Estimation Of Packet Loss For Wireless Sensor Network Based On Lora Modulation Technique Under Additive White Gaussian Noise Channel

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Abstract— **In this paper, estimation of packet loss for wireless sensor network based on LoRa modulation technique under Additive white Gaussian noise channel is presented. The analytical expressions relating the bit error probability (BEP) to the spreading factor and energy per bit to noise power spectral density is presented. Furthermore, the expression relating the energy per bit to noise power spectral density to the carrier to noise ratio is presented. Then, the packet loss probability is computed based on the BEP for the various spreading factors and carrier to noise ratio settings of the network. Some numerical computations were performed. Specifically, the bit error probability (BEP) was computed and packet loss probability were calculated for a set of carrier to noise ratio, C/N. Also, the amount of bits lost are computed. The computation was performed for the spreading factors 7,8,9,10,11 and 12. The results show that for a given spreading factor, SF the packet loss probability, PktLs decreases as the C/N value increases. For instance, for SF of 7, the PktLs decreased from 0.9999 at C/N of -20 dB to 2.173E-07 (or 0.0000002173) at C/N of -5 dB. Also, for a given C/N the packet loss decreases with increase in SF. For instance, for C/N of -20 dB, the PktLs decreased from 0.9999 at SF of 7 to 0.000285183 at SF of 12. Furthermore, the results show that for a given spreading factor, SF the number of bits lost decreases as the C/N value increases.**

Keywords: Packet loss, Wireless sensor network, LoRa, Modulation technique, Additive white Gaussian noise channel

I. INTRODUCTION

As the years go by wireless network technologies gain more relevance and application in more areas of human endeavour [1,2,3, 4,5,6, 7,8,9, 10, 11, 12, 13, 14, 16, 27]. Wireless network technology has dominated other forms of networking options like the wired and fibre optic networking technologies []17,18,19,20,21,22,23,24,25,26,27,8,29]. Also, the increasing adoption of Internet of things (IoT) and smart systems across the globe are making wireless technologies more ubiquitous [30,31,32,33,34,35,36,37]. Also, such sensor networks rely on transceiver technologies of which LoRa has been proven to be among the top in low energy and long range performance [38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54].

In any case, wireless sensor networks use sensor nodes which are constrained in their resource capacities and capabilities. Power and computing resources are most often limited and in some cases the sensor nodes are battery powered. In some cases, renewable energy harvesting mechanisms are deployed to ensure sustainable energy supply for the sensor nodes [55, 56, 57, 58, 59, 60]] . However, some of the energy sources for the harvester are stochastic and hence, sizing of the energy harvesting mechanism need adequate information about the energy consumption in the sensor node [61,62,63,64,65,66,67,68,69,70]. As such effort are made to understand and accurately estimate the various parameters of the sensor node so as to optimize the energy consumption and transmission range.

Among other things, LoRa transceiver are affected by the various transmission impediments which are often present in wireless transmission systems [71,72, 73,74, 75,76,77, 78,79]. As such, issues like path loss, multipath, interferences, fading and other factors are required to be accounted for in the design of LoRa based wireless network [80,81,82,83,84,85,86,87,88,89,90,91,92,93]. The essence is to ensure that the LoRa-based sensor node can deliver the required quality (QoS) of service in the face of these diverse network impediments. Among the top QoS parameter is the bit error rate and its attendant packet loss [94]. Accordingly, in this paper, the estimation of packet loss for wireless sensor network based on LoRa modulation technique under Additive white Gaussian Noise (AWGN) channel is presented.

II. METHODOLOGY

The focus of this paper if to study how the carrier to noise ratio (C/N0 affect the bit error rate and the packet loss for a wireless sensor network based on LoRa modulation technique under Additive white Gaussian Noise (AWGN) channel is presented. Meanwhile, the C/N I function of various wireless link parameters. Let P_{ktLs} denote the probability of losing a packet because at least one bit error occurred. Then, according to the work by **[95]**, P_{ktLs} is given in terms of bit error probability (BEP), coding rate , CR, packet size, Pkt_{sz} and packet header size, $PktH_{size}$ **as follows;**

$$P_{ktLs} = 1 - \left[(1 - BEP)^{\left(\frac{(Pkt_{sz} - PktH_{sz})}{CR}\right)}\right] \quad (1)$$

Also, for a LoRa transceiver with receiver sensitivity given as, S_{LoRa}, noise figure given as NF_{LoRa} and bandwidth given as BW_{LoRa}, the minimum required carrier to noise ratio (C/N_{rq}) and the operating carrier to noise ratio (C/N_{op}) are given as follows;

$$C/N_{rq} = S_{LoRa} + 174 - 10\log_{10}(BW_{LoRa}) - NF_{LoRa} \quad (2)$$

$$C/N_{op} = {}^{E_b}/_{N_O}\Big|_{dB} + 10\log_{10}(SF) + 10\log_{10}\left(\frac{4}{4+CR}\right) - 10\log_{10}(2^{SF}) \quad (3)$$

$${}^{E_b}/_{N_O}\Big|_{dB} = C/N_{op} - 10\log_{10}(SF) - 10\log_{10}\left(\frac{4}{4+CR}\right) + 10\log_{10}(2^{SF}) \quad (4)$$

where ${}^{E_b}/_{N_O}\Big|_{dB}$ is the energy per bit to noise power spectral density in dB, CR is the code rate and SF is the spreading factor. Then, the bit error rate denoted as BEP is given as;

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

where ${}^{E_b}/_{N_O}$ is the energy per bit to noise power spectral density in linear form given as;

$${}^{E_b}/_{N_O} = 10^{\left(\frac{{}^{E_b}/_{N_O}\big|_{dB}}{10}\right)} \quad (6)$$

Then, the packet loss is given as;

$$P_{ktLs} = \left(1 - \left(\frac{1}{2}\left[1 - erf\left(\left(\frac{\log_{12}(SF)}{\sqrt{2}}\right)\left({}^{E_b}/_{N_O}\right)\right)\right]\right)\right)^{\left(\frac{(Pkt_{sz} - PktH_{sz})}{CR}\right)} \quad (7)$$

The total bits in the packet, Bit_{pkt} is given as;

$$Bit_{pkt} = 8(Pkt_{sz}) \quad (8)$$

The amount of lost bits, Bit_{lost} is given as;

$$Bit_{lost} = 8(Pkt_{sz})(P_{ktLs}) \quad (9)$$

The packet loss was simulated using Visual Basic for Application (VBA) program. The simulation examined the values of BEP and packet loss probability are function of the operating carrier to noise ratio denoted as C/N.

III RESULTS AND DISCUSSION

The bit error probability (BEP) was computed and packet loss probability were calculated for a set of carrier to noise ratio, C/N. Also, the amount of bits lost are computed. The computation was performed for the spreading factors 7,8,9,10,11 and 12. The results of the packet loss probability versus C/N for spreading factors, SF 7,8,9,10,11 and 12 are shown in Table 1 and Figure 1. The results show that for a given spreading factor, SF the packet loss probability, PktLs decreases as the C/N value increases. For instance, for SF of 7, the PktLs decreased from 0.9999 at C/N of -20 dB to 2.173E-07 (or 0.0000002173) at C/N of -5 dB. Also, the results show that for a given C/N the packet loss decreases with increase in SF. For instance, for C/N of -20 dB, the PktLs decreased from 0.9999 at SF of 7 to 0.000285183 at SF of 12.

Similarly, the results of the bit error probability (BEP) versus C/N for spreading factors, SF 7,8,9,10,11 and 12 are shown in Table 2 and Figure 2. Again the results show that for a given spreading factor, SF the BEP decreases as the C/N value increases. For instance, for SF of 7, the BEP decreased from 0.42897183 at C/N of -20 dB to 7.5582E-09 (or 0.0000000075582) at C/N of -5 dB. Also, the results show that for a given C/N the BEP decreases with increase in SF. For instance, for C/N of -20 dB, the BEP decreased from 0.42897183 at SF of 7 to 9.92076E-06 (or 0.0000099207) at SF of 12.

Table 1 The results of the packet loss probability versus C/N for spreading factors, SF 7,8,9,10,11 and 12 and with packet size of 23 bytes

C/N (dBm)	PktLs for SF =7	PktLs for SF =8	PktLs for SF =9	PktLs for SF =10	PktLs for SF =11	PktLs for SF =12
-20	0.9999999	0.999998211	0.999855426	0.97276479	0.300602295	0.000285183
-17.5	0.99999865	0.99990662	0.9827801	0.39741674	0.000934965	4.6918E-13
-15	0.99993701	0.988899778	0.493525663	0.002531528	1.77023E-11	0
-12.5	0.99264779	0.582136672	0.005825061	3.68114E-10	0	0
-10	0.65902973	0.0116636	4.62735E-09	0	0	0
-7.5	0.02074319	3.79699E-08	0	0	0	0
-5	2.173E-07	0	0	0	0	0
-2.5	0	0	0	0	0	0
0	0	0	0	0	0	0
2.5	0	0	0	0	0	0
5	0	0	0	0	0	0

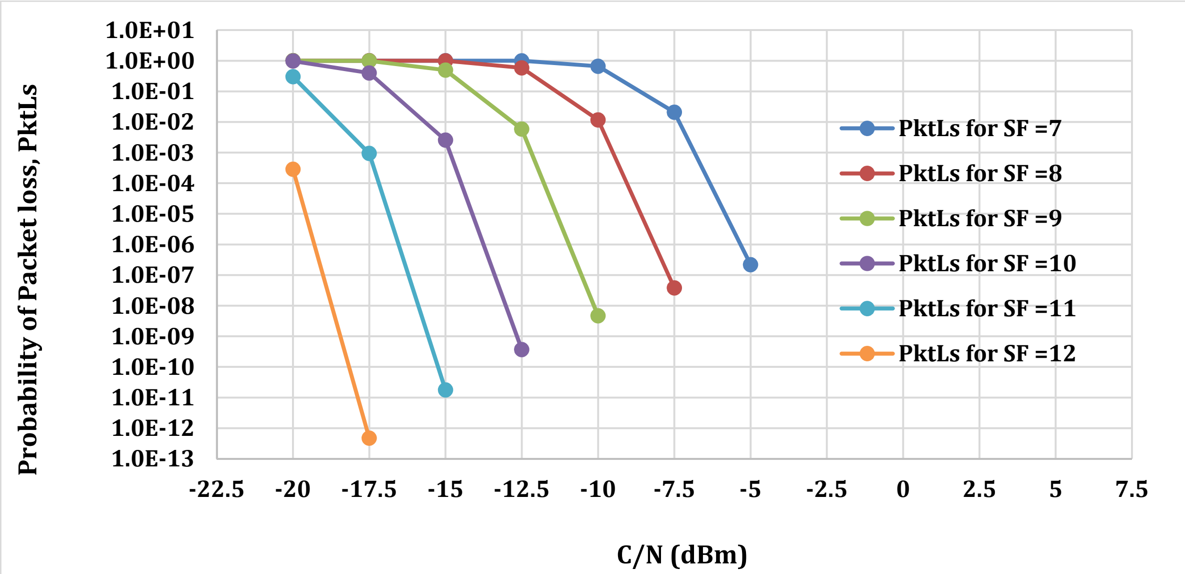

Figure 1 The graph of packet loss probability versus C/N for spreading factors, SF 7,8,9,10,11 and 12 and with packet size of 23 bytes

Table 2 The results of the bit error probability (BEP) versus C/N for spreading factors, SF 7,8,9,10,11 and 12 and with packet size of 23 bytes

C/N (dBm)	BEP forE/No=7	BEP for E/No=8	BEP for E/No=9	BEP for E/No=10	BEP for E/No=11	BEP for E/No=12
-20	0.42897183	0.368913806	0.264745071	0.117794493	0.012359018	9.92076E-06
-17.5	0.37512925	0.275839457	0.131750496	0.017464118	3.25352E-05	1.63203E-14
-15	0.28568882	0.144910573	0.02338422	8.81609E-05	6.15785E-13	0
-12.5	0.15707593	0.029895358	0.000203183	1.28039E-11	0	0
-10	0.03673305	0.000407992	1.60951E-10	0	0	0
-7.5	0.00072882	1.32069E-09	0	0	0	0
-5	7.5582E-09	0	0	0	0	0
-2.5	0	0	0	0	0	0
0	0	0	0	0	0	0
2.5	0	0	0	0	0	0
5	0	0	0	0	0	0

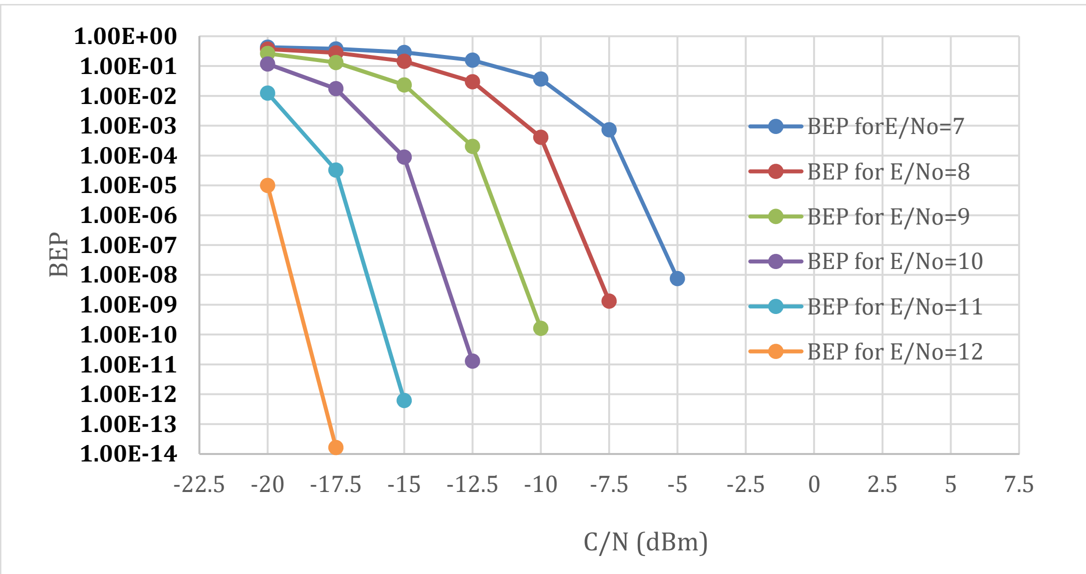

Figure 2 The graph of bit error probability (BEP) versus C/N for spreading factors, SF 7,8,9,10,11 and 12 and with packet size of 23 bytes

Again, the results of the number of bits lost versus C/N for spreading factors, SF 7,8,9,10,11 and 12 are shown in Table 3 and Figure 3. The results show that for a given spreading factor, SF the number of bits lost decreases as the C/N value increases. For instance, with packet size of 23 bytes or 184 bits, for SF of 7, the number of bits lost decreased from 184 at C/N of -20 dB to 0 at C/N of -5 dB. Also, the results show that for a given C/N the number of bits lost decreases with increase in SF. For instance, for C/N of -20 dB, the number of bits lost decreased from 184 at SF of 7 to 55 at SF of 11 and to at spreading factor of 12.

Table 3 The results of the number of bits lost versus C/N for spreading factors, SF 7,8,9,10,11 and 12 and with packet size of 23 bytes

C/N (dBm)	Bits Lost (bits) for SF =7	Bits Lost (bits) for SF =8	Bits Lost (bits) for SF =9	Bits Lost (bits) for SF =10	Bits Lost (bits) for SF =11	Bits Lost (bits) for SF =12	
-20	184	184	184	179	55	0	0
-17.5	184	184	181	73	0	0	0
-15	184	182	91	0	0	0	0
-12.5	183	107	1	0	0	0	0
-10	121	2	0	0	0	0	0
-7.5	4	0	0	0	0	0	0
-5	0	0	0	0	0	0	0
-2.5	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0

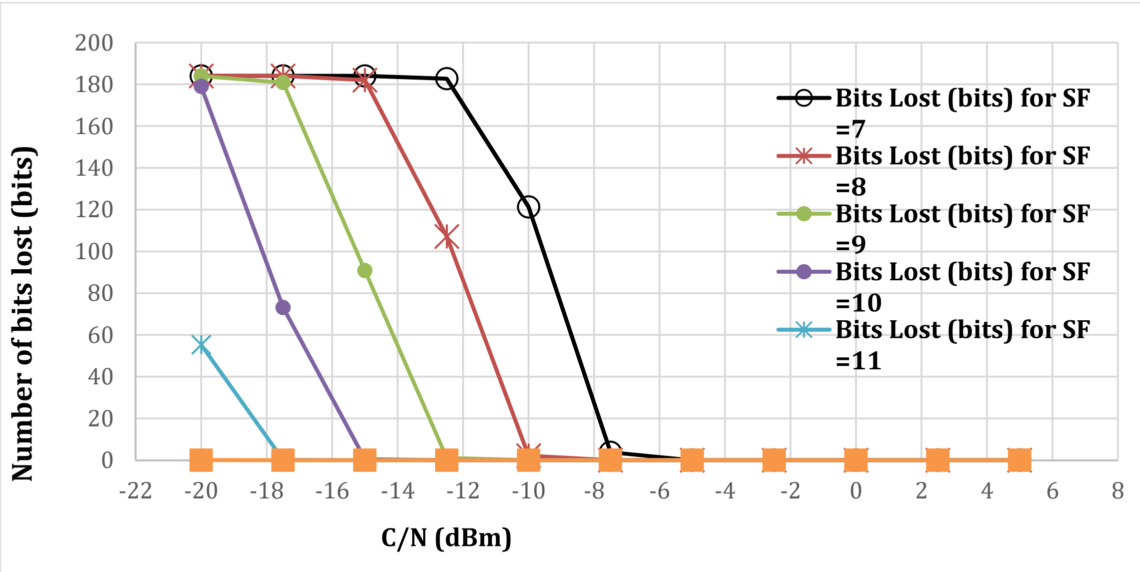

Figure 3 The graph of the number of bits lost versus C/N for spreading factors, SF 7,8,9,10,11 and 12 and with packet size of 23 bytes

The results for the comparison of the packet loss probability versus C/N for spreading factor of 7 operated with packet size of 23 bytes and 64 bytes are shown in Table 4 and Figure 4 while Table 5 and Figure 5 show the comparison of the number of bits lost versus C/N for spreading factor of 7 operated with packet size of 23 bytes and 64 bytes. The results show that the within C/N of -5 dB to -12.5 dB the packet loss probabilities of 64 bytes packet size are higher than that of the 23 bytes packet size. However, the packet loss probabilities for the two packet sizes approached 1 at lower C/N values (that is for C/N less than -12.5 dB). Also, the packet loss probabilities for the two packet sizes approached 0 at higher C/N values (that is for C/N above than -5 dB). Similar trends are observed in the number of packet lost versus C/N shown in Table 5 and Figure 5. In this case, the results show that within C/N of -5 dB to -20 dB the number of lost bits for the 64 bytes packet size are higher than that of the 23 bytes packet size. However, the number of lost bits for the two packet sizes approached 0 at higher C/N values (that is for C/N above -5 dB).

Table 4 Comparison of the packet loss probability versus C/N for spreading factor of 7 operated with packet size of 23 bytes and 64 bytes

C/N (dBm)	PktLs for SF =7 and Pktsz =23 bytes	PktLs for SF =7 and Pktsz = 64 bytes
-20	0.9999999	1
-17.5	0.99999865	1
-15	0.99993701	1
-12.5	0.99264779	0.99998142
-10	0.65902973	0.9079869
-7.5	0.02074319	0.04541589
-5	2.17E-07	4.82E-07
-2.5	0	0
0	0	0
2.5	0	0
5	0	0

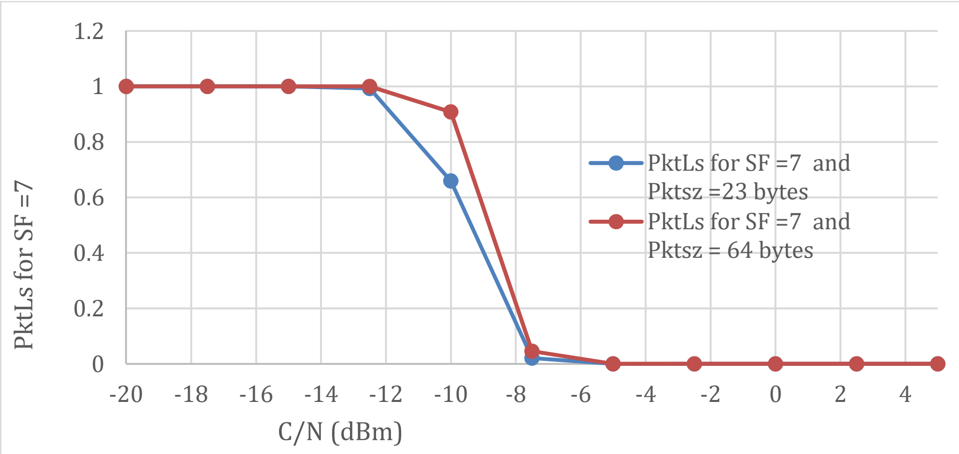

Figure 4 Comparison of the packet loss probability versus C/N for spreading factor of 7 operated with packet size of 23 bytes and 64 bytes

Table 5 Comparison of the number of bits lost versus C/N for spreading factor of 7 operated with packet size of 23 bytes and 64 bytes

C/N (dBm)	Bits Lost (bits) for SF =7 and Pktsz =23 bytes	Bits Lost (bits) for SF =7 and Pktsz =64 bytes
-20	184	512
-17.5	184	512
-15	184	512
-12.5	183	512
-10	121	465
-7.5	4	23
-5	0	0
-2.5	0	0
0	0	0
2.5	0	0
5	0	0

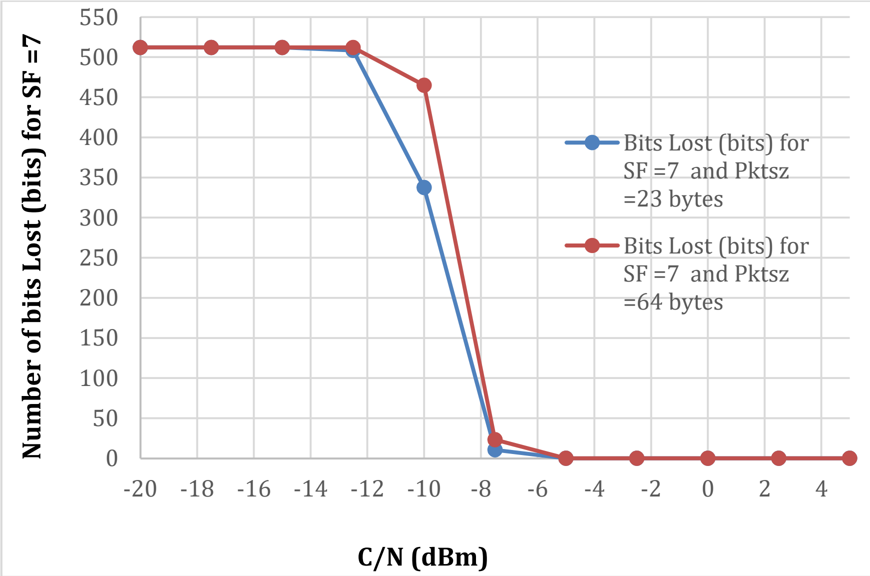

Figure 5 Comparison of the number of bits lost versus C/N for spreading factor of 7 operated with packet size of 23 bytes and 64 bytes

IV CONCLUSION

Analysis of bit error probability (BEP) and packet loss performance of based on LoRa modulation technique operated under Additive white Gaussian noise (AWGN) is presented. The analytical expressions relating the BEP to the spreading factor and energy per bit to noise power spectral density is presented. Furthermore, the expression relating the energy per bit to noise power spectral density to the carrier to noise ratio is presented. Then, the packet loss probability is computed based on the BEP for the various spreading factors and carrier to noise ratio settings of the network. The results show the impact of carrier to noise ratio on the BEP, the packet loss and the number of packets lost for each spreading factor of the LoRa network.

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