Feasibility test on the performance of LoRa technology incorporated in the wireless sensor network

R P Astutik* and H A Winarno

Department of Electrical, Faculty of Engineering, Universitas Muhammadiyah Gresik, Gresik, Indonesia.

*Email: astutik_rpa@umg.ac.id

Abstract. Wireless Sensor Network (WSN) and Internet of Things (IoT) technologies are developed rapidly in many implementations such as smart cities, smart offices, and smart transportations. They are closely related to communication technology which requires efficient power and covered long distance. To overcome these two problems, this paper proposes the design of a communication system for WSN using LoRa technology that has the ability to receiving lower power and wider area coverage. In this research, the implementation of this communication design is just a prototype that contains two nodes that communicate with each other by using LoRa technology as a communication system. The experiment which was based on measurement had the maximum distance of a point to point communication that reached about 200 m while the lowest received power was accounted at -98 dB. The use of the best spreading factor based on simulation was recorded at 7 using a bandwidth of 250 kbps and 10 using a bandwidth of 125 kbps. Showing the result, it can be concluded that 200 m was the longest distance which can be achieved by this prototype and this was useful for a small system.

1. Introduction
The development of communication system design is currently very rapid and sometimes it is needed to get information quickly also sometimes from a place that is very impossible for humans to retrieve data. One of the designs of the communication system is the incorporated WSN and IoT systems that form a network. This network usually contains an IP (Internet Protocol) network, some devices such as sensors or actuators, telecommunication interface devices, data processing, and storage units [1]. The network model of IP address with many nodes will cost a lot therefore it needs to replace it with technology that uses lower power and wide range.

Various communication devices have been implemented such as [2] discussed communication system model using Zigbee for determining the position of the node. The other implementation is as [3] discussed regarding monitoring air pollution in Gresik, Indonesia using Wi-Fi connection for communication. In this research, the longest distance which each node still could communicate was only 110 m. With this drawback, we try to use LoRa technology as a transceiver in this research. The same discussion which is about temperature monitoring in a data center used LoRa technology that was integrated with WSN [4]. Meanwhile, several papers discuss the performance of LoRa technology in different perspectives such as in [5], it discussed the evaluation of coverage model and channel attenuation for LoRa technology on wide area networks with low power. The analysis of feasibility
WSN using LoRa has discussed in [6] by collecting data obtained from vehicles and submitted to the central node for further processing. However, this paper did not discuss the Doppler Effect. Another paper investigated the limits of LoRa network capacity and the result was LoRa networks could measure fairly well with a note if they used dynamic communication parameter selection and multiple sinks. [7] Beside the limits of LoRa networks capacity, the evaluation performance of LoRa networks also has discussed in [8] with analyzing of total packet collisions that occurred and the result of the maximum total nodes that can communicate on LoRa channel can be determined by considering the duty cycle restrictions.

LoRa technology integrated with WSN has used in many applications either in the rural or urban areas, especially in wide-area since it can cover for wide areas. To explore the performance of LoRa technology, it needs to hold some tests on how far it can cover areas as well as how much cost needed. In this paper, the discussion focuses on the performance evaluation of the integrated LoRa technology in the WSN by testing the feasibility of its system performance. The feasibility of this work is indicated by distance and RSSI (Received Signal Strength Indicator) measurement, packet loss and variations of spreading factor. This paper is organized as follows the first section will discuss the introduction contained in the background of this work, some related work and the aim of this work. The next section will discuss WSN and LoRa technology also link budget analysis. The third section will explain the design of in communication system for WSN using LoRa technology and the following section will share the experiment result.

2. WSN and LoRa technology

In designing communication systems for networks, several components are needed. These components are generally divided into three parts, namely the sensor subsystem, the processor subsystem, and the communication subsystem. The detail discussion for three parts will be explained in the following subsections.

2.1. Wireless Sensor Network

WSN is a number of sensors that are interconnected and have a function to control and process data directly in an area. The more sensors that communicate, efficient protocols are needed to support bringing data collection to the center wirelessly. A WSN is not only sensing components but also a board that has a processing unit, storage data and can communicate with each other. A node as part of WSN is divided into three parts, the first part is for the sensing unit, the second part is for processing data and the third part is a communication device. The architecture of a node can be shown in Figure 1 [9].

![Figure 1. The architecture of a node as part of WSN](image)

The sensor subsystem serves to get data sensing from one or more sensors and integrates it for future processing. It contains a sensor, analog to digital converter (ADC) board and serial-parallel interface (SPI) as connecting to the main processor. The sensor is used to retrieve data from the environment such as temperature, humidity etc. Since the sensing data from the environment is analog data, so an analog to digital converter device is needed for the next process. SPI is needed to connect
the sensor subsystem to the processor subsystem, so data from the environment can process on the main processor.

The processor subsystem is the brain of a wireless sensor network which in this part, data processing will be obtained from the sensing subsystem. The main purpose of the processing subsystem is to execute commands related to sensing, communication, and self-organization. It consists of a processor chip, internal flash memory which is used to store command programs, active memory for the temporary storage of sensed data.

The communication subsystem is one of the factors that affect the performance and energy efficiency of wireless sensor networks. This performance is indicated by fast transferring data transmission between all of the nodes in the wireless sensor networks while the energy used for the data transfer process is the lowest.

2.2. LoRa technology

LoRa (Long Range) technology is one of the technologies communication that has long-range coverage area and lower power consumption. LoRa node is divided into three classes, they are A, B and C which each class has a different specification [8]. A class LoRa node has functions to send messages to other nodes for a certain period of time depending on the application used. After sending the message, the other device sends the acknowledgment message (ACK) to let the LoRa node know its message was successfully received while the LoRa device opens a slot of reception. The other node will either continue the process of the data or forward it to other nodes again depends on the needed. B class LoRa node is the extension of class A, by adding the scheduling system to open the acceptance slot so communication between nodes can be organized. C class LoRa node is the prolongation of class A when the message is sent then the receiving slots will always keep open to receive the ACK or other commands. Based on the mechanism of transfer data then A and B class use battery while C class uses an electrical network since it consumes a lot of energy.

LoRa technology uses spread spectrum modulation techniques created by Semtech. This modulation technique provides two-way communication through a special CSS (Chirp Spread Spectrum) mechanism that spreads narrowband signals over a larger frequency band with integrated FEC (Forward Error Correction). The sent message is formed into a packet message with structure as shown in Figure 2 [7].

![Figure 2. The structure of packet data using LoRa technology](image)

The structure of the packet message consists of preamble, header, payload, and CRC which is each part has different size bytes. The preamble is contained from 6 to 65535 symbols and it can be programmed, meanwhile, the header is just optional and always transmitted with a 4/8 FEC rate and its own CRC. The next header is payload and following by an optional 16-bit CRC. The symbols total, in the packet message, is called Spreading Factor which can be varied between 6 and 12.

There are five parameters in LoRa radio, namely Transmission Power, Carrier Frequency, Spreading Factor, Bandwidth and Coding Rate. To get the best performance by minimizing power consumption and noise resistance then it needs to determine those parameters. The variation of each parameter can be seen in Table 1.
Table 1. LoRa radio parameter

| Parameter           | Value                                                                 |
|---------------------|----------------------------------------------------------------------|
| Transmission Power  | -4 dBm to 20 dBm                                                     |
| Carrier Frequency   | 860 MHz to 1020 MHz with step 61 MHz depending on the chip           |
| Spreading Factor    | 6 to 12                                                              |
| Bandwidth           | 7.8 kHz to 500 kHz                                                  |
| Coding Rate         | 4/5, 4/6, 4/7 or 4/8                                                 |

LoRa modulation technology uses the chirp spread spectrum, this results in an increase and decrease in frequency during a certain time based on the encoded information. By using this modulation, the signal is resistant to interference since high frequency used and robust to face multipath fading due to the use of broadband chirps. Another effect is the maximum link budget of this technology modulation is 157dB so that the communication range can be longer and save energy. It is as said that LoRa as Long Range communication.

3. Design of communication system for WSN using LoRa technology

The design of the communication system on this project focuses on the performance of a communication system where there are some points to be reviewed, they are linked budget calculation based on theory and practice, model modulation used and packet losses. The following paragraphs are explained in detail for the design model and the basis of the system feasibility analysis.

3.1. Design hardware of LoRa-based WSN technology

In this project, two nodes are built where each node consists of a microcontroller, temperature and humidity sensors, LoRa as a transceiver and power bank as a source of electricity. This design can be seen in Figure 3.

![Indoor Design](image1) ![Outdoor Design](image2)

**Figure 3.** Design two node with LoRa technology (a) Indoor Design and (b) Outdoor Design

The hardware of each node consists of a DHT11 sensor, LCD, Arduino, and LoRa also power banks for the electrical resources. Some scripts for sending/receiving temperature and humidity data and also detect the signal strength of each node have been filled into each node. After that, each node is turned on and separated with a certain distance then checked the receiving data. Both data will appear in each of both nodes so it will be known that both nodes have communicated.

3.2. Link budget analysis

One indicator of network feasibility is propagation performance which with this we will know how far the coverage area based on frequency owned by LoRa and the received power was performed. The propagation performance depends on path loss, showing and multipath fading that occurs on the channel of wireless communication. The received power of link budget analysis can be calculated based on Equation (1) where $PT$ is the transmitted power, $GT$ is the transmitted gain, $GR$ is the received gain and $LP$ is the path loss of the link between transmitter node and received node.
\[ P_R = P_T + G_T + G_R - L_P \]  \hspace{1cm} (1)

Regarding the path loss, based on [6], the LoRa model of propagation has not been determined yet, nevertheless based on the Okumura-Hatta model, it can be calculated in (2) for wireless communication in the urban environment.

\[ L_P = 69.55 + 26.16 \log_{10}(f) - 13.82 \log_{10}(h_T) - a(h_R) + (44.9 - 6.55 \log_{10}(h_T)) \log_{10}(d) \]  \hspace{1cm} (2)

Where the correction parameter an \((h_R)\) is obtained from (3), \(f\) is the frequency used and \(h_T\) and \(h_R\) are the height of transmitter and receiver antenna. Since the area is for urban or suburban even a country then \(d\) is for the distance between transmitter and receiver in kilometers.

\[ a(h_R) = 3.2 \left( \log_2 \left( 11.75 h_R \right) \right)^2 - 4.97 \]  \hspace{1cm} (3)

3.3. Doppler effect

The Doppler Effect is the change in frequency or wavelength of a wave in relation to an observer who is moving relative to the wave source. The direction and the velocity of the source’s movement is determined the different of Doppler effect. This is can be used for another indicator of performance in LoRa technology by comparing between coherence time \((t_c)\) and symbol time \((t_s)\). Both times can be determined by (4) and (5) [10].

\[ t_c = \frac{2\pi}{\omega_D} \]  \hspace{1cm} (4)

where \(\omega_D\) is the angular frequency shift caused by Doppler Effect

\[ t_s = \frac{2SF}{BW} \]  \hspace{1cm} (5)

Where SF is spreading factor and BW is bandwidth, the relation of \(t_c\) and SF is \(t_s\) will double when SF is increased by one, in this case, bandwidth does not change. The Doppler Effect that triggers fast fading will cause signal distortion and it will happen when the symbol time more than the coherence time.

4. Results

The first examination is measuring the signal strength of LoRa versus the distance and getting results as the graph shown in Figure. 4. It can be seen that based on measurement, the signal strength plummeted while the distance was extended and the worst signal strength in this experience result fell to -98 dBm when the distance was 200 m. This achievement was almost as two times as previous research [3] which was reached at 110 m.
Figure 4. Experience result signal strength versus distance

Figure 5. Experiment result comparison coherence time versus symbol time

Besides the measurement both received power and distance between two nodes, experiment also calculated the signal strength based on (1) with selected parameter such as GT and GR was determined as unity, while frequency used was 915 MHz and the transmitted power used in three different values, they were 0 dBm, 5 dBm and 10 dBm. The simulation result shows the highest transmitted power has better signal strength. The best signal strength was achieved at \(-68.17\, \text{dBm}\) with a distance of 200 m when the transmitted power used at 10 dBm.

Another analysis of the feasibility test is the Doppler Effect, in this case, simulate the coherence time and the symbol time has been carried out as in Figure 5. Looking on the details, the three-line graphs of symbol time remained steadily at three different values such as around 30 ms when SF (Spreading Factor) = 12 and BW (Bandwidth) = 125 kbps, just under 20 ms when SF=11 and BW=125 kbps, around 10 ms when SF=10 and BW=125 kbps and just over 0 ms and BW=250 kbps. Looking at the coherence time, having plummeted to 20 ms when the velocity at 60 km/h, it leveled off at just under 20 ms while the velocity decreased. It can be said that when the SF value is greater than the fast
velocity, it will cause the Doppler Effect. When SF=12 and BW= 125 kbps, the Doppler Effect will occur at the velocity of more than 70.5 km/h. However, using SF=7 and BW= 250 kbps and SF=10 and BW 125 kbps, the coherence time will always be above the symbol time, it means that the Doppler Effect will not occur during observation.

5. Conclusion
In this paper, we have developed the design of a communication system for WSN using LoRa technology that focused on the communication system. Considering the two issues that should be coped for communication system design such as wider coverage areas and the lower received signal strength. The measurement result of the longest distance in which two nodes can still be communicated reached 200 m when the signal strength measured at -98 dBm. Based on the simulation, by selecting parameters, having the same length distance, the signal strength was accounted at -68.17 dBm. Doppler Effect, based on simulation, occurred when velocity more than 70.5 km/h by using SF=12 and BW=125 kbps. It did not occur when the spreading factor decreased.

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