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Data Transmission Distance Actual Measurement According to Receiver Height for LPWA-based IoT Application

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Abstract

The low-power wide area (LPWA) standard is attracting attention as a communication technology suitable for sensor-based IoT applications owing to its low power consumption and wide coverage. However, one disadvantage is that the communication distance differs depending on the application environment or gateway arrangement. In this paper, the data transmission distance is measured according to receiver height to check the influence of communication distance when the LPWA-based IoT application is deployed in different environments; the LoRaWAN of the LPWA standard technology is used to check the communication distance when the receiver height is different in an NLoS environment. Our experimental results demonstrate that smooth communication is impossible based on the receiver height, even at a position less than half of the maximum transmission distance.

Keywords: *Gateway Placement, Internet of Things, LoRaWAN, LPWA, NLoS*

1. Introduction

Recently, various Internet of things (IoT) applications have emerged, and there has been a significant increase in the number of devices in everyday life and industry [1,2]. Statista, a statistics-specialized agency, estimates that by 2025, 75.4 billion IoT devices will be distributed worldwide [3]. The application of IoT requires the cooperation of various fields such as hardware, software, wireless communications, and mobile communications. Therefore, various studies are underway that are studying IoT characteristics such as low power communication, platform, big data, and cloud [4-7].

Most IoT devices are provided with services such as monitoring through light-weight sensing data and device control. Therefore, IoT devices use low-power wireless communications, *e.g.*, Bluetooth low energy and Zigbee, and Wi-Fi standards, but they are difficult to apply to service models requiring a wide area because of their short communication range [2, 8, 9]. Therefore, a low-power wide area (LPWA) that can communicate over a long distance has emerged to transmit a small amount of data that is not delay-sensitive.

The LPWA is targeted at low data rate, low power, and low throughput applications and enables wide area connections of dozens of kilometers using sub-GHz bands with less congestion than the existing ISM (industry, science, medical) band [9, 10]. Owing to these characteristics, various studies on LPWA-based IoT applications are underway; however, the analysis of the effect of communication distance according to different arrangement environments of the application is insufficient. In this paper, we confirm the data transmission distance according to the height change of the receiver to verify the effect of communication distance when the LPWA-based IoT

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application is deployed in different environments. Therefore, the LoRaWAN of the LPWA standard is used to perform the data transmission experiment by changing the arrangement height of the receivers in a non-line-of-sight (NLoS) environment. Comparison of the measured results with the theoretical RSSI through link budget demonstrate the importance of placement such as the receiver and gateway location and height when the LPWA-based IoT application is deployed.

2. Related Work

2.1. LPWA Overview

LPWA aims at achieving long distance and low power operation at the expense of low data rates and high delay. It is difficult to use in industrial IoT, V2V (Vehicle to Vehicle) and V2I (Vehicle to infra) applications that require low delay and high reliability. However, it is suitable for sensors and IoT applications that transmit a small amount of data over long distances a few times per hour in various environments.

LPWA includes SigFox, LoRa, Weightless, and Ingenu using 169, 433, 868/915 MHz, and 2.4 GHz unlicensed band; LTE-M, EC-GSM, and NB-IoT using licensed band depending on the operating area. The major LPWA technologies and characteristics are shown in Table 1 [9-12].

Table 1. Major LPWA Technologies and Characteristics

	Unlicensed				Licensed		
Technology	SigFox	LoRa	Weightless	Ingenu	LTE-M	EC-GSM	NB-IoT
Frequency Band	915 to 928 MHz	868 and 915 MHz	Multiple bands in the sub-GHz	2.4 GHz	Licensed LTE in-bands	Licensed GSM bands	Licensed Sub-GHz
Modulation	DBPSK, GFSK	CSS	DBPSK, GMSK, OQPSK	RPMA	QPSK	GMSK, 8PSK	QPSK, OFDMA (UL), SC-FDMA (DL)
Range	20 km	15 km	5 km	15 km	15 km	15 km	15 km
Maximum Data Rate	100 bps	50 kbps	100 kbps	20 kbps	1 Mbps	200 kHz	250 kbps (UL), 170 kbps (DL)
Channel Bandwidth	100 Hz	125, 250 to 500 kHz	200 Hz to 12.5 kHz	1 MHz	1.08 MHz	200 kHz	180 kHz
Battery life	10 years	10 years	N/A	10 years	10 years	10 years	10 years

2.2. Related Work of LoRaWAN

In the research on LoRaWAN-based IoT applications, the maximum service coverage is first determined through actual measured data in the pertinent environment. In the study of J. Petäjäjärvi et al., an LPWA-based LoRaMote end device was used for remotely monitoring human health and wellbeing. Experiments were performed at the Linnanmaa Campus of Oulu University, Finland. The antenna of the base station was installed at the antenna tower at a height of 24 m from the sea level, and the monitoring data was received by attaching the end-device LoRaMote module to the researcher's arm. The LoRa parameters used in the experiments were SF 12, bandwidth 125 kHz, coding rate 4/5, and a successfully received researcher monitoring information on campus with a maximum radius of 420 m and a probability of 94.7% [13].

In the study of Yi *et al.*, the LoRa performance was analyzed based on the actual measured data in LoS (line of sight) and NLoS environments. Experiments were carried out in Busan, Korea, and the calculated RSSI (received signal strength indication) theoretical value through the path-loss model and the measured data value were compared. The LoRa parameters used in the experiment were SF 7, 12, bandwidth 125 kHz, and coding rate 4/5. In terms of the communication distance, maximum values of 8.96 km and 10.9 km were obtained when the SF values were 7 and 12, respectively, in an LoS environment based on receiving more than half of the valid data. In an NLoS environment, however, the maximum distance was 1.34 km when the SF value was 7 or 12 [14].

3. Experimental Environment

The experimental environment is set to the NLoS environment, and the highest residential building in the experimental environment has 14 stories. Packets are transmitted 100 times by the distance and receiver module height in the pertinent environment: each packet includes a packet count number for checking the message loss. Before measuring the communication distance by the height of the receiver module, the maximum communication distance in the experimental environment was checked to determine the communication distance measurement position by height.

For the maximum communication distance measurement, the receiver module is located in a 14-story apartment banister. For the communication distance measurement by height, the receiver module was positioned at the same position in each floor. The building elevation where the receiver module is located is 88 m, and the height of each floor is approximately 2.8 m. Each module was fixed with no motion in all experiments.

As shown in Figure 1, the modules used in the experiments were Semtech's SX1276MB1LAS LoRa module and two pairs of ST's Nucleo-L152RE MCU, each consisting of a transceiver and measured by a 1:1 communication. Table 2 shows the primary specifications of the LoRa module, Table 3 shows the maximum receive sensitivity for each spreading factor in the 125 KHZ band. In this paper, the experimental environment is constructed with parameters as shown in Table 4 for maximum receive sensitivity [15, 16].

Figure 1. LoRa TX/RX Modules

Table 2. SX1276MB1LAS Specifications

Estimated Sensitivity	−111 to −148 dBm
Max. Link Budget	168 dB
Bandwidth	7.8 to 500 kHz
Frequency	137 to 1020 MHz

Table 3. Receive Sensitivity by Spreading Factors (125 KHz)

SF	Sensitivity
6	−121
7	−124
8	−127
9	−130
10	−133
11	−135
12	−137

Table 4. LoRa Module Parameter Values

Parameter	Value
Frequency	917.1 MHz
Spreading Factor	12
Bandwidth	125 kHz
Coding Rate	4/5
Transmit Power	14 dBm
Antenna Gain	2 dBi
TX period	3 s

4. Results

The maximum reception distance measurement was performed at four positions, as shown in Figure 2, and the receiver module was installed on the 14th story of the apartment (approximately 39.2 m). The data reception results at each position are listed in Table 5.

Figure 2. Maximum Distance Measurement Points

Table 5. Maximum Distance Measurement Results

Point	Distance (km)	Packet			RSSI mean (dBm)	SNR mean (dBm)
		Received	Valid	PER		
A	1.4	78	76	2.6%	−120.6	−60.7
B	1.8	96	96	0%	−110.6	−29.8
C	2.0	70	68	2.9%	−123.5	−74.3
D	2.2	48	42	12.5%	−124.6	−75.8

Consequently, the point with the highest reception rate was point B at 1.8 km distance and four packets lost. When compared with other measurement points, we confirmed that the RSSI average and SNR (signal-to-noise ratio) average were both high. In particular, point A has many packet losses although it is closer than point B. The building distance is shown to be closer to the receiver module direction at points A, C, and D, such that the influence of the communication distance is large (within approximately 10 m). Further, no significant difference was observed in the average RSSI and SNR between point D at 2.2-km distance, and point C at 2.0-km distance. However, the maximum distance that can communicate smoothly in the experimental environment by loss of more than half of the packets was 2.0 km.

Based on the results of the maximum communication distance measurements, in terms of the communication distance measurement by height, a location without a building close to the receiver module direction was selected. Two points: 500 m and 800 m, were selected for smooth communication, and the measurement positions are shown in Figure 3. The receiver module location is set for each floor at the same position as the maximum communication distance measurement position; the experimental results are shown in Tables 6 and 7.

Figure 3. Measurement Point by Floor

Table 6. 500m Measurement Results by Floor

Floor	Packet			RSSI mean (dBm)	SNR mean (dBm)
	Received	Valid	PER		
3	70	67	4.3%	−93.4	−68.7
4	32	25	21.9%	−94.7	−78.8
5	19	13	31.6%	−97.5	−77.1
6	57	53	7%	−96.5	−60.9
7	84	82	2.4%	−93	−59.3
8	38	24	36.8%	−103	−76.9
9	100	100	0%	−93.5	−29
10	100	100	0%	−102	−25.2
11	100	100	0%	−91.5	−3.8
12	100	100	0%	−89.2	22.4
13	100	100	0%	−100.2	15.1
14	100	100	0%	−87	29.9

Table 7. 800m Measurement Results by Floor

Floor	Packet			RSSI mean (dBm)	SNR mean (dBm)
	Received	Valid	PER		
3	-	-	-	N/A	N/A
4	-	-	-	N/A	N/A
5	-	-	-	N/A	N/A
6	3	0	100%	−107.7	−95.3
7	15	4	73.3%	−106.3	−87.4
8	11	4	63.6%	−108.8	−87
9	39	34	12.8%	−106.8	−58.5
10	91	91	0%	−107.8	−42.3
11	84	80	4.8%	−104.4	−33.8
12	100	100	0%	−105.8	−25.5
13	100	100	0%	−108.4	−13.4
14	100	100	0%	−99.9	13.6

Our experimental results show a 100% packet reception ratio from the 14th to 9th floor, and that packet loss began to occur from the 9th floor boundary (approximately 25.2 m). In addition, the average packet reception rate between the 3rd and 8th floor where the packet loss occurred is 50% and the average PER (packet error rate) is 17.3%. The RSSI was observed at a maximum of −87 dBm and a minimum of −103 dBm, and the SNR increases as the receiver module is located at the higher floor number.

In the 800-m distance case, a 100% packet reception ratio was shown from the 14th to the 12th floor, and packet loss occurred at the 12th floor boundary (approximately 33.6 m). In addition, the average packet reception rate between the 6th and 11th floor where the packet loss occurred is 40.5% and the average PER is 42%. The RSSI was observed at a maximum of −99.9 dBm and a minimum of −108.8 dBm. All the data on the 3rd to 5th floor are lost, and communication is difficult from the 6th to 9th floor, where more than half of the packets are lost.

Comparing the two points, we found that the floor numbers in which packet loss occurred is the 3–8 for 500 m, and 6–11 for 800 m, and the floor number in which packet loss occurs increases as the communication distance increases. Further, compared with point B of 1.8 km, which shows the best result in the maximum distance measurement experiment, we found that the communication performance difference according to the receiver module height is large even when the communication distance is less than one-half.

To compare the theoretical received signal strength according to the installed height of the receiver module and actual measured result, the RSSI was calculated through the link budget. The link budget can be calculated using equation 1 [15].

$$P_{RX}[dBm] = P_{TX} + G_{SYS} - L_{SYS} - l_{CH} - M \tag{1}$$

In this case, P_{RX} is the received power (dBm) at the receiver module, and P_{TX} is the output (dBm) of the transmitter module. G_{SYS} is the gain within the transmission and reception system, which is the antenna gain (dBi). L_{SYS} is the loss (dB) in the transmission and reception system, and l_{CH} is the loss (dB) occurring on the channel. Lastly, M is the loss owing to other factors such as fading. Based on the results from [14], the Okumura-Hata path loss model was selected to calculate the l_{CH}. The Okumura-Hata path loss model can apply different models depending on the environment of the urban, suburban, and open area. When the transmission and receive antenna heights are h_{tx}, h_{rx} (m), frequency is f (MHz), and distance between transmitter module and receiver module is d (km), l_{CH} can be calculated from the following equation.

$$A = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h_t \tag{2}$$

$$B = 44.9 - 6.44 \log_{10} h_t \tag{3}$$

$$C = 2(\log_{10}(f/28))^2 + 5.4 \tag{4}$$

$$D = 4.78(\log_{10} f)^2 + 18.33 \log_{10} f + 40.94 \tag{5}$$

$$E = \begin{cases} 3.2(\log_{10}(11.7554 h_r))^2 - 4.97 & (for\ large\ cities) \\ (1.1 \log_{10} f - 0.7)h_r - (1.56 \log_{10} f - 0.8) & (for\ small\ cities) \end{cases} \tag{6}$$

$$l_{CH}[dBm] = \begin{cases} A + B \log d - E & (Urban\ Area) \\ A + B \log d - C & (Suburban\ Area) \\ A + B \log d - D & (Open\ Area) \end{cases} \tag{7}$$

Table 7. Comparison of LoS Link Budget with Maximum Distance Measurement Results

Point	Distance (km)	Link Budget RSSI	Actual Measurement RSSI (NLoS)	Difference (dBm)
A	1.4	−120.85	−120.6	−0.25
B	1.8	−125.63	−110.6	−15.03
C	2.0	−127.63	−123.5	−4.13
D	2.2	−129.44	−124.6	−4.84

As a result of comparing the RSSI calculated by the Okumura-Hata path loss model with the actual measured value, we obtained the result similar to the RSSI actually measured. The comparison of RSSI values calculated using the path loss model in the same way as shown in Table 7 and the measured reception strength at points 500 m, 800 m are presented in Tables 8 and 9.

Table 8. Comparison of Los Link Budget and 500m Measurement Results by Floor

Floor	Height (m)	Link Budget RSSI	Actual Measurement RSSI (NLoS)	Difference (dBm)
3	8.4	−111.25	−93.4	−17.85
4	11.2	−109.61	−94.7	−14.91
5	14.0	−108.26	−97.5	−10.76
6	16.8	−107.12	−96.5	−10.62
7	19.6	−106.12	−93	−13.12
8	22.4	−105.23	−103	−2.23
9	25.2	−104.43	−93.5	−10.93
10	28.0	−103.7	−102	−1.7
11	30.8	−103.03	−91.5	−11.53
12	33.6	−102.4	−89.2	−13.2
13	36.4	−101.82	−100.2	−1.62
14	39.2	−101.28	-87	−14.28

Table 9. Comparison of Link Budget and 800m Measurement Results by Floor

Floor	Height (m)	Link Budget RSSI	Actual Measurement RSSI (NLoS)	Difference (dBm)
3	8.4	−120.18	N/A	N/A
4	11.2	−118.54	N/A	N/A
5	14.0	−117.2	N/A	N/A
6	16.8	−116.05	−107.7	−8.35
7	19.6	−115.05	−106.3	−8.75
8	22.4	−114.17	−108.8	−5.37
9	25.2	−113.37	−106.8	−6.57
10	28.0	−112.64	−107.8	−4.84
11	30.8	−111.96	−104.4	−7.56
12	33.6	−111.34	−105.8	−5.54
13	36.4	−110.76	−108.4	−2.36
14	39.2	−110.21	−99.9	−10.31

For RSSI calculated from the path loss model, as the height of the receiving module increases, the intensity of the signal received by the transmitting module remote from the receiving module gradually increases to a similar intensity. In the measured values case, when comparing only the results of the lowest floor and the highest floor, the signal intensity increases as the receiver module height increases. However, in the middle floor case, it can be seen that the intensity of the signal increases and decreases. Also, compared with RSSI calculated theoretically through the path loss model, the actual measured value showed a higher RSSI value. However, considering the packet loss at each floor, it cannot be guaranteed that a high RSSI value will allow smooth communication at the distance. Therefore, when deploying IoT applications considering NLoS environment, it shows that the transmission distance may vary depending on the surrounding environment when installing the gateway for data reception.

5. Conclusions

In this study, we have confirmed the data transmission distance according to the receiver height in an NLoS environment using the LoRaWAN, among the LPWA standard technologies, to confirm the effect of communication distance in different distribution environments when an LPWA-based IoT application is distributed. Therefore, we measured the maximum communication distance in the experimental environment and then confirmed the data reception rate by changing the receiver module height at two positions with less than half the communication distance. Our experimental results demonstrate that the data reception rate differs depending on the receiver module height even when data is transmitted at the same distance. Further, we confirmed that the height at which the packet loss occurs increases as the communication distance increases; the performance difference according to the receiver module height occurs at a distance of less than half of the maximum communication distance. In addition, comparing the measured values with the RSSI values theoretically calculated from the Okumura-Hata path loss model, the middle floor transmission module showed an irregular signal strength changes although the height was increased. This indicates that when the LPWA-based IoT application is distributed in different environments, a considerable difference in the data reception ratio and the maximum communication distance may occur depending on the layout environment, such as the position and height of the receiver module or gateway.

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References

[1] L Atzori, A. Lera and G. Morabito, “The Internet of Things: A Survey”, Computer Networks, vol. 54, no. 15, **(2010)**, pp. 2787-2805.

[2] A. Whitmore, A. Agarwal and L. Da Xu, “The Internet of Things-A Survey of Topics and Trends”, Information Systems Frontiers, vol. 17, no. 2, **(2015)**, pp. 261-274.

[3] Statista, IoT Connected Devices Installed Based Worldwide from 2015 to 2025 [Internet], Available: https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/.

[4] J. Beh, K. Hur, W. I. Kim and Y. I. Joo, “An Energy-Efficient MAC Protocol for Wireless Wearable Computer Systems”, Journal of Information and Communication Convergence Engineering, vol. 11, no. 1, **(2013)**, pp. 7-11.

[5] L. Da Xu, W. He and S. Li, “Internet of Things in Industries: A Survey”, IEEE Transactions on Industrial Informatics, vol. 10, no. 4, **(2014)**, pp. 2233-2243.

[6] S. Husain, A. Prasad, A. Kunz, A. Papageorgiou and J. Song, “Recent Trends in Standards Related to the Internet of Things and Machine-to-Machine Communications”, Journal of Information and Communication Convergence Engineering, vol. 12, no. 4, **(2014)**, pp. 228-236.

[7] C. Perera, C. H. Liu and S. Jayawardena, “The Emerging Internet of Things Marketplace from an Industrial Perspective: A survey”, IEEE Transactions on Emerging Topics in Computing, vol. 3, no. 4, **(2015)**, pp. 585-598.

[8] Y.S. Cho, J. Kwon and S. Choi, “Design and Implementation of Wireless Sensor Network for Freeze Deyer”, Journal of Information and Communication Convergence Engineering, vol. 13, no. 1, **(2015)**, pp. 21-26.

[9] U. Raza, P. Kulkarni and M. Sooriyabandara, “Low Power Wide Area Networks: An Overview”, IEEE Communications Surveys & Tutorials, vol. 19, no. 2, **(2017)**, pp. 855-873.

[10] U. Noreen, A. Bounceur and L. Clavier, “A Study of LoRa Low Power and Wide Area Network Technology”, Proceedings of the Advanced Technologies for Signal and Image Processing(ATSIP), 2017 International Conference, Fez, Morocco, **(2017)** October 22-24.

[11] G. A. Akpakwu, B. J. Silva, G. P. Hancke and A. M. Abu-Mahfouz, “A Survey on 5G Networks for the Internet of Things: Communication Technologies and Challenges”, IEEE Access, vol. 6, **(2017)**, pp. 3619-3647.

[12] D. Ismail, M. Rahman and A. Saifullah, “Low-Power Wide-Area Networks: Opportunities, Challenges, and Directions”, Proceedings of the 19th International Conference on Distributed Computing and Networking(ICDCN), Varanasi, India, **(2018)**, January 4-7.

[13] J. Petäjäjärvi, K. Mikhaylov, M. Hämäläinen and J. Iinatti, "Evaluation of LoRa LPWAN Technology for Remote Health and Wellbeing Monitoring", Proceeding of the Medical Information and Communication Technology (ISMICT), 2016 10th International Symposium on IEEE, Worcester, MA, USA, **(2016)**, March 20-23.
[14] D. H. Lee and S. C. Kim, "Analysis of Computer Simulated and Field Experimental Results of LoRa Considering Path Loss under LoS and NLoS Environment", Journal of Korean Institute of Communications and Information Sciences, vol. 42, no. 2, **(2017)**, pp. 444-452.
[15] Semtech Corporation, SX1276/77/78/79 – 137 MHz to 1020 MHz Low Power Long Range Transceiver Datasheet [Internet], Available: https://www.semtech.com/uploads/documents/sx1276.pdf/.
[16] C. W. Cho and C. H. Oh, "Actual Measurement of Data Transmission Distance According to LPWA Transceiver Module Arrangement", Proceedings of the 4th Asia Workshop on IT Convergence of KIICE(AWITC), Busan, Korea, **(2018)**, February 9.

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