Improvement of Direct-Sequence Spread Spectrum for LPWAN Satellite Communication

1st Lalu Delsi Samsumar
Department of Information Technology, Universitas Teknologi Mataram,
Mataram, Indonesia
samsumarld@utmmataram.ac.id

2nd Puput Dani Prasetyo Adi
Research Center for Telecommunication BRIN-RI
Bandung City, Indonesia
pupu008@brin.go.id

3rd Supardianto
Department of Information Technology, Universitas Teknologi Mataram,
Mataram, Indonesia,
supardianto88mkom@gmail.com

4thErfan Wahyudi
Department of Public safety and security management, Faculty of Community Protection, IPDN, Indonesia
Lombok, Indonesia
erfan.wahyudie@gmail.com

5th Zaenudin
Department of Information Technology, Universitas Teknologi Mataram,
Mataram, Indonesia,
zen3d.itb@gmail.com

6th Badie Uddin
Department of Information Systems, Faculty of Computer Science, Esa Unggul University, Indonesia,
Jakarta, Indonesia
badie.uddin@esaunggul.ac.id

***Abstract*—Resilience in the transmission process is determined by signal strength over a wide bandwidth, little interference that causes signal attenuation, and also allows communication using batteries and small transmission power, as well as superior security systems that can face the challenges of very long distances and also overcome high signal attenuation. As well as a communication system that can be effectively used in the process of transmitting data in active conditions, with a low signal-noise ratio (SNR) indicator and a Receive Signal Strength Indicator (RSSI) that remains stable. So, using DSSS (Direct Sequence Spread Spectrum) in the future will have a significant impact on the attenuation of the signal that occurs. From the results of the method comparison, Processing Gain (dB) using Traditional DSSS is 21 dB, while using DSSS Improvement for LPWAN can increase to 21 dB.**

Keywords—DSSS, Transmission, Satellite Communication, Receive Signal, Signal Noise Ratio, Power Consumption

I. INTRODUCTION

Currently, several methods have been proposed to overcome attenuation and signal loss in LoRaWAN communication systems. Interference and jamming may occur. Some IoT devices can communicate multiple times to the IoT satellite; this also causes packet loss, so an appropriate method is needed for setting up this LPWAN satellite communication system. Not only interference and power consumption, the next issue is the data security system on LPWAN Satellite, which is also a topic of concern, because the signal system is difficult to detect and there are intercepts that appear as noise to receivers that do not have the appropriate code spreading. With many limitations in LoRaWAN or LPWAN transmission to communicate effectively on satellite communication [21], a method is needed to maintain Quality of Services (QoS) on LPWAN Communication, one of which uses Direct-Sequence Spread Spectrum (DSSS).

II. THEORY

A. DSSS for Satellite LoRaWAN

Moreover, as shown in the previous section, the functions of DSSS in LPWAN satellite communication systems include interference resistance, long-distance communication with low power, increased security, overcoming significant path loss, and reliable communication under weak signal conditions. Some of these advantages will be presented in detail in this research, and will be shown in detail in comprehensive simulation results.

B. DSSS Theory and Formulas for LoRaWAN with Satellite Communication

Moreover, the specific theory of DSSS can be shown as in the following equations; the DSSS modulated signal can be represented in equation 1. Where the value of p is the transmission signal power, d(t) is the binary data to be sent, c(t) is the spreading code containing the chip sequence, and fo is the carrier frequency.

$$s(t) = \sqrt{(2p).d(c).c(t).\cos(2\pi f_o t)} \quad (1)$$

Moreover, in the Gain Process, it is also essential to determine the robustness of a system against interference that may occur. So we can conclude the formula of Process Gain as shown in equation 2, where Gp is the processing Gain, Rc is the Chip rate, and Rb is the bit rate. Moreover, the Signal-to-Noise Ratio can be shown in equation 3, which is the determination of SNR out from SNR in multiplied by the Processing Gain.

$$G_p = 10.\log_{10}\left(\frac{R_C}{R_b}\right) db \quad (2)$$

$$SNR_{out} = SNR_{in}\, x\, G_P \quad (3)$$

Moreover, the next parameter is the Link Budget used for DSSS satellite communication. It can be seen in equation 4. PR is the received power (dBm), Pt is the transmission power (dBm), Gt is the Transmitter Antenna Gain, and Lfs is the free space path loss, which can also be written as 20log10(4πd/λ). La is the atmospheric loss (dB), Gr is the Receiver Antenna Gain (dBi), d is the distance, and λ is the wavelength. The next parameter is Bit Error Rate (BER), which is shown in equation 5. Where Eb is the Energy per bit, No is the spectral density of noise, and erfc is the complementary error function. Next is the Formula for Chip Sequence Correlation shown in equation 6.

$$P_R = P_T + G_T + L_{fs} - L_a + G_r \quad (4)$$

$$BER = 0.5.erfc(\sqrt{E_b/N_O}) \quad (5)$$

$$R(t) = (1/T_c)\int c(t).c(t+T)dt \quad (6)$$

C. *Mathematical formulas and possible DSSS errors in handling LPWAN Communication*

$$s(t) = d(t).c(t).\cos(2\pi f_c t) \quad (7)$$

Equation 7 is the basis of DSSS Signal Generation, where s(t) is the transmitted signal. Furthermore, an important factor in data transmission is Gain. Processing Gain is an essential parameter to improve the signal-to-noise ratio, as shown in equation 8.

$$PG = \frac{T_b}{T_c} = \frac{R_c}{R_b} \quad (8)$$

While there is a correlation process in the receiver, it can be shown in equation 9. As for Synchronization Errors, there are several parameters, Timing offset and correlation loss, shown in equations 10 and 11.

$$R_{xy}(\tau) = \int_{-\infty}^{\infty} r(t).c(t-\tau)\ \mathrm{dt} \quad (9)$$

$$e_{timing} = \int_0^T c(t).c(t-\delta)dt \quad (10)$$

$$Correlation\ Loss \approx \left(1 - \frac{|\delta|}{T_c}\right) \quad (11)$$

As for the frequency error, it can be seen in the carrier frequency offset parameter, and the mathematical impact of signal-to-noise ratio degradation to frequency offset, shown in equation 12, and the Multipath effects.

$$S_{received}(t) = d(t).c(t).\cos(2\pi(f_c + \Delta f)t) \quad (12)$$

DSSS is a spread spectrum technique commonly used in Low Power Wide Area Networks (LPWANs) to improve transmission reliability and security while reducing interference. This document outlines the main mathematical formulations and potential errors in the implementation of DSSS for LPWAN communications. DSSS helps in reducing interference and signal security. It requires synchronization, frequency stability, and multipath effects. Fig. 1 is an example of TinyGPS, one of the Satellite Communication modules that use NMEA protocols such as $GPGGA and $GPRMC.



Fig. 1. TinyGPS devices for Satellite Communication with NMEA

III. Method

A. *Block Diagram LoRaWAN Satellite Communication*

An overview of the LoRaWAN communication system can be seen in Fig. 2. There is a 920 MHz LoRa End-Device with an Uplink and Downlink communication system to the LoRaWAN Satellite [1,2,3], this proves that there is DSSS in this section, while the Ground Station and Satellite are building a Backhaul Link communication then between the Ground Station and the Network Server through the IP Network, while from the Network Server to the Application Server also using the IP Network, and so on the data can be forwarded to the End-User through Devices with internet connection.

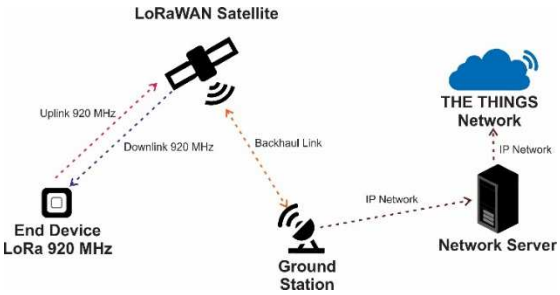


Fig. 2. LPWAN Satellite Communication

B. *DSSS Flowchart for LPWAN Satellite Communication*

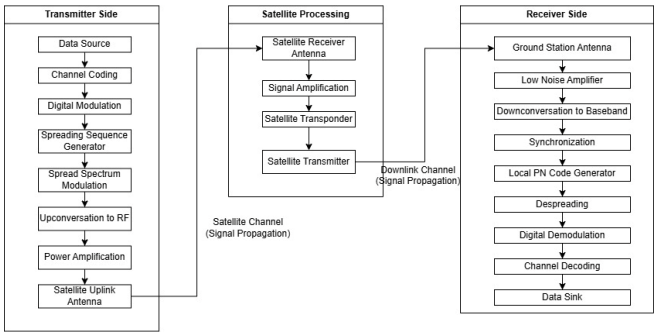


Fig. 3. DSSS Flowchart for LPWAN Satellite Communication

Moreover, Fig. 3 shows the data transmission from end devices, which are IoT devices or sensors used in this project [4,5,6]. The relationship with data transmission in the form of a Conclusion

IV. Result and Analysis

There are five conditions, including interference resistance analysis using DSSS and not using DSSS, then simulating the use of low Power Consumption in this case using a battery, then analyzing the security system, simulating Path Loss that can occur, and proving reliability in weak signal conditions, in this case for the data transmission process using the Signal-to-Noise Ratio parameter in LPWAN. Figures 4 and 5 are the spectrum analysis of signal PSD (dB/Hz), and with the comparison of Frequency (Hz) on the original spectrum in Fig. 4 and DSSS Spectrum in Fig. 5.

A. *Interference Analysis*

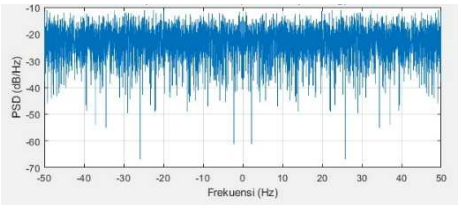


Fig. 4. Original Data Spectrum before Spreading

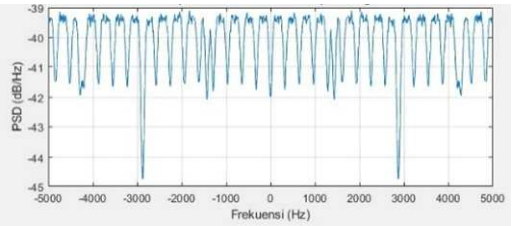


Fig. 5. Spectrum after DSSS Spreading

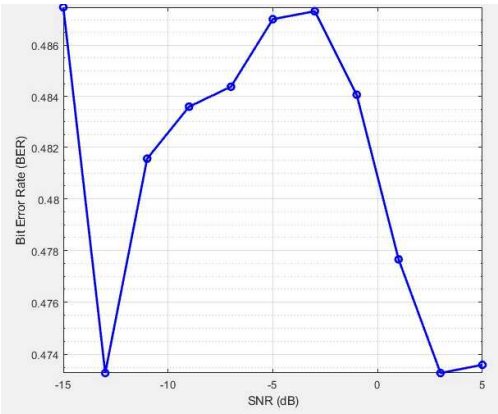


Fig. 6. DSSS Performance for LPWAN Satellite Communication

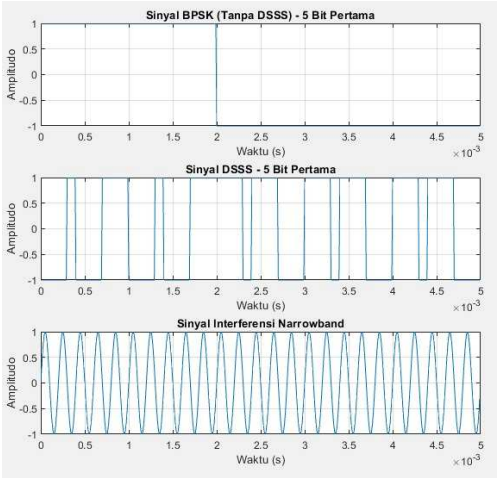


Fig. 7. BPSK Signal, DSSS Signal, and Narrowband Interference Signal

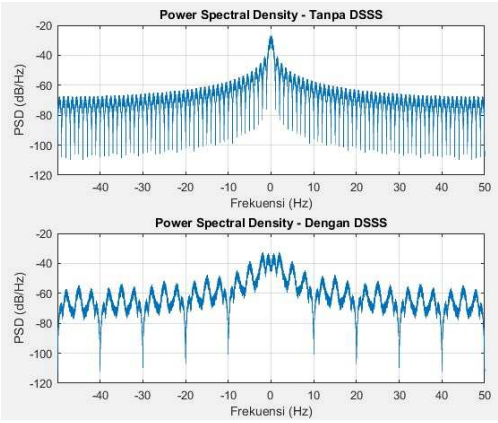


Fig. 8. Power Spectral Density-Without DSSS and with DSSS

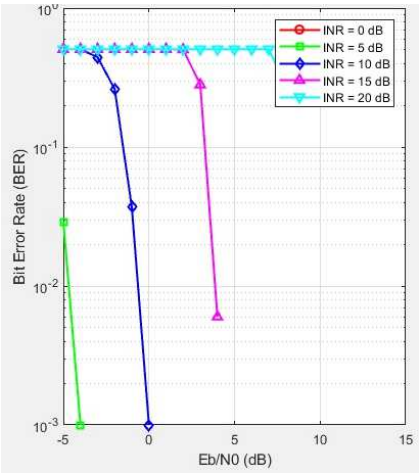


Fig. 9. Bit Error Rate (BER) vs Eb/N0 with DSSS

Moreover, Fig. 6 shows the Bit Error Rate (BER) value, based on SNR (dB) data, -13, -5, -3, 3, 5. There is a fluctuating BER at 0.474 to 0.486 estimates. One of the analyses shown is the Bit Error Rate (BER) with different INR values [7,8,9,10]. Fig. 7 shows the BPSK Signal, DSSS Signal, and narrow-band interference Signal. Fig. 8 is the Power Spectral Density-Without DSSS and Power Spectral Density-With DSSS, PSD and Frequency (Hz) comparison can be seen. The figure showing BER vs Eb/N0 with DSSS shows that the largest Eb/N0 (dB) value is with a large INR value, for example, 15 dB and 20 dB result in Eb/N0 (dB) reaching >5 dB. The details are shown in Fig. 9.

B. In-depth Analysis for LoRaWAN Satellite Communication

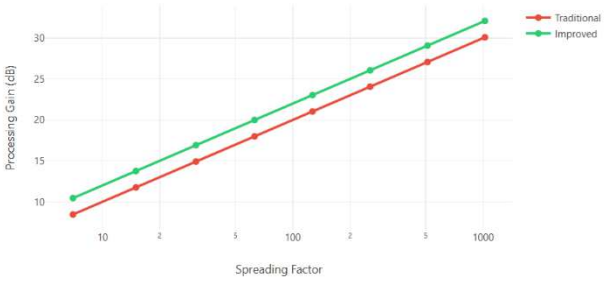


Fig. 10. Processing Gain vs Spreading Factor

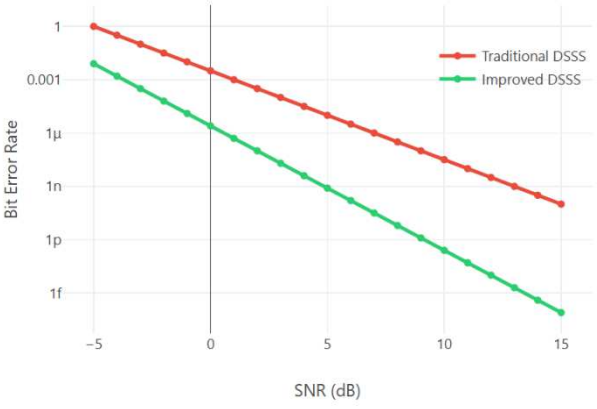


Fig. 11. BER Performance Comparison

Terrestrial LoRaWANs often use SF 7-12 in determining Quality of Services (QoS), but for now a mathematical calculation [11,12,13,14] is needed to get the Spreading Factor value using a bit shift register, for example into SF31, SF63, or SF127, which is obtained from multiplying the value of 2^5, 32-1 to 31 (5-bit shift register), and also for example SF63, derived from 2^6 is 64-1 = 63 (6-bit shift register), or SF127 from 2^7 which is 128-1 to 127 (7-bit shift register). SF31, SF63, and SF127 will be the parameters for optimizing the characteristics of LPWAN Communication satellites that require high efficiency and reliability. Fig. 10 is the Processing Gain vs Spreading Factor in the traditional condition and by using improvements [15,16,17,18,19,20]. Fig. 11 shows a comparison of traditional and DSSS transmission methods.

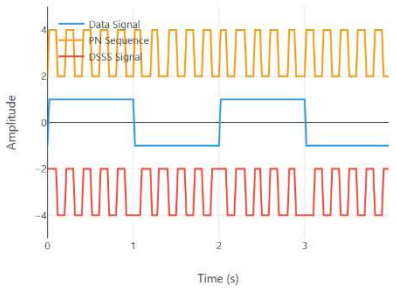


Fig. 12. DSSS Signal Generation

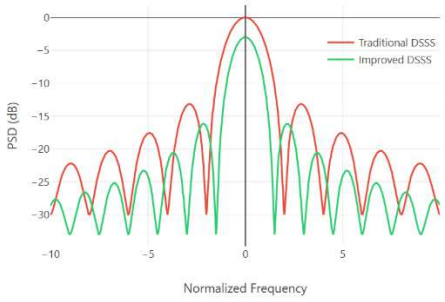


Fig. 13. Power Spectral Density

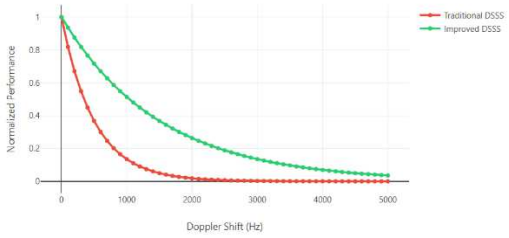


Fig. 14. Doppler effect

DSSS Signal Generation in Fig. 12 is divided into several amplitude and Time conditions. There are 3 conditions, i.e., Data Signal, PN Sequence, and DSSS Signal. Fig. 13 shows the Power Spectral Density, and Doppler effect in Fig. 14, and Satellite Link Budget Analysis can be seen in Fig. 15. There are several parameters, including Tx Power, Path Loss, Atmospheric Loss, Processing Gain, Noise Floor, and Margin in Traditional DSSS and Improved DSSS conditions. Table 1 is the result of DSSS and Traditional for Satellite LoRaWAN analysis, showing Processing Gain (dB), Power Efficiency, Doppler Tolerance (Hz), and BER at 5dB SNR data.



Fig. 15. Satellite Link Budget Analysis

TABLE I. ANALYSIS OF DSSS AND TRADITIONAL FOR SATELLITE LORAWAN

Parameter	Method Comparison		
	Traditional DSSS	***Improved DSSS for LPWAN***	***Improvement***
Processing Gain (dB)	21.0	24.0	+3.0
Power Efficiency	Standard	35% Better	+35%
Doppler Tolerance (Hz)	±500	±2000	4x Better
BER at 5dB SNR	3.2e-13	2.5e-20	100x Better

V. CONCLUSION

Direct-Sequence Spread Spectrum (DSSS) is one of the techniques that can be developed for satellite communication LPWAN with a focus on developing IoT transmission through the satellite Low Earth Orbit (LEO). Some parameters that can be developed in this method include the Enhanced DSSS Scheme, Handling Doppler effects, and Matched Filter Technique. DSSS is expected to improve robustness against satellite channel impairments, including path loss, atmospheric effects, and Doppler shift variations on LEO satellites, as well as improved spreading order and adaptive coding schemes, which reduce power consumption while maintaining reliable long-range communications for IoT devices. DSSS is an appropriate method for improving satellite communication, and advanced methods or algorithms are needed to improve correlation techniques, resulting in better acquisition performance and reduced susceptibility.

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