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Priority Based Queue Management with Adaptive Duty Cycle Control in WSN

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***Abstract*—This paper proposes a control-based approach to control the duty cycle dynamically for wireless sensor networks. In order to have a high performance under various traffic changes, the proposed method controls the duty cycle through the queue management. By minimizing the delay through feedback controller, an energy consumed by the node can be minimized by adapting priority based queue management considering the queue length. In this approach, the sleep time of a node can be adjusted dynamically to changing traffic rates. A priority module will be constructed to decide the priority of the incoming packets based on delivery time, delivery location, of packets. An efficient synchronization scheme is also proposed which guarantees that the receiver and sender nodes are active at the same time.**

***Keywords:* Wireless sensor network, duty cycle, priority, queue management, energy efficiency**

1. INTRODUCTION

Wireless sensor network are used in physical environment to monitor real world. These networks consist of small sensors called as sensor node. They are battery operated, resource constrained, with very small amount of memory. In recent few decades Wireless Sensor Network gain very much popularity due to its efficient, flexible and support of wide variety of application. But in such type of network battery replacement is infeasible and thus energy preservation is main concern of designed protocol. Normally energy consumption is reduced by turning off the radio of sensor node. Therefore, a major problem in deploying WSNs is their dependence on limited battery power.

2. LITERATURE REVIEW & RELATED WORK

Many research efforts in the recent years have focused on developing power saving methods for WSNs. These methods include power-efficient MAC layer protocols and network layer routing protocols.

Some of the TDMA-based protocols like PEDAMACS [1], BitMAC [2], uMAC [3], PMAC [4], [5] generally minimizes power consumption and guarantee the bounded latency in loaded traffic conditions. But these protocols require tight synchronization, which impacts scalability and flexibility.

Preamble sampling protocols [6], [7], [8] causes high collision rates.

Sensor MAC (SMAC) [9] forces sensor nodes to operate at low duty cycle by repeatedly putting nodes in active and sleep periods. Since it uses a fixed duty cycle for all the sensor nodes, it does not adapt to the network traffic change and the delay issue is neglected. In fact, the sleep periods in SMAC save power but introduce extra end-to-end delay, i.e., sleep delay.

TMAC [10] improves on SMAC by using an adaptive duty cycle in which the duration of active periods is no longer fixed. If there is no activity for a certain time, TMAC can switch its radio off before the active period ends. Therefore, the nodes can go to sleep rather early, which further saves power. However, lowering the power consumption induces the increased delay.

3. PROBLEM STATEMENT

As a solution, in this paper, an adaptive duty cycle control approach based on priority based queue management is proposed with the aim of saving the power with reduction in the delay. The proposed approach uses only the information like local queue length available at the node. Since queue states indicates the network status, so that any variation in the traffic or in the network can be inferred implicitly. Using the queue length and its variations of a sensor node, a control-based approach is proposed in addition with an efficient synchronization scheme with an active pattern. Priority of the incoming packet is considered with queue.

PROBLEM ANALYSIS

3.1. NETWORK MODELLING

To model the network, it is assumed that the average network condition of a link does not change frequently. The queue length of link l_m at the $(n+1)^{th}$ iteration is mathematically represented by the following discrete-time model where the duration of control period equals τ_c:

$$\begin{aligned} q_{l_m}(n+1) &= [q_{l_m}(n) + w_m(n) - D_{l_m}(\tau_c - k_m(n)\cdot c_m(n) \\ &\qquad - mod(\tau_c, c_m(n) + T_a))]^+ \\ &= [q_{l_m}(n) + w_m(n) - D_{l_m} k_m(n) T_a]^+, \end{aligned}$$

The value of T_a represents the active period with a fixed size. The value of $k_m(n)$ stands for the number of active times during iteration (n, n+1). Here, w_m is the total number of forwarded packets from descendants during iteration (n, n+1) including its own generated traffic. C_m is the set of child nodes of node m. D_{lm} represents the actual successful transmission rate of link l_m. Specifically, $D_{lm} = V_{lm}D$, where V_{lm} is the average successful packet transmission ratio of link l_m. The value of V_{lm} indicates the average link quality considering contention, collision, and retransmission. Thus, the value of V_{lm} is simplified to be stable during a control period. Active periods are of fixed size whereas the length of sleep periods depends on a value determined by the duty cycle controller. The value of $c_m(n)$ remains constant during iteration (n, n+1). Therefore, the value of $D_{lm}k_m(n)T_a$ denotes the average number of packets successfully transmitted to the receiver during iteration (n, n+1).

3.2. DUTY CYCLE CONTROLLER DESIGN

Figure 1 illustrates a basic model for the duty cycle controller. At every control period, each node computes its sleep time using the local queue length. During a single control period there may be multiple active times and the queued packets are transmitted during active times.

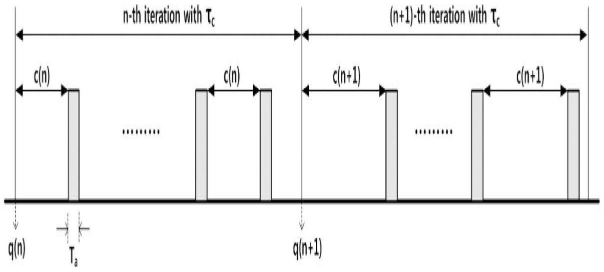

Fig. 1 Duty cycle control model

where,

τ_c is the time period of the duty cycle, specifically the time duration of iteration (n, n+1)

c(n), c(n+1) is the sleep time of node

T_a is the active period with fixed size

q(n), q(n+1) is the queue length of the link at the node.

Based on the network model, an adaptive duty cycle controller will be designed to control the duty cycle of each node by dynamically adjusting the sleep interval time under changing network condition. In each control period, the controller will be designed to determine a node's sleep time using the local information available at the node.

In WSN, queuing delay is one of the significant components of end-to-end delay with unpredictable packet generating time. Generally, a larger queuing occurs in a node when it receives more data than it can forward. In particular, in a sensor network where the packets converge towards a sink, the excessive packets received by a node eventually result in an excessively large queue length. This phenomenon may be incurred by a combination of several reasons, such as congestion, contention, collision, and high traffic. Thus, the priority module is designed which assigns the priority to the incoming packets based on its data length or size. For this, the trajectories of the queue (the queue length and its changing trends) will be used as an implicit indicator of network status, such as traffic load, route depth, or link quality. Based on the queue length and its variations, a dynamic duty cycle control scheme is proposed to meet time-varying non uniform traffic loads by constraining the queue length at a predetermined threshold value.

The proposed controller is supposed to adjust the sleep time so that the queue length at the steady state is equal to the predetermined queue threshold. The proposed controller at each sensor node does not account for the explicit number of nodes in the same transmission domain. Instead, it uses the local queue length and its variations for computing the duty cycle.

3.3. SYNCHRONIZATION MODULE

Existing schemes with common active periods adopt a constant duty cycle because of the difficulty in maintaining synchronization among the sensor nodes. However, unlike these schemes, this proposed controller for each node determines its duty cycle individually, and thus an efficient synchronization scheme, that guarantees that the receiver and sender nodes are active at the same time, while keeping the duty cycles different from those of all other nodes.

First, a control period, τc, is divided into K_{max} time slots

$$K_{\max} = \left\lfloor \frac{\tau_c}{T_a} \right\rfloor$$

An active pattern A_m, is introduced which indicates the active/sleep time slots for sensor node m over the overall K_{max} slots. The active pattern, A_m, is determined based on the duty cycle adjusted by the proposed controller of node m. The determined active pattern is added instead of the time of the next sleep in the existing SYNC packet.

Actually Am is denoted as the 3-tuple
(k_m, L_m, S_m), where
k_m: number of active time slots of node m during a control period.
L_m: interval between active time slots in R of node m.
S_m: starting time slot number of node m in R.
And R = {1, 2, . . .,K_{max}) be the set of overall time slots in a control period.

Whenever a sensor node receives a SYNC packet from its routing parent, it determines a new active pattern based on its own duty cycle and the active pattern given in the received SYNC packet. Otherwise, it simply updates its schedule table.

The distinct feature of the proposed synchronization scheme is its scalability, in the sense that the duty cycle adaptation of each node does not affect its neighboring schedules. Thus, a sensor node does not need to adopt a constant duty cycle by forming a virtual cluster, because the determined active schedule of a sensor node is automatically included in that of its routing parent. Accordingly, the receiver and sender nodes are active at the same time, while keeping the duty cycles different from those of all other nodes.

The proposed control and synchronization scheme require sensor nodes to control the duty cycle and transmit the determined schedule once every control period, which incurs a system overhead. To reduce this overhead, the control period can be set to be quite long if the network condition does not change dramatically. However, the increase in τ_c leads to longer settling times and a smoother evolution of the queue length due to there being fewer updates. In addition, a large value of τ_c could cause the network adaptation to be slow. Meanwhile, the decrease in τ_c leads to a shorter settling time, but an increase in the control overhead.

3.4 PRIORITY MODULE

To decide the priority of the incoming packets based on delivery time, delivery location, of packets (i.e, urgency of packets), a priority module will be constructed.

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