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# Proactive Load Control Scheme at Mobility Anchor Point in Hierarchical Mobile IPv6 Networks

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**SUMMARY** In IP-based mobile networks, a few of mobility agents (e.g., home agent, foreign agent, etc.) are used for mobility management. Recently, Hierarchical Mobile IPv6 (HMIPv6) was proposed to reduce signaling overhead and handoff latency occurred in Mobile IPv6. In HMIPv6, a new mobility agent, called mobility anchor point (MAP), is deployed in order to handle binding update procedures locally. However, the MAP can be a single point of performance bottleneck when there are a lot of mobile node (MNs) performing frequent local movements. This is because the MAP takes binding update procedures as well as data packet tunneling. Therefore, it is required to control the number of MNs serviced by a single MAP. In this paper, we propose a load control scheme at the MAP utilizing an admission control algorithm. We name the proposed load control scheme *proactive load control scheme* to distinct from the existing load control schemes in cellular networks. In terms of admission control, we use the cutoff priority scheme. We develop Markov chain models for the proactive load control scheme and evaluate the ongoing MN dropping and the new MN blocking probabilities. As a result, the proactive load control scheme can reduce the ongoing MN dropping probability while keeping the new MN blocking probability to a reasonable level.

***key words:*** *Hierarchical Mobile IPv6, proactive load control scheme, Markov chain, blocking (dropping) probability*

## 1. Introduction

In IP-based mobile networks, a few of mobility agents (e.g., home agent, foreign agent, etc.) are used for mobility management. Mobile IPv6 (MIPv6) [1] is a de facto mobility protocol in IPv6 wireless/mobile networks. To mitigate the high signaling overhead in Mobile IPv6 networks when mobile nodes (MNs) hand off frequently, Hierarchical Mobile IPv6 (HMIPv6) [2] was proposed. In HMIPv6 networks, the mobility anchor point (MAP) has been introduced in order to handle binding update (BU) procedures due to handoffs within a MAP domain in a localized manner, so that the signaling traffic for mobility over the whole network will be reduced. However, the MAP can be a single point of performance bottleneck when there are a lot of MNs which are using the MAP as their serving MAP. This is because the MAP not only handles binding update locally, but also performs encapsulation/decapsulation for every data packet destined for MNs. In other words, when a lot of MNs are serviced by a single MAP, the MAP suffers from traffic overload and this results in higher processing latency. In addition, as we expect a proliferation of mobile networking in the near future, how to control the traffic load on the MAP will be one of the most crucial issues. For the purpose of load control at the MAP, it is needed to limit the number of MNs serviced by the MAP.

However, the current HMIPv6 specification does not concern with this problem. According to the HMIPv6 specification, an MN can select a MAP with a lighter traffic load. However, the detailed procedures are not mentioned. Furthermore, although an MN takes the current load at the MAP into considerations, a load control scheme at the MAP is also needed for stable and fault-free mobile services.

In this paper, we propose a novel load control scheme. In the case of cellular networks, when there is an overflow in mobility agents (e.g., home location register (HLR) and visitor location register (VLR)), an existing registration entry in mobility agents is replaced with the newly incoming registration entry. In other words, the load control scheme in cellular networks is invoked only when there is no capacity in the mobility agent. Therefore, we classify the load control scheme into *reactive load control scheme*. On the other hand, the proposed load control scheme is named *proactive load control scheme*. Namely, the proactive load control scheme is invoked when the current MAP load is equal to a predefined threshold value. Furthermore, we classify MNs into ongoing MNs and new MNs, in order to give higher priority to ongoing MNs.

For proactive load control scheme, we utilize an admission control algorithm, which is widely used for resource management in wireless access networks. Specifically, we use a well-known guard channel schemes, i.e., cutoff priority scheme. In terms of performance analysis, we develop a Markov chain model for the proactive load control scheme and evaluate the ongoing MN dropping and the new MN blocking probabilities. As a result, the proposed proactive load control scheme can reduce the ongoing MN dropping probability and maintain the new MN blocking probability to a reasonable level compared with no load-control scheme in HMIPv6 specification [2].

The remainder of this paper is organized as follows. Section 2 introduces related works in both cellular networks and Mobile IP networks. Section 3 describes the basic operations of the proactive load control scheme at the MAP. In Sect. 4, we model the proactive load control scheme based on the Markov chain model and formulate the ongoing MN dropping probability and the new MN blocking probability. Section 5 shows numerical results and Sect. 6 concludes this paper.

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## 2. Related Work

For the purpose of load control at mobility agents used in cellular networks, various overflow control schemes were introduced in the literature [3]–[5]. In the case of overflow control scheme, when the capacity of mobility agents becomes full, an existing entry in the overloaded mobility agent is replaced with a new entry (i.e., a new mobile user). In terms of replacement policy, a number of algorithms have been proposed: the random selection policy [3], the inactive replacement policy [4], and the most idle replacement policy [5]. Although a few load control schemes were proposed for IP-based mobile systems in [6], [7], and [8], they focused the load balancing issues among multiple mobility agents and overload problem in HAs rather than local mobility agent (e.g., MAP). In large scale wireless/mobile networks, localized mobility management scheme (e.g., HMIPv6) will be widely used, so that more traffic loads will be concentrated to local mobility agents rather than HAs. Therefore, it is important to consider the load control scheme at local mobility agents.

To achieve the load control at local mobility agents, the existing replacement schemes may be utilized. These replacement schemes can be called *reactive load control schemes* because they are used only when the capacity of mobility agents becomes full. However, when a lot of MNs request the registration for an overloaded mobility agent, the reactive control scheme may cause longer processing latency and blocking at the mobility agent. Therefore, we believe that a kind of *proactive load control scheme* is required. Unlike the reactive load control scheme, the proactive load control scheme uses a threshold value, which is smaller than the total capacity of the mobility agent, and the mobility agent tries to keep the total number of MNs below the threshold value by the proactive load control scheme. In the case of proactive control scheme, since the total number of MNs is controlled with a conservative manner, it is possible to provide mobile users with more balanced and stable services. In this paper, we adapt an admission control algorithm, which are widely used in the resource allocation in wireless access networks, for the proactive load control scheme.

## 3. Proactive Load Control Scheme

### 3.1 Overview: Hierarchical Mobile IPv6

In HMIPv6, an MN configures two care-of-addresses (CoAs): a regional care-of-address (RCoA) and an on-link care-of-address (LCoA). The RCoA is an address on the MAP's subnet. An MN is attributed to an RCoA when it receives router advertisement (RA) messages with the MAP option. On the other hand, the LCoA is an on-link CoA attributed to the MN's interface based on the prefix information advertised by an access router (AR).

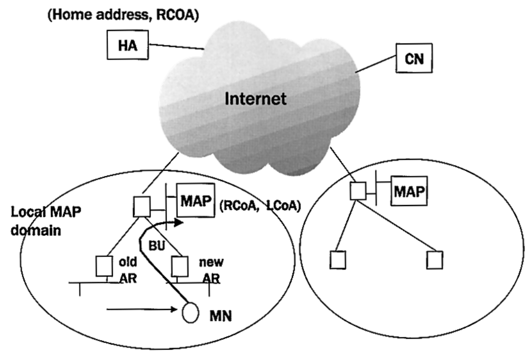


**Fig. 1** Basic binding update procedure in HMIPv6.

Figure 1 depicts the basic operations which are performed in HMIPv6. An MN entering a MAP domain will receive RA messages containing information on one or more local MAPs. Then, the MN selects the most suitable MAP by a number of criteria (distance, mobility, preference, etc.). However, the question of how to select a MAP is the beyond the scope of this paper. We simply assume that a specific MAP selection scheme is used and that the MN sends a BU message to the selected MAP. The MN can bind its current location (i.e., LCoA) with an address on the MAP's subnet (i.e., RCoA). Acting as a local HA, the MAP will receive all packets on behalf of the MNs it is serving and will decapsulate and forward them to the MN's current address. If the MN changes its current address within a local MAP domain, it only needs to register the new address to the MAP. The RCoA does not change as long as the MN moves within the MAP domain. This makes the MN's mobility transparent to the correspondent nodes (CNs).

### 3.2 System Model

In the proactive load control scheme, we assume the following system models.

**1** The capacity of a MAP ($C_{MAP}$) is represented by the maximum number of MNs that it can serve.
**2** An MN performs a binding update to only one MAP, which is selected by a MAP selection scheme.
**3** If the binding update message is rejected by the MAP, the rejected MN can perform another binding update procedure to another MAP or the HA/CNs.
**4** MNs are classified into three types: new MN, handoff MN, and refresh MN.
  **A** *New MN*: New MN refers to an MN performing the initial binding update to the MAP (e.g. when an MN is turned on).
  **B** *Handoff MN*: When an MN, which is serviced by a MAP, moves into another MAP domain, the MN sends a binding update to the new MAP. Since the handoff MN is registered in the previous MAP domain, the handoff MN should have a higher priority than the new MN [11].
  **C** *Refresh MN*: In Mobile IPv6 [1], a lifetime is specified in the binding update message, which indicates the

valid time of the binding information. After the specified lifetime, the binding information expires and the MN should refresh the binding information. The refresh MN is an MN performing a binding update for the purpose of refreshment.

Although an MN performs the binding refreshment, the MAP load does not change. Therefore, in the proactive load control scheme, the new MN and handoff MN are considered for the admission control procedure. In addition, only handoff MNs, having active connections with CNs when the handoff is triggered (i.e., the MNs in active state), have priority than new MNs. Since there is no explicit connection in IP networks, each MN maintains an active state timer [9] to distinguish active state from idle state. If an MN in idle state sends or receives data, the active timer is initialized and the MN enters into the active state. Every time the MN sends or receives data, the active timer is reset. If the MN does not send or receive data until the active timer expires, the MN returns to the idle state. We rename handoff MNs in active state *ongoing MNs*. In other words, the admission control algorithm considers two classes of MNs: *ongoing MNs* and *new MNs*.

In terms of implementation, the **H flag** is added to the existing BU message [1]. The H flag is set if the MN is in active state when it sends a BU message. If the H flag in the BU message is set, the MN is deemed to be an ongoing MN. Otherwise, the MN is regarded as a new MN.

### 3.3 Basic Load Control Procedure

In this section, we describe the basic operation of the proactive load control scheme at the MAP. As mentioned before, we utilize an admission control algorithm called the cut-off priority scheme [10] to limit the number of MNs to be registered to a MAP. In the cut-off priority scheme, the total number of MNs registered to a MAP is evaluated for the admission control. Figure 2 depicts the proactive load control scheme. More detailed procedure in each step are as follows:

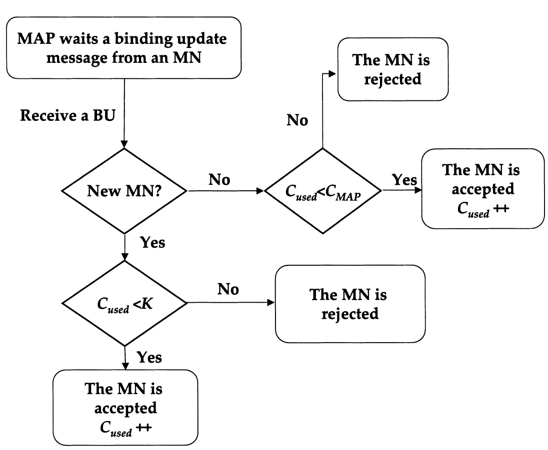


**Fig. 2** Proactive load control procedure.

- **Step 1**: An MN receives router advertisement (RA) [1] messages with MAP options from all available MAPs in its current location and then the MN selects one of them as its serving MAP. Then, the MN sends a BU message to the MAP for local binding update.

- **Step 2**: The MAP performs the admission control algorithm for the MN sending the BU message.

  i) in the case of ongoing MN
  If($C_{used} < C_{MAP}$)
  the MAP accepts the MN and $C_{used}++$
  Otherwise the MAP rejects the MN

  ii) in the case of new MN
  If($C_{used} < K$)
  the MAP accepts the MN and $C_{used}++$
  Otherwise the MAP rejects the MN

- **Step 3**: The MAP sends binding acknowledgement (BACK) to the accepted MN and binding no acknowledgement (BNACK) to the rejected MN. The rejected MN re-tries binding update to another MAP or performs binding update to the HA and CNs directly.

In the above procedure, $C_{used}$ and $C_{MAP}$ denote the number of current MNs registered to the MAP and the MAP capacity, respectively. $K$ is the threshold value for the admission control algorithm.

## 4. Performance Analysis

In this section, we evaluate the proposed load control scheme using Markov chain models. In terms of performance factors, we consider a new MN blocking probability ($P_{NB}$) and an ongoing MN dropping probability ($P_{OD}$). The new MN blocking probability refers to the probability that a binding update request of a new MN is rejected at the MAP because the total number of MNs exceeds the threshold value. In addition, the ongoing MN dropping probability is the probability that there is no available capacity at the MAP.

### 4.1 Assumptions

To develop the Markov chain models for performance evaluation, we assume followings related to arrival and departure processes.

A. 1. The arrival processes for the ongoing and new MNs follow Poisson distributions with rate of $\lambda_O$ and $\lambda_N$, respectively.

A. 2. The residence times of the ongoing and new MNs follow exponential distributions with mean of $1/\mu_O$ and $1/\mu_N$, respectively.

A. 3. When there is no separation between ongoing MN and new MN, the total offered load is the sum of the ongoing MN offered load ($\rho_O = \lambda_O/\mu_O$) and the new MN offered load ($\rho_N = \lambda_N/\mu_N$):

$$\rho_T = \rho_O + \rho_N$$

### 4.2 Markov Chain Analysis

Based on the above system models and assumptions, we develop Markov chain models for two schemes: the no load control scheme [2] and the proactive load control scheme. For the tactical anaysis, we use the approximated one-dimensional Markov chain models used in [10]. In the following Markov chain models, state $i$ represent the number of MNs in a MAP domain. $q(i, j)$ denotes the transition rate from state $i$ to state $j$.

#### 4.2.1 No Load Control Scheme

In the current HMIPv6 specification, no load control scheme is applied. In other words, all MNs, without separating new MNs and ongoing MNs, are accepted regardless of the number of MNs currently serviced by the MAP if there is remaining capacity in the MAP. Therefore, some of MAPs may be overloaded and MNs that are served by these MAPs suffer from longer processing latency. Figure 3 shows the one-dimensional Markov chain model in the case of no load control scheme.

The transition rates in the Markov chain are as follows:

$$\begin{array}{lll} q(i, i+1) = \rho_O + \rho_N & (0 \le i < C_{MAP}) \\ q(i+1, i) = \quad i+1 & (0 \le i < C_{MAP}) \end{array} \tag{1}$$

where $q(i, i+1)$ and $q(i+1, i)$ are the transition rate from state $i$ to state $i+1$ and the transition rate from state $i+1$ to state $i$, respectively. The steady state probability ($p_k$) can be obtained from Eq. (2).

$$p_k = \frac{(\rho_O + \rho_N)^k / k!}{\sum_{n=0}^{C_{MAP}} (\rho_O + \rho_N)^n / n!} \qquad (0 \le k \le C_{MAP}) \tag{2}$$

The new MN blocking probability and the ongoing MN dropping probability are obtained from Eq. (3).

$$P_{NB} = P_{OD} = \frac{(\rho_O + \rho_N)^{C_{MAP}} / C_{MAP}!}{\sum_{n=0}^{C_{MAP}} (\rho_O + \rho_N)^n / n!} \tag{3}$$

### 4.3 Proactive Load Control Scheme

In the proactive load control scheme, the number of total MNs served by a MAP is used to control the load at the MAP. Let $K$ be the threshold value for admission control in the proactive load control scheme. If the total number of MNs is less than $K$, the new MN is accepted; otherwise, the new MN is blocked. The ongoing MN is rejected only when the MAP capacity is used up. Figure 4 depicts the approximated Markov chain model for the proactive load control scheme.

$$\begin{array}{lll} q(i, i+1) = \rho_O + \rho_N & (0 \le i < K) \\ q(i+1, i) = \quad i+1 & (0 \le i < K) \\ q(i, i+1) = \quad \rho_O & (K \le i < C_{MAP}) \\ q(i+1, i) = \quad i+1 & (K \le i < C_{MAP}) \end{array} \tag{4}$$

Then, the steady state probability ($p_k$) can be expressed as follows:

$$p_k = \frac{(\rho_O + \rho_N)^k / k!}{\sum_{n=0}^{K} (\rho_O + \rho_N)^n / n! + \sum_{n=K+1}^{C_{MAP}} (\rho_O)^{n-K} \cdot (\rho_O + \rho_N)^K / n!} \qquad (0 \le k \le K)$$

$$p_k = \frac{(\rho_O)^{k-K} \cdot (\rho_O + \rho_N)^K / k!}{\sum_{n=0}^{K} (\rho_O + \rho_N)^n / n! + \sum_{n=K+1}^{C_{MAP}} (\rho_O)^{n-K} \cdot (\rho_O + \rho_N)^K / n!} \qquad (K < k \le C_{MAP}) \tag{5}$$

In the case of the proactive load control scheme, a new MN is blocked when the current MAP load is equal to the threshold value ($K$). On the other hand, an ongoing MN is dropped when the current MAP load is the same as the MAP capacity. Therefore, $P_{NB}$ and $P_{OD}$ are as Eqs. (6) and (7), respectively.

$$P_{NB} = \sum_{k=K}^{C_{MAP}} p_k \tag{6}$$

$$P_{OD} = p_{C_{MAP}} \tag{7}$$

## 5. Numerical Results

In this section, we conduct the numerical analysis. For the numerical analysis, $C_{MAP}$ is assumed to 50. The arrival rates of new MN ($\lambda_N$) and ongoing MN ($\lambda_O$) are assumed to 1/20 whereas the residence times of new MN ($\mu_N$) and ongoing MN ($\mu_O$) is varied from 20 s to 1180 s (the average residence time is 600 s). In terms of the threshold value ($K$), two values (i.e., 40 and 45) are evaluated.

### 5.1 Effect of New MN Load

First, we analyze the effect of new MN load. Figure 5 shows the new MN blocking probability in the no load control scheme and the proactive load scheme as a function of

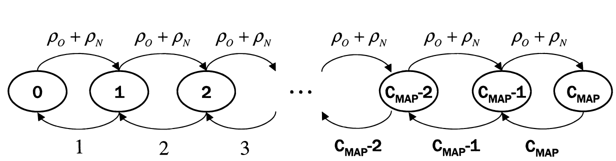


**Fig. 3** Markov chain model for the no load control scheme.

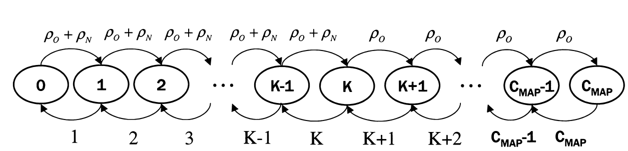


**Fig. 4** Markov chain model for the proactive load control scheme.

new MN load. As shown in Fig. 5, the proactive load control scheme shows higher new MN blocking probability than the no load control scheme. Also, as the threshold value decreases, the new MN blocking probability increases. This is because the proactive load control scheme reserves a certain of the MAP capacity for ongoing MNs. However, the relative ratio between two schemes does not apparently change as the new MN load increases.

On the other hand, Fig. 6 shows the ongoing MN dropping probability as the new MN load increases. Since the proactive load control scheme always gives priority to ongoing MNs, the ongoing MN dropping probability is extremely low. Furthermore, the ongoing MN dropping probability of the no load control scheme drastically increases as the new MN load increases, whereas the ongoing MN dropping probability of the proactive load control scheme remains in the almost constant level. Consequently, the proactive load control scheme is better than the no load control scheme to provide seamless mobile services.

### 5.2 Effect of Ongoing MN Load

Figures 7 and 8 exhibit the new MN blocking probability and the ongoing MN dropping probability as a function of ongoing MN load. As similar to Fig. 5, the new MN blocking probability increases as the ongoing MN load increases. Since the proacitve load control scheme is more sensitive to the change of the ongoing MN load than the change of the new MN load, the increasing rate of new MN blocking probability shown in Fig. 7 is greater than that in Fig. 5.

As shown in Fig. 8, the ongoing MN dropping probability is also sensitive to the increase of the ongoing MN load. Therefore, the ongoing MN dropping probability also

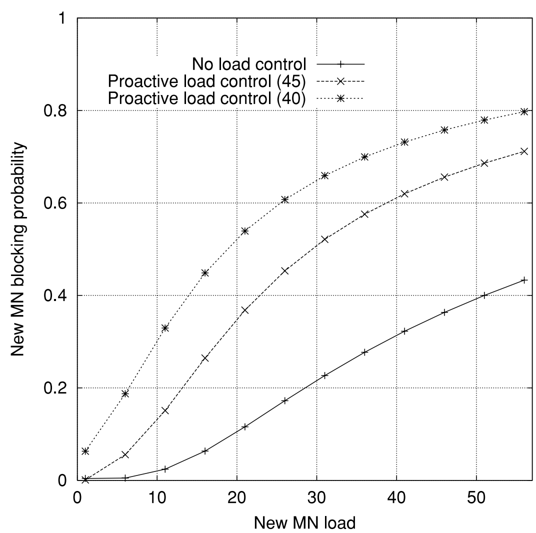


**Fig. 5** New MN blocking probability as a function of new MN load.

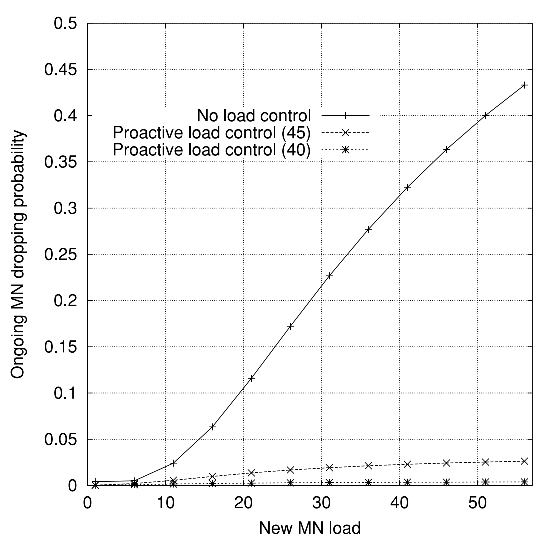


**Fig. 6** Ongoing MN blocking probability as a function of new MN load.

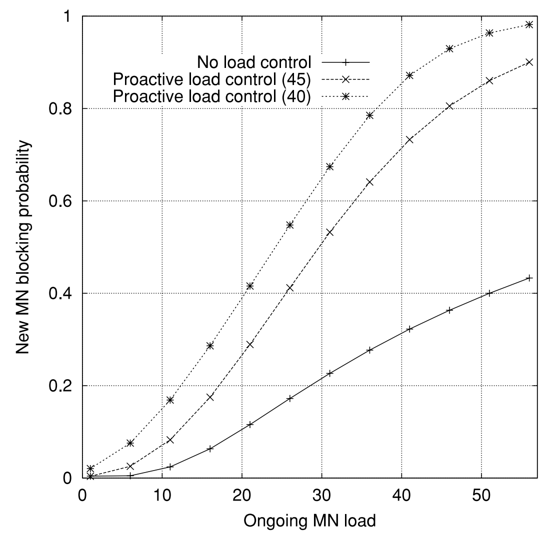


**Fig. 7** New MN blocking probability as a function of ongoing MN load.

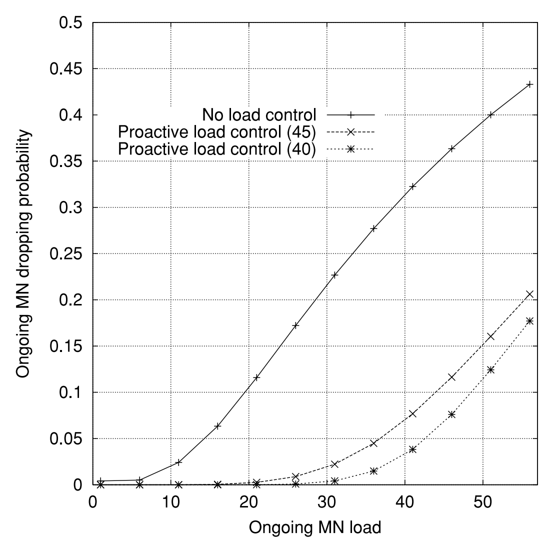


**Fig. 8** Ongoing MN blocking probability as a function of ongoing MN load.

increases when the ongoing MN load exceeds to a certain point (in Fig. 8, the point is about 30).

## 6. Simulation Validation

To validate the analytical results, we performed simulations in a wrap around simulation model shown in Fig. 9. In order to eliminate the edge effect, we use the wrap around model, which can guarantee that each MAP domain has six neighbors so that the handoff departure from the edge cells will not be ignored. For example, in Fig. 9, the edge MAPs and their neighbors are: 8 {2, 9, 19, 18, 14, 10}; 9 {8, 2, 3, 10, 17, 13}; 10 {9, 3, 11, 12, 16, 8}, and so on.

In terms of mobility model, we use the random-walk mobility model [13]. In the random walk model, the routing probability for each direction is the same. Since we assume the hexagonal cell configuration, the routing is 1/6. After deciding a movement direction, the MN stays in the MAP domain during $t_R$. $t_R$, which refers to the MAP domain residence time, is assumed to follow a Gamma distribution shown in Eq. (8).

$$f_R(t) = \frac{b^k t^{k-1}}{\Gamma(k)} e^{-bt}, \quad f_R^*(s) = \left(\frac{b}{s+b}\right)^k \tag{8}$$

where $b$ is equal to $k\lambda_m$ and $\Gamma(k)$ is the Gamma function, which defined as $\int_0^\infty t^{k-1}\mathrm{e}^{-\mathrm{t}}dt$. The mean and variance of the Gamma distribution are $1/\lambda_m$ and $1/k\lambda_m^2$, respectively. On the other hand, the arrival process of new MNs follows a Poisson distribution with rate of $\lambda_N$.

In terms of session-related processes, the session arrival process follows a Poisson distribution with rate of $\lambda_S$ (i.e., the inter-session time ($t_i$) follows an exponential distribution with mean of $1/\lambda_S$) and the session duration time ($t_S$) follows a Pareto distribution with shape parameter $a$ and scaling parameter $k$. The mean session duration time is $ak/(a-1)$. Eqations (9) and (10) show the probability density functions (PDF) of the session arrival process and session duration time, respectively.

$$f_A(k) = \frac{e^{-\lambda_S} \cdot \lambda^k}{k!} \tag{9}$$

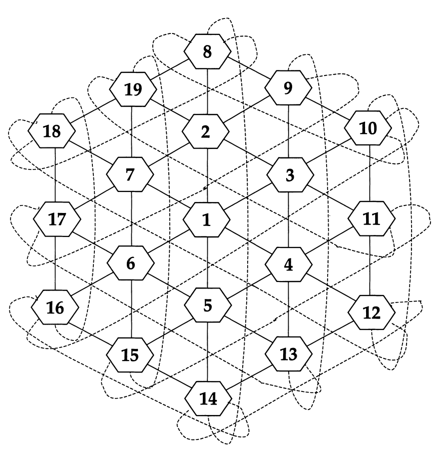


**Fig. 9** Wrap around simulation model.

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

In the simulations, if an MN moves to another MAP $j$ domain before the last session in MAP $i$ domain is terminated, the MN is considered to have performed a handoff and classified into an ongoing MN.

The mean arrival rate of new MNs is set to 1/20 whereas the mean and the variance of the residence time are set to 600 s and 6000 s, respectively. The handoff arrival rate can be obtained from repeated simulation results. In addition, the session arrival rate is 1/30 and the mean session duration time is 10 s. Figure 10 shows the timing diagram. From Fig. 10, the handoff probability that an MN performs a handoff to a MAP domain is as follows:

$$P_H = Pr(t_S > t_r)$$

where $t_r$ is the residual life time in MAP $i$.

For analytical results, if $t_S$ and $t_i$ follow exponential distribution with mean of $1/\eta_S$ and $1/\lambda_S$, respectively, the handoff probability can be derived as Eq. (11)†. Equation (11) is used for analytical results.

$$P_H = \frac{\lambda_S}{\lambda_S + \eta_S} \tag{11}$$

Tables 1 and 2 summarize the simulation and analytical results as the new MN load is varied. As shown in these tables, the analytical results are consistent with simulation results. Specifically, the differences between analytical results and simulation results are less than 1%–11% for most new MN loads. (According to Table 2, the difference of the ongoing MN dropping probability is 25% when the new MN

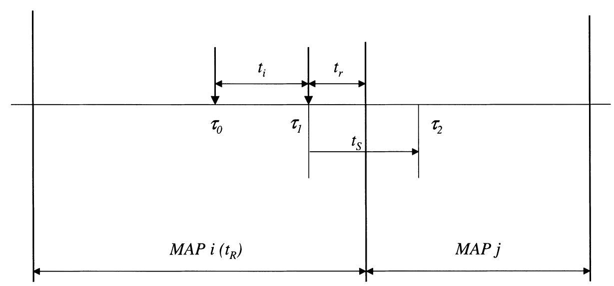


**Fig. 10** Timing diagram.

**Table 1** New MN blocking probability: Analytical results (A) vs. Simulation results (S).

| Load | Proactive | | Reactive | |
|---|---|---|---|---|
| | A | S | A | S |
| 10 | 7.73351E-07 | 0 | 7.63019E-09 | 0 |
| 20 | 0.002957897 | 0.0034 | 0.000220944 | 0.0002 |
| 30 | 0.068247585 | 0.0721 | 0.018690671 | 0.0192 |
| 40 | 0.209152878 | 0.2093 | 0.104787456 | 0.1032 |
| 50 | 0.338441605 | 0.3182 | 0.216118648 | 0.2231 |
| 60 | 0.437519591 | 0.4532 | 0.313802776 | 0.3282 |

†If $t_i$ follows an exponential distribution with mean of $1/\lambda_S$, $t_r$ also follows an exponential distribution with mean of $1/\lambda_S$ by residual lifetime theorem [12].

**Table 2** Ongoing MN dropping probability: Analytical results (A) vs. Simulation results (S).

| Load | Proactive | | Reactive | |
|---|---|---|---|---|
| | A | S | A | S |
| 10 | 2.38443E-10 | 0 | 7.63019E-09 | 0 |
| 20 | 9.11993E-07 | 0 | 0.000220944 | 0.0002 |
| 30 | 2.10424E-05 | 0 | 0.018690671 | 0.0192 |
| 40 | 6.4487E-05 | 0 | 0.104787456 | 0.1032 |
| 50 | 0.00010435 | 0.0001 | 0.216118648 | 0.2231 |
| 60 | 0.000134898 | 0.0001 | 0.313802776 | 0.3282 |

load is 60. However, this is mainly because the analytical result is very small.)

## 7. Conclusion

In this paper, we propose a novel load control scheme at the MAP for stable mobile services. We utilize the well-known guard channel admission control scheme, namely the cut-off priority scheme. In terms of performance analysis, we have developed Markov chain models for each load control scheme and evaluated the ongoing MN dropping and the new MN blocking probabilities. As a result, the proposed proactive load control scheme can reduce the ongoing MN dropping probability while keeping the new MN blocking probability to a reasonable low level. In addition, simulation results, which are performed in the wrap around simulation model, are consistent with the analytical results.

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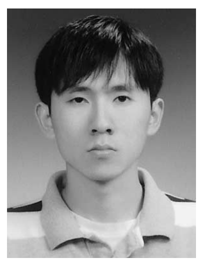

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