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PERFORMANCE EVALUATION OF CLUSTER BASED WIRELESS SENSOR NETWORK USING M/G/1 QUEUING MODEL

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Abstract

Wireless sensor network has broad application like, environment monitoring, target tracking. Wireless sensor network usually application specific. Unique characteristics of WSN as limited bandwidth, computing capacity, data delivery delay and severe energy constraints make their design more challenging. A critical issue is limited availability of energy within the network and hence optimizing the energy is very important. An important issue in wireless sensor network is the limited availability of energy and hence optimizing energy is very important. Most of the energy is consumed during packet transmission. The new scheme to reduce the energy consumption of node during packet transmission based on queue threshold by taking channel contention into account. For that we proposed an analytical model of a cluster based sensor network using M/G/1 queuing model. An analytical model that specifically represents the cluster head's behavior in IDLE state and BUSY state during its period of active time. M/G/1 queuing model is developed to investigate network performance in term of mean delay and average energy consumption. M/G/1 queuing model is applied to Heterogeneous and Homogeneous cluster based sensor network and analysis the comparative result of both

1. INTRODUCTION

A wireless sensor network (WSN) is envisioned as a cluster of tiny power constrained devices with functions of sensing and communications. Sensors closer to a sink node have a larger forwarding traffic burden and consume more energy than nodes further away from the sink An important issue in wireless sensor networks is the limited availability of energy and hence optimizing energy is very important. In any sensor node, most of the energy is consumed during packet transmission. We propose a new scheme to reduce the energy consumption of nodes during packet transmission based on queue threshold by taking channel contention into account. For that we propose an analytical model of a cluster based sensor network using M/G/1 queuing model and analyze the performance of the proposed scheme in terms of performance parameters such as average energy consumption and mean delay. We will also derive the expression for the optimal value of threshold. . For that develop an analytical model of a cluster based sensor network using M/G/1 queuing model.An analytical model that specifically represents the cluster head's behavior in IDLE state and BUSY state during it's period of active time. M/G/1 queuing model is proposed to investigate network performance in term of mean delay and average energy consumption. M/G/1 queuing model is applied to Heterogeneous and Homogeneous cluster based sensor network and analysis the comparative result of both. Queuing theory is the mathematical study of waiting line, using models to show results, and show opportunities, within arrival, service and departure process. In queuing theory, a queuing model is used to approximate a real queuing situation or system, so the queuing behaviour can be analysed mathematically.

1.1 Why Queuing Analysis?

An analytical model, which is one that can be expressed as a set of equations that can be solved to yield the design parameter like, response time throughput etc…

For computer, operating system, and networking problem and for many practical real world problems, analytical model based on queuing theory provide a reasonably good fit to reality.

Queuing analysis can literally be accomplished in matter of minutes for a well define problem.

2. LITERATURE REVIEW

The unique characteristics of WSNs such as limited bandwidth, computing capacity, data delivery delay and severe energy constraints make their design more challenging. 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.

ZhiQuan et al. explained [4] 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. One simple method proposed to prolong the lifetime of sensor networks is the introduction of active and sleep modes for sensor nodes.

J. Carle et al. presented [5] a good survey on energy efficient area Performance Analysis of Cluster Based Sensor Networks using N-Policy M/G/1 Queueing Model 178 monitoring for sensor networks. The authors have observed that the best method for conserving energy is to turn off as many sensors as possible, while still keeping the system functioning.

C.F. Chiasserini and M. Garetto presented [2] an analytical model to analyze the system performance in terms of network capacity, energy consumption and mean delay, against the sensor dynamics in on/off modes and found there exists trade-offs between energy consumption and mean delay.

Most existing work on sensor networks consider homogeneous sensor networks where all sensor nodes are assumed to have the same capabilities in communications, computation, memory storage, energy supply, reliability and other aspects. To avoid more delay in the data delivery that happens through multi-hop communication, clusters are formed in the sensor network and a cluster head is selected for each cluster. Here, all nodes in a cluster can communicate with the cluster head directly but the energy consumed and the time involved while selecting the cluster head is more. Heterogeneous Sensor Networks (HSNs) consists of two physically different types of sensor nodes and several recent papers have studied about HSNs and these literatures showed that HSNs can significantly improve sensor network performance.

3. SYSTEM MODEL

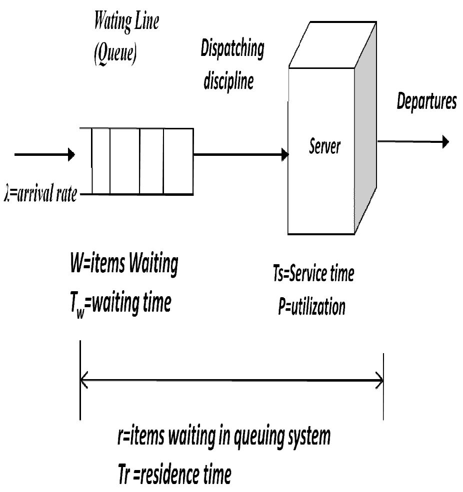

Fig.1. Queuing system structure and parameters for single-server Queue

In these models, three various sub-processes may be distinguished:

- **Arrival Process:** includes number of customers arriving, several types of customers, and one type of customers' demand, deterministic or stochastic arrival distance, and arrival intensity. The process goes from event to event, i.e. the event "customer arrives" puts the customer in a queue, and at the same time schedules the event "next customer arrives" at some time in the future.
- **Waiting Process:** includes length of queues, servers' discipline (First In First Out). This includes the event "start serving next customer from queue" which takes this customer from the queue into the server, and at the same time schedules the event "customer served" at some time in the future.
- **Server Process:** includes a type of a server, serving rate and serving time. This includes the event "customer served" which prompts the next event "start serving next customer from queue".

Queuing model can be represented using Kendall's notation.

❖ The notation is X/ Y/ N where
  - X – Inter-arrival time distribution
  - Y – Service time distribution
  - N – Number of servers

❖ Some standard notation for distributions (X and Y) are :
  - M – Markovian (Possion, exponential) distribution
  - D – Degenerate (Deterministic) distribution (Constant)
  - G – General Distribution (Arbitrary)
  - PH – A phase type distribution

The fundamental task of Queuing Model is as follows: Given the following information as a input,

- Arrival Rate
- Service time
- Number of Server

Provide as output information concerning:

- Item Waiting
- Waiting Time
- Items Queued
- Residence Time

3.1 M/G/1 Queuing Model

- M/G/1 (X/Y/N)
- Arrival distribution: Poisson rate (l) M tells the use of exponential probability
- Service distribution: G signifies general distribution time
- Number of server: N = 1 represent the number of server

M/G/1 queuing model is applied to Heterogeneous and Homogeneous cluster based sensor network.

In HSN model that consists of two physically different types of sensor nodes. A small number of powerful high-end sensors (H-sensors) and a large number of low-end sensors (L-sensors) uniformly distributed in the field.

Two major states of HSN are:

1. Active state
2. Sleep state

In this project we define two sub-operational states during **Active** state namely:

1. IDLE state
2. Busy State

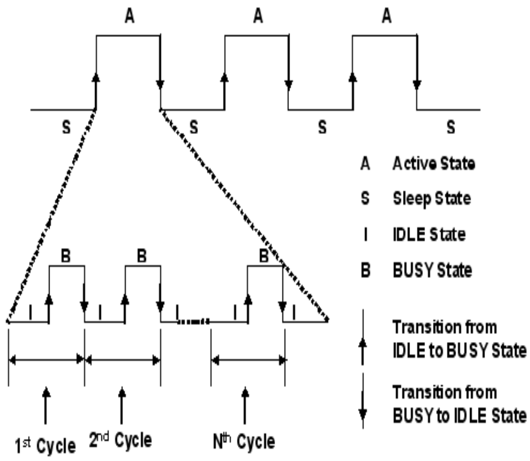

Fig. 2. Sub-operational states of H-sensor node during active state.

All the H-sensors in all clusters during its period of active time will be in IDLE state or BUSY state. Here, an H-sensor node in a cluster, 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. The average energy consumption of an H-sensor node or CH 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 for which the H-sensor nodes consume very less energy. Since the focus of this work is to minimize the energy consumption of individual H-sensor nodes in different clusters during its period of active time based on queue threshold, we analyse the behaviour of a single H-sensor node.

Performance Analysis of Cluster Based Sensor Networks using N-Policy M/G/1 Queuing Model

The following assumptions are made for analysis:

• All L-sensor nodes in a HSN are identical

• All H-sensor nodes in a HSN are identical

• The arrival of data packets to H-sensor nodes is assumed to follow a Poisson process withmean arrival rate per CH (λ)

• Packets are of fixed size

• Packets are delivered from H-sensor node to BS with mean service time (1/μ)

• Channel access time follows general distribution with mean 1/

• Buffer is assumed to be empty whenever the H-sensor node switches from sleep to active state

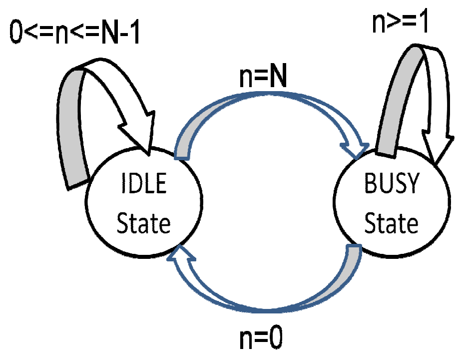

Fig. 3. Two-state transition diagram of an L-sensor in idle state and busy state

All the H-sensors in all clusters during its period of active time will be in IDLE state or BUSY state. Here, an H-sensor node in a cluster, 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 nopackets in the buffer. The two-state transition diagram of an H-sensor node in IDLE state and BUSY state is shown in figure 3. During BUSY state, the H-sensors deliver the packets to the BS. 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 an H-sensor node or CH depends on the queue thresholdsince 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 H-sensor nodes consume very less energy. Since the focus of this work is to minimize the energy consumption of individual H-sensor nodes in different clusters during its period of active time based on queue threshold, we analyses the behavior of a single H-sensor node.

4. PERFORMANCE ANALYSIS

In this section, we analyze the behavior of a single H-sensor node. As mentioned in section II, thearrival of data packets to H-sensors follows a Poisson process with mean arrival rate per node (λ) and an H-sensor in a cluster during its period of active time, remains in IDLE state and switches to BUSY state when the H-sensor 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. Weanalyze the performance of the system in terms of the following parameters.

(a) Mean Delay :

Mean delay experienced by the packets in an H-sensor node is defined as the average waiting time of the packets in the queue. Based on M/G/1 queuing model, the mean number of packets in the queue (L) is determined as,

$$L = \rho + \frac{\lambda^2 E[S^2]}{2(1-\rho)} + \frac{N(N-1) + 2N\sigma + \lambda^2 E[D^2]}{2(N+\sigma)}$$

where,

$$\rho = \frac{\lambda}{\mu}$$

and

$$\sigma = \frac{\lambda}{\gamma}$$

(b) Average Energy Consumption of an H-Sensor Node :

During active time, the H-sensor 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 H-sensor node waits for the free channel for a mean channel access time 1/_ [13]. Once the channel is available, the node switches from IDLE state to BUSY state and transmits a preamble packet (271 bytes). Preamble packet is used for synchronization of an H-sensor node with the BS for the packet transmission [14]. After synchronization with the BS, the H-sensor node transmits all packets (each packet is of 36 bytes long) to BS from its buffer and switches back from BUSY state to IDLE state when the buffer gets empty. Hence a cycle during the active time of an H-sensor node constitutes,

- Arrival of data packets
- Duration of time spent for channel access

Transition from IDLE state to BUSY state

- Synchronization with the BS
- Transmission of packets to BS
- Transition from BUSY state to IDLE state

The H-sensor node, during its period of active time undergoes many such cycles depending upon the value of N. To determine the average energy consumption of an H-sensor node during its period of active time, we consider the following parameters that are associated with the energyconsumption of an H-sensor node during transmission:

CH Energy consumption due to transmission of a packet from CH to BS in joules

CT Energy consumption due to transitions and synchronization in joules

E(N) Average energy consumption of an H-sensor node as a function of N in joules

E[I] Average duration of time the H-sensor node is in IDLE state

E[C] Average duration of cycle

NcyNumber of cycles per unit time

The value of queue threshold has significant effect on the average number of cycles or number of cycles per unit time (Ncy). The Ncyincludes arrival of data packets, time spent on channel access, transitions, synchronization and transmission of packets. Since the focus of this paper is to reduce the average energy consumption during transmission based on queue threshold, the parameters that consumes energy during BUSY state are alone considered i.e., CT energy consumed due to transitions and synchronization and CH energy consumed during transmission. The energy consumed during sleep state, the energy consumed during idle mode and receive mode, the energy consumed during data generation and channel access time in active state are not considered.

The average energy consumption of an H-sensor node E(N) is obtained and it is given by :

$$E(N) = C_H\left\{\frac{N(N-1)}{2(N+\sigma)} + \frac{\rho(2-\rho)}{2(1-\rho)} + \sigma\right\} + C_T\left\{\frac{\lambda(1-\rho)}{N+\sigma}\right\}$$

(c) 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 given as :

$$N^* = 0.5\left(\sqrt{\frac{8C_T\lambda(1-\rho)}{C_H} + (1+2\sigma)^2} - (1+2\sigma)\right)$$

5. CONCLUSION

In this work, we have proposed a new energy minimization scheme by which the average energy consumption of nodes that acts as cluster head in the sensor network is reduced based on queue threshold during its period of active time. We have developed an analytical model of a cluster based sensor network by taking channel contention into account using M/G/1 queuing model and the system performance in terms of average energy consumption and mean delay have been determined.

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