Evaluation of LoRa Performance in Underground Conditions

Keywords: LoRa, RSSI, SNR, WUSNs

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Introduction

Extreme weather is one type of evidence of global climate changes. Increments in heavy rainfall events have been reported at mid- and high-northern latitudes [1]. This heavy rainfall is the major triggering factor of slope failures since the heavy rainfall can diminish the shear stress of soil by raising both the pore water pressure and the unit weight of the soil [2]. Therefore, slope monitoring and an early warning system may be the promising way to reduce the damage caused by the slope failure. However, among the existing landslide monitoring systems, many of them are wired. The deployment of these systems is not flexible [3]. Therefore, wireless underground sensor networks (WUSNs) can be used for landslide monitoring systems. WUSNs will allow much denser deployment of sensors so that landslides can be better predicted and residents of affected areas can be warned sufficiently early to evacuate [4]. One of the wireless technologies for wireless sensor networks (WSNs) is LoRa. However, several problems exist with WUSNs. Certain aspects, such as temperature, soil composition, and soil moisture, directly impact the connectivity and communication success of WUSNs [4]. Therefore, the aim of this work is to evaluate the performance and transmission distance of LoRa in underground conditions.

Methodology

a. Measurement setup

The experimental platform used in our experiment is depicted in **Figure 1**. A GPS (Global Positioning System) tracker was used as the LoRa ED (Long-Range End Device) with a 920 MHz band. Shiroyama Station and Ehime University Station were used as gateways (GWs), which can receive radio wave signals from the LoRa ED.

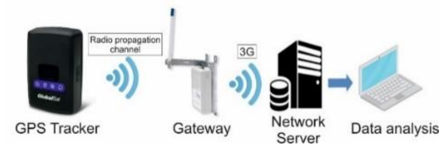

Figure 1: Scheme of radio wave propagation experiment

The performance of LoRa was assessed by the RSSI and SNR values. RSSI is the total signal power received in milliwatts and measured in decibel-milliwatts (dBm). Furthermore, SNR is a ratio between the level of the signal and the level of noise [5].

During all the measurements, the position of the GWs was fixed, whereas the ED was moved to different locations. The altitude of Shiroyama GW is 111 m above sea-level. Meanwhile, the altitude of Ehime University GW is 57.2 m above sea-level.

b. Underground conditions

The experiments were conducted in three different locations. The distance between the GWs and ED location was depicted in **Figure 2.** In each location, the box was buried within the soil at ten depths from the ground surface to 1.0 m below the ground surface. Furthermore, a hand shovel was used to manually create a 35-cm-diameter hole.

c. Soil Properties

The type of soil and soil water content directly affects the attenuation of EM (electromagnetic) signals passing through the soil [4]. Consequently, a particle size distribution test was conducted to determine the type of soil. The type of soil was identified using the Unified Soil Classification System (USCS). The particle size distribution test was conducted at five depths from 0.1 m to 0.9 m below the ground surface. Furthermore, the oven drying method was used to calculate the gravimetric water content (GWC). The GWC was calculated at ten depths from 0.1 m to 1.0 m below the ground surface

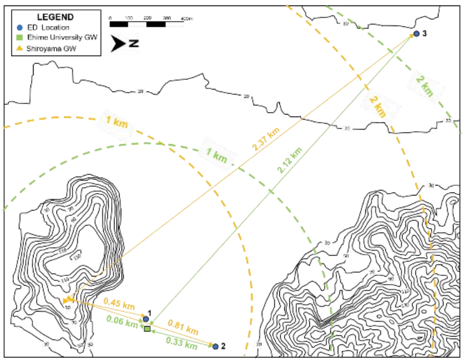

Figure 2: Distances between GWs and ED location

Results

The particle size distribution test was conducted for 15 soil samples from three different locations. Based on the results, all soil samples have the proportion of soil that passed through the No. 200 sieve (0.075 mm) was less than 50%. Furthermore, the proportion of soil that passed through the No. 4 sieve (4.75 mm) was more than 50%. Therefore, all soil samples were classified as sand. Moreover, the determination of well-graded soil (SW) or not was based on the grain size corresponding to the finest 10%, 30%, and 60% (D10, D30, and D60) of the soil. These parameters were used to determine the coefficient of uniformity (Cu) and the coefficient of curvature (Cc). The Cu must be greater than 6 for sand, while the Cc must be between 1 and 3. As shown in this **table 1**, the Cu and Cc of all soil samples fulfilled the criteria. Therefore, the type of soil was classified as well-graded sand (SW) based on the USCS.

The range of soil GWC for each location was shown in **Table 2**. A slight change in GWC was obtained at each location. The signal attenuation caused by the change in soil water content is dependent on the type of soil and the frequency being used. The sandy soils and lower frequencies show less attenuation as water content increases than clay soils and higher frequencies do [4]. In this experiment, the type of soil was SW (well-graded sand) and the ED was operated on the 920 MHz frequency band. Therefore, a slight change in GWC only generates a small signal attenuation.

Table 1 Particle size distribution results

Loc.	Depth (m)	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c	Soil type
1	0.1	0.26	0.70	1.81	6.98	1.05	SW
	0.3	0.19	0.58	1.67	8.89	1.06	SW
	0.5	0.17	0.50	1.37	8.27	1.09	SW
	0.7	0.19	0.52	1.42	7.63	1.03	SW
	0.9	0.19	0.52	1.36	7.29	1.07	SW
2	0.1	0.20	0.72	1.83	9.22	1.44	SW
	0.3	0.25	0.87	2.23	9.05	1.38	SW
	0.5	0.26	0.95	2.30	8.81	1.50	SW
	0.7	0.16	0.91	3.01	18.65	1.69	SW
	0.9	0.18	0.78	2.49	14.09	1.37	SW
3	0.1	0.21	0.60	1.45	6.97	1.19	SW
	0.3	0.28	0.73	1.67	6.03	1.15	SW
	0.5	0.17	0.50	1.37	8.27	1.09	SW
	0.7	0.19	0.52	1.42	7.63	1.03	SW
	0.9	0.30	0.85	1.88	6.37	1.30	SW

Table 1 The GWC of the soil

Loc.	Gravimetric water content (%)
1	10.45 - 13.54
2	12.28 - 16.19
3	6.48 - 10.13

The results of the radio wave propagation test in underground conditions was shown in **Figure 3**. When the ED is on the ground surface, better quality RSSI and SNR values are observed. Furthermore, the RSSI and SNR values dropped when the ED was buried to 0.5 m below the ground surface. The decrease in RSSI and SNR values was caused by the higher attenuation at the deeper depths [6]. When the burial depth more than 0.6 m, a fluctuation in the RSSI and SNR values was observed. The fluctuation in RSSI and SNR values may have been caused by the variation in hole diameter and the density of the soil. In this experiment, the hole was made manually. Consequently, the diameter of the hole could be varied at each burial depth. The density of the natural soil was larger than the density of the backfill soil. When a larger hole was made, a higher modification of the natural soil density occurred. Therefore, the better transmission quality of the signal was realized due to the decrease in soil density [4].

As shown in Figure 3, the greater distance between the ED location and the gateway caused a decrement in signal strength due to attenuation. Moreover, the Shiroyama GW was not able to receive any packet data from location 3 since the presence of hills might block the reception of the signal. However, the communication supposes to be achieved from location 3 by the Shiroyama GW if there was clear from a hill since the Ehime University GW received the packet data from location 3. Additionally, the elevation of the Shiroyama GW is higher than the Ehime University GW. The higher elevation of the gateway could improve the signal quality [7].

The performance of LoRa in the underground conditions was evaluated. When the ED was buried to 0.1 m below the ground surface, the maximum distance of both the Ehime University GW and Shiroyama GW to the ED location was 2.12 km. When the ED was buried from 0.2 m to 0.6 m below the ground surface, the maximum distance between the ED location and the Shiroyama GW and that between the ED location and the Ehime University GW were in the range 0.81 - 2.12 km and 0.33 – 2.12 km, respectively. Moreover, when the ED was buried more than 0.6 m below the ground surface, the maximum distance of both the Ehime University GW and Shiroyama GW to the ED location was less than 0.81 km. Therefore, the burial depth, gateway elevation, and the distance between the ED location and the gateway in underground conditions are important.

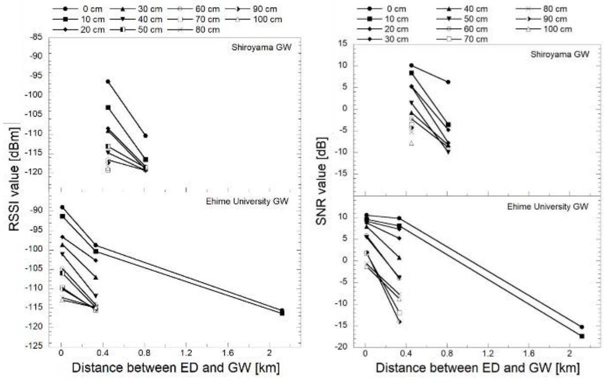

Figure 3: Results of RSSI and SNR values

Conclusion

A radio wave propagation test was conducted in underground conditions. The results show that the performance of LoRa (RSSI and SNR) decreased with the increase in burial depth and the increased in the distance between the gateway and the ED location. The reduction in the RSSI and SNR values was caused by attenuation. Therefore, the maximum distance between the gateways and the ED location is dependent on the burial depth. Therefore, the proper location for the gateway must be chosen conscientiously for WUSNs.

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