Experimental Performance Evaluation of the Collisions in LoRa Communications

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***Abstract*—With the development and spread of Internet of Things (IoT) technologies, various organizations in industry, academia, and government have begun collecting numerous types of data using sensor devices, which they then use to predict trends and identify potential problems with the services they provide. In the IoT, low power wide area (LPWA) networks can achieve low power consumption and provide a wide range of communication options that ensure constant service provision to deployed sensors. In particular, LoRa digital wireless communication technology, which has an open specification, uses an unlicensed band, and is inexpensive to install, is becoming increasingly popular and the number of sensors equipped with it is expected to grow in the future. However, since LoRa has insufficient specifications and verifications to resist channel contention within a heavily used frequency band, the performance of that technology is unclear when the number of sensors using the same frequency band increases. In this paper, we clarify the experimental performance of LoRa when multiple wireless communication nodes compete in different patterns.**

***Index Terms*—Wireless communication, LoRa, IoT**

I. INTRODUCTION

Internet of Things (IoT) technologies have attracted widespread attention because they can be used for various applications, not only by communication equipment such as conventional personal computers (PCs) and smartphones, but also everyday devices, such as home appliances, by equipping them with sensors and communication functions. Today, a wide variety of organizations in industry, academia, and government have adopted IoT technology and efficiency improvements, and new services can be expected to result from the data collected. One of the aims of the IoT is to facilitate the collection of huge amounts of data, commonly referred to as ”big data,” for analysis by artificial intelligence (AI) and use in statistics compilations, the results of which can then be used for predicting trends and creating future plans. However, in order to realize this objective, it is necessary to collect data from numerous sensor devices. Sensor device networks require long-distance communication systems capable of accommodating large numbers of devices using small numbers of base stations and sensors with low power consumption to reduce battery replacement costs. As one type of communication standard suitable for this, low power wide area (LPWA) networks have been shown to be capable of achieving low power consumption and providing a wide range of communication options that ensure constant service provision to deployed sensors. In fact, using LPWA network communications, it is theoretically possible to communicate in a wide range over a radius of up to 30 km with low power consumption. One disadvantage of this system type is that the data amount of one communication is small, but since the data amounts transmitted by most sensor devices (such as position information and water levels) is also small, problems seldom occur. Currently, as will be summarized in Section 3, research efforts involving coverage and configurable network scales are advancing. However, when the number of devices using an LPWA technology increases [1], one problem that is commonly encountered is that there has been very little investigation into the influence of those factors on communication performance.

In this paper, the authors focus on LoRa wireless communications technologies, which are thought to be capable of supporting the entry of new enterprises because the specification is open and the technology uses unlicensed bands.

II. LPWA COMMUNICATIONS

LPWA communication networks are popular among IoT designers because the amount of data that sensor devices exchange within one communication is usually small, the networks provide wide coverage, and power consumption amounts are low. There are various kinds of LPWA, and representative examples include LoRa [2], SigFox [3], NB-IoT [4], and the like. We will review the features of these three communication systems below, beginning with LoRa.

- Carrier Frequency
  LoRa designates the center frequency in the unlicensed band for use and communicates on that frequency. Note that the unlicensed band is different depending on the country and region; it is 863-870 MHz in the EU, 902-928 MHz in the US, and 920-928 MHz in Japan.
- Bandwidth
  After establishing the bandwidth to be used, LoRa communicates in three stages, 125, 250, and 500 kHz. When the bandwidth is small, the amount of data that can be transmitted decreases, but reception sensitivity becomes higher than when the bandwidth is high.
- Coding Rate
  The coding rate (CR) is refers to the forward error correction code. Losses can be reduced by increasing

redundancy via a high CR, but this increases the amount of data to be sent. Additionally, it is not possible to deal with bursts when droppage occurs in specific sections.

- Modulation method
  LoRa radio technology is based on a direct spreading type of chirp modulation called LoRa modulation. Using this method, even if noise is added when the spreading code is restored to the original signal, noise affecting the signal can be reduced because it is diffused within the frequency.

SigFox is a wireless communication method that was launched by a French company of the same name in 2012. The primary features of this method are that the transmission rate is as small as 100 bps and it is use of the 100 Hz ultra-narrow band (UNB). Since communications are tightly focused on the UNB, which is very rarely affected by interference, long-distance communications of up to 50 km are possible in prospective usage environments. Additionally, by setting the communication start point to the device start, power consumption can be significantly reduced because the network can be put into a sleep state whenever it is not transmitting data or waiting for data reception.

Narrow Band IoT (NB-IoT) is an LPWA network technology used by a number of existing carriers. Since the frequency band used by the carrier is licensed, it is possible to perform high-quality communications while avoiding the influence of interference from other types of communications. Additionally, since existing base stations can be repurposed by changing their software, the technology offers such advantages as wide coverage and ease of adaptation within the range covered by those base stations. Furthermore, since roaming is possible, it also offers the prospect of coverage expansion.

III. Related work

Numerous simulation and field testing studies have been conducted to evaluate the performance characteristics of LoRa networks and field test. In one study, the use of a LPWA network was expected to human health monitoring applications, and LoRa's indoor usage was evaluated based on device packet transmission success rates [5]. In that study, data was transmitted from a device attached to arms of the test subjects arm to a base station installed at a height of 24 m above the ground. During the experiment, test subjects equipped with wearable sensors performed routine work in Finland's Oulu University and the transmission packet transmission success rate obtained during the study period were evaluated. The sensor devices used were based on the Semtech SX1272 planar F type printed circuit board and were powered by a 9 V battery. The contents of the data transmission included the test subjects' temperature, blood pressure, and position information, as collected by their sensors. As for the parameter settings, the carrier frequency was 868 MHz, the spreading factor was 12, the bandwidth was 125 kHz, the transmission power was 14 dBm, the reception sensitivity was -137 dBm, and the transmission rate was 293 bps. In this experiment, each packet transmission was 13 seconds long and the parameters were set to ensure that the communication distance was long and the reception success rate was high. The result shows that the devices had a successful transmission rate of 96.7%, even when subjects were on different floors and far away from the base station, except for when they were isolated in a radio anechoic chamber. Based on that result, it is expected that the health conditions of people living in various environments and the participants of sports events can be monitored.

In a study conducted by researchers at the Indian Science University, the radio channel performance characteristics of two sub-GHz band modules (LoRa iM880A-L and two-frequency shifting key (2-FSK)) were evaluated and compared in various environments [6]. Specifically, the authors conducted investigations on open ground, straight roads, moderate and dense forest areas, inside concrete buildings, and on the roofs of campus buildings environment. The evaluation index was based on received signal strength indicator (RSSI) and packet error rate (PER). In order to compare the two communication standards, the packet size and the on-air time were set to the same values and the parameters of each device were set as follows: For the LoRa iM880A-L module, the carrier frequency was 865.5 MHz, the bandwidth was 125 kHz, the bit rate was 5.4 kbps, the spreading factor was 7, and the coding rate was 4/5. For the 2-FSK CC1200-DK module, the carrier frequency was 868 MHz, the bandwidth was 128 kHz, and the bit rate was 4.6 kbps. The number of packet transmissions varied depending on the environment, and both transceivers were installed on a table with a height of 48.26 cm. The results showed LoRa had lower RSSI than 2-FSK except for cricket ground, but PER was good. This is considered to be due to its use of a single spread spectrum modulation scheme that provides excellent immunity to interference and the acquisition of coding gain by forward error correction (FEC). However, problems such as protocol header inefficiency still need to be resolved. Another study investigating both LoRa and LoRaWAN networking protocols based on demonstration experiments was conducted. Here, we will only describe the LoRa demonstration experiment contained in the paper. The authors sent data from the Seventh floor of Glasgow Caledonian University that test participants received while walking on the campus grounds, after which reception success and reception strength were evaluated. The transmitter transmits data on a device controlling the SX1272 via an Arduino computing platform. The receiver is controlled by Raspberry Pi computer and uses a third generation global positioning system (3G-GPS) tracker, an SX1272, and a transmission time interval (TTi) portable spectrum analyzer. The receiver logs the RSSI, location information, and numbered beacon messages. The highest reception sensitivity is used, and the obtained data is plotted on a map. Data collection was carried out by the subject carrying the backpack. GPS and RSSI information was sent over the 3G line on the web server, thus allowing the user to check the data on his or her smartphone.

In this experiment, southward transmissions could be received at distances up to 2.2 km, northward transmissions could be received at distances up to 1.6 km due to the presence of a hill in that direction. On streets with high buildings and in pedestrian underpasses, where the transmissions were blocked,

TABLE I: RM-92A (Pair A)

Model	RM-92A
Frequency	920.6 - 928.0 MHz
Modulation method	LoRa
Maximum transfer speed	292.97 - 37500 bps
Maximum transmit power	13 dBm
Reception sensitivity	-137 dBm
Core processor	STM32L151
Built−in memory	Flash:128kB, SRAM:16kB, EEPROM:4kB

TABLE II: RM-922 (Pair B)

Model	RM-922
Frequency	920.6 - 928.0 MHz
Modulation method	LoRa
Maximum transfer speed	976.56 - 3906.25 bps
Maximum transmit power	13 dBm
Reception sensitivity	-132 dBm
Core processor	STM32L151
Built-in memory	Flash:128kB, SRAM:16kB, EEPROM:4kB

TABLE III: RM-92, RM-922 Configuration

Setting items	RM-92A， RM-922
Channel	920.6 MHz (24ch)
Transmission power	20mW (13dBm)
Bandwidth	125 kHz
Spread Factor (SF)	SF 7
Sleep mode	Not Use
CS	ON / retry 3 times

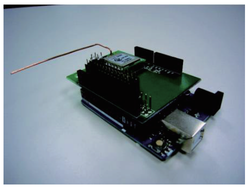

Fig. 1: LoRa device

Fig. 2: Experimental scene

the radio field intensity decreased. Since these characteristics show that a LoRa network is capable of long-distance communication at low data rates, the range in which interference must be taken into account is wide, and there is a high possibility that other IoT devices using the same frequency band will exist within the interference range. Additionally, since the data rate is low, the time required for one packet transmission is long, as is the occupation time of the communication band, so competition is more likely to occur compared to that seen in conventional communications. Since the number of IoT devices is expected to increase in the future, there are concerns that the incidence of competition will increase due to increased communications between LPWA technologies operating on the same band. However, it is considered difficult to solve the problem of LPWA communications that involve long bandwidth occupation times and large propagation delays within the carrier sense (CS). In addition, since only a few papers have considered performance levels in the face of competition in communications with large propagation delays due to CS issues, the verification aspect is also insufficient.

IV. Experimental Evaluation

In this study, the authors investigated the influence on communications that result when other communication devices exist within the same area. By changing the position of each of two pairs of transmitters and receivers that could be expected to conflict and which are engaged in communications at the same time, the authors investigated the difference in the number of transmitted and received packets due to the differences of three environment patterns. Communications were started manually. The devices used and experiment scenarios are described below.

A. Experiment environment

Used equipment: The authors created a device to use for the experiment.

The authors created a LoRa communication device for use in these experiments, which is shown in Figure 1. Specifically, they used RF Link's RM-92A and RM-922 as the LoRa communication modules and Arduino UNO Rev. 3 as the control microcomputer and control in order to permit the Arduino to send and receive packets. The start of packet transmission and the reception success were confirmed on a notebook PC connected to Arduino device. When it was necessary to rewrite the module settings, the authors used a development board to change the settings written in the electrically erasable programmable read-only memory (EEPROM) of the chip and created two pairs of devices. They then evaluated the operations of each module, and the communication performance when LoRa communication conflicts occurred.

Experiment scenario: For our experiment, the device was installed on the rooftop of the General Research building of the Kyushu Institute of Technology and near the road. Figures 1 to 3 show the outline of the three-pattern experiment. Pair A is a pair of RM-92A devices, and Pair B is a pair of RM-922 devices.

In Pattern A, the transmitters are located close to each other, and the case where data is transmitted to a receiver over a long communication distance is shown.

Pattern B shows a case where the transmitter and receiver are close but the distance between the pairs long.

Pattern C shows a case where the distance between the transmitter and receiver are long and the pairs of transceivers are positioned far from each other.

The distance is evaluated at the five points of 160, 340, 530, 730, and 860. These distances were selected to prevent obstacles such as pedestrian bridges from interposing between the devices when conducting our experiments. After experiments with these three patterns, the authors conducted performance evaluations based on the number of packets sent and received. In this experiment, the two respective transmitters sent 100 40-bytes packets every 300 ms to each receiver. The transmission interval and data volume are limit values based on Japan's Radio Law. The LoRa module avoids contention by using the CS function but does not have a retransmission guarantee function that activates when a packet collision occurs.

Fig. 3: Bird's eye view of experiment part (c)Google

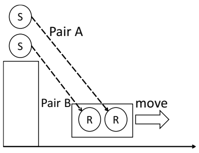

Fig. 4: Pattern A

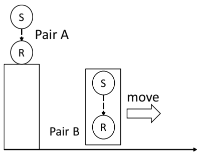

Fig. 5: Pattern B

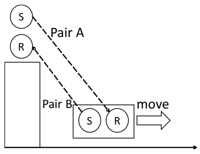

Fig. 6: Pattern C

B. *Experimental result*

Figures 7 to 9 show our experimental results. The horizontal axis represents the distance and the vertical axis represents the number of transmitted and received packets. For each result, the authors focused on the relationship between the distance and the total number of transmitted and received packets.

In Figure 7, since the transmitters communicate with each other by CS, the authors confirmed that only one transmitter, which was able to transmit the packet first, was always transmitting data. The receiver side achieves nearly 100% packet reception rate even when it is separated by the maximum distance of 860 m. From these results, when carrier sense works, it is considered that only one transmitting the packet is transmitting packets at the earliest.

In Figure 8, as the distance between transmitters increases, we confirmed that data is being transmitted from both transmitters. However, it can also be confirmed that the number of receptions on the receiver side is smaller than the number of transmissions. The number of packets to be transmitted on the transmitter side increases because they can be transmitted increases as the distance increases, but the number of received packets reaches nearly 100 at any distance. From these results, it can be seen that packet discard has occurred due to channel conflict because the CS can not be maintained well.

Finally, in figure 9, as transmitters leave each other, you can confirm that 100 packets have been sent from each transmitter. However, except at the closest location, the receiver side could not confirm any packet receipt. From this result, we conclude that since the CS becomes more difficult to maintain as the distance to the transmitter increases. Specifically, even though 100 pieces of data are transmitted from each transmitter, communication conflicts occur at the receiver side as the distance increases, so packet reception was not confirmed. Thus, it is conceivable that nearly all the packets were discarded because the transmitted data are completely blocked when there is a transmitter with strong radio field strength near the receiver.

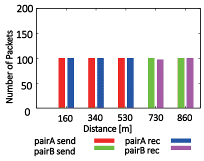

Fig. 7: Result A

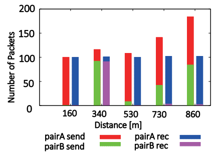

Fig. 8: Result B

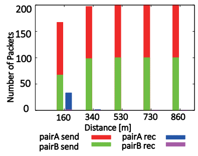

Fig. 9: Result C

V. Conclusion

In this paper, LoRa communication characteristics were evaluated using real devices. From our experimental results, we found that when communication conflicts result in bloackage, situations occur when the receiver could not receive any packets. Therefore, when using LoRa, it is clear that a mechanism is needed to ensure reliability against communication conflicts.

In the future, since this equipment implements vendor-specific MAC, we will verify the result with a simulator and verify the operation of LoRaWAN which is the MAC layer for LoRa in the same environment.

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