Analysis of Coverage Range and Data Transmission Success Rate of LoRaWAN in the Implementation of an Electrical Power Monitoring System

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***Abstract*— This research addresses PT. Indojaya Mitra Sarana's need to implement a LoRaWAN-based electrical power monitoring system. Since the company had not previously used LoRaWAN, its devices required field testing to assess reliability under real conditions, especially in environments with physical obstructions such as buildings and trees. To evaluate performance, field experiments compared LoRaWAN communication using two gateway antenna heights (15 m and 30 m) and a baseline Line-of-Sight (LOS) scenario. Key parameters measured were RSSI, SNR, number of packets received, and packet loss. Results show that raising the antenna from 15 m to 30 m consistently improves coverage, signal strength, and signal quality while reducing noise interference. This improvement is attributed to fewer propagation obstacles, conditions closer to LOS, and reduced multipath fading. For spreading factor (SF) selection, SF7 is recommended for short distances due to high speed and low power use, SF9 for medium distances due to balanced performance, and SF10 for long distances when using the 30 m antenna height. Overall, a 30 m gateway antenna provides optimal performance across distances, with SF adjusted based on range and efficiency needs, serving as a practical reference for deployment.**

***Keywords*— LoRaWAN, Power Monitoring, RSSI, SNR, Spreading Factor.**

I. INTRODUCTION

Electricity is a primary energy source that supports productivity and daily activities across industrial, commercial, and residential sectors, and its availability is closely linked to economic growth and operational continuity [1]. In many multi-tenant facilities such as office buildings, shopping centers, and residential complexes, property managers are responsible for monitoring tenants' electricity consumption for billing, control, and reporting purposes. However, in practice, energy metering is still frequently performed manually by visiting each tenant's kWh meter, recording readings, and compiling them into reports. This conventional approach is time-consuming, increases operational costs, and is highly prone to human error, especially when the process involves additional personnel or third-party vendors. In addition, manual recording typically lacks integrated data management, making it difficult to perform historical analysis, identify anomalies, or support fast decision-making for energy efficiency improvements.

To address these limitations, PT. Indojaya Mitra Sarana proposes an automated electrical power monitoring system based on Long Range Wide Area Network (LoRaWAN). In the proposed architecture, LoRaWAN nodes collect meter data from each tenant, transmit the readings to a LoRaWAN gateway, and forward them to ThingsBoard for visualization through dashboards. This approach enables periodic and automated monitoring without manual visits, reduces dependence on external vendors, minimizes miscalculation risks, and improves service quality through more accurate and consistent reporting. Similar energy monitoring initiatives using IoT concepts have demonstrated the feasibility of real-time consumption monitoring, especially for improving transparency and operational efficiency at the household and facility levels [2]. Moreover, IoT-based monitoring systems are increasingly used in various domains because they simplify data acquisition, support remote access, and improve system responsiveness [3].

LoRaWAN is particularly suitable for power monitoring in wide-area deployments because it offers long-range communication with low power consumption, making it effective for environments requiring distributed sensing and periodic reporting [4]. LoRaWAN-based monitoring systems have also been successfully applied in other operational contexts, such as hydroponic monitoring, illustrating its practicality for continuous measurement and alerting mechanisms in real deployments [5]. Nevertheless, LoRaWAN performance is strongly affected by the deployment environment, device configuration, network traffic characteristics, and propagation conditions. Recent research emphasizes the importance of analyzing LoRaWAN traffic and behavior using empirical datasets to understand reliability patterns, packet delivery trends, and network dynamics under realistic loads [6], [7]. Therefore, performance validation

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becomes essential before LoRaWAN can be deployed as a dependable backbone for power monitoring in real facilities.

Despite its promising potential, PT. Indojaya Mitra Sarana has never implemented LoRaWAN in previous projects, and the newly acquired commercial Milesight LoRaWAN devices must be validated for reliability under field conditions [8], [9]. In urban areas such as Malang City, LoRaWAN links may be degraded by physical obstructions, multipath fading, and noise interference, which can reduce packet reception and compromise monitoring continuity. Prior studies evaluating LoRaWAN in urban and mixed urban–rural environments show that communication quality can vary significantly depending on distance, gateway placement, and propagation barriers, reinforcing the need for site-specific testing [10]. In addition, system-level performance is commonly assessed through link and network metrics such as RSSI and packet delivery performance, which are also widely used as signal quality indicators in practical wireless evaluations [11].

Accordingly, this study focuses on analyzing the performance of LoRaWAN devices for an electrical power monitoring system under real operational conditions. Field testing is carried out by comparing device performance under two gateway antenna heights (15 m and 30 m) and by observing baseline Line-of-Sight (LOS) conditions when feasible. The evaluation metrics include received signal strength indicator (RSSI), signal-to-noise ratio (SNR), the number of received packets, and packet loss, which collectively represent link quality, reliability, and data delivery consistency. Furthermore, the study considers LoRaWAN configuration strategies through spreading factor (SF) selection, because SF directly influences range, data rate, and robustness, and must be tuned to meet monitoring requirements across short, medium, and long distances [12], [13]. The results of this evaluation are expected to provide practical guidance for PT. Indojaya Mitra Sarana in deploying a reliable LoRaWAN-based monitoring system and to support broader adoption in multi-tenant environments where scalable and low-maintenance infrastructure is required.

In addition to performance concerns, modern power monitoring infrastructures should also consider data integrity and operational security, particularly when monitoring devices interface with industrial protocols or supervisory systems. Prior work has shown that weaknesses in industrial communication protocols can be exploited if security is not properly addressed, highlighting the need for cautious system design and reliable data handling mechanisms in monitoring deployments [14], [15]. Therefore, this research not only evaluates LoRaWAN feasibility and reliability but also strengthens the foundation for scalable, automated, and more trustworthy energy monitoring services in office buildings, shopping centers, residential complexes, and other public infrastructures.

II. METHOD

This research adopts a quantitative experimental approach in order to evaluate the performance of LoRaWAN devices for electrical power monitoring. The process involves literature study, system design, prototype development, testing and data collection, data analysis, and system evaluation. The overall methodology was structured systematically to ensure accurate results and reliability in real implementation scenarios.

A. Research Flow

The research began with problem identification and formulation, focusing on the challenges of managing electrical energy consumption across different areas. A systematic framework was then established, followed by literature review, system design, prototype development, testing, analysis, and evaluation. The overall research flow is illustrated in the flowchart shown in Fig. 1.

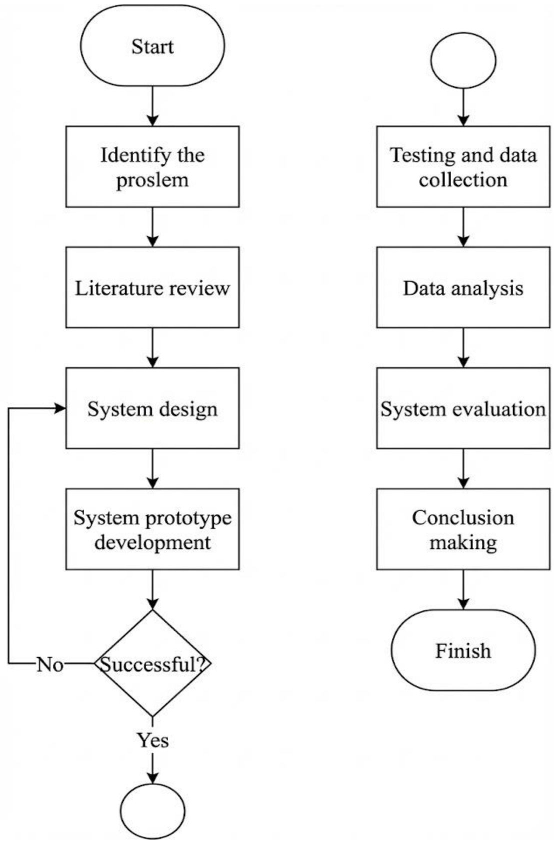
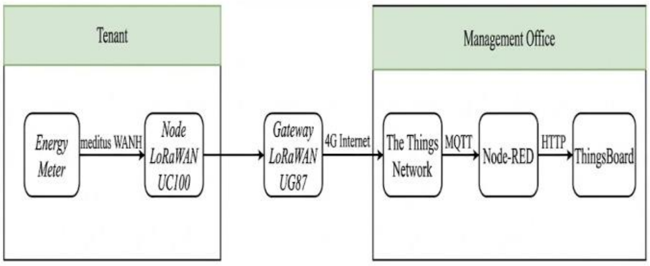


Figure 1. Research Flowchart

The flowchart describes each stage of the study, from identifying the problem to drawing the final conclusions. Each step was designed to ensure that the system could be built, tested, and refined to meet the intended objectives of power monitoring using LoRaWAN.

B. System Block Diagram

Before conducting performance analysis, a block diagram of the system was designed to illustrate the relationship between components, data communication flow, and the integration of hardware and software. The block diagram of the proposed LoRaWAN-based power monitoring system is presented in Fig. 2.



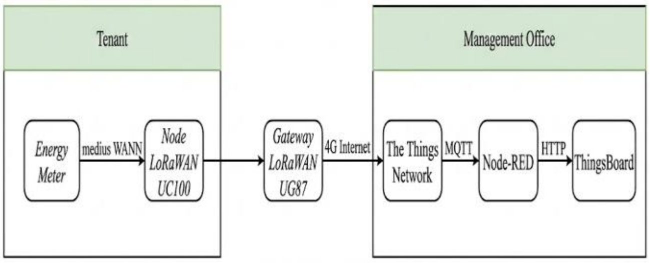


Figure 2. Block Diagram

As shown in Fig. 2, each tenant is equipped with an energy meter connected to a LoRaWAN node. The node transmits the measured parameters—including active power, reactive power, total energy consumption, voltage per phase, current per phase, power factor, input power, and output power—using the Modbus protocol. Data is then forwarded to the LoRaWAN gateway, which communicates with *The Things Network (TTN)*. From TTN, the data is processed by Node-RED before being visualized in ThingsBoard, providing a user-friendly dashboard for energy monitoring.

C. Sampling and Test Locations

Sampling was conducted using a purposive sampling technique, selecting locations in Malang City to represent realistic urban conditions. Two gateways were installed at different heights: 15 meters (at Jalan Bunga Srigading No. 18) and 30 meters (at the Informatics Engineering Building, State Polytechnic of Malang). LoRaWAN nodes were then tested at multiple distances, starting from 100 meters and extended until the signal could no longer be received by the gateway. This design allows evaluation of LoRaWAN performance across varying distances and antenna elevations.

D. Data Collection

Data collection was carried out to analyze the system's performance based on several communication and electrical parameters. The data included:

- Signal-to-Noise Ratio (SNR): Measures signal quality relative to background noise.
- Received Signal Strength Indicator (RSSI): Indicates the strength of the signal received by the gateway.
- Packet Loss: The percentage of lost data packets during transmission.
- Received Packets: The number of successfully delivered data packets.
- Electrical Power Data: Active power (kW), reactive power (kVAR), total energy consumption (kWh), voltage (V), current (A), power factor, input power (W), and output power (W).

The measurements were collected using an energy meter connected via Modbus RS485, with data transmitted through the Milesight UC300 LoRaWAN node to the UG67 gateway. All data was stored and processed through TTN and Node-RED before visualization in ThingsBoard.

E. Testing Parameters

Performance evaluation was based on four main parameters:

1. Packet Loss – reliability of communication.
2. RSSI – strength of the received signal.
3. SNR – quality of the received signal compared to noise.
4. Received Packets – effectiveness of data transmission.

These parameters were analyzed under different scenarios: varying spreading factors (SF7–SF10), different gateway heights (15 m and 30 m), and multiple distances between node and gateway.

III. RESULTS AND DISCUSSION

This section presents the experimental results of LoRaWAN performance testing, focusing on Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), packet loss, and the number of received packets. The tests were conducted at two gateway antenna heights, namely 15 meters and 30 meters, across multiple communication distances and spreading factors (SF7 to SF10). Additionally, a baseline test was performed as a reference for ideal conditions where data transmission is consistently successful. The results are presented in tables and figures, followed by detailed explanations and discussions.

A. Testing at 15 Meter Height

The first test scenario was conducted with the gateway antenna mounted at a height of 15 meters. Table 1 consolidates the results, showing both the closest tested distance with perfect reception and the maximum reliable distance achieved for each SF before performance degraded.

TABLE I
PERFORMANCE SUMMARY AT 15 M HEIGHT

SF	Test Distance (m)	Avg. RSSI (dBm)	Avg. SNR (dB)	Packet Loss (%)	Avg. Rx Packets (/min)
7	80	-73.8	5.3	0	1.256
	200	-78.7	-1.45	0	1.204
8	110	-80.4	-3.96	0	1.256
	300	-84.3	-10.97	40	0.653
9	140	-81	-2	0	1.250
	400	-85.2	-14.3	0	1.235
10	180	-80.4	-1.6	0	1.245
	500	-84.6	-16.06	0	1.250

The urban environment at 15m significantly impacts performance. SF7 proved to be the most robust for short-range applications, providing perfect packet reception from as close as 80 meters with a strong signal (SNR: 5.3 dB) up to 200 meters with a weaker but still functional signal (SNR: -1.45 dB). SF8's performance was limited; its reliable range was confined to 110 meters, beyond which packet loss soared to 40% and SNR became critically poor (-10.97 dB). SF9 and SF10 traded signal quality for range. They achieved much longer reliable distances (400m and 500m respectively) with 0% packet loss, but operated with very low negative SNR values (-14.3 dB and -16.06 dB), indicating they are on the very edge of usability and are highly susceptible to noise at this antenna height.

The visualization of this testing result is shown in Fig. 3.

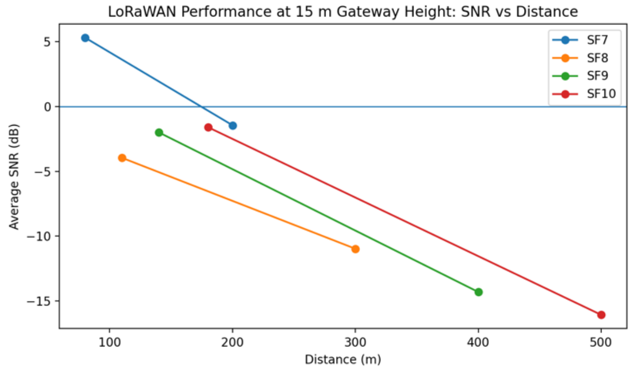


Figure 3. SNR vs Distance (Gateway Height 15 m)

B. *Testing at 30 Meter Height*

Elevating the gateway antenna to 30 meters dramatically improved performance by reducing urban obstructions. Table 2 summarizes the results, showing the impressive extension of both the closest and maximum reliable ranges.

TABLE II
PERFORMANCE SUMMARY AT 30 ANTENNA HEIGHT

SF	Test Distance (m)	Avg. RSSI (dBm)	Avg. SNR (dB)	Packet Loss (%)	Avg. Rx Packets (/min)
7	120	-85.6	12.26	0	1.250
	300	-104.8	-7.58	44.44	0.920
8	160	-95.6	6.32	0	1.250
	500	-104.8	-3.22	0	3.330
9	200	-96.4	6.88	0	1.250
	600	-105.8	-8.7	0	3.230
10	230	-100.4	1.88	0	1.250
	800	-108.2	-16.3	73.68	1.380

The higher antenna location drastically improved signal clarity. SF7 provided exceptional performance at 120 meters with a very high SNR (12.26 dB), making it ideal for short-range, high-reliability applications. SF8 reliably covered 160 meters with a good, positive SNR (6.32 dB). While it showed 0% packet loss at 500 meters, an abnormally high packet rate (3.33/min) indicated massive retransmissions due to an unstable connection, meaning this is not a reliable operating distance.

SF9 emerged as a strong candidate for medium range, operating flawlessly at 200 meters with a solid SNR of 6.88 dB. Similar to SF8, its performance at 600 meters was unstable due to retransmissions. SF10 provided the longest reliable range at 230 meters with a positive SNR (1.88 dB). However, pushing it to 800 meters resulted in catastrophic packet loss (73.68%), confirming the practical limit for this configuration.

The visualization of this testing result is shown in Fig. 4.

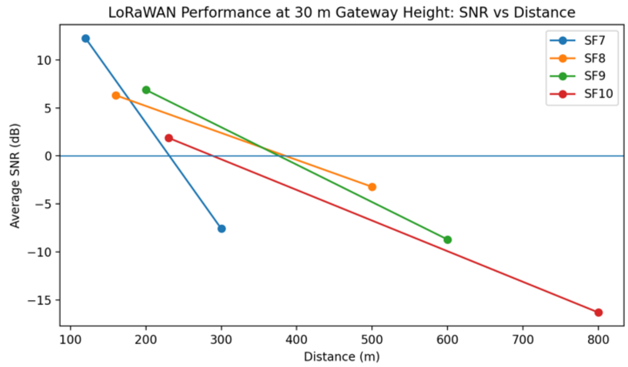


Figure 4. SNR vs Distance (Gateway Height 30 m)

C. *Baseline Testing (Line-of-Sight)*

A baseline test under optimal Line-of-Sight (LOS) conditions established the theoretical maximum performance for each SF, free from urban interference. These results, summarized in Table 3, serve as the benchmark for comparing the urban performance.

TABLE 1
BASELINE PERFORMANCE SUMMARY (LOS)

SF	Distance (m)	Avg. RSSI (dBm)	Avg. SNR (dB)	Packet Loss (%)	Avg. Rx Packets (/min)
7	200	-83.8	10.76	0	1.250
8	230	83.6	9.40	0	1.250
9	280	85.6	7.42	0	1.250
10	330	90.0	3.44	0	1.250

The visualization of comparison of maximum distance with 0% packet loss is shown in Fig. 5.

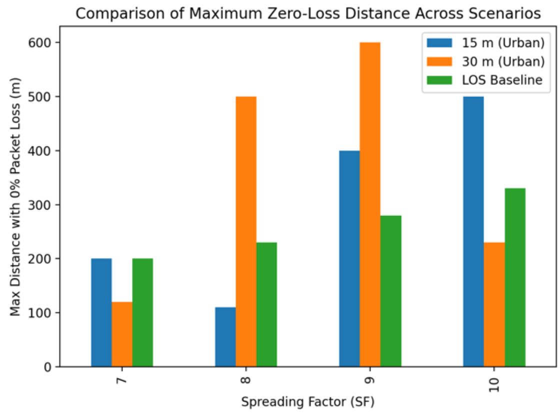


Figure 5. Perbandingan Max Distance dengan Packet Loss = 0%

D. Overall Discussion

The comparison between the baseline and urban tests quantifies the heavy impact of the urban environment. The reliable range for each SF was reduced to 40-55% of the baseline LOS range at 15m height, improving to 60-71% at 30m height.

The key finding is that antenna height is a primary determinant of performance, often more critical than the choice of SF. Elevating the antenna from 15m to 30m:

1. Increased reliable range for all SFs by reducing obstructions.
2. Dramatically improved signal quality (SNR) by minimizing multipath fading, often changing the SNR from critically negative to strongly positive.
3. SF7 is the most robust configuration for general use at both heights, offering the best signal integrity.
4. SF9 is the recommended choice for medium-range applications when using a 30m antenna, providing a excellent balance of range and reliability.
5. Higher SFs (SF10, SF9 at limit) achieve longer distances but at the cost of signal quality and increased airtime, making the network more susceptible to noise and congestion.

For practical deployment in urban areas, prioritizing antenna elevation is paramount. A 30m antenna with SF7 or SF9 provides the most reliable and efficient communication link.

IV. CONCLUSION

In conclusion, this study demonstrates that gateway antenna height is a primary factor influencing LoRaWAN performance in an urban environment. Elevating the antenna from 15 meters to 30 meters significantly expanded the reliable communication range for all Spreading Factors (SF) by reducing obstructions and minimizing signal fading. The optimal configuration was achieved at the 30-meter height, where SF7 proved best for short-range applications, SF9 for medium-range, and SF10 for the longest reliable distance. These findings highlight the critical importance of strategic antenna placement and SF selection for deploying reliable and efficient LoRaWAN networks in urban settings.

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