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A Study on Mobile IPv6 Based Mobility Management Architecture

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Mobile IPv6 is considered to be one of the key technologies for realizing Fixed Mobile Convergence (FMC), which enables seamless communication between fixed and mobile access networks. However, the original Mobile IPv6 does not support fast handover, which is an essential function for mobile networks. One of reasons for this is that only the home agent (HA) and correspondent nodes (CNs), which are not always near to a mobile node (MN), manage an MN's mobility in Mobile IPv6. To overcome this problem, various hierarchical approaches have been proposed in the IETF. These approaches are good for achieving fast handover, however, they also sacrifice route optimization, which is one of the features of Mobile IPv6.

In this paper, we propose a novel mobility management architecture based on a hierarchical approach that can support fast handover without sacrificing route optimization. We also analyze its effectiveness in regard to the number of handover-related messages and the average handover time.

1. Introduction

Lately, there has been a tremendous increase in the demand for mobile telecommunication networks. For example, the number of subscribers to mobile telecommunication networks in Japan was 38.2 million in 1998, 47.3 million in 1999, and 56.8 million in 2000.[1)]

At the same time, the Internet is continuing its rapid expansion. The number of hosts in Japan was about 27 million in 1999 and will be about 76.7 million by the year 2005. In addition to classical text-based services (e.g., NetNews and e-mail), the WWW provides users with easy network access and voice, image, and streaming transmissions.

In the upcoming decade, many people will have personal computers and mobile terminals with a Web browsing function, and these people will want to access multimedia information distributed via the Internet. In fact, the number of users who accessed the Internet though mobile networks in Japan was already 12.7 million in 2000. Along with this expansion in demand for Internet access through wired and wireless means, Mobile IPv6[2),6),7)] is considered to be one of the key technologies for realizing Fixed Mobile Convergence (FMC), which enables seamless communication between fixed and mobile access networks.[3),9),10)] However, the original Mobile IPv6 could not achieve the fast handover required for mobile networks. One of the reasons for this is that the mobility management of Mobile IPv6 is handled only by the HA and CNs, which may be far away from the MN. To overcome this problem, various hierarchical approaches have been proposed by the IETF.[4),5),8)] These approaches are good for achieving a fast handover, however, they sacrifice route optimization, which is one of the features of Mobile IPv6. This inefficient routing mechanism causes QoS deterioration and heavy network congestion, especially in a public-scale network.

In this paper, we propose a novel mobility management architecture based on a hierarchical approach that can support fast handover without sacrificing route optimization. In Section 2, we review the original Mobile IPv6 and Hierarchical Mobile IPv6 approach and discuss some issues of these existing mechanisms. In Section 3, we explain our proposed mobility management architecture, and in Section 4 we evaluate its effectiveness in regard to the number of handover-related messages and average handover time.

2. Existing Mechanism

2.1 Mobile IPv6 overview

The Mobile IPv6 protocol is currently being specified by the IETF IP Routing for Wireless/Mobile Hosts working group. **Figure 1** shows an example operation of Mobile IPv6. Each time the mobile node (MN) moves from one domain to another, it gets a new care-of address (CoA). It then registers its binding (association between its home address and CoA) with the home agent (HA) in its home domain using Binding Update (BU) messages. The HA records this binding in its Binding Cache. The HA works as a proxy for the MN until the MN's binding entry expires or the MN returns to its home domain. The HA intercepts any packets addressed to the MN's home address and tunnels them to the MN's CoA using IPv6 encapsulations. The MN also registers its binding by sending BU messages to its correspondent nodes (CNs), which can then send packets directly to the MN. In this way, in Mobile IPv6, only the HA and CNs manage an MN's mobility. As a result, if the HA and/or CNs are far from the MN, even if the MN's movement is small, BU messages travel across several IP networks, the latencies of which reduce the handover speed. Moreover route optimization, which supports direct routing from CNs to the MN, generates many BU messages and adds a significant extra load to the network.

2.2 Hierarchical Mobile IPv6

To improve the performance of Mobile IPv6 in terms of handover speed and to reduce the number of BU messages sent to CNs and the HA, the IETF is currently discussing Hierarchical Mobile IPv6. **Figure 2** shows the basic operation of Hierarchical Mobile IPv6. A new Mobile IPv6 node called the mobility anchor point (MAP) is introduced. It simply provides an optional mobility management function that can be located at any level in the hierarchy, starting from the access router (AR) upwards. When an MN moves into a MAP domain and attaches to an AR, the MN obtains a Regional Care-of address (RCoA) on the MAP's domain and an on-link care-of address (LCoA) from the AR. Then, the MN sends a BU message to the MAP. This BU message binds the RCoA and the LCoA. The MAP records this binding in its Binding Cache. The MN also sends BU messages to its HA and CNs. These BU messages

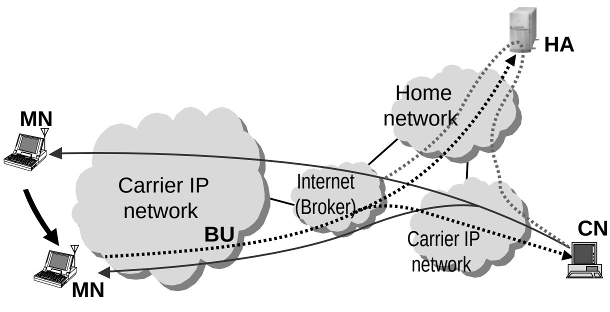


Figure 1
Mobile IPv6.

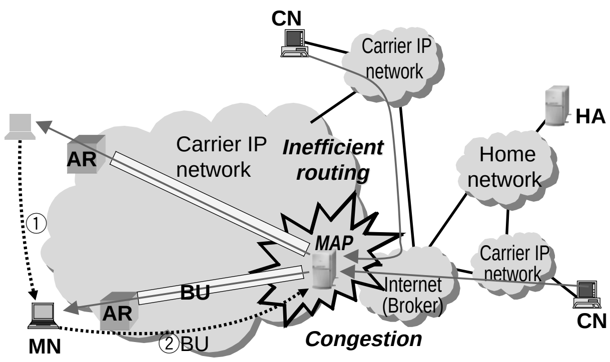


Figure 2
Hierarchical Mobile IPv6.

bind the home address of the MN and the RCoA.

The MAP works like an HA. The MAP receives packets addressed to the MN's RCoA from the HA or CNs. Packets are tunneled from the MAP to the MN's LCoA using IPv6 encapsulations. The MN decapsulates the packets and processes them in the normal way. As a result, the MNs only need to send BU messages to the HA and CNs when changing the MAP domain. Regional BU (BU to the MAP) is sufficient for an MN within a MAP domain. In this way, Hierarchical Mobile IPv6 enables an improvement in the handover speed of Mobile IPv6 and also enables a reduction in the amount of BU messages sent to CNs and the HA. However, the essential point is that in Hierarchical Mobile IPv6, packets tunnel from the MAP to the MN. This means that every packet to the MN travels via the MAP. If the MAP domain is very small, there may be no problems. However, in a large-scale public network, this inefficient routing mechanism causes QoS deteriorations and heavy node congestions, which is why Hierarchical Mobile IPv6 approaches sacrifice route optimization.

3. Proposed mobility management architecture

To overcome the above problems of the existing mobility management mechanisms, we propose a novel mobility management architecture based on a hierarchical approach which can support fast handover without sacrificing route optimization. **Figure 3** shows the basic concept of our mobility management architecture. Gateway-Edge Nodes (G-ENs) and a Temporary Home Agent (THA) are introduced. The combination of G-ENs and the THA works as a MAP of the Hierarchical Mobile IPv6. The Binding Update (BU) messages from the MN are almost the same as those of Hierarchical Mobile IPv6. When an MN moves into a THA domain and attaches to an AR, the MN gets a Temporary Care-of address (TCoA) on the THA's domain and an on-link care-of address (LCoA) from the AR (Figure 3 ①). Then, the MN sends a BU message to the THA (Figure 3 ②). This BU message binds the TCoA and the LCoA. The THA records this binding in its Binding Cache. The MN also sends BU messages to its HA and CNs if the MN has come from another carrier IP network (Figure 3 ③). These BU messages bind the home address of the MN and TCoA.

The THA works like an HA. The THA receives packets addressed to the MN's TCoA from the HA or CNs via G-EN (Figure 3 ④). Packets are tunneled from the THA to the MN's LCoA using IPv6 encapsulation (Figure 3 ⑤). The MN decapsulates the packets and processes them in the normal way. At the same time, when the G-EN receives packets addressed to the MN's TCoA from the HA or CNs, the G-ENs send a Binding Request (BR) message to the MN's TCoA (Figure 3 ⑥). The THA intercepts this BR message and registers a new binding which indicates the association between the home address of the MN and the G-ENs' addresses. The THA also sends a BU message to the G-ENs (Figure 3 ⑦). This BU message binds the RCoA of the MN and the LCoA. The G-EN records this binding in its Binding Cache. The G-ENs can then send packets directly to the MN (Figure 3 ⑧). If the MN moves within the same carrier IP network, the BU messages the MN sends to its HA and CNs are skipped.

In this architecture, a regional BU (BU to

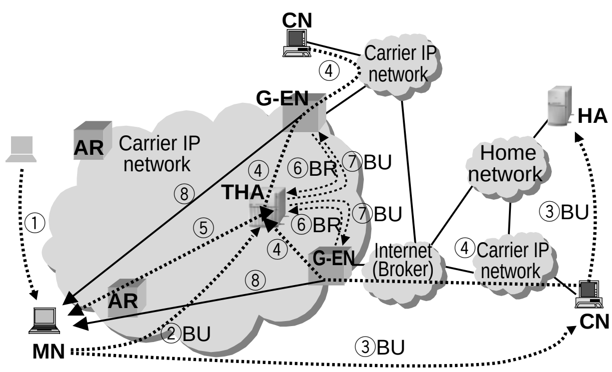


Figure 3
Proposed mobility management architecture.

the THA) is sufficient for any MN movement within our proposed network. Once an MN roams in our proposed network, the THA does not change. When the THA receives a regional BU message from the MN, the THA sends a BU message to the G-ENs. The G-ENs can then send packets directly to the MN. The MN sends BU messages to the HA and CNs only when an MN crosses the boundary of our proposed network. In this way, our proposed mobility management architecture can reduce the amount of BU messages sent to the HA and CNs and improve the handover speed of Mobile IPv6 without sacrificing route optimization.

4. Evaluation of the proposed mobility management architecture

In this section, we theoretically evaluate the performance of our proposed mobility management architecture. When evaluating the performance of a mobility management scheme, various factors have to be taken into account. Here, we evaluate two important factors in our proposal: 1) the efficiency of the hierarchical approach; that is, how much the hierarchical approach reduces the number of messages, and 2) the efficiency of route optimization; that is, how much the route optimization reduces the number of transit nodes and backbone link bandwidth.

4.1 Efficiency of the hierarchical approach.

In this chapter, we evaluate how much our hierarchical approach reduces the number of messages compared with the original Mobile IPv6. **Figure 4** shows the service area model of each AR. We assumed that each AR has a hexagonal service area and that each MN moves in a random straight direction. We also assumed that, in the original Mobile IPv6, the number of ARs in the network equals k. On the other hand, in our hierarchical approach, only when an MN crosses the boundary of our proposed network, the MN sends BU messages to the HA and CNs. The forwarding ratio to the HA and CNs of these BU messages depends on the arrangement of service areas. **Figure 5** shows an example of the relation between the arrangements of service areas and the forwarding ratio to the HA and CNs of BU messages when k equals 4. Figure 5 (a) shows the best-arrangement case, R min, where the forwarding ratio equals 7/12. Figure 5 (b) shows the worst-arrangement case, R max, where the forwarding ratio equals 9/12. The forwarding ratios of the worst and best cases, are defined as follows:

$$\mathrm{R\ max} = \frac{1}{3k}\,(2\,\mathrm{K} + 1) \qquad (1)$$

$$\mathrm{R\ min} = \frac{2x-1}{k} - \frac{1}{3k}\left\lfloor \left| \frac{3x^2 - 3x + 0.5 - k}{x-1} \right| \right\rfloor \qquad (2)$$

$$\text{where} \quad x = \left\lceil \frac{1}{2}\left(1 + \sqrt{\frac{4k-1}{3}}\right) \right\rceil .$$

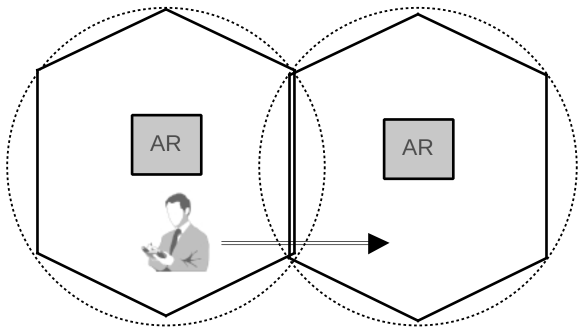
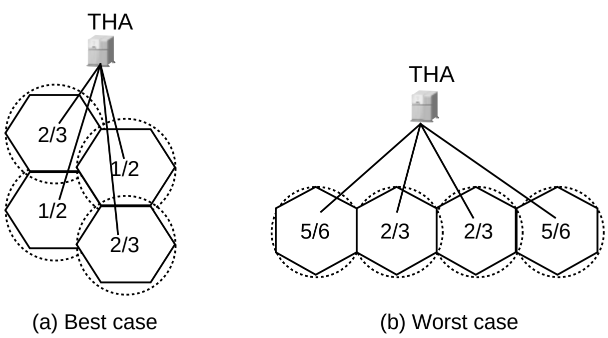


Figure 4
Service area model.



Notes: The numbers in the hexagons show the forwarding ratios to the HA and CNs.

Figure 5
Example of relation between arrangements of service areas and forwarding ratio to HA and CNs.

Figure 6 plots R max and R min as *k* varies from 1 to 24. These plots show the effect of reducing the number of messages sent to the HA and CNs. For example, when the AR number $k = 10$, the number of messages is reduced by about 30% in the worst arrangement and by about 60% in the best arrangement.

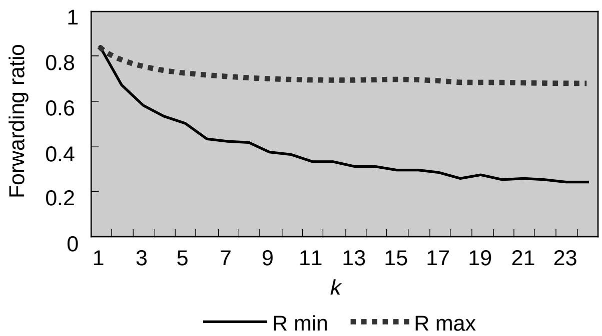


Figure 6
R max and R min.

4.2 Efficiency of route optimization

In this chapter, we evaluate how much the route optimization reduces the number of transit nodes and backbone link bandwidth compared with the existing Hierarchical Mobile IPv6. The network model that was used for this analysis is shown in **Figure 7**. The source terminal (HA and/or CNs) and the destination terminal (MN) were randomly selected from the leaf nodes (AR/G-EN).

Based on this network model, we evaluated the number of transit nodes between the source and destination. Compared with the conventional mobility management mechanism, the proposed mechanism achieves a 30% reduction in the number of transit nodes required when the distance between the source and destination terminals changes (**Figure 8**). This reduction leads to a reduced propagation delay and provides users with a high-quality service.

We also found that as the distance between the source and destination terminals increases, the proposed mechanism achieves an increasing advantage over the conventional mobility management in terms of the required bandwidth of the backbone link (**Figure 9**). For example, when the distance between the source terminal and the destination terminal is less than 4, the ratio of bandwidth reduction is more than 60%. This reduction of bandwidth makes it possible to avoid network congestion more efficiently.

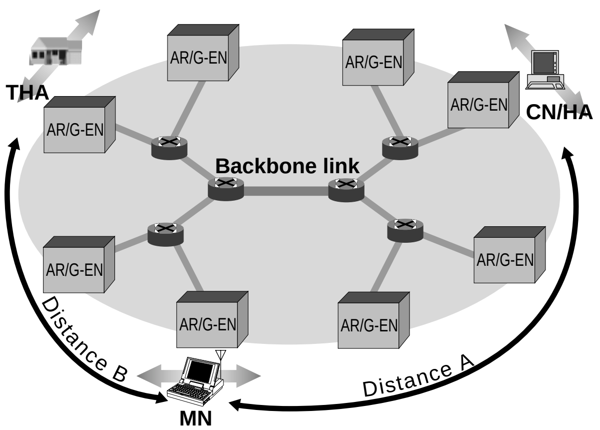


Figure 7
Network model for route optimization analysis.

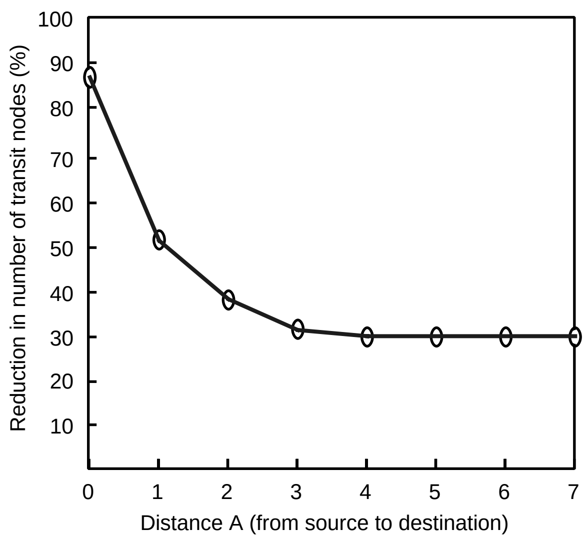


Figure 8
Reduction in number of transit nodes.

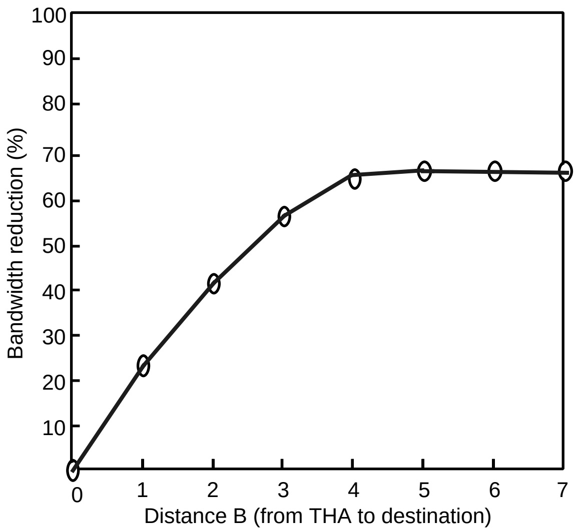


Figure 9
Reduction in required bandwidth in backbone link.

5. Conclusion

The demand for Internet access through wired and wireless access is expanding, and Mobile IPv6 is considered to be one of the key technologies for realizing seamless communication between fixed and mobile access networks. However, the original Mobile IPv6 cannot support fast handover and hierarchical approaches proposed in the IETF to support fast handover sacrifice route optimization, which is one of the features of Mobile IPv6.

In this paper, we proposed a novel mobility management architecture based on a hierarchical approach that can support fast handover without sacrificing route optimization. The HA and CNs do not require any change from the original Mobile IPv6. Our proposed scheme requires only a few minor changes to the MN from the existing hierarchical Mobile IPv6. Our scheme reduces the number of BU messages sent to the HA and CNs by between 20% and 60% compared with the original Mobile IPv6. It also reduces the number of transit nodes by more than 30% and reduces the bandwidth of the backbone link by more than 50% compared with the existing Hierarchical Mobile IPv6. This means that our proposed mobility management architecture can be used to create a large-scale mobile network that provides seamless communication between fixed and mobile access networks.

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