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On the energy utilization for WSN based on BPSK over the Generalized-K shadowed fading channel

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Abstract Energy is a scarce resource in the battery-powered nodes of wireless sensor networks (WSNs). In this paper the energy utilization for WSN based on BPSK communications has been investigated over the Generalized-K shadowed fading channel. A comprehensive analysis is reported based on the various important performance metrics like: amount of fading, average bit error probability, outage probability and energy utilized per bit (EUB). Simulation results reveal that composite use of shadowing and fading degrade energy levels to a considerable extent and hence contribute in downsizing the network life-span. We have derived the EUB metric and performed its evaluation with respect to optimal transmit energy levels by varying fading and shadowing severity parameters. We also considered the impact of varying transmit energy levels on the outage probability and hence on transmit and EUB levels. Although, embedding of training sequences and re-transmissions do help in enhancing effective synchronization and improved reliability, but this is done at a cost of higher energy utilization. Under the given set of assumptions, it is observed that an decrease in fading by about 11 %, improves the EUB by about 7 %. With increase in outage probability by about 10 %, EUB improves by about 3 %. An increase in SNR by 6 % improves the EUB levels by about 7 %. The investigations reported in this paper may enable designers to optionally choose suitable parameters to make WSN communications energy-efficient.

Keywords Wireless sensor networks · Energy utilization · Re-transmission · Outage probability

1 Introduction

WSNs have useful applications in many spheres of daily life, ranging from simple health care monitoring to challenging remote volcanic eruption alarming systems, but their performance is plagued by the fact that battery-operated WSNs have limited life-span. WSN lifetime maximization has been widely studied in recent past [1, 2].

The communications over wireless link are prone to short term fading caused by the arrival of multiple, randomly delayed, reflected and scattered signal components at the receiver side and long term fading because of shadowing. Realistically, fading occurs along with shadowing so the effects of both these random processes must be jointly considered in evaluation of energy utilization in WSNs [3].

In the past, the performance of coherent BPSK using compound fading model with the gamma-gamma distribution [3], WSN performance under impact of multicasting and varying effects of shadowing (constant and lognormal) [4], performance evaluation of digital communications over Generalized-K channel in terms of outage probability [5] have been addressed. In [6], the authors analyzed the performance of cascaded fading channel using the moment generating function (MGF) of the receiver's output SNR obtained with Padé approximation

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(PA) technique. Recently, Cui et al. [7] studied energy consumption by analyzing both transmission time and constellation size optimization for MQAM and MFSK communications.

In other attempts, different optimization methods have been adopted. For example, in [8], the effective energy-per-useful bit (EPUB) metric has been considered to maximize the WSN lifetime. The performance analysis of energy consumption has been conducted under AWGN and Rayleigh fading channel using MPSK, MQAM, and MFSK modulations in [9]. In the related line of research, a study with combination of Reed-Solomon codes with MPSK, MQAM, and MFSK modulations has been conducted in [10]. In [11], using MQAM transmission, the optimum scheme that results in minimum energy consumption for a given hop distance was derived. The authors in [12] used the optimal hop distance to find total energy consumed to transmit data at a certain distance. Setting of physical layer parameters to enhance the energy efficiency of WSN by deriving an expression for the energy consumed per successfully received bit for packet transmissions without including the effects of packet re-transmissions was done in [13].

In this paper, we have investigated the energy utilization for WSN based on BPSK communications. We considered the joint effects of fading as well as shadowing on energy consumption. We derived rational expressions for energy utilized per bit considering packet re-transmissions, reliability of links, structure of data and its acknowledgement packet, training sequences and outage probability for communications operating over Generalized-K shadowed fading channel. The well known Nakagami-m and Rayleigh-lognormal composite statistical distributions used to model the fading and shadowing effects have no closed-form mathematical solution. Consequently, better analytical solution is provided by K and Generalized-K distributions, which use a gamma distribution in place of lognormal one [14]. Generalized-K fading distribution is a good candidate for tractable mathematical manipulations and it effectively approximates most of the fading and shadowing distributions occurring in wireless communications [15]. We used BPSK modulation as it is optimal for error protection and is suitable for low-cost transmitters [16]. We used Probability Density Function (PDF) based average bit error rate and outage probability as in [3].

The paper is organized as follows. Section 2 describes the system and channel model including related expressions of average bit error probability, amount of fading and outage probability for shadowed fading distribution. The energy utilized per bit computations are performed in Sect. 3. Numerical results are discussed in Sect. 4. Finally, Sect. 5 concludes the work.

2 System and channel model

2.1 Scenario and assumptions

We consider a scenario involving packet and its acknowledgement transmissions over a wireless link. It is assumed that communicating nodes are separated by a fixed distance from each other and are homogeneous, both, in terms of energy levels as well as in energy consumption for processing various tasks. We use Generalized-K fading channel where BPSK modulated communications are exposed to joint effects of shadowing and fading. The energy consumption model as proposed in [7] is considered for determining power consumption of transmitter and receiver circuits. It is also assumed that for a given SNR in a symmetric radio channel, the energy utilized to transmit data in one direction is same as that in the reverse direction. Data and acknowledgement packets are assumed to be of fixed size and both packet header and training sequence are assumed to be error-free. Data packets are transmitted with repeated training sequences while acknowledgement packets are transmitted with a pre-fixed short training sequence. Link quality of both forward and reverse link is assumed to be same.

2.2 Channel model

In wireless communications, the baseband representation of the received signal is given by A = HX + N, where X is the transmitted baseband symbol which is modulation dependent, H is the shadowed fading channel envelop, and N is the channel noise. The PDF for the received power (p) in Generalized-K channel is given as [3]

$$f(p) = \int_0^\infty \frac{m^m p^{m-1}}{s^m \Gamma(m)} \exp\left(\frac{-mp}{s}\right) \frac{s^{g-1}}{y_0^g \Gamma(g)} \exp\left(-\frac{s}{y_0}\right) ds \qquad (1)$$

where, s is the average power, g and m are the parameters related to severity of shadowing and fading respectively, $\Gamma(.)$ is the Gamma function, y_0 is a parameter related to the average power. Since Eq. 1 has no closed solution, so we use PDF given in terms of Gamma and modified Bessel functions [3, 5] as given in Eq. 2

$$f(p) = \frac{2}{\Gamma(g)\Gamma(m)} \left(\frac{b}{2}\right)^{g+m} p^{\left(\left(\frac{g+m}{2}\right)-1\right)} K_{g-m}(b\sqrt{p})U(p) \qquad (2)$$

where, b is a parameter related to the average power, $K_{g-m}(.)$ is the modified Bessel function of the second kind of order $(g-m)$ and $U(p)$ is the unit step function. The moments of the PDF used to calculate amount of fading are given as

$$<p^k> = \frac{\Gamma(g+k)\Gamma(m+k)}{\Gamma(g)\Gamma(m)} \left(\frac{2}{b}\right)^{2k} \tag{3}$$

where $<.>$ represents statistical average and p^k is the kth moment of the PDF [17]. The amount of fading which is an important performance measure characterizing the severity of fading is given as [3]

$$AF = \frac{1}{m} + \frac{1}{g} + \frac{1}{mg} \tag{4}$$

PDF expressed in Eq. 2 is used to calculate channel average bit error probability and outage probability. We used the estimation of average bit error probability (ABEP) in shadowed fading channel for BPSK modulation scheme expressed in terms of hypergeometric functions as given in [3] and the outage probability of Generalized-K channel as mentioned in [18].

3 Energy modeling

Communications under constrained scenarios often use packet structure in which bits are preceded by training sequences which are used for channel estimation and synchronization. Longer training sequences are used for better channel estimation and synchronization. We refer to optimal training sequence length which is sufficient to successfully remove any kind of phase offset as given in [19]. In shadowed fading environments, the training sequence prefixed only at the beginning of a data packet cannot provide effective channel estimation. To overcome this difficulty, additional training sequences are inserted in the data packets. As acknowledgement packets are of small size, they are assumed to be transmitted with short training sequence prefixed at the beginning.

Let $link_p$ and $link_a$ represent the forward and reverse link respectively between the sender S and the receiver R. Let each data packet contain b_T bits, which include b_h bits (including training sequence and header bits) and b_i payload bits, while acknowledgement packet contains b_A bits (including b_a acknowledgement data bits and b_{ha} acknowledgement header bits). Let N_{tseq} represent the number of inserted training sequences (each of length b_h) and the channel coherence time be Γ ms. For attaining optimum efficiency and precise accuracy over channel bandwidth BW, we use following relation

$$\frac{b_i}{BW} + \frac{N_{tseq} \times b_h}{BW} \approx \Gamma \times N_{tseq} \tag{5}$$

$$or, N_{tseq} = \frac{b_i}{BW \times \Gamma - b_h} \tag{6}$$

Further, in the following sub-sections we discuss the energy utilized per bit (EUB) computations both with and without packet re-transmission considerations. The effects of training sequence as formulated above in Eq. 6 have been considered in the derivation of expressions for EUB.

3.1 Without using re-transmission of packets

The energy consumed in transmitting a data packet over $link_p$ between S and R is given as

$$E_{TR(S,R)}(P_t, P_{tck}, T_{b_T}) = (P_t + P_{tck}) \times T_{b_T} \tag{7}$$

where P_t is the power used in transmitting a data packet, P_{tck} is the fixed power consumed by transmitter circuitry and T_{b_T} is the time duration to transmit a data packet of size b_T and is given as

$$T_{b_T}(b_i, BW, N_{tseq}, b_h) = \frac{b_i}{BW} + N_{tseq} \times \frac{b_h}{BW} \tag{8}$$

Similarly, energy consumed in receiving a data packet is given as

$$E_{RX(S,R)}(P_{rck}, T_{b_T}) = P_{rck} \times T_{b_T} \tag{9}$$

where, P_{rck} is the fixed power consumed by receiver circuity. Therefore, total energy used in transmitting and receiving a single data packet over $link_p$ is given as

$$E_{TPKT}(P_t, P_{tck}, P_{rck}, T_{b_T}) = (P_t + P_{tck} + P_{rck}) \times T_{b_T} \tag{10}$$

Using Eqs. 6 and 8 in Eq. 10 we get

$$E_{TPKT} = (E_{b,t} + E_{tck} + E_{rck}) \times pkt_{load} \tag{11}$$

$$where, \quad pkt_{load} = b_i + \frac{b_i \times b_h}{BW \times \Gamma - b_h} \tag{12}$$

where, $E_{b,t}, E_{tck}$ and E_{rck} represent transmission energy, fixed transmitter and receiver circuit energies required per bit respectively. These fixed energies are determined by transceiver design and defined as the ratio of total circuit power $P_{circuit}$ to the bandwidth, where, $P_{circuit}$ is expressed as the sum of power consumption of all sub-circuits of transmitter and receiver units [7, 13].

Similarly, total energy consumed to communicate an acknowledgement packet over the $link_a$ is given as

$$E_{TACK} = (E_{b,t} + E_{tck} + E_{rck}) \times ack_{load} \tag{13}$$

$$where, \quad ack_{load} = b_a + b_{ha} \tag{14}$$

Now, total energy consumed in communicating a data packet and its acknowledgement is the sum of energy consumed in forward and the reverse path communication of data and acknowledgement packet respectively.

$$E_{total} = (E_{b,t} + E_{tck} + E_{rck}) \times (pkt_{load} + ack_{load}) \tag{15}$$

Further if $P_{e,b}$ is the average bit error probability in shadowed fading channel. Then, the probability of successful packet delivery, $P_{s,p}$ is given as

$$P_{s,p}(P_{e,b}, b_i) = (1 - P_{e,b})^{b_i} \tag{16}$$

The expected amount of data per packet, $data_{pkt}$ is computed as a product of packet payload and probability of packet success given as

$$data_{pkt}(b_i, P_{s,p}) = b_i \times P_{s,p} \tag{17}$$

The required metric EUB can be computed as ratio of total energy dissipated in transmitting and receiving data and acknowledgement packet with embedded training sequences to the expected amount of data successfully transmitted per packet and is computed using Eq. 15, 17 and is given as

$$\begin{aligned} EUB &= \frac{Total\,Energy\,dissipated}{Data\,per\,packet} \\ EUB &= \frac{(E_{b,t} + E_{tck} + E_{rck}) \times Tot_{load}}{b_i \times (1 - P_{e,b})^{b_i}} \end{aligned} \tag{18}$$

$$where, \quad Tot_{load} = pkt_{load} + ack_{load} \tag{19}$$

Now, since the good delivery in communication process is not only affected by error rates, but is also dependent on the outage probability. So, we further consider the effects of outage probability in Eq. 18 by incorporating a term $(1 - P_{out})$in the denominator as shown below

$$EUB = \frac{(E_{b,t} + E_{tck} + E_{rck}) \times Tot_{load}}{b_i \times (1 - P_{e,b})^{b_i} \times (1 - P_{out})} \tag{20}$$

where $P_{e,b}$ is as given in [3] and P_{out} which denotes the outage probability of Generalized-K channel is given as [18]

$$\begin{aligned} P_{out} = {} & \frac{\Gamma(m-g)}{\Gamma(m)\Gamma(g+1)} \\ & \times {}_1F_2\left(g, [1-m+g, 1+g], \frac{P_{th}b^2}{4}\right)\left(\frac{P_{th}b^2}{4}\right)^g \\ & + \frac{\Gamma(g-m)}{\Gamma(m+1)\Gamma(g)} \\ & \times {}_1F_2\left(m, [1-g+m, 1+m], \frac{P_{th}b^2}{4}\right)\left(\frac{P_{th}b^2}{4}\right)^m \end{aligned} \tag{21}$$

where P_{th} is the threshold, ${}_1F_2()$ is the hypergeometric function and b is a parameter related to average power. The average signal-to-noise ratio B_{av} can be computed from first moment of the PDF given in Eq. 2 and is given as $4mg/b^2$.

Further, $E_{b,t}$ can also be related to the received energy per bit. Assuming E_{rx} to be the energy received per bit at the receiver located at a distance d_{S-R} away from the source, n be the channel path-loss exponent and α parameter be defined as reciprocal of product of amplifier efficiency η and channel loss ℓ. Then, E_{rx} is given as [20]

$$\begin{aligned} E_{rx}(E_{b,t}, \alpha, d_{S-D}, n) &= \frac{E_{b,t}}{\alpha \times d_{S-D}^n} \\ where, \alpha &= \frac{1}{\eta \times \ell} = \frac{1}{\eta \times \frac{G_T G_R \times \lambda^2}{(4 \times \Pi)^2}} \end{aligned} \tag{22}$$

where G_T and G_R be the gains of transmitter and receiver antenna respectively and λ is the carrier wavelength.

Using the expression given in Eq. 21, we evaluate the impact of varying transmit energy levels on the outage probability and hence on the energy utilized per bit.

3.2 Using re-transmission of packets

Let NP and NA represent the number of transmitted data and acknowledgement packets respectively. The values of NP and NA are random and depend on the reliability of $link_p$ and $link_a$ respectively. Using PDF of NP and NA, the expected number of transmissions of data packet and acknowledgement can be found as in [21]. Let P_p and P_a represent the delivery probability of data and acknowledgement packet respectively. For large number of transmissions, expected number of packet transmissions $E[NP]$ and expected number of acknowledgement transmissions $E[NA]$ are given as

$$E[NP] \rightarrow \frac{1}{P_p P_a} \tag{23}$$

$$E[NA] \rightarrow \frac{1}{P_a} \tag{24}$$

The total load in bits on the communication system by considering the effects of both packet retransmissions and repeated training sequences can be expressed as

$$Tot_{loadR} = E[NP] \times pkt_{load} + E[NA] \times ack_{load} \tag{25}$$

Further, employing effects of large number of re-transmission in energy per bit computations, the expression given in Eq. 20 becomes

$$EUB = \frac{(E_{b,t} + E_{tck} + E_{rck}) \times Tot_{loadR}}{b_i \times (1 - P_{e,b})^{b_i} \times (1 - P_{out})} \tag{26}$$

Using the optimal transmit energy level for varying severity of fading and shadowing strengths, we finally performed the EUB evaluation. The dependence of outage probability on transmit levels has been taken into account. We expressed the average SNR of bit error given in [3] and outage probability expression given in [18] in terms of transmitted energy per bit, amplifier efficiency, path-loss, distance and noise power using Eq. 22. Since there is no closed-form solutions of Eqs. 20 and 26, so we performed numerical computations with MATLAB using constrained nonlinear optimization multi-variable function and employing derivative-free method.

Table 1 System parameters

Parameter	Value	Parameter	Value
P_{filter}	2.5 mW	Freq.	2.5 GHz
P_{DAC}	15.5 mW	n	0.47
P_{syn}	50.0 mW	BW	100 kHz
P_{mix}	30.3 mW	$G_T G_R$	5 dBi
$\sigma^2 = N_0/2$	-174 dBm/Hz	Modulation	BPSK
k	256 bits	Γ	1 ms
d	20 m	η	0.02

4 Results and discussion

In sub-sections to follow, we discuss results in terms of various performance metrics. We present the results by taking into consideration the effects of repeated training sequence, error rate and outage probability. Table 1 enlists some of important simulation parameters used in EUB computations.

4.1 Amount of fading

Figure 1 shows the upper and lower bound of amount of fading (AF) in Generalized-K channels by varying levels of fading and shadowing severity parameters. It is observed that with the decrease in the strength of fading and/or shadowing, the AF approaches to the lower bound resulting in reduction of channel uncertainty, which helps to improve the communication success rate and hence in preserving the energy levels of communicating nodes. Low values of m and g correspond to severe fading and shadowing conditions respectively and vice-versa. For higher values of g(>6), the channel depends completely on m, making it a Nakagami fading channel with little or no shadowing. Same interpretation applies for higher value of m also. With low value of m and g, results show higher values of amount of fading.

4.2 Average bit error probability

Figure 2 illustrates the variation of average bit error probability versus average SNR under the effects of different representative fading conditions obtained by jointly varying strengths of fading and shadowing. The plot depicts that the error rates drop with increasing SNR and also with the decrease in strength of fading and/or shadowing.

With an increase in SNR from 10 to 20 dB, the ABEP reduces approximately by 1/100. This indicates that for energy-efficient design under constrained environment, one must focus on minimizing the ABEP by reducing channel uncertainty.

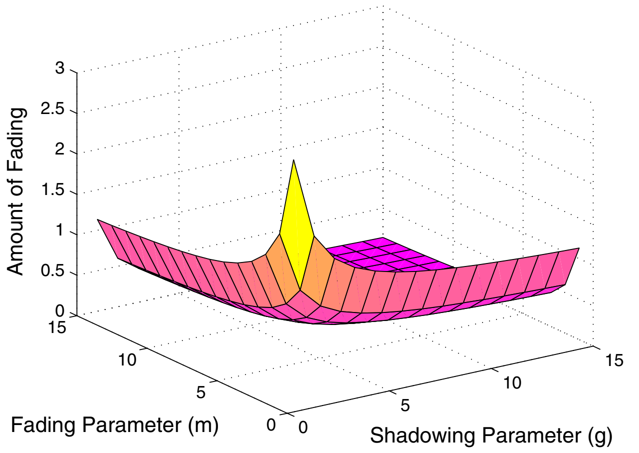

Fig. 1 AF in Generalized-K fading channel with respect to severity of fading (m) and shadowing (g)

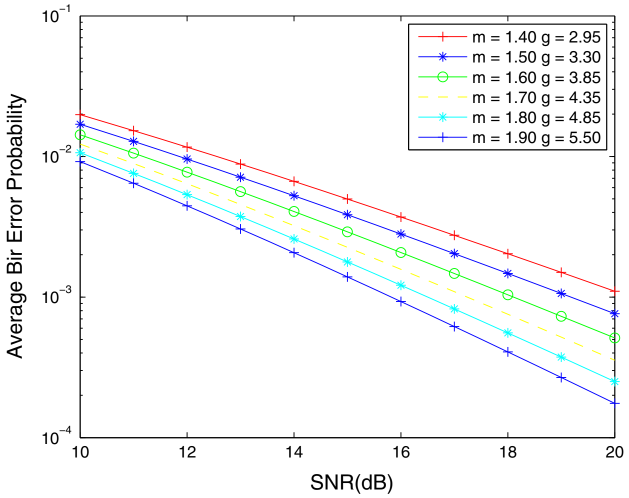

Fig. 2 ABEP versus SNR(dB) for Generalized-K fading channel for varying severity of fading and shadowing

4.3 Energy utilized per bit

Here, we present the results for energy utilized per bit obtained by considering the effects of repeated training sequences and outage probability in the numerical computations. We organize the results with respect to (1) Training Sequences and packet re-transmissions, (2) Optimal transmit energy (3) Relation between outage probability, optimal transmit energy and EUB.

4.3.1 Training sequences and packet re-transmissions

Figure 3(a, b) depict the variation of EUB metric with respect to SNR levels without and with training sequence considerations respectively for communication of single

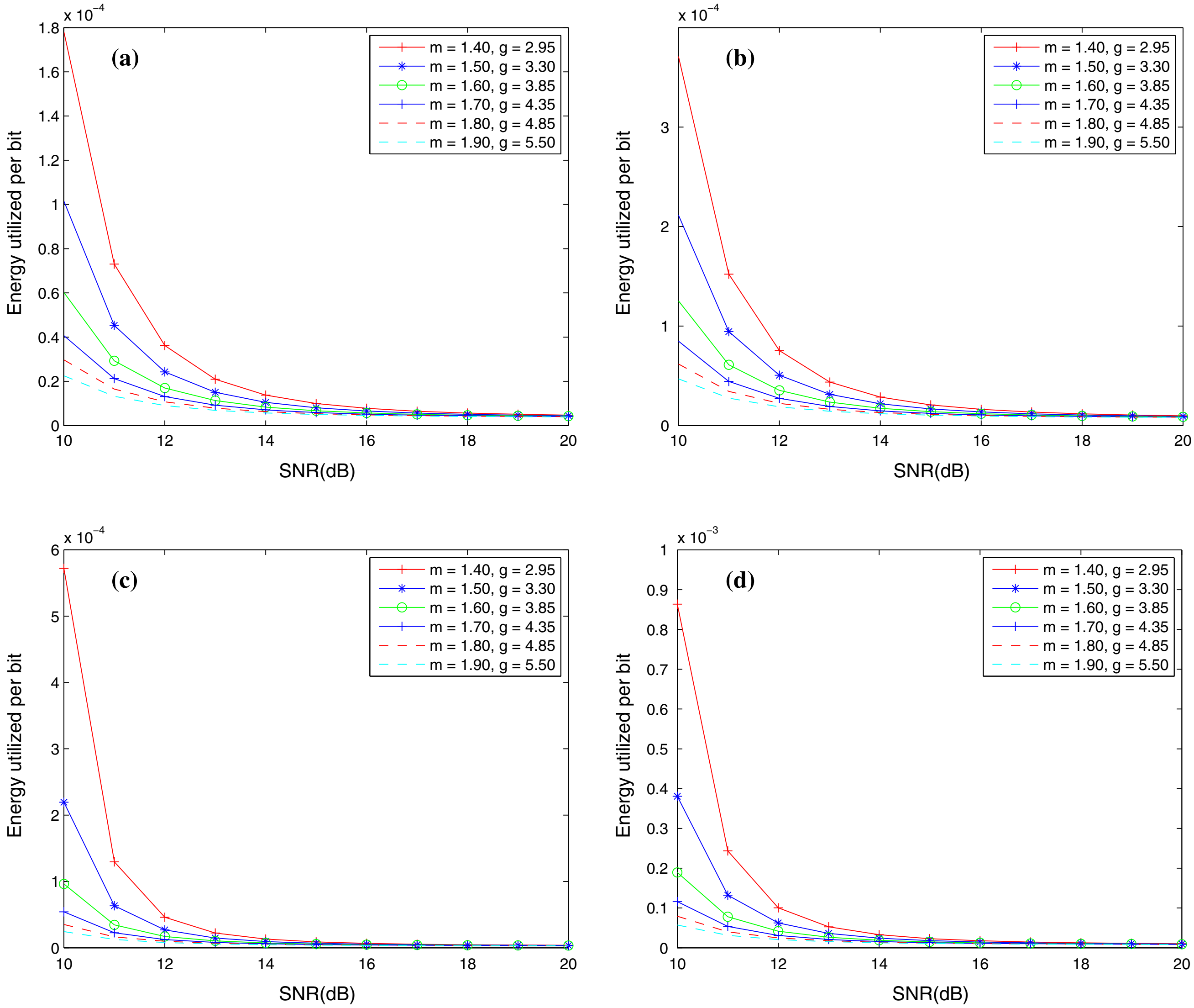

Fig. 3 EUB metric versus SNR (dB) for Generalized-K fading channel for varying strengths of fading (m) and shadowing (g). **a** Single packet transmission without training sequence considerations, **b** single packet transmission with training sequence considerations, **c** using re-transmissions without training sequence considerations, **d** using re-transmissions with training sequence considerations

data packet and its acknowledgement, while, Fig. 3(c, d) show the similar variations with respect to large number of re-transmissions.

We performed the simulations by varying severity of fading and shadowing and observed that the value of the EUB metric decreases with increase in SNR and also decreases with the decrease in severity of fading and/or shadowing as depicted in Fig. 3(a, c). It is further observed that energy utilization is higher with training sequence considerations as depicted in Fig. 3(b, d) as compared to results of Fig. 3(a, c) respectively. It is also observed that although re-transmissions do enhance the communication reliability, but it is done at the cost more EUB levels over the link. Results also indicate that the disastrous effects of joint use of shadowing and fading lead to increased channel randomness or uncertainty and hence higher levels of EUB are required for successful communications over the Generalized-K fading channel.

4.3.2 *Optimal transmit energy*

Using the optimal transmit energy levels, we performed the highly parameterized EUB computation which can be applied to variety of transceiver circuities and channel with different distributions like, double Nakagami (PDF with $m = g$), double Rayleigh (PDF with $m = m_1$ and $g = m_2$) and K distribution (PDF with $m = g = 1$).

Figure 4 shows the variation of EUB metric and corresponding optimal transmission energy levels for Generalized-K shadowed fading channel communications by

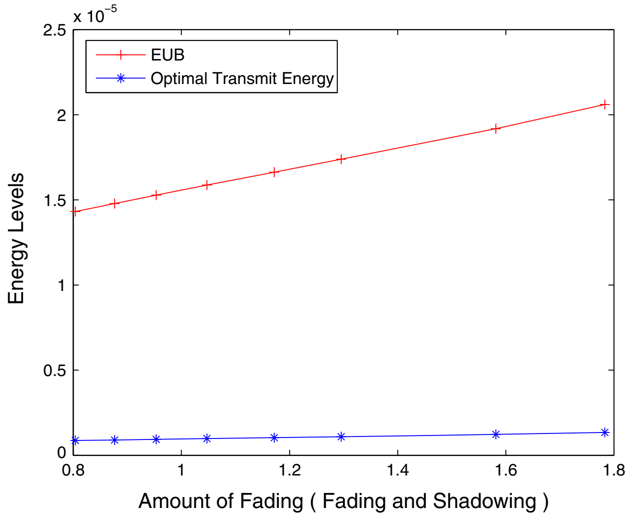

Fig. 4 Energy levels versus amount of fading for Generalized-K fading channel

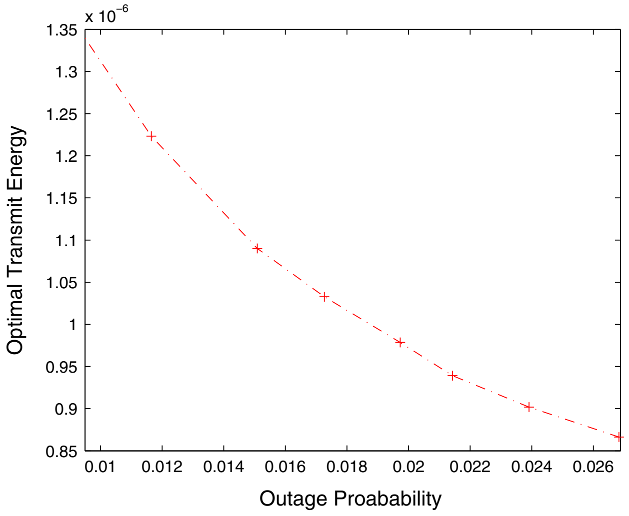

Fig. 5 Optimal transmit energy and outage probability for Generalized-K fading channel

varying strength of fading (m) and shadowing (g). It is observed that with increase in amount of fading the optimal transmit energy and corresponding EUB level increases. With higher values of amount of fading the increase in EUB levels is more.

With the decrease in amount of fading by about 11 %, the EUB levels improve by about 7 % and the corresponding optimal transmit energy levels show improvement by about 9 % .

4.3.3 *Relation between outage probability, optimal transmit energy and EUB*

To shed more light on the relation between outage and transmit levels, we used the outage probability mathematical formulation in Eq. 21 to obtain the results corresponding to variance of transmit energy and its impact on outage probability. Results in Fig. 5 depict that variation of optimal transmit energy required along with the outage probability levels. The results show a reduction in optimal transmit energy levels with increase in outage probability.

Furthermore, results in Fig. 6 depict the variation of EUB metric with outage probability. We observe that EUB decreases with increase in outage probability for different SNR levels. With higher SNR levels, the change is more. These results will enable network designers to reject or admit new service request by analyzing the outage.

Table 2 enlists the optimal transmit energy levels and corresponding EUB metric for different representative channel fading conditions. Measurements exhibit decreasing trend in EUB metric with decrease in amount of fading. It is observed that with increase in outage probability and/or decrease in AF, the EUB decreases. Our results depict that with increase in outage probability by 10 % and decrease in amount of fading by about 8 %, the energy utilization levels show improvement by about 3 % with corresponding optimal transmit energy improvement observed about 4 %.

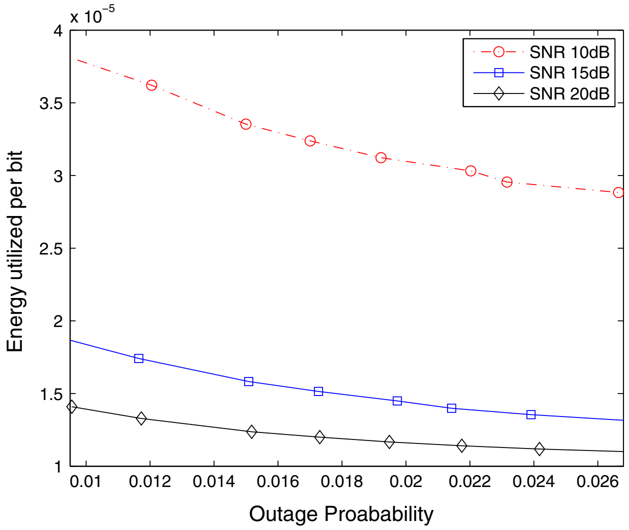

Fig. 6 EUB versus outage probability for Generalized-K fading channel

With increase SNR by about 6 % under constant fading and moderate shadowing parameters taken as 1.4 and 2.95 respectively, the EUB levels improve by about 7 % with corresponding increase in outage probability by 0.66 %. We used the value of m as 1.4 which is optimal value used for Nakagami-m distribution as in [22] and value of g as 2.95 which refers to a moderate shadowing strength.

Table 2 Optimal transmit energy and corresponding EUB metric for different representative channel fading conditions

Amount of fading (fading and shadowing)	Optimal transmit energy	EUB corresponding to optimal transmit energy	Outage probability
1.783	$1.339E-06$	$1.869E-05$	$9.610E-03$
1.582	$1.223E-06$	$1.741E-05$	$1.166E-02$
1.295	$1.097E-06$	$1.582E-05$	$1.434E-02$
1.172	$1.033E-06$	$1.515E-05$	$1.727E-02$
1.047	$9.820E-07$	$1.450E-05$	$1.920E-02$
0.953	$9.375E-07$	$1.398E-05$	$2.175E-02$
0.876	$9.002E-07$	$1.355E-05$	$2.425E-02$
0.804	$8.674E-07$	$1.315E-05$	$2.657E-02$

5 Conclusions

In this paper we investigated energy utilized per bit for WSN based on BPSK communications operating under Generalized-K channel using fixed size data and acknowledgement packets with repeated training sequence considerations. We derived the expressions for energy utilized per bit considering statistical performance characteristics like amount of fading, average bit error probability, packet re-transmissions and outage probability. We performed the numerical computation by jointly varying severity of fading and shadowing. Following are the some of the conclusions of our study:

- One of the main conclusions is that suitable choice of fading and shadowing severity along with ABEP, re-transmission considerations and outage probability, can be helpful in the design of energy efficient and reliable communications. Once the channel distribution and modulation schemes are known, one can easily find the optimal transmit energy and outage probability levels that result in energy-efficient communications.
- Our results show that when operating under optimal conditions satisfying Eqs. 20 and 26, EUB decreases with an increase in SNR. Results also conclude that higher levels of EUB are required to counter the enhanced channel uncertainty caused by the joint impact of fading and shadowing.
- Use of repeated training sequences and re-transmissions do help in effective synchronization and enhancing reliability respectively, but it is done at the cost of higher energy utilization levels.
- With the decrease in AF by about 11 %, the EUB levels improve by about 7 % and the corresponding optimal transmit energy levels improve by 9 %.
- With increase in outage probability and/or decrease in amount of fading, the EUB decreases. Our results conclude that with increase in outage probability by 10 % and decrease in amount of fading by about 8 %, the energy utilization levels show improvement by about 3 % with corresponding optimal transmit energy improvement observed as about 4 %.
- With increase in SNR by about 6 % under constant fading and moderate shadowing strengths taken as 1.4 and 2.95 respectively, the EUB levels improve by about 7 % with corresponding increase in outage probability by 0.66 %.

We infer that while evaluating the WSN energy utilization, although it is necessary to consider the simultaneous effect of fading and shadowing, yet, to facilitate energy-efficient and reliable communications one needs to employ effective mitigation techniques to ameliorate the disastrous effects of fading and shadowing and tailor optimal permutation and combination of various communication parameters like—optimal transmit power, outage probability, packet re-transmissions and severity of fading and shadowing.

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