Performance Evaluation of Point-to-Point LoRa Communication on a Mappi32-Based Outdoor Patrol Robot System

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***Abstract*—Outdoor patrol robots require reliable wireless communication to transmit sensor and operational data to a remote monitoring station. In wide-area outdoor environments, conventional short-range wireless technologies may suffer from limited coverage and increased power consumption. LoRa communication offers a low-power, long-range alternative suitable for periodic telemetry transmission. This study presents an experimental evaluation of point-to-point LoRa communication implemented on a Mappi32-based outdoor patrol robot system. The assessment was conducted through route-based experiments in a campus environment, where a mobile rover transmitted multi-sensor telemetry data to a stationary base station. Communication performance was analyzed in terms of Received Signal Strength Indicator (RSSI), Packet Delivery Ratio (PDR), and latency based on inter-packet arrival time. Experimental results show that RSSI decreases with distance while remaining within the operational range of the LoRa transceiver, an overall PDR of approximately 75% is achieved along the patrol route, and latency remains close to the nominal transmission interval with variations primarily caused by packet loss events. These results indicate that point-to-point LoRa communication using an integrated Mappi32 platform is feasible for outdoor patrol robot telemetry applications in campus-scale environments.**

Keywords: LoRa, RFM95, Mappi32, Patrol Robot, Data Communication

I. INTRODUCTION

Mobile robots have been increasingly deployed in outdoor monitoring and patrol applications, such as campus security, environmental observation, and infrastructure inspection. In these applications, robots are required to transmit telemetry data over wide coverage areas while operating under limited power resources, making long-range and energy-efficient wireless communication a critical system component [1].

Low-Power Wide-Area Network (LPWAN) technologies have emerged as promising solutions for long-range wireless communication in outdoor environments, particularly for applications that require low data rates and extended operational range. Among various LPWAN technologies, LoRa has gained significant attention due to its ability to provide long-distance communication in unlicensed sub-GHz frequency bands [2].

LoRa communication employs chirp spread spectrum modulation, allowing robust signal propagation and improved resistance to interference in outdoor environments. Key physical layer parameters such as spreading factor, bandwidth, and coding rate directly influence communication range, data rate, and reliability, making LoRa suitable for telemetry-based monitoring systems [3].

Despite its advantages, many LoRa-based systems adopt the LoRaWAN protocol, which introduces additional network-layer overhead and scalability constraints that may not be suitable for simple point-to-point telemetry scenarios. Previous studies have reported that LoRaWAN performance can degrade under certain conditions due to network congestion and protocol complexity, particularly when deterministic data delivery is required [4].

To evaluate the performance of LoRa communication systems, metrics such as Received Signal Strength Indicator (RSSI) and Packet Delivery Ratio (PDR) are commonly used. RSSI provides insight into signal attenuation and propagation characteristics, while PDR reflects the reliability of packet transmission over a given observation period. These metrics have been widely applied in experimental evaluations of LoRa communication systems operating in real environments [5].

Several experimental studies have investigated point-to-point LoRa communication and demonstrated its suitability for outdoor telemetry applications with mobile or semi-mobile nodes. However, most existing works focus on static sensor nodes or controlled test scenarios, while experimental evaluations involving mobile ground-based robotic platforms in outdoor campus-scale environments remain limited [6].

Based on this research gap, this study presents an experimental performance evaluation of point-to-point LoRa communication implemented on a Mappi32-based outdoor patrol robot system. The evaluation is conducted through real-world experiments in a campus environment, where a mobile rover transmits periodic telemetry data to a stationary base station. Communication performance is analyzed using RSSI, Packet Delivery Ratio, and inter-packet arrival time to assess the feasibility of the proposed system for outdoor patrol robot applications.

II. METHOD

A. System overview

This study adopts an experimental methodology to evaluate the performance of point-to-point LoRa communication in a mobile outdoor patrol robot system. The evaluation is designed to reflect realistic outdoor monitoring conditions, where a mobile node continuously transmits telemetry data to a stationary base station while traversing a wide operational area. In such scenarios, communication reliability becomes a determining factor for system feasibility, particularly when low-power and long-range communication technologies are employed [7].

A point-to-point LoRa communication scheme is selected instead of a network-based architecture such as LoRaWAN. This choice is motivated by the need for simpler communication mechanisms, reduced protocol overhead, and predictable transmission behavior, which are advantageous for telemetry-based mobile robotic applications. The experimental focus of this study is on evaluating communication performance under outdoor mobility and environmental variability rather than network scalability.

B. System Architecture

The proposed system consists of two primary subsystems: a mobile rover node and a stationary base station node. Both subsystems are implemented using the Mappi32 development board, which integrates an ESP32 microcontroller with an onboard LoRa transceiver from the SX127x family. The use of an integrated LoRa platform reduces wiring complexity and facilitates compact system deployment, which is suitable for mobile robotic applications [8].

The rover node functions as a mobile telemetry transmitter. It performs periodic data acquisition from onboard sensors, processes the collected data, and transmits telemetry packets via LoRa communication. The base station node operates as a dedicated receiver that continuously listens for incoming LoRa packets and forwards successfully received data to a host computer for logging and analysis.

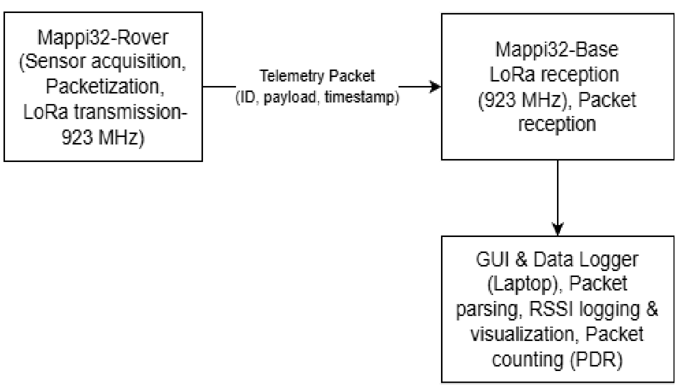

Figure 1. System Block Diagram

The overall system architecture and signal flow are illustrated in Fig. 1. The figure depicts the interaction between sensor acquisition, data processing on the Mappi32 platform, wireless LoRa transmission, and data reception and logging at the base station. This architecture is consistent with common implementations of LoRa-based outdoor monitoring systems reported in previous experimental studies [8].

C. System Workflow and Experimental Procedure

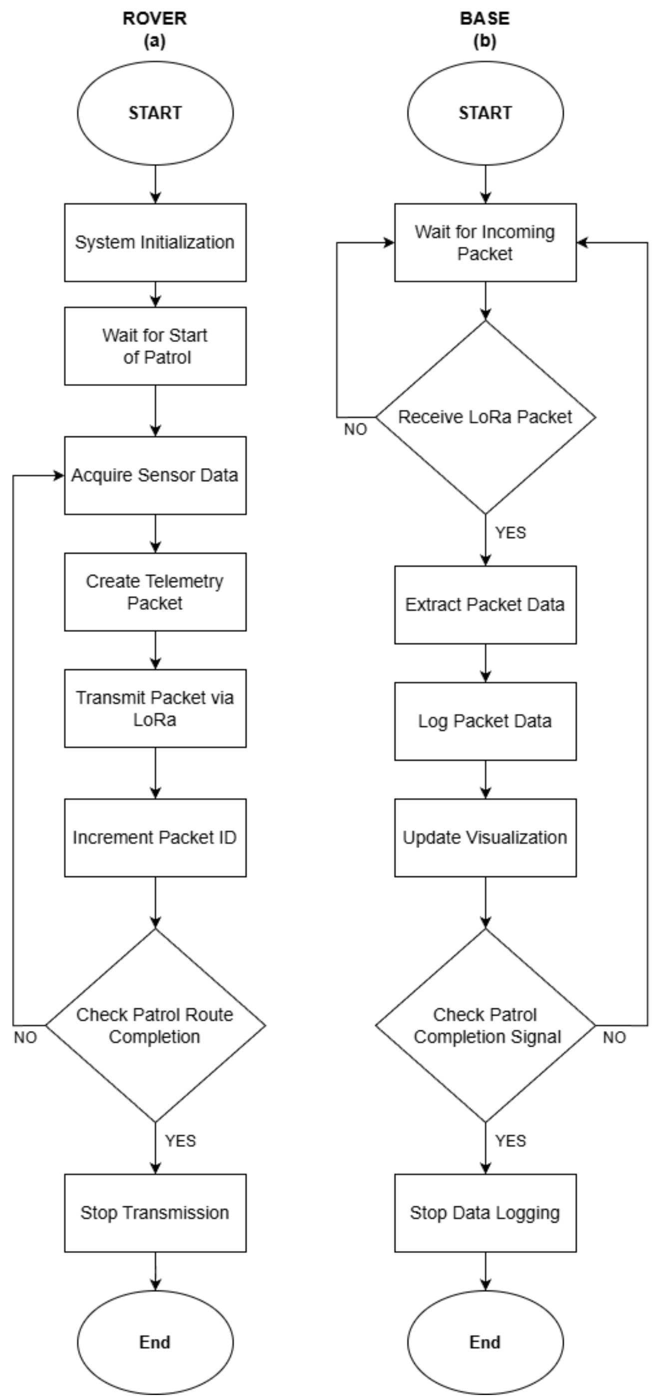

Figure 2. Flowchart of the rover–base station system workflow.

The operational workflow of the proposed system is illustrated in Fig. 2, which presents the sequential process from system initialization to experiment termination. On the rover side, the workflow begins with hardware initialization, including sensor modules and the LoRa transceiver. After initialization, sensor data are acquired periodically and organized into a structured telemetry packet.

Once packet formation is completed, the telemetry data are transmitted via the LoRa module at a fixed transmission interval. On the base station side, the Mappi32 board continuously operates in receive mode. When a telemetry packet is successfully received, the data are forwarded to a host computer through serial communication and stored for offline analysis.

The experiment continues according to this workflow until the predefined termination condition is met. In this study, the termination condition is defined as the completion of the rover's traversal of the entire predefined operational route. This experimental procedure follows established practices in point-to-point LoRa performance evaluation, ensuring repeatability and consistency of data collection [9].

D. Route-Based Evaluation Scenario

To evaluate the performance of point-to-point LoRa communication under realistic outdoor patrol conditions, this study adopts a route-based evaluation approach, where communication performance is observed continuously along a predefined operational route rather than at fixed static points. This approach is particularly relevant for outdoor patrol robot applications, in which the communication link is affected by node mobility, changing propagation environments, and varying line-of-sight conditions throughout the mission [10].

The evaluation route corresponds to the main road network within the campus area of Politeknik Negeri Batam, covering approximately 12.5 hectares. The route was selected to represent typical outdoor patrol scenarios, including open spaces, partial obstructions caused by buildings, vegetation, and non-line-of-sight (NLoS) conditions. By traversing the entire operational area, the rover experiences gradual variations in distance, orientation, and environmental characteristics relative to the stationary base station, allowing the communication system to be assessed under diverse real-world conditions.

During the experiment, the rover continuously transmits telemetry packets while moving along the predefined route until the entire campus road area is covered. The experiment is terminated once the rover completes the route, ensuring that all collected data correspond to the same operational mission. This termination criterion is chosen to maintain consistency between spatial coverage and communication performance evaluation, rather than relying on arbitrary time-based stopping conditions.

Figure 3. Robot Operate Area (Campus Area)

The route-based experimental procedure implemented in this study is illustrated in Fig. 3, which shows the sequential process from rover initialization, continuous telemetry transmission during movement, packet reception at the base station, to experiment termination after route completion. The flowchart emphasizes that communication performance data are collected continuously and synchronously with rover motion, ensuring that the resulting dataset reflects the dynamic behavior of the wireless link along the patrol route.

By employing a route-based evaluation framework, this study aims to capture the combined effects of mobility, environmental variability, and distance on LoRa communication performance. This approach provides a more representative assessment of communication reliability for outdoor patrol robot systems compared to static measurement setups, which may not fully reflect the operational conditions encountered during real deployment [10].

E. LoRa Communication and Experimental Parameters

The LoRa communication system in this study is configured using a point-to-point transmission scheme without employing the LoRaWAN protocol. This configuration is selected to minimize protocol overhead and simplify system implementation, which is particularly suitable for experimental performance evaluation involving direct communication between a mobile node and a stationary base station. Point-to-point LoRa communication has been widely adopted in experimental and embedded system studies where network scalability is not the primary concern and the focus is placed on link-level performance analysis [11].

All experiments are conducted using a fixed set of physical layer parameters, ensuring that observed variations in communication performance are primarily influenced by environmental conditions and rover mobility rather than dynamic parameter adaptation. Maintaining constant LoRa parameters throughout the experiment is a common practice in experimental evaluations, as it allows fair comparison of communication behavior under different propagation conditions within the same operational route [12].

TABLE I
. LoRa COMMUNICATION PARAMETER

Parameter	Value	Description
Frequency Operate	923 MHz	Indonesia Regulation
Communication Mode	Poin-to-Point	Without LoRaWAN
Spreading Factor (SF)	SF9	Reach and Data Rate
Bandwidth (BW)	125kHz	LoRa Standard
Coding Rate (CR)	4/5	Error Correction
Transmitting Power	ASCII Telemetry	Multi-sensor Data
Transmission Rate	1 Hz	Periodic Telemetry
LoRa Module	SX127x (RFM95)	Integrated in Mappi32
Antenna Type	External Monopole	Module Deffault
Environment	Outdoor (Campus Area)	NLoS & Multipath

The LoRa transceiver operates at a carrier frequency of 923 MHz, which complies with the sub-GHz frequency allocation for LoRa communication in Indonesia. A spreading factor of SF9 and a bandwidth of 125 kHz are selected as a compromise between communication range and data rate, enabling stable telemetry transmission while maintaining reasonable airtime. The coding rate is set to 4/5 to provide moderate forward error correction without excessive transmission overhead. The transmission power is configured at +17 dBm, corresponding to the maximum output power supported by the SX127x-based LoRa transceiver integrated within the Mappi32 platform.

Table I summarizes the complete set of LoRa communication parameters adopted in this study, corresponding to the configuration described above.

F. Data Collection and Logging Mechanism

During the route-based experiment, telemetry data are collected continuously at the base station through the reception of LoRa packets transmitted by the rover. Each received packet is forwarded from the Mappi32 base station to a host computer via serial communication and stored in a structured log file. This centralized logging approach ensures that all received data is recorded in chronological order and can be processed consistently for performance evaluation purposes [13].

Each telemetry packet contains a unique packet identifier, sensor payload data, and a reception timestamp generated at the base station. The packet identifier is used to distinguish between successfully received packets and missing packets during the experiment, enabling reliable computation of packet delivery statistics. The use of packet ID–based logging is a common technique in LoRa performance evaluations, as it allows accurate identification of packet loss without requiring bidirectional acknowledgment mechanisms [14].

Data logging occurs continuously along the entire patrol route outlined in Subsection D, commencing with the initiation of rover movement and concluding upon the route's completion. No intermediate filtering or packet retransmission mechanisms are applied during data collection. This design choice ensures that the recorded dataset reflects the raw behavior of the point-to-point LoRa communication link under mobility and environmental variability, without artificial improvement introduced by higher-layer recovery mechanisms [15].

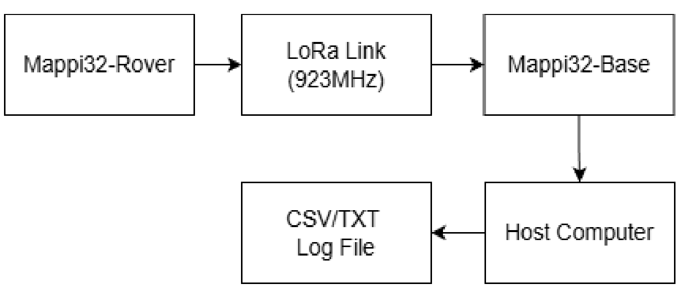

Fig 4. Data Collection & Logging Flow Diagram

The logged dataset includes both successfully received packets and gaps corresponding to missing packet identifiers. These data form the basis for subsequent performance analysis, including packet delivery ratio (PDR), received signal strength indicator (RSSI), and inter-packet arrival time analysis. The overall data collection and logging process implemented in this study is illustrated in Fig. 4, which highlights the unidirectional data flow from rover transmission to base station logging and storage.

G. Performance Metrics and Evaluation Parameters

The performance of the point-to-point LoRa communication system is evaluated using three primary metrics: Received Signal Strength Indicator (RSSI), Packet Delivery Ratio (PDR), and latency, represented by inter-packet arrival time at the base station. These metrics are widely adopted in experimental evaluations of LoRa-based communication systems, as they provide complementary insight into signal propagation, transmission reliability, and temporal behavior of data delivery under real-world conditions [16].

TABLE II.
TELEMETRY PACKET STRUCTURE

Field	Description
Packet ID	Packet Sequence Identifier
Timestamp	Transmission Time
Latitude	GPS Latitude
Longtitude	GPS Longitude
IMU Data	Yaw, Pitch, Roll
Encoder Data	Left and Right Wheel Encoder
Ultrasonic	Obstacle Distance
Battery Level	Battery Voltage
Denlimiter	Battery Voltage

1) Received Signal Strength Indicator (RSSI)

RSSI is used to characterize the received signal power at the base station and to reflect the propagation conditions experienced by the LoRa link during rover movement. Variations in RSSI values are influenced by transmission distance, environmental obstructions, antenna orientation, and multipath effects, particularly in outdoor and non-line-of-sight scenarios [17].

In this study, RSSI values are extracted directly from the metadata of each successfully received LoRa packet and logged at the base station, as described in Subsection F. By analyzing RSSI trends along the patrol route, the communication system's robustness against environmental variability can be assessed.

2) Packet Delivery Ratio (PDR)

Packet Delivery Ratio (PDR) represents the reliability of the communication link and is defined as the ratio between the number of successfully received packets and the total number of transmitted packets during the experiment. PDR is commonly used in LoRa performance studies to quantify the effectiveness of data delivery without relying on retransmission or acknowledgment mechanisms [18].

Packet Delivery Ratio (PDR):

$$PDR = \left(\frac{N_{received}}{N_{transmitted}}\right) \times 100\% \quad (1)$$

Where $N_{received}$ denotes the total number of packets successfully logged at the base station, and $N_{transmitted}$ represents the total number of packets transmitted by the rover during the route-based experiment.

This level of packet delivery indicates that the communication link remains operational and reliable under mobility and environmental variability, despite the absence of retransmission or higher-layer recovery mechanisms. Similar PDR values have been reported in outdoor LoRa experiments involving mobile or semi-mobile nodes operating under non-line-of-sight conditions [18].

3) Latency (Inter-Packet Arrival Time)

Latency in this study is evaluated using inter-packet arrival time at the base station, defined as the time difference between the reception timestamps of two consecutive packets. This definition avoids the need for clock synchronization between the rover and base station and is therefore suitable for unidirectional point-to-point LoRa communication experiments.

Inter-packet Arrival Time (Latency):

$$\Delta t_i = t_i - t_{i-1} \quad (2)$$

where t_i denotes the reception timestamps of the i-th and $(i-1)$-th packet at the base station, respectively.

These performance parameters collectively provide a comprehensive evaluation of LoRa communication performance under mobile outdoor patrol conditions [18].

III. RESULT AND DISCUSSION

A. *RSSI Characteristics Route-Based Outdoor Operation*

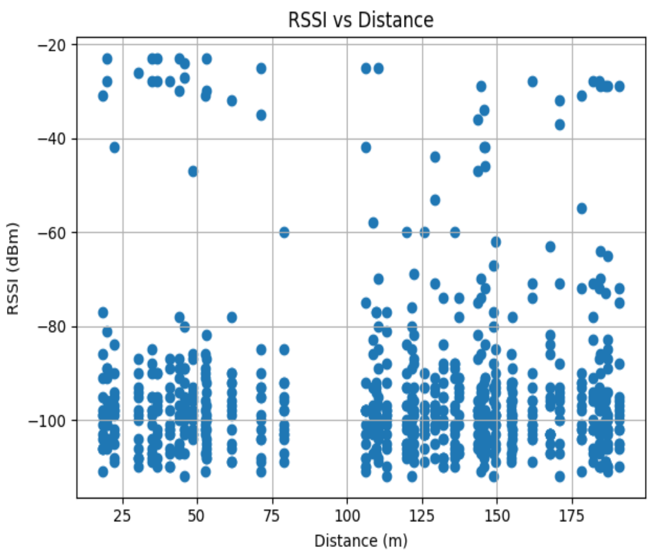

Fig 6. RSSI and the transmission distance

Fig.6 shows the relationship between RSSI and the transmission distance between the rover and the base station. The results indicate a clear decreasing trend in RSSI as the distance increases, which is consistent with radio propagation theory in outdoor environments. Signal attenuation occurs due to free-space path loss and environmental factors such as partial obstructions and multipath effects commonly present in campus areas. Despite these effects, the RSSI values remain within a range that supports reliable packet reception over most of the evaluated route.

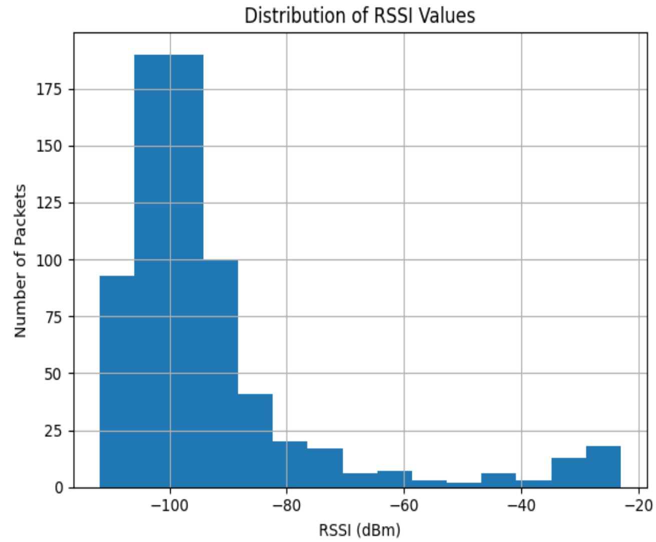

Fig 7. RSSI Distribution

The RSSI distribution is shown as a histogram in Fig.7. The majority of received packets are concentrated within a relatively narrow RSSI interval, suggesting consistent signal reception throughout the experiment. Based on the absence of severe RSSI degradation, the chosen LoRa physical layer configuration appears to offer sufficient robustness against channel fluctuation under rover mobility. This distribution demonstrates that LoRa modulation can sustain reliable link quality in outdoor telemetry applications.

The statistical distribution of RSSI values obtained during the experiment is summarized in Table III.

TABLE III.
RSSI STATISTICAL SUMMARY

RSSI Phase	Value
Mean RSSI	-93.33 dBm
Minimum RSSI	-112 dBm
Maximum RSSI	-23 dBm

The minimum RSSI value of -112 dBm indicates that packets were still successfully received at signal levels close to the sensitivity limit of the LoRa transceiver. This demonstrates the robustness of LoRa communication in low signal strength conditions. Conversely, the maximum RSSI value of -23 dBm corresponds to scenarios where the rover was located relatively close to the base station with minimal obstruction.

The average RSSI value of -93.33 dBm reflects the overall signal condition during the experiment, which involved a wide range of distances and propagation environments. These results are in line with reported RSSI ranges in outdoor LoRa experiments conducted in campus-scale and urban environments.

B. Packet Delivery Ratio (PDR)

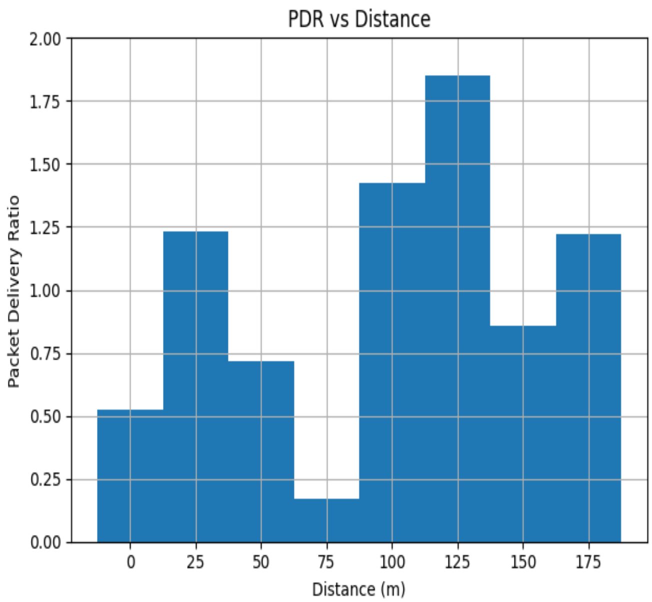

Fig 8. Evaluate PDR vs Distance

The Packet Delivery Ratio as a function of transmission distance, calculated using distance-based grouping, is shown in Fig. 8. The findings demonstrate that PDR decreases as the distance between the rover and the base station increases, while remaining high at shorter ranges. This tendency is a reflection of the growing probability of packet loss over longer distances because of weakened signals and interference from the environment.

Although PDR degradation is observed at extended ranges, the decrease occurs gradually rather than abruptly. This indicates that the point-to-point LoRa communication system maintains acceptable packet delivery reliability across most of the experimental route. Such characteristics are suitable for outdoor patrol robot telemetry, where periodic data transmission remains effective even with occasional packet loss.

The summary of packet transmission performance is presented in Table IV.

TABLE IV.
PACKET DELIVERY PERFORMANCE SUMMARY

Parameter	Value
Total Packets Transmitted	942
Total Packets Received	709
Packet Delivery Ratio (PDR)	75.27%

Based on the Packet Delivery Ratio (PDR) definition in (1), which represents the ratio between the number of successfully received packets and the total transmitted packets during the experiment, the measured PDR of 75.27% indicates that approximately three out of four transmitted telemetry packets were successfully delivered to the base station. This result demonstrates that the point-to-point LoRa communication link maintains a relatively high level of reliability under realistic outdoor operating conditions involving rover mobility and non-line-of-sight propagation.

Packet losses observed in the experiment are primarily associated with increased transmission distance, signal obstruction by campus buildings, and dynamic variations in the propagation environment as the rover moves along the patrol route. These factors reduce the probability of successful packet reception, which is directly reflected in the PDR value calculated using (1).

C. Latency Characteristics

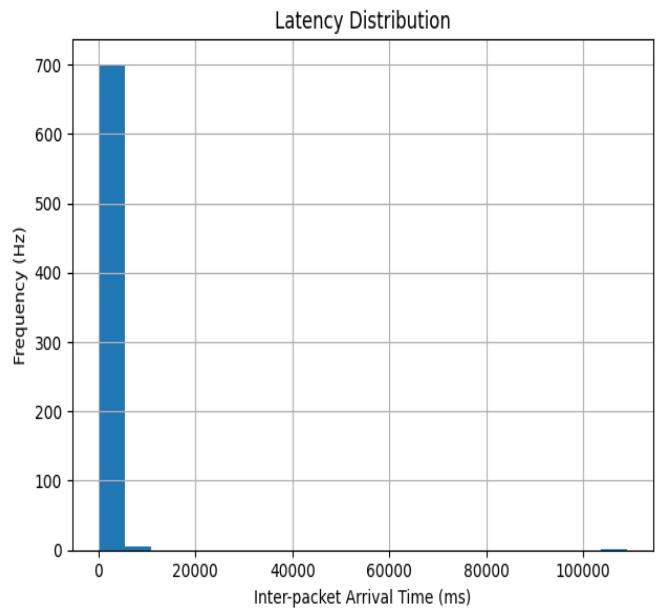

Fig 9. Latency Distribution

Latency performance is evaluated based on the inter-packet arrival time at the base station, as defined in (2), which represents the time difference between the reception timestamps of two consecutive packets. As shown in Fig. 9, the histogram indicates that most packets are received with inter-arrival times close to 1 s, corresponding to the fixed transmission rate of 1 Hz configured in the LoRa system. This result suggests that, under normal channel conditions, telemetry packets are delivered with minimal delay variation.

The latency distribution also exhibits larger inter-packet arrival times, which occur when one or more consecutive packets are not successfully received. In these cases, the measured latency reflects the cumulative transmission interval until the next packet is successfully received at the base station, as implied by the definition in (2). This behavior is inherent to unidirectional packet-based wireless communication systems operating without acknowledgment or retransmission mechanisms.

From a system-level perspective, the observed latency characteristics indicate that the LoRa communication link provides sufficiently predictable timing behavior for non-time-critical telemetry applications. The absence of prolonged latency gaps suggests that no extended communication outages occur during route-based rover operation.

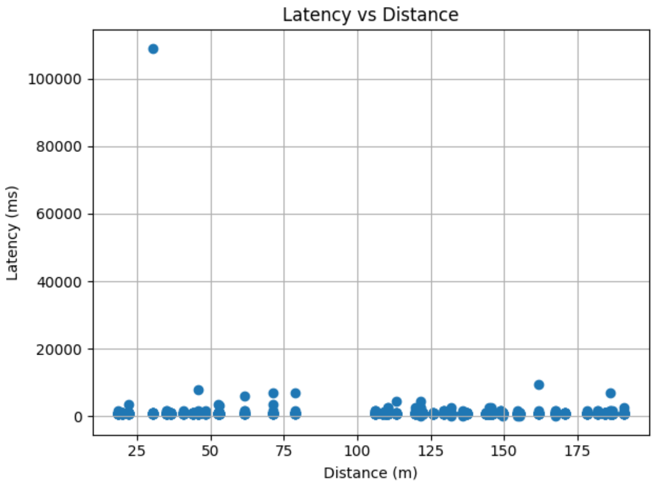

Fig 10. Relationship Between Latency And Transmission Distance

The relationship between latency and transmission distance is depicted in Fig.10. While most latency values remain clustered around the nominal interval regardless of distance, occasional higher latency values appear at longer distances. These instances coincide with regions where packet loss becomes more frequent, as indicated by the PDR analysis.

The lack of a strong monotonic increase in latency with distance suggests that latency is not directly dominated by propagation delay, which is negligible at the evaluated distances, but rather by packet loss events and channel reliability. This observation reinforces the interpretation that latency variations are primarily driven by the stochastic nature of packet reception in mobile outdoor environments rather than by distance alone.

For outdoor patrol robot systems, this latency behavior is acceptable for telemetry-based monitoring, where periodic updates are sufficient and strict real-time constraints are not required. The results indicate that the proposed LoRa-based communication system can support timely data delivery under route-based mobility conditions.

D. Discussion

The combined analysis of RSSI, PDR, and latency demonstrates that the Mappi32-based point-to-point LoRa communication system is capable of supporting outdoor patrol robot operations within a campus-scale environment. While signal attenuation and packet loss increase with distance and environmental complexity, the communication link remains operational throughout the entire route.

The results highlight that LoRa communication, when configured with fixed physical parameters and deployed in a point-to-point architecture, offers a practical balance between coverage, reliability, and energy efficiency for mobile ground robot telemetry. These findings support the feasibility of using integrated LoRa platforms for outdoor robotic monitoring applications, particularly in scenarios where low data rates and wide-area coverage are prioritized over high throughput and strict real-time performance.

IV. CONCLUSION

This study presented an experimental evaluation of a point-to-point LoRa communication system implemented on a Mappi32-based outdoor patrol robot and tested under real route-based operation in a campus environment. The evaluation focused on analyzing communication performance in terms of Received Signal Strength Indicator (RSSI), Packet Delivery Ratio (PDR), and latency, with all LoRa physical parameters kept constant throughout the experiment.

The results show that RSSI generally decreases with increasing distance along the patrol route, while exhibiting fluctuations caused by environmental factors such as partial non-line-of-sight conditions and multipath propagation. Despite these variations, the measured RSSI values remain within the operational sensitivity range of the LoRa transceiver, indicating that the communication link remains viable during outdoor mobile operation.

Packet Delivery Ratio analysis indicates that the system achieves an overall PDR of approximately 75% across the evaluated route. Although packet loss increases at longer distances, the observed PDR level is sufficient for periodic telemetry transmission in outdoor patrol scenarios, where continuous high-throughput communication is not required. Latency analysis based on inter-packet arrival time shows that most packets are received close to the nominal transmission interval, with occasional increases associated with packet loss events. This behavior reflects the inherent characteristics of packet-based LoRa communication operating without retransmission mechanisms and suggests that the system provides sufficiently predictable timing performance for non-time-critical monitoring applications.

Overall, the experimental results demonstrate the feasibility of using a Mappi32-based point-to-point LoRa communication system for outdoor patrol robot telemetry in campus-scale environments. Future work may focus on evaluating different LoRa parameter configurations, implementing acknowledgment or retransmission schemes, and extending the evaluation to more complex environments or longer operational routes.

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