Link Layer Assisted Mobile IP Fast Handoff Method over Wireless LAN Networks

Hidetoshi Yokota Akira Idoue Toru Hasegawa
KDDI R&D Laboratories, Inc.
2-1-15 Ohara, Kamifukuoka
Saitama 356-8502, Japan
{yokota,idoue,hasegawa}@kddilabs.jp

Toshihiko Kato
University of Electro-Communications
1-5-1 Chofugaoka Chofu
Tokyo 182-8585, Japan
kato@net.is.uec.jp

ABSTRACT

The growing popularity of IEEE 802.11 has made wireless LAN a potential candidate technology for providing high speed wireless access services. Also, by supporting Mobile IP, wireless LAN can meet demands for expanded wireless access coverage while maintaining continuous connectivity from one wireless LAN to another. In the Mobile IP procedure, mobile node movement can be detected from advertisements of foreign agents that differ from the previously received advertisement and the new "care-of" address is registered with the home agent. However, user packets are not forwarded to the new foreign agent until registration is completed and this interruption may degrade the quality of service especially in real-time applications such as audio and video or may lower the TCP throughput due to retransmission timeout. To tackle these issues, we propose a new low latency handoff method, where access points used in a wireless LAN environment and a dedicated MAC bridge are jointly used to alleviate packet loss without altering the Mobile IP specifications. In this paper, we present the design architecture of the proposed method and evaluate its performance in an actual network environment to verify the effectiveness of our approach.

Categories and Subject Descriptors

C.2.1 [**Computer Systems Organization**]: Computer-Communication Networks—*Network Architecture and Design, Wireless Communication*

General Terms

Design, Performance, Experimentation

Keywords

Mobile IP, fast handoff, IEEE802.11

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1. INTRODUCTION

Public wireless LANs are gaining attention for providing high speed wireless services to indoor hot spots such as airports and hotels and elsewhere at low costs. A series of IEEE 802.11 technologies have been standardized at a rapid pace and are expected to offer part of the capabilities for systems beyond third generation technologies. The resulting high speed network access will expand the possibilities for real time applications such as audio and video streaming, voice over IP, teleconferencing, and rapid data downloads.

Since wireless LAN technologies provide link layer roaming, a mobile node can move around different points of attachment within the same network. However, in order to accommodate more users in a wider area, such a large service area must be divided into separate networks to localize user traffic just as conventional fixed IP networks are subnetted according to the number of users. When each network has a different network address, however, each time a mobile node enters another network, it must reconfigure its IP address, which disables continuous communications.

Mobile IP[1] provides IP level mobility to allow these mobile nodes to roam around wireless LANs without disrupting transport sessions. By locating a Foreign Agent (FA) in each wireless LAN, packets destined for the mobile node are forwarded via the Home Agent (HA) in the home network of the mobile node and the FA in the visited wireless LAN. Figure 1 illustrates such a wide area wireless access network, where each wireless LAN is composed of multiple access points and those wireless LANs are connected with an FA. In Mobile IP, movement of wireless mobile nodes between networks is achieved by receiving advertisements from the FA and by subsequently registering their care-of addresses with the HA. And this procedure is performed every time the mobile node crosses the boundary of the visited network. Since packets destined for the mobile node are not delivered until registration is completed at the HA, this interruption may cause a degradation in quality especially when real-time applications such as audio and video are used. The higher the link speed is, the more packets will be lost during handoff. Further, when TCP is used for data downloading, changing networks may degrade the performance due to TCP retransmission timeout.

When we deal with this handoff interruption issue in Mobile IP, the following requirements are important to consider for practical deployment.

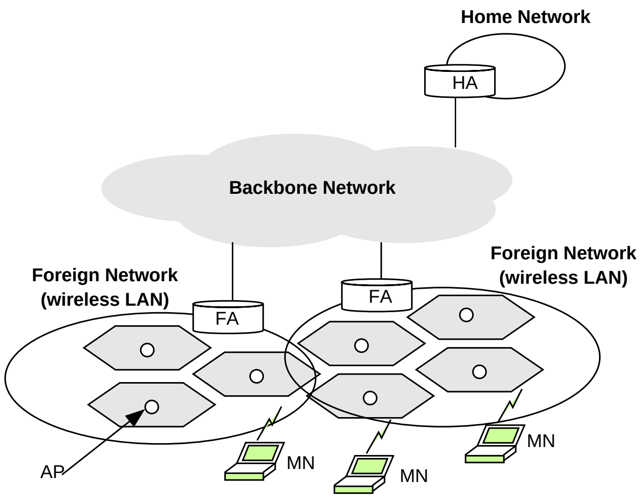

Figure 1: Public wireless LAN service with Mobile IP

- The Mobile IP specifications should not be changed. The HA and FA functionalities have already been implemented in several commercial router products. Therefore modifying the Mobile IP specifications or adding extra functions may not be practical and will have significant impact on already deployed backbone networks.
- Mobile users should be able to keep using currently available wireless LAN technologies such as IEEE 802.11a/b. It is not desirable to require proprietary software or hardware.

In this paper, we propose a new fast handoff method that alleviates packet loss without having to alter the Mobile IP specifications by jointly using a dedicated MAC bridge with access points used in a wireless LAN environment. We also evaluate our method by transmitting packets using UDP and TCP as transport layer protocols on a wireless LAN network and show improvement in packet loss in both the forward and reverse directions.

The remainder of this paper is organized as follows. In Section 2, we present performance degradation caused by Mobile IP handoff and investigate several approaches to it. The first half of Section 3 describes our proposal in the forward direction and the second half extends it to the reverse direction. Section 4 presents results of experiments with UDP and TCP packet transmission to evaluate performance improvement in both directions. We investigate the behavior of TCP retransmission in particular and clarify conditions for initiating TCP fast retransmit mechanism. Finally, in Section 5 we offer closing remarks.

2. MOBILE IP HANDOFF DELAY

Packet loss or delay due to Mobile IP handoff delay has been discussed in the IETF (Internet Engineering Task Force), and several mechanisms have been proposed and standardized. Simultaneous binding[1] is one type of handoff smoothing technique that maintains multiple care-of address bindings for the mobile node (MN) and transmits packets destined for the MN to all care-of addresses to reduce packet loss during handoff. This is effective if the MN knows where it will move *a priori* and can receive new advertisements in the current network to register new care-of addresses beforehand. However, the currently available wireless LAN card can only access one access point (*i.e.* one channel) at a time and the network does not know when and where the mobile node will move next until it actually initiates an association with a new access point. Another favored approach is called micro-mobility[2], where a network is divided in a hierarchical manner and location management is handled locally while the MN moves within a smaller area at the lower hierarchy level. This approach is intended to reduce the round trip time for registrations when there is a large distance between the visited network and the home network of the mobile node. Regional registration[3] is a technique to perform registrations locally in the visited domain in addition to home registrations. Cellular IP[4] and HAWAII[5] use proprietary control messages for location management and routing within a regional area. MobiLANe[6] takes an interesting approach which covers a large geographical area such as a metropolitan area with Layer2 switches. Notice that all of these approaches assume use of Mobile IP when the MN moves between regional areas.

Mobile IP handoff delay is divided into two elements; one is caused by movement detection and the other is caused by signaling for registrations. The above techniques are particularly effective on registration signaling delays, but not on movement detection delays. We will show later on that movement detection delay has a large effect on overall handoff delay. Movement detection and registrations of the MN are triggered by reception of agent advertisements. Section 2.3 of RFC2002, which specifies Mobile IP, says that:

> "a mobility agent MUST limit the rate at which it sends broadcast or multicast Agent Advertisements; a recommended maximum rate is once per second...,"

and this may affect the movement detection delay. Further, packets are not delivered to the MN at the new location until the Registration Request is accepted by the HA and the Registration Reply is sent back. Therefore, packets on the fly may be lost during this time period. In the IETF, a low latency handoff method has been proposed by El Malki et al.[7]. In this proposal, information regarding movement from the link layer (Layer 2) of the network where the MN was previously, and the network where the MN is now, are respectively called a "source trigger" and a "target trigger". Three methods for low latency handoff are proposed as below:

1. PRE-REGISTRATION handoff method
   This method allows the Mobile IP handoff to be made prior to the L2 handoff. The old FA, which resides in the network to which the MN has been attached, obtains Router Advertisements from the new FA which resides in the network to which the MN is expected to move, and advertises them in the old network. The MN detects movement by way of this information and completes a Mobile IP registration via the new FA before the L2 handoff. Two handoff cases are defined: one is initiated by the network and the other is initiated by the MN.
2. POST-REGISTRATION handoff method

This method makes the Mobile IP handoff after the L2 handoff. The old FA and the new FA establish a temporary tunnel by receiving source or target triggers from the link layer. Packets originated from or destined for the MN are transmitted to the new or old FAs by way of this tunnel. This method defines Handoff Request/Reply messages to notify handoff from the old FA to the new FA.

3. Combined handoff method
This method combines the above two methods. It attempts the PRE-REGISTRATION handoff method before the L2 handoff, and if it fails, the old FA attempts the POST-REGISTRATION handoff method.

The above proposal attempts to make the link layer as generic as possible. Therefore it does not specify a mechanism for obtaining source and/or target triggers. In IEEE 802.11 in particular, it is not easy to obtain a source trigger since the mobile node does not explicitly clear the association in the old network and does not inform the new access point about the previous point of attachment. As a more specific method, Wu *et al.* proposes a smooth handoff mechanism by introducing packet buffering at mobility agents, delivering a list of neighboring FAs to the MN, and enabling the L2 handoff event in the MN to trigger the L3 (Mobile IP) handoff. This proposal employs both PRE- and POST-REGISTRATION handoff methods to eliminate packet loss, however it also requires altering the behavior of the HA, the FAs and the MN, and extending the Mobile IP specifications, which makes it difficult to apply this proposal to networks where the standard Mobile IP is already deployed.

3. PROPOSAL FOR LINK LAYER ASSISTED FAST HANDOFF METHOD

In this paper, we propose a fast handoff method without altering the Mobile IP specifications. First, we discuss our fast handoff method for the forward direction (*i.e.* mobile terminated data), and then extend it to the reverse direction (*i.e.* mobile originated data).

3.1 Fast handoff method for the forward direction

In streaming applications, the primary direction of packet transmission is toward the MN, and it is important to reduce interruptions in packet transfer when communication continuity is important. In our proposal, fast handoff is achieved by joint use of access points (APs) and a dedicated MAC bridge. The AP we use here has a function to notify the MAC address of the MN that moves into the AP wireless coverage to the wired network. Our proposal also uses a MAC bridge connected to different wireless LANs (therefore different subnetworks) and configured so as not to send MAC frames unless their destination MAC addresses are registered in the filtering database (DB). This is the opposite of a normal MAC bridge that sends MAC frames to all ports if their MAC addresses are not in the filtering DB. Except for this point, the role and function of the filtering DB is the same as defined in IEEE 802.1D. The procedure for the proposed method is shown in Figure 2.

1. The MN establishes an association with AP1 as defined in IEEE 802.11 and registers the care-of address with the HA according to the Mobile IP.
2. Packets destined for the MN are encapsulated by the HA and tunneled to FA1. The FA1 then decapsulates those packets and delivers them to the MN. The MAC bridge used in this proposal does not relay any frame whose destination MAC address is not in the filtering DB.
3. When the signal level of the channel on which the MN is communicating with AP1 falls below the threshold, the MN attempts to find an AP with a higher signal level.
4. The MN establishes an association with a new AP, AP2.
5. Upon establishment of the association, the AP2 places the MAC address (or the BSS ID) of the MN in a MAC address registration request message and broadcasts it on the local segment.
6. On receiving the MAC address registration request message, the MAC bridge stores an entry of the MAC address contained in the message and the port on which the message was received into the Filtering DB. Each entry has an aging time, and if no new MAC address registration request message arrives within this time period, the corresponding entry is removed.
7. When the MAC bridge receives a MAC frame on a port, it refers to the filtering DB to see if the destination MAC address is registered. If it is registered, the MAC bridge sends it out to the corresponding port. Packets from FA1 are in this way bridged from port A to port B of the MAC bridge, and delivered to Network 2, to which the MN is now attached.
8. The MN detects movement by receiving new Agent Advertisements from FA2 and registers the new care-of address with the HA. When the registration is completed, packets destined for the MN are then tunneled to FA2 and delivered to the MN. Since no packets are bridged from that time onward, the entry for the MN in the Filtering DB must be removed upon expiration of its aging time.

Therefore in this procedure, the MN can receive packets even before Mobile IP registration is completed.

3.2 Fast handoff method for the reverse direction

When TCP is used to transfer packets to a mobile node, it is not only necessary to deliver packets for the mobile node to the new network but also to properly deliver acknowledgments to the sender during handoff. The MN directs those packets destined for the sender to the default router of the network that the MN has registered with the HA and the default router's IP address is obtained via the Mobile IP Agent Advertisement message from the FA. In this section, we discuss a method to reduce packet loss in the reverse direction.

In the case of the forward direction, a frame destined for the mobile node can be delivered to the network to which the mobile node is currently attached by way of the MAC bridge referring to the filtering DB for the destination MAC address of the frame as described in Section 3.1. Following this procedure, the simplest way of identifying a mobile

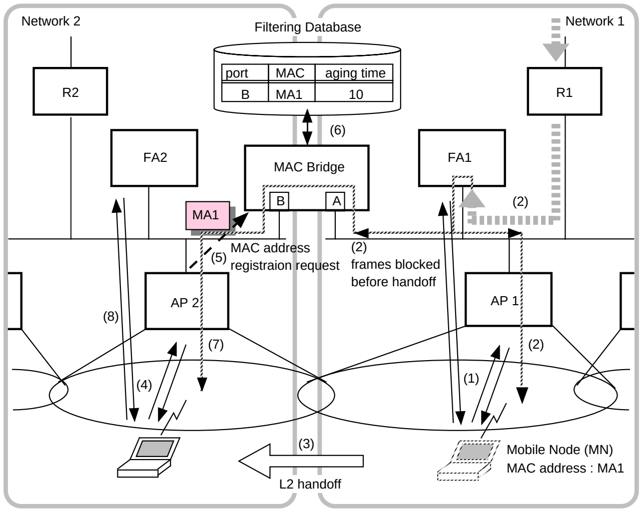

Figure 2: Proposed handoff procedure in the forward direction

originated frame is to look at the source MAC address of an incoming frame. If the MAC bridge relays only frames whose source MAC addresses are registered in the filtering DB to the network to which the mobile node is previously attached, then it can reduce transmission interruptions in the reverse direction as well. This method (for the reverse direction) is feasible when the MAC bridge has only two ports. Here a MAC bridge with two ports, checks the source MAC address of an incoming frame from one port with the filtering DB, and transfers it to the other port. However, if the MAC bridge has more than two ports as shown in Figure 3, the direction in which the frame should be transferred will differ according to the moving speed of the mobile node and the Mobile IP registration processing speed. Assuming that the mobile node is registered in Network 1 before movement and receives packets from FA1 in the same figure, when that mobile node moves consecutively to Network 2 and then to Network 3, two cases can be considered as follows.

Case 1 When the mobile node completes Mobile IP registration in Network 2 and moves to Network 3:

The Mobile IP Agent Advertisement message is an extension of the ICMP Router Advertisement[9]. When the mobile node receives an Agent Advertisement message, it sets its default router to the same router as in the message. So when the mobile node sends a packet, the next hop for it is the default router (The FA can be the default router). If this is the case, the default router of the mobile node is R2, so when it sends a packet just after it moves to Network 3 (before completing a registration in Network 3), the source MAC address of the frame is MA1 and the destination MAC address is MR2 (regardless of the final destination). The MAC bridge receives this frame on port C, and must send it out on port B.

Case 2 When the mobile node moves to Network 3 before a Mobile IP registration is completed in Network 2:

In this case, the default router of the mobile node is still R1, therefore when the mobile node sends a packet just after it moves in to Network 3, it sends a frame with the source MAC address of MA1 and the destination MAC address of MR1 (regardless of final destination). The MAC bridge receives this frame on port C, and must send it out on port A.

When the mobile node is attached to the network via an AP, the mobile node always establishes an association with the new AP. Thus, by cooperating with this AP, the MAC bridge can keep track of the network to which the mobile node is attached. However, when the mobile node leaves the network, it does not usually cancel its association, (which is called a disassociation in IEEE 802.11). It is therefore hard to obtain explicit information on the AP to which the mobile node is attached previously. Further, even if it is possible to obtain such information, it is still hard to decide which network the MAC bridge should send the frame originated by the mobile node to, unless it can obtain information on which network the mobile node has been registered in the Mobile IP context.

3.2.1 Proposal for fast handoff method by using Agent Advertisement

Taking into account that the next hop of a frame sent by the mobile node is always the default router of the network where the mobile node has been registered, we propose a fast handoff method in the reverse direction by registering the MAC address of the default router in the filtering DB. We show the procedure of the proposed method below.

1. The MAC bridge receives an Agent Advertisement message (a frame with ICMP Type=9 [Router Discovery], Code=16 [Mobility Agent]), and obtains the router address(es) in it (Figure 4).
2. The MAC bridge searches the ARP (Address Resolution Protocol) table for the MAC address(es) corresponding to the IP address(es). If it cannot find the MAC address(es), it broadcasts an ARP request message(s) on the port on which it receives the Agent Advertisement message, and finds it(them) (Figure 5). It registers the corresponding MAC address(es) and the port on which it received the ARP reply message(s) in the filtering DB. If the correspondent MAC address has already been registered, it only updates its aging time.
3. The MAC bridge maintains the filtering DB as shown in Figure 6, whereby frames destined for MR1a are transferred to the Network 1 via port A and received by R1.

In the procedure above, the MAC bridge in Figure 6 maintains the filtering DB to transfer frames destined for MR2a to port B by receiving an Agent Advertisement from FA2. Therefore, R1 can receive the frame even if the mobile node sends a frame for MR2 in Network 3 as in Case 1.

Now that the proposed MAC bridge is allowed to have multiple ports, one MAC bridge can accommodate multiple adjacent networks. Figure 7 shows the entries in the filtering DB when the MN moves around the networks shown in Figure 3. Here an entry for the MN was expired and removed from the filtering DB after a long period of stay in Netwrok 1 (before movement). When the MN starts moving, the forwarding port for MA1 is created as port B and overwritten

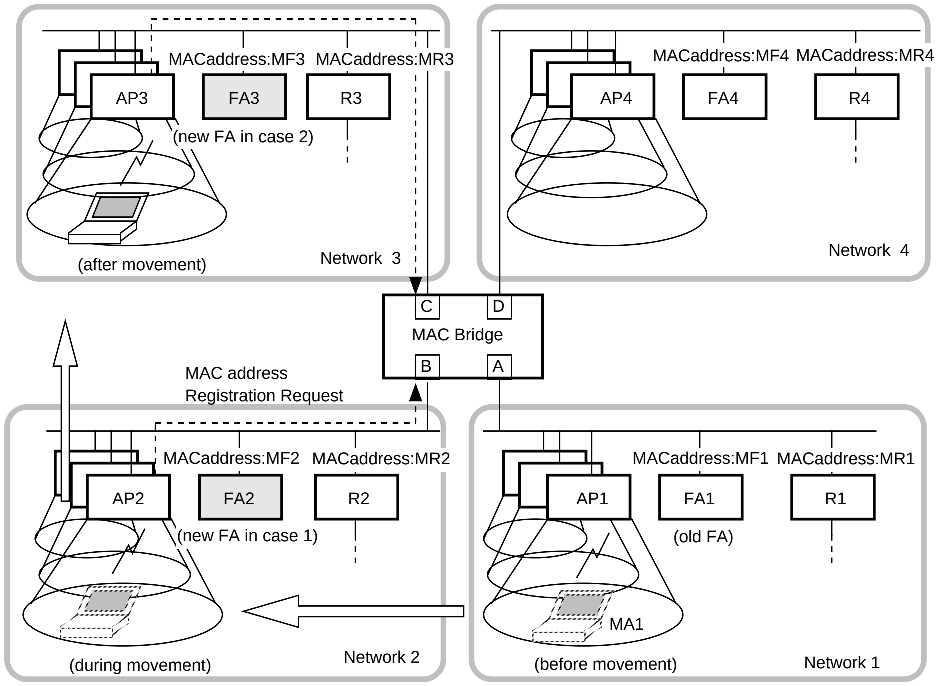

Figure 3: Mobile IP registration and data transmission in the reverse direction

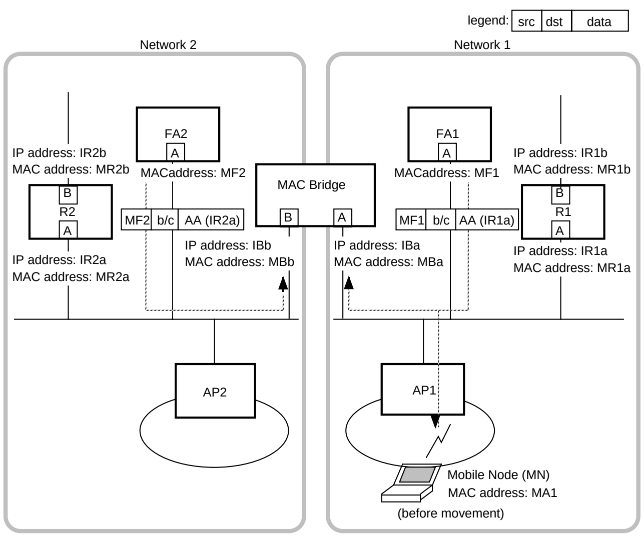

Figure 4: Reception of an Agent Advertisement

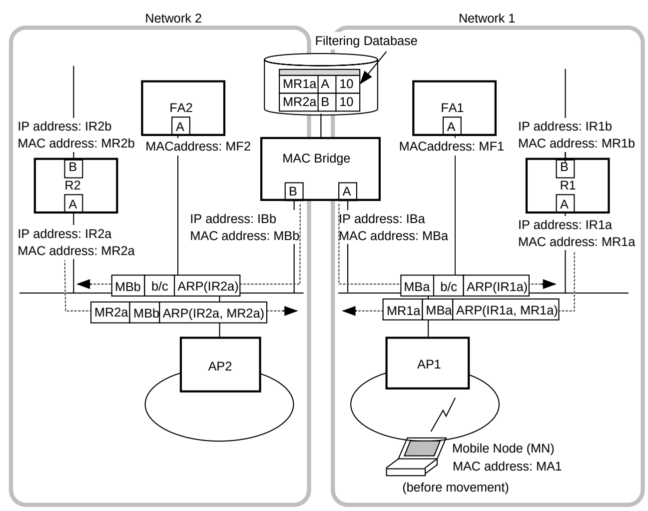

Figure 5: Router address resolution

to port C. Notice also that the proposed MAC bridge is not needed where multiple wireless coverage areas belong to the same network since only L2 handoffs occur there.

4. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the proposed method in an experimental network as shown in Figure 8. We used Monarch Release 1.1.0 developed by CMU[10] as a Mobile IP software suite. The network components we used and their specifications are shown in Table 1. The wired LAN portion was all constructed with 10Base-T and the wireless LAN portion was constructed with 802.11b.

4.1 Packet transmission experiment in the forward direction

The procedure among the MN, AP and FA in the handoff period is shown in Figure 9. The MN searches for an optimal AP by scanning the channels and sending probe request frames (1), authenticates itself with AP (2), and establishes an association (3). The MN detects movement at the expiry of the advertisement from the registered FA and sends

Table 1: Network components

node name	hardware (CPU)	OS
HA,FA	Intel Pentium 800MHz	FreeBSD2.2.2
CN (UDP experiment)	Intel Pentium 800MHz	FreeBSD2.2.2
CN (TCP experiment)	Intel Pentium 1GHz	FreeBSD4.2
MN	Intel Pentium 500MHz	FreeBSD2.2.2
Routers	AMD i486SX 66MHz	FreeBSD4.3
MAC Bridge	Intel Pentium 800MHz	FreeBSD4.3
AP	Motorola PowerPC 48MHz	Linux 2.2.13

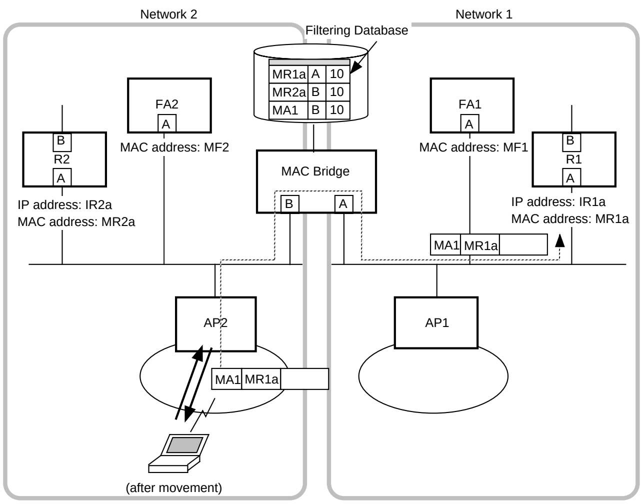

Figure 6: Data transmission in the reverse direction based on proposed method

Filtering DB

before movement

MAC address	forwarding port	aging time
MR1	A	10
MR2	B	10
MR3	C	10
MR4	D	10

after movement

MAC address	forwarding port	aging time
MR1	A	9
MR2	B	9
MR3	C	9
MR4	D	9
MA1	C	10

Figure 7: Filtering DB before and after movement

an Agent Solicitation message. When the MN receives an Agent Advertisement message (4), it registers itself with the HA (5). The transmission interval of beacons from the AP is 100 ms, so the L2 handoff procedure [(1)∼(3)] takes about 160 ∼ 200 ms. Further, Section 2.1 of [1] says that:

> If sent periodically, the nominal interval at which Agent Advertisements are sent SHOULD be 1/3 of the advertisement Lifetime given in the ICMP header.

Since the transmission interval of Agent Advertisements is once per second, its recommended lifetime becomes three seconds. This means movement detection (4) takes about 2 to 3 seconds. The signaling delay for registrations depends on the distance between the MN and the HA and the number of intermediate routers. In this experiment, it took about 3 to 6 ms for a registration. As a result, the time required for L2 and Mobile IP handoffs is respectively about 200 ms and 3 seconds.

Based on these configurations, we present the time required to transmit 256 bytes of packets from the corresponding node (CN) to the MN at the 50 ms interval shown in Figure 10. The figure (a) shows the case where only Mobile IP is used, and we see that 2.6 seconds of disruption occurs during handoff and 51 packets are lost. We can also see that the transmission times of the 30th and the 41st packets in the same figure are respectively 31 ms and 16 ms, which are larger than those of the other packets. This is thought to be caused by retransmissions on the wireless link. Figure 10(b) shows the case where a MAC bridge is used according to the proposed method. In this figure we see that it takes about 170 ms to establish an association with an AP, and 4 packets are lost, however UDP packets are transmitted afterwards before completing a Mobile IP registration. About 1 ms is added to the transmission time due to the processing in the MAC bridge, but the time between the reception of a MAC address registration request message and the start of packet transmission was less than 1 ms. This result shows that the proposed method can reduce to a tenth, the disruption due to movement detection and the registration process of Mobile IP when the MN moves to a new network.

4.2 Bi-directional packet transmission experiment

To evaluate the proposed fast handoff method for a bi-directional packet transmission, we performed a packet transmission experiment using TCP. In this experiment, we used FreeBSD4.2 as the OS for the CN, and assume that one MN handoff occurs during the 20 second TCP packet transmission from the CN to the MN. The sender follows Reno TCP[12] and the receiver uses the delayed ACK. The buffer size on the receiver side is 16K bytes (default setting). Figures 11 and 12 show the relation between transmission time and the sequence number of each TCP segment in the experiment environment described above. In Figure 11 only Mobile IP is used, while in Figure 12, our proposed method

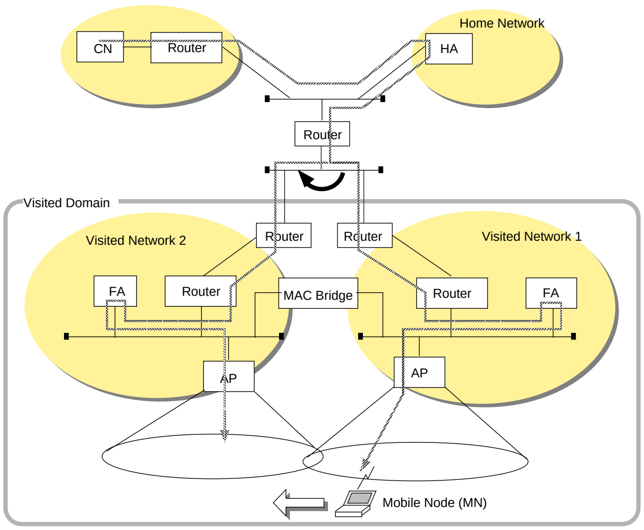

Figure 8: Experiment environment

is used. The time required for TCP packet transmission is measured in the network to which the CN is attached.

Figure 11 shows that packet loss occurs at the 9th second when the mobile node starts to move. The Mobile IP handoff completes at the 12.5th second, however it is not until the 16th second that the mobile node starts to receive packets again. The retransmission timeout value stored in `t_rxtcur`, is calculated by measuring the current RTT (Round Trip Time), the smoothed RTT stored in `t_srtt` and the smoothed mean deviation RTT stored in `t_rttvar`. Further, the upper and lower bounds of the retransmission timer are given by:

$$\texttt{TCPTV\_MIN} \le \texttt{t\_rxtcur} \le \texttt{TCPTV\_REXMTMAX}$$

In a typical TCP implementation, `t_rxtcur`, `t_srtt` and `t_rttvar` store the number of ticks, which are incremented every 500 ms, and `TCPTV_MIN` and `TCPTV_REXMTMAX` are set to 1 second and 64 seconds, respectively[13]. Since the experiment network is constructed on a LAN, the RTT was sufficiently small and the retransmission timer was 1 second (minimum value) at the 9th second. The retransmission timer expires during the mobile node handoff and after 1 second (at the 10th second), the lost packet was retransmitted. At this point, the retransmission timer is multiplied by an element of the array for the exponential backoff `tcp_backoff[]={1, 2, 4, ... ,64 }`, and is set to 2. At the 12th second, the packet is retransmitted for the second time and the retransmission timer is set to 4, therefore the third retransmission is attempted at the 16th second. As we can see in the Figure 11, the packet is retransmitted three times. Since Mobile IP handoff may take up to 3 seconds, retransmissions could occur 2 to 3 times, so that the interruption of the packet transmission due to handoff may be from 3 seconds to 7 seconds.

On the other hand, the L2 handoff completes in 200 ms when the proposed method is used as shown in Figure 12. Since the minimum value of the TCP retransmission timer is 1 second, the time when packet transmission resumes is at the time of 10, which is after 1 second from the retransmission timeout. Notice, however, that the duration that packet transmission is interrupted does not depend on Mobile IP handoff, and its maximum value is always 1 second.

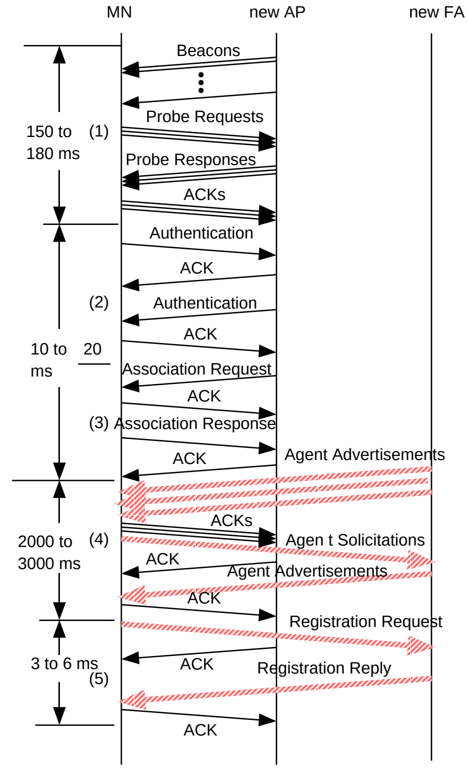

Figure 9: Handoff procedure

4.2.1 Handoff delay and TCP retransmission mechanism

Reno TCP supports the fast recovery mechanism as well as fast retransmit mechanism, which make it possible to start retransmission when packet loss occurs by receiving duplicate acknowledgments without waiting for a retransmission timeout. These also reduce throughput degradation by shifting to the congestion avoidance phase after the retransmission[11]. In this section, we discuss conditions under which these mechanisms are initiated in our experiments.

Figure 13 illustrates the sequence of packet transmission in the proximity of the time when TCP retransmission occurs due to the mobile node handoff. Three duplicate ACKs must be received so that the sender can start to retransmit versus packet loss at the receiver site. We can therefore give the following relationship among the Bandwidth Delay Product (BDP), the maximum window size that the receiver advertises to the sender, and the Maximum Transmission Unit (MTU), which is the maximum frame size on the link layer:

$$\min\{BDP, WS\} > 4MTU. \quad (1)$$

Since at least three of those packets that the sender can send without receiving the corresponding ACKs, need to arrive at the receiver, we can also give another necessary condition versus the link speed BW on the network to which

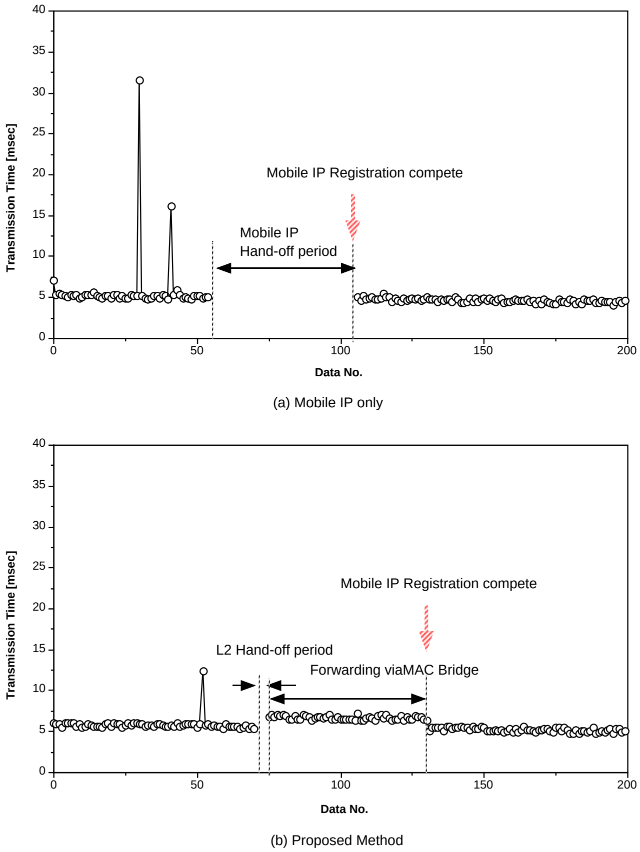

Figure 10: UDP packet transmission experiment in the forward direction

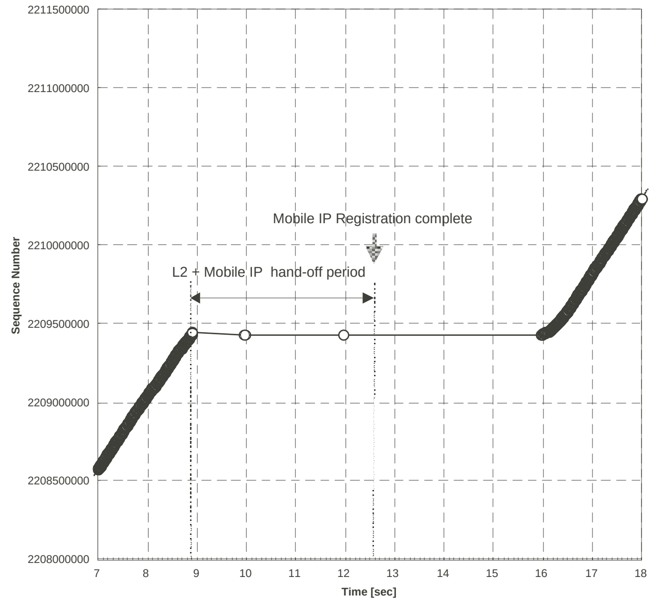

Figure 11: Bidirectional packet transmission by TCP (Mobile IP only)

the sender is attached by denoting $T_{L2handoff}$ as the time for L2 handoff:

$$T_{L2handoff} < RTT - 3MTU/BW \quad (2)$$

The RTT depends on the size of a packet transmitted and the number of intermediate nodes. In the network environment that we used, the measured RTT between the CN and the MN for a 1500 byte packet and 46 byte ACK[1] was about 20 ms as shown in Figure 13 (1). Therefore when the link speed is 10Mbps, the BDP is calculated to be 25K bytes. When the window size WS is 16K bytes, $4MTU$=6K bytes, which satisfies Equation (1). In this experiment, $WS/MSS = 12$ (MSS: the Maximum Segment Size of TCP) on the sender side, thus the sender was able to send 12 segments without waiting for their corresponding ACKs. On the other hand, since the time required for L2 handoff $T_{L2handoff}$ is about 200 ms (Figure 13 (2)), Equation (2) is not satisfied, which leads to loss of all unacknowledged packets from L2 handoff only. As a result, the sender is forced back to use the slow start algorithm to recover (Figure 13 (3)), and the fast retransmit mechanism is unlikely to be triggered. In order for the fast retransmit function to be triggered in a LAN environment, the time required for L2 handoff must be reduced to about a tenth of the current required time. Note that in environments where the HA is connected via WAN, the probability that the current L2 handoff will trigger the fast retransmit function becomes higher. Multiple packet loss is also likely to occur during handoff, but Reno TCP terminates the fast retransmit with loss of one packet, and subsequent packet losses cause the slow start, which makes it more difficult to alleviate interruptions in packet transmission[14]. In case of multiple packet loss during handoff, the NewReno TCP[15] or the SACK (Selective ACK) option[16] will prove effective.

[1]TCP header (20 bytes)+IP header (20 bytes) +padding (6 bytes)

5. CONCLUSION

In this paper, we proposed a fast handoff method for Mobile IP in a wireless LAN environment. In the proposed method, an IEEE 802.11 access point and a dedicated MAC bridge are jointly used to reduce packet transmission interruptions in both the forward and reverse directions. We evaluated the proposed method in an actual network environment and proved its effectiveness by measuring the time required for each procedure and by both UDP and TCP packet transmission experiments. By using the proposed method, the packet transmission interruption due to a Mobile IP handoff is reduced to the same time as an L2 handoff, which is a mere tenth of the case where only Mobile IP is used. When only Mobile IP was used in TCP, retransmissions occurred two or three times and even after Mobile IP registration was completed, the interruption remained for a maximum of 7 seconds due to the exponential backoff of the TCP retransmission timeout. On the other hand, by using the proposed method it was shown that only one retransmission occurred before the packet transmission resumed.

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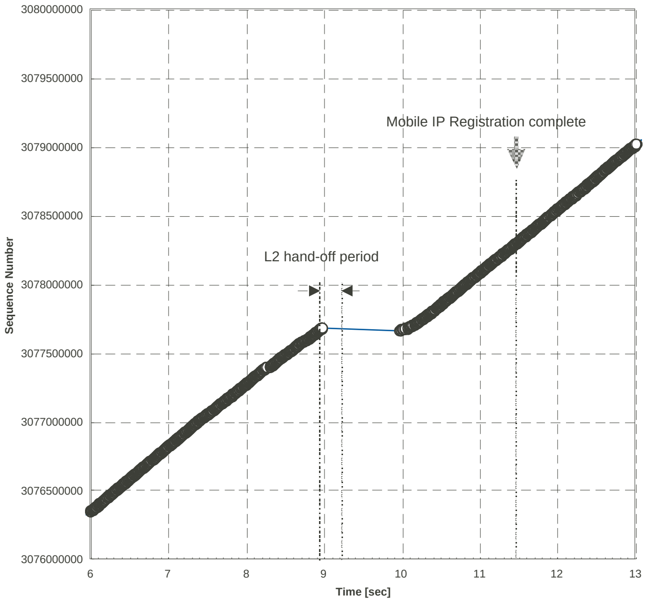

Figure 12: Bidirectional packet transmission by TCP (the proposed method)

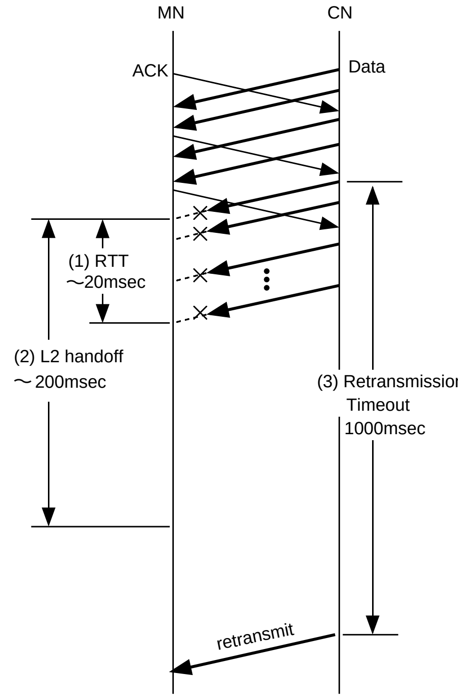

Figure 13: TCP packet transmission sequence during L2 handoff

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