Modified Power Save Model for Better Energy Efficiency and Reduced Packet Latency

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ABSTRACT

Devices constituting wireless ad-hoc networks generally operate in battery power, energy efficiency is a critical research issue. IEEE 802.11 Power Save Mode is a standard recommended for energy efficient operation of wireless ad-hoc networks. When there is no data to transfer, energy is still utilized by IEEE 802.11 PSM during the ATIM window. With this work, an attempt is made to address this drawback with the proposal of a variation in the PSM. Using IEEE 802.11 PSM, each frame travels only one hop during a beacon interval, leading to huge end to end latency and energy consumption. This issue is also addressed and history based prediction method is proposed. According to this method, a data frame can travel many hops from source to destination within a beacon interval. Simulation results using Network Simulator 2 (NS-2) show that the proposed method outperforms IEEE 802.11 PSM with respect to energy efficiency and end to end latency.

1. INTRODUCTION

An ad-hoc network is an adaptive self organizing collection of mobile nodes acting as wireless terminals or as repeaters. The devices that constitute a wireless ad-hoc network are basically driven by battery power. Energy efficiency becomes a critical factor for the operation of such networks. The performance of every layer of the protocol stack affects the performance parameters of the network like latency, energy consumption. Data link layer is the vital layer in IEEE 802.11 performing key functions like access control and flow control. The MAC protocols coordinate the access among active nodes. MAC protocols are responsible for handling errors like hidden terminal problem, the exposed terminal problem and signal fading effects which can deteriorate the throughput of wireless communication. As a power saving mechanism at the MAC layer, sleep mode operation is widely used. It is commonly used in the downlink control channels of second and third generation cellular systems like Code Division Multiple Access (CDMA 2000) and Wideband Code Division Multiple Access (WCDMA) technologies.

It is also applied to Wireless Local Area Networks (WLAN), Wireless Sensor Networks and the Radio Frequency Identification (RFID) networks. IEEE 802.11 operates in two modes, Point Coordination Function (PCF) and Distributed Coordination Function (DCF). PCF is suitable in a master slave model where a node acts as master (e.g., access point) and all other nodes act as slave. DCF is suitable for distributed model where all nodes have same privileges like ad-hoc networks. DCF can support only best affort service and does not guarantee hard real-time services, but PCF is suitable for hard real-time functions. This work focus on DCF mode of IEEE 802.11.

Power conservation in MAC protocols can be achieved by:

- Reducing collisions as much as possible resulting in lesser retransmission
- The transceiver should be in sleep mode to avoid energy consumption
- The transmitter should switch to lower power mode sufficient for the destination node to receive the transmission

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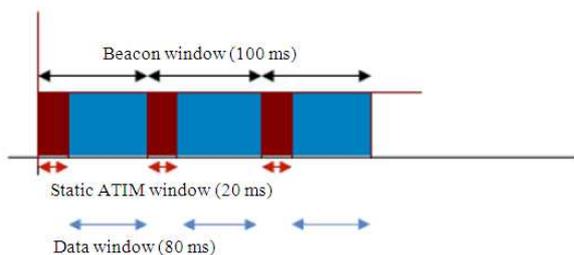National Institute of Technology, 620 015, Trichy, India
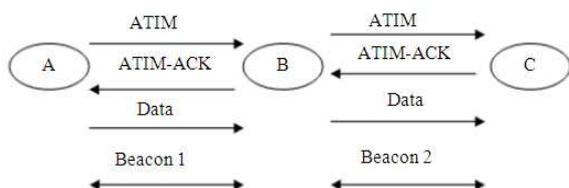
Fig. 1. IEEE 802.11 PSM

Fig. 2. IEEE 802.11 PSM in multi-hop network

IEEE 802.11 proposed a simple Power Save Model (PSM). In IEEE 802.11 PSM, a node may operate in two modes, active mode and power save mode. The network interface of a node is always in one of the following energy consumption states, transmit, idle, sleep and off. Energy consumed by a node in the active state is maximum compared to other states. Node in idle state also consumes energy slightly less than in active state as it continuously listens to the wireless medium for incoming communication requests. Least energy is consumed when the node is in sleep state. A node should be put to sleep for better energy efficiency in the absence of communication. A node can neither receive nor send data in sleep state, enforcing the outgoing data frames to be queued. All the senders to the sleeping node must also enqueue the data frames until it is awake to receive data. Sleeping for a considerable amount of time increases the end to end latency of the packet.

The working of IEEE 802.11 PSM is as follows:

- All nodes are time synchronized
- Nodes wake up at the beginning of each beacon interval
- All nodes stay awake for the Ad-hoc Traffic Indication Map (ATIM) window time period. During this time period, nodes that have enqueued packets to transfer advertise as ATIM packets
- When a sender sends an ATIMpacket, the receiver responds with an ATIMACK packet
- Both the sender and the receiver remain awake for the rest of the beacon interval for data transfer. If a node does not send or receive an ATIM, it will enter

sleep mode at the end of the ATIM window until the next beacon interval

Figure 1 explains the basic working of IEEE 802.11 PSM (Choi *et al*., 2003). The values of ATIM window and beacon intervals are 20ms and 100ms respectively. All nodes are forced to listen to the wireless channel for a minimum of 20ms irrespective of whether there is data traffic or not. IEEE 802.11 PSM results in significant amount of energy loss when the data traffic is very less. Energy efficiency can be improved by reducing the ATIM window size during very low data traffic. Hence ATIM window size cannot be static and need to be dynamic based on traffic load.

Consider a scenario with a sender and a receiver in a wireless ad-hoc network (Feeney *et al*., 2001; Zheng and Kravets, 2003) with IEEE 802.11 PSM which are multiple hops apart as shown in **Fig. 2**. An attempt by a sender to send a data packet to the receiver needs several beacon intervals, as the data packet needs to travel through many intermediate nodes. In one beacon interval, the data packet at best travels one hop, leading to huge packet delivery latency.

Related Work gives an overview of literatures addressing the issue. The Proposed Model is explained later. Simulation results are discussed followed by Conclusion.

1.1. Related Work

There are many different mechanisms at different layers of the protocol stack to improve the energy efficiency of IEEE 802.11, 1999 networks. In IEEE 802.11e, EDCA and HCCA schemes were proposed for better MAC access mechanisms to support Quality of Service (QoS). According to the EDCA scheme, different Inter Frame Space (IFS) and contention window sizes are associated with packets belonging to different access classes. EDCA helps to achieve per class QoS, but the power consumption of EDCA is similar to DCF. The HCCA scheme uses a hybrid coordinator similar to an access point for controlled access phase. The power consumption of HCCA is similar to PCF. The modulation and coding schemes for link adaptation are important parameters affecting energy efficiency. The fragmentation threshold at the MAC layer is also important.

The time a station has to wait for transmitting a packet is basically determined by contention window. Reducing the contention window size may reduce waiting, but shorter contention windows may cause collision and retransmission and consume more energy. Hence, an optimal contention window must be chosen to improve performance. Energy efficiency can be

improved by fine tuning the parameters, as suggested by Woesner *et al*. (1998) the optimal ratio of the ATIM window size to the beacon interval is approximately 0.25 (Tseng *et al*., 2002). Addressed the problems caused by in-synchronization and proposed the notion of asynchronous wakeup. DPSM is a dynamic power save mode protocol in which the ATIM window size is dynamically adjusted depending upon the number of packets pending for a node, the number of nodes that could not be advertised in the present beacon interval. In TIPS, the ATIM window is divided into two static time slots. Upon arrival of a beacon packet in the first slot, the node stays awake for the second slot to receive packets; else it goes to sleep state. At the higher layers, packet compression can be used to reduce the transmission time and hence energy consumption. Block acknowledgement allows a station to reply with an acknowledgement for multiple packets reducing the energy required to transmit multiple acknowledgement frames. When there are many short packets being transmitted, packet aggregation can be used to combine the shorter packets into single MAC frame requiring only one contention and one acknowledgement for transmission improving energy efficiency.

An adaptive scheme called power saving with p-persistent sleep decision for wireless communications was proposed. This scheme suites systems adopting frame structure with fixed length. At the beginning of a frame, a node decides its state (sleep or active) for the frame. This decision of the state of a node depends on a variety of sleep-decision parameters like number of queued packets, the channel condition, available battery power and packet latency. When a node receives an ATIM packet, it computes the sleep probability using an equation and determines its state by doing a persistent test with this probability. If the node decides to sleep, it sends an "ATIM-SACK" which indicates that a node received the ATIM packet but decided to sleep. If the node decides to be awake, it replies with ATIM-ACK like in conventional IEEE 802.11 PSM. Fast Flooding in Power Save Mode (FFPSM), a modification in standard IEEE 802.11 PSM is proposed, which tries to reduce end to end latency by fast flooding the packets. FFPSM does not reduce the duration of the awake state for energy efficiency, but tries to reduce end to end delay by flooding the packets. According to Power Aware Medium Access Control with Signaling (PAMAS), all the RTS-CTS exchanges are performed over the signaling channel and the data transmissions are kept separate over a data channel. While receiving a data packet, the destination node start sending out a busy tone over the signaling channel. Every mode makes its own decision to go to sleep mode or to be in active mode. In

Dynamic Power Save Mode (DPSM) proposed in (Jung and Vaidya, 2002), each node dynamically and independently chooses the length of the ATIM window. Every node can potentially have a different sized window. It allows the sender and receiver nodes to go into sleep mode immediately after they have participated in the transmission of packets announced in the prior ATIM frame. The length of the ATIM window is increased if some packets queued in the outgoing buffer are still unsent after the current window expires. Each data packet carries the current length of the ATIM window and any node that overhear such information may decide to modify their own window lengths based on the received information. But DPSM does not suit multi hop adhoc networks. In Power Control Medium Access Control (PCM) (Monks *et al*., 2001), the RTS and CTS are sent using maximum available power, the data and Acknowledgement packets are sent with minimum power required to communicate between the sender and the receiver. Power Controlled Multiple Access (PCMA) relies on controlling transmission power of the sender so that the intended receiver is just able to decipher the packet, helping in avoiding interference with other neighboring nodes not involved in the packet exchange. PCMA proposes to use two channels, one for sending out busy tone and the other for data and other control packets. Power control mechanism in PCMA is used to increase channel efficiency through spatial reuse rather than only increasing battery life. A challenge of PCMA is, determining the minimum power level necessary for the receiver to decode the packet distinguishing it from interference. In all the related works, there are many proposals to improve the energy efficiency without taking packet latency into consideration. In this work an attempt is made to improve the energy efficiency and also to decrease the packet latency simultaneously.

1.2. Proposed Model

In case of most Ad-hoc Networks, the data traffic is bursty and intermittent. Hence keeping the system awake for the static ATIM window can cause significant reduction in performance. In Dynamic ATIM window adjustment, the ATIM window is sliced into a smaller initial slot called as Contention slot. If any node has data packet to send, it will send an empty packet during the contention slot. The sending node and all the receiving nodes will be awake during the ATIM window enabling the sender to advertise with the ATIM packet. The receiver node will reply with an ATIM-ACK packet. All the other nodes except the sender and the receiver will go

to sleep state. The sender and the receiver node will exchange data frames during the beacon interval by staying awake. The advantage with this model is, when there is very less traffic load in the network, i.e., no data frames transferred most of the time, all nodes will go to sleep mode just after the contention slot instead of being awake for the whole ATIM window, hence achieving better energy efficiency. But when an empty frame is received during the contention slot indicating there are data frames to be transferred, a time value Tvalue is calculated as per (Miller and Vaidya, 2005; Jung and Vaidya, 2002) and set according to the below equation. The maximum contention window for the data frames is 1024. But for the ATIM window, the contention window can be equal to twice the maximum number of neighboring nodes. Only one sender and receiver will send the ATIM advertisement packet during an ATIM interval Eq. 1:

$$T_{value} = 2 \times DIFS + 2 \times T_{slot} \times CW + 2 \times \text{Propagationdelay} + SIFS + T_{ATIM} + T_{ACK} \qquad (1)$$

T_{value} is the time period for which a node must restrain itself from trying to send its ATIM advertisement, when the channel is idle. A timer is set to T_{value} and counts down, if it senses another node transmitting its ATIM advertisement or an ATIM acknowledgement, it must reset its timer to the initial value. If the T_{value} reaches 0 and there is no one accessing the medium, it is free to advertise its ATIM packet. DIFS is the DCF Interframe Spacing, T_{slot} is the time slot which is approximately 20 micro seconds. CW is the Contention Window for the ATIM advertisement set to twice the maximum number of neighboring nodes. Propagationdelay is the propagation time taken between the sender and the receiver. SIFS represents the Short Interframe Spacing, the time duration the medium should be idle to send out control frames. T_{ATIM} represents the transmission delay of ATIM frame and T_{ACK} represents the transmission delay of acknowlegement frame. Any system must have to sense the medium idle for DIFS time duration to access the medium. Then transmission delay for the ATIM advertisement. In case of collision or loss of ATIM advertisement time duration of contention window represented by $T_{slot} \times CW$. SIFS time followed by transmission delay of acknowledgement, its propagation delay, its time duration of contention window.

If there are two stations A and B who wish to communicate but are several hops apart. When A tries to send a packet to B, at the best case it takes number of beacon intervals equal to the number of hops resulting in drastic packet latency.
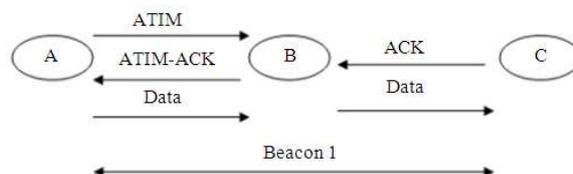

Fig. 3. Proposed model with reduced packet latency and energy efficiency

Table 1. Performance of the proposed modified PSM

Traffic model/ number of nodes	Less neighboring nodes	More neighboring nodes
Low Traffic	More Sleep, hence less energy used	Due to Sleep and multiple hops less energy used
High Traffic	Improved performance due to multiple hops	Improved performance due to multiple hops

In order to improve this, the following is proposed. A method called as History based prediction is used to determine whether a node listening to an ATIM-ACK must be a node ready to receive the packet as it might be forwarded to it. As shown in **Fig. 3**, if A, B and C are three nodes such that A wishes to send data packet to C but needs to be sent through B. Hence node A advertises an ATIM to node B, node B replies with ATIM-ACK to A which is also listened by node C, If node C is ready to accept the data packet from B, it can send an ACK to node B. So that Node B can f orward the data packet in the same beacon interval instead of waiting for another beacon interval and contending with an ATIM advertisement. With this method, energy is conserved due to reduction in buffering delay and also due to reduction in the number of beacon intervals required for the transfer of data frames and hence the number of ATIM and ATIM-ACK packets. This also helps in decreasing packet latency drastically.

The challenges with history based prediction method are:

- A node correctly predicting that a following transmission will be forwarded to it
- If there are many intermediate hops between the source and the destination, then deciding on how many hops can be performed in one beacon interval

The first challenge is addressed as follows, when a node B senses an ATIM-ACK in a beacon interval and it receives an ATIM in the successive next beacon interval, then the node can assume that it will be receiving forwarded packets and send an ACK to the sending node A. If the data packet is not destined to the node B, node A will discard the ACK else it will accept ACK just like ATIM-ACK and forward the data frame in the same beacon interval.
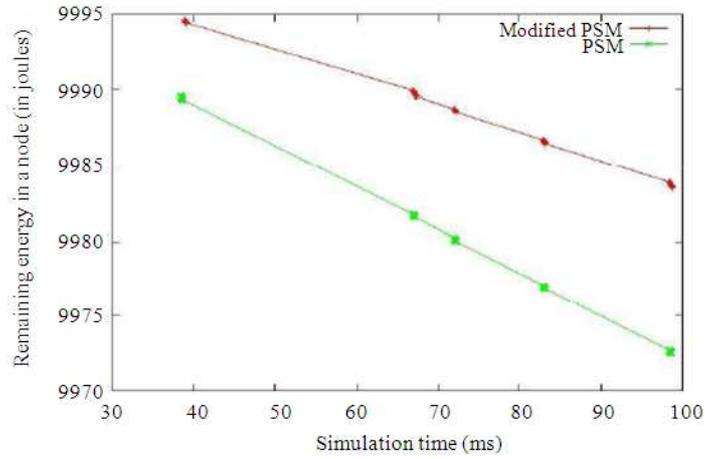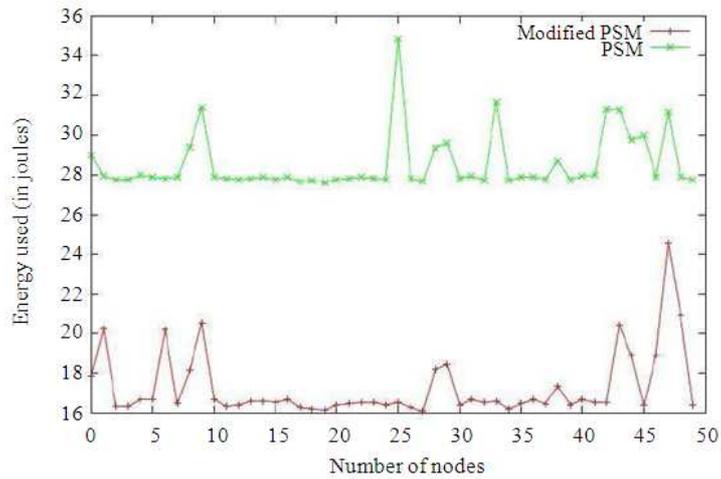
Fig. 4. Residual energy in a node

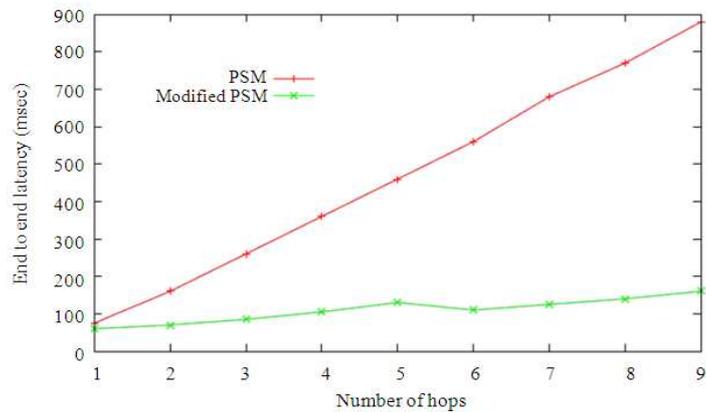**Fig. 5.** Energy consumed in each node

Fig. 6. End to end latency

When there are many intermediate hops between source and destination, as a packet is transmitted, at the worst case one hop is transferred in a beacon interval and as the best case scenario, many hops can be supported by the length of the beacon interval.

Table 1 analyzes the performance of the proposed Modified PSM model for different traffic models and Number of Nodes. When the traffic is low, due to the improvement in the ATIM window, the idle nodes would go to sleep early resulting in energy saving. During high traffic conditions, many data frames are destined to the same destination node helping in energy conservation due to multiple hops in each beacon interval. Only during rare cases(practically not feasible) like the data traffic is high but every other frames are destined for different nodes, that the proposed modified PSM model fails to perform better than IEEE 802.11 PSM.

In order to test the proposed model, Network Simulator NS 2 the network simulator is used. The number of nodes used in the simulation is 50. Simulation Area is 1000×1000 m, beacon interval time is 100 ms Transmission power is 1.4 W, reception power is 1 W, listening power is 0.83W and sleeping power is 0.13W. The traffic model used is Constant Bit Rate (CBR) traffic. The bandwidth is set to 1kbps. It can be observed from the graph in **Fig. 4** that residual energy in a node is significantly higher than the standard IEEE 802.11 PSM. The graph in **Fig. 5** describes that the energy consumed by the nodes is considerably lesser than that in the standard PSM. The end to end latency which was high in standard PSM is drastically reduced with modified PSM as shown in **Fig. 6**.

2. CONCLUSION

The proposed PSM model decreases energy consumption by allowing the nodes to sleep early when there is no data to transfer. The ATIM window size is dynamically set according to the proposed equation for optimal size. The end to end data packet delivery latency is also reduced by allowing transmission of a data packet by multiple hops in a single beacon interval instead of single hop per beacon interval. The simulation result shows that the proposed model performs better with respect to energy efficiency and end to end packet delivery latency.

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