

LoRa Network Performance Comparison between Open Area and Tree Farm based on PHY factors

Sungwook Ko
Computer Science and Engineering
Dongguk University
Seoul, Korea
kso0611@gmail.com

Yulim Cho
Mathematics
Dongguk University
Seoul, Korea
ikisee113@gmail.com

Sojeong Kim
Computer Science and Engineering
Dongguk University
Seoul, Korea
thwjddl94@naver.com

Daehan Jin
Computer Science and Engineering
Dongguk University
Seoul, Korea
hanguk46@gmail.com

Hyunji Song
Computer Science and Engineering
Dongguk University
Seoul, Korea
hysong6059@gmail.com

Jiwon Chung
Computer Science and Engineering
Sognag University
Seoul, Korea
chloe3260.o@gmail.com

Daeun Yim
Computer Science and Engineering
Sogang University
Seoul, Korea
deyim33@gmail.com

Anthony Smith
Computer Information Technology
Purdue University
West Lafayette, USA
ahsmith@purdue.edu

Abstract—IoT(Internet of Things) applied to agriculture can be a great help to increase efficiency of growing crops. For applying IoT to agriculture industry, using a kind of devices and data obtained by sensing are essential. Furthermore, in agriculture with IoT, networking is one of the most important parts. LoRa is one of the great representative among LPWAN to implement Agriculture IoT. It has a lot of advantages, especially in terms of low costs and excellent battery performance. In addition, it can be deployed with much less costs and have rich ecosystem due to alliance with partnership companies. Unfortunately, most of these researches are about experiments which is conducted in open area, urban area or several crop farms. Researches about tree farm were not done so far before. A lot of previous works tested the performance of the LoRa network in mountainous and urban areas. In mountainous areas, the packet transmission rate is affected by the altitude of the terrain. Urban areas are affected by the location of the building. Therefore, in this paper, we did some experiments to verify LoRa network performance according to changing PHY setting in tree farm and open area. We focused on investigating performance with changing PHY factors to measure the performances such as reliability and distance. Consequently, we can find some points. First, comparison between tree farm and open area is that the variation of tree farm is bigger than the variation of open area. So, we can recognize that PDR is more sensitive to PHY factors in the tree farm. Second, it appears that PDR is higher in the open area than the tree farm. However, in the open area, only the variation of PDR according to CR is theoretically increased. In addition, as SF increases, PDR also increases like odd numbered ID 001, 003, 005 and even numbered ID 002, 004, 006 in tree farm. At last, we can only find the difference according to changing BW 120 to 250 in the comparison of 001 and 007, 002 and 008 in 150M in the tree farm. And we can also find out the difference between 001 and 007 in 100M, 002 and 008 in 150M.

Keywords—LoRa network, Tree farm, Open Area, PHY factors, Precision Agriculture

I. INTRODUCTION

IoT(Internet of Things) applied to agriculture can be a great help to increase efficiency of growing crops. For applying IoT to agriculture industry, using a kind of devices and data obtained by sensing are essential. Sensing devices can make us gather useful and meaningful data from enormous farmland with little additional attentions. The data collected from wireless sensors in farmland also can help farmers to monitor the status of their crops and farmland and researchers to analyze the consistencies of growth of crops. There have been many attempts to implement IoT technology to agriculture.

Furthermore, in agriculture with IoT, networking is one of the most important parts. Recently, LPWAN(Low-Power Wide Area Network) is most widely used network in IoT data communications. Because it is wireless network which allows long range communications at a lower bit rate compared to other wireless network.

There are several kinds of LPWAN protocols, such as LoRa(Long-Range), NB-IoT(Narrow Band-Internet of Things), Sigfox and so on. NB-IoT has better advantages in coverage and QoS(Quality of Service). And Sigfox has better advantages in cost. On the other hand, LoRa is one of the great representatives among several LPWAN protocols to implement Agriculture IoT. Because LoRa has a lot of advantages, especially in terms of low costs and excellent battery performance in general. Although it is now on early stage, there have been a number of research focusing on evaluating the performance of LoRa, including reliability and coverage.

Unfortunately, most of these researches are about experiments which is conducted in open area, urban area or several crop farms. Researches about tree farm were not done so far before. Therefore, in our paper, we did some experiments to verify LoRa network performance according to changing PHY setting in tree farm and open area. We focused on investigating performance with changing PHY(Physical layer) factors to

measure the performances such as reliability and distance. As a result of, we can show up the results which is acquired by our experiments from this experiments in this paper.

II. RELATED WORK

In a tree farm, tree for Christmas sales needs a period of at least six years and takes up to 50 years to become timber for building or furniture. Failure to manage tree farm properly and not be able to harvest good quality trees will result in long losses of time and investment. If IoT is applied to manage the tree farm efficiently, in long losses of time and investment can be prevented.

As mentioned above, There are several kinds of LPWAN protocols like LoRa, NB-IoT, Sigfox and so on. Among these things, we thought Lora is the best for IoT network. Because it can reduce the cost of building initial equipment and environment for IoT network much more than NB-IoT. In addition, LoRa is open to everyone, therefore it can make a lot of partnership with companies and constructive ecosystem for IoT[12][13]. It means that it has richable environment than NB-IoT and Sigfox. There are no previous works that use the LoRa network in tree farm. On the other hand, there are works that have tested the performance of LoRa networks in urban areas, mountains, and open area. In urban areas, the packet delivery ratio varies depending on the location of the building[10]. In the mountain, the packet delivery ratio varies with the altitude of the terrain[8]. In the open area, the packet delivery ratio per distance was higher than that of mountain and urban area, because there is no obstacle in the open area[7].

Testing and analyzing LoRa network performance on a tree farm will provide useful information for someone who wants to use IoT to their tree farm. And testing and analyzing LoRa network performance in open area will provide useful information for comparing with a few areas such as mountains and urban areas.

Above all, we investigated technical background and definition of LoRaWAN, because it is main subject in our paper. LoRaWAN is a Low Power Wide Area Network (LPWAN). It is a chirp spread spectrum modulation scheme using wideband linear frequency which improves receiver sensitivity and tolerance to miscommunication between receiver and transmitter[3].

LoRa network has three significant features. The first one is low cost. It reduces costs in three ways: infrastructure investment, operating expenses and end-node sensors[4]. Also, LoRa uses license-free sub Gigahertz radio frequency bands like 169 MHz, 433 MHz, 868 MHz (Europe) and 915 MHz (North America). Since LoRa uses low frequency bands, we can minimize the cost for building network[5]. Second one is low power. Its protocol is designed specifically for low power consumption extending battery lifetime up to 20 years. And the last one is long range. Single base station provides deep penetration in dense urban/indoor regions, plus connects rural areas up to 30 miles away.

Besides, LoRa network uses a star topology network. A number of networks using LoRa can provide coverage that is

greater in range compared to that of existing cellular networks. [1] Existing studies on LoRa are so few, and most of them are focusing on experiments performed in mountain [8], underground[7] or over water with the end-device attached to the radio mast of a boat [9].

Furthermore, the concept of Fresnel zone clearance may be used to analyze interference by obstacles near the path of a radio beam. The first zone must be kept largely free from obstructions to avoid interfering with the radio reception. However, some obstruction of the Fresnel zones can often be tolerated. As a rule of thumb the maximum obstruction allowable is 40%, but the recommended obstruction is 20% or less[2].

III. PERFORMANCE COMPARISON

It takes up to 50 years to produce wooden timber. In addition, price fluctuations due to the quality of wood are very large. Therefore, if you cannot manage the tree farm properly and cannot harvest the quality trees, the profit and the loss is very high. Also, since the scale of the tree farm is considerably large, it is thought that it is necessary to manage it effectively. So, we considered about applying IoT. With IoT, everyone who wants to grow up own crops can efficiently manage large-scale tree farm and save a significant amount of time and money.

One of the most attended IoT communication technology is LoRa network. We used it to analyze network performance in a tree farm by changing PHY factors. Also, We conducted the same experiments in open area and analyzed LoRa network performance and compared characteristics of LoRa network by PHY factors.

A lot of previous works tested the performance of the LoRa network in mountainous and urban areas. However, there are no researches to test the performance of a LoRa network in a tree farm. In mountainous areas, the packet transmission rate is affected by the altitude of the terrain[8]; urban areas are affected by the location of the building[10]. Therefore, we supposed to have some experiments which check the effects of the factors affecting the packet transmission rate in the tree farm, and compared the performance according to locations, tree farm, open area.

In addition, the definition of PHY factors and understanding is very important part of this paper. LoRa's communication performance can be fine-tuned by varying the selection of several PHY settings, including bandwidth(BW), spreading factor(SF), coding rate(CR), transmission power(Tx).

1) Spreading Factor

Representing the number of chirps per symbol used in the treatment of data before transmission of the signal. It can take values from 6 to 12. The larger the spreading factor, the more the receiver will be capable to recognize the right symbol. However, a larger spreading factor also increases the transmission time to send a packet[8].

2) Bandwidth

Varying the range of frequencies (bandwidth) over which LoRa spread allows for trading radio air time against radio sensitivity, thus energy efficiency against communication range

and robustness. The higher is the bandwidth, the shorter is the air time and the lower is the sensitivity. A lower bandwidth also requires a more accurate crystal in order to minimize problems related to the clock drift. Typically the range of the bandwidth is between 125. . . 500 kHz[7].

3) Coding Rate

Coding Rate is the FEC(Forward Error Correction) rate used by the LoRa modem that offers protection against bursts of interference, and can be set to either 4/5, 4/6, 4/7 or 4/8. A higher CR offers more protection, but increases time on air. Radios with different CR can still communicate with each other if they use an explicit header, as the CR of the payload is stored in the header of the packet[11].

4) Transmission Power

Similar to most other wireless radios, LoRa transceivers also allow transmission power adjustment. However, increasing transmission power accompanies drastic increase of energy consumption for packet transmission[7]. Thus, adjusting transmission power is not a viable option to improve the performance of LoRa network.







Due to the reason stated above, we control only three PHY settings, leaving Transmission Power unchanged. Thus, the performance of the LoRa network is analyzed by adjusting only spreading factor, bandwidth, and coding rate.

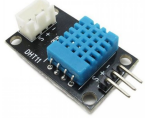

A. Research Environment

We used the LoRa IoT Development Kit made by Dragino company located in China. It offers LoRa shield based on Semtech SX1276 chip and ‘LG01-P’ LoRa Gateway. Furthermore, two arduino equipped with an SX1276 radio module that works in the 915 MHz band and photosensitive, flame, temperature and humidity sensor was packaged.

To get data on the temperature and humidity of the day we used DHT11 sensor made by Dragino which is a composite sensor that contains a calibrated digital signal output of temperature and humidity

TABLE 1. RESEARCH DEVELOPMENT ENVIRONMENT

H/W		
	LG01-P LoRa Gateway	Arduino Uno
		
	Dragino LoRa Shield	Soil Humidity Sensor
		
	Flame Sensor	Photosensitive Sensor

	
	DHT11 Temperature and Humidity Sensor
S/W	 Arduino Sketch IDE

B. Experimental Method

5) Sites

Our experiments were performed three times in the same tree farm. The tree farm is located at 13455 S 525 W, Romney, IN 47981, USA. It has a flat meadow, but some small hills in the middle and maple trees, oak trees, pine trees are planted. The other place is located at Stadium Mall, Purdue University, West Lafayette, IN 47907, USA.

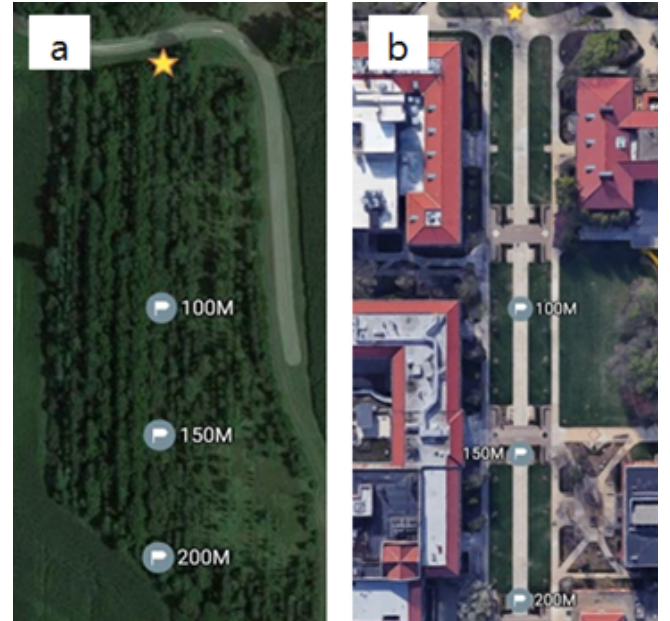


Fig. 1. Experiments sites (a: tree farm, b: open area)

6) PHY settings and Data Packet

TABLE 2. ARDUINO NODE ID ACCORDING TO PHY SETTING

Node ID	001	002	003	004	005	006	007	008
SF	7	7	9	9	11	11	7	7
BW (kHz)	125	125	125	125	125	125	250	250
CR	5	8	5	8	5	8	5	8
TX Power (dBm)	13	13	13	13	13	13	13	13

The experiment was carried out by assigning a Node ID according to each PHY Setting. Table 1 shows these variant settings.

In this experiment, we want to check the communication ability of each node according to PHY factor. SF can be set from 6 to 12. We set SF to 7 (default), 9, and 11 evenly distributed. The CR is set to a minimum value of 5 and a maximum value of 8. BW is basically set to 125kHz. But only SF7 can be set to 250kHz, so we tested SF7 in two cases of 125kHz and 250kHz. The value of TX power was fixed at 13(default). Considering the Fresnel Zone in 200m of 60% of 1st Fresnel zone, receiver's and transmitter's antenna were fixed 2.5m above the ground by using poll.

We needed 4 gateways since in LoRaWAN spreading factor and bandwidth are orthogonal. However, prior researches showed LoRa shields with different coding rate can transmit data packets to the same gateway. Therefore, each two settings with same spreading factor and bandwidth and different coding rate, such as 001 and 002, sent data packets to one gateway.

TABLE 3. DATA PACKET COMPOSITION

[0]	[1]	[2]	[3]	[4]
Node ID	Node ID	Node ID	Humidity	Temperature

[5]	[6]	[7]	[8]
Soil	Sunlight (Normalized)	Flame	Sequence Number

The data structures of payload used in transmitted data packets is character type and has 9 bytes of size. The first three bytes make it possible to distinguish which setting is sending data. We sent data with 3 second interval with 0.5 second of delay between sensing. Each time, nodes collected 150 data packets at one position according to distance 100, 150, 200M. We set the transceivers not to retransmit lost data so as to check packet delivery rate accurately. If we didn't get data packet right, we considered it as data loss and skipped to the next data packet transmission right away.

Maintaining same conditions, every end-device is operated on different distances, 100m, 150m and 200m. The same conditions mentioned here refer to the temperature and humidity of the day tested. First experiment was conducted on the day with temperature 25°C, humidity 80%, Second on temperature 24°C, humidity 62%. The third experiment was done on temperature 27°C, humidity 70%. We put shields in a box to minimize meteorological factors affecting experiment results. Every experiment was carried out for about three hours. Plus, all the experiments were performed at a height of 2.5m, considering Fresnel zone of LoRa network frequency and overall tree farm area. The result data was made by averaging each three experiment results.

In addition, Fresnel zone test were not done with every different setting. LoRa Shield's PHY Setting conditions are set to default values. SF was set to 7, BW was set to 125, and CR was set to 5, and the experiment was conducted under the same conditions with the change of height only at 0m, 1m, 2m, and 3m at 200m. we received only 100 packets to figure out tendency of performance improvement accordance with height.

C. Metrics

When experiments are done, we calculated reliability and RSSI (Received Signal Strength Indication) to analyze data of different settings at different distance. Reliability is calculated as the ratio of valid received packets to the number of packets transmitted to the Packet Delivery Ratio (PDR), which provides information about the reliability of the communication [8]. RSSI is a measurement of the power present in a received radio signal [6].

$$PDR = \frac{D}{T} * 100(\%) \quad (1)$$

D: The number of packets delivered successfully
T: Total packets transmitted

D. Experiment Results

1) Experiments with different PHY settings

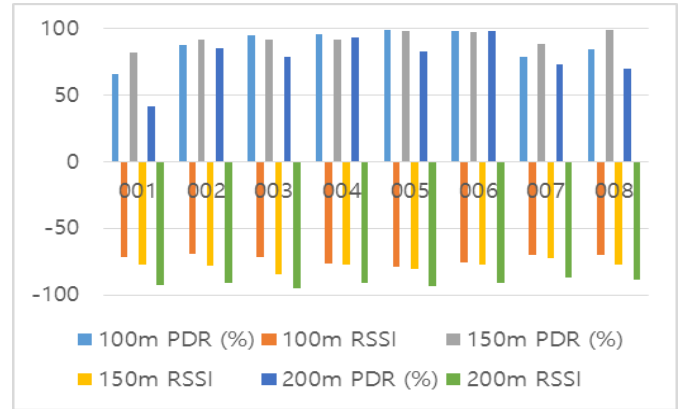


Fig. 2. Results of each setting at different distance in tree farm

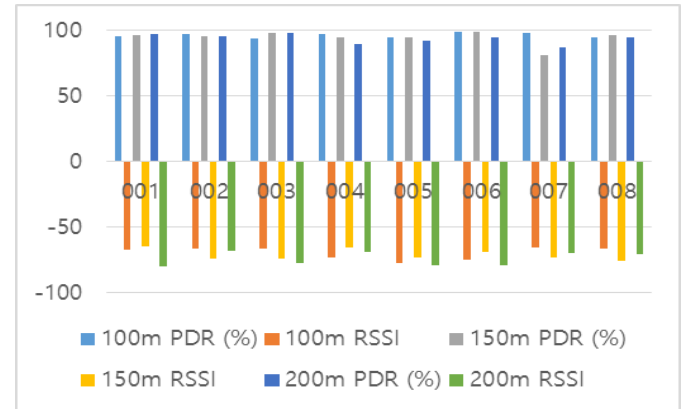


Fig. 3. Results of each setting at different distance in open area

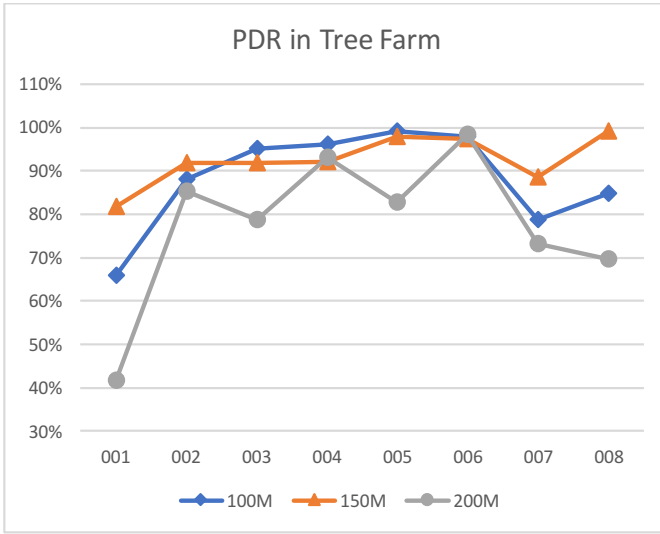


Fig. 4. PDR graph in tree farm

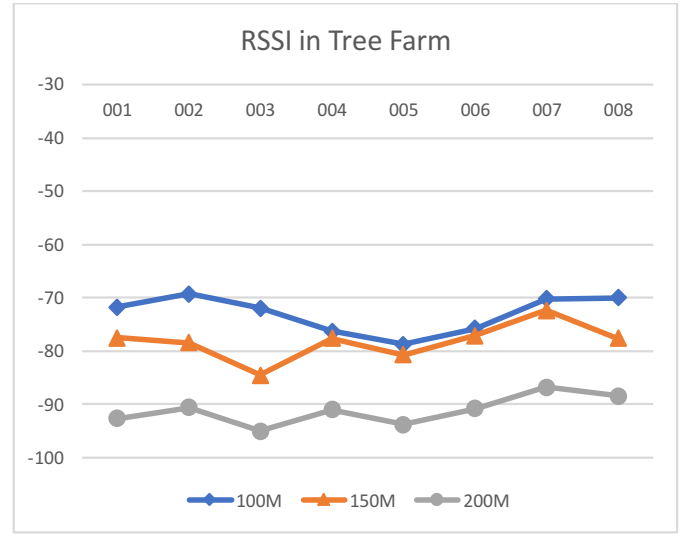


Fig. 6. RSSI graph in tree farm

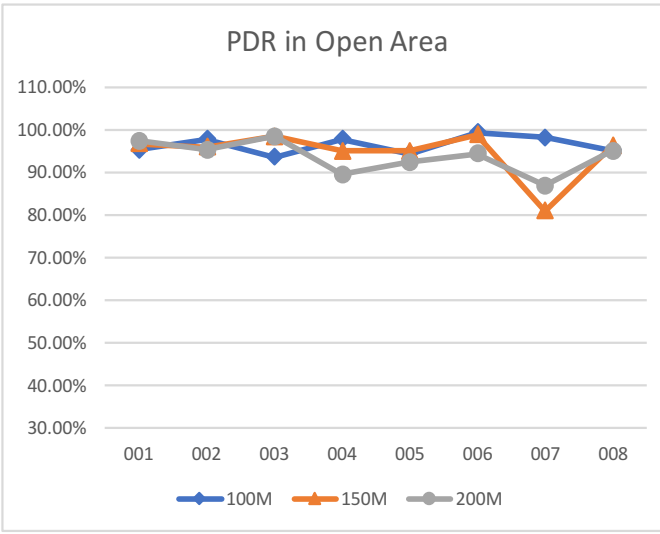


Fig. 5. PDR graph in open area

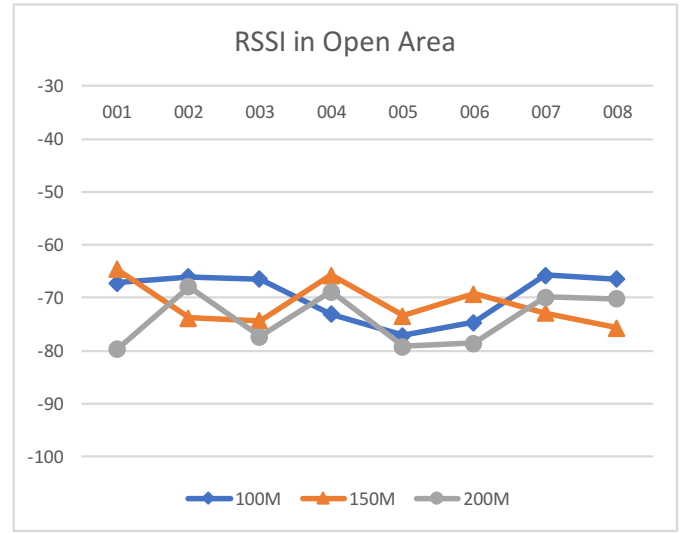


Fig. 7. RSSI graph in open area

First of all, a noticeable comparison between tree farm and open area is that the variation of tree farm is bigger than the variation of open area. For that reason, we can recognize that PDR is more sensitive to PHY factors in the tree farm. Therefore, setting PHY factors properly will be helpful for creating an environment of IoT in tree farm. This will be discussed in future studies.

In general, it appears that PDR is higher in the open area. In the tree farm, you can see that CR8 has higher PDR than CR5 in 100M and 200M; 001 and 002, 003 and 004, 005 and 006. However, in the open area, only the variation of PDR according to CR is theoretically increased. In addition, as SF increases, PDR also increases like odd numbered ID 001, 003, 005 and even numbered ID 002, 004, 006 in tree farm. At last, we can only find the difference according to changing BW 125 to 250 in the comparison of 001 and 007, 002 and 008 in 150M in the tree farm. And we can also find out the difference between 001 and 007 in 100M, 002 and 008 in 150M.

The variation of RSSI appears more consistently in tree farm than in open area. RSSI in tree farm are quite plain than RSSI in open area. The reason will be treated in future studies. In this study, we cannot identify why the measured RSSI in open area looked similar over the three different distances. we plan to find out the reason in the next stage of the work.

IV. CONCLUSION

In this paper, we had done some experiments to analyze the performance of LoRa network in two places, tree farm and open area. Among many LPWAN protocols, the reason why we choose LoRa is because it can be deployed with much less costs and have rich ecosystem due to alliance with many participating companies. In addition, there were no researches to verify the performance of LoRa network for tree farm. So, we had done three times experiments in tree farm by adjusting the PHY configuration setting of nodes using LoRa network. Also, we wanted to compare the performance of LoRa network in tree farm with open area after conducted three more times experiments in open area. It is for checking which PHY factors

have powerful effects to communications by using LoRa network.

Consequently, we can find some points. First, comparison between tree farm and open area is that the variation of tree farm is bigger than the variation of open area. So, we can recognize that PDR is more sensitive to PHY factors in the tree farm. Second, it appears that PDR is higher in the open area than the tree farm. However, in the open area, only the variation of PDR according to CR is theoretically increased. In addition, as SF increases, PDR also increases like odd numbered ID 001, 003, 005 and even numbered ID 002, 004, 006 in tree farm. At last, we can only find the difference according to changing BW 120 to 250 in the comparison of 001 and 007, 002 and 008 in 150M in the tree farm. And we can also find out the difference between 001 and 007 in 100M, 002 and 008 in 150M.

Additionally, the variation of RSSI appears more consistently in tree farm than in open area. RSSI in tree farm are quite plain than RSSI in open area. The reason will be treated in future studies.

In future work, we will study effects of external environment to LoRa network performance and make more nodes to compare each other and verify its performance more precisely.

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