Computation Of Transmitter Power Requirement For LoRaWAN With Specified Chirp Spread Spectrum Modulation Bit Error Probability

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Abstract— **The bit error rate (BER) is one of the key quality of service parameters used for communication systems. So, in this paper, an approach for computing the required transmitter power for achieving a specified BER value for LoRaWAN with its chirp spread spectrum modulation is presented. The requisite mathematical expressions for the computation are also presented. The analysis provided computation for the operating signal to noise ratio (SNR), the link margin and the required transmitter power. The results for bit error rate ranging from BER =10^{-1} to BER =10^{-1}5 show that the spreading factor (SF) of 12 has the lowest values of operating SNR ranging from -25.2 dBm to -17.3 dBm while the SF of 7 has the highest range of SNR of -11.5 dBm to -3.5 dBm. Also, the results show that the SF of 7 required the highest transmitter power (-7.5 dBm to 1.74 dBm) for each of the BER while the SF of 12 required the least transmitter power (- 20 dBm to 0.47 dBm). In all, the LoRa transceiver operating with SF of 7 requires more transmitter power to attain a given BER than the transmitter power it will require when operating with other SF values. The analysis provides requisite information for the selection of appropriate spreading factor and design parameters to achieve a specified quality of service in sensor networks employing the LoRa transceiver.**

Keywords — Bit Error Probability, Transmitter Power, LoRaWAN, Egli Model, Path Loss, Chirp Spread Spectrum Modulation

1. Introduction

Today, it has become obvious that wireless communication technologies are the backbone of the emerging smart city applications and other smart solutions across the globe [1,2,3,4,5,6,7,8]. In this wise, it has been noted that wireless sensor network are prominent in the smart solutions [9,10,11,12,13,14]. The design of the wireless sensor networks involves detailed calculations of the signal propagation loss, transmitter power requirement, signal to noise ratio, among other relevant parameter [15,16,17,18,19, 20,21,22, 23,24,25, 26,27,28, 29,30,31,32]. Also, the communication range of the sensor network is essential, whether for terrestrial or satellite-based sensor network [33,34,35,36,37, 38,39,40, 41,42,43,44, 45,46,47,48,49,50,51,52]. Now, as the quest for more smart solutions increases, there will be corresponding increase in the demand for higher quality of service from the supporting wireless networks. It is therefore important that in the design of the sensor network, effort is made to accommodate the various propagation losses in the signal path while at the same time satisfy the required quality of service.

Among the various quality of service performance parameters, bit error rate (BER) is popularly used to indicate the likelihood of error in the received digital signal [53,54,55,56,57,58,59,60]. Notably, for any given BER, there is associated required signal to noise ratio (SNR) and required transmitter power for any given propagation loss [61,62,63,64,65,66]. In this paper, the focus is to present analytical approach that will enable wireless sensor network designers using LoRaWAN technology to determine at design time the operating signal to noise ratio (SNR and the required transmitter power for any specified BER based on the LoRa chirp spread spectrum modulation technique [67,68,69,71]. The study also examines how the required SNR and transmitter power vary with the spreading factor and BER specifications. Sample numerical examples are also presented.

2. Methodology

The bit error probability (BER) of a communication link is a key quality of service performance parameter which is computed based on some set of input parameters of the communication link. However, when the BER of a communication link is specified, the necessary communication link parameter values that will be required to meet the performance specification can be computed in the reverse order, starting from the BER and working backwards towards determining the values of the various input parameters that can be used to achieve the BER. Now, for LoRaWAN with spreading factor (SF) and energy per bit to noise power spectral density ratio, ${E_b}/{N_O}$ the BER is given as;

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

Where erf is the error function. The task is to determine the ${E_b}/{N_O}$ and hence the operating signal to noise ratio (SNR). The ${E_b}/{N_O}$ is determined as follows;

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

$$\left({E_b}/{N_O}\right) = \frac{erfinv(1-2(BER))}{\left(\frac{\log_{12}(SF)}{\sqrt{2}}\right)} \quad (3)$$

Also

$$\frac{E_b}{N_0} = SNR - 10\log_{10}(SF) - 10\log_{10}\left(\frac{4}{4+n}\right) + 10\log_{10}(2^{SF}) \quad (4)$$

Hence, for the given $\frac{E_b}{N_0}$ the operating SNR is computed as;

$$SNR = \frac{E_b}{N_0} + 10\log_{10}(SF) + 10\log_{10}\left(\frac{4}{4+n}\right) - 10\log_{10}(2^{SF}) \quad (5)$$

The link margin, LM is given as

$$LM = SNR - SNR_{RQD} \quad (6)$$

$$LM = \frac{E_b}{N_0} + 10\log_{10}(SF) + 10\log_{10}\left(\frac{4}{4+n}\right) - 10\log_{10}(2^{SF}) - SNR_{RQD} \quad (7)$$

Where SNR_{RQD} is the required signal to noise ratio and it is always specified for the LoRa along with the sensitivity value for different spreading factors, as shown in Table 1.

Table 1 The required signal to noise ratio (SNR) and sensitivity of LoRa transceiver operating in 125 kHz bandwidth and with different spreading factors

SF, Spreading Factor	Required SNR_{RQD} (dBm) for BW of 125 KHz	Sensitivity (dBm)
7	-7.5	-124.5
8	-10	-127.0
9	-12.5	-129.5
10	-15	-132.0
11	-17.5	-134.5
12	-20	-137.0

In accordance with link budget equation, the received signal strength (P_{rx}) is given in terms of link margin and receiver sensitivity (S_{LoRa}) and also in terms of transmitter power (S_{LoRa}) and pathloss (L_{Path}) as follows:

$$P_{rx} = LM + S_{LoRa} \quad (8)$$

$$P_{rx} = P_{tx} + G_{tx} + G_{rx} - L_{Path} \quad (9)$$

Where G_{tx} and G_{rx} are the transmitter and receiver antenna gain. Hence,

$$P_{tx} = P_{rx} - G_{tx} - G_{rx} + L_{Path} \quad (10)$$

$$P_{tx} = LM + S_{LoRa} + L_{Path} \quad (11)$$

In this study, $G_{tx} = G_{rx} = 0$. In this paper we considered the pathloss value for two different cases.

Case I : The case of maximum pathloss that is attainable with zero link margin and 0 dB transmitter power

The first is the case of maximum pathloss that is attainable with zero link margin and 0 dB transmitter power. In this case, the different SF has different pathloss. In that case, $P_{rx} = S_{LoRa}$ and

$$L_{PathMax} = P_{tx} + G_{tx} + G_{rx} - P_{rx} \quad (12)$$

$$L_{PathMax} = -S_{LoRa} \quad (13)$$

Hence,

$$P_{tx} = LM + S_{LoRa} + L_{PathMax} \quad (14)$$

$$P_{tx} = LM + S_{LoRa} - S_{LoRa} = LM \quad (15)$$

$$P_{tx} = \frac{E_b}{N_0} + 10\log_{10}(SF) + 10\log_{10}\left(\frac{4}{4+n}\right) - 10\log_{10}(2^{SF}) - SNR_{RQD} \quad (16)$$

The LoRa datasheet specification indicates that the transmission power of SX1272/73 transceiver ranges from -1 dBm to 20 dBm [71]. In essence, any P_{tx} value obtained in Eq 16 that is outside the ranges from -1 dBm to 20 dBm is not supported by the SX1272/73 transceiver. In this paper, the value of BER and hence the resultant $\frac{E_b}{N_0}$ is varied and also computed for different SF and the transmitter power range that can be used to satisfy the BER specification is determined.

Case II : The case of the same pathloss for the different spreading factors

In this case, a given pathloss is selected, and it is denoted as $L_{PathFix}$. Then, the required transmitter power is given as ;

$$P_{tx} = LM + S_{LoRa} + L_{PathFix} \quad (17)$$

$$P_{tx} = \frac{E_b}{N_0} + 10\log_{10}(SF) + 10\log_{10}\left(\frac{4}{4+n}\right) - 10\log_{10}(2^{SF}) - SNR_{RQD} + S_{LoRa} + L_{PathFix} \quad (18)$$

3. Results and discussions

Some numerical examples are considered in the study. The results in Table 2 show the operating SNR for LoRa transceiver operating at different spreading factor (SF) and for different bit error rate ranging from BER $=10^{-1}$ to BER $=10^{-1}5$. mong the 5 different SF values, SF of 12 has the smallest value of operating SNR. This means that the transceiver operating at SF of 12 can operate at lower signal levels and with lower transmitter power than in the other SF values.

Table 2 The results of the operating SNR for LoRa transceiver operating at different spreading factor (SF) and for different bit error rate

SF, Spreading Factor	SNR (dBm) for BER $=10^{-1}$	SNR (dBm) for BER $=10^{-3}$	SNR (dBm) for BER $=10^{-6}$	SNR (dBm) for BER$=10^{-9}$	SNR (dBm) for BER$=10^{-12}$	SNR (dBm) for BER BER$=10^{-15}$
7	-11.5	-7.6	-5.8	-4.7	-4.1	-3.5
8	-14.2	-10.3	-8.5	-7.5	-6.8	-6.2
9	-16.9	-13.1	-11.2	-10.2	-9.5	-9.0
10	-19.7	-15.8	-14.0	-13.0	-12.3	-11.7
11	-22.4	-18.6	-16.7	-15.7	-15.0	-14.5
12	-25.2	-21.4	-19.5	-18.5	-17.8	-17.3

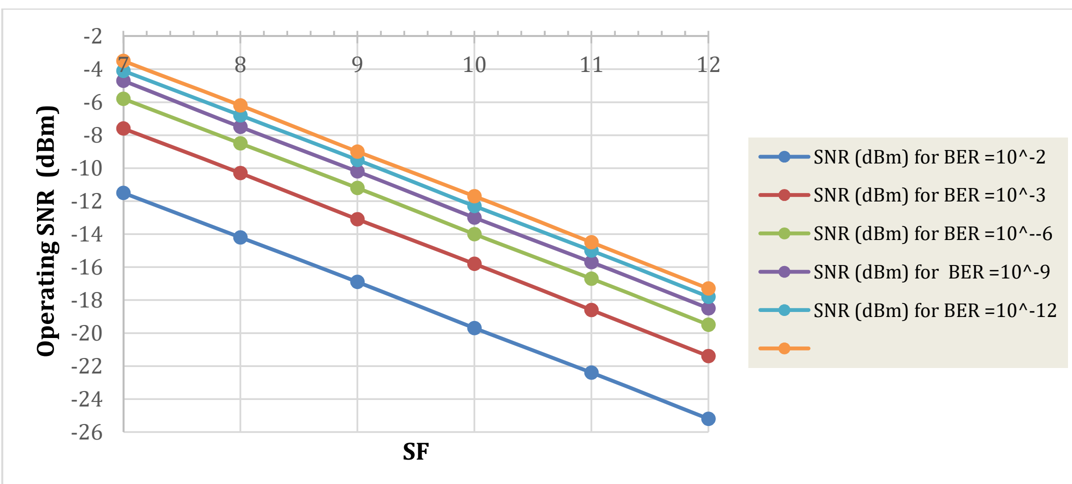

Figure 1 The operating SNR for LoRa transceiver operating at different spreading factor (SF) and for different bit error rate

3.1 Results for Case I : The case of maximum pathloss that is attainable with zero link margin and 0 dB transmitter power.

The results of the required SNR, the transceiver sensitivity, the operating Eb/No, SNR and link margin are shown in Table 3 and Figure 2 for BER = 1 x10^{-06}. The required transmitter power for a given pathloss for the various spreading factors are also shown in Table 3 and Figure 3. Also, the required transmitter power for LoRa transceiver operating at different spreading factor (SF) for different bit error rate ranging from BER $=10^{-1}$ to BER $=10^{-1}5$ are shown in Figure 4 and Table 4. The results show that the SF of 7 required the highest transmitter power in each of the BER while the SF of 12 required the least transmitter power.

Table 3 The results of the required SNR, the transceiver sensitivity, the operating Eb/No, SNR and link margin for BER = 1 x10^{-06}

SF, Spreading Factor	Required SNRrqd (dBm) for BW of 125 KHz	Sensitivity (dBm)	Eb/No (dBm)	Operating SNR (dBm)	Lpathloss (dB)	Link Margin (dBm)	Transmitter power (dBm)
7	-7.5	-124.5	7.83	-5.76	124.5	1.74	1.74
8	-10	-127.0	7.54	-8.48	127.0	1.52	1.52
9	-12.5	-129.5	7.30	-11.21	129.5	1.29	1.29
10	-15	-132.0	7.10	-13.97	132.0	1.03	1.03
11	-17.5	-134.5	6.92	-16.74	134.5	0.76	0.76
12	-20	-137.0	6.77	-19.53	137.0	0.47	0.47

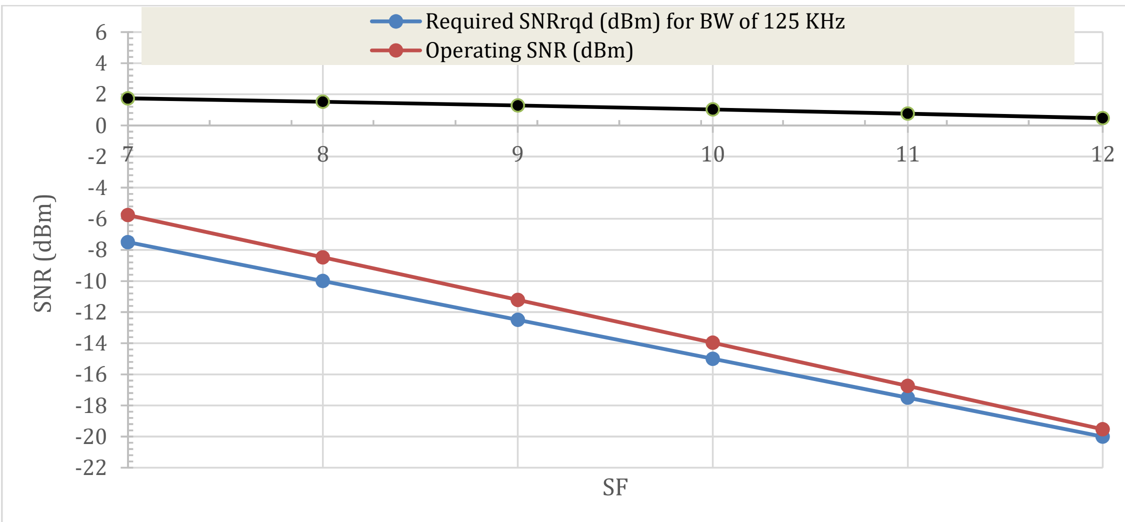

Figure 2 The required SNR , operating SNR and link margin for LoRa transceiver operating at different spreading factor (SF) and for bit error rate, BER = 1×10^{-06}

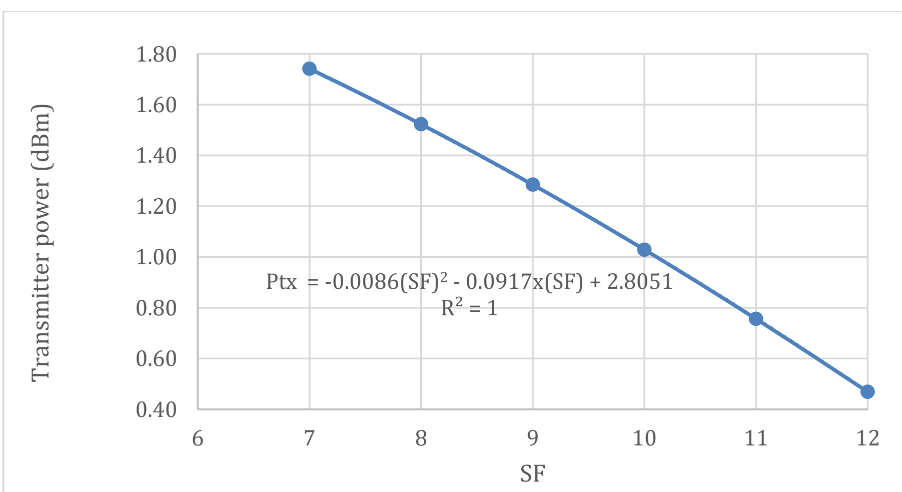

Figure 3 The required transmitter power for LoRa transceiver operating at different spreading factor (SF) and for bit error rate, BER = 1×10^{-06}

Table 4 The required transmitter power for LoRa transceiver operating at different spreading factor (SF) for different bit error rate ranging from BER $=10^{-1}$ to BER $=10^{-1}5$.

SF, Spreading Factor	Ptx (dBm) for BER $=10^{-1}$	Ptx (dBm) for BER $=10^{-3}$	Ptx (dBm) for BER $=10^{-6}$	Ptx (dBm) for BER$=10^{-9}$	Ptx (dBm) for BER$=10^{-12}$	Ptx (dBm) for BER BER$=10^{-15}$
7	-3.95	-0.13	1.74	2.75	3.44	3.97
8	-4.17	-0.35	1.52	2.53	3.23	3.75
9	-4.41	-0.59	1.29	2.29	2.99	3.51
10	-4.66	-0.84	1.03	2.04	2.73	3.26
11	-4.94	-1.11	0.76	1.77	2.46	2.99
12	-5.22	-1.40	0.47	1.48	2.17	2.70

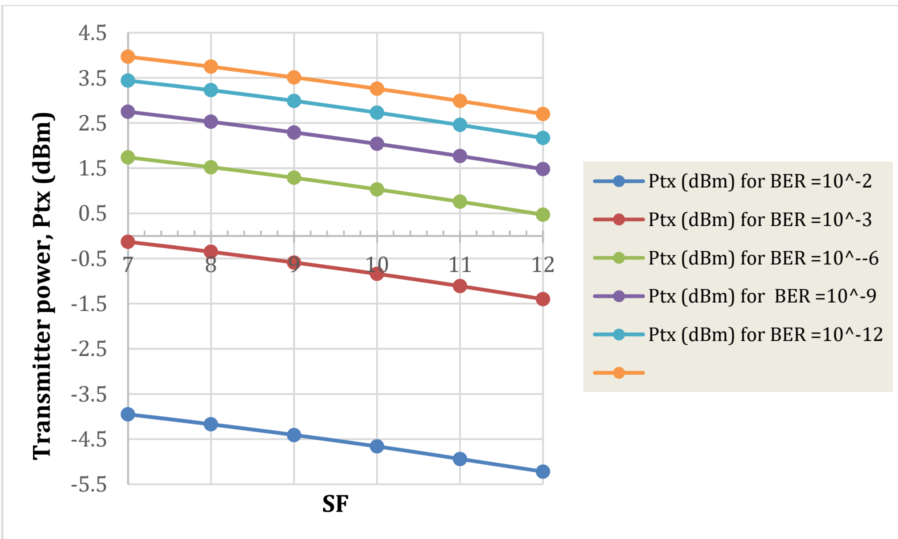

Table 4 The required transmitter power for LoRa transceiver operating at different spreading factor (SF) for different bit error rate ranging from BER $=10^{-1}$ to BER $=10^{-1}5$.

3.2 Results for Case II : The case of the same pathloss for the different spreading factors

The results of required transmitter power for LoRa transceiver operating at different spreading factor (SF) for a fixed pathloss of 137.0 dB and different bit error rate ranging from BER $=10^{-1}$ to BER $=10^{-1}5$ are shown in Figure 5 and Table 5. Again, the results show that the SF of 7 required the highest transmitter power in each of the BER while the SF of 12 required the least transmitter power. In all, the LoRa transceiver operating with SF of 7 requires more transmitter power to attain a given BER than the transmitter power it will require when operating with other SF.

Table 5 The results of required transmitter power for LoRa transceiver operating at different spreading factor (SF) for a fixed pathloss of 137.0 dB and different bit error rate ranging from BER $=10^{-1}$ to BER $=10^{-1}5$

SF, Spreading Factor	Ptx (dBm) for BER $=10^{-1}$	Ptx (dBm) for BER $=10^{-3}$	Ptx (dBm) for BER $=10^{-6}$	Ptx (dBm) for BER$=10^{-9}$	Ptx (dBm) for BER$=10^{-12}$	Ptx (dBm) for BER BER$=10^{-15}$
7	8.55	12.37	14.24	15.25	15.94	16.47
8	5.83	9.65	11.52	12.53	13.23	13.75
9	3.09	6.91	8.79	9.79	10.49	11.01
10	0.34	4.16	6.03	7.04	7.73	8.26
11	-2.44	1.39	3.26	4.27	4.96	5.49
12	-5.22	-1.40	0.47	1.48	2.17	2.70

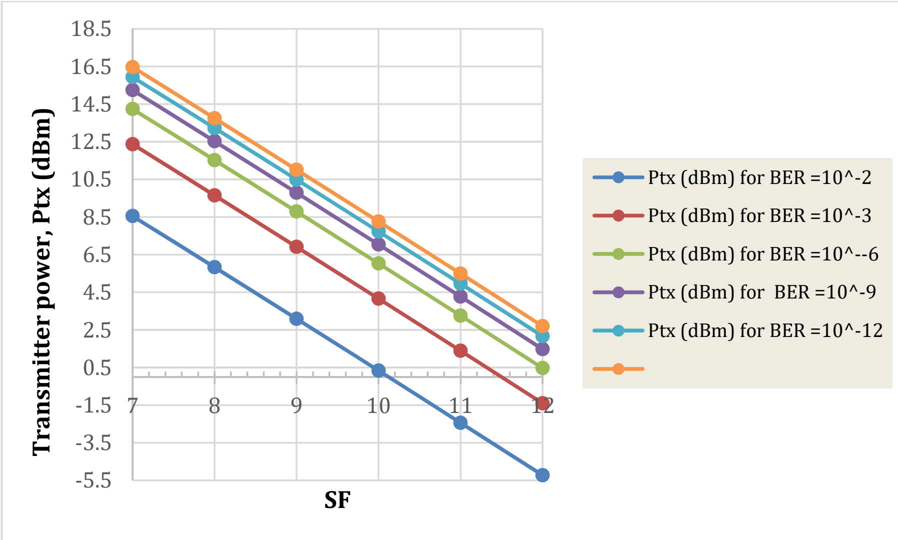

Figure 5 The results of required transmitter power for LoRa transceiver operating at different spreading factor (SF) for a fixed pathloss of 137.0 dB and different bit error rate ranging from BER $=10^{-1}$ to BER $=10^{-1}5$

4. Conclusion

An approach for computing the operating signal to noise ration and transmitter power of LoRa transceiver operating at different bit error rate is presented. The requisite mathematical expressions for the computation are also presented. The essence of the study is to determine the transmitter power requirement for achieving a given bit error rate performance in LoRa transceiver. Also, comparison is made on the transmitter power requirement for the same transceiver operating in different spreading factors. The analysis provides requisite information for selection of appropriate spreading factor and design parameters to achieve a specified quality of service in sensor networks employing the LoRa transceiver.

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