Water Level Monitoring System based on 429MHz LoRa with Packet Level Index Modulation

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***Abstract*—Monitoring of water levels for river monitoring is an effective disaster prevention measure. Low Power Wide Area Networks (LPWAN) can be applied to realize remote monitoring. The sensor network deployment in the 429 MHz band LPWAN is promising because of its long propagation distance and excellent radio wave diffractivity. However, the transmission bandwidth is extremely narrow, making it difficult to aggregate environmental information such as temperature and humidity other than water level. Packet Level Index Modulation (PLIM) uses the transmission time and channel number as an index of transmitted information. Since no change in packet format is required, additional information can be transmitted in compliance with wireless standards. However, LoRa, one of the LPWANs, is a competitive access environment. Therefore, when PLIM and access control are implemented simultaneously, there is a concern that accidental packet collisions may result in missing information. In this paper, we conducted a social demonstration using actual water level monitoring in a wireless sensor network applying PLIM to a 429 MHz band LPWAN, and verified the effectiveness of information aggregation in actual use.**

***Index Terms*—LPWAN,429MHzLoRa**

I. Introduction

In recent years, there has been a growing concern that global warming may lead to a rapid rise in water levels in rivers and other bodies of water, resulting in disasters as a result of concentrated heavy rainfall in a short period of time. Therefore, there is a need to realize a sensor network for remote and constant monitoring of water levels in rivers and streams [1].Low Power Wide Area Networks (LPWAN) are attracting attention as a wireless sensor network (WSN) to realize remote water level monitoring [2].Among LPWANs, Long Range (LoRa), which does not require a license and allows autonomous installation of wireless devices, is a promising wireless sensor network that can be deployed at an early stage [3].

In Japan, the 920 MHz band has been allocated for LoRa [4].However, the 920 MHz band LoRa has poor diffractive properties, and it is difficult to collect stable information due to disconnections caused by shielding by buildings and vegetation. Therefore, a stable information collection method using LoRa in the 429 MHz band is being considered [5].However, the bandwidth is narrow and limited to secure multiple channels in a low frequency band, and multiple types of sensor information cannot be transmitted.

The authors have previously studied packet level index modulation (PLIM), which transmits information in addition to the packet payload by switching the frequency channel number and transmission time timing of the transmitted packet in response to the information to be transmitted [6].The implementation of PLIM in the 429 MHz band will make it possible to transmit multiple types of information simultaneously, since LoRa is a competitive access environment where multiple sensors use the same channel competitively. Therefore, when PLIM switches the timing and frequency of packet transmission according to sensor information, packet collisions caused by simultaneous access by multiple sensors and transmission failure due to carrier sense may cause throughput degradation [7].

In this study, a remote water level monitoring system was constructed using LoRa in the 429 MHz band as the wireless infrastructure, and the amount of water level was notified by PLIM. The system consists of a monitoring terminal that observes water level, temperature, and humidity, and a central station that aggregates the observation results. For wireless transmission from the monitoring terminal to the aggregation station, PLIM, which switches the frequency channel and transmission time timing of the modulation signal according to the transmission information, was implemented, along with modulation signals based on the LoRa standard in the 429 MHz band. In this system, three types of information (water level, temperature, and humidity) are transmitted using LoRa standard modulation signals, while water level information is transmitted using PLIM. The accuracy of information aggregation is evaluated by transmitting the water level by dual modulation signals and PLIM. The system will be installed in actual rivers and lakes to monitor the water levels at all times, and the aggregation performance of the actually observed water levels using PLIM will be clarified. As a result of the evaluation of the actual equipment, it was clarified that stable information aggregation can be achieved in the 429 MHz band and in terms of radio propagation performance. In addition, although PLIM switches access according to the water level, packet collision could be effectively avoided by improving the transmission method. We quantitatively clarify the effectiveness of packet collision avoidance.

II. Outline of this System

The constructed water level monitoring system consists of a monitoring terminal that wirelessly transmits the amount of water level, temperature, and humidity observed by sensors, and a central station that aggregates the information transmitted wirelessly. In the wireless transmission, the amount of water level, temperature, and humidity are transmitted simultaneously using PLIM. This section describes the outline of PLIM, the constructed monitoring terminal, and the configuration of the aggregation station.

As shown in Figure 1, PLIM forms an index with multiple frequency channels and time slots, and transmits data by dividing the transmitted data into indices. In doing so, the index is selected on a packet-by-packet basis, allowing PLIM to transmit additional information while maintaining radio transmission in compliance with the LoRa standard. For the assignment of indexes and transmitted data, a mapping, which is a table that maps information and indexes in advance, is formed and held by both the transmitter and receiver.

In PLIM, if multiple sensors access the same index, packet collisions occur and data is missing. Thus, there is a depen-

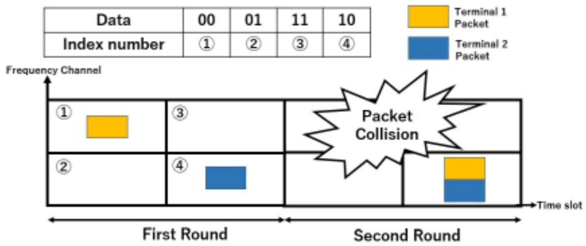

Fig. 1. PLIM Image

dency between missing data and transmitted data. Therefore, methods to suppress missing data by improving the mapping, which is the correspondence between information and indexes, have been considered [7].

In this study, we clarify the aggregation performance by PLIM in actual water level monitoring and the effect of packet collision caused by sending the same index.

This system can selectively send one of three types of information to be sent by PLIM: water level, temperature, and humidity. However, in this verification experiment, the water level is transmitted by PLIM. In addition, 120 indices are formed by combining 4 channels and 30 different time slots in PLIM. And each of the 100 PLIM mapping tables can be recorded in memory, and each terminal can specify one mapping table.

A. Monitoring Terminal Configuration

Figures 3 show the interior and configuration of the monitoring terminal used in this system.

The monitoring terminal consists of a sensor for water level measurement, a temperature/humidity sensor, a microcontroller for LoRa modulation and demodulation processing, and an integrated transmitter/receiver antenna (SLR-BAR by Circuit Design), and is powered by four single dry cell batteries.

In this demonstration, two types of transmitter/receiver antennas with different antenna gains were prepared, as shown in Figure 2. One antenna is about twice larger than the other to achieve a high antenna gain.

The water level sensor is a cable-shaped sensor with a diameter of about 27 mm, a length of about 107 mm, and a length of 6 m. The sensor body is submerged in the water. The sensor is submerged in water and measures the water level from the water pressure. The temperature and humidity sensor measures the outdoor air temperature and humidity around the terminal.

B. Aggregation Station

The inside view of the control equipment of the aggregation station and its configuration are shown in Figures 4. The aggregation station consists of four SLR-BARs, a processing board for PLIM demodulation, and a microcontroller for data transfer. Therefore, by using four SLR-BARs, information on four channels is received simultaneously.

When a packet is received by the SLR-BAR, the ID of the monitoring terminal that is the source of transmission in the header of the packet and the data in the payload are set and notified to the processing board. The processing board identifies the channel number from the SLR-BAR that notified the data, using the fact that each SLR-BAR corresponds to a receiving channel. It then obtains the data arrival time.

Fig. 2. Monitoring Terminal Antenna

Fig. 3. Inside Monitoring Terminal

This obtains the index information of the channel number and access time in PLIM. Then, from the ID information of the monitoring terminal in the header, the mapping table for PLIM used by the monitoring terminal is identified, and the amount of water level, which is sensor information, is obtained from the received index. information obtained by PLIM and the information in the payload and header of the packet. The information obtained by PLIM, the transmitted data (water level, temperature, and humidity), and the ID of the monitoring terminal are converted to ASCII comma-delimited data as a set and sent to the microcontroller for data transfer.

The data transmission microcontroller has two functions: control of the processing board and data aggregation. The data aggregation process transfers ASCII comma-delimited data notified by the processing board to a cloud server on the Internet. In this case, the microcontroller is connected to the Internet via a wired connection using an Ethernet cable for data transfer.

The cloud server saves the file sent from the microcontroller for data transfer as a csv file, and as a graphical interface, the live status can be checked by a web browser, as shown in Figure 5.

On the other hand, the second function of the micro-

Fig. 4. Inside the control equipment of the aggregation station

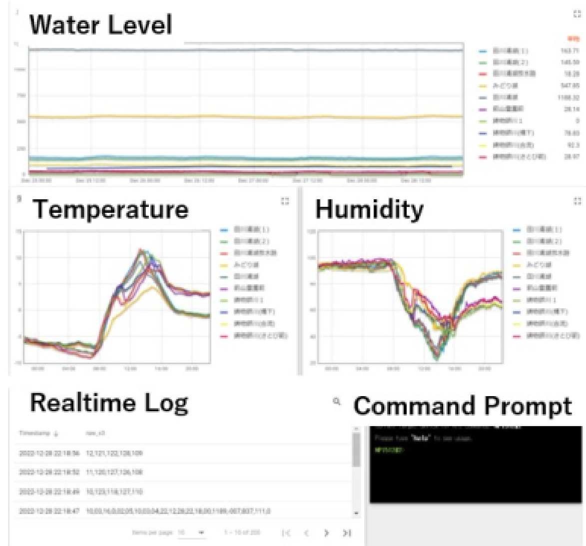

Fig. 5. Server

controller for data transfer is the control function of the constructed wireless sensor network. Specifically, each sensor can switch the transmission cycle of data packets and the mapping table of PLIM for each monitoring terminal. It is possible to control the wireless sensor network remotely, as instructions can be given by command input from the cloud server. Specifically, when a command to switch the transmission cycle or table is notified at the command prompt, the command is notified to the data transfer microcontroller at the aggregation station. The data transfer microcontroller then converts the commands for the transmission cycle and mapping table to the specified format and notifies them to the processing board that performs PLIM demodulation, etc. The aggregation station has a notification function that notifies data to all monitoring terminals at regular intervals, and this can be used to notify all terminals of the transmission cycle for notifying specified packets and the commands that indicate the PLIM mapping table.

C. PLIM frame of this system

An image of the PLIM frame of this system is shown in Figure 6. Communication is completed in one frame, and the length of the frame is 120 seconds.

The image of a slot during data transmission is shown in Figure 7. First, the center sends the same packet (center packet) twice to the transmitting terminal. These are sent to set the time and transmission CH. Then, 30 slots of 3.5 seconds each are communicated from the sending terminal to the center. After that, a rescue packet is sent once on the default frequency to rescue a terminal that is out of synchronization. The content of the relief packet is the same as the center packet.

D. Terminal startup

1) Time synchronization: Immediately after startup, the transmitting terminal does not transmit data until it synchronizes its time. Since the center packet sent from the center contains the time, the transmitting terminal receives the packet and performs time synchronization.

If the transmitting terminal fails to receive 15 consecutive center packets during normal operation (30 minutes), the transmitting terminal starts synchronization from the startup state.

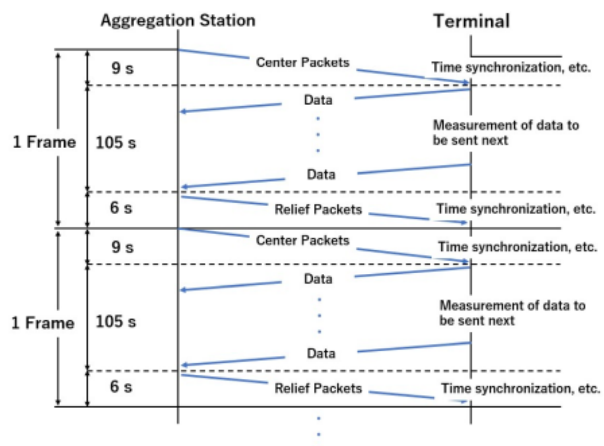

Fig. 6. Flame of PLIM

2) CH Setting:

1) When activated, the sending terminal starts receiving at the system's default communication CH1.
2) If the center's packets cannot be received after 2 minutes at CH1, it switches to CH2.
3) (2) Similarly, if reception is still not possible after switching CHs up to CH4, the system scans CHs at 2-minute intervals thereafter until a packet is received.

E. Packet Composition

1) Packets from sending terminal to center: The contents of the packet from the transmitting terminal to the center are shown in Table III.

A 19-byte transmission requires approximately 2.8 seconds (actual measurement 2.711 seconds), but in consideration of the time lag of the transmitting terminal, we allow a margin of 200 milliseconds until the next slot, so that each slot should be at least 3.0 seconds.

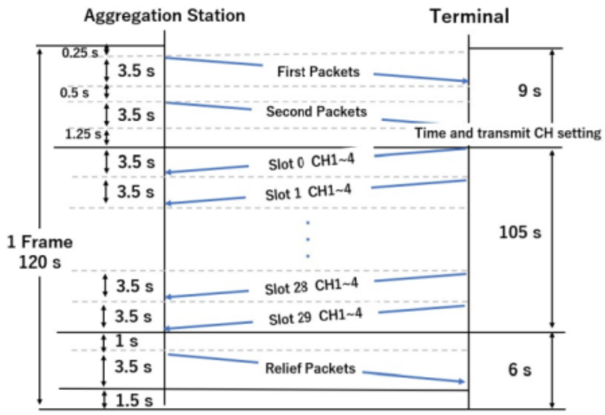

Fig. 7. Slot of PLIM

TABLE I
PACKETS FROM SENDING TERMINAL TO AGGREGATION STATION

Item	Bytes	Details
Source Type/Transmission Interval	1	Source to determine CH and slot (0x: water level 20mm/1x: temperature 2x: humidity/3x: water level 5mm 4x: random water level/5x: random temperature 6x: random humidity/7x: random water level 5mm), Transmission Interval(x1∼xF)
Terminal ID	1	Each terminal-specific value from 1 to F (max. 15 terminals)
Logical CH/Physical CH	1	Bit6,7:Logical CH Bit0∼5:Physical CH
Transmission slot	1	Slot number 0∼29(binary)
Table ID	1	Table ID used for transmission
Year when data was measured	1	Last two digits of the year(BCD)
Month when data was measured	1	1∼12(BCD)
Day when data was measured	1	1∼31(BCD)
Hour when data was measured	1	00∼23(BCD)
Minite when data was measured	1	00∼59(BCD)
Second when data was measured	1	00∼59(BCD)
Water Level	1	0∼5000mm (binary)
Temperature	1	-999∼+999(-99.9 ℃∼+99.9 ℃) (binary)
Humidity	1	0∼999(0∼99.9 %) (binary)
RSSI when received by aggregation station	1	0∼255(0∼-255dBm) (binary)
Error Code	1	x1:Water level error/x2:Temperature/Humidity sensor error x4:SD card error/x8:RTC error
Total bytes	19	

2) Packets from the center to the sending terminal: The contents of the packets from the center to the sending terminal are shown in Table II.

30-byte transmission requires about 3.4 seconds (actual measurement 3.379 seconds), but considering the time lag of the sending terminal, a margin of 100 milliseconds is assumed to be 3.5 seconds.

III. Environment of this Experiment

A. Monitoring Terminal Location

The monitoring terminals were located as shown in Figure 8 and 9. The numbers depicted in the figures represent the terminal numbers.

The locations are in Nagano City, Nagano Prefecture, Japan. One of the monitoring terminals is located at Midori-ko, which is about 5 km away from Shiojiri Incubation Plaza (SIP) where the aggregation station is located. 5 monitoring terminals were placed around the lake. It is about 2 km away from the SIP where the aggregation station is located.

The monitoring terminals are shown in Fig.. As shown in Figure2, SLR-BAR (diameter: 37 mm, length: 585 mm) was used at Midori-ko and ANT-400 (diameter: 21 mm (tip: 11 mm), length: 185 mm) was used in Shiojiri city. Prior to determining the observation sites, a communication test was conducted, and ANT-400 was able to detect the required signal power for demodulation along the Castomogawa River,

TABLE II
PACKETS FROM THE CENTER TO THE SENDING TERMINAL

Item	Bytes	Details
Year	1	Last two digits of the year 00∼99(binary)
Month	1	1∼12(binary)
Day	1	1∼31(binary)
Hour	1	00∼23(binary)
Minite	1	00∼59(binary)
Second	1	00∼59(binary)
Table ID	10	Transmission table IDs for sending terminals 1 to 10 Table IDs used for the next transmission (binary) The range of IDs that can be specified is 0 to 100
Source Type/Transmission Interval	1	Source to determine CH and slot (0x: water level 20mm/1x: temperature 2x: humidity/3x: water level 5mm 4x: random water level/5x: random temperature 6x: random humidity/7x: random water level 5mm), Transmission Interval(x1∼xF)
Total bytes	30	

Fig. 8. Monitoring Terminal Location (Midori-ko))

and communication was successful; however, the required signal power for demodulation could be detected along the Castomogawa River around Midori-ko Lake, and the required signal power for demodulation could be detected along the Castomogawa River and around Midori-ko Lake when SLR-BAR was used. In the case of using SLR-BAR, the required signal power was detected and communication was successful both in the area around Lake Midoriko and along the Castoji River. Therefore, the antennas used in Shiojiri City and Midori-ko are separated.

B. Location of Aggregation Stations

The aggregation station is located on the roof of the SIP (Figure 10). As shown in Figure 10, there are eight SLR-BARs (four each for transmitting, receiving, and communicating) on the fence, and a control device (Figure 2) in the middle of the fence, from which data is stored on a server on the Internet. The data is stored on a server on the Internet. Now, each of the four antennas for transmitting and receiving can access a different channel, so four channels are used as the index for PLIM.

IV. Comparison with 920MHz band LoRa

Communication experiments using 920MHz band LoRa were conducted between the center and monitoring terminals in Shiojiri City, and at the location where the monitoring terminals were installed in Midori-ko. The results are shown in Figure 11. In Shiojiri City, communication was possible up to a point slightly more than 1 km from the center, but not at the location where the monitoring terminals were installed. In Midori-ko, communication was also impossible

Fig. 9. Monitoring terminal location (Imoji River)

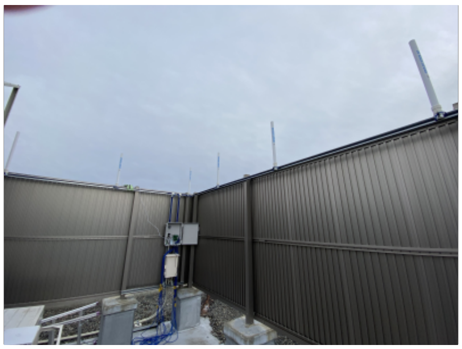

Fig. 10. View of the centralized station on the SIP rooftop

at the location where the monitoring terminals were installed. On the other hand, although the measurement results for the 429MHz band are omitted, the system confirmed a stable aggregation. Therefore, from the viewpoint of the superior long-range propagation and diffraction performance of LoRa in the 429MHz band, LoRa in the 429MHz band is considered suitable for this remote monitoring.

V. Actual Equipment Evaluation Results

The data from the monitoring terminal installed at Midori-ko has been obtained stably up to the present, although this is omitted in this report.

The data aggregation rate of the Casting River immediately after the start of operation is shown in Figure 12, where the number of data per unit time is known when all data are received since the system is set to transmit data every 2 minutes. Therefore, the aggregation rate is defined as the number of data actually received divided by the number of data per unit time.

Figure 12 shows that the missing data for monitoring terminal 8 is larger than the other terminals.

Therefore, we analyzed the causes of the low aggregation rate of monitoring terminal No.8. Possible causes are as follows.

1) The signal is stopped due to carrier sense.
2) Poor communication environment at the location where the terminal is installed.
3) Packet collision occurred and data is missing.

First, the signal is stopped due to carrier sense. The terminal is supposed to leave an error code in the packet when something goes wrong with the operation. Therefore, the information on

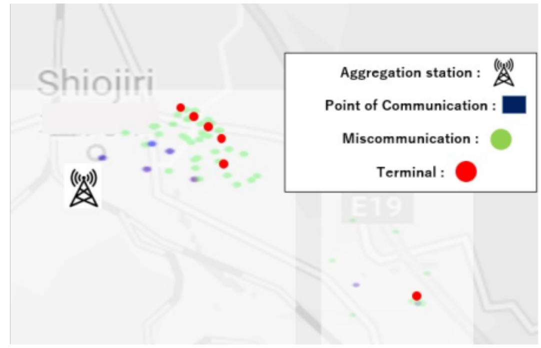

Fig. 11. 920MHz band LoRa communication experiment results

TABLE III
Diffusion Coefficient of 429 MHz band LoRa and 920 MHz band LoRa

	429MHz LoRa	920MHz LoRa
SF	7	7

the SD card in the terminal should indicate that there is no signal. However, since no error was recorded, it did not appear that the signal was stopped by carrier sense.

Next, let us discuss the possibility that the communication environment at the location where the terminals were installed was poor. In discussing the communication environment, we will discuss it together with monitoring terminal No.9, which is located near monitoring terminal No.8.

Figure 13 shows a comparison of the RSSI of monitoring terminals 8 and 9. Since both terminals have similar values and the aggregation rate of monitoring terminal 9 is not low, it cannot be said that the installation environment of monitoring terminal 8 is poor.

Finally, there is the possibility of missing data due to packet collisions. As mentioned above, monitoring terminal No.9 is located near monitoring terminal No.8, and there should be similarities in the environment (water level in this case); it is thought that packet collisions occur when information is sent using the same index when transmitted by PLIM.

Therefore, based on the expectation that the observed data (water level) of monitoring terminals No.8 and No.9 are similar, we changed the setting to one in which monitoring terminal No.8 sends random data. We checked the aggregation rate and found that the aggregation rate was improved compared to the previous system.

Furthermore, the mapping tables that had been set for monitoring terminals No.8 and No.9 were changed to different tables, and the settings were changed to send observation data. The conventional mapping tables were numbered in ascending order, but the new mapping tables are numbered randomly. This allows the same or close indexes to be selected, but the data are expected to be transmitted at different times in terms of frequency channels and time slots.

The aggregation rate was checked, and the aggregation rate was improved compared to the conventional method.

Figure 14 shows the change in the aggregation rate of monitoring terminal No.8 with the above changes, and table IV shows the change in aggregation rate expressed numerically.

From the above, it was found that the reason for the low aggregation rate of monitoring terminal 8 was due to packet collisions.

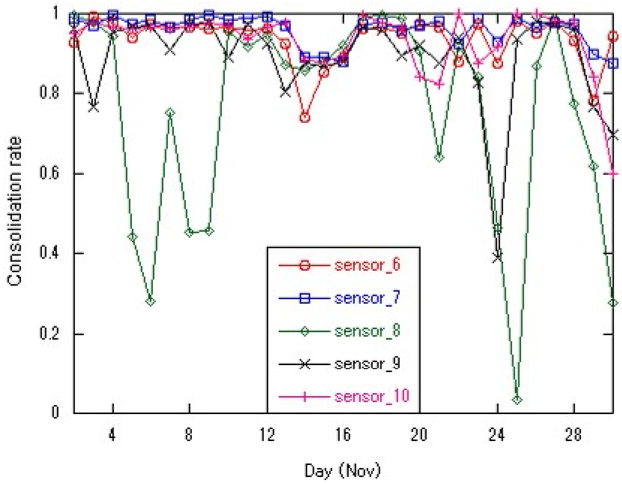

Fig. 12. Consolidation rate

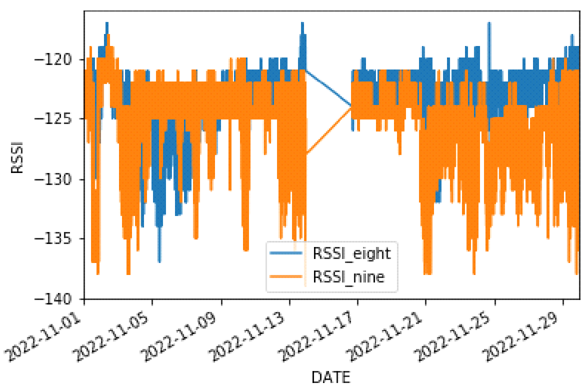

Fig. 13. RSSI comparison between terminal No.8 and No.9

VI. Summary

We installed a water level monitoring system in a river in Shiojiri City, Nagano Prefecture, and started a demonstration experiment, and introduced a description of the flow of this system.

Immediately after the start of the experiment, we analyzed the causes of monitoring terminals with low aggregation rates and improved the aggregation rate.

In addition, we are currently improving the aggregation frequency, and this time, using the aggregated data from the winter season, we conducted a simulation to dynamically change the transmission interval considering the difference between data and found that it is possible to reduce the frequency of transmission.

As a future prospect, we would like to conduct similar simulations using data from the summer season, when environmental changes are large. In addition, we would like to determine whether the reduced frequency of aggregation complements the data that has been removed, and to be able to determine the frequency of aggregation on a given day by using the correlation of the previous day's data.

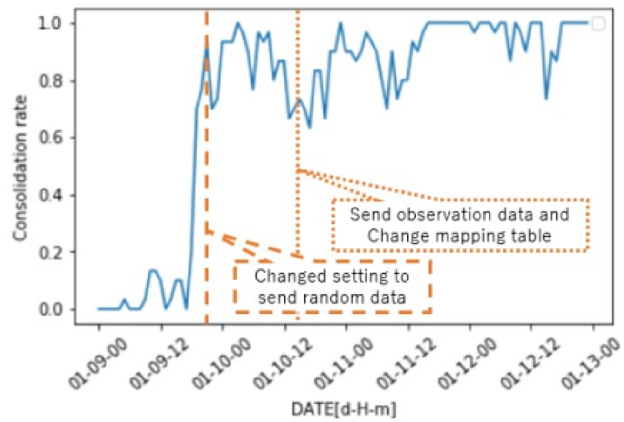

Fig. 14. After table change for terminal No.8

TABLE IV
CHANGE IN AGGREGATION RATE OF MONITORING TERMINAL NO.8 WHEN MAPPING TABLE IS CHANGED

Date-Time	Consolidation rate
1/9 14:00	0.033
1/9 15:00	0.1
1/9 16:00	0.1
1/9 17:00	0.0
1/9 18:00	0.2
1/9 19:00	0.7
1/9 20:00	0.766
1/9 21:00	0.933
1/9 22:00	0.7
1/9 23:00	0.733
1/10 00:00	0.933

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