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Reducing the Error Rate using Additive White Gaussian Noise and Rayleigh Channels in the Communication System

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ABSTRACT. *Long Range (LoRa) with chirp spread spectrum (CSS) modulation technique has been widely developed on the Internet of Things. In this study, we tested the LoRa performance of other LoRa users with additive white gaussian noise (AWGN) and Rayleigh fading characteristics where the distracting user was not aligned with the chip or phase with the desired signal. In addition, this study also proves that two symmetries in the interfering signal and low requirements can significantly reduce symbol computation and error rate compared to complete expressions. This paper focuses on LoRa performance by considering the error rate in the CSS modulation system. This study is based on coherent and noncoherent detection using binary frequency shift keying (BFSK). The method used in this study is comparative analytic with simulation results showing that the expression of bit error rate (BER), symbol error rate (SER), and packet error rate (PER) is based on analytical calculations obtained from 10,000 iterations. In contrast, using coherent and noncoherent detection, the numerical method got 61 iterations. These estimates generate precise numbers for SF = 7, BER = 0.03 against EbN0=1dB, SER=0.4 against EsN0=6 dB, and PER=0 against SNR 1 dB. In this study, coherence detection, AWGN channel, and numerical approach can reduce the required error rate in the communication system. In the future, the authors will implement this research on a smart grid communication system with a security system to produce high reliability.*

Keywords: LoRa, Error rate, AWGN, Rayleigh, BFSK

1. **Introduction.** It has become essential to carry out our daily operations. For instance, data centers are associated with commerce, education, business, social networking, communication services, and others [1]. The LoRa (Long Range) communication system has become excellent in the research community and commercial users because of its advantages in transmitting data over long distances with relatively low energy costs. This study presents new results for the bit error rate, symbol error rate, and packet error rate

performance of a Long Range (LoRa) system operating in the presence of AWGN and Rayleigh channels. In detail, this study proposes how to reduce the error rate to increase the reliability of the communication system. This study presents analytical and numerical equation validation using orthogonal signaling [2]. LoRa is an independent, spectrum-license-free wireless system with low costs, low power requirements, and low bit rates for long-distance communication. Users can create their network, gateway, and nodes using LoRa [3]. LoRa uses the Chirp Spread Spectrum (CSS) modulation, created by Semtech, at the Physical layer (PHY) of the protocol stack as a form of communication [4]–[8]. The noise power added by the AWGN Block is connected to the Signal power subsystem along with the Display Block to the input of the AWGN block, the output signal power of the channel, which will be the difference between the sum of the input signal power and the noise power [9], [10]. BER simulations are presented by a researcher and evaluated using parameters of the LoRa modulation patterns, such as spreading factor, code rate, symbol frequency, and SNR. The accuracy of the BER was described, and the LoRa performance was investigated using numerical results. The relationship between the energy per bit and the noise power spectral density (EbN0). According to the numerical results, these estimations yield accurate values for SF=7, BER values of 0.15, and SNR=10 dB for various variations of SNR, as well as multiple values of spread factor and coding speed [11]. A researcher tested the error probability performance of a LoRa communication system by proposing an accurate estimate for the bit error probability of CSS modulation in an AWGN channel. BER performance of LoRa systems uses both uncoded and coded transmissions with coherent and noncoherent detection for Hamming-coded LoRa signals with decoded and coherent (or noncoherent) detection, both in the AWGN channel. System performance has been simulated on multipath channels, utilizing a simplified equalizer on the receiving end. The SNR value in this study is up to 1 dB [12]. Other researchers have proposed that multicarrier modulation schemes such as orthogonal frequency division multiplexing (OFDM) provide an efficient solution to this problem. This researcher performs grayscale image processing using the least mean square (LMS) algorithm with a wavelet-based OFDM system using a quadrature phase shift keying (QPSK) modulation scheme on AWGN and Rayleigh channels in the SISO environment, and the results are compared with a conventional adaptive OFDM system based on Fast Fourier Transform (FFT). The researcher compared the SNR and BER values which showed that the adaptive discrete wavelet transform (DWT)-based OFDM system performed better than the conventional adaptive FFT OFDM system [13], [14]. Another researcher tested LoRa performance in the presence of AWGN and interference from other LoRa users by extending the existing interference model, which assumes perfect alignment of the desired signal and existing harmonized interference overestimating the effect of interference at an error rate of 1 dB [15]. This researcher proves two symmetries in the disturbing signal and formulates a low-complexity estimate that can significantly reduce computational symbol complexity and frame error rate.

This study also features numerical simulations to strengthen the theoretical analysis to verify the accuracy of the proposed estimates [16]. Other researchers measured the BER performance of AWGN and Rayleigh fading channels. The accuracy of the derived forecast is confirmed by comparison against the numerical results. This study discusses the receiver sensitivity and the associated coverage range in an AWGN-type environment. This study uses the SX1272 transceiver with a sensitivity of PRx = -137 dBm, while in this paper, the authors use the SX1276 transceiver with a sensitivity of -148 dBm [17]. The comparison to the numerical results confirms a relatively accurate estimate of the presented analysis. The results for the Rayleigh fading environment show that LoRa cannot sustain long-distance communication in an urban environment with Rayleigh fading characteristics [18]–[20].

The contribution of this research is to produce an appropriate coherent and noncoherent detection model used in the LoRa communication system to get the value of the BER to EbN0, R to EsN0, and PER to ideal SNR using the AWGN and Rayleigh methods using MATLAB by considering the parameters, the best input parameter to get a low error value using binary frequency shift keying (BFSK) modulation technique. In section 2 discusses the error rate namely BER, SER and PER. In section 3, this study discusses the method used, comparative analytical-numerical, where the author compares the analytical and numerical error rate calculations using AWGN and Rayleigh channels. Section 4.0 discusses the results and discussion of the values of SF with BER against EbN0, SER against EsN0, and PER against SNR at 125 kHz bandwidth using coherent and noncoherent detection. In part 5.0, the conclusion is to determine the correct detection and channel for the LoRa communication system using SX1276 analytically and numerically.

2. **Proposed Method.** The author analyzes the error rate calculation in the LoRa communication system using AWGN and Rayleigh channels analytically and numerically in a comparative method. AWGN is one type of noise in communication systems, commonly called thermal noise. The AWGN channel is a universal channel model for analyzing modulation schemes. In this model, the AWGN channel is added to the signal passing through it using coherent and noncoherent detection. This indicates that the channel amplitude frequency response is flat, and the phase response is linear for all frequencies. The modulation passes through it without amplitude, phase loss, or distortion of the frequency components. In this study, the code designed on the AWGN channel serves to optimize its inherent diversity. The performance of the communication system on Rayleigh fading can also be seen from the characteristics of BER, which theoretically has one path.

A message sent in binary data from the SM (smart metering) is modulated on the LoRa transmitter and then encoded using additional input parameters. In this experiment, the LoRa transmitter encodes the message before being sent as packets. The LoRa sends the packet-modulated signal to the frequency shifter, which creates a modulated signal. Figure 1 is a flowchart of the Lora communication system on the transceiver (transmitter and receiver).

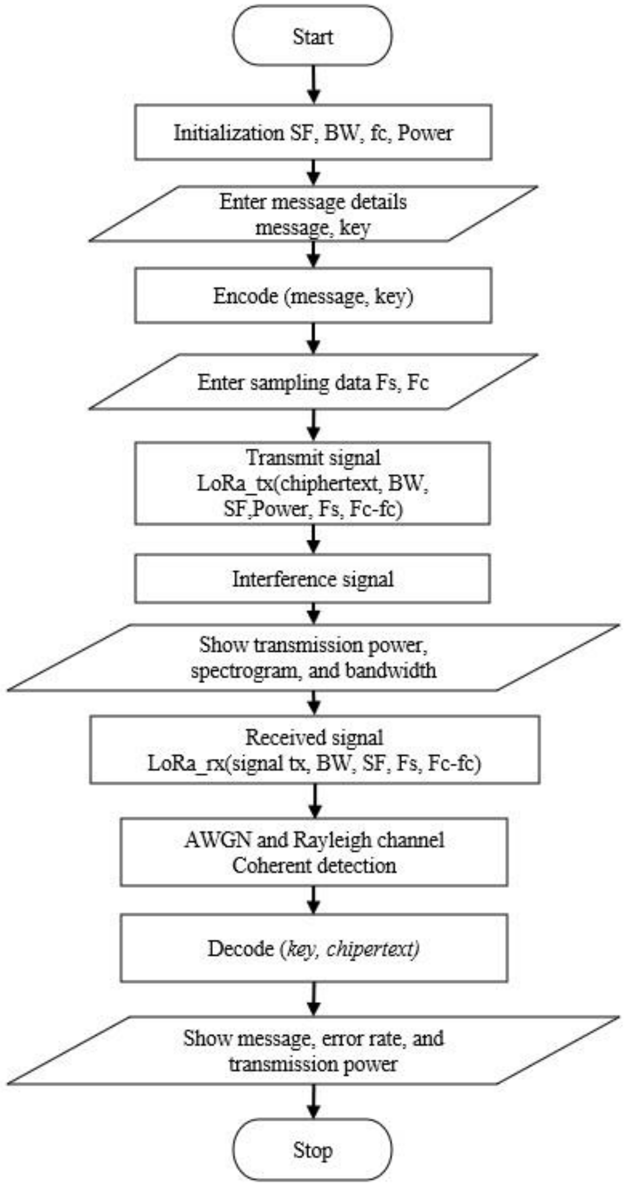

FIGURE 1. Flowchart of the LoRa communication system on the transceiver.

In Figure 1, the LoRa communication system begins with initializing the input value SF=7, BW=125 kHz, fc=915 MHz, and transmit power of 14 dBm. The message is sent from the transmitter to the receiver in the form of a message with 79 characters. The message is coded, and the input data sampling is Fs and fc. LoRa transmitter sends information to the receiver; this process is the same as the transmitter process in general, but what is different is on the receiver side. This study uses an unlicensed spectrum so that the interference on the channel will be substantial and requires special handling [21]. At the receiving end, LoRa receives the tx, SF, BW, Fs, and Fc-fc signals the same as those emitted. On the receiving side, research development was carried out to produce coherent and noncoherent detection models that are appropriate for use in LoRa communication systems using the AWGN and Rayleigh methods to obtain low error values by modulating binary frequency shift keying (BFSK) using MATLAB.

Figure 2 presents a demodulation process model developed in this study to compare channel optimization in reducing the effect of errors on LoRa communication channels. The signal modulation procedure has been examined and verified using MATLAB utilizing messages corresponding to the data sent [22].

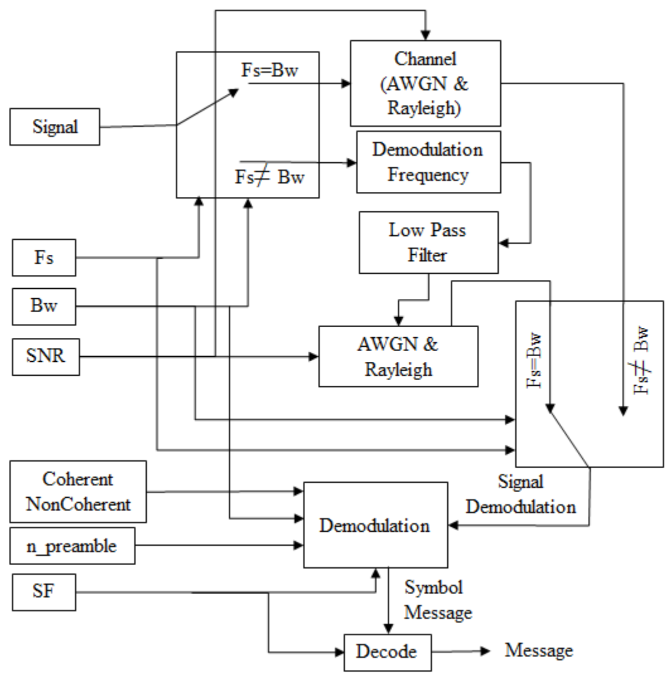

FIGURE 2. Demodulation process in the LoRa communication system.

The node will receive data from the transmitter on the receiver, which will then recapitulate the SNR. AWGN or Rayleigh channels will be used if the value of Fs = BW; otherwise, it will be transmitted to the frequency modulation process using binary FSK and filtered using LPF. In contrast to traditional frequency modulation, binary FSK is a constant-envelope version of angle modulation where the modulating signal alternates between two discrete voltage levels (1 and 0) instead of a continually changing value like a sine wave. Rayleigh or AWGN processes the following procedure due to signal interference or interference in overlapping bands. This study sends messages repeatedly to test the system's reliability [19]. A BER system can be used to evaluate the effectiveness of communication systems [23]–[25]. It is possible to see the power spectral density of the random signal by looking at the time domain signal in the baseband, produced by the information bit sent from the transmitter to the receiver in the communication system. Bit 1 denotes the transmission condition of the information from the transmitter to the receiver. To generate an independent noise sample and a flat noise spectrum labeled N0/2, which is two-sided such that the convenience factor of two in labeling is two, the AWGN channel also represents a Fourier transformation. The probability of bit error using BFSK can be seen in the following (1) for the binary case where M=2b, b=1 coherent (synchronous) detection:

$$Q\left(\sqrt{\frac{E_s/2}{N_0/2}}\right)=Q\left(\sqrt{\frac{SNR_r}{2}}\right) \quad (1)$$

E_s is an energy per symbol, N_0 is a noise energy, and SNR_r is an SNR in the RC (reference channel). For noncoherent detection (2) is as follows.

$$\frac{1}{2}e^{-SNR_r/4} \quad (2)$$

The binary case where $M=2^b$, $b>1$ using coherent (synchronous) detection in (3):

$$\frac{\frac{M}{2}}{M-1}\left\{1-\frac{1}{\sqrt{\pi}}\int_{-\infty}^{\infty}q(y)e^{-y^2}dy\right\} \quad (3)$$

M is a digit that indicates the number of conditions, levels, or combinations that can be made for a specific number of binary variables. $M=2^{SF}=Ts*BW=128$, (4) present the quality of SNR.

$$q(y)=Q^{M-1}\left(-\sqrt{2y}-\sqrt{b\ SNR_{r,b}}\right) \quad (4)$$

And for noncoherent detection presented in (5):

$$\frac{\frac{M}{2}}{M-1}\sum_{m=0}^{M-1}(-1)^{m+1}\binom{M-1}{m}\frac{1}{m+1}e^{-\frac{mbSNR_r}{2(m+1)}} \quad (5)$$

Therefore, the FSK coherent signal's bandwidth and bandwidth efficiency can be expressed as follows (6) and (7):

$$B_{COH,FSK}=2R_s+(M-1)\frac{R_s}{2}=\frac{(M+3)R_b/\log_2 M}{2} \quad (6)$$

$$\frac{R_b}{B_{COH,FSK}}=\frac{2\log_2 M}{M+3} \quad (7)$$

The receiver's sensitivity (S), is described in the following (8)

$$S=-148+10\log_{10}(B)+NF+SNR \quad (8)$$

where (-148) is the result of thermal noise at the receiver in a 1 Hz bandwidth, NF is the noise figure at the receiver (specified for hardware configuration data), and SNR is the signal-to-noise ratio necessary for modulation. The SER is evaluated while varying the SNR, defined as the device's received power to the noise power [26]. The SER can be used to determine the symbol error rate at the receiver and decoder performance evaluation. The symbol rate (Rs) is calculated using the following equation (9):

$$R_s(\text{symbol/sec})=\frac{BW}{2^{SF}}=\frac{R_c}{2^{SF}} \quad (9)$$

Rs = 125.000/27 = 976 symbol/sec. To offer functionality for ACK packets, PER measurement typically requires temporal dynamic of register configuration, interrupt handling (to verify valid/invalid packets), and switching between TX and RX modes. Bit Error Probability can be calculated as follows (10):

$$P_b \approx 0.5 \times Q\left(\frac{\sqrt{E_s}\,\mu_{\hat{\rho}}}{\sigma_{\hat{\rho}}^2 + N_0/2}\right) \tag{10}$$

Pb is a bit probability, Q (x) is the gaussian Q-function in a standard normal distribution or same as a tail distribution, and N0 is a noise density (watts/Hz) [12], [27], [28].

As a necessary form indicates the precise likelihood of error for simplex signals in AWGN, which can be laborious tocompute, shorter arrangements are of interest. Calculate simplex signals' error probabilities in AWGN. Coherent quaternary frequency-shift keying (FSK) and pulse-position modulation are two orthogonal sets that can easily be included in the new boundaries [29]. A simple radio signal merely indicates that the transmitter is still turned on. Signals need to be modified in some way before they can transfer data. There are numerous ways to accomplish this. The most common techniques involve modifying the frequency and amplitude [30]. In this study, the frequency is modified using binary FSK. Table 1 shows the input parameters used in this study.

TABLE 1. LoRa Parameters [12], [31]

Parameter	**Value**
Bandwidth (BW)	125 kHz
Spreading Factor (SF)	7
Frequency sampling (Fs)	10 MHz
Frequency carrier (Fc)	921.5 MHz
Transmit power in decibels (Pt)	14 dBm
Frequency center (fc)	915 MHz
Number of conditions (M)	128
Modulation technique	CSS
Digital Modulation	Binary FSK
Noise channels	AWGN, Rayleigh
SNR	-30: 30
Time duration (T_d)	0.999

This study uses SF = 7, the lowest spreading factor that increases the data rate, leading to faster transmission time and boosting energy to the signal more resilient to remote deployments.

A Gaussian distributed random number design array is created via the simulation loop method. To control the error of the communication system, parameters are utilized in communication. Here, the digital modulation technique uses the BER and SNR parameters.

$$\mathrm{SNR} = \Gamma$$

$$\Gamma = \frac{E_s/T_s}{N_0 \cdot \mathrm{BW}} = \frac{E_s}{N_0 2^{\mathrm{SF}}} \tag{11}$$

E_s is the power spectral density of signal energy, N_0 is the noise energy, and T_s is the time of signal energy.

3. **Simulation Result and Discussion.** Performance of Binary FSK Detection coherent and noncoherent features, such as known frequency and phase, known frequency and unknown phase, and unknown frequency and phase, are present. When the frequency or phase of the received signal is unknown, noncoherent detection should be used according to this knowledge-based characteristic of the received signal. With known frequency and unknown phase, the theoretical loss of incoherent BFSK detection performance is reduced by around 0.9 dB at Pbe = 10-5 relative to coherent BFSK detection. The theoretical loss of coherently detected BFSK close to antipodal signaling is 3 dB for all bit error situations. However, when the frequency and phase are unknown, the loss depends on the frequency uncertainty range, with a loss of 17 dB at P_{be} = 10-5 compared to coherent detection for the bit rate uncertainty range at a frequency of 104 times.

The results of a computer simulation program utilizing MATLAB using an analytical and numerical approach to wireless communication systems are covered in this chapter's portion, which also considers AWGN and Rayleigh Fading. Figure 3 shows the test results as the bit energy ratio to noise power spectral density (E_b/N_0) and BER.

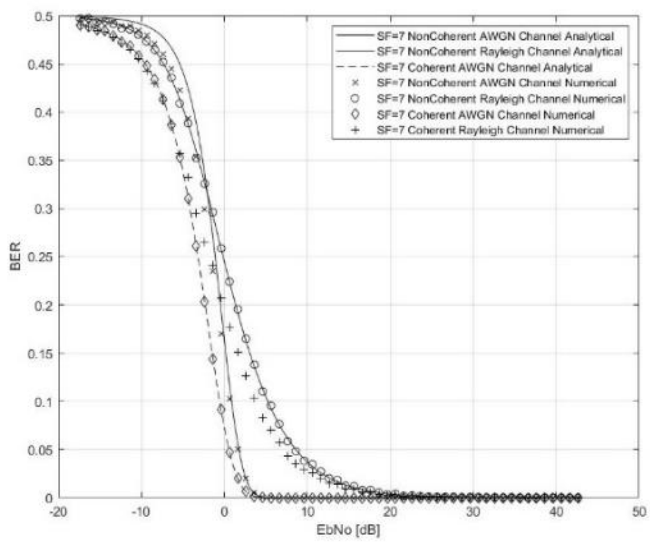

FIGURE 3. Bit error probability with coherent and noncoherent demodulation using AWGN and Rayleigh channel

BER and E_bN_o simulation results are shown in Table 2.

TABLE 2. Simulation Result BER Against E_bN_0

Method	**Channel**	**Detection**	**BER**	**E_bN_0 (dB)**
Numerical	AWGN	Coherent	3.10^{-2}	1
	AWGN	NonCoherent	8.10-^{2}	1
	Rayleigh	Coherent	7.10^{-2}	6
	Rayleigh	NonCoherent	9.10^{-2}	6

Figure 3 and Table 2 show that the numerical technique using the AWGN channel and coherent detection of the bit error rate value, namely a BER of 3.10^{-2} and an E_bN_0 of 1 dB, is optimal for the LoRa communication system. The greater the SF value, the more sensitive the receiver is. However, it also accounts for the faster bit rate, lengthening the transmission time, which is especially problematic if the subscriber is far from the base station. LoRa operates on a 125 kHz fixed bandwidth channel and offers a trade-off between sensitivity and data rate [32]. LoRa also uses an orthogonal dispersion factor. This higher dispersion factor provides increased processing gain and greater reception sensitivity. After being simulated on AWGN and Rayleigh channels, BER analysis shows that the LoRa modem performs well, with a BER value of 0.5 and an E_bN_0 value of up to 20 dB. Figure 3 shows the test results as the bit energy ratio to noise power spectral density (E_b/N_0) and BER Figure 4 displays the energy per symbol to noise power spectral density (E_sN_0) and SER ratios. The optimal value for the noncoherent AWGN channel is discussed in this simulation, which uses MATLAB software to analyze and numerically model wireless communication systems while considering AWGN and Rayleigh Fading.

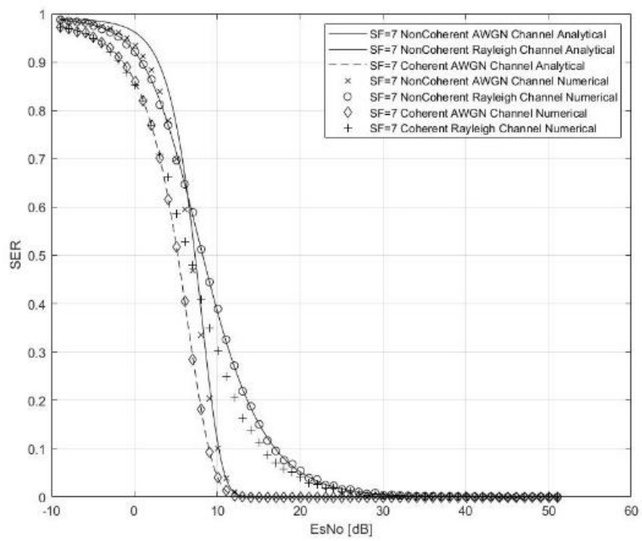

FIGURE 4. Symbol error probability with coherent and non-coherent demodulation using AWGN and Rayleigh channel

TABLE 3. Simulation Result SER Against E_sN_0

Method	**Channel**	**Detection**	**SER**	**E_sN_0 (dB)**
Numerical	AWGN	Coherent	4.10^{-1}	6
	AWGN	NonCoherent	6.10^{-1}	6
	Rayleigh	Coherent	5.10^{-1}	6
	Rayleigh	NonCoherent	6.10^{-1}	6

The numerical method employing the AWGN channel and coherent detection of the symbol error rate value, namely an SER of 4.10^{-2} and an E_sN_0 of 6 dB, is shown to be the best for LoRa communication systems in Figure 4 and Table 3. Assuming one LoRa device has 30000 symbols, Figure 4 depicts the symbol error rate versus the E_sN_o for SF = 7 in the LoRa network's performance. With fewer iterations and numerical calculations, the symbol error rate employing coherence detection on the AWGN channel can significantly lower the E_sN_o number. Figure 5 shows the power spectral density and PER ratios of the signal-to-noise.

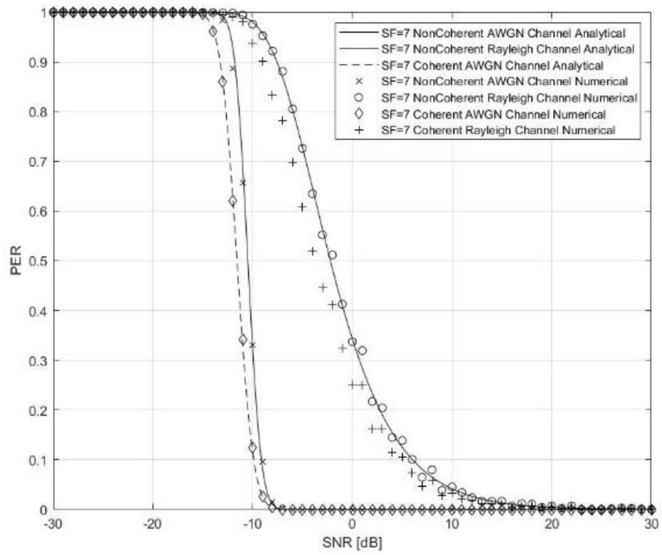

FIGURE 5. Packet error probability with coherent and non-coherent demodulation using AWGN and Rayleigh channel

Table 4 presents the outcomes of the simulations for PER and SNR.

TABLE 4. Simulation Result PER Against SNR

Method	**Channel**	**Detection**	**PER**	**SNR (dB)**
Numerical	AWGN	Coherent	0	1
	AWGN	NonCoherent	0	1
	Rayleigh	Coherent	2.10^{-1}	1
	Rayleigh	NonCoherent	3.10^{-1}	1

Figure 5 and Table 4 demonstrate that the numerical method employing the AWGN channel and coherent detection for packet error rate is the best for LoRa communication systems with PER 0 and an SNR equal to 1 dB. The packet error rate curve is used for LoRa, specifically on AWGN or Rayleigh channels, to forecast the performance of the communication system [33]. SNR supplied by the LoRa Semtech transceiver to calculate the whole curve using measurements, empirical representations, and closed-form estimation assuming AWGN or Rayleigh fading channels, which serve as benchmarks. In addition to considering interference effects and thinking of network-generated interference, this model forecasts LoRa performance. The average interference and noise power are added linearly to produce the SNR value. The typical LoRa SNR ranges from -20 dB to +10 dB. The received signal is less distorted when the value is closer to +10 dB. LoRa can demodulate signals between -7.5 dB and -20 dB below the noise level [34].

4. **Conclusions.** The performance of the LoRa network demonstrates that coherent detection on the AWGN channel is very effective in lowering noise values with 61 numerical calculation iterations and 10,000 analytical calculation iterations. This research's contribution has been demonstrated to accurately compare analytical and numerical

calculations with coherent and noncoherent detection using AWGN and Rayleigh channels successfully simulated in MATLAB. The coherent detection with the AWGN channel is the appropriate model in this study when considering the best input parameters.

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