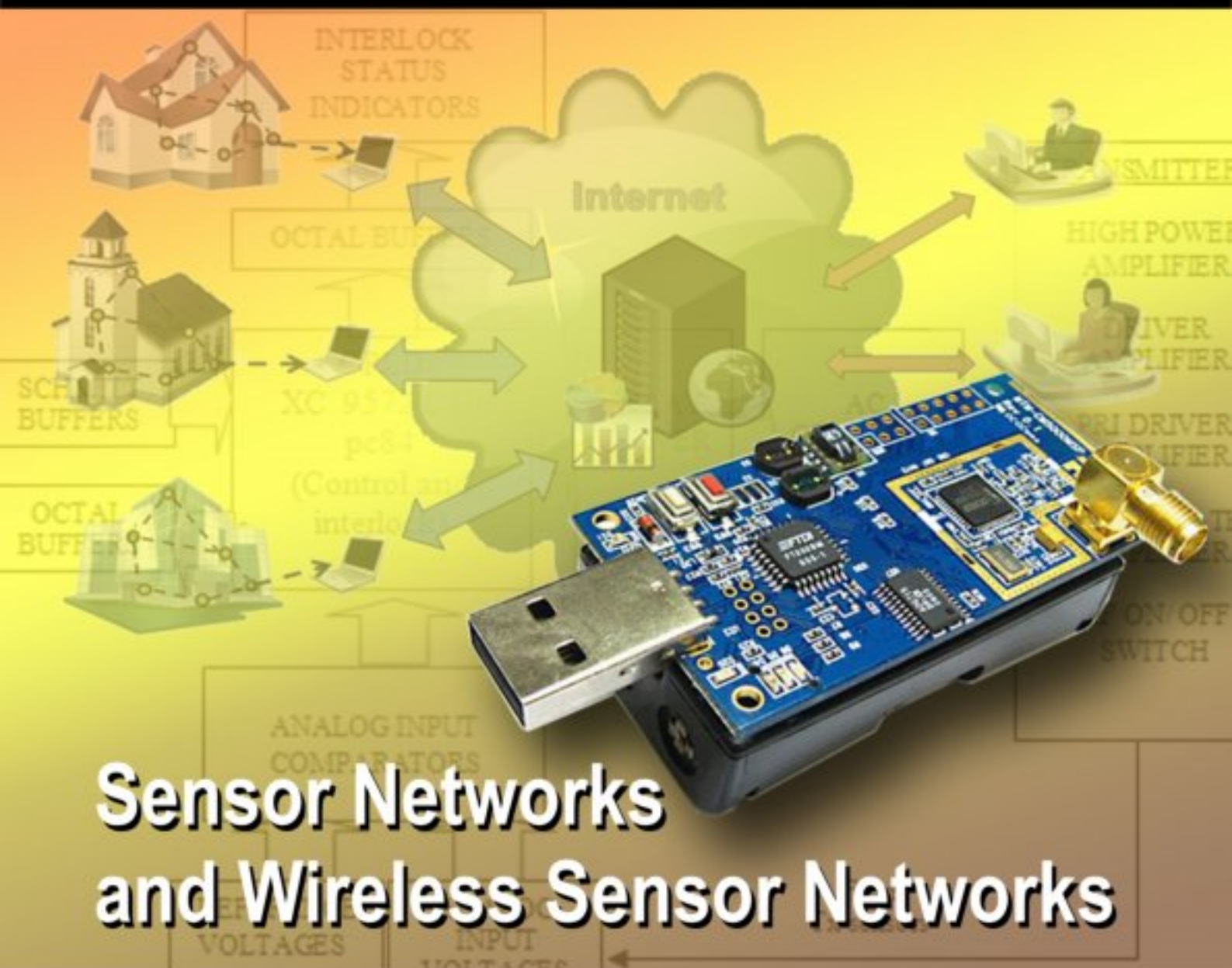


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Energy Level Performance of Packet Delivery Schemes in Wireless Sensor Networks in Shadowed Channel

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Abstract: This paper evaluates energy level performance of three packet delivery schemes in a Wireless Sensor Networks (WSN) in shadowed channel. Three different information delivery mechanisms are investigated using regenerative relays with or without error correction capability. Energy consumption for successful delivery of a data packet for each mechanism is evaluated and compared under several conditions of node density, bit rate, transmit power etc. Energy efficiency of different retransmission schemes is evaluated. Further an optimal packet length based on energy efficiency is derived. Impact of different level of severity of shadowing on energy consumption is also investigated. Further impact of fixed and optimal packet size on energy consumption is analyzed. *Copyright © 2010 IFSA.*

Keywords: Wireless sensor networks, BER; Shadowing, ARQ, Optimal packet size.

1. Introduction

Most of the research work on WSN assumes idealized radio propagation models without considering fading and shadowing effects. However network performance degrades due to shadowing and fading [1]. Relayed transmission is a promising technique that helps in attaining broader coverage and in combating the impairments of the wireless channel. Relaying information on several hops reduces the need of large transmitter power and distributes the use of power throughout the hops which results in extended battery life and lowered level of interference [2]. Energy conservation is one of the most important issues in WSN, where nodes are likely to rely on limited battery power. The connectivity of WSN mostly depends on the transmission power of the source nodes. If the transmission power is not

sufficiently high there may be single or multiple link failure. Further transmitting at high power reduces the battery life and introduces excessive inter node interference. Given that the sensors have limited energy, buffer space, and other resources, different MAC protocols are being developed by several researchers [3, 4]. Most of the previous research work in this field assumes free-space radio link model and Additive White Gaussian Noise (AWGN) [5-7]. However shadow fading impairs the performance of wireless link severely. Several approaches have been proposed in literature to prolong network lifetime. Sooksan et al. evaluated Bit Error Rate (BER) performance and optimal power to preserve the network connectivity considering only path-loss and thermal noise [5]. In [6] Bettstetter et al. derived the transmission range for which network is connected with high probability considering free-space radio link model. In [7] the relationships between transmission range, service area and network connectivity is studied in a free space model. Narayanaswamy et al. [8] proposed a protocol that extends battery life through providing low power routes in a medium with path loss exponent greater than two. In [9] a new method is proposed utilizing a diversity scheme to reduce power consumption in large scale sensor networks

In this paper energy level performance of three different information delivery mechanisms are considered in presence of shadowing. In all the three schemes, message packet is sent on hop-by-hop basis. Further in scheme I message is corrected 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 but in case III it propagates directly. Further we derived energy efficiency of those retransmission mechanisms. The energy requirement also depends on routing and the Medium Access Control (MAC) protocol used [10-11]. Energy requirement for successful delivery of a packet is evaluated under several conditions of network such as node density, severity of shadowing etc. Impact of shadowing on energy efficiency and energy spending are also investigated. Further impact of different level of severity of shadowing on energy expenditure is also studied. Optimal packet length which corresponds to highest energy efficiency is evaluated for each packet delivery scheme. Impact of shadowing on optimal packet is also investigated. Further impact of optimal size packet on energy consumption is analyzed.

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 of three different information delivery mechanisms in presence of shadowing. In Section III, we describe the simulation model developed. Section IV shows simulation results and discussions. Finally conclusions are drawn in Section V.

2. System Model

A square grid network architecture is considered as in [5]. Fig. 1 shows a two tier sensor network using square grid topology [5, 12].

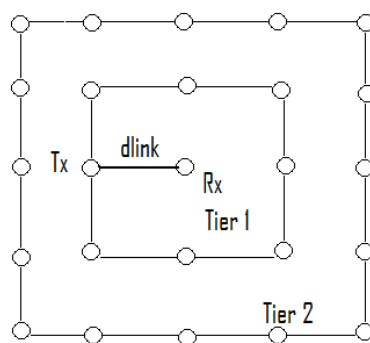


Fig. 1. Sensor nodes in square grid topology.

Distance between two nearest neighbor is d_{link} . It is assumed that N numbers of nodes are distributed over a region of area A obeying square grid topology. The node spatial density ρ_{sq} is defined as number of nodes per unit area i.e., $\rho_{sq} = N/A$. The minimum distance between two consecutive neighbors is given by [5]

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

When the node density increases, minimum distance between two nodes decreases following eqn. (1).

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 [10]. Therefore, we assume that a route between source and destination exists.

Further we consider a simple reservation-based MAC protocol, called reserve-and-go (RESGO) following [10-11]. In this protocol, a source node first reserves intermediate nodes on a route for relaying its packets to the destination. A transmission can begin 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 again. 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, 13]. 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. The receiver is often represented as being shadowed by such prominences. The statistics of large-scale fading provide a way of computing an estimate of path loss as a function of distance. This is described in terms of a mean path loss (nth-power law) and a log-normally distributed variation about the mean [10]. In the presence of shadowing, with a transmitter-receiver (T-R) separation of d , the path loss $PL(d)$ at a particular location is random and distributed log-normally about the mean distance dependent value of $\overline{PL}(d)$ [9]

$$PL(d)|_{dB} = \overline{PL}(d)|_{dB} + X_\sigma, \quad (2)$$

where X_σ denotes a zero mean, Gaussian random variable with standard deviation σ . Thus the received signal power can be expressed as

$$P_{sw}(d)|_{dBm} = G_t|_{dB} + G_r|_{dB} + P_t|_{dBm} - \left(\overline{PL}(d)|_{dB} + X_\sigma \right), \quad (3)$$

where P_{sw} is the received signal power in shadowed environment, P_t is the transmit power, G_t and G_r are the transmitting and receiving antenna gain respectively. Here we consider omni directional ($G_t=G_r=1$) antennas at the transmitter and receiver. The carrier frequency is in the unlicensed 2.4 GHz band.

It can be assumed without loss of generality that source node is at the center of the network. If a destination node is selected at random, the minimum number of hops to reach the destination can vary from 1 to $2i_{max}$, where i_{max} is the maximum tier order. Counting the number of hops on a route from the source to each destination node and finding the average value of it, we determine the average number

of hops. Assuming that each destination is equally likely, the average number of hops on a route can be written as [5]

$$\bar{n}_{hop} \cong \sqrt{N}/2 \quad (4)$$

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 the antenna, Y during each bit period can be expressed as [5]

$$Y = S_{sw} + \sum_{j=1}^{N-2} S_j + n_{thermal} \quad (5)$$

where S_{sw} is the desired signal in shadowed channel, S_j is the interference from the other nodes and $n_{thermal}$ is the thermal noise signal.

Assuming Binary Phase Shift Keying (BPSK) modulation, there can be two cases for the amplitude of the S_{sw}

$$\begin{aligned} S_{sw} &= \sqrt{\frac{P_{sw}}{R_{bit}}} = \sqrt{E_{bit}} \text{ for a } +1 \text{ transmission} \\ &= -\sqrt{\frac{P_{sw}}{R_{bit}}} = -\sqrt{E_{bit}} \text{ for a } -1 \text{ transmission} \end{aligned} \quad (6)$$

where R_{bit} is the bit rate and $\sqrt{E_{bit}}$ is the bit energy of the received signal in shadowed channel.

The interference power received from node j can be written using Frii's transmission equation [1]

$$P_{int j} = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_{link}^\alpha v_j^\alpha} \quad (7)$$

where v_j is the multiplicative factor depends on the position of the interfering node. It is observed that the significant part of the inter-node interference comes from the first two tires only. So we consider inter-node interference from first two tires only.

For each interfering node j, the amplitude of the interfering signal can be of three types [5]:

$$\begin{aligned} S_j &= \sqrt{\frac{P_{int j}}{R_{bit}}} \text{ for a } +1 \text{ transmission} \\ &= -\sqrt{\frac{P_{int j}}{R_{bit}}} \text{ for a } -1 \text{ transmission} \\ &= 0 \text{ for no transmission of node } j \end{aligned} \quad (8)$$

The probability that an interfering node will transmit and cause interference depends on the MAC protocol used. Considering the RESGO MAC protocol and assuming that each node transmits packets with length L_{pkt} , the interference probability is equal to the probability that an interfering node transmits during the vulnerable interval of duration L_{pkt}/R_{bit} . This probability can be written as [11]

$$P_{trans} = 1 - e^{-\frac{\lambda_t L_{pkt}}{R_{bit}}} \quad (9)$$

Thus S_j appears with different probabilities of transmission as given below

$$\begin{aligned} S_j &= \sqrt{\frac{P_{int j}}{R_{bit}}} \text{ with probability } \frac{1}{2} P_{trans} \\ &= -\sqrt{\frac{P_{int j}}{R_{bit}}} \text{ with probability } \frac{1}{2} P_{trans} \\ &= 0 \text{ with probability } (1 - P_{trans}) \end{aligned} \quad (10)$$

Size of the interference vector \bar{s}_j increases as the number of nodes increases in the network. The thermal noise power can be written as

$$P_{thermal} = FkT_0B, \quad (11)$$

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. The received thermal noise signal is simply

$$n_{thermal} = \sqrt{FkT_0B} \quad (12)$$

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.

Scheme I is based on hop-by-hop retransmission, as shown in Fig. 2a following [14], 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.

Scheme II is based on multi-hop delivery with intermediate nodes, performing as digital repeaters [15] 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.

Scheme III is based on multi-hop delivery with intermediate nodes, performing as digital repeaters [14] as shown in Fig. 2c. The packet is checked at the destination for correctness. However retransmissions are requested to source, with a NACK coming back to source directly from destination (without multi-hop).

It is assumed that each packet consists of header, message and trailer as shown in Fig. 3.

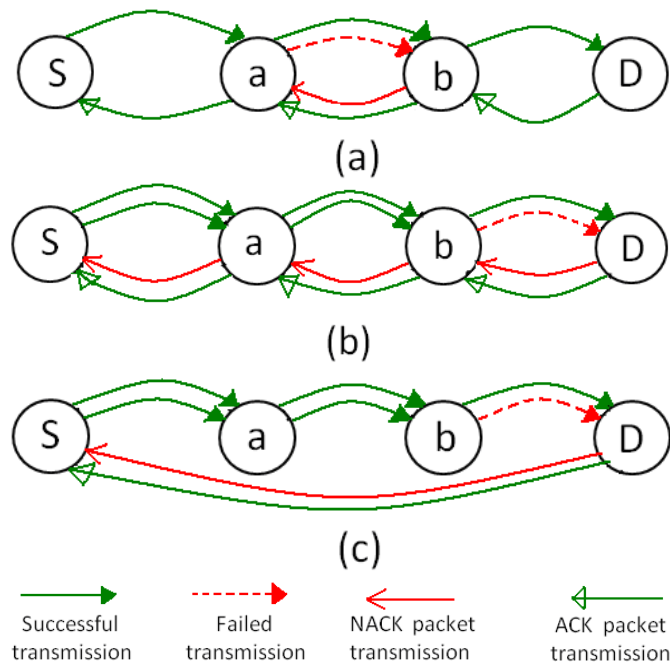


Fig. 2. Different Information Delivery Mechanisms.



Fig. 3. Simple structure of a packet.

So, transmitted packet length can be expressed as [16],

$$L_{pkt} = l_h + l_m + l_t, \quad (13)$$

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

$$E_t = \frac{P_t L_{pkt}}{R_{bit}} \quad (14)$$

Here it is assumed that 75% of the transmit energy is required to receive a packet [17]. So, energy required to communicate, i.e. transmit and receive a single packet is given by

$$E_{packet} = \frac{P_t (L_{pkt} + l_{ack})}{R_{bit}} \times 1.75 + E_d, \quad (15)$$

where E_d is the decoding energy to decode a single packet and l_{ack} is the acknowledge frame length. Since Forward Error Correction (FEC) technique is not used here, decoding energy and trailer length both are assumed zero [16]. Thus the energy to communicate a single packet is:

$$E_{packet} = \frac{P_t(l_h + l_m + l_{ack})}{R_{bit}} \times 1.75 \quad (16)$$

The minimum energy required to communicate a packet is the energy required to transmit and receive the message bits (l_m) only. Thus minimum energy is given by the following expression:

$$E_{min} = \frac{P_t l_m}{R_{bit}} \times 1.75 \quad (17)$$

Now we consider 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 [17]

$$PER_{link} = 1 - (1 - BER_{link})^{L_{pkt}}, \quad (18)$$

where, BER_{link} is the link BER in presence of shadowing. The effect of shadowing 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 nth transmission:

$$P_I[n] = (1 - PER_{link})(PER_{link})^{n-1} \quad (19)$$

Average number of retransmissions for scheme I, assuming an infinite ARQ

$$R_I = \sum_{n=1}^{\infty} P_I[n].n = \frac{PER_{link}}{(1 - PER_{link})} \quad (20)$$

We consider only path loss in reverse link. Further we assume that ACK/NACK from receiving node is instantaneous and error free. Considering receiver sensitivity S_i , the required transmit power for reverse link is given by [1]

$$P_{tl} = \frac{S_i (4\pi f)^2 d_{link}^2}{G_t G_r c^2} \quad (21)$$

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 [17]

$$E_I = \frac{1.75 \times (1 + R_I) \times \bar{n}_{hop}}{R_{bit}} [P_t (l_h + l_m) + P_{tl} l_{ack}] \quad (22)$$

Scheme II:

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

$$PER_{route} = 1 - (1 - PER_{link})^{\bar{n}_{hop}} \quad (23)$$

Average number of retransmissions for scheme II is given by

$$R_{II} = \sum_{n=1}^{\infty} P_{II}[n].n = \frac{PER_{route}}{(1 - PER_{route})}, \quad (24)$$

where $P_{II}[n]$ is the probability of n retransmissions considering Scheme II. The energy consumed per packet at the end of \bar{n}_{hop} number of hops is given by

$$E_{II} = \frac{1.75 \times (1 + R_{II}) \times \bar{n}_{hop}}{R_{bit}} [P_t(l_h + l_m) + P_{III}l_{ack}] \quad (25)$$

where P_{III} is the transmit power of reverse link and same as P_{II} .

Scheme III:

The energy consumed per packet at the end of \bar{n}_{hop} number of hops using Scheme III is given by

$$E_{III} = \frac{1.75 \times (1 + R_{III}) \times \bar{n}_{hop}}{R_{bit}} [P_t(l_h + l_m) + P_{III}l_{ack}], \quad (26)$$

where average number of retransmissions, R_{III} is same as R_{II} . Reverse link transmit power P_{III} is given as

$$P_{III} = \frac{S_i(4\pi f)^2 d_{avg}^2}{G_t G_r c^2}, \quad (27)$$

where d_{avg} is the average distance between source and destination.

Now the energy efficiency (η) of each scheme can be expressed as [17] :

$$\eta = \frac{E_{min}}{\text{Energy Required for that Scheme}} \quad (28)$$

3. Simulation Model

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

- At first digital data 1 and 0 with equal probability is generated for BPSK modulation. Our transmitted signal is +1 or -1 corresponding to data 1 or 0.
- The desired message signal is affected by lognormal shadowing, thermal noise and interference from other nodes. The signal received by the receiving antenna in destination node is generated following eqn. (5).

- Gaussian random variables (r.v.) with 0 mean and predefined standard deviation are generated. Corresponding to each Gaussian r.v. a lognormal r.v. is generated.
- The received signal Y as given in (5) 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.
- The energy efficiency for three information delivery mechanisms is evaluated using eqn. (28). The energy consumption of the three retransmission schemes is evaluated using eqn. (22), (25) and (26).

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_{sg})	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_{Tx})	10 mW, 100 mW
Receiver Sensitivity (S_i)	-60 dBm
Standard deviation shadowing (σ)	6 dB, 8 dB

Fig. 4 shows the link BER, denoted as BER_{link} for different values of node spatial density considering different bit rates, transmit power and severity of shadowing in a lognormal shadowed channel. It is observed that BER_{link} performance improves with the increase in node spatial density. However it is seen that beyond a certain node density the BER_{link} does not change with further increase in node spatial density and a floor in BER_{link} , as denoted by BER_{floor} appears. The desired signal power as well as the inter-node interference increases with increase in node density. As a result we obtain the BER_{floor} . This is expected because, increasing node spatial density beyond a certain limit no longer improves the signal to noise ratio (SNR), as the interfering nodes also become close enough to the receiver. It is seen that link BER performance degrades in presence of shadowing. Further link BER degrades with increase in severity of shadowing. It is also seen that BER_{link} performance degrades as bit rate decreases. This is due to increase in vulnerable interval with decrease in bit rate [5]. As a result, transmission probability of the interfering nodes increases. For a data rate of 10 Mbps, $P_t=10$ mW and node spatial density of 3.8×10^{-2} BER_{link} is 3.7×10^{-4} , while it increases to 1.8×10^{-3} for a bit rate of 2 Mbps. Further it is observed that BER floor appears earlier with increase in transmit power for a fixed bit rate.

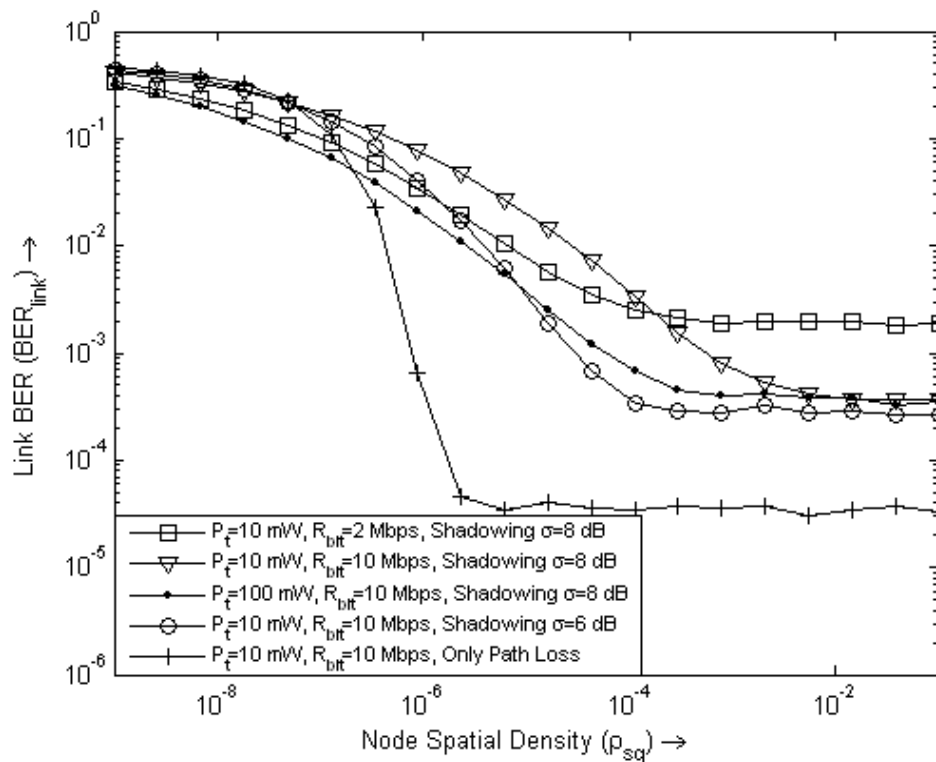


Fig. 4. Link BER as a function of Node Spatial Density for different bit rate and transmit power.

Fig. 5 shows the energy efficiency as a function of packet length in bits for different information delivery mechanisms. 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 [16]. Thus there exists an optimal packet size for a particular network condition. It is seen that optimal packet length increases with the increase in node spatial density. For example, in case of scheme II at node density of 7.8×10^{-4} and $\sigma = 8$ dB, optimal packet size is 44 bit but it increase to 64 bit when node density increases to 1.4×10^{-2} . Further optimal packet length decreases with increase in severity of shadowing. It is seen that the 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 [16]. 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. It is observed that energy efficiency degrades in shadowed channel. Further energy efficiency degrades with increase in severity of shadowing. It is also observed that energy efficiency improves with increase in node spatial density. It is seen that Scheme I is the most energy efficiency information delivery system. This is because in case of Scheme I, additional energy is spent for a single hop for erroneous packets. But in case of Scheme II and Scheme III, additional energy is spent for the entire multi hop route for erroneous packets. Further among the three retransmission schemes, Scheme I has the highest optimum packet size.

Fig. 6 shows the energy required to successfully deliver a file of size 10^6 bit using optimum size packets corresponding to each node spatial density in three different information delivery mechanisms. Energy consumption in presence of shadowing is compared with that of path loss case only. It is seen that in presence of shadowing energy requirement increases. Further it is observed that scheme I is the best retransmission scheme from energy consumption perspective. It is also seen that Scheme II and Scheme III consume nearly same amount of energy in high node density region. However Scheme II performs better in low node spatial density region. For example in shadowed channel using optimum

size packet and at a node density of 7.8×10^{-4} , required energy to transfer a file of size 10^6 bit is 31.7 mJ for Scheme II while it increases to 39.7 mJ for Scheme III.

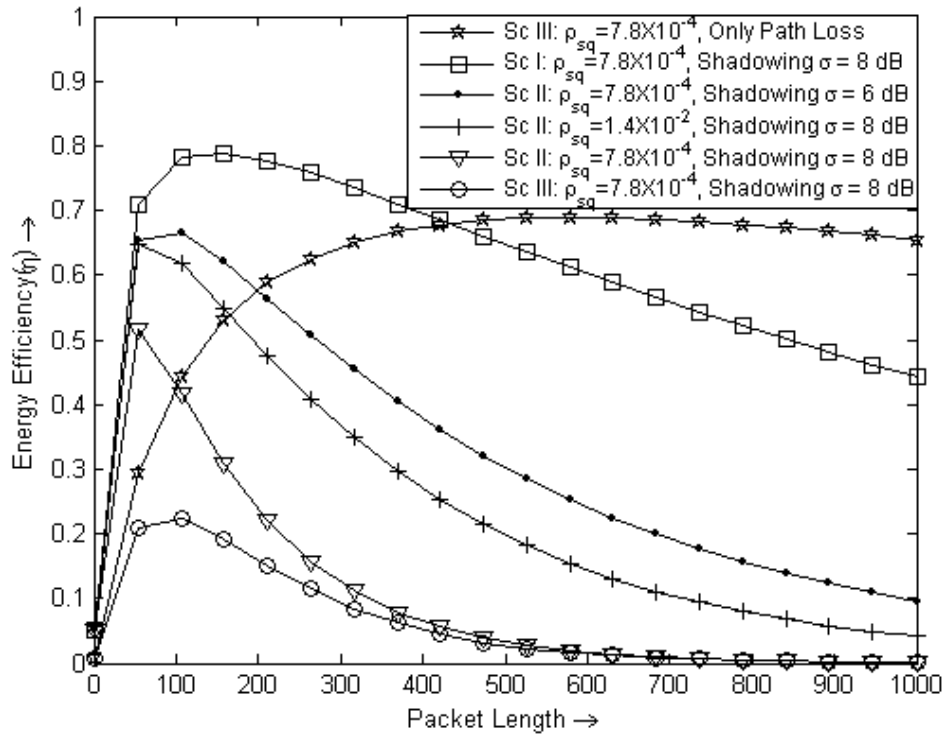


Fig. 5. Energy efficiency as a function of packet length for different retransmission schemes; $P_t=10$ mW.

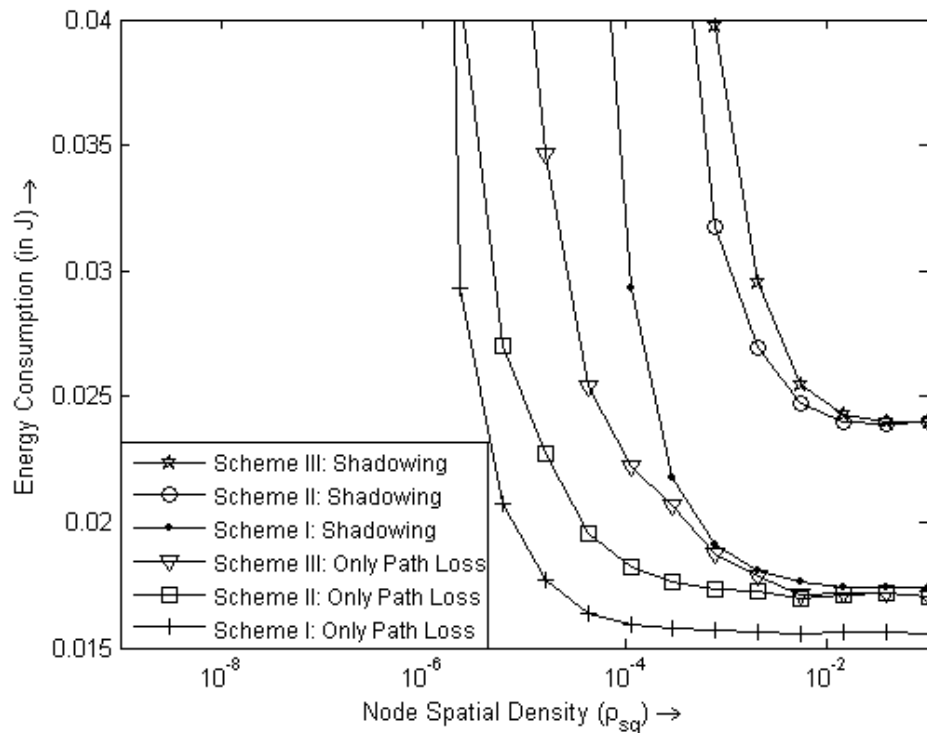


Fig. 6. Energy consumption to transfer a file (size of 10^6 bit) using optimal packet size in different retransmission schemes; $R_{bit}=10$ Mbps, $P_t=10$ mW and $\sigma = 8$ dB.

Fig. 7 shows the impact of severity of shadowing on energy spent to successfully transfer a file of size 10^6 bit using a fixed size packet of 100 bit. It is observed that energy expenditure increases in presence of shadowing. Further energy spending increases with the increase in severity of shadowing. In case of Scheme I, at a node density of 2.9×10^{-4} and $\sigma = 6$ dB energy required to transfer the file is 19.4 mJ, while it increases to 22 mJ for $\sigma = 8$ dB. This is because with increase in severity of shadowing the SNR degrades. This results in more number of retransmissions for successful delivery of a packet. Thus the energy spent to transfer data increases.

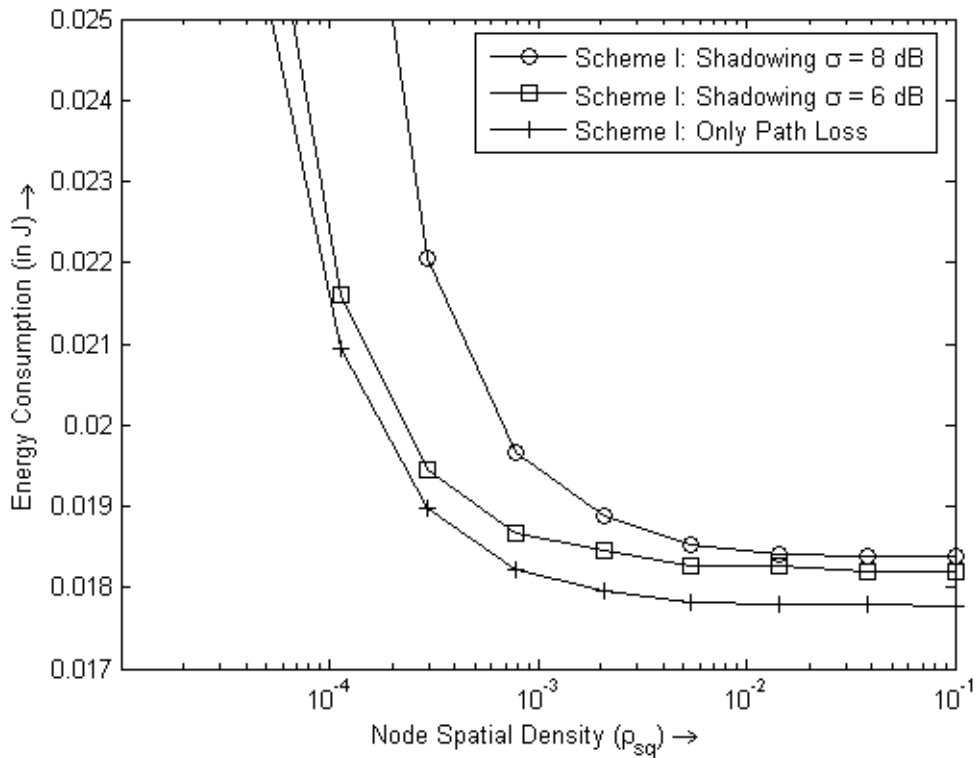


Fig. 7. Energy consumption to transfer a file (size of 10^6 bit) using fixed packet length of 100 bit for different severity of shadowing; $R_{bit}=10$ Mbps and $P_t=10$ mW.

Fig. 8 shows the energy required to successfully deliver a file of size 10^6 bit with different packet sizes using Scheme I and II. Energy consumption for optimal packet based transmission scheme is compared with fixed packet size based transmission. Two different fixed packet sizes of 150 bit and 200 bit are used. It is seen that energy requirement increases with increase in packet size. Further use of optimal size packets reduces energy requirement. For a node density of 5.4×10^{-3} , required energy to transfer the file is 24.7 mJ using optimal size packet, while it increases to 32.6 mJ for fixed packet of size 200 bit.

5. Conclusion

In this paper we have evaluated the energy level performance of three information delivery schemes in shadowed 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 types of information delivery schemes are studied and compared. It is seen that Scheme I performs better than the other two schemes. Further Scheme II consumes less energy than

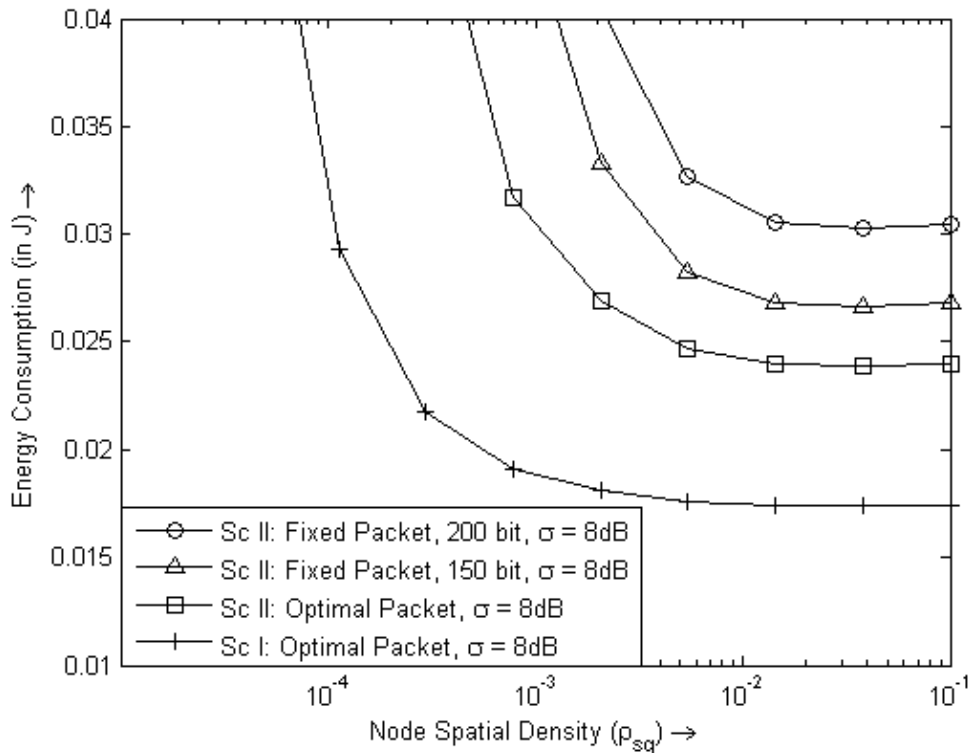


Fig. 8. Energy consumption to transfer a file (size of 10^6 bit) in different retransmission schemes using fixed and optimal packet size; $R_{bit}=10$ Mbps and $P_t=10$ mW, $\sigma = 8$ dB.

Scheme III in low node density region. Further energy consumption increases with increase in severity of shadowing. 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 seen that optimal packet length increases with the increase in node spatial density. Further 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 shadowing. 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.

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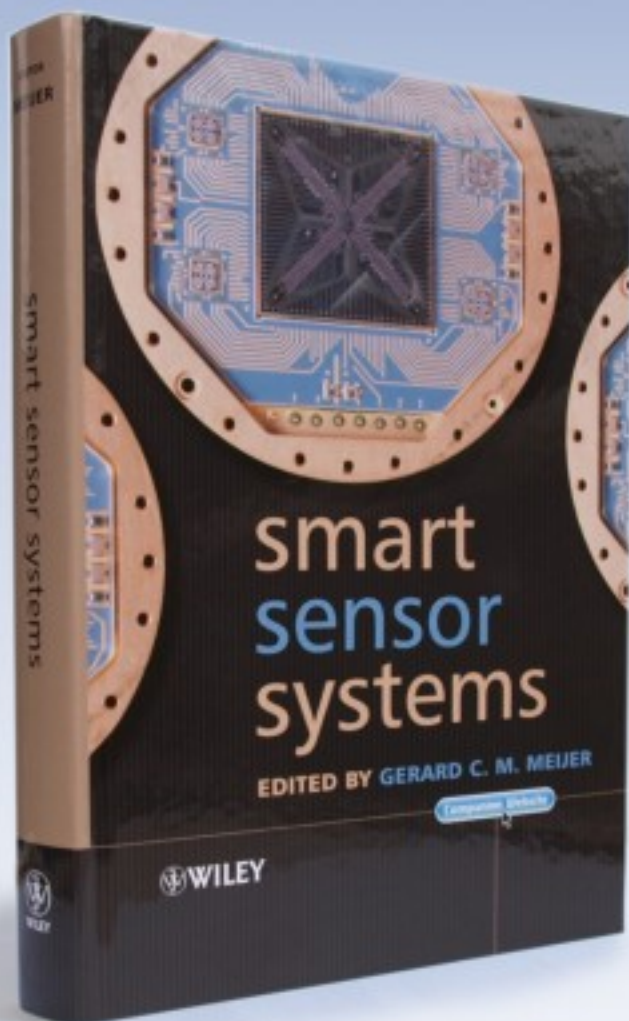
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