Performance Evaluation of LoRa 923 MHz for the Internet of Things

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Submission date: 07-Mar-2025 09:43AM (UTC+0700)
Submission ID: 2607564820
File name: rmance_Evaluation_of_LoRa_923_MHz_for_the_Internet_of_Things.pdf (1.4M)
Word count: 3243
Character count: 17036

2024 IEEE 10th Information Technology International Seminar (ITIS)
Surabaya, Indonesia, November 6 – 8, 2024

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2024 IEEE 10th Information Technology International Seminar (ITIS) | 979-8-3315-2129-5/24/$31.00 ©2024 IEEE | DOI: 10.1109/ITIS64716.2024.10845693

***Abstract*— This research focuses on enhancing the performance of data transmission in the Internet of Things (IoT) by leveraging LoRa technology. Specifically, it utilizes the LILYGO 923 MHz LoRa32 board, which integrates the ESP32 microcontroller with a LoRa module and additional devices like a 0.96-inch OLED display. This board also features a serial converter interface, simplifying the programming process, and uses a micro USB connection for both power and uploading code. One of the goals of this research is to enable the transmission of images using LoRa, though currently, only image conversion during transmission is implemented. The study includes reliability testing of the LoRa module over a distance of 10 km. The results show that the Packet Delivery Ratio (PDR) for Spreading Factor (SF) 7 is 50%, while for SF 12, it improves to 85%. Additionally, the Received Signal Strength Indicator (RSSI) measurements at a distance of 1000 meters with 3 Non-Line-of-Sight (NLoS) conditions yielded values of -120 dBm, -90 dBm, and -78 dBm. These results highlight the potential of LoRa technology in improving IoT data transmission, especially for long-range applications.**

Keywords*— Internet of things, interface device technology, sensor node, LoRaWAN, ESP-module

I. Introduction

The development of LoRa and LoRaWAN is growing. The need for the Internet of Things (IoT) continues to be one of the fundamental needs, where researchers continue to develop the performance of IoT devices that are flexible, have excellent Quality of Service (quality of service), and can compete in various capabilities in transmitting data and also services on the server side. Powerful Uplink and Downlink processes, small delay (ms), good Throughput, low Packet Loss (bytes), and long Tx-Rx range.

Various expectations must be realized to develop good sensor node performance in future IoT technology. The application can be on multiple sides, including Smart City, Smart Car, V2X, or Vehicular Communication, even towards the Internet of Medical Things (IoMT) and Internet of Video Things (IoVT). Meanwhile, IoMT and IoVT require a wide bandwidth to transmit data. LoRa has a Bandwidth (BW) of 125 kHz BW, 250 kHz BW, and 500 kHz BW on some LoRa Chips such as ES920LR, RFM95, RFM96, and Ebyte LoRa using 125 kHz BW as the default Bandwidth Setting of LoRa Module [1,2,3,4].

Furthermore, The LoRa low Bit-Rate Telecommunication System is not only on the terrestrial communication side which has many disadvantages, some of which are communication systems that are built based on obstacles or obstacles that cause signal Attenuation, including Diffraction, Scattering, and Signal Reflection, as well as Losses from various components mentioned in the Budget Link. Line of Sight (LoS) and Non-Line of Sight (NLoS) situations affect telecommunications systems using terrestrial mode. Also, the position of Tx and Rx, whether it exceeds or is higher than the Fresnel Zone condition.

Moreover, talking about the Internet of Things [5,6,7,8] is related to how to build a system consisting of three main components: The Transmitter, Gateway, an Application Server Transmitter, in this case, the Node sensor; the Gateway is an important part of the process of forwarding data to the Application or Internet server until the data is obtained or viewed on the End User side or End Devices with internet connection. From the Transmitter side, the Antenna also influences it; the LoRa used in this research uses a 3 dBi SMA Antenna, meaning that it has a 3 dBi Antenna Gain that can forward the signal to the Receiver at a certain distance; previous tests were able to reach 3 km on Non-Line of Sight (NLoS) [9,10,11,12].

In this research, the LoRa Transmitter and Receiver type used a LILYGO LoRa32 with a Frequency of 923 MHz. Moreover, this paper is also expected to be able to be configured from the measurement side to see the characteristics of the LoRa Module that need to be analyzed. In this research, a spectrum analyzer is used to explore the types of signals generated by LoRa and its parameters completely. For example, using Textronix RSA can show the Chirp Spread Spectrum (CSS) completely and in detail. In studying LoRa Transmission and LoRaWAN [13,14,15,16], a detailed and comprehensive comparison between theoretical and practical is required. Several equations were used to analyze LoRa Communication. In Equation 1, the Bit Rate is one of the parameters used to determine the performance of Throughput at Rx LoRa. The greater Rb shows the quality of the Tx-Rx communication and a certain Spreading Factor value. The relationship between SF, Rb, and other parameters can be seen in Table 1.

II. Theory

A. LoRa Parameters

In performing the analysis step, a detailed analysis is required from various sides, including Bandwidth (BW), Code Rate (CR), Sensitivity (s), and Bit Rate (bytes) in Equation 1. Table 1 compares the overall bandwidth, CR, Sensitivity, and Bit Rate of several Radio Frequency modules.

Moreover, Equation 2 shows the LoRa sensitivity (S). Equations 3 and 4 show the LoRa power receiver (Prx). Equations 5, 6, and 7 show the LoRa transmission approach's Fresnel zone.

TABLE I. SF, BW, CR, SENSITIVITY, AND BIT-RATE COMPARISON OF WIRELESS TECHNOLOGY

Technology	Rasio Signal -to-Noise (SF)	Bandwidth (BW)	Code Rate (CR)	Sensitivity (dB)	Bit-Rate (bytes)
WiFi	No direct SF	20 MHz - 160 MHz	1/2, 2/3, 3/4 (varies)	-80 dBm (typical)	0.375 - 250 MBps
LoRa	7 to 12	125 kHz - 500 kHz	Reed-Solomon (varies) example 4/5, or 4/6	-137 dBm (SF12)	0.0375 - 3.375 KBps
NB-IoT	No direct SF	180 kHz	LTE-like (varies)	-140 dBm	2.5 - 31.25 KBps
Sigfox	No direct SF	100 Hz (uplink), 600 Hz (downlink)	Custom coding	-148 dBm (uplink)	0.0125 - 0.075 KBps

```
[Rb]_LILYGO32=(4/(4+CR))/((2^(SF ))/BW) 1000   [1]

S = -174 + 10 [Log]_10 BW + NF + SNR   [2]

P_(rx_LILYGO32 ) (dBm) = P_(rx_LILYGO32 ) (dBm) + G_([LILYGO32]_ system) (dB) - L_([LILYGO32]_ system) (dB) - L_([LILYGO32]_ Channel) (dB) - M(dB)   [3]

P_(rx_LILYGO32) (dBm) = P_(rx_LILYGO32) (dBm) + S_LILYGO32 (dBm) [4]
L (fs) = 32,45 + 20 log[(D) + 20 log (f)] [5]
r = 8,657 x sqrt (D/f) [6]
H = (1000 x D^2) / (8 x R_bumi) [7]

ERP = Daya Tx (dBm) + Antenna Gain (dBi) - Cable losses (dBm)[8]

SNR (dB) = P_( signal_ received) (dBm) - P_noise (dBm)[9]
T_Preamble = (n_ Preamble + 4.25) * Tsym [10]

PayloadSymbNb=8+max (Ceil((8PL-4SF+28+16-20H)/4(SF-2DE) )(CR+4),0) [11]
T_Payload = payloadSymbNb * Tsym [12]
T_Packet = T_Preamble + T_payload [13]
T_Sym = 2 ^ SF / BW [14]
```

The value of Receiver Power can be seen in equations 3 and 4. Conditions without obstacles can be referred to as Non-Line of Sight (NLoS) or Free Space Path Loss, which can be seen in Equation 5. Some approaches, such as Fresnel Zone, can be seen in equations 6 and 7. Effective Radiated Power can be seen in equation 8. In addition to RSSI, SNR is also essential, as seen in equation 9 [17,18,19,20]. The preamble and payload of LoRa, as well as parameters for Time on Air and Payload such as Tpacket and Tsymbol, can be seen in equations 10, 11, 12, 13, and 14.

III. Method

The overall picture can be seen in Figure 1, the system flowchart. We can see carefully two things: from the measurement side with Signal Analyzers and also on the Application Server side.

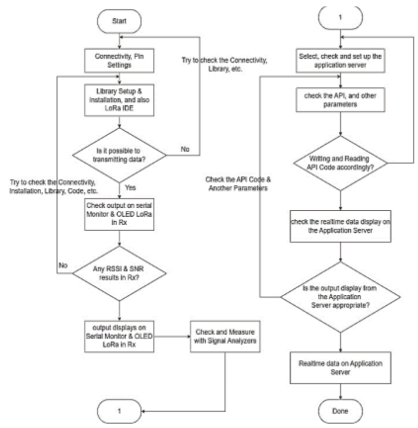

Fig. 1. The flowchart in this system

IV. Result and Discussion

A. LoRa OLED LED 920 MHz Transceiver

In this section, I will emphasize more the setup side of the Tx and Rx module [Figures 2, 3, and 4], the module use a LoRa LILYGO LoRa32 with 923 MHz frequency and measurements using spectrum analyzers and also testing RSSI (-dBm) and SNR (-dB), as well as other analysis.

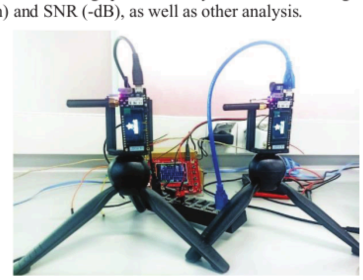

Fig. 2. Example of Transmitter and Receiver LoRa LILYGO LoRa32 923 MHz.

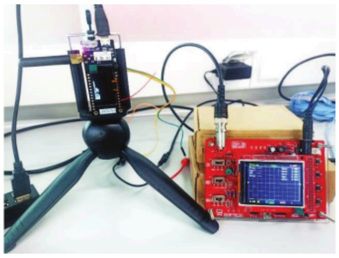

Fig. 3. Receiver LoRa LILYGO LoRa32 923 MHz with Mini Oscilloscope to see Voltage (VDC)

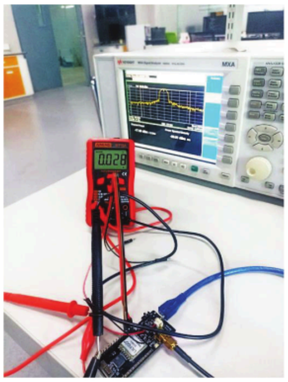

Fig. 4. Transmitter LoRa LILYGO LoRa32 923 MHz with Spectrum Analyzer and Multi Meter indicates Current (mA) is 28-30 mA

Moreover, in LoRa measurement and LoRaWAN management, there is a gap in research that must be monitored and examined carefully, starting from how to do practical and theoretical analysis coupled with the right measurement system at the time of measurement. In this case, it is also necessary to have the right methods to carry out the measurement system and ensure the accuracy in the Tx-Rx data transmission process using the LoRa Module and the process when using the Method or Algorithm.

B. *Analyzer Spectrum Testing LoRa using Spectrum Analyzer*

Tests such as Signal Power, Chirp Spread Spectrum (CSS), Bandwidth (BW), and other parameters will be comprehensively tested on the Spectrum Analyzer side [Figures 5, 6, and 7]. Figures 8 and 9 are the output during the image transmission test that has been converted using bytes data transmission.

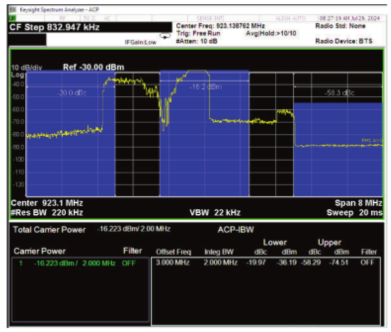

Fig. 5. SF 7 dan SF 12 Realibility of LoRa

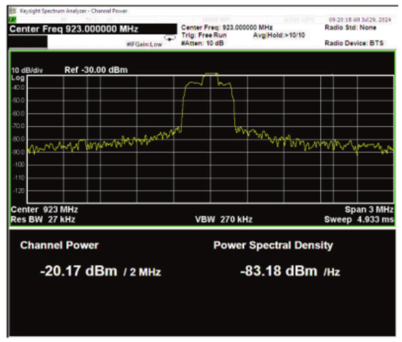

Fig. 6. Spectrum LoRa at Frequency Center 923 MHz LoRa detected using Spectrum Analyzer

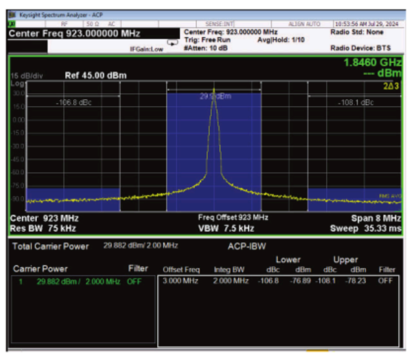

Fig. 7. Spectrum LoRa and Average Power at Frequency Center 923 MHz LoRa and Bandwidth (BW)

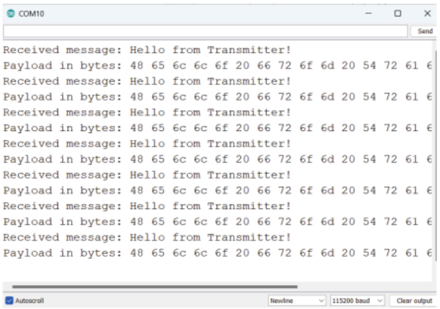

Fig. 8. Data with Payload in bytes

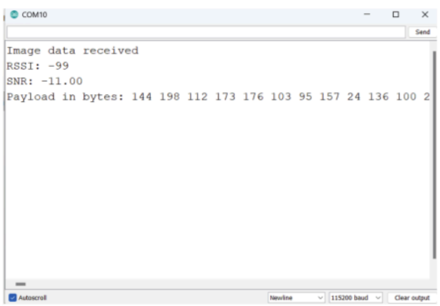

Fig. 9. Data with Payload in bytes

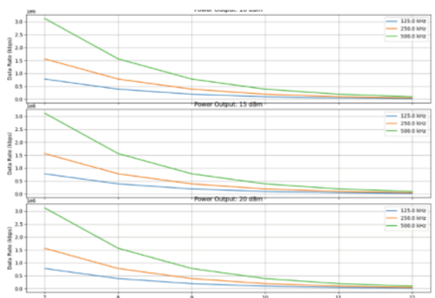

Fig. 10. Data-rate LoRa Comparison

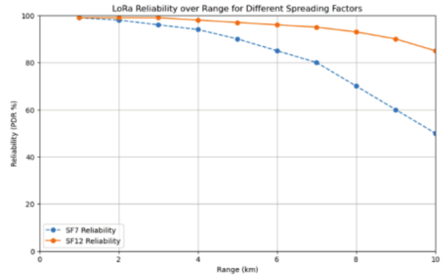

Fig. 11. SF 7 dan SF 12 Realibility of LoRa

Figures 8 and 9 are examples of output at the Receiver, when testing data with a certain payload, we can see how much data is successfully sent and lost, this depends on the tx and rx positions, as well as other factors such as signal attenuation, and the amount of payload data sent, Figure 16 shows that the RSSI and SNR parameters are an indicator of the quality of the transmitted signal and the resulting payload in bytes, this can be used for transmitting image data by going through a series of character conversion and bytes conversion processes. Figure 10 shows a comparison of data rates at different bandwidths of 125 kHz, 250 kHz, and 500 kHz; it can be seen that the greater the bandwidth will determine the amount of data rate generated and passed in the process of transmitting data; this determines the type of data whether images or sensor data only. Figure 11 will determine the amount of reliability (PDR) % that can occur with the use of the Spreading Factor, for example, the comparison of SF7 and SF12, where the greater the distance determines attenuation. The greater the distance between Tx and Rx determines the reduction in PDR, in the data seen to reach 50%.

As additional data that LoRa can be tested from the RSSI value (-dBm) at a certain distance with NLoS (Non Line of Sight) conditions when sending data takes place, if the RSSI value> -120 dBm, it is certain that data transmission will be error and data is not sent at all, so that the measurements in Figure 12 can be used as a reference to the extent to which data can be sent using the LoRa Module.

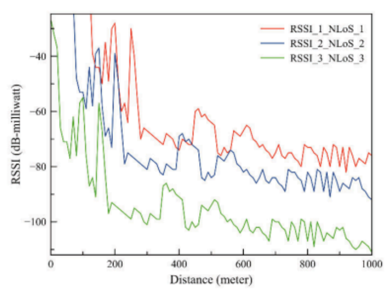

Fig. 12. NLoS data of LoRa

V. Conclusion

This 920 MHz LoRa LILYGO LoRa32 works at 125 kHz Bandwidth when sending a 10x10 px image with a bytes array conversion. It still takes a very long time, and the data that successfully enters the Receiver has a bytes array long enough for 1 image. It is still possible to do. However, it takes a long time, and it is not certain that this image is still intact or requires time. Also, there should not be a large byte rate or PER (%) error because this determines the integrity of each transmitted image structure. The development of the LILYGO version of LoRa can be used in the Application Server to support the Internet of Things (IoT) by paying attention to several factors, namely the method and accuracy of the Application Server. For example, in managing transmitting data on the server, MQTT can be used as one of the method options, and other Application Servers that are Free or Open Source can be tried; this is a suggestion.

Acknowledgment

Thanks to the entire team who participated in the completion of this research in terms of funds, as well as research data that was very useful for completing this research, I hope that this research is useful for many people so that science, especially about Internet of Thing Development, is growing, such as the Internet of Video Things, and the Internet of Medical Things. And hopefully, this research will also be cited by many people.

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