Journal of Zhejiang University SCIENCE A
ISSN 1673-565X (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Enhanced power saving mechanism for supporting multicast services in 802.11 wireless LANs*

Yong HE†1, Rui-xi YUAN†‡1, Xiao-jun MA2, Jun LI2
(1*Center for Intelligent & Networked Systems, Tsinghua University, Beijing 100084, China*)
(2*Thomson Broadband, R&D, Co., Ltd, Beijing 100085, China*)
†E-mail: heyong04@mails.tsinghua.edu.cn; ryuan@tsinghua.edu.cn

Received July 5, 2008; Revision accepted Jan. 8, 2009; Crosschecked Apr. 29, 2009

Abstract: Traditional 802.11 power saving mechanism (PSM) treats multicast and broadcast traffic equally, and suffers significant performance degradation with multicast background traffic. This paper proposes an enhanced PSM that effectively differentiates multicast streams. It re-arranges the virtual bitmap of the traffic indication map (TIM) to carry traffic status for multicast groups and introduces a concept of sequential transmission of multi-addressed data to facilitate differentiation among multicast groups. Our analysis shows that the enhanced PSM can effectively save power in mixed traffic environments.

Key words: 802.11, Wireless network, Power saving, Multicast services
doi:10.1631/jzus.A0820514 **Document code:** A **CLC number:** TN92

INTRODUCTION

Power management is a general concern for wireless communications. To save energy, a power saving mode (PSM) is introduced for the 802.11 device (IEEE Std. 802.11, 1999). Unlike the continuous active mode (CAM), in the PSM a mobile device can judiciously power off its transceiver to save energy when necessary. This paper aims to address the issue of 802.11 PSM for broadcast/multicast (B/M) services in wireless LANs.

In the legacy 802.11 PSM, the access point (AP) buffers incoming data destined for power saving stations and periodically announces the buffering information through the traffic indication map (TIM) piggybacked in the beacons. The mobile station wakes up periodically to listen to the beacons and obtains its own traffic information. For individually addressed traffic, one unique bit in the bitmap of TIM is assigned for each mobile station as the traffic indicator. For multi-addressed traffic, all mobile stations share one single bit in the TIM as the common traffic indicator. A mobile station can enter into sleep state once it ensures that all of its frames have been retrieved successfully. Our experiments on an HP iPAQ PDA suggest that an 802.11b wireless adapter with PSM enabled can extend its lifetime up to 250% for light to moderate traffic loads.

However, when there is background traffic in the network, especially multicast background traffic, the 802.11 PSM can have a significant degradation of power performance. Our prior experimental results (He *et al.*, 2008) show that using only one bit to indicate B/M traffic in the legacy 802.11 PSM does not provide sufficient granularity for multicast services. To solve this problem, an enhanced PSM is proposed in Section 3. It works by increasing information piggybacked in the TIM structure and enabling a mobile station to differentiate multicast groups. It further introduces a concept of sequential transmission for group services which allows a mobile station to sleep in the middle of the delivery procedure of multi-addressed data. We validate the effectiveness of the enhanced PSM by simulations in Section 4, where

---

‡ Corresponding author

* Project (Nos. 60574087 and 60721003) supported by the National Natural Science Foundation of China

we show that the enhanced PSM can effectively mitigate the impact of multicast background traffic on power consumption.

Similar to the enhanced PSM, in 802.11v (IEEE Std. 802.11v, 2008), a flexible B/M service (FBMS) is introduced to provide flexible delivery intervals for different multicast streams so as to reduce the mutual impact between different streams. While the standard is not finalized yet, the draft proposes a new TIM element to differentiate streams. However, 802.11v achieves multicast differentiation with extra signaling, and it does not address the issue of scheduling of stream deliveries. The enhanced PSM proposes a sequential delivery procedure to enhance power saving. In addition, there are experimental works (Feeney and Nilsson, 2001; Gupta and Mohapatra, 2007; He *et al*., 2008) aiming to provide insights for 802.11 PSM in practical test-beds, and recent works (Adams and Muntean, 2007; Tan *et al*., 2007; Namboodiri and Gao, 2008) focusing on improving the performance of 802.11 PSM against QoS-aware applications such as voice over IP (VoIP). Another recent work (Anastasi *et al*., 2008) gives an analytical model for 802.11 PSM and also provides a brief survey of research activities in this field. However, none of them are dedicated to address the issue of background traffic for 802.11 PSM.

IMPACT OF BACKGROUND TRAFFIC

Compared with the continuous active mode (CAM), the legacy 802.11 PSM allows a station to enter into sleep state as long as it has no pending traffic at the AP. Our measurement on a commercial PDA (He *et al*., 2008) shows that the legacy 802.11 PSM can significantly reduce the energy consumption and prolong the lifetime of battery-powered mobile devices, which is important for mobile communications.

However, the power saving can only be achieved in the absence of background traffic. In this study, we treat the traffic that is destined for a considered station A as the foreground traffic, and the traffic that is not destined for station A as the background traffic. In our prior work (He *et al*., 2008), we investigated the impact of background multicast traffic on the power performance of the legacy 802.11 PSM on commercial PDAs (HP iPAQ hx2750), and Figs.1 and 2 are two representative results. In Fig.1, we studied how the power consumption evolves with the background multicast traffic. We see that even though the foreground traffic load is invariant, the power consumption increases considerably with the load of background multicast traffic. In Fig.2, we further compared the power performance among three modes: CAM (no background traffic), PSM without and with a 1.5 Mbps background multicast traffic. As shown in this figure, the presence of a 1.5 Mbps background multicast traffic causes the power saved by legacy PSM reduced by about 50%, regardless of the foreground traffic rates.

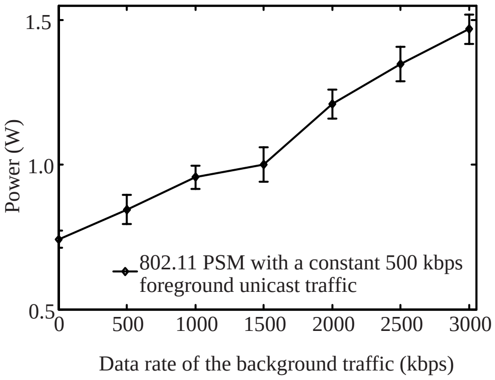

Fig.1 Power consumption of PDAs as a function of the data rate of the background multicast traffic (He *et al.*, 2008)

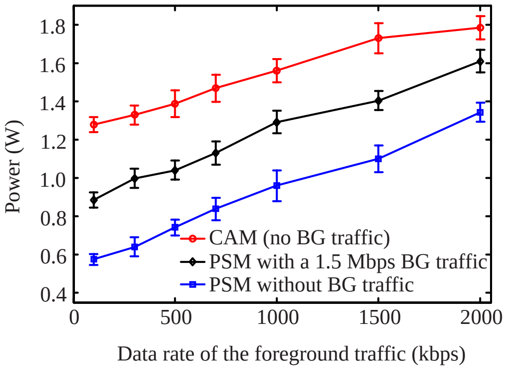

Fig.2 Comparison of power consumption of PDAs among three cases: CAM (no background traffic), PSM with and without background traffic (He *et al.*, 2008)
BG: background

Hence, the effectiveness of legacy 802.11 PSM can be significantly impaired by the background multicast traffic. This is because the legacy 802.11 PSM uses only a single bit to indicate the presence of all multicast traffic. It does not provide a fine granularity to differentiate multicast data belonging to different groups. Thus a station has to receive all multicast data including those not belonging to it, which places an extra burden on the mobile station's energy consumption.

THE PROPOSED PROTOCOL

Overview of the enhanced PSM

Being aware that using only one bit for indication of B/M frames provides too coarse granularity for the group service and is not effective for power saving, we propose to increase the space in the TIM structure to carry more information for B/M traffic. Our idea is to assign one more bit for each station as the multicast traffic indicator in the virtual bitmap. In the new TIM structure, two consecutive bits are reserved for each single mobile station in the virtual bitmap, with one corresponding to the unicast traffic indicator and the other to the multicast traffic indicator. Further, the significance of the one-bit B/M traffic indicator is now restricted to representing only the status of broadcasting traffic in the new TIM structure to distinguish the broadcast traffic from the multicast traffic. This feature is useful for a mobile station in extremely low power state that does not want to receive broadcast traffic.

To differentiate multicast data, the AP can maintain a look-up table, which establishes a mapping from a multicast group to its member stations in this network. This table may be constructed by passive snooping of the Internet group management protocol (IGMP) messages at the AP, or by proactive signaling with the mobile stations when they join multicast groups. The former approach has the advantage of less signaling overhead but requires more processing power at the AP, since the AP should examine all IGMP messages. The latter approach suffers more signaling overhead but it should be more reliable in case of encrypted IGMP communications.

Each time before the beacon launches, the AP examines its buffer pool and performs a table lookup to set the relevant unicast and multicast bits of the bitmap to appropriate values. By checking the multicast bit, a mobile station can determine whether or not there are multicast data outstanding. A station that does not join any multicast group can enter into sleep state immediately after receiving the beacon, given that the broadcast bit and its own unicast bit are unset.

In addition, the enhanced PSM requires that all multi-addressed frames be delivered by the AP in a predefined sequence. The rules are as follows: (1) the broadcast traffic is always delivered first; (2) when there are data from multiple multicast groups, they are delivered in a sequence based on the values of their multicast addresses, with the smallest delivered first. In addition, the end of a B/M stream can be indicated by mechanisms such as setting the end-of-service-period (EOSP) bit. Hence, all B/M frames can be delivered in a predefined order and frames of the same group are delivered successively without interruption of other multi-addressed frames. The adoption of such sequential transmission for multi-addressed data benefits power saving in the sense that a station can sleep within the frame delivery procedure, since it can determine whether or not its B/M data have been completely delivered in this procedure. Note that the use of multicast address values for sequence ordering is not mandatory and other intelligent algorithms can also be designed to decide the optimal service order.

An important issue of the new TIM element is the backward compatibility. For a legacy station to work with an enhanced AP, the AP can accommodate the legacy station by retaining the semantics of the B/M indicator as in the original PSM and assigning odd number AIDs for the legacy station. The cost is that a new station cannot tell directly from the TIM whether or not it has broadcast data at the AP, and it has to receive one more frame from AP before making the right decision.

Performance analysis

Define ρ as the ratio of awake time of the mobile station over one delivery TIM (DTIM) period T, namely awake ratio. To make our analysis possible, we put a simplified traffic scenario: k different background multicast streams present in the network, each having n frames arriving at the AP within a DTIM period; only one foreground multicast stream is imposed on the targeting mobile station, whose frames arrive at the AP in accordance with a Poisson process with rate λ packets/s. Suppose that each frame is served by the AP for an average period of τ, then with a probability $p_0(T)=\mathrm{e}^{-\lambda T}$, there is no frame arriving at the AP during the past DTIM interval. Hence the awake ratio ρ_0 in the current DTIM interval can be expressed as (the awake time to receive beacons is omitted)

$$\rho_0 = \begin{cases} 0, & \text{for enhanced PSM}, \\ kn\cdot\tau/T, & \text{for legacy PSM}. \end{cases} \tag{1}$$

And with a probability $p_i(T)=\mathrm{e}^{-\lambda T}(\lambda T)^i/(i!)$ (i=1, 2, 3, ...), there are i frames pending at the AP for delivery. In the enhanced PSM, because of the sequential transmission procedure, these frames can be delivered at the 1st, 2nd, 3rd, …, or (k+1)th place in the delivery sequence. Without loss of generality, we assume that the frames are delivered with identical probability at each place in the sequence. Then the awake ratio ρ_i in this case is given by

$$\rho_i = \begin{cases} \sum_{l=0}^{k} \frac{1}{k+1}\frac{(i+ln)\tau}{T}, & \text{for enhanced PSM}, \\ \frac{(i+kn)\tau}{T}, & \text{for legacy PSM}. \end{cases} \tag{2}$$

Taking expectation of the ρ_i (i=0, 1, 2, …), we can derive the expected awake ratio as

$$E(\rho) = \begin{cases} \lambda\tau + \frac{1-\mathrm{e}^{-\lambda T}}{2}\cdot\frac{kn\tau}{T}, & \text{for enhanced PSM}, \\ \lambda\tau + \frac{kn\tau}{T}, & \text{for legacy PSM}, \end{cases} \tag{3}$$

Notice that in Eq.(3), the first item in each equation represents the average time required for the mobile station to receive its multicast stream, and the second item represents the extra awake time used to receive the background multicast streams. In comparison with the legacy PSM, the enhanced PSM cuts down over 50% of the extra awake time. The average gain of the awake ratio over legacy PSM is given by

$$\rho_{802.11} - \rho_{\text{enhanced}} = \frac{1+\mathrm{e}^{-\lambda T}}{2}\cdot\frac{kn\tau}{T}. \tag{4}$$

Eq.(4) indicates that the enhanced PSM can greatly reduce the mobile station's awake time (hence the power consumption) at the presence of background multicast traffic, particularly for light to moderate foreground traffic where the frame arrival rate λ is small.

EVALUATION AND DISCUSSION

In this section, we investigate the performance of the enhanced PSM on platform ns2. We simulated a network consisting of an AP and three mobile stations labeled with ID 1 through 3. Station 1 was the measuring point and its traffic served as the foreground traffic while that of the other two served as background traffic. Three different multicast streams with Poisson arrivals were imposed across AP and three stations individually. For each stream, its address was changed to a new value that was randomly chosen from the multicast address pool at each second. We used the energy model from (Feeney and Nilsson, 2001). The power consumption was set to 1.346 W while transmitting, 0.900 W while receiving, 0.741 W while idle, and 0.048 W while sleeping. As for the state transition, we modeled its energy consumption as 2.0 mJ, with a transition time of 0.8 ms. Other parameter settings are listed in Table 1. For comparison with theoretical results, no channel errors were considered. Each simulation run lasted 100 s, and each data point was an average of 10 simulation runs.

Table 1 Simulation parameters

Parameter	Value	Parameter	Value
Packet size (byte)	1500	Slot time (μs)	20
Data rate (Mbps)	11	Preamble length (μs)	144
Beacon period (ms)	100	SIFS (μs)	10
DTIM period	1	RTS threshold	0

Fig.3 shows how the enhanced PSM successfully suppresses the impact of background traffic for a power saving station that does not join any multicast group (or does join a group but has no traffic). In this scenario, the foreground stream on station 1 has data rate 0 kbps while each of the two background streams has data rate increasing from 0 to 1.5 Mbps (thus gives a total volume from 0 to 3 Mbps). We see that the power consumption for the enhanced PSM remains quite steady when the background traffic increases; whereas for 802.11 PSM, a sharp linear increasing trend is observed, as we have seen in Fig.1. The power consumed to receive the background traffic accounts for the gap between the two curves.

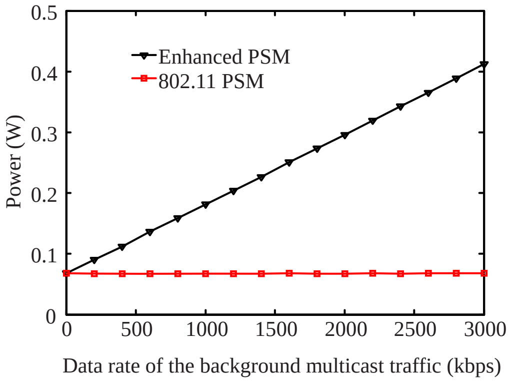

Fig.3 Power consumption as a function of the data rate of the background multicast traffic when no foreground traffic is imposed

Table 2 compares the power consumption between 802.11 PSM (denoted as P_{o1}) and the enhanced PSM (denoted as P_{en}) in a scenario where the load of foreground (FG) traffic increases from 0 to 2 Mbps but the load of background (BG) traffic is fixed at 2 Mbps. For comparison, we show the power consumption of 802.11 PSM when no background traffic is present (denoted as P_{o2}). The term $\Delta P_1=P_{o1}-P_{o2}$ represents the increased power for 802.11 PSM due to the presence of background traffic, and the term $\Delta P_2=P_{o1}-P_{en}$ represents the power saved by the enhanced PSM over 802.11 PSM. Clearly the ratio $\Delta P_2/\Delta P_1$ defines the efficiency of the enhanced PSM to mitigate the effect of background traffic. As shown by these results, for small foreground traffic loads such as 100 kbps, over 75% of the power incurred by background traffic can be saved, but for larger loads beyond 500 kbps, the percentage is reduced to around 50%. This observation is consistent with the analysis result Eq.(4).

We further validated our analytical results in Fig.4. In this figure, we have a varying foreground traffic load from 0 to 1000 kbps and fixed background traffic load as 2 Mbps. The *y*-axis shows the awake ratio incurred by background traffic, which is analytically expressed as

$$\Delta\rho=\begin{cases}\dfrac{1-\mathrm{e}^{-\lambda T}}{2}\cdot\dfrac{kn\tau}{T}, & \text{for enhanced PSM,}\\[2ex] \dfrac{kn\tau}{T}, & \text{for legacy PSM.}\end{cases} \tag{5}$$

Table 2 Comparison of power consumption for 802.11 PSM and enhanced PSM under different FG traffic rates

FG traffic rate (kbps)	P_{o1} (W)	P_{o2} (W)	P_{en} (W)	ΔP_1 (W)	ΔP_2 (W)	$\frac{\Delta P_2}{\Delta P_1}$
0	0.2963	0.0675	0.0675	0.2288	0.2288	1.0000
100	0.3075	0.0787	0.1356	0.2288	0.1719	0.7513
200	0.3199	0.0903	0.1731	0.2296	0.1468	0.6395
400	0.3435	0.1123	0.2186	0.2312	0.1249	0.5402
500	0.3543	0.1240	0.2326	0.2303	0.1217	0.5286
600	0.3652	0.1360	0.2484	0.2292	0.1168	0.5096
1000	0.4121	0.1812	0.2979	0.2309	0.1142	0.4946
1500	0.4685	0.2392	0.3527	0.2293	0.1158	0.5049
2000	0.5242	0.2963	0.4097	0.2279	0.1145	0.5025

P_{o1}: power consumption of 802.11 PSM; P_{o2}: power consumption of 802.11 PSM with no background traffic; P_{en}: power consumption of the enhanced PSM. $\Delta P_1=P_{o1}-P_{o2}$; $\Delta P_2=P_{o1}-P_{en}$. FG: foreground

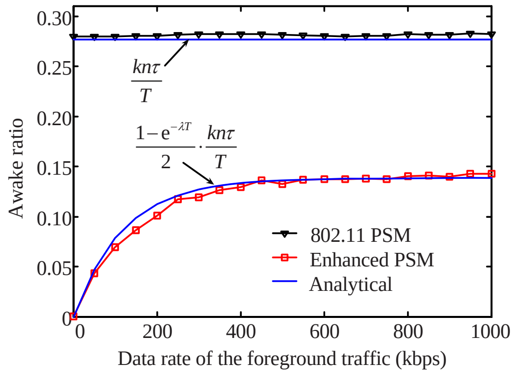

Fig.4 The awake ratio incurred by background traffic vs the data rate of foreground traffic when the background traffic is fixed at 2 Mbps (each background stream has a data rate of 1 Mbps)

As shown in Fig.4, the analytical curves achieve fairly accurate predictions for the simulation results. The enhanced PSM can successfully reduce the effect of background multicast traffic, particularly for small foreground traffic loads. For practical traffic that usually arrives in bursts, the enhanced PSM can have even better power performance because more DTIM periods have no (foreground) traffic volumes.

In summary, both theoretical and simulative results demonstrate that the enhanced PSM is an effective approach to saving power in mixed traffic environments.

References

Adams, J., Muntean, G.M., 2007. Adaptive-buffer Power Save Mechanism for Mobile Multimedia Streaming. Proc. ICC, Glasgow, Scotland, p.4548-4553. [doi:10.1109/ICC.2007.751]

Anastasi, G., Conti, M., Gregori, E., Passarella, A., 2008. 802.11 power-saving mode for mobile computing in Wi-Fi hotspots: limitations, enhancements and open issues. *ACM Wirel. Networks*, **14**(6):745-768. [doi:10.1007/s11276-006-0010-9]

Feeney, L.M., Nilsson, M., 2001. Investigating the Energy Consumption of a Wireless Network Interface in an Ad Hoc Networking Environment. Proc. INFOCOM, Anchorage, AK, p.1548-1557. [doi:10.1109/INFCOM.2001.916651]

Gupta, A., Mohapatra, P., 2007. Energy Consumption and Conservation in WiFi Based Phones: A Measurement-based Study. Proc. SECON, San Diego, CA, p.122-131. [doi:10.1109/SAHCN.2007.4292824]

He, Y., Yuan, R., Ma, X., Li, J., 2008. The IEEE 802.11 Power Saving Mechanism: An Experimental Study. Proc. WCNC, Las Vegas, Nevada, p.1362-1367. [doi:10.1109/WCNC.2008.245]

IEEE Std. 802.11, 1999. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. IEEE Computer Society LAN MAN Standards Committee.

IEEE Std. 802.11v, 2008. Amendment to IEEE Std. 802.11: Wireless Network Management, Draft 2.0. IEEE Computer Society LAN MAN Standards Committee.

Namboodiri, V., Gao, L., 2008. Towards Energy Efficient VoIP Over Wireless LANs. Proc. Mobihoc, Hong Kong, China, p.169-178. [doi:10.1145/1374618.1374642]

Tan, E., Guo, L., Chen, S., Zhang, X., 2007. PSM-throttling: Minimizing Energy Consumption for Bulk Data Communications in WLANs. Proc. ICNP, Beijing, China, p.123-132. [doi:10.1109/ICNP.2007.4375843]