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시분할 방법에 의한 IEEE 802.11 전력관리 메커니즘의 성능향상

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Enhancing IEEE 802.11 Power Saving Mechanism (PSM) with a Time Slotted Scheme

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요 약

데이터전송 증가에 따라 제한적인 배터리를 사용하는 모바일 단말에서 효율적으로 전력을 사용하는 것은 중요하게 여겨지고 있다. 802.11 표준에 있는 Power Saving Mechanism (PSM)은 부하가 많은 네트워크에서 적합하지 않다. AP(Access Point)는 버퍼링된 프레임을 PS (Power Saving) 단말들에게 즉시 보낼 수 없어서 단말들이 깨어있는 모드를 계속 유지함으로써 전력을 낭비하게 된다. 또한, PS단말들이 하나의 데이터 프레임을 받기 위해 AP에게 하나의 PS-POLL프레임을 전송하는 방식은 효율적이지 않다. 본 논문에서는 802.11 PSM의 성능을 향상하기 위해 PS단말들이 AP에게 데이터 받을 시간을 미리 예약하는 시분할 메커니즘을 제안한다. 제안된 메커니즘은 충돌가능성을 감소시킬 수 있으며 채널사용 효율을 높일 수 있다. 분석결과 및 시뮬레이션 결과로부터, 제안된 시분할 메커니즘은 전체 네트워크의 전력소비가 효과적으로 감소되며, PSM의 성능을 개선시킨다.

Key Words : Power Saving Mechanism, IEEE 802.11, Infrastructure WLANs

ABSTRACT

Power efficiency becomes more important in wireless LANs as the mobile stations send more data with limited batteries. It has been known that the IEEE 802.11 PSM is not efficient in high load networks: AP cannot deliver buffered packets to a PS station immediately and it can lead the station to stay in active state quite long and result in energy waste. Moreover, it is inefficient that only one data frame is retrieved by a PS-POLL frame. In this paper, we propose a time slotted scheme to enhance the PSM, in which a mobile station can reserve time slots to receive data frames. Our mechanism can reduce collisions by reservation and decrease the channel occupancy by transmitting multiple data frames via one PS-POLL. The analytic model and simulation results show that proposed scheme reduces power consumption significantly and enhances the performance of PSM.

Ⅰ. Introduction

As today's mobile stations usually transmit amounts of data traffic, power saving becomes a non-negligible issue in wireless LANs. IEEE 802.11 specifies a wireless network interface can stay in either awake or sleep state. In the awake state, the wireless interface can perform data transmission(TX)

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or reception(RX), or stay in idle(IDLE). In sleep state, the wireless interface turned off its radio cannot detect or sense the network behaviors of others. It is proved that wireless network interface consumes much less energy in sleep state than in awake state.

IEEE 802.11 PSM aims at enabling mobile stations to use power efficiently[1]. Based on this scheme, Access Point (AP) buffers incoming packets for PS stations. The PS stations wake up periodically to receive beacon frames delivered by AP, on receiving a beacon if they find from Traffic Indication Map (TIM) that there are packets buffered for them, these stations keep awake in the following period. In order to retrieve buffered packets from AP, PS stations contend to transmit PS-POLL frames, as response AP may deliver the buffered data packets immediately or send a MAC ACK and deliver the data packets later.

When AP dequeues a packet from the corresponding PS queue, if the queue is still non-empty, AP sets the more bit field in the dequeued packet to '1'. On receiving the packet, station keeps awake to retrieve the remaining packets. Otherwise PS station enters into SLEEP mode immediately. It may be noted that each PS-POLL packet permits the station to retrieve exactly one packet from AP.

Although station operated in PS utilizes power more efficiently compared with in Continuous Active Mode (CAM), 802.11 PSM is not efficient in high load network. The reason is first, contention for medium access in high load network usually leads to severly power waste[2]. Second, one packet per PS-POLL retrieving mechanism is inefficient. Furthermore, AP cannot guarantee to deliver the retrieved data packet immediately after receiving a PS-POLL frame which causes stations to keep awake for a long period.

Based on the above observations, we propose a time slotted scheme to enhance legacy PSM in this paper. This scheme divides a Beacon Interval(BI) into reservation window and communication period. PS stations contend to transmit PS-POLL frames during reservation window and reserve the time slots. In communication period PS stations wake up right before their reserved time slots and receive buffered packets from AP. We give more explanations in later section.

The remainder of the paper is organized as follows. Section II discusses the previous literature in PSM, Section III gives the details of our proposed scheme. In Section V, we briefly analyze the performance of proposed scheme, and in Section IV we perform the simulation to evaluate the scheme. Finally, Section Ⅶ draws concluding remarks.

Ⅱ. Related Work

There have been remarkable studies conducted to power saving. In[3] the authors investigate power management for infrastructure BSSs and propose a novel time-based power management mechanism. This mechanism develops a model which utilizes an efficient power management algorithm to optimize the idle timer and doze duration at the station and the frame buffer at the access point. In[4] a time slicing based PSM which enables the AP to divide the beacon period into a number of equal time slots is proposed. In this mechanism each PS station can be allocated a sequence of contiguous time slots by AP according to a scheduling algorithm. The mechanism enables PS station to transit its interface state adaptively which diminishes effect from background traffic and reduces collisions.

In addition to above approaches, there is much previous work focused on enhancing performance of 802.11 PSM. In[5] an adaptive PSM mechanism (A-PSM) to improve delay of packets delivered by AP to PS stations is proposed. According to A-PSM, PS stations are required to stay awake for period of time after have received packets from AP. Therefore packets that arrived later can be delivered by AP immediately.

In[6] a power saving mechanism which utilizes a scheduling scheme to eliminate collisions and save power consumption is proposed. According to this protocol, the packets will be delivered in current Beacon Interval selected via a First In First Out (FIFO) scheduling scheme, then the selected frames will be sorted via Shortest Job First (SJF) scheduling scheme and delivered in order. This energy saving protocol enables the whole network to minimize the total waiting time of PS stations which results in using battery energy more efficiently compared with pure FIFO scheme and IEEE 802.11. However, according to this scheme, AP is allowed to deliver only one packet to each station during a scheduled time sequence which leads to severely delay. In this paper, to reduce power waste and improve channel utilization, we propose an enhanced PSM scheme which allocates ample time slots to each PS station for retrieving data frame from AP.

Ⅲ. Time Slotted PSM

3.1. Overview

In proposed time slotted PSM, BI is divided into reservation window and communication period as Fig.1 shown. One byte is added to TIM information element of beacon frame in order to store the duration of reservation window. The initial value of reservation window is 20ms which is identical to ATIM (Ad hoc Traffic Indication Message) Window defined in Ad-hoc network PSM. As the fixed value which is not suitable in real world[7], we propose to tune the reservation window dynamically in this research. We define a threshold, when the number of stations that cannot transmit their PS-POLL frames because of the insufficient reservation window reaches to the threshold, AP increases the reservation window to a high level, otherwise decreases the reservation window to a low level, the difference between each level is 5ms.

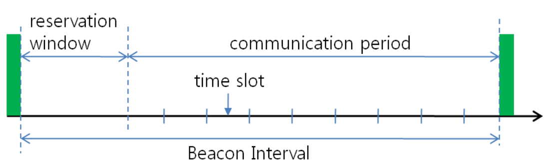

Fig. 1. Time-Slotted PSM

Communication period is divided into equal time slots. The duration of each slot is equal to the time for successfully exchanging a data packet, it depends on the bandwidth of the network, length of the data packet. Suppose the bandwidth is B, the propagation delay is δ, the length of the data packet header is H, and assuming the maximum data packet size equals the average data packet payload size which is denoted as $E(P)$, we get the length of time slot l_{slot} is:

$$l_{slot} = \frac{H + E(P) + ACK}{B} + 2\delta + SIFS$$

3.2. Transmission Procedure

During reservation window PS stations that want to retrieve buffered frames contend to transmit PS-POLL frames. On receiving a PS-POLL frame, AP checks the PSM buffer and allocates sufficient time slots to the station then piggybacks the start slot number into an ACK frame. On receiving the ACK frame the station checks its start slot number and compares it with current time, if there is still long time left, station enters into sleep state immediately, otherwise it keeps awake and receives frame during its time slots. In order to equip PS stations with high priority to transmit PS-POLL, we set the Contention Window of PS stations to a small number but for the CAM station to a larger number.

During communication period, each PS station wakes up a little earlier (SIFS) before their start time slots. When AP delivers the first data frame to a station, if there are still some packets buffered for this station it sets the More Data field to ‘1’ and stores the time needed for exchanging this packet and the remaining packets into duration field. The other CAM stations overhear this frame will set their NAV the same as the duration and refrain their transmission. When the PS station receives the data packet, if the More Data field is ‘1’, it subtracts the time for an ACK from the duration of data frame, saves the value in the duration field of ACK then delivers the ACK frame. All the CAM stations overhear this ACK will update their NAV and keep silence. The PS station keeps awake until all the buffered frames received, then it returns into sleep state again till the time for receiving a beacon frame.

We use Fig.2 to illustrate the transmission process. Here STA1, STA2, STA3 are all PS stations, STA4 is a CAM station. After the PS stations received a beacon frame they learn from TIM that there are some frames buffered in AP for them, so these stations stay awake and contend to access channel for PS-POLL transmission in the following reservation window. As STA1 accessed the channel first, it transmits the PS-POLL frame to AP first. On receiving the PS-POLL frame, AP checks its buffer and allocates to STA1 adequate time slots, in this case it allocates two slots to STA1. The start number 1 is stored in an ACK that transmitted to STA1.

After STA1 received the ACK it turns off its wireless network interface and enters into SLEEP mode until communication period begins. Then STA1 wakes up SIFS earlier before the first time slot and waits for packets delivered by AP. As there are two data frames for STA1, after first packet received, SIFS later STA1 responses to AP an ACK, then SIFS later AP transmits the second frame to STA1, again SIFS later STA1 response an ACK to AP. After STA1 received all its frames from AP it enters into sleep mode until the time to receive beacon. The other two PS stations STA2 and STA3 operate the same as STA1. As some idle time slots left, the CAM stations(ex, STA4) can contend for transmission during the idle time slots.

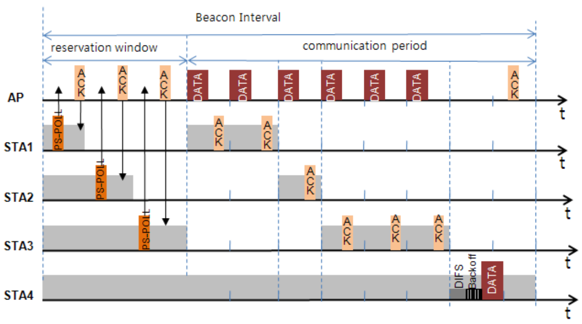

Fig. 2. Transmission Procedure

3.3. Medium Conditions and Synchronization

As the conditions of wireless medium are not perfect, channel noise or interference from other stations may prevent AP from transmitting packets during reserved time slots, it leads PS stations to useless waiting. In order to improve this problem, we propose that after DIFS, if there still no traffic arrived to PS station, the PS station enters into sleep immediately. Although the later arrived packets may be dropped due to PS station staying in sleep, power is reserved.

In previous section, we have assumed PS stations are perfectly synchronized with AP. However, synchronization via delivery of beacon frame is not guaranteed, and loose-synchronization with AP may lead stations to waking up at wrong time that results in packet loss and power waste. To improve the performance of proposed scheme, guaranteed synchronization mechanism is required to support. However, it is outside the scope of this paper.

Ⅳ. Performance Modeling

In this section, we develop a mathematical model to analyze the performance of proposed time slotted PSM. Based on[8], the energy consumption of mobile station implementing IEEE 802.11 protocol significantly depends on the MAC delay it experiences. We first have a review of the MAC delay experienced by a station operating in IEEE 802.11 PSM. In[8], the distribution of MAC delay T_{MAC} conditioned to experiencing i collisions, and successfully delivering the frame within MAX attempts is:

$$T^{MAC} = DIFS + \sum_{j=1}^{i+1} T^{bo}(CW_j) + \sum_{j=1}^{i} T_j^{coll} \frac{(1-p_f)^i . p_f}{1-p_{loss}}, i=0,.....,MAX-1. \quad (1)$$

Here $T^{bo}(CW_j)$ is the time elapsed to complete the backoff procedure as the congestion window size is CW_j, and $T^{coll}{}_j$ is the time that station cannot access the channel when a frame sent by the station undergoes collision, p_f is the probability that no other mobile stations transmit in the same time slot used by the modeled station to start a transmission, p_{loss} is the probability that a frame is discarded after being re-transmitted *MAX* times unsuccessfully.

Fig.3 illustrates the average MAC delay $E[T_{MAC}]$ versus number of stations, we find that the MAC delay increases as the load on the WLAN increases. In this figure, The dashed line illustrates the BI length, point which is the intersection between $E[T_{MAC}]$ and the BI can be seen as a limit for using the 802.11 PSM mechanism[8]. Because beyond this point the average time required to access the channel is greater than the BI, thus PS station has to keep active for whole BI without receiving any buffered data.

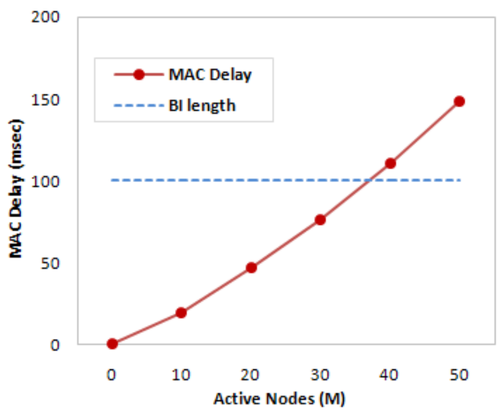

Fig. 3. MAC Access Delay

In following part we give an analysis of our proposed scheme, we model the power consumed during BI for a station operated in legacy PSM and time slotted PSM respectively. We first give some assumptions. We assume the contention window of both AP and stations keep the minimum value (CW_{min}), and after accessing channel AP or stations transmit data successfully(without collision and channel error). We assume that the stations are always synchronized in time with AP, the power consumption in sleep mode is negligible. We neglect the transition delays and the energy consumption when a station changes its states. We assume packets arrive continually over time, and the service is assumed to be gated, i.e, packets arriving in a BI are served only in or after the next BI (this is a reasonable assumption since the AP has to prepare the TIM in advance)[9].

We define power used for transmission as P_{TX}, for reception as P_{RX} and for staying in IDLE mode as P_{IDLE}. We know that before transmission station has to contend for channel, we define the power consumed for contention is P_C, it is calculated as (2).

$$P_C = P_{IDLE} \times (DIFS + \frac{CW_{\min}}{2}) \qquad (2)$$

When station exchanges a PS-POLL frame with AP, the P_P that power consumed for it is calculated as (3), here $T_{PS\text{-}POLL}$ is the time spent in transmitting a PS-POLL packet, T_{ACK} is the time spent in receiving a ACK packet :

$$P_P = P_{TX} \times T_{PS-POLL} + P_{RX} \times T_{ACK} + P_{IDLE} \times SIFS \qquad (3)$$

Apply the methodology discussed in[10], let M denote the total number of stations in network, T_{BI} denote beacon interval, λ denote the packet arrival rate of each station which is expressed a Poisson distribution, α_i as the number of buffered packets in the AP at the i th beacon interval, β_i as the number of stations that have buffered packets to receive in the AP at the i th beacon interval. Then α_i and β_i can be obtained as:

$$\alpha_i = M\lambda T_{BI} \qquad (4)$$

$$\begin{aligned}\beta_i &= MPN(T_{BI}) \geq 1 \\ &= M(1 - PN(T_{BI}) = 0) = M(1 - e^{-\lambda T_{BI}})\end{aligned} \qquad (5)$$

Before receiving all buffered packets station has to stay in active, we define the power consumed for it as P_W, it is calculated as (6), here T_{WAIT} is the time that station spends in waiting for receiving packets:

$$P_W = P_{IDLE} \times T_{WAIT}$$
$$= P_{IDLE} \times (T_{DATA} + T_{PS-POLL}) \times \frac{1}{\alpha_i} \sum_{j=1}^{\alpha_i - 1} j$$
$$= P_{IDLE} \times (T_{DATA} + T_{PS-POLL}) \times \frac{\alpha_i - 1}{2} \quad (6)$$

The P_D that power consumed for receiving a data frame from AP is expressed as (7), here T_{DATA} is the time spent in receiving data packet:

$$P_D = P_{RX} \times T_{DATA} + P_{TX} \times T_{ACK} + P_{IDLE} \times SIFS \quad (7)$$

Now we can calculate P_{PSM}, the total power consumed for receiving buffered frames in PS Mode during one BI as (8), here P_B is the power for receiving beacon frame.

$$P_{PSM} = P_B + \frac{\alpha_i}{\beta_i} P_{PS-POLL-transmissiosn} + \frac{\alpha_i}{\beta_i} P_{DATA-receiving}$$
$$= P_B + \frac{\alpha_i}{\beta_i} (P_P + P_C + P_D) + P_W \quad (8)$$

Next, let us calculate $P_{PSM\text{-}slotted}$, the total power consumed for receiving buffered frames in time slotted PS Mode during one BI. Since during communication period every station wakes up SIFS earlier before its allocated time slot, the total power spent in IDLE mode $P_{W'}$ can be calculated as:

$$P_{W'} = P_{IDLE} \times SIFS \quad (9)$$

Combine (2), (4), (5) and (7), $P_{PSM\text{-}slotted}$ can be expressed as (10) which is the sum of power for receiving one beacon frame, power for transmitting one PS-POLL frame during reservation window and power for receiving all buffered frames during the communication period:

$$P_{PSM-slotted} = P_B + P_{PS-POLL-transmissiosn} + \frac{\alpha_i}{\beta_i} P_{DATA-receiving}$$
$$= P_B + (P_P + P_C) + \frac{\alpha_i}{\beta_i} P_D + P_{W'} \quad (10)$$

We compare the $P_{PSM\text{-}slotted}$ and P_{PSM} via (8) and (10) assuming the system parameters reported in Table 1. We change traffic density defined as follows from 0.6 to 1.0.

traffic density = number of nodes × packet length × traffic rate ⁄ transmission rate

Table 1. Parameters

Parameter	Value
Packet Size	8000 bits
Transmission Rate	11 Mbps
CWmin	32
P_{TX}	1.65 mw
P_{RX}	1.4 mw
P_{IDLE}	1.15 mw

Fig.4 shows the variation of power consumption on traffic density. We conclude that as traffic density changes our proposed time slotted PSM mechanism consumes less power compared with legacy PSM. It is because first, in slotted PSM mechanism, station only transmits one PS-POLL frame for all the buffered frames, but in legacy PSM, station has to transmit a PS-POLL frame for each buffered data packet which results in server power consumption. Moreover when a station delivers the PS-POLL frame, it has to consume much additional power for channel contention. Second, in time slotted PSM mechanism, station wakes up SIFS earlier before its allocated time slot, after receiving all the buffered data, station enters into sleep mode immediately. But in legacy PSM, station has no knowledge when AP will deliver the buffered frames, it has to stay awake until it receives all the buffered frames which results in power waste quite much.

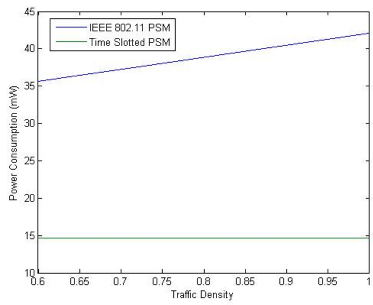

Fig. 4. Power Consumption vs. Traffic

Ⅴ. Simulation

5.1. Environment and Parameters

In this section we use OPNET to perform simulation and evaluate the performance of our proposed scheme. The simulation models a network consisting of an AP and five mobile stations. The stations transmit UDP packets to AP periodically and three of them are PS stations. We choose 802.11b as the default wireless protocol, set data rate to 11Mbps while basic data rate 2Mbps. To simulate the power consumption of the 802.11b interface card, we use an energy model that derived from[10]. The consumed power is set to 1.65mW while transmitting, 1.4mW while receiving, 1.15mW while idle. More details of parameters are shown in Table 2.

Table 2. Simulation Parameters

Parameter	Value
Beacon Interval	100 msec
Slot Time	50 ㎲
Packet Size	8124 bits
PS-POLL	192 bits
DIFS	128 ㎲
SIFS	28 ㎲

5.2. Result

Fig.5 shows the average power consumption for both schemes versus message inter arrival period. We find that as network load increases power consumed by legacy PSM increases quite much while it stays in a constant level in proposed scheme. It is because time slotted PSM reduces power consumpted in long time waiting. Also it decreases PS-POLL frame transmission.

Fig.6 compares the whole network throughput between proposed PSM and legacy PSM. As proposed PSM reduces PS-POLL frame transmission and cancels contention for medium access, the whole network throughput is improved much more.

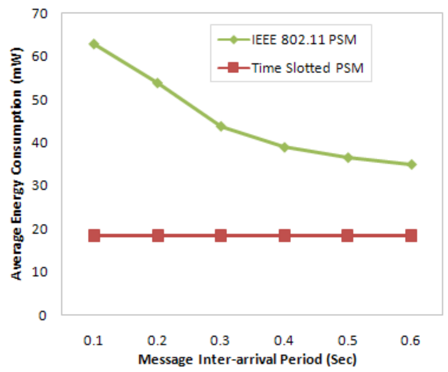

Fig. 5. Average Power Consumption

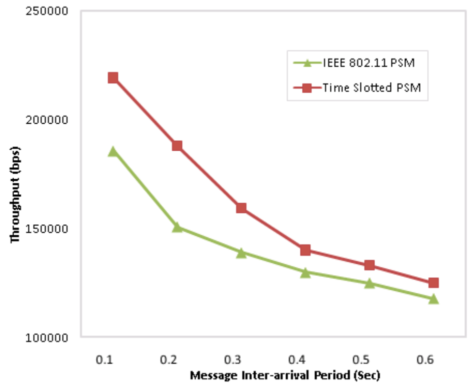

Fig. 6. Network Throughput

Ⅵ. Conclusion

In this paper we focus on improving the performance of 802.11 PSM. In order to reduce power consumpted in IDLE state we have proposed a time slotted scheme which allows PS station to reserve time slots for receiving buffered packets. In addition, we have modified the one data frame per PS-POLL retrieving scheme that several packets can be retrieved via a PS-POLL. Analytic model and simulation results show that proposed scheme reduces useless power consumption quite much and improve the whole network performance.

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<관심분야> 무선LAN MAC 프로토콜, Power Saving Mechanism

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