Vokasi Unesa Bulletin of Engineering, Technology and Applied Science (VUBETA)
https://journal.unesa.ac.id/index.php/vubeta
Vol. 1, No. 1, September 2024, pp. 46~58 DOI:
ISSN:xxxx-xxxx

Perfomance of LoRa SX1278 Using Yagi Antenna

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Article Info

Article history:

Received Aug 15, 2024
Revised Aug 27, 2024
Accepted Aug 28, 2024

Keywords:

LoRa SX1278
Arduino Uno
Yagi Antenna
Design of Directional Antenna
Impedance Matching

ABSTRACT

Long-distance communication with LoRa SX1278 faces challenges in range and signal quality, particularly in rural and urban environments. Standard spiral antennas often suffer from limited coverage and weak signal strength, especially over extended distances. To address these issues, this research explores a modified Yagi antenna with impedance matching to enhance the range and signal quality of LoRa SX1278 transceivers. This study provides empirical evidence that the modified Yagi antenna significantly outperforms the standard spiral antenna in transmission range and signal strength. The methodology involved testing the antennas at three different locations under horizontal conditions, focusing on comparing RSSI values and signal reception quality at varying distances. The results showed that the Yagi antenna achieved better coverage and signal strength, successfully transmitting signals up to 6250 meters. While the RSSI difference between the antennas was minor at shorter distances, the spiral antenna performed poorly in reception quality. The Yagi antenna maintained more stable signal strength over longer distances due to its effective electromagnetic energy focus. In conclusion, the Yagi antenna with impedance matching significantly enhances LoRa communication range and signal quality, particularly over longer distances.

1. INTRODUCTION

The development of telecommunication technology has made significant progress in recent years, especially with the advent of the LoRa SX1278 transceiver module[1]-[3]. This module is designed for long-distance communication by utilizing its advanced modulation technology, LoRa (Long Range)[4]-[6]. LoRa SX1278 offers advantages in terms of sensitivity and output power, allowing data transmission at distances up to 15 km in rural areas, and 5 km in urban areas[7], [8]. Operating at frequencies between 137 MHz and 525 MHz with sensitivity up to -148 dBm and maximum output power of +20 dBm, this module is an ideal choice for Internet of Things (IoT) applications that require long-range communication and energy efficiency[9], [10].

However, despite the LoRa SX1278's outstanding capabilities, there are significant challenges related to data transmission range. One of the main issues is the limited distance that can be achieved when using the default 3 dBi antenna that comes with the module[11]-[13]. This antenna, while good enough for general use, is often unable to meet the needs of applications that require longer range, especially in environments that have many obstructions or interference[14]-[17]. Several related studies have shown that while LoRa's internal antennas have some advantages, range limitations remain a challenge that needs to be overcome through the use of more efficient antenna designs[18], [19]. The use of antennas that are suitable for the surrounding conditions allows communication to be established. The standard spring antenna of the LoRa SX1278 module

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is an Omni-Directional antenna type, the radiation pattern of this type of antenna is to transmit and receive signals in only one coverage area. The antenna concept will not reach long distances in the presence of building or building terrain in the signal path [20], [21]. Therefore, a type of antenna is needed, namely Directional Antenna, which has a radiation pattern of emitted and received signals focused in one particular direction with a wider coverage area, making this type of antenna better able to communicate with long distances. Yagi antennas are a popular type of Omni-Directional antenna with strong directional characteristics, in addition to higher gain that can effectively overcome signal attenuation at long distances[22]-[24].

Some related researches are the development and innovation on modulation of remote communication system[25], [26], then the improvement of signal strength on the antenna used by LoRa module[27]-[30]. Thus, the purpose of this study is to analyze the effectiveness of using Yagi antennas in increasing data transmission distance and minimizing signal loss, so as to make a significant contribution in the development of LoRa-based telecommunications technology.

The contributions of this paper are:

- Application of yagi antenna on LoRa
- Adjustment of yagi antenna impedance with LoRa impedance
- The achievement of the proposed method is tested with several case variations.

In the second part of the article structure there is a discussion of the idea of LoRa, Arduino, and Yagi Antenna. Results and discussion are in the third section. The conclusion of the research is the last section

2. METHOD

2.1. Long Range (LoRa)

LoRa (Long Reach) is a remote correspondence innovation that has a place with the Low Power Wide Region Organization (LPWAN) classification and is intended for Web of Things (IoT) applications. In the field of LPWAN, two fundamental competitors are building up some decent momentum in the market today: LoRa and NB-IoT. LoRa is a specialized technology for operating long-distance communication links and operates in the unlicensed spectrum below 1 GHz[31], [32]. End nodes use LoRa RF signals to create a LoRaWAN star topology and transmit data. This is done by using a LoRa gateway. To guarantee protection, a symmetric key is safely settled between each end hub and the LoRa passage involving the actual layer for scrambled transmission. The door utilizes the symmetric key to unscramble the information and send it to the organization server. The application server processes and visualizes the data it downloads from the network server. In this framework model, the entryway utilizes surveying for key exchange and information correspondence with the terminal. Set random time parameters to update keys or achieve one-time pad performance thanks to this. Before sending any data to the network server, the gateway receives it all[14].

Within a fixed channel bandwidth, LoRa prioritizes sensitivity over data rate with a novel spread spectrum modulation scheme that is derived from chirp spread spectrum modulation (CSS). While LoRa was initially implemented at a low cost for commercial use, CSS was initially developed for military applications in the 1940s due to its long-range communication benefits and noise immunity. LoRa is intended for low information volume applications and gives transmission rates from 0.3 kbit/s to 50 kbit/s. It is suitable for sensor data transmission and IoT applications that do not require high bandwidth. Transmission power settings tailored to the operating frequency (920-925 MHz in Indonesia) enable optimization of coverage and energy consumption, while efficient packet management, including ACK/NACK transmission techniques, increases throughput and reduces packet loss[33], [34].

LoRa offers a wide communication range of 10-40 km in rural areas and 1-5 km in urban areas, with a reception sensitivity of up to -148 dBm. Signal categories based on RSSI (Received Signal Strength Indicator) show excellent signal at RSSI > -70 dBm, good at -70 to -85 dBm, moderate at -86 to -100 dBm, and poor at < -100 dBm[35], [36]. LoRa has advantages in range and energy efficiency compared to other technologies such as WiFi. While WiFi has a range of about 100 meters and higher power consumption, LoRa can accomplish a scope of up to 15 km in rustic regions and 2-5 km in metropolitan regions with low power utilization, permitting the gadget to work for a really long time on a solitary battery[37], [38].

LoRa's infrastructure costs are also lower, supporting many devices per base station, while WiFi requires more access points and higher costs for large-scale implementation. LoRa works best in Line-of-Sight (LoS) conditions, but it can also work in Non-Line-of-Sight (NLoS) conditions with less range[39]-[41]. The speed at which the transmitting node moves affects transmission performance, with higher speeds resulting in lower packet loss and greater throughput. Transmission performance is influenced by the speed at which the transmitting node moves, with higher speeds resulting in lower packet loss and increased throughput. More details about the specifications of the LoRa module used are in Table 1. For data transmission, LoRa makes use of the frequencies 433 MHz, 915 MHz, and 920 MHz. In Indonesia, 920 MHz is the frequency used[42], [43].

Table 1. LoRa SX1278 Module Transceiver Specifications

Parameters	Specification
Operating voltage	DC 1.8 V – 3.7 V
Frequency range	137 – 525 MHz
RF Input Level	+10 dBm
Modulation	FSK/OOK/LoRa™/GMSK/MSK
Bandwith	7.8 – 500 kHz
Receiver sensitivity	-111 dBm to -148 dBm
RF Output Power	+20 dBm
Impedance	50 Ω
Effektive bit rate	0.018 – 31.5 kbps

2.2. Arduino Uno

An open-source hardware device with straightforward inputs and outputs is the Arduino Uno R3 (Revision 3) Arduino Uno is an open-source microcontroller board intended to make it simpler for clients, particularly novices, to learn gadgets and programming. The Arduino Uno, which was released in 2005, combines software and hardware to make it simple to create a variety of electronic projects. This board has 32KB ISP streak memory with read or compose abilities, 2KB EEPROM, 2KB SRAM making it named as ATMEGA 328. Arduino has 2KB SRAM, 2KB EEPROM, and 32KB ISP flash memory. Arduino Uno gives 14 computerized pins, 6 simple pins, and a USB association for programming and testing[38], [41], [44], [45].

ATMEGA 328P is a 8-bit AVR-RISC-based microcontroller chip bundled by an organization called Atmel which is utilized on the arduino board. ATmega328P is equipped with main units such as CPU, memory, I/O ports, timer/counter, and ADC that work in an integrated manner. One important feature of the Arduino Uno is its ability to perform PWM, which is a pulse width modulation technique that allows analog control of digital outputs. PWM is very useful for controlling the speed of DC motors, adjusting the brightness of LEDs, and other applications. In addition, the Arduino Uno also supports various serial communication protocols such as UART, SPI, and I2C, which allows interaction with various external devices[46], [47].

The Arduino Uno offers benefits such as ease of use, affordable cost, and compatibility with various sensors and add-on modules. With extensive community support and numerous tutorials, the Arduino Uno is becoming a popular tool for education, hobbies, and technology development in various industries, including the Internet of Things (IoT). The Arduino Uno R3 pinout provides great flexibility in various projects. With 14 digital pins that can be configured as inputs or outputs, including 6 PWM pins for analog control, the Uno R3 allows interaction with various electronic components. In addition, 6 analog pins allow analog voltage measurement. Dedicated pins such as GND, 5V, 3.3V, and AREF provide the required power source and voltage reference. The TX and RX serial pins are used for serial communication with computers or other devices. The ICSP header allows direct reprogramming of the microcontroller. With a good understanding of these pinouts, you can start connecting sensors, actuators, and other electronic components to the Arduino Uno R3 to create a variety of interesting projects[48]-[50].

2.3. Yagi Antenna

The use of additional antennas such as Yagi antennas can significantly improve the performance of LoRa transceivers by extending communication range, reducing interference, and improving energy efficiency. Yagi antennas, with their higher gain and directional nature, can increase data transmission distance from 350 meters to 600 meters under Line of Sight (LOS) conditions[51]. It also reduces noise from other signal sources, which is especially important in environments dense with wireless devices. To maximize performance, the antenna must match the LoRa operating frequency, such as 868 MHz or 915 MHz, to prevent signal loss or damage to the LoRa module[52].

The Yagi antenna consists of three parts: Reflector, Driven, and Director, and is designed to focus the signal in one specific direction[28], [53]. Besides that each element has its own function, namely:

1. Driven Element: This is the core part of the Yagi antenna. Its function is like a converter, converting electrical signals from the transmitter into radio waves that can spread in the air. This element is

directly connected to the transmitting device through the antenna cable. Its size is usually half the wavelength of the transmitted or received signal.

3. Reflector Element: As the name implies, this element reflects the signal. It is located behind the driven element and is slightly longer. This reflected signal will amplify the main signal emitted by the driven element.
1. 3, Director Element: This element is used to direct the radio signal in a specific direction. It is slightly shorter than the driven element. The more director elements that are added, the more focused the direction of the emitted signal.

In the trial, acclimations to the Determined were made by enhancing the impedance, while the impedance of the Yagi recieving wire is 300 Ω, as opposed to the 50 Ω impedance of the LoRa SX1278. The Yagi recieving wire works at a recurrence of around 400 MHz with a return misfortune boundary of - 19 dB. What's more, the 3dBi radio wire, which works at a recurrence of 902-928 MHz, is likewise utilized for LoRa applications, offering medium reach and great transmission strength, with protection from different weather patterns[54], [55]. Under LOS conditions, the 3dBi antenna has a range of approximately 350 meters and is an omnidirectional antenna that transmits and receives signals equally in all horizontal directions. The Yagi antenna, on the other hand, is a directional antenna with a higher gain that can reach 600 meters in the same conditions. Yagi radio wires are great for applications that require significant distance correspondence with high transmission quality, while 3dBi radio wires are more reasonable for wide inclusion without a particular directional focus.

2.3.1. Antenna Design

Perform calculations using antenna formulas to determine the exact size and shape of the 12-element Yagi antenna in accordance with the desired objectives. The parameters used in designing the Yagi antenna are as follows[28], [56]:

1) The frequency wavelength can be determined using the equation below,

$$\lambda = \frac{c}{f} \tag{1}$$

Where c is the speed of light with a constant value of $3\ x\ 10^6$ and f is the frequency value to be used. From this formulation, the frequency wavelength is obtained.

$$\lambda = \frac{3\ x\ 10^8}{433\ x\ 10^6} \tag{2}$$

$$\lambda = 0{,}693 \text{ meters} \tag{3}$$

2) The length of the driven element is $\frac{1}{2}\ \lambda$, hence obtained,

$$Ld = \frac{1}{2}\ \lambda \tag{4}$$

$$Ld = \frac{1}{2}\ x\ 0{,}693 \tag{5}$$

$$Ld = 0{,}346 \text{ meters} = 35 \text{ centimeters} \tag{6}$$

3) Reflector length is set 5% longer than the driven element.

$$Lr = Ld + (\ Ld\ x\ 5\%\ ) \tag{7}$$

$$Lr = 35 + (\ 35\ x\ 5\%\ ) \tag{8}$$

$$Lr = 36{,}75 \text{ centimeters} \tag{9}$$

4) The director length is set 5% shorter than the driven element

$$Ld1 = Ld - (\ Ld\ x\ 5\%\ ) \tag{10}$$

$$Ld1 = 35 - (\ 35\ x\ 5\%\ ) \tag{11}$$

$$Ld1 = 33{,}25 \text{ centimeters} \tag{12}$$

2.3.2. Gain Measurement

To calculate the gain generated by a yagi antenna with 12 elements, 1 reflector, 1 driven, and 8 director elements, the following formula can be used:

$$G = 10\ log_{10}\ (1 + 1{,}66\ x\ N) \tag{13}$$

Where G is the measured antenna gain, and N is the number of elements in the director. So by entering the variables into the formula, the calculation results are obtained:

$$G = 10\ log_{10}\ (1 + 1{,}66\ x\ 8) \tag{14}$$
$$G = 10\ log_{10}\ (14{,}28) \tag{15}$$
$$G = 11{,}55\ dBi \tag{16}$$

From the results of these calculations, the gain value of the yagi antenna design is 11.55 dBi.

2.3.3. Impedance Matching

Matching Impedance in a balun circuit is an electronic component that functions as a link between balanced and unbalanced circuits. Simply put, a balun is like a bridge that connects two different types of roads. Baluns not only change the characteristics of the signal, but they can also adjust the impedance, which is the resistance to electric current. By adjusting the impedance, baluns ensure that electrical power can be transferred efficiently and minimize signal loss. One common type of balun is the transformer balun, which uses the principle of electromagnetic induction to change voltage and current. Baluns play an important role in various applications, such as in antennas, audio, and radio frequency systems. The use of baluns helps to improve signal quality, reduce noise, and ensure optimal system performance. LoRa communication systems, which often rely on coaxial cables as the transmission medium, generally have a characteristic impedance of 50 ohms. On the other hand, Yagi antennas, which are often used in LoRa systems, often have a higher input impedance, such as 300 ohms[57], [58]. This significant impedance difference can lead to signal reflection, decreased power efficiency, and overall signal quality degradation. To overcome these problems, impedance adjustment techniques are required. Figure 1 Show that the Balun 6:1 theory, which is one of the popular impedance adjustment methods, can be used to design a proper matching network. This matching network will serve as a 'bridge' between the impedances of the coaxial cable and the Yagi antenna, allowing power to be transferred optimally and minimizing transmission losses. The design results for the driven element of the Yagi antenna are shown in Figure 2 below.

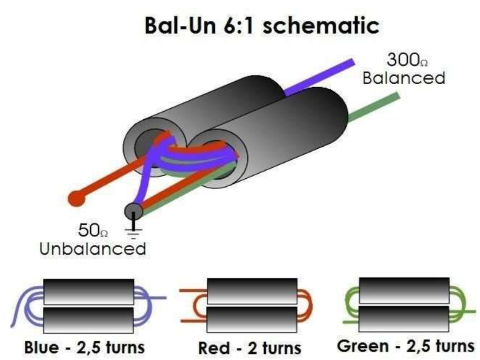


Figure 1. Balun 6:1

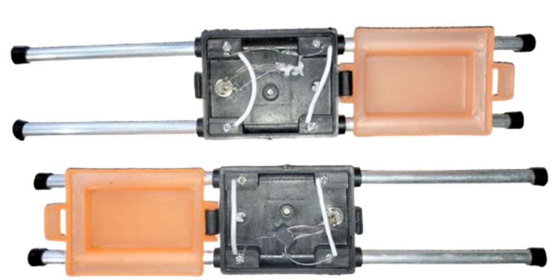


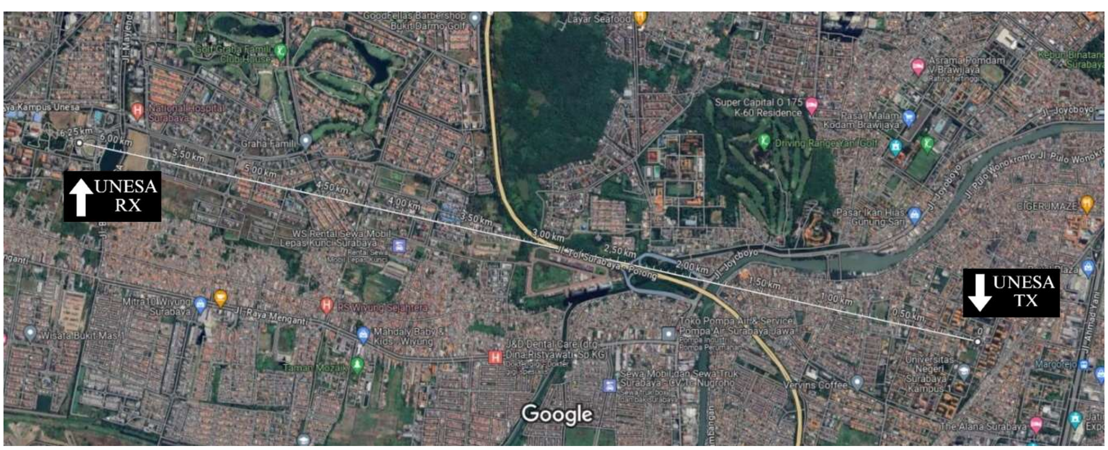
Figure 2. Design result of balun on driven yagi antenna

4. RESULTS AND DISCUSSION

Testing was carried out in 2 conditions, namely horizontal and vertical conditions. When horizontal conditions are carried out in 3 different places, namely Building K4 on the 2nd floor, Building K10 on the 3rd floor, and between UNESA campuses. Meanwhile, the vertical condition was carried out in Building K10 on the 3rd floor. In addition, the tool is carried out in two different states, each of which has TX (Transmitter) mode as a data sender and RX (Receiver) mode as a data receiver. This is done so that the tool does not run using only one-way communication, but can communicate in both directions to control. Figure 3, shows a map of the testing ground for each condition.

(a)

(b)



(c)

Figure 3. Test site map and distance measurement: (a) K4, (b) K10, (c) Between UNESA

3.1 Case Study of TX in Building K4

The first test was carried out by placing the LoRa Transmitter tool in Building K4 2nd floor Faculty of Vocational Studies with the surrounding conditions filled with buildings, so the first test in real conditions was in the N-LOS category. Distance tests are carried out with multiples of 50 meters, measuring the distance using the help of google maps as a determination point for the location of the LoRa Receiver tool. Based on Table 2.

in the 50meter distance test, the RSSI value in each use of the antenna type is in the bad category for spring antennas and moderate for yagi antennas. The yagi antenna has the ability to transceiver data up to 200 meters, compared to the spring antenna which is only capable of up to 100 meters in the case study of placing the transmitter location in the K4 2nd floor building.

Table 2. Test results when the TX in building K4

Transmitter Location	**Distance Test (meter)**	**Spring Antenna**		**Yagi Antenna**	
		RSSI (dBi)	Category	RSSI (dBi)	Category
Building K4 2nd floor Faculty of Vocational Studies	50	-101	Bad	-91	Medium
	100	-105	Not Connected	-100	Bad
	150	Not Connected	Not Connected	-102	Bad
	200	Not Connected	Not Connected	-104	Bad
	250	Not Connected	Not Connected	-105	Bad
	300	Not Connected	Not Connected	Not Connected	Not Connected

The Figure 4. shows a trend of decreasing signal strength as the distance from the transmitter increases, but the yagi directional antenna design performs significantly better than the spring antenna in terms of range and signal strength.

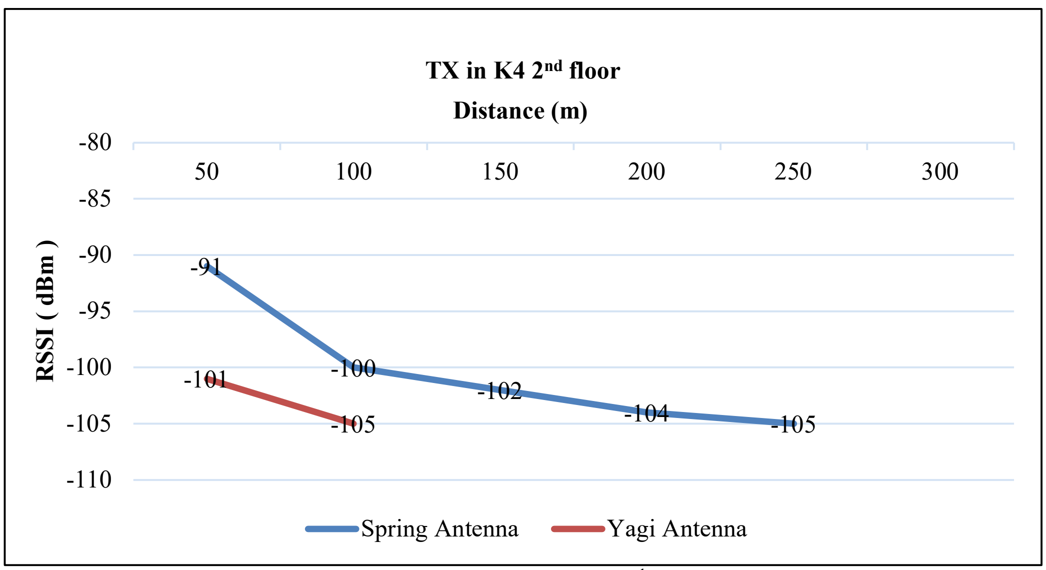


Figure 4. Graph TX in K4 2nd floor

3.2. Case Study of Tx in Building K10

The second test was carried out by placing the LoRa Receiver device in the K10 Building 3rd floor of the Faculty of Vocational Studies, the difference in location in the second case study is the surrounding conditions for conducting tests that are more open and less building obstructions, although there are several buildings on the right and left sides of the test route, but this place is better than the previous test site. Based on the Table 3. at the beginning of testing at a distance of 50 meters from the transmitter, the yagi antenna shows the RSSI value obtained is better by entering the very good category, compared to the spring antenna with a good category. In addition, the spring antenna is only able to transceiver data up to 450 meters, while the yagi antenna is at the maximum distance of 550 meters.

Table 3. Test results when the TX in building K10

Transmitter Location	Distance Test (meter)	Spring Antenna		Yagi Antenna	
		RSSI (dBi)	Category	RSSI (dBi)	Category
Building K10 3rd floor Faculty of Vocational Studies	50	-78	Good	-63	Very Good
	100	-81	Good	-66	Very Good
	150	-83	Good	-69	Very Good
	200	-88	Medium	-73	Good
	250	-95	Medium	-79	Good
	300	-97	Medium	-81	Good
	350	-99	Medium	-85	Good
	400	-105	Bad	-89	Medium
	450	Not Connected	Not Connected	-98	Medium
	500	Not Connected	Not Connected	-108	Bad
	550	Not Connected	Not Connected	-116	Bad
	600	Not Connected	Not Connected	Not Connected	Not Connected

The Figure 5. again shows the trend of decreasing signal strength as the distance from the transmitter increases, the spring antenna has the ability to transceiver shorter data distances with signal strength that is not better than the use of the yagi antenna.

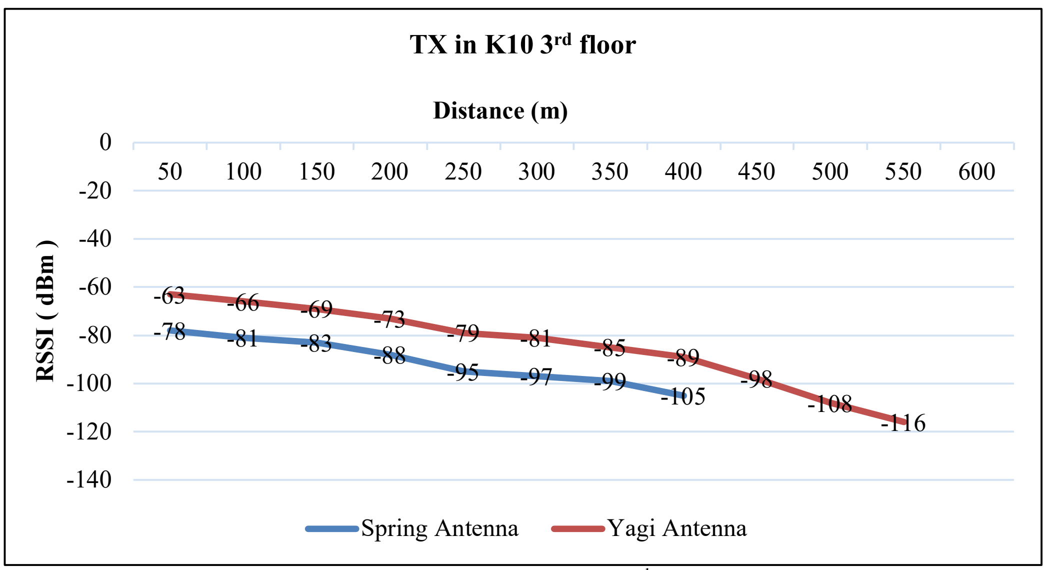


Figure 5. Graph TX in K10 3rd floor

3.3. Case Study between UNESA

Testing with the last vertical state was carried out with a greater distance than the previous two places. The LoRa Transmitter device was placed in the UKM Center Building 3th floor UNESA Ketintang, while the LoRa Receiver device in the Rectorate Building 13th Floor UNESA Lidah. This location selection is based on the placement of test conditions that have enough height and few obstructions. Based on the Table 4. five test times were conducted with a fixed distance of 6250 meters. The spring antenna does not show any data transceiver at all, in contrast to the yagi antenna that can be connected even though it is in a bad category.

Table 4. Test results between UNESA

Transmitter Location	Distance Test (meter)	Spring Antenna		Yagi Antenna	
		RSSI (dBi)	Category	RSSI (dBi)	Kategori
Between UNESA	6250	Not Connected	Not Connected	-109	Bad
	6250	Not Connected	Not Connected	-108	Bad
	6250	Not Connected	Not Connected	-107	Bad
	6250	Not Connected	Not Connected	-107	Bad
	6250	Not Connected	Not Connected	-107	Bad

The Figure 6. displays the test trend only on the yagi antenna, the spring antenna could not connect in 5 test times. The use of the yagi antenna has an increase in signal strength along with the test time. The 1st test RSSI obtained was -109 dBi, the signal stabilized after three tests at -107 dBi.

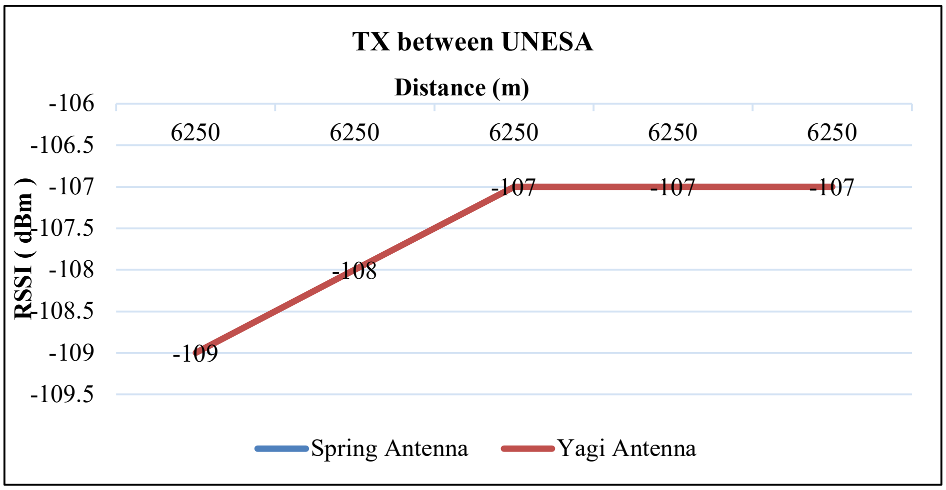


Figure 6. Graph TX between UNESA

3.4. Case Study of Vertical State

Tests were carried out in a vertical state, the LoRa Transmitter tool was placed on the K10 3th floor by adding an antenna pole. Based on the Table 5. shows the RSSI category on each antenna in the very good category, although the yagi antenna again shows better signal strength.

Table 5. Test results with vertical conditions

Transmitter Location	Distance Test (meter)	Antena Spring		Antena Yagi	
		RSSI (dBi)	Category	RSSI (dBi)	Category
Building K10 3rd floor Faculty of Vocational Studies	3	-50	Very Good	-36	Very Good
	6	-52	Very Good	-38	Very Good
	9	-56	Very Good	-41	Very Good
	12	-61	Very Good	-44	Very Good

The Figure 7. shows a decreasing trend in signal strength as the test distance increases. The yagi antenna has a better ability in the quality of a data transceiver, as evidenced by the stable graph line above the spring antenna.

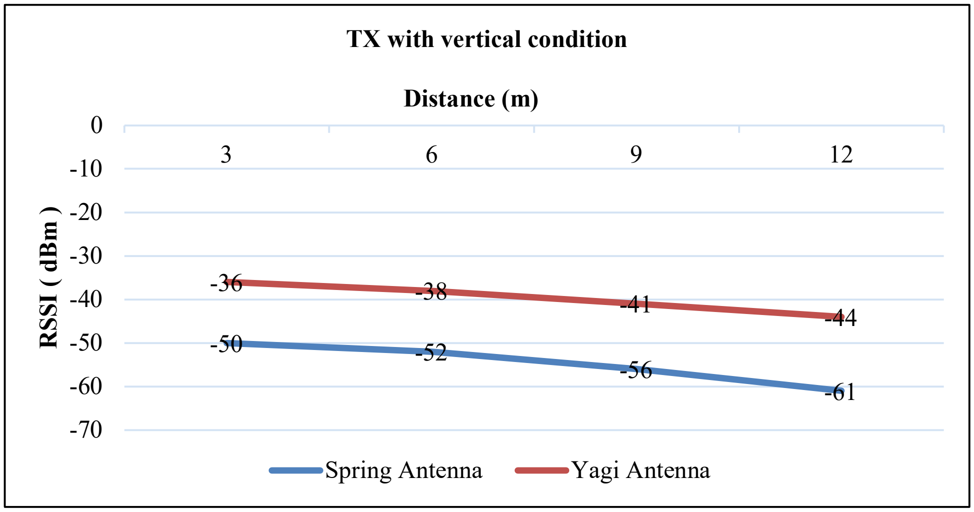


Figure 7. Graph TX with vertical condition

5. CONCLUSION

This research features the utilization of a remote communication system using Long Range (LoRa) technology, the modules used are divided into two, namely LoRa Transmitter and LoRa Receiver. There are several problems with range and signal strength when using a standard antenna, therefore a yagi antenna with modifications to the impedance is present to overcome them. Increasing the gain of the yagi antenna by 11.55 dBi and using a 6:1 Bal-Un schematic are the main modifications. Tests were conducted in 2 different conditions, namely horizontally and vertically. Horizontal testing using the yagi antenna gets the farthest distance of 6250 meters with the highest RSSI value of -107 dBi, while the spring antenna can only be reached at a distance of 400 meters with an RSSI value of -105 dBi. For vertical testing at a distance of 12 meters, the yagi antenna gets an RSSI value of -44, while the spring antenna is -12 dBi. Although in each test it can be seen that the graph of each antenna tends to show a loss of signal strength, the yagi antenna has an advantage at every distance or signal strength. From the experimental results, it is known that the yagi antenna has better capabilities than the standard spring antenna.

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