# Comparative Evaluation Of Two Different Analytical Models For Lora Transceiver Bit Error Performance

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***Abstract*— In this paper, comparative evaluation of two different analytical models for LoRa transceiver bit error rate (BER) performance is presented. The first analytical model denoted as $BER_{LoRa(FEC)}$ included the LoRa forward error correction code (referred to as coding rate, CR) while the second analytical model denoted as $BER_{LoRa(NFEC)}$ does not include CR. The simulation was performed using a program written in Visual Basic for Application (VBA). The four different LoRa transceiver coding rate (CR) values were considered, namely; 4/5, 4/6, 4/7 and 4/8. For each coding rate, a value of signal to noise ratio (SNR) is specified, then the $BER_{LoRa(FEC)}$ and $BER_{LoRa(NFEC)}$ were computed for the different LoRa transceiver spreading factors (SF). The results show that for a given SNR and CR, the energy per bit to noise power spectral density $\left({E_b}/{N_0}\right)$ increases with increase in spreading factor, SF. In one of the simulations, for SF of 7 and CR of 0.8, the result obtained for the value of Eb/No (dB) was 4.06dB and the value of Eb/No (dB) increased to 75.87 dB at SF of 12 and CR of 0.8. Also, the value of Eb/No (dB) increases with increase in the number of forward error correction bit, n. Notably, Eb/No (dB) had a value of 4.06 at n = 1 and CR = 0.8 for SF =7 and SNR = 7.5 dBm while Eb/No (dB) had a value of 6.5 at n = 4 and CR = 0.5 for SF =7 and SNR = 7.5 dBm. In all, although the BER method with forward error correction code, BERLoRa_FEC always gave smaller BER value, it will require empirical validation to know which of the two methods gives more accurate results and under what conditions are the results more accurate.**

***Keywords*— *LoRa Transceiver, Bit Error Rate, Spreading Factor, Signal To Noise Ratio, LoRa BER Models***

## 1. INTRODUCTION

The low power long range transceiver technology, known as LoRa, has been widely used for various sensor network communication applications [1,2]. The LoRa technology has the ability to trade long range transmission with small payload size [3,4]. LoRa transceiver uses the chirp spread spectrum (CSS) modulation technology which enables it to achieve various data rates and energy consumption capabilities [5,6].

One of the important performance parameters of wireless communication transceivers is the bit error rate (BER) [7,8]. There are different approaches to determine the BER of transceivers under different channel categories. Mostly, the BER are determined in white noise channel. Apart from empirical approach, some analytical models have been developed for estimating the LoRa transceiver BER. Many researchers have used a popular analytical model for LoRa BER estimation [9,10,11,12]. The popular LoRa BER model does not directly include the forward error correction parameters in LoRa which is denoted as coding rate, CR. In any case, the CR is included in the analytical expression for computing the energy per bit to noise power spectral density $\left({E_b}/{N_0}\right)$ with which the BER is determined.

On the other hand, another analytical expression has been proposed which included the CR directly in the BER model [13]. With the inclusion of the CR parameter, the resultant BER for any given ${E_b}/{N_0}$ is different from the value obtained from the popular BER model for LoRa, accordingly, in this study, the two models are examined and their BER values are compared for different parameter values of the LoRa transceiver. The study is a prelude to an empirical study which will later be used to validate the model that is more accurate and the different parameter configurations under which the model is more accurate than the other.

## 2. METHODOLOGY

Bit error rate of LoRa transceiver is the focus of this study. Specifically, two different analytical expressions for computing the bit error rate performance (BER) of LoRa transceiver are considered. The first analytical model for LoRa BER has coding rate (CR) that reflects the forward error correction in LoRa. The second analytical model for LoRa BER has no direct parameter that reflect the forward error correction in LoRa. The two models are presented and the impact of coding rate on the BER is examined and compared for the two models.

### 2.1 The LoRa transceiver Bit Error Rate (BER) without forward error correction

The LoRa transceiver Bit Error Rate (BER) without forward error correction is denoted as $BER_{LoRa(NFEC)}$ and it is a function of energy per bit to noise power spectral density $\left({E_b}/{N_O}\right)$ and the spreading factor (SF). Now, the signal to noise ratio, $SNR$ of LoRa receiver is expressed in terms of the bandwidth ($BW_n$), the coding rate (CR), the symbol rate (Rs), SF and ${E_b}/{N_O}$ where [9,10,11,12];

$$SNR = {E_b}/{N_O} + 10\log_{10}(R_s) + 10\log_{10}(SF) + 10\log_{10}(CR) - 10\log_{10}(BW_n) \quad (1)$$

$$R_s = \frac{BW_n}{2^{SF}} \quad (2)$$

$$CR = \frac{4}{4+n} \quad \text{where n= 1, 2, 3, or 4} \quad (3)$$

Hence;

$$ {E_b}/{N_O} = SNR - 10\log_{10}(R_s) - 10\log_{10}(SF) - 10\log_{10}(CR) + 10\log_{10}(BW_n) \quad (4)$$

$$BER_{LoRa(NFEC1)} = Q\left(\left(\frac{\mathrm{Log}_{12}(SF)}{\sqrt{2}}\right)\left({E_b}/{N_O}\right)\right) \quad (6)$$

$$BER_{LoRa(NFEC)} = \frac{1}{2}\left[1 - erf\left(\left(\frac{(\mathrm{Log}_{12}(SF))}{\sqrt{2}}\right)\left({E_b}/{N_O}\right)\right)\right] \quad (7)$$

### 2.2 The LoRa transceiver Bit Error Rate (BER) with forward error correction

The LoRa transceiver Bit Error Rate (BER) with forward error correction is denoted as $BER_{LoRa(FEC)}$ and it is a function of ${E_b}/{N_O}$ , SF and coding rate, $CR = \frac{4}{4+n}$, where [13];

$$BER_{LoRa(FEC)} = Q\left(\left(\frac{(2)(\mathrm{Log}_{12}(SF))\left(\frac{4}{4+n}\right)}{\sqrt{2}}\right)\left({E_b}/{N_O}\right)\right) \quad (8)$$

$$BER_{LoRa(FEC)} = \frac{1}{2}\left[1 - erf\left(\left(\frac{(2)(\mathrm{Log}_{12}(SF))\left(\frac{4}{4+n}\right)}{\sqrt{2}}\right)\left({E_b}/{N_O}\right)\right)\right] \quad (9)$$

### 2.3 The simulation approach

The simulation was performed using a program written in Visual Basic for Application (VBA). The four different coding rates in LoRa transceiver are considered, namely; 4/5, 4/6, 4/7 and 4/8. For each coding rate, a value of SNR is specified, then the $BER_{LoRa(NFEC)}$ and $BER_{LoRa(NFEC)}$ are computed for the different spreading factors available in LoRa transceiver.

## 3. RESULTS AND DISCUSSIONS

The results of the Eb/No (dB) for SNR =-7.5 dBm while the coding rate, is varied from 0.8 to 0.5 are presented in Table 1. The results in Table 1 and Figure 1 show that for a given SNR and CR the Eb/No (dB) increases with increase in SF, with Eb/No (dB) = 4.06dB at SF of 7 and CR of 0.8 to Eb/No (dB) = 75.87 dB at SF of 12 and CR of 0.8 (as shown in Figure 2).

Again, the results in Figure 3 and Figure 4 shows that for any given SF and SNR, the Eb/No (dB) decreases with increase in CR. Specifically, as the number of forward error correction bit, n increases, CR decreases and Eb/No (dB) increases. As such, the Eb/No (dB) increases with increase in the number of forward error correction bit, n, with Eb/No (dB) =4.06 at n = 1 and CR = 0.8 for SF =7 and SNR = 7.5 dBm while Eb/No (dB) = 6.5 at n = 4 and CR = 0.5 for SF =7 and SNR = 7.5 dBm.

Table 1 The results of the Eb/No (dB) for SNR =-7.5 dBm while the coding rate, is varied from 0.8 to 0.5.

| SF, Spreading Factor | Eb/No (dB) for n=1, CR = 0.8 and SNR =-7.5 dBm | Eb/No (dB) for n=2, CR = 0.67 and SNR =-7.5 dBm | Eb/No (dB) for n=3, CR = 0.57 and SNR =-7.5 dBm | Eb/No (dB) for n=4, CR = 0.5 and SNR =-7.5 dBm |
|---|---|---|---|---|
| 7 | 4.06 | 4.88 | 5.69 | 6.5 |
| 8 | 7.11 | 8.54 | 9.96 | 11.38 |
| 9 | 12.65 | 15.17 | 17.7 | 20.23 |
| 10 | 22.76 | 27.31 | 31.87 | 36.42 |
| 11 | 41.39 | 49.66 | 57.94 | 66.22 |
| 12 | 75.87 | 91.05 | 106.22 | 121.4 |

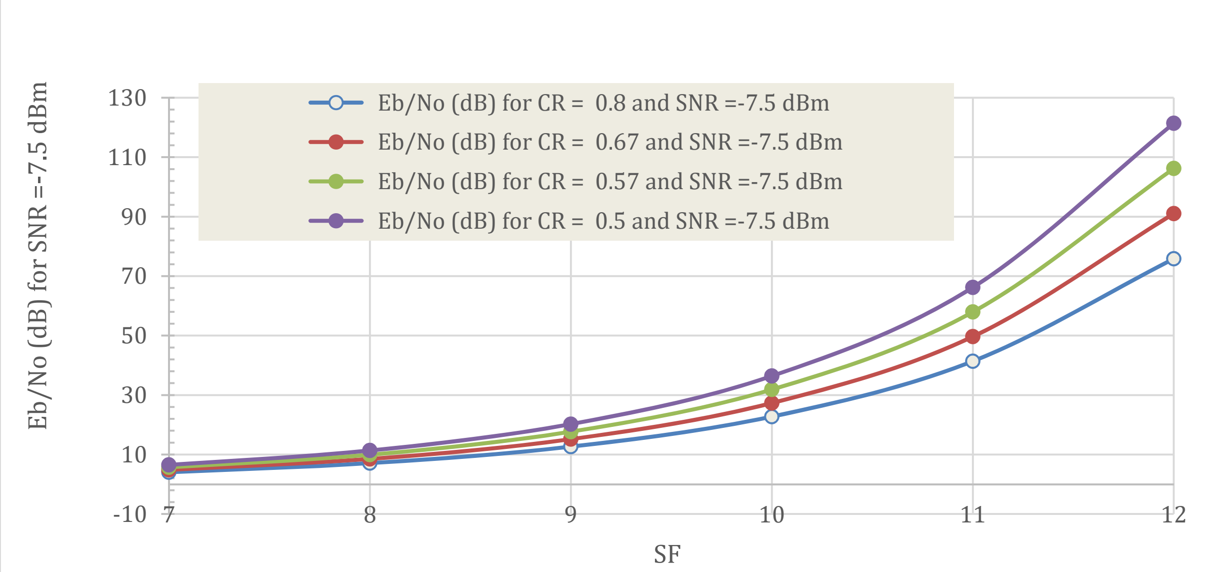


**Figure 1 The graph of Eb/No (dB) versus SF for SNR =-7.5 dBm and CR = 0.8. 0.67, and 0.57 and 0.5**

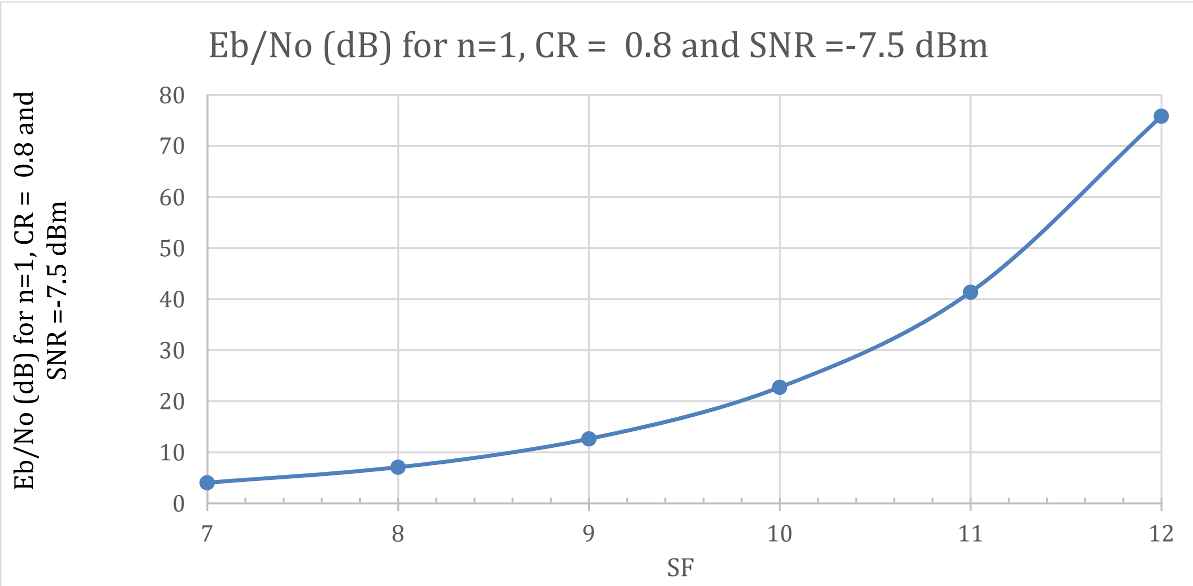


**Figure 2 The graph of Eb/No (dB) versus SF for SNR =-7.5 dBm and CR = 0.8**

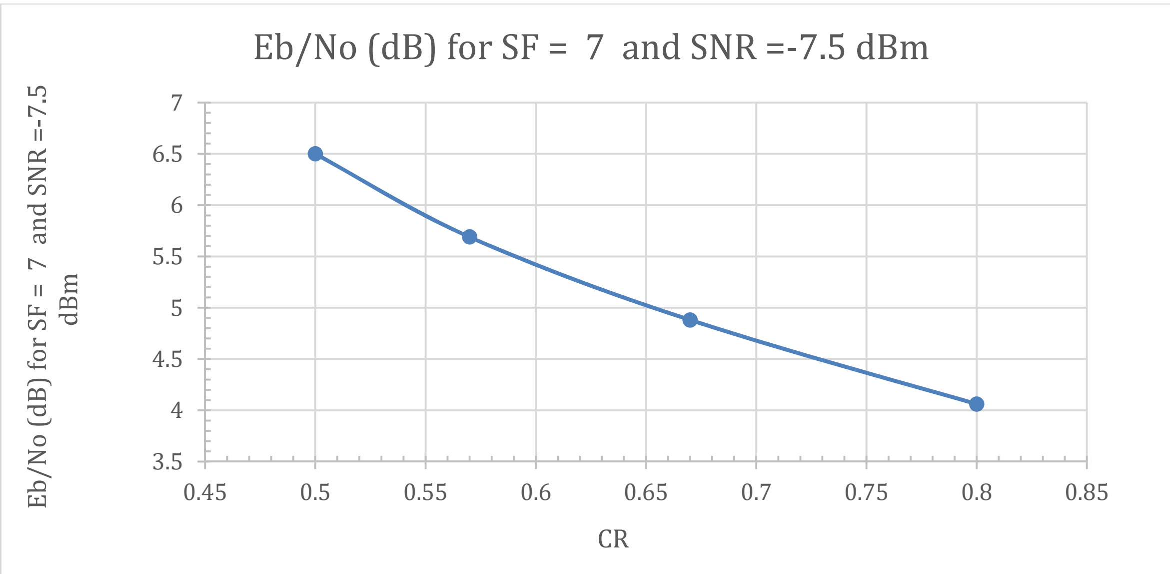


**Figure 3 The graph of Eb/No (dB) versus CR for SNR =-7.5 dBm and SF =7**

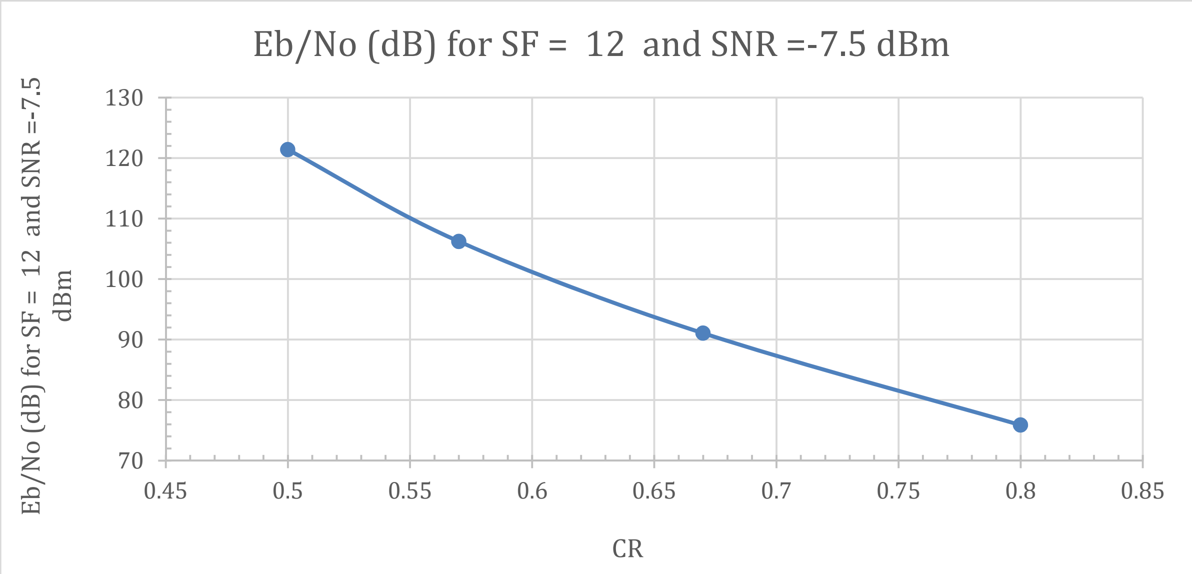


**Figure 4 The graph of Eb/No (dB) versus CR for SNR =-7.5 dBm and SF =12**

The results of the BER performance obtained using the two methods are shown in Table 2 and Figure 5. The results show that for a given Eb/No (dB), the BER obtained with the BERLoRa_NFEC model is always higher than the value obtained with the BERLoRa_FEC model. For instance, for SF =7, with CR = 0.8 and Eb/No = 4, the value of BERLoRa_NFEC = 8.6701E-04 while BERLoRa_FEC = 2.6963E-07 which gives a difference of 8.6674E-04. It means that the BERLoRa_FEC gives smaller BER value for any given CR and Eb/No. Similarly, the results obtained for CR = 0.8 and Eb/No = 4 also showed that the BERLoRa_FEC gives smaller BER value than the BERLoRa_NFEC model, as shown in Table 3 and Figure 6.

**Table 2 Comparison of the BER versus CR for the two methods for CR = 0.8 and Eb/No = 4**

| SF, Spreading Factor | BERLoRa_NFEC for CR = 0.8 and Eb/No = 4 | BERLoRa_FEC for CR = 0.8 and Eb/No = 4 | Difference (BERLoRa_NFEC - BERLoRa_FEC) for CR = 0.8 and Eb/No = 4 |
|---|---|---|---|
| 7 | 8.6701E-04 | 2.6963E-07 | 8.6674E-04 |
| 8 | 4.0799E-04 | 4.2612E-08 | 4.0795E-04 |
| 9 | 2.0242E-04 | 7.6102E-09 | 2.0241E-04 |
| 10 | 1.0507E-04 | 1.5108E-09 | 1.0506E-04 |
| 11 | 5.6708E-05 | 3.2894E-10 | 5.6708E-05 |
| 12 | 3.1671E-05 | 7.7688E-11 | 3.1671E-05 |

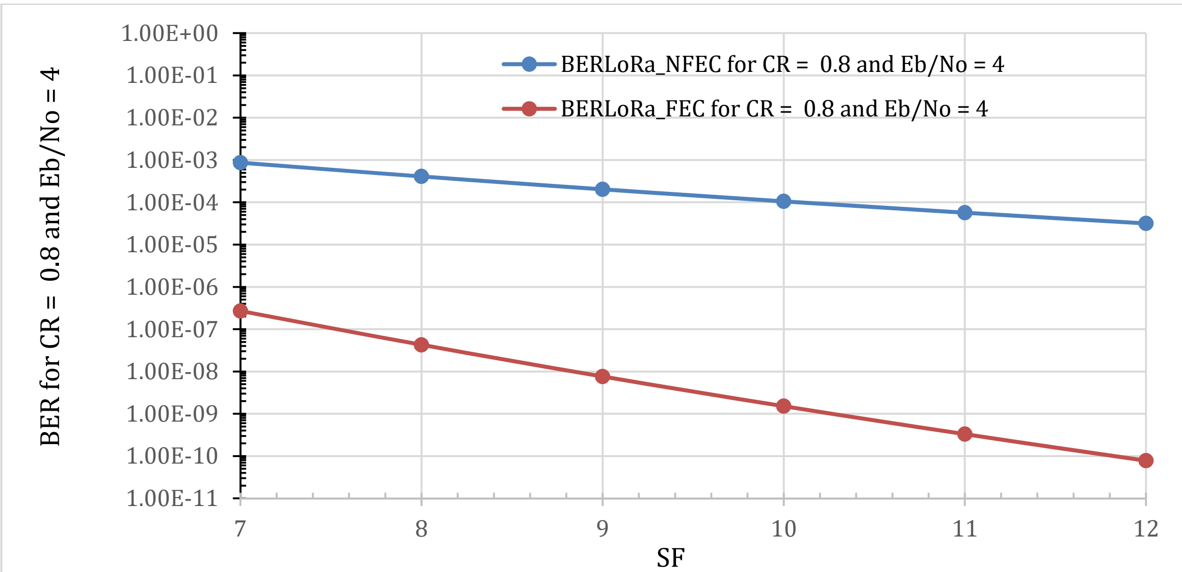


**Figure 5 The results of the BER performance obtained using the two methods for CR = 0.8 and Eb/No = 4**

**Table 3 Comparison of the BER versus CR for the two methods for CR = 0.67 and Eb/No = 4**

| SF, Spreading Factor | BERLoRa_NFEC for CR = 0.67 and Eb/No = 4 | BERLoRa_FEC for CR = 0.67 and Eb/No = 4 | Difference (BERLoRa_NFEC - BERLoRa_FEC) for CR = 0.67 and Eb/No = 4 |
|---|---|---|---|
| 7 | 0.000867 | 1.48E-05 | 8.5221E-04 |
| 8 | 0.000408 | 4.04E-06 | 4.0395E-04 |
| 9 | 0.000202 | 1.2E-06 | 2.0121E-04 |
| 10 | 0.000105 | 3.87E-07 | 1.0468E-04 |
| 11 | 5.67E-05 | 1.33E-07 | 5.6576E-05 |
| 12 | 3.17E-05 | 4.82E-08 | 3.1623E-05 |

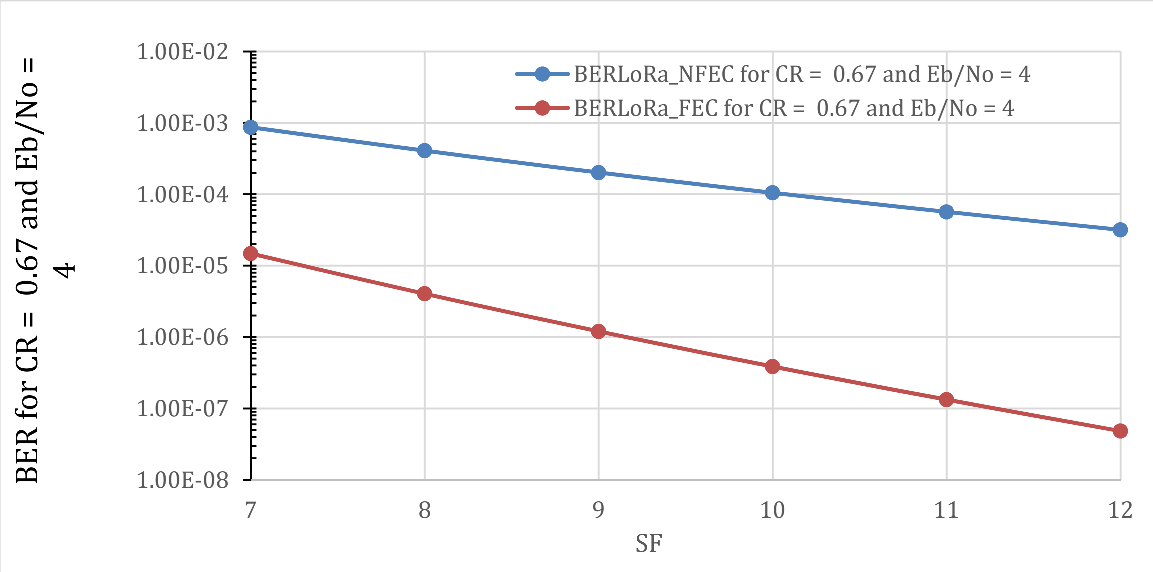


**Figure 6 The results of the BER performance obtained using the two methods for CR = 0.67 and Eb/No = 4**

The results for the comparison of the BER versus CR for the same SNR for the two methods are shown in Table 4 and Figure 7. The results show that the BERLoRa_FEC method give lower BER value than that of the BERLoRa_NFEC method. For SF of 7, with CR = 0.8 and SNR = -20dBm, the value of Eb/No = 0.23 and the BER obtained with BERLoRa_NFEC method is 4.2897E-01 while the BER obtained with BERLoRa_FEC method is 3.8729E-01 which is a difference of 4.1681E-02. Again, the results show that the BERLoRa_FEC method gives lower BER values than the BERLoRa_NFEC method, as shown in Table 5 and Figure 8. In all, although the BER method with forward error correction code, BERLoRa_FEC always gives smaller value of BER, it will require empirical validation to know which method gives more accurate results and under what conditions are the results more accurate.

**Table 4 Comparison of the BER versus CR for the same SNR for the two methods**

| SF, Spreading Factor | Eb/No for CR = 0.8 and SNR = -20dBm | BERLoRa_NFEC for CR = 0.8 and SNR = -20dBm | BERLoRa_FEC for CR = 0.8 and SNR = -20dBm | Difference (BERLoRa_NFEC - BERLoRa_FEC) for CR = 0.8 and SNR = -20dBm |
|---|---|---|---|---|
| 7 | 0.23 | 4.2897E-01 | 3.8729E-01 | 4.1681E-02 |
| 8 | 0.40 | 3.6891E-01 | 2.9613E-01 | 7.2786E-02 |
| 9 | 0.71 | 2.6475E-01 | 1.5719E-01 | 1.0755E-01 |
| 10 | 1.28 | 1.1779E-01 | 2.8866E-02 | 8.8929E-02 |
| 11 | 2.33 | 1.2359E-02 | 1.6329E-04 | 1.2196E-02 |
| 12 | 4.27 | 9.9208E-06 | 4.3455E-12 | 9.9208E-06 |

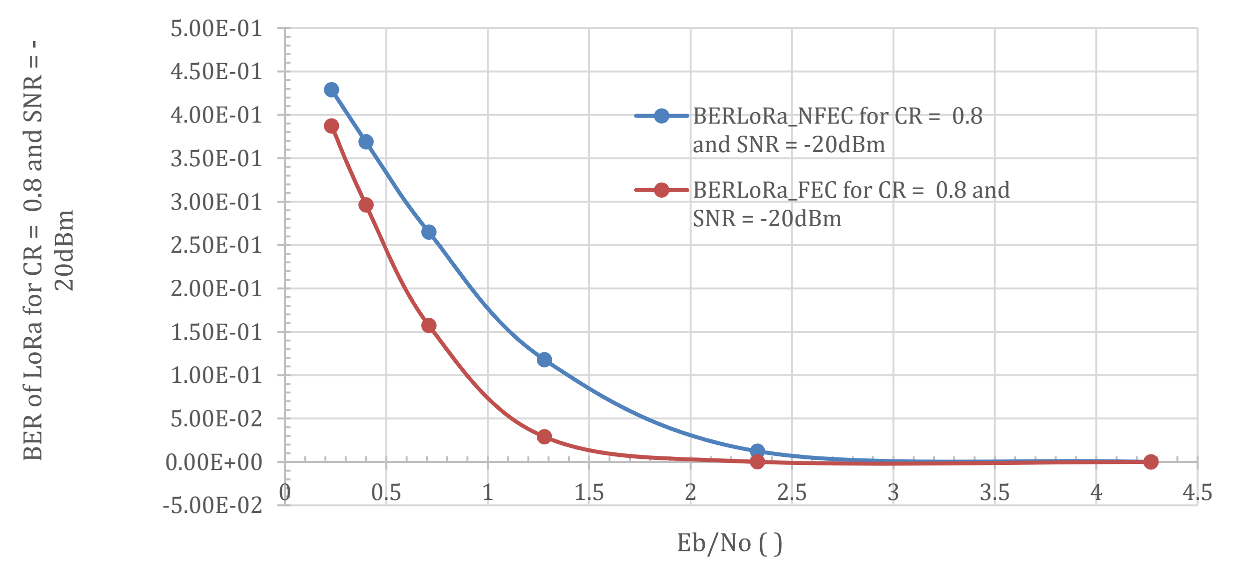


Figure 7 Comparison **of the BER versus CR for the same SNR for the two methods**

Table 5 Comparison of the Eb/No and the BER of LoRausing the two methods for CR = 0.8 and SNR = -20dBm

| SF, Spreading Factor | Eb/No for CR = 0.67 and SNR = -20dBm | BERLoRa_NFEC for CR = 0.67 and SNR = -20dBm | BERLoRa_FEC for CR = 0.67 and SNR = -20dBm | Difference (BERLoRa_NFEC - BERLoRa_FEC) for CR = 0.666666666666667 and SNR = -20dBm |
|---|---|---|---|---|
| 7 | 0.27 | 4.1497E-01 | 3.8729E-01 | 2.7675E-02 |
| 8 | 0.48 | 3.4396E-01 | 2.9613E-01 | 4.7833E-02 |
| 9 | 0.85 | 2.2526E-01 | 1.5719E-01 | 6.8068E-02 |
| 10 | 1.54 | 7.7324E-02 | 2.8866E-02 | 4.8459E-02 |
| 11 | 2.79 | 3.5201E-03 | 1.6329E-04 | 3.3568E-03 |
| 12 | 5.12 | 1.5277E-07 | 4.3455E-12 | 1.5276E-07 |

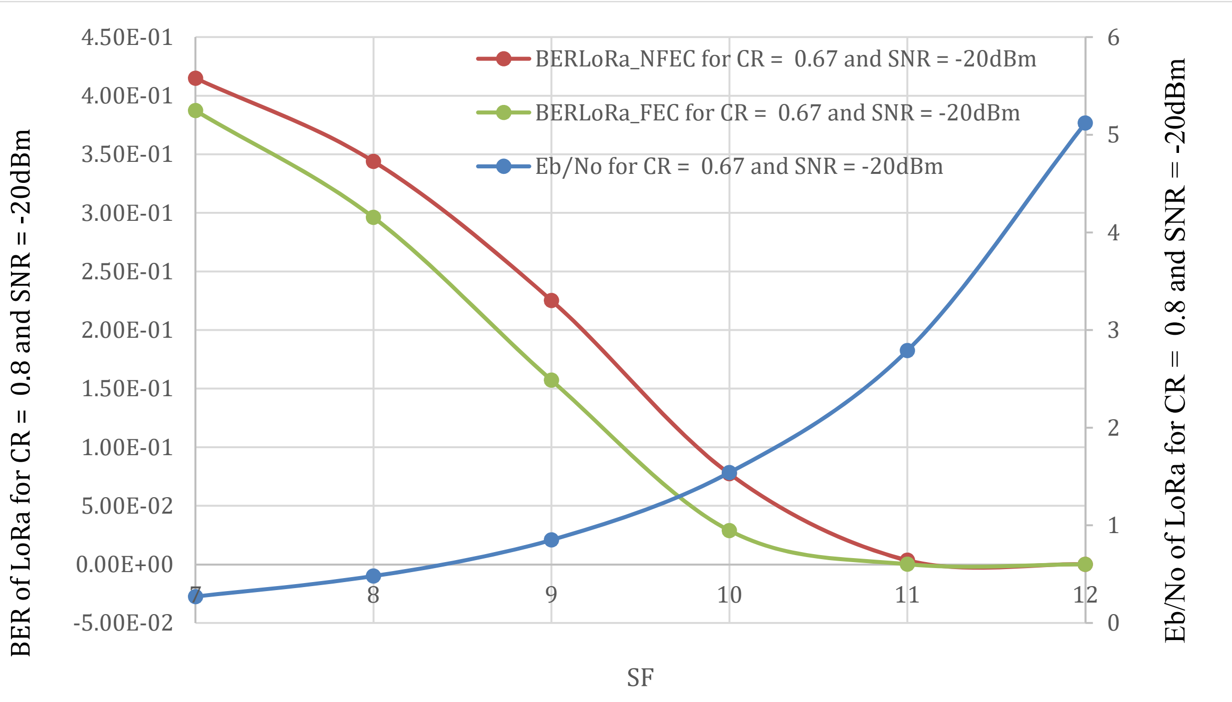


Figure 8 Comparison of the Eb/No and the BER of LoRausing the two methods for CR = 0.8 and SNR = -20dBm

## 4. CONCLUSION

The bit error rate (BER) performance of LoRa transceiver is computed using two different methods. One of the methods included the coding rate in the BER model while the second method does not include the coding rate. The BER values obtained from the two methods are compared under different configurations of signal to noise ratio, coding rate, spreading factor and energy per bit to noise power spectral density $\left({E_b}/{N_0}\right)$. The results show that in all the cases, the BER model with coding rate gives smaller BER value than the BER model without the coding rate. In any case, the results require empirical validation to determine which method is more accurate and under what parameter configurations doe the method give the accurate results.

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