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Schedule-Aware Power Management for Energy-Efficiency Improvement in 802.11u WLAN*

Di Zhang[1], Qinghe Du[1,2], Pinyi Ren[1], Li Sun[1]
[1]School of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an, China
[2]National Mobile Communications Research Laboratory of Southeast University, Nanjing, China
Email: dizhang2011@126.com, duqinghe@mail.xjtu.edu.cn, pyren@mail.xjtu.edu.cn, lisun@mail.xjtu.edu.cn

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ABSTRACT

Mobile stations supporting the 802.11u standard can access WLAN automatically when they are within the coverage of the network service provided by this WLAN. To achieve this goal, the stations need to keep "on" states including *idle* and *active* all the time. However, studies have noted that the idleness of stations often lead to considerable power consumption. Although the conventional power saving mode (PSM) can provide energy saving effect to some extent, its own disadvantage leads to lower energy efficiency when the number of stations accessing the target WLAN. In this paper, we propose a Schedule-Aware PSM (S-PSM), which can improve the energy efficiency in 802.11u WLAN. Particularly, we use the Generic advertisement service (GAS) defined in 802.11u standard to broadcast the transmission schedule information and all stations switch off their radios based on this information accordingly. We introduce the Respond Contention Window to reduce the collision probability of competition channel. When there is no packet in the access point (AP), AP broadcasts the GAS frame and actives the Idle Timer. All stations will turn into sleep and AP will not send GAS frame until Idle Timer expires. Simulations have shown that our proposed scheme can significantly reduce power consumption compared with the conventional PSM.

Keywords: 802.11u Standard; Power Saving; Transmission Schedule; Generic Advertisement Service (GAS)

1. Introduction

The 802.11u standard [1] is an amendment of the IEEE 802.11 medium access control (MAC), which can help users discover and select the network automatically. They defined the Generic advertisement service (GAS) to provide functionality that enables stations to discover the availability of information related to desired network services. When a mobile station moves into a WLAN area, the station can query and exchange information with other external networks through GAS, and access the network after and information authentication. Consequently, the precondition of access is that the station's wireless interface keeps "on" all the time. But this automatically access may result in that mobile stations stay in idle state for a long time. As mobile station is powered by the battery, in order to maximize the battery lifetime, we need an effective power management scheme for the stations to improve energy utilization efficiency. 802.11u employs the power saving mode (PSM), which was defined by IEEE 802.11 standard [2]. The PSM lets stations can spend time in the sleep state for energy saving and switch to idle or active state periodically to listen the information or receive the packets. This mechanism may solve the energy wasting problem above, but the limitation of the PSM scheme is that it doesn't consider the impact of stations number on energy efficiency. Because in the PSM, when one station occupies the channel, others need to be in idle state until the channel free for the next competition. Therefore, most energy of each station are wasted in idle state.

In the last few years much research were dedicated to improving the performance of the Power Saving Mode [3-6]. In [3], the authors proposed a new AP-centric PSM to let the AP chooses the best Beacon Interval (BI) and Listen Interval (LI) for all clients based on their traffic patterns. The authors of [4] proposed a dynamic wake up period in which each client chooses its LI according to the current round trip time of its TCP connection. The [5] presents an analysis of the effect of intermittent connectivity on minimizing energy consumption in PSM. Al-

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though these dynamic PSM compute the best system parameters for the clients in reducing energy consumption, they do not consider that the time-driven scheme will result in that stations be in active when they know that they have packets. In [6], the authors proposed a power-conserving algorithm, which dynamically switches off the Network Interface Card of nodes when they are neither transmitting nor receiving a packet in Mobile Ad-Hoc Network. In [7], the authors proposed a protocol that using a time-packet hybrid-driven method to dynamic switch-off the wireless interface in ad-hoc network. These measures only focus on saving energy by enlarging the sleep time and thus ignored the ineffective of the collision probability when completing the RTS/CTS dialogues. The higher collision probability means more time used in retransmission which will surely waste energy and decrease the system throughput. In this paper, under the 802.11u standard [2], we propose a new scheme called Schedule-Aware Power Saving Mode (S-PSM), which gets a better energy utilization efficiency and reduces the collision probability to some extent and gets an improvement in system throughput.

The rest of this paper is organized as follows. Section II presents the system model and the PSM in 802.11 standard. The design and implementation details of proposed S-PSM scheme are given in Section III. Section IV makes a performance analysis between these two schemes. In Section V, we verify the two schemes' energy saving ability. Finally conclusions and future works are remarked in Section VI.

2. System Model

We suppose that there are N wireless stations and an access point (AP) in an infrastructure WLAN. Stations communicate with the AP. We consider the downlink traffic that AP buffers the incoming traffic packets. The implementation of Power Saving Mode [8-10] allows the station to be in one of the three power states: active, idle or sleep. In the active or idle state, the station is fully powered and is ready to receive the packets or listen to the information at any time. During the sleep state, the station is not able to transmit or receive for energy saving. When a station works in PSM, it will listen to the beacon frame periodically. AP buffers the packets for the station and announces the corresponding station every beacon beginning via Traffic Indication Map (TIM) carried in beacon frame, then the station sends PS-Poll frame to retrieve the packets. Until all the packets are received, it goes back to sleep.

Figure 1 illustrates an example of the power saving mode in an IEEE 802.11 infrastructure network. In an infrastructure WLAN, AP sends beacon frames to message stations which have buffered packets at the beginning of a beacon period, at the same time, all the stations

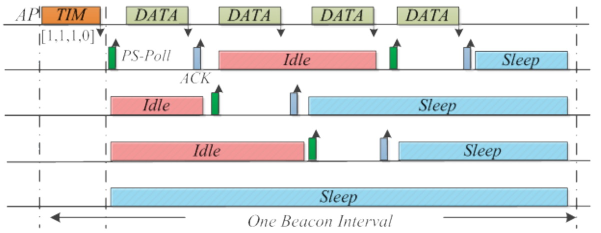

Figure 1. Procedure of Conventional PSM scheme.

wake up and listen to the buffer information which is in the TIM field. If the bitmap for one station is not set (*i.e.*, no buffered packets) in the TIM, the station goes back to sleep immediately. Otherwise, the station sends a PS-Poll frame to the AP by means of the standard distributed coordinate function (DCF) procedure. Upon receiving a PS-Poll, AP sends the destined packets and receives a corresponding acknowledgement (ACK) frame from the station. After this transmission, the station checks the MORE DATA bit field in the beacon frame header to know whether the received frame is the last one in this beacon. If the field is set to zero, the frame is the last one and therefore the station goes to sleep mode after receiving it. If the field is not zero, station sends another PS-Poll frame to request the next packet until there is no buffer packets during this beacon interval.

3. Design and Implementation of S-PSM

In this section, we proposed our Schedule-Aware Power Saving Mode (S-PSM). Compared with conventional PSM, the main difference of S-PSM is the message-driven mechanism and AP determines the transmission schedule for stations. In the following, we will describe the S-PSM scheme in detail.

3.1. Principle of the S-PSM Scheme

In our proposed S-PSM scheme, we let the stations switch off their interface dynamically according to the schedule information from AP. Stations may be in two operating states: active state and sleep state. In the active state, they receive the packets or listen to the information. During the sleep state, the station is powered down for energy saving. AP buffers the incoming packets for all stations and informs them of buffer information. In our scheme, we define one transmission process, during which every destination station receives one packet successfully, called Once Transmission Cycle. AP attaches the destination station ID, transmission schedule and packets length to the GAS frame, and broadcasts GAS frame to all stations. If the information of station ID is not set for this station, the station turns to sleep state immediately. The destination stations stay in active state and AP determines the transmission schedule by the First Come First Serve (FCFS) algorithm. Then AP announces a GAS frame to the active stations making clock synchronization and notifies all stations the transmission schedule. These stations according with the schedule switch off their interfaces when current transmission is irrelevant to them. When there is no packet for all the stations, AP attaches the sleep time in the packet length field and sends to all the stations and opens the Idle Timer. All stations will wake up and AP checks the buffer when the Idle Timer expires.

3.2. Protocol Description of the S-PSM Scheme

In our scheme, AP attaches the transmission schedule information in the GAS frame to inform stations buffer information [11]. These information include destination stations ID, transmission schedule, and packets length. In our implementation, we add one extra information element (using one of the reserved Element IDs) of the GAS frame for this purpose. The format of the information element is shown in **Figure 2**. We can use a field, which is reserved in the GAS Initial Request/Respond frame body format, to carry the relative information. Hence we use 8 bits to contain the destination station ID and queue length information respectively. The **Table 1** is the description of S-PSM process.

The overall scheme of proposed S-PSM is shown in **Figure 3**. In **Figure 3**, station S_4 receives the GAS frame and finds that there is no its packet in the buffer, then it turns to sleep state immediately. S_1, S_2, S_3 will be in active state and enter the Respond Contention Window (RCW). They send the GAS-Respond frames to inform AP that they are ready for receiving the data by means of DCF procedure. This basic access procedure (DCF) has clearly specified in 802.11u standard. When one destination station delivers the respond information successfully, it will not attend the competition anymore and get out Respond Contention Window. Finally, after all the destination stations GAS-Respond frame have been received, the Respond Contention Window closes. Then the transmission process starts. AP determines the transmission schedule under the First Come First Serve (FCFS) algorithm. In **Figure 3**, the transmission schedule is (S_1, S_3, and S_2). Then AP sends GAS frame, and stations according with the schedule and the packets length information to estimate the sleeping time as well as to wake up to receive the packets. For each transmission, AP sends a GAS frame to make the clock synchronization. When this transmission cycle ends, all the stations be in active state and waiting the next GAS frame.

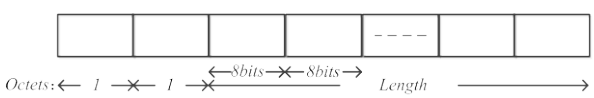

Figure 2. Format of the GAS frame in S-PSM.

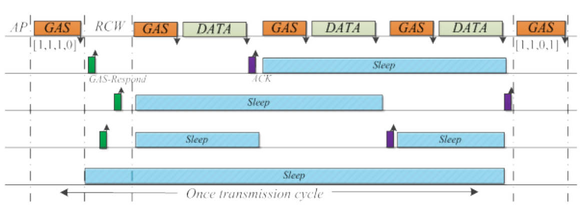

Figure 3. Procedure of S-PSM scheme

Table 1. The Process of S-PSM.

```
S-PSM process
01. AP checks the buffer;
02. IF Current Buffer Size > 0
03. AP achieves the destination stations ID;
04. AP sends GAS frame;
05. Other stations turn into sleep state;
06. Respond Contention Window opens;
07.         IF  Sj sends the frame successfully;
08.             Sj quits the compete process;
09.         END
10.         AP receives all stations' GAS -Respond;
11.         Respond Contention Window closes;
12.         AP determine the transmission sequence(FCFS);
13.         AP send GAS frame;
14.         Begin transmission;
15.         After transmission, turn to 1;
16.     ELSEIF Current Buffer Size = 0
17.                 AP broadcasts GAS frame;
18.                 Idle Timer opens;
19.                 All stations switch off the interfaces;
20.                 AP not check buffer anymore;
21.                 IF Idle Time expires
22.                    All the stations wake up at the set time;
23.                    AP checks the buffer
24.                    Turn to 1;
25.                 END
26.     END
```

4. Performance Analyses

4.1. Energy Saving Efficiency Analysis

The PSM provides that station who works in PSM must observe some provisions. First, when one station has packets buffered in AP, this station must be active until the last one is received during the entire beacon cycle. Second, the station sends frame to AP by means of the standard distributed coordinate function (DCF) procedure [12-14]. So, when one station occupies the channel, other stations will be in idle state until the channel becomes free. In order to analyze the idle time of stations conveniently, we fail to consider the back off time and collision situation and neglect some secondary factors like the transmission delay time. Let T_i is the transmission time (including the DCF inter-frame space (DIFS), frame transmission time t, and ACK) for one station receiving the packets. We can write T_i as $T_i = DIFS + t + ACK$. We assume that there are N stations in the network. The number of possible transmission schedules is $N!$. Let M_k be the kth schedule ($1 < k < N!$). $I(M_k)$ represents the total idle time of N station in M_k schedule. Then, the expected idle time $E[t]$ can be expressed as

$$E[T]=\frac{1}{N!}\sum_{k=1}^{N!}I(M_k) \quad (1)$$

according to the analysis results of references [13], we can get

$$\begin{aligned} E[T]&=\frac{1}{N!}\sum_{k=1}^{N!}I(M_k)=\frac{(N-1)!}{N!}\sum_{i=1}^{N-1}i\sum_{i=1}^{N}T_i \\ &=\frac{(N-1)}{2}\sum_{i=1}^{N}T_i \end{aligned} \quad (2)$$

So, we can clearly see that the total idle time of stations in one random schedule increase as the number of accessed stations. While considering our S-PSM, the problem of energy wasting in idleness is solved by utilizing the transmission schedule to driven stations' states. All the stations switch off their interfaces by the transmission schedule and the packets length information. During one transmission cycle, stations turn to sleep state when the transmission is irrelative to them. Then, we can obtain the total idle time of stations in the schedule, which is determined by FCFS algorithm:

$$E[T]=0 \quad (3)$$

In addition, the sleep time of *j*th station is

$$T_{sleep}(j)=\sum_{i=1,i\neq j}^{N}T_i \quad (4)$$

Therefore, with the increase of number of stations, each station has more time to sleep. Hence, we can conclude that our S-PSM scheme has a better energy saving effect than PSM.

Because of the massage-driven method, if there is no packet in the buffer, AP will check the buffer frequently, and stations will receive empty GAS frame and have nothing to do. After we introduce the Idle Timer, AP will not detect the buffer and all stations can turn to sleep state for energy saving. Let *Tc* be the time of once transmission cycle, then we can get

$$T^c=\sum_{i=1}^{N}(T_i+BO_i+2GAS)+GAS \quad (5)$$

where *BOi* is the back off time of *i*th stations, *GAS* is the GAS frame space. The inter packet arrival time *Tinter* takes on exponential distributions. We can get the probability of *Tinter* > *Tc*

$$\begin{aligned} p(T_{inter}>T^c)&=1-\int_0^{T^c}\lambda e^{-\lambda t}dt \\ &=1-(-e^{-\lambda t}\,|_0^{T^c})=e^{-\lambda T^c} \end{aligned} \quad (6)$$

We consider the situation that there is no packets arrive during this transmission time *Tc*. So, the probability of this situation can be regarded as

$$P=P_{zero}p^N(T_{inter}>T^c)=P_{zero}e^{-N\lambda T^c} \quad (7)$$

Where the *Pzero* represents the probability of that AP transits all the buffered packets in a transmission. In order to observe the effect of stations number *N* on the probability of this situation, we consider the average transmission time and back off time

$$T^c=N(T_{avg}+BO_{avg})+(2N+1)GAS \quad (8)$$

Then, we can write

$$P=P_{zero}e^{-[N^2(T_{avg}+BO_{avg})+N(2N+1)GAS]\lambda} \quad (9)$$

We can see that with the increase of N, the value of *P* will have a great decrease. So, this situation will not happen when more stations access the WLAN. Therefore, it is necessary to introduce the Idle Timer for energy saving when there are little stations in the WLAN. In the consequently simulations, we can see the impact of Idle Timer on the S-PSM scheme.

4.2. Collision Probability Analysis

We know that the basic 802.11 MAC protocol Distributed Coordination Function (DCF) is based on the Carrier Sense Multiple Access (CSMA). When more than two stations whose back off time is zero detect the channel as free at the same time, a collision occurs. The initial congestion window for all stations is *CWmin*, and the back off time is *BT* ($0<BT<CW_{\min}$). The probability of *BT* is $p=1/CW_{\min}$. In the conventional PSM, the probability of *i*th station access the channel successfully is

$$P_i^{psm}=1-\sum_{j=2}^{M}C_M^j p^j \quad N\geq M\geq N-i+1 \quad (10)$$

where *M* is the number of stations who involve in the channel competition.

In our scheme, we introduce the respond contention window (RCW) for stations competing the channel. During the window, when a station delivers the respond frame successfully, it will not attend the competition any more. The probability of *i*th station access the channel successfully is

$$P_i=1-\sum_{j=2}^{N-i+1}C_{N-i+1}^j p^j \quad (11)$$

Because of the 0 < *p* < 1, we know that

$$\begin{aligned} P_i-P_i^{psm}&=\sum_{j=2}^{M}C_M^j p^j-\sum_{j=2}^{N-i+1}C_{N-i+1}^j p^j \\ &=\begin{cases}\sum_{j=N-i+2}^{M}C_M^j p^j+\sum_{j=2}^{N-i+1}(C_M^j-C_{N-i+1}^j)p^j & M>N-i+1\\ 0 & M=N-i+1\end{cases} \end{aligned} \quad (12)$$

Therefore, we can get

$$P_i \ge P_i^{psm} \quad (13)$$

From the Equation (13), we can see the respond Contention window can reduce the probability of collision.

5. Simulation Evaluation

In this part, we have implemented the proposed S-PSM scheme and make a comparison with the PSM. The simulation environment and parameters are in **Table 2**. In addition, stations need to switch-off interface frequently, therefore we must consider the energy consumption of switch off which is twice of active state. In the PSM simulation process, we set the beacon interval (BI) and the listen interval (LI) is 100 milliseconds. Besides that, the minimal congestion window for all stations is 32 slots. We design and implement the simulator based on MATLAB. The set of energy consumption for each state is referenced [5,15].

Figures 4 and **5** show the comparison results between S-PSM and PSM. We can clearly find that our scheme can overcome the defect of PSM that stations waste energy in idle state. As shown in the **Figure 4**, the time being in idle state under PSM has a conspicuous increase as the number of stations increase, and the resident time of sleep state has a significant drop. On the other hand, the S-PSM scheme gets longer resident time of sleep state. In our scheme, stations utilize the transmission sequence to dynamically switch-off their interface when they have no data to receive, consequently, stations will be in sleep state to save energy. For the competition time, S-PSM is less than PSM. In S-PSM, all stations only take part in competition during the respond contention window, which will effectively reduce the competition time. **Figure 5** plots the throughput and energy consumption for one station during this simulation process. We can see the S-PSM has a preferable performance in throughput and the energy consumption has a significant downward. With increase of station number, the average throughput is bigger than PSM. This is because that the collision probability goes down by introduction the Respond Contention Window. So, more time will be utilized to transfer the packets. The energy consumption of S-PSM will be around 3*Joule*, which is about 80% lower than that of PSM. This is in agreement with theoretical analysis that station in S-PSM will has more time to sleep for energy saving.

Figure 6 shows the influence of Idle Timer on the

Table 2. Table type styles (Table caption is indispensable).

Simulation Parameters	***Values***
Number of clients	2 to 14
Data Transmission rate	11 Mbps
Packet size	1500 bytes
Beacon interval	100 ms
PS-Poll/ACK frame size	14 bytes
average inter-frame arrival time	10 ms
Slot Time	$20*10^{-6}$ s
SIFS	$10*10^{-6}$ s
DIFS	$50*10^{-6}$ s
Sleeping power	50 mW
Active/Idle power	750 mW
AP buffer size	2 GB

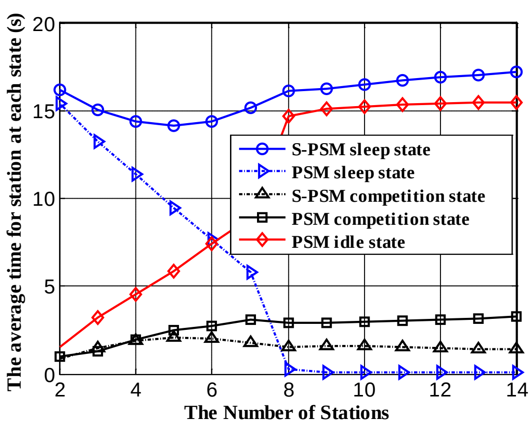

Figure 4. Comparison of Average Resident Time of each state between PSM and S-PSM.

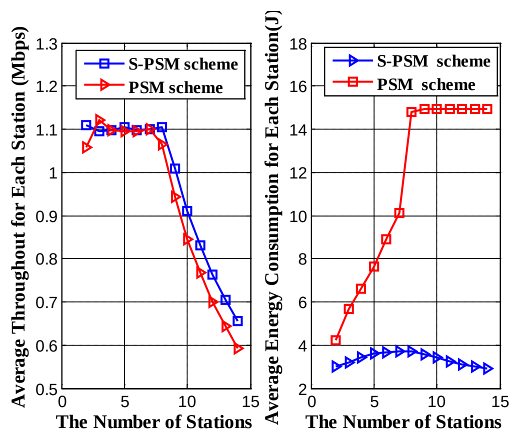

Figure 5. Comparison of Throughput and Energy Consumption between PSM and S-PSM.

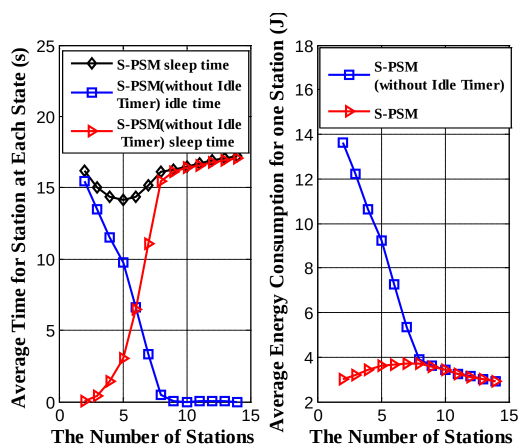

Figure 6. Impact of Idle Timer for S-PSM.

performance of S-PSM. First, let's observe the performance of S-PSM without Idle Timer. From the simulation result, we can see the station will spend some time in idleness when $M < 8$. And the corresponding energy consumption is very large. When AP has no buffered data, AP will check the buffer frequently, and stations will receive empty GAS frame and have nothing to do. When the number of stations is little or network load is low, this issue will appear frequently and cause the most energy wasting, which is consistent with the performance analysis of Equation (9). We introduce the Idle Timer whose value is set as 50 slots to solve this problem. When there are no packets buffered in AP, AP sends GAS frame to tell all the stations turn to sleep state and opens the idle timer. After the timer expires, all stations switch to active state and AP checks buffer information to begin the next transmission. We can see the energy consumption remaining about 3*Joule*, which is a huge energy saving improvement.

We have verified the two mechanism's validity and analyze their performances from three aspects (resident time, system throughput, and energy consumption). We observed that our proposed scheme has a better performance in energy saving. By introducing the Idle Timer and using message-driven scheme to let stations know the transmission schedule, S-PSM overcomes the shortage of the PSM and obtains a significant improvement in terms of energy saving.

6. Conclusions

We have proposed the S-PSM that increases energy efficiency of all wireless clients in an infrastructure network. The AP in S-PSM determines the transmission sequence and stations change their own states by the information attached in GAS frames. AP plays a centralized role that controls the transmission process. The stations convert the state according to the transmission sequence which can reduce unnecessary wake ups and maximize energy saving. The Respond Contention Window (RCW) could reduce collision probability effectively, which is helpful to improve the system throughput, and the transmission cycle assures fairness among stations. However, how the AP communicates with sleep stations through broadcast needs to be paid more attentions. We utilize the Idle Timer to solve this problem in our model, but cause unnecessary packets delay. Our needs to switch the interface frequently, and that does harm to the interfaces. So, in future work, we can improve S-PSM performance via these aspects.

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