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A Study on Gateway and Multiple Sensor Nodes Communication in IoT-Based Flood Monitoring System

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Abstract

This study describes the design and evaluation of an IoT-based flood monitoring system that uses LoRa technology to communicate between a gateway and various sensor nodes in flood-prone sections of the Muar River Basin. The goal is to determine the reliability and scalability of LoRaWAN connectivity for multi-node data transmission. A prototype system with an ultrasonic water level sensor was developed and deployed at various distances and node densities, with performance measured using Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), and Packet Success Rate (PSR). The findings indicate that network performance degrades as transmission distance and the number of sensor nodes increase, emphasizing the importance of optimized network configuration and gateway deployment. Specifically, the results show a consistent decrease in RSSI and SNR with distance, as well as a reduction in PSR, which is attributed to path loss and packet collision as node density increases. Overall, the findings demonstrate that LoRa-based systems are suitable for flood monitoring when properly configured, with future enhancements focusing on optimizing network characteristics and expanding gateway deployment to enhance reliability and overall system performance.

1. Introduction

Flooding remains one of the most frequent and damaging natural disasters in tropical regions, particularly in Malaysia, where monsoon rainfall and complex river basin topography regularly threaten vulnerable communities [1]. Recent advancements in Internet of Things (IoT) technologies, particularly long-range, low-power communication protocols such as LoRaWAN, have enabled real-time flood monitoring through distributed sensor networks. However, the reliability of communication between multiple sensor nodes and a central gateway under real environment and network conditions remains a critical challenge, particularly as the monitoring system scales in size and complexity [2].

Most existing studies focus on single-node or small-scale deployments, with limited investigation into multi-node communication performances, gateway reliability, and network scalability. This creates a critical research gap, as issues such as signal attenuation, packet collisions, and reduced data reliability can compromise the effectiveness of early flood warnings. Without addressing these challenges, flood monitoring systems may fail during peak flood events, leading to delayed responses and an increased risk to communities [3][4].

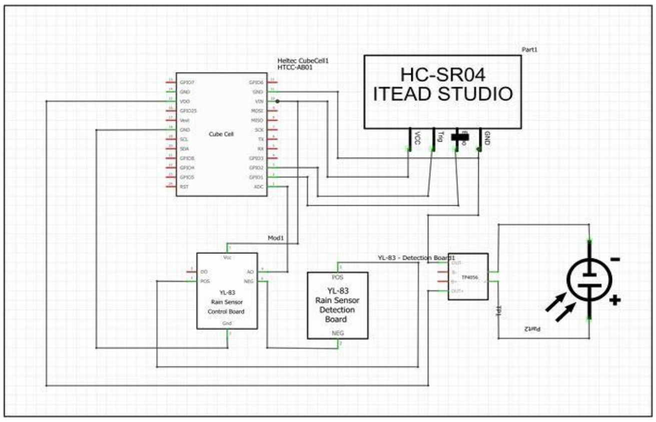
Therefore, this study aims to evaluate the communication between the gateway and multiple sensor nodes in a LoRa-based flood monitoring system. The research addresses how transmission distances and increasing node density affect signal strength and network reliability. The objective is to analyze the performance of LoRaWAN communication, develop a functional multi-node flood monitoring prototype, and evaluate the effectiveness of gateways, thereby contributing to more reliable and scalable flood early warning systems. By addressing these objectives, the study contributes to improving the scalability, reliability, and practical deployment of the IoT-based flood monitoring system, supporting more effective early warning and flood risk mitigation strategies.

2. Methodology

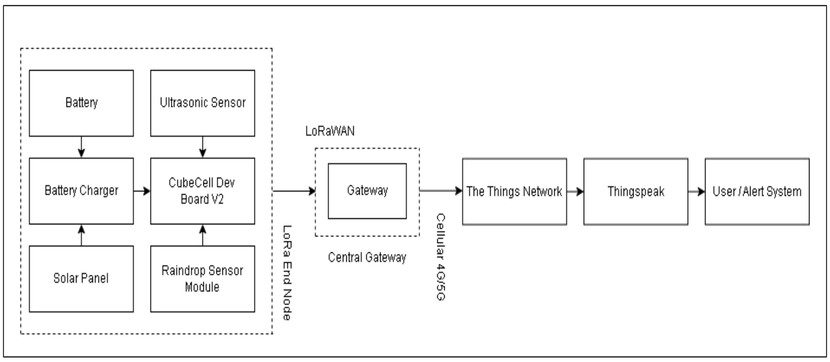
This methodology outlines the systematic approach used to design, implement, and evaluate a LoRa-based IoT flood monitoring system. It explains the system architecture, hardware and software integration, deployment strategy, performance evaluation, and methods used to assess communication reliability between the gateway and multiple sensor nodes under varying network and environmental conditions.

2.1 System Overview

This study employed an experimental method to design and evaluate a LoRa-based IoT flood monitoring system. The proposed system consists of multiple sensor nodes, a centralized gateway, and a cloud-based network server for data processing and visualization. Figure 1 illustrates the overall system architecture, where sensor nodes collect environmental data and transmit it to the gateway using LoRaWAN communication. Figure 1 (a) shows a schematic diagram of the detailed electrical connection between all hardware components of the sensor nodes, including the Heltec Cubecell microcontroller and ultrasonic sensor, which illustrates pin configurations and voltage connections, providing a clear reference for circuit implementation and hardware integration. Meanwhile, Figure 1(b) presents a block diagram of the system, providing a high-level functional overview of the sensor node. It highlights the main system modules and shows how the data flows from the sensors to the microcontroller, which is then transmitted wirelessly to the gateway.



(a)



(b)

Fig. 1 (a) Schematic Diagram of System (b) Block Diagram of System

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The experimental setup and deployment involved installing multiple sensor nodes at varying distances from a central LoRaWAN gateway to simulate real flood monitoring conditions in the targeted areas, as shown in Figure 2. The sensor nodes were deployed under actual environmental conditions, where factors such as terrain, surrounding structures, and atmospheric conditions could influence signal propagation. Each node was configured to periodically measure water level and transmit the data to the gateway using the LoRaWAN protocol. The transmission distance and the number of active sensor nodes were gradually increased to evaluate system behavior under realistic operating conditions and to examine the network's scalability during simultaneous data transmissions.

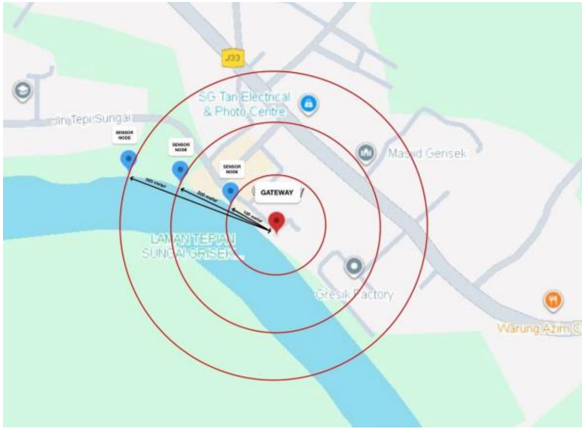

Fig. 2 Sensor Nodes Position from Gateway

The performance evaluation focused on assessing the reliability and quality of communication between the sensor nodes and the gateway. Key performance metrics, including Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR) and Packet Success Rate (PSR), were collected and analyzed. RSSI and SNR were used to evaluate signal strength and link quality over increasing distances, while PSR was calculated using the formula in (1) to measure transmission success as the number of sensor nodes increased. These metrics provide insight into gateway performance, network scalability and the effectiveness of the LoRa-based flood monitoring system in real deployment environments.

$$PSR\ (\%) = \frac{Total\ Packets\ Received}{Total\ Packets\ Sent} \times 100\ \% \tag{1}$$

The RSSI evaluation was performed using a path loss model to examine signal attenuation as transmission distance increased. Measured RSSI values from field tests were compared with predicted values calculated using the free-space path loss model, as shown in (2). The comparison highlights the influence of real environmental factors on signal propagation, enabling the assessment of LoRa communication reliability in practical flood monitoring deployments.

$$RSSI\ (dBm) = Transmit\ Power - Free\ Space\ Path\ Loss \tag{2}$$

The transmit Power value is fixed at 14 dBm. Meanwhile, free space path loss (FSPL) can be calculated using the formula at (3):

$$\boldsymbol{FSPL(dB) = 20log_{10}(d) + 20log_{10}(f) + 20log_{10}\frac{4\pi}{c}} \tag{3}$$

Where:

- d = Distance between transmitter and receiver (m/km)
- f = Signal frequency (923 MHz)

- c = Speed of light $3 \times 10^8\ m/s$

2.2 Materials

This study employed a LoRa-based IoT flood monitoring system consisting of multiple sensor nodes and a centralized gateway. Each sensor node was built using a few components and a centralized gateway, as listed in Table 1 below:

Table 1 List of Components Used

No.	Components	Functions
1	Cubecell HTCC-AB01 Dev Board (V2)	Primary microcontroller and wireless transceiver
2	AJ-SR04M Ultrasonic Sensor	Continuously measure the water level
3	TP4056 Battery Charger Module	Regulate the charging process
4	D5 Solar Panel	Renewable power source
5	3.7V Battery	Primary energy storage unit for the system
6	Dragino DLOS8N LoRaWAN Gateway	Central communication hub and local aggregator

The system utilizes a Dragino outdoor LoRaWAN gateway operating at 923 MHz, which supports multi-channel communication and enables reliable data transmission from multiple-sensor nodes to the cloud via Wi-Fi or cellular networks. Its outdoor-grade design makes it suitable for continuous operation in flood-prone environments. The software used includes Arduino IDE for sensor node programming and The Things Network (TTN) as the LoRaWAN network server for device authentication, data management, and real-time monitoring.

3. Results and Discussion

The experimental results demonstrate the communication performance of the LoRa-based flood monitoring system under varying transmission distances and sensor node densities. The distance versus RSSI analysis, as in Figure 3, shows a clear decline in signal strength as the distance between the sensor node and the gateway increases. RSSI value decreases gradually at shorter distances and more sharply at longer ranges, indicating increased path loss and reduced link reliability. Despite minor fluctuations caused by environmental factors, the system maintains acceptable communication within the tested deployment range, confirming the suitability of LoRa for long-range flood monitoring applications.

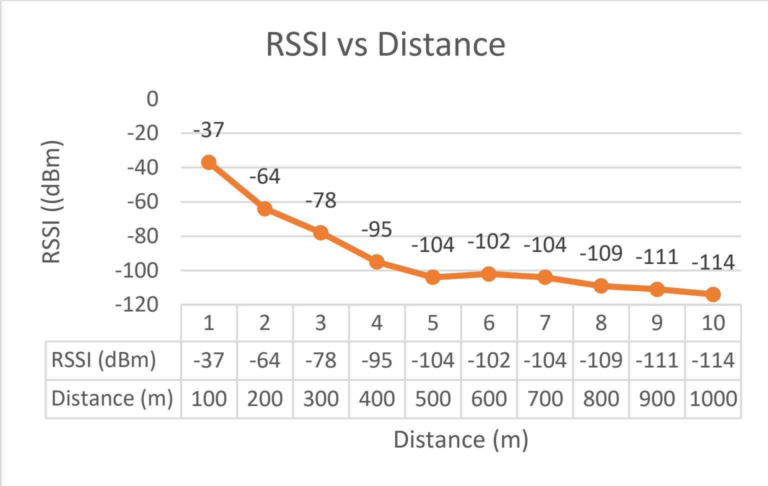

Fig. 3 Analysis Graph of RSSI vs. Distance

The Signal-to-Noise Ratio (SNR) results, as shown in Figure 4, further support this observation, where positive SNR values at shorter distances indicate strong and reliable links, while negative SNR values at longer distances reflect reduced link quality and increased sensitivity to interference. These results underscore the importance of optimal gateway placement and network planning, particularly in real-world deployment environments where terrain and surrounding structures impact signal propagation.

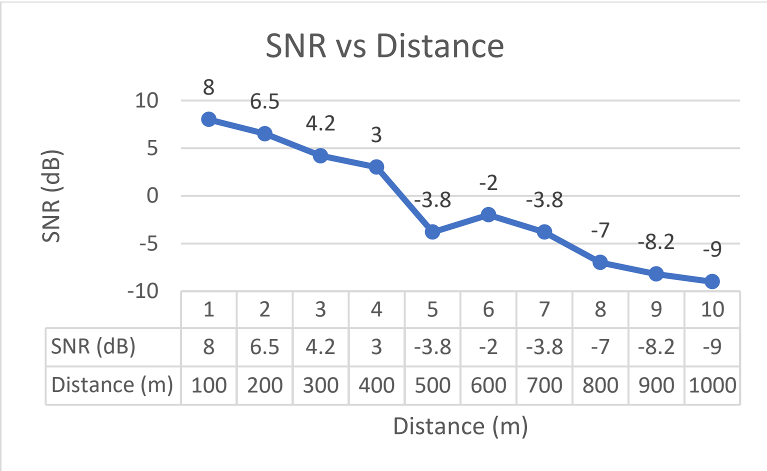

Fig. 4 Analysis Graph of SNR vs. Distance

The evaluation of network performance with an increasing number of sensor nodes as illustrated in Figure 5, shows a reduction in Packet Success Rate (PSR) as node density increases. This behavior is primarily attributed to packet collisions and channel congestion that occur when multiple nodes transmit data simultaneously to a single gateway. Although the gateway is capable of handling multiple nodes, the results indicate that network reliability decreases beyond certain node limits without further optimization. This finding emphasizes the need for adaptive transmission strategies, such as optimized transmission intervals or adaptive data rate mechanisms, to improve scalability.

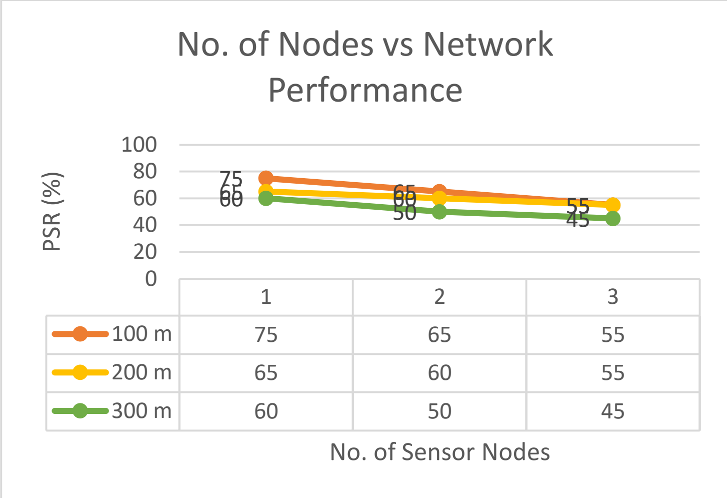

Fig. 5 Analysis Graph of No. of Nodes vs. Network Performance

A comparison between measured and predicted RSSI values using the path loss model reveals measurable differences, particularly at longer distances. Although the model serves as a useful baseline for estimating signal behavior, real-world environmental factors affect attenuation that is not captured by ideal propagation assumptions. Overall, the results confirm that the proposed LoRa-based flood monitoring system can support multi-node communication within practical deployment limits, while emphasizing the need for further optimization to enhance reliability and scalability in future implementations.

This study is limited by its small-scale deployment, use of a single gateway, and evaluation under constrained environmental conditions, which may not fully represent large-area flood monitoring scenarios. Nevertheless, the results underscore the importance of optimized gateway placement, adaptive data rate mechanisms, and controlled transmission scheduling in enhancing communication reliability and minimizing packet collisions. Future studies should focus on large-scale, multi-gateway deployments, long-term testing under various weather conditions, and the integration of predictive analytics to enhance system scalability, robustness, and the effectiveness of early warnings.

4. Conclusion

In conclusion, this study addressed the need for reliable and scalable flood monitoring by evaluating gateway and multiple sensor node communication in a LoRa-based IoT system deployed in the flood-prone Muar River Basin. A functional prototype integrating an ultrasonic water level sensor with LoRaWAN communication was successfully developed and experimentally evaluated under varying transmission distances and node densities. The results show that signal strength and network reliability decrease with increasing distance and simultaneous node transmissions due to path loss and packet collisions. However, effective multi-node communication is maintained within practical deployment limits when the system is properly configured, confirming the suitability of LoRa-based IoT systems for real-time flood monitoring and early warning applications. This study offers experimental insights into the performance of multi-node LoRaWAN at the gateway level. Future work should focus on large-scale, multi-gateway deployments, adaptive data rate optimization, and long-term testing under diverse environmental conditions to further enhance system reliability and scalability.

Acknowledgement

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