Piston: Journal of Technical Engineering Vol. 9, No. 1, July (2025) 18-29

PISTON

Journal of Technical Engineering:

Design of Handoff Communication Sequence Architecture in LoRa Networks

Istas Pratomo Manalu[1,a)], Frengki Simatupang[1], Eka Stephani Sinambela[1], Marojohan Mula Timbul Sigiro[1], Gerry Italiano Wowiling[1], Sari Muthia Silalahi[1]

[1]*Institut Teknologi Del, Jl. Sisingamangaraja, Sitoluama, Laguboti, Toba Samosir, 22381, Indonesia*

E-mail: [a)] istaspratomo8@gmail.com

Received: July 05, 2025 Revision: August 08, 2025 Accepted: August 10, 2025

Abstract: Technological advances have driven the development of IoT-based object tracking systems, where LoRa is an ideal wireless technology due to its long range and low power consumption. Challenges in implementing LoRaWAN, particularly its role in the handoff process between gateways that can disrupt communication, can be overcome by developing a more efficient handoff method. For this reason, this study presents the design of Handoff communication for the LoRa Network. We use two gateways and one transmitter node. The gateway node consists of a LoRa module and an ESP32, while the Transmitter consists of a LoRa module, an Arduino Nano, and a GPS sensor. The RSSI parameter is a determining factor in transferring connectivity paths from GW A or GW B, as it provides an RSSI threshold value of -100 dBm. We successfully designed handoff communication at each Node and conducted a mini-test. The test results show that LoRa can implement handoff techniques at a distance of 0-500 meters. This indicates that the node is in closer range to GW A. The RSSI value of GW1 is in the range of -52 dBm to -98 dBm, while the RSSI of GW2 is in a much weaker range, which is around -120 dBm to -100 dBm. As the distance increases, the RSSI value of GW1 shows a significant decrease, while the RSSI of GW B actually increases. At a distance of approximately 250 meters, there is an intersection point between the RSSI values of the two gateways, marking the optimal handoff point. Thus, this system is able to select the best gateway, provide redundancy, check gateway availability before handoff, and handle handoff failures, thereby improving the efficiency and effectiveness of data delivery.

Keywords: Handoff, LoRa, LoRaWAN, RSSI, IoT.

Abstrak: *Kemajuan teknologi telah mendorong pengembangan sistem pelacakan objek berbasis IoT, di mana LoRa menjadi teknologi nirkabel yang ideal karena jangkauan luas dan konsumsi daya rendah. Tantangan dalam penerapan LoRaWAN, khususnya perannya dalam proses handoff antar gateway yang dapat mengganggu komunikasi, dapat diatasi dengan mengembangkan metode handoff yang lebih efisien. Oleh karena itu, penelitian ini menyajikan rancangan komunikasi handoff pada jaringan LoRa. Sistem menggunakan dua gateway dan satu transmitter node. Gateway node terdiri dari modul LoRa dan ESP32, sedangkan transmitter menggunakan modul LoRa, Arduino Nano, dan sensor GPS. Parameter RSSI menjadi faktor penentu dalam pemindahan jalur konektivitas dari GW A ke GW B atau sebaliknya, dengan ambang batas RSSI sebesar -100 dBm. Rancangan komunikasi handoff berhasil diimplementasikan pada setiap node dan diuji secara mini. Hasil pengujian menunjukkan bahwa LoRa mampu menerapkan teknik handoff pada jarak 0–500 meter. Pada jarak ini, node berada dalam jangkauan lebih dekat dengan GW A. Nilai RSSI GW1 berkisar antara -52 dBm hingga -98 dBm, sedangkan RSSI GW2 berada pada kisaran yang lebih lemah, yakni -120 dBm hingga -100 dBm. Seiring bertambahnya jarak, nilai RSSI GW1 mengalami penurunan signifikan, sementara nilai RSSI GW B justru meningkat. Pada jarak sekitar 250 meter terjadi titik perpotongan nilai RSSI kedua gateway, yang menandai titik handoff optimal. Dengan demikian, sistem ini mampu memilih gateway terbaik, menyediakan redundansi, memeriksa ketersediaan gateway sebelum handoff, serta menangani kegagalan handoff, sehingga meningkatkan efisiensi dan efektivitas pengiriman data.*

Kata kunci: *Handoff, LoRa, LoRaWAN, RSSI, IoT.*

INTRODUCTION

In practice, Long Range (LoRa) technology is widely used in Internet of Things (IoT) systems because of its ability to transmit data over long distances with low power consumption. However, most LoRa applications are still static, with the transmitter node and gateway in fixed positions. When used in highly mobile scenarios, such as moving vehicles or objects, data communication is disrupted when nodes move away from the initial gateway and enter the coverage area of another gateway. The main problem that occurs is the lack of a reliable handoff mechanism in standard LoRa networks, leading to data loss (packet loss), increased latency, and reduced communication quality when nodes switch from one gateway to another. This issue is especially critical in real-time applications like logistics tracking, vehicle monitoring, or mobile security systems.

The development of information and communication technology is currently experiencing rapid growth, along with the ongoing progress of infrastructure and technological innovation. One important advancement is in the field of wireless technology. This technology, such as Wireless Local Area Network (WLAN), is now much easier to implement than wired networks, making it an essential part of modern communication systems [1], [2]. A WLAN, or Wireless Local Area Network, is a local network that utilizes high-frequency radio signals to transmit and receive data within a specific range. LoRaWAN technology enables long-distance communication with low data rates and minimal energy consumption, making it a popular choice in various IoT applications. Several studies have shown that this technology is capable of reaching communication distances of up to 10-15 km in rural or open areas [3]–[7].

Handoff is the process of transferring a connection from one gateway to another that occurs when a device moves across the signal coverage boundary [8]–[11]. This technique has been frequently applied in cellular networks, but its application to LoRa networks still requires further in-depth research and optimization. The differences in LoRa characteristics, such as higher latency and narrower bandwidth compared to cellular networks, pose a challenge to the development of handoff techniques on this network [12].

The purpose of this study is to provide a mechanism for handoff communication on the LoRa network. This study will provide instructions on how communication is established from one gateway to another to maintain communication. Furthermore, performance will be analyzed through RSSI comparison between gateways to provide the best path options that can handle data flow [13], [14]. This study will also compare various existing or developed techniques for LoRa networks, with the aim of finding the most effective method based on test results. Finally, this study will compile recommendations to optimize the implementation of the LoRa network, thereby improving the Quality of Service (QoS) in IoT applications that involve device mobility.

METHODS

The research conducted aims to apply handoff techniques to LoRa networks, similar to cellular networks [15]. Therefore, real simulations using physical devices are necessary. This study uses two gateway devices and one device that functions as a data sender.

Figure 1 shows that Gateway A and Gateway B (GW A and GW B) are receivers of data sent by the sender. This device is equipped with an RFM95 LoRa module, an Arduino Nano, and an antenna, which allows GW A to receive LoRa signals from the sender, measure the signal strength (RSSI value), and process the received data. GW A will be positioned at a specific location and serve as one of the two primary receivers in the system. If the signal received from the sender at GW A is stronger than at GW B, then GW A will prioritize receiving and sending the data. Gateway B has the same function as Gateway A, namely, as a data receiver from the sender. With the same device as GW A (Lora RFM95, Arduino nano, and Antenna). GW B will be placed at a different point from GW A to cover a wider area. GW B will function as the leading receiver if the signal received from the sender is stronger from GW B than from GW A. If GW A fails or cannot receive a signal, then GW B will become an alternative data receiver and forward the data. The sender acts as a data transmission device equipped with a GPS module, an LoRa RFM95 module, an Arduino Nano, and an Antenna. The primary function of the sender is to collect location data in the form of air quality values and select which Gateway will be prioritized for receiving data via LoRa signals. When moving through the area covered by GW A and GW B, the sender continuously transmits signals containing air quality data. The sender can also detect signals from gateways, so it can select the most optimal gateway (with the strongest signal) to receive and forward its data.

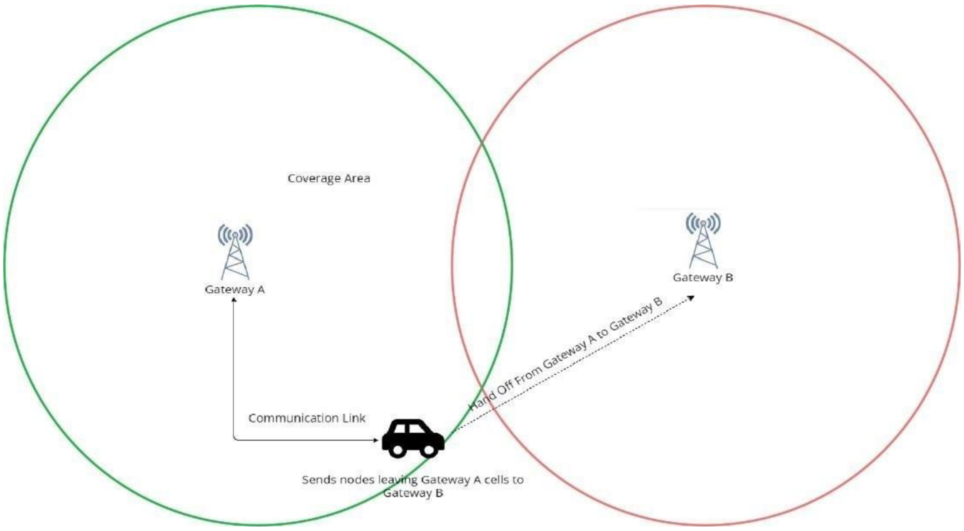

Figure 1. System Architecture Design

Tracking using LoRaWAN technology enables the remote monitoring and tracking of a device's position or movement. The tracking process using LoRaWAN involves installing a LoRa device on an object or other moving device that you want to track, such as a vehicle, animal, person, or other entity. Although tracking using LoRaWAN offers several advantages, such as a wide range and low power consumption, some problems still occur, one of which is data loss when the device moves from one coverage area to another. In overcoming these problems, implementing a handoff technique into a tracking system using LoRa can be an effective solution. The handoff technique enables the device to transition seamlessly from one coverage area to another without losing connection or data. By implementing an efficient handoff technique, the object tracking system can maintain connection reliability and data continuity as the object moves within the LoRaWAN network coverage area. This will help reduce the risk of data or network loss, thereby increasing the reliability and effectiveness of the tracking system using LoRa.

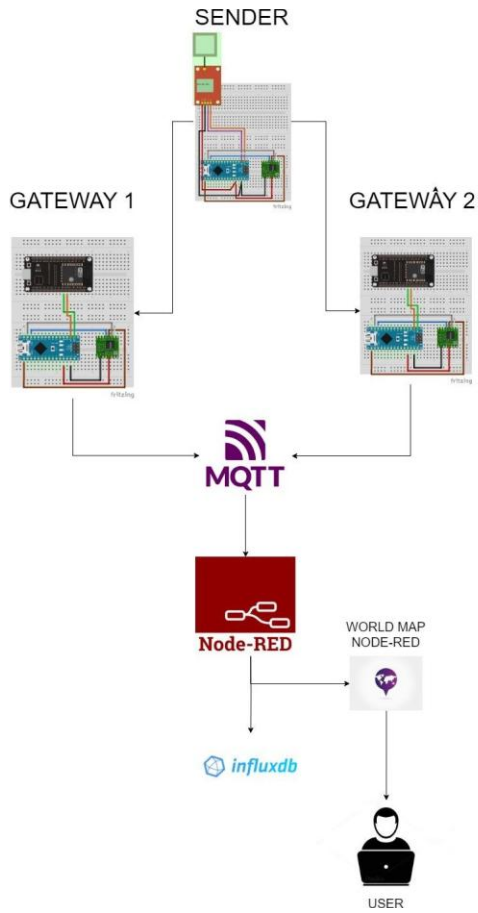

Figure 2. LoRa Network Topology with Two Gateways and MQTT–Node-RED Integration

The GPS module tracks the movement of an object or device and determines its accurate geographic position. Then, the data obtained from the Sender will be sent to the gateway using the LoRaWAN protocol with a string data format, where the tested parameter values, such as SNR and RSSI, are generated by the LoRa node using the `LoRa.packetRssi() and LoRa.packetSnr() commands`. The data obtained by the gateway will be converted to JSON and then transmitted using the ESP32 microcontroller to Node-RED, where Node-RED will parse the JSON data and store it in the InfluxDB database.

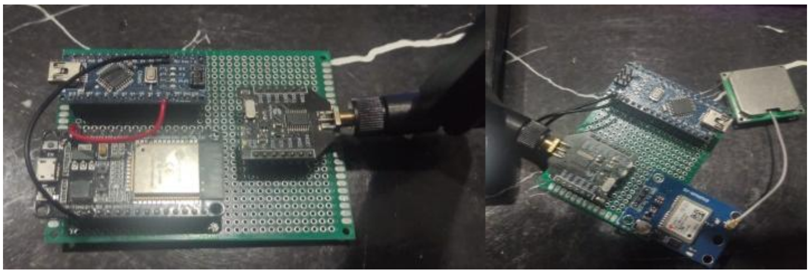

Figure 3. The transmitter and the Gateway Design

The components of the LoRa Gateway include an ESP32, an RFM95 LoRa module, a GPS module, and a power bank. All elements will be connected using jumper cables or a PCB. The components of the LoRa Node include LORA RFM95, a GPS module, and a power bank, and all elements will be connected using jumper cables or PCBs.

RESULT AND DISCUSSION

Handoff techniques enable devices to transition seamlessly from one coverage area to another without losing connection or data. To ensure the accurate detection of the moving device's location and obtain more valid data results, the use of handoff techniques in tracking systems utilizing LoRa technology can mitigate interference constraints when relocating the object. By implementing efficient handoff techniques, object tracking systems can maintain connection reliability and data continuity even when the device is moving within the LoRaWAN network. In addition to mitigating data loss, handoff techniques can also minimize the risk of network disruptions that may compromise the effectiveness of object tracking. The testing method applied to LoRa technology is expected to provide an in-depth understanding of system performance, including data transmission, application response, and optimization of height and distance. Positive results from implementing the Handoff Technique are expected to enhance the quality and reliability of object tracking, making a significant contribution to the development of object tracking technology using LoRaWAN.

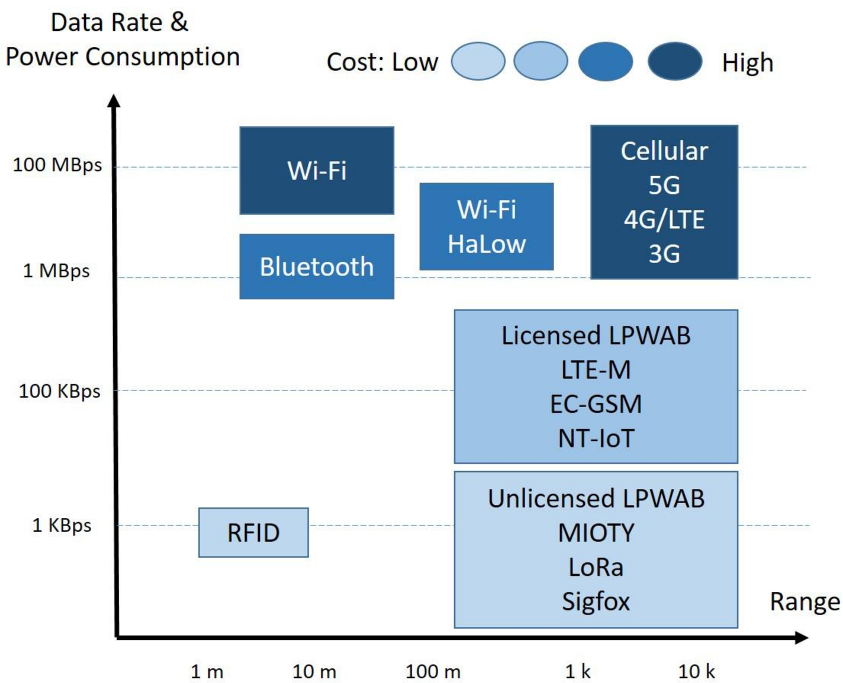

Figure 4. Comparison between LoRaWAN and other wireless technologies [1]

Compared to Wi-Fi and Bluetooth, LoRa provides a much greater range despite its significantly lower data rate. Wi-Fi and Bluetooth are suitable for short-range communications and high-speed applications but are not energy-efficient. In contrast, network technologies like LTE-M, EC-GSM, and NB-IoT operate in licensed spectrum (Licensed LPWAN), whereas LoRa uses license-free spectrum, reducing implementation costs significantly. The light blue color in the LoRa representation in the graph also indicates that its practical costs are relatively low compared to other technologies, such as cellular, which are darker in color. Therefore, although LoRa is not ideal for high-bandwidth or real-time communication, it is highly effective for long-range, energy-efficient, and low-cost communication systems.

The experiment was conducted in a semi-open environment within a campus area that features varied terrain, including open asphalt roads, sparse tree cover, and several low-rise buildings. The system consists of one mobile transmitter node (sender) equipped with a GPS sensor and two static gateways (GW1 and GW2), positioned at two different locations with a 500-meter distance between them. The transmitter node sends dummy sensor data every 5 seconds, along with GPS coordinate information and RSSI values received by each gateway. The handoff process is determined locally by the transmitter node based on the highest RSSI value received from the gateways, with a gateway switching mechanism every time there is a change in signal dominance.

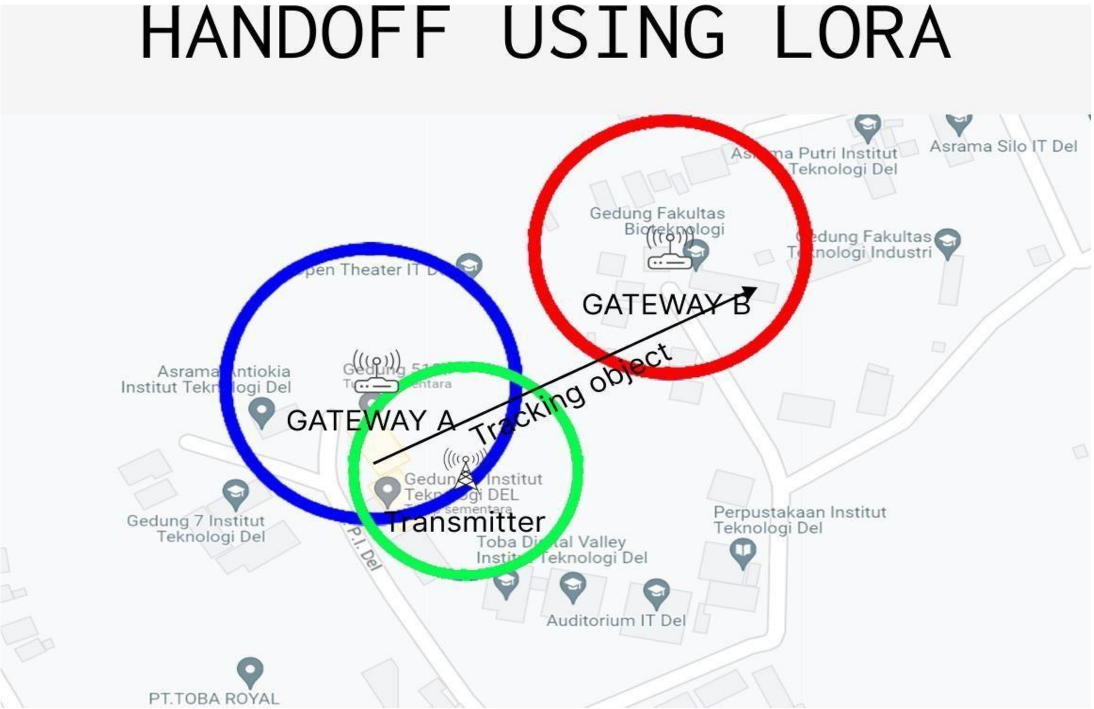

Figure 5. Maps of handoff implementation

Gateway A is a LoRa receiver comprising a LoRa RFM95 module, an antenna, an Arduino Nano, and a power bank as the power supply. Gateway B is a LoRa receiver that comprises an RFM95 module, an antenna, an Arduino Nano, an ESP32, and a power bank as its power supply. Node as a LoRa Transmitter composed of several components, such as LoRa RFM95, a GPS module that functions to receive data from the LoRa Receiver and send it to InfluxDB via Node-RED. In the design of this research, there are several components needed, such as Node sender, Gateway (there are two gateways), MQTTX (as data delivery media), Node-RED, InfluxDB (as database), and WorldMap (as interface). Each component has its function, such as a node device that will receive the location point results from the GPS module. Then, the received data will be sent to the gateway using the LoRa protocol. Furthermore, the gateway will receive the data and forward it to the InfluxDB database using a network (Wi-fi). The data obtained by Node-RED will be displayed on the world map.

Handoff Communication Process

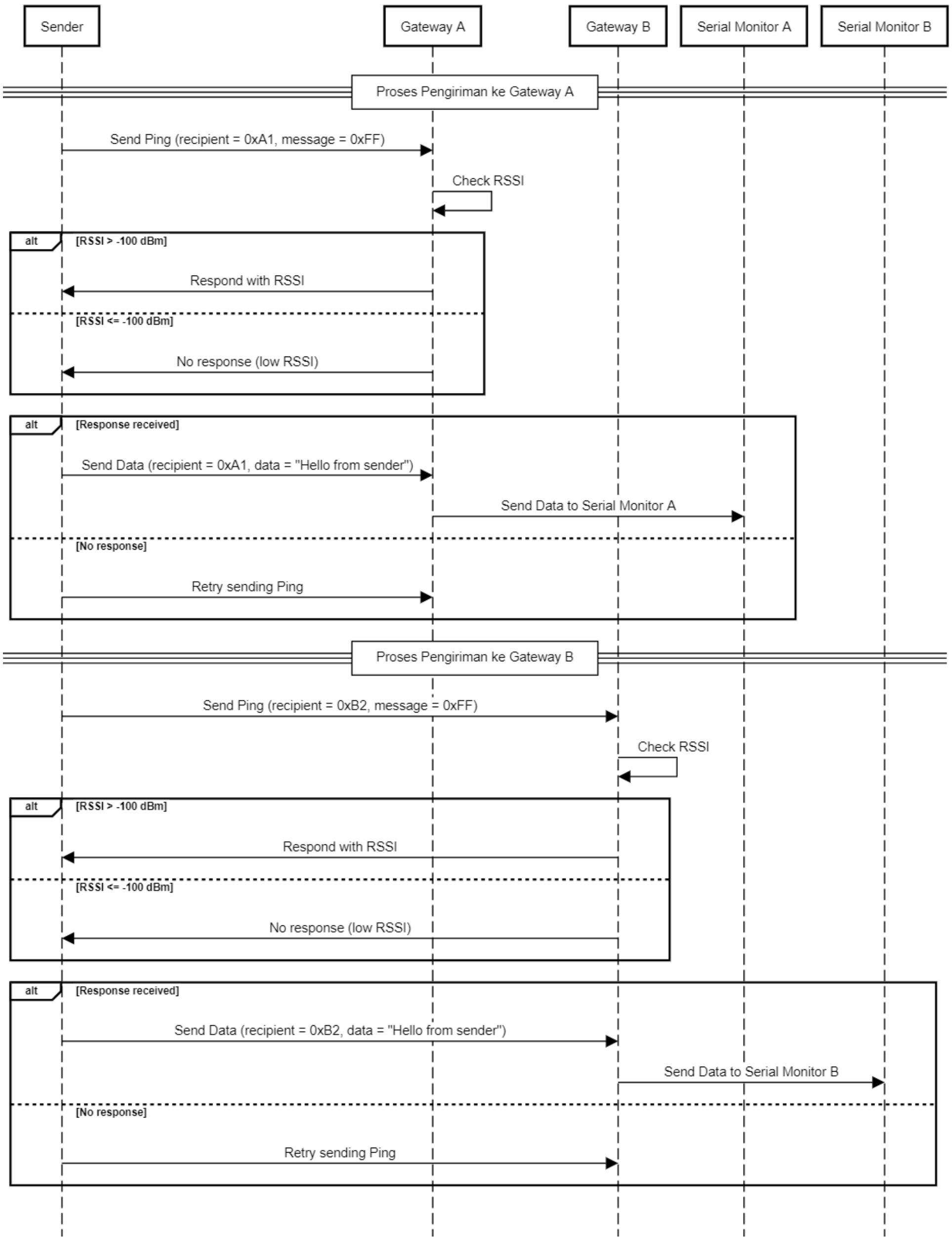

Figure 6. Data Communication Process

Figure 6 illustrates the communication process for implementing handoff techniques using LoRaWAN technology. The sender sends a ping signal to Gateway A with a receiver address of 0xA1 and a message of 0xFF. Gateway A checks the signal strength (RSSI). If the RSSI is greater than -100 dBm, the gateway will respond with that RSSI value. If the RSSI is less than or equal to -100 dBm, no response is received. If a response is received from GW A, the sender will send data with a receiver address of 0xA1 and a message of "Hello from sender". This data will be forwarded to Serial Monitor A. After the process with GW A, the sender then sends a ping to GW B with a receiver address of 0xB2 and a message of 0xFF. GW B also checks the RSSI. The process is similar to GW A; if the RSSI is greater than -100 dBm, the gateway will respond with the RSSI value. Otherwise, no response is received. If a response is received from GW B, the sender will send data with a receiver address of 0xB2 and a message of "Hello from sender". This data will be forwarded to Serial Monitor B. If there is no response from either gateway, the sender will try to resend the ping.

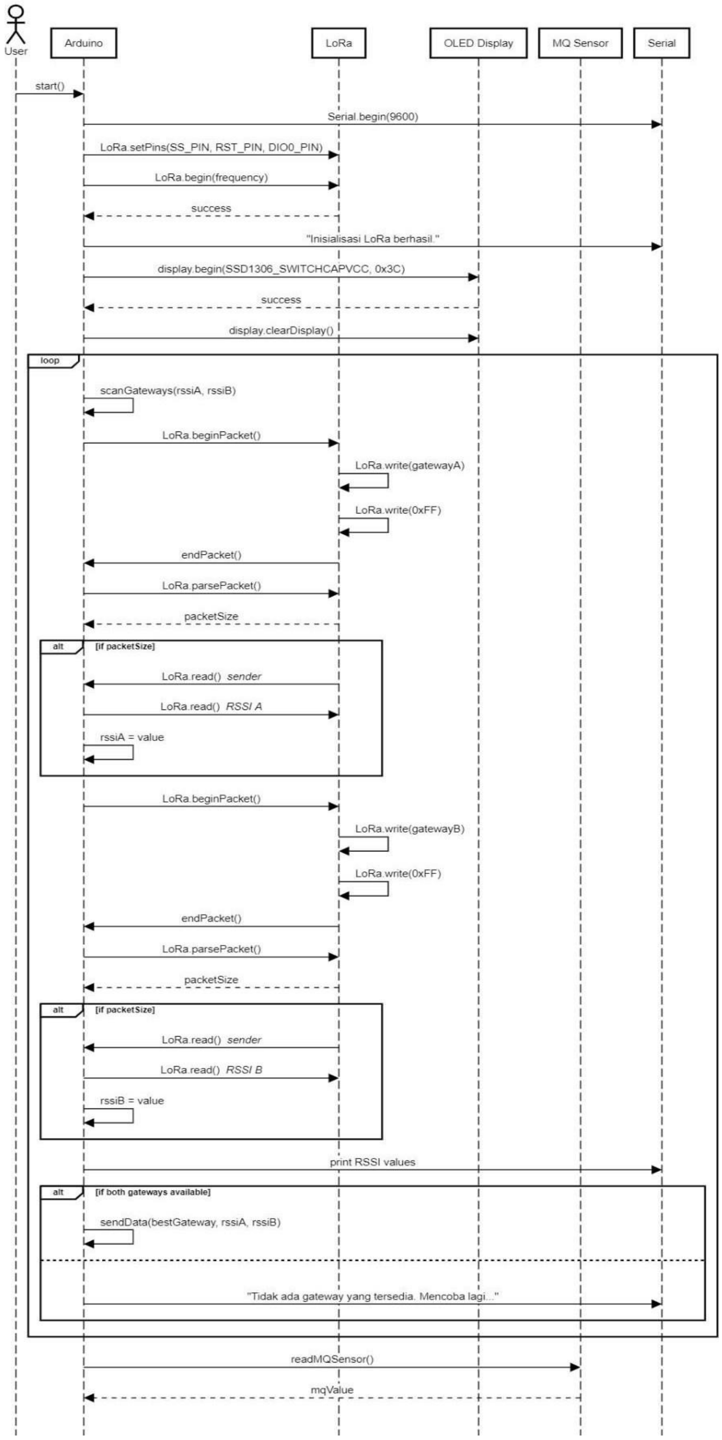

Figure 7. Sender Communication sequence

The sender communication sequence, which illustrates the communication between the user, Arduino, and LoRa module in the gateway system, outlines the structured steps involved in the initialization process, data packet reception, and message processing. The process begins with the setup() function, where serial communication is initialized and the LoRa module is set with the correct pins and frequencies. After that, the system checks whether the initialization was successful. If successful, the gateway address will be displayed. Next, the system enters the main loop, which continuously calls the parsePacket() function to check for any received packets. If there are packets, the system will read the sender and receiver addresses. The system then checks the RSSI (Received Signal Strength Indicator) value. If the RSSI value exceeds the specified threshold, the system generates a new packet containing the gateway address and the corresponding RSSI value. However, if the RSSI value is too low, the system will print a message that the ping was ignored. After that, the system reads the message character by character and stores it. Finally, information about the received message, including the gateway address and RSSI value, will be displayed.

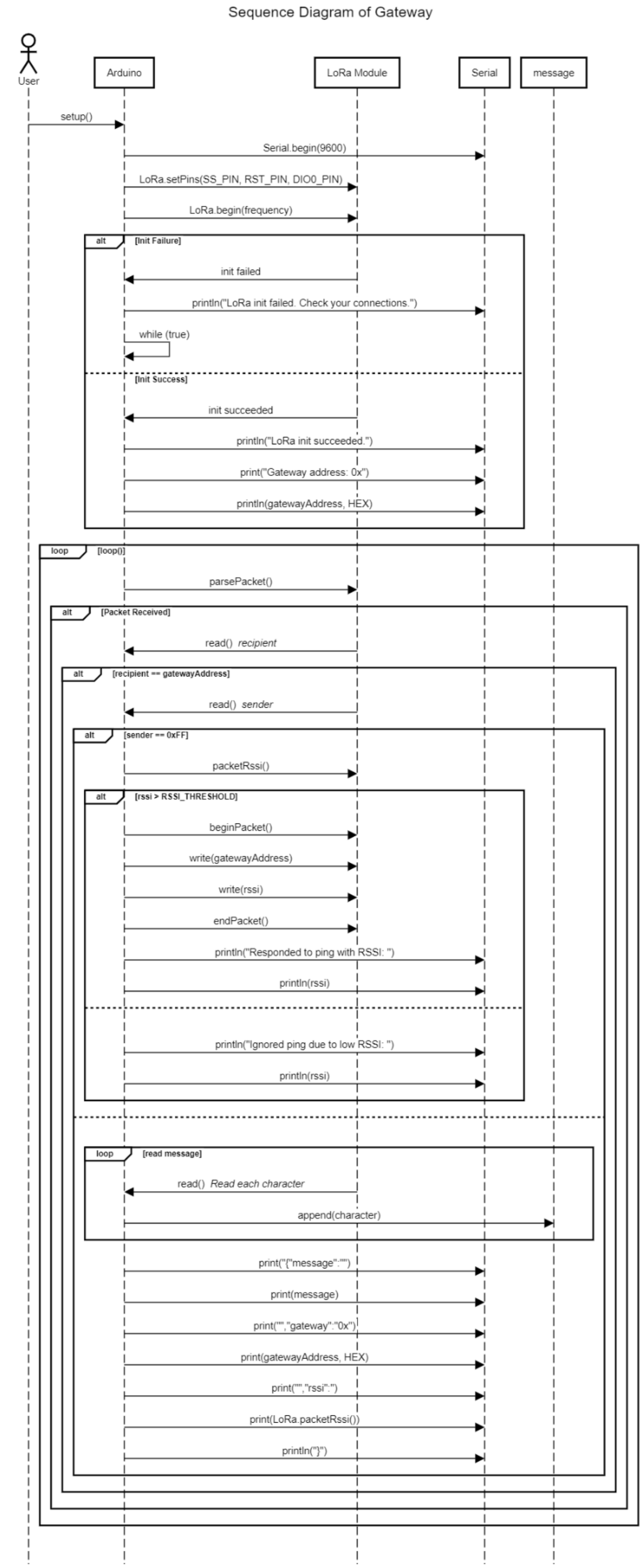

Figure 8. Gateway Communication Sequence

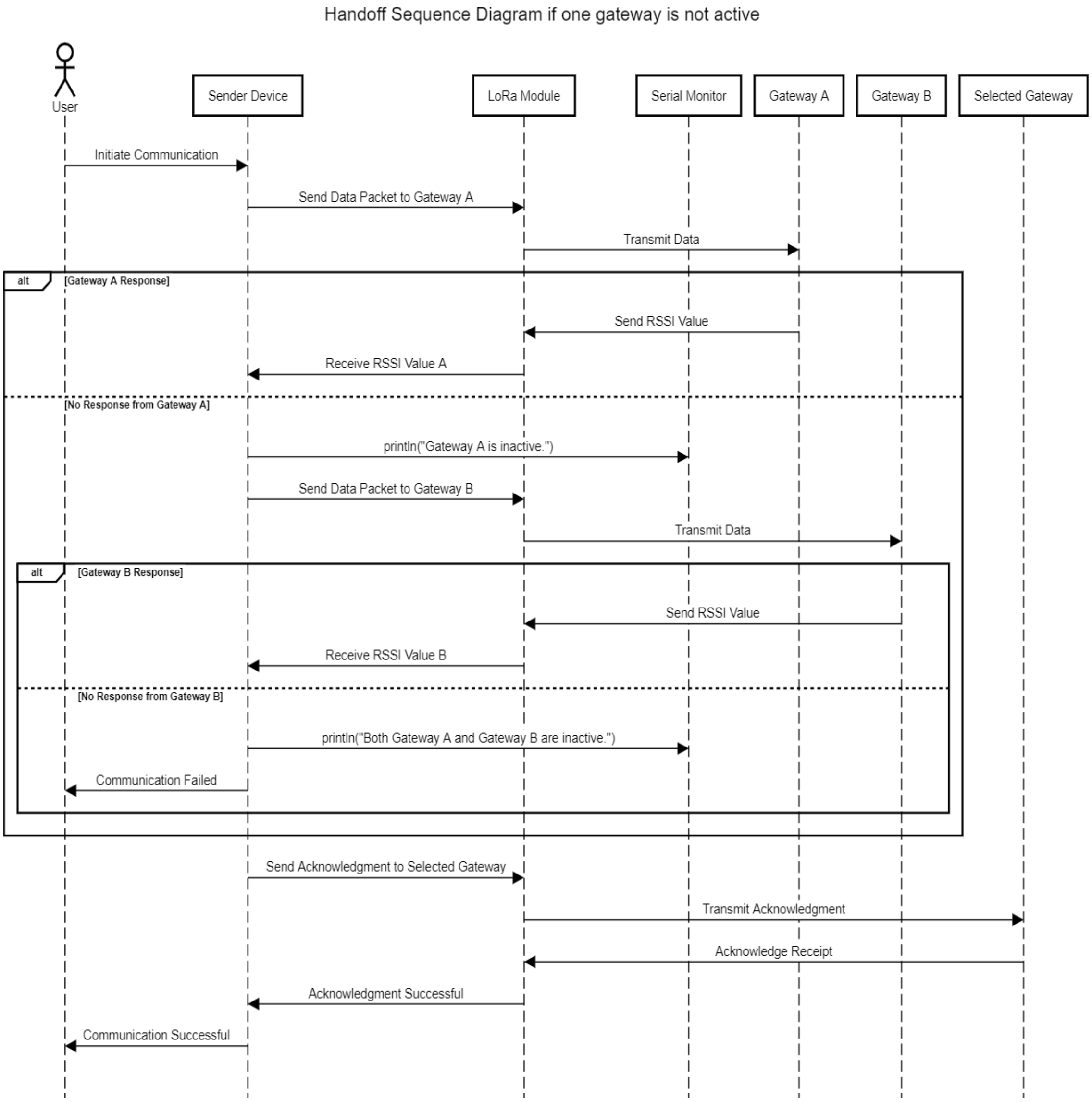

Figure 9. Handoff Sequence if one Gateway is inactivated

The handoff sequence in Figure 9 illustrates the handoff process in the LoRa communication system, outlining the steps necessary to maintain communication continuity when one of the gateways is unavailable. The process begins with the user initiating communication through the sending device, where data is first sent to GW A. After sending, the system waits to receive the RSSI value from GW A. If no response is received within a specific time, the system prints a message indicating that "GW A is down" and immediately switches to sending data to GW B. After sending data to GW B, the system waits again for the RSSI value. If GW B also does not respond, the system prints a message that "Both GW A and GW B are down," indicating a failure in communication. However, if one of the gateways responds positively, the system sends an acknowledgment to the gateway that successfully received the data, indicating that the delivery was successful.

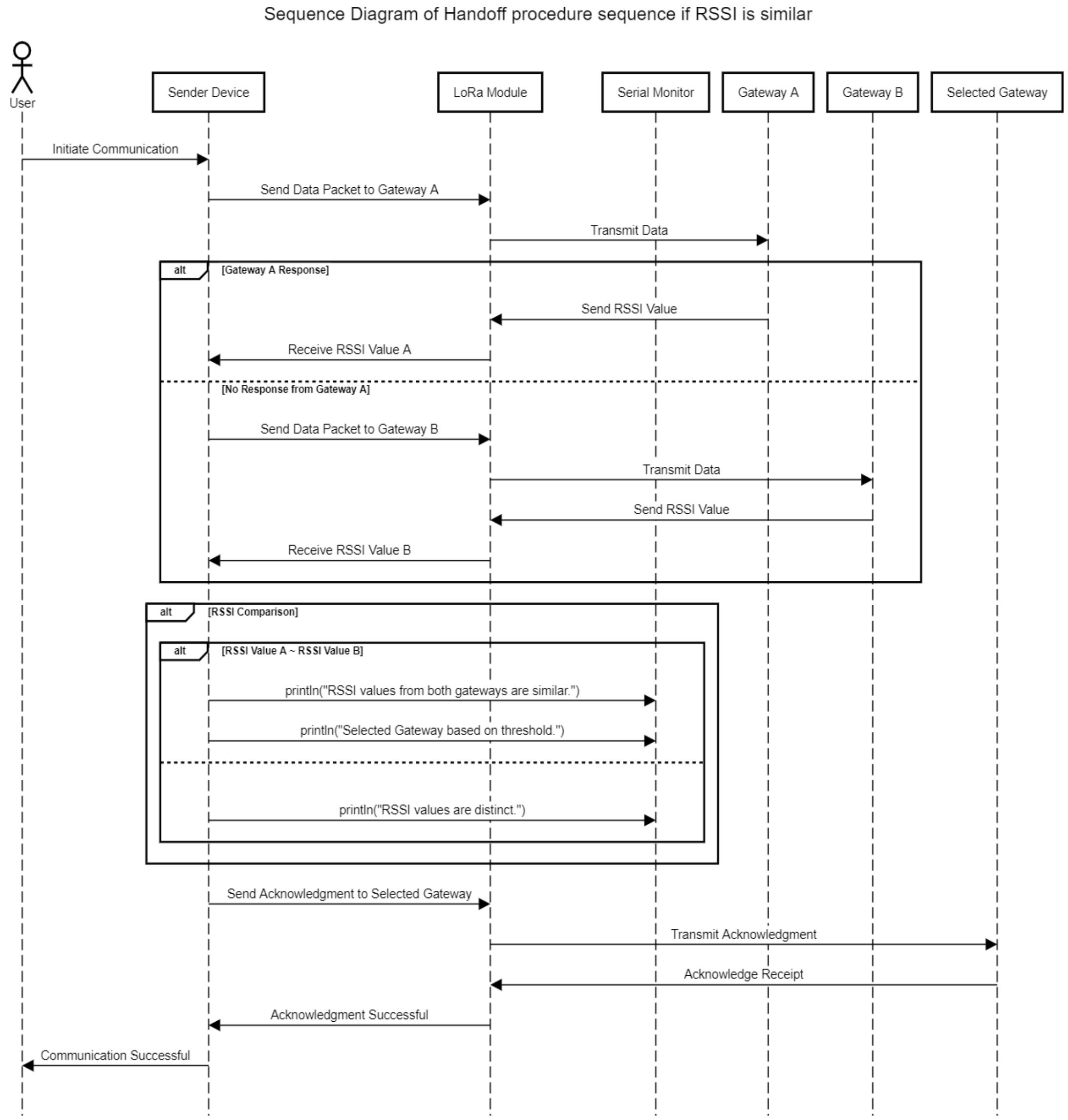

Figure 10. Sequence Diagram of Handoff procedure sequence if RSSI is similar

The sequence diagram of the handoff procedure illustrates the steps taken when the RSSI values of two gateways are similar, as shown in Figure 10. The process begins with the user initiating communication through the sending device, which then sends a data packet to GW A. After sending, GW A transmits the data and the RSSI value back to the sending device. If there is no response from Gateway A, the sending device will continue to send a data packet to GW B and receive the RSSI value from this gateway. Next, the RSSI values of both gateways are compared. If the RSSI values are similar, the program prints a message indicating that the values are the same and selects the gateway based on a predetermined threshold. Conversely, if the RSSI values differ, the program will suggest that the values are not the same. After determining the selected gateway, the sending device sends an acknowledgment to that gateway, which then transmits a confirmation back. If the acknowledgment is received successfully, the communication is considered successful.

RSSI Value Measurement and Comparison

Measurements were conducted on a track approximately 500 meters long, with a total of 100 data collection points spaced every 5 meters.

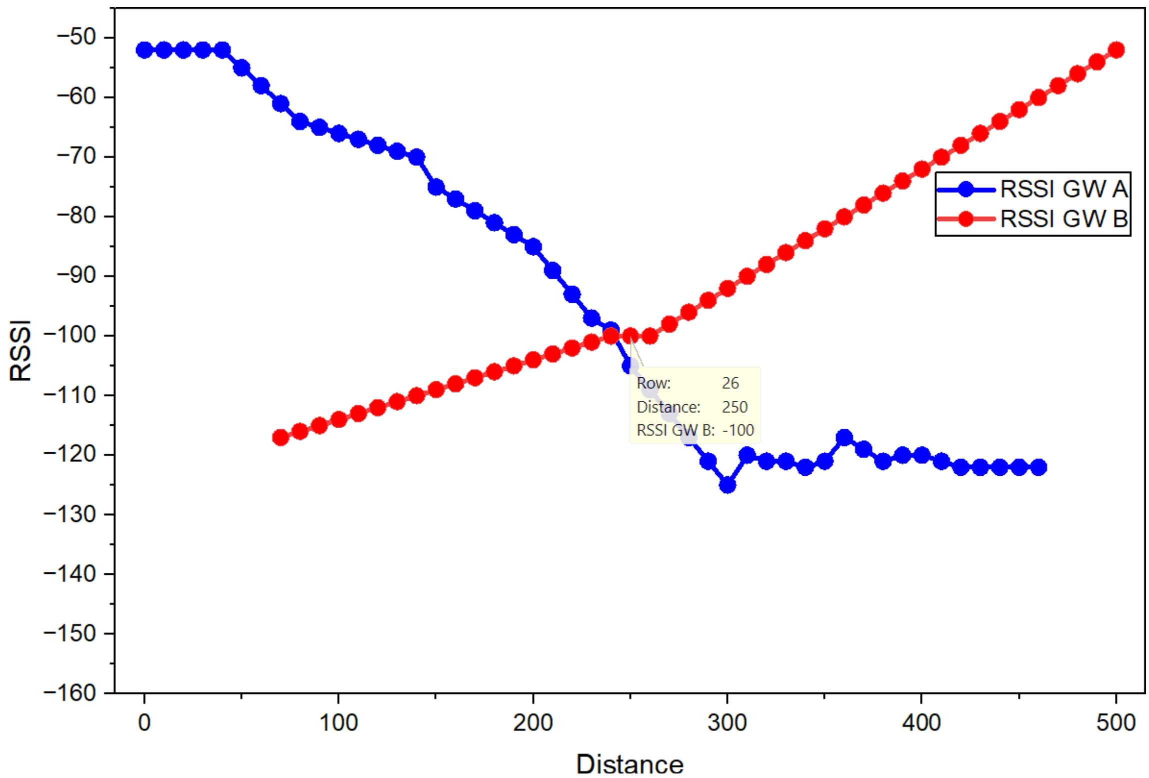

Figure 11. RSSI of Gateway A and B

Figure 11 shows a comparison graph of RSSI values against the distance between the sending node and two LoRa gateways. Measurements were made from a distance of 0 to 500 meters, with a constant interval. RSSI values were measured by each gateway for each node position, with the aim of identifying the handoff point based on signal strength. At the beginning of the measurement (distance 0–250 meters), the RSSI values received by GW A were consistently higher than those of GW B. This indicates that the node is in closer range to GW A. The RSSI value of GWA is in the range of -52 dBm to -98 dBm, while the RSSI of GW B is in a much weaker range, which is around -120 dBm to -100 dBm. As the distance increases, the RSSI value of GW A shows a significant decrease, while the RSSI of GW B actually increases. At a distance of approximately 250 meters, there is an intersection point between the RSSI values of the two gateways, marking the optimal handoff point. At this point, the signal strengths of both gateways are nearly around -100 dBm, making it an ideal condition for the system to perform a handover from GW A to GW B. After passing the handoff point, the RSSI value of GW B continues to increase until it reaches a peak at a distance of around 400 meters 70 dBm. In comparison, the RSSI of GW A continues to decrease until it approaches -122 dBm. This confirms that after the handoff point, GW B becomes the primary gateway for receiving data from the node.

CONCLUSIONS

We successfully created a handoff communication sequence starting from sending data from the sender to the Gateway. In the test, we used two nodes that function as gateways to capture data from LoRa and ESP32 modules. On the Sender side, we used only one node consisting of a LoRa module, a GPS Sensor, and an Arduino Nano. We placed two gateways at a distance of 500 meters, where LoRa still maintains a strong RSS signal at this distance. We made an RSSI threshold of -100 dBm only for testing the reliability of the system being built. From the results obtained, the handover of the communication path occurred from Gateway A to Gateway B at a distance of 250 meters when the RSSI value of Gateway A exceeded -100 dBm, and the RSSI of Gateway B was sensed to be greater than -100 dBm. Thus, Gateway A will give Gateway control over handling the communication path to the server. Therefore, this LoRa technology can be utilized in network handoff.

ACKNOWLEDGEMENT

I want to express my gratitude to all those who have contributed to the completion of this research. First, the researchers would like to express their sincere appreciation to the Ministry of Education, Culture, Research, and Technology (Kemdikbudristek), which has funded this research. I also thank Program Studi D3TK for their support, guidance, and valuable insights throughout the process. Their expertise and encouragement have shaped the content and direction of this journal. Finally, I would like to thank the sources, references, and institutions whose work and resources have been referenced and cited in this journal, as their contributions made this research possible.

REFERENCES

[1] A. Stateczny, K. Gierlowski, and M. Hoeft, "Wireless Local Area Network Technologies as Communication Solutions for Unmanned Surface Vehicles," *Sensors*, vol. 22, no. 2. p. 655, 2022. doi: 10.3390/s22020655.

[2] V.-D. Gavra and O. A. Pop, "Usage of ZigBee and LoRa wireless technologies in IoT systems," in *2020 IEEE 26th International Symposium for Design and Technology in Electronic Packaging (SIITME)*, 2020, pp. 221–224. doi: 10.1109/SIITME50350.2020.9292150.

[3] I. P. Manalu, M. T. M. Sigiro, F. Simatupang, A. A. P. Manik, N. G. A. Sitohang, and G. Pardede, "Multihop Data Transmission Using LoRa Technology," *Pist. J. Tech. Eng.*, vol. 8, no. 2, pp. 71–83, May 2025.

[4] V. S. Gloria Polly, A. Manalu, K. T. Simbolon, and I. P. Manalu, "LoRa-based IoT Device for Water Quality Monitoring (Case Study: Lake Toba)," *Pist. J. Tech. Eng.*, vol. 7, no. 2, pp. 75–81, Mar. 2024, doi: 10.32493/pjte.v7i2.35854.

[5] I. P. Manalu, S. M. Silalahi, G. I. Wowiling, M. M. T. Sigiro, R. P. Zalukhu, and P. K. Nababan, "Lora Communication Design and Performance Test (Case Study: Air Quality Monitoring System)," in *2023 International Conference of Computer Science and Information Technology (ICOSNIKOM)*, 2023, pp. 1–6. doi: 10.1109/ICoSNIKOM60230.2023.10364454.

[6] I. P. Manalu, F. Naibaho, E. S. L. Siahaan, and H. Hadi, "Analisa Kinerja LoRa di Bidang Pertanian di Desa Sitoluama, Toba," *Pist. J. Tech. Eng.*, vol. 6, no. 2, pp. 29–34, Feb. 2023, doi: 10.32493/pjte.v6i2.28473.

[7] I. P. Manalu, S. M. Silalahi, G. I. Wowiling, M. M. T. Sigiro, E. S. Sinambela, and F. Simatupang, "Performance Analysis of LoRa in IoT Application of Suburban Area," in *2023 29th International Conference on Telecommunications (ICT)*, 2023, pp. 1–4. doi: 10.1109/ICT60153.2023.10374037.

[8] Noprianto, H. E. Dien, M. H. Ratsanjani, and M. A. Hendrawan, "Analysis of LoRa with LoRaWAN Technology Indoors in Polytechnic of Malang Environment," *Sist. J. Sist. Inf.*, vol. 13, no. 2, pp. 698–712, Mar. 2024, doi: 10.32520/stmsi.v13i2.3884.

[9] G. Czeczot, I. Rojek, and D. Mikołajewski, "Analysis of Cyber Security Aspects of Data Transmission in Large-Scale Networks Based on the LoRaWAN Protocol Intended for Monitoring Critical Infrastructure Sensors," *Electronics*, vol. 12, no. 11. p. 2503, 2023. doi: 10.3390/electronics12112503.

[10] M. M. M. Zabidi, M. T. A. Rahman, A. Rahman, H. A. Munir, A. H. Adom, and A. F. A. Hamid, "Moving Cell Array Prediction for LORAWAN-Handover Based On Received Signal Strength Indicator (RSSI) Algorithm," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 705, no. 1, p. 12015, 2019, doi: 10.1088/1757-899X/705/1/012015.

[11] Z. A. Tan *et al.*, "Analysis on LoRa RSSI in Urban, Suburban, and Rural Area for Handover Signal Strength-Based Algorithm," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 705, no. 1, p. 12012, 2019, doi: 10.1088/1757-899X/705/1/012012.

[12] W. D. Paredes, H. Kaushal, I. Vakilinia, and Z. Prodanoff, "LoRa Technology in Flying Ad Hoc Networks: A Survey of Challenges and Open Issues," *Sensors*, vol. 23, no. 5. p. 2403, 2023. doi: 10.3390/s23052403.

[13] K. Z. Islam, D. Murray, D. Diepeveen, M. G. K. Jones, and F. Sohel, "LoRa-based outdoor localization and tracking using unsupervised symbolization," *Internet of Things*, vol. 25, p. 101016, 2024, doi: 10.1016/j.iot.2023.101016.

[14] S. N. Syed Taha, M. S. Abu Talip, M. Mohamad, Z. H. Azizul Hasan, and T. F. Tengku Mohmed Noor Izam, "Evaluation of LoRa Network Performance for Water Quality Monitoring Systems," *Applied Sciences*, vol. 14, no. 16. p. 7136, 2024. doi: 10.3390/app14167136.

[15] E. Otsetova-Dudin, "Handoff in Various Mobile Network Technologies," *Transp. Commun.*, vol. 7, no. 2, pp. 28–32, 2019, doi: 10.26552/tac.C.2019.2.6.