Performance of energy & path loss over Fading Channels of Packet Delivery in Wireless Sensor Networks

Kaibalya Kumar Sethi[1]
kaibalya_ece@gita.edu.in

Subharanjan Das[2]
suvranjandas@gmail.com

Santyanarayan Rath[3]
Satya_etc@yahoo.co.in

[1,2]GITA / ECE, Bhubaneswar, India
[3]TAT / ECE, Bhubaneswar, India

Abstract: **Simulations are currently an essential tool to develop and test wireless sensor networks (WSNs) protocols and to analyze future WSNs applications performance. Researchers often simulate their proposals rather than deploying high-cost test-beds or develops complex mathematical analysis. However, simulation results rely on physical layer assumptions, which are not usually accurate enough to capture the real behavior of a WSN. Such an issue can lead to mistaken or questionable results. Besides, most of the envisioned applications for WSNs consider the nodes to be at the ground level. However, there is a lack of radio propagation characterization and validation by measurements with nodes at ground level for actual sensor hardware. In this paper, we propose to use a low-computational cost, two slope, log-normal path loss near ground outdoor channel model at 868 MHz in WSN simulations. The model is validated by extensive real hardware measurements obtained in different scenarios. In addition, accurate model parameters are provided. This model is compared with the well-known one slope path-loss model. We demonstrate that the two slope log-normal model provides more accurate WSN simulations at almost the same computational cost as the single slope one. It is also shown that the radio propagation characterization heavily depends on the adjusted model parameters for a target deployment scenario: The model parameters have a considerable impact on the average number of neighbours and on the network connectivity.**

IndexTerm- Wireless Sensor Networks (WSNs); Rician Fading; Rayleigh Fading; Bit Error Rate (BER); ARQ; Energy Efficiency; Channel modelling; simulation

1. INTRODUCTION

Recent advances in wireless communication technologies led to great interest in wireless sensor networks (WSNs). WSN consists of wireless interconnection of several sensor nodes which comprise of sensor devices with wireless communication facilities [1]. Most of the works on performance of WSNs assume idealized radio propagation models without considering impact of fading and shadowing effects at physical layer. However network performance may degrade due to presence of channel impairments such as shadowing and fading [2-3]. Energy conservation is one of the most important issues in WSN, where nodes are likely to rely on limited battery power. If the transmission power is not sufficiently high there may be single or multiple link failure(s). Further transmitting at high power reduces the battery life and introduces excessive amount of inter node interference. Hence there is an optimal transmit power so as to strike a balance between the two effects [4]. Previous research works in this field assume free-space radio link model and Additive White Gaussian Noise (AWGN) [4-6]. However wireless channels are often accurately modelled as Rayleigh fading or Rician fading. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. It is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver. However if there is a dominant line of sight, Rician fading may be more applicable. Rician fading captures a wide range of fading model depending on the value of Rician factor. Rician factor, K defined as the power ratio of specular to diffused components [7]. Several approaches have been proposed in literature to prolong network lifetime. Panichpapiboon et al. evaluated Bit Error Rate (BER) performance and optimal power to preserve the network connectivity considering only path-loss and thermal noise [4]. In [5], Bettstetter derived the transmission range for which network is connected with high probability considering free-space radio link model. Tseng et al. studied the relationships between transmission range, service area and network connectivity in a free space model [6]. BER performance and optimal transmit power in WSN over Rayleigh fading channel has been derived in [8]. Narayanaswamy et al. proposed a protocol that extends battery life through providing low power routes in a medium with path loss exponent greater than 2 [9]. A minimum uniform transmission power of an ad hoc wireless network to maintain network connectivity considering only path loss has been proposed in [10]. In this paper energy level performance of three different information delivery mechanisms in a multihop WSN are considered in fading channel. In all the three schemes, message packet is sent on hop-by-hop basis. Further in scheme I message is corrected for error at every hop while in the other two schemes, message is corrected at the destination. However in case II, ACK/NACK propagates from destination to source via multiple hops through intermediate nodes. The energy requirement for successful packet transmission also depends on routing and the Medium Access Control (MAC) protocol used [4, 11-12]. More precisely energy requirement for successful delivery of a packet is evaluated for all the three packet delivery schemes under several conditions of network such as node density, packet size etc. Impact of Rayleigh and Rician fading on energy consumption is indicated. We derive energy efficiency of the three retransmission mechanisms. Energy efficiency is an optimization metric that captures the energy and reliability constraints [15-16]. Impact of Rayleigh and Rician fading on energy efficiency is also investigated. Further an optimal packet length which corresponds to highest energy efficiency for a particular set of network conditions is evaluated for each packet delivery scheme. Impact of fading on optimal packet is also investigated. A scheme utilizing optimal size packet is analyzed and the impact of optimal size packet on energy consumption is indicated for different types of fading channel.

The rest of the paper is organized as follows: In Section II, we describe the system model that is used in the derivation of energy consumption and energy efficiency of three different information delivery mechanisms in fading channel.

2. SYSTEM MODEL

We consider a simple scenario with square grid network topology as presented in [4]. Nodes are deployed in square grid fashion and sensor nodes remain stationary at their respective location. Distance between two nearest neighbour is d_{link}. It is assumed that „N" number of nodes are distributed over a region of area A following a square grid topology. The node spatial density ρ_{sq} is defined as number of nodes per unit area i.e., ρ_{sq} =N/A. The minimum distance between two consecutive neighbours is given by

$$d_{link} = \frac{\sqrt{N}}{\sqrt{N-1}} \times \frac{1}{\rho_{sq}} \quad (1)$$

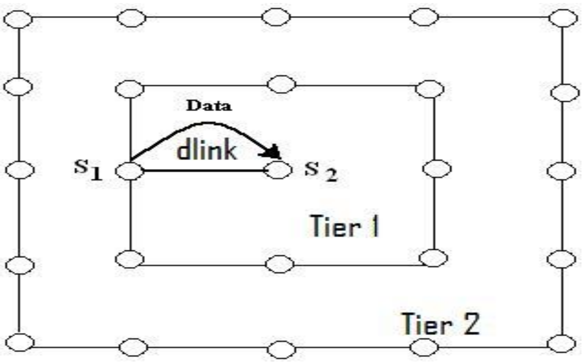

Fig. 1: Sensor Nodes in Square Grid Topology; a Link Interconnecting Node S_1 and S_2 in One Hop is Shown.

Here we assume a simple routing strategy such that a packet is relayed hop-by-hop, through a sequence of nearest neighbouring nodes, until it reaches the destination [11]. Further we consider a simple reservation based MAC protocol, called reserve and go (RESGO) following [12]. The major perturbations in wireless transmission are large scale fading and small scale fading [2-3]. Large scale fading represents the average signal power attenuation or path loss due to motion over large areas. This phenomenon is affected by prominent terrain contours (hills, forests, billboards, clumps of buildings, etc.) between the transmitter and receiver. However small-scale fading exhibits rapid changes in signal amplitude and phase as a result of small changes (as small as a half-wavelength) in the spatial separation between a receiver and transmitter. If the multiple reflective paths are large in number and there is a dominant non fading signal component, the envelope of the received signal is statistically described by a Rician pdf given as [2]

$$p_z(z) = z/b^2 \, exp\left[\frac{-(Z^2+S^2)}{2b^2}\right] I_0\left[\frac{zs}{b^2}\right], z \geq 0 \quad \text{------ (2)}$$

Where z is the envelope amplitude of the received signal, $2b^2$ is the average power in the non LOS multipath components, s^2 is the power in the LOS component and I_0 is the modified Bessel function of the first kind and zeroth order. In case of Rayleigh fading power in the LOS component (s^2) is equal to 0. In the present work we separately consider the two cases of multipath Rician fading and Rayleigh fading in addition to path loss and thermal noise.

Assuming that each destination is equally likely, the average number of hops on a route can be written as [4]

$$n_{hop} \cong \sqrt{n}/2 \quad \text{----- (3)}$$

The received signal at the receiver is the sum of three components (i) the intended signal from the transmitter, (ii) interfering signals from other active nodes and (iii) thermal noise. Since the interfering signals come from other nodes, we assume that total interfering signal can be treated as an additive noise process independent of thermal noise process. The received signal, Y at the receiving node during each bit period can be expressed as [4]

$$Y = hS_{rcv} + \sum_{i=1}^{N-2} S_j + n_{thermal} \quad ----(4)$$

Where h is the fading channel coefficient with respect to the receiving antenna, S_{rcv} is the desired signal in the receiving antenna considering only path loss, S_j is the interference from the other nodes and $n_{thermal}$ is the thermal noise signal. It is assumed that interference signal undergoes similar kind of fading as intended signal.

Next we derive the energy spent in successfully transmitting a data packet considering three different retransmission schemes between a pair of source and destination nodes. Fig. 2 shows three different packet delivery mechanisms.

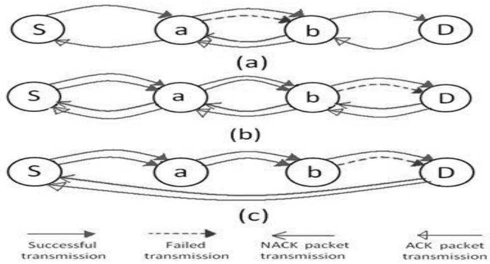

Fig. 2: Different Information Delivery Mechanisms

Scheme I is based on hop-by-hop retransmission, as shown in Fig.2a following [13], where at every hop the receiver checks the correctness of the packet and requests for a retransmission with a NACK packet to previous node until a correct packet is received. ACK packet is sent to the transmitter indicating a successful transmission. Thus every data packet is corrected in each hop.

Scheme II is based on multi-hop delivery with intermediate nodes, performing as digital repeaters [14] as shown in Fig.2b. The packet is checked only at destination for correctness; retransmissions are requested to source, with a NACK coming back from destination to source via intermediate nodes through multi-hop path.

It is assumed that each packet consists of header, message and trailer as shown in Fig. 3. So, transmitted packet length can be expressed as [15],

$$l_{pkt} = l_h + l_m + l_t \qquad ------ (5)$$

Fig. 3. Simple Structure of a Packet

where l_h, l_m and l_t are the header length, message length and trailer length respectively. So, the energy required to transmit a single packet is

$$E_t = \frac{P_t\, L_{pkt}}{R_{bit}} \qquad ------ (6)$$

With the above energy model, we evaluate the energy requirement for three different information delivery mechanisms as mentioned above to communicate a data packet from source to destination node until it is received successfully.

Scheme I:

Average probability of error at packet level at each hop is expressed as [16]

$$PER_{link} = 1 - (1 - BER)L_{pkt\ link} \text{ — } (7)$$

where, BER_{link} is the link BER. The effect of fading is incorporated in BER. The probability of "n" retransmissions is the product of failure in the (n-1) transmissions and the probability of success at the n^{th} transmission:

$$P_I[n] = (1 - PER_{link})(PER_{link})^{n-1} \qquad (8)$$

The energy consumed per packet at the end of n_{hop} number of hops is considered as the energy spent in forward transmission of information and reverse transmission for NACK/ACK is

$$E_t = \frac{1.75 \text{ x } (1 + R_I) \text{x } \overline{n_{hop}}}{R_{bit}} [P(l_h + l_m) + Pl_t] \qquad \text{-------- } (9)$$

Scheme II:

Average probability of error at packet level at the end of multihop route is given as

$$PER_{route} = 1 - (1 - PER)_{link} \quad --- (10)$$

The energy consumed per packet at the end of n_{hop} number of hops is given by

$$E_{II} = \frac{1.75 \text{ x } (1 + R_{II}) \text{x } \overline{n}_{hop}}{R_{bit}} [P(l_h + l_m) + Pl_t] \qquad \text{-------- } (10)$$

3. SIMULATION MODEL

We now present our simulation model developed in MATLAB to evaluate the performance of three different information delivery mechanisms in fading channel:

- Digital data 1 and 0 with equal probability is generated at base band. Our transmitted signal is +1 or -1 corresponding to data 1 or 0.
- Fading channel coefficients are generated following Rayleigh or Rician distribution depending on the case of investigation.
- Active interfering nodes are identified using Binomial distributed random variables for node activity.
- Interference from such active interfering nodes are generated assuming interference undergoes similar kind of fading as signal.
- The desired message signal is affected by multipath fading, thermal noise and interference from other nodes. The signal received by the receiving antenna in destination node is generated following eqn. (4).
- The received signal Y as given in eqn. (4) is then detected considering the threshold level at 0. If the received signal is greater than the threshold level 0 then it is detected as 1. Otherwise it is detected as 0.
- Each received bit is then compared with the transmitted bits. If there is mismatch an error counter is incremented. Now dividing the error count by the total number of transmitted bits, link BERs is obtained.

4. RESULTS AND DISCUSSION

Table 1 shows the important network parameters used in the simulation study.

Table 1. Network Parameters Used in the Simulation

Parameter	Values
Path loss exponent (γ)	2
Number of nodes in the network (N)	289
Node spatial Density (ρ_{sq})	$10^{-9} - 10^{-1}$
Packet arrival rate at each node (λ_t)	0.5 pck/s
Career frequency (f_c)	2.4 GHz
Noise figure (F)	6 dB
Room Temperature (T_0)	300k
Transmission Power (P_t)	10 mW, 100 mW
Receiver Sensitivity (S_i)	-60 dBm
Rician Factor (K)	0, 3 and 10

Table 2 shows the symbols used in the literature

Table 2. List of Symbols

Symbol	Details
K	Rician factor
PERlink	Link PER
BERlink	Link BER
PERlink	Route PER
R_I, R_{II}	Average number of retransmissions for scheme I, II
PtI, P_{tII}	Reverse link transmit power to send ACK/NACK packet for scheme I, II
E_I, E_{II}	Energy consumption of scheme I, II
η	Energy efficiency
davg	Average distance between source and destination
Emin	Minimum energy required to communicate a packet

Fig. 4 shows the energy required to successfully deliver a file of size 10^6 bit using packet of fixed size 100 bit in three different information delivery schemes. Energy consumption in multipath Rician fading is compared with that of path loss and Rayleigh fading case. It is seen that in presence of fading energy requirement increases [curve (ii, v)]. It is also observed that scheme I is the best retransmission scheme from energy consumption perspective [curve (ii, iii, vi)]. Further Scheme II consume nearly same amount of energy in high node density region [curve (ii, iii)]. However Scheme II performs better in low node spatial density region. For example, in Rician fading channel using fixed size packet of 100 bit, K=3 and $\rho_{sq} = 2.9\times10^{-4}$, required energy to transfer a file of size 10^6 bit is 22.7 mJ for Scheme II. Further energy spent to successfully deliver a file increases with increase in severity of multipath Rician fading [curve (iii, iv)]. This is because with increase in severity of fading the SNR degrades. This results in more number of retransmissions for successful delivery of a packet. Thus the energy spent to successfully transfer data increases.

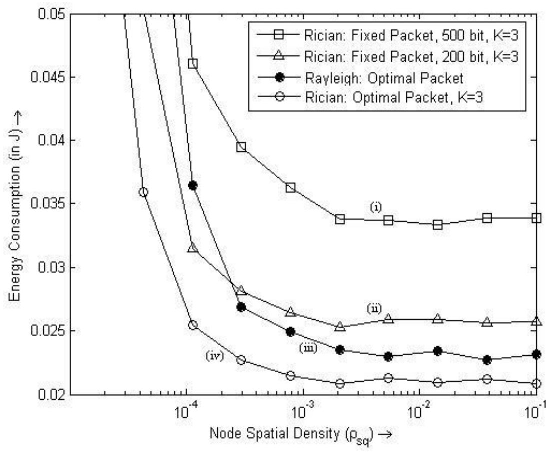

Fig. 4 Energy Consumption to Transfer a File Using Fixed Packet in Different Retransmission Schemes.

Fig. 5 shows the energy required to successfully deliver a file of size 10^6 bit with different packet sizes using Scheme II. Energy consumption for optimal packet based transmission scheme is compared with fixed packet size based transmission. Two different fixed packet sizes of 200 bit and 500 bit are used. In case of optimal packet based transmission, optimal packet size corresponding to the node density and other network condition has been used. It is seen that energy requirement increases with increase in packet size [curve (i, ii)]. Further use of optimal size packets reduces energy requirement significantly [curve (ii, iv)]. For a node density of 1.1×10^{-4} , required energy to transfer the file is 25.4 mJ using optimal size packet, while it increases to 46 mJ for fixed packet of size 500 bit

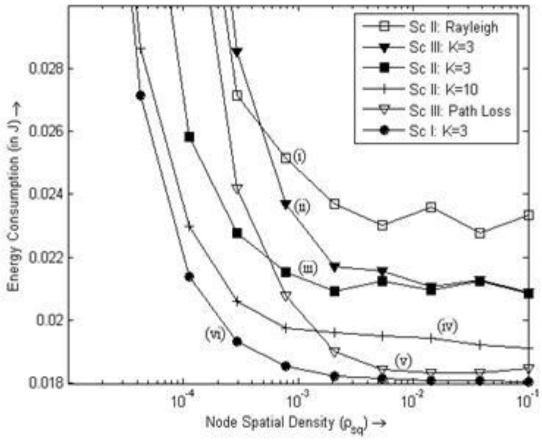

Fig. 5. Energy Consumption to Transfer a File in Scheme II using Fixed and optimal packet size.

5. CONCLUSION

In this paper we evaluated the energy level performance of three information delivery schemes in fading channel. A simulation test bed has been developed to assess the performance of such network in terms of energy consumption, energy efficiency and bit error rate. Energy consumption using three different information delivery schemes are studied and compared. It is seen that Scheme I performs better than the other two schemes. Energy consumption increases in presence of fading. It is also seen that Scheme I provides highest energy efficiency as compared to other schemes. An optimum packet length, which maximizes energy efficiency, is also derived. It is observed that scheme I yields highest size of optimum packet compared to other two schemes. It is also seen that optimal packet length decreases with increase in severity of fading. Decoding and retransmission for error correction at every node in multi-hop path seems to be more energy efficient compared to other mechanisms. The analysis is useful in designing energy efficient Wireless Sensor Networks. Further use of optimal size packets shows a significant reduction in energy consumption. Thus Scheme I and use of optimal size packets enhance network lifetime significantly.

REFERENCES

[1] Akyidiz I. F., Weilian Su, Y. Sankarasubramaniam, E. Cayirci, "A survey on sensor networks", IEEE Communication Magazine, Vol 40, Issue 8, pp 102–114, 2002.

[2] Goldsmith A., Wireless Communications, Cambridge University Press, 2005.

[3] Sklar B., "Rayleigh Fading Channels in Mobile Digital Communication Systems Part I: Characterization," IEEE Communication Magazine, pp. 90-100, July 2003.

[4] Panichpapiboon S., Ferrari G.,and Tonguz O. K., "Optimal Transmit Power in Wireless Sensor Networks" IEEE Transaction on Mobile Computing, Vol. 5, No. 10, October 2006, pp. 1432-1447.

[5] Bettstetter C. and Zangl J., "How to Achieve a Connected Ad Hoc Network with Homogeneous Range Assignment: An Analytical Study with Consideration of Border Effects," Proc. IEEE Int"l Workshop Mobile and Wireless Comm. Network, pp. 125-129, Sept. 2002.

[6] Tseng C. C. and Chen K. C., "Power Efficient Topology Control in Wireless Ad Hoc Networks," Proc. IEEE Wireless Comm. and Networking Conf. (WCNC), vol. 1, pp. 610-615, Mar. 2004.

[7] Davarian F., "Fade margin calculation for channels impaired by Rician fading", IEEE Transactions on Vehicular Technology, Vol-34, Issue-1, pp 41-44, 1985.

[8] Nandi A. and Kundu S., "Evaluation of Optimal Transmit Power in Wireless Sensor Networks in Presence of Rayleigh Fading," ICTACT Journal on Communication Technology (IJCT), Vol 1, Issue 2, pp. 107-112, 2010.

[9] Narayanaswamy S., Kawadia V., Sreenivas R. S., and Kumar P. R., "Power Control in Ad-Hoc Networks: Theory, Architecture, Algorithm and Implementation of the COMPOW Protocol," Proc. European Wireless 2002 Next Generation Wireless Networks: Technologies, Protocols, Services, and Applications, pp. 156-162, Feb. 2002.

[10] Dai Q. and Wu J., "Computation of Minimal Uniform Transmission Power in Ad Hoc Wireless Networks," Proc. IEEE Int"l Conf. Distributed Computing Systems Workshops (ICDCS), pp. 680-684, May 2003.

[11] Perkins C. E., Ad Hoc Networking, Addison-Wesley, 2001.

[12] Ferrari G. and Tonguz O. K., "Performance of Ad Hoc Wireless Networks with Aloha and PR-CSMA MAC Protocols", Proc. IEEE Global Telecomm. Conf. (GLOBECOM), pp. 2824-2829, Dec 2003.

[13] She H., Lu Z., Jantsch A., Zhou D. and Zheng L-R., "Analytical Evaluation of Retransmission Schemes In Wireless Sensor Networks", Proc. of the IEEE 69th Vehicular Technology Conference, Barcelona, Spain, pp. 1-5, April 2009.

[14] Taddia C. and Mazzini G., "On the Retransmission Methods in Wireless Sensor Networks", IEEE VTC Fall 2004, pp. 4573-4577, 26-29 September, Los Angeles.

[15] Sankarasubramaniam Y., Akyildiz I. F., and Mclaughlin S. W., "Energy efficiency based packet size optimization in wireless sensor networks", Proceedings of the First IEEE International Workshop on Sensor Network Protocols and Applications 2003, pp 1-8, 2003.

[16] Kleinschmidt J. H., Borelli W. C., and Pellenz M. E., "An Analytical Model for Energy Efficiency of Error Control Schemes in Sensor Networks", ICC '07. IEEE International Conference on Communications 2007, pp. 3895 - 3900, 24-28 June 2007.

[17] Nandi A. and Kundu S., " Energy Level Performance of Packet Delivery Schemes in Wireless Sensor Networks in Shadowed Channel," Sensors & Transducers Journal (S & T), Vol 118, Issue 7, pp. 73-86, 2010.