EVOLUTION IN ELECTRICAL AND ELECTRONIC ENGINEERING
e-ISSN: 2756-8458

EEEE

Vol. 7 No. 1 (2026) 83-90
https://publisher.uthm.edu.my/periodicals/index.php/eeee

Analysing the Effect of Humidity and Rain on LoRa Signal Performance

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DOI: https://doi.org/10.30880/eeee.2026.07.01.012

Article Info

Received: 20 February 2026
Accepted: 8 April 2026
Available online: 30 April 2026

Keywords

LoRa communication, rainfall intensity, SNR, RSSI, humidity, wireless communication, weather effects

Abstract

This project attempts to analyse the effects of humidity and rain on LoRa (Long-Range) signal performance. The range of the LoRa signal influenced by humidity and rain is considered for outdoor conditions up to 10 meters. The experimental design includes two Arduino Uno boards: the transmitter node connected to the DHT22 sensor for measuring humidity and rain, while the receiver node incorporates the LoRa SX1278 to measure the RSSI and SNR values. In dry conditions (humidity of 73-74%), the RSSI values measured -114 to -121 dBm at 1 to 4 meters. In moderate rain conditions (rain intensity of 70-95%), the RSSI values were within -115 to -121 dBm at 1 to 6 meters. In heavy rain conditions (rain intensity of 99-100% at a humidity level of 91-94%), the RSSI values steadily indicated -115 to -121 dBm at 1 to 10 meters. The experiment indicates that the signal became weak due to intense weather conditions while maintaining a stable range.

1. Introduction

Wireless communication technology has significantly improved due to the rapid growth of Internet of Things (IoT) applications. The technology associated with wireless communication has improved with the ever-increasing usage of IoT-related solutions. Long Range Communication, popularly known as LoRa, has been an essential part of Internet of Things communication. This method has been instrumental in the transmission of data over long ranges with low power utilisation. This is achieved using Chirp Spread Spectrum (CSS) modulation. The LoRa SX1278 module working at a frequency of 433 MHz is preferred in rural environments because of its better robustness to physical barriers compared to other modules working at a higher frequency. But weather conditions, especially rainfall and humidity, may act as an adverse factor in receiving proper signals. Rain attenuation is the absorption of radio energy by the water molecules in the atmosphere, which may decrease the Received Signal Strength Indicator (RSSI). Although LoRa is largely in use, there is a lack of research on the relationship existing between distinct factors in the surrounding environment and the transmission performance of LoRa signals, especially in the 433 MHz frequency band. Most research studies have concentrated on the 868 MHz and 915 MHz frequency bands.

Analysing atmospheric humidity and rainfall effects on the performance of LoRa technology signals are the objectives of this research. This aims to design and implement a wireless communication system using the LoRa technology with an SX1278 transmitter operating on a 433 MHz frequency that is accompanied by DHT22 sensors for detecting humidity and temperature levels, as well as YL-83 rain sensors to detect rainfall. The main objective of the project is to measure the RSSI and Signal-to-Noise (SNR) on a range of 1 to 10 meters in different weather conditions that range from dry to heavy rain.

LoRa is a Low Power Wide Area Network wireless solution based on chirp spread spectrum modulation, targeted for IoT applications such as smart city and environmental sensing, and it operates in unlicensed ISM bands such as 433 MHz, 868 MHz, and 915 MHz [1], [2]. The system supports a maximum communication distance of 20 km in free space, with spreading factors, SF7-12, which provide a balance between the communication range and data rate, and it provides a packet delivery ratio of 80% at 2800 meters with SF12 spreading factor [1]. Weather conditions have been found to greatly affect LoRa system performance, and a high correlation of 0.65 and 0.70 was found between LoRa signal variations and variations in temperatures and humidity, respectively, of 10-15 dB in a few hours due to tropospheric and multipath effects [3]. The digital receiver design and implementation include dechirping and DFT methods, and synchronisation by up-chirping the preamble signal [4]. Recent studies have been conducted for LoRa 2.4 GHz time-of-flight ranging in an outdoor environment and Vehicle-to-Vehicle communications, though there is a lack of studies regarding the effect of weather conditions in a comprehensive manner [5], [6].

2. Methodology

The experimental system consists of two distributed nodes: a transmitter node that is equipped with environment sensors and a receiver node for signal quality measurement. Even though this system is distributed, it has a centralised signal processing aspect for signal quality measurement.

Fig. 1 shows the data flow and process in the humidity and rainfall monitoring system using LoRa communication. DHT22 sensor measures temperature and humidity, whereas the rain sensor measures the presence or intensity of rain. Both these sensors transmit their information to the Arduino Uno transmitter node. Data from both sensors is read by the Arduino Uno transmitter, processed by it, and the rain information may also be converted into a wireless signal using ADC. After processing and conversion into wireless signals, the data is transmitted through the LoRa transmitter module. The LoRa receiver module receives the wireless signal and then decodes it into digital form. The digital data is then read, processed and displayed through Arduino Uno receiver node. The information is displayed to the user on the display output.

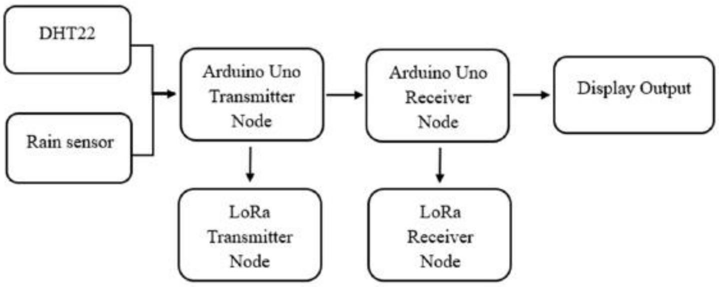


Fig. 1 *Block diagram of the proposed work*

Fig. 2 shows the system initiates the process. The initialisations of the Arduino Uno, LoRa SX1278, DHT22 sensor, and rain sensor occurred at this stage. The frequency and spreading factors in communication through LoRa are established. The system takes readings for the environmental conditions like temperature, humidity, and rainfall strength. Meanwhile, the parameters used to measure the quality of the connection are determined (SNR, RSSI). The Arduino sends the gathered information through the LoRa transmitter (TX). In case of successful sending, the LoRa receiver (RX) gets the data sent from the Arduino. This data is measured for its RSSI and SNR. The connection status is determined according to the results obtained. Otherwise, the system goes back to reading the environmental conditions. Processed information is shown in the output and serial monitor.

2.1 Experimental Setup

An experimental setup can be described as the equipment setup necessary for the performance of a scientific test. It highlights the positioning of each piece of equipment used and its interconnection, as well as the environmental conditions within which the experiment is conducted. It provides visual documentation of the physical layout of the experiments conducted. Fig. 3(a) shows the location of the experiment in dry conditions at the Tunku Tun Aminah Library, UTHM. Meanwhile, Fig. 3(b) shows the location at Kampung Padang Jambu, Dungun, Terengganu that is used for rainy and heavy rain conditions.

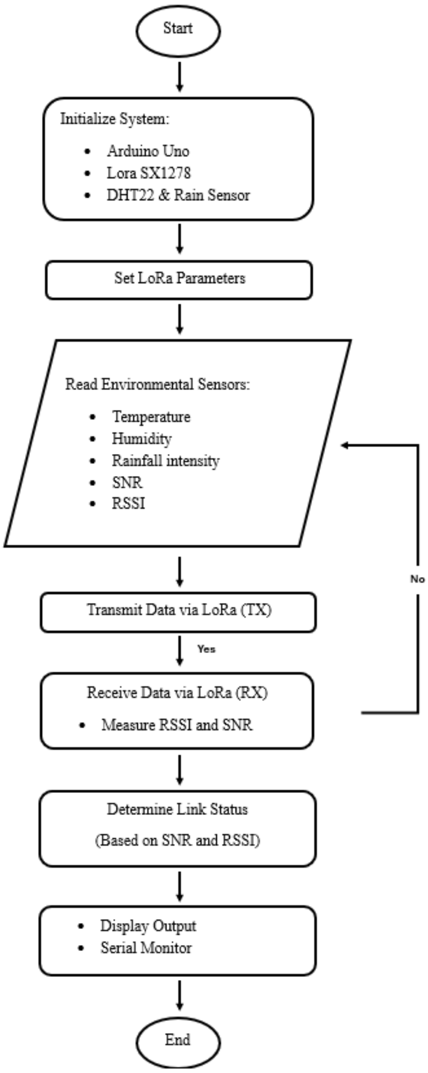


Fig. 2 *Flowchart of the proposed work*

(a) (b)

Fig 3 *Locations for the experiment (a) Tunku Tun Aminah Library, UTHM; (b) Kampung Padang Jambu, Dungun Terengganu*

2.2 Data Collection Parameter

Table 1 shows the classification of RSSI values to indicate wireless communication quality in LoRa systems. RSSI, measured in dBm, indicates the strength of the received signal. Signal strength is categorised as Very Good (≥ -80 dBm), Good (-80 to -95 dBm), Stable (-95 to -105 dBm), Weak (-105 to -115 dBm), or Very Weak (< -115 dBm).

Table 1 *RSSI parameters [7]*

Parameter (dBm)	Signal Status	Description
$\geq$ -80	Very Good	The signal is very strong and stable
-80 until -95	Good	Good signal, stable communication
-95 until -105	Stable	Simple gesture, still trustworthy
-105 until -115	Weak	Weak signal, possible packet loss
$\leq$ -115	Very Weak	The signal is very weak and unstable

There are five levels in the classification [7]. Very Good (equal to or greater than –80 dBm) refers to a strong and stable signal strength with effective communication. Good between –80 dBm and –95 dBm shows medium signal strength with stable and trustworthy data communication. Stable between –95 dBm and –105 dBm refers to sufficient signal quality, despite being trustworthy for communication. Weak between –105 dBm and –115 dBm shows weak signal strength with probable packet loss and unstable connection. Very Weak, less than –115 dBm, refers to extremely weak and unstable signals with frequent communication drops. According to [7], the RSSI can be determined as follows.

$$\mathrm{RSSI\ (dBm)} = 10 \times \log^{10}\left(\frac{\mathrm{P}}{1\mathrm{mW}}\right) \tag{1}$$

where P is the received power in milliwatts (mW), and 1 mW is the reference power level. Alternatively, if the power in Watts:

$$\mathrm{RSSI(dBm)} = 10 \times \log^{10}(\mathrm{P}) + 30 \tag{2}$$

In LoRa systems, RSSI is usually measured directly by the receiver chip and reported automatically. The more negative the value, the weaker the signal (e.g., -50 dBm is stronger than -120 dBm).

Table 2 classifies SNR values to indicate the quality of wireless communication by comparing the signal strength to background noise levels. SNR is measured in decibels (dB) and shows how much the desired signal stands out from interference. The classification includes five levels: Very Good (≥ 10 dB) indicates very low interference with excellent signal clarity where the signal is much stronger than background noise; Good (5 to 10 dB) shows clear signal with minimal noise interference and reliable communication; Stable (0 to 5 dB) represents acceptable signal quality where the signal is slightly stronger than noise and communication is still functional; Weak (-10 to 0 dB) indicates that noise is starting to dominate the signal, resulting in degraded communication quality; and Very Weak (< -10 dB) shows high noise levels where background interference exceeds the signal strength, causing severe performance decline. SNR is measured in decibels (dB). Referring to [7], the formulas for SNR are as follows.

$$\mathrm{SNR(dB)} = 10 \times \log_{10}\left(\frac{\mathrm{Signal\ Power}}{\mathrm{Noise\ Power}}\right) \tag{3}$$

or more commonly:

$$\mathrm{SNR(dB)} = \mathrm{Signal\ Level(dBm)} - \mathrm{Noise\ Level(dBm)} \tag{4}$$

where Signal Power is the power of the desired signal, and Noise Power is the power of background noise and interference. In LoRa communication, SNR can also be expressed as:

$$\mathrm{SNR} = \mathrm{RSSI} - \mathrm{Noise\ Floor} \tag{5}$$

Table 2 *SNR parameters [7]*

Parameter	Signal Status	Description
$\geq$ 10	Very Good	Very low interference
5 until 10	Good	Clear signal
0 until 5	Stable	Still acceptable
-10 until 0	Weak	Noise is starting to be dominant
$\leq$ -10	Very Weak	High noise, performance declines

Table 3 allows a systematic categorisation of rainfall intensity in mm/hr [7]. Rainfall intensity is classified into six levels, ranging from 'No Rain' at intensity 0 mm/hr to 'Extreme Rain' beyond 100 mm/hr. For each of these levels of rainfall intensity, there is a status message enabling users to grasp their prevailing weather conditions.

Table 3 *Rain intensity parameters [7]*

Rain Intensity	mm/hr	Status
No Rain	0	Dry
Light Rain	0.5 – 4	Drizzle
Moderate Rain	4 – 8	Normal Rain
Heavy Rain	8 -50	Heavy Rain
Very Heavy Rain	50 – 100	Downpour
Extreme Rain	+ 100	Cloudburst

The lower intensity categories are "No Rain," which symbolises dry weather; "Light Rain" (0.5-4 mm/hr), also known as drizzle; and "Moderate Rain" (4-8 mm/hr), which symbolises normal rain. The higher intensity categories are "Heavy Rain" (8-50 mm/hr), also known as heavy rain; "Very Heavy Rain" (50-100 mm/hr), also known as downpour; and "Extreme Rain" (> 100 mm/hr), also known as cloudburst conditions and necessary to identify if it is necessary to take shelter or continue with outdoor activities.

3. Result and Analysis

Results and analysis describe the design and testing of the LoRa-based environmental monitoring system. After the description of the transmitter and receiver node prototype designs, analyses the environmental testing that is conducted for three different weather conditions, the first with moderate or partially drying weather with no rainfall at all, the second with moderate or rainy weather with moderate rainfall, and the third with heavy rainfall close to the maximum level of rainfall in a day. In these testing phases, the results study the main environmental factors of temperature, humidity, and rainfall intensity while measuring the signal quality with the help of both RSSI and SNR ratios at varying transmission ranges.

3.1 LoRa Transmitter and Receiver Node Prototypes

Fig. 5 shows the prototypes of the transmitter node and receiver node. Fig. 5(a) shows the transmitter node collects environmental data and sends it over long distances to a receiver. It consists of an Arduino Uno for basic controlling purposes, a working LoRa SX1278 for wireless data transfer, a DHT22 sensor (the white grid-shaped object on the board), which is responsible for monitoring temperatures and humidity levels, and a YL-83 rain sensor (on the left side with a probe cable). The entire setup is powered by a USB cable located on the bottom side of the board.

Fig. 5(b) shows the receiver node receiving the data from the sensor stations. The components are arranged such that the Arduino Uno microcontroller is at the bottom and the LoRa SX1278 is on top of a breadboard, and are connected through the Orange and the Black wires that represent the SPI communication and the power connection, and the white wires that are the data connections. Finally, the Arduino is powered and connected to a computer through the USB cable on the left side of the setup. The way the system is implemented is that the LoRa module is continuously tuned to receive incoming radio signals on the 433MHz frequency band. When the data packets from the other nodes (like the weather station you showcased in the earlier demonstration) are received, the Arduino can process the data packets and display the resulting data on the serial monitor.

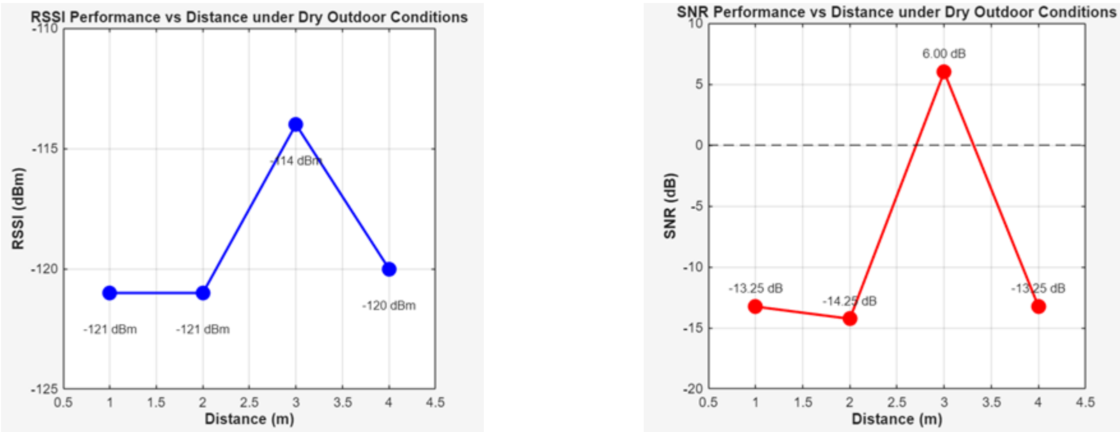
(a) **(b)**

Fig. 5 *Prototypes (a) Transmitter node; (b) Receiver node*

3.2 Performance vs Distance under Dry Outdoor Conditions

Fig. 6(a) shows the performance of RSSI with distance in dry outdoor conditions, measuring the strength of the signal from 1 m to 4 m. Analysing the result, there is odd behavior where the RSSI values are constant at -121 dBm for distances of 1 m and 2 m, then suddenly increase to -114 dBm at a distance of 3 m (a gain of 7 dB), and finally fall back to -120 dBm at a distance of 4 m. The signal strength measurements do not align with the Free Space Loss formula, which predicts a monotonic 6 dB decline for every doubling of distance. On the other hand, signal intensity unexpectedly escalated for mid-distances. There are potentially three major reasons for the differences between the measurements and the calculations of the formula: the effect of multipaths, the inapplicability of the formula for the close range measured at 1-2 m, and the antenna patterns resulting in nulls at some places.

Meanwhile, Fig. 6(b) shows SNR versus distance under dry outdoor conditions, revealing an unusual pattern where SNR remains poor at around -13 to -14 dB for distances of 1 m, 2 m, and 4 m, but dramatically peaks at 6 dB at 3 m, an improvement of nearly 20 dB. While figure SNR should theoretically decrease monotonically with distance as signal strength diminishes relative to noise, the experimental data show an unexpected sharp peak at 3 m. This anomaly could be primarily attributed to constructive multipath interference at 3 m, where ground reflections combine favourably with the direct signal to significantly boost received power. At other distances, ground reflections likely interfere destructively, reducing SNR. This highlights how real-world wireless propagation can deviate substantially from idealised free-space models due to environmental reflections.



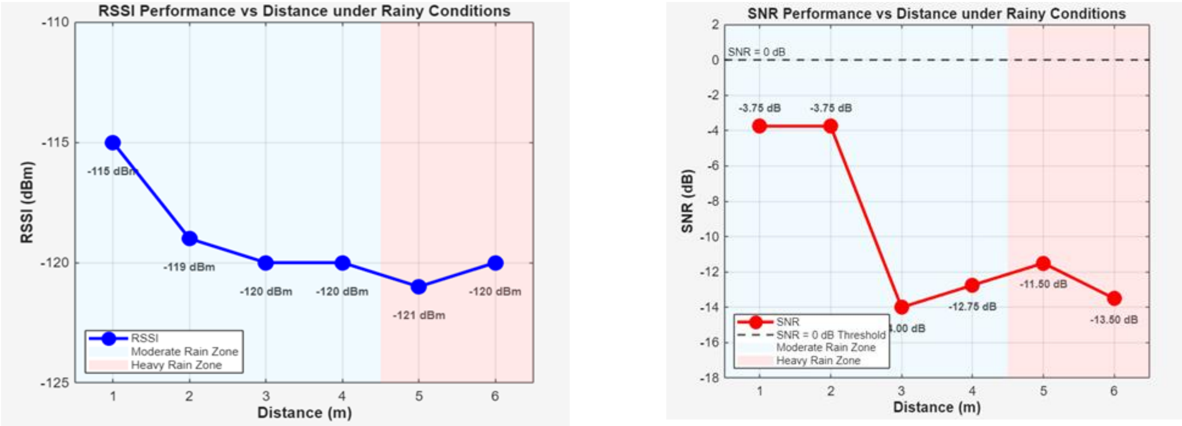
(a) **(b)**

Fig. 6 *Performance under dry outdoor conditions (a) RSSI performance; (b) SNR performance*

3.3 Performance vs Distance under Rainy Outdoor Conditions

Fig. 7 (a) shows RSSI performance versus distance under rainy conditions, measuring from 1 m to 6 m. The RSSI starts at -115 dBm at 1m, degrades to around -119 to -120 dBm between 2-4 m, experiences a slight dip to -121 dBm at 5 m, then recovers slightly to -120 dBm at 6 m. The graph also indicates a transition from moderate rain (1-4 m) to heavy rain conditions (5-6 m, shown in pink). Theoretically, RSSI should vary monotonically but negatively with the increase in distance as a function of path losses on a larger scale for heavy rain due to absorption/scattering from water droplets. On the other hand, the empirical evidence shows a decrease from 1 m to 5 m in a manner that corroborates the combined effects of the total path losses and rain. However, there is an increase in the RSSI value at 6 m.

Fig. 7 (b) shows SNR versus distance under dry outdoor conditions, revealing an unusual pattern where SNR remains poor at around -13 to -14 dB for distances of 1 m, 2 m, and 4 m, but dramatically peaks at 6 dB at 3 m—an improvement of nearly 20 dB. From the theoretical perspective, it can be deduced that SNR will gradually degrade with increasing distance due to path loss, with the strongest degradation in the 5-6 m region of heavy rain. Contrastingly, some discrepancies are observed between the theoretical and measurement outcomes. SNR remains constant in the 1-2 m region and suddenly drops by as much as 10 dB to become very low in the 3 m region, thereby supporting the effect of multipath interference rather than simple path loss. On the other hand, SNR increases in the 5 m region in the heavy rain region, in contrast to the 3-4 m region of moderate rainfall, contradicting the principle of rain attenuation. Also, it is noticed that in all cases, values for SNR are negative.



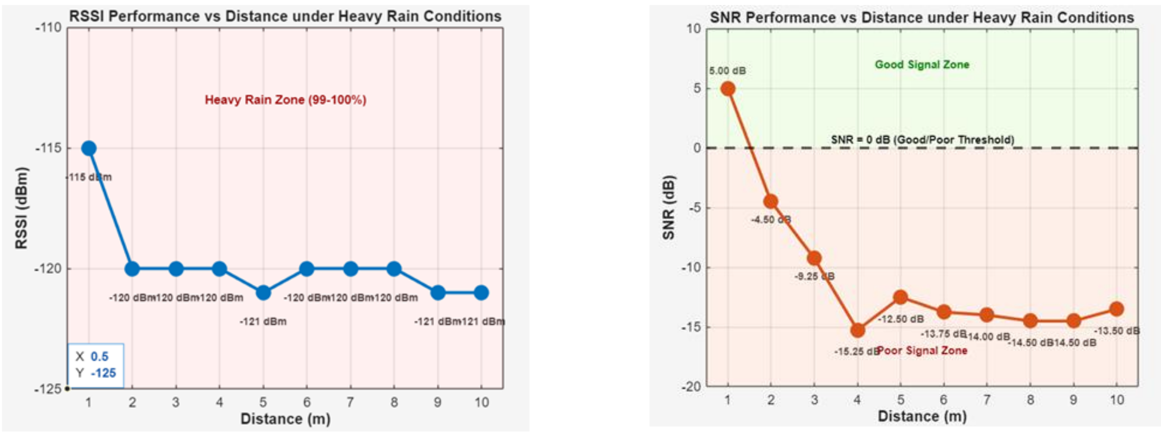
(a) **(b)**

Fig. 7 *Performance under rainy outdoor conditions (a) RSSI performance; (b) SNR performance*

3.4 Performance vs Distance under Heavy Rain Outdoor Conditions

Fig. 8(a) shows RSSI performance versus distance under heavy rain conditions (99-100% intensity) from 1 m to 10 m. The RSSI starts at -115 dBm at 1 m, then quickly drops to around -120 dBm at 2 m and remains relatively stable at -120 dBm for most distances (2-10 m), with a slight dip to -121 dBm at 5 m and another at 9-10 m. RSSI is theoretically expected to exhibit a gradual decline of around 6 dB with every doubling of the distance because of the path loss component. Further attenuation will be caused by the rain-induced absorption and scattering. As observed in the data set, RSSI initially exhibits a 5 dB loss from 1m to 2 m. Meanwhile, RSSI seems to become stable at an interval of -120 dBm with a variation of no more than 1 dBm from 2 m to 10 m. This counteracts the theoretical expectations of an ongoing progressive loss. Such behaviour is perhaps caused by the noise floor constraint of the receiver (cutoff at measurements below -121 dBm) or the dominance of the rain component establishing the signal at the baseline sensitivity level.

Fig. 8(b) shows SNR performance versus distance under heavy rain conditions from 1 m to 10 m, with a 0 dB threshold separating good signal quality (green zone, above 0 dB) from poor signal quality (pink zone, below 0 dB). The SNR starts strong at 5.00 dB at 1 m, rapidly degrades to -4.50 dB at 2 m, continues dropping to -9.25 dB at 3 m and -15.25 dB at 4 m, then stabilises around -12.50 to -14.50 dB from 5 m to 10 m. Theoretically, the SNR is supposed to drop proportionally to the distance due to path loss effects, and this is further accentuated by heavy rain with an even distribution of attenuation along the distance. However, the theoretical values are supported by a 4-m distance in the experiment data, where the SNR drops by 20 dB due to the joint effect of path loss and heavy rain. But the SNR suddenly retains its intensity in the distance from 5-10 m at an average of -13 to -14.5 dB.



(a) **(b)**

Fig. 8 *Performance under heavy rain outdoor conditions (a) RSSI performance; (b) SNR performance*

The effect of rainfall on the quality of communication seems to arise because the rainfall scatters the radio waves and causes the propagation medium to become less focused, reducing the possibility of destructive multipath reflection off the ground and surroundings. Consequently, the stability of the radio signals gets improved, and the effective communication range is seemingly increased during moderate to heavy rainfall.

From the theoretical point of view, the signal propagation behaviour may be understood through the free-space path loss and rain attenuation models. Yet, according to the experiment, reality is much more complicated than the ideal models suggest, as other environmental phenomena like multipath and scattering have a significant effect on the signal degradation.

4. Conclusion

It has been found that LoRa communication in the present study is very much dependent upon the external environmental factors, such as weather and other propagation effects. In fact, the findings prove that signal behaviour in a real-world environment does not always follow the perfect theoretical assumptions owing to some factors like multipath interference and rainfall.

As far as the effect of weather is concerned, it seems that rainfall has contributed positively to the improvement of signal range in contrast to dry weather conditions, owing to lesser interference effects and scattering effects. Despite this advantage, RSSI and SNR readings have varied based on weather effects. In this regard, 433 MHz radio frequency was chosen because it offers greater penetrating power and long-range signal stability.

Acknowledgement

The author gratefully acknowledges the support of the Faculty of Electrical and Electronic Engineering at Universiti Tun Hussein Onn Malaysia.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nur Fakhira Nabila Hasli, Mariyam Jamilah Homam;* ***data collection:*** *Nur Fakhira Nabila Hasli;* ***analysis and interpretation of results:*** *Nur Fakhira Nabila Hasli;* ***draft manuscript preparation:*** *Nur Fakhira Nabila Hasli, Mariyam Jamilah Homam. All authors reviewed the results and approved the final version of the manuscript.*

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