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Determination Of Lora Modulation Bit Error Rate In Additive White Gaussian Noise Channel Using Two-Fold Integral Method And Monte-Carlo Simulation Approach

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***Abstract*— In this paper, Determination of LoRa modulation bit error rate (BER) in additive white Gaussian noise channel using two-fold integral method and Monte-Carlo simulation approach is presented. The analytical expression of the two-fold integral-based BER computation for LoRa modulation scheme was presented along with the Monte-Carlo algorithm for the BER computation. The two methods were simulated using AnyLogic software. The results show that for spreading factor , SF of 7 at the upper SNR value (SNR = -6 dBm) and the lower SNR value (SNR = -18 dBm) of the curve the two methods gave the same BER value but there is a significant difference in the values of the two methods in between the upper and lower SNR values. At SNR = -12 dBm, the analytical approach gave BER of 0.15669895 while the Monte-Carlo simulation method gave BER of 0.22721347 which is about 45 % difference. Also, the results show that for spreading factor , SF of 12 at the upper SNR value (SNR = -16 dBm) and the lower SNR value (SNR = -36 dBm) of the curve the two methods gave the same BER value but there is a significant difference in the values of the two methods in between the upper and lower SNR values. At SNR = -26 dBm, the analytical approach gave BER of 0.1419188 while the Monte-Carlo simulation method gave BER of 0.21255 which is about 49 % difference. In all, the results show that the two methods gave similar BER values at some SNR values but vary significantly at other SNR values.**

Keywords*— *Lora Modulation, Monte-Carlo Simulation, Bit Error Rate, Two-Fold Integral Method, Additive White Gaussian Noise Channel

I INTRODUCTION

Wireless communication systems are increasingly adopted for terrestrial and also for satellite applications [1,2,3,4,5,6,7,8,9,10,11,12]. Also, in this era of Internet of Things and smarts systems, wireless technologies have dominated there wired and the fiber optic based networking options [13,14,15,16,17,18,19,20,21,22,23,24,25]. Moreover, wireless sensor networking has also become the driving technology for the IoT and smart systems [26,27,28,29,30,31,32,33]. In addition, with increasing introduction of intelligent algorithms such as deep learning and other forms of artificial intelligent methods, the application of wireless sensor technologies are unlimited [34,35,36,37,38,39].

In any case, wireless communication links are fraught with diverse challenges which affect the error rate and other quality of service (QoS) of the wireless communication system [40,41,42,43,44,45,46,47,48,49,50,51,52,53,54]. Notably, propagation loss, multipath loss, fading, diffraction loss and other kinds of impediments attenuates the signal strength and hence impact on the QoS of the wireless system [55,56,57,58,59, 60,61,62,63,64,65, 66,67,68, 69,70, 71, 72, 73,74,75,76,77,78].

Also, the impediment on the signal strength affect the received sign strength and the energy consumption of the wireless system. In wireless sensor network for instance, the sensor node battery life span is affected by the propagation loss and there other factors that do attenuate the signal strength. Also, the impediments are also considered in the clustering of sensor nodes and the selection of the optimal location of gateways or base stations in clustered sensor networks. As such, wireless communication systems design always take into consideration the impact of the various factor in the propagation channel on the QoS.

Notably, the impact of the propagation environment on the signal differs depending on the nature of the propagation environment. Also, remarkably, among the numerous options, LoRa transceivers with their chirp spread spectrum modulation scheme have become the de factor transceiver technologies for long range and low power sensor network applications [79]. Accordingly, in this paper, the BER of LoRa modulation scheme in additive white Gaussian noise channel is considered [80,81]. The noise or unwanted signal is additive being that received signal is the sum of the actual signal and the noise signal. Also, the noise termed white because it affect all frequencies uniformly. Finally, the noise signal strength has Gaussian probability distribution. The analysis in this paper is conducted to compare the analytical approach and Monte-Carlo simulation approach of estimating the BER of LoRa modulation bit error rate in additive white Gaussian noise channel [82,83]. The details of the methods and the simulations are presented.

II METHODOLOGY

The main aim of this paper is to present and compare two approaches for estimating the bit error performance of LoRa modulation scheme. The first method is analytical method based on two-fold integral while the second method is a Monte-Carlo simulation based approach.

A. The two-fold integral method for computing LoRa Bit Error Rate (BER) in AWGN Channels

According to **[84,85,86,87] the** average symbol error probability (P_s) for a LoRa modulation scheme in **AWGN channel** can be computed as two fold integral as follows:

$$P_s = \frac{1}{2}\int_0^{\infty}\int_0^{\infty}\{1-[1-\exp(-x/2)]^L\}\times exp\left(-\frac{x+2N\gamma y}{2}\right)\cdot I_0\left(\sqrt{2N\gamma xy}\right)f_{h^2}(y)dxdy \quad [1]$$

Then the bit error probability (P_b) can be presented as **[84,85,86,87]:**

$$P_b = \frac{2^{SF-1}}{2^{SF}-1}\cdot P_s \quad [2]$$

Where SF is the LoRa modulation spreading factor

B. Monte-Carlo Procedure for BER of AWGN channel

This section describes the Monte-Carlo simulation procedure for bit error rate of additive white Gaussian noise which is presented in Algorithm 1

Algorithm 1: Monte-Carlo Simulation Procedure for BER of AWGN

Inputs: Number of Samples $N_s > 0$
Set $E_s = SNR$
Set errors $e_{rr} = 0$
$N_s \leftarrow 10^5$
while $N_s > 0$ **do**
    generate noise coefficient using normal distribution
    generate h as arbitrary channel coefficient for a given fading distribution
    generate the maximum of exponential random variables ρ^2
    if $\rho^2 > \left|h\sqrt{E_s}+\phi_i\right|^2$ // **then**
        $e_{rr} = e_{rr} + 1$
    end if
end while

III RESULTS AND DISCUSSION

Simulation was performed using Monte-Carlo simulation based on the procedure presented in Algorithm 1. The model presented in Equation 1 representing the analytical closed form expressions for BER of AWGN was keyed to system as a comparative model to the procedure presented in Algorithm 1. $SF \in \{6, 12\}$ is selected as the lowest and highest spreading factor in this case to present two extreme scenarios, and some random samples equal to 10^5 is used to ensure statistical convergence.

The results for the values of analytical method and the Monte-Carlo simulation generated BER values for Lora in AWGN with $SF = 7$ are presented on Table 1 and Figure 1. The results show that at the upper SNR value (SNR = -6 dBm) and the lower SNR value (SNR = -18 dBm) of the curve the two methods gave the same BER value but there is a significant difference in the values of the two methods in between the upper and lower SNR values. At SNR = -12 dBm, the analytical approach gave BER of 0.15669895 while the Monte-Carlo simulation method gave BER of 0.22721347 which is about 45 % difference.

The results for the values of analytical method and the Monte-Carlo simulation generated BER values for Lora in AWGN with $SF = 12$ are presented on Table 2 and Figure 2. The results show that at the upper SNR value (SNR = -16 dBm) and the lower SNR value (SNR = -36 dBm) of the curve the two methods gave the same BER value but there is a significant difference in the values of the two methods in between the upper and lower SNR values. At SNR = -26 dBm, the analytical approach gave BER of 0.1419188 while the Monte-Carlo simulation method gave BER of 0.21255 which is about 49 % difference.

Table 1: The results for the analytically generated BER and the Monte-Carlo simulation generated BER values for Lora in AWGN with $SF = 7$

SNR(dB)	Analytically computed BER	Monte-Carlo simulation generated BER
-18	0.42794230	0.42794230
-16	0.37422894	0.40042497
-14	0.28500317	0.33915377
-12	0.15669895	0.22721347
-10	0.03664489	0.07878652
-8	0.00072707	0.00705259
-6	0.00000001	0.00000011

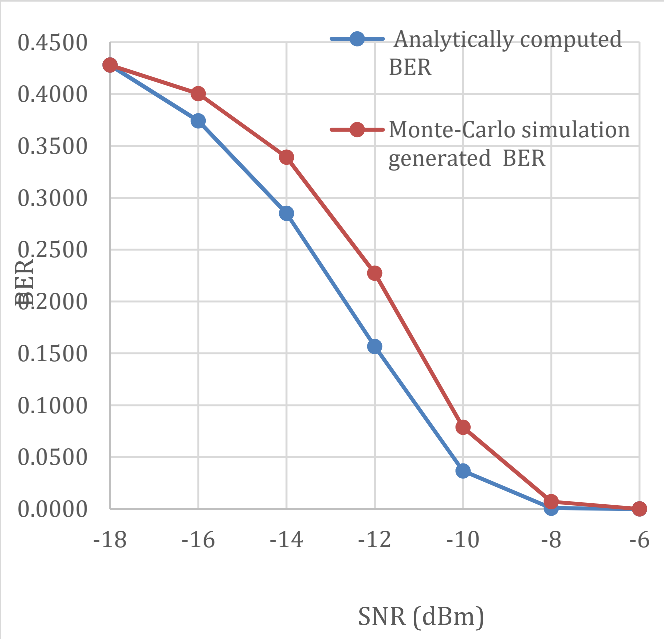

Figure 1 The graph for the analytically generated BER and the Monte-Carlo simulation generated BER values for Lora in AWGN with $SF = 7$

Table 2: The results for the analytically generated BER and the Monte-Carlo simulation generated BER values for Lora in AWGN with $SF = 12$

SNR(dB)	Analytically computed BER	Monte-Carlo simulation generated BER
-36	0.4573255	0.457326
-33.5	0.4244254	0.445647
-31	0.3673375	0.411418
-28.5	0.2733599	0.360835
-26	0.1419188	0.21255
-23.5	0.0283348	0.089255
-21	0.0003506	0.004207
-18.5	0	0
-16	0	0

Table 4.2 depicts the simulation values for the theoretical method of AWGN at $SF = 12$

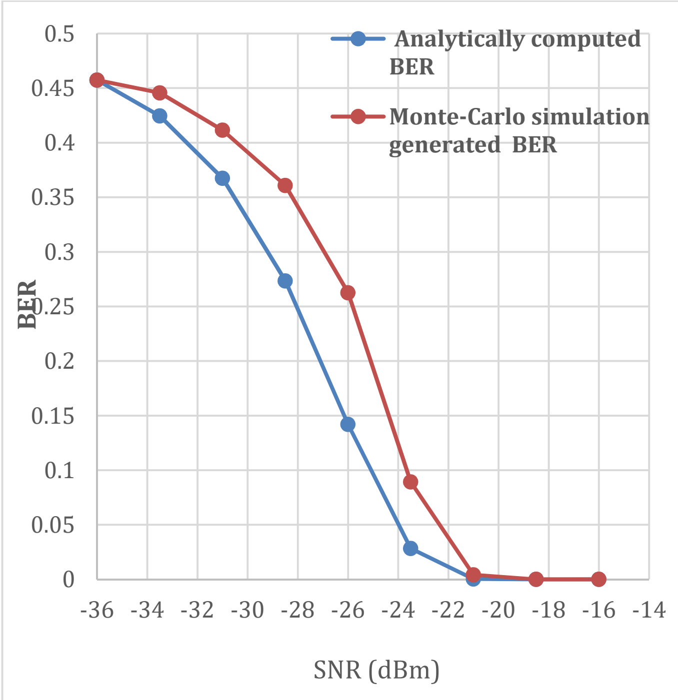

Figure 2 The graph for the analytically generated BER and the Monte-Carlo simulation generated BER values for Lora in AWGN with $SF = 12$

IV Conclusion

A comparison of analytical and simulated bit error rate (BER) methods for LoRa modulation bit error rate in additive white Gaussian noise channel is presented. The analytical method is based on two-fold integral method while the simulation method is based on Monte-Carlo simulation approach. The analytical expression is presented along with the Monte-Carlo algorithm. Sample numerical results were obtained for spreading factor of 7 and 12. The results presented the BER versus signal to noise ratio (SNR). The results show that the two methods gave similar BER values at some SNR values but vary significantly at other SNR values.

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