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EMPOWERING IOT: LEVERAGING DATA SENSOR COMMUNICATION WITH LORAWAN IN DIVERSE ENVIRONMENTS

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Abstract. The Internet of Things (IoT) connects countless devices, such as sensors and actuators, necessitating an efficient long-range communication technology. Low Power Wide Area Network (LPWAN) solutions, such as LoRAWAN, SIGFOX, and NB-IoT, address this demand. LoRAWAN, known for its low power consumption, excels in Line of Sight (LOS) conditions, offering an effective long-range wireless communication. It's ideal for monitoring open areas. In Non-Line of Sight (NLOS) scenarios, LoRAWAN provides wide coverage and energy efficiency, though the signal quality may slightly decline. This research tests LoRAWAN's performance for sensor data communication both inside multi-story buildings (up to 8 storeys) and outside. The results show successful data transmission in both scenarios, including up to 2.60 km with a 35 dBi outdoor antenna.

Keywords: Internet of things, communication technology, long-range, data transmission, line of sight, non-line of sight.

1. Introduction

The Internet of Things (IoT) provides connectivity for thousands of devices, such as sensors and actuators, allowing them to connect to a network and exchange data with each other. With the a rapid growth of internet-connected devices, IoT requires a long-range communication technology, widespread connectivity, low-cost consumption, and affordability. Low Power Wide Area Network (LPWAN) technology, consisting of LoRAWAN, SIGFOX, and NB-IoT, fulfills these requirements [1]. LoRAWAN (Long Range Wide Area Network) has emerged as one of the most promising wireless data delivery technologies in recent years. It offers long-range communication capabilities with extremely low power consumption, making it highly suitable for IoT applications and wireless sensor networks. The presence of this technology creates new opportunities across multiple sectors, including agriculture [2], healthcare, industry, and smart cities [3–10].

In addressing connectivity challenges in densely populated urban areas or remote locations with difficult terrains, LoRAWAN's ability to operate at long distances and through obstacles becomes an important consideration. When transmitting data using LoRAWAN, there are two schemes: Line of Sight (LOS) and Non Line of Sight (NLOS). LOS refers to the condition where the communication path between the transmitting and receiving devices is unobstructed by physical barriers or other interferences. In this scenario, LoRAWAN has proven to be highly effective in delivering sensor data over significant distances. The high communication quality in LOS conditions makes LoRAWAN an attractive choice for monitoring and data collection applications in open locations, such as agriculture, logistics, and urban infrastructure [11–13].

Non-Line of Sight (NLOS) is a situation in which the communication path between the transmitting and receiving devices is obstructed by physical barriers, such as buildings, trees, or complex terrain contours [14]. In NLOS conditions, LoRAWAN still offers advantages in terms of wide coverage and energy efficiency, although the signal quality may be somewhat reduced compared to LOS. LoRAWAN uses adaptive coding and modulation techniques to overcome interference and noise commonly found in NLOS environments. However, there are several alternative wireless delivery technologies, such as Sigfox and NB-IoT, which also offer long-range communication capabilities with low power consumption.

Data transmission faces specific challenges, and each region has unique constraints regarding its connectivity. Particularly in areas with limited access to electricity and internet connectivity, this poses a significant barrier. Hilly regions also present difficulties due to varying building heights. In addition, in rural areas, the considerable distances between houses and communication devices hinders data reception, internet signals, and the overall communication. The use of WiFi and Bluetooth has not fully overcome these challenges in data transmission, especially in areas with limited internet signal availability. Technologies like WiFi and Bluetooth are widely popular in the Wireless Sensor Network (WSN) domain, but have short transmission ranges with high power consumption. The application of WSN technology, a part of the Internet of Things (IoT), faces the need for long-range two-way machine-to-machine communication that is essential for IoT. Various communication technologies have been developed to connect IoT and WSN devices, and one such technology that has emerged is Low Power Wide Area Networks (LPWAN). LPWAN offers long-range communication, low power consumption, and wide coverage. There are four main types of LPWAN technologies: Long Range (LoRa), Long-Term Evolution for Machines (LTE-M), Sigfox, and Narrowband-IoT (NB-IoT)[15, 16]. Among these, LoRab or LoRa Wide Area Network (LoRaWAN), has proven to be the most dominant, with the highest number of network operators and countries using LoRaWAN networks [17]. LoRaWAN provides long-range communication, low power consumption, low costs, and extended battery life [7, 17–19].

2. Related work

Several studies have conducted performance analyses of LoRaWAN in various cases, including rescue operations [20], where LoRaWAN was compared with Wi-Fi, focusing on the technology's ability to transmit data in areas with weak signals. Simulations were performed by adjusting parameters, such as on-air transmission time, bit error rate, and other important metrics to study the overall behaviour of the communication mechanism. The simulation results indicated that optimising the spreading factor and bandwidth could improve signal coverage and battery life, contributing to improved performance in rescue monitoring applications.

In the agricultural domain [21], a similar optimisation of spreading factor to 12 was performed to reduce data packet loss by 50 % compared to a spreading factor of 7. This research showed that LoRaWAN performed well in real agricultural applications, especially when selecting the appropriate spreading factor based on the distance and communication requirements.

An evaluation was also performed in a multi-story building [22] to assess the performance of LoRa (Long Range) wireless communication in dynamic indoor environments. Two LoRa devices were used as the receiver and the transmitter on multiple storeys, and communication performance was evaluated on each storey using Received Signal Strength Indicator (RSSI) and Packet Reception Rate (PRR) indicators. The findings indicated a PRR of 60 %, meaning only 60 % of data packets were successfully received at that specific position. Moreover, it was observed that the dynamic environment had a greater impact on RSSI than on PRR.

In the context of supporting smart transportation systems (shuttle buses) on a campus [23], LoRaWAN's performance was evaluated using GPS-based trackers on shuttle buses with different data rates (DR0-DR5). The evaluation results showed average SNR values above 0dB, average RSSI values above -100 dBm, and packet loss values below 3 % for each tested data rate (DR0–DR5).

LoRaWAN technology has also been tested in health monitoring, specifically pulse status monitoring using pulse sensors in a Wireless Sensor Network [24]. The analysis indicated that the HEED (Hybrid Energy-Efficient Distributed Clustering) method was the best approach to achieve average power consumption (in mW) with LoRaWAN.

Additionally, other research involving LoRa transmitters and receivers explored heartbeat monitoring using ECG sensors and other sensors that alternately transmitted data, involving Machine-to-Machine (M2M) communication [25]. The aim was to address data packet loss caused by simultaneous data transmission from multiple end nodes. Furthermore, the impact of using Adaptive Data Rate (ADR) on power efficiency in LoRa devices was investigated.

Research into the performance of LoRa technology in multi-storey buildings has similarly explored aspects, such as large-scale fading, temporal fading, coverage, and energy consumption. These studies show how signal strength decreases as it travels between storeys and fluctuates over time due to environmental conditions, impacting the indoor coverage. In addition, the research emphasises that energy consumption can vary significantly, sometimes by as much as 145 times, depending on the parameter configurations. This makes it essential to carefully choose parameters and enable the adaptive data rate (ADR) feature to improve energy efficiency, especially in energy-constrained settings. These insights highlight the importance of customised configurations to optimise LoRa deployments in complex indoor environments such as smart buildings [26].

The coexistence of LoRaWAN and Sigfox, two prominent low-power wide-area network (LPWAN) technologies, has been thoroughly studied in various urban scenarios with different duty cycles and traffic conditions. This research examines the performance of these technologies when applying protection distance mechanisms, a strategy aimed at mitigating interference between them. The results provide new insights into how LoRaWAN and Sigfox can coexist effectively, highlighting the importance of interference management in maintaining their operational integrity in real-world applications. The study's analysis demonstrates that by implementing these protection distances, both technologies can function optimally without any significant degradation in performance [27].

The study presents an energy-autonomous wireless sensor node (EAWSN) specifically designed for large-scale, long-term IoT applications in remote, inaccessible areas. This node is self-sustaining, relying on photovoltaic cells that can harvest ambient indoor light to operate without the need for maintenance. Using the LoRaWAN technology, the EAWSN can transmit 30-byte data packets over distances up to 560 meters, adjusting transmission rates based on the opportunistic LoRaWAN data rate selection. The reliability and performance of the EAWSN are further validated through tests in an urban environment, where it demonstrates excellent performance over long distances, proving its effectiveness for remote IoT deployments [28].

A LoRa packet generator was used to explore the performance of LoRa communication in various forest environments, with particular attention to how different LoRa configurations influenced communication quality when operating in the 433 MHz and 868 MHz frequency bands. Through a combination of theoretical analysis and extensive field measurements, the authors evaluated the link quality and transmission performance of LoRa. Their findings identified the optimal configuration parameters for both the lightly dense and very dense forest settings, offering valuable insights into the impact of frequency bands and other settings on the overall performance of LoRa networks in challenging environmental conditions [29].

Numerous studies have tested the performance of LoRaWAN in various fields, using diverse parameters, such as RSSI, SNR, packet loss, data rate, and appropriate spreading factor usage. However, only a few studies have evaluated the performance in Line of Sight (LOS) and Non-Line of Sight (NLOS) conditions, and real-world scenarios, instead of simulations. In addition, 10 dBi and 35 dBi antennas were tested. In this case, data processing using the Lorawan platform is our consideration in claiming the difference from the previous one.

In order to meet the research needs and opportunities related to LoRa technology, further research is required to analyse the performance of LoRa implemented in sensor data transmission using LoRaWAN modules as the data transmission medium. The ability of LoRaWAN in data packet delivery is highly influenced by the environmental conditions in certain regions, such as the presence of tall buildings, radio frequency interference, and other factors. This makes the research very interesting to analyse in depth.

The objective of this study is to analyse the extent of LoRaWAN's influence in sensor data transmission in Line of Sight (LOS) and Non-Line of Sight (NLOS) conditions in an educational environment, specifically at the State Polytechnic of Malang, Indonesia. This research will provide comprehensive insights into LoRa's ability to transmit data wirelessly, beyond the scope of Bluetooth or WiFi technologies, particularly in Internet of Things (IoT) applications.

The results of this analysis can serve as a basis for the deployment of LoRa modules in various sectors, including education, and serve as a basis for developing more advanced and extensive IoT applications. Consequently, LoRa technology will become increasingly relevant as one of the alternative wireless transmission technologies capable of overcoming various network constraints and offering efficient solutions for future connectivity.

3. Methods

In the design of the application in this research, there are stages and techniques used, namely the research time and location, data collection method, data processing method, system design, and system testing.

3.1. Research time and location

This research was conducted in a multi-store building located on the campus of a Polytechnic institution in the city of Malang, Indonesia. The study was carried out over a period of 6 months, from January to June 2023.

3.2. The method of data collection

The data collection can be performed in both Line of Sight (LOS) and Non-Line of Sight (NLOS) conditions at specific distances and predetermined points [14, 30, 31]. The data acquisition is achieved by using LoRa with multiple sensors as transmitters, which transmit data to a Raspberry Pi acting as a LoRa gateway, and subsequently forwarded to LoRaWAN. In addition to the sensor data from the nodes, evaluation parameters, such as RSSI and SNR, generated by the Raspberry Pi upon receiving the data, are also forwarded. The data transmission is repeated 10 times with a 10-second interval between the transmissions. The received data are then fed into the database and can be used for monitoring purposes.

3.3. Data processing method

The data obtained from sensor readings, including timestamp, temperature, humidity, and light intensity, are stored in the database. They are will be transmitted via LoRa Nodes to a LoRaWAN Gateway serving as the receiver. The parameters used in this research include Received Signal Strength Indicator (RSSI), Signal Noise Ratio (SNR), and Delay in transmission time [1, 21, 23, 24]. These parameters will be used for analysing the feasibility of data transmission.

3.3.1. Received signal strength indication (RSSI)

RSSI is a measurement of the strength of the signal received by the receiver. The unit used is decibel (dB). The minimum standard for RSSI is −120 dB to ensure that the LoRa receiver can process the received data [25, 32, 33]. The RSSI values can be categoried into several categories, as shown in Table 1, by classifying the signal strength values.

3.3.2. Signal to noise ratio (SNR)

SNR is a measurement parameter used to examine the ratio between the received signal and the receiver's noise. By default, a LoRa receiver can process data packets if the minimum SNR value is 20 dB. The higher the SNR value, the greater the power acquired [34, 35]. Apart from SNR information, there is also information related to frequency and power requirements for each country as presented in Table 2.

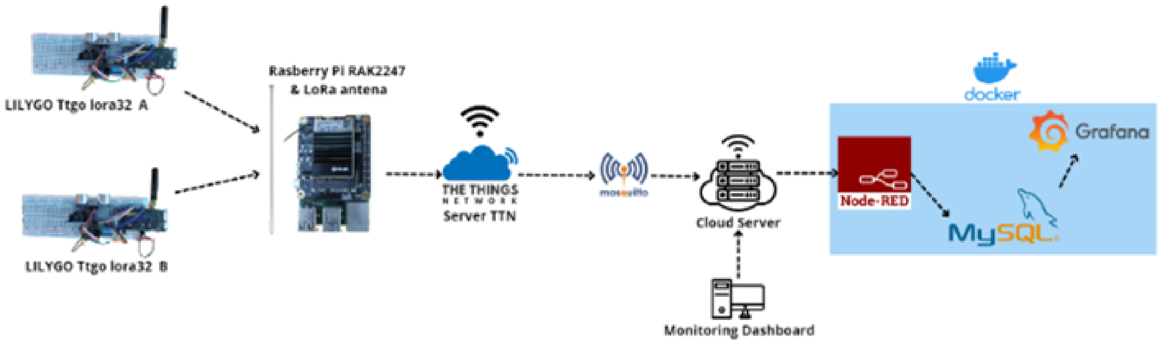

Figure 1. System architecture

RSSI [dBm]	Description
−30 to −60	Very strong. The transmitter and receiver are very close together.
−60 to −90	Excellent. Close proximity
−90 to −105	Sure. There are several data that were not received.
−105 to −115	Poor. Able to receive, but frequently experiences drop-outs.
−115 to −120	Very poor. Weak signal, data are frequently lost

Table 1. RSSI value categories.

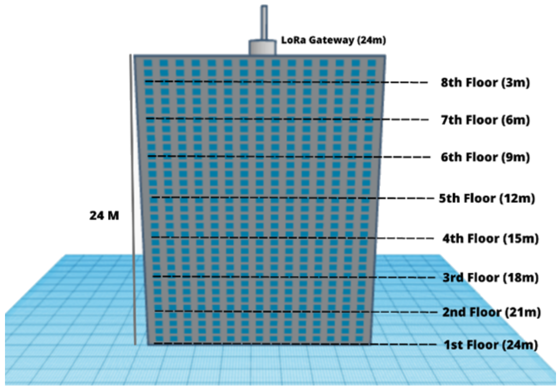

Figure 2. Illustration of NLOS conditions

Region	Frequency Band	Power [dBm]
US	902–928 MHz	30
Europe	863–870 MHz	14
UK	863–870 MHz	14
Ireland	863–870 MHz	14

Table 2. Region-specific transmission power limits of LoRaWAN [36–38].

3.4. Design system

In the design, there are 2 units of LILYGO Ttgo Lora32 with a frequency of 915 MHz, which are NodeMCU devices equipped with LDR, DHT11, HC-SR04, and RTC DS3231 sensors, along with a LoRa module. These nodes will transmit data to a LoRaWAN gateway using two different antennas, namely 10 dBi and 35 dBi. The LoRaWAN gateway is a Raspberry Pi with a RAK2247 module and a LoRa fiberglass antenna operating at 902–930 MHz to receive data. Once the data are received, they are forwarded to The Things Network server as the data recipient in the cloud. In the TTN Server, MQTT is used to publish the data, which are then be subscribed through Node-Red running on the Cloud Server. The system design can be seen in Figure 1.

Then, in Node-Red, the data received from MQTT are processed and inserted into the Mysql database. The data stored in the database are visualised using Grafana to enable real-time monitoring through a web browser. Docker, the container technology used in this research, plays a crucial role in packaging various software files into units known as containers. Node-Red, Mysql, and Grafana are combined into one container within Docker, operating on a public cloud server.

3.5. System testing

In the hardware testing phase, the sensors used are tested to determine their performance in accurately measuring air temperature, air humidity, light intensity, and distance. If any of the sensors fail to function properly, a reconfiguration of the circuit will be performed. During the software testing phase, the focus is on verifying whether the data transmitted by the LoRa transmitter can be successfully received by the LoRaWAN Gateway with sensors placed at specific distances and points. The testing involves reading sensor data from each LoRa Node, transmitting it to the LoRaWAN Gateway, and measuring key parameters, such as RSSI, SNR, and Delay time. Two testing conditions are performed, Line of Sight (LOS) and Non-Line of Sight (NLOS), are conducted. For NLOS testing, the LoRa Gateway is placed on the top storey or approximately 24 metres high, while the LoRa Nodes are placed on the 8th floor, 3 metres away from the LoRa Gateway, which is located on the rooftop of the Civil Building, according to the illustrated setup shown in Figure 2.

In the Line of Sight (LOS) test, the LoRa Nodes are placed both within the campus premises and in the

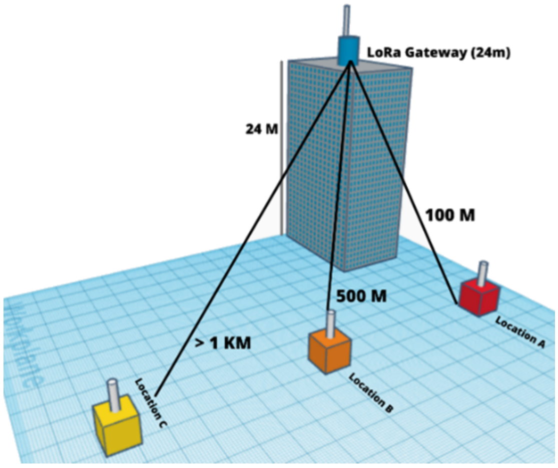

Figure 3. Illustration of Line of Sight (LOS) condition

Locations	Distance between Gateway and Node
8th Floor	3 meter
7th Floor	6 meter
6th Floor	9 meter
5th Floor	12 meter
4th Floor	15 meter
3rd Floor	18 meter
2nd Floor	21 meter
1st Floor	24 meter

Table 3. Non-Line of Sight (NLOS) distance scenario.

Locations	The distance Gateway to Node
Gedung AS Polinema	0.1 km
Gedung Graha Polinema	3.50 km
Gedung AQ Polinema	0.50 km
Pesen kopi plus betek Malang	0.10 km
Perumahan Brantas Indah Malang	1.25 km
Transmart Malang	1.50 km
Sumber Harta Gypsum Malang	2.20 km
Amberlee kitchen Malang	2.60 km

Table 4. Line of Sight (LOS) distance scenario.

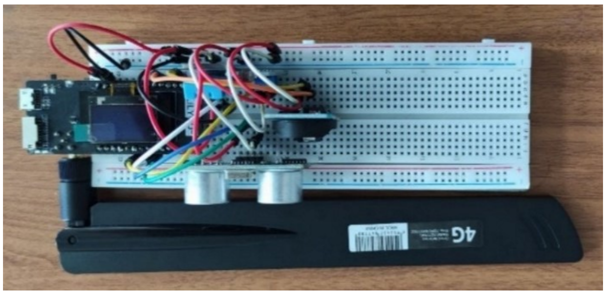

Figure 4. LoRa node.

Figure 5. LoRa gateway.

surroundings outside the campus, ensuring minimal obstruction, at varying distances. Meanwhile, the LoRa Gateway remains positioned on the rooftop of one of the buildings, as illustrated in Figure 3.

The LoRa testing scenarios in NLOS conditions can be seen in Table 3, which shows the distance between the LoRa nodes and the Gateway on each floor of the building, with a distance of 3 metres. Meanwhile, the LOS conditions are depicted in Table 4, where the locations are outside the building with distances ranging from 100 metres to 2 600 metres.

4. Results and discussion

The analysis of LoRaWAN usage for monitoring involves the implementation of LoRa technology on the Lilygo TTGO32 microcontroller device. This microcontroller device plays a crucial role in collecting data from various sensors, such as DHT22 (temperature and humidity sensor), RTC (Real-Time Clock), HCSR04 (ultrasonic distance sensor), and LDR (Light Dependent Resistor). The process of collecting data from these sensors is conducted wirelessly through the LoRa module installed on the Lilygo TTGO32 device. The collected data are then transmitted using LoRa technology to the LoRa RAK2247 device integrated into the Raspberry Pi.

After the data have been successfully transmitted, the next step is to receive the data by the TTN (The Things Network) server. The TTN server functions as a central hub for collecting and managing the data received from the LoRa devices, allowing users to access and analyse the data efficiently. The entire hardware components involved in this system can be seen in Figure 4. The figure illustrates the relationship and connections between the Lilygo TTGO32 microcontroller and the sensors used, as well as how they are interconnected using jumper cables.

As an illustration, Figure 5 depicts the implementation of a LoRa Gateway (enclosed in the red frame)

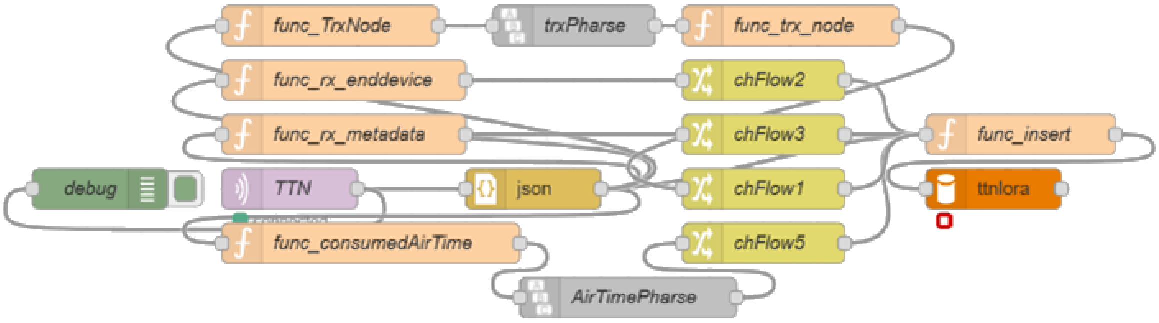

Figure 6. Flows of Node-RED.

and a LoRa fiberglass antenna (enclosed in the black frame) securely installed on the rooftop of one of the buildings. This configuration is designed to capture and receive data transmitted by various sensor nodes scattered around the location.

The data that has been sent (published) by the LoRa Gateway receiver are subsequently received (subscribed) by Node-RED on the Cloud server for data management and stored into a database. Subsequently, the data are displayed in the form of visualisations. Node-RED is an Internet of Things platform that facilitates both data processing and data visualisation. Figure 6 illustrates the flow of nodes within Node-RED.

First, the incoming data from the MQTT server TTN are converted into JSON format, and then certain data to be extracted are separated using the trxPharse function, where this function aims to retrieve only the necessary data from the received JSON. The payload originating from the entire JSON data sent is transformed using the trxPharse function to obtain the required data, including mac address, temperature, humidity, LDR, and distance. The incoming time data from the TTN server is not yet in the desired format; therefore, a function is provided to convert the time format using the Moment library. Subsequently, after the data conversion process, these data are stored in a single database for storage and later visualisation.

The results of data collection taken from various locations and different distances show that the RSSI and SNR values of LoRa improve as the locations and distances get closer and there are no obstacles with the gateway. The longest distance the for NLOS conditions during the research test was 24 metre, or 8 storeys, between the LoRa Node and the LoRa Gateway and for the LOS conditions, it was 2.60 km at Amberlee kitchen Malang. At distances of 1.25 km and 2.20 km, data cannot be transmitted at all using a 10 dBi antenna, which could be attributed to obstacles or interference in the environment around the LoRa Node and the limited coverage of the antenna. Data transmission is no longer possible at a distance of 3 400 metres, specifically at NK Kafe Malang. Upon examining the TTN server, the LoRa Node repeatedly attempted to connect with the LoRa Gateway, but failed, resulting in data not being delivered. This issue occurred due to the limited coverage of the gateway's antenna, making it difficult to establish a reliable connection.

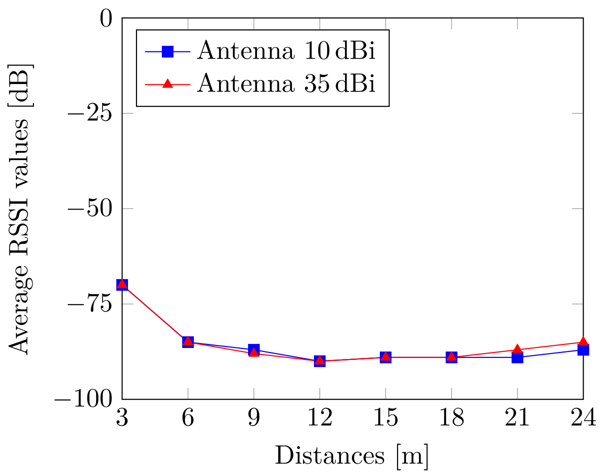

Figure 7. Graph of the average RSSI values for NLOS conditions.

Based on the data presented in Figure 7, it can be seen that the best average Received Signal Strength Indicator (RSSI) value is approximately −70 dB. This measurement was obtained for the 8th floor at a distance of 3 metres from the signal source. These results indicate that at the nearest distance, approaching 0 meters, the signal quality status can be categorised as excellent, in accordance with the classification in Table 1.

The measurement results of the average Signal-to-Noise Ratio (SNR) values can be found in Figure 8, with particular emphasis on the highest values observed for the 8th floor. This observation indicates that on this floor, the received signal quality is relatively optimal, reaching its maximum SNR value. A significant difference in SNR values is evident when comparing the use of antennas with 35 dBi gain and antennas with 10 dBi gain. As the distance between the Gateway and the nodes increases, the difference in SNR values between the two antenna types becomes more pronounced. This suggests that the antenna with 35 dBi gain outperforms the antenna with 10 dBi gain in receiving signals at longer distances.

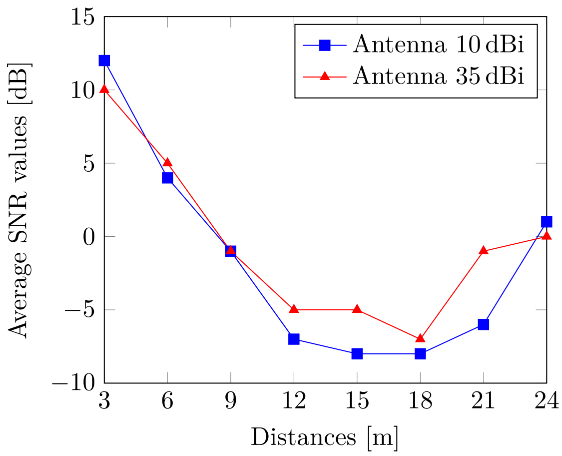

Figure 8. Graph of the average SNR values for NLOS conditions.

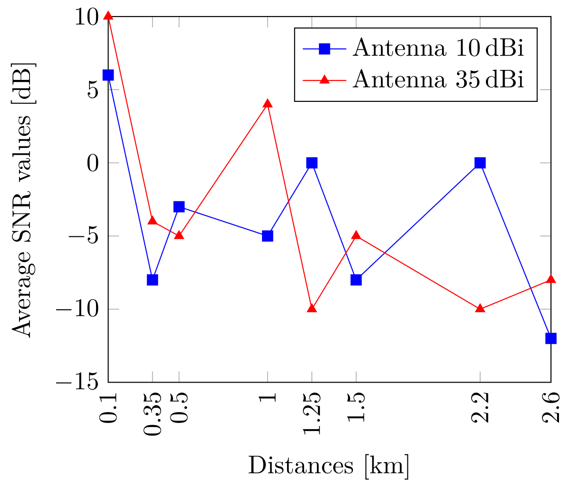

Figure 10. Graph of the average SNR values for LOS conditions.

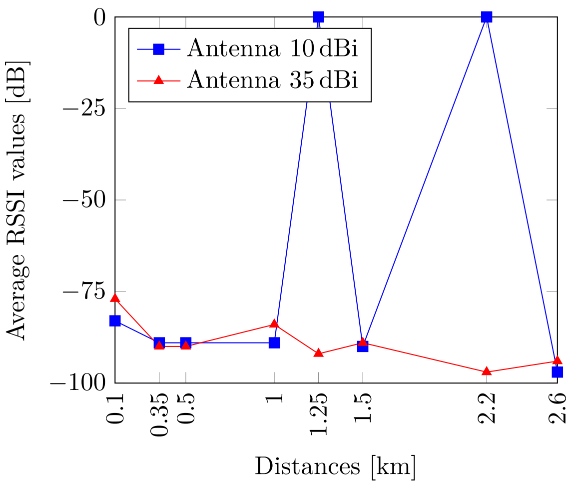

Figure 9. Graph of the average RSSI values for LOS conditions.

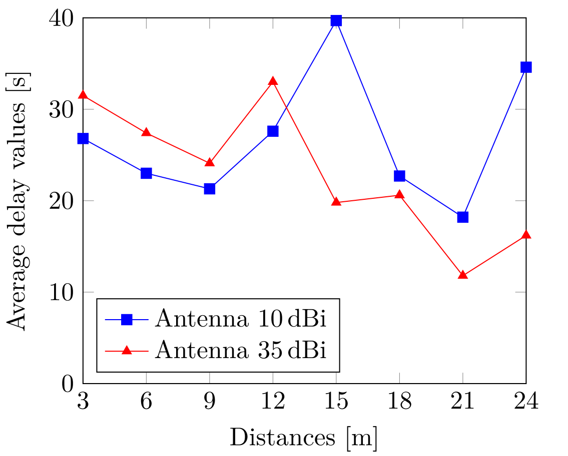

Figure 11. Average delay values for NLOS conditions.

Based on the data presented in Figure 9, it was found that the best average RSSI (Received Signal Strength Indicator) value is −77 dB. This value was obtained for a distance of 2.20 km from the signal source, using a 35 dBi antenna. The result indicates that even at a greater distance, the signal still maintains good quality. With an RSSI value of −77 dB, the signal is classified as "Good" according to the categories in Table 1. This indicates that despite the considerable distance, the LoRaWAN signal still has sufficient strength, demonstrating a reliable and satisfactory network performance.

From the data observed in Figure 10, it can be seen that the average Signal-to-Noise Ratio (SNR) values exhibit an interesting pattern. This condition illustrates that as the distance increases from the signal source, there is a significant increase in the noise level. This indicates that the further way the device is from the signal source, the weaker the received signal strength, and the greater the effect of ambient noise. The increasing noise at greater distances can have a negative impact on the quality of LoRaWAN communication. Decreasing SNR values can lead to a reduction in the accuracy and reliability of data received by the gateway, thus affecting the overall network performance.

From the comprehensive results of the RSSI test, the data transmission using the LoRaWAN module, it can be seen that it falls into the excellent category. Throughout the measurements, the RSSI values never exceeded −102 dB when using the 35 dBi antenna. These findings demonstrate a remarkably strong and reliable signal quality, indicating optimal performance in transmitting data through the LoRaWAN network. The use of the 35 dBi antenna contributed to an improved transmission efficiency and range, providing additional advantages in optimising the network connectivity and durability. These positive outcomes reinforce the confidence that implementing the LoRaWAN module with the appropriate antenna can offer a reliable and effective solution for Internet of Things (IoT) applications that rely on wireless data transmission.

In Figure 11, it can be observed that the data transmission delay time in the LoRa Node using a 35 dBi

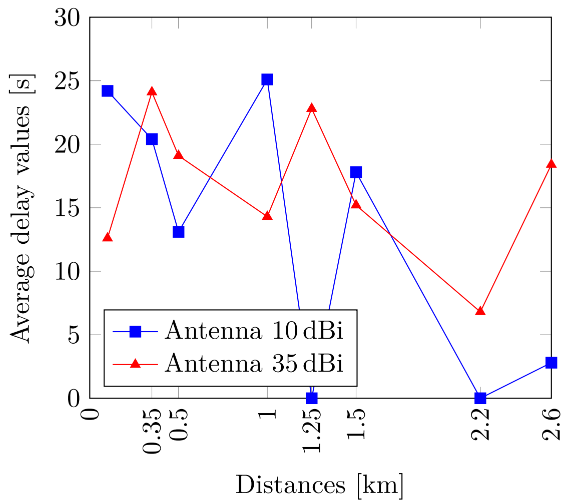

Figure 12. Average delay values for LOS conditions.

Figure 13. Dashboard page interface.

antenna in Non-Line-of-Sight (NLOS) conditions is significantly improved, approximately 6.4 seconds faster compared to the 10 dBi antenna.

From Figure 12, a comparison of Node LoRa performance in Line-of-Sight (LOS) conditions using two different types of antennas is shown. The 35 dBi antenna exhibits a faster response time of approximately 0.5 seconds compared to the 10 dBi antenna. However, it is important to note that this response time may increase with greater distance between the Node LoRa and the gateway, and can be influenced by environmental conditions. When using the 35 dBi antenna, LoRa Node achieves more responsive and faster data communication, optimising the transmission and reception of data with greater efficiency.

In Figure 13, we can observe a comprehensive display that provides information regarding the LoRaWAN network. This presentation includes graphs of RSSI (Received Signal Strength Indicator) and SNR (Signal-to-Noise Ratio), which aid in understanding the signal quality and interference levels within the network. Additionally, the visualization of sensor readings is depicted in various panels. The number of panels displayed corresponds to the number of active or illuminated Nodes at a given time. Each panel represents data from a distinct Node, providing relevant information regarding the sensor measurements conducted by each Node.

5. Discussions

From the conducted research in both Line of Sight (LOS) and Non-Line of Sight (NLOS) conditions, the implementation of LoRaWAN architecture aids in transmitting sensor data, particularly for sensor node placement in multi-storey buildings. The addition of antenna specifications with varying dBi values does not significantly affect the success of data transmission in indoor settings, whereas it does have a considerable impact when transmitting data in outdoor settings.

Parameters, such as Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), data loss, and data rate, are commonly used for evaluating the use of LoRaWAN technology [1, 30, 35]. Specifically, RSSI and SNR provide insights into signal energy and interference levels in LoRaWAN communication. In LoRaWAN devices, the signal strength and quality can influence the communication range, communication reliability, and power consumption. While previous evaluations of LoRaWAN in indoor settings [22] only used RSSI and Packet Reception Rate (PRR).

When conducting the experiment of transmitting sensor data from the LoRa node to the LoRaWAN Gateway (uplink), the data cannot be directly transmitted or received by the gateway, especially in NLOS conditions. The LoRaWAN gateway does not respond directly to the LoRa node (downlink), even though the node has been periodically sending sensor data. Overall, when testing for data loss in NLOS conditions, the success rate of transmitted data is approximately 45 %. This indicates a relatively high data loss rate, necessitating the appropriate LoRaWAN configuration or parameter adjustments.

The results of this study demonstrate the capability of LoRaWAN in transmitting data in Line of Sight (LOS) and Non-Line of Sight (NLOS) conditions, providing deeper insights when considering the real-world implementation of the LoRaWAN technology in various fields. Although this research has presented the data transmission capability of LoRaWAN with parameters similar to previous studies, the positioning of Gateway nodes needs to be carefully considered, taking into account the locations of each individual node. By placing the Gateway nodes in appropriate positions, the potential noise generated by the surrounding environment can be minimised, and the reception of node signals can remain strong. The percentage of data loss experienced by the LoRa nodes in this study was relatively high, which was an undesired outcome, necessitating the optimization of data transmission performance from the LoRa nodes to the LoRaWAN gateway. Such optimisation can be achieved, for example, by implementing Adaptive Data Rate (ADR) techniques. The use of ADR can impact communication latency, where increasing the data rate may result in lower latency due to the faster data transmission, whereas decreasing the data rate to enhance reliability could lead to higher latency, as it would take more time to transmit the data.

6. Conclusion

Several studies have evaluated the performance of LoRaWAN in various fields, such as agriculture, transportation, and healthcare to support long-range data transmission [1, 20–25, 30, 39]. In this research, the same parameters, namely RSSI, SNR, and data loss, were used and applied to both Line of Sight (LOS) and Non-Line of Sight (NLOS) conditions to investigate the performance of LoRaWAN in data transmission. Real-world use cases were also used to depict practical scenarios when applied in specific domains. Other studies [1] used simulation tools to assess the performance of LoRaWAN. The addition of signal boosters, such as antennas, did not significantly affect the transmission of sensor data. Both the 10 dBi and 35 dBi antennas were able to perform data transmission effectively in multi-storey buildings, particularly in NLOS conditions. However, in LOS conditions, the use of signal boosters on the LoRa nodes showed an impact on data transmission performance, as evidenced by the 35 dBi antenna achieving a transmission range of 2.60 km, which is a much greater range than in the case of the 10 dBi antenna.

To support a more in-depth investigation of LoRaWAN performance, testing the Adaptive Data Rate (ADR) is necessary. With ADR, LoRa devices can adjust the data rate based on the current network conditions. In favorable network conditions, the devices will use higher data rates, resulting in faster data transfer rates. Conversely, in challenging network conditions or when interference is present, the devices will lower the data rate to enhance communication reliability, albeit at the expense of slower data transfer rates. Additionally, the use of a standalone or private LoRa server, such as the ChirpStack Network Server, allows for a flexible configuration and parameter adjustment to achieve optimal LoRaWAN performance.

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