Modeling and Simulation of Long Range (LoRa) Communication System on Smart Grid

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2022 Seventh International Conference on Informatics and Computing (ICIC) | 979-8-3503-4571-1/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICIC56845.2022.10006938

***Abstract*— A large amount of sensing data generated by multiple sensors is collected through the cloud platform, while the amount of data over the network is increasing rapidly. IoT applications use several wireless technologies, such as Long Range (LoRa), which has many advantages, one of which is the level of reliability. However, there are still many cases that test the reliability of the LoRa communication system. This study builds a communication system model on a smart grid network that focuses on the communication network layer. This study discusses the reliability of data transmission from transmitter to receiver to produce high reliability on the receiving side. This research method is descriptive-analytic in building a smart grid model of information and communication systems over a wide area network (WAN) employing chirp spread spectrum (CSS) modulation. This study uses additive white gaussian noise (AWGN) to decrease noise in the demodulation process. It has been validated using MATLAB with a signal-to-noise-and-interference-ratio (SINR) value equal to 0 dB, a bit error rate of 0.2e-4, a symbol error rate of 0.5e-4, and a packet error rate of 0.1e-3. The occupied bandwidth is 99% accurate.**

***Keywords*— CSS, LoRa, WAN, SINR, Error rate**

I. INTRODUCTION

A smart grid (SG) combines two-way digital information and communication technology in the electricity process, starting from generation, transmission, distribution, and retail/consumer. Communication technology is at the network layer, divided into the core network, wide area network, and private network—modeling of information and communication systems using LoRa on smart grids developed by researchers worldwide. Regulation of frequency usage in several countries varies and has been regulated in the ITU-R SM.328-10 standard for smart grid communication and LoRaWAN 1.1 Regional Parameters for the frequency used in Indonesia and several other countries worldwide [1][2].

Smart grid architecture has three layers: application, power, and communication. The application layer consists of several protocols. One is the hypertext transfer protocol (HTTP) protocol used in distributed information systems and empties into the formation of the world wide web (www). Layer power as a renewable energy source into the power generation system and two-way communication to all power plants in the transmission and distribution system, especially to the customer site. Internet of Things (IoT) platforms are attractive to integrated networks. IoT platform end devices are smart objects with reliable sensing, processing, and network capabilities in the SG environment.

A researcher contrasts LoRaWAN with RF Mesh technologies, comparing LoRaWAN's reliability in terms of technology maturity, endpoint mobility, and aggregation/concentrator. [3]. However, this study uses a star topology so that this research is not head-to-head. Therefore, to prove its reliability, the author will use star topology in this study to get the expected reliability.

Another study has investigated the reliability of LoRa by planning a theoretical approach to develop a LoRa channel model in SG that considers propagation attenuation, shadow effects, and multipath fading [4]. The packet error rate for transmission between two nodes is provided for each trial. The theoretical distance between nodes is computed, and the packet error rate is measured.

Another study evaluates LoRa's reliability based on the types of applications that directly influence the communication within the LoRa network, such as the center frequency, the spreading factor, the bandwidth, and the coding rates selected by each node. Only 23% of the observation time is spent changing the configuration, and the average gain in SNR is 4,68%, according to the researcher's observations of the characteristics and configuration of the LoRa physical layer based on the quality of SNR (signal-to-noise ratio) and by a practical scenario [5].

IoT applications use the following wireless technologies, such as LoRa, which has advantages in the coverage range of 10–20 km, power consumption, radio bands, and unlicensed industrial, scientific, and medical (ISM) bands, so it is cost-effective. In Singapore, a reliable power distribution system from generation to end-user depends on these devices' ability to generate accurate information [6]. Network performance is divided into intrinsic and extrinsic factors [7].

This research contributes to using CSS modulation techniques and AWGN channels to reduce noise in the demodulation process with an SINR value, bit error rate, symbol error rate, and packet error rate equal to 0 dB in building a smart grid information and communication system model. The occupied bandwidth has an accuracy of 99%, as recommended by ITU-R SM.328-10.

The outline of the paper is structured as follows. Section II describes the LoRa communication system related to the work of LoRa packages, modulation, and demodulation processes using input parameters and AWGN channels in general. Section III presents how to build a LoRaWAN communication system model, shown in building modulation and demodulation block diagrams using AWGN channels. Section IV discusses the results of the simulation and discussion and proves by simulation that the message sent is successfully received and forwarded with an error rate and SINR value that significantly affects the reduction of interference values.

II. LoRa Communication Systems

All networks, including smart grids, telecommunications, and internet networks, consist of nodes and links. The node function consists of input, processing, and output. The input data can be from the upstream node via the link or the sensors embedded in the node. Its processing functionality is versatile. Almost all algorithms for control mechanisms are related to processing functionality. Processing functionality is distributable and requires cloud support [4]. Information and communication technology (ICT) presents opportunities to develop smart cities. In this case, city management and citizens are given access to a wealth of real-time information about the surrounding environment for making decisions, actions, and planning for the future.

LoRa packets synthesized by the LoRa synthesizer are modulated and encoded with the following features, as shown in TABLE I.

TABLE I. LoRa packet parameter

Parameter	Value
Spreading Factor (SF)	7-12
Bandwidth (Bw)	125, 250, 500 kHz
Oversampling factor	8
Sampling Rate (CR)	1
Rate	4/(4+CR)=4/5
N_bits_raw	160

This research will use Arduino and LoRa SX1276 nodes, while the gateway uses Raspberry Pi and SX1276. The communication model uses point-to-point at a frequency of 915MHz with a frequency bandwidth of 125, 250, and 500 kHz, while the SF value is 7-12. The higher the SF, the more information is sent per bit. Therefore, higher processing is required. For a given SF, a narrow Bw means an increased reception sensitivity despite an increase in ToA (Time on Air). This study will discuss starting from the LoRa packet structure to the modulation and demodulation processes on the transceiver

A. LoRa Packet

LoRa packet consists of three main elements preamble, header, and data payload, as shown in Fig. 1 [8].

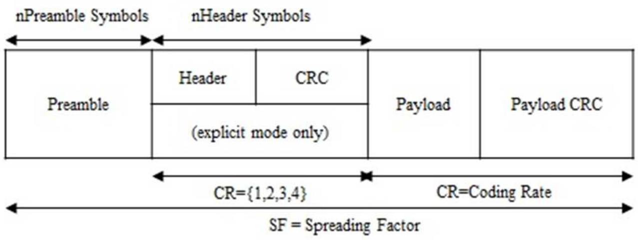

Fig. 1. LoRa packet structure

The preamble synchronizes the receiver with the incoming data stream. By default, data packets are configured with 12 sequential symbols. Symbol variables can be programmed so that the preamble length can be extended, for example, to reduce the duty cycle of the receiver in receiving intensive applications. The transmitter preamble length can be changed by setting the length register length from 6 to 65535 to produce a total preamble length from symbols 6+4 to 65535+4. Preamble data is still considered at the time of overhead conditions. The receiver performs an opening detection process that repeatedly starts at regular intervals.

For this reason, the aperture length must be configured to equal the transmitter preamble length.
If the preamble length is unknown or varies, the receiver must program the maximum preamble length. Synchronization between transmitter and receiver is required to accurately decipher and demodulate the signal. There are two sorts of header modes: implicit and explicit. While the explicit header is the default mode of operation, the implicit header chooses the header type in the bits located in the modem reg config1 register. The payload's length in bytes, forward error correction code rate, and an optional 16-bit CRC value are all included in the header as payload information. Additionally, the header carries a CRC that enables the recipient to ignore any invalid headers.

Payload encoded the message up to 255 bytes in length, and an uplink cyclic redundancy check followed the payload, which is only available in uplink frames and is up to 2 bytes long. The header, the payload's level of encoding, and whether a payload CRC check or a header CRC check is present are all utilized to enter data about the payload length in PL_b bytes. When transmitting in explicit mode, the header is present and has a 3-byte length. The degree of encoding, check flags, implicit header flags, and optimization controls affect the number of symbols encoded in the header and combined payload. LoRa packet structure using the following (1), (2), and (3).

$$N_{hp}=n_{payload}= 8+\max\left\{\left\lceil\frac{8PL_b\text{-}4SF+28+16CRC\text{-}20IH}{4SF\text{-}8DE}\right\rceil(4+CR),0\right\} \quad (1)$$

PL_b (number of payload bytes) consists of 1 to 255 bytes, SF (spreading factor) consist of 7 to 12, IH (implicit header), 0 when the header is enabled and 1 when it is not; DE is the optimization mode flag, 1 when the adaptive level is on (LowDataRateOptimize=1) and 0 otherwise. CR is the LoRa payload encoding parameter, with a value of 1 if the cycle code rate is used and 0 otherwise. Explicit packets include a short header containing information about the packet's byte count, encoding speed, and CRC usage. The header and payload are encoded first before the modulation process.

$$T_{paylod}=n_{payload}\,.\,T_s \quad (2)$$

The payload duration is the number of payload symbols multiplied by the symbol duration/sweep time.

$$T_{packet}=T_{preamble}+T_{payload} \quad (3)$$

The packet duration/Time on Air (ToA) is the sum of the preamble and payload duration.

B. Modulation and Demodulation Process

Spread spectrum LoRa is a patented modulation developed by semtech [8] based on CSS modulation. LoRa modulation is called "chirp modulation" [9]. LoRa offers long-distance data transfer security, efficiency, and speed. Compared to cellular networks, LoRa can provide more expansive coverage on public, private, or hybrid networks. Low-power, battery-powered Internet of Things applications are made possible by LoRa technology, which integrates readily with current networks. Radio transmissions used by LoRa contain only an always-on transmitter and no other information. The signal must be modified in some way to convey information. Several methods will do; one of the most popular methods is to alter the amplitude and frequency [10]. In the 1940s, CSS was created for radar applications and is now utilized in military and aerospace communications. LoRa operates on fixed bandwidth channels with 125 kHz uplink channels and 500 kHz for downlink channels, offering a trade-off between sensitivity and data rate. LoRa also uses an orthogonal dispersion factor. Due to the more excellent spread factor, processing gain and reception sensitivity are both improved.

In the demodulation process, resampling will do to balance the data, that is, by drawing a sample from some of the available data. The oversampling technique takes the minority class so that the proportion in the sample is greater than the original proportion.

SINR is the ratio between the primary signal emitted and the interference and noise received by the user. SINR parameter measures signal quality to determine the relationship between radio frequency access conditions. BER is the number of bits received in error divided by the total number of bits transferred. Using a conventional signaling method where 0V for "0" and 1V for "1" over a noise-free channel with no ISI at the receiver is 0V or 1V, it is possible to estimate BER by calculating the chance that the received bit is incorrect due to noise. The number of 0V samples is nearly comparable to the number of 1V pieces, assuming that one is equally likely in the transmission stream.

III. LoRaWAN Communication Systems Model

The end nodes (end devices/sensors) placed on the LoRa smart metering (SM)/end nodes consist of a LoRa radio, microcontroller, sensors, power supply unit (PSU), and antennas. Sensors can also be connected to end nodes to periodically transmit sensor data to SM via LoRa/wifi wireless, as shown in **Fig. 2**.

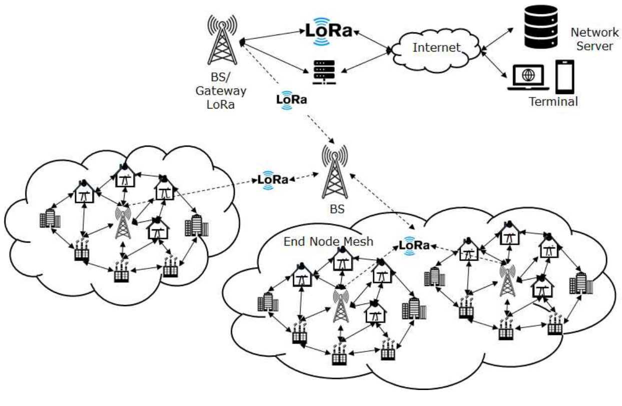

Fig. 2. Communication systems model on LoRAWAN

On the LoRaWAN network, there is a non-line-of-sight (NLOS) area where the end device signal does not reach the gateway due to topographical problems. In the NLOS area, the end device nodes cannot transmit data and cannot determine the shadow area within the LoRaWAN distance, so the development of the LoRa Mesh network is a solution [11]. The LoRa has a built-in semtech SX1276 engine and a received signal strength indicator (RSSI) 127 dB dynamic range allowing control of a wide range of equipment from 3-12 km [12]. The chirp signal is the carrier signal encoding the message. LoRa emulator consists of two main components: the LoRa transmitter emulator (LE-Tx), which can encode and modulate data into LoRa waveforms, and the LoRa receiver emulator (LE-Rx), which is responsible for demodulation and decoding to extract data on the payload [13]. A cyclic chirp signal is the result of symbol encoding, where the initial position of the chirp (shift) encodes the symbol value. A parameter that can control the chirp speed is the spread factor (SF), where a higher SF means longer chirps, allowing more bits per symbol encoding. Chirp LoRa represents $M = 2^{SF}$[9]. where the duration (symbol) of the chirp is $T_S = M/Bw$ and Bw is the bandwidth. LoRa modulation can use equation (4):

$$(t)=\exp\left(j2\pi\int_0^t\left[(\beta x+\gamma_n)_{\mathrm{modBw}}-\frac{Bw}{2}\right]dx\right) \quad (4)$$

Where γ_n is a frequency shift as equation (5) follows.

$$\gamma_n=m_n\Delta_f=\frac{m_n}{T_s} \quad (5)$$

Where m_n is the value of the data symbol, n is the symbol's index, and Δ_f is the step frequency between each frequency shift. In LoRa, the step frequency is the same as the symbol rate, i.e., Bw/M, the representation of the chirp slope, which is a function of bandwidth and symbol time. Bandwidth is calculated using the following equation (6) where $m_n \in \{0, 1, 2, ...M-1\}\Delta_f$

$$\beta=\frac{f_{high}-f_{low}}{T_s}=\frac{Bw}{T_s} \quad (6)$$

Where f_{high} and f_{low} are the lower and upper limit frequencies of each chirp, the LoRa frame consists of the following (7).

$$x(t)=\sum_{n=1}^{N_m} s_n(t-nT_s) \quad (7)$$

Where N_m is the total number of symbols per frame. This study uses the following input parameters, as shown in TABLE II.

TABLE II. Transmitter input parameters

Parameter	Value
SF	7-12
Bw	125, 250 and 500 kHz
F_c	915 MHz
PT_x	14 dBm
F_s	10 MHz
CR	(4/(4+CR):4/5
Message	"Modeling and Simulation of Long Range (LoRa) Communication System on Smart Grid"

The transmitter input parameters in TABLE II above are according to the LoRa structure [8] and [14]. After simulation, the larger the SF value, the higher the receiver's sensitivity. Considering the faster bit rate and longer transmission duration, customer coverage to remote base stations is also the main focus of this study. Fig. 3 is a model of signal modulation on the LoRa transmitter.

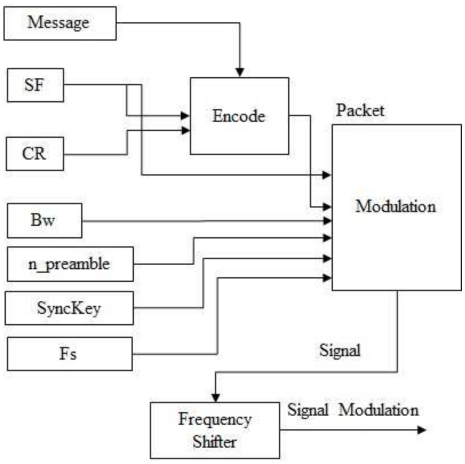

Fig. 3. Signal modulation on LoRa transmitter

The signal modulation process on the LoRa transmitter is a message sent in binary data from the SM (smart metering) and then encoded with other input parameters. In this study, the LoRa transmitter encodes the message and then sends it in packets. The LoRa transmitter sends the modulated packet to the frequency shifter in the form of a modulated signal that produces a modulated signal.

The dechirp signal is the signal term at the receiver, which is described in equation (8) as follows.

$$s^*(t)=\sum_{n=1}^{N_m} \exp\ (j\pi Bt-j2\pi\beta t^2)\circledast\delta(t-nT_s) \quad (8)$$

The signal decoders are then combined to produce the following (9).

$$y(t)=gx(t)+[i(t)+n(t)]s^*(t)$$
$$= r(t)+\tilde{i}(t)+\tilde{n}(t) \quad (9)$$

Where n(t) is the AWGN multiplied by the dechirp signal, i(t) is the radio interference spectrum, and gx is the channel function. So the received signal becomes in (10).

$$r(t)=\sum_{n=1}^{N_m} \exp\ (j2\pi\gamma_n t)\circledast\delta(t-nT_s) \quad (10)$$

where γ_n is the offset frequency waveform at the LoRa receiver, Fig. 4 is a model of signal demodulation on the LoRa receiver.

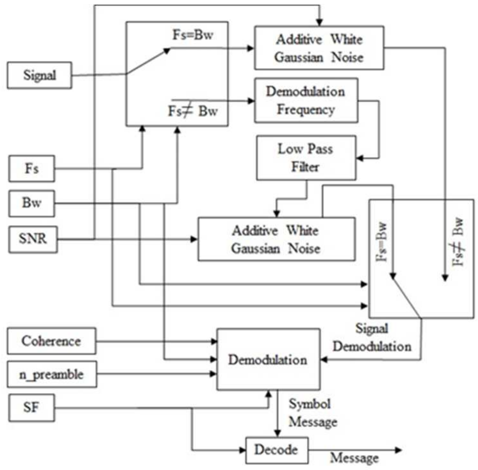

Fig. 4. Signal demodulation on LoRa receiver

The block diagram in Fig. 4 is a signal modulation process on the receiving side that has been tested and validated using MATLAB with messages that match the information sent. The node on the receiver will receive data from the transmitter and will recapitulate the RSSI and SNR. If the value of Fs = Bw, then the process will be carried out on AWGN, and if not, then it will be forwarded to the frequency modulation process using FSK and filtered using LPF. Signal interference or interference in overlapping bands distorts so that AWGN processes the following method. This study uses the trial of sending messages repeatedly to see the system's reliability.

In Fig. 5, the spectrogram time is getting closer, indicating that the data sent is very long because it goes through a layered authentication process that takes twice as long as the transmission process.

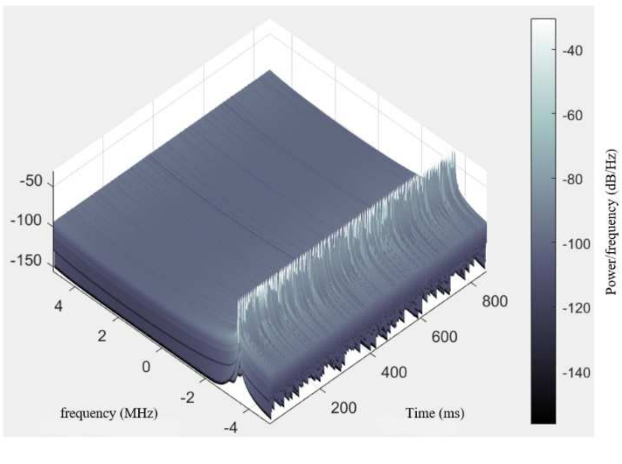

Fig. 5. The spectrogram on LoRa packet transmission with 14 dBm power

AWGN and fading interference are caused by one of the unlicensed spectrums due to technological developments that are not limited to LoRa. Radio spectrum congestion correlates with population density, so measuring it, especially in urban environments, is critical. Spectrum availability also varies not only spatially but also temporally.

Therefore, the impact of interference cannot be abstracted into a single parameter but needs to be modeled statistically or can be regenerated based on empirical measurements.

Thus, it is possible to configure the SDR to capture the radio spectrum near the expected gateway location. Fig. 5 illustrates the spectrogram on LoRa packet transmission wherein a linearly emulated LoRa frame is superimposed onto the measure. The resulting signal is then forwarded to LE-Rx to demodulate and decode the LoRa signal.

Interference is one of the main types of channel interference in the unlicensed spectrum. Population density is correlated with radio spectrum congestion. In an urban setting, taking measures is crucial. Spectrum accessibility varies throughout both time and space [13]. It is crucial to gather interference measurements, sample the variability throughout several periods, and run the emulator during those times if there is substantial interference variability throughout the day. As a result, the emulator can deliver typical performance and variance for a long time.

IV. Simulation Result and Discussion

LoRa demodulates its signal below 19.5 dB of the noise floor. In contrast, other network technologies can only demodulate signals with power less than 10 dB above the noise level. One of the significant channel interferences in the unlicensed spectrum is interference. The simulation results in Fig. 6 present that the SINR using the AWGN channel on the receiving side significantly affects the reduction of the interference value.

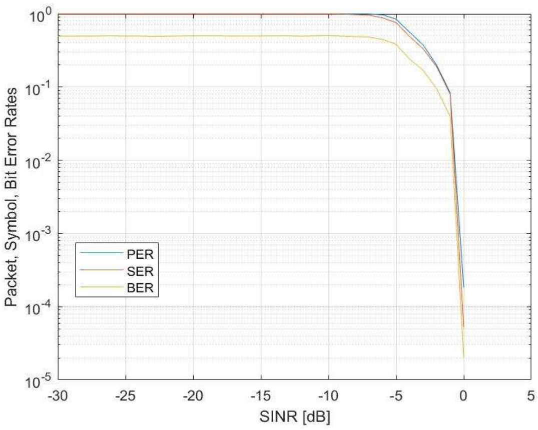

Fig. 6. SINR simulation

TABLE III displays the simulated error rate values for the LoRa communication system.

TABLE III. Simulation of SINR against BER, SER, and PER

SINR (dB)	BER	SER	PER
-10	$0.3e^{0}$	10^{0}	10^{0}
-5	$0.2e^{0}$	$0.1e^{0}$	$0.1e^{0}$
0	$0.2e^{-4}$	$0.5e^{-4}$	$0.1e^{-3}$

The simulation results in TABLE III show that with the AWGN channel function in the LoRa communication system during the demodulation process, an SINR value of 0 dB with an error rate of bits, symbols, and packets is ideal for use in a communication system. Fig. 6 shows the results of the MATLAB simulation, which displays an SINR value equal to 0 dB with a bit error rate of $0.2e^{-4}$, a symbol error rate of $0.5e^{-4}$, and a packet error rate of $0.1e^{-3}$. The occupied bandwidth present in Fig. 7 percentage is 99%, which means that the bandwidth used has met the standard.

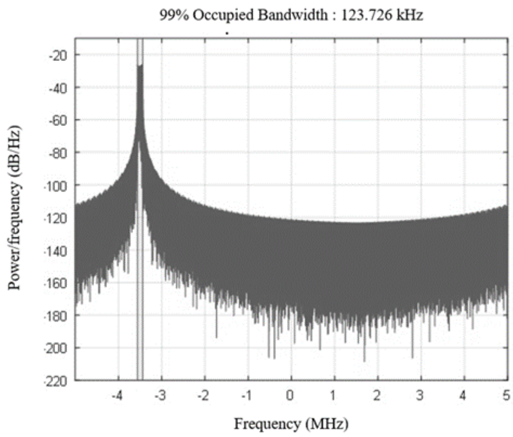

Fig. 7. Width of occupied bandwidth

In some countries, like Japan and the US, equipment must meet specific regulatory standards, as seen in Fig. 7. The ITU-R originally defined it as the maximum bandwidth, excluding emissions that do not exceed a certain percentage of total emissions. Occupied bandwidth is the frequency bandwidth below the lowest frequency limit and above the highest frequency limit. The average transmits power is equal to the percentage β/2 of the total radiated average power, defined as a bandwidth consisting of 99% of the average transmit power.

V. Conclusion

This study proposes a model of information and communication systems on a WAN on a smart grid using CSS modulation. This study reduces noise on the transceiver using AWGN so that the SINR value equals 0 dB with a bit error rate of 0.2e-4, the symbol error rate of 0.5e-4, and the packet error rate of 0.1e-3 with the occupied bandwidth is 99% accurate. Simulation using MATLAB has proven the process of modulation and demodulation.

Acknowledgment

This research is a part of the doctoral dissertation and granted with the research scheme of Penelitian Disertasi Doktor (PDD) 2022, sponsored by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia.

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