ILKOM Jurnal Ilmiah Vol. 16, No. 3, December 2024, pp. 255-270
Accredited 2nd by RISTEKBRIN No. 200/M/KPT/2020; E-ISSN 2548-7779 | P-ISSN 2087-1716

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Performance Analysis of LoRaWAN Communication Utilizing the RFM96 Module

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Article history: Received August 07, 2024; Revised September 26, 2024; Accepted October 19, 2024; Available online December 12, 2024

Abstract

This research discusses the utilization of LoRa and LoRaWAN or Low Power Wide Area (LPWA) and Low Power Wide Area Network (LPWAN). In this study, the application server is utilized using Telkom IoT. In its utilization, Telkom IoT can provide comprehensive results regarding LoRa quality of service capabilities such as bit rate, latency, and longitude and latitude data. Terrestrial measurements conduct tests in different areas with different conditions that cause different data obstruction, with several LoRa end-node points transmitting data with low bit-rate. For example, heart rate data. Some other parameters are the spreading factor (SF) and power consumption. Some parameters that determine the quality of transmitting data include the Spreading Factor and the Bandwidth used. From the analysis dan Experiment results, the Delay (ms) generated from measurements using RFM96 LoRa for IoT is around 0.02 seconds or 20 ms to around 0.05 seconds or 50 ms, and sometimes it can reach 0.07 ms to 0.09 ms. RSSI and SNR show the quality of the signal obtained which will provide a Quality of Service (QoS) value. From the measurement results using Telkom IoT in several times of data collection and testing, the average RSSI (-dBm) is at -110 dBm to -115 dBm. While SNR is at -10 dB to -16 dB.

Keywords: Indonesia Provider; LoRaWAN; LoRa Communication; Low Power Consumption; LPWA; LPWAN.

Introduction

Internet of Things (IoT) technology now continues to develop with the existence of new technologies in the field of IoT that continue to develop [1], [2], including the Internet of Video Things (IoT) and the Internet of Medical Things (IoMT). This development is supported by parameter devices with certain specifications, such as the LoRa module, compared to SigFox, NB-IoT, and WiFi, 3G, 4G, 5G, or 6G (still in the development stage). Having different specifications, we also added LoRAWAN with Satellite Communication technology called Lacuna Space and other comprehensive developments. This research does not use satellite communication types but only LoS and NLoS, meaning that Terrestrial communication will be affected by the presence of Diffraction, Reflection, and Scattering Signals. Satellite communication is affected by Free Space Path Loss (FSPL), the distance between the satellite and the ground station, Atmospheric Attenuation, and Rain Attenuation.

In this research using LoRa, LoRa is one of the devices that belong to the LPWAN type, and its ability is long-distance transmission (km). This ability is its advantage, compared to WiFi, BLE or LiFi, but the drawback is in terms of data rate or bit-rate, only a maximum of around 0.3 kbps to 50 kbps, depending on the LoRa frequency. Specifically, the RF96 LoRa Module, with a bandwidth of 125 kHz, SF7, has a bit rate of 5.47 kbps. Bandwidth 500 kHz, SF7, the resulting Bit-rate is 37.5 kbps. Moreover, LoRa devices excel in power consumption and distance traveled, making them perfect for building IoT applications [3]–[5]. However, in developing IoVT and IoMT based on image transmission, it is better to use other devices such as Bluetooth Low Energy (BLE). Then the next advantage is the Application Server side. That IoT-Telkom is the nation's own work, can be developed more advanced, meaning that the novelty obtained is being able to provide real-time data specifically using a homemade Application Server. Similar to The Things Networks, AWS, Thingspeak, Tago.io, and others.

http://dx.doi.org/10.33096/ilkom.v16i3.2326.255-270

This LoRa research GAP is shown in reference [6] tried to do research on LoRa system that is integrated into campus security infrastructure in Taiwan, and also approaches Artificial Intelligence for the development of LoRa with high bit-rates in the future. Also done in research references [7], This research uses SX1278 LoRa radio module at 433 MHz to analyze Duty Cycle, SNR, PRR, RSSI, NLoS, and other parameters. from this study, the maximum possible capability of up to 100% in packet delivery ratio is produced. The next research was conducted by [8], they conducted research in the field of LoRa, evaluate LoRa and LoRaWAN performance and characteristics, and approach future LoRa research. Specifically on RSSI and SNR, research from [9] This research explains in detail about Received signal strength indicator (RSSI) in multistory round layout buildings, and also uses a method namely KNN. In the research [10], In this study, a comprehensive data breakdown of the environmental effects of RSS on LoRa was conducted and field experiments were conducted to obtain a comparison of RSSI and SNR.

Method

The following are formulas used to express signal attenuation processes specifically used in LoRa Module Communication on Line of Sight (LoS) and Non-Line of Sight (NLoS) [11]–[15]. Furthermore, some formulas in LoRaWAN can be applied to analyze LoRaWAN Communication conducted in this research comprehensively [16]–[18]. This L(fs) value is the Free Space Path Loss in dB, while D is the Distance between End-Devices and Gateway in km. In calculating the km distance, it is necessary to consider the Freznel Zone equation only as a comparison. At the same time, f is the Frequency (MHz) value. Usually, Indonesia uses Dragino LoRa 915 MHz with LoRa RF95 or RF96 chips, and other types, such as ES920LR, can also be used for testing. Usually, this LoRa chip is used in Japan, and it is 920 MHz.

Moreover, another approach can also be done by searching for the right frequency for LoRa, for example, EBYTE 920 MHz LoRa. For the Fresnel Zone itself, the radius or r value can be known as Equation 2 [19]–[23], where this r value is the Fresnel zone radius in meters (m). D is Distance in km, some of which is in the previous research section. Furthermore, to calculate the height of the radius used for the Fresnel Zone is called H, where the value of H is calculated as in Equation 3. The value of R_earth is 8504 km. What needs to be known is that the distance used for LoRa measurements with the Freznel Zone approach starts at Distance. If the antenna built on this Tx-Rx communication is too low, it will cause Blockage by the earth's curvature, as shown in Equation 4. Depending on what percentage of Blockage, for example, 35%, it is calculated by Equation 4. The next factor is the Effective Radiated Power (ERP). ERP is the energy required by the LoRa module to send the device from the transmitter to the receiver, and its components include Tx_Power, Gain, and Cable Loss. This ERP is determined by Tx_Power, Antenna_Gain (dBi), and Cable Loss (dBm) as in Equation 5. The essential factor in knowing the strength of the LoRa signal is determined by two parameters: Received Signal Strength Indicators (RSSI) in -dBm and Signal Noise Ratio (SNR) in dB. RSSI has a value of -30 dBm, a strong signal category, while -120 dBm is a weak signal. As for SNR, it has a formula as shown in Equation 6. [24]–[28].

$$L(fs) = 32.45 + 20\log(D) + 20\log(f) \tag{1}$$

$$r = 8.657\ x\ sqrt\left(\frac{D}{f}\right) \tag{2}$$

$$H = \frac{1000\ x\ D^2}{8\ x\ R_{earth}} \tag{3}$$

$$r = 8.657\ x\ sqrt\ \left(\frac{0.65\ x\ D}{f}\right) \tag{4}$$

$$ERP = Tx\ Power\ (dBm) + Antenna\ Gain\ \ (dBi) - Cable\ Loss\ (dBm) \tag{5}$$

$$SNR\ (dB) = P_{received_{signal}}(dBm) - P_{noise}(dBm) \tag{6}$$

Moreover, in LoRa Transmission which is terrestrial, this research uses the formula about path loss for free-space path loss (FSPL) conditions as in Equation 1. this formula is used for signals that experience loss or attenuation. but only used in conditions without obstacles. the unit used is dB. In LoRa transmission that uses a long distance (km), it is necessary to consider the curvature distance of the earth, and we can use the radius in the first zone of the Fresnel zone as in Equation 2. where r is the radius, D is the distance between the transmitter and receiver in km, f is the frequency in GHz, and 8.657 is the constant of the Fresnel equation. Moreover, Equation 3 is the formula for the curvature of the earth, or the minimum height of an object, where h is the height of the object, D is the distance between the two points in Line of Sight conditions, R_earth is the radius of the earth about 6372 km, and 1000 is the conversion factor. while Equation 4 is the formula for modifying the radius of the first Fresnel zone with 0.65 being the 65% of the first Fresnel zone that must be free of obstructions to achieve the best signal. Equation 5 describes Effective Radiated Power or ERP for short, which is the power of an antenna in wireless communication with the calculation or consideration of the antenna gain value and cable losses. while Equation 6 is a formula for calculating the ratio of signal strength to noise measured in decibels (dB).

Furthermore, the type of signal used in LoRa Communication is using Chirp Spread Spectrum (CSS), this is the type of signal used in Radar technology, we also call it Frequency Shift Keying (FSK) Modulation. There are two types in this CSS, Up-Chirp, and Down-Chirp, Up-chirp if the frequency goes up, and Down-Chirp if the frequency goes down as well as a Whale that detects a sound or an approaching object, we also call it the Doppler effect, the same as when we hear the sound of an Ambulance, or a Bat that detects an object. We can see an illustration of this CSS in the following image. Moreover, LoRa is a technology that is used for the needs of transmitting low Data-Rate data and its ability to be long distance so it is very appropriate for disaster or areas with damaged infrastructure. And only uses a 5-9 Volt DC battery to handle the End-Node so that it can send data as far as possible. LoRa has a maximum transmission power of 25 mW (depending on LoRa types). In full LoRa can be compared as in **Table 1**. The advantages compared to WLAN and Cellular are in terms of Power Consumption or Power Transmission, range, and Price. LoRa does not require complex infrastructure development, LoRa can be built with existing frequencies determined, for example in Indonesia is 915-920 MHz. It does not require building expensive infrastructure like cellular, The Chirp Signal of LoRa can be seen in **Figure 1** [29]–[33].

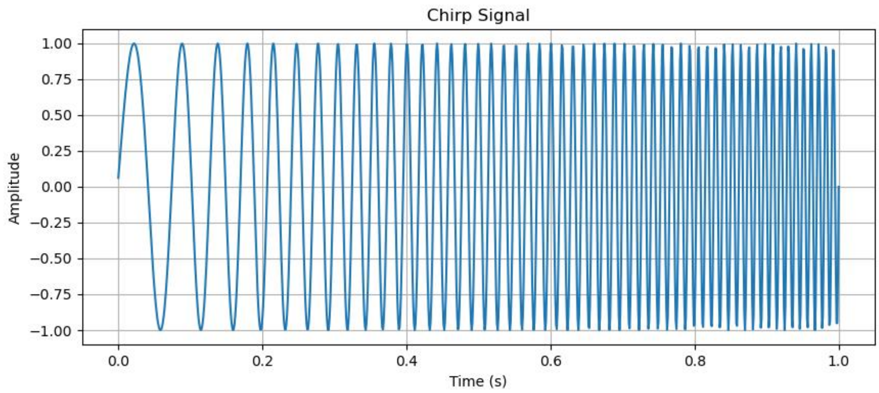

Figure 1. Chirp Signal of LoRa.

Furthermore, **Table 1** is a comparison between LoRa and other Wireless Technologies, WLAN and Cellular, it can be seen that LoRa is superior in range and cost, but weak in data rate. So the placement and use of wireless technology needs to look at many elements including the type of use and benefits. Moreover, there is a type of LoRa that is used to function as a Tranceiver, namely SX1261 which has Frequency Shift Keying (FSK) and LoRa Modulation modulation types. Comprehensively can be seen in **Table 2**. The development of the SX1261 is the SX1262 LoRa chip as shown in **Figure 2**.

Table 1. Comparison of LoRa with other Wireless Technology

Wireless Technology | Parameter	WLAN	LoRa	Cellular
Range	<100 meter	2000-3000 meters (city) >10000 (country)	<300 meter (city) <10000 meter (country)
Maximum Data Rate	6933 Mbit/s	50 kbit/s	1000 Mbit/s
Costs	Medium	Low	Very High
LoRa Frequency	2.4 GHz 5 GHz 60 GHz	433 MHz 868 MHz 915 MHz 920 MHz	800 MHz 900 MHz 1800 MHz 2100 MHz 2600 MHz
Maximum transmission Power	1000 mW	25 mW	20-50 w (Base station) 200 Mw (Terminal devices)

Table 2. Different of Frequency Shift Keying (FSK) & LoRa Modulation

Tranceiver	Modulation	Maximum Sensitivity according to be datasheet	Data rate	RX-bandwidth
CC1020	FSK	-118 dBm	2.4 kBit/s	12.5 kHz
CC1101	FSK	-116 dBm	0.6 kBit/s	58 kHz
SX1261	FSK	-125 dBm	0.6 kBit/s	4 kHz
SX1261	LoRa	-149.2 dBm	0.02 kBit/s	8 kHz

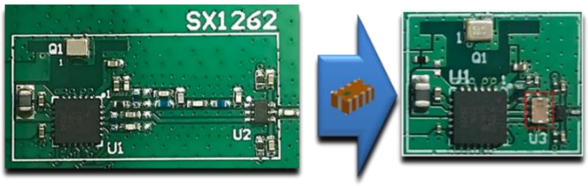

Figure 2. SX1262 chip LoRa (*Sources*: johansontechnology.com)

$$S = -174 + 10log_{10}BW + NF + SNR \quad (7)$$

The Sensitivity (S) value is obtained as in Equation 7, where, the S value is determined from the Signal of Noise Ratio (SNR), and Noise Figure (NF), the value of NF is 6 Db to 10 Db, for Code Rate (CR) values are 4/5, 2/3, 4/7, and ½. The next parameter that is no less important is the LoRa Link Budget. With the formula as in Equation 8. If it has to do with the Sensitivity value, then the Link Budget (dBm) value is added to the Sensitivity as shown in Equation 9.

$$P_{RX}(dBm) = P_{TX}(dBm) + G_{SYSTEM}(dB) - L_{SYSTEM}(dB) - L_{CHANNEL}(dB) - M(dB) \quad (8)$$

$$P_{RX}(dBm) = P_{TX}(dBm) + S(dBm) \quad (9)$$

Where for LoRa Budget Link this is a Power value on the LoRa receiver side, which is the same as Receiver Power this is obtained from the summation of Transmitter Power with Gain at the transmitter, minus losses such as Feed-lines, etc. Moreover, **Table 3** shows the significant difference between the data rate generated by several LoRa Chip modes such as CC1020, CC1101, and SX11261 with FSK Modulation and LoRa Modulation. Another important parameter to know is Time on Air (ToA), ToA is used to determine the time it takes for the signal to flow in the air from Tx to Rx. The greater the ToA, it is possible that the Spreading Factor (SF) is large or the distance between Tx and Rx is too far, and one of the parameter results is that the value of the Bit-Rate is too small (bps). Comprehensively, ToA is expressed in Equation 10, Equation 11, Equation 12, Equation 13, and Equation 14.

$$T_{Preamble} = (n_{Preamble} + 4.25) * TSym \quad (10)$$

$$PayloadSymbNb = 8 + \max\left(Ceil\left(\frac{8PL - 4SF + 28 + 16 - 20H}{4(SF - 2DE)}\right)(CR + 4), 0\right) \quad (11)$$

$$T_{Payload} = payloadSymbNb * Tsym \quad (12)$$

$$T_{Packet} = T_{Preamble} + T_{Payload} \quad (13)$$

$$T_{Sym} = \frac{2^{SF}}{BW} \quad (14)$$

Table 3. Different Sensitivity Data-rate of LoRa Chip

Data-rate | Modulation	CC1020	CC1101	SX1261	SX1261
	FSK	***FSK dBm***	***FSK***	***LoRa***
1.2 kBit/s	-117 dBm	-112 dBm	-123 dBm	-129 dBm
2.4 kBit/s	-117 dBm	-111 dBm	-121 dBm	-126 dBm
4.8 kBit/s	-114 dBm	-109 dBm	-118 dBm	-123 dBm
9.6 kBit/s	-112 dBm	-107 dBm	-116 dBm	-120 dBm

Furthermore, Several methods can be written in this article, including how the process of transmitting data, Uplink and Downlink, and other parameters that are important in the process of analyzing this data. Details can be seen in the following flowchart. The important thing that needs to be created is the sensor node and needs to be known in detail. After determining the sensor node creation, the next step is to determine the communication mode, whether Point-to-point or Multi-point communication. The next step is to determine whether the communication mode is Line of Sight (LoS) or Non Line of Sight (NLoS). If the output on the serial monitor or monitor on the LoRa Receiver has been able to be seen properly, then certainly the analysis can be continued by changing several test points, then the RSSI (-dBm) and SNR (Db) values are obtained. As for the Spectrum Analyzer, it can be used to determine the type of signal produced, such as FSK, or Chirp Spread Spectrum (CSS) LoRa. Furthermore, a Block Diagram in detail can be shown in the following Block Diagram for LoRa Communication, the big picture is how End Devices in this case the LoRa End Node that has been built can be sent to the Gateway and can be indicated by the Uplink value. There are two types that I can introduce, Uplink data LoRaWAN Communication [34]–[36] which can also be made Multi-Communication or Point-to-point communication, between End-Devices communicating with each other on transmissions or signals that are free in the air which most likely the signal will encounter problems causing Attenuation, Reflection, Diffraction, and Scattering Signal. Moreover, On the Network Server side, there will be a LoRaWAN communication system that can be analyzed from the type of Downlink data, whether class A, class B, or Class C, Class A stands for All [37]–[39], where the transmission process is carried out by Tx to Rx based on the request from Rx if it is needed to be sent by Tx, then it can be sent, and vice versa, this type of Class A is often used for the development of LoRa-based IoT today [36], while Class B stands for Beacon, meaning that there are additional receiver slots in this form of setting, while Class C is Continues, here the Downlink process is carried out continuously, the factor that will occur is High Power Consumption on the Server side. Moreover, Data that can be received from the Network server from this series of downlink preparation processes will enter end devices such as Smartphones and other devices with Interface Device Technology and Internet Connection for sure. Moreover, LoRa data transmission is also influenced by the Budget Link Factor, as well as the Antenna, the greater the Gain owned by the Antenna to be able to transmit data, the further the possibility of large data that can be transmitted. So it is necessary to make the antenna radiation pattern, and there is a need for learning to simulate the S11 and S21 antenna designs.

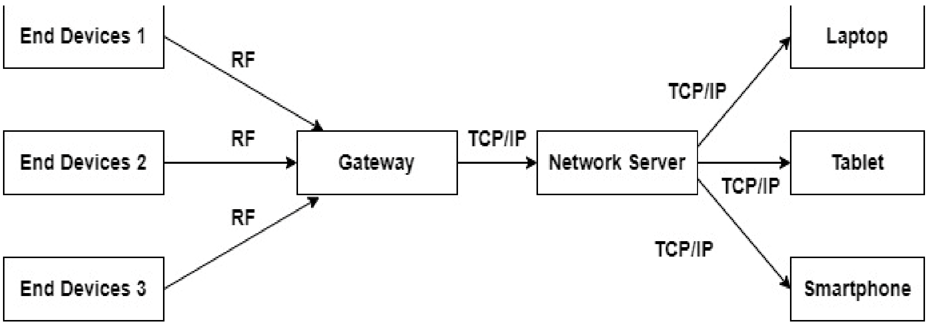

Figure 3. Block Diagram for LoRaWAN Communication

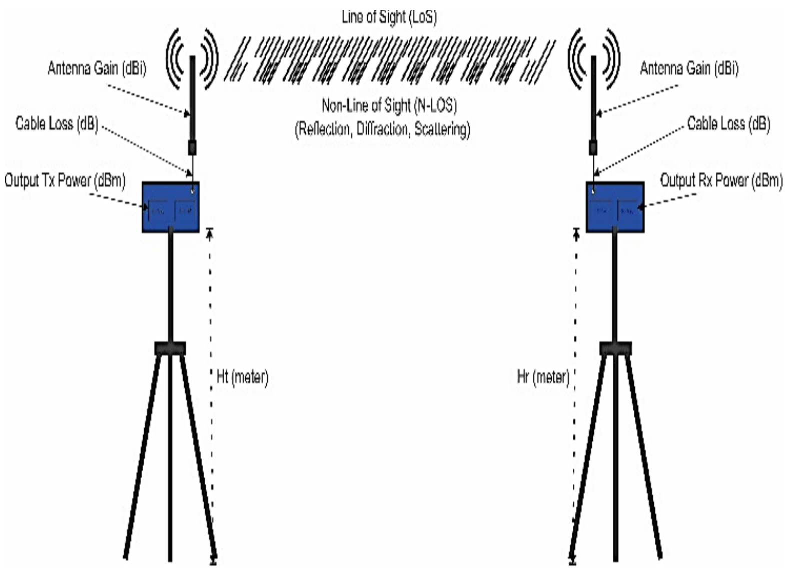

Figure 4. Data Transmission Method using LoRa RFM96 Module Point-to-point use of RSSI data (-dBm)

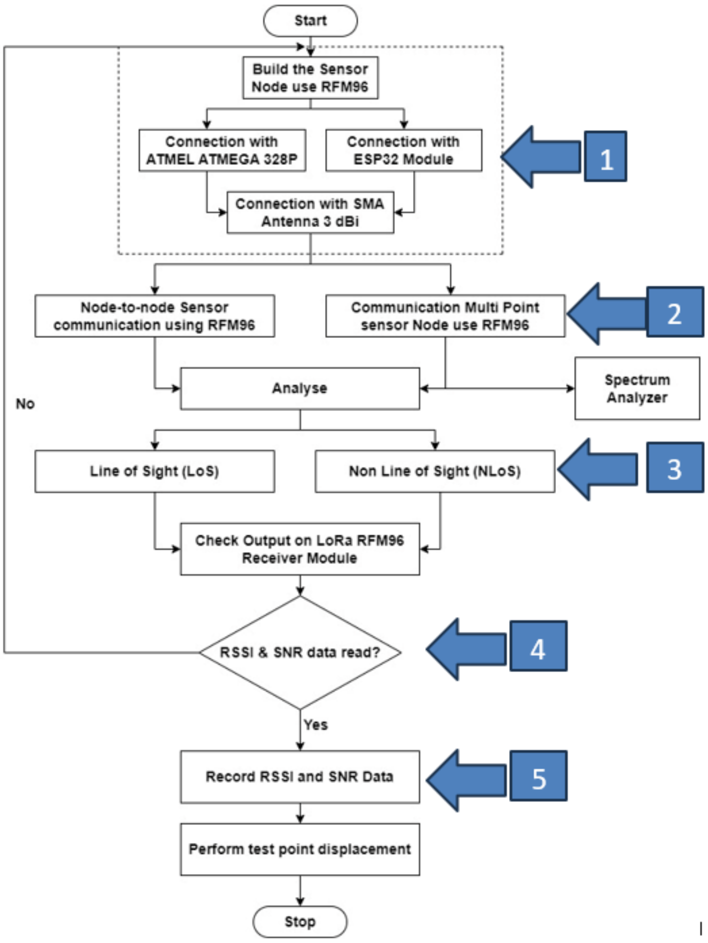

Figure 5. Flowchart of the system used in this research

In **Figure 4** or system flowchart, hardware setup is shown in number 1, while the telecommunication system or QoS [40] is shown in number 2, simulation software is also developed in number 2 where the simulation approach can also use OMNET++ for example, and the use of Arduino IDE and Telkom IoT server can be in number 2 and 4, testing scenarios can be done starting from number 3 and the results in number 4 and 5.

Result and Discussion

In this session, more about the results of the analysis of the End-Node built, LoRa RFM96 combined with ESP32 LoRa with SMA Antenna to build a sensor Node that can send sensor data from one place to another at different distances. The data generated is RSSI data and SNR data. Furthermore, it is necessary to use a casing to protect some important components and add a tripod for the Tx-Rx data transmitting process. In the testing process, LoRa can use a simulation approach, namely using Flora simulation. In this simulation process, all parameters used for the real data-transmitting process can be used. The simulation process can use all the parameters used for Flora simulation. Starting from data rate, Bandwidth, chip rate or coding rate, Spreading Factor, etc. The way to compare in real time is to use a comparison table by looking at the same parameters. From the comparison process, conclusions can be drawn or drawn about the error (%) that exists. The additional analysis is how to determine the distance of the Gateway to the end node this also determines how the Quality of Service (QoS) of LoRaWAN Communication is built. Furthermore, by using LoRa simulation, it is possible to replace real-time LoRa Communication in terms of Hardware availability or Hardware requirements of LoRa, Antenna, and Gateway. In the next figure, data transmission can be seen using a red line or red dotted line that shows the data transmission process from the LoRa End-Node to the LoRa Gateway or Another LoRa End-Node or LoRA Receiver. From this simulation process, specific data will be obtained about the Quality of Service of the LoRa or LoRaWAN Communication built.

Figure 6. LoRa RFM96 Node and it's testing in NLoS Area or building area

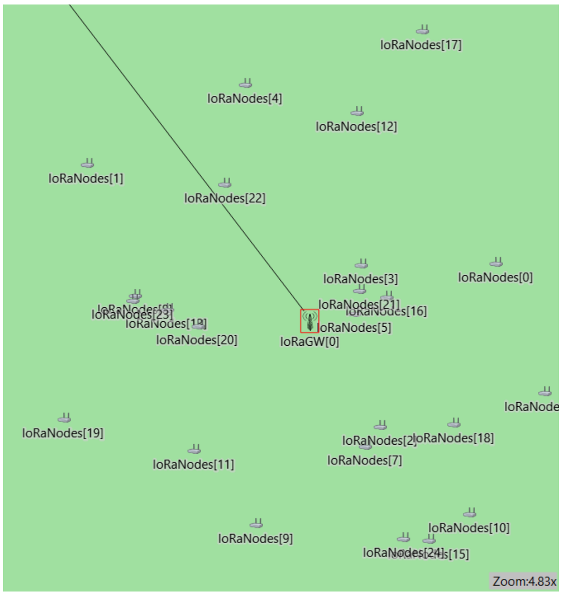

Figure 7. LoRa RFM96 Node in Flora Simulation software

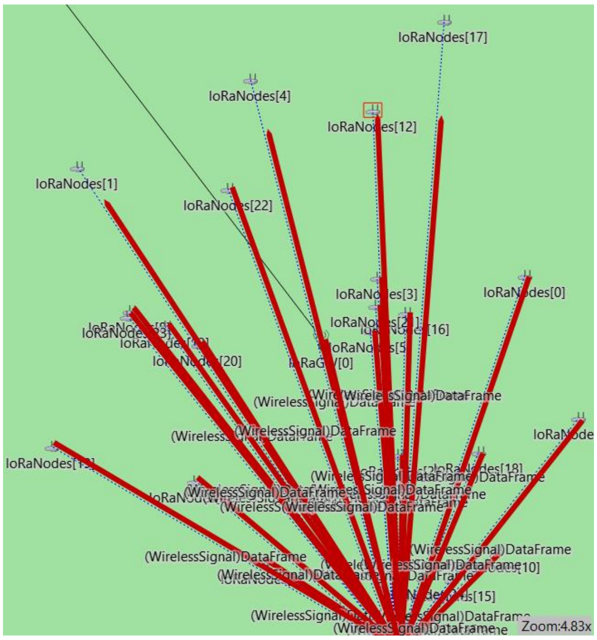

Figure 8. LoRa RFM96 Node in Flora Simulation software running or transmitting the data

Furthermore, From the results of the analysis or data transmission based on the number of Nodes or End-Nodes transmitted to the Gateway or Internet server, data in the form of Bits/s is obtained which shows the data quality of the LoRa Communication built. The greater the Throughput or the smaller the Packet Loss (%) generated or shown on the graph, it shows the quality of the successfully transmitted data. The blue color shows bits/sec on received data, while the orange color shows bits/sec on sent data. The thing that causes Packet Loss (%) is that it is in real communication built from testing in NLOS, in urban areas or forest areas that have many obstacles in the form of buildings, and trees. One solution is to elevate the position of the transmitter and receiver. To be able to avoid packet loss of data or signal attenuation.

The results of LoRaWAN Simulation are different from real LoRa transmission data in the field using complete End-Node hardware, this is because the simulation does not take into account several factors such as the percentage of causes of Attenuation, for example, Diffraction, reflection, and Scattering. Moreover, for the Telkom IoT console, you can visit the website from the console. Telkomiot. Id, what needs to be done is a registration and at least use email, phone number, and devices compatible with Telkom IoT, for example, using the RFM96 LoRa module registered to the IoT console such as API Number, so that it can be registered with Telkom IoT. Next is to enter the Dashboard which consists of several menus such as Overview, Dashboard Report, Personal Dashboard, Applications, Access Key, Event Trigger, API Integration, and Documentation. Furthermore, after the LoRa Device registration process, continued with coding using Arduino IDE or C++ Code which is used for the Library installation process and also for Application Programming Interface (API) registration. The following figure is real-time data from LoRa Communication using Telkom IoT and LoRa rfm96 code which is shown with real-time data such as Counter, data, dev EUI, Port, radio, and so on.

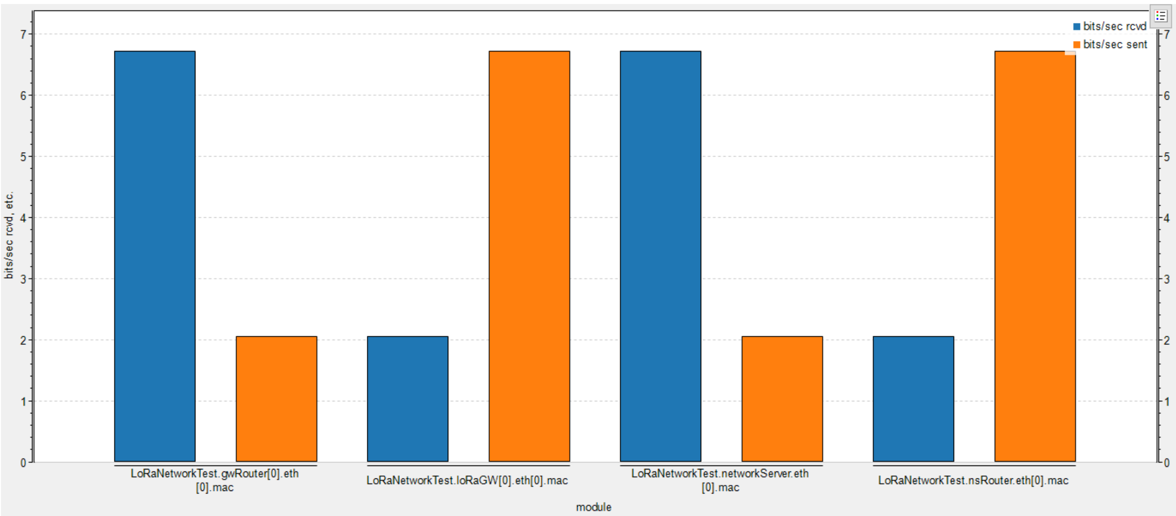

Figure 9. Data bits/s from LoRa simulation sent and received

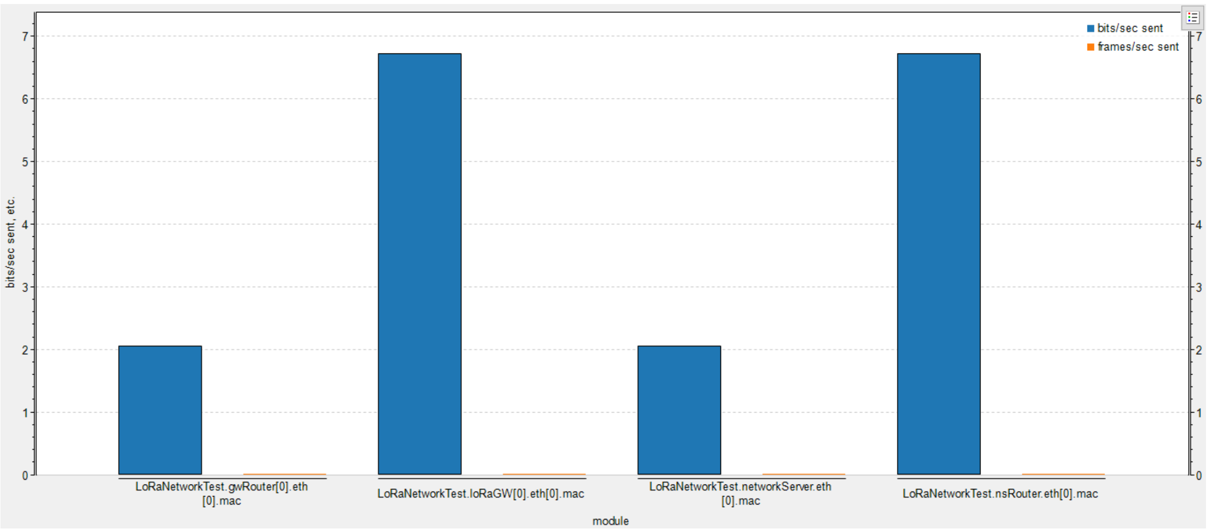

Figure 10. Data bits/s from LoRa simulation sent and Frame/s data

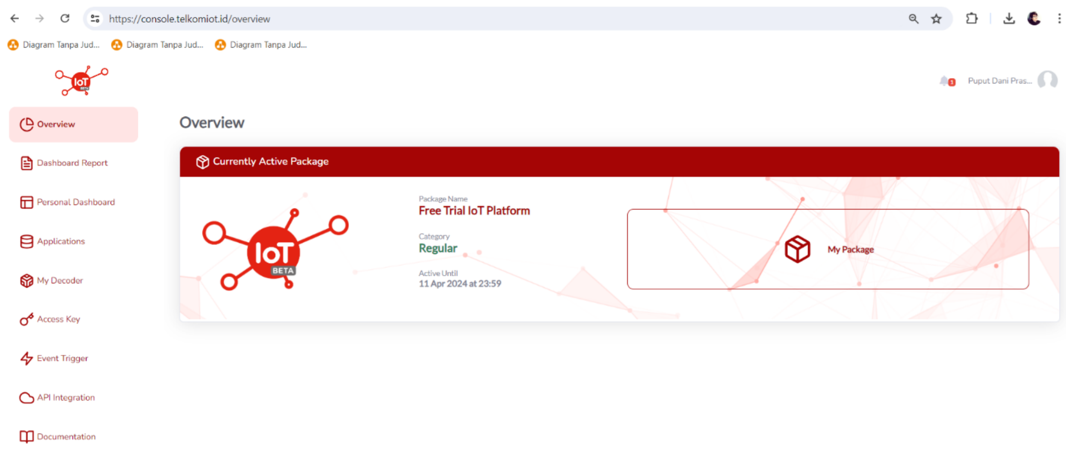

Figure 11. Console or Dashboard of Telkom IoT

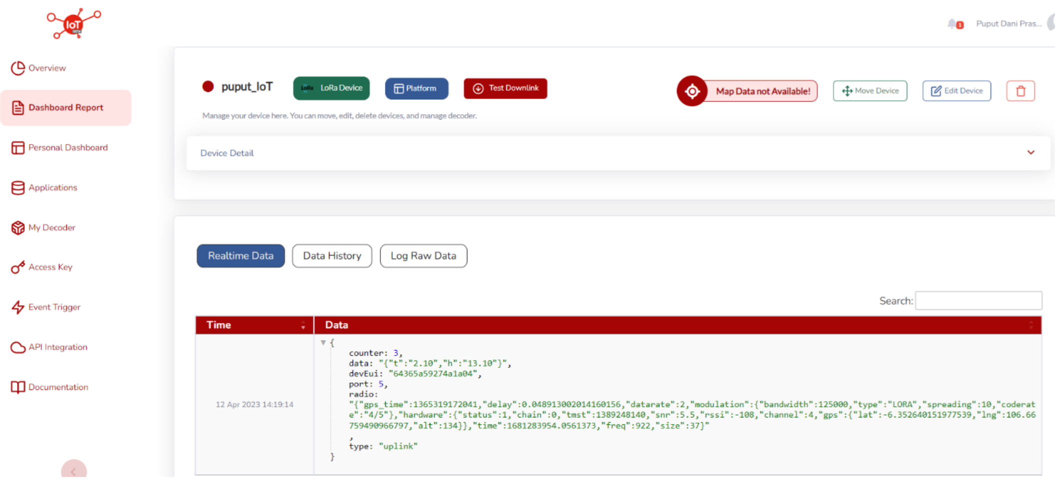

Figure 12. Realtime Data from LoRa Communication on Telkom IoT

Data that can be collected from the Telkom IoT Server is data from the position or GPS, Delay, data rate, modulation type, Bandwidth, Spreading Factor, Frequency, and Size of Data (bytes) sent. And each of these points produces different values in RSSI and SNR, and LoRa provides different values based on the conditions of the test area, because of the NLOS Area, the signal results are not so good in full urban conditions due to diffraction, reflection, and scattering signals. And the QoS parameter is shown from the Budget Link or Prx value of LoRa Communication. In addition to RSSI and SNR, the concern is Time on Air as shown in Equations 10, 11, 12, 13, and 14.

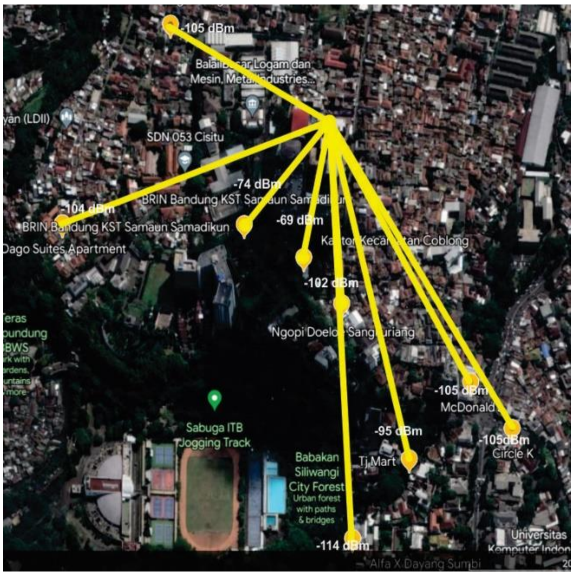

Figure 13. Realtime aiming at multiple points in NLOS

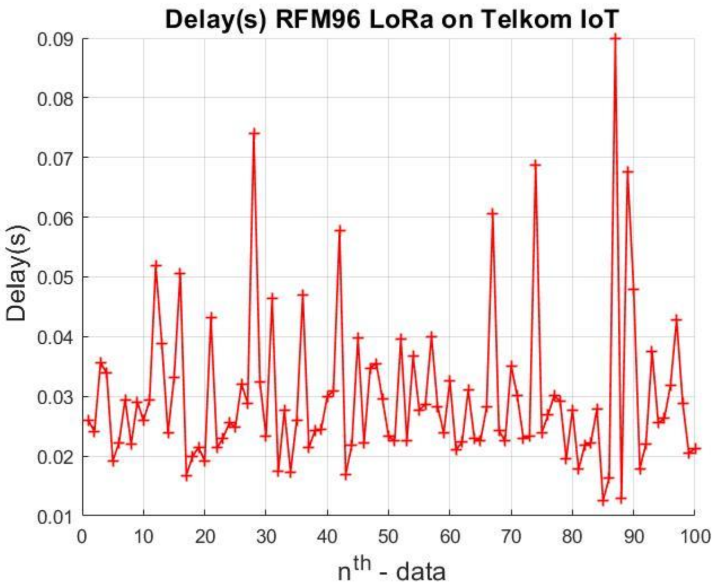

Figure 14. Delay (second) RFM96 LoRa on Telkom IoT

Delay in **Figure 14** is one of the essential parameters to show the Quality of Services (QoS) of LoRaWAN. Delay (ms) is also called latency, which is a disadvantage if the value is large, delay takes place when transmitting data from LoRa end-nodes to the Gateway, in this case the server application used is using Telkom-IoT. In the data transmission experiment in **Figure 14**, the value obtained in ms is in the range of 0.01 seconds or 10 ms to 90 ms. In the experiment the average range is in the range of 20 ms to 30 ms or 0.02 - 0.03 seconds. This is still considered a normal speed, not too much delay occurs. But if it can go down to 10 ms on average it will be better. By using certain algorithms applied to data transmission, especially multiple nodes, the LoRaWAN communication network can be well organized to produce a small delay. Delay is affected by the following LoRa parameters: Spreading Factor (SF), Bandwidth, Payload, Interference and Network Density, Duty Cycle, Reception Time, and Tx-Rx Distance. **Figure 14** is the pure delay (ms) from the results of this research and is obtained from direct experiments using Telkom IoT, not simulation results.

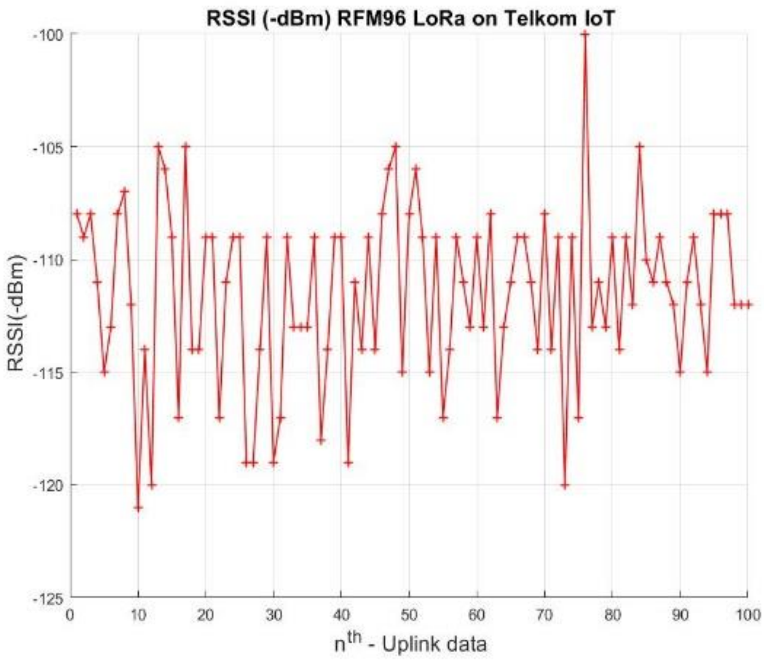

Figure 15. RSSI (-dBm) RFM96 LoRa on Telkom IoT

From the analysis results, the Delay (ms) generated from measurements using RFM96 LoRa for IoT is around 0.02 seconds or 20 ms to around 0.05 seconds or 50 ms, and sometimes it can reach 0.07 ms to 0.09 ms. This depends on the internet network connection at that time. If the internet network is good, the communication system can certainly be smoother and reduce or even eliminate delay or latency. RSSI and SNR show the quality of the signal obtained which will provide a Quality of Service (QoS) value. From the measurement results using Telkom IoT in several times of data collection and testing, the average RSSI (-dBm) is at -110 dBm to -115 dBm. While SNR is at -10 dB to -16 dB. as explained earlier that RSSI is an important indicator in measuring the signal strength received by the receiving device. expressed in dBm (decible-milliwatts). RSSI value is negative, which indicates a weak or strong signal on the LoRa module. In **Figure 15**, the signal strength of LoRa to the Gateway is around -110 dBm and -115 dBm on average at this strength is actually said to be weak, and it is necessary to strengthen the system or increase the antenna gain or antenna position on LoRa, for example -60 dBm is a good achievement in RSSI, let alone -45 dBm, but above -100 dBm it is said that this condition is still weak signal.

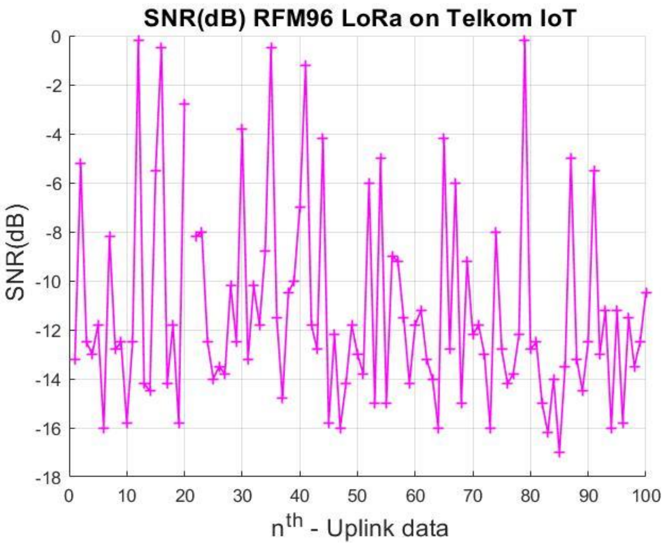

Figure 16. SNR (dB) RFM96 LoRa on Telkom IoT

As shown in Equation 6, SNR is the ratio of signal strength compared to the accompanying noise. The SNR value is -10 dB to +30 dB, if SNR >10 dB then it is said that the signal is stronger than the noise generated but if it is between 0 dB-10 dB, it means that data errors are still possible. In addition, SNR < 0 dB, this indicates that the noise is superior to the signal itself, the result is difficulty in detecting the signal. The experiment shows that the SNR value is around SNR < 0 Db. LoRa can demodulate signals that are -7.5 dB to -20 dB below the noise floor.

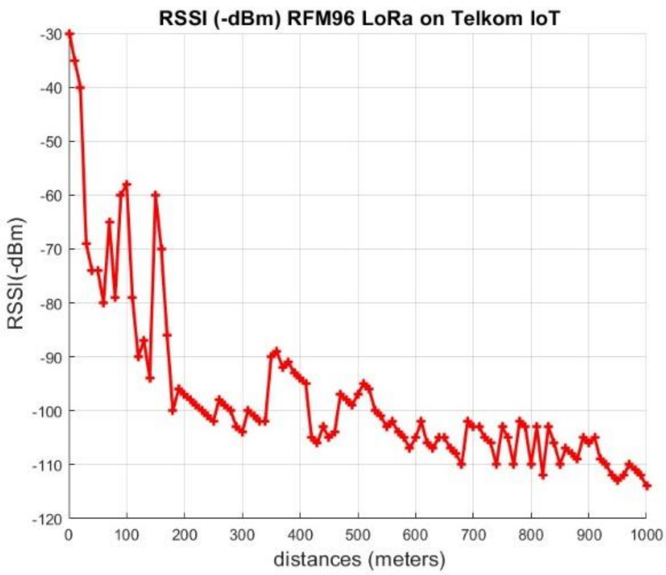

Figure 17. RSSI (-dBm) of RFM96 LoRa on Telkom IoT

Furthermore, in **Figure 17**, The RSSI shown continues to experience signal attenuation (-dBm), this is due to the attenuation signal caused by obstruction, reflection, scattering, and diffraction signals. so it is very important to adjust the Tx and Rx antennas. then influenced by the inverse square law where the signal decreases proportional to the square of the distance. the use of SF, antenna placement, and antenna optimization are ways to optimize the performance of this LoRa transmission through the RSSI indicator. The RSSI is shown at -30 dBm at a distance of 1 km to about -115 dBm at a distance of 1 km.

Figure 18 is one of the optimization steps, namely measuring with LoRa outdoor transmission by 5-8 dB to get better RSSI results at a long distance, to avoid data errors or packet loss. While the RSSI (-dBm) value is taken from the field directly, this depends on the distance (meters or Km), if the farther away, the weaker the signal or the value of RSSI (-dBm) is getting weaker, from **Figure 17**, it is obtained that the RSSI value starting at 1 meter is -30 dBm, up to a distance of 1 km, has an RSSI (-dBm) value of -115 dBm. Moreover, From the measurement results in **Figure 17** about RSSI of RFM96 LoRa Telkom IoT, it is then compared with the approach to the Antenna in indoor and outdoor positions of 3 dBi, but with a larger dBi value, it is possible to extend the position or process of transmitting Low Bit-rate data using the LoRa module.The comparison of simulation and practical results is very different, the difference can be seen in **Figure 19** where blue is the real result and red, pink and green are simulations. The results of the simulation are always smooth and there is no impact of obstruction from buildings, and other obstructions on terrestrial communication.

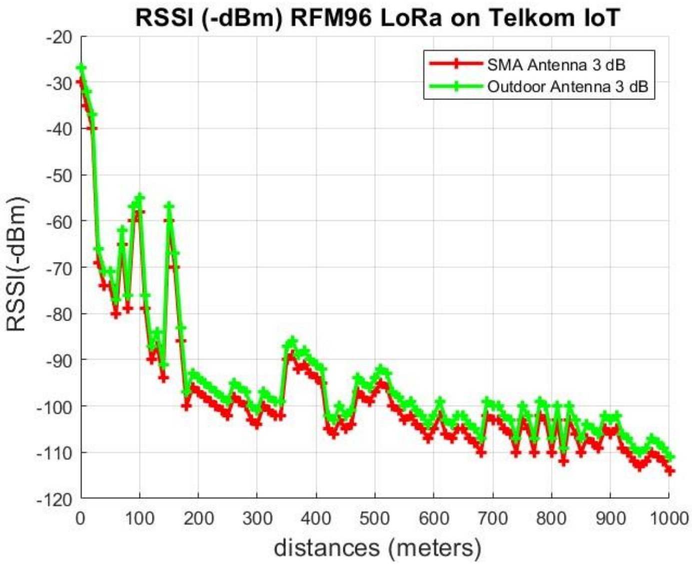

Figure 18. RSSI (-dBm) of RFM96 LoRa on Telkom IoT with comparison Antenna indoor and Outdoor 3 dBi

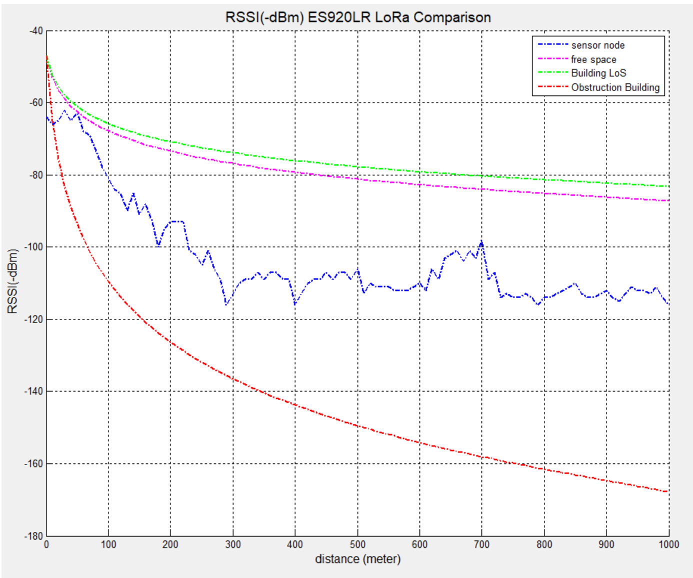

Figure 19. simulation and practice comparison

Conclusion

From the analysis, several Quality of Service values of RFM96 LoRa IoT on the Telkom IoT Application Server were obtained. Some of the analysis is as follows, the Delay (ms) generated from measurements using RFM96 LoRa for IoT is around 0.02 seconds or 20 ms to around 0.05 seconds or 50 ms, and sometimes it can reach 0.07 ms to 0.09 ms. This depends on the internet network connection at that time. If the internet network is good, the communication system can certainly be smoother and reduce or even eliminate delay or latency. RSSI and SNR show the quality of the signal obtained which will provide a Quality of Service (QoS) value. From the measurement results using Telkom IoT in several times of data collection and testing, the average RSSI (-dBm) is at -110 dBm to -115 dBm. While SNR is at -10 dB to -16 dB. The results of this analysis are not significant, but it is estimated that the results are close to the results in this research, depending on the internet connection used. The results of simulations using OMNET, fLORA, and other software are an approach to the number of nodes that can be connected in simulation, with an approach to the parameters used in LoRa such as Bandwidth, Spreading Factor, Coding Rate, and other related parameters.

Future research is shown in **Figure 20**, where to avoid signal attenuation in terrestrial areas, a LoRaWAN communication system using satellites is needed, this has been done by Lacuna Space where they have used LPWAN satellites in Low Earth Orbit (LEO) which can be used for internet of things applications such as agriculture or monitoring animal movements.

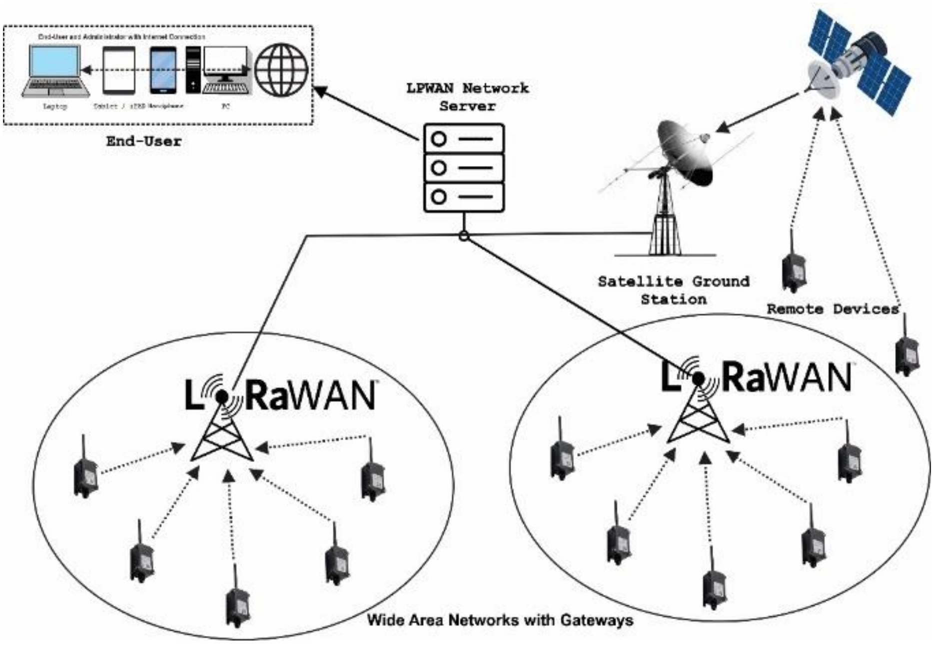

Figure 20. LoRaWAN Satellite based

Acknowledgment

Thanks to the entire team from Makassar State University, Nobel Institute of Technology and Business, National Research and Innovation Agency, and various parties, as well as the laboratory at BRIN who helped in the analysis process. Hopefully, this research can be utilized by various parties so that it can be a good reference and become a reference for researchers and all circles. Hopefully, this research can be used and developed to the fullest.

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