

On Energy Level Performance of Adaptive Power Based WSN in Presence of Fading

Arnab Nandi¹ and Sumit Kundu²

Department of ECE

¹*National Institute of Technology, Arunachal Pradesh, India*

²*National Institute of Technology, Durgapur, India*

nandi_arnab@yahoo.co.in and sumitkundu@yahoo.com

Abstract

We propose an adaptive power based transmission scheme for WSN (Wireless Sensor Networks) where transmit power is adapted depending on node density and channel conditions so as to maintain a desired level of signal detection probability at a receiving node as demanded by sensing range. In existing Fixed Transmit Power Scheme (FTPS), detection probability degrades with decrease in node spatial density leading to reduction in sensing range. We investigate the performance of the proposed Adaptive Transmit Power Scheme (ATPS) for a square grid WSN under multipath fading. Further energy consumption for an optimal packet length which yields highest energy efficiency is evaluated for both fixed and proposed adaptive power based schemes. Impact of node density, packet length and Rician fading on energy efficiency for both the ATPS and FTPS scheme is also shown.

Keywords: *Sensing Range; Wireless Sensor Networks (WSNs); Rician Fading; Optimal Packet Size; Detection Probability*

1. Introduction

The wireless communications revolution which is leading the convergence of all media and data services appears to be gaining wide acceptance. Wireless sensor networks consist of small battery powered devices with limited energy resources. Once deployed, the small sensor nodes are usually inaccessible to the user, and thus replacement of the energy source is not feasible. Hence, energy consumption is a key design issue that needs to be reduced in order to improve the life span of the network. Other important issues involved in sensor networks include node deployment, power management, and sensing range. In particular, sensing range is an important factor for a WSN, as it influences performance or quality of service offered by a sensor network. Most of the research work on WSN assumes idealized radio propagation models. However signal fading due to multipath propagation severely impairs the performance of wireless communication systems [1]. Hence, it important to evaluate the performance of WSN in multipath Rician fading channels. Rician fading captures a wide range of fading model. It represents Rayleigh fading when $K=0$, and no fading when $K \rightarrow \infty$, where K is the Rician factor defined as the power ratio of specular to diffused components [2]. In [3] Bettstetter et al. derived the transmission range for which network is connected with high probability considering free-space radio link model. In [4], Qian et al. proposed an adaptive transmit power scheme based on S-MAC named Adaptive Transmit Power MAC to reduce energy consumption in WSN. The proposed scheme calculates the distance between the sender and the receiver by measuring the received power, and then adaptively decides the appropriate transmit power level according to the propagation model and distance. In [5] the

impact of the shadowing effects on the sensing coverage is investigated. It shows that increase in standard deviation of the shadowing severely degrades the sensing coverage. In [6], performance of an adaptive power based scheme is evaluated in lognormal shadowed environment.

In an ideal scenario, the transmit power of a node should be modified on a link-by-link basis to achieve the maximum possible power savings [7-9]. However, in ad hoc network, performing power control on a link-by-link basis is a complicated and cumbersome task. A straightforward solution in the view of practical implementation is to use a common transmit power for all the nodes. This is very much desirable in inaccessible terrain where adjustment of the transmit power after deployment is impossible or very much costly. Moreover, the performance disparity, in terms of traffic carrying capacity, between adjusting the power locally and employing a common transmit power is small, especially when the number of nodes is large [10].

In this paper we propose an algorithm for adapting transmit power so as to maintain a given level of detection probability [5]. In FTPS (Fixed Transmit Power Scheme), a sensor node transmits at a fixed power level for any given node density. In this scheme detection probability degrades with decrease in node spatial density. This is caused due to increase in inter node distance with decrease in node spatial density. Further decrease in detection probability degrades sensing range and signal quality. Our proposed scheme of adapting transmit power to maintain a given level of detection probability overcomes this. The contributions of this paper are as follows: Energy level performances of fixed and the above proposed adaptive transmit power schemes (FTPS and ATPS) are evaluated in presence of multipath Rician fading. Transmit power for the proposed adaptive scheme is evaluated for several conditions of node spatial density, detection probabilities and severity of fading. Further energy requirement for successful delivery of a file based on an ARQ based scheme is evaluated and compared under several conditions of network such as node density, channel fading and detection probability for both fixed and adaptive power schemes. An optimal packet based transmission [7] which yields highest energy efficiency [11] is also considered in our proposed framework of adaptive power scheme. Energy expenditure corresponding to optimal packet length is also evaluated for both the schemes (i.e. FTPS and ATPS) and compared with an arbitrary fixed packet based transmission under same network conditions. Further, impact of fading and node density on energy efficiency and optimal packet length are discussed. Moreover, impact of severity of fading on energy efficiency and optimal packet length are also evaluated.

2. System Model

The sensing range depends on the signal propagation path. The received signal power S_r can be expressed as [1]

$$S_r(d_{link}) = \frac{\gamma S_t G_t G_r \lambda^2}{(4\pi)^2 d_{link}^\alpha} \quad (1)$$

where γ is the fading channel coefficient, S_t is the transmit power, G_t and G_r are the transmitting and receiving antenna gain respectively, α is the path-loss exponent, d_{link} is the distance between source and destination node (as shown in Fig. 1) and λ is the wavelength of the used transmitted signal. Here we consider omni directional ($G_t = G_r = 1$) antennas at the transmitter and receiver. The carrier frequency is in the unlicensed ISM band (2.4 GHz). The

parameter γ is introduced to represent the Rician fading effects in the propagation path, as well as the asymmetric property in the sensing ability. Transmission from a sensor node will be sensed by a receiving node when the received signal power is larger than the sensitivity (S_{sen}) of the receiving node. Therefore, the probability that the target location is detected by this node is [5]

$$P_D(d_{link}) = P(S_r(d_{link}) > S_{sen}) \quad (2)$$

where $P_D(d_{link})$ denotes the probability of detection of the signal at a distance d_{link} .

A square grid network architecture following [12] is considered in present work. Figure 1 shows a two tier sensor network using square grid topology. Distance between two nearest neighbor (d_{link}) is determined by the detection probability (P_{det}) and propagation environment. The node spatial density ρ_{sq} is given as [12].

$$\rho_{sq} = \frac{1}{d_{link}^2} \quad (3)$$

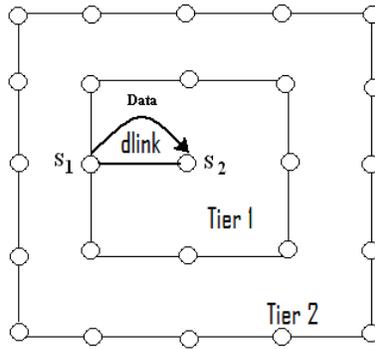


Figure 1. Sensor Nodes in Square Grid Topology; a Link Interconnecting Node S1 and S2 in one hop is shown

Here we assume a simple routing strategy such that a packet is relayed hop-by-hop, through a sequence of nearest neighboring nodes, until it reaches the destination [13]. Therefore, we assume that a route between source and destination exists. Infinite ARQ is considered between the pair of adjacent nodes. We would present a simulation model in Section III to assess the performance of the above network in presence of multipath fading. The necessary mathematical framework useful for simulation is presented below:

Here we consider a simple reservation-based MAC protocol, called reserve-and-go (RESGO) following [14]. In this protocol, a source node first reserves intermediate nodes on a route for relaying its packets to the destination. A transmission can begin only after a route is discovered and reserved. If the destination node is busy, it waits for an exponential random back-off time before transmitting or relaying each packet. When the random back-off time expires, node starts transmitting a packet. The random back-off time helps to reduce interference among nodes in the same route and also among nodes in different routes. Throughout this paper, we assume that the random back-off time is exponential with mean $1/\lambda_t$, where λ_t is the packet transmission rate.

The major perturbations in wireless transmission are large scale fading and small scale fading [1, 15]. 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 [15]

$$p_z(z) = z/\sigma^2 \exp\left[-\frac{(z^2 + s^2)}{2\sigma^2}\right] I_0\left(\frac{zs}{\sigma^2}\right), \quad z \geq 0 \quad (4)$$

where z is the envelope amplitude of the received signal, $2\sigma^2$ 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 0th order. In the present work we consider the multipath Rician 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 expressed as [12]

$$\bar{n}_{hop} \cong \sqrt{N}/2 \quad (5)$$

where N is the number of nodes present in the network under consideration.

The received signal at the receiver is the sum of three components (i) the intended signal from a 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 in terms of amplitude, $Y(d_{link})$ during each bit period can be expressed as [16, 12]

$$Y(d_{link}) = V_s(d_{link}) + \sum_{j=1}^{N-2} v_j + n_{thermal} \quad (6)$$

where $V_s(d_{link})$ is the desired signal at a distance of d_{link} in presence of Rician fading, v_j is the interference from the other nodes and $n_{thermal}$ is the thermal noise signal. We also assume that interference from other active nodes (i.e., v_j) undergo similar multipath fading as the desired signal.

Assuming BPSK modulation, there can be two cases for the amplitude of the $V_s(d_{link})$

$$V_s(d_{link}) = \begin{cases} \sqrt{\frac{S_r(d_{link})}{R_{bit}}} = \sqrt{E_{bit}(d_{link})} & \text{for } +1 \text{ transmission} \\ -\sqrt{\frac{S_r(d_{link})}{R_{bit}}} = -\sqrt{E_{bit}(d_{link})} & \text{for } -1 \text{ transmission} \end{cases} \quad (7)$$

where R_{bit} is the bit rate and $E_{bit}(d_{link})$ is the bit energy of the received signal in presence of Rician fading at a distance of d_{link} .

For each interfering node j , the amplitude of the interfering signal can be of three types with different probabilities [12]:

$$v_j = \begin{cases} \sqrt{\frac{S_{int_j}}{R_{bit}}} & \text{for } +1 \text{ transmission with probability } \frac{1}{2}P_{trans} \\ -\sqrt{\frac{S_{int_j}}{R_{bit}}} & \text{for } -1 \text{ transmission with probability } \frac{1}{2}P_{trans} \\ 0 & \text{for no transmission with probability } (1-P_{trans}) \end{cases} \quad (8)$$

where S_{int_j} is the interference power received from node j ; and P_{trans} is the transmission probability [14]. The probability that an interfering node will transmit and cause interference depends on the MAC protocol used. Size of the interference vector \bar{v}_j increases as the number of nodes increases in the network. The vector \bar{v}_j is defined as: $\bar{V}_j = \{v_j\}_{j=1,2,\dots,(N-2)} = \{v_1, v_2, \dots, v_{N-2}\}$, where v_j (as given in eqn. (8)) is the amplitude of the signal received at the receiver from an interfering node j .

The received thermal noise signal is simply

$$n_{thermal} = \sqrt{FkT_0B} \quad (9)$$

where F is the noise figure, $k=1.38 \times 10^{-23}$ J/K is the Boltzmann's constant, T_0 is the room temperature and B is the transmission bandwidth.

Next we derive the energy spent in successfully transmitting a data packet considering a simple Automatic Repeat Request (ARQ) schemes between a pair of source and destination nodes via intermediate nodes. Fig. 2 shows the used ARQ scheme.

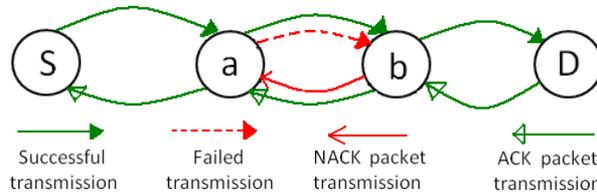


Figure 2. Different Information Delivery Mechanisms

The ARQ scheme is based on hop-by-hop retransmission, as shown in Figure 2 following [16], 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.

It is assumed that each packet consists of header, message and trailer as shown in Figure 3. So, transmitted packet length can be expressed as [11],

$$L_{pkt} = l_h + l_m + l_t \quad (10)$$



Figure 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

$$E_{packet} = \frac{P_t(l_h + l_m + l_t + l_{ack})}{R_{bit}} \times 1.75 + E_d + E_{st} \quad (11)$$

where E_d is the decoding energy to decode a single packet; E_{st} is the startup energy consumed in the transmitter and receiver; and l_{ack} is the acknowledge frame length. For RFM-TR1000 transceiver that has been incorporated in MICS Mote startup energy is assumed to be 24.86 μ J [17]. Since Forward Error Correction (FEC) technique is not used here, decoding energy and trailer length both are assumed zero [11]. Here it is assumed that 75% of the transmit energy is required to receive a packet.

The minimum energy required to communicate a packet at the destination is the energy required to transmit and receive the message bits (l_m) only. Thus minimum energy is given as:

$$E_{min} = \frac{P_t l_m}{R_{bit}} \times 1.75 \times \bar{n}_{hop} \quad (12)$$

Now we consider the energy requirement for ARQ scheme as mentioned above to communicate a data packet from source to destination node until it is received successfully.

Average probability of error at packet level at each hop is expressed as [1]

$$PER_{link} = 1 - (1 - BER_{link})^{L_{pkt}} \quad (13)$$

where, BER_{link} is the link BER. The effect of propagation path is incorporated in BER_{link} . The probability of 'n' retransmissions is the product of failure in the (n-1) transmissions and the probability of success at the nth transmission [18]:

$$P_I[n] = (1 - PER_{link})(PER_{link})^{n-1} \quad (14)$$

Average number of retransmissions for an infinite ARQ scheme is given by,

$$R_I = \sum_{n=1}^{\infty} P_I[n], n = \frac{PER_{link}}{(1 - PER_{link})} \quad (15)$$

We consider only path loss in reverse link. Further we assume that ACK/NACK from receiving node is instantaneous and error free.

The energy consumed per packet at the end of \bar{n}_{hop} number of hops is considered as the energy spent in forward transmission of information and reverse transmission for NACK/ACK as in [16]

$$E_I = \left[\frac{1.75 P_t}{R_{bit}} (l_h + l_m + l_{ack}) + E_{st} \right] (1 + R_I) \bar{n}_{hop} \quad (16)$$

Now the energy efficiency (η) of the scheme can be expressed as [11]:

$$\begin{aligned} \eta &= \frac{E_{min}}{\text{Energy Required for that Scheme}} \\ &= \frac{\frac{P_t l_m}{R_{bit}} \times 1.75}{\left[\frac{1.75 P_t}{R_{bit}} (l_h + l_m + l_{ack}) + E_{st} \right]} \times \frac{1}{(1 + R_I)} \\ &= U \times (1 - BER_{link})^{l_h + l_m + l_{ack}} \end{aligned} \quad (17)$$

Our aim is to maximize η with respect to the message length l_m to reduce the energy consumption. It is seen that there exists a unique maximum value of η for a given message length [11]. The corresponding optimal packet length is obtained by setting $\frac{d\eta}{dl_m} = 0$, in (17).

After solving, we obtain

$$L_{opt} = \frac{\sqrt{\left(l_h + l_{ack} + \frac{E_{st}R_{bit}}{1.75P_t}\right)^2 - \frac{4\left(l_h + l_{ack} + \frac{E_{st}R_{bit}}{1.75P_t}\right)}{\ln(1-BER_{link})} - \left(l_h + l_{ack} + \frac{E_{st}R_{bit}}{1.75P_t}\right)}}{2} \quad (18)$$

In practice L_{opt} is rounded off to the nearest integer.

Next we discuss the simulation model developed for evaluating the performance of above discussed network in the presence of multipath fading. We develop a simulation test bed to evaluate the optimal transmit power, optimal packet length, energy efficiency, energy consumption for successful packet transmission using Matlab[®].

3. Simulation Model

We now present our simulation model developed in MATLAB to evaluate the performance of fixed and adaptive transmit power schemes in multipath fading environment:

- At first digital data 1 and 0 with equal probability is generated for BPSK modulation.
- The detection probability is evaluated using eqn. (2).
- In adaptive transmit power scheme, transmit power is increased gradually from a small value to a high value. The minimum transmit power which satisfies the predefined detection probability is the transmit power corresponding to that node density and network condition.
- The desired message signal is affected by multipath Rician fading, thermal noise and interference from other nodes. The signal received by the receiving antenna in destination node is generated following eqn. (6).
- Rician random variables (r.v.) for different values of K are generated.
- The received signal $Y(d_{link})$ as given in eqn. (6) is then detected considering the threshold level at 0.
- Each received bit is then compared with the transmitted bits. Now dividing the error count by the total number of transmitted bits, link BERs are obtained.
- The energy consumption for the two schemes is evaluated using eqn. (16).

4. Results and Discussion

In this section, we present a performance analysis of different network parameters to present a comprehensive overview. The simulation parameters are listed in Table 1. All the simulations are performed at a confidence level of 95% using Matlab.

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)	1 pck/s
Career frequency (f_c)	2.4 GHz
Noise figure (F)	6 dB
Room Temperature (T_0)	300° K
Transmission Power (P_{Tx})	10 mW
Receiver Sensitivity (S_i)	-100 dBm
Rician Factor (K)	0, 2 and 10

Figure 4 shows the detection probability (P_d) of the signal at the receiving node for the two schemes: (i) FTPS and (ii) ATPS. It is seen that in FTPS detection probability gradually increases from 0 to 1 with increase in node spatial density. Thus for low node density P_d may be very low leading to significant reduction in sensing range and link failure due to loss of internode connectivity. However in our proposed ATPS detection probability remains at a predetermined fixed level (say 0.8 in present case) as transmit power is adapted with respect to change in node density and channel condition. It is also seen that detection probability degrades as severity of Rician fading increases (i.e., decrease of K factor) in FTPS.

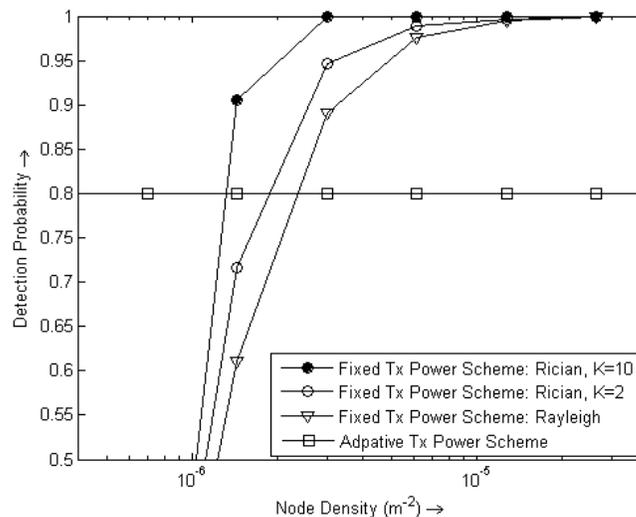


Figure 4. Detection Probability as a function of Node Spatial Density

Figure 5 shows the required transmit power for ATPS to keep the detection probability at a chosen fixed level in the receiving node in presence of multipath Rician fading. It is seen that required transmit power decreases with increases in node spatial density. Required transmit power increases in presence of fading. It is also seen that transmit power increases as severity of fading increases. Further high transmit power is required to maintain higher P_D in case of ATPS. At a node density of 2.1×10^{-6} , a transmit power of 0.79 mW is required to maintain a detection probability of 0.8. However, it increases to 1.5 mW to meet a detection probability of 0.95.

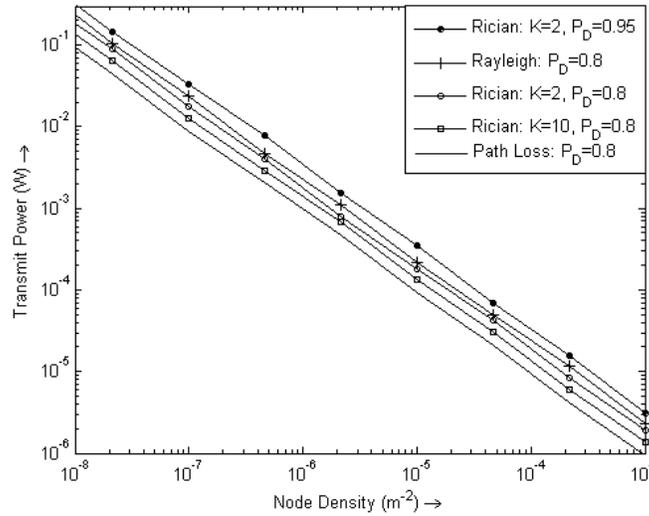


Figure 5. Transmit Power as a Function of Node Spatial Density

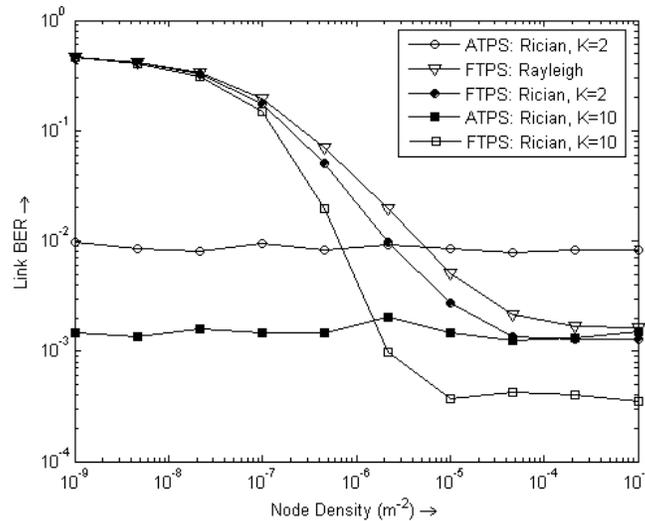


Figure 6. BER link as a Function of Node Spatial Density; bit rate= 1Mbps; $P_D=0.9$.

Figure 6 shows the link BER performance for the two schemes. It is seen that in case of fixed transmit power scheme, link BER performance improves with increase in node spatial density. However in ATPS, link BER performance remains at a fixed level. Further link BER performance of adaptive transmit power scheme is significantly improved as compared to the fixed transmit power scheme in low node spatial density region. However, BER performance of adaptive transmit scheme is poor as compared to fixed transmit power scheme in high node spatial density region. It is also observed that BER performance degrades with increase in severity of Rician fading. In case of FTSP and at a node density of 10^{-5} , link BER is 3.7×10^{-4} for a Rician coefficient $K=10$ while it degrades to 2.7×10^{-3} for $K=2$.

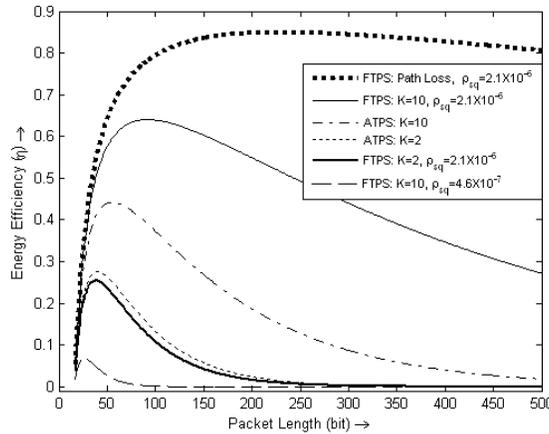


Figure 7. Efficiency as a Function of Packet Length for ATPS and FTPS

Figure 7 shows the energy efficiency as a function of packet length for both the schemes (i.e. ATPS and FTPS). It is seen that there exists a peak value of efficiency for a given packet size. The message length corresponding to maximum efficiency is the optimal packet size from energy efficiency perspective [11]. Thus there exists an optimal packet size for a particular network condition. It is also seen that optimal packet length decreases with increase in severity of multipath Rician fading. Further energy efficiency shows a steep drop for message lengths smaller than the optimal length. This behavior can be attributed to the higher overhead and start-up energy consumption of smaller packets [11]. On the other hand, for message length larger than the optimal length, the drop in energy efficiency is much slower due to increase in average retransmission. With the increase of packet length the vulnerable interval increases and the probability of transmission of an interfering node becomes high. Energy efficiency degrades in presence of multipath fading. It is also seen that energy efficiency degrades with increase in severity of fading. Further, in case of FTPS, energy efficiency improves with increase in node spatial density. However, in case of ATPS, energy efficiency is independent of node density (i.e., in case of ATPS, we get same energy efficiency curve for two different node density 4.6×10^{-7} and 2.1×10^{-6} when other conditions are same). In FTPS, optimal packet length increases with increase in node spatial density.

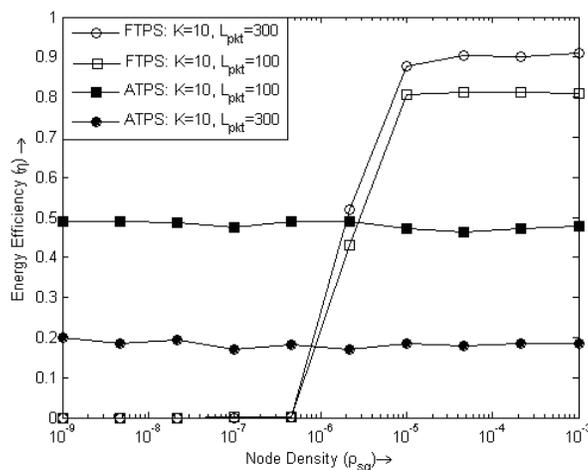


Figure 8. Energy Efficiency as a Function of Node Density for ATPS and FTPS; $P_D=0.9$.

Figure 8 shows the energy efficiency of ATPS and FTPS scheme as a function of node spatial density for several sizes of packet. It is seen that, in high node density region FTPS is more energy efficient than ATPS scheme. However in moderate and low node density region ATPS outperforms FTPS in terms of energy efficiency. It is also seen that energy efficiencies in FTPS scheme improve with increase in node spatial density. However beyond a certain node density the efficiency does not change with further increase in node density. This occurs as there is no improvement in SINR beyond a certain limit. However in case of ATPS energy efficiency remains at a constant level throughout the entire region. In FTPS, energy efficiency degrades with decrease in packet size while in ATPS, energy efficiency improves with decrease in packet size.

Figure 9 shows the energy required to successfully deliver a file of size 10^6 using fixed and optimum size [16] packets in ATPS and FTPS. Optimum size packet is that length of packet which yields highest energy efficiency [16, 11] as explained in Fig. 7. It is seen that transmission using optimum size packets consumes less energy than that of fixed packet based transmission over a wide range of node density which may be region of interest. Further, use of optimum size packet in ATPS consumes less energy as compared to that of FTPS over wide range of node densities. In case of ATPS, energy requirement increases with decreases in packet length. Further, optimum packet based ATPS requires significantly less energy than ATPS using a fixed size packet. For example, at a node density of 10^{-5} , optimum packet based ATPS consumes 18% less energy than ATPS using fixed packet of size 200 bit.

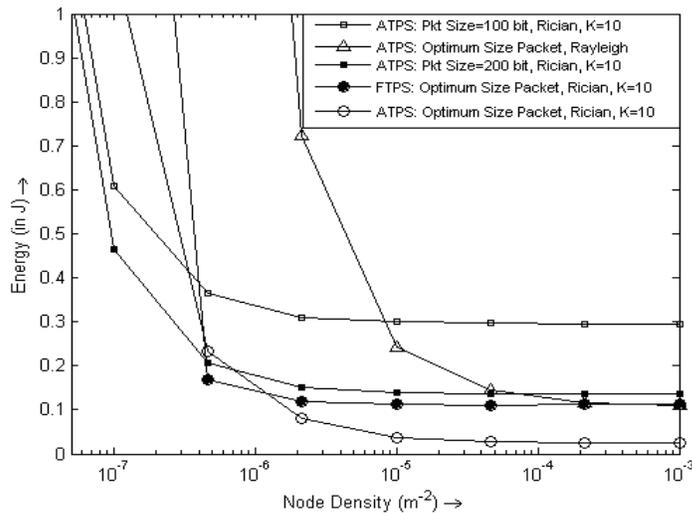


Figure 9. Energy Consumption as a Function of Node Spatial Density

5. Conclusion

In this article, we have compared the energy level performance of fixed and a proposed adaptive transmit power schemes (FTPS and ATPS) in presence of Rician fading for a square grid WSN. Performance of such network is analyzed in terms of detection probability and energy consumption. In ATPS, transmit power is varied according to node density and channel condition so as to keep the detection probability at a fixed level. However in case of FTPS, detection probability decreases with decrease in node spatial density. Further an

optimum packet length based transmission is studied. It is seen that ATPS consumes less energy than FTPS in moderate and high node spatial density region (i.e. region of interest from operational point of view) to successfully deliver a file. Transmission exploiting optimum size packets consumes less energy in moderate and high node spatial density region compared to that of an arbitrary fixed packet size based transmission in ATPS. Thus simultaneous use of optimal size packets and ATPS shows a significant reduction in energy consumption. Further, in high node density region FTPS is more energy efficient than that of ATPS scheme. However in moderate and low node density region ATPS outperforms FTPS in terms of energy efficiency. Our results are significant in designing energy efficient WSN in presence of fading.

References

- [1] A. Goldsmith, *Wireless Communications*, Cambridge University Press, (2005).
- [2] F. Davarian, "Fade margin calculation for channels impaired by Rician fading", *IEEE Transactions on Vehicular Technology*, vol. 34, Issue 1, pp. 41-44, (1985).
- [3] C. Bettstetter and J. Zangl, "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, (2002) September.
- [4] H. Qian and T. Zhenzhou, "An adaptive transmit power scheme for wireless sensor networks," 2010 *Proc. 3rd IEEE International Conference on Ubi-media Computing (U-Media)*, pp. 12-16, (2010) July.
- [5] Yuh-Ren Tsai, "Sensing Coverage for Randomly Distributed Wireless Sensor Networks in Shadowed Environments," *IEEE Transactions on Vehicular Technology*, vol. 57, Issue 1, pp. 556-564, (2008).
- [6] A. Nandi and S. Kundu, "On Energy Level Performance of Adaptive Power Based WSN in Shadowed Channel," *Proc. IEEE Interference Conference on Devices and Communication (ICDeCom 2011)*, pp. 1-5, (2011) February 24-25.
- [7] S. Agarwal, R. Katz, S. V. Krishnamurthy and S. K. Dao, "Distributed Power Control in Ad-Hoc Wireless Networks", *Proc. IEEE Int'l Symp. Personal, Indoor, and Mobile Radio Comm. (PIMRC)*, pp. F59-F66, (2001).
- [8] R. Ramanathan and R. Rosales-Hain, "Topology Control of Multihop Wireless Networks Using Transmit Power Adjustment", *Proc. IEEE Conf. Computer Comm. (INFOCOM)*, pp. 404-413, (2000).
- [9] T. Elbatt and A. Ephremides, "Joint Scheduling and Power Control for Wireless Ad Hoc Networks", *IEEE Trans. Wireless Comm.*, vol. 3, no. 1, pp. 74-85, (2004).
- [10] S. Narayanaswamy, V. Kawadia, R. S. Sreenivas and P. R. Kumar, "Power Control in Ad-Hoc Networks: Theory, Architecture, Algorithm and Implementation of the COMPOW Protocol", *Proc. European Wireless Next Generation Wireless Networks: Technologies, Protocols, Services, and Applications*, pp. 156-162, (2002).
- [11] Y. Sankarasubramaniam, I. F. Akyildiz and S. W. McLaughlin, "Energy efficiency based packet size optimization in wireless sensor networks", *Proc. First IEEE International Workshop on Sensor Network Protocols and Applications*, pp. 1-8, (2003).
- [12] S. Panichpapiboon, G. Ferrari and O. K. Tonguz, "Optimal Transmit Power in Wireless Sensor Networks", *IEEE Transaction on Mobile Computing*, vol. 5, no. 10, pp. 1432-1447, (2006).
- [13] C. E. Perkins, "Ad Hoc Networking", Addison-Wesley, (2001).
- [14] G. Ferrari and O. K. Tonguz, "Performance of Ad Hoc Wireless Networks with Aloha and PR-CSMA MAC Protocols", *Proc. IEEE Global Telecomm. Conf. (GLOBECOM)*, pp. 2824-2829, (2003) December.
- [15] Sklar, "Rayleigh Fading Channels in Mobile Digital Communication Systems Part I: Characterization," *IEEE Communication Magazine*, pp. 90-100, (2003) July.
- [16] A. Nandi and S. Kundu, "Energy Efficient Packet Data Service in Wireless Sensor Network in Presence of Rayleigh Fading", *International Journal of Grid and High Performance Computing (IJGHPC)*, vol. 3, Issue 3, pp. 31-44, (2011). DOI: 10.4018/jghpc.2011070103.
- [17] MICS Mote Datasheet. Crossbow Corp. [Online]. Available <http://xbow.com>
- [18] Kleinschmidt J.H., Borelli, W.C. and Pellenz, M.E, "An Analytical Model for Energy Efficiency of Error Control Schemes in Sensor Networks," *Proc. IEEE International Conference on Communications (ICC)*, pp. 3895 – 3900, (2007) June 24-28.

Authors



Arnab Nandi received his B. Tech degree from the Kalyani Govt. Engg. College, India, in 2003 and the M. Tech degree from University of Burdwan, India in 2005, all in Electronics and Communication Engineering (ECE). He is currently Assistant Professor in the ECE Department at National Institute of Technology, Arunachal Pradesh (NIT AP), India. Before joining NITAP he worked as Assistant Professor in ECE at Dr. B. C. Roy Engg. College (BCREC), Durgapur, India. Before joining BCREC, he worked as SRF in National Institute of Technology, Durgapur up to November 2011. Before that, he was with the ECE Department as Lecturer at Bankura Unnayani Institute of Engineering and University Institute of Technology since July 2005. His research interests include ad hoc wireless networks, Wireless sensor networks, cross layer issues and medium access control. He has published 19 research papers in various International Journals and Conferences. He is reviewer of several International Conferences.



Sumit Kundu received his B.E. (Hons.) degree in Electronics and Communication Engineering in 1991 from NIT, Durgapur, India and M.Tech. degree in Telecommunication Systems Engineering and Ph.D. in Wireless Communication Engineering from IIT Kharagpur, India, respectively. He has been a faculty in the department of ECE, National Institute of Technology, Durgapur since 1995 and is currently an Associate Professor there. His research interests include radio resource management in wireless networks, Wireless Ad Hoc and sensor networks, and Cognitive Radio Networks. As of today, he has published hundred (100) research papers in various journals and conferences. He is a member of IEEE (Communication Society) and is a reviewer of several IEEE journals.

