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Determination Of Bit And Packet Error Probabilities And Retransmission Performance For Lora Sensor Node Based On The Operating Signal To Noise Ratio

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***Abstract*— In this work determination of bit error probability (BEP) and packet error probability (PEP) and retransmission performance for LoRa sensor node based on the operating signal to noise ratio (SNR) is presented. In the simulation, a range of values of SNR and Npbit (which is the number of bits in the packet or the packet size in bit) were selected. Then, several simulations were conducted for different spreading factor (SF) and n (which is the number of bits used for forward error correction code) values for different combinations of SNR and Nbit values. The simulation were conducted only for bandwidth of 125 kHz. One set of the results showed that the Eb/No, which is the sensor node's energy per bit to noise power spectral density increases with SNR while BEP and PEP decrease with increase in SNR. For instance, at SNR of -5.5 dBm , Eb/No was 8.09 dBm and BEP was 2.27E-07 whereas at SNR of -10.5 dBm , Eb/No was 3.09 dBm and BEP was 5.53E-02. Also, the results show that for a given SF and n, the Ntrans decreases with increase in SNR. For instance, at SNR of -5.5 dBm , Ntrans was 1 for all the Nbits whereas at SNR of -10.5 dBm Ntrans = 1.58 for Nbit of 1, Ntrans = 6.18 for Nbit of 32, and Ntrans = 1458.46 for Nbit of 128. This also shows that for a given SNR the number of retransmission required for a successful packet transmission increases with increase in the packet size. In all, the SNR has significant impact on the transmission performance of the LoRa sensor node however, it requires careful selection and combinations of the various parameters to achieve the desired performance.**

Keywords*— *Bit Error probability, Retransmission Performance, Signal To Noise Ratio, Packet Error Probabilities, LoRa Sensor Node

1. INTRODUCTION

Nowadays sensor nodes are widely adopted for internet of things applications [1,2]. The applications also extends to smart systems such as smart agriculture, smart homes, smart transportations, and smart grids, among others [3,4]. The ease of deployment of such wireless sensor nodes when compared to wired approach makes it much better especially when the installation is outdoor and in complex applications where large number of such nodes may be required [5,6].

Over the years, several wireless technologies have been developed to suit wireless sensor nodes which are often resource constrained [7,8]. Among the numerous options, LoRa with its chirp spread spectrum (CSS) modulation scheme has emerged as the dominant technology for low power long distant sensor node communication [9,10]. LoRa CSS modulation scheme relies on a number of parameters for effective communication, among them are the spreading factor (SF), the coding rate which id determined from the forward error correction code number (n), the bandwidth and noise figure [11,12] Apart from these parameters, noise has significant impact on wireless communication signals. However, the LoRa CSS modulation scheme is designed with very good receiver sensitivity and this makes it good for sensor node [13].

Accordingly, in this work, the impact of noise on the transmission performance of LoRa sensor node is studied. The study focused on the variation of the BEP, the PEP, and Ntrans with signal to noise ratio (SNR). The study seek to provide relevant results that will aid LoRa sensor node designers and user on how to select the appropriate configurations of the sensor node for optimal transmission performance.

2. METHODOLOGY

The main aim of this work is to use analytical model to determine the data and packet delivery error probabilities along with packet retransmission performance and packet delivery success ratio for LoRa sensor node. In the LoRa modulation scheme, the forward error correction code is denoted as code rate (CR) given as [12.13];

$$CR = \frac{4}{4+n} \qquad (1)$$

Where n is the number of redundant added to the packet for the forward error correction computation. The value of n can be 1, 2, 3 or 4. The BEP is given as;

$$BEP = Q\left(\left(\frac{(\mathrm{Log}_{12}(SF))}{\sqrt{2}}\right)\left({}^{E_b}/_{N_O}\right)\right) \qquad (2)$$

$$BEP = \frac{1}{2}\left[1 - erf\left(\left(\frac{(\mathrm{Log}_{12}(SF))}{\sqrt{2}}\right)\left({}^{E_b}/_{N_O}\right)\right)\right] \qquad (3)$$

Where ${}^{E_b}/_{N_O}$ represents the sensor node's energy per bit to noise power spectral density while SF represents the spreading factor of the LoRa modulation scheme. The ${}^{E_b}/_{N_O}$ is determined from the Signal to Noise Ratio (SNR) as follows;

$$SNR = S_{LoRaRq} + 174 - 10\log_{10}(BW) - NF \qquad (4)$$

Where S_{LoRaRq} is the minimum required signal to noise ratio of LoRa modulation, BW is the bandwidth while SF is the noise factor, where;

$$S_{LoRaRq} = -174 + 10\log_{10}(BW) + NF + SNR \qquad (5)$$

The value of BW can be 125 kHz, 250 kHz and 500 kHz.

$$\left.\frac{E_b}{N_0}\right|_{dBm} = SNR - 10\log_{10}(SF) - 10\log_{10}\left(\frac{4}{4+n}\right) + 10\log_{10}(2^{SF}) \qquad (6)$$

$${}^{E_b}/_{N_O} = 10^{\left(\frac{\left[SNR - 10\log_{10}(SF) - 10\log_{10}\left(\frac{4}{4+n}\right) + 10\log_{10}\left(2^{SF}\right)\right]}{10}\right)} \qquad (7)$$

At this point, ${}^{E_b}/_{N_O}$ expressed as a function of SNR, then, the BEP is given from Equation 3 and Equation 8 as;

$$BEP = \frac{1}{2}\left[1 - erf\left(\left(\frac{(\mathrm{Log}_{12}(SF))}{\sqrt{2}}\right)\left(10^{\left(\frac{\left[SNR - 10\log_{10}(SF) - 10\log_{10}\left(\frac{4}{4+n}\right) + 10\log_{10}\left(2^{SF}\right)\right]}{10}\right)}\right)\right)\right] \qquad (8)$$

The packet error probability (PEP) is computed as;

$$PEP = 1 - (1 - \mathrm{BEP})^{(\mathrm{Npbit})} \qquad (9)$$

$$PEP = 1 - \left(1 - \frac{1}{2}\left[1 - erf\left(\left(\frac{(\mathrm{Log}_{12}(SF))}{\sqrt{2}}\right)\left(10^{\left(\frac{\left[SNR - 10\log_{10}(SF) - 10\log_{10}\left(\frac{4}{4+n}\right) + 10\log_{10}\left(2^{SF}\right)\right]}{10}\right)}\right)\right)\right]\right)^{(\mathrm{Npbit})} \qquad (10)$$

Where Npbit is used to represent the packet size in bits. The number of transmission, which is represented as N_{trans} can be computed as;

$$N_{trans} = \frac{1}{1 - PEP} = \frac{1}{(1-\mathrm{BEP})^{(N_{pbit})}} \qquad (11)$$

$$N_{trans} = \frac{1}{\left(1 - \frac{1}{2}\left[1 - erf\left(\left(\frac{(\mathrm{Log}_{12}(SF))}{\sqrt{2}}\right)\left(10^{\left(\frac{\left[SNR - 10\log_{10}(SF) - 10\log_{10}\left(\frac{4}{4+n}\right) + 10\log_{10}\left(2^{SF}\right)\right]}{10}\right)}\right)\right)\right]\right)^{(\mathrm{Npbit})}} \qquad (12)$$

3. RESULTS AND DISCUSSION

In the simulation, a range of values of SNR and Npbit were selected. Then, several simulations were conducted for different SF and n values for different combinations of SNR and Nbit values. The simulation were conducted only for bandwidth of 125 kHz. The results in Table 1show how Eb/No, BEP, PEP and Ntrans vary with respect to variations in SNR. In addition, Figure1 and Table 1 show that for a given SF and n, the Eb/No increases with SNR while BEP decreases with increase in SNR. For instance, at SNR of -5.5 dBm , Eb/No is 8.09 dBm and BEP is 2.27E-07 whereas at SNR of -10.5 dBm , Eb/No is 3.09 dBm and BEP is 5.53E-02.

Table 1 The results in Table 1show how Eb/No, BEP, PEP and Ntrans vary with respect to variations in SNR.

SNR (dB) Required for BW of 125 KHz	Eb/No (dBm) for SF=7 and n=1	Bit Error Probability (BEP) for SF=7 and n=1	Packet Error Probability (PEP) for SF=7 and n=1	Ntrans for SF=7 and n=1
-4.25	9.34	8.65E-12	6.92E-11	1.00
-5.5	8.09	2.27E-07	1.82E-06	1.00
-6.75	6.84	7.75E-05	6.20E-04	1.00
-8	5.59	2.28E-03	1.81E-02	1.02
-9.25	4.34	1.67E-02	1.26E-01	1.14
-10.5	3.09	5.53E-02	3.66E-01	1.58
-11.75	1.84	1.16E-01	6.26E-01	2.68
-13	0.59	1.85E-01	8.05E-01	5.13
-14.25	-0.66	2.51E-01	9.00E-01	10.05
-15.5	-1.91	3.07E-01	9.47E-01	18.79

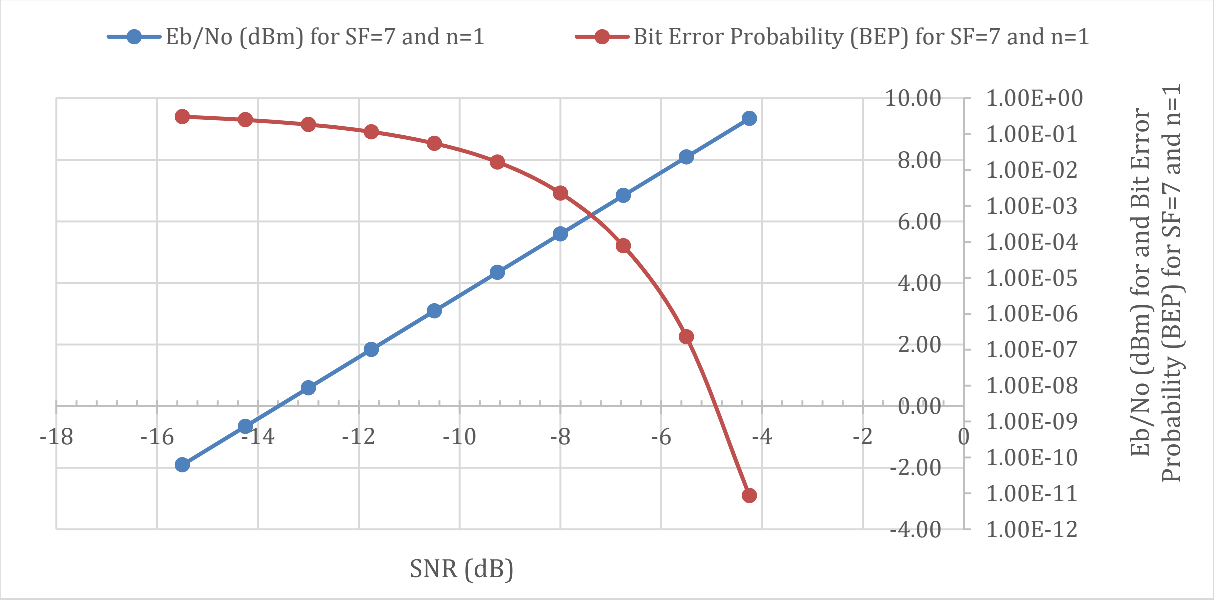

Figure 1 Line graph of BEP versus SNR for for SF=7 and n=1

Again, the results for the variations in BEP with SNR for SF=7 , n=1 and for Nbit =8, 32 and 128 are shown in Figure2 and Table 2 . The results show that for a given SF and n, the Eb/No increases with SNR while BEP decreases with increase in SNR. For instance, at SNR of -5.5 dBm , Eb/No is 8.09 dBm and PEP is 1.82E-06 whereas at SNR of -10.5 dBm , Eb/No is 3.09 dBm and BEP is 3.66E-01.

Table 2 Variations in BEP with SNR for SF=7 , n=1 and for Nbit =8, 32 and 128

SNR (dB) Required for BW of 125 KHz	Eb/No (dBm) for SF=7 and n=1	Packet Error Probability (PEP) for SF=7 and n=1 and Nbit=8	Packet Error Probability (PEP) for SF=7 and n=1 and Nbit=32	Packet Error Probability (PEP) for SF=7 and n=1Nbit=128
-4.25	9.34	6.92E-11	2.77E-10	1.11E-09
-5.5	8.09	1.82E-06	7.27E-06	2.91E-05
-6.75	6.84	6.20E-04	2.48E-03	9.87E-03
-8	5.59	1.81E-02	7.04E-02	2.53E-01
-9.25	4.34	1.26E-01	4.17E-01	8.84E-01
-10.5	3.09	3.66E-01	8.38E-01	9.99E-01
-11.75	1.84	6.26E-01	9.81E-01	1.00E+00
-13	0.59	8.05E-01	9.99E-01	1.00E+00
-14.25	-0.66	9.00E-01	1.00E+00	1.00E+00
-15.5	-1.91	9.47E-01	1.00E+00	1.00E+00

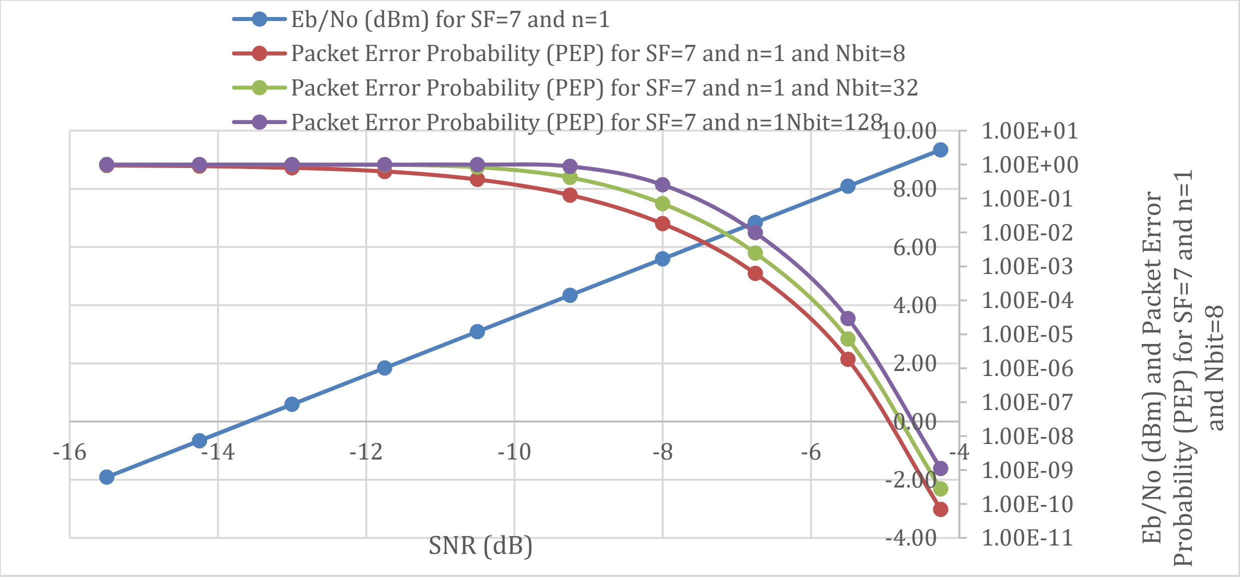

Figure 2 Line graph of PEP versus SNR for for SF=7 and n=1

Again, the results for the variations in number of required transmission (Ntrans) with SNR for SF=7, n=1 and for Nbit =8, 32 and 128 are shown in Table 3. The results show that for a given SF and n, the Ntrans decreases with increase in SNR. For instance, at SNR of -5.5 dBm , Ntrans is 1 for all the Nbits whereas at SNR of -10.5 dBm Ntrans = 1.58 for Nbit of 1, Ntrans = 6.18 for Nbit of 32, and Ntrans = 1458.46 for Nbit of 128. This also shows that for a given SNR the number of retransmission required for a successful packet transmission increases with increase in the packet size.

Table 3 Variations in number of required transmission (Ntrans) with SNR for SF=7 , n=1 and for Nbit =8, 32 and 128

SNR (dB) Required for BW of 125 KHz	Ntrans for SF=7 and n=1 and Nbit=8	Ntrans for SF=7 and n=1 and Nbit=32	Ntrans for SF=7 and n=1Nbit=128
-4.25	1.00	1.00	1.00
-5.5	1.00	1.00	1.00
-6.75	1.00	1.00	1.01
-8	1.02	1.08	1.34
-9.25	1.14	1.71	8.63
-10.5	1.58	6.18	1458.46
-11.75	2.68	51.32	6935452.11
-13	5.13	692.09	229430175367.20
-14.25	10.05	10196.89	9007199254740990.00

The results showing the impact of the n (the forward error correction code) on the BEP for various SNR are presented in Table 4 and Figure 3. The results show that for a given SNR or a given Eb/No, the BEP decreases as the number of forward error correction code, n increases. For instance, at SNR of -5.5 dBm , Eb/No is 8.09 and BEP is 2.27E-07 for n = 1, BEP is 7.08E-10 for n = 2, BEP is 8.17E-13f or n = 3, and BEP is 3.33E-16for n = 4.

Table 4 The impact of the n (the forward error correction code) on the BEP for various SNR

SNR (dB) Required for BW of 125 KHz	Eb/No (dBm) for SF=7 and n=1	Bit Error Probability (BEP) for SF=7 and n=1	Bit Error Probability (BEP) for SF=7 and n=2	Bit Error Probability (BEP) for SF=7 and n=3	Bit Error Probability (BEP) for SF=7 and n=4
-4.25	9.34	8.65E-12	3.33E-16	0.00E+00	0.00E+00
-5.5	8.09	2.27E-07	7.08E-10	8.17E-13	3.33E-16
-6.75	6.84	7.75E-05	2.82E-06	5.91E-08	7.12E-10
-8	5.59	2.28E-03	3.32E-04	3.57E-05	2.83E-06

-9.25	4.34	1.67E-02	5.34E-03	1.45E-03	3.32E-04
-10.5	3.09	5.53E-02	2.78E-02	1.28E-02	5.35E-03
-11.75	1.84	1.16E-01	7.56E-02	4.70E-02	2.78E-02
-13	0.59	1.85E-01	1.41E-01	1.05E-01	7.56E-02
-14.25	-0.66	2.51E-01	2.10E-01	1.73E-01	1.41E-01
-15.5	-1.91	3.07E-01	2.72E-01	2.40E-01	2.10E-01

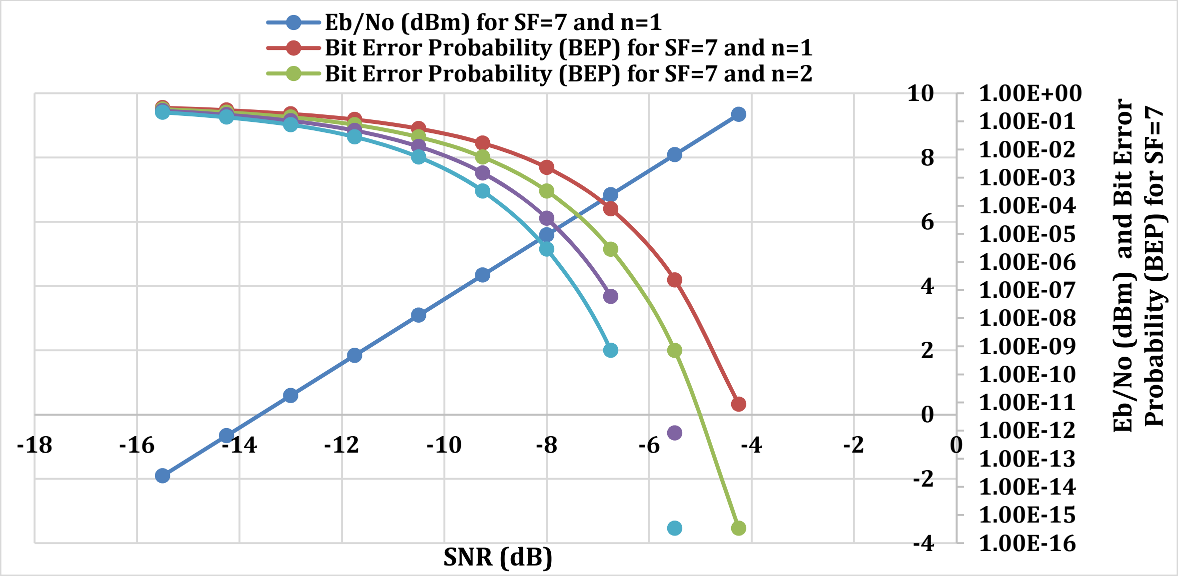

Figure 3. The graph of BEP versus SNR for various n where SF =7

The results showing the impact of the n (the forward error correction code) on the PEP for various SNR are presented in Table 5 and Figure 4. The results show that for a given SNR or a given Eb/No, the PEP decreases as the number of forward error correction code, n increases. For instance, at SNR of -5.5 dBm , Eb/No is 8.09 and PEP is 1.82E-06 for n = 1, PEP is 5.66E-09 for n = 2, PEP is 6.54E-12 for n = 3, and PEP is 2.66E-15 for n = 4.

Table 5 The impact of the n (the forward error correction code) on the PEP for various SNR

SNR (dB) Required for BW of 125 KHz	Eb/No (dBm) for SF=7 and n=1	Packet Error Probability (PEP) for SF=7 and n=1	Packet Error Probability (PEP) for SF=7 and n=2	Packet Error Probability (PEP) for SF=7 and n=3	Packet Error Probability (PEP) for SF=7 and n=4
-4.25	9.34	6.92E-11	2.66E-15	0.00E+00	0.00E+00
-5.5	8.09	1.82E-06	5.66E-09	6.54E-12	2.66E-15
-6.75	6.84	6.20E-04	2.25E-05	4.73E-07	5.69E-09
-8	5.59	1.81E-02	2.65E-03	2.86E-04	2.26E-05
-9.25	4.34	1.26E-01	4.20E-02	1.15E-02	2.66E-03
-10.5	3.09	3.66E-01	2.02E-01	9.76E-02	4.20E-02
-11.75	1.84	6.26E-01	4.67E-01	3.20E-01	2.02E-01
-13	0.59	8.05E-01	7.03E-01	5.87E-01	4.67E-01
-14.25	-0.66	9.00E-01	8.48E-01	7.82E-01	7.03E-01
-15.5	-1.91	9.47E-01	9.22E-01	8.89E-01	8.48E-01

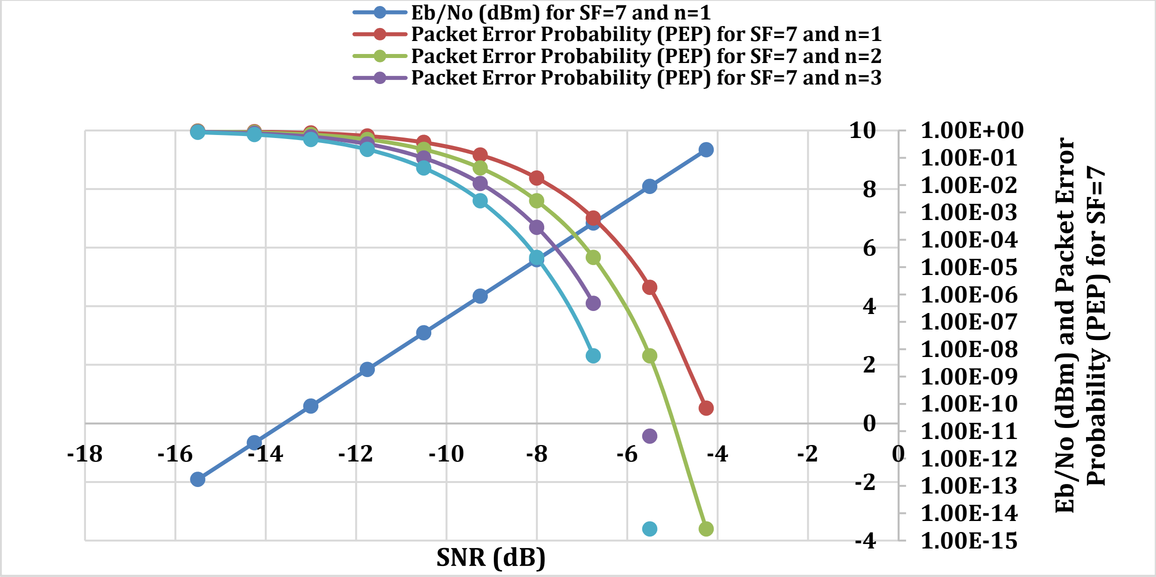

Figure 4. The graph of PEP versus SNR for various n where SF =7

The results showing the impact of the n (the forward error correction code) on the number of required transmission (Ntrans) for various SNR are presented in Table 6 and Figure 5. The results show that for a given SNR or a given Eb/No, the Ntrans decreases as the number of forward error correction code, n increases. For instance, at SNR of -10.5 dBm , Eb/No is 3.09 the Ntrans is 1.58 for n = 1, PEP is 1.25 for n = 2, PEP is 1.11 for n = 3, and PEP is 1.04 for n = 4.

Table 6 The impact of the n (the forward error correction code) on the number of required transmission (Ntrans) for various SNR

SNR (dB) Required for BW of 125 KHz	Ntrans for SF=7 and n=1	Ntrans for SF=7 and n=2	Ntrans for SF=7 and n=3	Ntrans for SF=7 and n=4
-4.25	1.00	1.00	1.00	1.00
-5.5	1.00	1.00	1.00	1.00
-6.75	1.00	1.00	1.00	1.00
-8	1.02	1.00	1.00	1.00
-9.25	1.14	1.04	1.01	1.00
-10.5	1.58	1.25	1.11	1.04
-11.75	2.68	1.87	1.47	1.25
-13	5.13	3.37	2.42	1.88
-14.25	10.05	6.58	4.58	3.37
-15.5	18.79	12.74	8.99	6.58

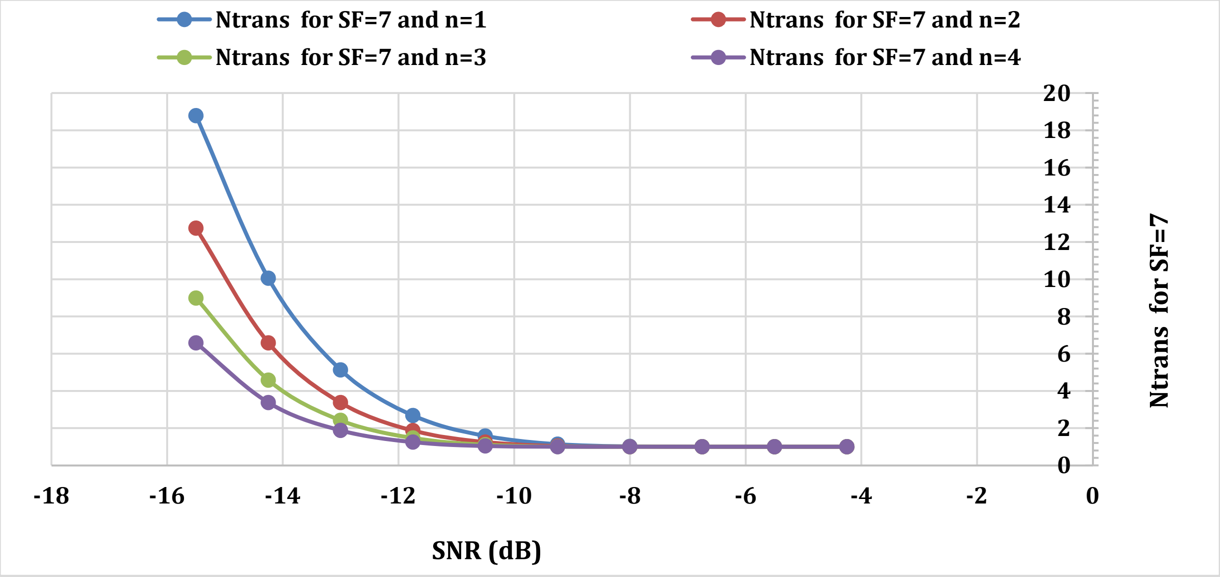

Figure 5. The graph of Ntrans versus SNR for various n where SF =7

The results of Eb/No versus SNR for different SF and n =1 is shown in Figure 6. The results show that for a given SNR, the Eb/No increases with increase in SF. For instance, for SNR of -15 dBm, the Eb/No is about -1.91dBm for SF of 7, Eb/No is about 0.52 dBm for SF of 8, Eb/No is about 3.02 dBm for SF of 9, Eb/No is about 5.57 dBm for SF of 10, Eb/No is about 8.45 dBm for SF of 11, and Eb/No is about 11.05 dBm for SF of 12.

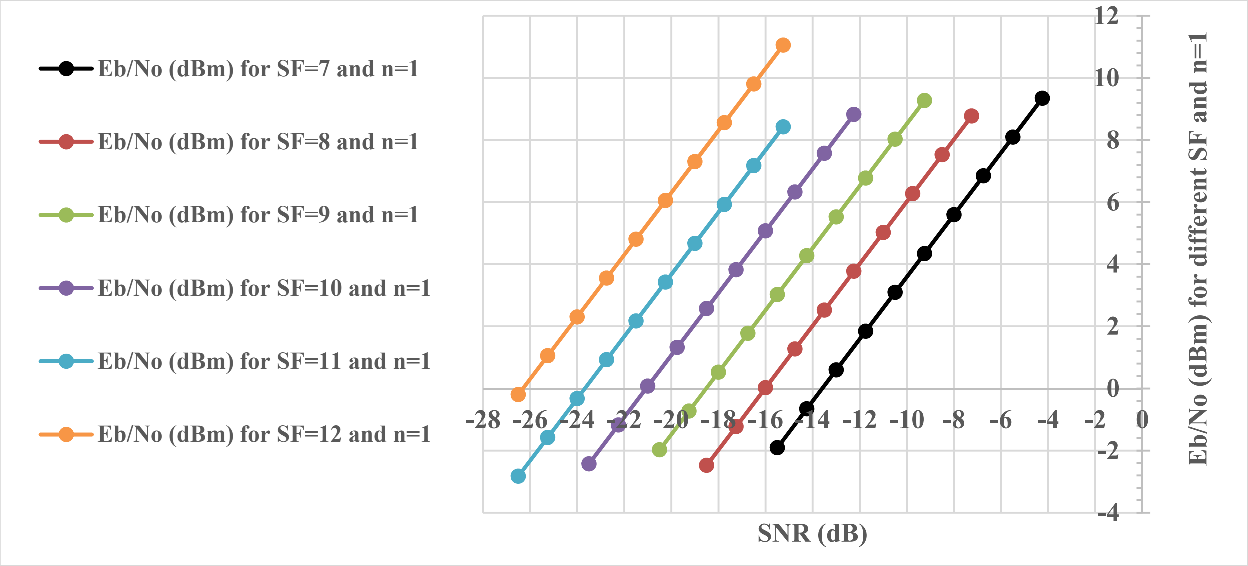

Figure 6 The line graph of Eb/No versus SNR for different SF and n =1

The results of BEP versus SNR for different SF and n =1 is shown in Figure 7. The results show that for a given SNR, the BEP decreases with increase in SF. For instance, for SNR of -15 dBm, the BEP is about 3.07E-01 for SF of 7, BEP is about 1.72E-01 for SF of 8, BEP is about 3.82E-02 for SF of 9, BEP is about 8.78E-04 for SF of 10, BEP is about 1.01E-11 for SF of 11, and BEP is about 0.00E+00 for SF of 12.

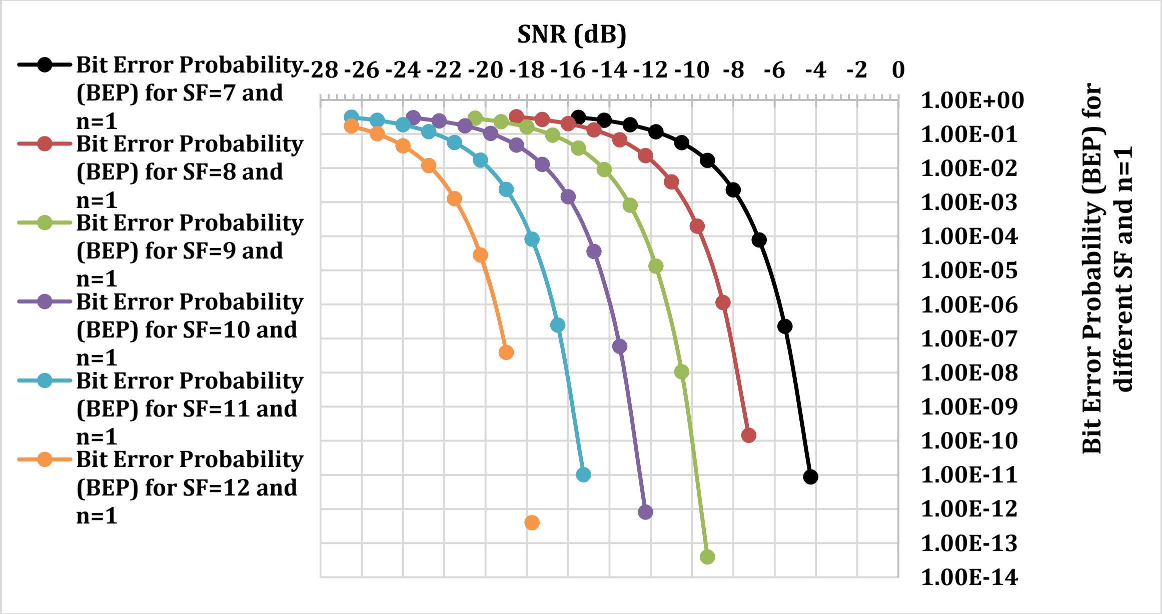

Figure 7 The line graph of BEP versus SNR for different SF and n =1

The results of PEP versus SNR for different SF and n =1 is shown in Figure 8. The results show that for a given SNR, the PEP decreases with increase in SF. For instance, for SNR of -15 dBm, the PEP is about 9.47E-01 for SF of 7, PEP is about 7.70E-01 for SF of 8, PEP is about 2.68E-01 for SF of 9, PEP is about 7.01E-03 for SF of 10, PEP is about 8.08E-11 for SF of 11, and PEP is about 0.00E+00 for SF of 12.

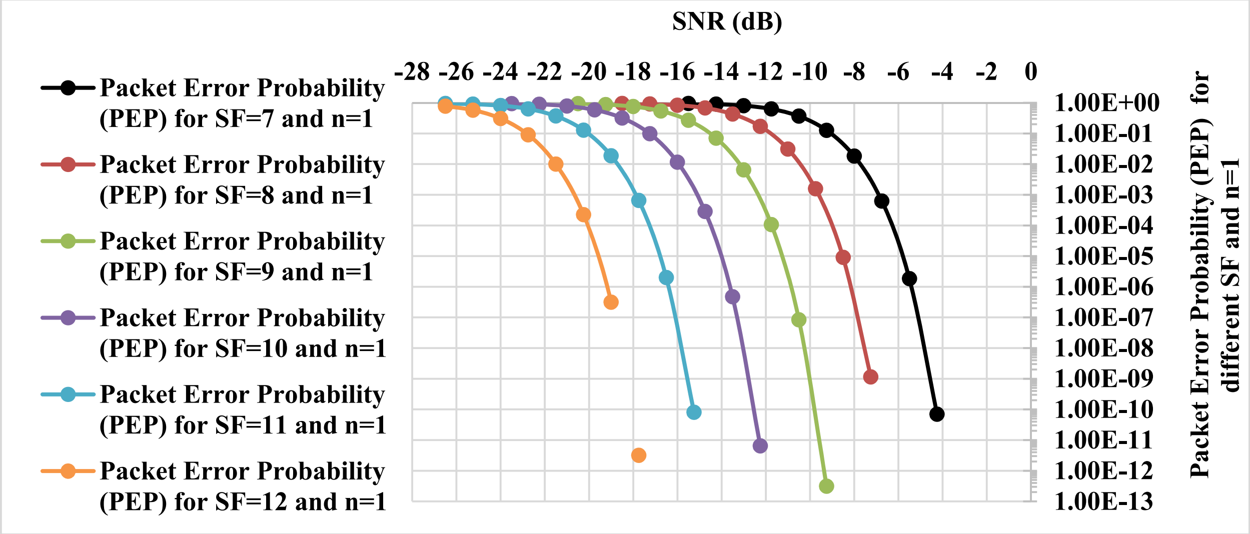

Figure 8 The line graph of PEP versus SNR for different SF and n =1

The results of the number of required transmission (Ntrans) versus SNR for different SF and n =1 is shown in Figure 9. The results show that for a given SNR, the Ntrans decreases with increase in SF. For instance, for SNR of -15 dBm, the Ntrans is about 18.79 for SF of 7, Ntrans is about 4.814 for SF of 8, Ntrans is about 1.37 for SF of 9, Ntrans is about 1.006 for SF of 10, Ntrans is about 1.00 for SF of 11, and Ntrans is about 1.00 for SF of 12.

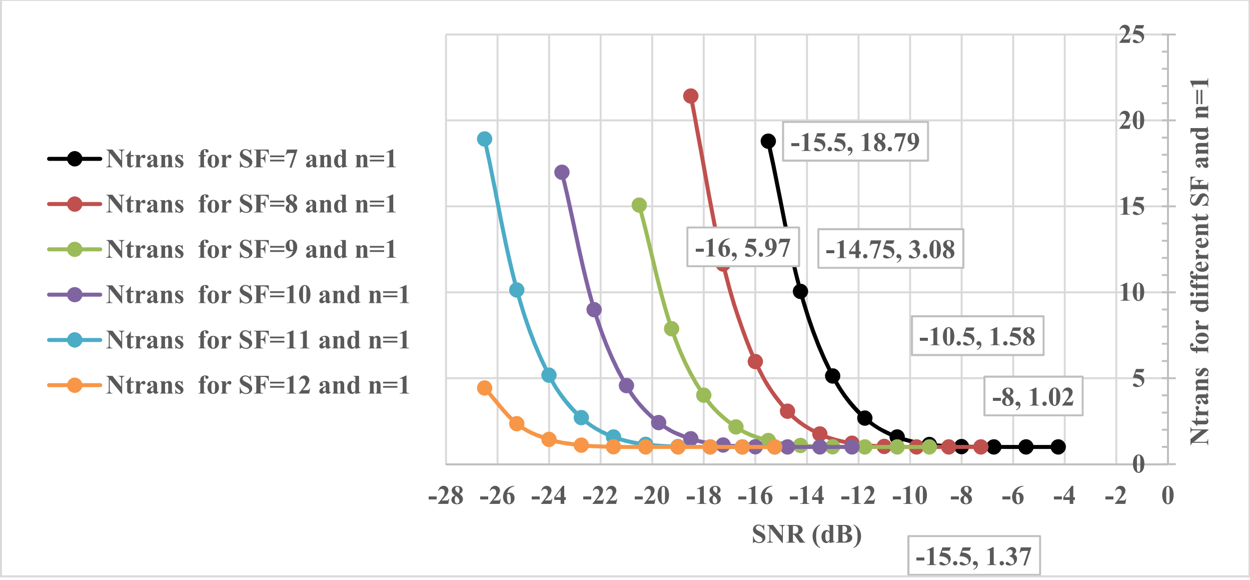

Figure 9 The line graph of the number of required transmission (Ntrans) versus SNR for different SF and n =1

4. CONCLUSION

The impact of signal to noise ratio (SNR) on the bit and packet deliver performance of the LoRa sensor node is examine. The study also examined how SNR affect the E_b/N_0 which is the sensor node's energy per bit to noise power spectral density considered how the bit error probability (BEP), the packet loss probability (PEP), and the required number of packet retransmission (Ntrans) vary with SNR for different sensor node modulation scheme spreading factor (SF), forward error correction code number (n) and packet size (Nbit). In all, the results showed that there are many different combinations of the various parameters listed which give different impact on the sensor node transmission performance. As such, careful selection and combinations of the various parameters is needed to achieve the desired performance.

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