IEEE 802.11 WLAN을 위한 Idle Mode Operation: Prototype 구현 및 성능 측정

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A Novel Idle Mode Operation in IEEE 802.11 WLANs: Prototype Implementation and Performance Evaluation

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요 약

IEEE 802.11 Wireless Local Area Networks (WLANs)는 광대역 무선 인터넷 접속기술로 널리 이용되고 있으며 WLAN을 기반으로 하는 음성 서비스(VoWLAN)와 같은 새로운 응용들이 등장하고 있다. VoWLAN 서비스들은 휴대형 장치를 통해 서비스가 되며 베터리 전력을 이용해서 동작하는 휴대형 장치들을 위해 사용 전력을 최소화하여 대기시간을 최대화 하는 기술이 필수적이다. 그러나 IEEE 802.11 WLAN 규격은 VoWLAN 서비스와 관련하여 사용 전력을 최적으로 이용하는 동작을 지원하지 않는다. 본 논문에서 페이징, idle 핸드오프 및 지연 핸드오프로 구성되는 새로운 Idle Mode operation을 제안 한다. Idle mode operation를 기반으로 동작하는 모바일 호스트는 미리 정의되어 있는 페이징 영역내에서는 핸드오프를 하지 않는다. 모바일 호스트가 새로운 페이징 영역으로 진입할 때에만 최소한의 호처리 신호를 발생시키는 idle 핸드오프를 수행한다. 기존의 IEEE 802.11 WLAN은 idle mode를 지원하지 않기 때문에 Power Saving Mode (PSM)과 IP paging 기법을 동시에 이용해 왔으나 전력소비 효율이 좋지 못하였다. 본 논문은 구현을 통하여 새롭게 제안한 방식인 idle mode operation이 실현가능 함을 증명하고 기존의 방식과 비교하여 전력소비 효율이 더 뛰어남을 보인다.

Key Words : Idle Mode, IEEE 802.11 WLAN, Energy Management, Mobile Computing

ABSTRACT

IEEE 802.11 Wireless Local Area Network (WLAN) became a prevailing technology for the broadband wireless Internet access, and new applications such as Voice over WLAN (VoWLAN) are fast emerging today. For the battery-powered VoWLAN devices, the standby time extension is a key concern for the market acceptance while today's 802.11 is not optimized for such an operation. In this paper, we propose a novel Idle Mode operation, which comprises paging, idle handoff, and delayed handoff. Under the idle mode operation, a Mobile Host (MH) does not need to perform a handoff within a predefined Paging Area (PA). Only when the MH enters a new PA, an idle handoff is performed with a minimum level of signaling. Due to the absence of such an idle mode operation, both IP paging and Power Saving Mode (PSM) have been considered the alternatives so far even though they are not efficient approaches. We implement our proposed scheme in order to prove the feasibility. The implemented prototype demonstrates that the proposed scheme outperforms the legacy alternatives with respect to energy consumption, thus extending the standby time.

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Ⅰ. Introduction

Recently, IEEE 802.11 Wireless Local Area Network (WLAN) became a prevailing technology for the broadband wireless Internet access. Along with that, new types of applications such as Internet Protocol (IP) telephony over WLAN are fast emerging today. In order to support IP telephony, the functionality to inform a Mobile Host (MH) of incoming calls becomes indispensable even if the user with an idle MH moves around. Along with such a functionality, considering the battery-powered IP phone devices, the standby time extension is a key concern for the market acceptance while today's 802.11 is not optimized for such an application. The reason is rooted on the fact that the 802.11 WLAN Medium Access Control (MAC) protocol [1] defines only two operational modes, which an MH can operate in, namely, Active Mode (AM) and Power Saving Mode (PSM).

In both modes, since an MH always has to stay connected with one of the APs even when there is no traffic to/from the MH, it has to perform a handoff at every AP cell boundary. The inevitable handoffs, at every AP cell boundary, cause an MH to consume redundant energy. As the handoff frequency, approximately proportional to the MH's speed, increases, the MH consumes more energy. Even worse, when IEEE 802.11i [2] is employed for security enhancement, a larger amount of message exchanges during the handoff operation are expected, and these incur more energy consumption. That is, IEEE 802.11 WLAN is naturally lack of an efficient support of the MH mobility when there is no traffic to be served for the MHs. Therefore, it is desired to have a new Idle Mode (IM), different from the AM and the PSM, in the 802.11.

Due to the lack of the IM operation, both IP paging [3,5] and the PSM [1] have been considered the alternatives to the IM operation so far [4]. Since the IP paging to support the IP-level mobility is independent of layer-2 (L2) MAC operations, IP paging and the PSM are performed independently, and it makes the combined IP paging and PSM very inefficient. For example, since the 802.11 MAC cannot differentiate IP paging-related packets (which are of broadcast type) from other packets, the MH's MAC has to receive all the broadcast packets, and forward them to the IP layer, thus consuming considerable energy.

In order to overcome these problems, which cause redundant energy consumption, we propose an IM operation, comprising paging, idle handoff, and delayed handoff, which can be used when an IEEE 802.11 WLAN standard-based MH does not have traffic or on-going sessions. Under the proposed IM operation, the MH can stay in the doze state consuming very little energy for an extended period, and performs less operation than in the PSM. In our scheme, an MH does not perform any handoff within a predefined Paging Area (PA). The handoff with minimum operation, called idle handoff, is performed only when an MH enters a new PA. The paging provides a way to inform an MH in the IM of a new packet arrival. The IP-level handoff should be deferred until a paging success in order to reduce redundant operations, and hence it is referred to as delayed handoff.

Ⅱ. Problems to Support Ilde Mode in IEEE 802.11 WLANs

The purpose of paging is to locate an idle MH when an incoming call destined to it arrives. However, if an IP-based wireless access network does not offer a paging scheme, IP paging can be used as the substitutable scheme of the original access network level paging. In the case of IEEE 802.11 WLANs, utilizing both PSM and IP paging has been considered [4]. However, since the PSM is developed without considering IP paging, the use of IP paging along with the PSM is an inefficient approach. In this section, we analyze the reason why the combined PSM and IP paging are not suitable as an alternative to the

IM for IEEE 802.11 WLAN.

An MH consists of Wireless Network Interface Card (WNIC) and Handheld Device (HD) such as Personal Digital Assistance (PDA) or smart phone. The WNICs implemented based on the IEEE 802.11 WLAN standard have a MAC layer while HDs implement the IP layer, which belongs to Operating System (OS). Therefore, in the perspective of functionality, WNIC is identical to the MAC while HD is identical to the IP. For this reason, in this paper, we use the term of WNIC instead of station (STA) used in IEEE 802.11 WLAN standard.

2.1 Limitation of IEEE 802.11 PSM

According to [1], a WNIC can be in either of awake and doze states at a given moment. In awake state, a WNIC can transmit, receive or sense the physical channel, and it actually continues to sense the channel unless it either transmits or receives a frame. On the other hand, in doze state, a WNIC is not able to transmit or receive, and consumes very little energy. How a WNIC switches between these two states is determined by the WNIC's power management mode, i.e., AM and PSM. When a WNIC is in the AM, the WNIC always operates in the awake state. On the other hand, when a WNIC is in the PSM, the WNIC can change its state between the awake and doze states depending on the traffic pattern. However, the PSM as an alternative to the IM has the following limitations.

Since a WNIC running in the PSM should stay associated with an AP, the handoff should be performed at every AP cell boundary in order to maintain its association. During a handoff procedure, the WNIC has to stay in the AM since the handoff can be severely delayed otherwise. The requirement for a WNIC to keep associated, even during performing handoff, exert a significant influence on the energy consumption of the MH.

2.2 Limitation of IP Paging

The original IP paging is targeted at the MHs which do not have an on-going IP session. With the aid of IP paging, the network load and signaling cost to manage the mobility for the idle MHs are reduced. However, most of the IP paging protocols are designed without considering the underlying MAC operation. This implies that the IP paging and MAC-specific paging operate independently. We can easily assume that a particular wireless access network has its own paging algorithm and IP paging is also adopted by the wireless access network. In such a case, the IP paging protocol actually generates redundant overheads since both MAC and IP provide the same functionality, i.e., paging. However, due to the lack of a paging scheme in IEEE 802.11 MAC, the IP paging would be a useful alternative to the MAC-level paging. However, the IP paging scheme as an alternative to the MAC-level paging in IEEE 802.11 WLANs has the following limitations.

Since the IM is not defined in [1], an MH should be in the PSM instead of the IM, and has to get associated with an AP all the time. In order to support the IP paging, the MH, being associated with an AP, periodically listens to the broadcast paging packets for signaling, and performs IP paging-related operations. Despite the fact that the energy consumption should have been a major concern, the research efforts related to IP paging made so far have been limited only to the signaling cost reduction.

Additionally, the IP layer, located right above the 802.11 WLAN MAC, receives all types of IP packets through the MAC. Such a tightly coupled relationship causes unexpected side effect to the PSM operation. For instance, if we assume that P-MIP [3] is adopted to IEEE 802.11 WLAN, the routers or MIP agents broadcast advertisement messages periodically when some of MHs are in the IM. Upon receiving the advertisement messages, the MHs in the IM are forced to wake up and receive the advertisement messages to perform P-MIP-related operations. It is impossible for a WNIC to differentiate P-MIP control packets from other broadcast packets. Therefore, the WNIC has to receive all broadcast packets, and after that, it is possible for the P-MIP layer to pick P-MIP control packets out of the received packets. From such a mechanism, one can easily imagine that an MH with both WNIC and HD having P-MIP consumes more energy due to the unnecessary broadcast packets

Ⅲ. Proposed Idle Mode Operation

In order to overcome the problems discussed in the previous section, we define a new mode, i.e., Idle Mode (IM), for the 802.11 WLAN. We attempt to minimize required operations for the IM in order to minimize the energy consumption. When a WNIC is in the IM, it performs only essential operations to wake up in the future. A number of neighboring AP cells can be grouped into a PA. The APs belonging to different routers can also be grouped into the same PA. The APs in the same PA have the same identifier, which is broadcast through the beacons via a newly-defined Paging Area Identifier (PAID) field. Each WNIC in the IM can differentiate a PA from the received PAID.

We define a new procedure in order to support the IM. Fig. 1 shows the procedure when a WNIC enters and leaves the IM. After a session

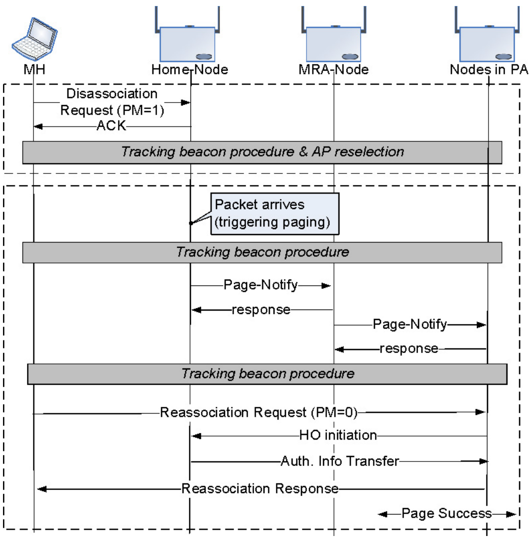

Figure 1. Procedure for the idle mode operation

(e.g., a VoIP session) completion, the WNIC transmits a Disassociation-Request frame with Power saving Mode (PM) bit (in the frame control field) set to '1' in order to enter the IM. After receiving the corresponding Disassociation-Response from its AP, the WNIC in the IM can move around within the same PA while the AP, which transmitted the Disassociation-Response, keeps the WNIC's context to perform a handoff procedure in the future. This AP is referred to as Home-Node. Even when a WNIC recognizes the change of AP cell through the beacon information, the WNIC keeps listening to only the beacons as long as the WNIC stays in the same PA. This continual beacon listening operation is called AP-Reselection. For an efficient AP-Reselection, there could be many optimization issues as addressed in [12]. However, we do not consider the AP-Reselection issues since they are beyond the scope of the paper. For simplicity, AP-Reselectionis assumed to be performed without overhead, e.g., scanning, via optimization. For example, the Neighbor Report information from the emerging 802.11k [12] will make this possible in the near future.

When a packet destined to a particular WNIC in the IM arrives at the Home-Node, the Home-Node broadcasts a Page-Notify message to all the APs, belonging to the same PA, which in turn start paging the destination WNIC. That is, the APs convey the paging information via their beacon frames. If a WNIC recognizes that it is paged by receiving such beacon(s) from an AP, it attempts to associate with the AP by transmitting a Reassociation-Request. After finishing all the preparations for serving the WNIC, the new AP replies to the WNIC with an Association-Response frame and broadcasts Paging-Success to the APs in the same PA to stop paging operations of these APs. At the same time, after successful paging for the WNIC, the MH having the WNIC starts toperform the delayed handoffoperation. Delayed handoff is explained later in this section.

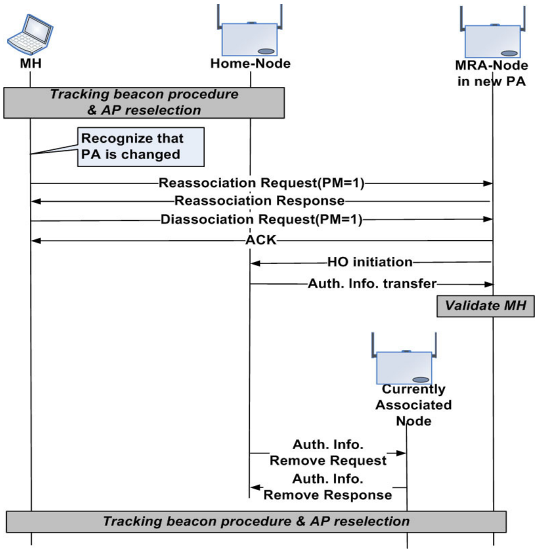

Figure 2. Idle handoff

Idle handoff is the handoff that is performed whenever a WNIC in the IM moves across a PA boundary. Fig. 2 shows the procedure for idle handoff. After a WNIC enters a new PA, which can be identified by a newly-received beacon, it transmits a Reassociation-Reques frame with the BSSID of its Home-Node in the "Current AP address" field. The PM bit of the Reassociation-Request frame is set to '1' in order to discriminate Reassociation-Request frame used for the L2 handoff in the PSM or the AM.

Upon receiving the Reassociation-Requestframe, the new AP replies with a Reassociation-Response frame. Then, the WNIC transmits Disassociation-Requestframe in the same manner as to initially enter the IM, i.e., with PM set to '1'. After the completion of a successful 3-way management frame exchange, the WNIC resumes listening to the beacons periodically in order to receive the paging information. The AP, which is involved with the 3-way frame exchange, is referred to as Most Recently Associated Node (MRA-Node). In Fig. 2, once the MH enters PA2, it starts to perform AP-Reselection until paging or idle handoff.

Now, the MRA-Node initiates to obtain the authentication information about the WNIC from the Home-Node. Through the operations, the MRA-Node performs a user validation check using the MAC address of the WNIC. After a successful validation check, the Home-Node informs the old MRA-Node in the PA, which the WNIC previously visited immediately before entering the new PA, by transmitting a Remove-Context message, that the WNIC moves to the new MRA-Node. After receiving the Remove-Context, the old MRA-Node removes the context of the WNIC. There could be several security issues about our scheme. However, more detailed security issues are beyond the scope of this paper.

When there is at least one idle handoff, the Home-Node actually transmits a Page-Notifyto the MRA-Node, which in turn forwards it to all the APs in the same PA. Since our proposed scheme enables IEEE 802.11 WLAN to keep track of the locations of the MHs in the IM, the IP layer-related operations including IP paging becomes redundant. That is, our proposed protocol replaces IP paging. Therefore, in our approach, the handoff operations related to the IP layer are postponed until the successful completion of a paging. For this reason, we call this handoff operation, which delays the reactivation of IP layer, a delayed handoff. While performing the delayed handoff, the operations to check the user validity are also performed.

Ⅳ. Prototype Implementation

An mobile host necessarily has to minimize its power consumption when the mobile host is in the IM. For the minimization, most components in the mobile host should keep staying in sleep state wherein the components hardly perform their operation. Our new mobile host architecture leverages power saving efficiency as follows.

As explained in Section Ⅱ, a mobile host is composed of HD and WNIC. When a mobile host is in the IM, the IP-related operation is not necessary anymore since the IM performed by WNIC replaces IP paging. It implies that a perfect functional separation between WNIC and

HD is possible. Due to such separation, HD should be able to remain asleep without disturbance caused by IP operation. In order to realize the separation between WNIC and HD, WNIC and HD need to operate independently, and hence there should be no information and control signal exchanges between them. For this reason, the device driver running in HD should not control the WNIC. Accordingly, the IM-related operation should be embedded in a WNIC in the form of firmware.

According to our proposed mobile host architecture, during the IM, the WNIC with the HD turned off has to listen to the beacons in order to wake up for paging. At this time, most of HD components, even Central Processing Unit (CPU), are turned off, except the logic required to receive interrupt signal from the WNIC to wake up the HD when paged. It supports a possible way to minimize aggregate energy consumption when the mobile host is in the IM. When a packet destined to a mobile host, after completing successful paging, the WNIC informs the HD of the event occurred through internal interrupt signal. Since the successful paging indicates the initiation of new IP session, HD has to wake up to perform IP operation.

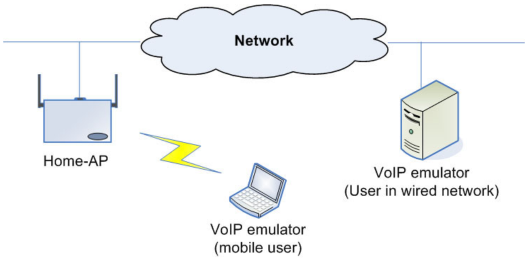

Figure 3. System configuration for the experiments

Table 1. The employed resources of the mobile host

Laptop model	LG-IBM X40
CPU	Intel(R) Pentium(R) M processor 1.2 GHz
WNIC model	MMC Tech. Inc. MW-500CB
WLAN chip model	Atheros Communications, Inc. AR5212

We have built a prototype system to demonstrate our proposed IM operation. The system is composed of a mobile host, a Home-AP, and a VoIP system emulator. Both mobile host and Home-AP have a WNIC capable of performing the IM operation. We have developed the system on the Linux Operating System (OS). The kernel version of the Linux OS is 2.6.5-1.358.

LG-IBM R32 laptop is used for a Home-AP and LG-IBM X40 laptop is used as a testbed for a mobile host. We install VoIP system emulator in both a PC server and the mobile host as shown in Fig. 3. The resources of the mobile host used in our implementation are shown in Table 1. As a WNIC, we choose an Atheros chipset-equipped WNIC since open source of its device driver is distributed under the name of madwifi project [9]. The madwifi is an open source project to implement the Linux device driver for Atheros chipset-equipped WNICs. The versions of the device driver we employ are shown in Table 1.

When the Home-AP receives a packet destined to a mobile host in the IM, it begins to locate the mobile host. Netfilter technology enables Home-AP to detect the packet arrival. Netfilter is a packet filtering framework inside Linux2.4.x and Linux 2.6.x kernel series. It is a set of hooks inside the Linux kernel that allows kernel modules to register callback functions with the network stack [8].

After the detection, Home-AP begins to transmit beacon conveying paging information. For this purpose, we define a new command in ioctl(), called PAGE-MH. If the device driver is requested for paging via PAGE-MH command of ioctl(), it prepares a beacon which contains the paging information comprising the element identity and the MAC address of the paged mobile host.

Fig. 4 shows the state transitions including the SLEEP state which is newly defined state in madwifi for our implementation. We skip the state transitions to INIT from other states because every state has a path to INIT to perform

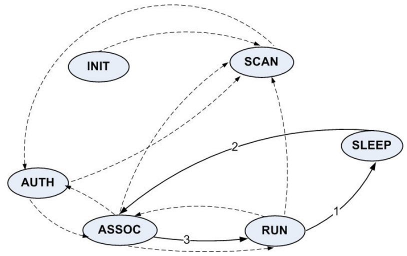

Figure 4. State transitions of the device driver for a mobile host

initialization and to treat abnormal conditions. The transitions depicted by the dotted lines are originally defined in the madwifi. The solid numbered lines represent newly defined transitions. The transition related to the IM starts at the RUN state.

When we started to develop the IM, madwifi did not support the PSM for a mobile host. In order to obtain the energy consumption rate when a mobile host is in the PSM, we choose the following approach. In case of the PSM, when a mobile host is in the PSM, Traffic Indication Map (TIM) is transferred to the mobile host when new packet arrives at an AP. On receiving the TIM, the mobile host transmits a frame with ower-Saving-Poll (PS-Poll) to its AP, and after receiving the PS-Poll, the AP starts to transmit buffered packet. The procedure, at least in the energy consumption's perspective, is rather similar to the IM operation when a new packet arrives at an AP. Reminding that the paging beacon is transmitted to a mobile host in the IM, and then, the mobile host, receiving the paging beacon, wakes up to transmit a Reassociation-Request frame for the packet reception. Therefore, if we set the sleep duration for the IM to be 100 ms, the energy consumption rates of the IM and the PSM, while there is no tra켧, are expected to be very similar. For this reason, we decide to use the IM with the sleep duration set to 100 ms instead of the PSM for the measurement.

V. Experimental Results

We have two goals with our experiments. First, we prove the functionality provided by our new paging scheme, which is a part of the IM. Second, we evaluate the energy consumption efficiency provided by the paging. Since there has never been a paging scheme in IEEE 802.11 WLANs, it is important to prove the effectiveness.

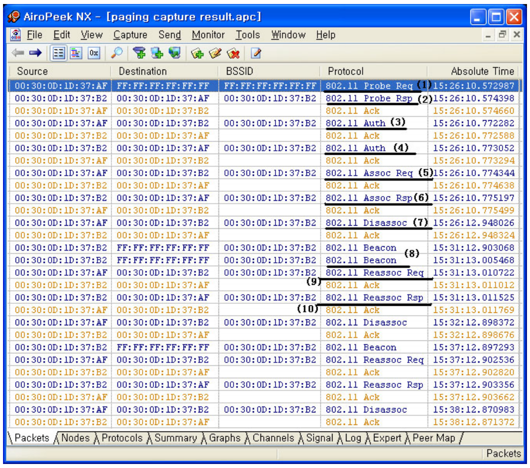

Figure 5. Captured IEEE 802.11 WLAN frames

We perform an experiment in order to observe the paging operation. For this experiment, we prepare a scenario that an MH spends five minutes in the IM and one minute in the AM repeatedly. Fig. 5 shows the frames captured by a commercial tool, called airopeek [10], which is an efficient tool to capture the frames transmitted by WNICs compliant with IEEE 802.11 WLAN standards. In the figure, (1) and (2) represent Probe-Request and Probe-Response frames for scanning, respectively. (3) and (4) indicate the message exchanges to authenticate each other. After the authentication, the MH attempts to associate with the Home-Node as shown in (5) and (6). Finally, the MH enters the IM by transmitting a Disassociation-Request with the PM bit set to '1' as shown by (7). After the MH spends five minutes staying in the IM, the MH is paged by receiving the paging beacon (8). Immediately after receiving the paging beacon, the MH wakes up to exchange Reassociation-Request and Reassociation-Response frames with the Home-Node (9), (10). After a paging success, the

VoIP session lasts for one minute. In the figure, the procedure, in which the MH enters the IM and wakes up, repeats three times.

Since the energy consumption of a WNIC in the PSM is almost identical to that of the IM with sleep duration T_{sleep} set to 100 ms as long as there is no traffic, we measure the energy consumption rate of the IM with T_{sleep}=100 ms instead of the PSM. In case of the AM, we measure the energy consumption rate of a WNIC when the WNIC is activated with/without VoIP traffic. In addition, we measure the energy consumption rate when only the HD, i.e., without a WNIC, is activated. Based on these scenarios, we observe the energy consumption rate of an MH. For every measurement, we measure the remaining energy of an MH until the battery of the MH is drained of the remaining energy.

Fig. 6 shows the measurement results. With these experimental results, we can obtain the energy consumption rate of a WNIC when each of IM, PSM, and AM is employed, respectively, by subtracting the energy consumption rate of an MH without WNIC from that of the MH with WNIC in each mode. We estimate the standby time extension when the IM is applied to a PDA. For our estimation, we choose HP3715 [11] as a portable device and measure the energy consumption of it.

The measurement results are shown in Fig. 7. The energy consumption rate of the PDA also shows a linear trend as was the case with the laptop. In the figure, the dotted line with white circles represents the remaining energy when the PDA is in the *active* mode. On the other hand, the line with black circles indicates the energy consumption rate when the PDA is in the *standby* mode. When there is no traffic, the PDA must be in the *standby* mode, in which the PDA turns off almost every component inside the PDA. When the PDA is operated in *active mode*, the energy consumption rate is 207 mW while it consumes 5.6 mW in *standby mode*.

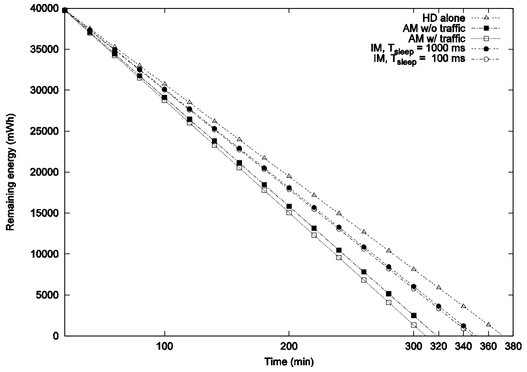

Figure 6. Energy consumption measurement of the MH

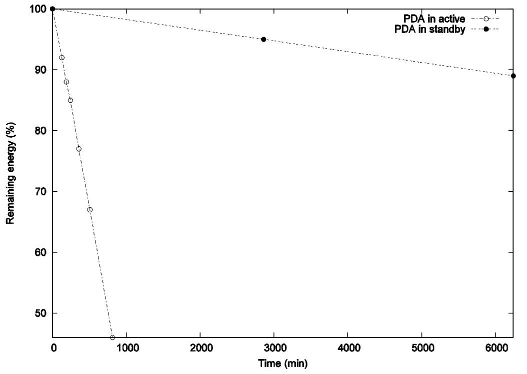

Figure 7. Energy consumption measurement of the PDA

In brief, as to both IP paging and the PSM limitation, they require L2 handoffs at every AP cell boundary, and the reception of every broadcast packet for IP paging, while a user moves around. It implies that the HD has to be activated, and the energy is wasted mostly in vain. Keeping those concepts in mind, we estimate the standby time of the PDA in each WNIC mode.

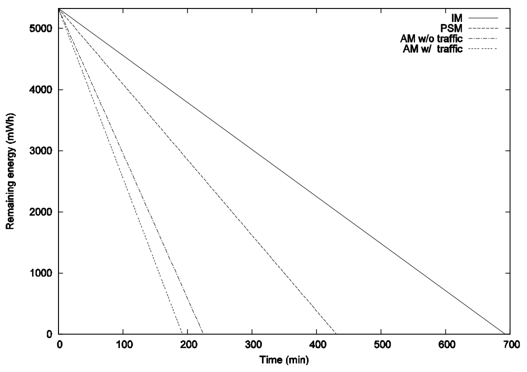

Figure 8. Estimated energy consumption of the PDA

For the AM, both the WNIC and the HD belonging to the same MH are activated all the time even if traffic does not exist, thus incurring a significant energy consumption. In the case of the PSM, a WNIC of the MH can save its energy when there is no traffic. However, the PSM still requires the HD to remain activated since the IP paging should be performed. For this reason, when the PSM is employed, the energy consumption required by the HD should be considered. The IM provides a benefit entirely distinguishable from the PSM and the AM. When the IM is employed, the WNIC in an MH does not need the HD because the IM replaces the IP paging. For this reason, we can ignore the energy consumed for the HD. Considering these features about each operation of AM, PSM, and IM, we can estimate the standby time in each mode.

Table 2. Estimated standby time of the PDA

WNIC mode	IM	PSM	AM
Standby time (min.)	692	430	224

Each of P_{AM}, P_{PSM}, and P_{IM} indicates the energy consumed by the PDA in AM, PSM, and IM, respectively. Considering the obtained energy consumption rate values and the battery capacity of HP3715, we estimate the standby time when each of IM, PSM, and AM is employed for the PDA, respectively. As shown in Fig. 8, if the portable device employs the IM, the standby time is extended remarkably. The standby time we have estimated are summarized in Table 2.

Ⅵ. Conclusion

In this paper, we propose a novel protocol to support the Idle Mode operation in the 802.11 WLANs. The proposed protocol can be easily applied to already-deployed products by just updating their firmwares or device drivers. In order to prove the above statement, we have implemented our proposed schemes based on the device driver source code distributed under the madwifi project. The results obtained through extensive experiments demonstrate that our proposed the IM operation outperforms legacy schemes with respect to the energy consumption. As a result, it enables a longer standby time of the 802.11-equipped mobile hosts.

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