

Performance Evaluation of LoRa ES920LR 920 MHz on the Development Board

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Abstract—This study contains the LoRa ES920LR test on obstruction or resistance conditions and its comparison with Free Space Path Loss (FSPL) using Drone means without obstacles. The ES920LR has 920 MHz frequency channel settings, 125 kHz Bandwidth, and SF 7-12, with 13 dBm Output Power. Comes with Sleep mode operation with Command Prompt based settings. The development board used is a leafony board, Leafony board is a board with a small size that is compatible with Arduino IDE, using a micro ATmega M328P microcontroller, this board is mounted tiled with complete facilities, e.g., a power supply board, four different sensor boards, MCU boards, communication boards e.g., WiFi and Bluetooth, specifically in this article using the LoRa ES920LR on the Leafony board, using LoRa because it requires a long range (km) and low power, and expansion boards that can be developed, Expansion to Leafony boards is expected to reduce the power consumption of the sensor node, lifetime, lif, small size, and lightweight. Furthermore, this algorithm is used to optimize LoRa Coverage and LoRa Lifetime. The results of receiving the FSPL LoRa 920LR have a Power Receiver (Pr) of 30 dB at a distance of 1 meter or A, at 500 meters 85 dB, 1500 meters 95 dB, 2.5km 100 dB. Attenuation is caused by distance, although not significant, other factors are obstacles or obstacles, bad weather (rain, snow).

Keywords—Coverage; lifetime; low power; lightweight; long range; development; board; free Space; drone

I. INTRODUCTION

LoRa ES920LR is a type of LoRa that works at 920 MHz. LoRa ES920LR is indeed used in Japan, principally it is important to study the Quality of Service (QoS) of LoRa as seen from various factors such as Radio Propagation, Ability of LoRa eg, Power save management, bandwidth, SF, Output Power, Sleep management mode, ability on Receive Signal Strength Indicator (RSSI)[14],[16], etc. In research [1] monitoring of soil and environmental information was collected in 17 km, in research [2] using Semtech products at a 915 MHz LoRa frequency. moreover, compatibility and configuration on the Application server e.g., TTN (The Things Network), Ambient.io, or Thingspeak are important that communication between a LoRa module can run properly. Previous research used the same sensor, Pulse sensor [3],[15], in research [4], LoRa was used in the analysis of WaterGrid-Sense, as a full-stack node based on LoRa deployed on a smart water management system.

Furthermore, it is important to pay attention to the Power Consumption factor as in research [5], [6], the results of data compression in wireless sensors nodes that use LoRa technology to transmit data. An energy consumption

comparison is made with other data communication protocols used in WSN. In managing the LoRa and LoRaWAN networks, an appropriate protocol is needed in setting the Medium Access Control (MAC) random access, in research [7], using ALOHA protocol analysis, ie, normalizing the communication of LoRaWAN networks using a Reservation-ALOHA (R-ALOHA). With the continued development of LoRa and LoRaWAN-based End nodes, a protocol that is capable of handling millions of end nodes is needed, it also requires continuous renewal in terms of performance, security [8], robustness, in research [9] discussing the revolution of LoRaWAN network technology considering the IoT requirements. In addition to Software Development, Protocols with security and methodology settings, LoRa acceleration is also developed with various devices, such as Leafony Board and PSoC [10]. In this study, a blackboard-based board developed specifically for LoRa ES920LR communication and applied to drones and GPS technology to obtain SF, SNR [17], and RSSI values, the application in subsequent studies is to get patients (Longitude and Latitude) that can be accessed with Google maps, furthermore, it can be seen that each patient's BPM is in a different location. Because of the shape of the Leafony board is small, it can be placed and flown by a drone.

II. THEORY

A. Receiver Sensitivity of ES920LR

As the purpose of this research is an analysis of RSSI, SNR, and other parameters such as power consumption, Gain, Power Receiver, obstacles [Fig. 1], receiver sensitivity, Time on Air, and how to manage the uplink and downlink data on the server or internet gateway and application the server. Moreover, Power Receiver depends on several factors, including receiver gain and lost signal packet factor or attenuation on the Free Space Path Loss. An illustration of the signal reduction can be seen in Fig. 1. The LoRa ES920LR has a transmitting Power (PTX) of -13 dBm, and the Power Receiver depends on the current state of signal propagation including the presence of Obstacles for all circumstances, e.g., bad wheater (snow, rain [18],[21],[22]), the distance that will affect the Time On Air (ToA), The antenna used, Connector Loss and Gain, we can refer to as Receiver Sensitivity (s).The sensitivity of LoRa (-dB) can be seen in equation 1. Where S or sensitivity depends on the value of Bandwidth, Noise Fig. 2, and Signal Noise Ratio (SNR). Table I shows the relationship between SF, S, and ToA. Moreover, the factor to consider is the Fresnel Zone calculation factor [12] if the transmitter and receiver distance is ≥ 5 km [13].

$$S = -174 + 10 \log_{10}(BW) + NF + SNR_{limit} \quad (1)$$

B. Time on Air (ToA) of ES920LR

The time needed for data from the Transmitter (Tx) to arrive right at the receiver (Rx) while in the air is Time On Air (ToA). [11] ToA is calculated using equation 2 and equation 3.

$$ToA = T_{preamble} + T_{payload} \quad (2)$$

$$T_{preamble} = N_{b \text{ Preamble}} (8) + \text{symbols added by radio} (4.25) \times T_{symbol}$$

$$T_{payload} = N_{b \text{ PayloadSymbol}} \times T_{symbol}$$

$$N_{payload} = 8 + \max(\text{ceil} [(8PL-4SF+28+16CRC-20IH) / 4(SF-2DE)] (CR+4), 0) \quad (3)$$

Furthermore, the relationship between SF, Chips, SNRlimit, ToA, and BitRate is shown in Table II.

TABLE II. LoRa Spreading Factor Comparison with SNR_{Limit}

Spreading Factor (SF)	Chips /Symbol	SNR _{Limit}	ToA (10 byte Packet)	Bitrate
7	128	-7.5	56 ms	5470 bps
8	256	-10	103 ms	3125 bps
9	512	-12.5	205 ms	1758 bps
10	1024	-15	371 ms	977 bps
11	2048	-17.5	741 ms	537 bps
12	4096	-20	1483 ms	293 bps

C. Budget Link (-dB) of ES920LR

Calculation of LoRa Budget Link ES920LR LoRa specification can be seen on equation 4, Before is determined the LoRa ES920LR sensitivity value, then as a deduction for the Transmit Power (dB) ES920LR LoRa. Moreover, Fig. 3 is Time On Air from the ES920LR LoRa, and Fig. 4 is the Link Budget (-dB) ES920LR with a -13 dB Power transmit.

$$\text{Budget Link (dB)} = \text{Tx Power (dB)} - \text{Sensitivity (dB)} \quad (4)$$

In detail, the ToA of ES920LR with different bandwidths (125, 250, and 500 kHz) is shown in Table III.

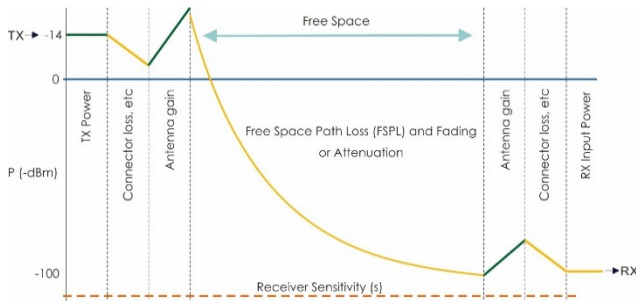


Fig. 1. Condition on the Signal Transmitting Process.

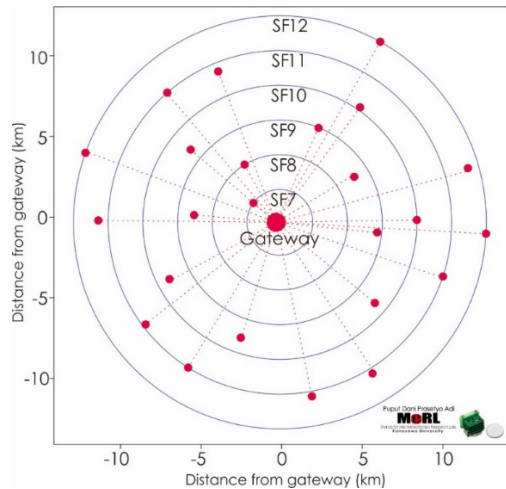


Fig. 2. Spreading Factor.

TABLE I. SENSITIVITY, TOA, AND SPREADING FACTOR

Spreading Factor (SF)	Sensitivity (S)	Time on Air (ToA)
SF7	-123 dBm	41 ms
SF8	-126 dBm	42 ms
SF9	-129 dBm	144 ms
SF10	-132 dBm	288 ms
SF11	-134.5 dBm	577 ms
SF12	-137 dbm	991 ms

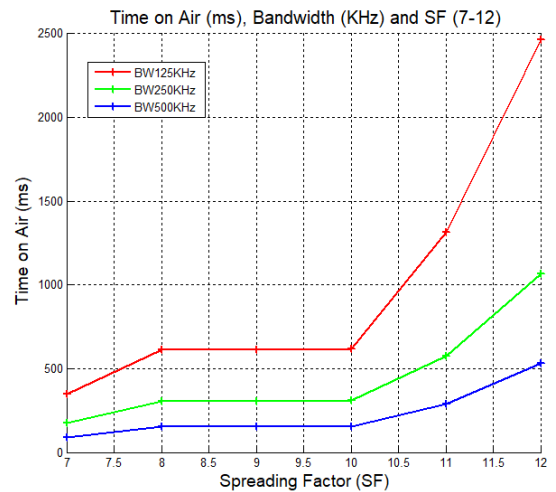


Fig. 3. Time on Air (ToA) ms.

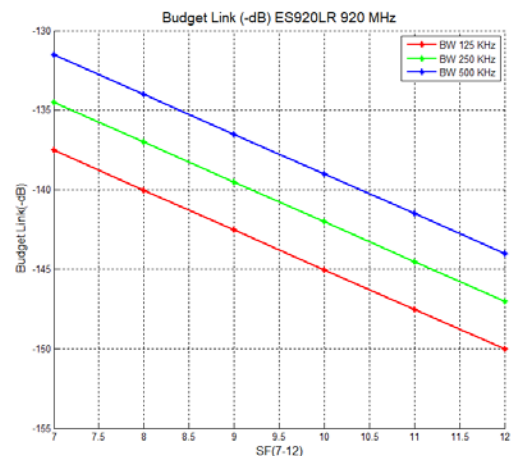


Fig. 4. Link Budget (-dB).

TABLE III. TIME ON AIR COMPARISON WITH BW, AND SF

SF	BW125KHz	BW250KHz	BW500KHz
7	348.42 ms	174.21 ms	87.1 ms
8	614.91 ms	307.46 ms	153.73 ms
9	615.42 ms	307.71 ms	153.86 ms
10	616.45 ms	308.22 ms	154.11 ms
11	1314.82 ms	575.49 ms	287.74 ms
12	2465.79 ms	1069.06 ms	534.53 ms

III. METHODS

A. Flowchart, Devices and Design

The flowchart in Fig. 6 is the steps used in this research, very clearly illustrated in the flowchart, that the initial step is to build a sensor node. Before using the Arduino Pro Mini, the Arduino board [23] is used to make it easier to get a tx and Rx pin [Fig. 7]. After success, furthermore, a communication test Between ES920LR LoRa [Fig. 5] was conducted.

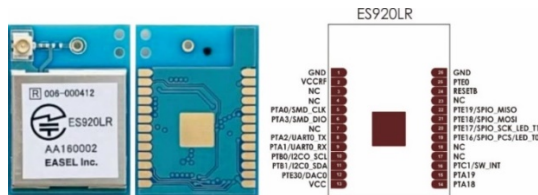


Fig. 5. ES920LR Pins.

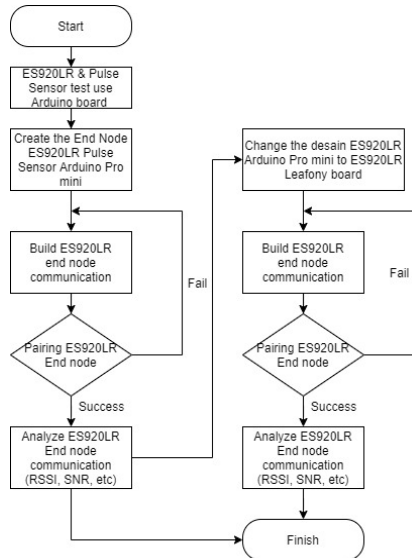


Fig. 6. Flowchart on this Research.



Fig. 7. Pairing ES920LR LoRa use Arduino board (Design_1).

Table IV is a detailed specification of the LoRa ES920LR, Fig. 7 and Fig. 8 are the steps in making a Sensor Node. Fig. 7 still uses Arduino Uno, while Fig. 8 has been changed to Arduino Pro mini. The transformation of Fig. 7 and 8 was completed in this research objective, namely using the Leafony Board in Fig. 11. Moreover, Fig. 9 is a mesh communication that can be carried out by the ES920LR in collaboration with the ES920GW and Application server. LeafBus in Leafony is shown in Fig. 10, there are 5 pins used by LoRa ES920LR.

TABLE IV. ES920LR SPESIFICATION

Specification	Description
Model	ES920LR
JAPAN Government Certification /Standar ISM Band	ARIB STD-T108
Frequency	920.6 – 928.0 MHz
Modulation type	LoRa Modulation CSS (Chirps Spread Spectrum)
Number of Channels	37 ch (at 125 kHz bandwidth or less)
	18 ch (at 250 kHz bandwidth)
	12 ch (at 500 kHz bandwidth)
Bandwidth	62.5 kHz – 500 kHz
Spreading Factor	7-12
Transmission Speed	146 bps – 22 kbps
Transmission Output	13 dBm (20 mW)
Receiver Sensivity	-118 dBm ~ -142 dBm
MCU	ARM Cortex M0+
Memory	Flash ROM : 128 KB, RAM : 16 KB
Power Consumption	Tx : 43 mA (13 dBm setting) Rx : 20 mA During Sleep : 1.7 uA (when the timer starts)
interface	UART, SPI, I2C, ADC, GPIO
Antenna	Wire Antenna, External Antenna (U.FL)
Power Supply Voltage	2.4 Volt to 3.6 Volt
Operating Temperature range	-40 ~ +85° celcius
Connection Terminal	26QFN
Board Mounted PCB	SMT mounting type
Dimensions	24.00 x 17.0 x 2.3 mm
Construction Design Certification acquired	Certification Number : 006-000412

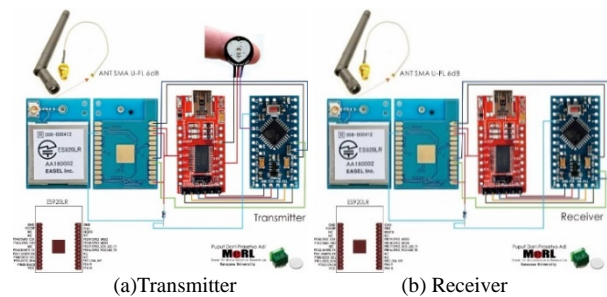


Fig. 8. Pairing ES920LR LoRa use Arduino Pro mini (Design_2).

Table V is the connection pin between ES920LR and Arduino, reset is on pin D12, because Pin 13 is used by the LED on the arduino Pulse sensor interrupt program.

On same time, setting the Receiver Pins, e.g., Table VI.

The following pseudocode can facilitate the understanding of how to pair or communicate between the ES920LR End nodes.

Pseudocode of LoRa E920LR_arduino

1. **Describe the E920LR Library**

```
#include <SoftwareSerial.h>
#define LORA_RECV_RecvData 100
#define ES920LR_RST_PIN 13
#define LORA_RX 2
#define LORA_TX 3
```
2. **Describe the PAN ID and Destination ID**

```
String dstId = "00010002";
```
3. **Determine the Maximum Sending the Data**

```
const int maxSendTimes =50;
```
4. **Determine How Long the Delay**

```
const int setCmdDelay = 100;
```
5. **Determine the type of Communication**

```
SoftwareSerial LoRa_Serial(LORA_RX, LORA_TX);
```
6. **Determine the Output Pin and delay**

```
pinMode(ES920LR_RST_PIN, OUTPUT);
digitalWrite(ES920LR_RST_PIN, LOW);
delay(100);
digitalWrite(ES920LR_RST_PIN, HIGH);
delay(1500);
```
7. **Describe the BoudRate or Speed the data sending**

```
Serial.begin(9600);
LoRa_Serial.begin(9600);
```
8. **Describe the Case or Scope on the Program**

```
loraInit();
```
9. **Describe the type of data sending, delay and Looping**

```
String sendData = "";
for (int i = 1; i <= maxSendTimes; i++) {
sendData = dstId + "Times" + i;
delay(2000);
Serial.println(sendData);
LoRa_Serial.println(sendData);
while(LoRa_Serial.available(>0) LoRa_Serial.read();
delay(4000);
```
10. **Initialize the LoRa Parameter**

```
void loraInit()

  - LoRa Serial initialize Node type (ED or Coord)
  - LoRa Serial initialize Bandwidth of Node
  - LoRa Serial initialize Spreading Factor (SF)
  - LoRa Serial initialize The Channel of node
  - LoRa Serial initialize PAN ID
  - LoRa Serial initialize OWN ID
  - LoRa Serial initialize DEST ID
  - LoRa Serial initialize Acknowledge
  - LoRa Serial describe the Retry count
  - LoRa Serial describe the type of Transfer mode
  - LoRa Serial describe the RSSI ON or OFF
  - LoRa Serial describe the Transfer mode (Frame or Payload)
  - LoRa Serial initialize a Save Command
  - LoRa Serial initialize run command
```
11. **Describe the Reading Command**

```
while(LoRa_Serial.available(>0) LoRa_Serial.read();
```

TABLE V. CONNECTION PIN ON TRANSMITTER

ES920LR	Arduino
GND	GND
VCCRF	3.3 Volt
TX	D2
RX	D3
VCC (3.3 Volt)	3.3 Volt
RST	D12

TABLE VI. CONNECTION PIN ON RECEIVER

ES920LR	Arduino
GND	GND
VCCRF	3.3 Volt
TX	TX 1
RX	RX 0
VCC (3.3 Volt)	3.3 Volt
RST	D13

The development system can be seen in Fig. 3. Fig. 9 uses the ES920LR Leafony Board that mesh with each other on end-devices and sends sensor data to the edge router or border router to the ES920GW as an Internet Gateway and displays it on the internet server.

The difference between Leafony boards and other boards is the port in Fig. 10. LeafBus Leafony boards are pins that are used to connect with other boards. LeafBus LoRa uses these five LeafBus pins i.e., 3V3, Reset, Pins 8 (F11), and Pin9 (F13) as Tx and Rx, and GND. Fig. 11 is the LoRa ES920LR design on the Leafony board, created using kiCAD Software, as described in Fig. 4, there are five LoRa pins identified i.e., Tx, Rx, 3V3, GND, and Reset Pin. And there is the addition of a 10 k Ohm resistor on the Reset pin to Pin 13 and V3V.

Therefore, there were three times the changes in the form of LoRa ES920LR end node, i.e., end node LoRa ES920LR use Arduino Uno, LoRa ES920LR use Pro mini, and LoRa ES920LR Leafony board, as shown in Fig. 12.

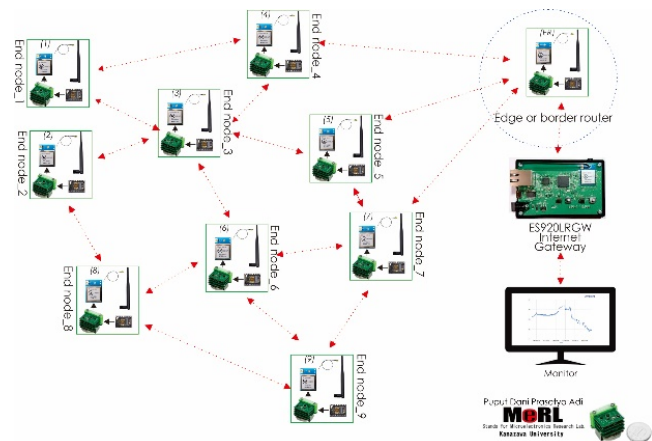


Fig. 9. Mesh Communication of Leafony board LoRa.

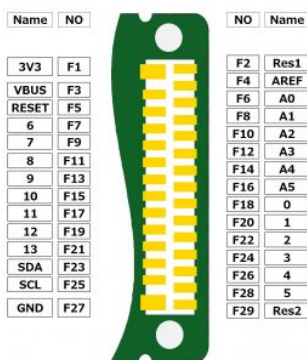


Fig. 10. LeafBus Leafy Board.

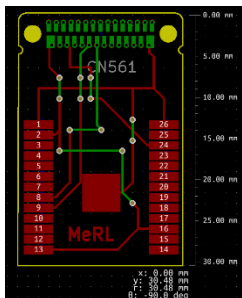


Fig. 11. Design to LoRa ES920LR Leafy (Design_3).

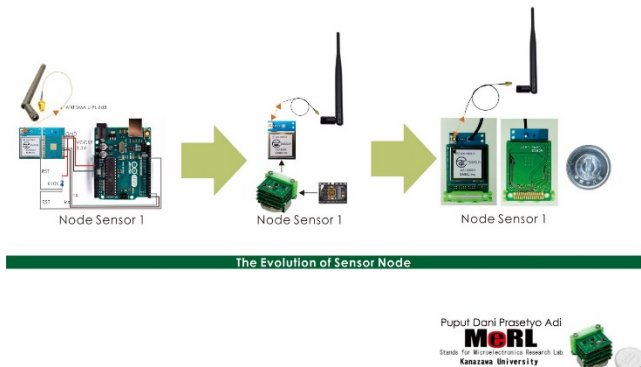


Fig. 12. Sensor node Evolution.

B. ES920LR Radio Propagation

Before the ES920LR was made in the form of a Leafy board, the Arduino Pro mini-board was tested first. Please note, the mini-board pro requires FTDI. FTDI functions as a regulator as well as a programmer board to program the Arduino Pro mini. The LoRa ES920LR transmitting data experiment uses drones using the FSPL approach. Moreover, Free Space Path Loss (FSPL) is a condition where the process of sending sensor data from the transmitter to the receiver does not pass through any obstacles, the application of Free Space Path Loss (FSPL) using a drone is one of the right efforts to get the value of Receive Signal Strength (RSS) without obstacles. Furthermore, Fig. 13 is one method of using drones in the process of transmitting LoRa data. There are two equations about FSPL (-dB) in RSSI (-dBm) or Power Receiver (Pr) parameters. Where the equation Pr (-dB) as equation x shows. Where the value of $c = 3 \times 10^8$ or 299 792 458 m / s, with frequency (f) LoRa ES920LR is 920000000 Hz, so that the

wavelength $\lambda = 0.3258613673913043$ meters or 32.5861367 cm or 325.861367 mm.

Equation 5 is the FSPL formula obtained from the specific wavelength and frequency parameters of the LoRa ES920LR, and equation 6 is a logarithmic equation with a value reduction of -147.55.

$$FSPL = (4\pi d/\lambda)^2 \text{ or } (4\pi df/c)^2 \text{ from } \lambda = c/f \quad (5)$$

$$FSPL \text{ (dB)} = 20\log_{10}(d) + 20\log_{10}(f) - 147.55 \quad (6)$$

Developing an equation for LoRa Path Loss by considering the environment (n or exponent) or data transmission area as equation 7 [20].

$$PL(d) = PL(d_0) + 10\log\left(\frac{d}{d_0}\right) + X\sigma \quad (7)$$

Fig. 14 is an example of Lora's ES920LR test area with Obstacle buildings and trees. This will produce a different RSSI (-dBm), RSSI can't experience attenuation even with longer distances, this is wherefore the signal is a combination of reflected and direct signals. FSPL gives the direct signal greater amplitude of the waves which causes RSSI (-dBm) greater than those affected by obstacles that cause reflected, scattered, and diffraction.

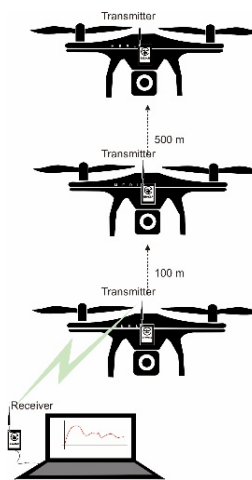


Fig. 13. LoRa Drone on FSPL Test.



Fig. 14. ES920LR LoRa Test on Building and Trees Obstacles.

IV. RESULT AND DISCUSSION

An important part of this chapter is an analysis of the signals generated by ES920LR with an approach to Free Space Path Loss. For the signal analyzer used Tektronix RSA 3408B, LoRa signal contains preamble and symbol, the amount of bytes of data is 255 bytes, on ES920LR 293 bytes on SF12, seen in Fig. 15 is a chirp which shows the existence of LoRa signal, the resulting chirp is up-chirp and down-chirp. Channel power shows how close the distance between transmitters - receiver, -46.13 dBm shows the value of Signal strength, in general, this value is greater based on the distance of the transmitter-receiver that is increasingly far away until a loss occurs.

Fig. 16 is another analysis of the LoRa signal i.e., Carrier Frequency, in this section, the signal power (-dBm) can be set, seen in the -30 dBm signal analyzer. The real signal power is -49.66 dBm (-83 dBm / Hz). Fig. 17 shows the value of FSPL (-dB) using the FSPL LoRa equation at 920 MHz frequency according to equations 4 and 5.

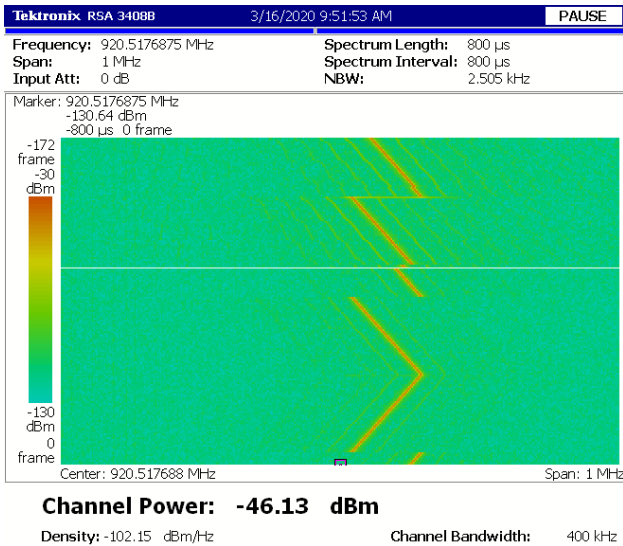


Fig. 15. Chirps LoRa 920LR.

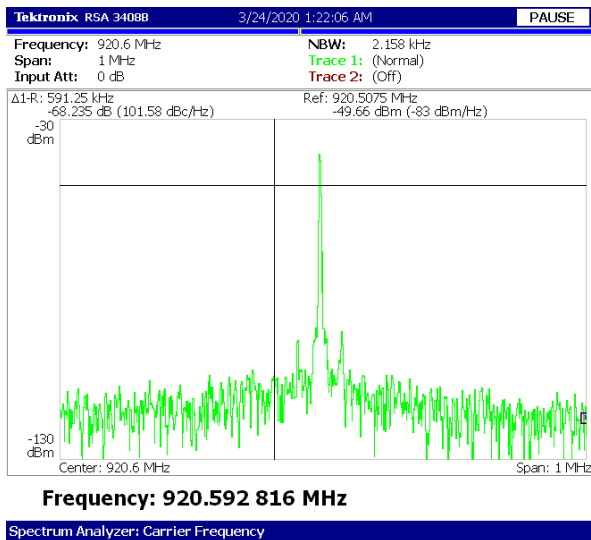


Fig. 16. Frequency Carrier of LoRa 920.592 MHz.

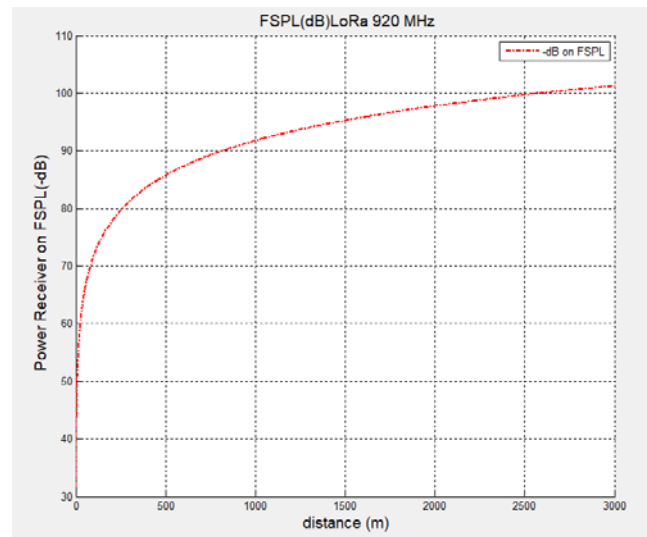


Fig. 17. FSPL use Drone LoRa ES920LR.

Fig. 18 is a real experiment from this research, where the transmitter and receiver have different distances, with the transmitter fixed position, and the receiver moves according to the specified point. RSSI data at a distance of 400 meters to 800 meters do not show regular attenuation, this is due to different levels of obstacles, at a distance of 400 meters there are many obstacles that block the direct signal to the receiver, but at a distance of 700-800 meters, the direct signal is greater than reflected signal. thus producing a combined signal that gives a smaller RSSI (-dBm) value or a stronger signal.

While Fig. 19 is an RSSI and SF approach, there is no equation or relationship between SF and RSSI in the equation, because SF talks about the time between Transmitter-receiver in sending data or signals. This is shown in equation 8. [16].

$$T_{sym} \text{ or } T_s = \frac{2^{SF}}{BW} \quad (8)$$

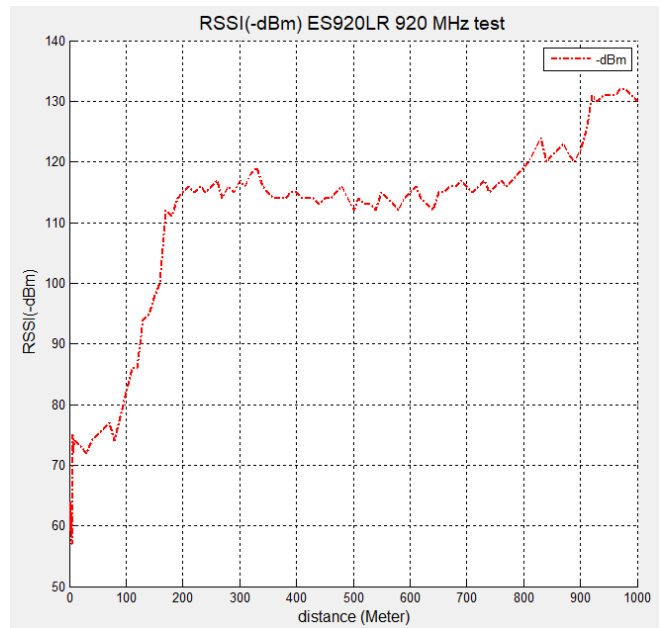


Fig. 18. RSSI (dBm) Real Experiment.

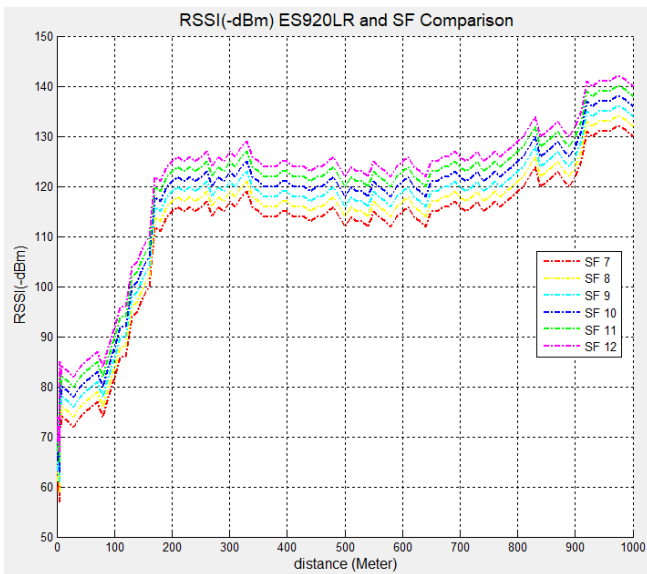


Fig. 19. SF and RSSI (dBm) Comparison.

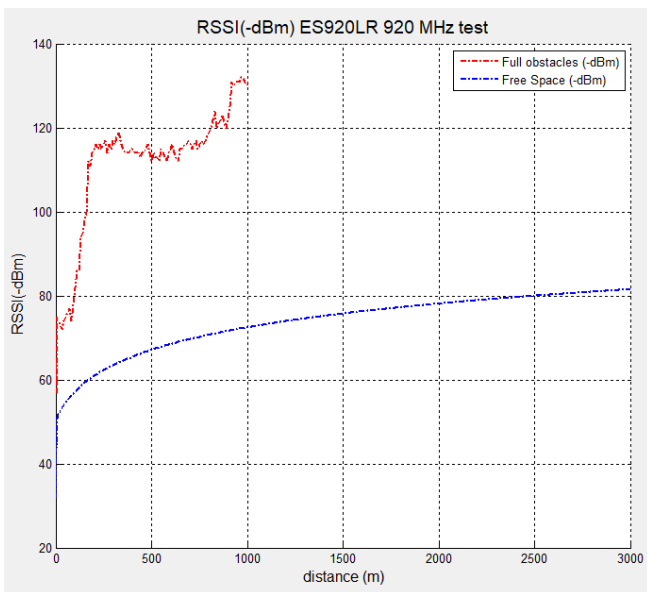


Fig. 20. FSPL and Obstacle (-dBm) RSSI Comparison.

Time is influenced by SF and BW, the greater SF (12), and the smaller the bandwidth, the greater travel time, and vice versa. This causes attenuation, the farther the distance between the transmitter and receiver (SF12). Then the weaker the signal produced, accordingly, the minimum RSSI is -120 dBm, so the greater the Spreading Factor (Fig. 2) [19], the weaker the signal produced.

Finally, if these signals are combined (Fig. 20), they will produce very different signals, between FSPL and full Obstacle, at a distance of 1000 meters, the full obstacle signal is lost and down. This is why the FSPL approach uses drones, the resulting value is indeed not significant on equations 4 and 5. However, it is close to the RSSI (-dBm) value.

In addition to using drones or FSPL [Fig. 17], testing is carried out using Tx and Rx ES920LR transmitting in areas of

buildings and trees [Fig. 18]. So that the comparison is obtained as in Fig. 20. Fig. 15 and Fig. 16 are output Chrip and Signal LoRa ES920LR in real-time using Signal Analyzer. The change in the Spreading Factor causes a change in Time on Air and causes an attenuation signal to the receiver (Pr) or RSSI (-dBm) shown in Fig. 19.

V. CONCLUSION

Receiving a Signal Strength indicator (RSSI) on the ES920LR generally decreases based on distance or Time On Air (ToA), so that ToA can cause attenuation signal strength. Free Space Path Loss (FSPL) is a condition where there are no obstacles and signals that are better than this experimental research where experiments are conducted with many obstacles e.g., buildings and trees. Furthermore, drones are the solution to get FSPL values on Propagation radio. In the full obstacle situation the ES920LR loses the LoRa signal at 1 km distance, but can be re-tested by changing the measurement area so that the mileage is in accordance with the LoRa ES920LR specifications.

VI. FUTURE WORK

End node devices have to the ability to long life or survive longer with a Power Supply Battery, and a wide range of distances, small and lightweight e.g., Leafony LoRa board for the drone, in the network design that is made there are additional gateways to reduce the load heavily of the gateway in accommodating the end node sensor data to maintain the stability and value of Packet Receive Ratio (PRR (%)).

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