A SEAMLESS HANDOFF APPROACH OF MOBILE IP PROTOCOL FOR MOBILE WIRELESS DATA NETWORKS

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ABSTRACT

With recent advances in wireless communication technology, mobile computing is an increasingly important area of research. Enabling mobility in IP networks is a significant issue for making use of many portable devices appearing on the Internet. The IP mobility support being standardized in the IETF utilizes tunneling of IP packets from a Home Agent to a Foreign Agent to make the mobility transparent to the higher layer. In this paper, we propose an approach to optimize routing path and avoid triangular routing problem in IP mobility, which is an extension of Mobile IP architecture. We propose an efficient handoff scheme in which a routing table, called Mobile Routing Table (MRT), is designed in each edge router such as Home Agent, Foreign Agent and general router. In addition, a packet retransmission scheme is also proposed to reduce the packet loss during handoff. We analyze and compare both the standard Mobile IP and the proposed seamless handoff approach. Finally, the simulation results are presented.

Keyword: *Internet, Mobile Wireless, Network, Handoff, Roam, IP Mobility Management Protocol, Mobile IP, Home Agent, Foreign Agent, Mobile Node, Mobile Routing Table*

I. INTRODUCTION

Wireless networks are rapidly evolving from actual 2G cellular telephony networks to 3G and beyond. Following the drastically expanding markets of cellular phone network and Internet services today, mobile high-bandwidth data communications are now becoming the next candidate of new targeting business. The current IP protocol version 4 (IPv4) [1] brings this world into the "Net-Era" stage. Both data and voice communications rely increasingly on IP-based techniques [2][3]. These trends are motivating a great deal of interest in making sure that these new all-IP systems allow end users to handoff within wireless access networks or roam between these networks while providing efficient data transfer services and seamless connectivity with the Internet or any other network. All-IP wireless networks are networks where IP is used end-to-end, from the mobile end-user station to a gateway connecting the wireless network to the Internet. To allow these evolutions, IP must obviously evolve to support users mobility [4]. Thus, a protocol that cannot support mobility is useless for the future networks.

IP mobility [4] working on OSI layer 3 is intended to provide mobile hosts with Internet connectivity when they are away from their home network to a visiting network. Internet Engineer Task Force (IETF) formed the IETF Mobile Working Group to draw up a standard of mobility support for IPv4, called Mobile IP [5]. Mobile IP technique, as shown in Fig. 1, is the most common solution for offering seamless roaming to mobile devices in the Internet. There are a number of problems associated with Mobile IP, such as triangular routing, each host needing a home IP address and a temporary unfixed address, tunneling management, etc. [6]-[9].

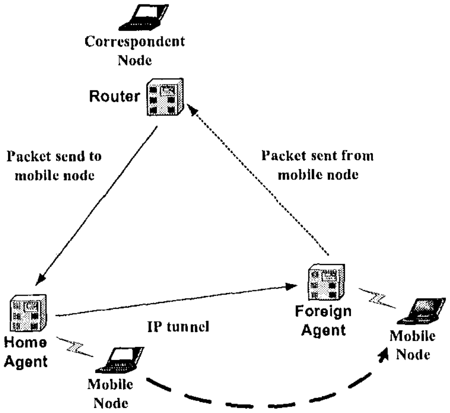

Fig. 1. A high-level picture of Mobile IP protocol. An inefficient datagram flow, called triangular routing problem, exists in the protocol.

For solving the so-called triangular routing problem shown in Fig. 1, route optimization [10] is proposed by using binding update to inform the correspondent node its current IP address for the mobile node. However, route optimization technique has several drawbacks [8][9]. The objectives of the

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new handoff mechanism are to reduce packet loss and handoff latency. Accordingly, in this paper we aim to propose a seamless handoff mechanism to modify Mobile IP protocol so that it may perform handoff smoothly and fast.

Following the introduction in Section I, the remaining of this paper is organized as follows. Section II gives an overview of Mobile IP protocol. Section III presents the proposal of a seamless handoff approach. Section IV shows the simulations and the experimental results. Finally, a conclusion is presented in Section V.

II. OVERVIEW OF MOBILE IP

In this section, we give the overview of Mobile IP protocol. Providing data services to end users with mobile stations to mobile wireless networks poses a large set of problems that are totally new with respect to standard wired networks. Several all-IP based protocols for mobility management have been investigated [4]. Mobile IP (abbreviate MIP) [5] was first proposed to support user host mobility on the Internet. It is useful in host roaming at layer 3. It is believed that MIP is the oldest and probably the most widely known mobility management proposal. Generally, MIP is most useful in environments where a wireless technology is being utilized. This includes cellular environments as well as wireless LAN situations that may require roaming. MIP has been designed with the IETF to serve the needs of the burgeoning population of mobile computer users who wish to connect to the Internet and maintain communications as they move from place to place. In recent literature, several solutions have been proposed to support IP mobility [4]-[9]. In the following, we describe MIP protocol in some details. We will begin with introducing the main components of MIP and describe afterwards the basic five operations of MIP. The problems of MIP are presented to finalize this section.

A. Main Components of MIP

We assume that a *Mobile Node* (or *Mobile Host*) is attached to a wireless access network. It can be, for instance, the network of the wireless access provider to which the mobile node is registered. This network is called the mobile node *Home Network* and the address of the mobile node in this network is its *Home Address*. Every other wireless access network at which the mobile node can connect is called *Foreign Network* and the network at which a mobile node is currently connected is called *Visited Network*.

The basic concept of Mobile IP is described as follows. Each MN must have a Home Address in its Home Network. When visiting any network away from home, each MN gets a temporary local address, called *Care-of Address (CoA)*, on the visiting network. The MN registers with its home agent in order to track the MN's current IP address. Thus, in MIP proposal there are a couple of IP addresses associated with each MN to manage users movements, one for identification, the other for routing. The association between the current CoA and the Home Address of the MN is maintained by a mobility binding. Based upon the concept, Mobile IP defines some functional components [5]:

Mobile Node (MN)

A host that changes its point of attachment from one network or subnet to another is called the *Mobile Node (MN)*. The MN may change its location without changing its IP address (i.e., home address) assigned in the home network's address space. It may continue to communicate with other Internet nodes at any location using its home IP address, assuming link-layer connectivity to a point of attachment is available.

Home Agent (HA)

A router on an MN's home network is called the *Home Agent (HA)* that maintains current location information for the MN and tunnels datagrams for delivery to the MN when it moves away from home network.

Foreign Agent (FA)

A router on an MN's visited network is called the *Foreign Agent (FA)* that provides routing services to the MN while registered with the HA. The FA de-tunnels and delivers datagrams to the MN that were tunneled by the MN's HA. For datagrams sent by an MN, the FA may serve as a default router for registered MNs.

Correspondent Node (CN)

A peer with which a mobile node communicates is called the *Correspondent Node (CN)*. A CN may be either mobile or stationary. If the node is mobile, it transmits and receives the packet via its HA. However, if the node is stationary, it transmits and receives the packet via a traditional IP router that has no mobility management capabilities.

B. Basic Operations of MIP

In this section, we briefly investigate the basic operations of the standard MIP. A high-level picture of Mobile IP protocol is shown in Fig. 1. Mobility agents (HA or FA) advertise themselves on the local network by periodic *Agent Advertisement* messages; these beaconing packets enable an MN to acquire the IP address of the network it attaches.

If an MN is on its home network, it sends and receives the packets according to the conventional IP mechanisms. When moving away from its home network, each MN gets a *CoA* on the foreign network, which may be either *Foreign Agent CoA* assigned by the FA or *collocated CoA* assigned by using Dynamic Host Configuration Protocol (DHCP). After having obtained the CoA, the MN sends a *Registration Request* to inform its HA of its current location. A

Registration Reply message is sent back by the HA to acknowledge the *Binding Update*.

After a successful registration, the HA will begin to attract the packets destined for the MN and tunnel them to the new CoA. The packets destined to the MN's home address are intercepted by its HA, encapsulated with the FA's address, tunneled by its HA to the CoA, received at the tunnel endpoint which may be the MN itself or the FA, and finally decapsulated and delivered to the MN.

In reverse transmission direction, the packets sent by the MN are normally routed to its destination using the conventional IP routing mechanism, not necessarily passing through the HA.

Although the packets sent from the CN and destined to the MN must pass through the HA when the MN is away from home, the packets from the MN to other stationary Internet nodes can still be routed directly to their destinations. This asymmetric routing as shown in Fig. 1, called *triangular routing problem*, is generally far from optimal, especially in cases when the CN is very close to the MN. Therefore, Mobile IP with route optimization (ROMIP) [10] was proposed to solve the triangular routing problem in the standard Mobile IP. According to the hosts cache address bindings method in ROMIP, whenever an address binding is cached (called *Binding Update*), the packets addressed to that particular host are tunneled directly bypassing the destination HA intervention.

In summary, the following are the five main operations in the standard MIP and ROMIP proposals in which the operations *Mobile Agent Discovery*, *Registration*, and *Tunneling* are part of the standard MIP proposal while the operations *Binding Update* and *Foreign Agent Smooth Handoffs* are related to ROMIP proposal.

Mobile Agent Discovery. Mobile Agents (Home Agent and Foreign Agent) advertise their presence via *Agent Advertisement* messages. The source IP address in the advertisement message is used by MNs to determine if they are still linked to the home network. If the network-prefix of the source address in the IP header of the advertisement message is equal to the network-prefix of the MN's home address, then the MN decides that it is still linked to its home network. Otherwise, the MN assumes that it is not linked to its home network and moves to a foreign network, and thus proceeds to get a CoA from the FA at the visited network.

Registration. Registration is the process by which an MN requests routing services from an FA on a foreign network, informs its HA of its current CoA, renews a registration which is due to expire, and deregisters with the HA when it returns to its home network. The registration process consists of an exchange of a *Registration Request* message and a *Registration Reply* message between an MN and its HA, possibly by involving an FA. It is of importance that the registration in Mobile IP must be made secure so that fraudulent registrations can be detected and rejected. The default authentication method in Mobile IP is keyed MD-5 algorithm.

Tunneling. Tunneling is the mechanism by which the HA forwards the packets to the MNs. Using this mechanism, the IP packets are placed within the payload part of new IP packets, and the destination address of the encapsulating (outer) IP header is set to the MN's CoA. Upon reception of each IP packet, the FA decapsulates it by removing the outer IP packet and sends the original packet to the MN. Two ways of encapsulation are suggested: IP Encapsulation within IP by IETF RFC 2003 [11] and Minimal Encapsulation within IP by IETF RFC 2004 [12].

Binding Update. In the absence of any binding cache entry, the packets destined to an MN will be routed to the MN's home link in the same way as any other IP packet and then tunneled to the MN's current CoA by the MN's HA. If the CN had a binding cache entry for the MN, it would be able to send packets directly to the MN without the services of the HA. Any node may maintain a binding cache to optimize its communication with an MN. A node may create or update a binding cache entry for an MN only when it has received and authenticated the MN current location. Each binding in the cache also has an associated lifetime period. After the expiration of this time period, the binding is to be deleted from the cache. A node can use any reasonable strategy for managing the space within the binding cache. The HA sends a *Binding Update* message to those CNs that need them and the *Binding Acknowledgement* message is used to acknowledge the reception of binding update message. Securing the binding update is also an important issue. Whenever a binding update is transmitted, it has to be accompanied by an authentication extension.

Foreign Agent Smooth Handoffs. This operation is useful to define a smooth handoff mechanism when an MN moves away from one foreign network to another (i.e., changing FA). During registration with the new FA, the MN requests the new FA to send a *Binding Update* message to the previous FA. This node will then be able to re-tunnel the packets destined to the MN. This will reduce the number of packets lost and speed up the CN's binding cache entries update process.

C. Problems in MIP

One of the challenges, in keeping connection with the Internet as a mobile user roams, is to provide multiple real-time services while also achieving high quality of service support. However the standard Mobile IP proposal has a triangular routing problem with a mobile user roaming from the HA to the FA. This problem causes longer packet transmission time while the handoff process results in packet loss.

Some methods, such as route optimization [10] and Mobile IPv6 [13], are proposed to solve this problem and design a smooth handoff. The former method needs to implement a binding cache for MIPv4 in each MN and CN. This is very difficult, even infeasible. For the latter method, the route optimization is mandatory. However, most nodes still use IPv4 rather than IPv6 in the world nowadays or in the near future. Therefore, it is still worth to investigate the handoff problem in IPv4. The main goal of this paper is to propose a new route optimization scheme to solve the triangular routing problem in MIPv4, and then to design a seamless handoff approach.

III. A SEAMLESS HANDOFF APPROACH

In this section, we present a seamless handoff approach of MIP protocol. Having identified the problems of MIP, we will propose our seamless handoff approach based on a new route optimization scheme presented below. Most of the operational elements of our approach have functionality similar to the standard MIP. In addition, our approach whose architecture is shown in Fig. 2 designs a special address-mapping table, called mobile routing table (MRT), in each mobile agent. With this special structure, it is advantageous to apply our route optimization scheme to both IPv4 and IPv6 to design a seamless MIP handoff approach.

In the standard MIP, the HA maintains an IP address-mapping table that records the mapping relationship between the home addresses of all MNs and the associated CoAs. In MIP with route optimization, except the table in the HA, each node, which may be either the CN or the MN, must maintain a binding cache in itself. The cache is also used to record the CoA associated with the MN communicating with the node. With this scheme of using binding cache, the CN may send the packet directly to the MN, rather than forward it via the HA.

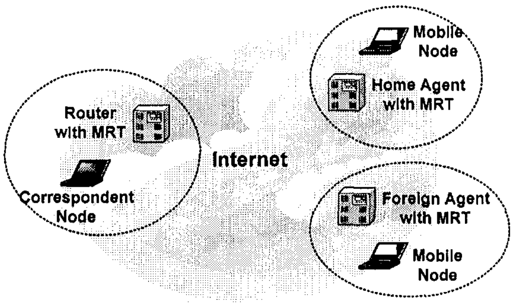

Fig. 2. Architecture of Mobile IP with MRT.

However, it is impossible to implement a binding cache in all of the nodes within the entire Internet. If we may construct an MRT in each mobile agent (including the HA, FA, and router), as shown in Fig. 2, instead of the binding cache in each node, the binding cache in each node may be removed. As a result, any MN may link to any network on the Internet, even without a binding cache.

A. Mobile Routing Table (MRT)

The MRT actually is an extension of the traditional address-mapping table used in the standard MIP for recording the CoAs of the MNs, maintained by the HA, FAs and Routers for use in tunneling the packets from the CN to the MN, no matter how stationary or mobile the CN is. Fig. 3 shows the structure of the record in the MRT. Each record is associated with an MN. Each record consists of four fields: field 1 represents the home IP address of the MN, field 2 represents the current CoA of the MN, field 3 is the V-Flag, and field 4 records the so-called *Last Elapsed Time (LET)*. The V-Flag is a 1-bit flag that records whether an MN is in its home network or in a foreign network at present. V-Flag="0" indicates that the MN is in its home network while "1" indicates the MN in the foreign network. The LET field records the instant when the last packet in a transmission session between the MN and the CN passes through the agent. An example of the MRT is shown in Table 1. The empty CoA field means the associated MN is in its home network at present.

Field 1	Field 2	Field 3	Field 4
Home Address	CoA	V-Flag	LET

Fig. 3. Structure of record in the MRT.

Table 1. Example of the MRT.

Home Address	CoA	V-Flag	LET
140.134.28.17	140.134.30.23	1	2830
140.134.28.3	-	0	2847
140.113.2.14	163.22.2.250	1	2816

Each MN or CN may operate in one of two states: active or idle. A node is in the active state means that it is transmitting the packets to some other node. On the other hand, it goes into the idle state as no packet transmission proceeds for a period of time. Notice that if the V-Flag value is "0," the MN always is in the active state. If a node is in the active state, characterized by the flow of downstream/upstream user traffic, it is necessary to keep its record in the associated MRT. In this system, we define a time threshold, called *Active State Timeout (AST)*, which is the time difference between when the MN goes into the idle state and when the packet transmission terminates. In other words, the AST corresponds with the lifespan period of a record, associated with an MN, existing in the MRT. The state transition diagram, shown in Fig. 4, describes the conditions of state exchange between active and idle.

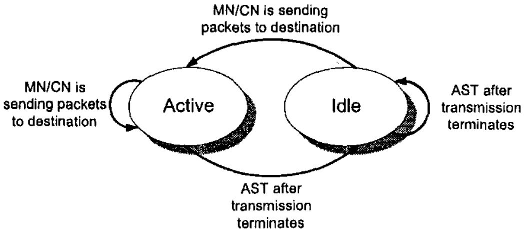

Fig. 4. The state transition diagram. Each node within the network is in either active state or idle state.

B. MRT Registration/Update Process

In the MRT scheme, there are three types of messages used to manage binding cache entries, including:

(1) *MRT Registration*: An MRT Registration message is sent by the MN to the FA and the FA forwards it to register the HA the MN's new CoA.
(2) *MRT Update*: An MRT Update message is sent by the HA to the associated FA/Router of the CN to inform them of the MN's current CoA.
(3) *MRT Acknowledgement*: Upon receiving the MRT Registration message from the MN to the HA or the MRT Update message from the HA to the FA/Router, an MRT Acknowledgement message will be returned by the HA to the MN or by the FA/Router to the HA to inform that they have successfully received the MRT Update or Registration message.

Each of these messages begins with a one-octet field indicating the type of the message. The beacons of the MRT messages in this scheme are transmitted by using the UDP protocol.

The flow chart of the MRT registration/update process is shown in Fig. 5. The process is stated as follows. Once an MN changes its point of attachment, the MRTs in the HA and the associated FA/Router of the CN must be simultaneously updated. While away from home, an MN registers each new CoA with the HA. This MRT registration process is done by sending an "*MRT Registration*" message from the MN to the HA. Then the HA replies an "*MRT Acknowledgement*" message to the MN if it received indeed the MRT Registration message. Meanwhile, the HA informs the associated FA/Router of the CN to update its MRT by sending an "*MRT Update*" message. The FA/Router also replies an "*MRT Acknowledgement*" message to the HA.

In order to keep the table size adequately, the MRT must be refined periodically. The refinement frequency may be preset appropriately in the system. The refinement operation is accomplished by deleting some records that the associated MNs go into the idle state by checking the LET field. The deletion criterion is as follows. If the V-Flag value is "0," the MN always is in the active state and the associated record will be kept in the MRT. If the time difference between the current time and the LET is greater than the AST, then this record is deleted.

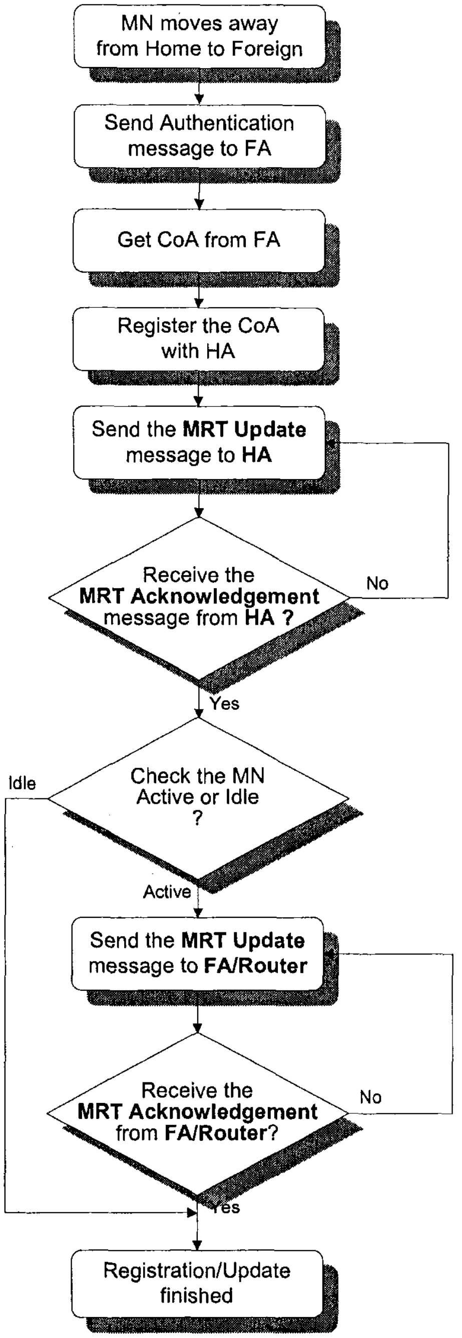

Fig. 5. Flow chart of the MRT Registration/Update process.

C. Operations in the MRT

When each upstream packet is going to be sent out through its agent (possibly the HA, FA, or Router), the agent first searches its MRT to learn whether the destination's IP address exists or not. If not, the node with the destination's IP address may be a fixed node or an MN which is newly connected with the node, and thus the packets will be sent via an optimal path by using the IP routing protocol. On the other hand, the packets are sent out to the current CoA of the node, stored in field 2 of the associated record.

The MRT is also useful as the packets are transmitted into the network from the Internet. Intercepting a packet from the Internet, the HA first searches its MRT to learn whether the destination's IP address exists or not. If not, the HA will discard this packet since it judges the IP address wrong. If the destination's address exists in the first field of the HA's MRT, then again the HA checks the V-Flag field. If the V-Flag value is equal to "0," the MN is in the home network now and the packet will be delivered to the MN directly. If the V-Flag value is equal to "1," the MN is in the foreign network now and the HA tunnels the packet to the MN's CoA, and finally send an "*MRT Update*" message to the FA/Router to update its MRT.

D. The Proposed Handoff Scheme

Now we describe in some details the operation flows of: 1) the packet transmission from the CN to the MN (denoted by **CN→MN**); 2) the packet transmission from the MN to the CN (denoted by **MN→CN**); and 3) the **inter-network handoff** (or **MN roaming**). For simplicity and clarity, we summarized the operations of the standard Mobile IP and our seamless MIP with MRT scheme as follows. Notice that the symbol "∗" stands for the original standard Mobile IP and the symbol "◇" is our seamless Mobile IP with MRT.

(1) CN→MN:

∗ The CN sends the packet to its FA/Router.

◇ The FA/Router searches its MRT to learn whether the destination's IP address exists or not. If yes, tunnel it to the CoA and go to the final step. If not, the packet is sent directly to its destination's IP address.

∗ The HA intercepts this packet sent from the FA/Router.

◇ The HA searches the destination's IP address in its MRT. If not, the HA discards this packet.

◇ If the destination's IP address exists in the HA's MRT, then again the HA checks the associated V-Flag field. If V-Flag= "1," the HA tunnels it to the MN's FA via the current CoA. Otherwise, the HA delivers it to the MN.

◇ The HA also sends the "*MRT Update*" message to the FA/Router of the CN.

◇ Upon receiving the "*MRT Update*" message, the FA/Router of the CN updates its MRT.

◇ The FA/Router then replies an "*MRT Acknowledgement*" message to the HA.

◇ According to the newly extracted CoA from the FA/router's MRT, the following packets are sent directly to the MN's new CoA.

∗ Upon reception of this packet, the FA decapsulates it and forwards to the MN.

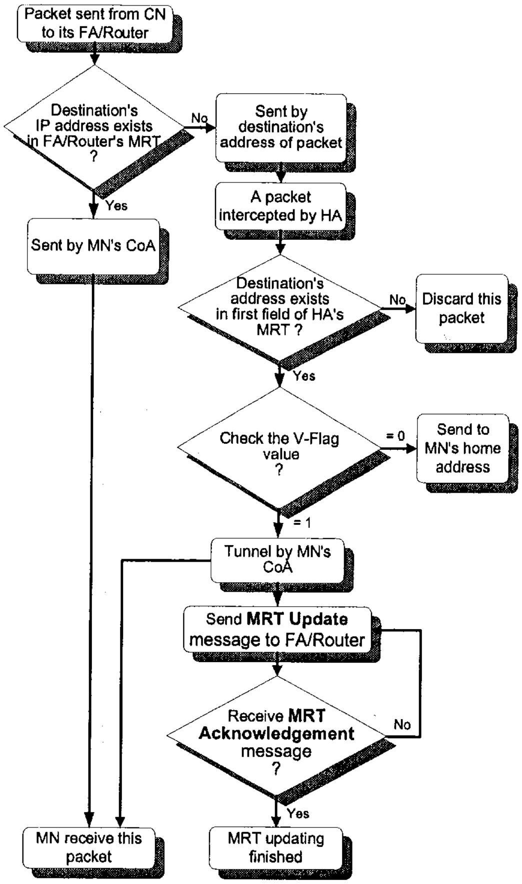

Fig. 6. Flow chart of **CN→MN** process.

The flow chart of **CN→MN** process is shown in Fig. 6 in detail. Following the flow chart, the message sequence chart of **CN→MN** is also depicted in Fig. 7.

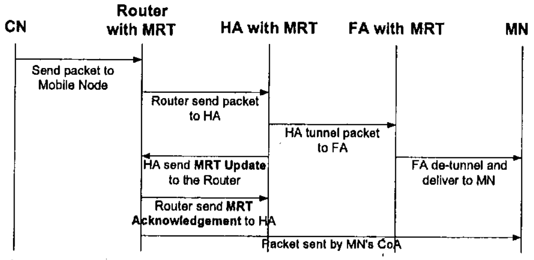

Fig. 7. The message sequence chart of **CN→MN** process.

(2) MN→CN: (The flow chart is shown in Fig. 8)

∗ The MN sends the packet to the CN.

- ∗ The packet routes to its agent.
- ◇ The agent searches its MRT to learn whether the destination's IP address exists or not. If yes, the packet is sent via the CoA of the CN and the procedure stops. Otherwise, go to the next step.
- ∗ The packet routes to the CN with the destination's IP address by using the IP routing protocol.

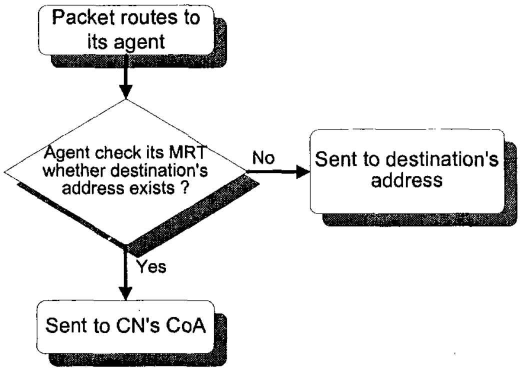

Fig. 8. Flow chart of **MN→CN** process.

(3) **MN Inter-Network Handoff:**

- ∗ When the MN roams into new coverage, it gets a new CoA from the FA of the visiting sub-network after authentication by the HA.
- ∗ The MN registers the new CoA with the HA.
- ◇ The MN sends the "*MRT Registration*" message to the HA.
- ◇ The HA sends the "*MRT Update*" message to the FA/Router of the CN to update its MRT.
- ◇ The FA/Router of the CN replies the "*MRT Acknowledgement*" message to the HA.
- ◇ The HA replies the "*MRT Acknowledgement*" message to the MN.

The message sequence chart of the inter-network handoff process is depicted in Fig. 9.

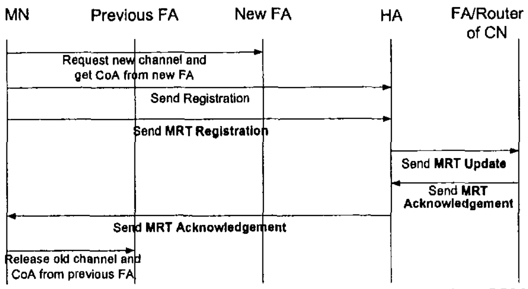

Fig. 9. The message sequence chart of the **MN inter-network handoff** process.

E. Packet Retransmission Mechanism

To achieve a smooth handoff (i.e., no packet loss), we propose a "packet retransmission" scheme to avoid packet loss during handoff. For a packet retransmission mechanism, every agent must have a buffer to store downstream packets that will be retransmitted to the MN. The architecture of the proposed packet retransmission mechanism is shown in Fig. 10.

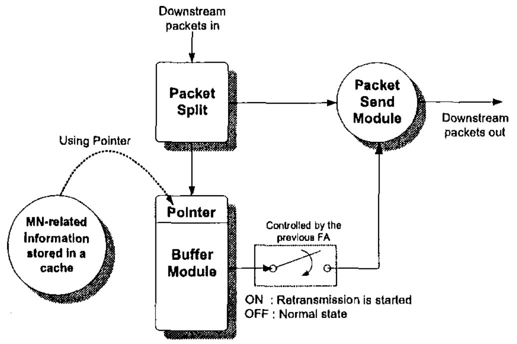

Fig. 10. Architecture of agent's buffer in the packet retransmission mechanism.

After the MN handoff, the previous agent will retransmit packets stored in its buffer to the new agent. Upon receiving those packets, the new agent delivers them to the MN. The message sequence of the handoff process with the packet retransmission scheme is demonstrated in Fig. 11 and the procedure is described as follows.

- ∗ When the MN moves into a new foreign network, it gets a new CoA from its FA.
- ∗ The MN registers the new CoA with the HA.
- ◇ The MN sends the "*MRT Registration*" message to the HA.
- ◇ The HA sends the "*MRT Update*" message to the FA/Router of the CN to update its MRT.
- ◇ The FA/Router of the CN replies the "*MRT Acknowledgement*" message to the HA.
- ◇ The HA replies the "*MRT Acknowledgement*" message to the MN.
- ◇ The MN informs the previous FA to release resource.
- ◇ The previous FA retransmits the packets stored in the buffer to the MN via the new CoA.

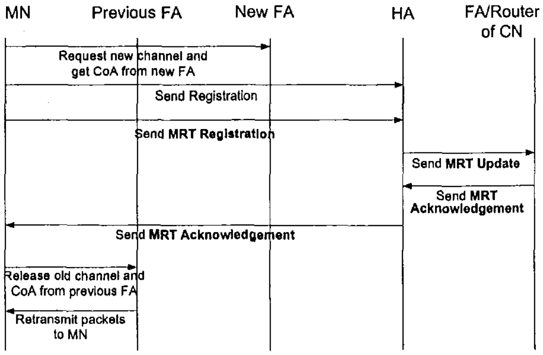

Fig. 11. The message sequence chart of the MN handoff with packet retransmission.

IV. SIMULATION AND RESULTS

In this section, we present a simulator that is implemented by using C language to evaluate the performances of the standard MIP system and our Mobile IP system. The comparisons between them are also presented. In this simulated network, five components, including the HA, FA, Router, CN and MN, are designed. The network architectures of the standard MIP and our MIP with MRT scheme are shown in Fig. 12 and Fig. 13, respectively.

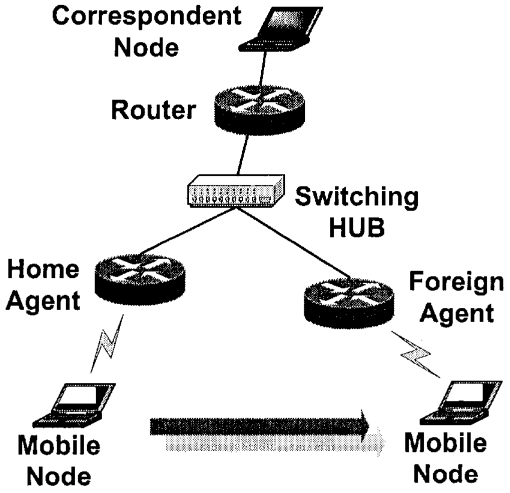

Fig. 12. Simulation architecture of the standard Mobile IP. The HA, FA, and Router are without MRT.

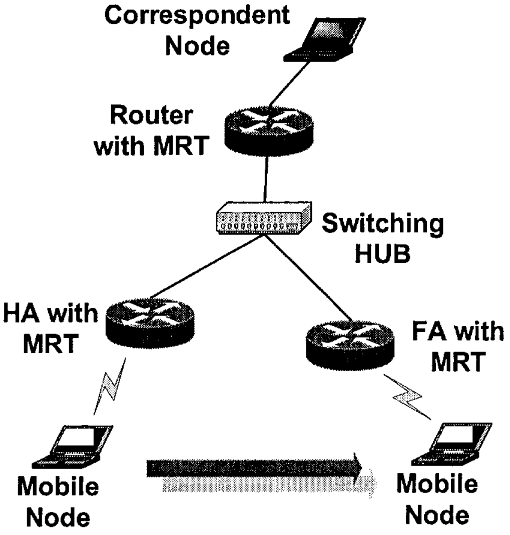

Fig. 13. Simulation architecture of our Mobile IP with MRT scheme. The HA, FA, and Router are with MRT.

Here, we first present some analytical results, then followed by some numerical results and comparisons obtained by the simulation. We consider the following parameters for estimating transmission time:

- $\Delta 1$: time required for packet transmission from a CN to either the HA or the FA, which possibly is a typical delay in wide-area network (WAN).
- $\Delta 2$: time required for packet transmission from the FA to an MN, which is a delay in wireless link.
- $\Delta 3$: time required for packet transmission from the HA to the FA or from the previous FA to the new FA, which possibly is a typical delay in metropolitan-area network (MAN).

By actual measurement, the referenced parameters of $\Delta 1$ and $\Delta 3$, respectively, are 300ms (From Feng Chia University in Taiwan to Massachusetts Institute of Technology in USA) and 20 ms (From Feng Chia University to Tunghai University, both in Taiwan).

To achieve a satisfied communication quality, the VoIP network must be less than 500ms in delay over the Internet. For the standard Mobile IP system, once an MN leaves its home network, the packets sent to the MN's home address are intercepted by its HA and tunneled by its HA to the CoA. Therefore, downstream path linked from the CN to the MN would become larger so that the transmission time increases. For real time applications, such as VoIP and videophone, the increase of transmission time causes a serious delay effect. On the other hand, our Mobile IP with MRT may avoid this problem. Table 2 shows an analytical comparison of transmission time between our Mobile IP with MRT and the standard Mobile IP.

Table 2. Transmission time comparison.

Architectures	Transmission time between CN and MN
Standard Mobile IP	$\Delta 1+\Delta 2+\Delta 3$
Mobile IP with MRT	$\Delta 1+\Delta 2$

The extra routing path that the MN moves from the HA to the FA will cause the triangular routing problem and increase network traffic seriously. The increasing traffic comes from the traffic between the HA and FA. For measuring the traffic effect, we assume the following two parameters:

- T: Traffic between MN and CN.
- N: The number of MNs that move from HA to FA.

When the number of the MNs that move from the home network to a foreign network increases, the traffic will increase obviously. Comparatively, our Mobile IP with MRT will not increase any extra traffic when the MN moves from the home network to any foreign network since the extra traffic amount between the HA and the FA is removed. Table 3 shows the result of extra traffic in the network.

Table 3. Comparison of traffic effect.

Architectures	Extra traffic in network
Standard Mobile IP	$T\times N$
Mobile IP with MRT	No

In the following, we present the simulation results and the comparison of our MIP and the standard MIP. We design a simulation environment described below. The five components of our MIP system, including the HA, FA, Router, MN, and CN, are simulated on Desktop PC with Intel Pentium III 1G Hz CPU and run under Windows 2000 server and professional operating system. In the experiments, in order to measure the status of packet loss during handoff, a CN transmits the packets with different sizes steadily to the MN when it moves from the HA to the FA using UDP protocol. Our MIP approaches with and without packet retransmission scheme, respectively, are carried out in the simulation.

In the experiment, we set the transmission rate at 400 Kbits per second. The performances of packet loss due to handoff are measured for different packet sizes. In the MN, we employ a network analysis tool, named Analyzer [14], to record the sequence index of each UDP packet in a transmission session. Those packet sizes, ranging from 50 Bytes to 1,400 Bytes, are tested. Table 4 lists the number of packet transmitted per second and the period of packet transmission for different packet sizes.

Table 4. Packet size used in the simulation.

Packet size (Bytes)	Number of packets transmitted	Period of packet transmission (ms)
50	1000	1
100	500	2
200	250	4
400	125	8
600	83	12
800	63	16
1000	50	20
1400	36	28

Fig. 14 shows the number of packet loss during MN handoff. The UDP packet size increases from 50 Bytes to 1,400 Bytes; the number of packet loss decreases from 27 to 5. This is because of the effect of the period of packet transmission. A smaller packet size makes the period of packet transmission smaller. In consequence, the number of packet loss gets bigger. Fig. 15, Fig. 16 and Fig. 17, respectively, demonstrate the total amount of packet loss, total amount of payload loss, and percentage of payload loss for different packet sizes during the MN handoff. Here, the percentage of payload loss is defined as the ratio of total amount of payload loss and total amount of transmitted payload. From the results, we observe that the total amount of packet loss gets smaller when the packet size gets smaller, and vice versa. It is the same for the total amount of payload loss. The result in Fig. 18 shows that a higher effective payload transmission may be achieved when the packet size gets bigger, though the percentage of payload loss is big. As a result, we conclude that the packet size should set to be big under the environment of wireless and the cases of frequent handoff.

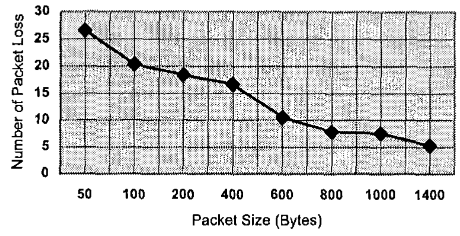

Fig. 14. Number of packet loss vs. packet size.

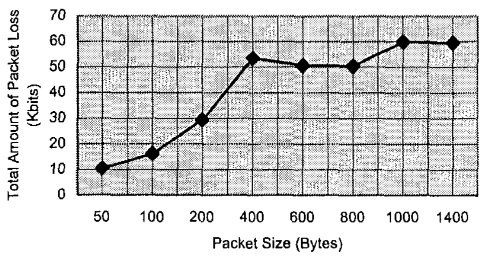

Fig. 15. Total amount of packet loss vs. packet size.

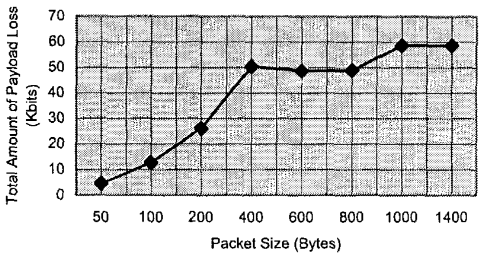

Fig. 16. Total amount of payload loss vs. packet size.

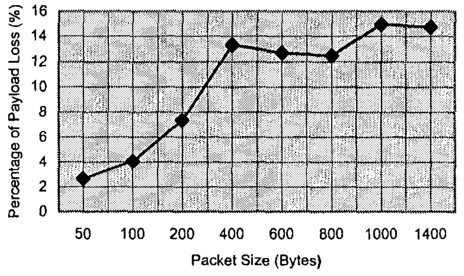

Fig. 17. Percentage of payload loss vs. packet size.

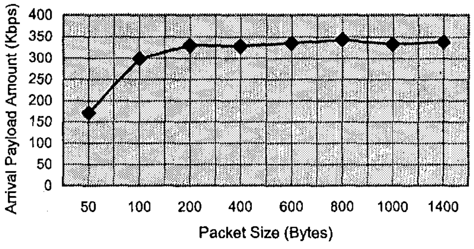

Fig. 18. Arrival payload amount vs. packet size.

Fig. 19 shows that the packet retransmission scheme may effectively lessen the amount of packet loss. When the MN performs handoff, the cease of a session link will cause packet loss. Using the packet retransmission scheme, we can recover most lost packets after the MN handoff. In addition, we observe that the size of packet retransmission buffer significantly affects the amount of packet loss. If the size of packet retransmission buffer gets larger, the amount of packet loss decreases. Accordingly, to obtain a low packet loss, the size of packet retransmission buffer must be adequately increased. However, it also increases the requirement of memory. Fig. 19 reveals that the packet loss will almost approach to zero when we design the packet retransmission buffer with a memory space of about 6 KBytes only.

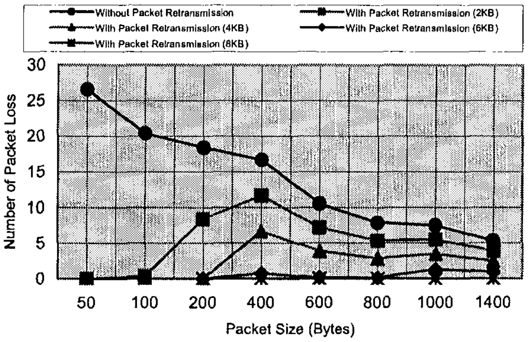

Fig. 19. Amount of packet loss vs. packet size for our MIP with and without packet transmission scheme.

Finally, we discuss the search problem in the MRT. Data packets are normally routed by agent's MRT. When the number of MNs is getting much bigger and the handoff operations become more frequent, the size of the MRT becomes larger so that the search in the MRT becomes time-consuming. In our implementation, the MRT is stored in a binary tree to achieve a fast table lookup. Here we assume that the number of address-mapping table is 1,000,000. Table 5 shows the node search time measured by using linear search and binary-tree search algorithms. A binary search may effectively reduce the node search time in the MRT.

Table 5. Search time in the MRT.

	Search Time (ms)	
Number of Search	Linear Search	Binary Search
1,000	72,022	<1
10,000	698,846	10
100,000	8,479,756	37
1,000,000	75,685,458	863

V. CONCLUSION

With recent advances in wireless communication technology, mobile computing is an increasingly important area of research. An excellent IP mobility protocol, such as Mobile IP, is a key technique in realization of a mobile system. To design a seamless handoff algorithm is very important in the research of Mobile IP. In this paper, we propose a Mobile IP with MRT scheme to avoid the triangular routing problem and a packet retransmission scheme to reduce packet loss during handoff. Based on the proposed MRT scheme, an MIP system with a seamless handoff scheme is realized. The comparison between our Mobile IP with MRT and the standard Mobile IP is presented. The experimental results show that the Mobile IP with MRT can effectively avoid the triangular routing problem and get a smaller packet loss than the standard Mobile IP.

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