Dynamic Adjustment of Ad hoc Traffic Indication Map (ATIM) window to save Power in IEEE 802.11 DCF

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Abstract—Wakeup schemes that turn off sensors' radio when communication is not necessary have great potential in energy saving. At the start of each beacon interval in the IEEE 802.11 power saving mode specified for DCF, each node periodically wakes up for duration called the ATIM Window. However, in the power saving mechanism specified in IEEE 802.11, all nodes use the same ATIM window size. Since the ATIM window size critically affects throughput and energy consumption, a fixed ATIM window does not perform well in all situations. This paper proposes an adaptive mechanism to dynamically choose an ATIM window size according to network condition. Simulation results show that the proposed scheme outperforms the IEEE 802.11 power saving mechanism in terms of the amount of power consumed and the packet delivery ratio.

Index Terms—ATIM, Asynchronous wakeup schemes, Power saving mechanism, IEEE 802.11 DCF

I. INTRODUCTION

Wireless sensor networks (WSNs) are an emerging paradigm posing new challenges for researchers in wireless communications. This new class of networks closely resembles the behavior of wireless ad hoc networks. Nevertheless, they have a few unique differences; the principal one is the small size of nodes constituting a WSN. Although smaller nodes make WSNs suitable for several existing and emerging applications related to information sensing, this also implies that the nodes have limited resources, i.e., CPU speed, memory, battery, and radio interface.

One typical form of ad hoc networks is composed of portable mobile terminals such as laptop computers. "Ad hoc network" in this paper can be a fully connected network or a multi-hop network. Among all the components, the wireless Network Interface Card (NIC) is a very power-consuming one. One critical issue for almost all kinds of portable devices supported by battery powers is power saving. Battery power is a limited resource, and it is expected that battery technology is not likely to progress as fast as computing and communication technologies do. Hence, how to lengthen the lifetime of batteries is an important issue, especially for MANET, which is all supported by batteries. One method is to switch NIC off dynamically whenever possible, it can be realized through a time-driven mechanism or a packet-driven mechanism.

The IEEE 802.11 Wireless LANs (WLANs) have been extensively deployed in the recent years in many different environments for enterprise, home, and public networking. They support two types of WLAN: one in infrastructure mode and the other in ad hoc mode. In the infrastructure mode, a station serves as the access point and communications can only take place between the access point and the other members of the basic service set (BSS). When the infrastructure does not exist or does not work, the ad hoc mode is useful. In the IEEE 802.11 standards [1], an ad-hoc network is called an Independent Basic Service Set (IBSS), in which all of the stations are within each other's transmission range.

The IEEE 802.11 consists of two components: PCF and DCF [1]. PCF (Point Coordination Function) is a centralized medium access control protocol, whereas DCF (Distributed Coordination Function) is a fully distributed protocol. IEEE 802.11 specifies a power saving mechanism for both PCF and DCF. This paper focuses on the power saving mechanism proposed for DCF. The IEEE 802.11 supports two power modes: active and power-saving (PS). A host in the active mode is fully powered and thus may transmit and receive at any time. On the contrary, a host in the PS mode only wakes up periodically to check for possible incoming packets from the access point (AP). A host always notifies its AP when changing modes.

In the power saving mechanism specified in IEEE 802.11, all nodes use the same ATIM (Ad hoc Traffic Indication Map) window size, as well as identical beacon intervals [1]. Since the ATIM window size critically affects throughput and energy consumption, a fixed ATIM window does not perform well in all situations [2]. If the ATIM window is chosen to be too small, there may not be enough time available to announce buffered packets, potentially degrading throughput. If the ATIM window is too large, there would be less time for the actual data transmission, since data is transmitted after the end of the ATIM window, again degrading throughput at high loads. Large ATIM windows can also result in higher energy consumption since all nodes remain awake during the ATIM window. Thus, a static ATIM window size cannot always perform well. This

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paper proposes a dynamic mechanism for choosing an ATIM window size according to network condition. We refer to our mechanism as Dynamic adjust ATIM window Mechanism (DAM). We present the rules for increasing the ATIM window size and the rule for decreasing the ATIM window size.

To verify the effectiveness of our mechanism, we implement it using IEEE 802.11 MAC in ns-2. Simulation results show that our scheme achieves 40 ~ 50% savings in power consumption as compared to a network without power management.

The rest of this paper is organized as follows. Section II reviews the related works, and Section III presents an overview of the DCF power saving mechanism in IEEE 802.11. In section IV, we present the proposed mechanism, DAM. Section V describes our simulation model and discusses the simulation results. Section VI concludes this paper.

II. RELATED WORKS

There are several solutions addressing the problem of energy wastage due to idle listening. Energy conservation is of paramount importance in sensor networks. One approach to prevent energy wastage is to control the node receiver by setting it to sleep mode when no data is expected and to wake up mode when communication is expected (wakeup schemes).

Wakeup schemes can be categorized as synchronous or asynchronous schemes [3]. The power saving mechanism defined in IEEE 802.11 is one example of synchronous wakeup [1]. Nodes all wakeup during the wakeup rendezvous and communicate with each other. Time synchronization in large scale distributed networks such as sensor networks, is generally very costly.

Many proposals exist for asynchronous wakeup schemes, wherein each node follows a certain schedule of periodic wakeup and sleep. The final objective of all the schemes is to guarantee the overlap of wakeup times of neighboring nodes within finite time. There exist several proposals for asynchronous wakeup. [4] proposes three asynchronous power management protocols, in which each node follows a certain schedule to periodically wake up and go to sleep.

PAMAS (Power Aware Multi-Access) protocol [5] is an adaptation of the basic mechanisms of IEEE 802.11 to a two-radio architecture. Using the control channel, a node determines when to power off and the power off duration. This scheme has the disadvantage of requiring two channels for communication.

STEM (Sparse Topology and Energy Management) [6] also uses two radios, one functions as wakeup radio and the other is used for data transmissions. In STEM, each node periodically turns on their wakeup radio for T_{wake} every T duration, where T_{wake}/T is defined as the duty cycle ratio. STEM achieves low power consumption of wakeup radio by using a large duty cycle ratio, instead of assuming a low power wakeup radio.

S-MAC [7] is a protocol developed to address the energy issue in the sensor networks, building on contention based protocols like IEEE 802.11. S-MAC follows a simple scheduling scheme that allows neighbors to sleep for long periods and to synchronize wakeups. A complete sleep/wake cycle constitutes a frame. Each frame begins with a listen period for nodes that have data to send. A sleep period follows, during which nodes sleep for a certain period if they have no data to send or receive. Otherwise, they remain awake and exchange data, if they have data to communicate. All nodes independently choose their listen/sleep schedules and share their schedules with neighbors. S-MAC needs synchronization to some extent, but that is not as critical as in TDMA-based protocols.

III. POWER SAVING MECHANISM IN IEEE 802.11

Power saving in IEEE 802.11 consists of a timing synchronization function (TSF) and the actual PS mechanism [2]. In the TSF for an infrastructure network (PCF), the AP is responsible for generating beacons which, along with other information, contain a valid timestamp. Stations within the BSS adjust their local timers to that timestamp. If the channel is in use after the beacon interval the AP has to defer its beacon transmission until the channel is free again. The power management in the PCF is simple due to the existence of the AP as a central buffer for all packets destined for the stations in doze mode. Along with the beacon the AP transmits a so-called traffic indication map (TIM). All unicast packets for stations in doze mode are announced in the TIM. Afterward the mobiles request the packets from the AP. If broadcast/multicast frames are to be transmitted, they are announced by a delivery TIM (DTIM) and are sent immediately after.

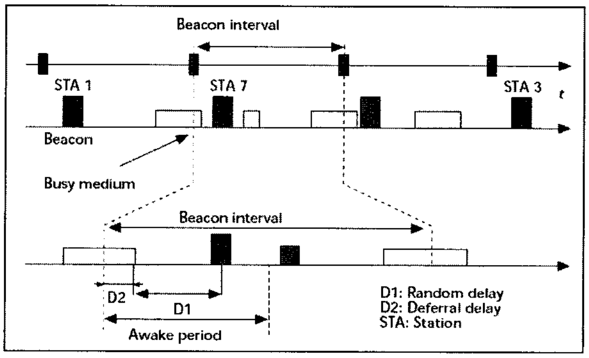

Fig. 1 The TSF for ad hoc networks in 802.11

The TSF is more complicated for an ad hoc network (the DCF, Fig. 1). Due to the absence of a trusted authority the timers adjust in a distributed way: Every station is responsible for generating a beacon. One purpose of the beacons is to synchronize the different nodes. After the beacon interval all stations compete for transmission of the beacon using the standard backoff algorithm. The first station "wins" the competition and all others have to cancel their beacon transmission and adjust their local timers to the timestamp of the winning beacon. Power management in the DCF is based on the same distributed method used for the TSF. Packets for a station in doze state have to be buffered by the sender until the end of the beacon interval. They have to be announced using ad hoc TIMs (ATIMs), which are transmitted in a special interval (the ATIM window) directly after the beacon. ATIMs are unicast frames which have to be acknowledged by the receiver. After sending the acknowledgment, the receiver does not fall back into doze state but stays awake and waits for the announced packet.

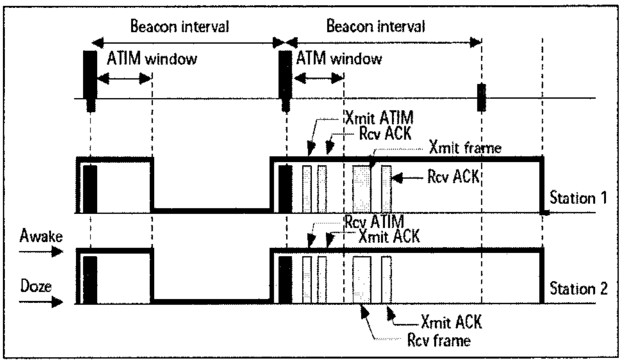

Fig. 2 Power management in the DCF of 802.11

Fig. 2 illustrates the power saving mechanism in DCF. Time is divided into beacon intervals. At the start of each beacon interval, each node must stay awake for a fixed time interval, called ATIM window. Thus, during an ATIM window, all nodes are in awake state. The ATIM window is utilized to announce any packets pending transmission to nodes in doze state.

In the power saving mechanism, when any node has a packet destined for another node, this packet is announced during a subsequent ATIM window. For instance, in Fig. 2, station 1 announces a packet destined for station 2 by transmitting an "ATIM frame" during the ATIM window. The transmission of an ATIM frame is performed using the CSMA/CA (collision avoidance) mechanism specified in IEEE 802.11. When a node has sent an ATIM frame to another node, such as station 1 in our example, the node remains awake for the entire beacon interval. A node that receives an ATIM frame replies by sending an ATIM-ACK. Such a node remains awake for the entire beacon interval, after transmitting the ATIM-ACK. In our example, station 2 sends ATIM-ACK to station 1 and remains awake for the rest of the beacon interval. Transmission of one or more data packets from station 1 to station 2 can now take place during the beacon interval, after the end of the ATIM window. A node that has no outstanding packets to be transmitted can go into the doze state at the end of the ATIM window, if it does not receive an ATIM frame during the ATIM window.

IV. PROPOSED SCHEME

We propose a Dynamic adjust ATIM window Mechanism (DAM). In the proposed DAM, we specify a finite set of ATIM window sizes that may be used by each node. Each node chooses an ATIM window size according to its round-trip time (RTT). This might potentially result in each node using a different ATIM window size.

The basic operation of DAM is similar to the power saving mechanism specified in IEEE 802.11, but the following modifications are made.

1) Piggybacking of the transmit time

Each node piggybacks its transmit time on all transmitted packets. Thus, each node may be aware of the round trip time between sender and receiver. When each node receives a packet from sender, it calculates the RTT, and updates its neighbor list. To implement the protocol, each node keeps a neighbor list in which each entry has the fields as shown in Table 1.

Table 1 Fields in an entry in a neighbor list

node id	round trip time	schedule

The neighbor discovery procedure operates as follows. Whenever a node wakes up, it broadcasts a beacon piggybacking its own id, the transmit time and other information subject to channel contention/resolution rule. A new entry is added whenever a new neighbor is discovered.

2) Backoff algorithm for ATIM frame

As noted previously, transmission of each ATIM frame is performed using the CSMA/CA mechanism in IEEE 802.11. In the IEEE 802.11, a random value is selected from a range (0, *CW*-1), where *CW* denotes the contention window, to calculate backoff time. The backoff interval is decremented by 1 after each "clock tick" if the channel is sensed as idle [1]. An ATIM frame is transmitted when the backoff interval reaches 0. When the ATIM frame is received by the destination node, it responds by sending an ATIM-ACK. However, the ATIM frame may collide with an ATIM frame transmitted by another node. In this case, the ATIM-ACK will not be sent. If an ATIM-ACK is not received in response to the transmitted ATIM frame, the node transmitting the ATIM frame doubles the value of *CW*, selects a new backoff interval, and repeats the process. However, it is possible to select a small backoff time regardless of a large *CW*. It is due to the fact that the backoff timer is randomly chosen in the range (0, *CW*-1). To address this problem, we substitute the initial value of range (0, *CW*-1) with *InitRng*, so the backoff timer is randomly chosen in the range (*InitRng*, *CW*-1) [8]. It chooses a large backoff time, and also provides a very low collision probability over the IEEE 802.11 standard. *InitRng* is calculated as follows.

$$InitRng_i = \begin{Bmatrix} 0 & i = 0,1 \\ i \times CW_{\min} & i \geq 2 \end{Bmatrix} \quad (1)$$

Now we describe the rules for dynamic adjustment of the ATIM window size. Initially, each node begins with ATIM window size equal to $ATIM_{min}$ – in our simulations, $ATIM_{min}$ is chosen to be 2 *ms*.

We present the rules for increasing the ATIM window size, followed by the rule for decreasing the ATIM window size. DAM allows different nodes to use different ATIM window sizes.

There are two rules for increasing the ATIM window size, as listed below.

1) When a node transmits an ATIM frame, an ATIM-ACK may not be received in response. In such cases, the node will retransmit the ATIM frame. We set the retry limit for ATIM frame as 3 – that is, an ATIM frame will be transmitted three times, before the retry limit is reached. If ATIM-ACK has not been received after three transmissions, the transmitted packet is "marked" and rebuffered for another try (also up to 3 times) in the next beacon interval. When a node receives a marked packet, the node will increase its ATIM window size to the next higher level.
2) When a node receives an ATIM frame, it retrieves the transmit time, calculates the RTT, and compares the calculated RTT with the round trip time in its neighbor list. If the value of new calculated RTT is greater than that in its neighbor list, a node increases its own ATIM window size.

If any of the above rules are satisfied, a node will increase its ATIM window size to the next higher value at the beginning of the next beacon interval. In our simulations, we calculated ATIM window values as follows.

$$\textbf{\textit{new ATIM window}} = \textbf{\textit{ATIM}}_{\textbf{\textit{min}}}\ \mathbf{X}\ \mathbf{2}^{\#\ \text{of increase}} \quad (2)$$

Once the ATIM window size reaches 26 *ms*, it is not allowed to increase further.

During an ATIM window, if a node has successfully announced one ATIM frame to all destinations that have pending packets and no window increasing rule defined above is satisfied, it means that the current ATIM window size was big enough. In such cases, the node will be decreasing its ATIM window size to $ATIM_{min}$.

$$\textbf{\textit{new ATIM window}} = \textbf{\textit{ATIM}}_{\textbf{\textit{min}}} \quad (3)$$

V. PERFORMANCE EVALUATION

To validate and evaluate the proposed design, we have implemented the proposed asynchronous wakeup mechanisms and the corresponding power management protocols in *ns-2* [9] with the CMU wireless extension. As a baseline, we also evaluate the performance in the absence of power management (NPM).

To understand how well our proposed protocol works under more realistic traffic patterns, we simulate on-off traffic with 30 sender-receiver pairs (Fig. 3). Both busy and idle intervals follow exponential distribution with means of 10s and 100s respectively. The simulations run for 900*s*. Note that with 30 sender-receiver pairs, most of the 50 nodes in the network are either involved in data forwarding, sending or reception at some time in the simulation.

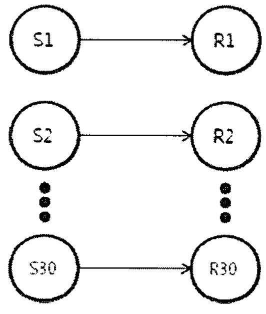

Fig. 3 Topology for testing multiple connections

The performance metrics of interest are the amount of power consumed and the packet delivery ratio. The simulated radio power consumption characteristics are shown in Table 2.

Table 2 The power consumption model

Transmit	Receive	Idle	Sleep
1400*mW*	1000*mW*	830*mW*	130*mW*

The beacon interval and ATIM window are set to 0.4*s* and 0.02*s* respectively. In all simulation scenarios, the network is never partitioned and there are no error-induced losses.

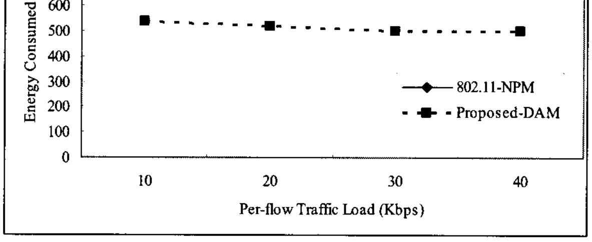

Fig. 4 Energy consumed by NPM and DAM

From Fig. 4, we find that DAM provides a considerable amount of energy savings over 802.11-NPM. The transmission of beacon messages consumes power. Furthermore, regardless whether there is an announcement or acknowledge frame, a node must be awake during the ATIM window. Therefore, it can be expected that the more the length of the ATIM window, the more power will be consumed. Since with NPM, all nodes are always awake, the energy consumption is higher than DAM. Although PSM in 802.11 allows a node to be in power saving mode, all nodes use the same ATIM window size, and consume more the energy than DAM.

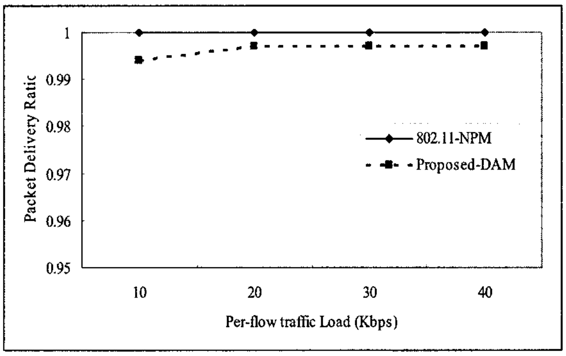

Fig. 5 Packet Delivery Ratio

Fig. 5 depicts the packet delivery ratio as traffic load changes. As shown in Fig. 5, we observe significant energy saving under the proposed DAM, while the packet delivery ratio is comparable to that in the case without power management.

VI. CONCLUSIONS

In this paper, we present a Dynamic adjust ATIM window Mechanism (DAM) that reduces energy consumption in ad hoc networks while maintaining effective throughput. In the proposed DAM, we specify a finite set of ATIM window sizes that may be used by each node. Each node chooses an ATIM window size according to its round-trip time. This might potentially result in each node using a different ATIM window size.

We implement a prototype of our mechanism based on the IEEE 802.11 MAC in the *ns-2* simulator. Simulation studies show that our mechanism consumes significantly less energy than a network without power management, while the packet delivery ratio is comparable to that in the case without power management.

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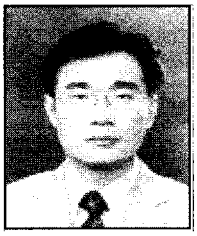

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