Performance Measuring Test Results of 920MHz Band Wireless Sensor Network in Buried Condition

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***Abstract*— Increasing number of aging structures and damage caused by natural disasters are major issues in railways. It is difficult to instantly detect the deterioration and damage of structures in normal inspection cycles, hence, studies of the condition monitoring system for railway facilities have been developed to grasp these conditions frequently. Most of condition monitoring systems for railway structures in recent years consist of Wireless Sensor Networks (WSN). To design a WSN, it is necessary to grasp the characteristics of the frequency for the railway environment. In our research, the 920 MHz band of radio wave frequency, which was released as Industry Science and Medical (ISM) band since 2012 in Japan, was focused. Also, as an example of condition monitoring for railway structures, the WSN for railway embankment was selected. We considered the case where the sensor was buried underground and the case of rain as factors affecting wireless transmission and confirmed that the signal strength of 920 MHz radio waves were attenuated in these cases.**

Keywords- Wireless Sensor Network; 920MHz; Railway; Buried Condition.

I. INTRODUCTION

Railways in Japan are excellent transport infrastructure with mass, high speed, safety features, therefore, it plays an important role in passenger and freight transport [1]. However, the number of aging structures is increasing since many of the railway structures were built before the 1970s. Furthermore, railway structures have been severely damaged due to many natural disasters in recent years [2]. Hence, it is required to properly maintain railway structures. On the other hand, in Japan, the aging of workers and the decline of the working population have become serious issues. Under these circumstances, it is an urgent issue to efficiently maintain the increasing aging structures and to take disaster prevention.

At present, maintenance of railway structures is carried out by inspection and soundness evaluation every 2 years, and repair or replacement is performed as necessary [1]. However, a lot of manpower is required in normal inspection since a visual inspection is performed. Hence, it is desirable to develop a method that can efficiently maintain and manage many structures. Additionally, there is a growing need for technology that can quickly grasp the situation in the field when a natural disaster occurs. One of the methods for realizing these requirements is condition monitoring using a WSN. Figure 1 shows an example of WSN [3]. There are various choices for the frequency band of radio waves used for WSN. Among them, the 920 MHz band which is newly released in Japan as an ISM band since 2012, is especially attracting attention. Therefore, research and development of WSN using the 920MHz band has been

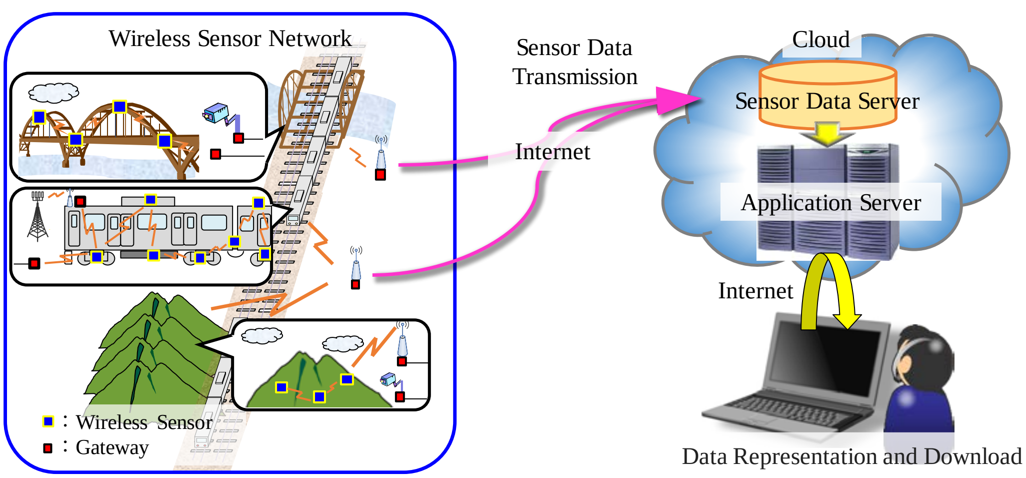

Figure 1. An example of the condition monitoring system using the WSN (adapted from [3])

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actively conducted in recent years [3]-[8].

The 920 MHz band can be used without a license when the transmission power is 20mW or less, which corresponds to the 860 MHz band in Europe. Compared with the 429 MHz band which has been used conventionally for a WSN, the 920 MHz band has a high transmission rate and can perform large-scale multi-hop transmission. Similarly, compared with the 2.45 GHz band, it has a longer transmission distance and radio waves are easily diffracted. Therefore, it is expected to be one of the effective frequency bands for use in a railway environment which is spread linearly and has a large number of various facilities [4].

However, in order to receive the desired data stably with WSN in the railway, it is necessary to design an appropriate WSN in consideration of the various railway-specific environment [5][6]. In general WSN design, the transmitter is installed at a high position to improve the radio wave propagation environment [7][8]. On the other hand, in railways, the safe operation of trains is the top priority, so transmitters can't be installed in free places. For example, when constructing a WSN for facilities on the railway slope or near track, if the transmitter is installed at a high position, it may fall and interfere with train operation when a disaster occurs. Therefore, we must design the WSN assuming the transmitter is installed in a low position or buried in the ground.

Japanese railway structures have a high rate of embankment and cutting, and natural disasters can severely damage railway slopes. Therefore, in this study, we selected embankment monitoring as an example of a WSN for railway structures.

To build a WSN that monitors the condition of embankment, we first conducted a transmission characteristic test of the 920 MHz band with the transmitter buried in the ground. Next, based on the test results, we constructed a WSN in the railway test embankment and conducted a performance measuring test for about 1 month.

The rest of the present paper is organized as follows: Section 2 introduces related works about a WSN for slope monitoring and a transmission characteristic test for the 920MHz band. Section 3 describes the transmission characteristic test where the transmitter is buried in the ground. Section 4 describes the performance measuring test of WSN, and Section 5 describes the conclusion and future work.

II. Related Work

When constructing a WSN on the embankment, it is conceivable to early detection the slope failure by measuring the soil moisture content and the inclination angle in the embankment. As a similar existing research, there is research on sensor networks aimed at detecting slope failure [9][10]. Existing research considers data loss rate and sensor measurement values, but does not consider attenuation characteristics by the Received Signal Strength Indicator (RSSI). Also, as existing research that measured the RSSI, there is research that considers the effects of vegetation [11]. Existing research is evaluating the effects of vegetation growth on radio wave propagation based on RSSI measurement values. By measuring RSSI, it is possible to quantitatively grasp the attenuation characteristics of radio waves. In the WSN on the railway embankment that we are aiming for, not only the effects of vegetation but also the possibility of transmitting data with a transmitter buried in the ground. In addition, it may be affected by rainfall due to the outdoor environment. Therefore, in order to receive the desired data stably, it is very important to quantitatively grasp the attenuation characteristics due to the buried condition and rainfall, and improve the accuracy of WSN design.

III. Transmission Characteristic Test In Buried Condition

We conducted a test to confirm to the transmission characteristic of the 920MHz band radio wave in buried condition. This section describes the test methods and results and discussion.

A. *Test Method [5]*

In this test, we used the transmitter of Wireless Smart Utility Network (Wi-SUN), which is one of the 920 MHz band radio communication standards (Table I) [12]. Wi-SUN uses IEEE 802.15.4g, which is an extension of IEEE 802.15.4 used in the Zigbee physical layer, and because it

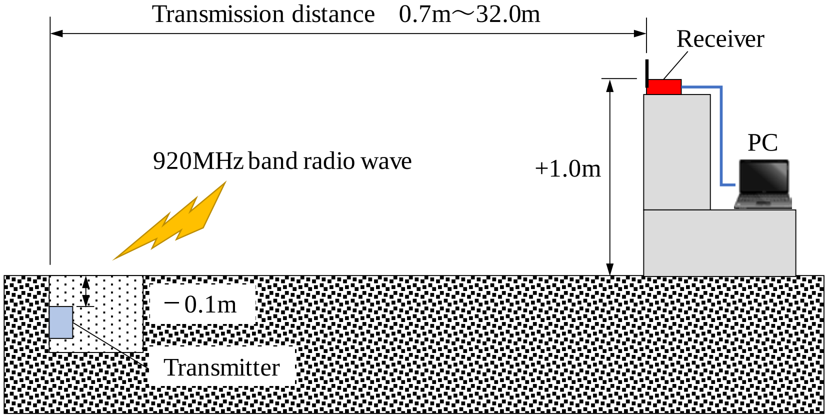


Figure 2. Test Configuration (adapted from [5])

TABLE I. Transmitter Specifications

Radio Communication Standard	Wi-SUN
Modulation Method	2GFSK
Transmission Rate	100kbps
Transmission Power	20mW

can transmit IPv6 packets, it is suitable for storing data in the cloud via a network such as Wi-Fi [4].

Figure 2 and Table II show the test configuration and test conditions. As shown in Figure 2, the transmitter was buried 0.1m below the ground and the receiver was installed 1.0m above the ground surface. First, we measured the RSSI where the transmitter was a normal condition (not buried condition). Then, we buried the transmitter in the ground and measured RSSI again. Also, dry soil was used when burying the transmitter to exclude the influence of moisture originally contained in the added soil. Evaluation of the test results was performed by comparing the RSSI in the normal condition and the buried condition. Also, when the transmission distance was 0.7m, we measured RSSI by changing the soil depth (0.05m, 0.1m, 0.15m). WSN is required to be able to easily perform maintenance such as battery replacement. For that reason, it is not realistic to buried a transmitter deep underground. Therefore, the soil depth was set on the assumption that maintenance is easy.

B. *Results and Discussion [5]*

Figure 3(a)(b) shows the test result. In Figure 3(a), the red dots are the RSSI in the normal condition, and the blue triangles are the RSSI in the buried condition, and the green squares are the Loss (difference between normal condition and buried condition). Each RSSI value is an average value of 100 transmission data. As shows Figure 3, when the transmitter is buried, it can be confirmed that radio waves are attenuated by about 20 dB regardless of the transmission distance. From the above results, we propose to consider a margin of at least about 20 dB when designing WSN with the transmitter buried 0.1m below the ground.

As shown in Figure 3(b), in this test, there was no difference in Loss when the soil depth was 0.05m and 0.1m, but when the soil depth was 0.15m, the Loss was increased by about 3dB. The loss is based on the buried condition of 0.7m transmission distance and 0.1m soil depth.

IV. Performance Measuring Test Of WSN In Buried Condition

We conducted a test to confirm to the performance of the 920MHz band WSN in buried condition. This section describes the test methods and results and discussion.

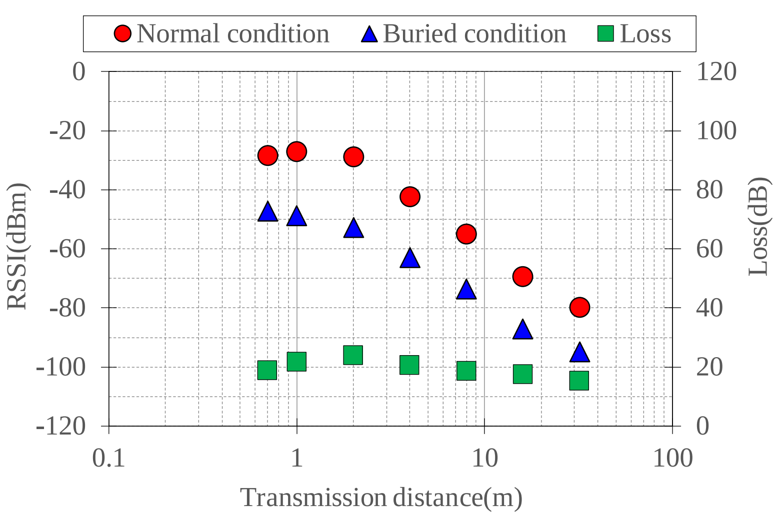
A. *Test Method*

We constructed a WSN in the test embankment based on the above test results. In railway slope condition monitoring, the sensors must be installed at various positions depending on the shape of the slope. For this reason, in this test, the sensor placement was determined assuming the condition monitoring for the railway slope. Figure 4 shows the transmitter architecture and the construction status of WSN.

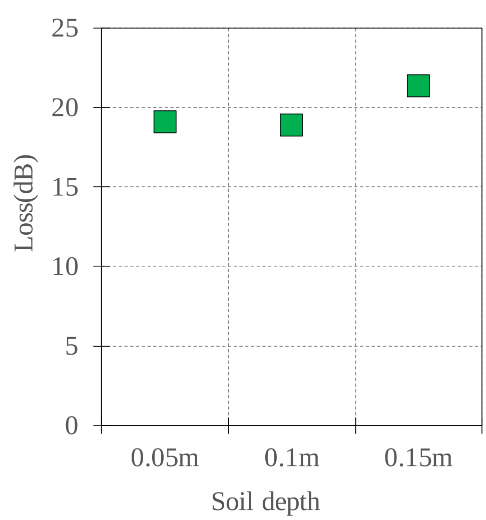
As shown in Figure 4, a chip antenna was used as the transmitter antenna, and the transmitter is powered utilizing a rechargeable battery. Also, regarding the construction status of WSN, a total of seven transmitters were installed, where four transmitters were buried 0.1m below the ground, and three transmitters were installed 1.2m above the ground. On the other hand, the receiver was installed on the second floor of the laboratory (4.5m above the ground).

TABLE II. TEST CONDITIONS (ADAPTED FROM [5])

Transmitter Height (m)	-0.1
Receiver Height (m)	1.0
Transmission Distance (m)	0.7, 1.0, 2.0, 4.0, 8.0, 16.0, 32.0



(a) Comparison of normal condition and buried condition (adapted from [5])



(b) Comparison when changing the soil depth (Transmission distance 0.7m)

Figure 3. Comparion of RSSI in buried condition

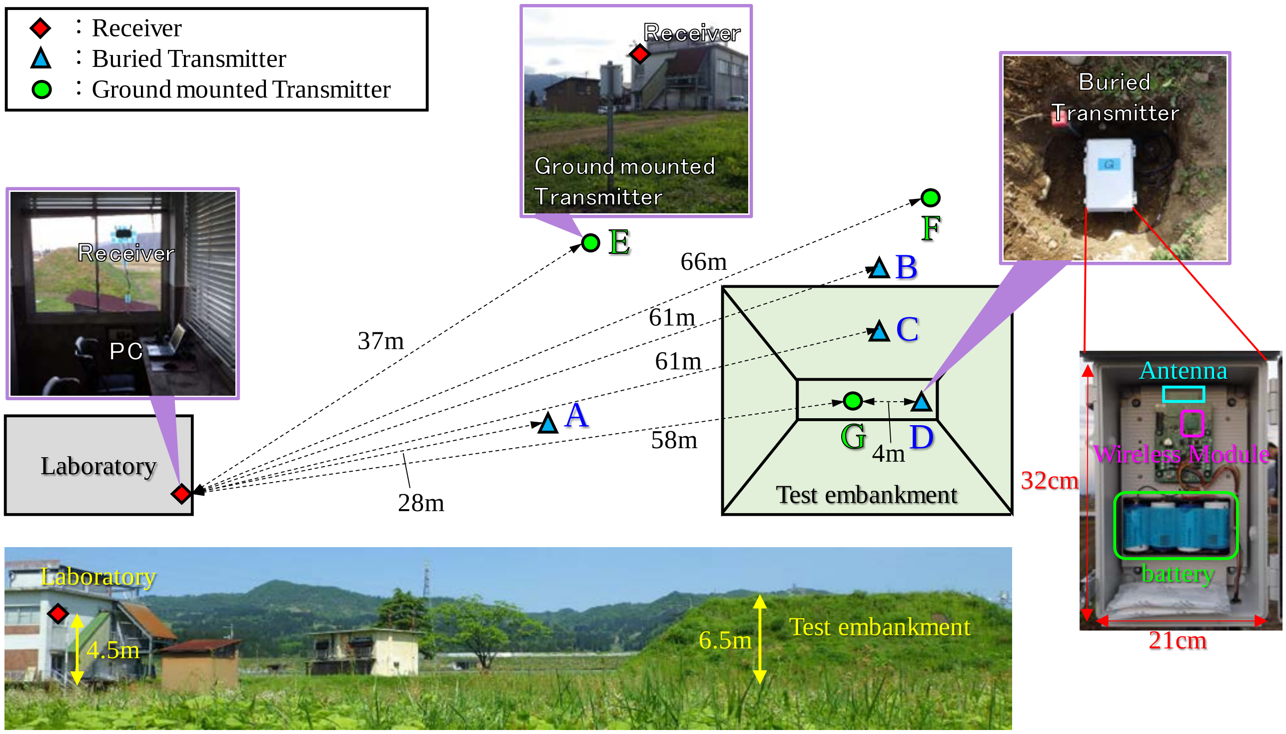


Figure 4. Construction status of WSN and transmitter archtecture (adapted from [5])

TABLE III. MEASUREMENT ITEMS AND THE MEASUREMENT/TRANSMISSION INTERVALS

Measurement Items	RSSI
	Transmission path data
	Weather data(Rainfall, Temperature)
Measurement / Transmission Interval	10 minutes

Table III shows measurement items and transmission intervals. In this test, the transmitters were improved so that transmission path data could be acquired along. If the buried transmitter can't transmit directly to the receiver, the WSN is designed to switch transmission paths and transmit data to the receiver using multi-hop transmission through the ground mounted transmitter. Then, the test for about 1 month was conducted at a data transmission interval of 10-minutes. Also, the weather data was measured by wired communication with a weather observation equipment.

In addition, in this test, the measurement interval is 10-minutes, but we consider that a measurement interval of 1 hour to 1 day is sufficient for continuous condition monitoring in a production environment [13]. When the interval of measurement and transmission is 1 hour, the battery lifetime is assumed to be about half a year.

B. Results and Discussion

This section shows the results of change over time of transmitter RSSI and 10-minutes rainfall. Also, among transmitters that are large attenuated the RSSI due to rainfall, the result of buried transmitter C are shown in Figure 5(a) and the ground mounted transmitter E are shown in Figure 5(b). Although the RSSI attenuation was some difference, similar results were obtained with other transmitters. Additionally, the color of each dot in a figure represents the communication destination, and the green dot shows communicated with the transmitter E and the red dot shows communicated with the receiver. Thereby, the transmission path of each transmitter can be grasped.

Firstly, we describe the attenuation characteristics of radio waves in rainfall. As shown in Figure 5(a), the buried transmitter confirmed that the RSSI was attenuated in conjunction with the rainfall. Furthermore, it was confirmed that it takes a certain time to recover to the normal value after the attenuation. The existing research [6] showed that the 920 MHz band radio waves became more attenuated according to the increase of moisture content of the snow on the transmission path. Therefore, it can be considered that the increase in soil moisture due to rainfall attenuates the RSSI, and influences radio wave propagation until drainage is completed. On the other hand, as shown in Figure 5(b), the ground mounted transmitter shows little fluctuation in RSSI during this test. It seems that the influence of rainfall directly on RSSI attenuation is small.

Also, regarding buried transmitter C, the relationship between rainfall and loss is shown in Figure 6 for the period in which continuous rainfall is observed. The target period is

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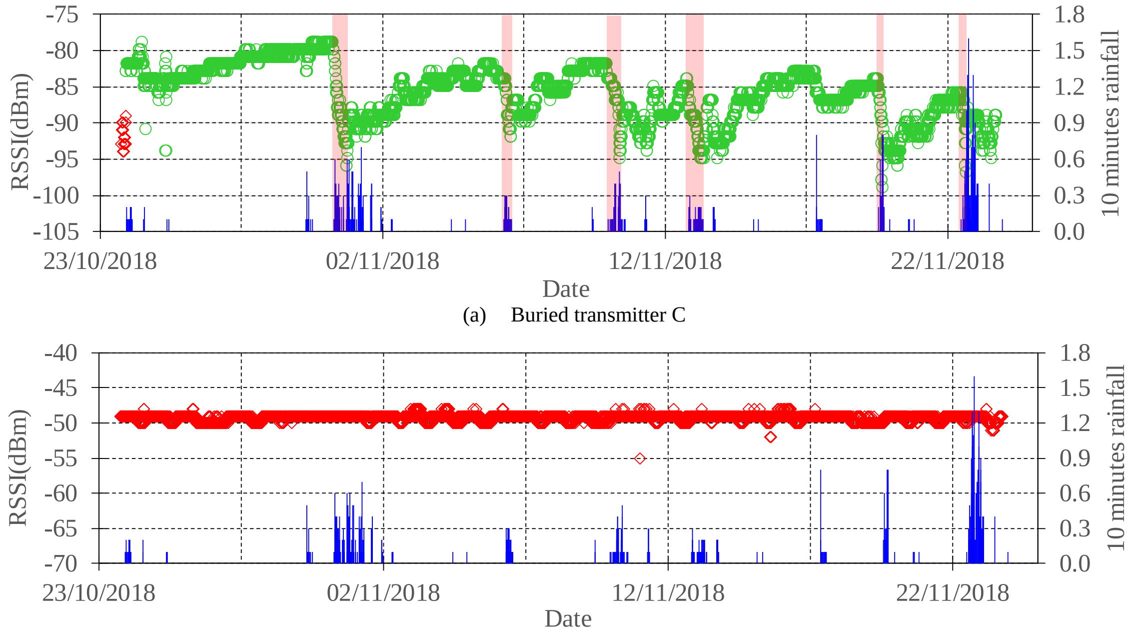

(a) Buried transmitter C

(b) Ground mounted transmitter E

Figure 5. Change over time of RSSI and 10 minutes rainfall

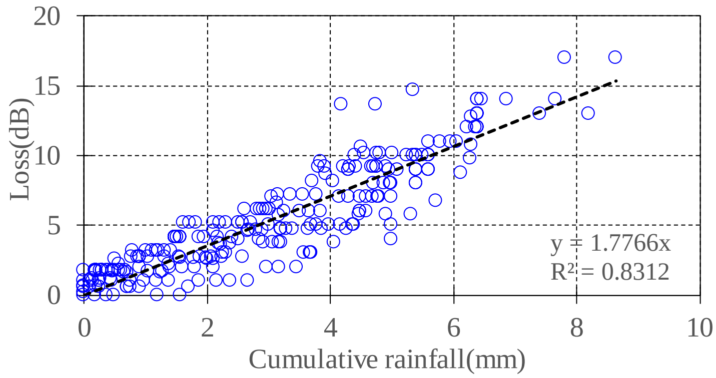

Figure 6. Relationship between Cumulative rainfall and Loss

the portion highlighted in red in Figure 5(a). Here, rainfall is a cumulative value from the observation of rainfall to the point where RSSI has most attenuated, and the loss is a difference between the average value of RSSI before rainfall observation (2 hours) and the RSSI during the rainfall observation. As shown in Figure 6, the loss increases in proportion to the cumulative rainfall, and in this test, a loss of up to 17 dB is confirmed at about 9 mm of cumulative rainfall.

Next, we describe the transmission path. As shown in Figure 5(a), the communication destination is switched from the receiver to the transmitter E at the beginning of the test. Figure 7 shows the result of extracting 6 hours before and after path switching. As shown in Figure 7, the transmission path is switched at the timing of rainfall. Furthermore, when data was directly transmitted to the receiver, the RSSI was -90dBm or less, but after path switching, the RSSI improved by about 10dB. Therefore, we estimate that the path has been switched to the transmitter with a better propagation environment, triggered by the deterioration of the radio wave propagation environment due to rainfall. Additionally, as the results, it has been confirmed that multi-hop transmission is possible in the buried condition. Table IV shows the data arrival rate to the receiver from each transmitter. As shown in Table IV, in the buried transmitters, data loss occurred in 3 out of 4 transmitters. As mentioned above, we estimate that one of the main factors is that the radio wave propagation environment is deteriorated due to rainfall and the RSSI is attenuated.

V. CONCLUSION AND FUTURE WORK

In this study, we carried out a transmission characteristic test of 920 MHz band in a buried condition and a performance measuring test of WSN on the test embankment. As the results, in the transmission characteristic test, it is confirmed that there is an attenuation of about 20 dB regardless of the transmission distance when the transmitter is buried in the soil about 0.1m. Furthermore, in the performance measuring test, it is confirmed that multi-hop transmission with switched transmission path is possible

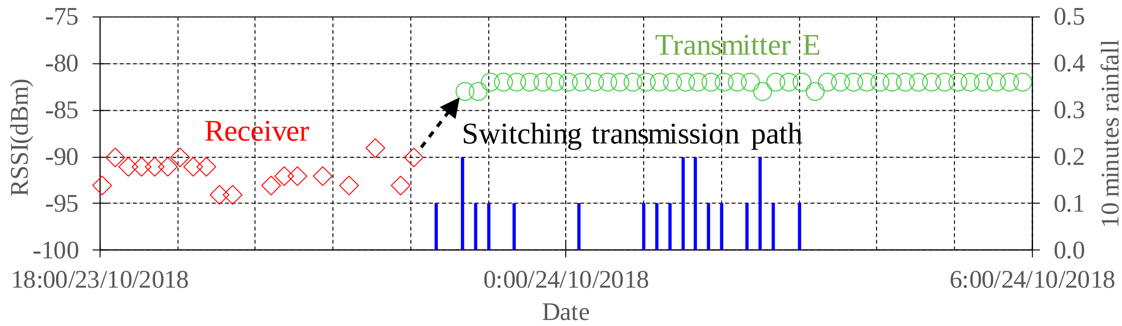

Figure 7. Test result at the switching transmission path

TABLE IV. DATA ARRIVAL RATE

	Installation Method of Transmitter	Number of Transmitted Data	Number of Received Data	Data Arrival Rate
A	Buried 0.1m below the ground	4460	4460	100%
B		4457	4374	98%
C		4458	4411	99%
D		4455	3834	86%
F	Installed 1.2m above the ground	4458	4454	100%
G		4456	4455	100%

even when direct transmission of data to the receiver becomes difficult. On the other hand, when the soil on the propagation path contains moisture due to continuous rainfall, it has been confirmed that the attenuation is so large, and data loss occurs. Consequently, we regard that WSN design in a buried environment needs to consider the attenuation due to burial and rainfall.

In the future, we are going to continue testing to further improve the WSN design in the railway environment. Furthermore, we are also going to confirm the long term performance of WSN and the relationship between soil moisture content and loss. In addition, since the place where the test was conducted this time is a snowfall area, we will also examine the effects of snow depth and melted snow on radio wave propagation in the 920 MHz band. In addition to the embankment where this test was conducted, the railway has many facilities with severe transmitter installation conditions. This result is expected to be used as basic knowledge for constructing a large-scale 920 MHz band WSN in the railway environment in the future.

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