Priority Based Power Saving Mode in WLAN

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Abstract—According to employing Power Saving Mode (PSM) scheme or not, stations (STAs) in Wireless Local Area Networks can be classified into two categories: STAs using PSM (PS-STAs) and STAs staying in Active Mode (AM-STAs). In IEEE 802.11 standard, a PS-STA periodically wakes up and retrieves data buffered at the Access Point through contending with both other PS-STAs and AM-STAs for its PS-Poll’s transmission. Although AM-STAs usually have no concern with energy, their contention degrades the energy efficiency of PS-STAs, which usually have life concern, by 1) increasing the time duration for data retrieving and 2) increasing the number of PS-STAs which contend throughout the whole beacon interval but get no access opportunity. This paper first proposes a general Priority Based Power Saving Mode (PBPSM) scheme which achieves PS-STAs’ higher energy efficiency than PSM by assigning different channel access priorities. Then, we choose Enhanced Distributed Channel Access in IEEE 802.11e to implement the general mechanism and analyze PS-STAs’ energy efficiency for both PSM and PBPSM. Numerical results show the effectiveness of our mechanism.

I. INTRODUCTION

In Wireless Local Area Networks (WLANs), life time of mobile stations (STAs) powered by limited batteries is a critical limiting operational factor. Therefore, it is important to reduce power consumption of wireless hosts in order to prolong the operation time.

In the past few years, Power Saving (PS) has been an active research area and a number of approaches have been proposed. The methods can be classified according to 1) application scenario ranging from WLAN [2]-[6], Wireless Sensor Network [10]-[11], to IEEE 802.16e Wireless MAN [7]-[9], 2) operating layer of the protocol stack including Medium Access Control (MAC) layer [2]-[9], routing layer [12]-[13], and transport layer [14]; 3) the saved power’s usage, which includes transmitting, receiving, and just being idle.

For the third type of classification, [19] proposes a power control mechanism to save transmitting energy. [20] proposes a relay structure enabling the mobile station with low battery to utilize a nearby station to forward its call rather than connect directly to the base station and thus also save transmitting energy. By reducing unnecessary carrier sensing and signal reception, the approach in [21] can be used to save the energy consumed on receiving. In IEEE 802.11 standard, a sleep based Power Saving Mode (PSM) scheme is adopted to save energy consumed on being idle by introducing a doze state and putting the wireless interface in the doze state when reasonable. In this paper, we focus on the sleep based power saving technique at MAC layer in WLAN.

According to employing PSM schemes or not, STAs in WLANs can be classified into two categories: STAs using PSM (PS-STAs) and STAs not using PSM but staying in Active Mode (AM-STAs). In the MAC header, the Power-Management (PM) bit of the frame control field is used to indicate whether an STA is in AM or PSM.

Before entering PSM, an STA informs the Access Point (AP) through a successful frame exchange including a frame with PM bit set to 1 sent from the STA to the AP and an acknowledgement sent from the AP to the STA [1]. Then the AP buffers packets towards PS-STAs and informs them the corresponding buffer status through Traffic Indication Map (TIM) included as an element within the beacon generated by the AP. With Listen Interval (LI) generally the same as Beacon Interval (BI), a PS-STA periodically wakes up to listen for the beacon and determines the existence of its buffered traffic. If there is no packet buffered for it, the STA will transit to doze state immediately to save power, otherwise it will keep awake and contend for sending a PS-Poll frame to request for its packet. Hereafter, we call PS-STAs that keep awake after the beacon “Aw-STAs”.

If an Aw-STA succeeds in PS-Poll’s transmission in this BI, the AP immediately responds with the corresponding buffered traffic, which should be acknowledged by the Aw-STA. Then the STA can doze to save power. Otherwise, if the Aw-STA fails in contention in this BI, it consumes the energy on keeping awake throughout the whole BI. The operations are shown in Fig. 1. Note that the subscripts “0” and “1” denote the first and second Aw-STAs that have sent PS-Polls in this BI rather than two particular Aw-STAs.

In PSM, an STA’s wireless interface has two different power states: awake and doze, and we may say that an STA is in a certain state, when its wireless interface is in that state. The STA in awake state consumes much more power than in doze state [18] and stays in one of the three different states: idle, transmitting and receiving. To be specific, an Aw-STA is in idle, transmitting and receiving states respectively when it is performing carrier sensing, transmitting a PS-Poll and receiving its buffered traffic. The classifications of different
STAs and states are shown in Fig. 2.

Several studies have been made to improve PSM. [3] focuses on the contention inside PS-STAs and proposes a priority based scheme in which the PS-Polls’ transmission order is determined by STAs’ remaining power in order that the power of all STAs are consumed uniformly. By optimizing the timing and duration of doze state, [5] proposes an adaptive algorithm with the objective of minimizing power consumption. An “arranged PS scheme” which reduces the number of collisions by avoiding the transmissions of redundant control packets and then enhances the system throughput is proposed in [4], [6] proposes a load aware power saving scheme, which adapts the buffered data’s delivery order to the traffic load.

This paper focuses on the effect of contention between PS-STAs and AM-STAs on PS-STAs’ energy efficiency, i.e. the average power consumed for one unit of payload. The remainder is organized as follows. In Section II, a Priority Based Power Saving Mode (PBPSM) scheme is presented. In Section III, the total power consumption and energy efficiency for both the conventional PSM and PBPSM are analyzed. Numerical results and performance evaluation are presented in section IV. Finally, we conclude our paper in Section V.

II. PRIORITY BASED POWER SAVING MODE SCHEME

In this section, we first introduce the approximation of expressing STAs’ power consumption in terms of awake time duration. Then, we describe the general idea of PBPSM and its implementation by adopting Enhanced Distributed Channel Access (EDCA) in IEEE 802.11e protocol.

As stated in the previous section, except for Aw-STAs, other PS-STAs transit to doze state to save power immediately after the beacon and consume a constant value of energy, which is quite less than that of Aw-STAs. Hence, we only consider Aw-STAs’ power consumption and neglect the energy performance of other PS-STAs.

Generally, Aw-STAs’ three states have different power consumption rates and the power consumption of an Aw-STA in one BI should be computed as the weighted sum of three states’ time duration. However, for an Aw-STA in the contention environment consisting of a certain number of other STAs, the duration of receiving and transmitting is much less than that of being idle, i.e. carrier sensing. Moreover, different from the simple idea that power rate for being idle is very small and much less than transmitting/receiving’s power rate, research and tests have shown that the value of three power rates are relatively of the same order. For example, the Lucent IEEE 802.11 WaveLan PC Card consumes 0.74W, 0.9W, and 1.4W in idle, receiving, and transmitting states respectively [18]. So, we could use the total awake duration of Aw-STAs to represent their total power consumption, which is a reasonable approximation.

PBPSM’s motivation is based on the investigation of the effect of AM-STAs’ contention with Aw-STAs on Aw-STAs’ power consumption and energy efficiency. For an Aw-STA, it contends with other Aw-STAs and AM-STAs as well for sending the PS-Poll. While the contention inside Aw-STAs brings different transmission order but has little impact on their total awake duration, the contention from AM-STAs has two effects on Aw-STAs’ awake duration. First, Aw-STAs may receive their packets and transit to doze state at a later time. For example, comparing Fig. 3 with Fig. 1, it can be seen that Aw-STA$_1$ in Fig. 3 transits to doze state later than in Fig. 1 because AM-STA$_0$ has accessed channel earlier than it. Second, with AM-STAs’ contention, more Aw-STAs may wait and “waste” energy throughout the whole BI on trying to send PS-Polls but finally get no access opportunity, since BI is limited time duration. Both effects impair Aw-STAs’ energy efficiency.

Opposite to AM-STAs, Aw-STAs have the concern for prolonging lifetime, which is also the network’s objective. So the fairness between Aw-STAs and AM-STAs of accessing channel is “unfair” considering the need of power saving and
prolonging lifetime. However, such problem is not addressed in PSM.

Based on the above observation, we propose PBPSM, which assigns different access priorities to Aw-STAs and AM-STAs. The advantage of PBPSM over other PSM’s enhancement schemes is that there is enhancement but no modification to conventional PSM. Moreover, the access priority differentiation can be easily realized by Enhanced Distributed Channel Access (EDCA) in a distributed way. Note that PBPSM is not restricted to the existence of IEEE 802.11e support but can be implemented by other access methods with priority in WLAN.

EDCA, an extension of IEEE 802.11 Distributed Coordination Function (DCF), is a contention based channel access method and is considered as the mandatory mode for MAC layer in IEEE 802.11e [16]. Whereas all DCF backoff slots begin after Distributed Inter-Frame Space (DIFS) from the end of the last indicated busy medium, EDCA backoff slots begin after different Arbitration Inter-Frame Spaces (AIFSs) to achieve differentiation for different Access Categories (ACs). The AIFS for a given AC is defined as

\[
AIFS[AC] = AIFSN[AC] \times \sigma + SIFS
\]

(1)

where AIFSN is an integer, SIFS is the Short Inter-Frame Space and \(\sigma\) is the fixed small time duration taken by backoff counter.

The default parameter set in IEEE 802.11e EDCA assigns the same contention window (CW) but different AIFSNs to the Best Effort AC and the Background AC. Similarly, PBPSM assigns Aw-STAs and AM-STAs with different AIFSNs in order to enhance the network’s power saving performance. Let \(am\) and \(aw\) in the following variables’ subscripts denote the AM-STA and Aw-STA. The two parameters of PBPSM are two AIFSNs denoted by \(N_{am}\) and \(N_{aw}\). To give Aw-STAs an advantage of channel access over AM-STAs, \(N_{aw}\) is set smaller than \(N_{am}\). Note that when \(N_{am}\) and \(N_{aw}\) are both set to 2, PBPSM is the same as PSM since \(DIFS = 2\sigma + SIFS\).

Although PBPSM brings little impact on all STAs’ average access delay, it indeed will increase AM-STAs’ average access delay. However, this expense is considered to be worthwhile since the network’s lifetime is effectively prolonged.

### III. PERFORMANCE ANALYSIS

In this section, the impacts of AM-STAs’ contention on the Aw-STAs’ power saving performance are analyzed for both PSM and PBPSM. The analysis includes four parts. In the first part, the assumptions are listed. In the second part, the transmission opportunities’ allocation by contention between Aw-STAs and AM-STAs in a beacon interval is presented. Aw-STAs’ power consumption and energy efficiency for both mechanisms are analyzed in the third and fourth parts respectively.

#### A. Assumptions

The assumptions below simplify the analysis, however they are not necessary for the correct and efficient operation of our proposed mechanism.

We first assume the same packet length and a perfect physical wireless channel, i.e. we do not consider wireless transmission error, fading, etc.

The two sets of STAs’ contention not only results in the transmission order, but also brings collision and additional waiting time, which is the time spent by all STAs to decrease their CWs. This paper, however, considers a perfect MAC without collision and additional waiting time except DIFS and SIFS since we focus on the impacts of contention on the transmission order and hence on the power saving performance.

It is also assumed that AM-STAs are continuously backlogged, i.e. in the saturated condition. So an AM-STA will keep on contending for transmission opportunities throughout the BI and its contention duration is BI which is used to denote the length of BI. At the opposite, an Aw-STA will transit to doze state and stop contending when it receives its buffered traffic. Since it is unreasonable to assume Aw-STAs in saturated condition, we assume that each Aw-STA has one buffered packet and will transit to doze state after receiving the packet. So an Aw-STA’s contention duration is the same as its awake duration. As this paper focuses on the contention between Aw-STAs and AM-STAs for channel access rather than the downlink scheduling at the AP, we assume that AM-STAs have no downlink traffic.

#### B. Transmission opportunities’ allocation

The limited transmission opportunities in one BI are allocated between Aw-STAs and AM-STAs according to their contention. Let \(m\) denote the number of Aw-STAs among which an expected number of \(u\) STAs can be served in this BI. Similarly, let \(n\) denote the number of AM-STAs among which \(v\) STAs are expected to be served. So the transmission opportunities’ allocation is denoted by \(u\) and \(v\), which are to be calculated in this subsection.

Let \(POLL\), \(P\), and \(ACK\) denote the packet duration of a PS-Poll, a data packet and an ACK. Let \(c\) and \(p\) in all variables’ superscripts denote the conventional PSM and proposed PBPSM respectively. The time duration \(L^c_{aw}\) and \(L^p_{aw}\) representing the whole procedures of retrieving the buffered packet by an Aw-STA for both mechanisms can be expressed as

\[
\begin{cases}
L^c_{aw} = DIFS + POLL + SIFS + P + SIFS + ACK \\
L^p_{aw} = (SIFS + N_{aw}\sigma) + POLL + 2SIFS + P + ACK
\end{cases}
\]

(2)

The duration \(L^c_{am}\) and \(L^p_{am}\) of sending a packet by an AM-STA for both mechanisms can be expressed as

\[
\begin{cases}
L^c_{am} = DIFS + P + SIFS + ACK \\
L^p_{am} = (SIFS + N_{am}\sigma) + P + SIFS + ACK
\end{cases}
\]

(3)

Note that the ACK in (2) is the acknowledgement from Aw-STAs to the AP while the ACK in (3) is from the AP to AM-STAs.

With AM-STAs always backlogged, whatever the number of Aw-STAs is, BI will always be fully utilized. By ignoring the additional waiting time and the small duration of a beacon,
we have
\[
\begin{align*}
   uL_{aw}^c + vL_{am}^c &= BI & \text{for PSM} \\
   uL_{aw}^p + vL_{am}^p &= BI & \text{for PBPSM}
\end{align*}
\]  

Equation (4) represents one relation between \( u \) and \( v \) for both mechanisms respectively. Another relation needed to solve \( u \) and \( v \) is presented as follows.

Similar to that in [15], we use \( \lambda \) to denote the transmission probability of one STA in a fixed duration slot \( \sigma \). Let \( \lambda_{aw}^c \), \( \lambda_{aw}^p \), \( \lambda_{am}^c \) and \( \lambda_{am}^p \) denote the transmission probabilities of Aw-STAs and AM-STAs in both mechanisms. For PSM, which supports no access priority, we have
\[
\lambda_{am}^c / \lambda_{aw}^c = 1
\]  

For PBPSM, once the channel status transits from “busy” to “idle”, there first will be \((N_{am} - N_{aw})\) slots in which only Aw-STAs can access the channel. Similar to that in [17], we assume a constant CW for simplicity and use \( \lambda_{idle} \) to denote the transmission probability of one STA in an idle slot. \( \lambda_{idle} \) can be expressed as
\[
\lambda_{idle} = 2/(CW + 1)
\]  

Note that \( \lambda_{aw}^c \), \( \lambda_{aw}^p \), \( \lambda_{am}^c \) and \( \lambda_{am}^p \) are all “averaged access probabilities” in one \( \sigma \), while \( \lambda_{idle} \) is a conditional probability. With the advantage of \((N_{am} - N_{aw})\) slots, the ratio \( r \) between \( \lambda_{aw}^p \) and \( \lambda_{aw}^c \) can be calculated as
\[
r = \frac{\lambda_{aw}^p}{\lambda_{aw}^c} = \frac{1 - \lambda_{idle}}{2 - (1 - \lambda_{idle})N_{am} - N_{aw}}
\]  

Similar to [15] in which throughput is computed by multiply access probability \( \lambda \), time duration and the successful transmission probability, we define the “access capability” of one STA as the product of its \( \lambda \) and contention duration in this BI. The “aggregated access capability”, defined as the sum of a set of STAs’ access capabilities, of \( m \) Aw-STAs as a whole is compared with that of \( n \) AM-STAs to obtain the other relation between \( u \) and \( v \).

For PSM, let \( C_{am}^c \) and \( C_{am}^c \) denote the aggregated access capabilities of AM-STAs and Aw-STAs in one BI respectively when the conventional PSM is used. We use the notation \( E[] \) to stand the expectation function. So the other formula between \( u \) and \( v \) can be expressed as
\[
\frac{v}{u} = \frac{E[C_{am}^c]}{E[C_{aw}^c]}
\]  

The contention duration of an AM-STA is \( BI / \sigma \) and we have
\[
C_{am}^c = n\lambda_{am}^c BI / \sigma
\]  

Let \( S_i (0 \leq i \leq m - 1) \) denote Aw-STA\(_i\) and \( T_{aw,i} \) denote the awake duration of \( S_i \). We have
\[
C_{aw}^c = \sum_{i=0}^{m-1} \frac{T_{aw,i}}{\sigma} \lambda_{aw}^c \sigma = \begin{cases} 
   \sum_{i=0}^{u-1} \frac{T_{aw,i}}{\sigma} \lambda_{aw}^c \sigma & u = m \\
   \sum_{i=0}^{m-1} \frac{T_{aw,i}}{\sigma} \lambda_{aw}^c \sigma & u < m 
\end{cases}
\]  

When \( u = m \), as \( S_{m-1} \) is last served, the average awake duration is \( T_{aw,m-1} / 2 \). So we have
\[
E[C_{aw}^c] = m\lambda_{aw}^c T_{aw,m-1} / (2\sigma)
\]  

When \( u < m \), by ignoring the small duration of the beacon, the \( u \) STAs’ average awake duration is \( BI / 2 \). For the other \((m-u)\) STAs not served in this BI, their awake duration is \( BI \) as they wait throughout the whole BI. So the expected value of \( C_{aw}^c \) can be calculated as
\[
E[C_{aw}^c] = E[\sum_{i=0}^{u-1} T_{aw,i}] \lambda_{aw}^c / \sigma + E[\sum_{i=u}^{m-1} T_{aw,i}] \lambda_{aw}^c / \sigma = (m - u / 2) \lambda_{aw}^c BI / \sigma
\]  

Before solving \( u \) and \( v \), we calculate the parameters’ threshold to determine the conditions of \( u < m \) and \( u = m \). When \( m > BI / L_{aw}^c \), we have \( u < m \) since not all the \( m \) STAs can be served in this BI. For a fixed \( m < BI / L_{aw}^c \), let \( n_m^c \) be the threshold of AM-STAs’ number in PSM. If \( n \) is smaller than the threshold, all Aw-STAs are expected to be served in this BI and \( u \) equals \( m \). Otherwise, \( u \) is smaller than \( m \). With \( (5, 8, 9, 11) \) and let \( T_{aw,m-1} = BI, u = m \) to denote the critical condition, the threshold \( n_m^c \) can be obtained as
\[
n_m^c = (BI - mL_{aw}^c) / (2L_{am}^c)
\]  

When \( m < BI / L_{aw}^c \) and \( n < n_m^c \), \( u \) equals \( m \). Otherwise, by substituting \((5, 8, 9, 12) \) into \((4)\), we have
\[
u^2 - u(2mL_{aw}^c + BI + 2nL_{am}^c) + 2mL_{aw}^c + 2mBI / L_{aw}^c = 0
\]  

By solving the quadratic equation \((14)\), \( u \) can be obtained. Note that we must have \( u \in [0, BI / L_{aw}^c] \) and being an integer. Let \( u_0^c \) denote the solution of \((14)\), then \( u \) can be expressed as
\[
u = \begin{cases} 
   m & m < BI / L_{aw}^c, n < n_m^c \\
   u_0^c & \text{others}
\end{cases}
\]  

With \((4)\) and \((15)\), \( v \) can be accordingly obtained. Note that we have \( v \in [0, BI / L_{am}^c] \) and being an integer.

For PBPSM, the transmission opportunities’ allocation can be calculated in the same way as for PSM except that 1) the ratio between \( \lambda_{aw}^p \) and \( \lambda_{aw}^c \) is \( r \) and 2) \( L_{aw}^c \) and \( L_{am}^c \) should be replaced by \( L_{aw}^p \) and \( L_{am}^p \). The threshold \( n_m^p \) can be expressed as
\[
n_m^p = (BI - mL_{aw}^p) / (2rL_{am}^p)
\]  

We have the quadratic equation as
\[
u^2 - u(2mL_{aw}^p + BI + 2nL_{am}^p) / L_{aw}^p + 2mBI / L_{aw}^p = 0
\]  

Let \( u_0^p \) denote the solution of \((17)\). Then we have
\[
u = \begin{cases} 
   m & m < BI / L_{aw}^p, n < n_m^p \\
   u_0^p & \text{others}
\end{cases}
\]  

Similarly, \( v \) can be accordingly obtained.
C. Power consumption

For PSM, let $T_{aw}^c$ denote the total awake duration of Aw-STAs. We have

$$E[T_{aw}^c] = \frac{E[C_c]}{\lambda_{aw}^c}\sigma = \left\{ \begin{array}{ll} \frac{mT_{aw,m-1}}{2} & u = m \\ (m - u/2)BI & u < m \end{array} \right.$$  \hspace{1cm} (19)

By substituting (15) into (19), we have

$$E[T_{aw}^c] = \left\{ \begin{array}{ll} mT_{aw,m-1}/2 & m < BI/L_{aw}^c, n < n_m^c \\ (m - [u_0^c]/2)BI & others \end{array} \right.$$  \hspace{1cm} (20)

When $u = m$, BI can be divided into two phases. While both the set of Aw-STAs and the set of AM-STAs contend to access channel in the first phase, only AM-STAs contend to access channel in the second phase (Fig. 4).

D. Energy efficiency

Energy efficiency is defined as the power consumed for one unit of payload. In the whole procedure of retrieving a packet from the AP, since the same packet length is assumed, the overhead of MAC and Physical Layer (PHY) headers, PS-Polls and ACKs, DIFS and SIFS is constant. In addition, Aw-STAs’ total awake duration is used to denote the total power consumption. So we could use the average awake duration for receiving a packet to represent the Aw-STAs’ energy efficiency.

Let $\eta_p$ and $\eta_c$ denote the energy efficiency for the conventional and proposed mechanisms respectively. With (15) and (23), we have

$$\eta_c = \frac{E[T_{aw}^c]}{u} = \left\{ \begin{array}{ll} (mL_{aw}^c + 2nL_{am}^c)/2 & m < BI/L_{aw}^c, n < n_m^c \\ (m/[u_0^c] - 1/2)BI & others \end{array} \right.$$  \hspace{1cm} (26)

With (18) and (25), we have

$$\eta_p = \frac{E[T_{aw}^p]}{u} = \left\{ \begin{array}{ll} (mL_{aw}^p + 2nrL_{am}^p)/2 & m < BI/L_{aw}^p, n < n_m^p \\ (m/[u_0^p] - 1/2)BI & others \end{array} \right.$$  \hspace{1cm} (27)

IV. NUMERICAL RESULTS

The model and analysis in the previous section are used to evaluate PBPSM. The parameters in the evaluation follow the standard [1] for direct sequence spread spectrum (DSSS) PHY and are listed in Table I. In the following figures, the number of Aw-STAs is 30. Power consumption is represented by awake duration and energy efficiency is represented by the average awake duration for receiving a packet, as explained in section II.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC header</td>
<td>224 bits</td>
<td>Channel bit rate</td>
<td>11 Mbps</td>
</tr>
<tr>
<td>PHY header</td>
<td>192 bits</td>
<td>Basic bit rate</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>Data packet</td>
<td>1024 bytes</td>
<td>SIFS</td>
<td>10 us</td>
</tr>
<tr>
<td>PS-Poll</td>
<td>160 bits + PHY header</td>
<td>DIFS</td>
<td>50 us</td>
</tr>
<tr>
<td>ACK</td>
<td>112 bits + PHY header</td>
<td>Slot time</td>
<td>20 us</td>
</tr>
<tr>
<td>CW</td>
<td>32</td>
<td>Beacon interval</td>
<td>100 ms</td>
</tr>
</tbody>
</table>

Fig. 5 shows Aw-STAs’ energy efficiency by using PSM and PBPSM with different parameters when the number of AM-STAs varies. The curves have segmented behavior and the increasing rate is higher after the inflexion because in the first part of each curve all Aw-STAs are expected to be served in this BI while in the second part there exist some Aw-STAs not served. Since this paper focuses on the transmission order brought by contention rather than the additional waiting time, as explained in section III, the curves are straight lines like.

It can be seen that PBPSM obtains better results of energy efficiency than PSM by preventing unit payload’s corresponding power consumption from increasing rapidly with the increase in AM-STAs’ number. The curves show PBPSM’s...
three advantages of power saving over PSM: 1) the increasing rate is lower before the inflexion, 2) the AM-STAs' number corresponding to the inflexion is larger and 3) the increasing rate is lower after the inflexion. The reason for the first advantage is earlier access time while the reason for the second and third advantages is fewer Aw-STAs waiting throughout the whole BI but getting no access opportunity and hence not served in this BI, as shown in Fig. 6.

Fig. 6 shows the decrease in the number of Aw-STAs served in a BI when the number of AM-STAs increases. The threshold of AM-STAs' number, which is related to the inflexion in each curve, is larger for our mechanism. Furthermore, even after the threshold, the served Aw-STAs' number in our mechanism has a lower decreasing rate. With more Aw-STAs served, fewer Aw-STAs will wait and waste energy at the same time throughout the whole BI trying to send PS-Polls, which has an important impact on energy efficiency.

In both figures, comparing the curves of PBPSM with different priority-related parameters, it can be seen that the larger ratio between $N_{aw}$ and $N_{am}$, the better power saving performance our proposed mechanism has. The reason is that access priority differentiation is determined by the ratio.

V. CONCLUSION

This paper proposes a general Priority Based Power Saving Mode (PBPSM), which requires no modification to the conventional PSM. Our scheme could be easily implemented by setting different AIFSs in IEEE 802.11e EDCA, though it is not restricted to the existence of IEEE 802.11e support but can be implemented by other prioritized access methods. Power consumption and energy efficiency for both PSM and PBPSM are analyzed and numerical results show that PBPSM outperforms PSM in PS-STAs' earlier time to doze and fewer PS-STAs waiting throughout the whole BI but getting no access opportunity. Both effects contribute to PBPSM's better power saving performance of energy efficiency and total power consumption.

REFERENCES