# Blocking Probability Analysis at Local Mobility Agent in Large Scale Hierarchical Mobile IPv6 Networks

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## Abstract

Hierarchical Mobile IPv6 (HMIPv6) has been proposed by the Internet Engineering Task Force (IETF) to reduce handoff latency and signaling overhead. HMIPv6 introduces a new local mobility agent called mobility anchor point (MAP) to handle mobile node (MN) mobility with a localized manner. However, a MAP may be a single point of performance bottleneck because the MAP should not only handle signaling traffic (e.g., binding update) but also process data tunneling traffic for all MNs registered to the MAP domain. In this paper, we analyze the blocking probability at the MAP using Markov chain models. We consider the extended HMIPv6 model supporting network mobility as well as the basic HMIPv6 model. As a result of analysis, efficient load control schemes are required to reduce the blocking probability at the MAP and to provide more stable mobile services with mobile users. Therefore, we propose a simple load control scheme using an admission control algorithm.

## 1. Introduction

In IP-based wireless/mobile networks, a variety of mobility agents (e.g., home agent, foreign agent, etc.) are used to support seamless mobility. In terms of network performance, scalability at these agents is one of the most important issues in wireless/mobile networks.

In Hierarchical Mobile IPv6 (HMIPv6) [3], a new mobility agent, called mobility anchor point (MAP), is deployed to handle binding update procedures in a localized manner and to improve handoff performance. Figure 1 shows a simple HMIPv6 architecture and basic binding update procedures. A mobile node (MN) entering a MAP domain will receive router advertisement (RA) messages containing information on one or more local MAPs. The MN can bind its current location (i.e., on-link CoA (LCoA)) with an address on the MAP's subnet (i.e., regional CoA (RCoA)). Acting as a local home agent (HA), the MAP will receive all packets on behalf of the MNs it is serving and will encapsulate and forward them to the MNs' current address. If the MN changes its current address within a local MAP domain, it only needs to register the new address with the MAP. The RCoA does not change as long as the MN moves within a MAP domain. This makes the MN's mobility transparent to the correspondent nodes (CNs) it is communicating with.

However, a MAP can be a single point of performance bottleneck in the HMIPv6 when there exist a lot of MNs, which are using the MAP as their serving MAPs. This is because the MAP should take a lot of jobs such as packet decapsulation/encapsulation, local binding update, etc. In other words, when a lot of MNs are serviced by a single MAP, the MAP suffers from traffic overload and it results in higher processing latency and the MAP blocking. Therefore, it is required to control the number of MNs serviced by a MAP to provide a certain quality of services with mobile users. However, the current HMIPv6 specification does not concern with this problem. A few research works [1-2] have been conducted for the load balancing at the HA not MAP. However, since an MN's mobility is bounded to a limited local network, the load control at the local agent (e.g., MAP) rather than HA is more critical problem.

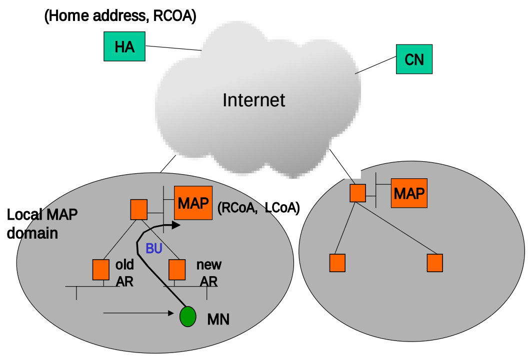


Fig. 1. HMIPv6 Architecture

In this paper, we analyze the blocking probability at the MAP when the MAP is under the heavy-loaded state. In terms of HMIPv6, we consider not only the basic HMIPv6 model but also the extended HMIPv6 model supporting network mobility [4]. In our analysis, we use the Markov chain model and present several numerical results. Also, we propose a simple load control scheme using an admission control algorithm based on analysis results.

## 2. Markov Chain Model

In this section, we develop Markov chain models to obtain the blocking probability at the MAP. In this paper, we define the MAP blocking probability as a probability that the number of MNs registered to a MAP exceeds the pre-defined MAP capacity, which is represented by the number of MNs to be admitted.

### A. System Model and Assumptions

To develop the Markov chain models for performance evaluation, we assume following system models.

1. The capacity of a MAP, which means the maximum number of MNs to be supported, is equal to *C*.
2. The average size of a Mobile NETwork (MNET) is $m$.
3. An MN performs a binding update to only one MAP, which may be the most appropriate MAP selected by the MAP selection scheme [3].
4. If the binding update request was rejected by the MAP, the rejected MN performs another binding update procedures to another MAP or the HA/CNs.
5. The arrival process of MN to a MAP domain follows a Poisson distribution with rate of $\lambda$.
6. The residence time of MN in a MAP domain follows an Exponential distribution with mean of $1/\mu$.
7. The arrival process of MNET a MAP domain follows a Poisson distribution with rate of $\lambda_M$.
8. The residence time of MNET in a MAP domain follows an Exponential distribution with mean of $1/\mu_M$.

### B. Case 1: Basic Hierarchical Mobile IPv6

In the current HMIPv6 specification [3], no load control scheme is applied. In other words, all MNs are accepted regardless of the number of MNs currently serviced by the MAP. Therefore, more MNs than the available MAP capacity may be concentrated to a specific MAP and it results in higher processing latency (i.e., longer binding update time and packet delivery time) and the MAP blocking. Fig. 2 shows a one-dimensional Markov chain model in the basic HMIPv6 model.

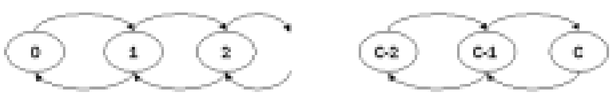


Fig. 2. Markov chain model for the basic HMIPv6 model

The transition rate and the steady-state probability in the Markov chain can be obtained as Eq. (1) and (2)

$$\begin{aligned} q(i,i+1) &= \lambda \qquad (0 \le i < C) \\ q(i+1,i) &= (i+1)\cdot\mu \qquad (0 \le i < C) \end{aligned} \qquad (1)$$

$$p_k = \frac{(\lambda/\mu)^k / k!}{\sum_{n=0}^{C} (\lambda/\mu)^n / n!} \qquad (0 \le k \le C) \qquad (2)$$

Then, the blocking probability can be calculated as Eq. (3) by Erlang's loss formula [6].

$$P_B = \frac{(\lambda/\mu)^C / C!}{\sum_{n=0}^{C} (\lambda/\mu)^n / n!} \qquad (3)$$

### C. Case 2: Extended Hierarchical Mobile IPv6 for Network Mobility

The extended HMIPv6 model was initially proposed in the HMIPv6 specification [3]. However, it is currently being discussed in the IETF NEMO (Network Mobility) working group [7]. In the case of the extended HMIPv6, an MNET can register to a MAP domain as similar to an MN. However, since the MNET consists of a number of MNs, the number of MNs registered to the MAP increases by the size of the MNET. In this paper, we assume the mean size of an MNET is $m$. Fig. 3 shows a Markov chain model for the extended HMIPv6 when the average MNET size is 3. In the Markov chain model, state $(i, j)$ refers to a state that there are $i$ MNs and $j$ MNETs in a MAP domain. $q(i, j; i', j')$ denotes the transition rate from state $(i, j)$ to state $(i', j')$.

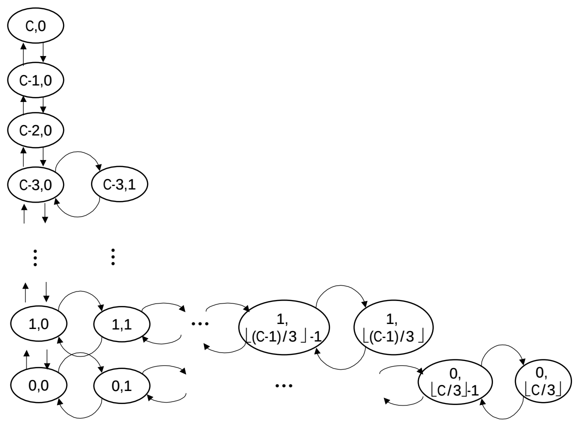


Fig. 3. Markov chain model for the extended HMIPv6 (*m*=3)

The transition rate in the Markov chain model for the extended HMIPv6 model is as follows:

$$
\begin{aligned}
&q(i,j;i-1,j)=i\cdot\mu \quad (0<i\le C,\ 0\le j\le\lfloor C/m\rfloor,\ i+j\le C)\\
&q(i,j;i+1,j)=\lambda \quad (0\le i<C,\ 0\le j\le\lfloor C/m\rfloor,\ i+j\le C)\\
&q(i,j;i,j-1)=j\cdot\mu_M \quad (0\le i\le C,\ 0<j\le\lfloor C/m\rfloor,\ i+j\le C)\\
&q(i,j;i,j+1)=\lambda_M \quad (0\le i\le C,\ 0\le j<\lfloor C/m\rfloor,\ i+j\le C)
\end{aligned} \quad (4)
$$

To find the steady-state probability ( $p(i,j)$ ), the global balance equations of the Markov chain should be resolved. However, since the Markov chain has an asymmetric characteristic when the total number of MNs is larger than $C-m$ and the computation intensive increases as the state dimension become large, it is difficult to find the steady-state probability. Therefore, we use a one-dimensional approximated model used in [8]. In this approximated model, the average service time is normalized to unity. Then, the MN and MNET arrival processes follow a Poisson with rate $\rho=\lambda/\mu$ and with rate $\rho_M=\lambda_M/\mu_M$ , respectively. Eq. (5) shows the steady-state probability in the approximated Markov chain model.

$$
p_k=\begin{cases}\dfrac{(\rho+\rho_M)^k}{k!}p_0, & k\le C-m\\[2ex] \dfrac{(\rho+\rho_M)^{C-m}\rho^{k-C+m}}{k!}p_0, & C-m+1\le k\le C\end{cases} \quad (5)
$$

where

$$
p_0=\left[\sum_{k=0}^{C-m}\frac{(\rho+\rho_M)^k}{k!}+\sum_{k=C-m+1}^{C}\frac{(\rho+\rho_M)^{C-m}\rho^{k-C+m}}{k!}\right]^{-1}
$$

Then, the MN blocking probability ( $P_B$ ) and MNET blocking probability ( $P_B{}^M$ ) are as follows.

$$
P_B=\frac{\dfrac{(\rho+\rho_M)^{C-m}\rho^m}{C!}}{\sum_{k=0}^{C-m}\dfrac{(\rho+\rho_M)^k}{k!}+\sum_{k=C-m+1}^{C}\dfrac{(\rho+\rho_M)^{C-m}\rho^{k-C+m}}{k!}}
$$

$$
P_B{}^M=\frac{\sum_{k=C-m}^{C}\dfrac{(\rho+\rho_M)^{C-m}\rho^{k-C+m}}{k!}}{\sum_{k=0}^{C-m}\dfrac{(\rho+\rho_M)^k}{k!}+\sum_{k=C-m+1}^{C}\dfrac{(\rho+\rho_M)^{C-m}\rho^{k-C+m}}{k!}}
$$

## 3. Numerical Analysis

For numerical analysis, $C$ is assumed to 50. The MN residence time is set to 1/30 and the MN arrival rate is varied from 300 to 1200. Thus, the MN offered load ( $\rho$ ) is from 10 to 40. In addition, the MNET residence time and MNET arrival rate are set to 1/30 and 600, respectively (i.e., the MNET offered load ( $\rho_M$ ) is 20.) In terms of the MNET size, both small ( $m$ =3) and large sizes ( $m$ =6) are evaluated. Fig. 4 shows the blocking probability.

As shown in Fig. 4, the MN blocking probability in the basic model is the lowest among blocking probabilities. However, the difference between the MN blocking probability in the basic and extended models is not significant. On the other hand, the MNET blocking probability in the extended model is larger than the MN blocking probability. However, the blocking probability of the small-sized MNET is less than 0.1 for all offered loads. Fig. 4 also shows the MN and MNET blocking probability in the case of the large-sized MNET. As shown in Fig. 4, the MN and MNET blocking probabilities drastically increase as the MNET size increases.

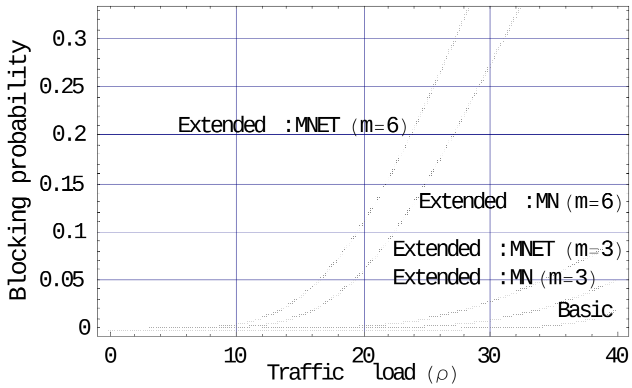


Fig. 4. Blocking probability

From these observations, we conclude that a suitable load control scheme for both MN and MNET is required. This is because the blocking probability is very sensitive to the offered load. Furthermore, the size of MNET affects on the blocking probability.

## 4. Load Control Scheme at MAP

As shown in numerical analysis, a load control scheme at the MAP is necessary to reduce the MAP blocking probability. In [9], we proposed a novel load control scheme using an admission control algorithm called *cut-off priority scheme* [8]. Let *C*, *Cused* and *K* be the MAP capacity, the number of current MNs, and the threshold value, respectively. Then, the load control algorithm is as follows. In this scheme, we classify MNs into two types: on-going MN and new MN. On-going MN includes handoff MN and refresh MN having expired lifetime. Therefore, on-going MN has higher priority than new MN.

***Step 1****: An MN receives RA 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 Binding Update (BU) message to the MAP for local binding update.*
***Step 2****: The MAP performs the admission control scheme for the MN sending the BU message.*
  *i) in the case of on-going MN (i.e., handoff MN or Refresh MN),*
    *If(Cused<C)*
      *the MAP accepts the MN and Cused++*

*Otherwise*
*the MAP rejects the MN*
*ii) in the case of new MN*
*If(Cused<K)*
*the MAP accepts the MN and Cused++*
*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.*

Fig. 5 and 6 show the new MN blocking and ongoing MN dropping probabilities, respectively, when the load control scheme is used. In the proposed load control scheme, an ongoing MN always has higher priority than a new MN. Therefore, the new MN blocking probability is larger than that of no load control scheme. However, it is possible to reduce the ongoing MN dropping probability to an extremely small value. Consequently, the load control scheme based on admission control scheme is better than no load control scheme in terms of QoS.

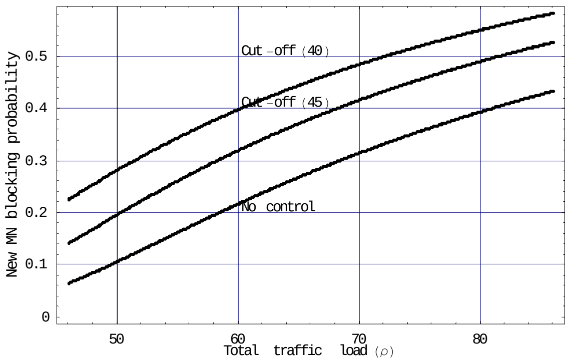


Fig. 5. New MN blocking probability

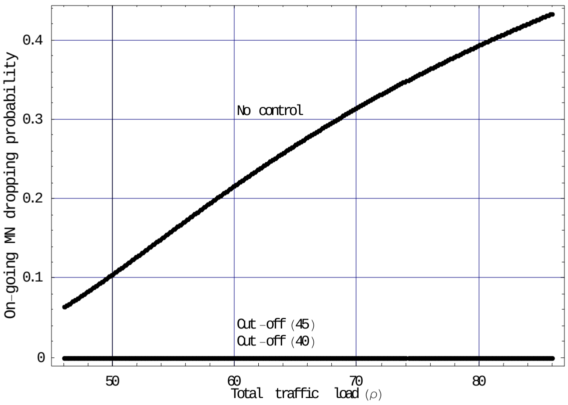


Fig. 6. Ongoing MN dropping probability

## 5.Conclusion

In this paper, we analyzed the blocking probability at a MAP when the offered load to the MAP is high. As a result, we have concluded that new load control schemes are need to reduce the blocking probability and to provide more stable mobile services in HMIPv6 networks. To do this, we proposed a simple load control scheme using an admission control algorithm at the MAP. In our future work, we will propose an adaptive admission control scheme to control the number of MNs and MNETs in a MAP domain. In this scheme, a MAP limits the number of MNs and MNETs and accepts only a few MNs with low session-to-mobility ratio (SMR) in order to reduce the impact of the MNET size.

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## 6. Acknowledgement

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