Enhanced Power Saving in Next Generation Wireless LANs

Harkirat Singh, Huai-Rong Shao and Chiu Ngo
Advanced Technology Lab
Samsung Electronics R & D Center
75 W Plumeria Dr., San Jose, CA, 95134, USA
Email: (har.singh, hr.shao, chiu.ngo)@samsung.com

Abstract ***– Battery powered handheld devices need to operate for extended periods of time, and thus require to be energy conserving. This paper evaluates the performance of a new power saving scheme, called PSMP (Power Save Multiple Poll), developed for the upcoming IEEE 802.11n WLANs. Using both analysis and simulations, we investigate the benefits of using PSMP in a wireless LAN having multiple Voice-over-IP (VoIP) clients. To boost the reliability of a PSMP sequence, we propose a new recovery scheme, which we call PSMP recovery. Our results show that the PSMP recovery scheme significantly improves the efficiency of the original PSMP sequence.***

Keywords: IEEE 802.11, WLAN, QoS, Power Saving, PSMP

1. Introduction

Next generation wireless LANs will support sophisticated devices with a wide range of integrated applications such as web browsing, email, streaming video, gaming console, and telephony. In [5], power saving access points are presented for 802.11 networks. Power consumption is a critical issue for handheld devices. Currently, the IEEE 802.11n task group is working on the next generation of WLAN standard [1] and has proposed a new power management scheme, PSMP (Power Save Multiple Poll), for handheld stations (STAs) controlled by an Access Point (AP). The AP periodically initiates a PSMP sequence by transmitting the PSMP MPDU (Medium Access Control Protocol Data Unit) according to the service period (Service Start Time) within the TSPEC of the STAs being served in the current PSMP sequence. The PSMP MPDU conveys the scheduled down-link (DL) and up-link (UL) durations for each PSMP enabled STAs. The STAs wake up at the scheduled interval for data communication. It is possible to extend the PSMP sequence to transmit unacknowledged packets for some STAs. This scheme is suitable for scheduled and unscheduled streams.

Since the PSMP MPDU is a broadcast/multicast packet, it is highly likely that it can collide with other simultaneous transmissions. Furthermore, it is not possible to protect the PSMP frame against collisions using a scheme which is suitable to protect unicast packets. For instance, an RTS/CTS exchange is used to protect unicast packet delivery. Typically, the PSMP frame may follow the CTS-to-self after a PIFS delay to allow sensing of the physical carrier. Since the CTS-to-self has no feedback mechanism, it is quite possible that the PSMP frame is not correctly received by one or more PSMP enabled STAs in a PSMP sequence. This leads to the following problems:

- Wastage of shared wireless medium.
- A STA can mistakenly interpret idle medium to start its own transmission, which could collide with other UL/DL transmissions.
- PSMP enabled STAs remain awake throughout the whole PSMP duration, and hence, expend more power.

We propose a new recovery scheme, called PSMP recovery, to enhance the reliability of a PSMP sequence. In our proposed scheme, the AP takes control of the channel whenever the UL slot is idle for more than PIFS duration. The AP then invokes the *PSMP recovery* scheme. This algorithm does not require any changes in the original PSMP protocol. Furthermore, only AP's behavior needs to be modified.

The rest of the paper is organized as follows. In the next section, we summarize power management procedures in the current IEEE 802.11 standard [1–3]. Section 3 describes the PSMP scheme in the upcoming 802.11n. Section 4 presents both analytical and simulation results of PSMP in a wireless LAN having variable number of VoIP clients. The PSMP recovery algorithm and results of a Monte Carlo simulation are presented in Section 5. Finally, Section 6 concludes this paper.

2. Power Management in Current IEEE 802.11

The 802.11 standard defines various power management schemes suitable for both isochronous and asynchronous applications. These schemes are described in the following subsections.

2.1. Power Save Poll (PS-Poll)

A STA in power save mode initiates a frame sequence by transmitting a PS-Poll frame to solicit data frames from an AP [3,6]. A single buffered MSDU or management frame shall be transmitted to the STA after a successful PS poll is received from the STA. The AP sends data with the More Data bit set to 1, if more data is buffered for this STA. Upon receiving the data frame with the More Data bit set to 1, the

1-4244-0063-5/06/$20.00 ©2006 IEEE

STA sends another PS-Poll. After downloading all the buffered frames, the STA switches to sleep mode. A sequence of this happening is shown in Figure 1.

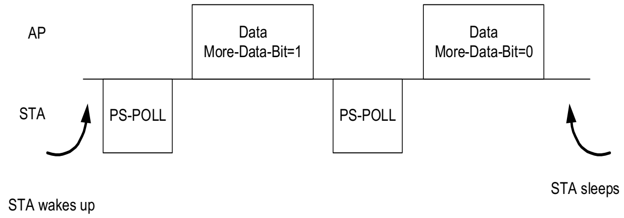


Figure 1: A typical frame exchange sequences of PS-Poll

A noticeable drawback of this scheme is that it requires one PS-Poll per data frame, this is inefficient. Moreover, this overhead becomes significant for small packets such as voice, which are typically 120bytes [4].

2.2. Automatic Power Save Delivery (APSD)

The 802.11e standard [2] defines a power saving scheme called APSD for QoS (Quality of Service) enabled devices. APSD defines two delivery mechanisms, namely, Unscheduled-APSD (U-APSD) and Scheduled-APSD (S-APSD).

2.2.1. S-APSD

S-APSD is used for an isochronous stream which periodically generates MSDUs of constant or variable sizes. A STA supporting isochronous traffic negotiates Traffic Specifications (TSPEC) with an AP. These TSPEC parameters specify the bandwidth required to support an isochronous stream. The AP invokes an admission control algorithm to determine if the new stream can be admitted. Finally, the AP responds with accept, reject or an alternate TSPEC. Once a TSPEC is accepted, the AP sends the schedule element (as shown in Figure 3A), which conveys anticipated service start time, service interval, that is, time difference between two adjacent service periods. A service period is contiguous periods of time granted to a STA.

A few drawbacks of this scheme are: (1) as shown in Figure 3(A), any packet being lost in a service period cannot be transmitted until the start of the next service period. This could severely affect the end-to-end latency of a delay bound isochronous stream; and (2) it does not provide any power management for an asynchronous stream.

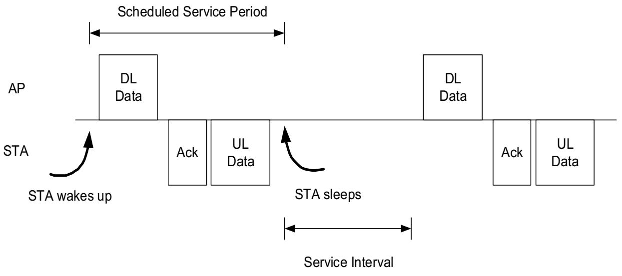
2.2.2. U-APSD

A STA initiates U-APSD by transmitting a trigger frame, which is a frame associated with a trigger-enabled AC (access category). Figure 3(B) shows a typical U-ASPD sequence. After acknowledging the trigger frame, the AP transmits frames to the triggering STA. The AP sets the more data bit to false in the last frame, this enables the triggering STA to go back to sleep state after transmitting UL data and ACK.

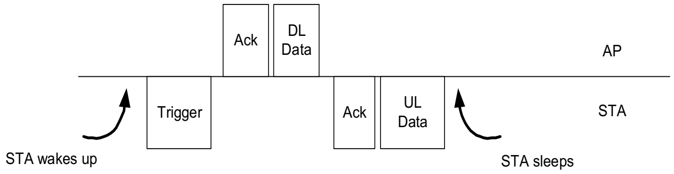
Since the STA does not have any scheduled periods, sending a trigger every time the STA wants to retrieve/transmit frame is not energy efficient.

Element ID	Length	Schedule Info	Service Start Time	Service Interval	Specification Interval

Figure 2: Scheduled Element Format



(A): S-APSD



(B): U-APSD

Figure 3: A typical frame exchange sequences of S-APSD and U-APSD

3. Power Saving Scheme in IEEE 802.11n

A handheld device can effectively conserve battery power if it knows when to wake up to transmit or receive a packet and when to go back to sleep. The 802.11n task group proposes a power management scheme called PSMP (Power Save Multiple Poll) to enable further power savings [1]. The PSMP sequence starts with the transmission of a non-aggregated PSMP, and terminates when the last scheduled UL (uplink) transmission ends. The PSMP frame comprises of PSMP control header and one or more STA info fields, as shown in Figure 4. The STA info field carries timing details of scheduled UL and DL periods. The STA info includes two additional sub-fields for UL and DL offsets, which help in determining the exact time instant when the UL and DL durations would start. The More PSMP field, in the PSMP control header, when set to 1 indicates whether this PSMP sequence will be followed immediately by another PSMP sequence. When set to 0 it indicates that the current PSMP sequence is the last in the current service period. Figure 5 shows a typical PSMP sequence. It is possible to aggregate multiple streams such as MP3 audio, email chat, VoIP, etc. for a single

STA in a PSMP sequence. Some benefits of PSMP over other power saving mechanisms in the IEEE 802.11 standard are:

- Erroneous packets can be retransmitted in the same service period.
- For a single STA, multiple data packets belonging to different applications can be aggregated together and transmitted in one DL period.
- Burst traffic such as real-time video can be supported using multiple PSMP frames in the current service period.

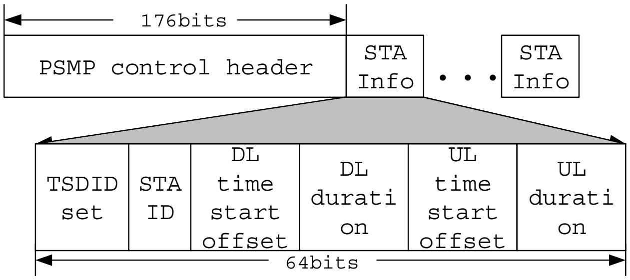


Figure 4: PSMP control header and STA info frame formats

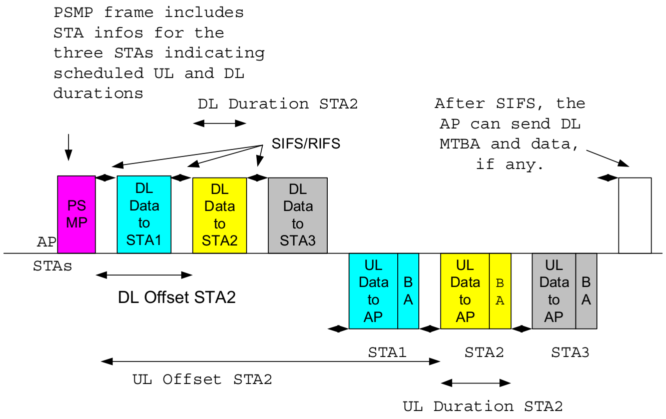


Figure 5: A typical PSMP sequence

4. Performance Study of PSMP

In this section, we evaluate the benefits of using PSMP in the context of VoIP clients[1]. We consider two important performance metrics as call capacity and average wake time for the evaluation study. The two metrics are described below:

Call capacity: number of VoIP calls supported per unit of PSMP sequence time.

Average wake period/STA: the time a STA remains awake to participate in UL/DL transmissions.

4.1. Analytical results

Table I shows the parameters used in our analysis. Based on these parameters, we want to determine average wake time. The PSMP frame duration including the PSMP control header and STA info duration(s) can be expressed as:

$$T_{PSMP} = T_{PHY} + (L_{PSMP} + N*L_I)/P \tag{1}$$

Since VoIP application is a symmetric stream, the UL and DL traffic will be identical.

$$T_{UL} = T_{DL} = T_{PHY} + (L_D + L_A)/P \tag{2}$$

The average wake time can be expressed as:

$$T_{wake} = T_{DL} + T_{UL} + T_{PSMP} + T_{Sifs} \tag{3}$$

TABLE I: PARAMETERS USED IN THE ANALYTICAL MODEL

Parameter	Details	Value
L_{PSMP}	Length of PSMP control header in bits	176
L_I	Length of STA info frame in bits	64
L_D	VoIP packet length in bits	960
L_A	Ack packet length in bits	112
T_{PHY}	Time to transmit the PHY header	40µs
T_{wake}	Average wake time per STA	
P	PHY rate	Variable
T_{Sifs}	SIFS duration	16µs
T_{UL}	Up-link duration	
T_{DL}	Down-link duration	
T_{PSMP}	PSMP frame duration	
N	Number of VoIP clients in a BSS	Variable
IAA	VoIP call inter arrival time	10msec

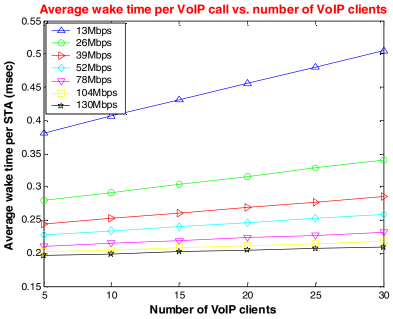


Figure 6: Analytical results of average wake time as a function of the number of VoIP clients.

Figure 6 plots the average wake time as a function of the number of VoIP clients. We observe that increasing the PHY rate reduces the average wake time. However, the PHY header overhead does not result in linear decrease in the average wake time. For a fixed PHY rate, we notice that the average wake period increases with the increase in the number of

---

[1] We consider one VoIP client per STA (station).

VoIP clients. This is because increasing the number of VoIP clients also increases the PSMP frame size, since one STA info frame is required per STA. However, we notice diminishing increase in the average wake period with the increase in the PHY data rate.

We used Matlab to analytically estimate the call capacity. The number of VoIP clients that can be aggregated in a PSMP sequence is limited by the VoIP packet inter arrival time, which is set to 10msec in this study. Figure 7 plots the call capacity as a function of the number of VoIP clients supported at different PHY rate. We notice that increasing the PHY rate increases call capacity significantly. The PHY rate of 130Mbps can support 135 VoIP clients. On the other hand, the PHY rate of 52Mbps can support approx. 100 VoIP clients. *This suggests that increasing the PHY rate does not result in the proportional increase in the number of VoIP clients. This result is very important from the network design point of view.*

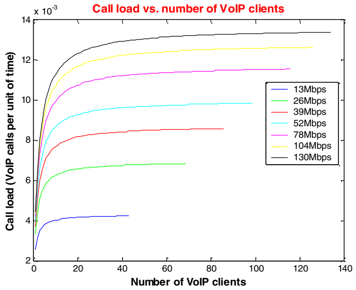


Figure 7: Analytical results of call capacity

4.2. OPNET Simulation results

We implement PSMP protocol in OPNET. We modified the radio pipeline stage of OPENT to include MIMO-PHY features which support PHY rate of 117 Mbps. The VoIP application is modeled using a CBR stream which generates a UDP packet of 120 bytes every 10msec. The average wake time as a function of the number of VoIP clients is presented in Figure 8. The slight difference in the simulation and analytical results can be attributed to retransmissions occurring in the simulation only.

The maximum end-to-end (maxe2e) delay which includes both transmission[2] and buffer delays is presented in Figure 9. The maxe2e delay increases with the increase in the number of VoIP clients served in a PSMP sequence. Furthermore, for a fixed number of VoIP clients, varying maxe2e delays are observed. This is because a VoIP client scheduled at the beginning of the PSMP sequence observes minimum buffer delay. On the other hand, a client scheduled at the end of the sequence achieves maximum buffer delay. A round-robin scheduling will help in smoothening the delay across different clients.

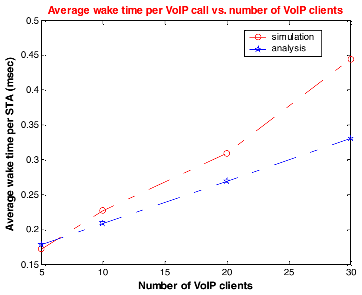


Figure 8: Average wake time as a function of the number of VoIP clients.

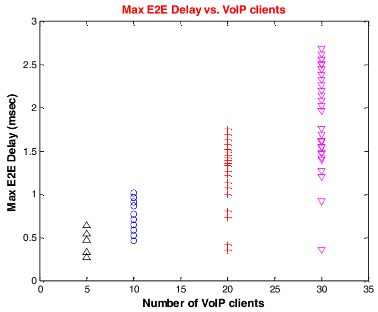


Figure 9: Maximum E2E delay as a function of the number of VoIP clients

5. Enhanced PSMP Recovery

Due to change in the propagation environment, mobility, or other effects, the PSMP frame, which is a broadcast/multicast frame, can be missed by some PSMP enabled nodes, thereby these nodes remain awake for the entire PSMP sequence duration. This leads to both waste of power and throughput. An example of this happening is shown in Figure 10.

To enhance the performance of original PSMP, we developed a *PSMP-recovery* scheme where the AP takes control of the channel whenever the channel is idle for PIFS (point coordination function interframe space) duration at the start of a UL schedule. The following steps are performed in *PSMP-recovery*:

1. The channel is idle for more than PIFS duration after the start of an UL duration.
2. Invoke *PSMP-recovery* if the current UL duration less PIFS is sufficient to transmit the PSMP-recovery frame including at least one STA info field. Otherwise, skip the rest of the steps.
3. Construct a new PSMP frame, PSMP-recovery.
4. Modify the UL duration of the STA scheduled in the current UL duration by taking into account the time required to transmit the PSMP-recovery frame.
5. Include unmodified STA info fields for some or all STAs which belong to this PSMP sequence and are scheduled later in the future. However, modify the UL and DL off-

---

[2] Since all VoIP streams have identical traffic specifications, the transmission delay is same for all clients.

sets to compensate for the time already lapsed in the PSMP sequence. Other STAs, who received the original PSMP frame correctly, must be sleeping at this time. This is the reason that we include unmodified STA info fields for these STAs.

6. Transmit the PSMP-recovery frame.

Figure 11 illustrates the functioning of PSMP-recovery when used in the scenario presented in Figure 10.

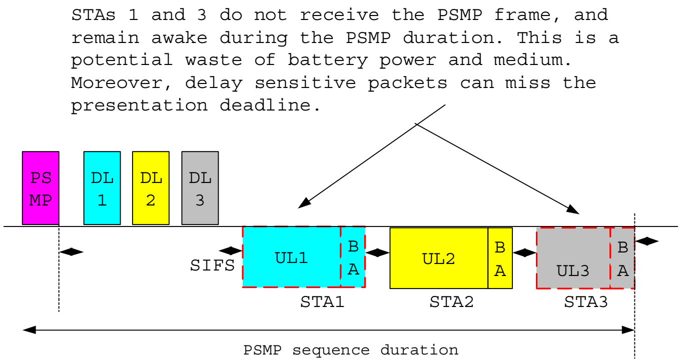

STAs 1 and 3 do not receive the PSMP frame, and remain awake during the PSMP duration. This is a potential waste of battery power and medium. Moreover, delay sensitive packets can miss the presentation deadline.

Figure 10: Some limitations of the PSMP

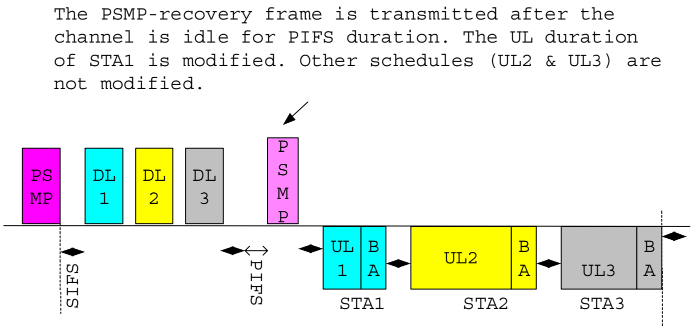

The PSMP-recovery frame is transmitted after the channel is idle for PIFS duration. The UL duration of STA1 is modified. Other schedules (UL2 & UL3) are not modified.

Figure 11: The behavior of PSMP sequence when PSMP-recovery is used.

As shown in Figure 11, the PSMP-recovery frame is transmitted after the channel is idle for a PIFS duration after the scheduled UL duration for STA1. STA3 also receives this PSMP-recovery frame and successfully joins the PSMP sequence. Furthermore, if there are other STAs who did not receive the original PSMP frame successfully, these STAs would also get benefited from the PSMP-recovery frame.

5.1. Monte Carlo Simulations

We evaluate the performance of PSMP-recovery using Monte Carlo simulations in Matlab. We consider a scenario where each STA has three applications: email chat, VoIP client, and MP3 audio with packet sizes of 300, 120, 418 bytes, respectively. The MAC layer aggregates these packets. The inter arrival time of each kind of packet is 10msec. We evaluate the channel efficiency as a ratio of time spent in effective communication and total PSMP sequence duration. We consider 30 STAs in a BSS. Figure 12 presents the simulation result of the channel efficiency as a function of % of STAs failed to receive the PSMP frame. We notice that even with 10% failed STAs the channel efficiency degrades significantly, and continues to reduce with the increase in % failed STAs. On the other hand, PSMP-recovery results in almost constant channel efficiency. These results show that the PSMP-recovery can help in improving the reliability of a PSMP sequence. We have simulated different scenarios and observed similar results. Due to space limitation, those results are not presented here.

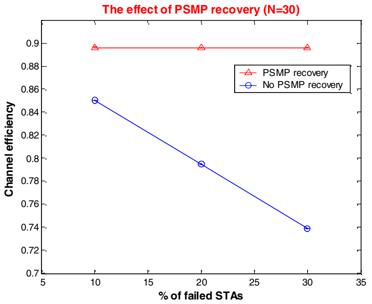


Figure 12: Monte Carlo simulation results of the channel efficiency as a function of % failed STAs

6. Conclusions

In this paper, we examine the power management schemes in the current and next generation Wireless LANs. We evaluated the performance of the PSMP scheme developed in the 802.11n [1] that can provide enhanced power saving mechanism for handheld devices. We examined the impact of PSMP frame loss by a few nodes because of asymmetric links, mobility, or other effects. We proposed a PSMP-recovery scheme that combated the PSMP frame loss problem. Simulations showed that this scheme could significantly improve the channel efficiency. Furthermore, the scheme can be easily incorporated in the AP without modifying the original PSMP protocol.

7. References

[1] IEEE P802.11n/D1.0 (March 2006), “Amendment: Medium Access Control (MAC) and Physical Layer (PHY) specifications, enhancement for higher throughput.”

[2] IEEE P802.11e/D13.0 (January 2005), “Amendment: Medium Access Control (MAC) Quality of Service (QoS) Enhancements.”

[3] IEEE standard for Wireless LAN MAC and PHY layer specifications, ISO/IEC 8802-11:1999(E), 1999.

[4] IEEE 802 11-03/802r23, TGn Usage Models.

[5] Feng Zhang, Todd, T.D., Dongmei Zhao and Kezys, V., “Power Saving Access Points for IEEE 802.11 Wireless Network Infrastructure”, IEEE Transactions on Mobile Computing, Volume 5, Issue 2, March-April 2006 Page(s):144 – 156.

[6] Chen, Ye, Smavatkul, Natt, Emeott, Steve, “Power Management for VoIP over IEEE 802.11 WLAN”, IEEE WCNC 2004.