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ORIGINAL ARTICLE

Field Study of Low-Energy Long-Distance Wireless Communication for IoT Application in Remote Areas

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ABSTRACT – Long Range (LoRa) is a wireless radio frequency technology under the Low Power Wide Area Network (LPWAN). LoRa is able to communicate long range and low energy consumption. The communication range has become an essential element in the wireless radio frequency technology in the Internet of Things (IoT). The presence of LoRa is able IoT application performs in long communication distances with high noise sensitivity ability. People can operate, monitor, and do a variety of tasks from a remote distance. Therefore, this research aims to evaluate the performance of the LoRa connection between radio transceivers in remote locations. The different environment and structural elements affect the LoRa performance. This thesis will be supported by the experiment that LoRa communication in different environments and tests. This experiment tests in line of sight (LOS) and non-line of sight (NLOS). Two sets of LoRa parameters, including Spreading Factor (SF), Bandwidth, and coding rate, are tested in different environments. The experiment tests the LoRa performance in various aspects: received signal strength indicator (RSSI) and packet received ratio (PPR) at different coverage ranges. In addition, the LoRa performance is evaluated in university, residential areas and vegetation areas under similar temperature, weather, and time. The LoRa coverage distance in the vegetation area and university area is reached 900 meters in the LOS test. Still, the vegetation area's signal is more stable and able to receive weaker RSSI signals. The LoRa coverage distance in the NLOS test is shorter compared to the LOS test. NLOS test has only one-third of the LOS LoRa communication distance. It is due to the signal penetration on structural elements such as buildings and woods cause the signal power loss and only transmitting a shorter distance. The LoRa parameter with SF9, 31.25kHz bandwidth and 4/8 coding rate has a better coverage range and stable connection.

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RSSI
PRR

INTRODUCTION

Long Range (LoRa) is a patented wireless communication technology promoted by the LoRa Alliance [1]. LoRa is a spread spectrum modulation technique derived from chirp spread spectrum (CSS) technology and utilizes frequency chirps with the linear variation of frequency over time to encrypt data. This wireless communication system can run under ultra-low power consumption with an effective long-range. LoRa can link with two separate layers, which physical layer and the MAC layer protocol (LoRaWAN). The physical layer applies a spread spectrum modulation technique to transport the data to the receiver and operate in a fixed bandwidth channel. LoRaWAN is a network architecture in which gateways transport the information between end-devices and central network servers [2]. End devices transport the data to the gateway through LoRa radio frequency (RF) modulation. The gateways support bidirectional communication in which the end device (sensors) can deliver data to the gateway and receive the messages from the gateway. Gateway receives LoRa RF messages from the end device and transports these data messages to LoRaWAN network server. The gateway requires an ethernet or cellular connection to deliver the data to LoRaWAN network server [2]. An end device can be activated and controlled by the user through the LoRaWAN network server. Common use cases for end devices are temperature sensors, leak detection, meter monitoring, human tracking, and wireless lock.

Every technology has its limitation include LoRa. The limitations of LoRa restrict high data rate IoT applications. Lora data rate can reach up to 27Kbps and is only suitable for low-bandwidth applications [3]. LoRa duty cycle limits the number of data that can be transmitted in a period. MCMC listed the frequency bands limitations on the maximum transmit power and duty cycle in Table 1. Maximum transmit power can refer to Equivalent Isotropic Radiated Power (EIRP). EIRP is the maximum amount of power that could be radiated from an antenna, given its antenna gain and the Radio Frequency system's transmitter power. EIRP is expressed in decibels over isotropic, dBi. LoRa is a high latency communication IoT that is not suitable for real-time applications [3].

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Table 1. Frequency Bands and Operating conditions in Malaysia (Source from Class Assignment No. 1 Of 2017 MCMC)

Frequency Bands	Operating Conditions
433 - 435 MHz	100 mW EIRP
916 - 919 MHz	25 mW EIRP with duty cycle of <1%, Frequency Hopping or LBT

RELATED WORK

Goldoni et al. [4] studied the RSSI evaluation on indoor and outdoor localization using LoRa radios operating in the 868MHz ISM band. The indoor localization environment has a line of sight (LOS) and Non-line of sight (NLOS) configuration which the range is 1-35meters. The outdoor RSSI evaluation was only conducted in LOS configuration in the urban area. Based on the graph given in the study, the estimated RSSI is inversely proportional to the distances. The indoor RSSI values are close to the estimated RSSI values, but the outdoor RSSI curve shows a floor in higher distances due to its exponential nature. There is a minimum error indoor that provides high accuracy, and the obstacles and walls decrease the strength of the received signal. The outdoor localization's reliability is not acceptable, although some RSSI value is accurate in which there is a high average error in urban areas when it reaches hundreds of meters.

In the paper by Zhao et al. [5], he started the design and bicycle location management system using LoRa technology. This paper is to measure the Signal-to-Noise Ratio (SNR), received packet and packet RSSI. SNR is the ratio between the received power signal and noise floor power level. Lora module is installed on the bicycle. It will transfer the signal to the gateway when the bicycle moves 100m or moves for 3 minutes. The LoRa module resends data a maximum of three times when the bicycle in a rural area increases the successful transmission rate. From the result of the experiment in the paper, Zhao et al. [5] stated that the successful transmission rate depends on the SNR and Last packet RSSI. Low Spreading Factor (SF) can increase the transmission range, but the communication error will also increase. The moving Lora module affects the communication quality and decreases packet RSSI.

Madoune Seye et al. [6] studied LoRa coverage based on range evaluation and channel attenuation model in the region of Dakar. He set up four base stations to transfer data through LoRa communication in the whole city. The base stations were built at high positions with a LOS between the base station and mobile station. The performance evaluation of range was shown the distance between the base station and mobile station increases; the packet loss ratio increases, which means the number of packet losses increases. The lowest base station has the minimum range and best measured path loss among the four base stations. The highest height base station has the best range among the four base stations because there are no obstacles that block the LoRa communication.

In the paper by Ahmad, K. A [7], he studied LoRa propagation at 433Mhz in Malaysia. This study has three different tests: LOS test, NLOS test, spreading factor, and Bandwidth on RSSI. The LOS test was conducted under the ranges of 20meters to 1500meters in the urban area. The test result is RSSI depends on the distance between the transmitter and receiver. RSSI drops when the distances increase. In the test on the effect of spreading factor (SF) and Bandwidth (BW) on the RSSI, it measured RSSI and the symbol period (time on-air). Spreading factor and Bandwidth affect RSSI and transmission time. From the study results, the relationship between the spreading factor and RSSI is a positive correlation. High Bandwidth will decrease the symbol period and the time taken to send data is shorter. The condition that increases the range and data rates is to increases the spreading factor and Bandwidth. In NLOS test, the test conducted about the readings of RSSI after penetrating through several buildings. The test result showed that the signal able to penetrate through buildings and RSSI readings decreases when passing through number of buildings.

METHODOLOGY

The experiment is to collect data from peer-to-peer communication channel using two LoRa radio transceiver modules. The two LoRa radio transceivers is built into one LoRa sensor node and one LoRa receiver node. LoRa sensor node contains one temperature sensor required to send the temperature data to the LoRa receiving node. LoRa receiver node will receive temperature data and send a signal back to the LoRa sensor node to notice the data received. Arduino serial monitor will show the temperature reading and signal RSSI on Arduino serial monitor. The packet received ratio (PRR) and RSSI will record on each distance.

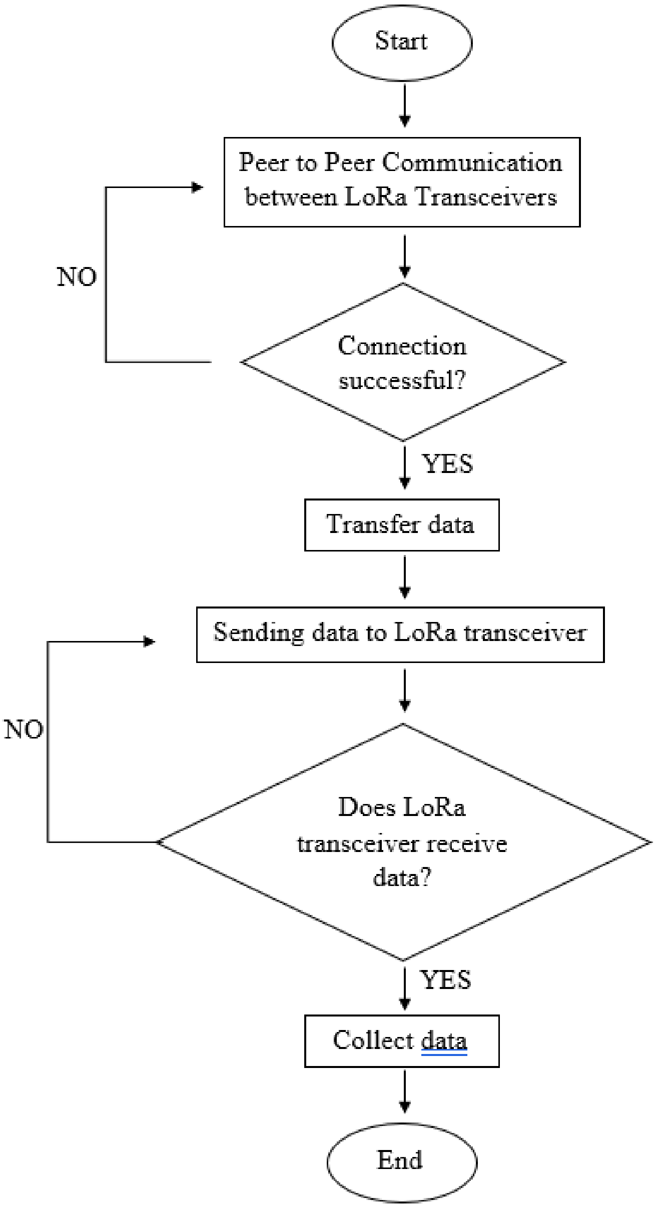


Figure 1. Data collection flowchart

Experiment Setup

Several experiments are carried out in this study on the LoRa sensor node and LoRa receiver node connection. These experiments were conducted in different environments and test. The test consists of LOS test and NLOS test. The environment in these tests is the university area, residential area, and vegetation area. We record the received packet from LoRa node on RSSI values and packet received ratio.

RFM9x radio transceiver modules 868/915 MHz, Microcontroller ATmega328P, and DHT11 temperature sensor were used in this experiment. There are two RFM9x radio transceiver modules which required to build one sensor node and one receiver node. The DHT11 sensor collects the temperature reading, and the sensor node sends the data receiver node. The software for the experiment is Arduino IDE.

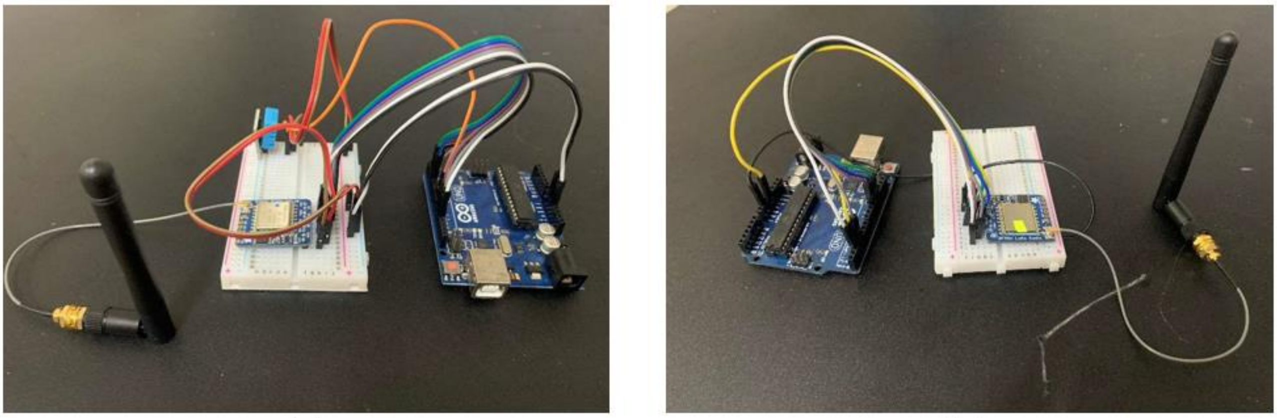
All experiments should be conducted between 4 pm-6 pm in May 2021. They were carried out on sunny days and in the temperature range of 29°C-33°C. It is done to minimize the impact these parameters may have on the results because these parameters will not be considered. There are two types of mode in radio frequency parameters. Mode 1 is 125Khz on Bandwidth, 4/5 on coding rate and 128 chips/symbol on spreading factor. Mode 2 is 31.25kHz on Bandwidth, 4/8 on coding rate and 512 chips/symbol on spreading factor. The LoRa node transfers a packet every 10 seconds with +23 dBm power transmit. The experiment takes 20 measurements in each distance to gain accurate reading of the results. The average RSSSI readings are used as the RSSI measurement in the graph. LoRa sensor node stationary stay and LoRa receiver node will move further away from the LoRa sensor node. We will do the measurement every 50 meters. The experiment will end at the distance that the LoRa receiver node cannot receive the data package for around 10 minutes.

LoRa Sensor Node

Adafruit RFM95W LoRa Radio Transceiver is connected to the Arduino UNO, as shown in Figure 2(a). Arduino IDE is used in the LoRa node setup for Adafruit RFM95W LoRa Radio Transceiver. The LoRa transceiver is connected to the DHT11 temperature sensor to make up the sensor node. The sensor node collects the environment temperature data and transfers the data to the transceiver. The frequency band set in LoRa radio transceiver module is 915mHz. The antenna that was used in this experiment is a 2.4G antenna with IPEX to SMA adapter cable. The uFL SMT antenna connector is required to solder on the radio transceiver signal pad.

LoRa Receiver Node

Adafruit RFM95W LoRa Radio Transceiver was plugged onto the Arduino UNO shown in Figure 2(b). Arduino IDE are used in the LoRa receiver node setup for Adafruit RFM95W LoRa Radio Transceiver. The receiver node receives the data from the sensor node. 2.4G antenna with IPEX to SMA adapter cable also used as the antenna for the radio transceiver in receiver node.



(a) (b)

Figure 2. (a) Setup for transmitter sensor node, (b) Setup for receiver node

Table 2. Controlled Parameter

Types of field test	Types of test	Types of mode	Measured Parameter
University Area	Line of Sight (LOS)	Mode 1	• Received Signal Strength Indicator (RSSI) • Packet Received Ratio (PRR) • Coverage Distance
		Mode 2	
	Non-line of sight (NLOS)	Mode 1	
		Mode 2	
Residential Area	Line of Sight (LOS)	Mode 1	
		Mode 2	
	Non-line of sight (NLOS)	Mode 1	
		Mode 2	
Vegetation Area	Line of Sight (LOS)	Mode 1	
		Mode 2	
	Non-line of sight (NLOS)	Mode 1	
		Mode 2	

Experiment Parameters

There are a few variable parameters and measured parameters in this experiment. The parameter that we can set is spreading factor, Bandwidth, transmission power, centre frequency and coding rate. The centre frequency is 915mHz, and transmission power is +23 dBm which is fixed in this experiment. The parameter that we can change is spreading factor, Bandwidth, and coding rate. High spreading factors can increase the transmission range, increasing the airtime of data packets and energy consumption. Bandwidth will affect the data rate and sensitivity to noise. A high coding rate will increase the protection level due to noise, but it also increases the airtime of the data packet.

The measured parameter in this experiment is RSSI, PPR and coverage distance. RSSI stands for Received Signal Strength Indicator. It is an estimated power measurement level that the radio frequency device is receiving from the other radio frequency sender and measured in dBm. The typical LoRa RSSI range is between -20dBm to -120dBm. The bigger the RSSI value, the stronger the signal strength. The RSSI get weaker when the distances increase. Packet received ratio is the ratio of the number of packets received from the LoRa receiver to the number of the packet sent from LoRa sensor node. The performance is poor when the packet received ratio is low. The coverage distance of LoRa connection is the communication distance between the LoRa sensor node and receiver node. The different environments will cause the diverse coverage range of LoRa connections. The obstacles between LoRa communication device affect the LoRa signal.

University Area

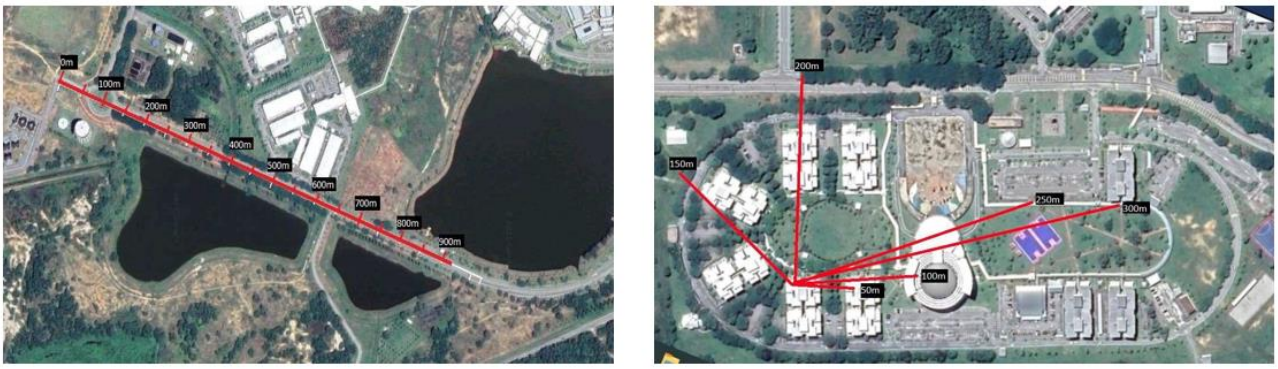
The experiment was set up at the university area for two tests: LOS test and NLOS. The location for the LOS test has 1.5-kilometer road distance with a free LOS. Figure 3(a) shows the experiment location for the LOS test on the university area. The site for the NLOS test is the university resident area. The building in this university area is three-story buildings. Figure 3(b) shows the experiment location for NLOS test in the university area.

(a) (b)

Figure 3. (a) LOS test location, (b) NLOS test location

We measured various distances between the LoRa sensor node and receiver node with a free line of sight for the LOS test. There is a 1.5 kilometre distance to measure the maximum coverage for the LoRa connection. The LoRa sensor node was set up at one point, which stationary stay and the LoRa receiver node moved every 50 meters for each measurement. The height for the two LoRa node is the same level. The RSSI and PRR values are measured and recorded in the graph. The LoRa connection coverage in mode 1 is 700 meters and 900 meters for mode 2 shown in Figure 4(a)

For NLOS measurement, several locations with different distances in the university area were used. Three-story tall buildings blocked the location. The LoRa sensor node is stationary while the receiver node position was moved to the locations in Figure 4(b). The RSSI and PRR values are measured and recorded in the table and graph. The maximum distance for mode 1 can be reached 250 meters, and mode 2 can reach 300 meters.



(a) (b)

Figure 4. (a) LOS test positions, (b) NLOS test positions

Residential Area

The measurements were done inside a city which at Pekan town, Pahang. There is the LOS and NLOS in the residential area. The LOS test has at least a one-kilometre distance with a free line of sight. Figure 5(a) shows the experiment location for the LOS test in the residential area. The site for NLOS test is the residential area with houses of the same height. Figure 5(b) shows the experiment location for NLOS test on the residential site.

(a) (b)

Figure 5. (a) Line of Sight test location, (b) non-Line of Sight test location

The line of sight (LOS) experiment was set up at the roadside at the residential with at least a one-kilometre free line of sight distance. The LoRa sensor node is placed in Figure 6(a) and LoRa receiver node move every 50 meters to take the measurement. There is the same level of height on LoRa sensor node and receiver node. The LoRa communication distance reached 700 meters in mode 1 and 750 meters in mode 2.

The non-LOS experiment was conducted in a city neighbourhood with single-story houses. We set several locations with different distances to place the LoRa receiver node. The LoRa sensor node is set at a place, and the receiver node is moved to the location in Figure 6(b). RSSI and PRR readings are recorded in the table and graph. The maximum LoRa communication distance is 300 meters for mode 1 and 400 meters for mode 2.

(a) (b)

Figure 6. (a) LOS test positions, (b) NLOS test positions

Vegetation Area

There have two different experiment test fields in the plantation area. The LOS test experiment conducts at a paddy field, and there are two kilometres of distance with a free line of sight. The paddy field has the same land level. Figure 7(a) shows the experiment location for the LOS test on the vegetation area. The site for the non-line of sight test is a palm oil farm with dense trees. The height of the tree in the palm oil farm is around 3-5 metres. Figure 7(b) shows the experiment location for non-line of sight test on plantation area.

(a) (b)

Figure 7. (a) Line of Sight test location, (b) non-Line of Sight test location

The LOS measurement was set up at the paddy field with a flat environment. There are at least two kilometers distance with a free of sight in this field. The experiment was made to maintain a +/-0 height differential for the LoRa sensor node and receiver node. The LoRa sensor node stationary stay at one point and the receiver node moved in increments of 50 meters in Figure 8(a). The RSSI and PRR readings are measured and recorded in the graph and table. The maximum coverage only can reach 750 meters for mode 1 and 900 meters for mode 2.

The non-LOS measurement was set up in an area with dense forest and mostly made up of palm oil trees. There is no height differential for the LoRa sensor node and receiver node. The LoRa sensor node set up and stay stationary at one point and receiver node moved every 50 meters for record the RSSI and PRR measurement. Figure 8(b) shows the measurement location for this test in plantation area. The maximum LoRa connection between the LoRa transceiver are 250 meters for both modes.

(a) (b)

Figure 8. (a) Line of Sight test positions, (b) non-Line of Sight test positions

EXPERIMENTAL RESULTS

The experiment was carried out in different environments with different tests and radio frequency parameters. The environment in this experiment is the university area, residential area, and vegetation area. This is to investigates the effect of maximum coverage LoRa communication on different environment. There is the LOS test and non-line of sight test conducted in these environments. The LoRa radio frequency parameter that changed is the spreading factor and Bandwidth. We set two types of radio frequency parameter modes in the experiment. Figure 9 shows the graph for RSSI versus LOS distance sensors in a different environment, and Figure 10 illustrates the graph for PRR versus LOS distance sensor in different environment. Figure 11 represents the graph for RSSI versus NLOS distance sensors in a different environment, whilst figure 12 describes the PRR versus NLOS distance sensor in different environments.

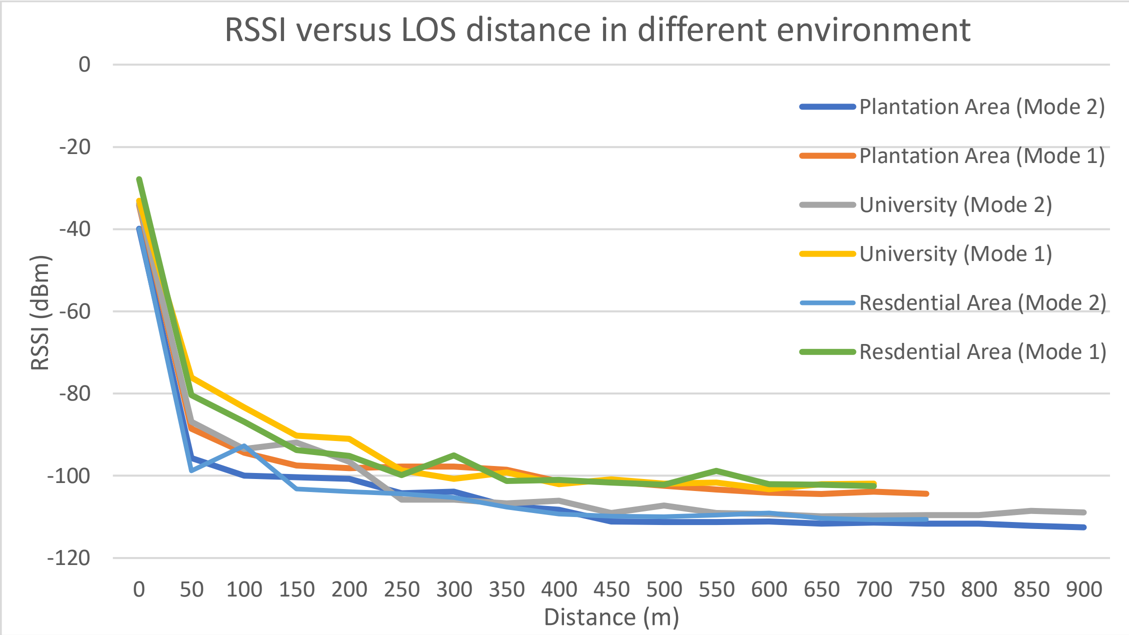


Figure 9. The graph for RSSI versus LOS distance sensors in different environments

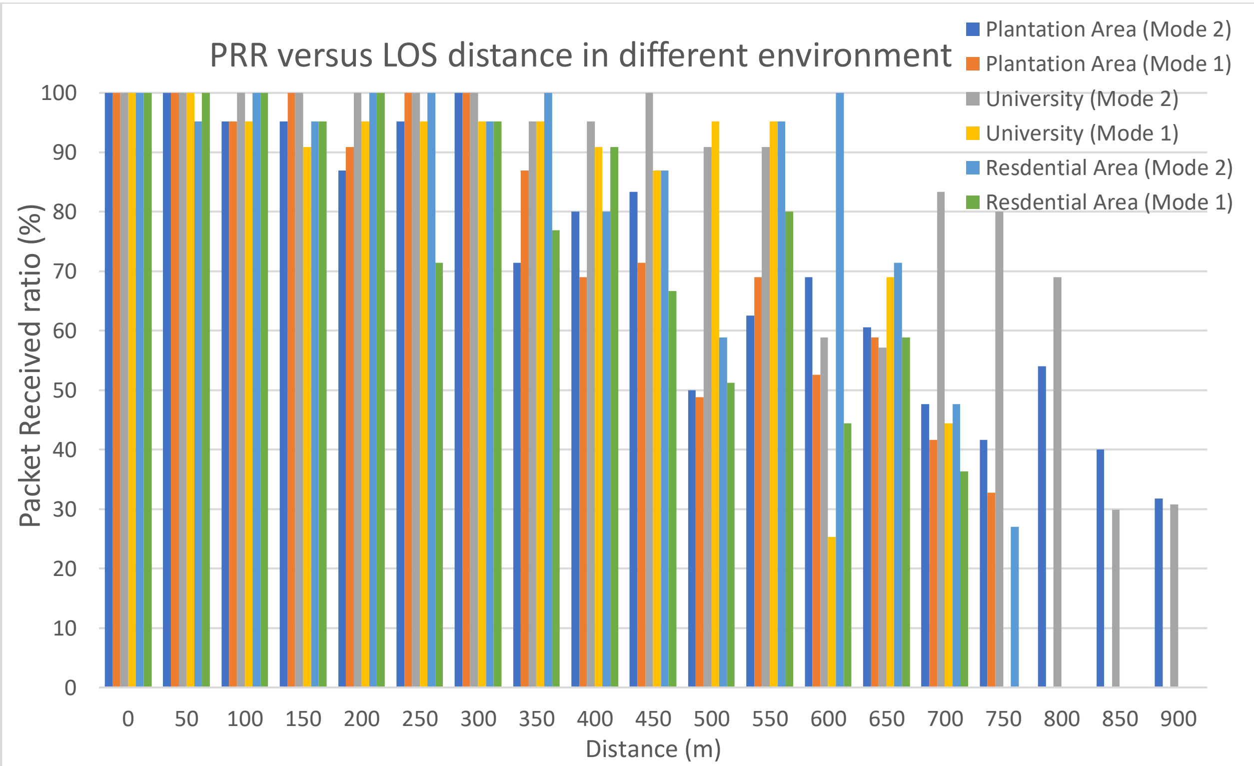


Figure 10. The graph for PRR versus LOS distance sensors in different environments

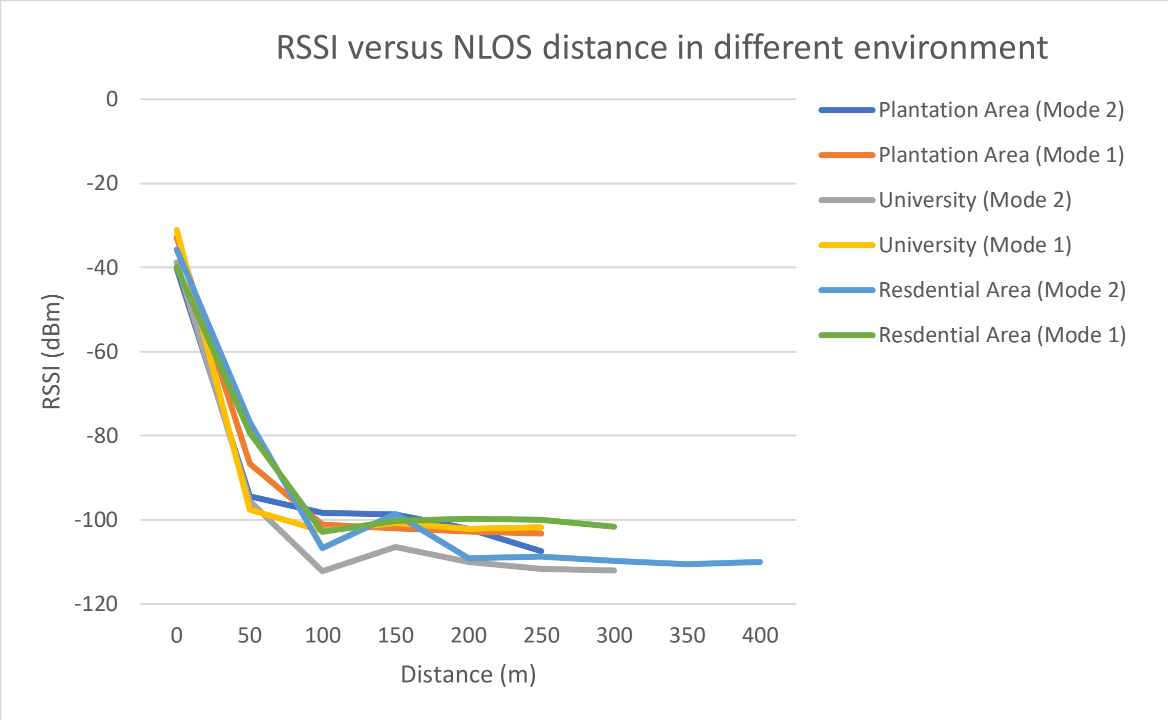


Figure 11. The graph for RSSI versus NLOS distance sensors in different environments

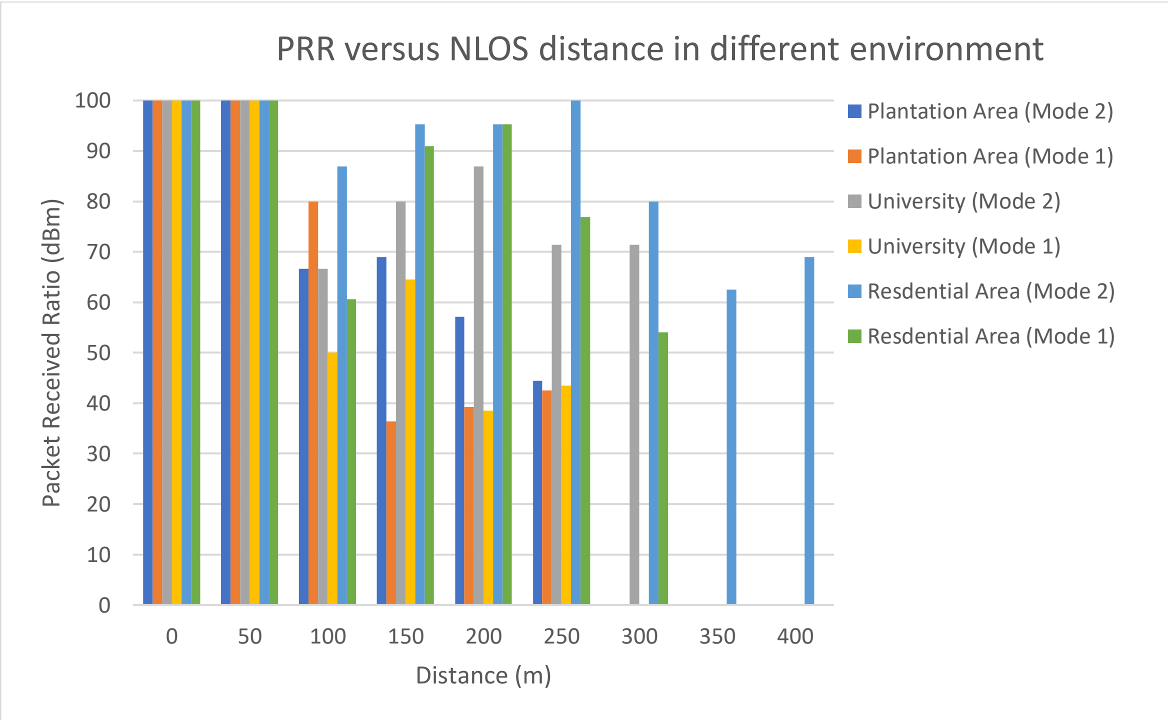


Figure 12. The graph for PRR versus NLOS distance sensors in different environments

Result and discussion

We can see from the LOS and NLOS test that the LOS test has a better performance and higher LoRa connection distance. In the LOS test, the LoRa signal power loss increases into the air when the distance travelled increases. The LoRa receiver node can receive a low RSSI packet in the LOS test because the LoRa signal does not pass through the obstacles. NLOS test has only one-third of the LOS LoRa connection distance due to the NLOS test with buildings and dense forests between the LoRa transceiver that reduce the LoRa signal strength and quality. The distance of non-line of sight is short because of the path losses through the buildings, brick walls and woods. The power of the sending LoRa signal will be reduced as signal power passes through the obstacle in the sending direction. It may affect the LoRa communication quality and coverage range.

Compared to the two modes in a different environment, we can see that mode 2 have a better LoRa connection coverage. Mode 2 have a higher spreading factor and lower Bandwidth. Mode 2 gain the lowest RSSI readings on the last distance compared to mode 1. Low Bandwidth will affect the data rate and sensitivity to noise. A high coding rate will increase the protection level due to noise, but it also increases the airtime of the data packet. The high spreading factor provides high receiver sensitivity. The LoRa transceiver can receive the data packet although the signal is weak. Lee & Ke [8] also found that the higher spreading factor can improve the data transmission and data delivery performance.

Mode 2 has a stable LoRa connection in the different environments from the two different modes in two tests. The three different environments give different maximum LoRa communication distance. The residential area has a higher coverage distance compared to the university area and vegetation area. The residential area has lower obstacles or buildings that LoRa signal is able to transmit through the sky. There are some low PRR values at a certain distance which may cause the radio frequency interference of the electronic device around the area. Zourmand et al. [9] also found similar findings. The significant standard deviation in the RSSI gives an unstable LoRa connection. There might have electronic interference such as Wi-Fi and other radio frequency in the area.

The vegetation area and the university area have the best maximum LoRa communication distance from these three environments. There might be other radio frequency interference in the residential area that interference with the LoRa signal. When the distance travelled of the LoRa signal increases, the LoRa signal power that is radiated in the air will also be reduced. The vegetation gains the lowest RSSI measurement among the three environments. It means less interference in the vegetation that the LoRa transceiver can receive the weak LoRa signal. The weak LoRa signal is lost in the university and residential areas. The LoRa signal power lost through the building or brick walls is higher compared to wood and forest. Carlsson et al. [10] state that the LoRa signal power loss that passes through different material have different values. The city environment has a severe effect on the LoRa communication, which affect the signal quality. The LoRa communication distance in oil palm is short due to the difficult propagation conditions in this environment. This might be caused by the presence of dense wood and trees in the oil palm area.

CONCLUSION

This report has discussed the performance of the LoRa connection between radio transceivers in remote locations. The Lora performance is measured and analyzed in a different environment. The objectives of this study were to measure the LoRa maximum coverage range, RSSI and PPR on received packets in different environments under similar weather and temperature condition. The effect of line of sight, radio frequency interferences and structural elements affect the LoRa connection and signal quality. The vegetation area has the best performance on the maximum coverage and signals quality among three different environments. There has less other radio frequency interference and can receive weak LoRa signal. Crowd radio frequency area cause weak LoRa signal loss and affect the signal quality. Line of sight test has better performance and high coverage distance between LoRa transceivers. The distance travelled of the LoRa signal increases, and the LoRa signal power radiated in the air will also be reduced. The structural elements between LoRa transceivers will affect the LoRa performance and reduce the coverage distance due to the signal power loss to penetrate through the obstacles. LoRa performance is also affected by the LoRa physical parameter such as spreading factor, Bandwidth, transmission power, centre frequency and coding rate. The high spreading factor, low bandwidth, high transmission power and high coding rate gives higher LoRa communication distances. For future research, an omnidirectional antenna that fits with the Lora centre frequency shall be considered to enhance LoRa performance.

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