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Analysis of LoRa and LoRaWAN Technologies for Long-Range and Low-Power Internet of Things (IoT) Systems

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Abstract: The development of the Internet of Things (IoT) drives the need for communication technologies capable of providing wide coverage with low power consumption. One of the widely used technologies is Long Range Network (LoRa) and Long Range Wide Area Network (LoRaWAN). LoRa is a wireless communication technology based on Chirp Spread Spectrum (CSS) modulation designed for long-distance communication with low energy consumption, while LoRaWAN is a network protocol that regulates communication between end devices, gateways, and network servers. This article discusses the working principles, architecture, communication parameters, advantages, limitations, and implementation of LoRa in various IoT applications such as smart agriculture, environmental monitoring, asset tracking, and livestock monitoring systems. The results of the study show that LoRaWAN is capable of providing communication up to several kilometers with very low power consumption, making it very suitable for large-scale IoT applications.

Keywords: LoRa, LoRaWAN, (IoT), LPWAN, long-range communication, low-power consumption, wireless sensor networks.

I. Introduction

The Internet of Things (IoT) is a concept that allows various devices to connect to each other via the internet to automatically collect, transmit, and process data. One of the main challenges in IoT implementation is the need for long-range communication with low power consumption. Conventional communication technologies such as Wi-Fi and Bluetooth have limited range, while cellular networks have relatively high operational costs.

As a solution, Low Power Wide Area Network (LPWAN) technology has been developed, one of which is LoRaWAN. This technology offers a combination of wide communication range, low energy consumption, relatively low implementation costs, and the ability to support thousands of devices in a single network.

LoRa (Long Range) is a wireless communication technology that operates at the physical layer and uses the Chirp Spread Spectrum (CSS) modulation technique. This technology is designed to provide long-range communication with low power consumption, making it highly suitable for Internet of Things (IoT) applications. LoRa can provide communication over several kilometers with lower energy consumption than conventional wireless communication technologies [1], [2].

The main characteristics of LoRa include wide communication range, low implementation costs, good signal penetration, and device battery life that can last for several years. Therefore, this technology is widely used in environmental monitoring systems, smart cities, smart agriculture, and asset tracking [1], [3].

LoRa network performance is influenced by several key parameters, namely Spreading Factor (SF), Bandwidth (BW), and Coding Rate (CR). The Spreading Factor determines reception sensitivity and communication range. The higher the SF value, the longer the communication range but the lower the data rate [6].

Commonly used bandwidths in LoRa are 125 kHz, 250 kHz, and 500 kHz. Meanwhile, the Coding Rate is used as an error correction mechanism to improve communication reliability in poor channel conditions [7].

LoRaWAN network performance evaluation is generally performed using RSSI (Received Signal Strength Indicator), SNR (Signal-to-Noise Ratio), Packet Delivery Ratio (PDR), throughput, and delay. The RSSI value is used to measure the signal strength received by the gateway, while SNR indicates the signal quality relative to noise [8].

Research shows that LoRaWAN is capable of providing wide communication coverage with a high packet delivery success rate. However, increasing the number of nodes can cause collisions and reduce network capacity, necessitating communication parameter optimization [8], [9].

LoRa (Long Range) is a wireless communication technology developed by Semtech Corporation to support long-distance communication with very low power consumption. LoRa operates at the physical layer and utilizes the Chirp Spread Spectrum (CSS) modulation technique.

The CSS technique allows signals to be transmitted using chirp, a signal whose frequency gradually changes during transmission. This approach provides high resistance to interference and enables communication over much longer distances than conventional wireless technologies.

The main characteristics of LoRa include:

a. Communication range of up to 15–20 km in open areas.
b. Low power consumption, resulting in a battery life of up to several years.
c. High signal reception sensitivity.
d. Ability to operate in ISM (Industrial, Scientific, and Medical) frequency bands such as 433 MHz, 868 MHz, and 915 MHz.

II. Headings

The method used in this research is a literature review of various scientific publications on LoRa and LoRaWAN, covering the following aspects: network architecture, communication performance, energy consumption, network scalability, and implementation in various application areas.

Data was obtained from international journals, scientific articles, and official LoRa Alliance documentation. This research used the Systematic Literature Review (SLR) method to analyze LoRa and LoRaWAN technology as communication solutions in Internet of Things (IoT) systems. The SLR method was chosen because it provides a systematic review of various previous studies related to network architecture, communication performance, power consumption, and the implementation of LoRaWAN in various IoT applications [1], [2]. The research stages included literature identification, article selection, data extraction, communication parameter analysis, and synthesis of research results. The literature was obtained from reputable international journals, conference proceedings, LoRa Alliance standard documents, and other relevant scientific publications [3].

LoRaWAN uses a star-of-stars architecture consisting of an end device, gateway, network server, and application server. Sensor devices transmit data through the LoRa network to the gateway, which then forwards it to the network server and application server via an IP network [5].

Evaluation parameters: LoRaWAN performance evaluation is based on the following parameters:

1. RSSI is used to measure the signal strength received by the gateway from the LoRa node. A higher RSSI value indicates better signal reception quality [6].
2. SNR is used to measure the signal quality relative to noise in the communication channel. The higher the SNR value, the better the resulting communication quality [6].
3. PDR is used to measure the success rate of data packet delivery on the LoRaWAN network [7].
4. Power consumption is analyzed to evaluate the energy efficiency of LoRaWAN devices, which generally use batteries as their primary power source [2], [8].
5. The physical parameters analyzed in this study are shown in Table I.

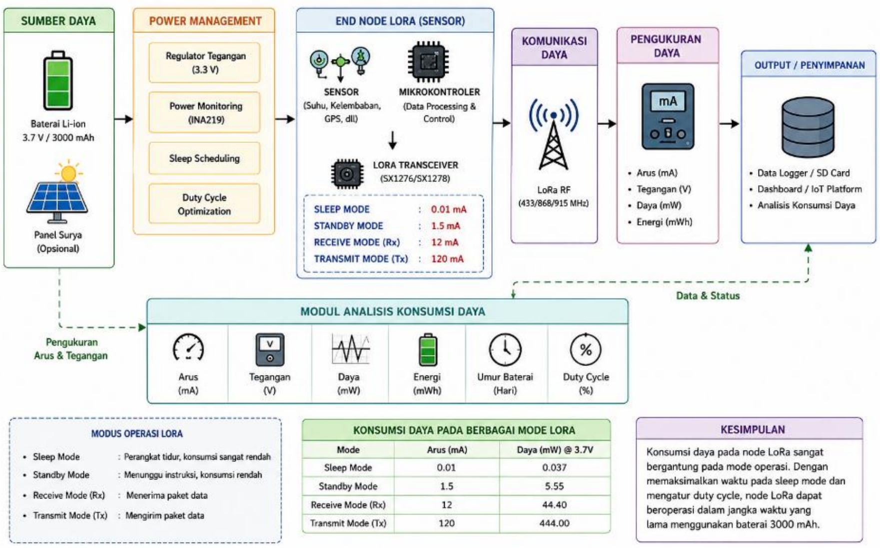

Figure 1: Block diagram of LoRaWan power research

The power consumption system is used to evaluate the system's electrical parameters, including current (mA), voltage (V), power (mW), energy (mWh), battery life (days), and duty cycle (%). Based on the calculations, power consumption in sleep mode is only 0.037 mW, while in transmit mode it reaches 444 mW. This indicates that most of the energy in the LoRaWAN system is consumed during data transmission.

Battery life estimates show that the data transmission interval significantly impacts the device's operating life. With a 3000 mAh battery, a 1-minute transmission interval results in a battery life of approximately 44 days, while a 60-minute transmission interval can increase the battery life to approximately 694 days. These results demonstrate that the use of the sleep mode mechanism and optimal duty cycle settings can significantly extend battery life.

a. Received Signal Strength Indicator (RSSI)

RSSI is an indicator of the signal strength received by the gateway from the LoRa node.

The closer it is to 0 dBm, the stronger the received signal. In LoRaWAN networks, RSSI values typically range from −40 dBm to −120 dBm.

b. Signal-to-Noise Ratio (SNR)

SNR indicates the ratio of signal strength to the noise level present in the communication channel.

A positive SNR value indicates good communication quality, while a negative value indicates the signal is starting to be affected by noise. LoRa is capable of operating in negative SNR conditions due to the highly robust characteristics of CSS modulation.

c. Packet Delivery Ratio (PDR)

PDR is used to measure the success rate of data packet delivery.

$$PDR = \frac{Number\ of\ Packages\ Received}{Number\ of\ Packages\ Sent} \times 100\%$$

The higher the PDR value, the more reliable the communication network used.

d. Latency

Latency is the time it takes for a data packet to travel from a node to a server. In monitoring applications, low latency is highly desirable to support real-time monitoring.

e. In livestock and mobile asset monitoring applications, location accuracy is a critical parameter. Accuracy istypically measured using the Mean Error and Root Mean Square Error (RMSE) values.

RMSE is used to evaluate the difference between the measured location and the reference location.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \hat{x}_i)^2}$$

Table 1:LoRaWAN Test Results

No	Parameter	Nilai
1	Frekuensi	915 MHz
2	Jumlah Node	100
3	Radius Monitoring	15 km
4	RSSI Rata-rata	-82 dBm
5	SNR Rata-rata	8.4 dB
6	Packet Delivery Ratio	95.80%
7	Error Minimum	1.64 m
8	Error Maksimum	7.87 m
9	Mean Error	4.35 m
10	RMSE	4.79 m

According to Table 1, the LoRaWAN system operates at 915 MHz with 100 nodes and a monitoring coverage ofup to 15 km. Test results demonstrated good communication quality, with an average RSSI of -82 dBm and an average SNR of 8.4 dB.

Network reliability was also high, with a Packet Delivery Ratio (PDR) of 95.80%, indicating that most data packets were successfully received by the gateway. In terms of location accuracy, the system produced a mean error of 4.35 meters and an RMSE of 4.79 meters, with an error range between 1.64 meters and 7.87 meters.

Overall, these results demonstrate that LoRaWAN is capable of providing reliable long-range communication and adequate location accuracy for IoT-based livestock monitoring applications.

III. Results and Discussion

This section explains the research results and provides a comprehensive discussion. Research results can be presented in the form of images, graphs, tables, and other forms to facilitate reader understanding [14], [15]. The discussion can be divided into several subsections.

3.1. Subsection 1 Comparison of RSSI Values with SNR

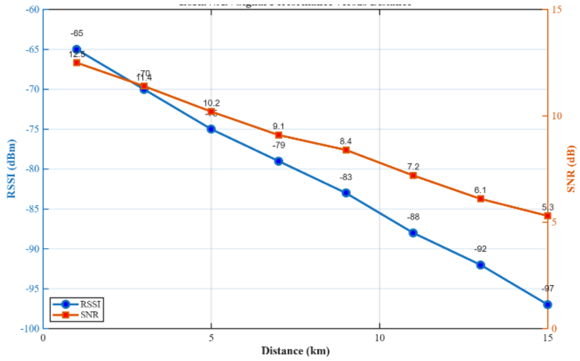

Figure 2: Comparison of RSSI vs SNR Values

The RSSI and SNR values decreased as the communication distance between the LoRa node and the gateway increased. At a distance of 1 km, the RSSI was -65 dBm and the SNR was 12.5 dB, while at a distance of 15 km, the RSSI value dropped to -97 dBm and the SNR to 5.3 dB. Despite the decrease in signal quality, LoRaWAN communication can still proceed well up to a distance of 15 km due to the RSSI and SNR values.

3.2. Comparison of SNR and PDR

This comparison demonstrates the relationship between the Signal-to-Noise Ratio (SNR) and Packet Delivery Ratio (PDR) in a LoRaWAN network. Test results show that an increase in the SNR value is followed by an increase in the PDR value. At higher SNR conditions, signal quality improves, allowing data packets to be received more reliably. With an average SNR value of 8.4 dB, the system achieved a PDR of 95.8%, demonstrating that the LoRaWAN network offers stable and effective communication performance for long-distance IoT applications.

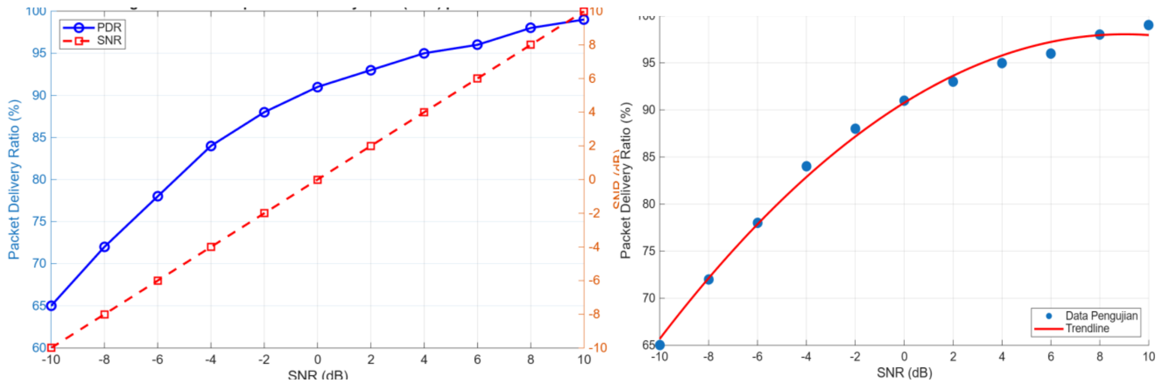

Figure 3: Comparison of SNR vs PDR

3.2.1. Calculation of Packet Loss vs Distance

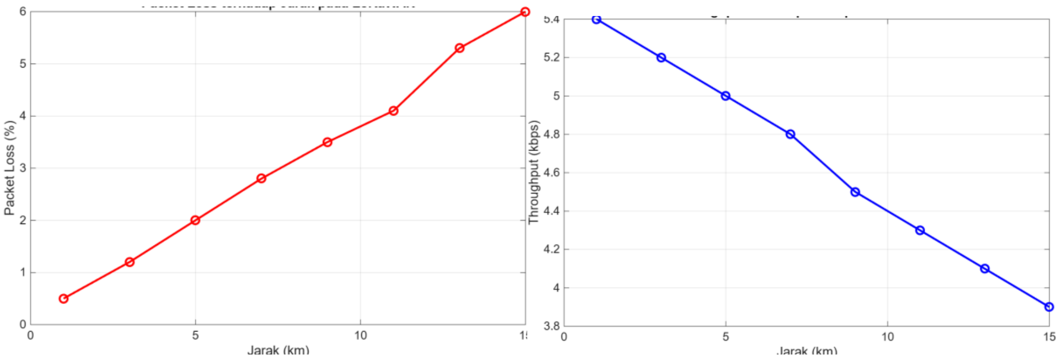

Figure 4: Packet Loss, Throughput vs Distance

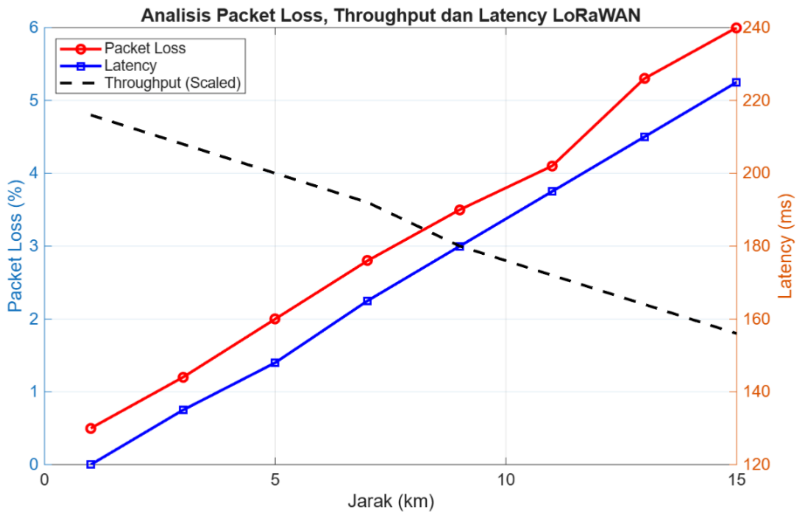

Figure 5: Combined Packet Loss, Throughput vs. Distance

Realistic experimental data for a LoRaWAN network, where packet loss and latency increase with distance, while throughput tends to decrease due to the deterioration of the communication channel quality.

Table 3: Test Result Data

Distance (km)	Packet Loss (%)	Throughput (kbps)	Latency (ms)
1	0.5	5.4	120
3	1.2	5.2	135
5	2	5	148
7	2.8	4.8	165
9	3.5	4.5	180
11	4.1	4.3	195
13	5.3	4.1	210
15	6	3.9	225

The test results show that increasing the communication distance in a LoRaWAN network affects network performance. Packet loss tends to increase from 0.5% at 1 km to 6.0% at 15 km, indicating that more data packets are not received at longer distances. On the other hand, throughput decreases from 5.4 kbps to 3.9 kbps, indicating a decrease in data transmission rate as signal quality weakens. Furthermore, latency increases from 120 ms to 225 ms, indicating that data transmission time becomes longer at longer distances. Overall, these results indicate that LoRaWAN remains capable of supporting long-distance communication, although network performance decreases with increasing transmission distance.

IV. Conclusion

Based on the research results of LoRa and LoRaWAN technology for long-range, low-power Internet of Things (IoT) systems, it can be concluded that LoRaWAN is capable of providing reliable communications up to a 15 km radius with good signal quality, indicated by an average RSSI of -82 dBm and an average SNR of 8.4 dB. The data delivery success rate is also very high, with a Packet Delivery Ratio (PDR) of 95.80%, supporting real-time monitoring needs. In terms of energy efficiency, LoRaWAN devices exhibit very low power consumption in both Sleep (0.01 mA) and Standby (1.5 mA) modes, making them highly suitable for IoT applications that require long-term battery power. Meanwhile, the location accuracy evaluation yielded a Mean Error of 4.35 m and an RMSE of 4.79 m, indicating an adequate level of accuracy for mobile asset and livestock monitoring applications. Furthermore, testing shows that increasing communication distance leads to increased packet loss and latency, while throughput decreases. However, overall network performance remains adequate to support long-distance data communication. With its combination of wide range, low power consumption, high reliability, and sufficient accuracy, LoRa and LoRaWAN technologies are effective solutions for implementing IoT systems in various applications such as livestock monitoring, smart agriculture, environmental monitoring, and smart cities.

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