Analysis Of The Energy Per Bit To Noise Power Spectral Density And Operating System Margin For Lora-Based Wireless Sensor Network

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Abstract— **In this paper, analysis of energy per bit to noise power spectral density (Eb/No) and operating system margin (SOM) for LoRa-based wireless sensor network with any specified bit error rate (BER) performance is presented. Semtech SX1272 LoRa transceiver parameters were used for numerical examples. The results showed that for any given BER, the Eb/No decreases with increase in the spreading factor (SF) and for a given SF, the Eb/No increases with decrease in BER. For BER = 1.0E-06, the SF 7 has the highest Eb/No value of 7.832 dB while for the same BER = 1.0E-06 the SF 12 has the least Eb/No value of 6.770 dB. Also, the SF 7 has the least Eb/No value of 6.770 dB for BER = 1.0E-06 and the same SF7 has the highest Eb/No value of 10.061 dB for BER = 1.0E-15. In addition, the results showed that the value of SOM peaked at SF value of 10. Hence, for any given BER, the SOM increases for SF = 7 to SF = 10 and then the SOM decreases for SF = 10 to SF = 12. The results are useful in selecting LoRa communication link parameters to achieve any specified BER performance.**

Keywords— Energy Per Bit To Noise Power Spectral Density, Operating System Margin, Bit Error Rate, Lora Transceiver, Wireless Sensor Network

1. Introduction

Wireless sensor communication networks are widely used nowadays for diverse purposes including monitoring various environmental systems and processes, smart systems applications, Internet of Things applications, among others [1,2, 3,4, 5,6, 7,8, 9,10, 11,12, 13, 14, 15, 16, 17]. Such sensor networks are presently implemented using different transceiver technologies. LoRa is among the most widely used transceiver technology for wireless sensor communication applications [18,19,20,21,22,23,24,25,26,27,28,29]. In some applications that require high level quality of service, the Bit Error Rate (BER) of such sensor communication networks are specified and must be satisfied by careful selection of the link parameters [30,31,32,33,34,35]. In this case, the LoRa transceiver parameters must be used to determine the link parameter values that will ensure that the required quality of service is met.

Particularly, for any given BER specification, there is corresponding required carrier to nose ratio, the operating energy per bit to noise power spectral density (Eb/No) and the operating system margin (SOM) values that must be satisfied by the LoRa-based sensor node communication link [36,37,38,39,40,41,42,43,44]. Hence, in this paper, the determination of the requisite link parameters for any BER specification is presented. The SEMTECH SX1272 LoRa transceiver datasheet specifications were used for sample computation 46,47,48,49,50,51]. The parameter values were computed for the LoRa spreading factors 7, 8, 9, 10, 11 and 12 operating in the 125 KHz bandwidth category. The essence of the study is to provide requisite ideas on how to determine LoRa-based sensor node parameters to achieve any given BER quality of service specification.

2. Methodology

When the bit error performance of a LoRa-Based sensor network is given, the operating energy per bit to noise power spectral density $\left({E_b}/{N_O}\right)$ can be determined for the different spreading factors. Furthermore, the System

Operating Margin (SOM) for each of the spreading factor (SF) can be established based on the knowledge of E_b/N_O, along with the bandwidth (BW) and code rate (CR). Further application of these data can yield the required transmitter power and other wireless link parameters. In this paper, the focus is on the analysis of the E_b/N_O and the SOM, where the SOM is given in terms of the required signal to noise ratio (SNR_{rq}) and the operating signal to noise ratio (SNR_{op}), as follows;

$$\text{SOM} = SNR_{op} - SNR_{rq} \quad (1)$$

Where SNR_{rq} in dB is related to LoRa transceiver sensitivity (S_{sens}) in dBm, bandwidth (BW) in KHz and noise figure NF (which is usually given as 6 dB) as follows;

$$SNR_{rq} = S_{sens} + 174 - 10\log_{10}(BW) - NF \quad (2)$$

On the other hand, the operating signal to noise ratio (SNR_{op}), is given as;

$$SNR_{op} = \frac{E_b}{N_0} + 10\log_{10}(SF) + 10\log_{10}\left(\frac{4}{4+CR}\right) - 10\log_{10}(2^{SF}) \quad (3)$$

Where code rate (CR) can e have values like 1,2,3, and 4. Now, the bit error rate (BER) for LoRa modulation technic is related to E_b/N_O in terms of Q-function and also in terms of error function (erf) as follows;

$$BER = Q\left(\left(\frac{\log_{12}(SF)}{\sqrt{2}}\right)\left(E_b/N_O\right)\right) \quad (4)$$

$$BER = \frac{1}{2}\left[1 - erf\left(\left(\frac{\log_{12}(SF)}{\sqrt{2}}\right)\left(E_b/N_O\right)\right)\right] \quad (5)$$

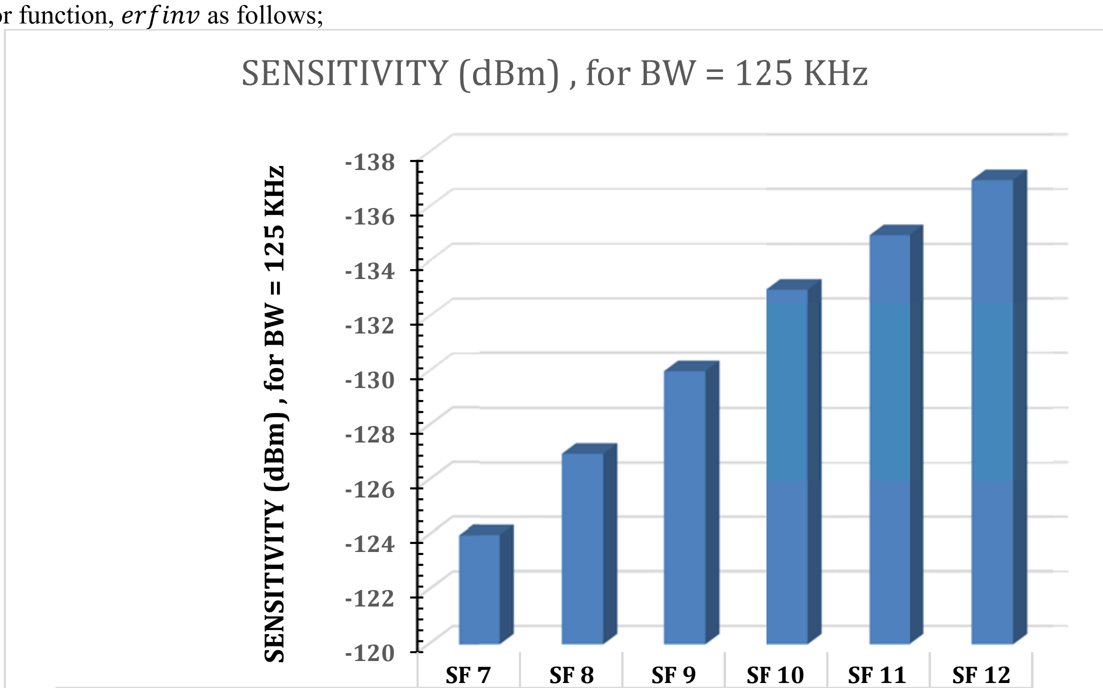
Hence, from the erf function, the is given in terms of the inverse error function, $erfinv$ as follows;

$$E_b/N_O = \frac{erfinv(1-2(BER))}{\left(\frac{\log_{12}(SF)}{\sqrt{2}}\right)} \quad (6)$$

So, for the analysis in this paper, the expected bit error rate, BER is specified. Then, the E_b/N_O is determined along with the SNR_{op} for different SF and BW. The SNR_{rq} and hence, the SOM are determined for different SF and BW.

3. Results and discussion

The bit error rate (BER) performance specified for a LoRa transceiver is used to determine the energy per bit to noise power spectral density $\left(E_b/N_O\right)$ and operating system margin (SOM). Particularly, in this paper, BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15 are considered and the corresponding values of E_b/N_O, the operating signal to noise ratio (SNR_{op}) and the SOM are determined for Semtech SX1272 LoRa transceiver. The data on the sensitivity of the Semtech SX1272 LoRa transceiver for the various spreading factors are shown in Figure 1. The required signal to noise ratio (SNR_{rq}) based on the sensitivity of the Semtech SX1272 LoRa transceiver for the various spreading factors are shown in Figure 2. According to Figure 1, the LoRa transceiver has as low as -137 dBm sensitivity for spreading factor of 12 and the corresponding required signal to noise ratio (SNR_{rq}) is -20 dB. The results of the sample computation for SX1272 LoRa transceiver operating with BER value of 1.0E-09 are given in Table 1 while the results for BER value of 1.0E-15 are given in Table 2.



	SF 7	SF 8	SF 9	SF 10	SF 11	SF 12
SENSITIVITY (dBm) , for BW = 125 KHz	-124	-127	-130	-133	-135	-137

Figure 1 The data on the sensitivity of the Semtech SX1272 LoRa transceiver for the various spreading factors

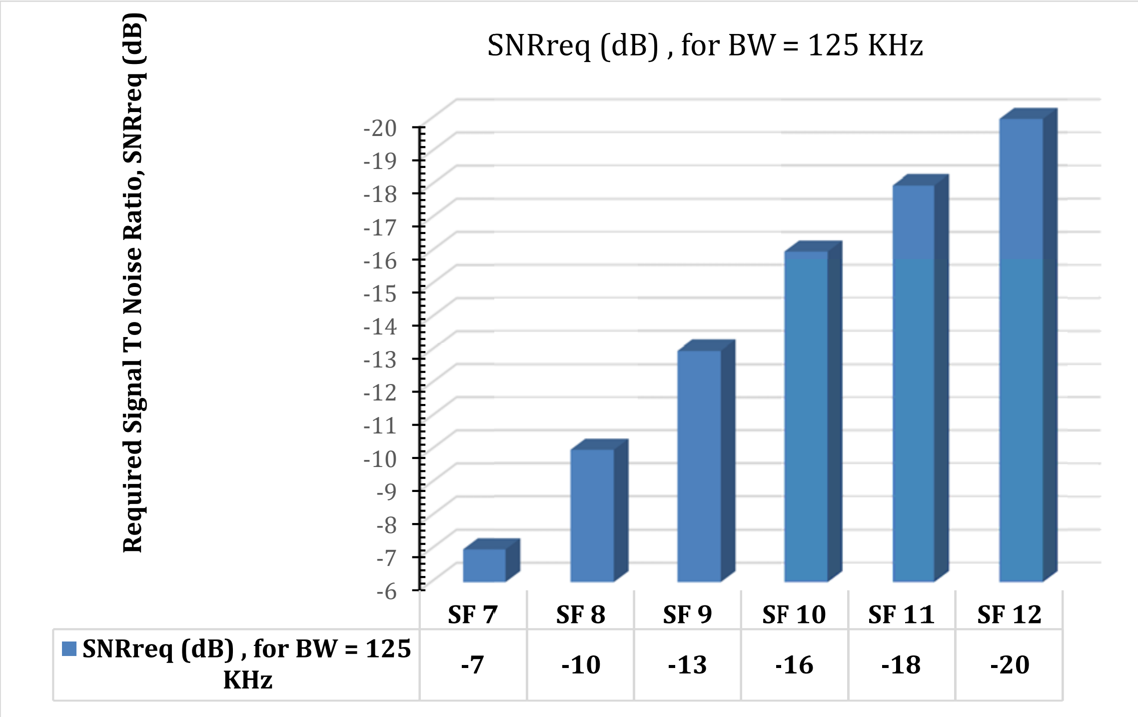


Figure 2 The required signal to noise ratio based on the sensitivity of the Semtech SX1272 LoRa transceiver for the various spreading factors

Table 1 The results of the sample computation for SX1272 LoRa transceiver operating with BER value of 1.0E-09

BER	**Eb/No (linear)**	**Eb/No (dB)**	SF	BW (kHz)	**Sensitivity (dBm)**	**SNRrq (dB)**	**SNRop (dB)**	**SOM (dB)**
1.0E-09	7.659	8.842	7	125	-124.0	-7.0	-4.7	2.2
1.0E-09	7.167	8.554	8	125	-127.0	-10.0	-7.5	2.5
1.0E-09	6.783	8.314	9	125	-130.0	-13.0	-10.2	2.8
1.0E-09	6.473	8.111	10	125	-133.0	-16.0	-13.0	3.0
1.0E-09	6.215	7.935	11	125	-135.0	-18.0	-15.7	2.3
1.0E-09	5.998	7.780	12	125	-137.0	-20.0	-18.5	1.5

Table 2 The results of the sample computation for SX1272 LoRa transceiver operating with BER value of 1.0E-15

BER	**Eb/No (linear)**	**Eb/No (dB)**	SF	BW (kHz)	**Sensitivity (dBm)**	**SNRrq (dB)**	**SNRop (dB)**	**SOM (dB)**
1.0E-15	10.141	10.061	7	125	-124.0	-7.0	-3.5	3.5
1.0E-15	9.490	9.773	8	125	-127.0	-10.0	-6.2	3.7
1.0E-15	8.981	9.533	9	125	-130.0	-13.0	-9.0	4.0
1.0E-15	8.570	9.330	10	125	-133.0	-16.0	-11.7	4.2
1.0E-15	8.230	9.154	11	125	-135.0	-18.0	-14.5	3.5
1.0E-15	7.941	8.999	12	125	-137.0	-20.0	-17.3	2.7

The summary of the Eb/No results extracted from the computation for the SX1272 LoRa transceiver operating with BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15 are shown in Table 3 and Figure 3. The results in Table 3 and Figure 3 show that for any given BER value, the Eb/No decreases with increase in the spreading factor (SF) value and for a given SF, the Eb/No increases with decrease in BER value. For instance, for BER = 1.0E-06, the SF 7 has the highest Eb/No value of 7.832 dB while for the same BER = 1.0E-06 the SF 12 has the least Eb/No value of 6.770 dB. Also, the SF 7 has the least Eb/No value of 6.770 dB for BER = 1.0E-06 and the same SF7 has the highest Eb/No value of 10.061 dB for BER = 1.0E-15.

Table 3 The extract of **Eb/No** results from the computation for SX1272 LoRa transceiver operating with BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15

SF	**Eb/No (dB) for BER** = 1.0E-06	**Eb/No (dB) for BER** = 1.0E-09	**Eb/No (dB) for BER** = 1.0E-012	**Eb/No (dB) for BER** = 1.0E-015
7	7.832	8.842	9.534	10.061
8	7.544	8.554	9.246	9.773
9	7.304	8.314	9.007	9.533
10	7.101	8.111	8.803	9.330
11	6.925	7.935	8.627	9.154
12	6.770	7.780	8.472	8.999

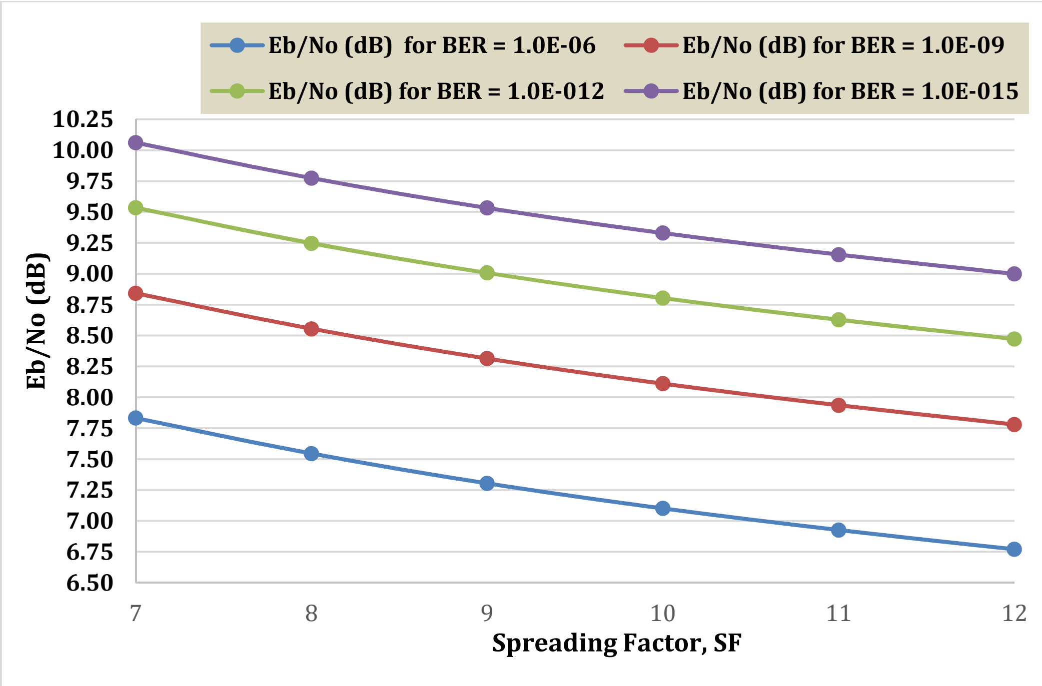


Figure 3 The graph of Eb/No (dB) versus SF for SX1272 LoRa transceiver operating with BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15

The extract of SNRrq(dB) and SNRop(dB) results from the computation for the SX1272 LoRa transceiver operating with BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15 are shown in Table 4 and Figure 4. The results in Table 4 and Figure 4 show that for any given BER value, the SNRop(dB) decreases with increase in the spreading factor (SF) value and for a given SF, the SNRop(dB) increases with decrease in BER value. For instance, for BER = 1.0E-06, the SF 7 has the highest SNRop(dB) value of -5.8 dB while for the same BER = 1.0E-06 the SF 12 has the least SNRop(dB) value of -19.5 dB. Also, the SF 7 has the least SNRop(dB) value of -5.8 dB for BER = 1.0E-06 and the same SF7 has the highest SNRop(dB) value of -3.5 dB for BER = 1.0E-15. In any case, for any given SF, the SNRrq(dB) is same for all the BER values.

Table 4 The extract of SNRrq(dB) and SNRop(dB) results from the computation for SX1272 LoRa transceiver operating with BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15

SF	**SNRrq(dB)**	**SNRop(dB) for BER** = 1.0E-06	**SNRop (dB) for BER** = 1.0E-09	**SNRop(dB) for BER** = 1.0E-012	**SNRop (dB) for BER** = 1.0E-015
7	-7	-5.8	-4.7	-4.1	-3.5
8	-10	-8.5	-7.5	-6.8	-6.2
9	-13	-11.2	-10.2	-9.5	-9
10	-16	-14	-13	-12.3	-11.7
11	-18	-16.7	-15.7	-15	-14.5
12	-20	-19.5	-18.5	-17.8	-17.3

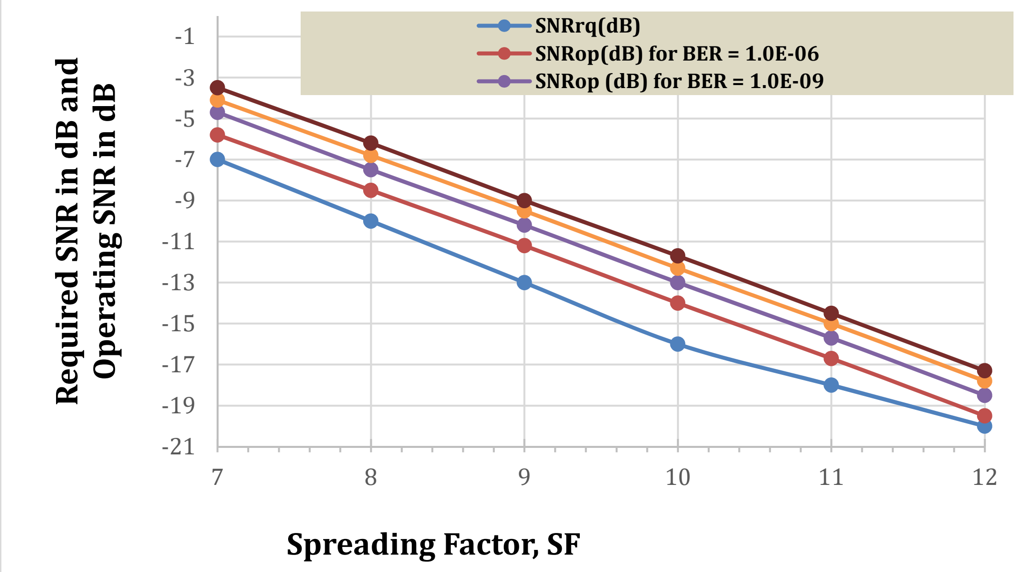


Figure 4 The graph of SNRrq(dB) and SNRop(dB) results from the computation for SX1272 LoRa transceiver operating with BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15

The extract of SOM results from the computation for the SX1272 LoRa transceiver operating with BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15 are shown in Table 5 and Figure 5. The results in Table 5 and Figure 5 show that for any given BER value, the SOM decreases with increase in the spreading factor (SF) value from SF = 7 to SF =10 and then the SOM decreases for SF = 10 to SF =12. In essence, the value of SOM peaks at SF = 10. Also, for a given SF, the SOM increases with decrease in BER value. For instance, for BER = 1.0E-06, the SF 7 has SOM value of 1.2 dB, the peak SOM value of 2 dB at SF =10 and SOM value of 1.2 at SF = 11 and SOM value of 0.5 at SF =12. Again, SF 7 has the SOM value of 1.2 dB for BER = 1.0E-06 and the same SF7 has the highest SOM value of 3.5 dB for BER = 1.0E-15. Hence, for the same SF, the SOM increases with decrease in BER value.

Table 5 The extract of SOM (dB) results from the computation for SX1272 LoRa transceiver operating with BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15

SF	**SOM (dB) for BER =** 1.0E-06	**SOM (dB) for BER =** 1.0E-09	**SOM (dB) for BER =** 1.0E-012	**SOM (dB) for BER =** 1.0E-015
7	1.2	2.2	2.9	3.5
8	1.5	2.5	3.2	3.7
9	1.8	2.8	3.5	4.0
10	2.0	3.0	3.7	4.2
11	1.2	2.3	3.0	3.5
12	0.5	1.5	2.2	2.7

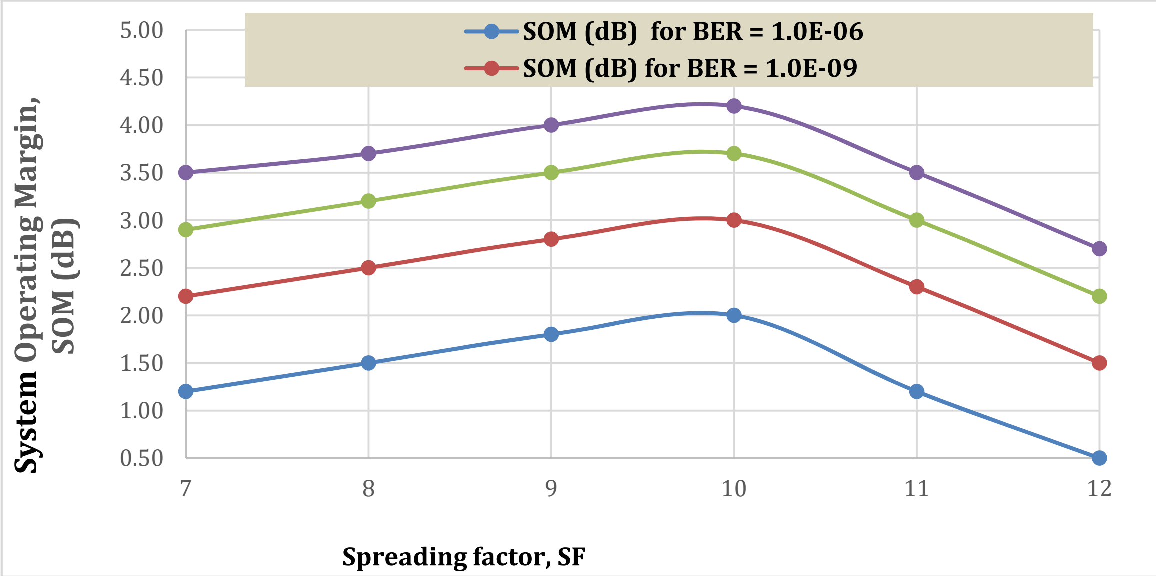


Figure 5 The graph of SOM (dB) results from the computation for SX1272 LoRa transceiver operating with BER values of 1.0E-06, 1.0E-09, 1.0E-12 and 1.0E-15

4 . Conclusion

Evaluation of the operating energy per bit to noise power spectral density $\left({E_b}/{N_o}\right)$ and operating system margin (SOM) for any specified bit error rate (BER) performance specified for a LoRa transceiver is presented. The analysis also determines the required signal to noise ratio and the operating signal to noise ration from which the SOM is computed. The computation compares the operating $\left({E_b}/{N_o}\right)$ and SOM for any BER for the five notable spreading factors in LoRa transceivers. The results show that the Eb/No decreases with increase in the spreading factor (SF) value and for a given SF, the Eb/No increases with decrease in BER value. On the other hand, the SOM peaks at SF value of 10 , hence, for any given BER, the SOM increases for SF = 7 to SF = 10 and then the SOm decreases for SF = 10 to SF = 12. The results are useful in selecting LoRa communication link parameters to achieve any specified BER performance.

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