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Investigating Path Loss Effect in Wireless Sensor Networks

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Abstract---In Wireless communication, the average received power decreases logarithmically with distance. The main factor responsible for this is path loss, which represents signal attenuation as a positive quantity measured in dB. In this paper, we investigate the effects of noise level on various parameters such as Bit Error Rate (BER), Packet Success rate (PSR), Transmit Energy and total energy required to transmit each information bits successfully. In this paper, energy metric is also derived which helps to calculate the optimal transmit energy.

Keywords: Wireless communications; Energy efficiency; Path loss exponent; Noise spectral density (NSD); Propagation model;

I. Introduction

In wireless communications, as the distance between source to destination i.e. (d) increases, the minimum energy required to successfully transmit a data packet between them also increases. This is due to the fact that the strength of the received signal decreases as a function of d. By using the inverse power law (d^{-n}), one can model the decrement in the received signal strength in which n is the path loss exponent. The average path loss for an arbitrary separation is expressed as a function of distance by using path loss exponent ' n'.

$$P_L = 10\, n \log (d) \qquad \text{(I)}$$

Where d is the distance between the transmitter and receiver and n is the path loss exponent whose value ranges between 2 to 4, For free-space propagation model, n is 2 (d^{-2} power loss with distance) and n is 4 for the two-ray ground propagation model (d^{-4} power loss) [1].

Here we are exploring the optimal transmit energy in an idealized channel model, as well as the effects of the path loss on parameters like bit error rate(BER), packet success rate(PSR), transmit power and total energy required to transmit each information bits successfully. To obtain all the parameters and required results mentioned above, the following propagation model is derived.

II. Model

Then the expected number of information bits received successfully per packet will be the product of packet success rate (PSR) to the total number of information bits, which is represented by $\mathbf{IB_{rs}}$ (information bits received successfully)

$$IB_{rs} = (M - M_0)P_{SP} \qquad (4)$$

Where M is the total number of bits in a packet and M_0 is the number of overhead bits in a packet

The received energy per bit, (E_b) at a destination located d_{SD} distance away from a source (Fig.1) can be expressed as follows:

$$E_b = \frac{E_{tx}}{d^n{}_{SD}} \qquad (1)$$

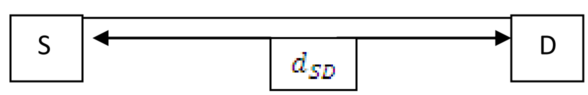

Fig.1. Source & Destination nodes are denoted by S & D

Where, E_{tx} is the energy required to transmit a bit from S to D and n is the path-loss exponent for the channel. Assuming binary phase shift keying (BPSK) modulation and an additive white Gaussian noise(AWGN) channel, the bit error rate (**BER**) for the channel is given by [1]

$$P_{eb} = \frac{1}{2}\,\mathrm{erfc}\left[\sqrt{\frac{E_b}{N}}\right] \qquad (2)$$

Where N is the noise spectral density, assuming no channel coding, the packet success rate (**PSR**) or probability of success, for an M-bit packet is given as

$$P_{SP} = (1 - P_{eb})^M \qquad (3)$$

Then the total energy required to transmit each information bits successfully is nothing but the ratio of the **total energy required to send one packet** to the **expected number of information bits received successfully per packet**, which is denoted by **EPSB** and it can be defined as:

$$\text{EPSB} = \frac{\text{Total energy to send one packet}}{\text{expected number of information bits received successfully per packet}}$$

The total energy required to send one packet is given by:

$$M\,(E_{tx} + 2 * E_{FIXED}) \qquad (5)$$

Where E_{FIXED} is the constant energy dissipation for transmission and reception, this fixed energy is dissipated to run electronic circuitry of transmitter and receiver nodes and E_{tx} is the energy required to transmit a packet from source to destination.
The EPSB metric i.e. the total energy required to transmit each information bits successfully can be written as,

$$\text{EPSB} = \frac{M(E_{tx} + 2 * E_{FIXED})}{(M - M_0)P_{SP}} \qquad (6)$$

The above equation shows an energy metric (EPSB) which should be reduced to obtain an energy efficient communication model .With the help this equation we can find the optimum transmit energy and the other needful results.

III. Results

We have evaluated the reference noise value N_0 which is the noise spectral density, such that the bit error rate (BER) of a BPSK symbol is 10^{-5} for an energy per received bit, E_b = 50nJ. In simulations where a range of noise values are considered, the values are logarithmically spaced from N_0 to $32N_0$. As we know that path loss exponent is related to noise spectral density by the following relation N=$2^n * N_0$. Therefore, as the values of n increase, different values of NSD can be obtaining e.g.: for n=1, N=2N_0, for n=2, N=4N_0 and so on. In this way we get different values of NSD and the following graphs are extracted in accordance with the different values of NSD or we can say that in accordance with path loss.

A range of optimum values of E_{tx} is calculated for each set of parameters which are typically given in wireless sensor network [2] – e.g. : n = 2, N = 4N0, M = 500 bits, M_0 = 25 and E_{FIXED}= 50nJ. The distance between the source and the destination is kept fixed to 10 meters. Once optimal parameter is found, corresponding values of EPSB are calculated from equation (6). This graph shows that value of E_{tx} for which EPSB has its minimum value.

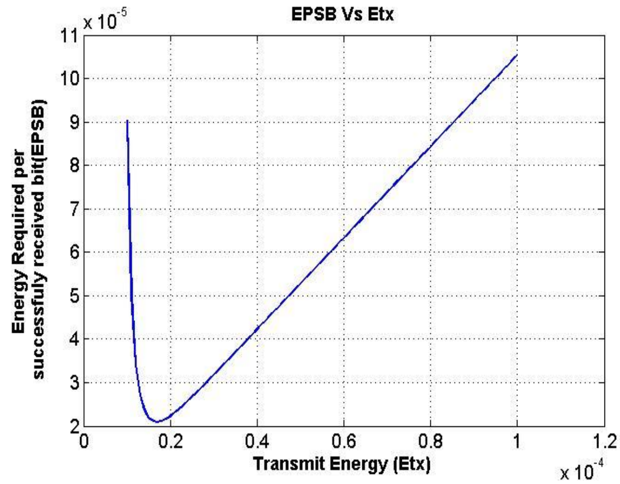

Fig.2. Curve between E_{tx} and EPSB.

Again Fig (3) and Fig (4) represents respectively the values of BER and PSR as a function of path loss exponent, n for constant noise level and optimum values of E_{tx}. It is clear that as n increases, BER increases and PSR reduces.
An interesting point from these two figures is that, the PSR is lower than 1 due to the fact that ensuring the successful delivery of each packet (i.e., PSR = 1) is less energy-efficient than letting some of the packets be dropped and retransmitted. For example, at n = 2, approximately 7 out of 100 packet transmissions are lost due to packet errors, and thus these packets must be retransmitted. The transmit power and EPSB decrease with the increasing path-loss exponent. Again BER increases with increasing the value of n. This is because as n increases, path loss, P_L increases (from equation I) & as PL increases, BER also increase, since in digital transmission, the number of **bit errors** is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion or bit synchronization errors.

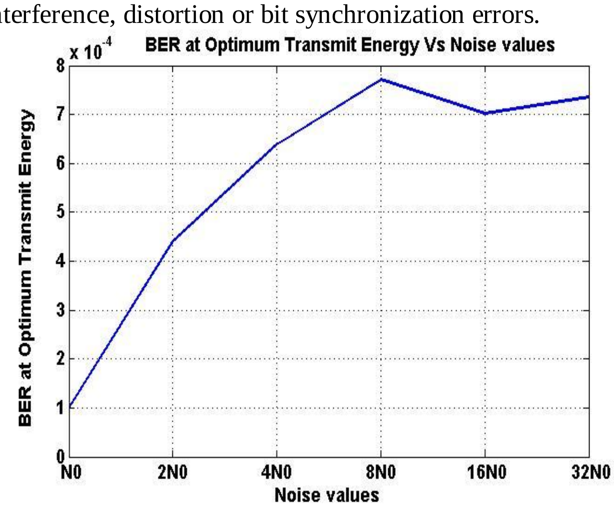

Fig.3. Curve between BER and NSD for optimal E_{tx} .

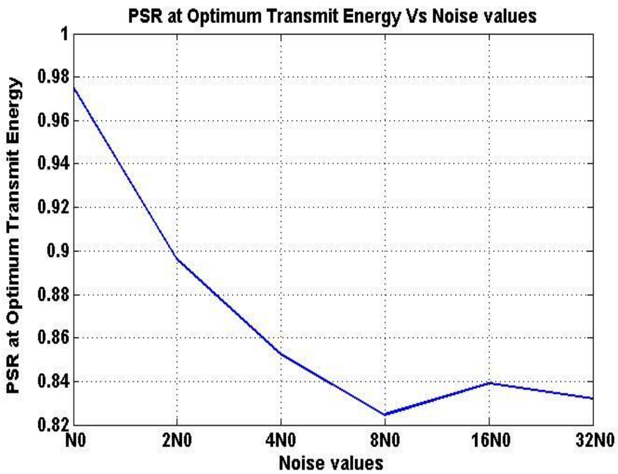

Fig.4. Curve between PSR and NSD for optimal E_{tx}.

Fig (5) is a curve drawn for analyzing the variation of optimum values of E_{tx} and path loss exponent, n. It can be understood that, as the value of noise spectral density increases, path loss exponent increase, therefore energy required to transmit bits from a particular node, also increases. This justifies the result that E_{tx} also increases.

Similarly, Fig(6) is generated for optimum values of EPSB and path loss exponent, n. Noise spectral density increases the path loss exponent, so optimum EPSB increases.

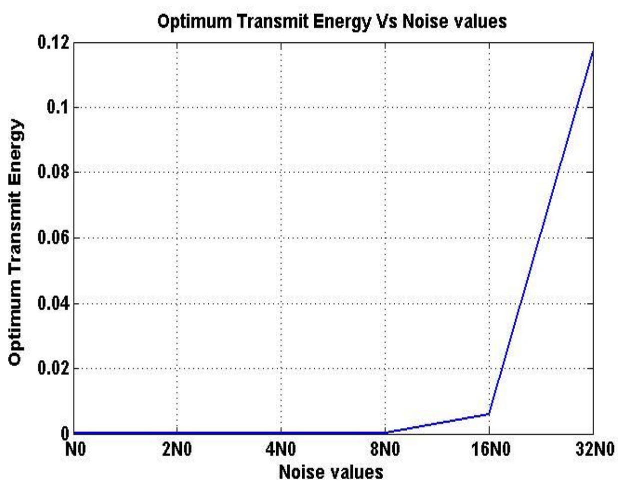

Fig.5. Curve between optimum E_{tx} and NSD.

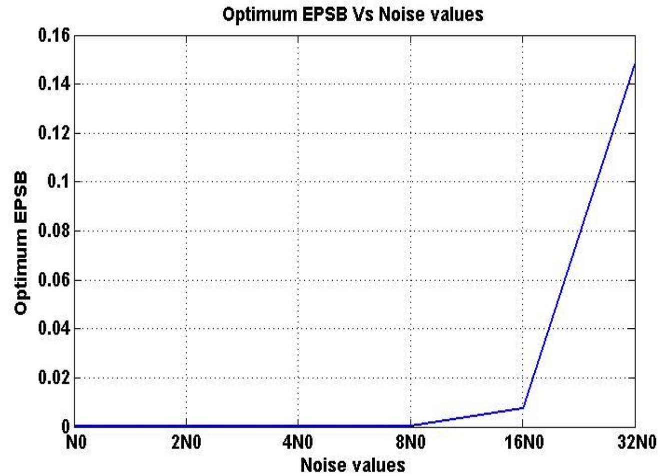

Fig.6. Curve between optimum EPSB and NSD.

IV. Conclusion

In this paper, we have investigated the effects of, path-loss exponent, and noise level on the minimal transmit power and energy per successfully received bit, EPSB for wireless communication systems, in general. The results also show that, when operating under the optimal conditions, required EPSB is reduced. Therefore the lifetime of the WSN is improved.

Here, the path-loss exponent and noise level also affect the bit error rate and success probability also. With increase in noise level, BER decreases & PSR increases, this PSR is less than 1.

The transmit power E_{tx} and EPSB decrease with the increasing path-loss exponent.

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