Performance Analysis of LoRa in Indoor Settings: A Data Descriptor

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***Abstract*—LoRaWAN (Long Range Wide Area Network) has emerged as a prominent wireless communication protocol, mainly for Internet of Things (IoT) applications due to its long-range capabilities and low-power requirements. While LoRaWAN has been extensively studied in open environments, its performance and challenges in closed environments, such as indoor or urban settings, remain relatively unexplored. We investigate factors such as signal propagation and interference that significantly impact LoRaWAN's effectiveness in closed environments. Through a series of experimental evaluations and data collection, we provide insights into the limitations and potential enhancements for LoRaWAN in closed environments. Our findings contribute to understanding the feasibility and optimization strategies of deploying LoRaWAN systems in indoor or urban settings, enabling more efficient and reliable communication in closed environments.**

I. Introduction

LoRaWAN (Long Range Wide Area Network) is a wireless communication technology designed to connect low-power devices over long distances. It allows devices, such as sensors and other Internet of Things (IoT) devices, to communicate with each other and with central systems through a network of gateways. Here's a brief explanation of how it works, also depicted through Figure 1. LoRaWAN consists of four main components:

- End Nodes (IoT devices): These are the sensor nodes or devices that collect data and communicate over the network. E.g thermostat regulation or water monitoring in a smart home setting.
- Gateways: Gateways act as base stations that receive data from end devices and forward it to the network server.
- Network Server: The network server manages the communication between end devices and gateways. It also handles device authentication, data encryption, and routing.
- Application Server: It processes and decrypts data from end devices and acts as a bridge between the LoRaWAN network and end-user applications, facilitating data processing and enabling IoT use cases.

In LoRaWAN, the payload of the data transmitted by end devices is encrypted to ensure data security and privacy. AES (Advanced Encryption Standard) is the encryption algorithm used to secure the payload data in LoRaWAN.

LoRa technology has gained significant attention in the field of wireless communication, particularly for applications in

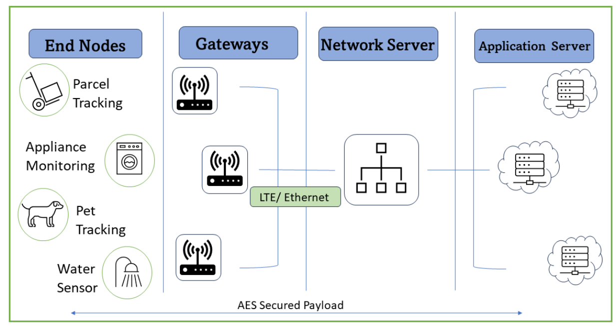


Figure 1. Network Architecture of LoRa [1]

the Internet of Things (IoT). Its ability to provide long-range connectivity, low-power operation, and cost-effectiveness has made it an appealing choice for various IoT deployments. We aim at exploring the effectiveness and optimization of LoRa in closed environments such as a building. Understanding the behavior of LoRaWAN in closed environments is crucial for realizing the full potential of IoT applications in domains such as smart buildings, industrial automation, asset tracking, and healthcare monitoring. The potential of LoRaWAN in closed settings is evident, but as of now, there has been limited research conducted in this area [2]. Similarly, there is a scarcity of available datasets pertaining to the practical application of LoRaWAN in various scenarios. Therefore, in this paper, we carried out an experiment to understand the reception of LoRa in closed settings and generate a dataset explaining the important metrics, RSSI (Received Signal Strength Indicator) and Reception Ratio that are found to dictate LoRa's performance. The experiment was carried out on a single day, in the NW1 building of University of Bremen, Bremen, Germany. Figure 2 shows the map of the NW1 building which consists of multiple blocks each indicated through its specific symbol or letter. The data's primary goal is to provide researchers with the understanding of factors such as distance, obstacles and interference with other wireless devices etc that dictate LoRa's performance. Through this paper, our primary objective is to investigate and understand the characteristics of LoRa technology. Additionally, we aim to enhance our existing deployment by addressing the following key questions:

- Assess the current performance of our LoRa deployment by rating its effectiveness.
- Identify deployment gaps with no access at all, pinpointing areas where the LoRa coverage is insufficient or absent.
- Analyze areas with Reception Ratio below 50%, to understand the reasons behind this suboptimal performance.
- Propose potential locations for new gateway installations to improve network coverage in areas with identified shortcomings.

As we progress in this paper, we will present the methodology, discussing gathered data and analyzing results. The conclusion will summarize findings and offer strategies to optimize our LoRaWAN network.

II. Methodology

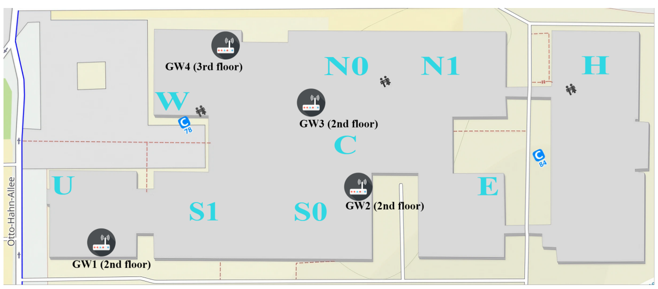


Figure 2. Map of NW1 with blocks and router positions indicated [3]

The experiment setup phase was fairly simple.

- 4 gateways/routers were deployed in different locations in the NW1 building. Figure 2 shows the location of the gateways indicated by a router symbol.
- We had a LoRa test device that we used to send packets.
- The NW1 building consists of different blocks named as U, S1, S0, C, N0, N1, H, E, W and 5 floors from 0 to 4. From each location, for example block U floor 0 we sent exactly 4 packets. In total, there are 45 positions in our dataset. However, data was recorded for only 44 positions because position S1 on floor 3 was inaccessible due to construction.
- The locations for data collection are marked through a grid box as shown in Figure 3 for floor 0 which indicates that this test area would be the best possible for recording readings but during the actual experiment some parts of the buildings were found to be inaccessible due to construction or spaces with limited entry. Hence, the actual spot where the reading was taken is indicated by a cross symbol.
- Timestamps were noted for each packet sent.
- We transmitted data through the various blocks and floors in order to compare the different RSSI (Received Signal Strength Indicator) and see how they vary accordingly.
- The time stamps and respective RSSI were stored in an excel file. Figure 4 shows an excerpt of the raw data.

Figure 3. Floor map of level 0 with data collection spots indicated [4]

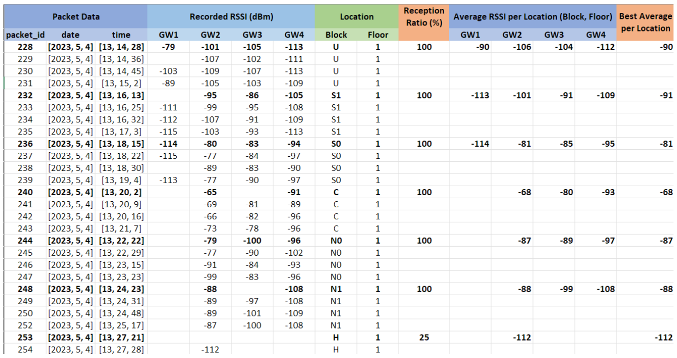
Packet Data			Recorded RSSI (dBm)				Location	
packet_id	date	time	GW1	GW2	GW3	GW4	Block	Floor
228	[2023, 5, 4]	[13, 14, 28]	-79	-101	-105	-113	U	1
229	[2023, 5, 4]	[13, 14, 36]		-107	-102	-111	U	1
230	[2023, 5, 4]	[13, 14, 45]	-103	-109	-107	-113	U	1
231	[2023, 5, 4]	[13, 15, 2]	-89	-105	-103	-109	U	1
232	[2023, 5, 4]	[13, 16, 13]		-95	-86	-105	S1	1
233	[2023, 5, 4]	[13, 16, 25]	-111	-99	-95	-108	S1	1
234	[2023, 5, 4]	[13, 16, 32]	-112	-107	-91	-109	S1	1
235	[2023, 5, 4]	[13, 17, 3]	-115	-103	-93	-113	S1	1
236	[2023, 5, 4]	[13, 18, 15]	-114	-80	-83	-94	S0	1
237	[2023, 5, 4]	[13, 18, 22]	-115	-77	-84	-97	S0	1
238	[2023, 5, 4]	[13, 18, 30]		-89	-83	-90	S0	1
239	[2023, 5, 4]	[13, 19, 4]	-113	-77	-90	-97	S0	1
240	[2023, 5, 4]	[13, 20, 2]		-65		-91	C	1
241	[2023, 5, 4]	[13, 20, 9]		-69	-81	-89	C	1
242	[2023, 5, 4]	[13, 20, 16]		-66	-82	-96	C	1
243	[2023, 5, 4]	[13, 21, 7]		-73	-78	-96	C	1
244	[2023, 5, 4]	[13, 22, 22]		-79	-100	-96	N0	1
245	[2023, 5, 4]	[13, 22, 29]		-77	-90	-102	N0	1
246	[2023, 5, 4]	[13, 23, 15]		-91	-84	-93	N0	1
247	[2023, 5, 4]	[13, 23, 23]		-99	-83	-96	N0	1
248	[2023, 5, 4]	[13, 24, 23]		-88		-108	N1	1
249	[2023, 5, 4]	[13, 24, 31]		-89	-97	-108	N1	1

Figure 4. Excerpt of raw data, floor 1 [4]

III. Data Description

The open-access dataset contains records stored in CSV (Comma-Separated Values) files. The data collection was spanned over three hours on a single day. The data was logged on a PC/server connected to all the gateways. The logged raw data consisted of Packet ID, Date, Time and the RSSI values of each packet received by each gateway (duplicates included). The data was further processed by adding the respective block and floors and was then stored in a CSV file as shown in Figure 5. The Excel file consists of the following fields/ columns:

- Packet_id: Tells the packet number that was sent through the LoRa device. This column represents a unique identifier, a numerical value for each packet of data. It helps to distinguish one packet from another.
- Date: This column indicates the date on which the experiment was conducted in the format [Year, Month, Date].
- Time: This column shows the time when a certain packet was sent. It uses the format [Hour, Minute, Second].
- GW1 - GW4: This comprises of different gateways/receivers. Their values indicate the signal strength from different gateways. For some instances, a data packet has been received by several gateways. For others the packet was not received by any gateway, hence the field is left empty.



Packet Data			Recorded RSSI (dBm)				Location		Reception Ratio (%)	Average RSSI per Location (Block, Floor)				Best Average per Location
packet_id	date	time	GW1	GW2	GW3	GW4	Block	Floor		GW1	GW2	GW3	GW4	
228	**[2023, 5, 4]**	**[13, 14, 28]**	**-79**	**-101**	**-105**	**-113**	**U**	**1**	**100**	**-90**	**-106**	**-104**	**-112**	**-90**
229	[2023, 5, 4]	[13, 14, 36]		-107	-102	-111	U	1						
230	[2023, 5, 4]	[13, 14, 45]	-103	-109	-107	-113	U	1						
231	[2023, 5, 4]	[13, 15, 2]	-89	-105	-103	-109	U	1						
232	**[2023, 5, 4]**	**[13, 16, 13]**		**-95**	**-86**	**-105**	**S1**	**1**	**100**	**-113**	**-101**	**-91**	**-109**	**-91**
233	[2023, 5, 4]	[13, 16, 25]	-111	-99	-95	-108	S1	1						
234	[2023, 5, 4]	[13, 16, 32]	-112	-107	-91	-109	S1	1						
235	[2023, 5, 4]	[13, 17, 3]	-115	-103	-93	-113	S1	1						
236	**[2023, 5, 4]**	**[13, 18, 15]**	**-114**	**-80**	**-83**	**-94**	**S0**	**1**	**100**	**-114**	**-81**	**-85**	**-95**	**-81**
237	[2023, 5, 4]	[13, 18, 22]	-115	-77	-84	-97	S0	1						
238	[2023, 5, 4]	[13, 18, 30]		-89	-83	-90	S0	1						
239	[2023, 5, 4]	[13, 19, 4]	-113	-77	-90	-97	S0	1						
240	**[2023, 5, 4]**	**[13, 20, 2]**		**-65**		**-91**	**C**	**1**	**100**		**-68**	**-80**	**-93**	**-68**
241	[2023, 5, 4]	[13, 20, 9]		-69	-81	-89	C	1						
242	[2023, 5, 4]	[13, 20, 16]		-66	-82	-96	C	1						
243	[2023, 5, 4]	[13, 21, 7]		-73	-78	-96	C	1						
244	**[2023, 5, 4]**	**[13, 22, 22]**		**-79**	**-100**	**-96**	**N0**	**1**	**100**		**-87**	**-89**	**-97**	**-87**
245	[2023, 5, 4]	[13, 22, 29]		-77	-90	-102	N0	1						
246	[2023, 5, 4]	[13, 23, 15]		-91	-84	-93	N0	1						
247	[2023, 5, 4]	[13, 23, 23]		-99	-83	-96	N0	1						
248	**[2023, 5, 4]**	**[13, 24, 23]**		**-88**		**-108**	**N1**	**1**	**100**		**-88**	**-99**	**-108**	**-88**
249	[2023, 5, 4]	[13, 24, 31]		-89	-97	-108	N1	1						
250	[2023, 5, 4]	[13, 24, 48]		-89	-101	-109	N1	1						
252	[2023, 5, 4]	[13, 25, 17]		-87	-100	-108	N1	1						
253	**[2023, 5, 4]**	**[13, 27, 21]**					**H**	**1**	**25**		**-112**			**-112**
254	[2023, 5, 4]	[13, 27, 28]		-112			H	1						

Figure 5. Excerpt of performance metrics, floor 1 [5]

- Loc: This column indicates the location/block in the NW1 building from where the packet was sent.
- Floors: This column indicates the floor associated with the recorded data.

This data was further processed to calculate the two main metrics of performance, average RSSI measured in dBm and the Reception Ratio as a percentage, depicted through Figure 5. The average RSSI for each gateway can be clearly seen. The dataset is accessible on Zenodo, and the link to access it is provided in the Reference section. To analyze and visually represent the data, we utilized graphs generated using Excel and Python libraries that are discussed in the section followed.

IV. Discussion

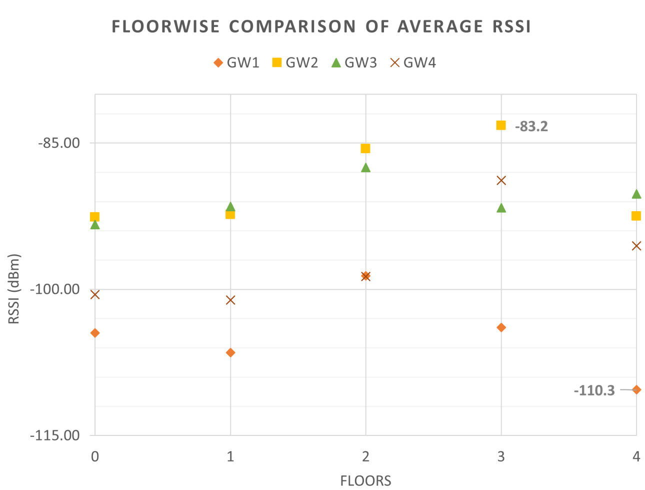


Figure 6. Average RSSI floor-wise performance

In Figure 6, the scatter plot illustrates the average performance of the four gateways across different floors. The trends reveal that GW2 consistently outperforms the other gateways on all floors, making it the best overall performer. On the other hand, GW1 exhibits the lowest performance amongst the four gateways. On floor 4, the lowest RSSI value was recorded, measuring -110.3 dBm for GW1. Conversely, the highest RSSI value of -83.2 dBm was recorded on floor 3 for GW2. As

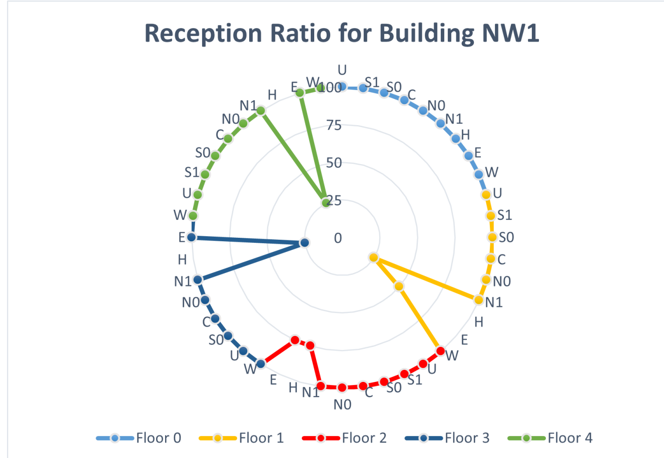


Figure 7. Reception Ratio for all locations in NW1 building

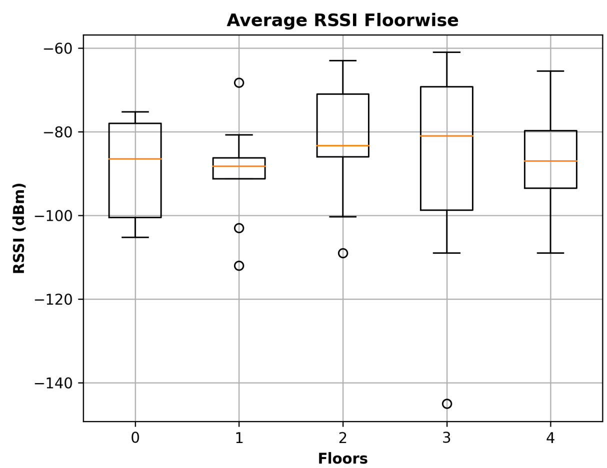


Figure 8. Box-plot representing average RSSI across all floors

expected floor 2 exhibits better RSSI values, considering that three of our gateways are situated on that floor.

In Figure 7, the overall reception ratio for the entire NW1 building is depicted through a radar chart. As a fact, data was only recorded for 44 out of 45 positions, a 100% (ideal) reception ratio was recorded for 38 positions, indicating that 86% of the building is fully covered by the current deployment scenario. The data clearly indicates that block H has the lowest coverage, with the lowest recorded reception ratios of 25% across floor 1, 3 and 4. Following that, block E shows a reception ratio of 50% on floor 1 and 75% on floor 2, suggesting a comparatively weaker coverage in those areas.

The box-plot in Figure 8 gives us a statistical representation of our average RSSI values across floor 0 to 4. It can be seen that the average RSSI on floors 1,2,4 do not deviate too much, which indicates consistent performance. It must be noted since the data was not recorded for S1, 3rd floor it is represented at -142 dBm as an outlier and is not reflected in the plot data. Regardless of that it can be seen that floor 0 and 3 perform

relatively lower than the other floors.
All the above discussed graphs and the processed data can we found on our GitHuB repository which can be accessed through the link provided in the Reference section.

V. Conclusion

After a thorough analysis of our data, we can confidently address the key questions outlined in the introduction. As discussed previously in Section 4, the analysis represented in Figure 7 indicates that our current deployment scenario provides a reasonably good coverage of approximately 86% (Figure 10) of the entire building, this reflects the effectiveness of our LoRaWAN network in reaching a significant portion of the building. Furthermore, all of RSSI values are within the plausible range of 0 to -130 dBm. On this basis we can say that our current performance is pretty good but can be improved further as discussed below.

As shown in Figure 10, in our current deployment scenario, we have coverage in all areas and there are no identified gaps. Even though some areas have as low as 25% coverage, we have ensured that every location receives at least some level of signal reach.

In our analysis, we have identified areas of low performance where the reception ratio is less than 50% in three instances. All these instances occur in block H on floor 1, 3, and 4. These areas are experiencing suboptimal signal reception, indicating the need for improvements to enhance the coverage and performance in block H.

To enhance our existing deployment scenario, we propose the addition of a new gateway in block H on the second floor as demonstrated through Figure 9. This placement will effectively cover the gaps in that block, improving signal reception and overall performance. Choosing the second floor aligns with the best approach, as it has been shown that placing gateways in the middle of the building, where there are multiple floors, leads to optimal coverage and better signal distribution throughout the building. By implementing this improvement, we can address the areas of low performance in block H and ensure a more robust and reliable LoRaWAN network across all floors.

Removing a gateway is not recommended, especially since the current gateways are providing good enough coverage. Instead, we suggest repositioning GW3 as shown in Figure 9 to better cover block E, as its reception ratio was observed to be slightly lower on the first floor.

Performance	Reception Ratio Criteria	Total Occurrence
Ideal	R = 100	86.4%
Good	100 > R > = 50	6.8%
Low	R < 50	6.8%
No Access	R = 0	0.0%

Figure 10. Table indicating reception ratio criteria and total occurrence

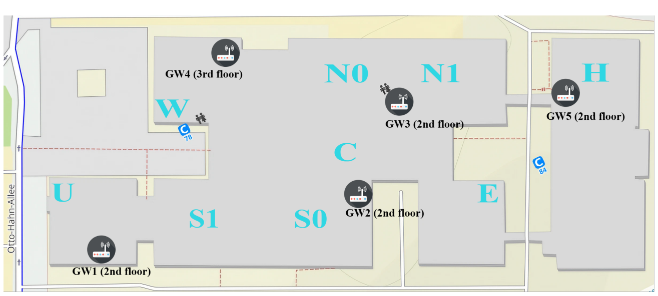


Figure 9. Suggested router positions in NW1 [3]

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