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Performance and Analysis of Wireless Sensor Network Using Square Grid Topology

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Abstract— **This paper is to analyze the energy label performance of wireless sensor network (WSN) using error control schemes and to find the energy efficient error control schemes for WSNs. Energy efficiency involves operating a wireless system within specifications and requirements using less energy. Therefore finding a error control scheme for WSNs which has maximum energy efficiency and consumes minimum energy to transmit data both for single and multi-hop scenario of WSNs.**

Index Terms— **WSN, Network Topology, Energy Efficiency.**

I. Introduction

Wireless sensor networks (WSNs) have gained worldwide attention in recent years, particularly with the development in Micro-Electro-Mechanical Systems (MEMS) technology which has facilitated the development of smart sensors. These sensors are small with limited processing and computing resources and they are inexpensive as compare to traditional sensor. These sensor nodes can sense, measure, and gather information or they can transmit the sensed data to the user. Depending on the application and types of sensor used, power supply may be used in sensor network. Since the sensor nodes have limited memory and power supply and battery is the main power source in a sensor node.

WSN is one that contains a dense collection of sensor nodes. Sensor nodes may be arranged in ad hoc manner into the field is known as ad hoc wireless network. In an ad hoc wireless network, where nodes are likely to operate on limited battery life, power conservation is an important issue. Conserving power prolongs the lifetime of a node and also the lifetime of the network as a whole. In addition, transmitting at low power reduces the amount of excessive interference. One of the goals of forming a network is to have network connectivity—that is, each node should be able to communicate with any of the other nodes, possibly via multiple hops. The connectivity level of an ad hoc wireless network depends on the transmit power of the nodes. It is intuitively clear that the optimal transmit power is the minimum power sufficient to guarantee network connectivity. This is to analyze the energy label performance of wireless sensor network (WSN) using error control schemes and to find the energy efficient error control schemes for WSNs. Energy efficiency involves operating a wireless system within specifications and requirements using less energy. Therefore finding a error control scheme for WSNs which has maximum energy efficiency and consumes minimum energy to transmit data both for single and multi-hop scenario of WSNs.

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Energy efficiency, a suitable optimization metric that captures the energy and reliability constraints is used here for comparing performance of FEC and ARQ. WSNs necessitate simple error control schemes because of the low complexity requirement of sensor nodes. ARQ scheme is based on hop-by-hop retransmission, 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. WSNs require simple error control schemes because of the low complexity requirement of sensor nodes. Automatic repeat request (ARQ) and forward error correction (FEC) are the key error control strategies used in WSNs.

II. Network Topology

Fig. 1.1 shows the sensor network using square grid topology. Throughout the analysis we consider a scenario where N nodes are distributed over a surface with finite area A.

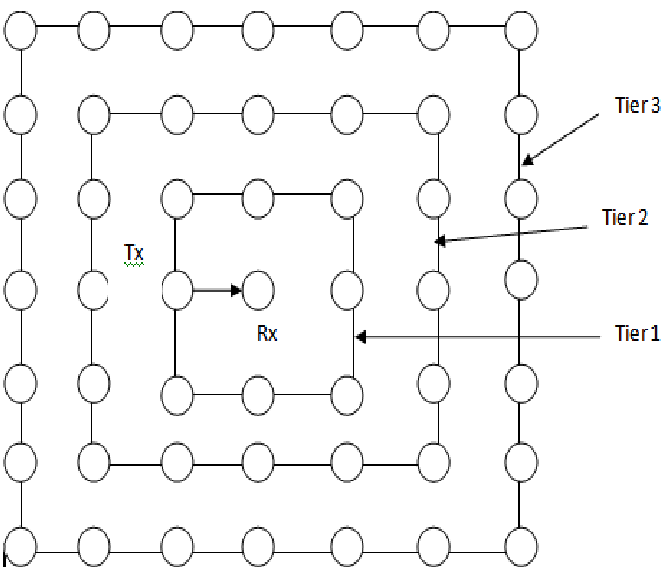

Fig 1.1 Sensor network using square grid topology

The node spatial density is defined as the number of nodes per unit area and is denoted as P_{sq} =N/A. Fig. 1.1 shows the sensor network having M number of tires with torus assumption. Due to the regularity of this topology, the distance to the nearest neighbor, denoted by d_{link}, is fixed, and a route is constituted by a sequence of hops with equal length. The distance d_{link} can be computed as follows: One can first observe that constructing a square lattice of 'N' nodes over a surface of a torus with area 'A' is equivalent to fitting 'N' small square tiles of area d_{link} into a large square of area 'A'. Hence, it must hold that Nd_{link}^2 =A and, therefore, the distance to the nearest neighbor can be written as

$$d_{link} = \sqrt{\frac{A}{N}} = \sqrt{\frac{1}{P_{sq}}}$$

III. Energy Efficiency And Energy Expenditure in Different Schemes

Scheme1: Scheme 1 is based on hop-by-hop retransmission, as shown in Fig.5.2a following [15], 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.

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

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

where BER_{link} is the link BER (expression of link BER is discussed in section 3.3 of chapter 3) in presence of Rayleigh fading. The probability of 'n' retransmissions is the product of failure in the (n-1) transmissions and the probability of success at the n^{th} transmission

$$P_I(n) = (1-PER_{link})(PER_{link})^{n-1}$$

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

$$R_1 = \sum_{n=1}^{\infty} P_I(n).n = \frac{PER_{link}}{1-PER_{link}}$$

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 [18]

$$P_{t1} = \frac{S_i(4\pi f)^2 d_{link}^{\gamma}}{G_t G_r c^2}$$

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]

$$E_1 = \frac{1.75\times(1+R_1)\times \bar{n}_{hop}}{R_{bit}}[P_t(l_h+l_m)+P_{t1}l_{ack}]$$

Scheme 2: Scheme 2 is based on multi-hop delivery with intermediate nodes, performing as digital repeaters [33] as shown in Fig5.2b. 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.

Average probability of error at packet level at the end of multi hop route is expressed as

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

Average number of retransmissions for scheme 2, assuming an infinite ARQ

$$R_2 = \sum_{n=1}^{\infty} P_2(n).n = \frac{PER_{route}}{1-PER_{route}}$$

where $P_2(n)$ is the probability of n retransmissions considering scheme 2.The energy consumed per packet at end of the $\bar{n}_{hop}$ number of hops is given by:

$$E_2 = \frac{1.75\times(1+R_2)\times \bar{n}_{hop}}{R_{bit}}[P_t(l_h+l_m)+P_{t2}l_{ack}]$$

where P_{t2} is transmit power of reverse link and same as P_{t1}

Scheme 3: Scheme 3 is based on multi-hop delivery with intermediate nodes, performing as digital repeaters [15] as shown in Fig5.2c. 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).

The energy consumed per packet at end of the $\bar{n}_{hop}$ number of hops using scheme 3 is given by:

$$E_3 = \frac{1.75\times(1+R_3)\times \bar{n}_{hop}}{R_{bit}}[P_t(l_h+l_m)+P_{t3}l_{ack}]$$

where average number of retransmissions, R_3 is same as R_2. Reverse link transmit power P_{t3} is given as

$$P_{t3} = \frac{S_i(4\pi f)^2 d_{avg}^2}{G_t G_r c^2}$$

where d_{avg} is the average distance between source and destination. Now the energy efficiency (η) of each scheme can be expressed as [14]:

$$\eta = E_{\min}/\text{Energy required for that scheme}$$

IV. Simulation Results

Table 1.1 shows the important network parameters used in the simulation study.

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}.

Table 1.1 Important network parameters used in the simulation study.

Parameter	Values
Path loss exponent(γ)	2
Number of nodes in the network (N)	289
Node spatial density(p_{sq})	$10^{-9}-10^{-2}$
Packet arrival rate at each node (λ_t)	0.5 pkts/s
Carrier frequency(f_c)	2.4GHz
Noise figure(F)	6 dB
Room temperature(T_0)	300K
Transmission power(P_t)	10mW,100mW
Receiver Sensitivity(S_i)	-60dBm

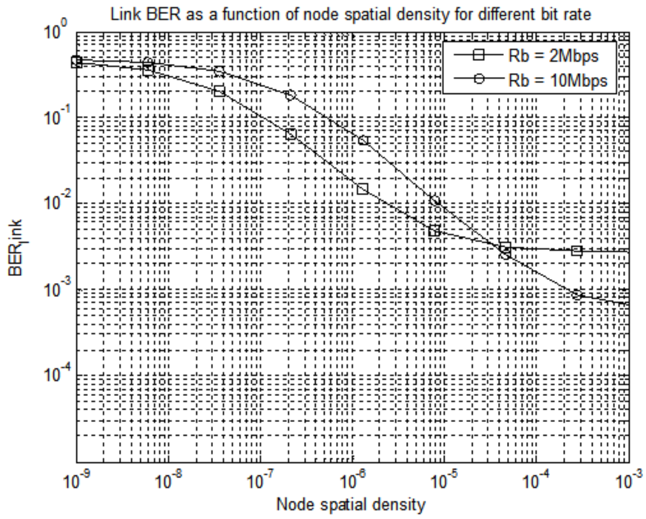

Fig. 1.2 Link BER as a function of node spatial density for bit rate

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 also seen that BER_{link} performance degrades as bit rate decreases. This is due to increase in vulnerable interval with decrease of bit rate [4]. As a result, transmission probability of the interfering nodes increases. For a data rate of 10 Mbps and node spatial density of 10^{-4} BER_{link} is 7.9×10^{-4}, while it increases to 5×10^{-3} for a bit rate of 2 Mbps.

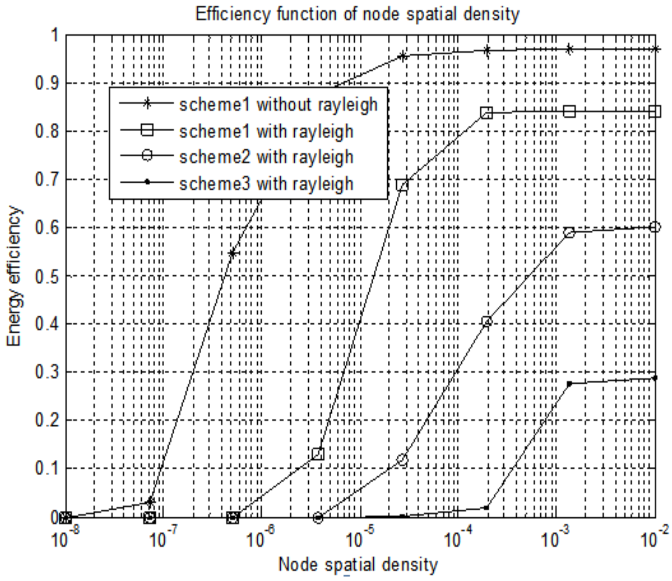

Fig. 1.3 Energy efficiency as a function of node spatial density considering packet size 511

Fig. 1.3 shows energy efficiency as function of node spatial density considering packet size 511 using different information delivery mechanisms. It is observed that energy efficiency performance degraded in Rayleigh environment. It is seen that scheme 1 is the best transmission scheme in Rayleigh environment. As a example at node density 3×10^{-4} energy efficiency using scheme 1 is 0.85, using scheme 2 is 0.42, using scheme 3 is 0.15. It is also seen that energy efficiencies in all three schemes improves 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 signal to interference noise ratio (SINR) beyond a certain limit.

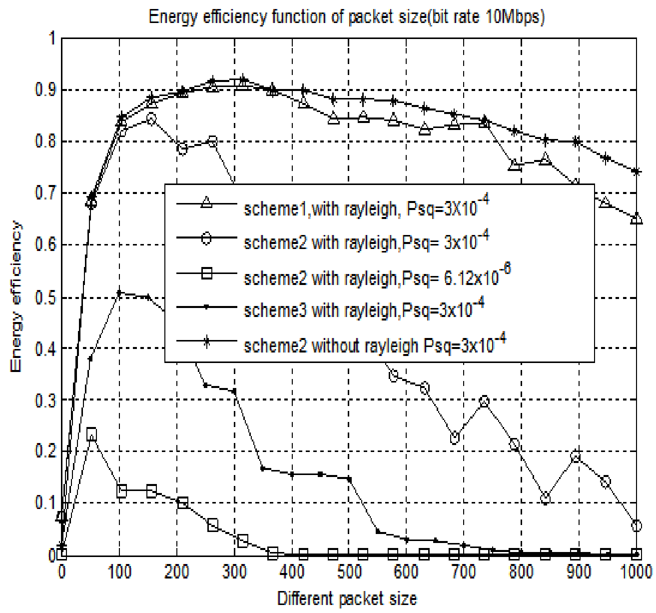

Fig. 1.4 Energy efficiency as a function of packet length for different retransmission schemes, $P_t = 100$ mw

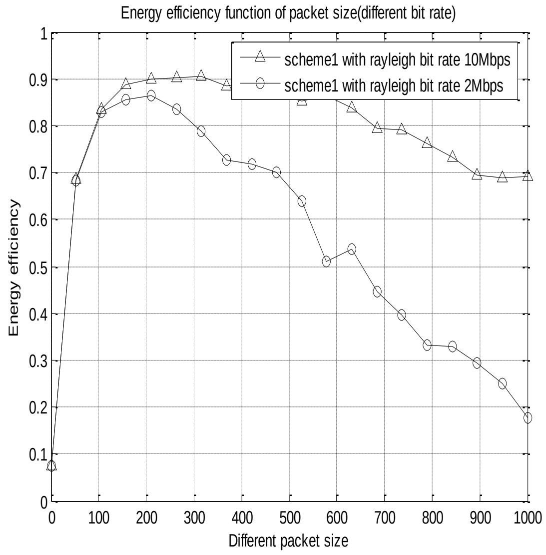

Fig. 1.5 Energy efficiency as a function of packet length for different bit rate using scheme 1.

Fig. 1.4 shows the energy efficiency as a function of packet length 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 optimal packet size from energy efficiency perspective. Thus there exists an optimal packet size for a particular network condition. Further optimal packet length increases with the increase in node spatial density. For example, in case of scheme 2 at node density of 6.12×10^{-6} optimal packet size is 55 bit but it increase to 150 bit when node density increases to 3×10^{-4}. 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. 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 presence of Rayleigh fading. Further energy efficiency improves with increase in node spatial density. It is seen that Scheme 1 is the most energy efficiency information delivery system. This is because in case of Scheme 1, average number retransmission is less compared to other two schemes. Further among the three retransmission schemes, Scheme I has the highest optimum packet size.

From fig 1.5 we observed the energy efficiency as function of packet size at fixed node density and different bit rate (10Mbps, 2Mbps). It is seen that decrease in bit rate at fixed node density efficiency performance degraded as compared to larger bit rate. it is also seen that in both bit rate value there is a optimum value of packet size at which efficiency is maximum at fixed bit rate, but decrease in bit rate decrease in efficiency of optimum packet, further it is seen that message length larger than optimal length at low bit rate, drop in energy efficiency much sharper than high bit rate.

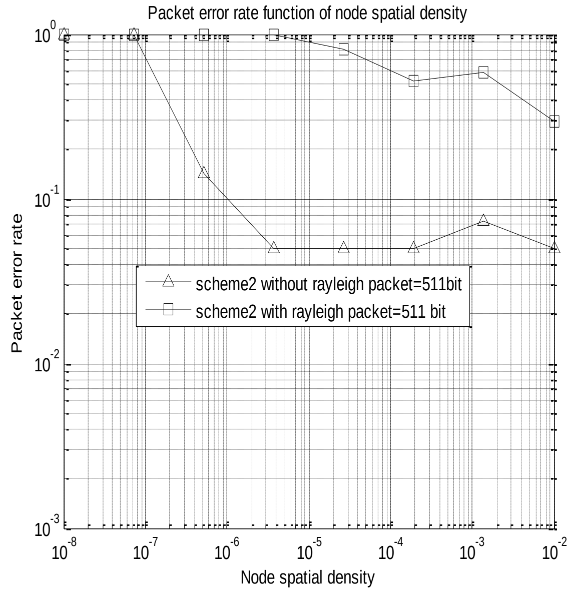

Fig. 1.6 Packet error rate (PER) as function of node density using scheme 2.

Fig. 1.6 shows the effective packet error rate (PER) using scheme 2. It is observed that performance is degraded in presence of Rayleigh Fading. It is also seen that PER performance improves with the increase in node spatial density. However it is also seen that beyond a certain node density the PER does not change with further increase in node spatial density and a floor in PER, as denoted by PER_{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 PER_{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 become close enough to the receiver. The nature of the curve of PER using scheme 3 is same that of scheme 2.

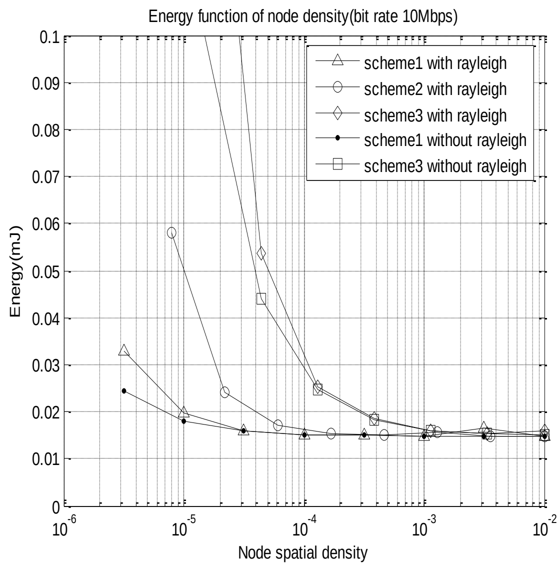

Fig. 1.7 Energy consumption to communicate a packet of length 100 bit vs node spatial density for different retransmission schemes, R_{bit} =10Mbps and P_t =100mW

Fig. 1.7 shows the energy required to successfully deliver a fixed packet of size of 100 bit considering three different information delivery mechanisms. Energy consumption in presence of Rayleigh fading is compared with that of path loss case only. It is seen that in presence of Rayleigh fading energy requirement increases. Further it is observed that scheme 1 is the best retransmission scheme in energy consumption perspective. Further it is observed that Scheme 1 and Scheme 2 consume nearly same amount of energy in high node density region. However Scheme 2 performs better in low node spatial density region. For example in presence of Rayleigh fading and at a node density of 6×10^{-6} required energy to communicate 100 bit of data is 58 μJ for Scheme 2 while it is more than 100 μJ for Scheme 3.

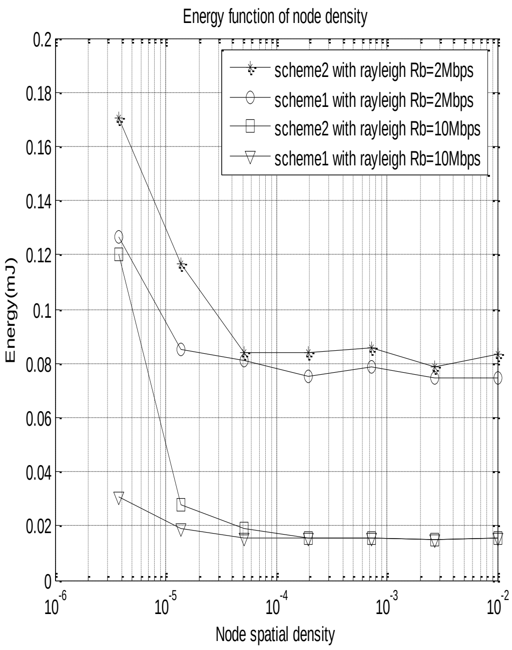

Fig. 1.8 Energy consumption to communicate a packet of length 100 bit vs node spatial density for different retransmission scheme for different bit rate, P_t =100mW

Fig. 1.8 shows the energy required to successfully deliver a fixed packet of size of 100 bit considering two different information delivery mechanisms for different bit rate. We observed the impact of bit rate on energy consumption, and concluded that energy consumption increases with decrease in bit rate and vice-versa. The reason behind more energy consumption with decrease in bit rate is, with less number of bits transmission we have to switch on the transmitter for long time.

It is seen that Scheme 1 performs better than the other two schemes. Further Scheme 2 consumes less energy than Scheme 3 in low node density region. It is also seen that Scheme 1 provides highest energy efficiency 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 1 yields highest size of optimum packet compared to other two schemes. 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 an energy efficient Wireless Sensor Network.

V. Conclusion

In this thesis route BER performance for end to end connectivity of wireless sensor network following square grid topology decreases with increase in node spatial density and beyond a certain node density BER route does not change with increase in node density and a floor appears. Route BER performance degrades with decrease in bit rate. Optimal common transmit power of sensor nodes in WSN increase with increase in bit rate and decrease with increase in node spatial density. The FEC scheme which utilizes optimum value of error correcting capability for a particular network condition is the optimum FEC scheme. By utilizing optimum FEC scheme we obtain maximum energy efficiency for a particular packet size for fixed node spatial density. In optimum FEC scheme energy requirement decreases with increase in packet size as well as increase in node spatial density. In infinite ARQ scheme initially energy requirement decreases with increase in packet size and then increases. Optimum FEC provides highest energy efficiency as compared to infinite ARQ scheme for single hop scenario. Optimum FEC scheme consumes less energy as compared to infinite ARQ for single hop scenario. Packet error rate (PER) performance of FEC scheme is better than infinite ARQ for single hop scenario. In case of multi hop communication, the optimum‘t’ value increases compared to single hop scenario. Optimum FEC for multi hop yields almost same energy efficiency as that of single hop with larger value of error correcting capability compared to single hop. Optimum FEC for multi hop consumes more energy as compared to single hop at same networking scenario. Value of optimum error correcting capability at different node densities for different sizes of packet is more than single hop.

Energy lavel performance of Scheme 1 is better than scheme 2 and 3 for transmission of information at the end of the multi hop using infinite ARQ in presence of Rayleigh Fading. Scheme 1 has the highest energy efficiency as compared to other schemes for multi hop scenario. However Scheme 2 consumes less energy than scheme 3 in low node density region. Scheme 1 has highest optimal packet length as compared to other schemes. With decrease in bit rate energy efficiency of different schemes decreases and total energy consumption increases. PER performance degrades in presence of Rayleigh Fading as compared path loss for different schemes.

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