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Waste Level Monitoring System Based on Internet of Things Using Long-Range Technology

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Abstract: *The increasing need for efficient waste management encourages the development of monitoring systems that can provide timely information on the condition of waste bins. This study proposes an Internet of Things (IoT)-based waste level monitoring prototype that employs LoRa communication for wireless data transmission. The system was developed using Arduino Uno, Arduino Mega, LoRa modules, Raspberry Pi, and an ultrasonic sensor to detect the waste level and transmit the collected data to a monitoring dashboard. A quantitative experimental method was applied, supported by Quality of Service (QoS) analysis to evaluate LoRa network performance. The testing was conducted in a non-line-of-sight (NLOS) environment using a 433 MHz LoRa frequency. The experiment involved 30 testing scenarios, consisting of five transmission distances, namely 20 m, 40 m, 60 m, 80 m, and 100 m, combined with six spreading factor settings from SF7 to SF12. The evaluation focused on packet loss, throughput, and time on air. The results indicate that transmission performance was influenced by environmental obstruction and spreading factor configuration. Packet loss was mainly observed at 80 m, with the highest loss reaching 9% at SF7, while higher spreading factor values tended to reduce packet loss. In terms of throughput, increasing the spreading factor decreased the transmission rate, whereas the time on air became longer. These findings show that LoRa communication can be implemented for waste bin level monitoring, although signal barriers in NLOS conditions may affect data transmission quality.*

Keywords: *IoT, LoRa, Ultrasonic Sensor, Waste, Waste Monitoring.*

1. Introduction

Waste management remains one of the major challenges in urban and industrial environments because the amount of waste generated can fluctuate constantly and is difficult to predict manually. In many locations, waste collection is still carried out based on fixed schedules or visual inspections by staff. This approach is often inefficient because some waste bins may be collected before reaching full capacity, while others may overflow before being emptied. Therefore, a monitoring system that can provide real-time information on the condition of waste bins is needed to support more responsive and efficient waste collection management [1].

Advances in Internet of Things (IoT) technology have created new opportunities to improve waste monitoring systems. Through IoT, physical objects such as trash bins can be equipped with sensors, microcontrollers, and communication modules so that data can be collected, transmitted, and displayed remotely. Ultrasonic sensors are commonly used in these types of systems because they can measure the distance between the sensor and the surface of the waste, which can then be converted into information about the trash can's fill level [2]. Several previous studies have implemented IoT-based waste monitoring systems using ultrasonic sensors, Arduino or NodeMCU platforms, web dashboards, mobile apps, SMS, or cloud-based services.

However, although IoT-based waste monitoring using ultrasonic sensors has been extensively studied, much of the previous research has primarily focused on detecting waste levels and displaying data via an app or dashboard [3]. The system's communication performance, particularly in outdoor environments with obstacles, has not always been studied in detail. In practical implementations, trash bins are often placed in locations where wireless signals can be affected by buildings, trees, walls, or other physical barriers. These conditions can reduce the reliability of data transmission and may lead to packet loss, delays, or unstable monitoring performance [4].

LoRa technology offers a potential solution for waste monitoring systems because it supports long-range communication with relatively low power consumption. Compared to Wi-Fi-based systems, LoRa is better suited for monitoring objects located far from internet access points or in areas with limited network infrastructure [5]. However, LoRa's performance is significantly influenced by communication parameters such as the spreading factor, transmission distance, and environmental conditions. In non-line-of-sight (NLOS) environments, selecting an inappropriate spreading factor can reduce data reception quality and affect the reliability of the monitoring system [6].

Based on this gap, this study not only developed an IoT-based waste level monitoring prototype using ultrasonic sensors but also evaluated LoRa communication performance under NLOS (Non-Line-of-Sight) conditions [5]. The novelty of this study lies in the integration of waste level monitoring with a systematic analysis of LoRa transmission Quality of Service (QoS). The evaluation focused on several parameters, including packet loss, throughput, and transmission time, by testing various values of the spread factor and transmission distance. Through this approach, this study aims to identify how LoRa configurations affect the reliability of data transmission in waste monitoring applications [7].

Therefore, the objective of this study is to design and test an IoT-based waste level monitoring system using LoRa technology and to analyze its communication performance in NLOS scenarios. The results of this study are expected to provide a technical basis for selecting the appropriate LoRa configuration in real-world waste monitoring implementations, particularly in environments where obstacles may interfere with wireless data transmission.

2. Literature Review

a. IoT-Based Waste Level Monitoring System

An IoT based waste monitoring system is designed to support the more efficient collection, transmission, and visualization of data on the status of trash bins. In this system, sensor units are responsible for detecting the level of waste inside the bins, while communication units transmit the collected data to a server or monitoring platform [8]. The use of IoT in waste management allows sanitation workers to obtain up-to-date information without having to manually check each trash bin. This approach is particularly useful in areas where waste accumulation is difficult to predict, as the number of users and the amount of waste disposed of in each trash bin can vary over time. In the proposed system, an ultrasonic sensor is used as the primary sensing component to estimate the waste level.

by measuring the distance between the sensor and the surface of the waste. The measured values are then processed by a microcontroller and transmitted via a LoRa communication module [9]. Compared to conventional short-range wireless communication, LoRa is considered suitable for waste monitoring applications because it supports long-range transmission with relatively low power consumption. Therefore, LoRa network performance is a critical aspect that must be evaluated, especially when the system is deployed in outdoor environments with potential obstacles such as buildings, trees, or other physical barriers.

b. LoRa Communication and Network Performance

LoRa, or long-range communication, is a wireless communication technology that uses spread-spectrum modulation to support low-power, long-range data transmission. In IoT applications, LoRa is often used when devices need to transmit small amounts of data over a wide area. However, LoRa network performance can be affected by several technical and environmental factors, including transmission distance, antenna position, physical obstacles, spreading factor configuration, and signal quality [10]. In trash bin monitoring, the reliability of LoRa communication is critical because the system relies on continuous data transmission from sensor nodes to receivers or gateways. If the transmitted data is not received correctly, the monitoring dashboard may display incomplete or inaccurate information [11]. Given this, evaluating LoRa communication based solely on the success of prototype development is insufficient. The system must also be assessed using network performance indicators such as Quality of Service, packet loss, throughput, Time in the Air, Received Signal Strength Indicator, and Signal-to-Noise Ratio.

c. Service Quality in LoRa-Based Monitoring

Quality of Service, or QoS, refers to a set of parameters used to evaluate the quality and reliability of data transmission in a network. In LoRa-based IoT systems, QoS analysis is necessary to determine whether a communication link can support stable data transmission under specific test conditions. QoS evaluation is particularly important in non-line-of-sight environments, where the transmitter and receiver are separated by obstacles that can weaken the signal or disrupt packet delivery [12]. Several QoS parameters are relevant for evaluating LoRa communication. Packet loss indicates the percentage of transmitted packets that fail to reach the receiver. Throughput describes the amount of data successfully transmitted within a given period [13]. Time-in-Air represents the duration required for a LoRa packet to be transmitted through the air. Additionally, RSSI and SNR can be used to characterize signal strength and signal quality during transmission. These parameters provide a more comprehensive understanding of LoRa performance because they indicate not only whether data is received, but also how efficiently and reliably it is transmitted.

d. Packet Loss and Data Reception Reliability

Packet loss is one of the most important indicators for evaluating wireless communication performance. In an IoT monitoring system, packet loss occurs when data sent from a transmitter is not successfully received by the receiver. A high packet loss rate indicates an unstable communication link, while a low packet loss rate indicates that the system is more reliable in transmitting sensor data [14]. In the context of waste monitoring, packet loss can affect the accuracy of the information displayed on the dashboard. For example, if several packets containing trash level data are lost, the system may fail to display the latest bin status [15]. This can slow down the response of sanitation workers, especially when a trash bin is nearly full. Therefore, packet loss analysis is necessary to determine whether the LoRa communication link can support real-time or near-real-time monitoring. Packet loss is generally calculated by comparing the number of packets sent to the number of packets successfully received. The result is typically presented as a percentage. A lower packet loss percentage indicates better transmission reliability. However, packet loss does not depend solely on distance. It can also be influenced by obstacles, antenna placement, interference, propagation factors, and environmental conditions during testing.

e. Throughput in LoRa Transmission

Throughput refers to the amount of data successfully sent and received within a specific time period. In LoRa communications, throughput is generally lower than in other wireless technologies because LoRa is designed for low-power, long-range transmission, not for high-speed data transfer [16]. Nevertheless, throughput remains an important parameter because it indicates the efficiency of the communication process. In waste-level monitoring systems, the data transmitted typically consists of small sensor readings, such as waste level, bin status, or gas concentration. Although the data size is relatively small, throughput analysis is still necessary to understand how quickly the system can transmit information from the sensor node to the receiver. A decrease in throughput can occur when the spreading factor is increased, as a higher spreading factor requires a longer transmission duration [17]. Therefore, there is a trade-off between communication range, reliability, and data transmission speed. Evaluating throughput helps determine whether the selected LoRa configuration is suitable for the monitoring scenario. If the throughput is too low, the system may experience delays in updating dashboard information. On the other hand, if processing capacity remains stable at different distances and spreading factor settings, the communication configuration can be considered adequate for a trash bin monitoring implementation.

f. Time on Air dan Spreading Factor

Time on Air is the duration required for a LoRa packet to be transmitted from the sender to the receiver via a wireless channel. This parameter is closely related to the spreading factor configuration [18]. The spreading factor determines how widely the signal is spread during transmission. A higher spreading factor can improve communication sensitivity and increase the likelihood of successful reception, especially over longer distances or in obstructed environments. However, it also increases transmission time. The relationship between the spreading factor and Time on Air is important in LoRa-based IoT systems. When the spreading factor is increased, the LoRa signal becomes stronger, but the data packet remains in the air longer. These conditions can reduce throughput and increase transmission delay. Conversely, a lower spreading factor can shorten transmission time and increase throughput, but may be less reliable over longer distances or when there are obstacles between the transmitter and receiver [19]. In wastewater monitoring applications, selecting the appropriate spreading factor requires a balance between reliability and efficiency. If the monitoring area contains many physical obstacles, a higher spread factor can help reduce packet loss. However, if the transmission distance is short and the signal path is relatively clear, a lower spread factor may be sufficient and more efficient. Therefore, testing various spread factor values is necessary to identify the most suitable LoRa configuration for the intended deployment environment.

g. RSSI and SNR as Signal Quality Indicators

The RSSI represents the strength of the signal received at the receiver end. In LoRa communication, RSSI is generally expressed in dBm, where a value closer to zero indicates a stronger received signal [20]. A higher RSSI value generally indicates better signal reception, although it does not always guarantee successful packet transmission because noise and interference can also affect communication quality. The Signal-to-Noise Ratio (SNR) describes the ratio between the received signal power and the noise level in the communication channel. A higher SNR value indicates that the received signal is clearer relative to the surrounding noise. In a LoRa network, SNR is useful for determining whether the receiver can distinguish the transmitted signal from background interference. Even when RSSI is relatively weak, LoRa can still receive data as long as the SNR remains acceptable. RSSI and SNR are important because they provide additional information beyond packet loss and throughput [20]. Packet loss indicates the final outcome of a successful or failed transmission, while RSSI and SNR help explain why a transmission performed well or poorly. For example, packet loss may increase when RSSI decreases or when SNR becomes unstable due to obstacles, interference, or environmental changes. Therefore, discussing RSSI and SNR can strengthen the analysis of LoRa performance in waste monitoring systems, particularly under non-line-of-sight testing conditions.

3.Methods

This study uses a quantitative experimental method to evaluate the performance of an IoT-based trash level monitoring system using LoRa communication. The prototype consists of two main components: a transmitter node and a receiver node. The transmitter node is mounted on a trash can and uses an Arduino Uno, an ultrasonic sensor, and a LoRa module to measure and transmit trash level data. The receiver node uses an Arduino Mega, a LoRa module, and a Raspberry Pi to receive, process, and display the data on a monitoring dashboard. LoRa communication testing was conducted at a frequency of 433 MHz under non-line-of-sight (NLOS) outdoor conditions. The NLOS scenario was chosen because real-world implementation environments may contain obstacles such as trees, walls, buildings, or other physical objects between the transmitter and receiver. The tests were conducted at five distances: 20 m, 40 m, 60 m, 80 m, and 100 m. At each distance, the spreading factor was varied from SF7 to SF12 to observe its effect on communication performance. The Quality of Service parameters evaluated in this study were packet loss, throughput, and transmission time. Packet loss was calculated as the difference between the number of packets sent and the number of packets received. Throughput was calculated as the amount of data successfully received divided by the transmission time, while transmission time was used to measure the duration required for LoRa packet transmission. These measurement results were analyzed to determine the most suitable LoRa configuration for monitoring waste levels under NLOS (Non-Line-of-Sight) conditions.

4. Result and Discussion

Testing of the LoRa-based trash level monitoring system was conducted under Non-Line-of-Sight (NLOS) conditions to determine the system’s ability to transmit sensor data in environments with physical obstacles. The tests were conducted at distances of 20 meters, 40 meters, 60 meters, 80 meters, and 100 meters with varying spreading factor (SF) values ranging from SF7 to SF12. The parameters analyzed included throughput, packet loss, packet reception success rate, and Time on Air (ToA).

a. Throughput Test Results

Table 1. NLOS Test Throughput Results

Distance	SF	Packet Received	Elapased Time (s)	Throughput (bit/s)
20 Meter	SF 7	30	0.925	32.432
	SF 8	30	0.926	32.397
	SF 9	30	0.953	31.480
	SF 10	30	0.966	31.056
	SF 11	30	0.973	30.832
	SF 12	30	0.989	30.334
40 Meter	SF 7	30	0.949	31.612
	SF 8	30	0.950	31.579
	SF 9	30	0.951	31.546
	SF 10	30	0.955	31.414
	SF 11	30	0.957	31.348
	SF 12	30	0.964	31.120

60 Meter	SF 7	30	0.906	33.113
	SF 8	30	0.915	32.787
	SF 9	30	0.922	32.538
	SF 10	30	0.928	32.328
	SF 11	30	0.936	32.051
	SF 12	30	0.941	31.881
80 Meter	SF 7	30	0.895	33.520
	SF 8	30	0.927	32.362
	SF 9	30	0.937	32.017
	SF 10	30	0.942	31.847
	SF 11	30	0.950	31.579
	SF 12	30	0.955	31.414
100 Meter	SF 7	30	0.898	33.408
	SF 8	30	0.901	33.296
	SF 9	30	0.906	33.113
	SF 10	30	0.915	32.787
	SF 11	30	0.922	32.538
	SF 12	30	0.940	31.915

Based on Table 1, throughput tends to decrease as the spreading factor increases. At a distance of 20 meters, throughput decreases from 32,432 packets/s at SF7 to 30,334 packets/s at SF12. The same pattern is also observed at a distance of 100 meters, specifically from 33,408 packets/s at SF7 to 31,915 packets/s at SF12. This decrease in throughput indicates that the higher the SF value, the longer it takes to transmit data packets. This occurs because an increase in SF results in a longer transmission duration for the LoRa signal. In other words, using a higher SF can improve signal resilience under certain conditions, but the consequence is a decrease in data transmission efficiency.

b. Packet Loss Test Results

Packet loss is used to determine the number of packets that the receiving node failed to receive. Packet loss is calculated by comparing the number of packets sent to the number of packets successfully received. The formula used is as follows:

$$\text{Packet Loss } (\%) = \frac{(\text{Packet Sen } - \text{ Packet Received})}{\text{Packet Sent}} \times 100\% = 75\%$$

Based on that formula, some values in the previous table need to be corrected. For example, if 12 packets were sent and only 3 were received, then 9 packets were lost. Therefore, the packet loss is:

$$\text{Packet Loss } (\%) = \frac{(12 - 3)}{12} \times 100\% = 75\%$$

Therefore, the packet loss rate under those conditions is not 9%, but 75%.

The Nlos test results were then analyzed using the packet loss metric. The proportion of lost packets received was calculated using the packet loss measurement. The table below shows the test results:

Table 2. NLOS Test Packet Loss Results

Distance	SF	Packet Sent	Packet Recieved	Packet Loss (%)
20 Meter	SF 7	12	12	0 %
	SF 8	12	12	0 %
	SF 9	12	12	0 %
	SF 10	12	12	0 %
	SF 11	12	12	0 %
	SF 12	12	12	0 %
40 Meter	SF 7	12	12	0 %
	SF 8	12	12	0 %
	SF 9	12	12	0 %
	SF 10	12	12	0 %
	SF 11	12	12	0 %
	SF 12	12	12	0 %
60 Meter	SF 7	12	12	0 %
	SF 8	12	12	0 %
	SF 9	12	12	0 %
	SF 10	12	12	0 %
	SF 11	12	11	1 %
	SF 12	12	12	0 %

The test results show that the highest packet loss occurred at a distance of 80 meters, particularly for SF7 and SF8, at 75%. For SF9, packet loss decreased to 50%, while for SF10, SF11, and SF12, it was 16.67%, 8.33%, and 16.67%, respectively. These results indicate that increasing the SF value at a distance of 80 meters tends to improve packet reception success, although it does not completely eliminate packet loss. Interestingly, at a distance of 100 meters, all packets were successfully received at all SF values. This suggests that packet loss is influenced not only by distance but also by environmental conditions along the communication path. At the 80-meter test point, there are likely physical obstacles such as buildings, trees, or other objects that interfere with LoRa signal propagation. Conversely, at a distance of 100 meters, the communication path is likely more open, allowing for more stable packet reception. Overall, 360 packets were sent during the packet loss test. Of these, 330 packets were successfully received and 30 were lost. This means that the overall packet reception success rate is:

$$\text{Packet Reception Success Rate} = \frac{330}{360} \times 100\% = 91{,}67\%$$

Meanwhile, the total packet loss is:

$$\text{Packet Loss} = \frac{30}{360} \times 100\% = 8{,}33\%$$

Based on these results, the previous claim that the system had a 99% data reception success rate and a 1% packet loss rate needs to be revised. A claim that is more consistent with the test data is that the system achieved a 91.67% packet reception success rate with an 8.33% packet loss rate under NLOS test conditions.

c. Time on Air Test Results

The next test was conducted on the Time on Air (ToA) parameter. ToA indicates the amount of time a LoRa packet spends on the transmission channel. The higher the ToA value, the longer it takes to complete the packet transmission process:

Table 3. NLOS Test Packet for Time on Air

Distance	SF	Time On Air (s)
20 Meter	SF 7	0.925
	SF 8	0.926
	SF 9	0.953
	SF 10	0.966
	SF 11	0.973
	SF 12	0.989
40 Meter	SF 7	0.949
	SF 8	0.950
	SF 9	0.951
	SF 10	0.955
	SF 11	0.957
	SF 12	0.964
60 Meter	SF 7	0.906
	SF 8	0.915
	SF 9	0.922
	SF 10	0.928
	SF 11	0.936
	SF 12	0.941
80 Meter	SF 7	0.895
	SF 8	0.927
	SF 9	0.937
	SF 10	0.942
	SF 11	0.950
	SF 12	0.955
100 Meter	SF 7	0.898
	SF 8	0.901
	SF 9	0.906
	SF 10	0.915
	SF 11	0.922
	SF 12	0.940

Based on Table 3, the ToA value tends to increase as the SF value increases. At a distance of 20 meters, ToA increases from 0.925 s at SF7 to 0.989 s at SF12. At a distance of 100 meters, the ToA value also increases from 0.898 s at SF7 to 0.940 s at SF12. This pattern indicates that the higher the SF value, the longer the time required to transmit a packet. This increase in ToA aligns with the observed decrease in throughput at higher SF values. As SF increases, packets require a longer transmission time, resulting in a lower number of packets that can be sent per unit of time. Therefore, the selection of SF must consider a balance between transmission reliability and data delivery efficiency

Compared to previous studies, this study has a slightly different focus. The studies by Ishu et al. (2021) [5] and Bhuvaneswari et al. (2020) [7] place greater emphasis on IoT-based trash level monitoring and the delivery of notifications via apps, SMS, or email. Meanwhile, Chandra et al. (2020) [4] developed a trash level monitoring system using ultrasonic sensors and a web-based application. Unlike these studies, this research not only presents waste level monitoring data but also evaluates LoRa communication performance through parameters such as throughput, packet loss, and ToA under NLOS conditions. Thus, the main contribution of this study lies in the analysis of LoRa data transmission reliability for waste monitoring systems in outdoor environments with physical obstacles.

Test results show that LoRa can be used as a communication medium for waste level monitoring systems. However, its performance is significantly influenced by environmental conditions, node position, antenna height, and the spreading factor value used. Under certain conditions, increasing the spreading factor (SF) can help improve packet reception but may also reduce throughput and increase transmission time. Therefore, the use of LoRa in waste monitoring systems must take into account technical configurations and the conditions at the implementation site. In general, the developed system is capable of transmitting sensor data under non-line-of-sight (NLOS) conditions with a packet reception success rate of 91.67% and a packet loss rate of 8.33%. These values indicate that the system performs reasonably well but still requires optimization in terms of device placement and communication configuration. For field implementation, LoRa devices should be placed in higher positions to reduce signal obstructions. Additionally, the use of additional antennas or improved antenna quality can be considered to enhance communication range and stability.

5. Conclusions

Based on the reported experimental results, the developed IoT-LoRa prototype was capable of transmitting waste level monitoring data under non-line-of-sight (NLOS) conditions. The system was evaluated at distances of 20 m, 40 m, 60 m, 80 m, and 100 m using spreading factor values ranging from SF7 to SF12. The results show that LoRa communication performance is influenced by distance, spreading factor, and the presence of physical obstacles in the test environment. Packet loss was primarily observed at a distance of 80 m, with the highest loss occurring at SF7 and SF8, while some other combinations of distance and spreading factor did not exhibit packet loss. The throughput results indicate that an increase in the spreading factor generally reduces the data transmission rate, while the Time on Air results show that higher spreading factor values require longer packet transmission durations. Therefore, the selection of the spreading factor must be tailored to the distance and environmental conditions of the monitoring area. Overall, this study demonstrates that LoRa communication is viable for waste level monitoring in outdoor NLOS scenarios. However, further testing is needed to evaluate additional sensor components and notification features before broader claims regarding the system’s overall capabilities can be made.

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