**Industry Paper**

# On the Effectiveness and Stability of Multi-channel Time Division Multiple Access Using LoRa

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***Abstract*** -We are developing a bus operation management system using LoRa. The main part of the system is a bus location information system called "BusDoko System" which presents the current location of the bus. This system uses GPS and IoT SIM to collect real-time location information from running buses. We are currently in the process of changing to LoRa communication to reduce operational costs. In recent years, the number of users of the 920 MHz band has been increasing, making stable operation of the system more difficult. Therefore, in this paper, we studied how to enable stable communication even in such an environment. In a bus location system, the accuracy and stability of the system are important. Therefore, we constructed a multi-channel LoRa communication system using Time Division Multiple Access (TDMA) and a channel hopping method. This enables us to cope with changes in the communication environment over time. First, we confirmed the effectiveness of these methods through the results of indoor experiments. Next, we confirmed whether the system actually works in the outside, and we will introduce the results. From these results, we will report the normal operation of the system and its effectiveness against communication interference in the communication system.

***Keywords***: LPWA, LoRa, TDMA, Channel Hopping, Bus location

## 1 INTRODUCTION

Community buses play an important role in the transportation of local residents. However, the operation of it is depend on weather and traffic conditions. Therefore, it may give the bus users anxiety about whether the bus will arrive. In recent years, efforts have been made to develop and operate the bus location systems that present the current location of buses in order to remove unstable elements [1] - [3]. These use LoRa, which does not require communication costs, in order to reduce operating costs. Fig. 1 shows the overall bus location system, the "BusDoko System" which we are developed [4]. This system presents the current location of community buses Notty circling Nonoichi City, Ishikawa Prefecture, on a website.

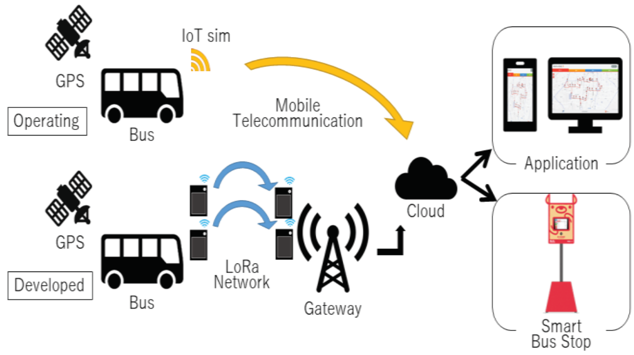



Figure 1: Bus location system which is called BusDoko system

In the system, GPS, IoT sim and LoRa module has been used to collect the real-time bus location information from running buses. In recent years, there are many users in the 920MHz band which is unlicensed bands, and stable system operation has become difficult. In the system interference is a problem that needs to be resolved to improve system stability, and to enable frequency sharing. Many wireless standards in recent years have capable of long-distance transmission, and since the timing and transmission channel can be freely set, they are susceptible to interference. Therefore, in order to ensure the communication quality of the service(QoS), the time occupancy rate of other system signals arriving at the Gateway (hereinafter referred to as the out-of-system interference time ratio) is estimated each channel with high accuracy, and the channel of LoRa of the our system is decided based on the estimation result. We need to assign the communication between bus and gateway to the appropriate channel to maintain the system stability.

There are existing studies [5] - [7] as a highly accurate radio wave environment prediction method. The method of acquiring, accumulating, and utilizing the radio wave condition is an important method from the viewpoint of radio wave utilization efficiency. In the existing studies [6] - [7], the actual observation type database is discussed, and its usefulness is reported. This database is a collection of environmental information such as received signal power and reception position information acquired by the receiver in the actual environment. Using this, the communication

| Antenna power | CH number | CH used in a bundle | Carrier sense time | Sending duration | Pause duration | The sum of emission time per arbitrary 1 hour |
|---|---|---|---|---|---|---|
| 250mW (24dBm) or less | 24-32 | 1-5ch | 5ms or more | 4s | 50ms | None |
| | 33-38 | | | | | 360s or less |
| | 33-38 | 1ch | 128μs or more | More than 200ms, and 400 ms or less | Ten times or more of the former transmitting time or 2ms | 360s or less |

Figure 2: 920MHz band channel allocation specified by ARIB [12]

parameters of wireless channels, and channels can be adaptively assigned. In the existing research [5], a method of allocating to a channel with a low interference ratio has been proposed. However, this method assigns to only one channel. In recent years, the use of this database has been discussed in the field of frequency sharing. On the other hand, research is being conducted on LoRa to suppress interference [8] – [9]. However, these do not allow the system to consider the effects of interference.

In order to improve the accuracy and reliability of the system, we have created a method for multi-channel LoRa communication method using Time Division Multiple Access (TDMA) for the bus location system. We also create the channel hopping method which use the observation type wireless database. This makes it possible to handle changes in the communication environment over time. Multi-channel TDMA have been used to improve the QoS [10] – [11]. The conventional methods require submillisecond (sub-ms) accuracy synchronization. Therefore, expensive equipment is required. In addition, dynamic management of the TDMA slot needs to be done promptly. However, in the bus location system using LoRa it was difficult. Because LoRa have a transmission distance of several km with a large transmission delay. According to the report of [1], it is a dozen seconds. Therefore dynamic management of the TDMA slot is difficult in short TAT. The method we propose does not require accurate time synchronization and is not require fast dynamic TDMA slot management.

We have confirmed the effect of TDMA as a result of experiments in the room and the outdoor. We will explain the details of the experiments. And we report on the successful operation of the communication system and its effectiveness against communication interference.

## 2 BUSDOKO SYSTEM

In this section, we will explain the hardware and software configuration of the BusDoko system. The BusDoko system is a system that allows bus users to check the location information of buses in the real time on a Web page, a mobile terminal, or a terminal installed at bus stops.

By using the bus location system, it is possible to visualize the arrival, the departure, and the location of buses, and it is possible to eliminate the anxiety and dissatisfaction

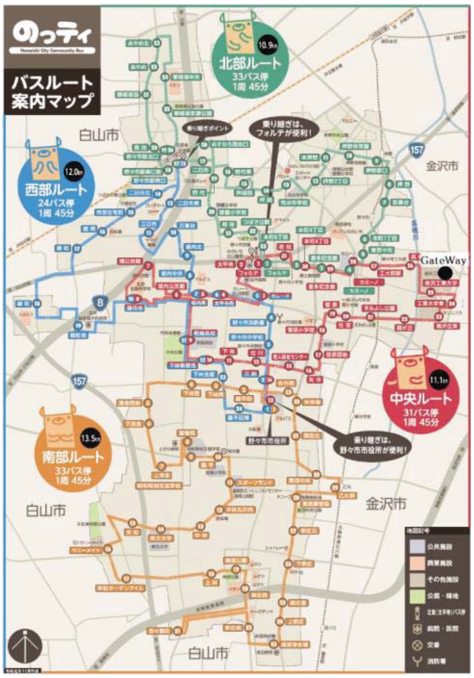



Figure 3: Bus route of the community bus Notty

that bus users have. Figure 1 shows the configuration of the bus location system we have developed. The buses are equipped with an in-vehicle device equipped with Private LoRa, IoT sim and GPS, acquires the current position information from the GPS at intervals of several seconds, sends it to the gateway using Private LoRa. And then gateway send data to cloud via the Internet and store the data in the upper server. By displaying the bus position information on a Web page using the stored the bus position information data, the bus position can be confirmed on the user's terminal. In addition, some of the bus stops we have developed have a built-in tablet, and some of the bus stop are equipped with a panel that allows you to check the bus position using LEDs. The LoRa gateway send the bus locations to the bus stops. Therefore the bus stops can display the current position of the buses.

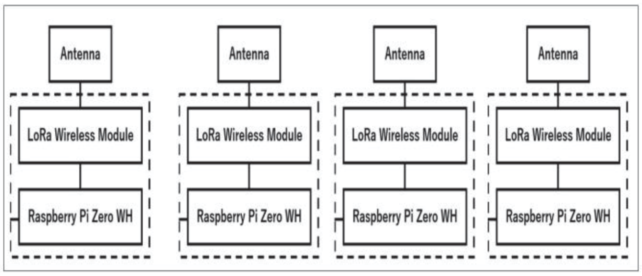
The domestic standard for the use of the 920MHz band is specified in ARIB STD-T 106-108. Figure 2 shows an excerpt of the ARIB STD-T108 standard. LoRa is a low-power wireless system that uses the 920MHz band, and it is possible to perform communication according to the purpose by changing the output power to 20mW or less and 250mW or less. The standard defines a combination of usable channel bandwidth, carrier sense time, maximum transmission time, pause time, and total transmission time per hour for each of 20 mW or less and 250 mW or less. We are using 250mW LoRa in the BusDoko system.

Figure 3 shows the bus route map of the community bus Notty. The gateway was installed on the roof of the 12-story Kanazawa Institute of Technology Library Center. There are four bus routes for the community bus. As a system requirement to realize QoS, location information of bus must be displayed at least once between bus stops.

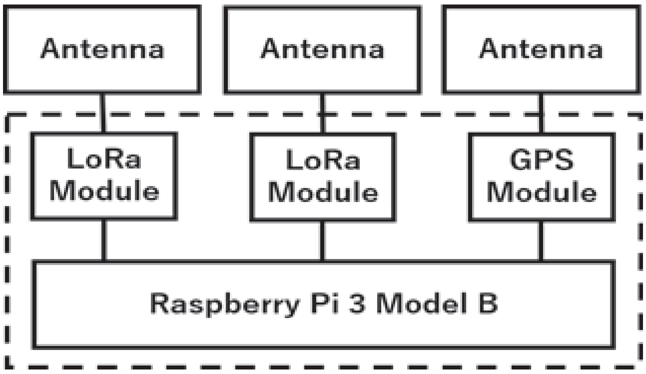
## 2.1 Hardware Design

Figure 4(a) shows the hardware configuration of the LoRa gateway and Fig. 4(b) shows the hardware configuration of the end devices on the bus. The LoRa gateway has two boxes with four Raspberry Pi Zero WH and four LoRa modules each. The end device is a Raspberry Pi 3 Model b with a built-in GPS module and a LoRa module. The LoRa module is the RM-92C module of RF-LINK Co., Ltd. The RM-92C module operates in the 920Mhz band and achieves a maximum receive sensitivity of -137dBm by changing the transmit power from 13dBm to 24dBm and setting the SF (Spreading Factor). The SF parameters of LoRa can be set from 6 to 12.

Figure 5 shows the gateway installed on the rooftop of the library center, which contains two boxes with four LoRa modules. In order to determine the exact location of the bus, the gateways were installed in two locations: the library center and a facility at the same height as the library center. The experiment was conducted within the area covered by the gateway installed at the library center




(a) LoRa Gateway




(b) The end device mounted in bus

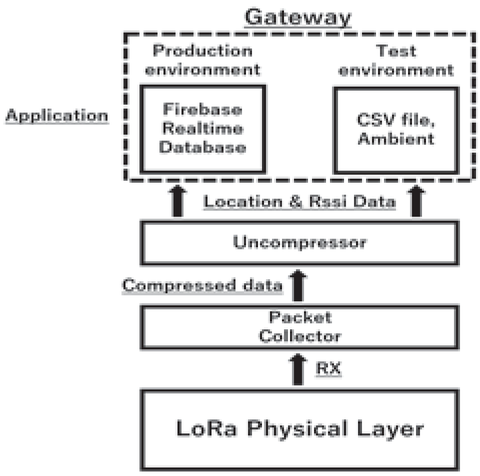
Figure 4. Hardware configuration of the system

Figure 5. Gateway on the Library center

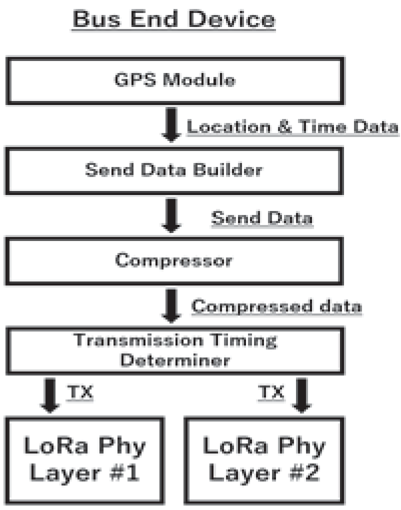
## 2.2 Software Configuration

Figure 6(a) shows the software configuration diagram of the LoRa gateway system of the BusDoko system. Figure 6(b) shows the software configuration diagram of the bus end device system of the BusDoko system. In the LoRa gateway, the data acquired by the LoRa Physical Layer is imported into the host computer by the Packet Collector. After that, the uncompressor decompresses the compressed data. The data is then uploaded to the Firebase realtime database in the production environment.

In the LoRa end device, the GPS module acquires the current position data and current time data. Of the data acquired by Send Data Builder, the current position data and bus ID are combined to create the send data. The Compressor compresses the transmission data. Transmission Timing Determiner determines which of the two LoRa Modules is used for transmission based on the current time data acquired by GPS.




(a) Gateway system




(b) End device system

Figure 6. Software configuration diagram of the BusDoko system

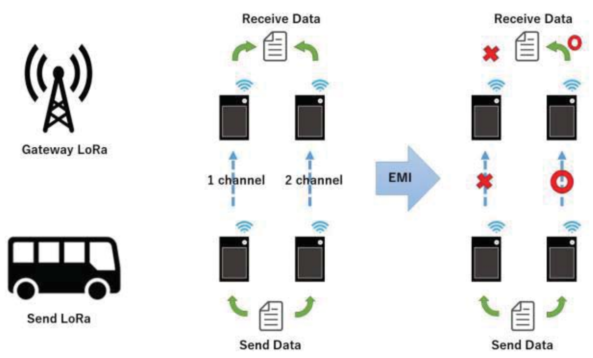



Figure 7. Effect of using multiple channels

## 3 MULTI-CHANNEL COMMUNICATION

If an end device on a bus sends data using one channel, it cannot be sent if that channel is used by another system. To avoid this danger, we decided to use two channels (see Fig. 7). This allows the location of the bus to be sent to the gateway, even if either channel is used by the other system. On the other hand, due to the limited number of channels, it is not good for one end device to occupy two channels. Therefore, we decided to use two Channels in common by two end devices.

### 3.1 Multi-channel Communication

In the case of communication using a single channel, regular communication may become difficult due to interference by others, which may impair the quality and real-time performance of the system. Therefore, we decided the multiple devices will communicate using different channels to solve these problems. Figure 8 shows the system diagram of LoRa communication using multi-channel in Nonoichi Notty bus routes. In this communication, two LoRa modules are installed in the end device of each bus, and the location information acquired by GPS is transmitted alternately. Each LoRa parameter sets a different channel. At the LoRa gateway, a module adapted to the channel receives the data and uses the bus route ID assigned to the data to determine the route.

### 3.2 Time-division Multiple Access of LoRa Link

When multiple communications are performed in the same channel, data loss due to communication collision is considered. We decided to synchronize the time between buses and gateway by using the the time that is gotton at the same time by acquiring the position of the bus using the GPS. By synchronizing the time in all LoRa of the end device, setting the time frame, and controlling the transmission module and time, the communication within the same channel is possible between two devices. Figure 9 shows the time frame diagram of the TDMA-based multi-channel communication. The LoRa gateway is always active

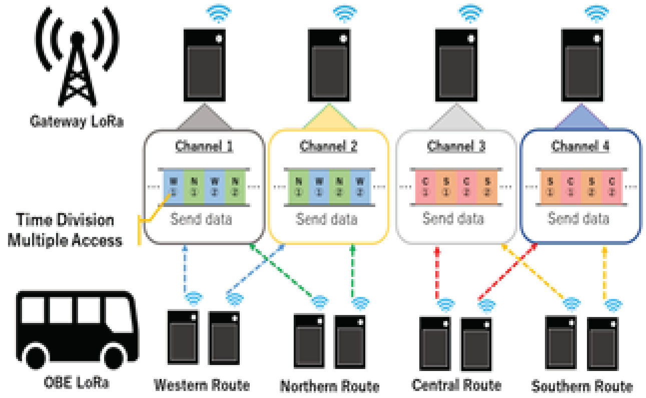



Figure 8. Channel assignment of Nonoichi nottey bus route

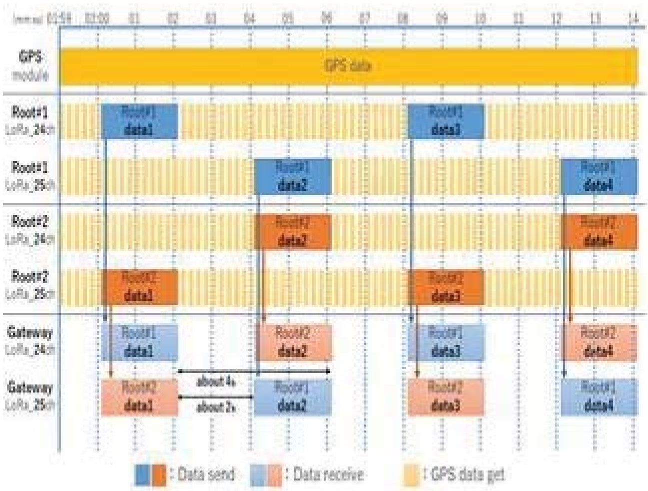
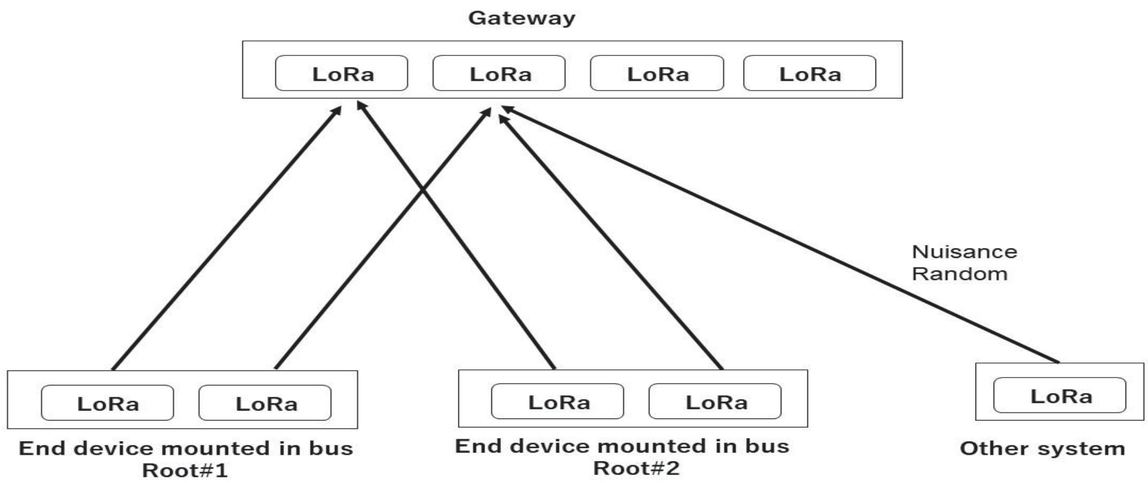



Figure 9. Multi-channel communication image

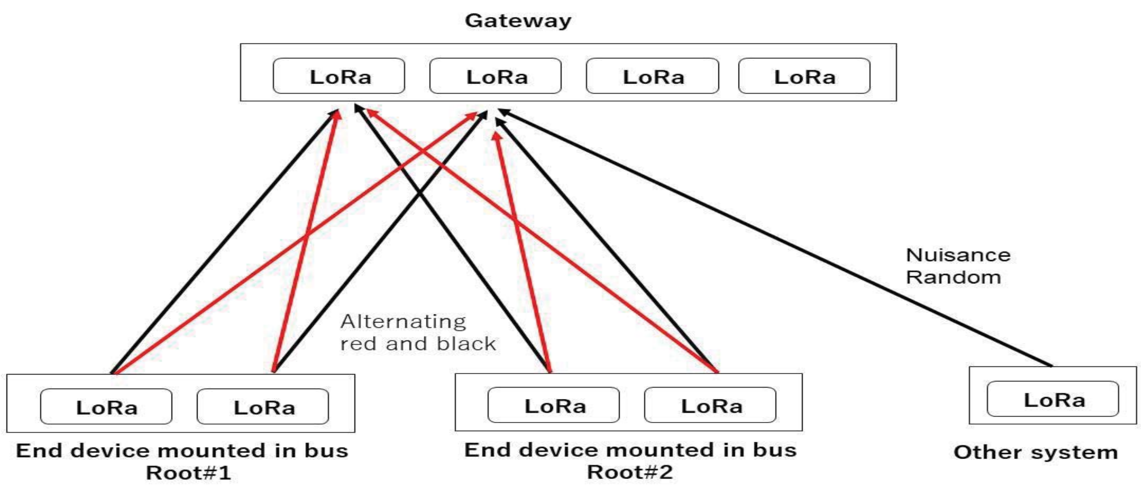
and waits for transmission from the LoRa end device. The end device synchronizes the time based on the time data obtained from GPS. The time frame starts at exactly even minutes, and the end device communicates every 4 seconds on the selected channel. By limiting the number of transmitting modules in the same time frame, one connection is established for each channel to realize TDMA.

### 3.3 Channel Hopping

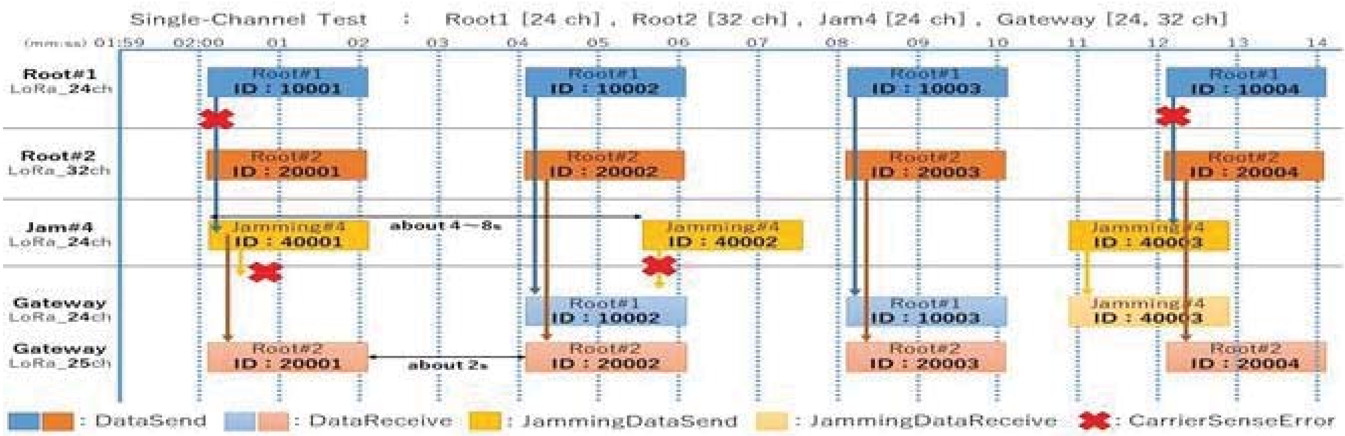
The channel used by the end device is determined using an actual observation database. The actual observation database is collected and created using a gateway data. The channel number will be updated using the time when all buses gather at Nonoichi City Hall for transfer on each bus route and stop for about 5 minutes. That is, the channel number to be transmitted is changed once an hour. This makes it possible to handle temporal channel congestion.



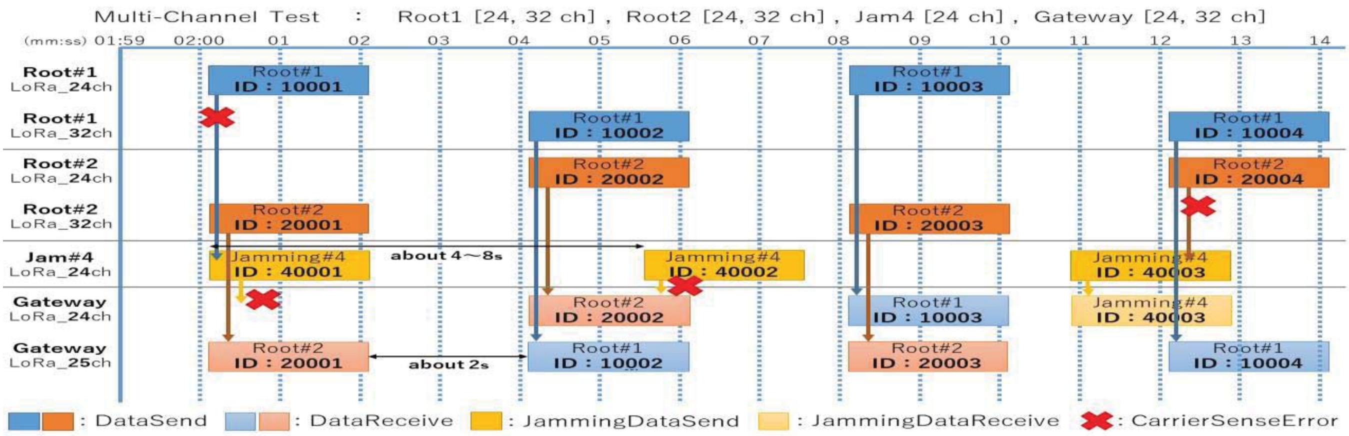

(a)State of the experiment: pattern 1




(b) State of the experiment: pattern 2




(c) Test sequence of the experiment: pattern 1




(d) Test sequence of the experiment: pattern 2

Figure 10. Test overview of with jamming and without jamming

## 4 EXPERIMENTAL RESULTS

Experiments were conducted both indoors and outside to verify the effectiveness of multichannel communication in the presence of jamming. The experimental configuration diagram is shown in Fig. 10. Figure 10(a) shows the configuration diagram of the experiment in which the end-bus equipment transmits using one channel. Figure 10(b) shows the block diagram of the experiment where the end-bus device transmits using two channels. Figure 10(c) shows the test sequence for one channel. Figure 10(d) is the test sequence for two channels. The end device sent test data for two routes using 24 and 32 channels, and the 24 channels of the jamming device sent different data at intervals of 4 to 8 seconds. The experiment was conducted indoors on one and two channels, and outside on two channels for actual use.

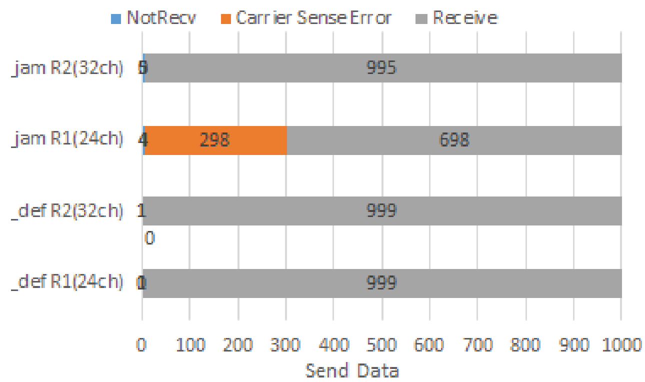
The national standard for the use of 920 MHz band is defined in ARIB STD-T 108 [12]. In BusDoko system, the parameters of LoRa are set to 24 dBm output power and no limit on the sum of transmission time in order to achieve real-time communication in the path. In this experiments, the parameters of LoRa are limited to 24 dBm output power, SF=12, and 24,32 channels used in the room. We also assume that the TDMA time frame is 4 seconds, the device of payload tendency to transmit is 5 bytes, the transmission time is 2 seconds, and the carrier sense and pause time is about 2 seconds. In the outside, LoRa parameters are limited to 24 dBm transmit power, SF=10, and 24,32 channels used. The TDMA time frame is set to 4 seconds, the device of payload tendency to transmit is set to 7 bytes, the transmission time is set to 4 seconds, and the carrier sense and pause time is set to about 4 seconds.

### 4.1 Indoor Experiments

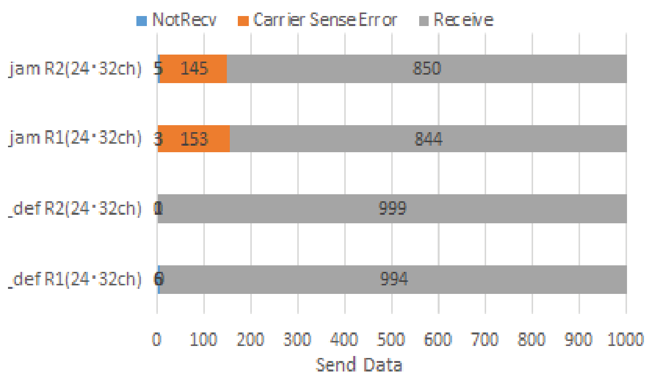
We will explain the experiment that was conducted indoors. Figure 11 shows the number of successful and unsuccessful transmissions when interference is given. Figure 11 (a) shows the result of an example using only one channel in the end device. Figure 11 (b) shows the results of an example using two channels in the end device. In the 1-channel communication, the number of carrier sense errors is biased toward route 1. In the 2-channel communication, the number of errors is successfully distributed.

Figure 12 shows the transmission time when interference is given in 1-channel communication. Figure 12 (a) shows the result without the disturbing wave, and Fig. 12 (b) shows the result with the jamming wave. Figure 13 shows the transmission time when interference is given in 2-channel communication. Figure 13 (a) shows the result without the disturbing wave, and Fig. 13 (b) shows the result with the jamming wave. From these results, it can be seen that the multi-channel system eliminates the bias of transmission errors and suppresses the variation of transmission time.

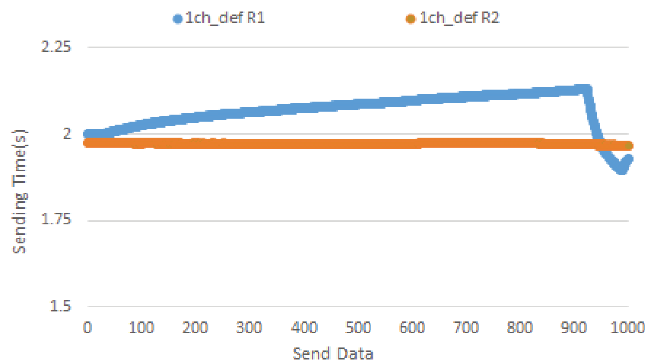
From the experiments, we checked whether data could be transmitted at an acceptable time, even in situations where other systems used the same channel as the bus-end device and had collisions. From the results, it was found that the data could be transmitted within a reasonable time and the system worked.



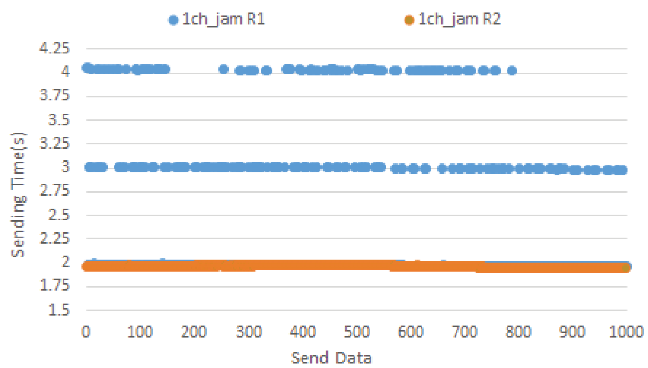

(a) Experimental results of pattern 1
(With / Without interference)



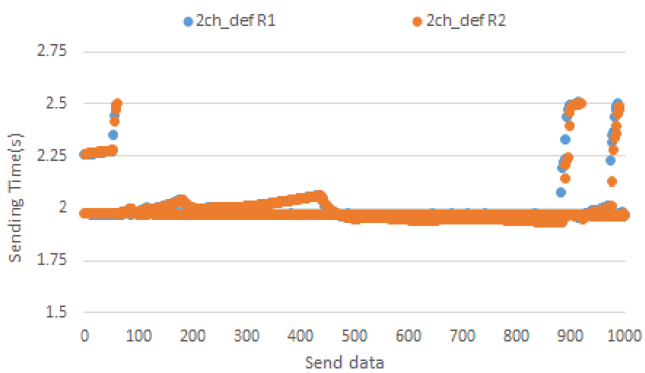

(b)Experimental results of pattern 2
(With / Without interference)
Figure 11. Transmission success/failure results



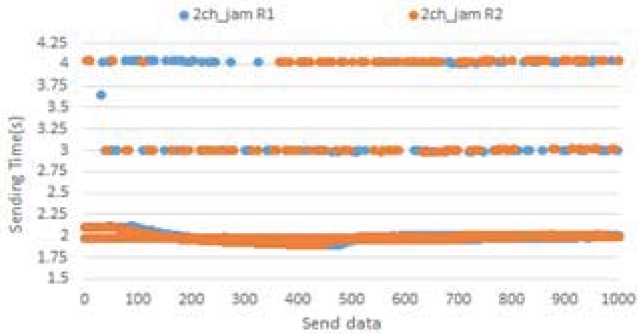

(a)Experimental results of pattern 1




(b)Experimental results of pattern 2
Figure 12. Transmission time of with jamming and without jamming




(a)Experimental results of pattern 1




(b)Experimental results of pattern 2
Figure 13. Verification experiment contents


Figure 14. Experimental route map

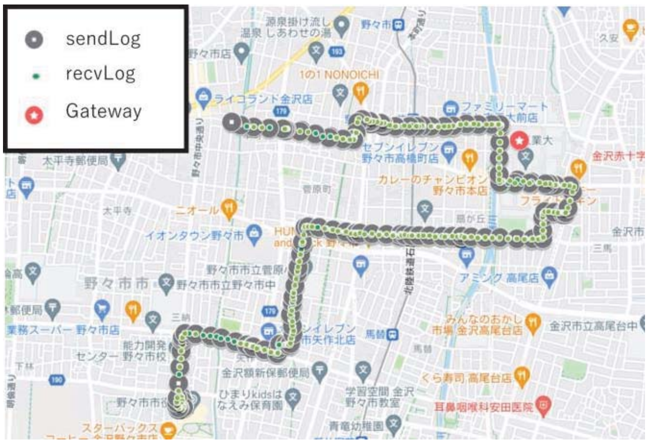
## 4.2 Outdoor Experiments

We will introduce the experiments conducted on the actual bus route. The experiment was conducted on a bus route within the range covered by the gateway installed on the roof of Kanazawa Institute of Technology, which is one of the bus routes, the north route. Figure 14 shows the entire route of the north route, the range used in this experiment, and the location of the gateway. The experiment was conducted by installing two end devices in one car. One end device is assumed to be route 1 in Fig. 10, and the other end device is assumed to be route 2. Since we assumed a different route, we installed the two devices diagonally and conducted the experiment.

LoRa parameters are limited to transmit power 24dBm, SF = 10, channels 24 and 32 used. The TDMA time frame is set to 4 seconds, the payload to send is set to 7 bytes, the send time is set to 4 seconds, and the carrier sense and pause time is set to about 4 seconds. Jamming is randomly transmitted to channel 24 every 4 to 8 seconds.

Figure 15 shows the results of the experiment with Pattern 2. Figure 15 (a) shows the result when there is jamming in pattern 2, and Fig. 15 (b) shows the result when there is no jamming in pattern 2. The gray circle in the figure is the transmission location, the green dot. Indicates where the transmitted data could be retrieved at the gateway. And the red circle is the gateway. You can see that the transmitted point and the received data are in the same place in both Fig. 15 (a) and Fig. 15 (b). Therefore, you can see that the data has been received properly. Also, comparing Fig. 15 (a) and


(a)Experimental results with jamming of pattern 2




(b)Experimental results without jamming of pattern 2

Figure 15. Results of communication experiments in the outside

Fig. 15 (b), the results are almost the same. In other words, it can be said that our system is robust in terms of communication performance. It meets the system requirements for achieving QoS even under the condition that noise is inserted at intervals of 4 to 8 seconds.

Figure 16 shows the results of the transmission success rate conducted in Pattern 2. It shows the number of successful and unsuccessful transmissions with and without interference. In Fig. 16, the top two are the experimental results without jamming radio waves, and the bottom two are the experimental results with jamming radio waves. R1 indicates route 1 and R2 indicates route 2. In this experiment, the jamming signal was generated on channel 24. Therefore, you can see that a carrier sense error has occurred on 24 channels. In the example with jamming waves, one carrier sense error occurred in R1 and four carrier sense errors occurred in R2. However, it can be seen that it operates without major errors even in a harsh environment where disturbing waves are randomly emitted at intervals of 4 to 8 seconds. From these results, the effectiveness of this system was shown.

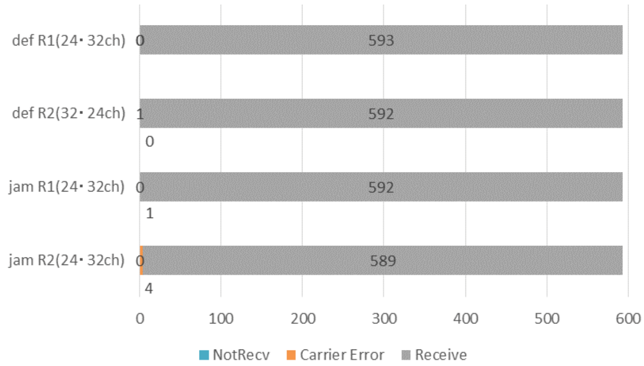
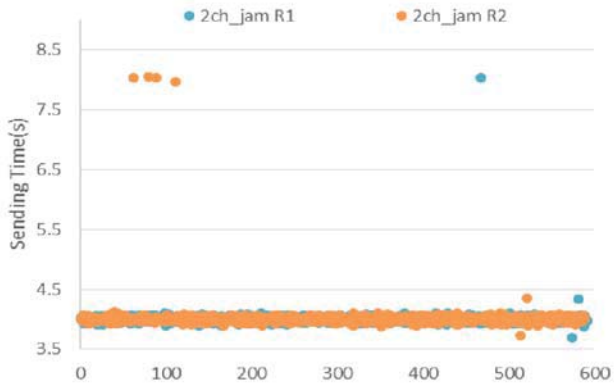
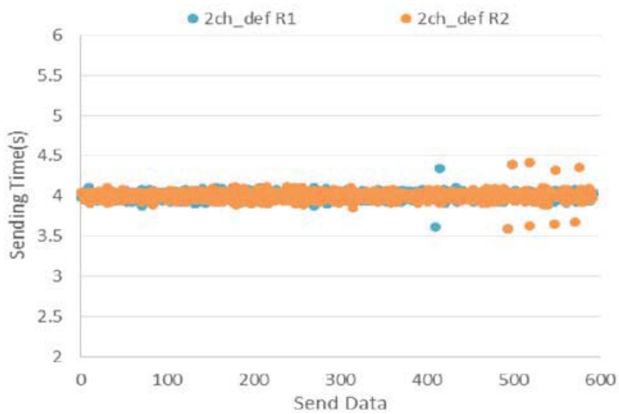



Figure 16. Transmission success/failure results of pattern 2




(a) Experimental results with jamming of pattern 2




(b) Experimental results without jamming of pattern 2

Figure 17. Transmission time when jamming in the outside

| Bus stop name - Bus stop name | No Jamming | Jamming |
|---|---|---|
| Nonoichi City Hall-Sanno | 31 | 26 |
| Sanno - Senior Citizens Welfare Center | 26 | 19 |
| Senior Citizens Welfare Center-Yahagi | 17 | 15 |
| Yahagi - Sugawara Danchi | 28 | 17 |
| Sugawara Danchi - Sugawara Elementary School | 13 | 13 |
| Sugawara Elementary School-Sugawara | 31 | 33 |
| Sugawara-Sumiyoshi | 11 | 10 |
| Sumiyoshi-Sumiyoshi Park | 20 | 16 |
| Sumiyoshi Park -Ougigaoka | 37 | 28 |
| Ogigaoka-Ougigaoka Higashi | 26 | 28 |
| Ougigaoka Higashi - Kanazawa Institute of Technology Higashi | 28 | 24 |
| Kanazawa Institute of Technology Higashi - Kanazawa Institute of Technology | 24 | 24 |
| Kanazawa Institute of Technology -Takahashi | 36 | 39 |
| Takahashi - Koudai mae Station | 29 | 26 |
| Koudai mae Station - Camino | 27 | 29 |
| Cammino-Kita Family Residence | 19 | 7 |
| Kita Family Residence-Honmachi 4 chome | 10 | 11 |

Figure 18. Number of times received between bus stops

Figure 17 shows the result of the transmission time in pattern 2. Figure 17 (a) shows the result with the disturbing wave, and Fig. 17 (b) shows the result without the jamming wave. If there is a carrier sense error, the transmission time will be longer because the carrier sense is repeated. It can be seen that the transmission time may increase in the presence of the interference wave shown in Fig. 17 (a). However, this result shows that the ratio is small and the increase in transmission time is within the allowable time. From this result, it was confirmed that even if another system is using the same channel as the bus end device and a collision occurs, data can be transmitted within an acceptable time. It took less than 1 second from the time when the bus location information was obtained at the gateway until it was displayed on the WEB page. Figure 18 shows the number of times bus location information was successfully sent to the gateway between bus stops. The probability of successful location data transmission at least once between bus stops was 100% with jamming.

## 5 CONCLUSION

We are working on the development of a bus operation management system using LoRa. In recent years, there are many users in the 920MHz band, and stable system operation has become difficult. Therefore, in this paper, we have examined a method that enables stable communication even under such circumstances. In order to improve the accuracy of the system, we have created a method for multi-channel LoRa communication using TDMA for the bus location system. We also created the channel hopping method. This makes it possible to handle changes in the communication environment over time.  We have confirmed the effect as a result of experiments in the room and the outdoor, so we explained the details. And we reported on the successful operation of the communication system and its effectiveness against communication interference. By adopting the proposed method, we were able to improve QoS. It is predicted that the number and density of wireless ad hoc networks in the 920MHz band will continue to increase in the future. We plan to study a stronger communication method.

## ACKNOWLEDGMENTS

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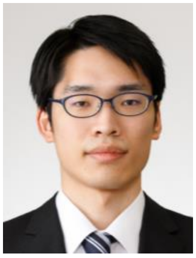

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