A distributed location management strategy for next-generation IP-based wireless networks

1 Introduction

Mobility management is a key technical aspect in mobile communication systems. The main purpose of mobility management is to enable mobile terminals or users to communicate with each other continuously while moving—while minimizing data losses and satisfying the needs of demanding low-latency, isochronous, real-time applications. The mobility management problems, including handoff, location management, paging, authentication, authorization, and accounting (AAA) and security, exist in the physical layer, link layer, and network layer of the mobile communication system[1, 2]. The traditional mobility management in current 2.5G and 3G mobile communication networks that incorporate data services (such as wideband code division multiple access (WCDMA) and code division multiple access 2000 (CDMA2000)) and public wireless local access network (WLAN) is loosely based on IP (loose and tight coupling)[3], but domain-specific protocols make it difficult to implement internetwork roaming with real-time fast and seamless handoffs. In beyond 3G, which may be the integration of multiple wireless systems, it is widely anticipated that the control and data planes will be unified over All-IP core networks. This lays the foundation for all wireless services to be integrated into a unified platform with advanced mobility control and management. At present, wireless wide area network (WWAN) data networks are being deployed using a diverse variety of radio technologies such as WCDMA, CDMA2000, and (time division – synchronous code division multiple access(TD-SCDMA), Chinese standards for 3G and beyond 3G). In future, it is expected that these networks coexist with each other. Consequently, ubiquitous access is only possible if issues such as mobility management and handoffs between these heterogeneous networks are solved. It is believed that currently researched solutions are inadequate for carrier-grade deployments.

The studies show that if convergence/integration could occur at the PHY and link layers formerly, it will be most efficient and most scalable at the IP/network layer. While the internet engineering task force (IETF) continues to work on mobile IPv6 (MIPv6)[4], it is believed that the currently used protocol cannot meet the requirements for carrier applications like voice over internet protocol (VoIP) that can only tolerate about 50 ms of latency. Earlier work on scalable network architectures like hierarchical MIPv6 (HMIPv6) [4] needs to be proven. More work is needed to enhance and integrate features such as seamless handoff, location management, and paging [5] (dormant mode host handoffs). And [6 – 12] the performance of mobile IP in cellular system has been enhanced. The proposed — hierarchical network-layer mobility management (HNMM) [13] aims to develop a comprehensive framework for IP-based mobility management that can support the integration, while meeting the needs of applications and services, which are expected to be deployed over high-speed beyond 3G carrier-grade data networks.

This article is structured as follows: The framework and characteristics of HNMM are presented in Section 2. Then the general model and main functions of HNMM are described in Section 3. Section 4 presents the signaling cost analysis of HNMM...
and gives the signaling cost comparison of HNMM with mobile IP in Ref. [14]. The conclusion is presented in Section 4.

2 Framework of HNMM

HNMM is IP-based and attempts to combine the advantages of IP mobility and the robust and efficient telecommunication network and provides high performance for the next-generation mobile Internet. The framework is based on the IP mobility, as shown in Fig. 1. By extending IP protocol, HNMM implements all the functions including location management, fast handoff, paging, and quality of service (QoS) control[15]. The mobile terminal obtains the mobility support from the embedded agent software. The mobility management agent of the network may be located in the routers, gateways, or hosts. The control messages with special format and content are exchanged between these agents and thus implement the mobility management of the mobile node (MN).

Fig. 1 Framework of HNMM

Mobility can be divided into three levels according to the geographical scope, i.e. global mobility, macromobility, and micromobility. Global mobility refers to the seamless roaming of mobile subscribers/terminals globally. Macromobility means the mobile terminals roam between different subnets or wireless communication systems, e.g. WLAN and WCDMA. And micromobility refers to mobility management across two radio access entities—for example, base stations or access points. And mobile IP may never solve the macro- and micromobility problem efficiently. So HNMM aims to be an optimal macro and micromobility management framework, incorporating layer-2 mobility management, as needed.

The following were the design goals when the HNMM framework was studied:

1) A framework (combining notions of hierarchy and redundancy) that is truly robust, scalable, and capable of spanning heterogeneous wireless networks, each of which may in turn incorporate heterogeneous wireless links within its infrastructure.

2) A framework that takes advantage of the trend to move away from high-cost dedicated infrastructure interconnections such as frame relay—to lower-cost, fully interconnected meshes of IP routers.

3) A framework that incorporates layer-2 abstracted mobility triggers and presents a uniform interface enabling services such as location management.

The entire network can be abstracted as a three-level structure including wireless access, edge access, and core transportation, which is very similar to the real deployment of an IP network. In fact, this structure can be considered a real operation network.

The functions of each entity in the model are described as follows:

a) Mobility management agent (MMA)

MMA is located in a radio access router on the hop between MN and MMA. MMA obtains more information than other entities because of its special position. Generally, MMA does not control the MN’s mobility, but acts as a popular access router. In the process of MN handover, MMA will buffer and forward the packets to the new MMA. MMA can also support domain self-organized scheme to reduce the location update signaling costs caused by handover.

b) Region mobility management agent (RMMA)

RMMA is another important entity in HNMM. In fact, RMMA is the visit location register (VLR) of MN. RMMA performs the function of region management for MN, including signaling analysis, location management, and hand-over management. And RMMA also responds to the initialization of paging. RMMA records temporary information of MN, including regional care of address (RCoA), local care of address (LCoA), roaming history of MN, and the information of MMAs in the domain.

c) Home mobility management agent (HMMA)

HMMA is the home location register (HLR) of MNs and records all the basic information of all the MN managed by the HMMA. Also the first packet sent to MN from correspondent node (CN) will arrive at HMMA and be forwarded to the RMMA, to which the MN belongs. Also, HMMA will store the historical record of the information on the location of the MN, which is very helpful for effective paging strategies. Thus, the data stored in HMMA include the current location of MN, MN profile, and historical location record. Also HMMA will be connected to authentication center (AuC) to complete the user and security management.

d) Terminal mobility agent (TMA)

TMA is located in the MN and its functions include location
management, paging, handover control, radio resources management, etc. TMA is compatible to mobile IPv6. MN can select mobility management protocol between mobile IPv6 and HNMM depending on the network. When the access networks support HNMM, MN can select HNMM as its location management protocol. Otherwise, MN will act as a popular mobile terminal with MIPv6 support. With TMA, the MN obtains better support in fast and seamless handover, multi-tier function, and location.

3 Distributed location management model

In HNMM, the attachments between TMA and MMA, MMA and RMMA can be dynamically changed. In the case of overlapped coverage by more than one MMA, the TMA in the MN can itself select the MMA that it attaches to depending on the QoS requirements of the applications in the MN. MMA can itself select the RMMA that it attaches to when the following three cases occur.

The first case is that the MMA currently attached to the MN is unavailable and MN has to change its RMMA.

The second is that MMA finds that there exists very frequent handoff process between it and one of its neighboring domains. So this domain can request to attach to the RMMA, which the neighboring domain is now attached to. Thus, the interdomain handoff changes to intradomain handoff and the signaling cost can be reduced and handoff performance also can be enhanced. Fig. 2 shows the domain self-organized case. MMA obtains the handoff frequency of its neighboring domain by statistic.

The third case is that RMMA1 can send “domain change request” to MMA and notify it to change its attached RMMA2 when the traffic load in RMMA1 is very high, while being low in RMMA2, so that the load can be balanced.

The signaling cost model is shown in Fig. 3. The factors that influence the location management signaling cost in HNMM include the structure of location management system, hops between the message sender and receiver, the frequency of location update, number of users in location area, size of the location area, and the moving speed of the user, etc.

![Fig. 2 Domain self-organized](image)

For simplicity, the signaling cost between HMMA, RMMA, and MMA is ignored because of the wide band link between them and low-frequency update. The main cost centers on signaling are attributed to the messages between MN and MMA, RMMA, HMMA, CN, respectively.

So the cost caused by single MN is

$$C = (H_c + wH_w)[r_H + r_u]$$

Here $H_c$ is the number of hops in wire links; $H_w$ is the number of hops in wireless links; $w$ is the weight of each hop in wireless links; $r_H$ is the handoff rate of MN; $r_u$ is the update rate of MN for its lifetime in other nodes.

It is assumed that the cell and location are hexagonal in shape. The length of side is $1$. $n$ is the number of cells in an RMMA area. MN moves at an average velocity of $v$ in directions that are uniformly distributed over $[0, 2\pi]$. MN is uniformly distributed with density $\rho$. So the cell boundary handoff rate $R_H$ is

$$R_H = \int_0^{\pi} \frac{v\rho \sin \theta}{2\pi} d\theta = \frac{v\rho}{2\pi} \int_0^{\pi} \sin \theta d\theta = \frac{v\rho}{4\pi}$$

Then the signaling cost in a RMMA area caused by MNs is

$$C_s = n(H_c + wH_w)[r_H + r_u] = n(H_c + wH_w)\left[\frac{\rho v l}{4\pi} + \rho \frac{3\sqrt{3}}{2} r_u^2\right]$$

(3)

Generally, there is only one hop in the wireless networks. So the signaling cost of the network using MIP as its mobility protocol is

$$C_{s-MIP} = n(H_c + w)\left[\frac{\rho v l}{4\pi} + \rho \frac{3\sqrt{3}}{2} r_u^2\right]$$

(4)

In HNMM, the intradomain handoff just causes the location update in RMMA. Then the cost of HNMM is

$$C_{s-HNMM} = (H_c + w)\left(\frac{\rho v l}{4\pi} + (1 + w)np \frac{3\sqrt{3}}{2} r_u^2\right)$$

(5)

Considering the cost caused by paging, the cost will be
modified as given in Eq. (6).

\[
C_{op-HNMM} = (H_c + w) \frac{\rho vl^{(n-1)}}{4\pi} + \rho \frac{3\sqrt{3}}{2} l^{(n-1)} (1-\alpha) (\lambda_n + \lambda_{out}) + (n-1)(1+w) \cdot \\
\rho \frac{3\sqrt{3}}{2} l^{(n-1)} (1-\alpha) \lambda_n + \lambda_{out} = (H_c + w) \left[ \frac{\rho vl \sqrt{n}}{4\pi} + \alpha \frac{\rho vl}{4\pi} (n-\sqrt{n}) + \\
\rho \frac{3\sqrt{3}}{2} l^{(n-1)} (1-\alpha) (\lambda_n + \lambda_{out}) \right] + (n-1)(1+w) \cdot \\
\rho \frac{3\sqrt{3}}{2} l^{(n-1)} (1-\alpha) \lambda_n
\]

(6)

Here \( r_p \) is the handoff rate between location areas; \( \alpha \) is the ratio of active MN to total number of MNs; \( \lambda_n \) is the incoming packets rate for MN; \( \lambda_{out} \) is the outgoing packets rate for MN.

The costs caused by MN's update for its lifetime to CN and HMMA are relatively unchanged and do not influence the comparison between different mobility management protocols and thereby can be ignored temporarily. The Eq. (4) changes to

\[
C_{op-MIP} = n(H_c + w) \frac{\rho vl}{4\pi}
\]

(7)

Eq. (6) changes to

\[
C_{op-HNMM} = (H_c + w) \left[ \frac{\rho vl \sqrt{n}}{4\pi} + \alpha \frac{\rho vl}{4\pi} (n-\sqrt{n}) + \rho \frac{3\sqrt{3}}{2} l^{(n-1)} (1-\alpha) (\lambda_n + \lambda_{out}) \right] + (n-1)(1+w) \rho \frac{3\sqrt{3}}{2} l^{(n-1)} (1-\alpha) \lambda_n
\]

(8)

Considering the domain self-organized strategy, the low rate update between RMMA and MMA also can be ignored, and the cost can be defined as:

\[
C_{wp} = (H_c + H_w) [\rho_{sat} r_p + \alpha (nr_n - r_p)] + \\
\rho \frac{3\sqrt{3}}{2} l^{n-1} n_r + \rho \frac{3\sqrt{3}}{2} l^{n-1} (1-\alpha) (\lambda_n + \lambda_{out}) + \\
(n-1)(1+w) \rho \frac{3\sqrt{3}}{2} l^{n-1} (1-\alpha) \lambda_n
\]

(9)

Here \( \rho_{sat} \) is the enhancement coefficient and set \( H_c = 16 \), \( \lambda_n = \lambda_{out} = 0.000 \text{ s}^{-1} \), \( \alpha = 0.05 \).

In the following two scenarios (shown in Table 1), the numerical results are shown in Figs. 4 and 5.

In Fig. 3, the signaling cost of HNMM is considerably lesser than that of MIPv6. Even when the user density is twice that of the MIPv6, HNMM's cost is still lesser than that of MIPv6 when the number of cells is less than 200. From Fig. 4, it can be seen that the cost of HNMM with user speed 30 m/s is lesser than that of MIP with user speed 10 m/s when the number of cells is less than 150. Also it can be drawn from Fig. 5 that the cost performance of HNMM is also better than that of MIP when the perimeter of the cell changes from 1 km to 4 km.

### Table 1 The parameters of A and B scenario

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Param.</th>
<th>( \rho ) (m/s)</th>
<th>( V ) (m/s)</th>
<th>( L ) (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8</td>
<td>0.000</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>0.000</td>
<td>10 vs. 30</td>
<td>1</td>
</tr>
</tbody>
</table>

4 Conclusions

The hierarchical structure of HNMM can considerably reduce the cost caused by the mobility of mobile node. The
location information distributes among HMMA, RMMA, and MMA and thereby provides a flexible and robust location management framework, whereas Mobile IPv6 and HMIPv6 may fail when the foreign agent (FA) or mobility anchors point (MAP) is at fault. Combining the advantages of hierarchical structure and distributed system, HNMM can support high-performance mobility management in large mobile Internet.

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References

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