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Handoff Technique Using LoRaWAN Technology

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***Abstract*—This research introduces an innovative handoff methodology for LoRaWAN in IoT systems. This approach, validated through empirical testing, not only markedly enhances connection quality but also facilitates the system in selecting the optimal gateway, providing redundancy, verifying gateway availability prior to handoff, and managing handoff failures. Experimental evaluations were performed using two LoRa gateways (Arduino Nano and LoRa RFM95) and a single LoRa end device (comprising Arduino Nano, LoRa RFM95, MQ135 sensor, and OLED), during which the node transitioned between two positions (Gateway A and Gateway B) approximately 500 meters apart. Handoff was triggered when one RSSI value fell below the other. The experimental handoff threshold was established at an RSSI of -93 dB; exceeding this value resulted in the transmitter losing service from the gateway. During the experiment, the transmitter gradually moved from Gateway A to Gateway B over a period of 40 seconds. At the 20th second, a critical juncture was observed wherein the RSSI and SNR values of Gateway B gradually exceeded those of Gateway A. Gateway B recorded an RSSI of -92 dBm and an SNR of 4 dB, whereas Gateway A recorded an RSSI of -97 dBm and an SNR of 2 dB. This signifies that Gateway B exhibited superior signal quality. Based on a dynamic comparison of these parameters, the system effectively executed a handoff at the midpoint, thereby redirecting data transmission to the gateway with the higher link quality.**

***Keywords*—Lorawan; Lora; handoff; wireless.**

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I. Introduction

Current technological developments are progressing rapidly, particularly in systems that utilize the Internet of Things (IoT) to collect data from specific environments. Especially in IoT, with large numbers of nodes and gateways, reliable communication channels will be required. To support data delivery to the server, most IoT systems rely on the internet, even though they have dozens of transmitters, gateways, or receiver nodes. This causes increasing costs. Several factors must be considered, particularly the transmission distance and the communication channels that must always be available to ensure uninterrupted data delivery. The system must have a communication path option if the communication path cannot forward data, especially for monitoring nodes that move dynamically. In this context, LoRa (Long Range) communication technology emerges as an innovative solution that enables efficient long-distance data transmission with low power consumption, thereby demonstrating significant potential for IoT-based systems. The potential of LoRa is a reason for optimism because it uses the Chirp Spread Spectrum module, which enables wireless communication over a wide frequency range, thereby allowing it to adapt to various environmental conditions. This has the potential to overcome challenges similar to those faced by GPS-based tracking systems in remote areas with limited internet connectivity. This shows the need to develop more robust methods for object tracking systems.

Furthermore, research by [1] introduced the use of LoRaWAN in tracking systems, enabling GPS data transmission without an internet connection. Although successful, the application of this technology remains limited and warrants further analysis of the maximum achievable distance. Another study conducted by the ref [2]. Based on these findings, the handoff process presents significant challenges, particularly when transferring devices between gateways over long distances. Improper handoffs can cause communication disruptions and data packet loss. Therefore, this study aims to implement efficient handoff techniques for LoRaWAN. The development of appropriate methods is expected to improve the efficiency and reliability of wireless communication and optimize the scalability of LoRaWAN networks.

As shown in Table 1, wireless communication technology has advantages and limitations. In general, this is influenced by several parameters, including range, data transmission speed, and power consumption. Especially in the transfer of communication paths (handoffs), which are often used in the Internet of Things. Handoff enables a reliable transfer of communication paths without disrupting other active communication paths. Therefore, the appropriate technology is needed to support the handoff process for the communication path. LoRa was chosen in this study because it offers characteristics well-suited to handoff applications in large networks with minimal infrastructure, such as in rural areas, plantations, or smart cities. LoRa enables devices such as vehicles, drones, or other IoT devices to remain connected to the network even as they move from one gateway to another. Although LoRa has a relatively low data rate, LoRa still provides relatively stable connectivity. Unlike LoRa, Wi-Fi is typically used in areas with limited coverage, with a maximum range of approximately 60 meters. Transferring communication paths from one access point to another is time-consuming and consumes additional node power.

TABLE I

COMPARISON OF SEVERAL WIRELESS COMMUNICATION TECHNOLOGIES [3]

Type	Distance	Maximum Rate	Consumption Power
Bluetooth	10 M	2 M/S	Low
LoRa	0 – 15 KM	600 KB/S	Low
Wi-Fi	0 – 60 M	54 M /S	High
ZigBee	0 – 1500 M	250 KB/S	Low

Bluetooth, which has a range of only about 10 meters, supports handoff via methods such as piconet-scatternet switching, but is suitable only for very local personal device applications. The limited range makes Bluetooth irrelevant for wide mobility applications.

Meanwhile, ZigBee offers a broader range than Bluetooth (up to 1,500 meters) and low power consumption. ZigBee also supports limited handoff in mesh networks, in which devices can switch connection paths in response to changes in network topology. However, ZigBee is primarily used in stationary systems, such as smart homes and industrial settings, rather than in highly mobile systems. Given its energy efficiency, wide range, and topology flexibility, LoRa is a suitable choice for handoff system development, particularly in mobile IoT applications with large coverage areas and distributed gateway infrastructure. Handoff implementation in LoRa is typically performed by detecting signal degradation (RSSI) and SNR, and then automatically switching the device to the nearest gateway with the strongest signal. This mechanism can be implemented using an RSSI-based decision approach, GPS-assisted switching, or a central server (network server) within the LoRaWAN architecture.

A. *Overview of LoRa Technology*

Long Range Access (LoRa) is a wireless communication technology that provides long-distance connectivity with low power consumption. LoRa enables wireless data transmission over long distances, up to 15 km (in ideal conditions), depending on environmental factors. [4], [5], [6], [7]. LoRa operates within the radio spectrum, utilizing frequencies of 433 MHz, 868 MHz, or 915 MHz, depending on local building regulations and the ability to overcome physical obstacles such as buildings and vegetation (including trees, flowers, and grass) [8], [9], [10]. LoRa uses chirp spread spectrum (CSS) modulation, developed by Semtech, to transmit data [11]. The CSS modulation method leverages the properties of chirps (frequencies that vary over time) to enhance interference resistance and extend range.

LoRa is a communication system that uses the LoRaWAN (Long Range Wide Area Network) communication protocol [12]. This protocol operates on top of LoRa physical-layer (PHY) modulation and defines rules for the media access control (MAC) layer [13]. LoRaWAN supports half-duplex communication, in which the sending and receiving devices alternately use the same radio channel. Therefore, devices that communicate with the LoRa network transmit or receive data only at specific times [14].

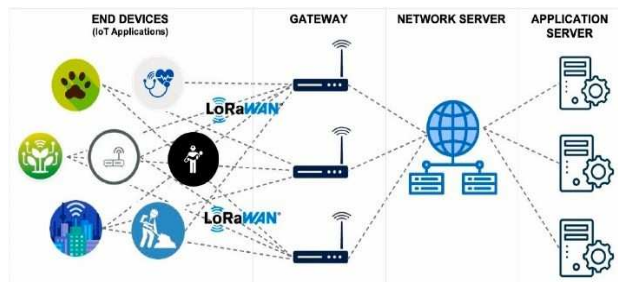


Fig. 1 General architecture of LoRaWAN network in IoT [6]

As shown in Fig. 1, the architecture of the LoRaWAN (Long Range Wide Area Network) communication system comprises four main layers: end devices, gateways, network servers, and application servers [15]. This architecture is designed to support long-distance communication with incredibly low power consumption, making it ideal for a wide range of Internet of Things (IoT) applications [16].

On the leftmost layer, various end devices representing IoT applications are located, including livestock monitoring, smart agriculture, and smart city systems. These devices act as environmental data collectors, periodically transmitting data via radio signals using the LoRa protocol [17]. Due to LoRa's long-range capabilities, these devices can operate several kilometers from the nearest gateway, eliminating the need for cellular or Wi-Fi connectivity. Data sent by the device will be received by the gateway, which acts as a bridge between the LoRa network and the internet. The gateway does not process data, but only forwards data packets from the device to the network server via an IP connection. In many cases, a device can be reached by more than one gateway simultaneously, especially when in an overlapping area, in which case the network server is responsible for filtering duplicate traffic.

Next, the network server becomes a core component in the LoRaWAN architecture. Its function is to decode, verify, and process data received from the gateway; perform deduplication when the same data is received from multiple gateways; and manage data delivery back to the device (downlink) via the optimal gateway [18]. The network server also manages security aspects, such as device authentication and data encryption, and can run the Adaptive Data Rate (ADR) algorithm to optimize data transmission efficiency [19]. After the network server processes the data, the information is sent to the application server, where the application system uses it to meet user needs. This is where various backend services, including storage, visualization, data analysis, and user interfaces, are executed. The application server enables end users to access data in real time and make decisions based on that information.

Lora has several parameters in determining LoRa sensitivity, including:

1) Frequency: Lora operates on various frequencies, such as 433 MHz, 868 MHz, and 915 MHz. The choice of LoRa frequency depends on regional regulations and application objectives. This frequency affects the range and penetration of the LoRa signal. Lower frequencies generally yield narrower bandwidths, whereas higher frequencies can yield broader bandwidths and better connectivity [4], [20].

2) Bandwidth (BW): Bandwidth (BW) is the width of the frequency band used for data transmission. Lora supports bandwidth options of 125 kHz, 250 kHz, and up to 500 kHz. Higher bandwidth allows for faster data transfer but also affects power consumption (more power) and can reduce range [4], [6].

3) Spreading Factor (SF): Spreading factor (SF) refers to how LoRa stretches its signal within a frequency range. The spreading factor controls the symbol duration and data rate in LoRa transmission. A higher spreading factor yields a slower signal with a greater range. However, this also means that the data throughput will be lower. The spreading factor usually ranges from 7 to 12; SF 7 yields the highest throughput and the shortest distance, whereas SF 12 yields the lowest throughput and the longest distance [20], [21]

4) Coding Rate (CR): Coding Rate (CR) is a parameter that determines the amount of overhead added to the data for error correction purposes. The higher the coding rate, the greater the overhead, which increases transmission reliability but reduces data rate. The coding rate usually ranges from 4/5 to 4/8 [4], [21]

5) Transmission Power: Transmit Power is the power level used to transmit signals. It is typically measured in dBm (decibels milliwatts). This power level affects the device's transmission distance and power consumption. The higher the transmission power, the further the distance, but it will consume more energy [22]

In LoRa settings, parameter selection must be tailored to the application's specific requirements. For example, if a longer range is required, the parameters are lower frequency, higher SF, and higher transmission power. However, if higher power rates are necessary, the parameters to select are higher frequency, lower SF, and higher CR [7], [23].

In the study "Simple LoRa Protocol: LoRa Communication Protocol for Multisensory Monitoring System" [24], researchers tested the range of the LoRa Chip using RSSI and Packet loss parameters in urban areas. In this study, researchers compared test results with RSSI predictions based on the log-normal shadowing model. However, based on average test results and calculations conducted by researchers, RSSI decreased while packet loss increased with increasing distance. In the Final Document they did, they were able to obtain several conclusions, such as:

- Distance significantly affects RSSI and packet loss
- The closer the end node is to the gateway, the better the signal in the transmission process
- The maximum range of LoRa in urban areas obtained from the study is 2 km

In the study "Analysis of Indoor LORA Transmission Characteristics" [25], researchers tested the range of the LoRa Chip using RSSI and Packet loss parameters in indoor environments. In this study, researchers compared test results with RSSI calculations, providing a comprehensive examination of LoRa behavior and parameter analysis in indoor settings. This test was conducted to determine the reliability and stability of LoRa when applied in Building F at the Faculty of Computer Science, Brawijaya University, Malang. Data collection was carried out at three points, namely at distances of 50m, 100m, and 150m vertically inside the building. The results showed that RSSI values ranged from -81 dB to -101 dB, with TP 5, SF 11, and Bandwidth 125 kHz yielding the most appropriate results under the conditions of Building F at the Faculty of Computer Science, Brawijaya University, Malang.

B. Handoff Techniques in Wireless Networks

Handoff, also known as handover, is a process in wireless communication in which a device moves from one node or base station to another without interrupting ongoing service [26]. This process is performed to maintain connection continuity without interruption as the device moves from one node to another with a stronger or more suitable signal. The handoff technique is crucial for providing smooth and uninterrupted telecommunications services to users. For example, when a user moves from one cell coverage area to another, a handoff will occur between the two cells. The cell that served the call before the handoff will release its responsibility, and the call will be transferred to the new cell. Handoff can also occur if the number of subscribers using a particular cell has reached its maximum capacity. The decision to perform a handoff typically occurs when the signal strength of the current cell falls below a threshold, and the signal strength of the other cell (the one the user is approaching) is higher. Factors that trigger handoffs include user movement and signal-strength fluctuations.

Handoffs can be classified into three types: hard handoff, soft handoff, and softer handoff. In a hard handoff, communication is explicitly transferred from one channel to another. When the connection is interrupted, the device is temporarily disconnected and then reconnects to the new signal. Soft handoff devices can simultaneously connect to multiple channels without interrupting communication. Soft handoff is commonly used in CDMA networks. With a softer handoff, mobile devices can simultaneously connect to multiple channels without interrupting or disconnecting communication.

II. MATERIAL AND METHOD

A. *Handoff Design and Mechanism*

System design is the initial stage that serves as a reference for system development. This design stage minimizes all possibilities that can hinder its implementation. The overall System Architecture Design is shown in Fig. 2. The handoff concept in a LoRa network relies on local decision-making by gateways. In the illustration, there are two gateways—Gateway A and Gateway B—each with its coverage area (Area A and Area B) that partially overlap. A transmitter node moves across these areas, periodically sending uplink data. In this system, each gateway has its own logic to determine whether to receive and process data packets from the node, based on signal quality metrics such as RSSI and SNR. When the node is in Area A, the signal received by Gateway A is stronger than that of Gateway B, so Gateway A will process the packet. However, when the node moves to Area B, the signal quality at Gateway A degrades, whereas Gateway B receives a stronger signal. Under this condition, Gateway B automatically assumes control of the communication process.

This mechanism reflects a decentralized handoff model in which each gateway independently evaluates the incoming signal. This approach is efficient and straightforward, as it reduces dependence on central infrastructure and is suitable for small to medium-scale IoT systems that require flexibility and energy efficiency. Although it does not involve a network server, the handoff process can still occur dynamically and responsively in response to node movement, provided that the gateway can assess and process signal quality. This approach also eliminates the need for complex synchronization, enabling a simpler implementation suitable for areas with limited internet connectivity or centralized networks.

Thus, the handoff decision in this system is local and autonomous: connections are transferred naturally from one gateway to another based on the best signal quality, making the system more independent and adaptive to node mobility in the field.

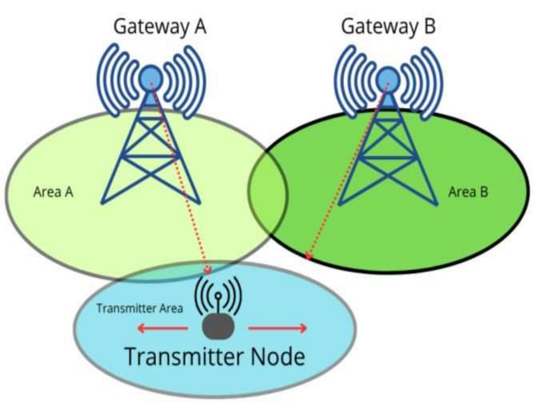
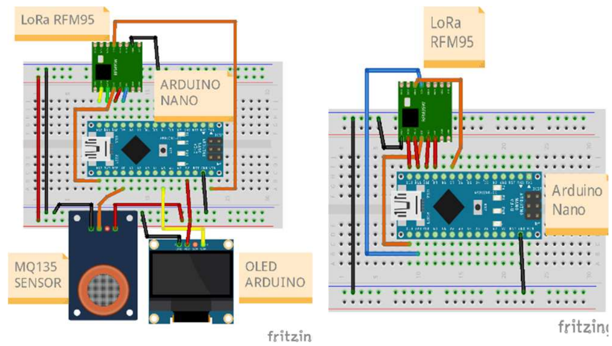


Fig. 2 System Architecture Design

B. *Design and Hardware Specification*

Gateway A (Fig. 3) and Gateway B (Fig. 4) are equipped with LoRa RFM95, Arduino Nano, and an Antenna. The RFM95 LoRa module is designed with advanced features to support efficient and reliable long-distance wireless communication. It is capable of operating at a constant transmit power of up to +20 dBm (approximately 100 mW equivalent), enabling strong signal transmission even in challenging terrain. This capability, combined with a maximum link budget of 168 dB, makes it well-suited for applications in remote areas.



(a) (b)

Fig. 2 Design of receiver and transmitter (a) Transmitter (b) Gateway A and B

The module boasts a very high signal reception sensitivity of up to -148 dBm, enabling it to detect extremely weak signals. To ensure reliable communication under various signal conditions, the module also has a dynamic RSSI range of 127 dB and excellent blocking immunity. Its front-end capability is also robust, with an IIP3 of -12.5 dBm, which mitigates substantial signal interference. For power efficiency, RFM95 is highly energy efficient. In receive mode, the register consumes approximately 10.3 mA; in standby, it draws only 200 nA, making it highly suitable for battery-powered devices. The module supports up to 256 bytes of data and includes an automatic error-checking system using CRC (Cyclic Redundancy Check).

Additionally, it supports preamble detection, which helps synchronize signals prior to the transmission of primary data. Other essential features include an internal temperature sensor and a low-battery indicator, which enable real-time monitoring of device conditions. The module is also equipped with active channel detection (CAD) and automatic RF sensing capabilities, as well as very fast automatic frequency correction (AFC), ensuring smooth communication without channel collisions.

In terms of modulation flexibility, RFM95 supports various modulation methods, including FSK, GFSK, MSK, GMSK, OOK, and, notably, LoRa, which is the primary mode for long-distance communication with high efficiency. This module also includes a bit synchronizer that precisely aligns data during transmission. With high-resolution internal frequency synthesis up to 61 Hz, the RFM95 provides excellent frequency stability. All these features make the LoRa RFM95 a reliable, efficient, and flexible module for implementing IoT communication systems that require broad coverage and low power consumption. Arduino Nano is used as an additional controller or as a connector between LoRa RFM95 modules. The Arduino Nano also facilitates signal processing, including RSSI (Received Signal Strength Indicator) measurement. The antenna is connected to the LoRa RFM95 module and is used to amplify and optimize the reception and transmission of radio signals from the gateway to the sender. On the sender (Fig. 5), there is a dust sensor serving as a data generator and an LCD to display the sensor values, as well as gateways connected to it.

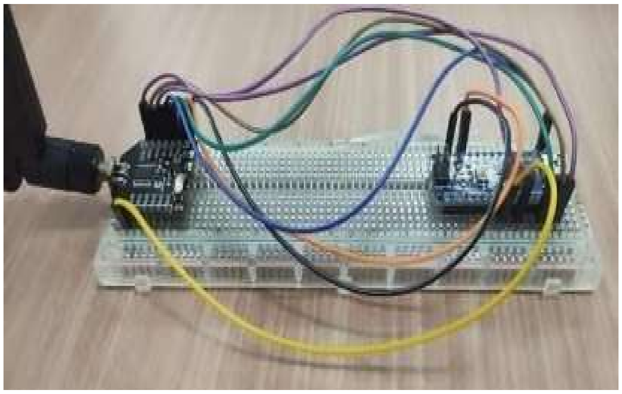


Fig. 3 Lora Gateway A Design

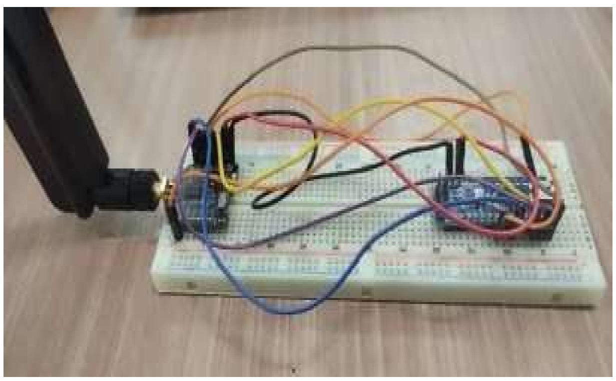


Fig. 4 Lora Gateway B Design

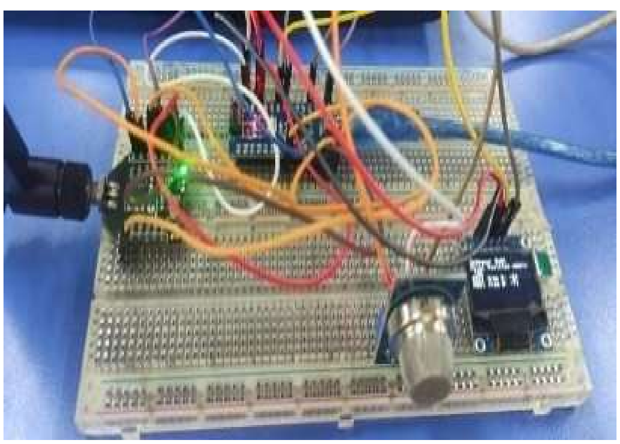


Fig. 5 Transmitter/sender Design

C. Handoff Data Flow

Fig. 6 shows the communication process between the sender and the gateway. It begins with the sender sending a ping signal to Gateway A using the recipient address 0xA1 and the message 0xFF. Gateway A then checks the signal strength (RSSI); if the RSSI exceeds -93 dBm, Gateway A responds with that value. However, if the RSSI is less than or equal to -93 dBm, no response is received.

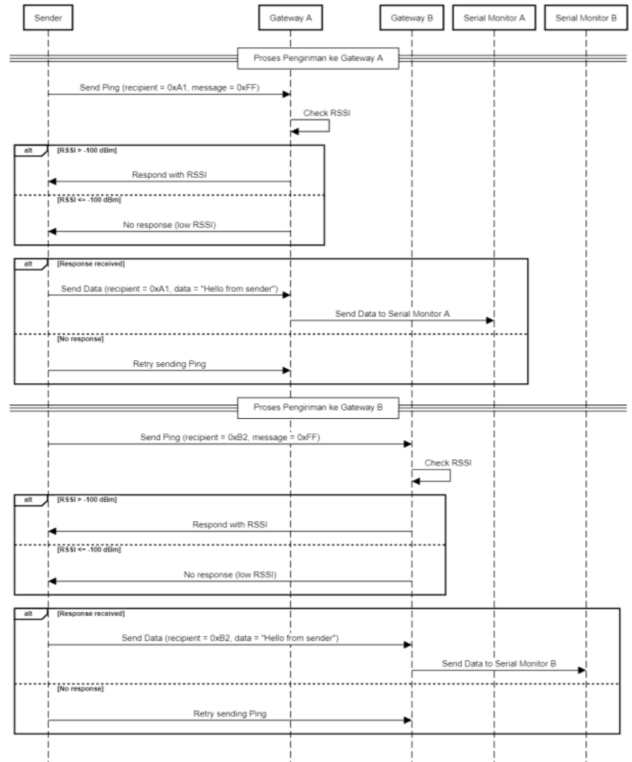


Fig. 6 Data Flow Sequence between sender and gateway

Fig. 6 shows the communication process between the sender and the gateway. It begins with the sender sending a ping signal to Gateway A using the recipient address 0xA1 and the message 0xFF. Gateway A then checks the signal strength (RSSI); if the RSSI exceeds -93 dBm, Gateway A responds with that value. However, if the RSSI is less than or equal to -93 dBm, no response is received.

Suppose a response from Gateway A is received. In that case, the sender will continue by sending data to the recipient address 0xA1 and the message "Hello from sender", which will be forwarded to Serial Monitor A. After that, the sender sends a ping to Gateway B with the recipient address 0xB2 and the message 0xFF. Gateway B also checks the RSSI in the same way: if the RSSI exceeds -93 dBm, the gateway responds; otherwise, no response is received.

If Gateway B does not respond, the sender will send data with the recipient address 0xB2 and the message "Hello from the sender," which is then forwarded to Serial Monitor B. This process will be repeated; if neither gateway responds, the sender will attempt to resend the ping.

The sequence diagram in Fig.7 illustrates the process that begins when a user sends a handoff request to the current gateway. Upon receiving the request, the current gateway verifies the new gateway's availability by sending a probe. If the new gateway responds with a status of ‘available’, the handoff is allowed, and the user is connected to the new gateway. A confirmation of the connection follows; if successful, the handoff is declared successful. Conversely, if the new gateway responds that it is ‘not available’ or does not respond at all, the handoff is rejected, and the status is declared a failure. Once the handoff is successful, the user can begin sending data to the new gateway, which then confirms receipt.

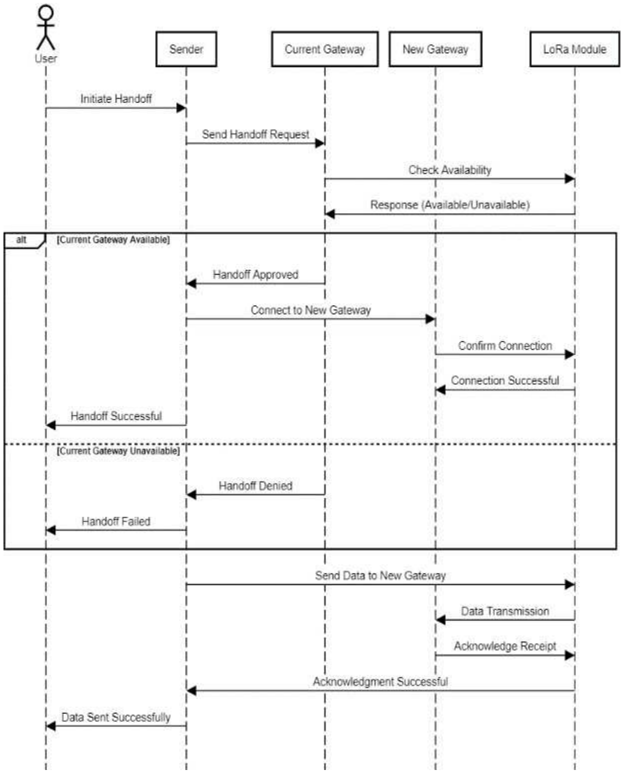


Fig. 7 Sequence Diagram Handoff Procedure

III. RESULTS AND DISCUSSION

The testing stages comprise 2 test cases: basic connection testing, gateway selection via handoff techniques, and dynamic sender movement testing. Sending node testing involves verifying the accuracy of gateway selection based on the constructed sequence diagram and the reliability of the connections between nodes and gateways. In contrast, gateway node testing involves verifying the gateway response and the connection change between the gateway and the sender, as outlined in the established flow and sequence diagrams.

A. *Noise latency, RSSI, and SNR measurements on Gateway A and B*

LoRa communication performance was measured to evaluate data transmission quality in the network. The three main parameters analyzed include RSSI (Received Signal Strength Indicator), SNR (Signal-to-Noise Ratio), and Noise Latency. Measurements on 49 samples indicated that the LoRa network exhibited relatively stable performance with low levels of interference. The RSSI value falls within the range 35-42, indicating that the signal strength received by the receiving node is relatively strong. Although there is a slight fluctuation, this value remains within the LoRa system's tolerance threshold, indicating that the signal can be received consistently without significant degradation that would interfere with communication. Meanwhile, the SNR parameter ranges from 26 to 34, indicating good signal quality relative to environmental interference (noise). A high SNR indicates that the signal dominates the noise, enabling successful demodulation. This is important for ensuring data reliability in long-distance communication systems, such as LoRa. Furthermore, Noise Latency was relatively constant, ranging from 8 to 9 ms throughout the measurement. This low, stable latency indicates that interference-induced delay is minimal. This strengthens the assumption that the communication channel is relatively clean and does not experience significant environmental interference.

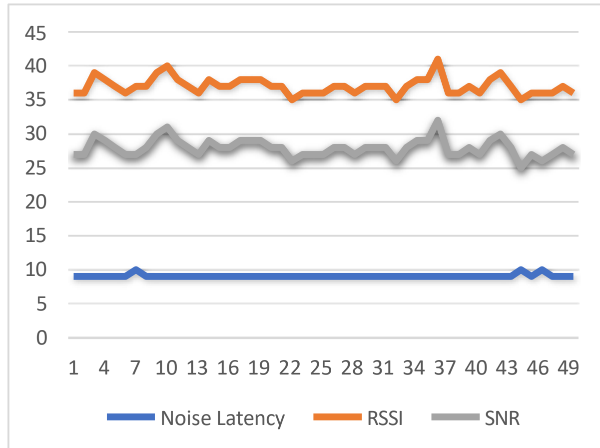


Fig. 8 LoRa Parameter measurement at Gateway A

Further testing was conducted to evaluate the stability and quality of the signal in the LoRa communication system based on three primary parameters: RSSI (Received Signal Strength Indicator), SNR (Signal-to-Noise Ratio), and Noise Latency. Observations were made on 49 data points to represent network performance under real operational conditions. In the measurement graph, RSSI ranges from 45 to 55. This value is higher than the previous test, indicating an increase in the signal strength received by the node. Although there were fluctuations at the beginning of the observation period, the RSSI value tended to remain stable from the 35th data point onward, indicating that the communication system was approaching a steady-state condition.

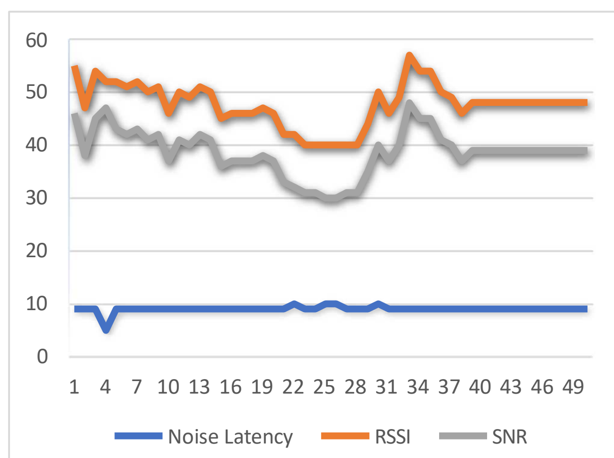


Fig. 9 LoRa Parameter Measurement at Gateway B

The SNR in this graph is in the range of 40 to 50, indicating a very good signal-to-noise ratio. Although SNR decreases around the 25th data point, it remains within the range that supports reliable data transmission. The increase in SNR beyond the 30th point reaffirms that signal quality dominates interference on the communication channel. Meanwhile, Noise Latency remains consistently low, at approximately 9 ms, except for a minor interference peak at the initial data point. This low, consistent latency indicates that the system does not experience significant delays due to noise or frequency interference, which is crucial for real-time monitoring applications.

B. Basic Connection Testing and Gateway Selection using the handoff technique

Testing is done to ensure that the sender can detect and connect to the gateway with the strongest signal using the handoff technique. Thus, data sent by the sender is expected to be received by the gateway with the highest RSSI. The basic connection testing process and gateway selection using the handoff technique are illustrated in Fig. 10, while the test results are presented in Table 2.

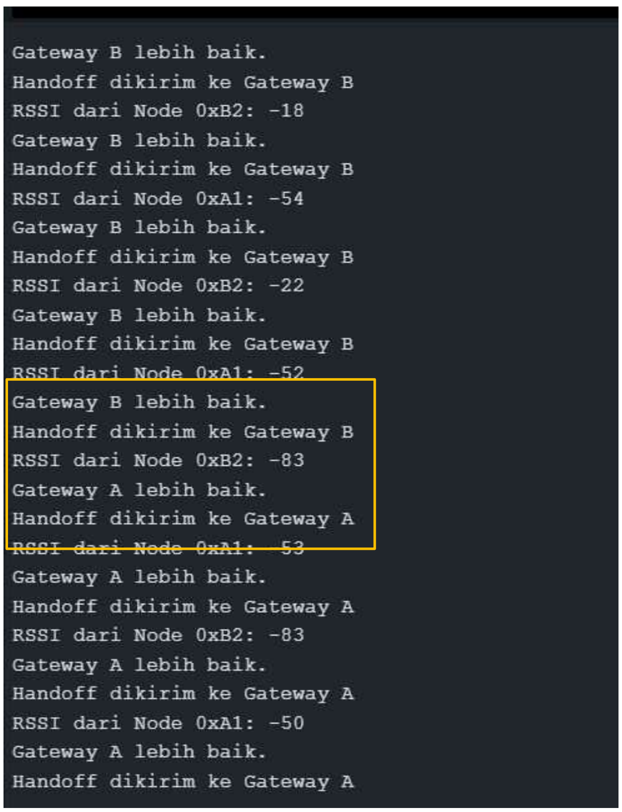


Fig. 10 Sender connected to gateway A

Test Case 1 successfully demonstrated that the sender could detect and connect to the gateway with the strongest signal. In a scenario in which all three devices were active, and Gateways A and B were placed at predetermined coordinates, the dynamically moving sender was able to transmit data that was well received by the gateway with the highest RSSI. These results indicate that the system functions in accordance with the stated test objectives.

TABLE II
INITIAL TRIALS WERE CONDUCTED TO EVALUATE THE SYSTEM'S PERFORMANCE AND ASSESS ITS EFFECTIVENESS

Identification	**TS-01**
Test Name	Test Cace1
Testing Objectives	The sender detects and connects to the gateway with the strongest signal. The most robust gateway can receive data sent from the sender
Test Scenario	• All three devices are active. Gateway A is placed at coordinates 2.3862988, 99.1471837, while Gateway B is placed at coordinates 2.3860389, 99.1477231. • The test was conducted in the middle of the IT Del field, and the sender was dynamically moved starting from point 2.3865966, 99.1480105.
Expected results	The sender can detect and connect to the gateway with the strongest signal. The gateway with the highest RSSI can receive the data sent from the sender
Testing Results	The sender successfully detected and connected to the gateway with the strongest signal. The gateway with the highest RSSI successfully received the data from the sender

C. Dynamic sender movement testing

Testing is done to ensure that the sender can select the Gateway when moving dynamically. The test result image shows that the Gateway selection can switch smoothly during dynamic motion.

TABLE III
BEST GATEWAY SELECTION

Identification	**TS-02**
Test Name	Test Cace2
Testing Objectives	• The sender detects and connects to one of the gateways when the sender's position is between the two gateways. • The sender can choose a gateway and maintain it. • One of the gateways will be disabled and re-enabled.
Test Scenario	• All three devices are active • Gateway A is placed at coordinates 2.3862988, 99.1471837 • Gateway B is placed at coordinates 2.3860389, 99.1477231 • Testing is done in the middle of the IT Del field • The sender is moved dynamically starting from point 2.3865966, 99.1480105
Expected results	• The sender can choose a Gateway when the sender is moving dynamically. • When the gateway has a problem or is inactive, the sender can switch to one of the gateways.
Testing Results	• The sender successfully selects the correct Gateway when the sender is moving dynamically. • Gateway successfully resolves issues such as inactive gateways when moving; the sender can switch to a proper gateway

After designing and building the system and conducting several tests, it can be concluded that the system has several advantages. First, this system improves connection quality by selecting the gateway with the best signal. It provides redundancy, allowing operations to continue even if one gateway fails. Second, this system can check the availability of a new gateway before performing a handoff, ensuring that users are connected to the most optimal network. This, in turn, improves communication quality and reduces latency. Additionally, the presence of a mechanism to handle handoff failures, such as connection rejection, provides an extra layer of stability by preventing redirection to a gateway with low signal quality. Finally, this system enables users to adjust connections in response to changing network conditions, thereby enhancing the efficiency and effectiveness of LoRa data transmission.

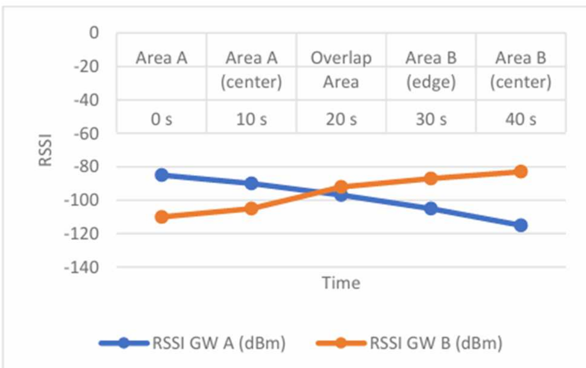


Fig. 11 Handoff process from Gateway A to Gateway B based on RSSI

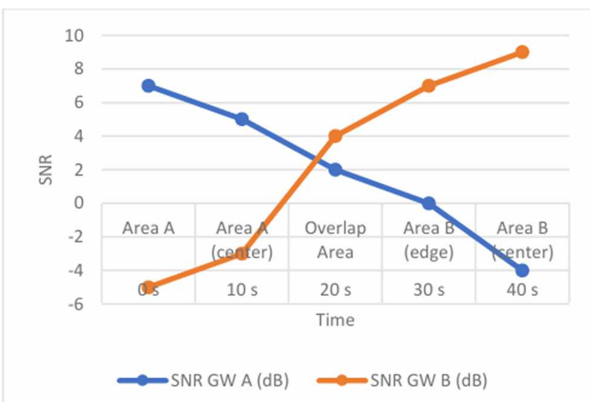


Fig. 12 Handoff process from Gateway A to Gateway B based on SNR

The handoff process in the LoRa network occurs when a transmitting node moves from one gateway's coverage area to another, and the communication path is switched due to a decrease in signal quality at the initial gateway and an increase in signal quality at the destination gateway. Figures 11 and 12 illustrate the event in which a transmitting node moves from Area A to Area B, as shown in the initial illustration. The experiment was carried out from 0 to 40 seconds to obtain handoffs on both Gateways. At 0 seconds, the transmitting node remains entirely within area 1, with a received RSSI of -85 dBm and an SNR of 7 dB, indicating very good signal quality. Meanwhile, the signal received by Gateway 2 remains very weak, with an RSSI of -110 dBm and an SNR of -5 dB, so communication is still routed through Gateway A. As time progresses and the node moves toward the overlap area, the signal quality of Gateway A decreases. At the 20th second, a critical point occurs where the RSSI and SNR values of Gateway 2 slowly surpass those of Gateway A. Gateway B records an RSSI of -92 dBm and an SNR of 4 dB, and Gateway 1 records an RSSI of -97 dBm and an SNR of 2 dB. This indicates that Gateway B has better signal quality.

Based on this comparison, the system performs a handoff, moving the communication path from Gateway A to Gateway B. After the handoff, at the 30th and 40th seconds, the node is entirely within range of Gateway B, as indicated by the signal quality continuing to improve. In this state, Gateway B has an RSSI of -83 dBm and an SNR of 9 dB, whereas the signal from Gateway A continues to drop below -110 dBm, indicating that Gateway A is no longer the optimal path. This handoff process demonstrates that monitoring RSSI and SNR enables the LoRa communication system to respond quickly to dynamic transmitter node motion. Although it operates without a network server, the gateway can make switching decisions based on received signal strength, thereby maintaining communication.

IV. Conclusion

We have successfully implemented the handoff technique using LORA technology. First, the system enhances connection quality by selecting the gateway with the strongest signal. This system provides redundancy, enabling operations to continue even if one gateway fails. Second, the system can check the availability of a new gateway before performing a handoff, thereby ensuring that users are connected to the optimal network. This study identified the sequence of communication between the transmitter and the gateway, thereby ensuring smooth operation of the communication path. Initially, we analyzed the RSSI and SNR values to verify that the distances between Gateway A and B and the Transmitter were consistent with the scheme. Subsequently, the transmitter moved slowly for 40 seconds, and the system recorded RSSI and SNR values, which were displayed in the serial monitor. The results were very satisfactory: the gateway transfer occurred in both directions (A to B and vice versa), and the transmitter moved. By implementing efficient handoff techniques, the LoRa system can enhance network reliability, minimize data loss, and distribute load evenly across gateways, particularly in areas with high node density or dynamic channel conditions. This is becoming increasingly important in large-scale IoT applications such as smart transportation systems, precision agriculture, and environmental monitoring.

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