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Power Saving Control Method for Battery-Powered Portable Wireless LAN Access Points in an Overlapping BSS Environment

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SUMMARY This paper proposes a power saving control method for battery-powered portable wireless LAN (WLAN) access points (APs) in an overlapping basic service set (OBSS) environment. The IEEE802.11 standard does not support power saving control for APs. Some conventional power saving control methods for APs have been proposed that use the network allocation vector (NAV) to inhibit transmission at stations (STAs) while the AP is sleeping. However, since with these approaches the actual beacon interval in the OBSS environment may be extended due to the NAV as compared to the beacon interval which is set at the AP, the power consumption and delay may be increased as compared to a single BSS unaffected by interference from neighboring APs. To overcome this problem, this paper introduces a new action frame named *power saving access point* (*PSAP*) *action frame* which the AP uses to inform STAs within its BSS about the AP's sleep length. In addition, a function of the *PSAP action frame* is that STAs enter the sleep state after receiving the *PSAP action frame*. The proposed control method avoids the postponement of beacon transmission and reduces the power consumption in an OBSS environment, as compared to the conventional control method. Numerical analysis and computer simulation reveal that the newly proposed control method conserves power as compared to the conventional control method. The proposed control method achieves the minimum consumed power ratio at the AP, which is 44% as compared to the standard, when the beacon interval is 100 ms and the sleep length is 60 ms, even if the number of neighboring APs in an OBSS environment is increased.

key words: *IEEE802.11, power saving, portable access point, overlapping BSS*

1. Introduction

Over the past decade, wireless LAN (WLAN) devices have been installed in many types of electronic devices such as personal computers, portable gaming machines, and portable music players. Although there are major WLAN areas such as in the homes, offices, and public hotspots, environments in which electronic devices can access the Internet are still limited. In other words, electronic devices that only incorporate WLAN devices cannot access the Internet in a mobile environment. To address this, some vendors have developed WLAN access points (APs) that incorporate a cellular network function, which is used as a wide area network (WAN) interface, for systems such as 3G, WiMAX, or PHS, as shown in Fig. 1 [1], [2]. In battery-powered APs, power consumption is a very important problem. Although the IEEE 802.11 standard [3] supports power saving control for stations (STAs), it does not support this for APs because it is assumed that APs are always supplied by mains electric power. This means that the specification does not consider battery-powered portable APs. To address this problem, it is necessary to introduce a method of power saving control for APs.

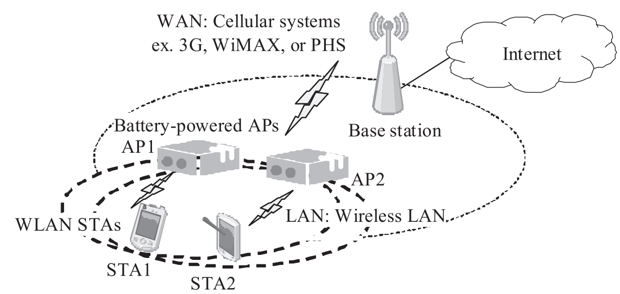

Fig. 1 Battery-powered portable APs in OBSS environment.

Recently, several power saving control methods for APs have been proposed [4]–[9]. In one of the conventional control methods is that the network allocation vector (NAV) specified in the IEEE 802.11 standard is extended to allow an AP to go into the sleep state during one or more future non-overlapping time periods [4], [5]. Since STAs set the NAV for these periods and the AP also wakes up in these periods, it is required that the AP and STAs have a scheduler to manage one or more future time period. Hence, this type of control methods requires a modification to the IEEE802.11 standard. In other type of conventional control methods, the AP uses the duration field of frames that it transmits to set the NAV in the STA, so allowing it to enter the sleep state [6]–[9]. However, these conventional control methods do not take account of the overlapping BSS* (OBSS) environment, as shown in Fig. 1, because, except for [8], [9], these do not focus on battery-powered portable APs that may be used anywhere. In addition, even for the control methods that do focus on battery-powered portable APs [8], [9], the special problems of an OBSS environment are not clearly

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*The overlapping BSS means that the two or more APs are operating in the same channel and can hear each other.

evaluated. If the conventional control methods [8], [9] are applied to an OBSS environment, the actual beacon interval in the OBSS environment may be extended, as compared to the beacon interval which is set at the AP, on account of the NAV. As a result, the power consumption and delay may be increased as compared to a single BSS unaffected by interference from neighboring APs. The problem with conventional control methods is that they use the NAV to allow an AP to enter the sleep state. Since the STAs or APs, which receive a frame, are set their NAV according to the duration field of its received frame, they cannot transmit in an OBSS environment.

This paper presents a method of power saving control for battery-powered portable WLAN APs which is applicable to an OBSS environment. To overcome the problem mentioned above, this paper uses a new action frame named *power saving access point* (*PSAP*) *action frame* which the AP uses to inform STAs within its BSS that the AP enters a sleep state. In addition, a function of *PSAP action frame* is that STAs enter the sleep state after receiving a *PSAP action frame*. The proposed control method avoids the postponement of beacon transmission and reduces the power consumption in an OBSS environment, as compared to conventional control methods.

The rest of the paper is organized as follows. Section 2 reviews the related studies and the remaining problems. Section 3 describes the proposed power saving control method. Section 4 presents the numerical analysis and simulation results, and compares the performance of the standard and conventional control method with the proposed control method. Finally, Sect. 5 concludes the paper.

2. Related Studies and Remaining Problems, Concerning Power Control Method

2.1 Related Studies Concerning Power Control Method

The IEEE 802.11 standard specifies power control method for STAs [3]. This paper refers to this control method as *PS_STD*. The power control has two states, an awake state and a sleep state. An STA wakes up from the sleep state when the STA has frames to transmit to the AP or when it receives a delivery traffic indication message (DTIM). The STA enters the sleep state when the AP has no frames to send to the STA and the STA has no frames to send to the AP. The power control method for STAs is described briefly as follows.

An AP periodically transmits a beacon that includes a traffic indication map (TIM) element, as shown in Fig. 2. The TIM element consists of the DTIM Count, DTIM Period, Bitmap Control, Partial Virtual Bitmap, etc. When the DTIM Count is zero, this is a special case called the DTIM. The DTIM Count represents the number of beacons before the next DTIM is transmitted. The DTIM Period represents the number of beacon intervals between successive DTIMs. Whenever an AP broadcasts a beacon, the value of the DTIM Count is reduced by one until it reaches zero.

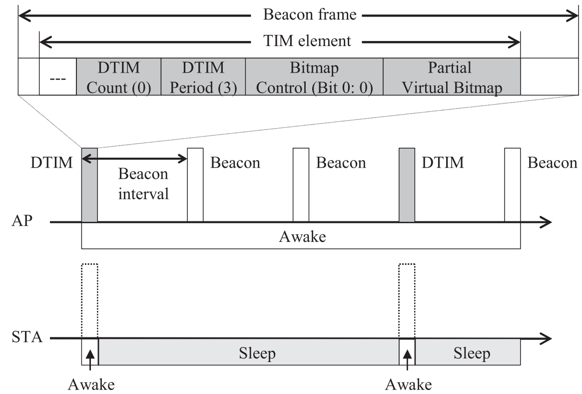
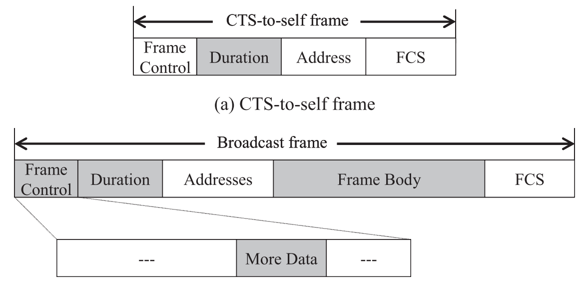


Fig. 2 Beacon frame format and operation procedure in standard, *PS_STD*.



(a) CTS-to-self frame

(b) Broadcast frame

Fig. 3 CTS-to-self frame format and Broadcast frame format.

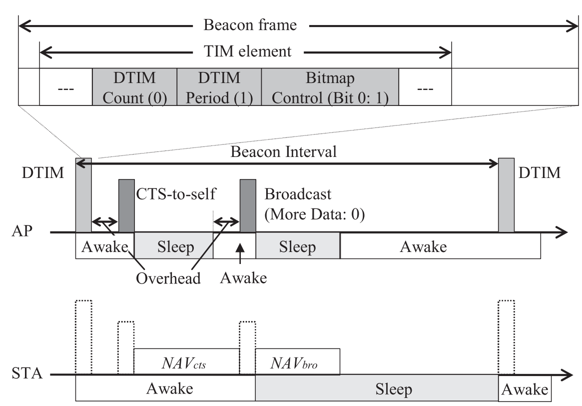


Fig. 4 Operation procedure in conventional control method, *PS_NAV*.

When the DTIM Count reaches zero, it is reset to the value of the DTIM Period. In addition, Bit 0 of the Bitmap Control represents the buffer status for broadcast or multicast frames, and the Partial Virtual Bitmap represents the buffer status per destination for the STAs. Hence, the AP and STAs manage broadcast or multicast frames and unicast frames separately, and the STAs know the buffer status at the AP from the Bitmap Control and Partial Virtual Bitmap. To simplify, it is assumed in Fig. 2 that no data frames are being generated. Hence Bit 0 of the Bitmap Control is set to zero and all the bits of the Partial Virtual Bitmap are set to zero. In this situation, after receiving the DTIM, each STA

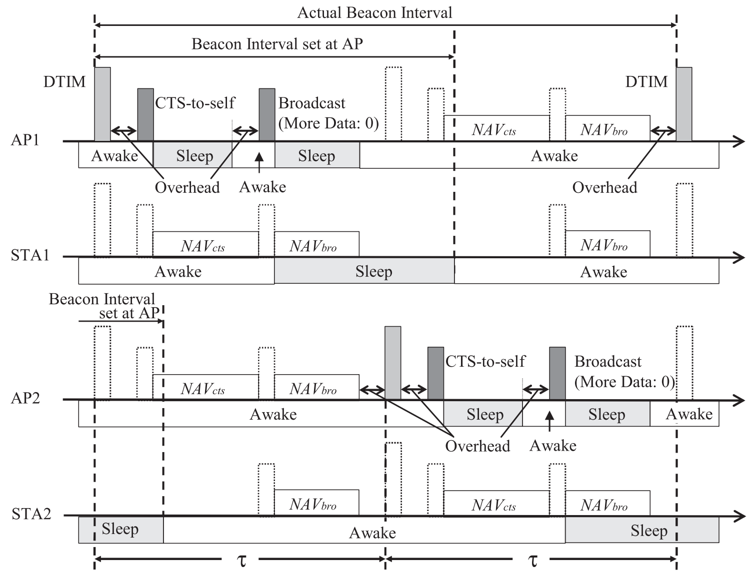


Fig. 5 Problems of conventional control method, *PS_NAV*, in OBSS environment.

enters the sleep state. As shown in Fig. 2, the STAs remain in the sleep state except when receiving a DTIM, but the AP is always in the awake state. Hence, the power consumed by the AP is greater than that consumed by the STA.

To reduce the power consumption at the AP, power saving control method for battery-powered portable APs has been proposed [9]. This control method uses the NAV to ensure conditions in which the AP can enter the sleep state. This paper refers to this control method as *PS_NAV*. To make possible the sleep state for the AP using the frames that are specified in the IEEE802.11 standard as shown in Fig. 3, the AP causes the STAs to refrain from transmission using the NAV while the AP is sleeping. The operation procedure when no data frames are being generated is shown in Fig. 4. The Overhead shown in this figure represents the average waiting time for transmissions in a CTS-to-self or a broadcast frame, which is given later. At first, an AP checks whether or not its own buffer is empty during the awake state before transmitting a DTIM. To force the STAs to maintain the awake state after the AP broadcasts a DTIM if the buffer is empty, according to a sleep length for the AP the AP creates one or more CTS-to-self and one broadcast frames or creates one broadcast frame. This broadcast frame contains null data in the Frame Body and is broadcasted only when an AP allows the STAs to enter the sleep state. In addition, this frame has the value of zero in the More Data field of the Frame Control, which is a part of the MAC header. After that, the AP broadcasts the DTIM with the value of one in Bit 0 of the Bitmap Control. After the DTIM has been transmitted, the created frames are also transmitted. Using the NAV, NAV_{cts} created by the CTS-to-self frame and NAV_{bro} created by the broadcast frame, the AP enters the sleep state. Since these frames are transmitted after the DTIM to allow the AP to enter the sleep state, the DTIM Period is set to one in the TIM elements so as to increase the opportunity for the AP to enter the sleep state. If the buffer is not empty during the awake state before transmitting the DTIM, the AP executes *PS_STD*. That is, the AP continues to remain in the awake state. Therefore, this method of control is effective when the downlink traffic (AP to STAs) is low. In addition, this method of control is fully compatible with the IEEE802.11 standard. The detail is described in [9].

2.2 Problems of Conventional Control Method in an OBSS Environment

Since battery-powered portable APs may be used anywhere, an OBSS environment is formed in places where many people gather, such as stations, buses, and trains. Hence, it is necessary to address the problems of an OBSS environment because the frequency of occurrence of this situation is high in a urban area. The problem of which the *PS_NAV* is applied to an OSBB environment is described as follows.

If two or more APs in OBSS environment use the NAV to allow each AP to enter the sleep state, the actual beacon interval may be extended as compared to the normal beacon interval which is set at the AP. Assuming that two APs, AP1 and AP2 in Fig. 1, are present, the NAVs set by the two APs affect each other's BSS as shown in Fig. 5. This figure shows the behaviors in an OBSS environment when no data frames are being generated. For example, if AP1 receives a CTS-to-self or a broadcast frame from a neighboring AP (AP2), AP1 sets the NAV by the duration field in the received frame. Since AP1 cannot transmit frames while it sets NAV, the actual beacon interval of AP1 may be extended. Moreover, since it may be considered that the sleep length should be set to a large value so as to reduce power consumption more effectively, the actual beacon interval is greater than the normal beacon interval which is set at AP.

The problems resulting from an extended beacon interval are that the delay is increased and the consumed power is also increased as compared to a single BSS. The evaluations related to these problems are discussed in Sect. 5.

3. Power Saving Control Method for Battery-Powered Portable WLAN APs in an Overlapping BSS Environment

To overcome the above problem, this paper proposes a power saving control method for battery-powered portable WLAN APs which is applicable to an OBSS environment. The key of this proposal is the introduction of a new action frame named *power saving access point* (*PSAP*) *action frame*. The function of this frame is that the AP informs the STAs within its BSS about a sleep length† which is going to be initiated at the AP. Using the *PSAP action frame*, the STAs within its AP which received the frame set the sleep length of the AP. That is, since the STAs decide whether the frame is received or not by the source address in the frame, the sleep length of the AP is set up for each BSS. Another aim of this proposal is to maintain the compatibility with the IEEE802.11 standard. This is achieved by using the vender-specific action frame shown in Fig. 6. This proposed control method is called *PS_ACT* in this paper. In addition, the function of power saving control is called *PSAP*. As well as the conventional control method, *PS_NAV*, since these frames are transmitted after the DTIM to allow the AP to enter the sleep state, the DTIM Period is set to one in the TIM elements so as to increase the opportunity for the AP to enter the sleep state. The proposed control method is effective in low downlink traffic, as well as the conventional control method.

First, after an STA has been associated with an AP, the STA informs the AP of its *PSAP* capability using a *PSAP action frame* whose action value shown in Table 1 is zero. After the AP receives this frame, the AP replies to the STA using a *PSAP action frame* whose action value is one. By this negotiation, the AP can manage information about the capability information of STAs within its BSS. Only if all associated STAs have the *PSAP* capability, the AP can attempt to enter the sleep state.

The procedure of operation of the proposed control method is described as follows. Figure 7 shows the operation procedure when no data frames are being generated. In this figure, the STA1 and STA2 shown in Fig. 1 are associated with the AP1 and AP2, respectively. The Overhead shown in this figure represents the average waiting time for transmissions in a *PSAP action frame* or a broadcast frame which is given later. An AP checks whether or not its own buffer is empty while in the awake state before transmitting a DTIM. If the buffer is empty, the AP creates a *PSAP action frame* whose action value shown in Table 1 is two and also a broadcast frame. The content of the *PSAP action frame* is the sleep length of the AP. In addition, the broadcast frame contains null data in the Frame Body, and this frame has the value of zero in the More Data field of the Frame Control, which is a part of the MAC header. The AP then broadcasts the DTIM with the value of one in Bit 0 of the Bitmap Control, and after that also transmits the *PSAP action frame*. After the AP has broadcast the *PSAP action frame*, the AP enters the sleep state. On the other hand, the STA receiving the DTIM, maintains the awake state to receive broadcast or multicast frames. Although STAs normally maintain the awake state to receive broadcast or multicast frames, STAs within the BSS can enter the sleep state to avoid the unnecessary power consumption, but they only do this after receiving the *PSAP action frame*. Here, the sleep length for the AP is the value in the information field of the *PSAP action frame*. However, the sleep length for STAs is extended as compared to the value in the information field of the *PSAP action frame*. The amount of extension is DIFS. The reason why the extended length is used is that the AP broadcasts the created broadcast frame on a

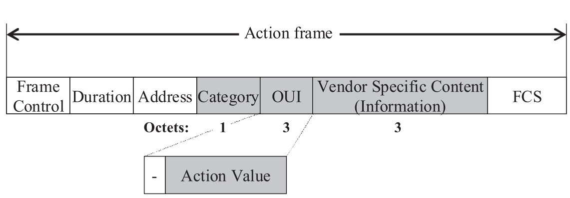


Fig. 6 *PSAP action frame* format.

Table 1 *PSAP action frame* contents.

Action Value	Meaning	Information
0	*PSAP* Capability Notification (STA → AP)	N/A
1	*PSAP* Capability Response (AP → STA)	N/A
2	*PSAP* Duration (AP → All associated STAs)	Sleep length at AP

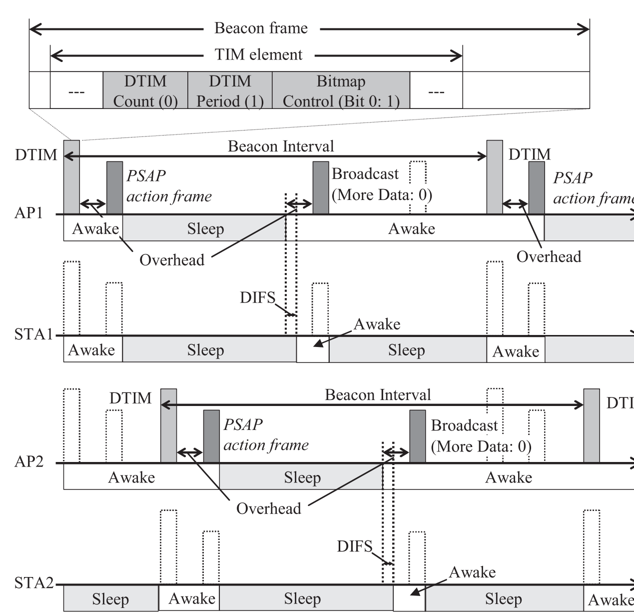


Fig. 7 Operation procedure in proposed control method, *PS_ACT*.

†The sleep length is a system parameter for products.

high priority basis. When the sleep length has expired, the AP or STA returns to the awake state. Finally, the AP broadcasts the broadcast frame with the value of zero in the More Data field. The procedure after that is the same as for the standard, *PS_STD*.

4. Evaluation for Proposed Control Method

4.1 Performance Criteria and Parameter Setting

To evaluate the performance of the proposed control method, the following criteria are defined.

- Consumed power ratio:

This represents the ratio of the consumed power in *PS_ACT* to that in *PS_STD*, or the ratio of the consumed power in *PS_NAV* to that in *PS_STD*.

- Difference in delay†:

This represents the difference in delay between *PS_ACT* and *PS_STD*, or the difference in delay between *PS_NAV* and *PS_STD*.

- Throughput:

This represents the amount of traffic successfully transmitted with *PS_ACT* or with *PS_NAV*.

The main parameters for analysis and simulation are given in Table 2††. The power consumption refers to Cisco Aironet 350 series [10], which was also used in [9]. In the simulation, the data frames are generated following a Poisson Process. In addition, the number of stations within a BSS is one, and the volume of offered traffic††† at an AP is the same value at a STA.

4.2 Numerical Analysis

First of all, to clarify the performance when no data frames are being generated, the consumed power is evaluated for the standard, *PS_STD*, the conventional control method, *PS_NAV*, and the proposed control method, *PS_ACT*.

To analyze the performance, some terms need to be defined. Let the time taken by the AP to broadcast a beacon frame, the time taken by the AP to broadcast a *PSAP action frame*, and the time taken by the AP to broadcast a broadcast frame be T_{beacon}, T_{act}, and T_{bro}, respectively. In addition, let the time taken by the AP to transmit a CTS-to-self frame, used in *PS_NAV*, be T_{cts}.

The awake state may be sub-divided into the transmission, receiving, and listening states. In the related studies [4], [6], [9] the consumed power in the receiving state was set to the same value as that in the listening state, and, for simplicity, this paper makes the same assumption. Let the value of the consumed power in the transmission state, the value in the listening/receiving state, and the value in the sleep state be E_t, E_l, and E_s, respectively.

Using these terms, the consumed power is evaluated without considering the contention among neighboring APs, for simplicity. First, the values of the consumed power for the AP and STA during DTIMs in the standard, *PS_STD*, E_{ap_ps-std} and E_{sta_ps-std}, are expressed below.

$$E_{ap\_ps-std} = E_t \cdot T_{beacon} + E_l(Beacon\_Interval - T_{beacon}), \quad (1)$$

$$E_{sta\_ps-std} = E_l \cdot T_{beacon} + E_s(Beacon\_Interval - T_{beacon}) \quad (2)$$

where, the DTIM Period is set to one, to evaluate the proposed method, standard, and conventional control method fairly. Even if neighboring APs are present, the above equations are satisfied. Since the STAs are in the sleep state except when the DTIM is received, the STAs do not receive frames from neighboring APs. Hence, the consumed power for the STA is not changed by the number of neighboring APs. In addition, since the AP is always in the listening/receiving state except when the DTIM is received, the consumed power for the AP is not changed by the number of neighboring APs.

The values of the consumed power for the AP and STA during DTIMs in the conventional control method, *PS_NAV*, E_{ap_ps-nav} and E_{sta_ps-nav}, are evaluated. As shown in Fig. 5, the actual beacon interval may be extended as compared to the beacon interval which is set at the AP. The actual beacon interval is changed by the number of neighboring APs in the OBSS environment, N_{ap}, and the sleep length. The sleep length including Overhead related to transmission is shown as τ in Fig. 5. If the beacon interval which is set at the AP is smaller than $\tau(N_{ap} + 1)$, the actual beacon interval is extended to $\tau(N_{ap} + 1)$. Hence, two conditions for evaluation are considered.

If $Beacon\_Interval \geq \tau(N_{ap} + 1)$;

$$E_{ap\_ps-nav} = E_t(T_{beacon} + T_{cts} \cdot N_{cts} + T_{bro}) + E_s \cdot SLEEP_{ps-nav} + E_l \cdot (Beacon\_Interval - (T_{beacon} + T_{cts} \cdot N_{cts} + T_{bro} + SLEEP_{ps-nav})), \quad (3)$$

$$E_{sta\_ps-nav} = E_l(T_{beacon} + (T_{cts} + NAV_{cts})N_{cts} + T_{bro} + Overhead) + E_s(Beacon\_Interval - (T_{beacon} + (T_{cts} + NAV_{cts})N_{cts} + T_{bro} + Overhead)) \quad (4)$$

If $Beacon\_Interval < \tau(N_{ap} + 1)$;

$$E_{ap\_ps-nav} = (E_t(T_{beacon} + T_{cts} \cdot N_{cts} + T_{bro})$$

Table 2 Parameters for evaluations.

Parameter		Value
Beacon Interval		100 ms
Power consumption	Transmission state	450 mA
	Listening /Receiving state	270 mA
	Sleep state	15 mA
Transmission rate	Data	11.0 Mbps
	Beacon, Broadcast, ACK	2.0 Mbps
	PSAP action, CTS-to-self	2.0 Mbps
Data frame length		1500 bytes

†The delay represents the time from frame generation until the frame is completely sent out, i.e., the ACK is successfully received.

††The transmission rate means the speed of wireless links.

†††The offered traffic means the traffic generation rate at each AP or STA.

$$+E_s \cdot SLEEP_{ps-nav} + E_l(\tau(N_{ap}+1) -(T_{beacon}+T_{cts}\cdot N_{cts}+T_{bro}+SLEEP_{ps-nav}))) \cdot Beacon\_Interval/\tau(N_{ap}+1), \quad (5)$$

$$E_{sta\_ps-nav}=(E_l(T_{beacon}+(T_{cts}+NAV_{cts})N_{cts} +T_{bro}+Overhead+\tau(N_{ap}+1)-Beacon\_Interval) +E_s(Beacon\_Interval -(T_{beacon}+(T_{cts}+NAV_{cts})N_{cts}+T_{bro}+Overhead))) \cdot Beacon\_Interval/\tau(N_{ap}+1) \quad (6)$$

where $Overhead$, $SLEEP_{ps-nav}$, and τ are expressed below.

$$Overhead=DIFS+CW_{min}/2\cdot SlotTime,$$
$$SLEEP_{ps-nav}=(NAV_{cts}-Overhead)N_{cts}+NAV_{bro},$$
$$\tau=T_{beacon}+(T_{cts}+NAV_{cts})N_{cts}+T_{bro}+NAV_{bro} +2\cdot Overhead.$$

Moreover, N_{cts} is the number of transmitted CTS-to-self frames. This value is determined by the sleep length. The detail is described in [9]. In addition, since the beacon interval is extended, the consumed power is normalized by the beacon interval which is set at the AP if the beacon interval which is set at the AP is smaller than $\tau(N_{ap}+1)$.

Next, the values of the consumed power for the AP and STAs during DTIMs in the proposed control method, *PS_ACT*, E_{ap_ps-act} and E_{sta_ps-act}, are expressed below.

$$E_{ap\_ps-act}=E_t(T_{beacon}+T_{act}+T_{bro}) +E_s\cdot SLEEP_{ps-act}+E_l(Beacon\_Interval -(T_{beacon}+T_{act}+T_{bro}+SLEEP_{ps-act})), \quad (7)$$

$$E_{sta\_ps-act}=E_l(T_{beacon}+T_{act}+T_{bro} +2\cdot Overhead-DIFS)+E_s(Beacon\_Interval -(T_{beacon}+T_{act}+T_{bro}+2\cdot Overhead-DIFS)) \quad (8)$$

where *Overhead* is expressed by the equation given above. Moreover, as mentioned above, the values of the consumed power for the AP and STA are not changed by the number of neighboring APs.

4.3 Analysis and Simulation Results

First, the consumed power ratio is evaluated when no data frames are being generated, using the above equations. The consumed power ratio of *PS_ACT* and *PS_NAV* as compared to *PS_STD* is expressed as $E_{ap\_ps-act}/E_{ap\_ps-std}$ and $E_{ap\_ps-nav}/E_{ap\_ps-std}$ for the AP and is expressed as $E_{sta\_ps-act}/E_{sta\_ps-std}$ and $E_{sta\_ps-nav}/E_{sta\_ps-std}$ for the STA. The analysis results for the AP and STA are shown in Figs. 8 and 9, respectively. As shown in Fig. 8, the consumed power ratio of *PS_ACT* is reduced. For example, the proposed control method achieves the minimum consumed power ratio at the AP, which is 44% as compared to the standard, when the sleep length is 60 ms, even if the number of neighboring APs in an OBSS environment is increased. However the consumed power ratio of *PS_NAV* at the AP in an OBSS environment, i.e., N_{ap} is one or two, is not reduced even

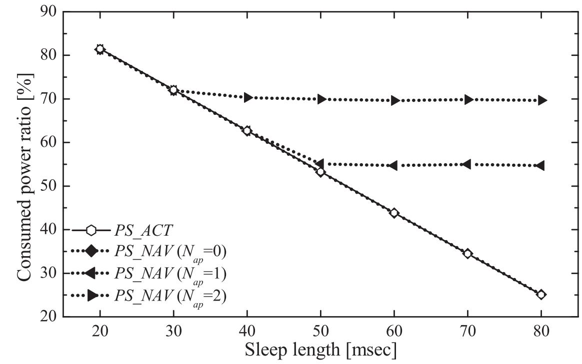


Fig. 8 Consumed power ratio at AP as compared to *PS_STD* if no data frames are generated.

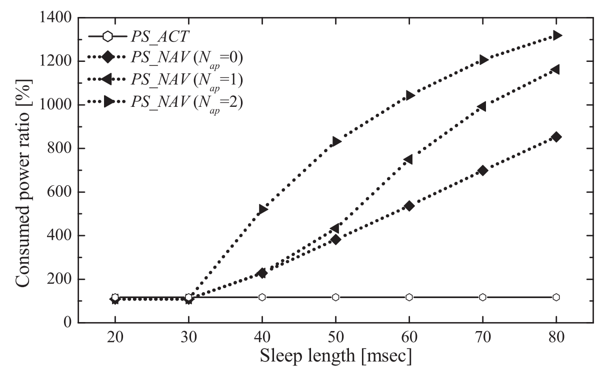


Fig. 9 Consumed power ratio at STA as compared to *PS_STD* if no data frames are generated.

if the sleep length is increased. The reason for this is that the actual beacon interval is extended as compared to the beacon interval which is set at the AP. Moreover, when the sleep length is short or the number of neighboring APs is zero, the consumed power ratio of *PS_ACT* at the AP is the same as that of *PS_NAV*, because the actual beacon interval is not extended as compared to the beacon interval which is set at the AP. As shown in Fig. 9, the consumed power ratio of *PS_NAV* at the STA increases as N_{ap} increases. The reason why the consumed power ratio with N_{ap}=0 is more than 100% is that the STA is in the awake state while the AP is sleeping. Moreover, the consumed power of *PS_ACT* at the STA is small as compared to *PS_NAV* because the STA enters the sleep state while the AP is sleeping, but is slightly increased as compared to *PS_STD*. Hence, the AP of *PS_ACT* achieves a lower power as compared to both *PS_STD* and *PS_NAV*. In addition, although the consumed power at the STA of *PS_ACT* is slightly increased as compared to *PS_STD*, this is lower than *PS_NAV*.

Next, the performance considering data traffic[†] when the number of neighboring APs is two, that is in an OBSS environment, is evaluated by computer simulation. Figures 10 and 11 show the consumed power ratio of *PS_ACT*

[†]It is assumed that data frames are unicast frames. The AP informs the STAs about the buffer status per destination for the STAs using the Partial Virtual Bitmap of the TIM element.

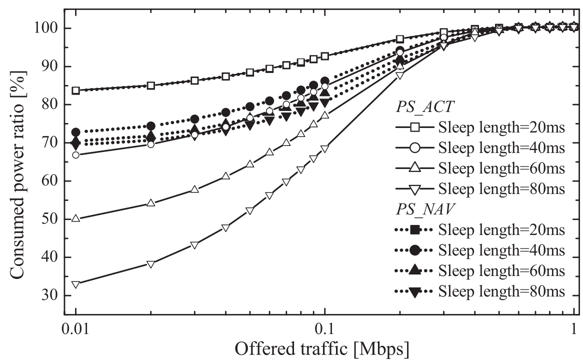


Fig. 10 Consumed power ratio at AP as compared to *PS_STD* if data frames are generated.

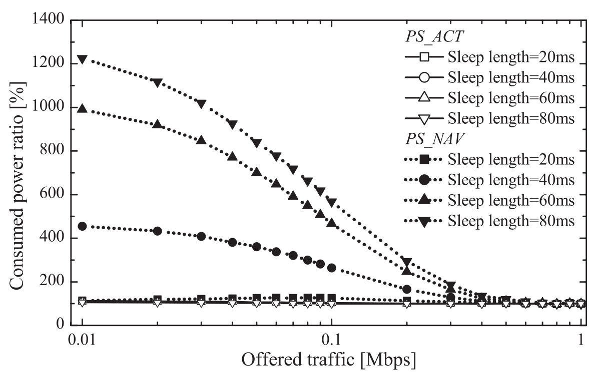


Fig. 11 Consumed power ratio at STA as compared to *PS_STD* if data frames are generated.

and *PS_NAV* as compared to *PS_STD*, at the AP and STA, respectively. As well as the previous results, it is verified that *PS_ACT* outperforms *PS_NAV*. Moreover, if the offered traffic is greater than about 0.5 Mbps, the consumed power ratio is approximately 100%. This means that the AP executes *PS_STD* because the AP has frames while in the awake state before transmitting a DTIM. This is analyzed as follows. Let λ, $P(\lambda)$, and L be defined as the generation rate of data frames at the AP, the probability that the AP has data frames before transmitting a DTIM, and the data frame length, respectively. This probability is expressed as $P(\lambda) = 1 - \exp(-\lambda \cdot Beacon\_Interval)$. From this equation, it is confirmed that the offered traffic, λL, is greater than 0.55 Mbps when the $P(\lambda)$ is greater than 0.99.

Figures 12 and 13 show the difference in delay as compared to *PS_STD*, at the AP and STA, respectively. As shown in Fig. 12 for AP, the difference in delay of *PS_NAV* increases with the sleep length. The reason for this is that the actual beacon interval is larger than the beacon interval which is set at the AP. The delay of *PS_ACT* is the same as that of the *PS_STD* because the actual beacon interval is not extended in an OBSS environment. On the other hand, as shown in Fig. 13 for the STA, the delay of both *PS_ACT* and *PS_NAV* are increased as compared to *PS_STD*. The reason for this is that the STA cannot transmit data frames to the AP while the AP is sleeping. In addition, the delay of *PS_NAV*

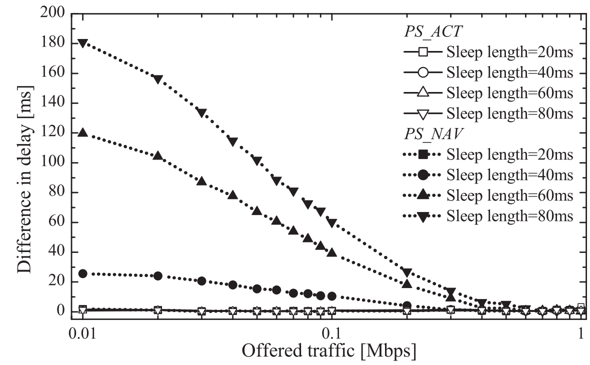


Fig. 12 Difference in delay at AP as compared to *PS_STD*.

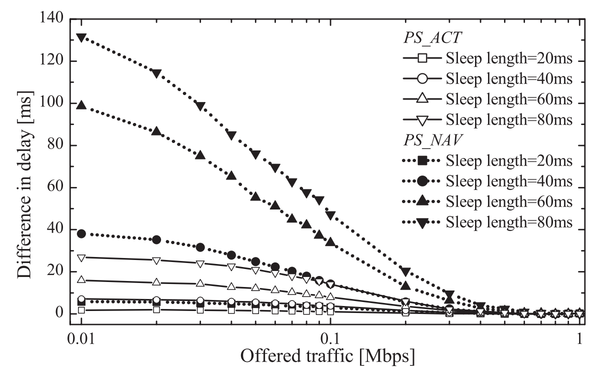


Fig. 13 Difference in delay at STA as compared to *PS_STD*.

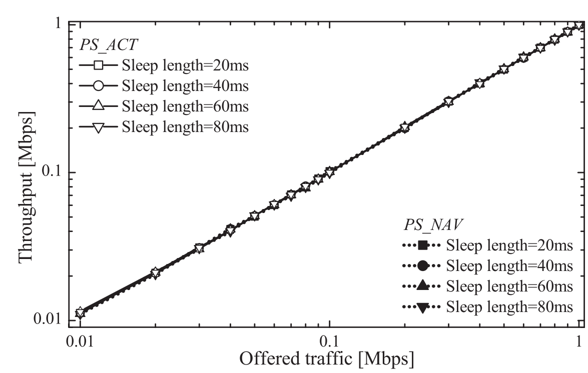


Fig. 14 Throughput characteristics of *PS_ACT* and *PS_NAV* at AP.

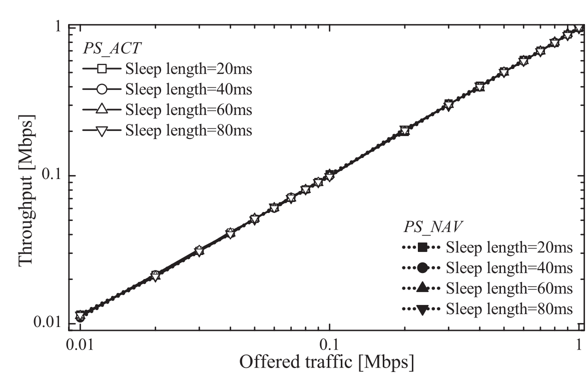


Fig. 15 Throughput characteristics of *PS_ACT* and *PS_NAV* at STA.

is increased as compared to *PS_ACT* because the actual beacon interval is larger than the beacon interval which is set at the AP.

Finally, Figs. 14 and 15 show the throughput characteristics at the AP and STA, respectively. Both *PS_ACT* and *PS_NAV* show the same throughput, with no degradation. The reason for this is that the AP enters the sleep state only when the offered traffic is low. Therefore, even if the offered traffic is greater than 1.0 Mbps, the throughput characteristics of *PS_ACT* and *PS_NAV* are the same as those of *PS_STD*.

As mentioned above, numerical analysis and computer simulation results show that the proposed control method, *PS_ACT*, is effective for a battery-powered AP in an OBSS environment. Specifically, the proposed control method is effective for low offered traffic at the AP. That is, this situation means that the frequency of transmitting frames at the AP is low after STAs are associated with the AP. Usually, the AP does not always transmit frames to STAs because STAs intermittently request to transmit. For example, the AP may not transmit frames to STAs while the user is reading e-mails. Therefore, low power consumption in low offered traffic condition is important.

5. Conclusion

This paper has proposed a power saving control method for battery-powered portable WLAN APs which can accommodate an OBSS environment. The proposed control method introduces the *PSAP action frame*, by which the AP informs STAs within its BSS about the AP's sleep length. The main contribution is that the proposed power saving control method for APs is compatible with the IEEE 802.11 standard, and the proposed control method can coexist with the existing WLAN systems with no adverse effect because this power saving control is performed for each BSS. The analysis and simulation results reveal the following.

1) As compared to the standard, the consumed power at the AP is decreased by the proposed control method, while the consumed power at the STA is slightly increased. The degree of this increase is small as compared to the conventional control method in an OBSS environment. For example, the proposed control method achieves the minimum consumed power ratio at the AP, which is 44% as compared to the standard, when the beacon interval is 100 ms and the sleep length is 60 ms, even if the number of neighboring APs in an OBSS environment is increased.

2) As compared to the standard, the delay of the proposed control method at the AP is the same, and the delay of the proposed control method at the STA is increased. However, the degree of this increase is also small as compared to the conventional control method in an OBSS environment.

3) The throughput at both AP and STA is not degraded when the proposed control method is introduced.

The proposed control method does not take account of unscheduled automatic power saving delivery (U-APSD) for QoS specified in the IEEE802.11e because the STA requires the transmission to the AP at an arbitrary timing. Therefore, the cooperation of control between the power control for an AP and U-APSD is a challenging issue for future study.

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