Parametric Analysis Of Iot Sensor Packet Error Probability And Required Number Of Packet Retransmissions Based On Automatic Repeat Request Technique

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Abstract— **In this work, parametric analysis of IoT sensor packet error probability and required number of packet retransmissions based on automatic repeat request technique is presented. The study seeks to evaluate how the packet size affect the required bit error probability (BEP), the packet error probability (PEP) and also the number of packet retransmission required for a wireless IoT sensor network. The essence of the study is to help in the selection of appropriate error performance value for different packet sizes. The expression for determination of PEP and the expected number of transmission, N_{trans} for successful delivery of a packets with size Npbit are presented. The results show that, for a given BEP, the PEP increases as the packet size, N_{pbit} increases. For instance, for BEP = 1.00E-02, the PEP increased from a value of 7.73E-02 (or 0.0773) for N_{pbit} = 8 bits to a value of 9.82E-01 (or 0.9820) for N_{pbit} = 8 bits. Also, the simulation results showed that BEP of one packet error in 10,000 pickets (that is PEP of 1.00E-04) is attained with BER of one bit error in 10,000 bits (that is BEP of 1.00E-04) for Nbit of 8 bits. However, for Nbit of 80 bits, PEP of 1.00E-04 is attained with BEP of 1.00E-05; for Nbit of 400 bits and above, PEP of 1.00E-04 is attained with BEP of 1.00E-06. Hence, it requires a lower BEP to attain the same PEP as the packet size increases. Finally, the results show that for a given number of transmission, the value of PEP is constant irrespective of the packet size. However, for a given BEP the value of PEP increases with increase in packet size. Hence, it requires lower BEP to attain the same PEP with higher packet size.**

Keywords— Parametric analysis, IoT sensor, packet error probability, packet retransmissions , wireless network, automatic repeat request technique

1. INTRODUCTION

As the internet of sensor network in increasingly deployed in diverse applications, researchers and designers are faced with the challenges of satisfying the network requirement with acceptable Quality of Service (QoS) [1,2,3,4]. Some key network QoS parameters are the bit error probability (BEP) and packet error probability (PEP) [5,6,7]. The two parameters a related and they are used to determine the number of transmissions that must be done before the packet is successfully delivered.

Notably, available studies have shown that the PEP is related to the BEP via an expression that includes the packet size [8,9]. Also, the automatic repeat request technique used in network applications requires a number of retransmissions to be done when error occurs before the packet can be successfully delivered [10,11]. In this study, the effect of packet size and the BEP on the PEP and the number of retransmission required in an IoT sensor network is presented. The study specifically seeks to evaluate how the packet size affect the required bit error probability (BEP), the packet error probability (PEP) and also the number of packet retransmission required for a wireless IoT sensor network. The essence of the study is to help in the selection of appropriate error performance value for different packet sizes.

2. METHODOLOGY

2.1 The packet error probability and number of transmission for ARQ technique

The packet error probability (PEP) is given in respect of the bit error probability (BEP) and packet size in bits (Npbit) as follows [8,9]

$$PEP \quad = 1 - (1 - \text{BEP})^{(\text{Npbit})} \qquad (1)$$

In the ARQ technique, the expected number of transmission, N_{trans} for successful delivery of a packets with size Npbit and with Bit Error Probability BEP is given as [10,11]

$$N_{trans} \quad = \frac{1}{(1-\text{BEP})^{\left(N_{pbit}\right)}} = \frac{1}{1-PEP} \qquad (2)$$

2.2 Determination of bit error probability (BEP) and packet error probability (PEP) for a specified number of retransmission in ARQ technique

The expected number of transmission, N_{trans} includes retransmission. Hence, for any single packet, the number of retransmission, NR_{trans} is given as;

$$NR_{trans} = N_{trans} - 1 = \left[\frac{1}{(1-\text{BEP})^{\left(N_{pbit}\right)}}\right] - 1 \qquad (3)$$

$$NR_{trans} = N_{trans} - 1 = \left[\frac{1}{1-PEP}\right] - 1 \qquad (4)$$

$$N_{trans} = NR_{trans} + 1 \qquad (5)$$

Specifically, NR_{trans} represents the number of retransmissions for a single transmission before a packet of size N_{pbit} is successfully delivered. The packet size, N_{pbit} determines the required BEP for a specified NR_{trans}. Hence, for any given bit, N_{pbit}, from Equation 2, the following expressions apply for determination of the required BEP and PEP;

$$1 - PEP = \frac{1}{N_{trans}} = \frac{1}{(1-\text{BEP})^{\left(N_{pbit}\right)}} \qquad (6)$$

$$PEP = 1 - \left[\frac{1}{N_{trans}}\right] = 1 - \left[\frac{1}{NR_{trans}+1}\right] \qquad (7)$$

$$(1 - \text{BEP})^{\left(N_{pbit}\right)} = \frac{1}{N_{trans}} \qquad (8)$$

$$1 - \text{BEP} = \left(\frac{1}{N_{trans}}\right)^{\frac{1}{N_{pbit}}} \qquad (9)$$

$$\text{BEP} = 1 - \left[\left(\frac{1}{N_{trans}}\right)^{\frac{1}{N_{pbit}}}\right] = 1 - \left[\left(\frac{1}{NR_{trans}+1}\right)^{\frac{1}{N_{pbit}}}\right] \qquad (10)$$

It must be noted that NR_{trans} means the number of retransmission required for every single packet transmitted. Hence, Hence, if the number is state with respect to number of packets transmitted, the total number n=must be scaled down to one packet to obtain the actual value of NR_{trans}. For instance, if it is specified that one (1) retransmission is required for every 1000 packets delivered, then, the total number is 1000+1 = 1001 which when scaled to 1 gives N_{trans} =1001/1000 = 1.001 where 1.001-1 = 0.001 if the value of NR_{trans}. That is, for the stated scenario, there is 0.001 or 10^{-3} retransmissions for each packet to be successfully delivered.

3. RESULTS AND DISCUSSION

Some sample computations are conducted for evaluating the PEP and N_{trans} as functions of BEP and N_{pbit}. The results of this particular set of computations are useful in understanding how the packet error probability, PEP and the number of packet transmission, N_{trans} vary with the bit error probability, BEP for any given packet size, N_{pbit}.

The results for the Packet Error probability, PEP versus bit error probability, BEP and packet size, N_{pbit} are shown in Table 1. The graph of PEP versus BEP for different packet size, N_{pbit} is shown in Figure 1 while the graph of PEP versus packet size, N_{pbit} for BEP = 1.00E-02 is shown in Figure 2. The results show that, for a given bit error probability, BEP, Packet Error probability, PEP increases as the packet size, N_{pbit} increases. For instance, for BEP = 1.00E-02 , the PEP increased from a value of 7.73E-02 (or 0.0773) for N_{pbit} = 8 bits to a value of 9.82E-01 (or 0.9820) for N_{pbit} = 8 bits. Also, the PEP is directly proportional to BEP; hence, as BEP decreases the PEP decreases. Specifically, the simulation results showed that BEP of one packet error in 10,000 pickets (that is PEP of 1.00E-04) is attained with BER of one bit error in 10,000 bits (that is BEP of 1.00E-04) for Nbit of 8 bits. However, for Nbit of 80 bits, PEP of 1.00E-04 is attained with BEP of 1.00E-05; for Nbit of 400 bits and above, PEP of 1.00E-04 is attained with BEP of 1.00E-06. Hence, it requires a lower BEP to attain the same PEP as the packet size increases.

The results for the Number of transmissions, N_{trans} versus bit error probability, BEP and packet size, N_{pbit} are shown in Table 2. The graph number of transmissions versus bit error probability, BEP for 8 bit packet size is shown in Figure 3 while the graph of number of transmissions, Ntrans versus packet size, Npbit for BEP = 1.00E-03 is shown in Figure 4. The results show that, for a given bit error probability, BEP, the number of transmissions, Ntrans increases as the packet size, N_{pbit} increases. For instance, for BEP = 1.00E-03, the value of Ntrans increased from 1.0837 for N_{pbit} = 8 bits to a value of 55.7086 for N_{pbit} = 400 bits. Specifically, the simulation results showed that the number of transmissions, Ntrans of 1.008 is attained with BER of one bit error in 10,000 bits (that is BEP of 1.00E-04) for Nbit of 8 bits. However, for Nbit of 80 bits, Ntrans of 1.008 is attained with BEP of 1.00E-05; for Nbit of 400 bits and above, Ntrans of 1.008 is attained with BEP of 1.00E-06. Hence, it requires a lower BEP to attain the same Ntrans as the packet size increases.

Table 1 Packet Error probability, PEP versus bit error probability, BEP and packet size, N_{pbit}

BEP	PEP for 8 bit packet	PEP for 80 bit packet	PEP for 400 bit packet	PEP for 800 bit packet
1.00E-01	5.70E-01	1.00E+00	1.00E+00	1.00E+00
1.00E-02	7.73E-02	5.52E-01	9.82E-01	1.00E+00
1.00E-03	7.97E-03	7.69E-02	3.30E-01	5.51E-01
1.00E-04	8.00E-04	7.97E-03	3.92E-02	7.69E-02
1.00E-05	8.00E-05	8.00E-04	3.99E-03	7.97E-03
1.00E-06	8.00E-06	8.00E-05	4.00E-04	8.00E-04
1.00E-07	8.00E-07	8.00E-06	4.00E-05	8.00E-05
1.00E-08	8.00E-08	8.00E-07	4.00E-06	8.00E-06
1.00E-09	8.00E-09	8.00E-08	4.00E-07	8.00E-07
1.00E-10	8.00E-10	8.00E-09	4.00E-08	8.00E-08
1.00E-11	8.00E-11	8.00E-10	4.00E-09	8.00E-09
1.00E-12	8.00E-12	8.00E-11	4.00E-10	8.00E-10
1.00E-13	8.00E-13	8.00E-12	4.00E-11	8.00E-11
1.00E-14	7.99E-14	7.99E-13	4.00E-12	7.99E-12
1.00E-15	7.99E-15	7.99E-14	4.00E-13	7.99E-13
1.00E-16	0.00E+00	8.88E-15	4.44E-14	8.88E-14
1.00E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00

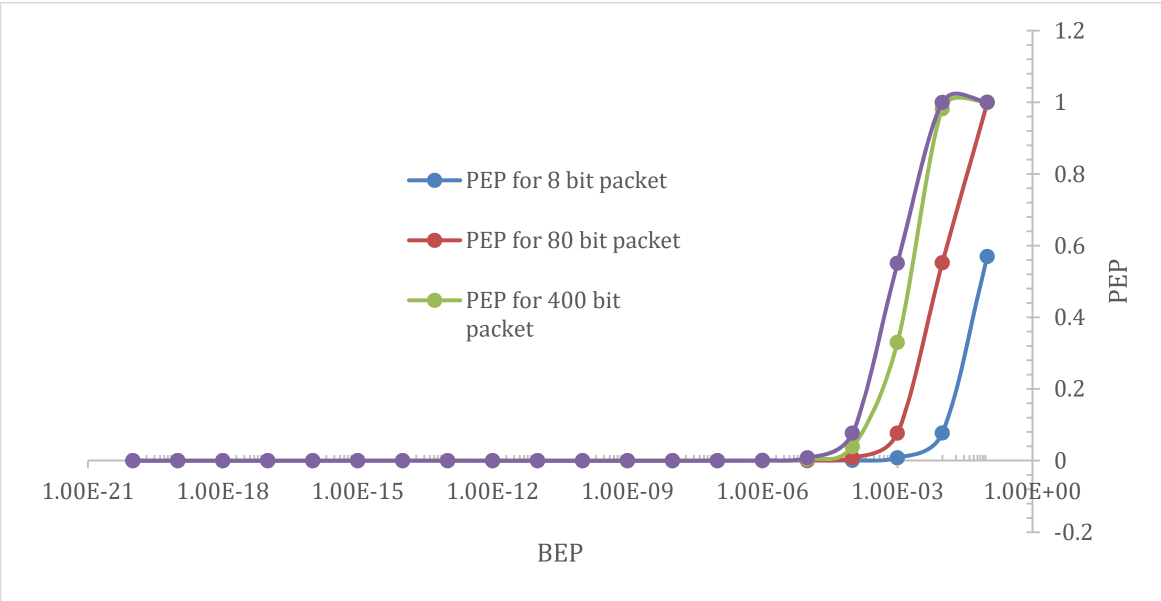

Figure 1 The graph of Packet Error probability, PEP versus bit error probability, BEP for different packet size, N_{pbit}

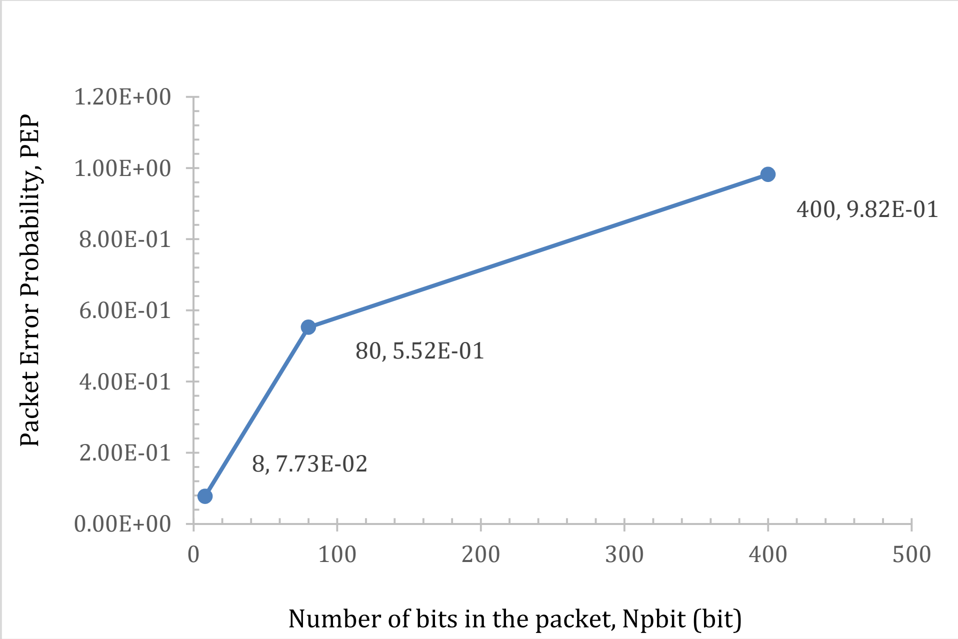

Figure 2 The graph of Packet Error probability, PEP versus packet size, N_{pbit} for BEP = 1.00E-02

Table 2 Number of transmissions, N_{trans} versus bit error probability, BEP and packet size, N_{pbit}

BEP	No. of Transmission for 8 bit packet	No. of Transmission for 80 bit packet	No. of Transmission for 400 bit packet	No. of Transmission for 800 bit packet
1.00E-01	2.323057	4577.193	2.00908E+18	4.03638E+36
1.00E-02	1.083723	2.234521	55.70858929	3103.446921
1.00E-03	1.008036	1.08333	1.492123292	2.226431917
1.00E-04	1.0008	1.008032	1.040812856	1.083291401
1.00E-05	1.00008	1.0008	1.004008031	1.008032126
1.00E-06	1.000008	1.00008	1.00040008	1.00080032
1.00E-07	1.000001	1.000008	1.000040001	1.000080003
1.00E-08	1	1.000001	1.000004	1.000008
1.00E-09	1	1	1.0000004	1.0000008
1.00E-10	1	1	1.00000004	1.00000008
1.00E-11	1	1	1.000000004	1.000000008
1.00E-12	1	1	1	1.000000001
1.00E-13	1	1	1	1
1.00E-14	1	1	1	1
1.00E-15	1	1	1	1
1.00E-16	1	1	1	1
1.00E-17	1	1	1	1
1.00E-18	1	1	1	1
1.00E-19	1	1	1	1
1.00E-20	1	1	1	1

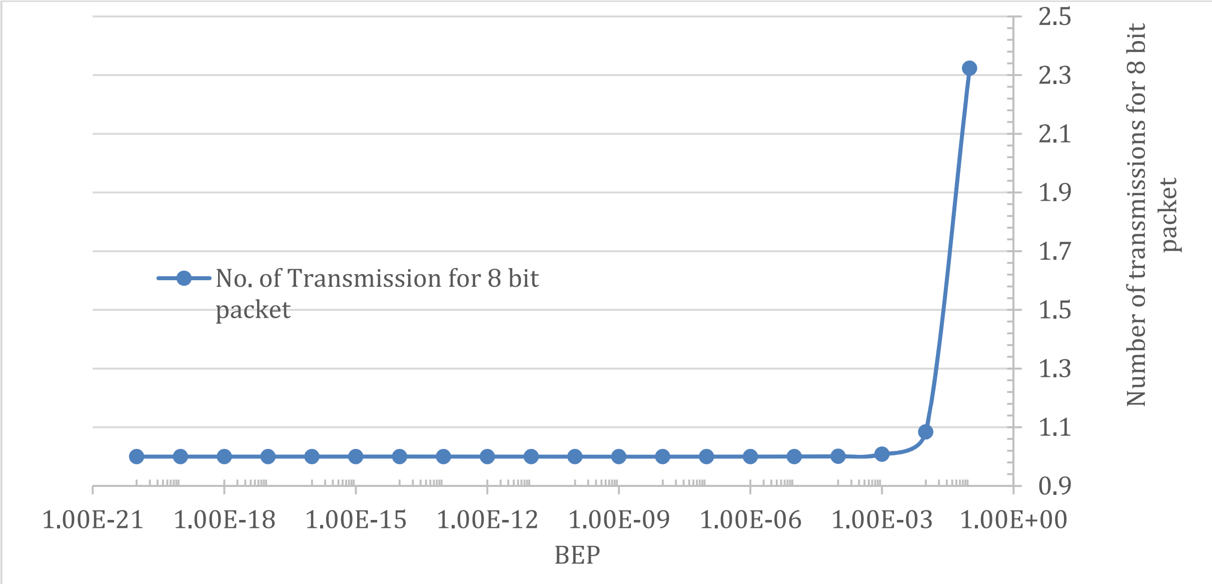

Figure 3 The number of transmissions versus bit error probability, BEP for 8 bit packet size

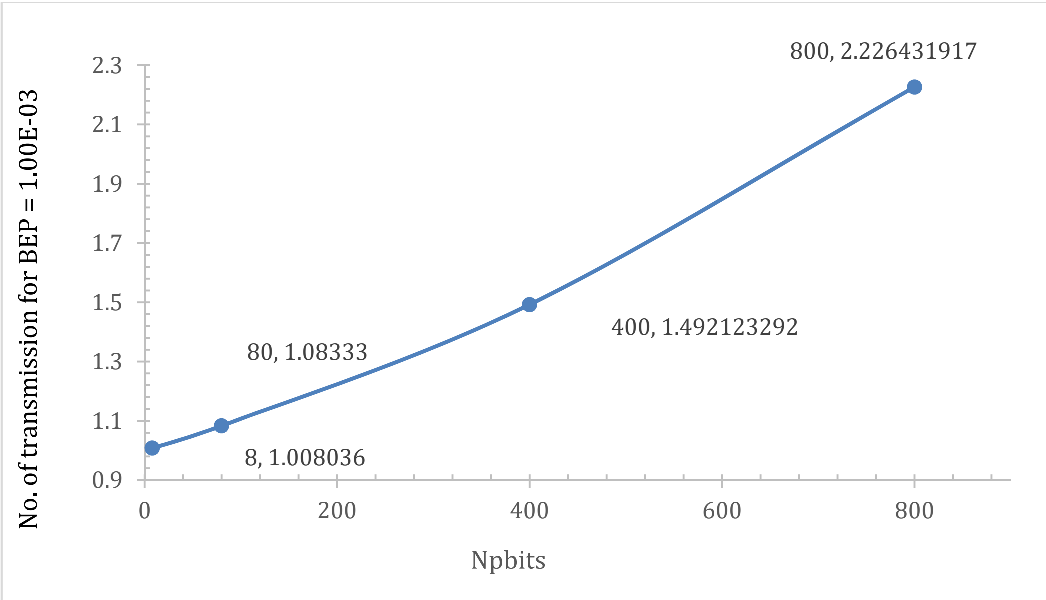

Figure 4 Number of transmissions, Ntrans versus packet size, Npbit for BEP = 1.00E-03

Next, the BEP and PEP are evaluated as function of NR_{trans} and N_{pbit}. The results of this particular set of computations are useful in understanding how the bit error probability, BEP can be selected to be suitable for any selected number of packet transmission, NR_{trans} and packet size, N_{pbit}. The results for BEP and PEP versus N_{pbit} for N_{trans} = 1.001 and N_{Rtrans} = 0.001 = 10^{-3} are presented in Table 3 and Figure 5. The results show that for a given N_{trans} (say N_{trans} = 1.001) the value of PEP is constant for all the packet sizes but the required BEP to attain the given PEP decreases with increase in packet size. In this case, the required BEP to attain N_{trans} = 1.001 decreased from a value of 1.25E-04 for packet size of 8 bits to a value of 1.25E-06 for packet size of 800 bits.

The results for BEP versus N_{pbit} for N_{Rtrans} = 0.1, 0.01, 0.001 and 0.0001 are presented in Table 4 and Figure 6. The results show that for a given number of retransmission, NRtrans the required BEP decreases as packet size, Npbits increases. In essence, lower BER is required for a given NRtrans as the packet size increases.

The results for PEP versus N_{pbit} for N_{Rtrans} = 0.1, 0.01, 0.001 and 0.0001 are presented in Table 5 and Figure 7. The results show that for a given number of retransmission, NRtrans the required PEP is constant for all the packet sizes.

Table 3 The BEP and PEP versus N_{pbit} for N_{trans} = 1.001 and N_{Rtrans}= 0.001= 10^{-3}

Npbits	BEP	PEP
8	1.25E-04	9.99E-04
80	1.25E-05	9.99E-04
400	2.50E-06	9.99E-04
800	1.25E-06	9.99E-04

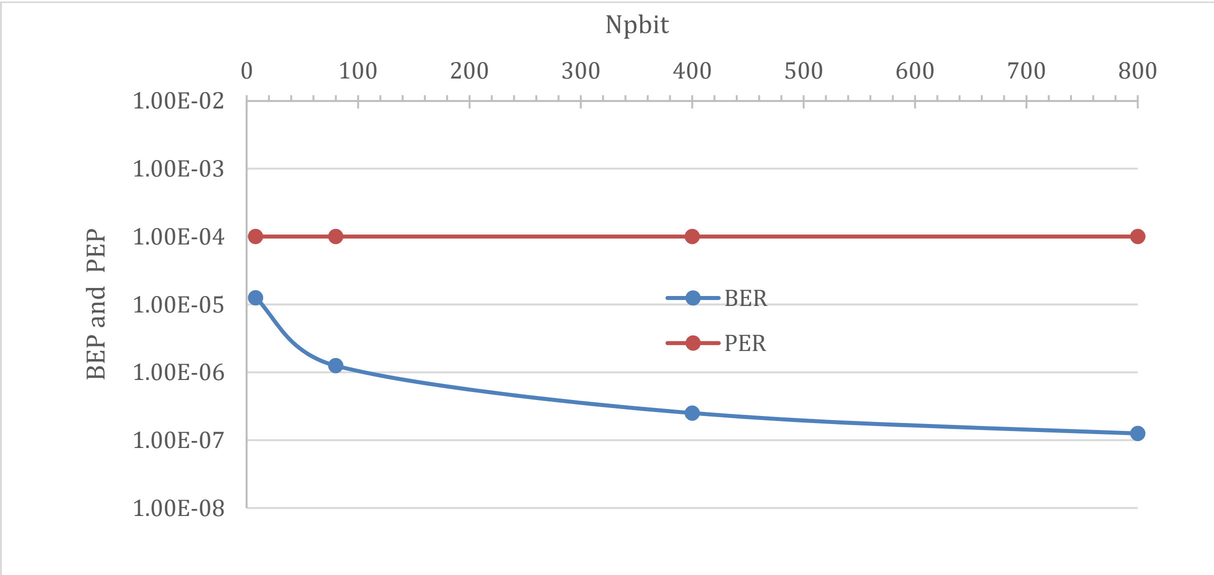

Figure 5 The graph of BEP and PEP versus N_{pbit} for N_{trans} = 1.001 and N_{Rtrans}= 0.001= 10^{-3}

Table 4 BEP versus N_{pbit} for N_{Rtrans}= 0.1, 0.01, 0.001 and 0.0001

Npbits	BEP for NRtrans =0.1	BEP for NRtrans =0.01	BEP for NRtrans =0.001	BEP for NRtrans =0.0001
8	1.18E-02	1.24E-03	1.25E-04	1.25E-05
80	1.19E-03	1.24E-04	1.25E-05	1.25E-06
400	2.38E-04	2.49E-05	2.50E-06	2.50E-07
800	1.19E-04	1.24E-05	1.25E-06	1.25E-07

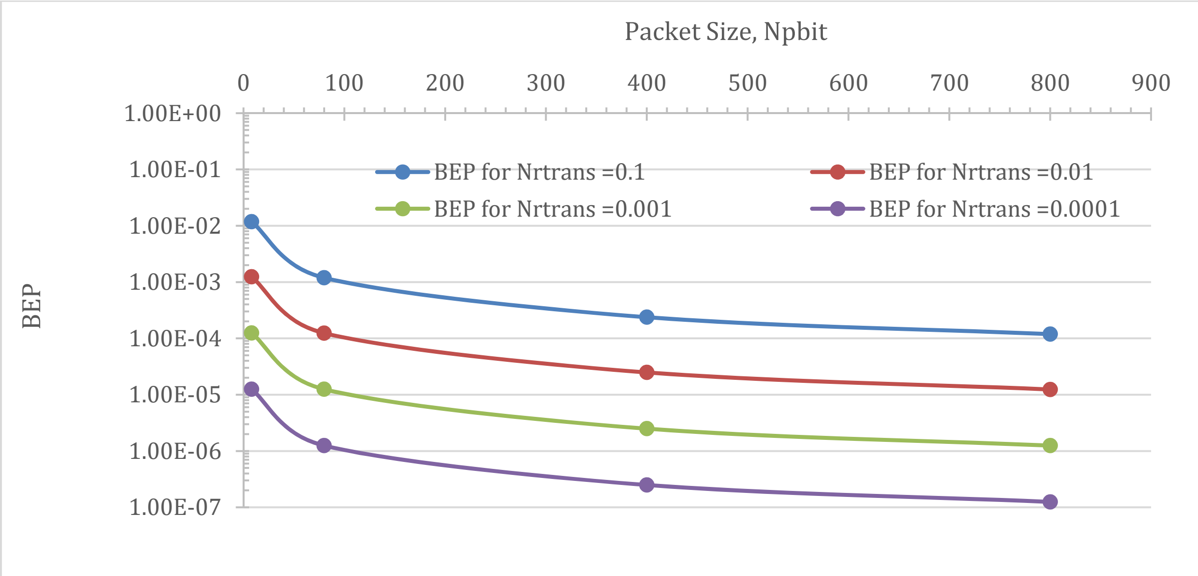

Figure 6 Graph of BEP versus N_{pbit} for N_{Rtrans}= 0.1, 0.01, 0.001 and 0.0001

Table 5 PEP versus N_{pbit} for N_{Rtrans}= 0.1, 0.01, 0.001 and 0.0001

Npbits	PEP for NRtrans =0.1	PEP for NRtrans =0.01	PEP for NRtrans =0.001	PEP for NRtrans =0.0001
8	9.09E-02	9.90E-03	9.99E-04	1.00E-04
80	9.09E-02	9.90E-03	9.99E-04	1.00E-04
400	9.09E-02	9.90E-03	9.99E-04	1.00E-04
800	9.09E-02	9.90E-03	9.99E-04	1.00E-04

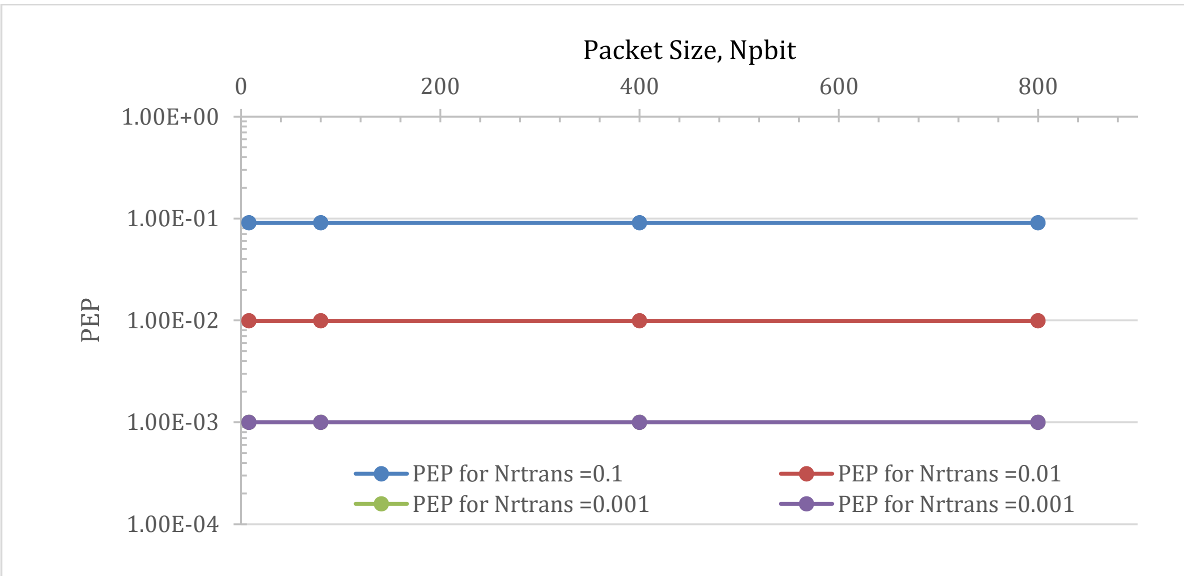

Figure 7 Graph of PEP versus N_{pbit} for N_{Rtrans}= 0.1, 0.01, 0.001 and 0.0001

4. CONCLUSION

The effect of packet size, and bit error probability, BEP on the packet error probability, PEP and the number of transmission and retransmission for successful delivery of a packet are presented. The requisite mathematical expressions for computing the PEP for any given BEP and packet size are presented along with the expressions for computing the number of transmissions and retransmissions for any given PEP value. The results show that for a given number of transmission, the value of PEP is constant irrespective of the packet size. However, for a given BEP the value of PEP increases with increase in packet size. Hence, it requires lower BEP to attain the same PEP with higher packet size.

REFERENCES

1. Singh, A. P., Luhach, A. K., Gao, X. Z., Kumar, S., & Roy, D. S. (2020). Evolution of wireless sensor network design from technology centric to user centric: An architectural perspective. *International Journal of Distributed Sensor Networks*, *16*(8), 1550147720949138.
2. Bukar, U. A., & Othman, M. (2022). Architectural design, improvement, and challenges of distributed software-defined wireless sensor networks. *Wireless Personal Communications*, *122*(3), 2395-2439.
3. Khalifeh, A., Darabkh, K. A., Khasawneh, A. M., Alqaisieh, I., Salameh, M., AlAbdala, A., ... & Rajendiran, K. (2021). Wireless sensor networks for smart cities: Network design, implementation and performance evaluation. *Electronics*, *10*(2), 218.
4. Nurlan, Z., Zhukabayeva, T., Othman, M., Adamova, A., & Zhakiyev, N. (2021). Wireless sensor network as a mesh: Vision and challenges. *IEEE Access*, *10*, 46-67.
5. Shafique, T., Tabassum, H., & Hossain, E. (2019). End-to-end energy-efficiency and reliability of UAV-assisted wireless data ferrying. *IEEE Transactions on Communications*, *68*(3), 1822-1837.
6. El-Rajab, M., Abou-Rjeily, C., & Kfouri, R. (2020). Buffer-aided relaying: a survey on relay selection policies. *IET Communications*, *14*(21), 3715-3734.
7. Jaksic, B., Todorovic, J., Jovanovic, M., Bandjur, M., & Bandjur, D. (2023). Impacts of Diversity Technique Application in Order to Reduce the Fading in IEEE 802.15. 4 Networks. *Applied Sciences*, *13*(17), 9775.
8. Jacobsson, M., & Rohner, C. (2019). Link quality estimation for arbitrary packet sizes over wireless links using packet reception events. *International Journal of Communication Systems*, *32*(16), e4115.
9. Umoren, I. J., Asuquo, D. E., Gilean, O., & Esang, M. (2019). Performability of Retransmission of Loss Packets in Wireless Sensor Networks. *Comput. Inf. Sci.*, *12*(2), 71-86.
10. Bhunia, C. T. (2008, April). Error forecasting schemes of error correction at receiver. In *Fifth International Conference on Information Technology: New Generations (itng 2008)* (pp. 332-336). IEEE.
11. Tiguiane Y., Boureima Z., Mesmin T. D., 1doda A. Rollande S. (2020)Analysis Of Ad-Hoc Network Routing Metrics Efficiency. *Journal of Theoretical and Applied Information Technology Vol.98. No 23*