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Multihop Data Transmission Using LoRa Technology

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Abstract: The use of Long Range (LoRa) technology in Internet of Things (IoT) networks has grown rapidly to support applications that require wide coverage with low energy consumption. However, physical obstacles and indoor use often cause significant signal attenuation, reducing range and increasing energy consumption. To overcome these limitations, this study implements multihop communication using LoRa repeaters to extend network coverage. In this study, DHT11 sensors are used to measure air temperature and humidity, with data transmitted through a multihop scheme consisting of three LoRa devices: transmitter, repeater, and receiver. The purpose of this study is to analyze the performance of LoRa communication in a multihop scheme, focusing on measuring key parameters such as Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), and Packet Loss. Point-to-point experiments showed that the RSSI was in the range of -103 dBm to -105.5 dBm, while in multihop, the recorded RSSI ranged from -102 dBm to -105 dBm. Meanwhile, the SNR in point-to-point ranged from -2 dB to -22 dB, and in multihop, the SNR value varied from -1.00 dB to -14.50 dB. At a distance of 1.5 kilometers, the point-to-point method suffers from a high packet loss of 65%, with only 23 out of 67 packets received, indicating inadequate performance. In contrast, the multihop method successfully reduces the packet loss to only 0.8%, with 33 out of 36 packets received, indicating improved data transmission quality and reliability. Tests show that the use of LoRa repeaters in multihop networks can significantly extend communication range and improve energy efficiency, with successful data delivery and performance that meets expectations. This research makes an important contribution to understanding the implementation of multihop LoRa networks, especially in the context of IoT applications that require wide coverage in congested environments.

Keywords: LoRa, Multihop, Internet of Things (IoT), Packet Loss, Received Signal Strength Indicator (RSSI).

Abstrak: *Penggunaan teknologi Long Range (LoRa) dalam jaringan Internet of Things (IoT) berkembang pesat untuk mendukung aplikasi yang membutuhkan jangkauan luas dengan konsumsi energi rendah. Namun, hambatan fisik dan penggunaan di dalam ruangan sering menyebabkan pelemahan sinyal yang signifikan, sehingga mengurangi jangkauan dan meningkatkan konsumsi energi. Untuk mengatasi keterbatasan ini, penelitian ini mengimplementasikan komunikasi multihop menggunakan repeater LoRa guna memperluas cakupan jaringan. Dalam penelitian ini, sensor DHT11 digunakan untuk mengukur suhu dan kelembaban udara, dengan data dikirim melalui skema multihop yang terdiri dari tiga perangkat LoRa: pemancar, repeater, dan penerima. Tujuan dari penelitian ini adalah untuk menganalisis kinerja komunikasi LoRa dalam skema multihop, dengan fokus pada pengukuran parameter utama seperti Received Signal Strength Indicator (RSSI), Signal-to-Noise Ratio (SNR), dan Packet Loss. Eksperimen point-to-point menunjukkan bahwa nilai RSSI berada dalam rentang -103 dBm hingga -105,5 dBm, sedangkan pada skema multihop, RSSI tercatat antara -102 dBm hingga -105 dBm. Sementara itu, nilai SNR pada metode point-to-point berkisar antara -2 dB hingga -22 dB, dan pada skema multihop bervariasi dari -1,00 dB hingga -14,50 dB. Pada jarak 1,5 kilometer, metode point-to-point mengalami kehilangan paket yang tinggi sebesar 65%, dengan hanya 23 dari 67 paket yang berhasil diterima. Sebaliknya, metode multihop berhasil menurunkan kehilangan paket menjadi hanya 0,8%, dengan 33 dari 36 paket berhasil diterima, yang menunjukkan peningkatan kualitas dan keandalan transmisi data. Pengujian menunjukkan bahwa penggunaan repeater LoRa dalam jaringan multihop secara signifikan dapat memperluas jangkauan komunikasi dan meningkatkan efisiensi energi, dengan pengiriman data yang sukses dan kinerja yang sesuai harapan. Penelitian ini memberikan kontribusi penting dalam memahami implementasi jaringan LoRa multihop, terutama dalam konteks aplikasi IoT yang membutuhkan cakupan luas di lingkungan padat.*

Kata kunci: *LoRa, Multihop, Internet of Things (IoT), Kehilangan Paket, Indikator Kekuatan Sinyal yang Diterima (RSSI).*

INTRODUCTION

The development of Internet of Things (IoT) technology has significantly improved various aspects of life by enabling multiple devices to communicate and work together to provide innovative services in different environments. One of the main challenges in implementing IoT is ensuring reliable communication in environments with physical obstacles and large distances, such as in smart homes and innovative farming applications. For this reason, wireless networks are very important, especially in reaching large areas that are sometimes blocked by buildings or other objects [1], [2].

In recent years, Low Power Wide Area Networks (LPWAN) have been developed to provide energy-efficient solutions and are able to cover large areas [3]–[6]. Among the various LPWAN technologies, Long Range Wide Area Network (LoRaWAN) has become one of the most prominent, thanks to its ability to build private networks operating in unlicensed frequency bands (923-925 MHz in Indonesia) [7], [8]. 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 [9], [10].

However, challenges remain when LoRaWAN is used in urban areas or inside buildings, where signal coverage can be significantly reduced due to attenuation and fading effects. This condition can lead to data loss and transmission errors. In situations where signals encounter many obstacles, devices must consume more power to maintain communication, which ultimately increases energy consumption and reduces device lifetime [11], [12]. To overcome this problem, multihop communication has been widely applied in network topologies to extend coverage. Multihop networks allow data to pass through several intermediate points (nodes) in the network before reaching its final destination, which not only extends coverage but also improves energy efficiency and extends device battery life. In this context, the LoRa Repeater becomes an important device that functions as an intermediary in the LoRa network, allowing data delivery from devices that are out of range directly to the receiver [13]–[16].

To achieve wider coverage and overcome existing physical obstacles, this study proposes the use of a multihop scheme with a LoRa Repeater. This study aims to analyze the performance of data transmission using LoRa technology in a multihop scheme, especially by using the DHT11 sensor as a temperature and humidity data generator. By implementing LoRa Repeater, this research is expected to increase communication coverage in a wide area and gain a better understanding of the influence of communication parameters on signal quality in multihop networks. The results of this study are expected to provide significant contributions to the development of IoT technology, especially in the context of applications that require broad coverage and energy efficiency.

LoRaWAN is a data link protocol developed by the LoRa Alliance in 2015 to provide low-power connectivity solutions for battery-powered devices. The protocol uses the LoRa physical layer, designed by Semtech with Chirp Spread Spectrum (CSS) modulation. CSS modulation allows devices to use the same frequency but with different Spreading Factors (SF), enabling efficient communication within the network [17]. LoRaWAN supports three bandwidths: 125, 250, and 500 kHz, with 125 kHz being the most commonly used [18].

LoRa operates on the Industrial, Scientific, and Medical (ISM) frequencies, with each country or region using a different frequency range—for example, Europe uses 868 MHz. In comparison, the United States and Brazil use 915 MHz. This frequency scheme divides the frequency range into multiple channels to separate networks operating in the same area [19]. The basic topology of a LoRaWAN network involves an end device, a receiver, and a LoRaWAN Network Server. The end device collects data and generates LoRaWAN packets, which are received by the receiver and forwarded to the Network Server over an IP-based network [20]. The Network Server consists of three main components: Network Server, Application Server, and Join Server. The Network Server manages network management functions, the Application Server forwards packets to related applications, and the Join Server handles the device authentication process [21].

Long Range (LoRa)

LoRa (Long Range) is a radio modulation technology developed by Semtech for long-range applications in Internet of Things (IoT) networks. The technology operates on unlicensed sub-gigahertz frequencies, which vary depending on geographic region, such as 915 to 928 MHz in Asia [17]. LoRa uses Chirp Spread Spectrum (CSS) modulation, which enables low-power communications with a long range, reaching up to 15 km in line-of-sight (LoS) conditions [22]. This technology utilizes the unlicensed ISM frequency band, making it ideal for applications requiring energy efficiency and long-distance communications.

Parameter measurements in LoRa communication are essential to optimize network performance. Key parameters include Received Signal Strength Indicator (RSSI), which measures the strength of the signal received by a device. Factors that affect RSSI include antenna gain, cable/connector loss, and path loss. Path loss, or the loss of signal energy during transmission, can occur due to distance, frequency, and obstacles between the transmitter and receiver [22].

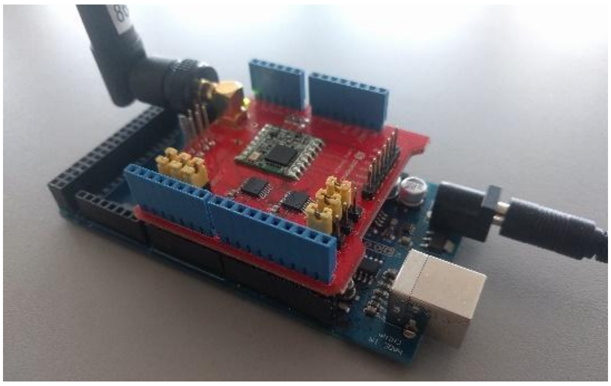

Figure 1. Arduino LoRa Model [23]

Data transmission in LoRa (Long Range) technology involves several essential parameters that need to be considered to optimize wireless communication performance [24]:

1. RSSI measures the strength of the signal received by the device from the transmitter. RSSI values are in the negative range, measured in dBm, ranging from 0 to -127 dBm. The closer the RSSI value is to zero, the stronger the signal received. Factors that affect RSSI include antenna gain, cable/connector loss, and path loss, where longer distances will significantly reduce the RSSI value. In indoor environments, RSSI values are usually better than outdoors due to the effects of multipath and fading.
2. SNR is the ratio between the received signal power and the noise that occurs during transmission. SNR is used to determine signal quality, where a higher value indicates better signal quality. SNR is measured in dB, with categories ranging from very good (>29 dB) to poor (<6.9 dB). High noise will decrease the SNR value, especially at greater distances from the transmitter.
3. Packet Loss Packet loss refers to the number of data packets that fail to reach their destination during transmission. It is affected by distance and obstacles in the communication path. In good line-of-sight (LoS) conditions, packet loss can be minimized, but it will increase with distance and more obstacles. Packet loss is measured as a percentage of data lost compared to the total data sent, with categories ranging from very good (0-2%) to poor (>25%).

Three main parameters affect the sensitivity of LoRa performance [24]:

1. Spreading Factor (SF): Determines the speed at which data is spread in the radio spectrum. Higher SF values allow reception of signals with negative SNR but increase noise and reduce throughput.
2. Bandwidth (BW): The frequency width used in LoRa signal modulation, with options of 125 kHz, 250 kHz, and 500 kHz. The larger the bandwidth, the lower the transmission range.
3. Coding Rate (CR): This determines the level of data coding before sending, which affects resistance to interference. Higher CR values add redundancy, increasing signal resistance to interference and transmission time.

Related Works

Research by [25] conducted a trial using the LoRaWAN End Node LGT92 connected to the LoRa Gateway RAK7243. The end node and gateway are registered on The Things Network (TTN) server, and various test scenarios were conducted to assess the communication performance. The test results showed that the position of the LGT92 node was successfully sent in real-time to the TTN server, and its coordinates were displayed on the dashboard using the Cayenne application. The maximum range achieved by the RAK7243 in Non-Line of Sight (NLoS) conditions was 900 meters. Research [26] compares the performance of Gossip-based routing protocols with LoRaWAN. One of the drawbacks of the discussed routing protocols is the absence of significant delay in packet delivery from source to destination, which is a problem in LoRaWAN networks. This study reveals that Gossip-based routing protocols offer improvements in packet delivery compared to LoRaWAN, especially in applications with more than two hops, which is essential in smart IoT applications. The proposed protocol is capable of delivering packets with minimal hop count without the need to calculate the path explicitly.

Research [12] examines Low Power Wide Area Networks (LPWANs), which meet many IoT requirements such as energy efficiency, low cost, and wide coverage. LoRaWAN networks generally use a single-hop topology, where end devices transmit data directly to receivers. However, recent research has proposed the development of multihop LoRaWAN networks to form wireless mesh networks, which can improve the flexibility and range of LoRa networks. Research [27] propose a new multi-hop LoRa protocol that improves data delivery reliability in dynamic LoRa networks. This study extends the previous Two-Hop RT-LoRa protocol to address various challenges in multi-hop LoRa networks, such as auto-configuration, dynamic topology management, and real-time slot schedule updates. This protocol aims to optimize network performance under changing conditions. Research [24] focuses on testing the range of the LoRa Rfm95/96 chip at a frequency of 920 MHz with a Spreading Factor (SF) of 7 in urban areas. The test results show that the RSSI value produced is close to the theoretical calculation with the log-normal shadowing model. However, RSSI decreases and packet loss increases as the distance increases. The maximum range obtained in urban conditions reaches 2 km, in accordance with the LoRa specifications.

METHODS

This study aims to analyze the performance of the LoRa network by implementing a multihop communication scheme using a LoRa repeater. To achieve this goal, the research method used includes several stages, namely: system design, data collection, testing, and result analysis.

System Design

At this stage, a LoRa network architecture is designed, consisting of several end-device nodes, LoRa repeaters, and gateways. The end-device nodes are equipped with DHT11 sensors to measure temperature and humidity, the data of which is sent via the LoRa protocol to the gateway. The LoRa repeater is used to extend the communication range, allowing data to be sent from end-device nodes outside the gateway's direct range. This system is implemented using the DraginoShield RFM95 LoRa module operating at a frequency of 945 MHz.

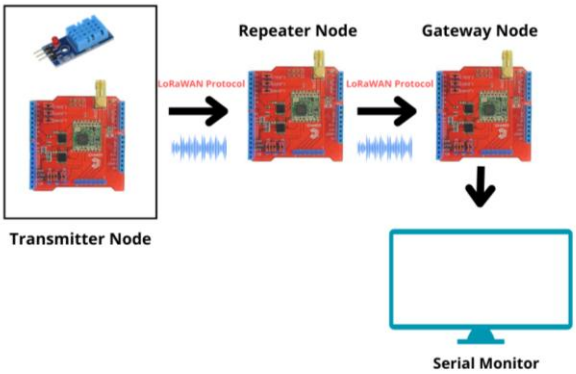

Figure 2. Multihop LoRa Network Topology

Data was collected through field testing with various distance scenarios and environmental conditions. Testing was carried out by varying the distance between the end-device nodes, repeaters, and gateways, and by considering obstacle factors that can affect signal quality. The data measured included RSSI, SNR, and Packet Loss. Each measurement was carried out with three repetitions to ensure data accuracy.

Node Transmitter

The transmitter node is done by involving several main hardware components, including Antenna (1), DHT11 sensor (2), LoRa Shield Dragino (3), USB Arduino (4), and Arduino Uno (5) as shown in Figure 3. This sensor node functions as a data sender to the Receiver. First, the DHT11 sensor is connected to the Arduino Uno microcontroller using a jumper cable according to the previous plan. The DHT11 sensor is used to measure the temperature and humidity of the surrounding environment. Furthermore, the LoRa Shield Dragino module is also connected to the Arduino Uno microcontroller using a jumper cable. This LoRa module is tasked with sending data measured by the DHT11 sensor to the Receiver using LoRa communication. After all the hardware is connected correctly, the Arduino Uno is powered so that it can be activated. This is done by connecting the Arduino Uno to a monitor or other power source using the Arduino USB cable. With all devices connected and the Arduino Uno active, the sensor node is ready to collect data from the DHT11 sensor and send it via the LoRa module to the Receiver for further processing. This process allows continuous measurement of ambient temperature and humidity and remote monitoring via the LoRa network. The transmitter node circuit can be seen in Figure 3.

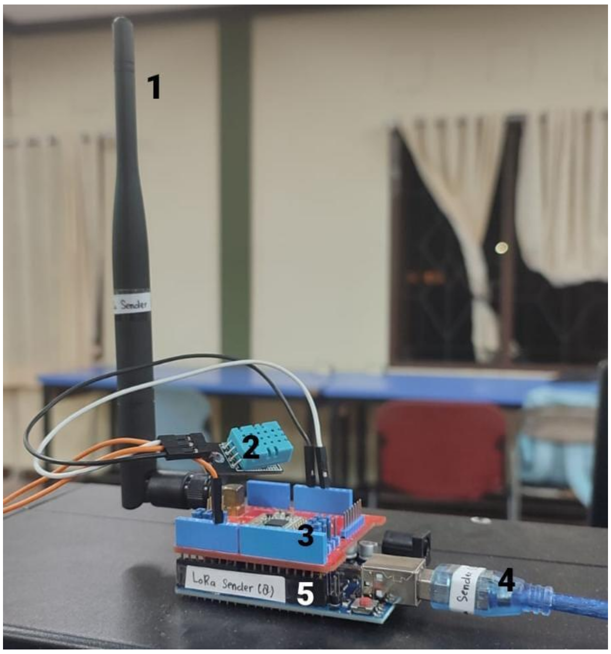

Figure 3. Node Transmitter

Node Repeater

Repeater nodes are additional devices in the LoRa network that function to expand the network coverage by receiving and forwarding data packets between transmitter and receiver nodes, as shown in Figure 4. The implementation of repeater nodes usually involves hardware similar to sensor nodes, such as Arduino microcontrollers, LoRa modules, and appropriate power sources. First of all, repeater nodes must be placed in strategic locations where LoRa signals from transmitter nodes can be received well and have sufficient range to reach the receiver. This allows repeater nodes to act as intermediaries between sensor nodes that are in more remote areas or have limited signal coverage with the receiver. Repeater nodes are connected to a power source and programmed to forward data packets received from sensor nodes to the receiver using the LoRa communication protocol. In this way, repeater nodes help expand the coverage of the LoRa network and improve service availability in the broader area. In addition, the placement strategy of repeater nodes also needs to be carefully considered to ensure optimal coverage in the use of resources. With repeater nodes, the LoRa network can be more flexible and adaptable to cover a larger area effectively, allowing for wider and more accurate monitoring and data collection.

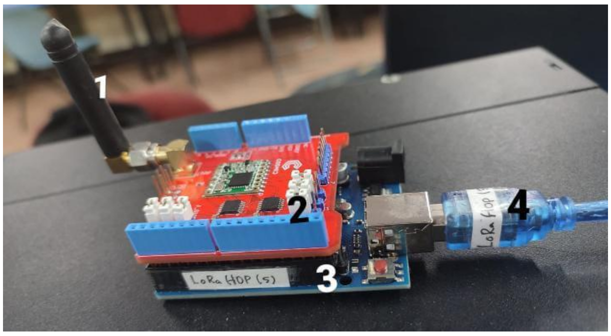

Figure 4. Node Repeater

Node Receiver

The implementation of the receiver node plays an essential role in the wireless communication process, as shown in Figure 5, which consists of an antenna (1), a LoRa shield dragino (2), an Arduino Uno (3), and a USB Arduino (4). When receiving data from the transmitter node through the repeater node intermediary, the main task of the receiver is to process and display the received data. In this context, the receiver will immediately display the data to the serial monitor. This is done to ensure that the data sent by the transmitter is received correctly and as expected. By displaying data to the serial monitor, we can monitor and check the communication results directly, thus facilitating the debugging and troubleshooting process if there is interference or error in communication. Thus, the implementation of the receiver node is key to ensuring the success of wireless communication between the transmitter and receiver in the network.

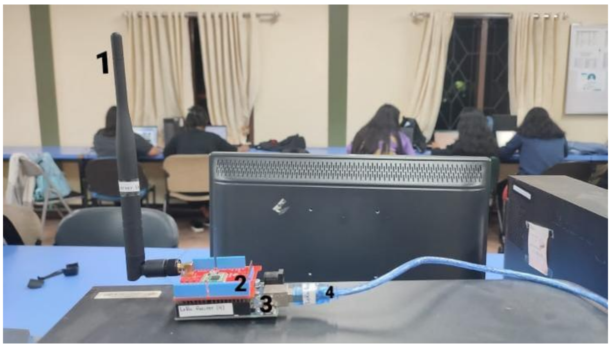

Figure 5. Node Receiver

RESULT AND DISCUSSION

Testing was conducted in two main scenarios: point-to-point communication and multihop communication. In the point-to-point scenario, testing was conducted to measure network performance without repeaters, while in the multihop scenario, repeaters were used to connect end-device nodes that were out of the gateway's direct range. Testing was conducted at various distances, ranging from 500 meters to 2.2 kilometers, to evaluate the effectiveness of using repeaters to extend network coverage.

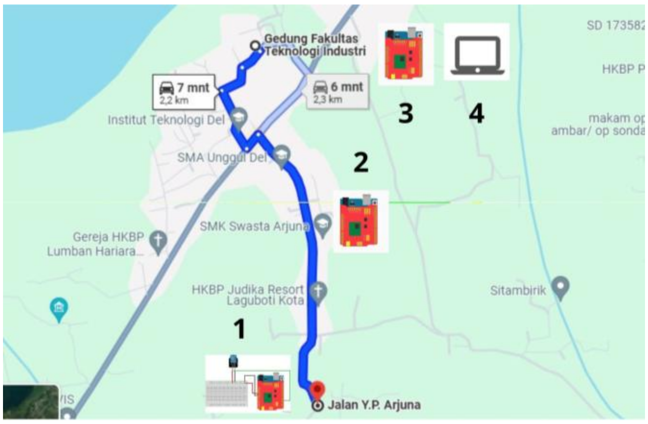

Figure 6. Multihop scenario in LoRa network 1=Transmitter Node, 2= Repeater, 3= Gateway, 4=Serial Monitor

The collected data was analyzed to assess the performance of LoRa communication in point-to-point and multihop scenarios. The analysis was carried out by calculating the average RSSI, SNR, and Packet Loss in each test scenario. These results were then compared to determine the extent to which the use of repeaters can improve the range and quality of communication. In addition, an analysis was carried out on factors that affect performance, such as distance, obstacles, and other technical parameters such as Spreading Factor (SF), Bandwidth (BW), and Coding Rate (CR).

Point-to-Point Test Results at a Distance of 1.5 Kilometers

Point-to-point testing has been conducted to evaluate the quality of the network connection between the IT DEL Industrial Technology Faculty (FTI) Building and the GKPI Tanding Church, with a total distance of 1.5 kilometers.

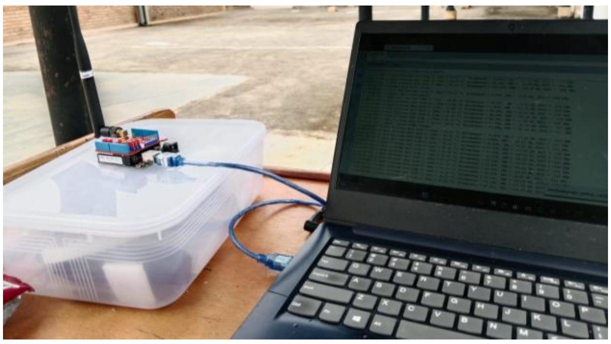

Figure 7. LoRa Receiver Location in FTI IT Del Building during Point-to-Point Testing

Figure 8. LoRa Transmitter Location at GKPI Tanding Church at a Distance of 1.5 Kilometers in Point-to-point Testing

In this 1.5-kilometer distance test, we collected data using the SF value of 10, which was chosen to optimize the signal range. The test results on the serial monitor can be seen in the Figure 9.

```
17:03:06.775 -> Data diterima dari node 1: Suhu = 26.70 °C, Kelembaban = 75.00%, SNR = -9.25 dB, RSSI = -104 dBm
17:03:18.061 -> Format data tidak valid!
17:03:23.709 -> Data diterima dari node 1: Suhu = 26.70 °C, Kelembaban = 75.00%, SNR = -15.75 dB, RSSI = -105 dBm
17:03:29.354 -> Format data tidak valid!
17:03:34.974 -> Data diterima dari node 1: Suhu = 26.70 °C, Kelembaban = 77.00%, SNR = -12.25 dB, RSSI = -104 dBm
17:03:40.610 -> Format data tidak valid!
17:03:46.255 -> Format data tidak valid!
17:03:57.532 -> Format data tidak valid!
17:04:03.172 -> Format data tidak valid!
17:04:08.821 -> Format data tidak valid!
17:04:14.457 -> Data diterima dari node 1: Suhu = 27.10 °C, Kelembaban = 77.00%, SNR = -9.00 dB, RSSI = -104 dBm
17:04:20.098 -> Data diterima dari node 1: Suhu = 27.10 °C, Kelembaban = 76.00%, SNR = -15.75 dB, RSSI = -104 dBm
17:04:31.380 -> Format data tidak valid!
17:05:33.397 -> Alamat tujuan tidak sesuai!
17:08:34.668 -> Data diterima dari node 1: Suhu = 27.10 °C, Kelembaban = 79.00%, SNR = -17.00 dB, RSSI = -103 dBm,
17:08:40.300 -> Data diterima dari node 1: Suhu = 27.10 °C, Kelembaban = 79.00%, SNR = -17.25 dB, RSSI = -105 dBm,
17:08:45.171 -> Format data tidak valid!
17:08:50.799 -> Data diterima dari node 1: Suhu = 27.10 °C, Kelembaban = 80.00%, SNR = -16.75 dB, RSSI = -106 dBm
17:09:08.489 -> Format data tidak valid!
17:09:24.634 -> Format data tidak valid!
17:09:25.396 -> Alamat tujuan tidak sesuai!
```

Figure 9. Point-to-point Receiver Test Results During Testing at a Distance of 1.5 Kilometers in Point-to-point Testing

We can see the results on the transmitter's serial monitor. During the time span from 17.03 to 17.09, the amount of data sent was 67. The serial monitor display on the receiver showed that the data received was 23. This indicates a possible problem in the data transmission process, such as data loss, due to interference, signal interference, or difficulties in network configuration. The difference in the amount of data sent and received is essential to analyze further to ensure the reliability of the communication system used and to identify potential sources of data loss. In addition, the 1.5-kilometer distance is the last limit where data can still be received using point-to-point communication. At this distance, the signal begins to weaken, and data transmission becomes unstable. Therefore, after this distance, multihop communication is needed to ensure that data can continue to be appropriately received. In multihop communication, data is not only sent directly from the sender to the receiver, but also through one or more intermediary devices that help extend the transmission range. The use of this method becomes very important when the distance between the sender and receiver exceeds the capabilities of point-to-point communication, as seen in this test. With multihop, signals can be amplified or forwarded, so that data can still be received more reliably even at greater distances. This is important to note in the implementation of long-distance communication systems so that the reliability and consistency of the data received are maintained.

```
17:03:55.639 -> Data akan dikirim: Suhu: 26.70 °C, Kelembaban: 76.00%
17:04:01.267 -> Data akan dikirim: Suhu: 26.70 °C, Kelembaban: 77.00%
17:04:06.914 -> Data akan dikirim: Suhu: 26.70 °C, Kelembaban: 77.00%
17:04:12.550 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 76.00%
17:04:18.204 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 77.00%
17:04:23.830 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 76.00%
17:04:29.470 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 76.00%
17:04:35.118 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 76.00%
17:04:40.744 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 77.00%
17:04:46.407 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 77.00%
17:04:52.052 -> Data akan dikirim: Suhu: 27.50 °C, Kelembaban: 77.00%
17:04:57.676 -> Data akan dikirim: Suhu: 27.60 °C, Kelembaban: 76.00%
17:05:03.330 -> Data akan dikirim: Suhu: 27.60 °C, Kelembaban: 76.00%
17:05:08.945 -> Data akan dikirim: Suhu: 27.60 °C, Kelembaban: 75.00%
17:05:14.582 -> Data akan dikirim: Suhu: 27.60 °C, Kelembaban: 74.00%
17:05:20.238 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 74.00%
17:05:25.869 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 74.00%
17:05:31.498 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 74.00%
17:05:37.165 -> Data akan dikirim: Suhu: 27.10 °C, Kelembaban: 74.00%
```

Figure 10. Point-to-point Test Results on Transmitter During Testing at a Distance of 1.5 Kilometers in Point-to-point Testing

The test results in Table 1 show some variability in the quality of data transmission. In some trials, the received data showed a valid format, as indicated by correctly recorded temperature and humidity and appropriate SNR, RSSI, and SF values. However, in many other trials, errors occurred that caused invalid data. These errors may be caused by signal interference, noise, or other technical issues affecting the data transmission process. In some cases, the received data was formatted incorrectly, so it could not be processed correctly. In addition, some entries noted that the destination address was incorrect, indicating problems in sending data to the correct destination. Overall, these test results show that at a distance of 1.5 kilometers, LoRa technology can transmit data correctly under certain conditions. Still, there are many challenges related to data validity and delivery accuracy. Further testing and system improvements may be needed to improve the reliability of data transmission at longer distances.

Table 1. Recorded temperature and humidity, and appropriate SNR, RSSI, and SF values in Point-to-Point

Distance 1,5 Kilometer				
Temperature (*C)	**Humidity (%)**	**SNR (dB)**	**RSSI (dBm)**	**SF**
26.70	75.00	-9.25	-104	10
Invalid Data Format				
26.70	75.00	-15.75	-105	10
Invalid Data Format				
26.70	77.00	-12.25	-104	10
Invalid Data Format Invalid Data Format Invalid Data Format Invalid Data Format Invalid Data Format				
27.10	77.00	-9.00	-104	10
27.10	76.00	-15.75	-104	10
Invalid Data Format Destination Address Does Not Match				
27.10	79.00	-17.00	-103	10
27.10	79.00	-17.25	-105	
Invalid Data Format				
27.10	80.00	-16.75	-106	10
Invalid Data Format Invalid Data Format Destination Address Does Not Match				

The results in the graph below show that the RSSI in this graph is in the range of -103 dBm to -105.5 dBm. A more negative RSSI value indicates that the signal strength received at a distance of 1.5 kilometers is relatively weak. This indicates that the signal is significantly degraded due to the long distance. The SNR in this graph shows quite a significant variation. The SNR at some points is around -2 dB to -22 dB. A lower (more negative) SNR value indicates that the signal is increasingly degraded by noise, indicating a significant decrease in signal quality at this distance. The results of this test indicate that at a distance of 1.5 kilometers, point-to-point transmission begins to be ineffective. The received signal is not only weak, but its quality is also greatly affected by noise. This confirms that at this distance, the point-to-point concept is no longer adequate and requires other approaches, such as multihop, to maintain the reliability of data transmission. Multihop implementation will allow data to be forwarded through multiple intermediate nodes, which can strengthen the signal and ensure that data reaches its destination better and more accurately despite the long transmission distance.

Furthermore, to assess the performance of the point-to-point network at a distance of 1.5 Kilometers that has been tested, a vital parameter calculation is carried out, namely, packet loss. This calculation helps understand the signal quality and efficiency of data transmission in the network.

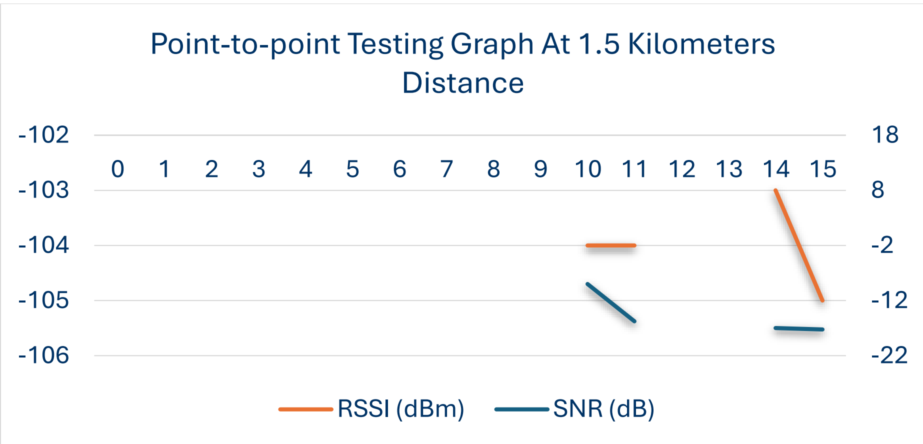

Figure 11. Point-to-point Testing Graph At 1.5 Kilometers Distance in Point-to-point Testing

Here is the calculation along with the final result table of the parameters. Based on the test results, we have the following data.

- Total packages sent: 67
- Total packages received: 23

$$Packet\ loss\ (\%) = \left(\frac{Number\ of\ Lost\ Packages}{Number\ of\ Packages\ Sent}\right) \times 100 = \left(\frac{67-23}{67}\right) \times 100 = \left(\frac{44}{67}\right) \times 100 = \mathbf{65}\%$$

The calculation results show that the packet loss that occurred in the test at a distance of 1.5 kilometers was 65%. This value is considered very bad because, ideally packet loss in a good communication network should be close to 0% or at least below 1%. A high packet loss rate, such as 65%, indicates that most of the data sent did not reach its destination. This can result in a decrease in service quality, such as slow data transmission, loss of communication, or even complete loss of data. It is better not to use the point-to-point communication method for sending data over a reasonably long distance, such as 1.5 kilometers, without adequate infrastructure. Point-to-point is a direct communication method between two points, and over long distances, many factors can interfere with the stability and reliability of data transmission, such as signal interference, physical obstacles, and signal degradation. Therefore, the multihop method is recommended for sending data over longer distances. Multihop is a communication method in which data is sent through several intermediate points or hops before reaching its final destination. Each hop acts as a connector that receives data from the previous point and forwards it to the next point until the data reaches its destination.

Multihop Test Results at a Distance of 1.5 Kilometers

After considering the results of point-to-point testing that showed a packet loss of 65% at a distance of 1.5 kilometers, testing was then carried out using the multihop method at the same distance. This test aims to reduce packet loss and improve the quality of data transmission by dividing the 1.5-kilometer distance into several shorter segments. In this multihop test, the receiver device is placed in the IT Del Industrial Technology Faculty Building, while the signal repeater device is positioned at SMK Arjuna. The signal is then forwarded from this repeater to the transmitter device located at the GKPI Tanding Church. With this strategy, the signal sent from the transmitter does not go directly to the receiver. Still, it is amplified and forwarded through the repeater at SMK Arjuna before finally reaching the receiver at IT Del. This multihop method is expected to overcome the problems found in point-to-point testing, especially in terms of reducing packet loss and maintaining signal stability throughout the data journey. With the placement of repeaters at SMK Arjuna, the distance that the signal must travel becomes shorter in each segment, thus reducing the risk of data loss due to interference or significant signal attenuation.

Figure 12. LoRa Receiver Location at GKPI Tanding Church with a Distance of 1.5 Kilometers in Multihop Testing

Figure 13. LoRa Repeater Location at SMK Arjuna with a Distance of 1.5 Kilometers in Multihop Testing

Figure 14. LoRa Receiver Location in FTI IT Del Building with a Distance of 1.5 Kilometers in Multihop Testing

In this 1.5-kilometer distance test, we collected data using the SF value of 10, which was chosen to optimize the signal range. The test results on the serial monitor can be seen in the Figure 15.

```
17:33:05.672 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 69.00%
17:33:11.325 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 69.00%
17:33:16.963 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 69.00%
17:33:22.583 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 69.00%
17:33:28.239 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 70.00%
17:33:33.860 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 70.00%
17:33:39.519 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 71.00%
17:33:45.134 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 72.00%
17:33:50.785 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 72.00%
17:33:56.431 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 72.00%
17:34:02.053 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 73.00%
17:34:07.707 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 74.00%
17:34:13.332 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 74.00%
17:34:18.991 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 75.00%
17:34:24.618 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 75.00%
17:34:30.253 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 75.00%
17:34:35.909 -> Data akan dikirim: Suhu: 28.90 °C, Kelembaban: 75.00%
17:34:41.536 -> Data akan dikirim: Suhu: 29.30 °C, Kelembaban: 75.00%
17:34:47.174 -> Data akan dikirim: Suhu: 29.30 °C, Kelembaban: 75.00%
17:34:52.806 -> Data akan dikirim: Suhu: 29.30 °C, Kelembaban: 76.00%
17:34:58.446 -> Data akan dikirim: Suhu: 29.30 °C, Kelembaban: 75.00%
17:35:04.117 -> Data akan dikirim: Suhu: 29.30 °C, Kelembaban: 75.00%
17:35:09.726 -> Data akan dikirim: Suhu: 29.30 °C, Kelembaban: 75.00%
17:35:15.365 -> Data akan dikirim: Suhu: 29.30 °C, Kelembaban: 75.00%
17:35:21.021 -> Data akan dikirim: Suhu: 29.30 °C, Kelembaban: 75.00%
17:35:26.645 -> Data akan dikirim: Suhu: 29.80 °C, Kelembaban: 74.00%
17:35:32.305 -> Data akan dikirim: Suhu: 29.80 °C, Kelembaban: 74.00%
17:35:37.944 -> Data akan dikirim: Suhu: 29.80 °C, Kelembaban: 73.00%
```

Figure 15. Point-to-point test results on the Transmitter When Testing at a Distance of 1.5 Kilometers in Multihop Testing

```
17:33:57.118 -> Repeater mengirim ulang data ke receiver: 28.90 C, 72.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:02.687 -> Repeater menerima data dari node 1: 28.90 C, 73.00 %, SF=10, BW=125000.00, CR=6
17:34:02.751 -> Repeater mengirim ulang data ke receiver: 28.90 C, 73.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:08.318 -> Repeater menerima data dari node 1: 28.90 C, 74.00 %, SF=10, BW=125000.00, CR=6
17:34:08.414 -> Repeater mengirim ulang data ke receiver: 28.90 C, 74.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:13.962 -> Repeater menerima data dari node 1: 28.90 C, 74.00 %, SF=10, BW=125000.00, CR=6
17:34:14.026 -> Repeater mengirim ulang data ke receiver: 28.90 C, 74.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:19.599 -> Repeater menerima data dari node 1: 28.90 C, 75.00 %, SF=10, BW=125000.00, CR=6
17:34:19.663 -> Repeater mengirim ulang data ke receiver: 28.90 C, 75.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:25.235 -> Repeater menerima data dari node 1: 28.90 C, 75.00 %, SF=10, BW=125000.00, CR=6
17:34:25.331 -> Repeater mengirim ulang data ke receiver: 28.90 C, 75.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:30.878 -> Repeater menerima data dari node 1: 28.90 C, 75.00 %, SF=10, BW=125000.00, CR=6
17:34:30.974 -> Repeater mengirim ulang data ke receiver: 28.90 C, 75.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:36.498 -> Repeater menerima data dari node 1: 28.90 C, 75.00 %, SF=10, BW=125000.00, CR=6
17:34:36.593 -> Repeater mengirim ulang data ke receiver: 28.90 C, 75.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:42.157 -> Repeater menerima data dari node 1: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6
17:34:42.253 -> Repeater mengirim ulang data ke receiver: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:47.795 -> Repeater menerima data dari node 1: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6
17:34:47.892 -> Repeater mengirim ulang data ke receiver: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:53.443 -> Repeater menerima data dari node 1: 29.30 C, 76.00 %, SF=10, BW=125000.00, CR=6
17:34:53.508 -> Repeater mengirim ulang data ke receiver: 29.30 C, 76.00 %, SF=10, BW=125000.00, CR=6 R1
17:34:59.056 -> Repeater menerima data dari node 1: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6
17:34:59.153 -> Repeater mengirim ulang data ke receiver: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6 R1
17:35:04.715 -> Repeater menerima data dari node 1: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6
17:35:04.780 -> Repeater mengirim ulang data ke receiver: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6 R1
17:35:10.364 -> Repeater menerima data dari node 1: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6
17:35:10.428 -> Repeater mengirim ulang data ke receiver: 29.30 C, 75.00 %, SF=10, BW=125000.00, CR=6 R1
```

Figure 16. Point-to-point test results on Repeater When Testing at a Distance of 1.5 Kilometers in Multihop Testing

In the test using the multihop method carried out with a distance of 1.5 kilometers, the results displayed on the serial monitor on the receiver showed a significant increase in data transmission quality compared to the point-to-point method. From the test results, we can see that in the time span between 17.33 and 17.35, a total of 36 data points were successfully sent from the transmitter. This data was then passed through the repeater located at SMK Arjuna, and it turned out that the number of data points passing through the repeater increased to 33. This shows that the repeater not only succeeded in forwarding all the data sent, but also functioned to repair or add data that might have been disrupted during transmission. Furthermore, on the serial monitor display on the receiver located in the IT Del Industrial Technology Faculty Building, it can be seen that all 33 data points forwarded by the repeater were successfully received without any packet loss. This indicates that the multihop method with the placement of the repeater in the middle of the transmission route is able to overcome the problems previously found in the point-to-point method effectively. The repeater not only helps strengthen the signal but also ensures that all data is sent completely and received well by the receiver. We can see the serial monitor display on the Receiver in the following figure.

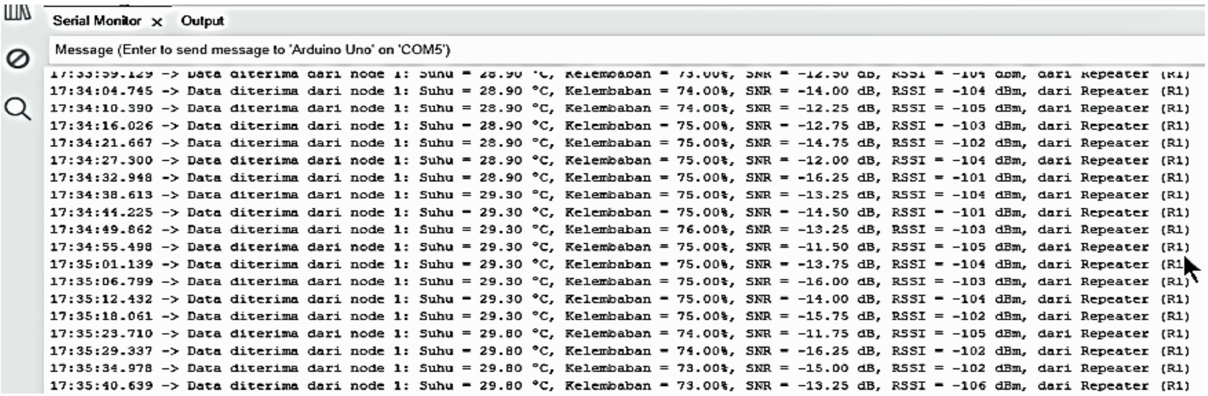

Figure 17. Point-to-point test results on the Receiver When Testing at a Distance of 1.5 Kilometers in Multihop Testing

In Figure 17, a multihop test at a distance of 1.5 kilometers is obtained involving several essential aspects of data transmission, such as temperature, humidity, signal quality, and other factors that affect network performance. During the test, the ambient temperature ranged from 28.90°C to 30.30°C, with humidity ranging from 69.00% to 78.00%. These environmental conditions are essential factors that can affect data transmission, especially since changes in temperature and humidity can affect radio signal propagation.

In terms of signal quality, the SNR values vary from -1.00 dB to -14.50 dB. A lower SNR value indicates that the noise level is relatively high compared to the signal strength, which can result in decreased data reception quality. On the other hand, the RSSI recorded in this test ranged from -102 dBm to -105 dBm, indicating that the received signal is relatively weak, although the device can still accept it. All tests used a Spreading Factor (SF) of 10, a parameter in LoRa technology that affects range and data rate. With an SF of 10, the network can achieve a more extended range but with a lower data rate.

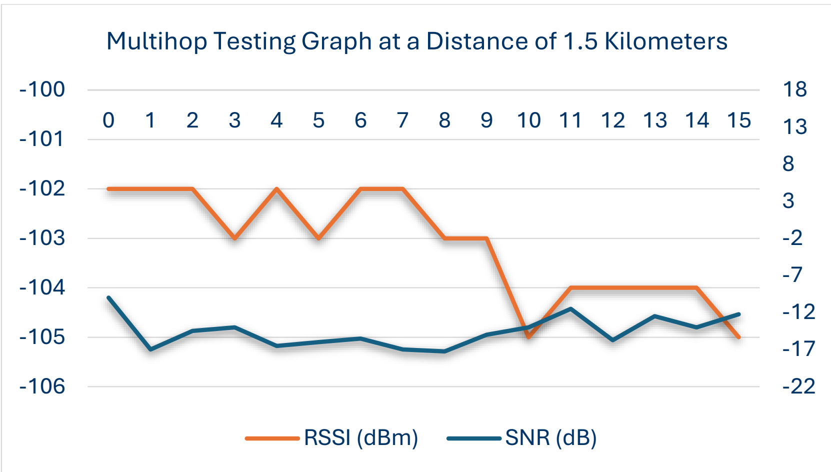

Figure 18. Multihop Testing Graph At 1.5 Kilometers Distance

RSSI, shown by the orange line, records the signal strength received by the receiver. Lower (more negative) RSSI values indicate a weaker signal. In this graph, RSSI ranges from -102 dBm to -105 dBm. Overall, RSSI values tend to be stable, although there is minor instability at some test points. This instability could be caused by variations in environmental conditions or signal interference at specific points. SNR, represented by the blue line, shows the ratio of the received signal strength to the noise level. Higher SNR values indicate better signal quality, while lower values indicate increased noise relative to the signal. In this graph, the SNR varies from -1 dB to -14 dB. In general, the SNR shows a more evident instability pattern compared to the RSSI, with a sharp drop at some test points, indicating increased noise at certain times.

From this graph, we can conclude that although the RSSI is relatively stable during the multihop test, SNR experiences more significant instability. This shows that although the device still receives a signal with a reasonably consistent strength, the transmission quality can be affected by varying noise, which can affect the reliability and speed of data communication at a distance of 1.5 kilometers. The use of the multihop method helps maintain signal stability, but environmental factors and interference still affect the quality of the received signal.

Furthermore, to assess the performance of the multihop network at a distance of 1.5 kilometers that has been tested, a vital parameter calculation, namely packet loss, is carried out. This calculation helps understand the signal quality and efficiency of data transmission in the network. The following is the calculation along with the final result table of these parameters. Based on the test results, we have the following data.

- Total packages sent: 36
- Total packages received: 33

$$Packet\ loss\ (\%) = \left(\frac{Number\ of\ Lost\ Packages}{Number\ of\ Packages\ Sent}\right) \times 100 = \left(\frac{36 - 33}{36}\right) \times 100 = \left(\frac{3}{36}\right) \times 100 = \mathbf{0,8}\%$$

The calculation results show that the packet loss in the multihop network test at a distance of 1.5 kilometers is 0.8%. This value is quite good because, ideally, packet loss in an efficient communication network should be close to 0% or at least below 1%. The packet loss rate of 0.8% indicates that most of the data sent successfully reaches its destination with little loss. This generally results in adequate network quality, with little impact on data transmission speed. In contrast, point-to-point testing at a distance of 1.5 kilometers may not provide as complex a Figure as multihop testing, because it does not consider the influence of additional nodes that act as intermediaries.

CONCLUSIONS

The test shows that the multihop method significantly improves the performance and range of LoRa data transmission compared to the point-to-point method. At a distance of 1.5 kilometers, the point-to-point method suffers from a high packet loss of 65%, with only 23 out of 67 packets received, indicating inadequate performance. In contrast, the multihop method successfully reduces the packet loss to only 0.8%, with 33 out of 36 packets received, indicating improved data transmission quality and reliability. This proves that the multihop method effectively enhances the performance of LoRa data transmission and meets the goal of extending the transmission range. In addition, the test also confirms that the multihop method is very efficient in increasing the range of LoRa data transmission, with evidence that the use of multiple intermediate nodes can significantly reduce packet loss and extend the transmission range. These results indicate that the multihop method is a better solution for applications that require data transmission over longer distances, offering clear advantages in data transmission quality and wider range compared to the point-to-point method.

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