter setting for the iL-LoRa 1272 module. From the result, 621 meters of the test point C is the maximum distance for stable transmission under the condition of SF set to 9. Thus, this result is also in line with the theoretical distance threshold between 538 meters and 639 meters in the literature [13].

Comparing the test point D is 20 meters farther than the test point C (641m) but the packet loss rate is significantly increased by 22.33%. This result shows that the test point D is not suitable as an effective transmission distance. Additionally, the test point D exceeds the theoretical distance threshold of Table 2 by 2 meters. This is because the communication marginal signal is quite weak for the 17dBm low transmit power communication technology in the 2 meters beyond the theoretical distance threshold range, resulting in communication instability.

Finally, refer to the article [16, 18] to know that the best communication angle of the helical antenna is the same antenna direction as the +Z axis in Fig. 9. This direction is the same as the vertical ground direction in this experiment, but is different from the horizontal monopole antenna used by LoRa dongle that is parallel to the ground [19]. This factor causes poor signal transmission quality. Therefore, the antenna direction of the LoRa module must be considered to ensure communication quality.

5 Conclusion

This paper explains the network evaluation method for LoRa, which is one of the many LPWAN technologies that can self-build the network and programmatically control the communication parameters. First of all, the R_b and l_{SF} can be obtained from the parameters of LoRa (such as SF, BW, CR, Power, and frequency) to evaluate the characteristics of the network in terms of transmission speed and distance. Next, the type of antenna used by the LoRa module affects the signal radiation angle is another aspect of the evaluation. Finally, the lightweight iL-LoRa1272 module and dongle are used to conduct transmission stability experiments from different distances. According to the experimental results, the actual effective transmission distance of the lightweight LoRa module from the packet loss rate is 621 meters. Moreover, the iL-LoRa1272 module using helical antenna is compared with the iL-LoRa1272 dongle using monopole antenna, the signal in the vertical antenna direction is obviously weaker than the main beam radiated from the antenna direction. Therefore, the evaluation method described in this paper is a reference solution that can be considered using self-built LoRa networks with such programmable parameters and different antenna types.

6 Acknowledgement

The authors acknowledge the anonymous review, and the support of the Aerospace Technology Research and Development Center (ATRDC) of ROCAF for research grants in 2022.

References

[1] B. Gates, The Road Ahead, Viking Press, USA, 1995.
[2] O. Said, M. Masud, Towards Internet of Things: Survey and Future Vision, International Journal of Computer Networks 5(1)(2013) 1-17.
[3] O. Elijah, T.A. Rahman, I. Orikumhi, C.Y. Leow, M.N. Hindia, An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges, IEEE Internet of Things Journal 5(5)(2018) 3758-3773.
[4] W.J. Yang, M. Wang, J.J. Zhang, J. Zou, M. Hua, T.T. Xia, X.H. You, Narrowband Wireless Access for Low-power Massive Internet of Things: A Bandwidth Perspective, IEEE Wireless Communications 24(3)(2017) 138-145.
[5] Y. Song, J. Lin, M. Tang, F. Dong, An Internet of Energy Things Based on Wireless LPWAN, Engineering 3(4)(2017) 460-466.
[6] LoRa Alliance. <https://lora-alliance.org>, 2021 (accessed 21.05.19).
[7] Semtech Co., SX1272/3/6/7/8: LoRa Modem Designer's Guide, AN1200.13, 2013.
[8] S.S. Lin, C.W. Lan, S.T. Chen, K.C. Li, Design and Development of Portable LoRa-based Teleoperation Controller, Sensors and Materials 32(6)(2020) 2057-2075.
[9] LoRa Alliance, What is LoRaWAN. <https://lora-alliance.org/sites/default/files/2018-04/what-is-lorawan.pdf>, 2018 (accessed 20.06.18).
[10]N. Sornin, M. Luis, T. Eirich, T. Kramp, O. Hersent, LoRaWAN Specification, LoRa Alliance Inc., Ver. 1.0, 2015.
[11]Y.P. Tu, Design and Implementation of Frequency Hopping based LoRa Communicate Systems, [M.S. dissertation] Taipei: National Taipei University of Technology, 2018.
[12]L. Leonardi, F. Battaglia, G. Patti, L.L. Bello, Industrial LoRa: A Novel Medium Access Strategy for LoRa in Industry 4.0 Applications, in: Proc. IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society, 2018.
[13]A. Waret, M. Kaneko, A. Guitton, N.E. Rachkidy, LoRa Throughput Analysis With Imperfect Spreading Factor Orthogonality, IEEE Wireless Communications Letters 8(2)(2019) 408-411.
[14]iFrogLab, iFrpgLab LoRa, iL-LORA1272. <http://www.ifroglab.com/tw/?p=7086>, 2016 (accessed 20.06.18).
[15]S.T. Chen, Development of Internet of Things Monitoring Platform Based on LPWAN Technology, [Ph.D. thesis] Taoyuan: National Defense University, 2020.
[16]J.D. Kraus, The Helical Antenna, Proceedings of the IRE 37(3)(1949) 263-272.
[17]Feko. <https://www.altair.com/feko>, 2022 (accessed 10.02.22).
[18]J.D. Kraus, A helical-beam antenna without a ground plane, IEEE Antennas and Propagation Magazine 37(2)(1995) 45.
[19]K.L. Wong, S.W. Su, C.L. Tang, Broadband omnidirectional metal-plate monopole antenna, IEEE Transactions on Antennas and Propagation 53(1)(2005) 581-583.