Performance Analysis of IP Paging Protocol in IEEE 802.11 Networks

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Abstract

Recently, IEEE 802.11 wireless networks have been widely deployed in public areas for mobile Internet services. In the public wireless LAN systems, paging function is necessary to support various advanced services (e.g. Voice over IP and message applications) and to provide efficient power management scheme. In next-generation mobile networks, the so-called ***all-IP networks****, the paging function will be supported in the IP layer (i.e. IP paging). When IP paging protocol is deployed in IEEE 802.11 wireless networks, it may utilize the power saving mechanism supported in the IEEE 802.11 standard for more efficient power management. However, since the current power saving mechanism is based on a periodical wake-up mechanism with a fixed interval, it is difficult to optimize the power saving performance. In this paper, we analyze the performance of IP paging protocol over IEEE 802.11 Power Saving Mode (PSM). We define a wake-up cost and a paging delay cost. Then, we study the effect of varying the length of the wake-up interval and the session arrival rate. In addition, we analyze the distribution of the session blocking probability due to the coarse-grained wake-up interval. Also, we investigate the optimal wake-up interval to minimize the total cost through simulations. These results indicate that it is necessary to find the optimal wake-up interval in order to minimize the total cost while satisfying the given paging delay constraints.*

keywords. IP paging protocol, IEEE 802.11 Power Saving Mechanism, Performance analysis, Optimal wake-up interval.

1 Introduction

In wireless/mobile networks, since mobile hosts (MHs) are free to change their attachments to the networks, location management scheme is required to provide mobile hosts with continuous services. The location management scheme is divided into two procedures: *location update* and *terminal paging*. The operation wherein the MH informs the network about its current location is known as *location update*, and the network's determining the exact location of the MH is called *terminal paging*. For existing cellular networks, such as GSM and IS-41 systems, many efficient location update and paging schemes have been proposed in [1], [2], and [3].

More recently, with the advent of IP technologies, IP-based location management schemes have become the focus of the research area. In terms of location update, the Mobile IP Working Group [4], which is a part of the Internet Engineering Task Force (IETF), has proposed various protocols based on Mobile IP. On the other hand, in terms of terminal paging, several protocols have been proposed in [5], [6], and [7]. Unlike the protocols designed for cellular networks, they are based on IP-layer messages, so that they are called *IP paging protocols*.

Although the concept of IP paging is quite novel and represents an important research area in the field of IP-based wireless/mobile networks, it has to take into consideration the lower layer (i.e. data link layer) protocols being used in order to obtain reasonable performance. Among the various link layer protocols, we focused on wireless LAN systems based on the IEEE 802.11 standard. Wireless LAN systems based on IEEE 802.11 are widely deployed in hot spot areas for public Internet access. Furthermore, they are considered as a complementary solution to the next-generation mobile networks. When IP paging is deployed in IEEE 802.11 wireless networks, it should utilize the power saving mechanism supported in the IEEE 802.11 standard for efficient power management. However, since the current power saving mechanism is based on a static wake-up mechanism, it is difficult to obtain the optimized power saving performance.

In this paper, we study the performance issues involved in IP paging protocol deployed in IEEE 802.11 wireless networks using the IEEE 802.11 Power Saving Mode (PSM). For the analysis, we define a wake-up cost and a paging delay cost. And then, we divide the power saving mechanism into two classes: one has a fixed wake-up interval and the other has an adjusted wake-up interval. We present an analysis of the probability distribution for the session blocking. Also, we analyze the impact of the session arrival rate on the total cost in both the delay-sensitive session and the delay-insensitive session. Furthermore, we perform some simulations and investigated the optimal wake-up interval to minimize the total cost in different cases.

The reminder of this article is organized as follows. Section II introduces the power saving mechanism defined in the IEEE 802.11 standard. In Section III, we describe the reference architecture and protocol required for IP paging protocol over wireless LAN. Section IV formulates the cost functions to analyze the performance of the IP paging protocol over the IEEE 802.11 PSM. Section V shows the analytic results and Section VI shows the simulation results. At last, Section VI concludes this paper.

2 IEEE 802.11 Power Saving Mode (PSM)

In wireless communication, it is preferable to turn off MHs while they are idle, in order to save power. However, since MHs in power saving mode cannot know when packets arrive for them, it is impossible to follow this rule exactly. Therefore, there are two problems to be addressed in the case of power saving for MHs:

- How does an MH in power save mode (PS mode) receive packets from other MHs?
- How does an MH send to another MH which is in power save mode?

In IEEE 802.11 PSM, the basic idea is all MHs in PS mode to be synchronized to wake up at the same time. At this time, a window period starts during which the sender announces that it has buffered frames for the receiver. Any MH that receives such an announcement frame stays awake until the entire frame is delivered.

Specifically, IEEE 802.11 supports two power modes: *active* and *power saving*. The power saving protocols for infrastructure networks and ad-hoc networks are different. Since IP paging protocol operates in infrastructure networks, this section focuses on the power saving protocol in infrastructure mode. In the infrastructure mode, there is an access point (AP) to monitor the mode of each MH. An MH in the active mode is fully powered and thus may send and receive packets at any time. On the other hand, an MH in the PS mode only wakes up periodically to check whether there are any incoming packets from the AP. The MH always notifies its AP when changing modes. Periodically, the AP transmits beacon frames spaced by a fixed *Beacon Interval*. An MH in the PS mode should monitor these frames. Once every *BeaconPeriod*, typically 100ms, the AP sends a beacon containing a *traffic indication map (TIM)*, which contains the ID's of those MHs in PS mode for which there are buffered unicast packets waiting in the AP. Upon hearing its ID, the MH in PS mode should stay awake for the remaining beacon interval. During the contention period (i.e., DCF (Distributed Coordination Function)), an awakened PS host can issue a PS-POLL to the AP to retrieve the buffered packets. On the other hand, during the contention-free period (i.e., PCF (Point Coordination Function)), the PS host waits for the AP to poll it. Typically, MHs listen to every beacon, but the MHs can also be configured to skip *ListenInterval* beacons between listen times. Spaced by a fixed number of beacon intervals, the AP will send *deliver TIMs (DTIMs)* within beacon frames to indicate the presence of buffered broadcast packets. Immediately after the DTIMs, the buffered broadcast packets will be sent. Whenever the AP sends data to an MH, it indicates whether or not there is more data outstanding, and the MH goes to sleep only when it has retrieved all pending data from the AP. If the MH has data to send, it can wake up in order to send the data without waiting for a beacon.

Power saving protocol in ad-hoc mode, where the packet store/ forward and the timing synchronization has to be done in a distributed manner, is more complex. Details of the power saving protocol used in ad-hoc networks can be found in [8].

3 IP Paging Protocol in Hierarchical Mobile IPv6 Architecture

As mentioned above, several IP paging protocols have been proposed in [5], [6], and [7]. However, there are no dominant protocols in standardization process. Therefore, we use a generic IP paging protocol, which can be used in the Hierarchical Mobile IPv6 (HMIPv6) architecture [9], and which is based on the functional architecture defined in [10].

Fig. 1 shows the reference architecture used for the performance analysis. There are different entities defined in the HMIPv6 architecture such as home agent (HA), access router (AR), and mobility anchor point (MAP). Among these entities, the MAP, which is a new functional unit in HMIPv6, acts as a local HA in the HMIPv6 architecture. An MH entering a MAP domain will receive Router Advertisements containing information on one or more local MAPs. The MH can bind its current on-link care-of address (LCoA) with an address on the MAP's subnet (regional CoA (RCoA)). Acting as a local HA, the MAP receives all packets on behalf of the MH it is serving and will encapsulate and forward them directly to the MH's current address. If the MH changes its current address within a local MAP domain, it only needs to register the new address

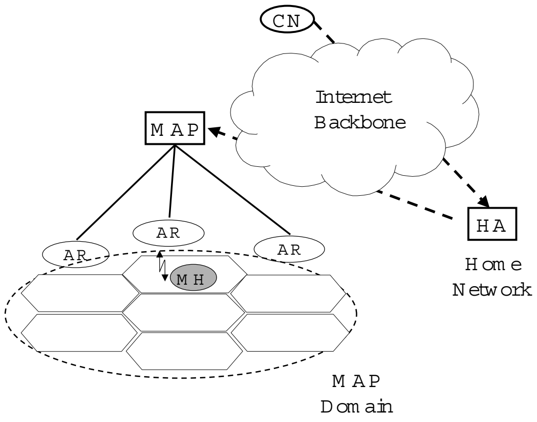


Figure 1. Hierarchical Mobile IPv6 architecture.

with the MAP. Hence, only the RCoA needs to be registered with the correspondent nodes (CNs) and the HA. The RCoA does not change as long as the MH moves within the same MAP domain. This makes the MH's mobility transparent to the CNs which it is communicating with. A MAP domain's boundaries are determined by the ARs which advertise the MAP information to the attached MHs.

Since wireless IP networks support connectionless services, it is difficult to identify an MH in idle mode. In most of the protocols which have been proposed [5], [6], simple timer-based schemes are used. In these schemes, an MH is in one of two states: active or idle. An MH is considered to be active for an active timer period, which starts from the instance the MH sends or receives data. Namely, while it is actively transmitting or receiving packets, the MH remains in the active state. In this state, since the MH updates the network each time it changes its point of network attachment, the network knows the precise location of the MH and the data delivery time is low. Each time an active MH sends or receives data, the timer is reset. However, if the MH is inactive for a period of time (*active timer*), it will go into idle mode. In this idle state, the MH updates the network less frequently only when it changes its paging area. Therefore, if the MH spends sufficient time in the idle state, power saving is achieved by means of a reduction in the transmission of location updates. Whenever the idle MH sends or receives data, its operational mode is changed to active and its active timer is re-started. By these procedures, IP packet stream is classified into several sessions, called *data session*. The active timer value is implementation dependent. In this paper, we follow the timer-based identification scheme with timer T.

In terms of the functional architecture for IP paging, it is important to define where the *Paging Agent* to be located. In this paper, we assume that the Paging Agent is located in the MAP. Paging function is invoked by the arrival of a paging request packet. In general, the paging request packet is typically the first packet of a session. When the paging request packet is arrived at the MAP, the MAP performs terminal paging. In the wireless networks supporting paging, the paging area construction and paging request delivery mechanism (e.g. unicast, multicast, or other schemes) are important design issues. However, we do not consider these issues in this paper because the main focus is to minimize power consumption in the MH.

4 Performance Analysis

To evaluate the performance of IP paging protocol in the IEEE 802.11 networks with power saving mechanisms, we define two types of cost: wake-up cost and paging delay cost. In the IEEE 802.11 PSM, an MH in sleep mode wakes up periodically to check whether there are some incoming packets. In the current IEEE 802.11 PSM, the wake-up period is the same as Beacon Interval. However, when there exists a long idle period, waking up every Beacon Interval is unnecessary. In this analysis, we investigate the impact of the wake-up interval on the wake-up cost (C_{wakeup}). We assume that the minimum wake-up interval is Beacon Interval and that the adjusted wake-up interval is an integer multiple of the Beacon Interval.

As mentioned above, since an MH wakes up only at the beginning of the wake-up interval, if a paging request packet arrives during the sleep period then the MH can receive the paging request packet only at the next wake-up time. In other words, when the IEEE 802.11 PSM is deployed in wireless/mobile networks supporting IP paging, paging delay can occur. To represent this paging delay, we define the paging delay cost (C_{delay}). Also, if the delay associated with a paging request packet is longer than the given delay constraint, the session may become blocked. Therefore, the paging delay is related to the session blocking probability (P_B).

4.1 Cost Function Definition

As mentioned above, the cost of IP paging protocol over IEEE 802.11 PSM can be expressed as Eq. 1. The total cost includes both the wake-up cost and the paging delay cost incurred during inter-session time.(refer Fig. 2)

$$C_{total} = C_{delay} + C_{wakeup} \tag{1}$$

The wake-up cost, C_{wakeup}, is proportional to the number wake-ups which occur during the inter-session time.

$$C_{wakeup} = \alpha K \tag{2}$$

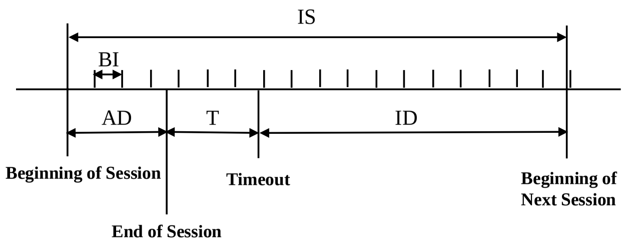


Figure 2. Timing diagram in IEEE 802.11 PSM with the fixed wake-up interval.

where K denotes the number of wake-up events and α is the unit cost for a wake-up event.

On the other hand, the paging delay cost, C_{delay} is related to the arrival time of the paging request packet during a wake-up interval. The paging delay may vary depending on the length of the wake-up interval. In this paper, we assume that one-step uniform paging scheme [11] is used in the paging architecture. Therefore, to locate an MH in a paging area, only one paging procedure is performed. In Eq. 3, D denotes the paging delay and β is a weighting factor used to take into account the sensitivity of session. For example, β of a session, which requires a strict session setup delay bound, is larger than that of session in elastic applications.

$$C_{delay} = \beta D \tag{3}$$

4.2 IEEE 802.11 PSM with the Fixed Wake-up Interval

First, we formulate the wake-up cost and paging delay cost corresponding to the IEEE 802.11 PSM with the fixed wake-up interval. Fig. 2 shows the timing diagram when the IEEE 802.11 PSM is associated with a fixed interval. In Fig. 2, IS denotes the inter-session time of two consecutive data sessions. AD and ID are the active duration time and the idle duration time of a session, respectively. T refers to an active timer value for state transition in IP paging protocol. BI denotes the length of a Beacon Interval in the IEEE 802.11 PSM, which is typically set to 100ms. Then, the paging delay can be calculated as follows:

$$D = \left\lceil \frac{ID}{BI} \right\rceil BI - ID \tag{4}$$

In the case of the IEEE 802.11 PSM with a fixed interval, although an MH is in idle state for a long time, the MH wakes up every Beacon Interval. Therefore, the number of wake-ups during inter-session time is as follows.

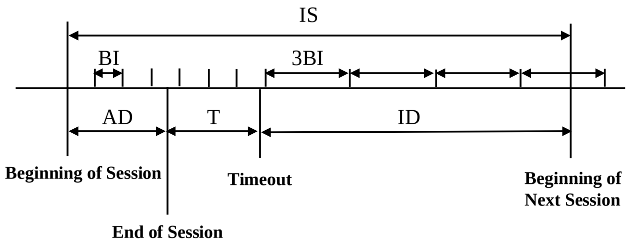


Figure 3. Timing diagram in IEEE 802.11 PSM with the adjusted wake-up interval ($\rho = 3$).

$$K = \left\lfloor \frac{IS}{BI} \right\rfloor \tag{5}$$

4.3 IEEE 802.11 PSM with the Adjusted Wake-up Interval

Second, we consider the power saving mechanism with a larger wake-up interval during the idle period. According to the specification of the IEEE 802.11, the wake-up interval can be adjusted by applying Listen Interval during the idle period. When Listen Interval is set to ρ times of Beacon Interval, the MH wakes up only every ρBI without any intermediate wake-ups. Fig. 3 shows the timing diagram in the IEEE 802.11 PSM with the adjusted wake-up interval. ρ is an adjustment constant, which is larger than 1. Then, the paging delay in the adjusted wake-up interval is as Eq. 6.

$$D = \left\lceil \frac{ID}{\rho BI} \right\rceil \rho BI - ID \tag{6}$$

In the IEEE 802.11 PSM with an adjusted wake-up interval, the original wake-up interval (i.e. Beacon Interval), is used before the expiration of the active timer. After the expiration of the active timer, an MH switches to the idle state. During the idle period, the MH wakes up only every ρBI, because the MH usually remains in the idle state for a long time. In other words, the adjusted wake-up interval in the idle state is ρBI. Therefore, the total number of wake-ups during inter-session time can be represented by Eq. 7.

$$K = \left\lfloor \frac{AD+T}{BI} \right\rfloor + \left\lfloor \frac{ID}{\rho BI} \right\rfloor \tag{7}$$

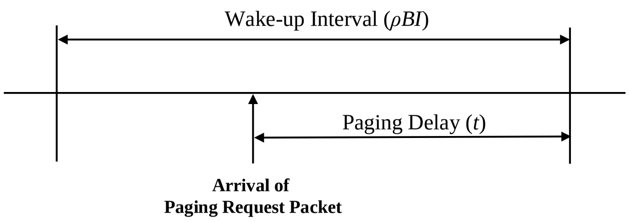


Figure 4. Uniform arrival pattern of the paging request packet.

4.4 Session Blocking Probability

In wireless/mobile networks supporting the paging function, the paging delay determines the session blocking probability, which is one of the most important performance factors. If a paging request packet is delayed more than the given delay constraints, the session will be blocked. In IP paging protocols deployed in the IEEE 802.11 networks, the paging delay is related to the wake-up interval used in the IEEE 802.11 PSM. Fig. 4 shows a timing diagram corresponding to the case where a paging request packet arrives during a wake-up interval.

Since we assumed that paging requests arrive at the MAP in a uniformly distributed manner during a wake-up interval, the probability density function of the paging delay is $\frac{1}{\rho BI}$. Of course, ρ is one for the IEEE PSM with the fixed wake-up interval. If the delay of a paging request is larger than the delay constraint, D_{const}, the session becomes blocked. Therefore, the session blocking probability, P_B, is calculated as follows:

$$P_B = \Pr(t > D_{cosnt}) = \int_0^{\rho BI - D_{cosnt}} \frac{1}{\rho BI} dt \qquad (8)$$

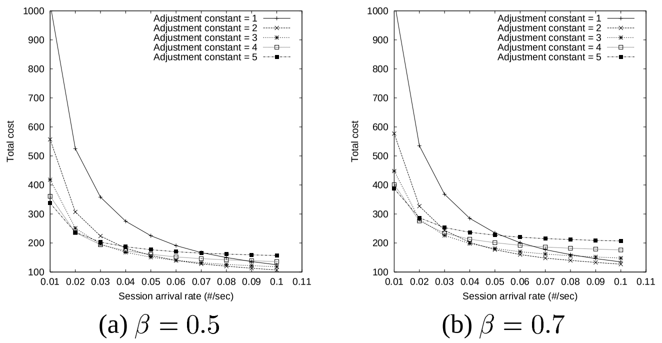
where t is a random variable that refers to the paging delay.

5 Analytical Results

To investigate the performance of the IEEE 802.11 PSM in wireless networks supporting IP paging, we analyze the impact of session arrival rate and weighting values. In this section, we use the analytic cost functions defined in the previous section. In terms of the paging delay cost, we consider the average paging delay cost. The average paging delays of the IEEE 802.11 PSM with the fixed interval and the adjusted interval are as follows:

$$E_{fixed}(t) = \int_0^{BI} \frac{1}{BI} \cdot t{\cdot}dt = \frac{BI}{2}$$

$$E_{adjusted}(t) = \int_0^{\rho BI} \frac{1}{\rho BI} \cdot t{\cdot}dt = \frac{\rho BI}{2}$$



(a) $\beta = 0.5$ (b) $\beta = 0.7$

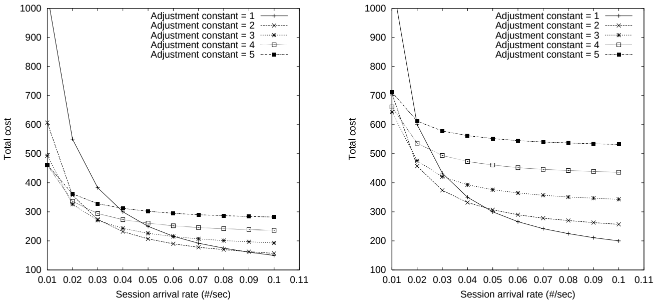
Figure 5. Total cost as a function of session arrival rate (Delay insensitive session).

5.1 The Impact of the Session Arrival Rate

In this analysis, α is set to 1. The average active duration ($E(AD)$) and T are set to 1000ms and 500ms, respectively. Fig. 5 and 6 show the total costs when β, representing the delay sensitivity of sessions, is set to 0.5, 0.7, 1.0, and 2.0. The used adjustment constants (ρ) are 1, 2, 3, 4, and 5.

Fig. 5 shows the impact of the session arrival rate on the total cost in delay insensitive sessions. When β is 0.5 and the session arrival rate is less than 0.02 packets/sec, the total cost is at a minimum when the adjustment constant has a value of 5. However, when the arrival rate is larger than 0.07, the total cost was at a minimum when the adjustment constant had a value of 1. Namely, it is better to lengthen the wake-up interval when the arrival rate is small and the inter-session time is large. In other words, since there is a sufficient idle time in this case, it is better to lengthen the wake-up interval. However, if the arrival rate is large, then the inter-session time will be small. Therefore, in this case, a large wake-up interval cause excessive paging delay costs. This trend becomes more apparent as β increase, because the paging delay cost is proportional to β.

Although similar overall decreasing patterns of the total cost are obtained in all cases, the overall reduction degree in total cost is different in each case. For example, in Fig. 6, since β is 2.0, the paging delay cost make up a higher proportion of the total cost than the wake-up cost. Therefore, it is more important to minimize the delay cost in this



(a) $\beta = 1.0$ (b) $\beta = 2.0$

Figure 6. Total cost as a function of session arrival rate (Delay sensitive session).

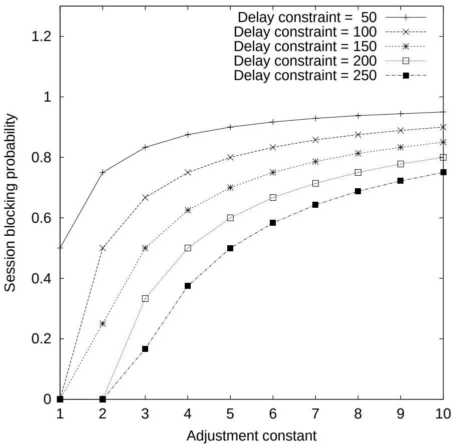


Figure 7. Session blocking probability distribution.

case. As a result, the value of the adjustment constant required to minimize the total cost is either 1 or 2, which is smaller than the optimal value in the previous cases. (Note that the paging delay is inversely proportional to the adjustment constant.)

5.2 Session Blocking Probability Distribution

Fig. 7 shows the session blocking probability as a function of the adjustment constant. Intuitively, it would be expected that as the delay constraint decreases, the session blocking probability would increase. Using Fig. 7, we can find the largest adjustment constant which keeps the blocking probability below the specific threshold blocking probability. For example, let's assume that the delay constraint is 100ms and the upper bound of the blocking probability is 0.8. In this case, if the adjust constant is 5, then the session blocking probability is 0.8. On the other hand, the session blocking probability is 0.83 when the adjustment constant is 6. Therefore, the adjustment constant should be equal to or less than 5 to satisfy the given delay constraint. In wireless/mobile networks, the session blocking probability is one of the most important factors, because it determines users' quality of service and the buffer requirement in the paging agent. However, the result shown in Fig. 7 does not consider the total cost, as it does not include the wake-up cost. Therefore, it is necessary to find the optimal adjustment constant required to minimize the total cost, while satisfying the given delay constraints.

6 Simulation Results

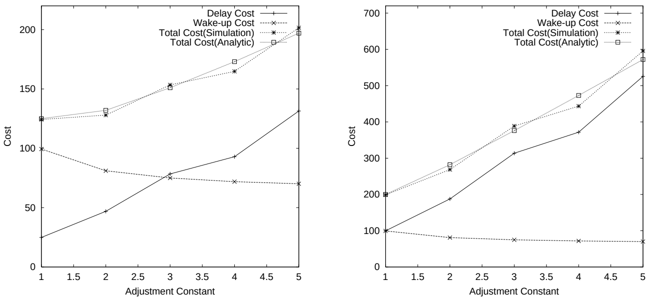
To investigate the impact of the adjusted wake-up interval on the total cost and to find the optimal adjustment constant, we simulated and calculated the total cost using 200 data sessions. In addition, simulation results are used to validate against our analytical results. In the simulation, we assume that the session arrival process is a Poisson distribution. Therefore, the inter-session time follows an Exponential distribution with a mean time of $1/\lambda$. In general, the session duration distributions of IP sessions don't follow an Exponential distribution. Therefore, we assume that the session duration distribution is a Pareto distribution with shape parameter a and parameter k, which determines the minimum value. This Pareto distribution has a heavy-tailed property reflecting the characteristics of IP sessions and its mean time is $\frac{a}{a-1} \cdot k$. Eq. 9 and 10 show the probability density functions of the inter-session time and the active duration, respectively.

$$f_{IS}(t) = \lambda e^{-\lambda t} \tag{9}$$

$$f_{AD}(t) = \frac{a}{k}\left(\frac{k}{t}\right)^{a+1} \tag{10}$$

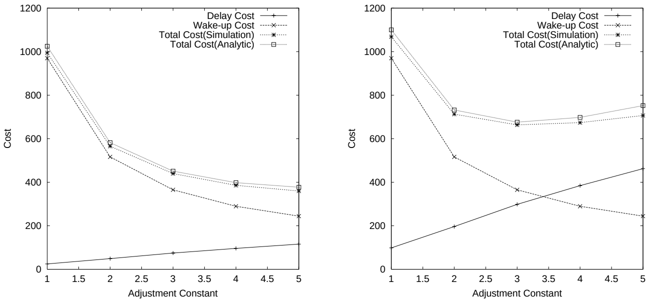
We analyze the impact of the adjusted wake-up interval for two types of sessions: One is with high session arrival rate ($\lambda = 0.1$) and the other with low session arrival rate ($\lambda = 0.01$). In terms of the distribution of the active duration, a and k are set to 1.2 and 1.0 according to [12], respectively. The active timer, T, is set to 500ms, which is same as that of analysis.

Fig. 8 shows the averaged total cost in 100 data sessions with high session arrival rate. In delay-insensitive sessions ($\beta = 0.5$), the total cost is minimized when the adjustment constant is 1. Similarly, in delay-sensitive sessions ($\beta = 2.0$), the adjustment constant minimizing the total cost is 1. Although the optimal adjustment constant of delay-insensitive sessions is larger than that of delay-sensitive sessions, the optimal adjustment constant for both



(a) $\beta = 0.5$ (b) $\beta = 2.0$

Figure 8. Total cost as a function of adjustment constant (High session arrival rate: $\lambda = 0.1$).



(a) $\beta = 0.5$ (b) $\beta = 2.0$

Figure 9. Total cost as a function of adjustment constant (Low session arrival rate : $\lambda = 0.01$).

cases are just 1 or 2. This is because longer sleeping is more costly in sessions with short inter-session time.

On the other hand, Fig. 9 shows the averaged total cost in 100 data sessions with low packet arrival rate. In Fig. 9, the optimal adjustment constants are 5 and 3 for delay insensitive and sensitive sessions, respectively. Compared with the results of Fig. 8, the optimal adjustment constants are relatively large. Because there exists a longer idle period in sessions with low packet arrival rate, so that a large wake-up interval is benefit to reduce the total cost.

In addition, Fig. 8 and 9 compare simulation results with analytical results. As shown in Fig. 8 and 9, simulation results and analytical results are almost same. Specifically, the result indicate that the discrepancy between analytic analysis and simulation is within about 6% in most cases.

7 Conclusion

In this paper, we analyzed the performance of IP paging protocol in IEEE 802.11 networks with power saving mechanism. In terms of the IP paging protocol, we considered a generic paging protocol based on Hierarchical Mobile IPv6. For performance evaluation, we formulated the wake-up cost and the paging delay cost incurred when IP paging protocol is employed in IEEE 802.11 networks. Analytical results indicated that the total cost is largely dependent not only on the session arrival rate but also on the length of the wake-up interval. In addition, simulation results showed that the optimal adjustment constant values minimizing the total cost vary as a function of the session arrival rate and the weight value used. Therefore, it is important to find the optimal wake-up interval to minimize power consumption under different network environments. We proposed a session blocking probability distribution with the assumption of a uniform arrival pattern and it is possible to find the optimal adjustment constant satisfying the delay constraints using this distribution. However, since wireless networks are unpredictable , it is difficult to determine the exact session arrival pattern and to find out the session blocking probability. Therefore, in a future study, we will propose a new algorithm which can be used to find the optimal adjustment constant for a given delay constraints and which utilizes an estimation scheme to determine the packet arrival pattern [13].

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