Effect of Vegetation Profile and Air Data Rate on Packet Loss Performance of LoRa E32-30dBm 433 MHz as a Wireless Data Transmission

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Abstract. Internet of Things (IoT) communication network is currently one of the rapidly expanding uses a technology called the Long Range (LoRa) module using unlicensed industrial, scientific, and medical (ISM) radio frequencies. For sensor data transmission, the propagation depends on many parameters, such as transmit power, antenna, and vegetation obstacles on the propagation path. This work presents a 30 dBm LoRa E32-433T30D module of 433 MHz used for biosensor data transmission. LoRa performance testing was carried out in obstacle-dense areas (NLoS) of the Tempuling forest Riau that varies the distance parameters, and the programmable transmission speed (ADR) ranges from 1.2 Kbps to 9.2 Kbps. Results show that the higher the ADR value, the shorter the signal range, which is represented by the increase of the packet loss number. The highest ADR value is 19.2 Kbps signal coverage is only able to cover a distance of 1.4 Km with a data loss number of 86 %, while for 1.2 Kbps experiences a data loss of 20 % at a distance of 2 Km. The highest signal strength RSSI value was obtained at -67 dBm at a distance of 200 m and the lowest at -102 dBm at a distance of 2 Km. The decrease in RSSI value is caused by attenuation and signal interference from the obstacle height that exceeds the height of the antenna.

1. Introduction

The LoRa module is one technology that is rapidly developing and evaluated as an implementation of the Low-Power-Wide-Area Network (LPWAN) in supporting the Internet of Things (IoT) communication network. LoRa technology is produced by the SemTech Company as an open-source network to support its growth and utilization. The LoRa signal propagation system is modulated using unlicensed industrial, science, and medical radio (ISM) bands. The ISM frequency that is relevant and most commonly used is 868 MHz in Europe and 915 MHz in the United States, whereas, in Asia, the ISM band used to test LoRa applications is 433 MHz [1, 2].

LoRa uses the Chirp Spread Spectrum (CSS) technique, which uses a frequency band to send each symbol. In this technique, chirp pulses such as sinusoidal pulses, which have variable frequencies, modulate the signal. This CSS modulation increases LoRa resistance to interference, Doppler and multipath effects, and environmental influences that affect LoRa signal propagation. The environmental impact on the performance of the LoRa signal has been analyzed in several previous studies. Research by [3,4] examines the LoRa signal propagation at 868 MHz modulations, while Transviñav [5] compares the performance of LoRa modulation in Europe between 868 MHz and 433 MHz. Studies on LoRa performance are also carried out in urban environments [6, 7], maritime [3], mountainous areas [8], and even in snow and frost areas that cover polar regions [9]. In [10], the effects of temperature, PHY Physical Layer, and channel characteristics on indoor, outdoor, and...
underground environments on LoRa propagation has been observed in a broader scope. Ahmed [11] shows that LoRa is susceptible to the presence of vegetation. However, there has not been much research discussing data propagation of LoRa caused by vegetation in the transmission path that has been considered.

The main objective of this study is to present the propagation performance of the LoRa E32 modulation with a power of 30 dBm of 433 MHz in the Non-LOS area in a tropical forest environment. The structure of vegetation components such as density or tree height and leaf surface width is very susceptible to interference in the propagation of the LoRa signal; disturbances in this transmission system can reduce the quality of data received by the receiver. One solution that can be made to overcome this problem is to modify the parameters of the LoRa transmission system architecture such as bandwidth, code rate, spreading factor, and transmission power. Parameter modification can reduce packet loss, but the consequences of each parameter also need to be considered. Therefore, this experiment uses a variation of Air Data Rate, which is an overall representation of the LoRa parameter with values of 1.2, 2.4, 4.8, 9.6, and 19.2 Kbps in the Non-Line of Sight (NLoS) area. These preliminary results can trigger further analysis in understanding the environmental impact of vegetation on LoRa performance.

2. The Architecture of Transmission System

2.1. Frequency-Based CSS Modulation Techniques

LoRa uses linear wideband frequency-based CSS modulation techniques that can increase receiver sensitivity and tolerance of communication errors between the receiver (Rx) and transmitter (Tx) [9]. This LoRa CSS technique is the main factor in the long-distance signal transfer method with high-quality connections, even when the signal power is up to 20 dB lower than the noise floor [12,13].

![Figure 1](image_url)  
*Figure 1. The data encoding process of LoRa signal [1]*

Figure 1 shows the LoRa signal coding process using CSS technique, which consists of 2 signal parts, namely up-chirps; a change in frequency from low to high and down-chirps; a decrease in frequency from high to low. The first part of the preamble spectrogram depicted in Fig. 1 consists of five up-chirps that are used to detect LoRa Chirp and two down-chirps as time synchronization and subsequently are modulated signal data.

The LoRa has the advantage of a continuous phase flanked by altered chirp in the preamble section of the PHY LoRa, which enables simpler and more accurate time and frequency synchronization. Single LoRa gateway covers an area of hundreds of square kilometres [14]. LoRa technology has several key features among others and scalability in bandwidth, which can be used in narrowband and wideband services with some configuration changes. LoRa has exceptional reliability because it can withstand the Doppler Effect, multipath, fading mechanism, and other interference mechanisms [15]. The LoRa protocol is specifically intended for low power consumption that extends battery life up to 20 years [16], in addition to that LoRa uses the FSK (shift keying frequency) method in demodulating signals located 19.5 dB under the noise floor. Conversely, other network technologies are usually only able to demodulate signals with a strength range from 8db to 10 dB beyond the noise floor [10].
2.2. Physical layer (PHY)

The LoRa performance can be designed by setting PHY parameters configured into 6720 different settings that offer various options in maximizing signal quality or reducing the level of energy consumption [17]. These essential parameters are spreading factor (SF), bandwidth (BW), encoding rate (CR), and transmission speed (ADR).

a. Spreading Factor (SF)

SF is the ratio between the symbol rate and chip rate, which has a value between 6 to 12 [18]. Each SF has 2SF chips per symbol, which has significant effects on energy consumption represented by the communication range. Therefore, modifying SF is more useful to reduce energy consumption and to maintain a wide coverage communication range. Greater SF can increase communication sensitivity and data bit rate and reduce Time on Air (TOA).

b. Bandwidth (BW)

BW is the frequency range available for the 433 MHz LoRa transmission that has magnitude depending on the frequency width of fmin and fmax, as shown in Figure 1. Besides, BW represents the variation rate of the chip per unit time (Rc), the value of Rc = BW, a more significant value of BW allows the transmission to have higher data rates however with lower TOA and lower sensitivity. Conversely, lower BW allows higher sensitivity but decreases the data bitrate. Instead, the bandwidth can be selected in ranges of 7.8 kHz to 500 kHz range, LoRa networks typically operate at 500 kHz, 250 kHz, or 125 kHz lower than Local Area Networks (LANs) such as Wi-Fi or Bluetooth.

c. Coding-Rate (CR)

Coding Rate (CR) is a form of Forward Error Correction (FEC), which allows the recovery of bits of information due to corrupt affected by interference that requires the addition of data encoding in packets sent [9]. CR is expressed in fractional numbers as shown in equation 1.

\[
CR = \frac{4}{4+n}
\quad (1)
\]

n is an integer of 1,2,3 and 4. Larger CR can increase data reliability and resistance to damaged bits but increases TOA and power consumption [4].

2.2.1. Air Data Rate (ADR)

ADR or bit rate is the LoRa speed factor in sending data, the higher the ADR value, the faster the transmission speed, and lower TOA but the transmission range will decrease. ADR is part of the more general PHY because it consists of SF, BW, and CR as in equation (2).

\[
ADR = SF \times \frac{BW}{2^{SF}} \times CR
\quad (2)
\]

ADR values range from 0.3 Kbps to 19.2 kbps, which can be set programmable. The default value is 2.4 kbps, but it can be set to the lowest recommended value of 1.2 kbps. A value of 0.3 gives a prolonged data transmission result.

2.3. Range Strange Signal Indicator (RSSI)

RSSI indicates the received signal quality from the transmitter, which represents an indicator of signal strength. The RSSI value can be determined through equation (3).

\[
RSSI(dBm) = -10 \cdot n \cdot \log_{10}(d) + A
\quad (3)
\]

Equation (3) shows RSSI as a function of distance in dBm, n is an exponent path loss constant depends on the environment, d is the distance between Tx and Rx, and A is the receiver power at a distance of 1 meter.
2.4. Vegetation Profile and NLOS Conditions

The propagating wave mechanism can be complex due to the tree structure formed by different types of leaves, stems, and branches. The structure of tropical forest vegetation is shown in Figure 2. Tropical forests consist of bushes 1 m to 2 m high and trees with an average height of 3 m to 12 m [19]. Loss of power can occur through scattering, fraction, reflection, multipath dispersion when radio waves travel in a vegetation environment. Foliage attenuation differs based on wind, humidity, and vegetation thickness. It can be predicted that in tropical vegetation areas, the foliage attenuation will be higher than the attenuation in vegetation areas far from the equator. This attenuation is due to tree leaves wider in tropical environments, whereas leaves in much sub-tropical regions have needle-like leaves [20].

![Figure 2. Tropical forest vegetation](image)

The Non-Line-of-Sight (NLoS) condition is defined when the transmitted signal reaches the receiving antenna not only by direct path but by other means such as reflection and diffraction. One of the features of LoRa is its ability to work well on multipath channels so that the signal can be received even after crossing two or more building walls. Besides, low frequencies provide good penetration in brick, tree, and concrete walls so that these frequencies usually have fewer losses than high-frequency bands [21].

3. Research Methods

3.1. Block Diagram and LoRa Electronic System Design

This experiment uses a 30 dBm LoRa E32-433T30D module with a frequency of 433 MHz which adopts the SX-1278 chip from SEMTECH company. This module is equipped with an omnidirectional antenna that has a gain of 4 dBi integrated with the ATmega8 Microcontroller (MCU) minimum system. Figure 3 shows the block diagram of measurement.

![Figure 3. Block diagram of the measurement](image)
Figure 4. System electronics of LoRa E32 Module

Figure 4 illustrates the block diagram of the LoRa test and the developed LoRa electronic system. The minimum system is a simple electronic circuit system needed for the MCU to work, which has the advantage to reduce battery consumption for long-operation in an environment without electricity. The minimum system is used to control serial data via the UART connection found on the DIO port and the PHY parameter regulator of the LoRa module. This device is supplied with a 5 VDC to activate the microcontroller and 3.3 V for the LoRa module.

3.2. Measurement Set-up
3.2.1. Location
LoRa performance testing was conducted in the forest area of Tempuling Indragiri Hilir Riau (coordinates 0°25′30.0″ S 103°00′24.9″ E). This forest categorized as obstacle-dense areas (NLoS) consists of a collection of trees with an average height of 12 meters with very tight leaves, as shown in Figure 5.

Figure 5. LoRa measurement points with varying distances (Tx =30 dBm)

The transmitter and receiver antenna were mounted at the height of 200 cm and 100 cm above the ground, respectively. The maximum distance between Tx and Rx was 2 km with a 200 m increase for each measurement.
3.2.2. PHY and Data Package Settings
The parameters varied in this experiment include the distance between Tx and Rx and the Air Data Rate (ADR) of the LoRa module, which is programmable. The ADR setting variations for each measurement distance are shown in Table 1. The smallest setting ADR = 0.3 was not used since the TOA value is too high implies slower the data transmission speed is.

| Tx Power (dBm) | ADR (Kbps) | BW(kHz) | SF | CR |
|----------------|------------|---------|----|----|
| 30             | 1.2        | 250     | 11 | 4/5|
| (default)      | 2.4        | 500     | 11 | 4/5|
| 4.8            | 4.8        | 250     | 8  | 4/6|
| 9.6            | 9.6        | 500     | 8  | 4/6|
| 19.2           | 19.2       | 500     | 7  | 4/6|

ADR presents the PHY parameter of the LoRa module consisting of SF, BW, and CR, which determines the transmission range and the amount of data received by Rx. Data packet structure (payload) is transmitted in the form of 28 bytes characters and divided into the first 12 bytes time (hours, minutes, and seconds) and the next 16 bytes denote data packet numbers. The maximum payload that can be sent by LoRa E32 is 58 bytes per data packet. This experiment was carried out by sending 50 data packets in one distance measurement at 2-second intervals/data. The transceiver is set not to retransmit lost data so that the number of data packets received by Rx can be accurately identified.

The performance of LoRa in this experiment is evaluated by comparing the number of packet data lost (Packet Loss) against the amount of initial data transmitted by Tx, after (4).

\[
\text{Packet Loss} = \frac{\sum \text{Data loss}}{\sum \text{Data transmitted}} \times 100\% \tag{4}
\]

Eq. (5) shows, the smaller the percentage of lost packages, the higher the reliability level of LoRa E32-30 dBm as a low-power wireless device.

4. Results and Discussion
The performance characteristics of the LoRa module in the Forest area with various ADR variations are shown in Figure 5.

![Figure 5. Comparison of packet loss to the distance for each ADR increase](image)

ADR values vary from 1.2 Kbps to 19.2 Kbps with a maximum communication distance of 2 Km. The experimental results show the higher the ADR used, the shorter the signal range, which is
indicated by the increasing amount of packet loss. An ADR 19.2 Kbps signal coverage is only able to cover a distance of 1.4 Km with data loss of 86%, for ADR 9.6 Kbps and 4.8 Kbps increase the packet loss value of more than 50% at a distance of 2 Km. While the default ADR of 2.4 Kbps and 1.2 Kbps experienced data loss of 48% and 20% at a distance of 2 Km.

**Table 2. Effective working range of local ADR E32-30 dBm in the NLOS area**

| No. | ADR (Kbps) | Range efektif (m) | Packet loss (%) |
|-----|------------|-------------------|-----------------|
| 1.  | 19.2       | 200               | 8               |
| 2.  | 9.6        | 600               | 6               |
| 3.  | 4.8        | 1000              | 2               |
| 4.  | 2.4        | 1400              | 6               |
| 5.  | 1.2        | 1600              | 10              |

The effective working range is the amount of data received ≥ 90% for each ADR, as shown in table 2. Increasing the amount of packet loss implies a decrease in the level of signal strength (RSSI), which represents the ability of Rx to receive the transmitted signal. Figure 5 shows a significant decrease in RSSI as the distance between Tx and Rx increases.

![Figure 6. The decrease in RSSI value due to the increased transmission distance of Tx](image)

The RSSI value is obtained after equation (4) which is affected by distance, not from SF that belongs to ADR. The more positive the RSSI value, the better the signal strength [16]. This experiment shows the highest overall RSSI value is -67 dBm at a distance of 200 m and -102 dBm at a distance of 2 Km. The decrease in RSSI value is due to attenuation and signal interference from the NLOS environment and obstacle height that exceeds the height of the Tx antenna. Compared to the research conducted [16], this experiment obtained a more extended signal range because of the different types of LoRa used and the transmission power used is quite large, about 30 dBm.

5. **Conclusion**

LoRa performance in the NLOS area varies for each ADR, where the lower ADR has a wider signal range and lower packet loss. The highest ADR value is 19.2 Kbps signal coverage is only able to cover a distance of 1.4 Km with a data loss number of 86%, while for 1.2 Kbps experiences a data loss of 20% at a distance of 2 Km. The highest signal strength RSSI value was obtained at -67 dBm at a distance of 200 m and the lowest at -102 dBm at a distance of 2 Km. The decrease in RSSI value is affected by attenuation and signal interference from the obstacle height that exceeds the height of the antenna. Overall, this experiment demonstrates that LoRa can be used in forested areas with high vegetation as an implementation of Wireless Sensor Networks (JSN) in remote areas.
Acknowledgments
The authors acknowledge the Ministry of Research, Technology, and Higher Education for their funding through the 2020 DRPM Basic Research Program with the theme Biosensor, contract no. 163/SP2H/AMD/LT/DRPM/2020.

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