Performance Analysis of Fault Tolerant Node in Wireless Sensor Network

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Abstract. An important issue in wireless sensor networks is the limited availability of energy and hence optimizing energy is very important. We propose a new scheme to reduce the energy consumption of nodes during packet transmission based on queue threshold by considering node failures into account. We develop an analytical model of a sensor network and analyze the performance of the proposed scheme in terms of performance parameters such as average energy consumption and mean delay considering node failures. We also derive the expression for the optimal value of threshold. Results show that the average energy consumption savings is 68% for the optimal threshold value when compared to no threshold condition and mean delay increases as failure rate increases. We perform simulations and the results obtained show that the analytical results match with the simulation results thus validating the analytical model.

Keywords: wireless sensor network; mean delay; average energy consumption; queue threshold.

1 Introduction

A critical issue in wireless sensor networks is represented by the limited availability of energy within the network and hence optimizing energy is very important. Zhi Quan et al. in [1] explained the two major techniques for maximizing the sensor network lifetime: the use of energy efficient routing and the introduction of sleep/active modes for sensors. J. Carle et al. presented a good survey in [2] on energy efficient area monitoring for sensor networks. C.F. Chiasserini and M. Garetto presented an analytical model in [3] to analyze the system performance in terms of network capacity, energy consumption and mean delay. For the first time in WSN applications, R. Maheswar and R. Jayaparvathy in [4] introduced a new energy minimization technique using IDLE and BUSY states where the energy consumed is minimized based on queue threshold using $M/G/1$ queueing model. However, in the above paper, node failures are not considered which in reality is not true.

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In this paper, we propose a new energy minimization scheme by which the average energy consumption of individual nodes in the sensor network is reduced during packet transmission based on queue threshold by considering node failures into account We develop an analytical model of a sensor network by considering node failures into account for analyzing the system performance in terms of average energy consumption and mean delay by considering node failures.

2 System Model

We consider a WSN that consists of large number of sensor nodes uniformly distributed in the field. All nodes send data to the sink node. A sink node collects data from all nodes and sends data to the BS. The two major operational states of a sensor node are sleep state and active state. The sleep state corresponds to the lowest value of the node energy consumption; while being asleep, a node cannot interact with the external world. During active state, a node may be in idle mode or it may generate data or it may transmit and/or receive data packets. Apart from the above said operational states, we define two sub-operational states during active state namely, IDLE state and BUSY state. During IDLE state, the node will be in idle mode or receive mode or the node may generate data but the node will not be in transmit mode. During BUSY state, the node will be in transmitting mode but the node will not be in idle mode.

All the nodes in the network during its period of active time will be in IDLE state or BUSY state. Here, a node in a network, during its period of active time, remains in IDLE state, switches to BUSY state when the node's buffer is filled at least with threshold number of packets (N) i.e., queue threshold and the node switches back from BUSY state to IDLE state when there are no packets in the buffer. Node failures during transmission are common and if any fault occurs during BUSY state, the transmission is stopped and a fault at node is detected [6]. The faulty node is removed from the fault and the packet transmission is continued at BUSY state. Such switching actions between IDLE state to BUSY state and BUSY state to IDLE state are referred to as transitions. The average energy consumption of a node depends on the queue threshold since most of the energy is consumed during transmission i.e., during BUSY state. We also determine optimal threshold value (N^*) of N for which the sensor node consume very less energy.

3 Performance Analysis

In this section, we analyse the behaviour of a single sensor node. The arrival of data packets to sensors follows a Poisson process with mean arrival rate per node (λ) and a node during its period of active time, remains in IDLE state and switches to BUSY state when the node's buffer is filled at least with threshold number of packets (N) and switches back from BUSY state to IDLE state when there are no packets in the node's buffer. We analyze the performance of the system in terms of the following parameters.

3.1 Mean Dealy

Mean delay experienced by the packets in a node is defined as the average waiting time of the packets in the queue. Based on *M/G/1* queueing model, the mean number of packets in the queue (L) is determined as,

$$L = \rho_{br} + \frac{N-1}{2} + \frac{\alpha\lambda\rho E[Br^2]}{2(1-\rho_{br})} + \frac{\lambda^2 \rho_{br}^2 E[S^2]}{2\rho^2(1-\rho_{br})} \tag{1}$$

where, $\rho = \frac{\lambda}{\mu}$, $\rho_{br} = \rho\left(1+\frac{\alpha}{\beta}\right)$, $E[S^2]$ is the second order moment of service time and $E[Br^2]$ is the second order moment of mean repair time. Since the packet size are equal, we consider a deterministic service time with mean $1/\mu$, and assuming, failure rate follows Poisson process with mean $1/\alpha$ and with mean repair time $1/\beta$, the mean number of packets in the queue (L) is determined as,

$$L = \rho_{br} + \frac{N-1}{2} + \frac{\alpha\lambda\rho}{2\beta^2(1-\rho_{br})} + \frac{\rho_{br}^2}{2(1-\rho_{br})} \tag{2}$$

3.2 Average Energy Consumption of a Node

During active time, the node remains in IDLE state when the number of packets is less than the queue threshold. When the threshold value is reached due to the arrival of packets, the node switches from IDLE state to BUSY state and transmits a preamble packet (271 bytes). Preamble packet is used for synchronization of a node with the sink node for the packet transmission [6]. After synchronization with the sink node, the node transmits all packets (each packet is of 36 bytes long) to sink node from its buffer and switches back from BUSY state to IDLE state when the buffer gets empty. The average energy consumption of a node $E(N)$ is obtained and it is given by

$$E(N) = C_H\left(\rho_{br} + \frac{N-1}{2} + \frac{\alpha\lambda\rho}{2\beta^2(1-\rho_{br})} + \frac{\rho_{br}^2}{2(1-\rho_{br})}\right) + C_T\left(\frac{\lambda(1-\rho_{br})}{N}\right) \tag{3}$$

3.3 Optimal Threshold value (N^*) of N

The optimal threshold value (N^*) the value of N for which the sensor node consumes minimum energy and it is determined and it is given by,

$$N^* = 0.5\left(-1 + \sqrt{\frac{8C_T\lambda(1-\rho_{br})}{C_H} + 1}\right) \tag{4}$$

4 Simulation Model

In this section, we present the simulation model. We consider Mica2 motes forming a wireless sensor network. We perform the simulation for a sensor network using the various parameters given in [6-7]. The values of C_T and C_H are determined as $C_T = 6.9$ mJ and $C_H = 0.8$ mJ. Simulations results are obtained for various scenarios by varying the mean arrival rate per node, failure rate and threshold number of packets to determine the average energy consumption of a node and the mean delay experienced by the packets per node in a network. Simulation results show that the average energy consumption is reduced by increasing the threshold value N and the minimum energy is consumed for optimal threshold value N^*. Results clearly show that there exists trade-offs between the energy consumption and the mean delay and the results also show that mean delay increases as failure rate increases the results.

5 Results and Discussions

In this section, we present the simulation and analytical results. Simulation and analytical results are taken to find the mean delay and the average energy consumption of a node by varying the queue threshold (N) and it is shown in Fig. 1 and Fig. 2. From Fig. 1, it is inferred that the mean delay increases linearly as queue threshold (N) increases because the packets has to wait for longer period for larger threshold value. From Fig. 2, it is inferred that, as N increases, the average energy consumption per node decreases and increases and minimum energy is consumed for the optimal threshold. By assuming $N = 4$, $N^* = 6$ and $N = 10$ and mean arrival rate per node = 2, the energy consumption savings (%) is determined and it is found to be 66%, 68% and 63% respectively when compared to no threshold condition (i.e., $N = 1$). The optimal threshold value (N^*) using equation (4) for mean arrival rate per node of 2 is 6. Hence, it is also clear that the maximum energy savings of 68% is achieved for the optimal threshold value (N^*) = 6 and it is shown in Fig. 3. From Fig. 4, it is also inferred that mean delay increases as the failure rate increases.

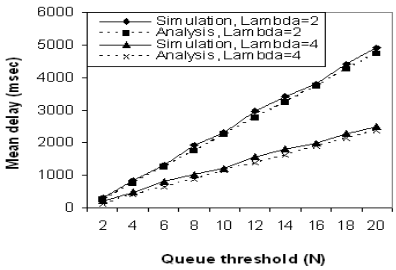

Fig. 1. Queue threshold (N) vs mean delay (msec)

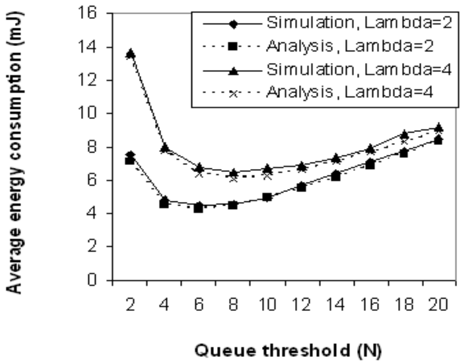

Fig. 2. Queue threshold (*N*) vs average energy consumption (mJ)

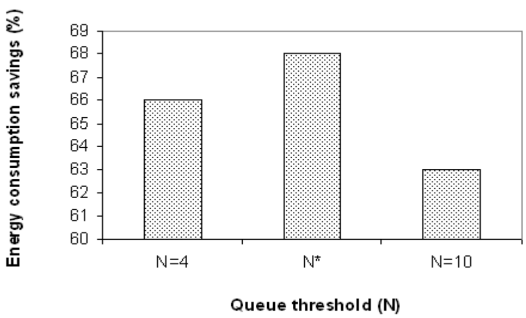

Fig. 3. Queue threshold (*N*) vs energy consumption savings (%)

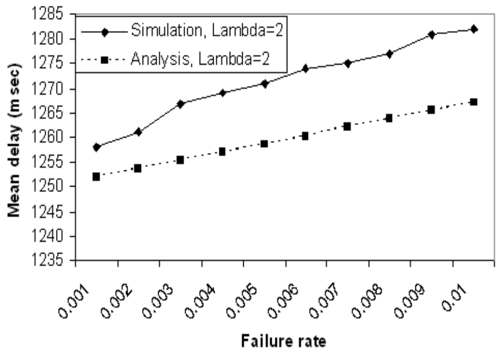

Fig. 4. Failure rate vs mean delay (msec)

6 Conclusions

In this work, we have proposed a new energy minimization scheme by which the average energy consumption of nodes in the sensor network is reduced based on queue threshold during its period of active time. We have developed an analytical model of a sensor network by considering node failures into account using $M/G/1$ queueing model and the system performance in terms of average energy consumption and mean delay have been determined. The results show that the average energy consumption savings is 68% for the optimal threshold value when compared to no threshold condition for mean arrival rate per node of 2 and there exists trade-off between the average energy consumption and mean delay. Also, it is inferred that mean delay increases as the failure rate increases. The simulations were performed for 100 runs and a confidence interval of 95% is obtained and thus the results show that our analytical results present an excellent matching with simulation results under various scenarios showing the accuracy of our approach.

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