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A three-level mobility management scheme for hierarchical mobile IPv6 networks*

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Abstract: Performance evaluation shows that Hierarchical Mobile IPv6 (HMIPv6) cannot outperform standard Mobile IPv6 (MIPv6) in all scenarios. Thus, adaptive protocol selection under certain circumstances is desired. Moreover, it is necessary to balance the load among different Mobility Anchor Points (MAPs). This paper proposes an efficient three-level hierarchical architecture for mobility management in HMIPv6 networks, in which a mobile node (MN) may register with either a higher/lower MAP or its home agent according to its speed and the number of connecting correspondent nodes (CNs). An admission control algorithm and a replacement algorithm are introduced to achieve load balancing between two MAP levels and among different MAPs within the same MAP level. Admission control is based on the number of CNs but not MNs that an MAP serves. In case there is no capacity for an MN, the MAP chooses an existing MN to be replaced. The replaced MN uses the MAP selection algorithm again to choose another mobility agent. Simulation results showed that the proposed scheme achieves better performance not only in reducing the signaling overhead, but also in load balancing among different MAPs.

Key words: Mobile IPv6, Mobility management, Admission control, Load control
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INTRODUCTION

Mobile IPv6 (MIPv6) (Johnson *et al*., 2004) was proposed to maintain network connectivity in the next generation Internet. However, communication quality of MIPv6 degrades because of the high signaling overhead and the long signaling delay when a mobile node (MN) performs handover. Hierarchical Mobile IPv6 (HMIPv6) (Soliman *et al*., 2005) was proposed to improve the performance of MIPv6, where the Mobility Anchor Point (MAP) handles mobility inside the local domain. Therefore, HMIPv6 reduces the amount of signaling between the MN, its home agent and its correspondent nodes (CNs).

Extensive experiments were conducted to analyze the performance of HMIPv6 (Perez-Costa *et al*., 2003a; 2003b; Peng *et al*., 2003), with results indicating that HMIPv6 cannot outperform standard MIPv6 in all cases. When the number of CNs (N_c) and the number of handoffs of each MN are low, decreased signaling outside an MAP domain cannot compensate the increased signaling inside the MAP domain. Thus, an MN should determine whether it is efficient to use HMIPv6 under certain circumstances. Peng *et al*.(2003) and Hwang *et al*.(2003) suggested that an MN should make the decision according to the MN's speed and dwell time, respectively. However, although both schemes considered the handoff frequency, they neglect the influence of N_c.

On the other hand, as an MAP serves more and more MNs, it may become a single point of bottleneck. A number of schemes have been proposed to achieve load balancing among different MAPs. Kawano *et al*.(2002) introduced multiple MAP levels and an MAP selection algorithm based on the MN's speed. Different MAP levels share the traffic load. And high

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speed MN chooses a higher MAP to reduce handover signaling. However, signaling reduction is still limited because these schemes also neglect the influence of N_c. Others schemes (Bandai and Sasase, 2003; Kumagai *et al*., 2004; Pack *et al*., 2004) proposed threshold-based admission control algorithms to avoid load concentration at particular MAPs. A threshold is set for each MAP to limit the number of serving MNs (N_m). Since N_c of each MN may be different, such algorithms can only achieve the balancing of N_m, but not the balancing of the actual traffic load.

This paper proposes an efficient mobility management and load control scheme for HMIPv6 networks and introduces a three-level hierarchical architecture enabling an MN to determine whether it is suitable to use HMIPv6. The proposed mobility and traffic based MAP selection algorithm provides load balancing among three mobility agent levels and reduces the overall registration cost. The admission control algorithm based on the number of serving CNs (N_t) achieves actual load balancing among MAPs. Moreover, a replacement mechanism is introduced to decrease the new MN blocking probability and the handoff MN dropping probability.

The rest of the paper is organized as follows. Section 2 presents some related work. Section 3 describes system architecture and MAP selection algorithm. Section 4 provides the details of load control mechanisms. In Section 5, three extensions of the proposed scheme are presented. Section 6 discusses an example scenario. Section 7 presents and discusses simulation results. Section 8 concludes the paper and presents some future work.

RELATED WORK

Multilevel HMIPv6 architecture

Multilevel HMIPv6 architecture (Kawano *et al*., 2002) aims to reduce the number of signaling messages to and from outside networks and avoid the problem of load concentration at particular MAPs. There are multiple MAP levels (two or more) in this architecture. An MN chooses a suitable MAP level according to its speed. Since high speed MN always experiences more handoffs, it should choose a higher MAP to reduce the number of binding updates to its home agent and CNs. The MAP selection algorithm achieves load balancing among different MAP levels.

The speed of an MN in the previous access area (*speed*) is calculated from the dwell time of the MN in the previous access area, together with the standard distance of that access area (Kawano *et al*., 2004a). The recorded time when an MN enters previous access area and the time when it moves into current access area are used to calculate the dwell time. The standard distance is a constant distance defined in advance that substitutes for the actual moving distance of an MN in the access area. To reduce the extent of the estimation errors, when the speed of an MN is calculated, the previous calculated speed ($speed_{p\_h}$) is also considered historically. The historically calculated speed ($speed_h$) is calculated as:

$$speed_h=\alpha\times speed+(1-\alpha)\times speed_{p\_h}, \quad (1)$$

where parameter α is a positive constant less than 1.

However, since N_c of an MN also affects the amount of signaling, the performance gain of speed based MAP selection algorithm is limited. This scheme also does not provide the choice of standard MIPv6 to MNs.

Admission control mechanisms

To avoid extreme load at particular MAPs, Pack *et al*.(2004) proposed a threshold-based admission control algorithm wherein an N_m threshold is defined. When an MAP receives a binding update message and N_m has exceeded the threshold, the MAP fails to accept the new MN. To reduce the new MN blocking probability and the handoff MN dropping probability, a session-to-mobility ratio (SMR) based replacement algorithm was proposed. Here, SMR is defined as the ratio of the session arrival rate to the handoff rate. When N_m of an MAP reaches to the full capacity, the MAP replaces an existing MN at the MAP, whose SMR is higher than that of a threshold, with the MN being just rejected by the admission control algorithm. The replaced MN is redirected to its home agent.

Simulation results showed that the proposal decreases the new MN blocking probability and the handoff MN dropping probability as expected. However, N_m of an MAP cannot reflect the actual amount of traffic, as mentioned above. Thus, this scheme does not control actual traffic load for MAPs and also suffers from high signaling overhead outside

MAP domain because MAPs are not classified and the mobility parameter of the MN is not considered.

ARCHITECTURE AND MAP SELECTION

Three-level architecture

Mobility agents are classified into three classes: higher MAP, lower MAP and home agents of mobile nodes (MNs), which constitute a three-level architecture. The concept of multilevel MAPs was adopted to take advantage of the mobility and traffic parameters of MNs for the purpose of reducing the number of binding update messages outside the MAP domains. Moreover, the home agent level was increased to enable adaptive selection between the HMIPv6 and the standard MIPv6 for MNs to achieve further signaling reduction. Another advantage of adding this third level is that the overall capacity is increased. When higher and lower MAPs both reach their full capacity, new MNs can be served by their home agents. Fig.1 shows the novel architecture.

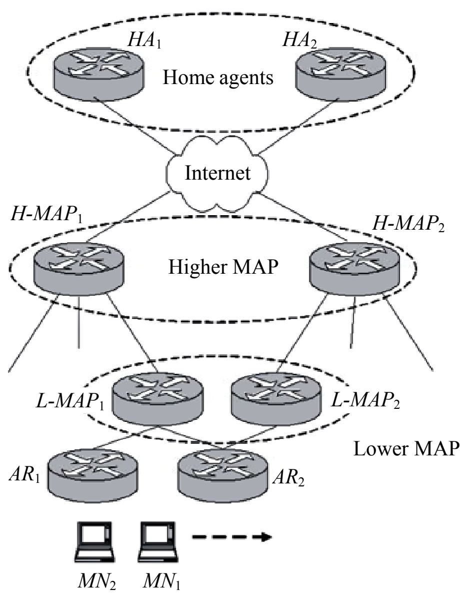

Fig.1 The three-level architecture

Extension of MAP option

The current MAP option is extended to perform load control function in the proposed three-level mobility management architecture. Fig.2 shows the contents of the new MAP option, which include the following additional fields:

(1) *Level*: indicating the level of an MAP. "1" indicates higher MAP and "0" indicates lower MAP. With this 8 bits level field, a hierarchical architecture of maximum 256 levels is allowed.

(2) *Sat*: current saturation degree of an MAP. It is defined as the ratio of the total number of CNs that an MAP currently serves (N_t) to the maximum allowed number of CNs (N_a) that an MAP can handle. This field is used for load balancing within one MAP level, which will be discussed later. The value of *Sat* for an MAP is computed as:

$$Sat=\lceil (N_t/N_a)\times 255 \rceil. \tag{2}$$

(3) *Range*: standard distance of access routers within the MAP area, which is used to substitute for the actual moving distance of an MN in an access area. An MN uses this field and its dwell time to estimate its speed when it leaves an access area. It is obvious that within the same MAP domain, all access routers have the same standard distance.

<table>
<tr><td>0</td><td>8</td><td>16</td><td>20</td><td>24</td><td>25</td><td>31</td></tr>
<tr><td>Type</td><td>Length</td><td>Dist</td><td>Pref</td><td>R</td><td colspan="2">Reserved</td></tr>
<tr><td>Level</td><td>Sat</td><td colspan="5">Range</td></tr>
<tr><td colspan="7">Lifetime</td></tr>
<tr><td colspan="7">Reserved2</td></tr>
<tr><td colspan="7">Global IP address for MAP</td></tr>
</table>

Fig.2 Contents of New MAP Option

MAP selection

The performance evaluation results obtained by Perez-Costa *et al*.(2003b) and Peng *et al*.(2003) are used to combine the number of connecting CNs (N_c) of an MN with its speed (S) as the parameter for MAP selection (defined as "combined measure", referred to as M). The same speed estimation method as in (Kawano *et al*., 2004a) is used. Generally, a weight equation for combining two parameters is as follows:

$$M=\alpha N_c+(1-\alpha)S. \tag{3}$$

Sometimes N_c and S of an MN may be quite different. For example, they may be 3 and 12.5 m/s respectively. It is better to transform N_c (S) into a value close to S (N_c) so that the two parameters have the same importance. Since N_c is always an integer, Lagrange multiplier λ is used to transform S into N_c. Thus the following equation is obtained:

$$M=N_c+\lambda S. \tag{4}$$

Let T_{m_h} and T_{m_l} denote two thresholds of M for choosing higher MAP and lower MAP, respectively. The MAP selection strategy is defined as:

$$MA=\begin{cases} MAP_h, & T_{m\_h}<M; \\ MAP_l, & T_{m\_l}<M\le T_{m\_h}; \\ HA, & M\le T_{m\_l}, \end{cases} \tag{5}$$

where MA indicates the mobility agent that an MN selects. MAP_h, MAP_l and HA denote higher MAP, lower MAP and home agent, respectively. If there is no mobility agent at the desired level, the MN may choose a mobility agent at the next lower level.

In real networks, MAP domains always overlap with each other to maintain mobile communications when MAP failure occurs. Therefore there may be more than one available MAP in the same level for an MN. In this case, the MN should choose the MAP with the lowest value of *Sat*. The introduction of *Sat* and *Level* fields achieves the goal of load balancing. The MN could choose an MAP at proper level based on M, which results in load balancing between two MAP levels. Furthermore, choosing an MAP with lowest *Sat* can avoid load concentration at a particular MAP within an MAP level.

Rules for setting λ, T_{m_l} and T_{m_h}

(1) A suitable λ should transform S into a value which is close to N_c, for most MNs in the system.

(2) T_{m_l} should be very small because an MN chooses its home agent only when it has a very low speed and a small N_c.

(3) T_{m_h} should not be very small, although a small T_{m_h} could decrease registration cost when the network is underloaded. The capacity of higher MAPs may be occupied by those MNs with small M when the network is overloaded, leading to heavy registration cost.

(4) T_{m_h} and T_{m_l} are determined by λ. A suitable [T_{m_h},T_{m_l}] pair should keep a proper ratio among the number of MNs which choose home agents, the number of MNs which choose lower MAPs and the number of MNs which choose higher MAPs.

LOAD CONTROL

Admission control

In the proposed scheme, incoming MNs are classified into two types: new MN and handoff MN.

(1) New MN: The MN performing the initial binding update (BU) to the MAP (e.g. when an MN is turned on).

(2) Handoff MN: When an ongoing MN moves into a new MAP domain, the MN sends a local BU message towards the new MAP to complete local registration. Since the handoff MN is registered, it is probably communicating with one or more CNs. Thus, the handoff MN should have higher priority than the new MN.

An MAP should determine whether the received BU message comes from a handoff MN or a new MN. The mechanism proposed by Pack *et al*.(2004) was adopted. An H flag is added to the existing BU message, and it is set if the MN is in the active state when it sends a BU message. To distinguish the active state from the idle state, each MN maintains an active state timer. If an MN in idle state sends or receives data, the active timer is initialized and the MN changes to 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. If the H flag in BU is set, the MN is recognized as a handoff MN. Otherwise, it is regarded as a new MN.

In the proposed admission control algorithm, two thresholds (T_{c_n}, T_{c_h}) for the total number of CNs that an MAP currently serves (N_t) are set to distinguish two MN types. Here N_t includes N_c of the incoming MN. Normally T_{c_h} is equal to the capacity of an MAP (C_{map}), which is the maximum number of CNs that the MAP can serve. The admission control mechanism is defined as:

$$MN_{al}=\begin{cases} \text{neither}, & T_{c\_h}<N_t; \\ MN_h, & T_{c\_n}<N_t\le T_{c\_h}; \\ \text{both}, & N_t\le T_{c\_n}, \end{cases} \tag{6}$$

where MN_{al} indicates the MNs which can be accepted under certain circumstances and MN_h denotes the handoff MNs.

In addition, a new type of mobility option is defined and referred to as "MNInf Option" (as depicted in Fig.3), to enable the MN to include N_c and S in the BU message. A relatively high value of Type (16) is chosen to avoid conflict with other protocols based on standard Mobile IPv6. The *Speed* field actually has the value of λS. Both N_c and *Speed* fields are 16 bits unsigned integers.

0	16	24	31
	Type=16	Length=4	
N_c	S		

Fig.3 Content of MNInf Option

Given a higher threshold, the dropping probability of handoff MNs can be decreased. However, the new MN blocking probability increases as a penalty. To further reduce both probabilities, the following replacement mechanism is proposed.

Replacement mechanism

When a new MN or a handoff MN cannot be accepted, it should not be blocked or dropped directly. The MAP will choose an MN from existing MNs to be replaced. If N_c of an MN is equal to or larger than that of the incoming MN, it becomes a candidate to be replaced. The MAP then sends binding acknowledgement (BACK) to the chosen MN. The BACK message contains status code 130 with the reason "Insufficient resources" (Johnson *et al*., 2004). Then, the replaced MN performs the process of MAP selection based on the value of M once again to choose another suitable MAP among the remaining MAPs. When the MN registers with a higher MAP, it tries to choose another higher MAP. If no higher MAPs are available, it can also choose a lower MAP. In case there are no lower MAPs available either, the MN has to register with its home agent. However, when the original MAP is a lower MAP, the MN would rather choose another lower MAP than to register with its home agent.

In proposed scheme, MN maintains a table containing information on available MAPs until new router advertisement arrives. Thus, it enables the MN to choose different MAPs.

THREE EXTENSIONS

The proposed three-level HMIPv6 can be easily extended to contain more levels. For example, if it is desired an n-level HMIPv6 protocol, the following modifications are required: (1) The value of level field in MAP option varies from 0 to $n-2$; (2) MNs have $n-1$ thresholds of M. The MN chooses an MAP at a proper level according to its M value. If there is no MAP at proper level, the MN may also choose an MAP at the next lower level.

In general, all MAPs maintain the same thresholds for the combined measure. As an extension, each MAP may also include its own threshold in the MAP option, i.e., higher MAP and lower MAP with T_{m_h} and T_{m_l}, respectively. This dynamic mechanism presents two advantages. One is that an MAP can change its threshold according to its current number of connecting CNs. For example, if the number is much smaller than the capacity of an MAP, the MAP can adaptively decrease its threshold. The other advantage is that the MN need not maintain any threshold. However, T_{m_h} and T_{m_l} should be consistent to avoid confusion in MAP selection, e.g. T_{m_h} is always larger than T_{m_l}.

The third extension is conditional. N_c only approximately indicates the amount of data traffic of an MN. Thus, the admission control mechanism should be based on the actual amount of data traffic if available.

AN EXAMPLE

Let us consider the scenario depicted in Fig.1 as an example. Two higher MAPs ($H\text{-}MAP_1$ and $H\text{-}MAP_2$) and two lower MAPs ($L\text{-}MAP_1$ and $L\text{-}MAP_2$) are placed above two access routers (AR_1 and AR_2). Parameters of two MAP levels for admission control are described in Table 1. Two MNs (MN_1 and MN_2) are moving from AR_1 to AR_2, resulting in handoffs and the process of MAP selection. Here, we assume that the MAPs that the two MNs registered previously are no longer valid. We assume that MN_1 is a "new MN" and MN_2 is a "handoff MN". The thresholds of M are 3.6 and 6.4, respectively. The value of λ as defined in Eq.(3) is 1/5 $(m/s)^{-1}$ and the values of N_c, S and M are shown in Table 2.

AR_2 achieves MAP options through route advertisements. The information of available MAPs is described in Table 3. When MN_1 attaches to AR_2's link, it finds that its value of M is between two thresholds. Therefore, MN_1 selects a lower MAP. Since the saturation degree of $L\text{-}MAP_1$ is lower than that of $L\text{-}MAP_2$, MN_1 decides to register with $L\text{-}MAP_1$. Using the same algorithm, MN_2 chooses $H\text{-}MAP_1$.

Table 1 Parameters for admission control

	T_{c_n}	T_{c_h}	Capacity
Higher	224	256	256
Lower	56	64	64

Table 2 Parameter definitions for MNs

	N_c	S	M
MN_1	2	10	4
MN_2	3	20	7

Table 3 Available MAPs

	Level	*Sat*
$H\text{-}MAP_1$	1	228
$H\text{-}MAP_2$	1	240
$L\text{-}MAP_1$	0	220
$L\text{-}MAP_2$	0	232

Upon receiving local binding update of MN_1, $L\text{-}MAP_1$ obtains N_c and S of MN_1. Suppose the current number of CNs that $L\text{-}MAP_1$ handles is 55, and MN_1's request cannot be accepted since 55+2>56. Thus an MN is replaced and told to choose another mobility agent. As for MN_2, the current number of CNs that $H\text{-}MAP_1$ handles is 228. The replacement operation will not be performed because MN_2 is a handoff MN and the threshold is 256.

PERFORMANCE EVALUATION

Simulation model

There are 16 (4×4) higher MAPs distributed in the simulated network. Each higher MAP is connected by 4 (2×2) lower MAPs and each lower MAP covers 16 (4×4) access routers (ARs). The service area of an AR is assumed to be 50 m×50 m. T_{c_n} and T_{c_h} standing for higher MAP and lower MAP are (56, 64) and (13, 16) respectively. For simplicity it is assumed that MAP domains do not overlap. λ is set to 1/5 according to rule 1 in Section 3.4.

The mobility characteristics of mobile nodes are categorized into three classes, i.e., vehicle, bicycle and pedestrian. The mobility class of a mobile node keeps unchanged during the simulation. The vehicle nodes are referred to as "high speed MNs", and the bicycle nodes and pedestrian nodes are referred to as "low speed MNs". The ratio of high speed MNs to low speed MNs is defined as a simulation parameter. MNs are also divided into two classes according to their traffic characteristics. N_c for low traffic MNs may be 1 and 2, and for high traffic MNs may be 3 and 4. The ratio of these traffic classes is also defined as a simulation parameter. The traffic class of each MN is redefined individually after a duration which has exponential distribution with parameter β=1/500.

As for the mobility model, the smooth random mobility model (Bettstetter, 2001) is used. The model's parameters for vehicle, bicycle and pedestrian classes are shown in Table 4 and are similar to those used in (Kawano *et al*., 2004b). The difference is that an MN should choose a speed from v but not from $[0,v_{max}]$ when it does not use v_{pref}. The simulation time for each experiment is 10000 s. Each MN selects an access router randomly at the beginning. Each experiment is repeated ten times and the average result is presented. Table 5 summarizes the major parameters used in the experiments.

Table 4 Parameters for three mobility classes

	Vehicle	Bicycle	Pedestrian
v (m/s)	8.34~19.46	2.52~5.88	0.66~1.54
v_{pref} (m/s)	0, v_{max}	0, v_{max}	0, v_{max}
Pv_{pref}	(0.1, 0.3)	(0.1, 0.3)	(0.1, 0.3)
a_{min} (m/s^2)	−5.6~−2.4	−1.68~−0.72	−0.42~−0.18
a_{max} (m/s^2)	1.5~3.5	0.48~1.12	0.12~0.28
μ_v (s)	25	75	125
$\mu_{\varphi new}$ (s)	120	360	600

Numeric results

Let us first consider the number of binding updates (BUs, N_b) outside MAP domains as N_M, R_M, and R_T changes. To compare with the proposed scheme (referred to as "CN scheme"), the "MN scheme" containing speed-based MAP selection algorithm and the admission control algorithm based on N_m is implemented. The thresholds for MAP selection are 2 and 6 m/s, and the thresholds for admission control

Table 5 Simulation parameters

Parameters	Description	Value
N_H	The number of higher MAPs	4×4
N_L	The number of lower MAPs	8×8
N_A	The number of ARs	32×32
N_M	The number of simulated MNs	600~1400
R_M	Ratio for high to low speed MNs	1:5~5:1
R_T	Ratio for low to high traffic MNs	5:1~1:5
λ	Factor to transform S into N_c	1/5
α	Constant for speed estimation	0.5
T_{m_h}	Thresholds for MAP selection	4
T_{m_l}		1.5
T_{c_n}	Thresholds for admission control	56/13
T_{c_h}		64/16

are (24, 28) and (6, 7).

Fig.4 shows that N_b of both solutions increases with increasing N_M. However, N_b of CN scheme is much less than that of MN scheme. Although speed-based MAP selection can reduce the signaling load of high speed MN, it does not consider N_c of an MN. Low speed MN with a larger N_c may issue more binding updates to its home agent and CNs. Thus, the proposed scheme achieves better performance.

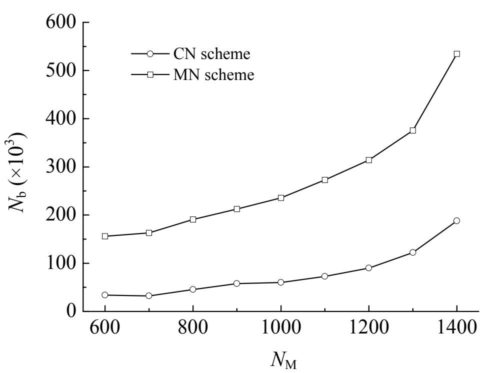

Fig.4 N_b when N_M varies (R_M=1:1, R_T=1:1)

Fig.5 shows the results when the proportion of high speed MNs increases. The influences from two aspects are discussed below. If an MN which had chosen a lower MAP speeds up but does not change its MAP choice, its handover frequency definitely increases. But in MN scheme the MN should change to choose a higher MAP, which significantly decreases the number of inter-domain handovers. Thus there is a decrease in registration cost. On the contrary, it was observed that the registration cost of CN scheme increases slightly when more MNs become high speed MNs. This is because N_c is also the parameter for MAP selection. Thus the number of MNs which change to choose a higher MAP is much less than that in MN scheme. On the other hand, more MNs speeding up increase the overall number of handovers. Thus the registration cost is an increasing function of the proportion of high speed MNs.

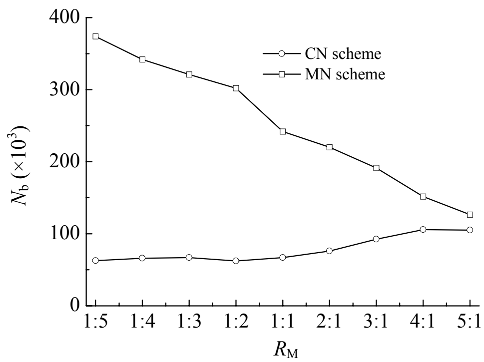

Fig.5 N_b when R_M varies (N_M=1000, R_T=1:1)

When the proportion of high traffic MNs increases, registration cost in MN scheme increases significantly, as shown in Fig.6. Served by the same MAP, an MN with a large N_c issues more binding updates. More high traffic MNs indicates larger registration cost. On the contrary, CN scheme shows its adaptability to various ratios of traffic classes because high traffic MNs try to choose a higher MAP according to the novel MAP selection algorithm. Changing from a low traffic MN to a higher traffic MN, the number of binding updates increases when an MN performs handover. However, handover frequency is also reduced by choosing a higher MAP. As a consequence, the registration cost keeps steady.

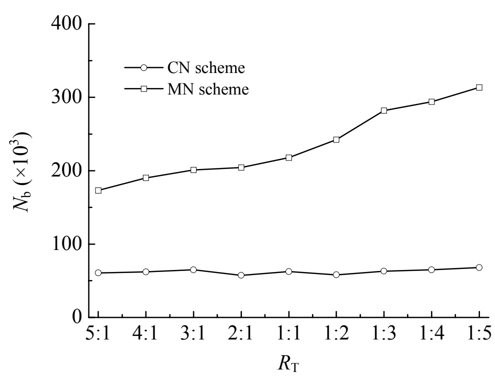

Fig.6 N_b when R_T varies (N_M=1000, R_M=1:1)

The performance with respect to the load balancing was also evaluated. The variance of N_t for each MAP was calculated to measure the load balancing. Only the case when the ratio of traffic classes varies is considered since the other two parameters (N_M and R_M) do not affect the results here. N_M and R_M are set to 1000 and 1:1 respectively. As shown in Fig.7, when the number of high-traffic MNs increases, variance in the MN scheme keeps increasing. The reason is that more high traffic MNs leads to larger gap between N_t and N_m. Assuming a higher MAP with 10 MNs connected. If N_c of each MN is 2, N_t of the MAP is 20. If N_c of each MN is 4, the result is doubled. Although the difference of N_m between two MAPs may be slight, the difference of N_t is notable. On the contrary, the influence of the ratio of traffic classes can be neglected in the CN scheme since its admission control is based on N_t.

Finally, the new MN blocking probability and the handoff MN dropping probability are evaluated. The authors compared their scheme, referred to "CN based admission control and replacement algorithm" (referred to as CAR) here, with two traditional schemes. The first traditional scheme uses only N_t based admission control mechanism (referred to as NAC) and the second traditional scheme does not use any load control mechanism (referred to as NLC). In this experiment, it was assumed that the number of distinct home agents is 20 and that the capacity (i.e., the number of CNs) of each home agent is 30. Initially there are 200 MNs in the network, and the ratio of new MNs to handoff MNs is 1:1. The arrival intervals of new MN and handoff MN both follow uniform distribution on the entire interval [15 s, 25 s]. As shown in Fig.8, the new MN blocking probability of NAC is higher than that of NLC, because NAC trades new MN blocking probability for the handoff MN dropping probability. In the CAR scheme, the new MN blocking probability and the handoff MN dropping probability are significantly reduced as com-

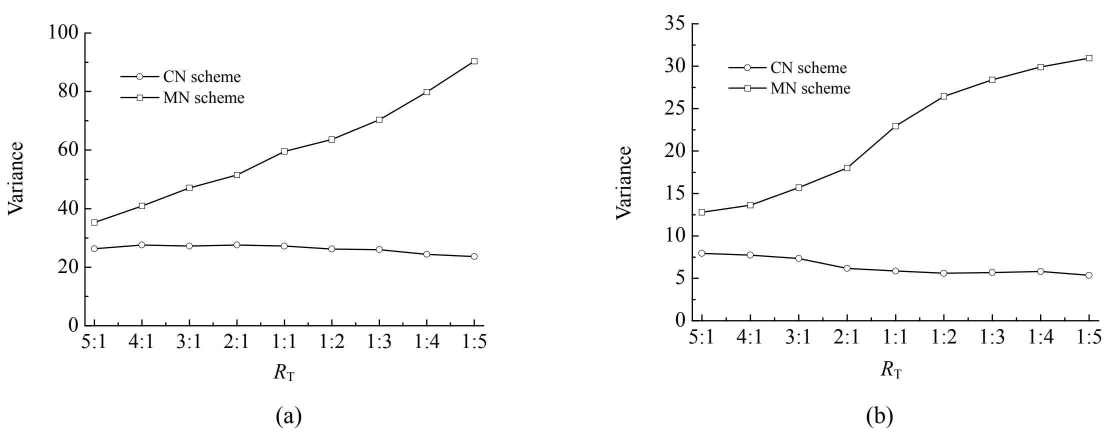

Fig.7 Variance of N_t. (a) Higher MAP level; (b) Lower MAP level

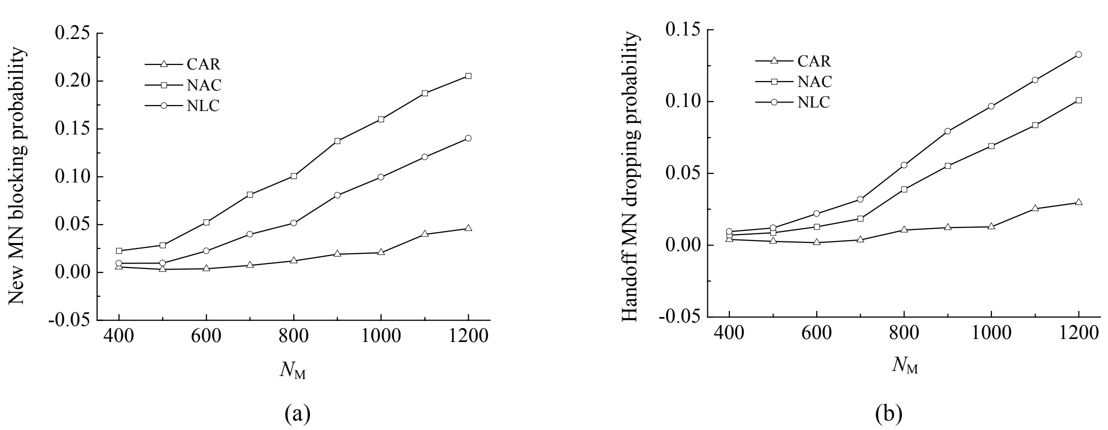

Fig.8 New MN blocking probability (a) and handoff MN dropping probability (b)

pared to NAC and NLC, because the replacement mechanism uses the capacity of home agents to reduce both probabilities.

CONCLUSION

This paper proposes a three-level hierarchical architecture for mobility management in HMIPv6 networks, which consists of three types of mobility agents: higher MAPs, lower MAPs and home agents. The level of home agents enables standard MIPv6 selection for an MN and additional capacity of the whole system. The mobility and traffic based MAP selection algorithm significantly reduces the signaling overhead outside MAP domains. The traffic-based admission control algorithm avoids load concentration at particular MAPs and the replacement mechanism reduces both the new MN blocking probability and the handoff MN dropping probability. Simulation results showed that the proposed scheme achieves better performance in reducing the signaling overhead, balancing traffic load among different MAPs, and improving system capacity.

In future work, efforts will be made to implement the last two extensions mentioned in Section 5.

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