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LoRa Communication in the Service Level Monitoring Satu Duit Bogor Bridge

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A B S T R A C T

Lora is a solution to the problem of the need for long-distance two-way communication between machines that are targeted by IoT (Internet of Things). LoRa has the ability to transmit over long distances, power, and low bit rates. Based on the needs related to LoRa, further research is needed to analyze the performance of LoRa communication. The LoRa communication protocol will be applied to the Satu Duit Bogor bridge monitoring system using the website and LabVIEW. This study uses LoRa SX1276 with a frequency of 915MHz with LoRa point-to-point and LoRa gateway methods. Parameters analyzed include RSSI (Received Signal Strength Indicator), SNR (Signal Noise Ratio), Delay, Throughput, and Packet loss to determine the quality of LoRa performance with the TIPHON standard. Based on the tests that have been carried out, prove that LoRa communication has good performance. In urban areas or around the Satu Duit Bogor bridge, LoRa can transmit data from a distance of 0 to 500 m with an average delay of 217 ms, an average packet loss of 10.237%, an average throughput of 137.881 bps, an average SNR of 7.54 dB, and the average RSSI is -71,798 dBm. At a distance of 0-400 m, there is an insignificant change in the LoRa parameter, but at a distance of 500 m there is a high change, this is because distance greatly affects data transmission. The farther the range, the more obstacles will be passed so that data transmission is disrupted.

INTRODUCTION

Bridges are indispensable infrastructure in every area that serves as a link between two roads or areas that are cut off by valleys, rivers, fire lanes, and highways. According to the PUPR Ministry's website data, there are 18,916 national bridges in Indonesia until 2020, of which there are 903 bridges in West Java with a length of 26,508.13 meters [1]. The Satu Duit Bridge is one of the bridges in West Java that provides access to the city of Bogor to connect Warung Jambu and Jalan Ahmad Yani roads. This bridge was built in the 1850s over the Ciliwung River and has a high traffic volume so that it has received repeated loading of more than 100,000 times [2]. Repeated loading that occurs can cause the level of service on the bridge to decrease due to fatigue damage and can cause the collapse of the bridge building.

SHMS (Structural Health Monitoring System) is an effort to minimize the possibility of the bridge collapse. SHMS is a technology-based structural monitoring system consisting of various sensors to collect building and bridge component data. The SHMS aims to monitor the performance and service levels of structures under various loads by measuring load frequency, deflection, and stress. The accumulation of these parameters can cause bridge deformation [3]. SHMS can extend the life of a building by detecting a decrease in performance and early warning damage so that it can reduce the cost of building rehabilitation [4].

The Surabaya-Madura Bridge has implemented a Structural Health Monitoring System (SHMS) system in the bridge monitoring process using various types of sensors in real-time connected via cable media [5]. Research on bridge condition monitoring systems has been carried out using dynamic responses with Wireless Sensor Networks via the internet or WiFi communication [6]. Other research has also produced an Android-based bridge monitoring system using the internet or WiFi communication media [7]. This research has disadvantages in wired or WiFi communication media because it has a limited communication range. Technically WiFi network can reach up to 46 meters (indoors) and 92 meters (outdoors) with high power consumption.

The obstacle to implementing wireless sensor network technology in IoT or the Internet of Things is the need for remote two-way communication from the machine that is the target of IoT. Currently, there is the latest IoT technology that provides solutions to the above problems, namely the LoRaWAN (Long Range Wide Area Network) protocol which was released in 2015.

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LoRaWAN is a type of network for wireless communication areas designed for long distance communication with bitrates [8].

Based on the needs and opportunities for research related to LoRa, further research is needed, so the authors will conduct research by simulating data transmission through this LoRa technology. The author uses predetermined test parameters to analyze the performance of the LoRa implemented at the Satu Duit Bridge. The title of the research is "Implementation of the LoRa Communication Protocol on the Bogor Satu Duit Bridge Monitoring System". Data transmission is carried out point-to-point from the ESP32 microcontroller with LoRa Transmitter to the ESP32 microcontroller with LoRa Receiver, after which the data is sent serially to the Raspberry Pi 3B to be processed into an FFT (Fast Fourier Transform) value. The data is then sent in real-time to the Antares platform as a cloud server and website database in numerical form.

METHOD

Planning and Design Tools

The planning and design of the system created is the development of the previous system. In the previous system, the wireless sensor network-based bridge monitoring system still uses the internet as a communication or data transmission medium, which causes the data transmission distance to be limited and internet costs to be more expensive. In the system to be created, development is carried out using the LoRa (Long Range) wireless communication protocol to transmit data from sensors and stored on the Antares IoT platform as a cloud server which will be monitored through the website, so that data transmission can reach long distances (0- 15KM) at low cost to make the system more efficient and practical.

LoRa is a Low Power Wide Area Network (LPWAN) communication system with low power and low bit-rate long-distance transmission capabilities. LoRa was developed by IBM, Semtech, and Actility which are members of the LoRa Alliance. LoRaWAN is a standard protocol developed by the LoRa Alliance for LoRa communication technology. The LoRaWAN protocol which is remote, cost-effective, energy-efficient, high scalability, and has QoS (Quality of service) has fulfilled the objectives of LPWAN [9]. While LoRaWAN is a communication protocol whereas LoRa is the physical layer used in LoRaWAN. Based on the OSI layer, LoRaWAN links communications from the physical layer to the network layer. LoRaWAN is a telecommunications standard that enables data transmission at low data rates, long distances, and low energy consumption. [13].

Figure 1 is a block diagram of the system as a whole, while Figure 2 is a block diagram of a sub-system consisting of three block units, namely input, process and output blocks:

1) The input block consists of an AKF 394B sensor to detect bridge vibrations that produce output in the form of X, Y, Z axis acceleration values.
2) The process block consists of ESP32 which is integrated with LoRa SX1276 (transmitter) and ESP32 which is integrated with LoRa SX1276 (receiver) which functions to send and receive data from AKF 394B sensor readings using LoRa communication with the point-to-point method. There is a Raspberry Pi 3B which functions as a data processor to accelerate the X, Y, and Z axes on the AKF 394B sensor to become FFT (Fast Fourier Transform) values using the Python programming language. Raspberry Pi 3B also functions as a LoRaWAN gateway with an internet network (WiFi) as a sender of FFT data to the Antares server to be stored in a cloud database.
3) In the output block, there is an Antares server that functions as a storage place for FFT (Fast Fourier Transform) data from sensor readings sent by the Raspberry Pi3B via an internet connection or WiFi with a LoRaWAN gateway. The data that has been submitted will be stored in the Antares cloud database in a numeric form that can be connected to the web platform. How this sub-system works can be explained through the flowchart in Figure 3.

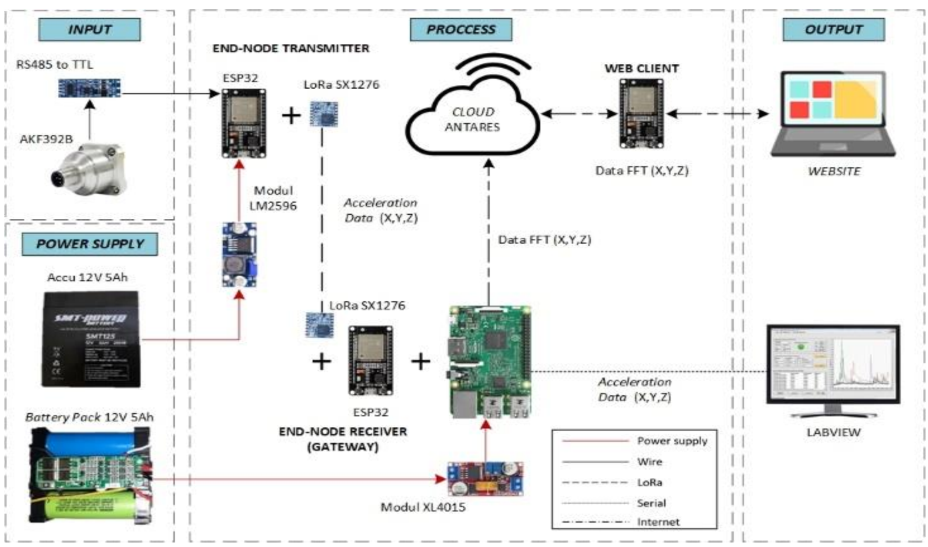

Figure 1. Block Diagram of Service Level Monitoring Satu Duit Bridge System

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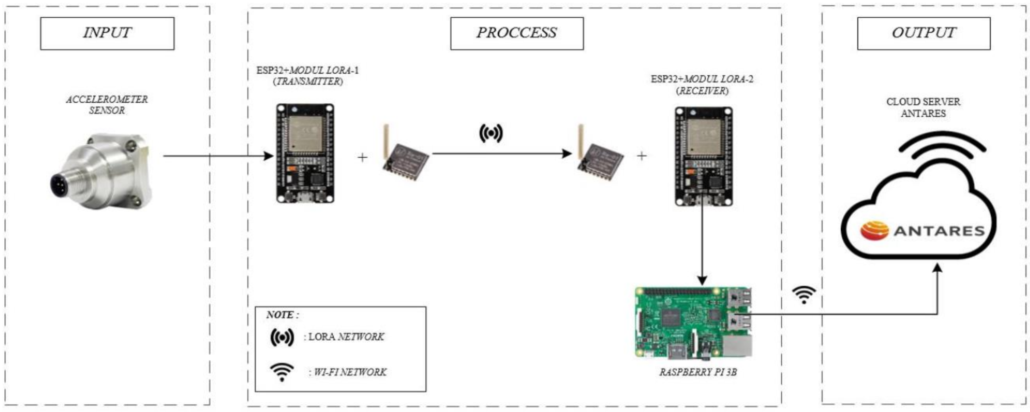

Figure 2. Block Diagram of Implementation of LoRa in Service Level Monitoring Satu Duit Bridge System

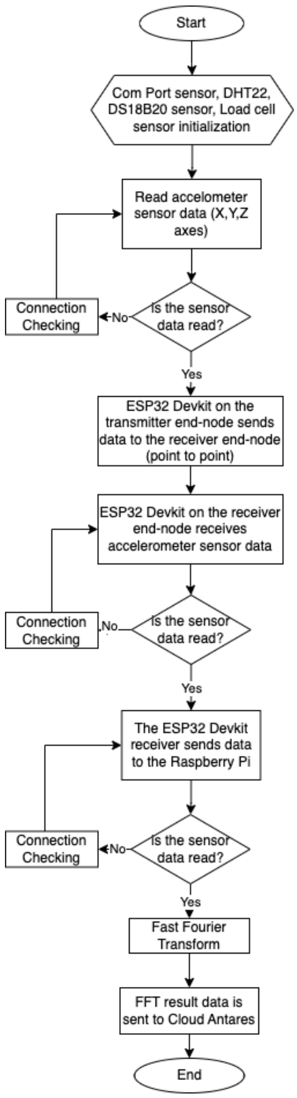

Figure 3. Parts of LoRa transmitter

Based on Figure 3, it can be explained how the sub-system works starting from initializing the AKF 394B sensor on the ESP32 microcontroller and connecting to LoRa communication (transmitter). After the ESP32 is connected to the LoRa (transmitter), the sensor will begin to read the vibrations of the X, Y, Z axis acceleration values on the Satu Duit Bogor bridge. If the data is not read by the sensor, it will be read again, whereas if the data is read, it will be sent to ESP32 as a receiver using LoRa receiver communication with the point-to-point method.

The data read on the ESP32 receiver will be analyzed according to the parameters of the LoRa test. The read data will also be sent to the Raspberry Pi 3B serially using the RX/TX pin to be processed into an FFT value. FFT data will be sent to the Antares server to be stored in the cloud database in numerical form.

From the explanation in Figure 3, the design of the LoRa transmitter and LoRa receiver can be illustrated in Figures 4 and 5. Figure 4 below is the actual design of the LoRa transmitter. Based on Figures 4 and 5 it is explained that each section has certain functions, which are as follows:

1. The AKF 394B sensor functions as a vibration sensor to detect vibrations on the Satu Duit Bogor bridge
2. ACCU 12 V serves as a current and voltage source for energy supply on the AKF 394B sensor with 12V input and a transmitter board with 5V input.
3. Rs485 to TTL converter serves Media interface between the sensor and the microcontroller as the output reader.
4. LM 2596 functions as a voltage lowering from 12V ACCU to 5V so that it can provide input voltage to ESP32 (transmitter).
5. LoRa SX1276 serves as a long-distance two-way wireless communication for sending data.
6. Electrical cable terminals function as cable connectors between components.
7. ESP32 functions as a sensor data reader and sends data to the receiver.
8. The antenna serves to strengthen the communication signal during the data transmission process.
9. Raspberry Pi 3B functions to convert acceleration data into FFT values.
10. The LM2576 module functions to reduce the voltage for the transmitter end-node.
11. The XL4015 module functions to step down the voltage for the receiving end node.
12. The battery pack is the primary power source for the receiving end node.

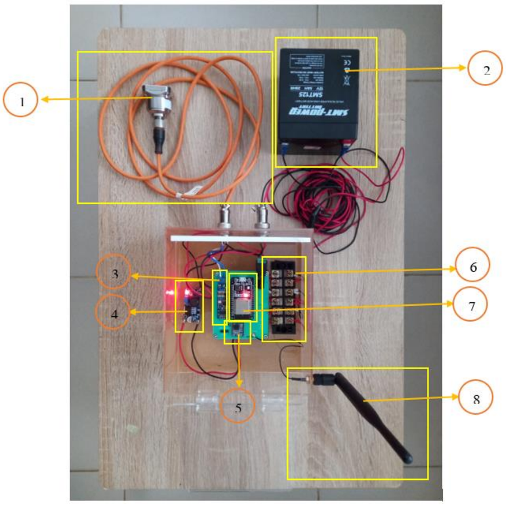

Figure 4. Parts of LoRa transmitter.

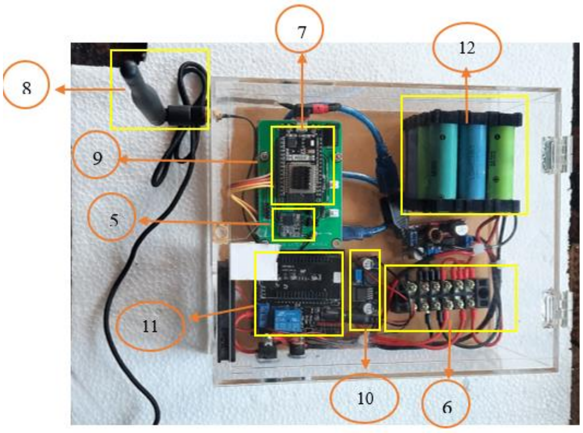

Figure 5. Parts of LoRa receiver

The following is a programming flowchart focused on reading sensor data, transmitting sensor data to the ESP32 receiver using point-to-point LoRa, and transmitting data to the Antares server.

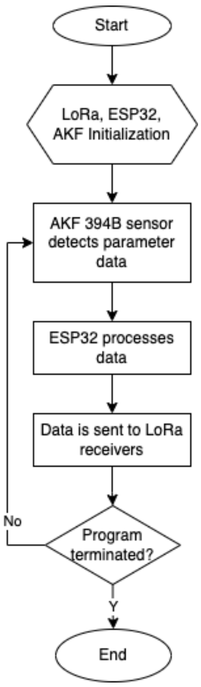

Figure 6. Flowchart LoRa transmitter

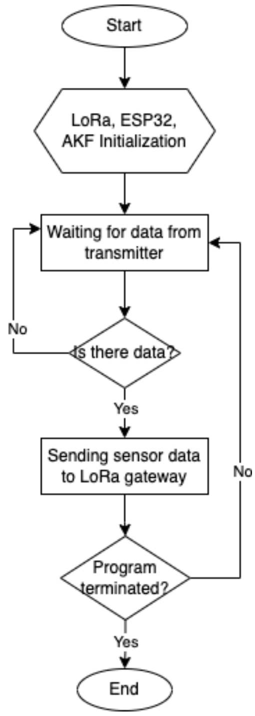

Figure 7. Flowchart LoRa receiver

Figure 6 is a flowchart of the microcontroller system on the LoRa transmitter. First, when the system starts up, initialization of the Lora, ESP32, and AKF394B sensors is performed. Then the process continues with the detection of sensor data based on the parameters carried out by the AKF394B sensor. Then the sensor data is read in the form of acceleration values X, Y, Z by the ESP32 microcontroller, after the sensor data is obtained, ESP32 will send this information via LoRa SX1276. This process will continue until the program is terminated.

Figure 7 is a flowchart of the microcontroller system on the LoRa receiver. First, when the system is started, LoRa is initialized, then LoRa will wait for data to be received. When data is not received, it will be reinitialized. When data is received, it will be sent to the Raspberry Pi 3B as a LoRa gateway and data processor. This process will repeat continuously until the program is stopped.

Figure 8 is a system flowchart at the LoRa gateway. First, when the system starts, Lora and Raspberry Pi 3B initialization is performed. Then it checks if the system is connected to the internet, if not it will check again. LoRa Gateway receives sensor data from LoRa Receivers. The data received will be checked package. If it is appropriate, then the data received will be processed into an FFT value and if it is not appropriate then the data will be received again. The LoRa Gateway sends FFT data to Antares and then displays the FFT data for monitoring.

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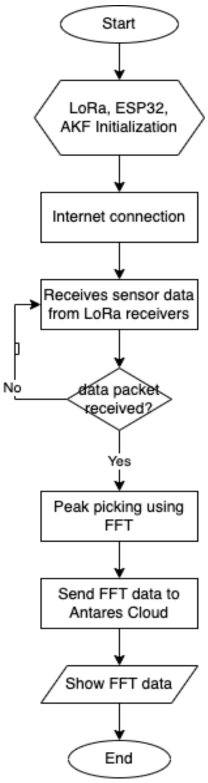

Figure 8. Flowchart LoRa gateway

RESULTS AND DISCUSSION

In this process, testing is carried out to determine the performance of the delivery system on LoRa point-to-point and gateway to the cloud server that has been designed. The LoRa coverage distance test was carried out at the Satu Duit Bogor Bridge with a distance of 100 meters to 500 meters. Data taken for each test is based on real-time travel times every 100 meters. The distance is determined using Google Maps from the midpoint of the Satu Duit Bogor bridge to a distance of 500 meters. The measurement data was obtained from the Arduino IDE serial monitor timestamp using two laptops to find out whether the system is running according to design. The test includes:

a. Testing RSSI (Received Signal Strength Indicator) on the line of sight (LOS)
b. SNR (Signal to Noise Ratio) testing on line of sight (LOS)
c. Quality of Service (QoS) testing on the line of sight (LOS)
d. Antares platform testing.

Figure 9. Observations of LoRa transmitters

Figure 9 is the result of documentation of observations of the installation of a LoRa transmitter on the bridge body. Meanwhile, Figure 10 is the result of observing the installation of LoRa receivers on the outside of the bridge.

Figure 10. Observation of LoRa receivers

The HMI display as a whole is divided into four pages in one LabVIEW front panel, namely tool information, parameter setup, dashboard, and data logger. The first page of the HMI display contains basic information regarding the monitoring system created as shown in Figure 11.

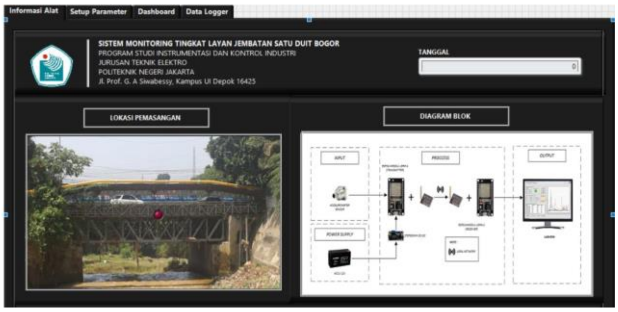

Figure 11. HMI Interface

The following is an example of sensor measurement data successfully sent by a LoRa transmitter and received by a LoRa receiver contained in the Arduino IDE ESP32 LoRa devkit LoRa receiver monitor serial.

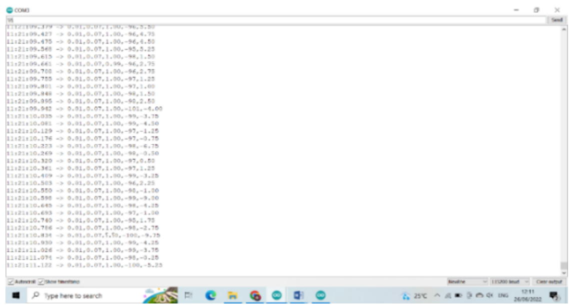

Figure 12. Data displayed on the Arduino IDE series monitor

Figure 13. Data stored on the Antares cloud server

Sample data that has been successfully received and calculated on the Raspberry Pi 3B is then sent to the Antares cloud in the form of the amount of data in one packet in one data transmission cycle, the average RSSI value, the average SNR value, the peak value of the frequency value for the X, Y, and Z axes.

Proximity RSSI Testing (Received Signal Strength Indicator) and SNR (Signal Noise Ratio) on Line of Sight (LoS)

RSSI testing is carried out to measure the strength of the signal emitted by LoRa and SNR testing is carried out to measure the ratio between signal strength and noise strength (noise) so that the quality of the signal emitted by LoRa can be known when sending and receiving point-to-point data. The test was carried out by carrying out the process of receiving data from the device (LoRa receiver) which is the measurement data by the AKF 394B sensor with LOS conditions (without any obstructions on the Satu Duit Bogor bridge). The component tested is the LoRa SX1276 which is integrated with the ESP32 board as a transmitter and receiver. Table 1 is Proximity Test Results RSSI (Received Signal Strength Indicator) and SNR (Signal Noise Ratio) at Line of Sight (LoS).

Table 1. RSSI and SNR Test Results

Distance (m)	No	X	Y	Z	RSSI (dBm)	RSSI Average (dBm)	SNR (dB)	SNR Average (dB)
100m	1	0.01	0.02	1.00	-52	-52,87790698	9,75	10,22044574
	2	0.01	0.02	1.00	-52		10	
	3	0.01	0.02	1.00	-52		10,25	
	4	0.01	0.02	1.00	-52		10,25	
	5	0.01	0.02	1.00	-52		10,25	
	6	0.01	0.02	1.00	-52		10,5	
	7	0.01	0.02	1.00	-52		10,25	
	8	0.02	0.04	1.01	-53		10,25	
	9	…	…	…	…		…	
	616	0.01	0.02	1.00	-53		10,25	
200m	1	0.01	0.02	1.00	-53	-56.30781759	10,5	10.09271845
	2	0.01	0.02	1.00	-53		10	
	3	0.01	0.02	1.00	-54		10,25	
	4	0.01	0.02	1.00	-53		10,25	
	5	0.01	0.02	1.00	-54		10,5	
	6	0.01	0.02	1.00	-54		10	
	7	0.01	0.02	1.00	-54		10,25	
	8	0.01	0.02	1.00	-54		10	
	9	…	…	…	…		…	
	516	0.01	0.02	1.00	-54		10	
300m	1	0.01	0.02	1.00	-56	-68.79805825	10	10,06514658
	2	0.01	0.02	1.00	-57		10	
	3	0.01	0.02	1.00	-58		10	
	4	0.01	0.02	1.00	-58		10,25	
	5	0.01	0.02	1.00	-59		10,25	
	6	0.01	0.02	1.00	-59		9,75	
	7	0.01	0.02	1.00	-60		9,25	
	8	0.01	0.02	1.00	-63		9,25	
	9	…	…	…	…		…	
	515	0.01	0.02	1.00	-68		9,25	
400m	1	0.01	0.02	1.00	-76	-78.92244898	9,75	9.228061224
	2	0.01	0.02	1.00	-77		9	
	3	0.01	0.02	1.00	-77		9,5	
	4	0.01	0.02	1.00	-79		9,25	
	5	0.01	0.02	1.00	-80		9,5	
	6	0.01	0.02	1.00	-82		9,5	
	7	0.01	0.02	1.00	-83		8,75	
	8	0.01	0.02	1.00	-84		9	
	9	…	…	…	…		…	
	491	0.01	0.02	1.00	-86		8,75	
500m	1	0.01	0.02	1.00	-99	-102.0792079	6,25	-1.915841584
	2	0.01	0.02	1.00	-101		1	
	3	0.01	0.02	1.00	-104		-0,75	
	4	0.01	0.02	1.00	-105		-1	
	5	0.01	0.02	1.00	-101		-2,5	
	6	0.01	0.02	1.00	-102		-5,75	
	7	0.01	0.02	1.00	-103		-6,5	
	8	0.01	0.02	1.00	-105		-8,25	
	9	…	…	…	…		…	
	245	0.01	0.02	1.00	-105		-10,75	

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From the tests carried out, the RSSI value obtained is still in the range of 0 to -120 dBm, which means that it meets the regulations stated on the LoRa 915 MHz datasheet. The SNR value obtained is still in the range of -20 dB to ± 29 dB, which means that it meets the regulations stated in the LoRa 915 MHz datasheet. It can be concluded that the LoRa RSSI and SNR values are relatively stable at each test point. This is due to changes in the SMALL RSSI and SNR values. Despite traveling long distances and the many obstacles that disrupt the data transmission process, LoRa still shows consistency with the stability of the RSSI and SNR values.

Quality of Service (QoS) Testing on Line of Sight (LoS)

QoS testing is carried out to measure the quality level of data transmission on LoRa with the Point-to-Point method. Maintenance of data transmission quality is done by looking at the proportion of delay, throughput, and packet loss. Tests were carried out by analyzing data from the Arduino IDE serial monitor (transmitter) with the Arduino IDE serial monitor (receiver) in LOS conditions (without any obstructions on the Satu Duit Bogor bridge). The component tested is the LoRa SX1276 which is integrated with the ESP32 board as a transmitter and receiver. Table 2 is the testing result of Quality of Service (QoS) on Line of Sight (LoS).

Table 2. Quality of Service Testing Results

No	Distance (m)	Delivery time	Receive Time	Delay (ms)	Packet loss	Throughput (bps)	Quality
1	100	12:14:50.173 to 12:15:22.080	12:14:50.210 to 12:15:22.083	63	0%	154,613	Very Good
2	200	12:15:22.129 to 12:15:48.906	12:15:22.130 to 12:15:48.935	64	0,194%	153,972	Very Good
3	300	12:15:48.947 to 12:16:15.647	12:15:48.981 to 12:16:15.703	64	0,389%	153,616	Very Good
4	400	12:16:15.687 to 12:16:41.334	12:16:15.750 to 12:16:41.344	66	0,405%	153,161	Very Good
5	410	12:16:15.761 to 12:17:07.359	12:16:15.797 to 12:16:19.521	66	0,416%	154,672	Very Good
6	420	12:16:23.016 to 12:16:26.864	12:16:23.088 to 12:16:26.928	68	1,74%	143,182	Very Good
7	430	12:16:26.905 to 12:16:30.725	12:16:26.976 to 12:16:30.794	68	1,7%	156,209	Very Good
8	440	12:16:30.764 to 12:16:34.510	12:16:30.840 to 12:16:34.590	72	1,9%	155,136	Very Good
9	450	12:16:34.562 to 12:16:38.355	12:16:34.636 to 12:16:38.431	84	4,17%	155,816	Very Good
10	460	12:16:38.396 to 12:16:42.168	12:16:38.431 to 12:16:42.381	104	4,17%	149,628	Good
11	470	12:16:42.209 to 12:16:43.361	12:16:42.428 to 12:16:43.797	300	8,7%	122,717	Enough
12	480	12:16:43.405 to 12:16:46.220	12:16:43.937 to 12:16:47.412	1.031	8,3%	126,618	Bad
13	490	12:16:46.262 to 12:16:50.589	12:16:47.459 to 12:16:52.633	1.465	38,8%	129,880	Bad
14	500	12:16:50.624 to 12:16:54.177	12:16:52.823 to 12:17:7.429	5.898	40,9%	26,576	Bad

Based on the LoRa point-to-point testing that has been done, QoS analysis on LOS can be carried out. This test produces three QoS parameters, namely delay, packet loss, and throughput. It can be seen in Table 2 that LoRa has the best performance based on the average values of delay, packet loss, and throughput which are in the very good category according to the TIPHON standard.

From the tests carried out, the delay value obtained is still in the very good category according to the TIPHON standard. The highest delay value at a distance of 500 m is 832 ms and the lowest delay value at a distance of 100 m is 63 ms. At a distance of 100 m to 400 m, the delay change is not significant, namely <70 ms. However, at a distance of 500 m the delay value experiences a high change, reaching 832 ms, this is because the distance greatly affects the time of data transmission.

The value of packet loss is also included in the very good category according to the TIPHON standard. The highest packet loss value at a distance of 500 m is 50.2% and the lowest packet loss value at a distance of 100 m is 0%. At a distance of 100 m to 400 m, the change in packet loss is not significant, which is <1%. However, at a distance of 500 m the packet loss experiences a high change, reaching 50.2% data loss, this is because the distance greatly affects packet loss.

In addition, the tests that have been carried out have obtained very good throughput according to TIPHON standards. The highest throughput at a distance of 100 m is 154 bps and the lowest throughput at a distance of 500 m is 74 bps. At a distance of 100 m to 400 m, the change in throughput is not significant, which is around 153 – 154 bps. However, at a distance of 500 m the throughput experienced a high change, reaching 74 bps, this is because the distance greatly affects the speed of data transmission.

Many factors affect the non-achievement of the maximum distance set by LoRa, including:

1. Test site conditions. The test was carried out in urban areas (Satu Duit Bogor Bridge) with long distances, resulting in an increase in obstacles that could affect the transmission process.
2. Antenna height. If the antenna is low, then the condition of the area will be NLoS, so packet delivery will be disrupted. In this study, the receiving antenna has a height of 1 m. The Okumura Hata method determines that in urban areas the

transmitting antenna height is 1-10 m and the receiving antenna height is 30-200 m.

3. There is a possibility that packets will collide or be dropped, due to a large number of incoming end-node data so the channel becomes busy.

Antares Platform Testing

The Antares Platform test is carried out at a distance of sending and receiving data that varies from 100m to 500m. The results of testing data transmission are in Table 3.

Table 3. Antares Platform Test Results

No	Distance (m)	Time	RSSI (dBm)	SNR (dB)	Amount of Data	Delay (s)
1	100	12:14:56	-52	10	256	-
		12:15:02	-65	9,912	384	6
		12:15:09	-57	10	512	7
		12:15:16	-53	10	640	7
2	200	12:15:22	-53	10	768	6
		12:15:29	-53	10,20	896	7
		12:15:36	-53	10	1024	7
		12:15:42	-53	10	1152	6
3	300	12:15:49	-53	10	1280	7
		12:15:56	-53	10	1408	7
		12:16:02	-70	10	1536	6
		12:16:09	-74	10	1664	7
4	400	12:16:16	-79	10	1792	7
		12:16:22	-78	10	1920	6
		12:16:29	-74	10	2048	7
		12:16:36	-74	10	2176	7
5	500	12:16:42	-96	5	2304	6
		12:16:53	-102	-1	2432	7
		12:16:54	-102	-1	2432	1

Based on the test of sending processed data on the Raspberry Pi 3B to the Antares platform, an analysis can be carried out on the LOS uplink experiment at a distance of 100 to 500 m for 2 minutes on the Satu Duit Bogor bridge, the performance has been good. This is evidenced by the highest average RSSI is -53 dBm and the lowest RSSI is -102 dBm in accordance with the RSSI limit of 0 to -120 dBm. The highest SNR is 10 dB and the lowest SNR is -1 dB according to the SNR limit of -20 to 29 dB. Antares has a stable delay with an average of 6 to 7 seconds. At the time of testing the gateway was placed near the Antares platform, so that the distance did not affect the data transmission process or there were no obstacles.

CONCLUSIONS

LoRa communication can be implemented on the One Duit Bogor bridge monitoring system using the point-to-point method using the integrated ESP32 board LoRa SX1276 as a transmitter and the integrated ESP32 board LoRa SX1276 as a receiver which has managed to reach a distance of 500 m at LOS. The process of sending data is carried out in two stages, namely the LoRa point-to-point method and the LoRa gateway. The data transmission process begins with the LoRa transmitter sending AKF 394B sensor readings to the LoRa receiver using the SX1276 LoRa chip connected to a 915MHz antenna. Then the LoRa receiver forwards the data to the Raspberry Pi 3B as a gateway to be processed into an FFT value. The FFT value is sent to the Antares platform to be stored on the cloud server and becomes a website database in numerical form.

Based on the test results, it proves that LoRa communication has good performance. In urban areas, LoRa can transmit data from a distance of 0 to 500 m with an average delay of 217 ms, an average packet loss of 10.237%, an average throughput of 137.881 bps, an average SNR of 7.54 dB, and an average RSSI of -71,798 dBm. At a distance of 0-400 m, there is an insignificant change in the LoRa parameter, but at a distance of 500 m there is a high change, this is because distance greatly affects data transmission. The farther the range, the more obstacles will be passed so that data transmission is disrupted.

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