Link Layer Assisted IP Mobility Protocol

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Abstract: **As the popularity of IEEE 802.11 rises, many problems have been arisen that were absent in the traditional wired networks. A serious problem has arrived from the movement of mobile nodes - this *mobility* characteristic will make the data transmission mechanisms differ from before. A general solution to this problem is Mobile IP. But Mobile IP in itself has problems and will create a big latency. The roaming nodes will need to complete all registrations before being able to receive data. The registrations then become the bottleneck in data transmission. In this paper, it is proposed that a novel link layer handoff is designed to deliver that data to a destination before the roaming nodes complete its Mobile IP registrations. The proposed method is completely independent of network layer; therefore, no matter Mobile IPv4 or Mobile IPv6 is used, the proposed method can work correctly. No modification to the existing specification is necessary in Mobile IP.**

Index Terms: **Mobile IP, Handoff, IEEE 802.11, Bridge, Router, Wireless.**

I. INTRODUCTION

The IEEE 802.11-based wireless local area networks (LANs) are becoming an important part in the networking environment. A growing number of wireless LANs have been set up in university campus or public buildings as access networks to the Internet. These wireless LANs are consisting of mobile nodes (MNs) which access services hosted on servers residing on the wired network, and access point (AP) that serves as a layer-2 bridge between wired and wireless network.

With the growing popularity of IEEE 802.11 technology, many problems have been arisen which were absent in the traditional wired networks. One of the problems caused by the MN characteristic - *mobility* is that it will make data transmission mechanisms in a traditional wired network fault, requiring a new approach to solve this problem.

A general solution to the problem of data transmission of the MN is Mobile IP [12], [9]. It provides IP level mobility to allow MNs to roam across wireless LANs without loss of network-layer connectivity and disrupting transport sessions. In Mobile IP, there are home agents (HAs) and foreign agents (FAs) running on the wired network. These mobile agents (MAs) periodically broadcast Mobile IP advertisements on the wireless LANs. Whenever a MN migrates from one subnet to another, it will receive Mobile IP advertisements from the corresponding FA. The MN intercepts these advertisements and sends a registration request to the newly discovered FA. There is an IP-over-IP tunnel between FA and HA be established after due authentication. Finally, the MN sent a Binding Update message to the HA. From this point onwards, the data transferred between MN and servers can through the bidirectional tunnel. If the MN migrates to a new foreign subnet, it needs to bind with the FA of the new foreign subnet, and needs to dismantle the association with the FA in the previous subnet. This procedure is performed every time the MN enters a new wireless IP subnet. The entire process of switching from one MA to another as a MN moves across adjacent wireless IP subnets is called Mobile IP handoff.

Before the Mobile IP handoff completes, packets destined for the MN will not be delivered. The MN is essentially disconnected with the wired network. This handoff latency may cause degradation in communication quality, specifically when real-time applications such as audio or video are used. The faster the link speed, the more packets will be lost during handoff. In addition when the TCP is used for data transmission, roam around wireless networks may diminish the performance due to TCP retransmission policy. Therefore, it is important to reduce this handoff latency.

In this paper, it is proposed that a novel link layer handoff is designed to deliver data to a correct destination before a roaming node completes its Mobile IP handoff. No modification to the existing specifications is necessary in Mobile IP. Since the proposed approach is worked in link layer, whatever Mobile IPv4 or Mobile IPv6 is used, the proposed approach still works correctly. To the best of the authors' knowledge, the proposed approach is the fastest known handoff performance for such infrastructure-mode wireless LANs.

The remainder of this paper is arranged as follows. Section II summarizes related work followed by a general description of the networking environment in Section III. Section IV introduces the Fast Link Layer Handoff (FLLH) and an enhanced version of the FLLH to eliminate the problem caused by message delays. The results of experiments with UDP and TCP packet transmissions to evaluate performance enhancement are presented in Section V. In Section VI the influence of TCP retransmission policy and a buffer agent designed are discussed. Finally, Section VII evaluates the research and the conclusions are presented.

II. RELATED WORK

The delay caused by the Mobile IP handoff can be divided into two elements; firstly the movement detection and secondly the registrations.

Micro-Mobility [3]: A network that is divided into a hierarchical structure and location management is handled locally while the MN enters into a smaller area at a lower hierarchical level. This approach is intended to reduce the round trip time registrations and the handoff delay when there is a large distance between the visited network and the home network of the MN.

Cellular IP [19]: It is a technique to use proprietary control messages for location management. The messages will be routed in a regional area therefore speeding up the registrations and reducing the handoff delay.

The above solutions to reduce the handoff delay are focused on registration signaling delay and have no discussions about movement detection.

NeighborCasting [17]: This mechanism is based on utilizing of collected information. During the handoff, each MN informs the new MA about the previous MA, helping it to build a map of its neighbors. When a notification from the link layer is received, each MA utilizes the neighbor map to forward the data to all the neighboring MAs. In stable state, this mechanism can make MN continuously receiving data from wired network before the registration completed. This mechanism requires modifications to Mobile IP to support the discovery of neighboring MAs. Although the movement detection and registration have few influences to handoff in this mechanism, it wasting the wired bandwidth in order to multicast data to the neighbors and violates the standard of IEEE 802.11-based infrastructure-mode to make wireless interface card communicate with the previous MA during the handoff. This mechanism also assumes the availability of a notification mechanism from link layer to the Mobile IP software about the impending handoff, but it is incompatible for the existing wireless interface card.

Fast Handoff [20]: This proposal is based on link layer and uses a bridge and AP to reduce the handoff delay of the Mobile IP allowing for a better performance. In addition, this approach also has problems, including the lack of ability to oversee the entire network, restricting it to a simple LAN network which can not be enlarged to an Extended LAN environment. The change in the message transmission of a bridge causes many differences when compared to the traditional bridge, because of this it may not be used on an existing bridge directly.

Low-Latency Handoff [16]: This proposal combines link layer and network layer. It uses a software probing mechanism to reduce the latency of movement detection and adds caching agent into each wireless subnet to replay Mobile IP advertisement. It sets some policies in HUT dynamic Mobile IP software implementation [6] to accelerate the registration request sent from MN to reduce the latency of registrations. The handoff latency in this approach can reduce to 100 ms. Although it gives low handoff latency, there are some problems existing. The caching agent needs to broadcast a dummy Ethernet frame periodically to trick switches and bridges. The periodically broadcast may affect the traffic in the network. All the MNs and caching agents have been required to know a well-known MAC address to make this approach work. The policies used to accelerate the registration are not completely compatible with Mobile IP standard.

Therefore a novel approach is needed to eliminate the problems mentioned before, which is compatible with existing network devices to be able work correctly in an infrastructure-mode wireless network and has no modifications to the existing specifications in Mobile IP.

III. NETWORK ENVIRONMENT

In the LAN environment, the number of users continually grows, increasing the amount of congestion. To provide services to more users, the Segmenting Share-Media LAN separates the users to several different segments, using a bridge to connect each segment together. Therefore the many segments become a large and complex Extended LAN.

In a Large Extended LAN, a bridge (learning bridge) [8] with a self-adjusting function is used to forward the data between the different segments. This can prevent data being forwarded to the incorrect segment and consequently influencing the speed of the communication. In order to forward data to the correct segment, the bridge must contain a Forward Database (FDB) table. The data frame will be received from the port and the FDB table will record the entry, this entry has time limit to avoid the data frame from being forwarded to incorrect segment.

A router is used to divide a network into several subnets and each subnet may consist of many segments. It has the similar functions to bridge but handles in network layer. Wireless networks add APs to every segment which wants to provide wireless communication. The APs only function is to receive and forward packets allowing the MN to exchange packets with hosts residing on the wired network. Since the MN is appended to the network, therefore the topology of the network will change. The network topology will change because the hosts residing on the wired network are fixed nodes, as the MNs are appended and roam around the network this makes the data transmission mechanism differ from before. Take Fig. 1 for example.

In Fig. 1, the router and bridge connect each segment together and the MN can exchange packets with the host residing on the wired network through the AP. The general network environment will work correctly as before. However, the effect of the MN roaming becomes an uncertain factor in the topology of the whole network. This makes the traditional mechanism of data transmission not able to provide correct data for communication. In this situation the Mobile IP could resolve the data transmission problem, but in itself creates a big latency. This latency will cause degradation in the quality of communication. It then becomes apparent that there is a need to condense this latency.

IV. FAST LINK LAYER HANDOFF

A. Preliminary

The function of the Mobile IP has been implemented in many commercial products. It may be impractical to change any specifications of the Mobile IP as the result of doing this may mean an extensive change in the backbone of the networks. Therefore it is essential not to alter any characteristics of the Mobile IP. In the proposal, the approach that is used is based on link layer to reduce the handoff delay which is compatible with the existing Mobile IP specifications. A software probing mechanism is used to detect the link-layer handoff and trigger a control message. A dedicated router and bridge with a control message can reduce the handoff delay successfully. The control message will notify the router and bridge to change the forwarding path, making the

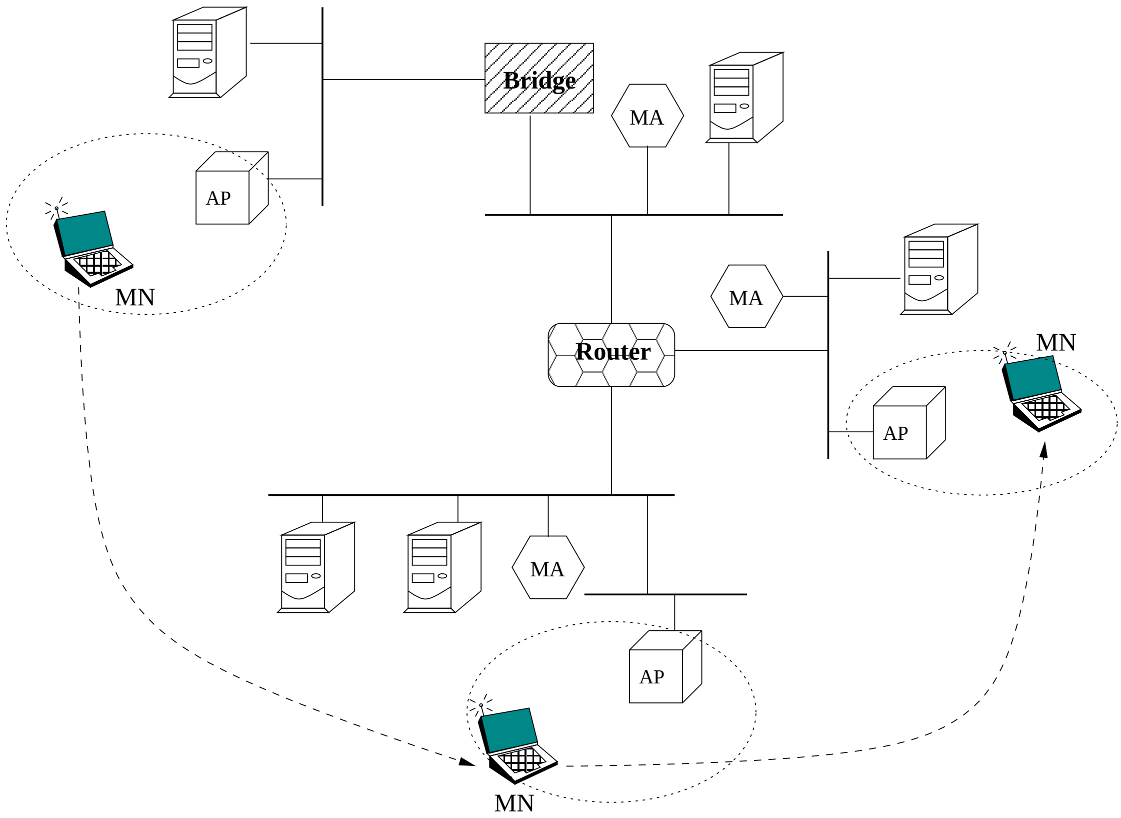


Fig. 1. The general network environment.

roaming node receive the data before the Mobile IP registrations are completed.

B. Fast Link Layer Handoff

B.1 Movement detection

In an IEEE 802.11-based infrastructure-mode wireless LANs, the movement of MN can be detected after its wireless interface card compares the difference between the signal strengths of the two APs and initiates a link-layer handoff. In all known IEEE 802.11 cards, this link-layer handoff logic is built into the firmware, and does not generate any interrupts to notify the system. Although the wireless interface cards do not provide any information to notify the system about link-layer handoff happened, there is a hardware control functionality that allows software to probe the identity of the AP with which a wireless interface card is currently associated.

To detect the change of these kinds' registers, the proposed approach uses the software probing algorithm in the Fig. 2 of [16]. The designed control message will be sent when the associated AP changed to trigger the following operations. Actually, in order to reduce the cost and commoditize cards, IEEE 802.11 card vendors [1], [14] are minimizing the functionality of the code residing in the microcontroller of their cards. These next generation of wireless interface cards implement just the basic time-critical MAC functions, while leaving their control and configuration to the operating system. Therefore, the operating system can detect the change of associated AP directly, and the cost of the software probing algorithm can be eliminated completely.

B.2 Fast data forwarding

Taking into consideration a simple network in Fig. 2, the host B is attempting to send packets to the MN A in segment S_1, but due to A moving to a new area, area S_2, it can not receive any data packets before it completes all Mobile IP registrations.

By only using the Mobile IP to handle this handoff it will create a big latency and will degrade the transmission performance. This occurs because A must detect itself entering into a new communication range by receiving the Mobile IP advertisement from AP_2 and registering the MA on S_2 to be its FA. The FA needs to exchange the registration information with the HA of A and completes the data forwarding transfer, then A can continue to receive packets from B. According to the experiment in Section V, this Mobile IP handoff will take about 3 seconds, causing B to start TCP retransmission policy and leave a gap in data transmission. This gap will cause several seconds delay before A can receive the packets sent from B.

This handoff delay is a serious consequence in real-time application and will degrade the transmission quality. So the proposed method endeavors to reduce this handoff delay and make sure data packets can be delivered to the correct communication range before the MN completes its Mobile IP registration.

Bridge and L2-Module are used to change the transmission path of the data frame before the Mobile IP registration is complete. This can reduce the handoff delay to prevent the loss of many packets allowing the data packets to be continually received by the receiver. This approach requires the following

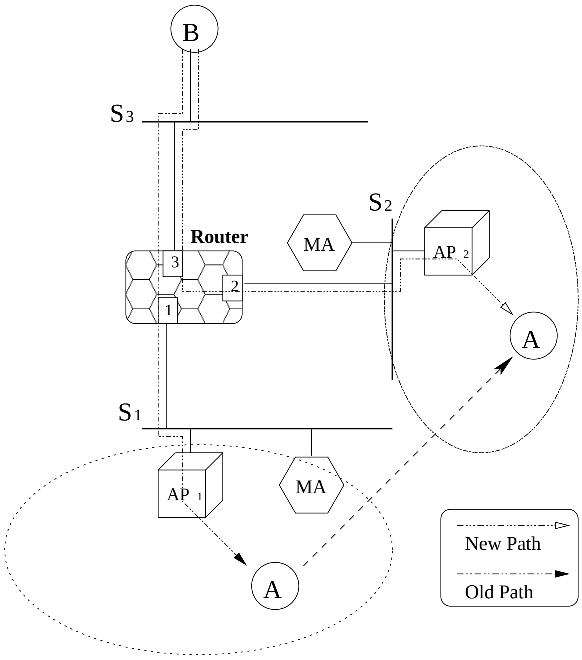


Fig. 2. A simple network.

Host	Port
A	1 → 2

Table 1. The FDB table in Fig. 2.

Router (L2−Module)

Host	Port
A	1 → 2
B	2
C	3
D	2
E	1

Bridge 1

Host	Port
A	2
B	2
D	1
E	2

Bridge 2

Host	Port
A	1 → 3
B	3
D	3
E	2

Bridge 3

Host	Port
A	2 → 1
B	3
D	2
E	2

Table 2. The FDB table in Fig. 3.

changes to be made in an existing network.

MN: When the MN detects its migration by software probing, a control message will be sent - the *routing update message (RUM)*. The MN will put its own MAC address in the message then it has the same source and destination MAC address in the Ethernet header.

Bridge: When the bridge receives a RUM, it will forward the data frame to all the ports exclusive of the received port and then rely on the MAC address in this frame to update its FDB table. Other forwarding procedures remain unchanged. The algorithm in Algorithm 1 is used to describe this method[1].

L2-Module: This module is worked as a bridge and added into router to create a fast forwarding data path. The different is it only forwards the frame which destination matches the entry in FDB table, if it passes all other frames to upper layer. The algorithm in Algorithm 2 is used to describe this method.

Take Fig. 2 as an example. After A reaches S_2 and detects AP_2, it will send a *RUM*. This message goes through AP_2 which is then received by router from port2. This makes L2-Module update its FDB table and forward it to port1. The change of FDB table is show in Table 1.

The previously discussed approach concerning a network with Large Extended LANs is demonstrated in Fig. 3. The result of this approach in the FDB table can be seen by the change from Table 2. This effect can make the data frame be delivered to the correct destination before all Mobile IP registration is completed which reduces the data loss caused by handoff delay.

The detailed actions are described below:

(i) After A detects AP_2, it knowingly enters into a new segment S_2, and then A will send a *RUM*.
(ii) AP_2 receives the *RUM* and sends it out to $Bridge_3$. $Bridge_3$ will then receive the message from its port1.
(iii) After $Bridge_3$ uses the proposed algorithm to handle the data frame it will forward this *RUM* to port2 and port3 then update its FDB table.
(iv) The *RUM* which is sent out from the port2 of $Bridge_3$ will be received by the port2 of $Bridge_1$, and Router. After updating the FDB table the *RUM* will be sent out from the port1 of $Bridge_1$, and Router.
(v) The *RUM* which is sent out from the port1 of Router will be received by port3 of $Bridge_2$. After updating the FDB table, $Bridge_2$ will send out the message from its port1 and port2.

After the above actions are performed, all FDB tables are updated in the entire network. The data transmission path from C to A also changes and allowing the data to travel faster forward within the link layer.

C. Enhanced Fast Link Layer Handoff

Regardless of a wired or wireless network, the data transmission has a message delay problem. Therefore, this problem may also affect the *RUM*. In the Fast Handoff method [20], if the message delay problem occurs in any control message, it will result in the data frame continuing to deliver to an incorrect destination until the Mobile IP registration is completed. This will lead to the Fast Handoff method becoming useless.

In the proposed approach, the MN will add a Sequence Number (SN) into every *RUM*. This SN will increment every time

[1]The bridge also needs to use Distributed Spanning Tree Algorithm [13] to prevent the loop-path situation.

When the bridge receives a frame from port **x**, it determines the physical addresses of its source, **i** , and of its destination, **j**. If **j** is a multicast address, the frame is then forwarded through all other ports except the port **x**.

If the pair [**i** , **x**] does not exist in the FDB table, it is added.
If [**j** , **x**] is in the FDB table and **j != x** then
    the frame is discarded
else if **i == j** then **(this means the received frame is *routing update message*)**
    it is forwarded to all ports except **x** and update the FDB table
else if there is a pair [**j** , **y**] in the cache then
    the frame is forwarded through port **y**
else
    it is forwarded to all ports except **x**

Algorithm 1. The operations of the bridge.

When the L2−Module receives a frame from port **x**, it determines the physical addresses of its source, **i** , and of its destination, **j** .

If **i == j** then **(this means the received frame is *routing update message*)**
    it is forwarded to all ports except **x** and update the FDB table
If there is a pair [**j** , **y**] in the cache then
    the frame is forwarded through port **y**
else
    it is passed to upper layer

Algorithm 2. The operations of the L2-Module.

Host	Port	SN
A	1	4
B	3	2

Table 3. FDB table in enhanced FLLH.

the MN sends out the *RUM*. As the bridge and L2-Module can only process the data frame of link layer, so the SN is to be placed into the *type* field of Ethernet header. If the bridge and L2-Module receive a *RUM*, it will compare whether the SN in the control message is larger than the SN in its FDB table or not. If it is larger, the entry in FDB table will be updated in addition to discarding the control message[2].

The FDB table is used by enhanced FLLH similar to Table 3, if the bridge and L2-Module receive a *RUM* from A and its SN is 3, this means that a message delay has occurred and the control message will be discarded. The SN must be larger than 4, then the FDB table can be updated by the control message.

V. PERFORMANCE ANALYSIS

In this section, the performance of the FLLH is analyzed in an experimental network environment as shown in Fig. 4. Mobile-IP releases for FreeBSD 4.9 of Secure Mobile Networking project developed by PSU [15] are used as a Mobile IP software suite. The driver used for the Orinoco wireless interface card is a modified version. The modification is to provide the software probing functionality to retrieve the ID of the current AP. The HA, AP_1 and FA, AP_2 are multi-function stations and work as a Mobile Agent and Access Point at the same time. The L2-Module is added into router. The wired LAN portion was constructed with 100Base-T and the wireless LAN portion was constructed with 802.11b.

A. Link-layer Handoff Experiment

The link-layer handoff is controlled by the wireless interface card itself. From the empirical analysis by Mishra *et. al.* [11], it shows that link-layer handoff latency has large variation. This handoff duration is between 30 to 550 ms due to the particular AP and wireless interface card are used. In this experiment, the beginning and the end of link-layer handoff latency are marked by reception of the last packet on the old subnet and the first packet on the new subnet. The Fig. 5 illustrates the link-layer handoff time measurements. It can be observed that the different values ranging from 30 to 90 ms with no apparent distribution. However, most of the link-layer handoffs are observed to be completed in the range from 40 to 50 ms. The average value of the link-layer handoff in our testing bed is 46.72 ms. Thus, the control message usually can be triggered after 50-60 ms from the link-layer handoff begins if the **Threshold** of software probing sets to two.

[2]The *type* field only has two bytes, so it has an opportunity for wrapped SN. Therefore, if the SN in *RUM* is smaller and far from the one in FDB table, e.g. 3 in *RUM* and 65530 in FDB table, the FDB table still will be updated.

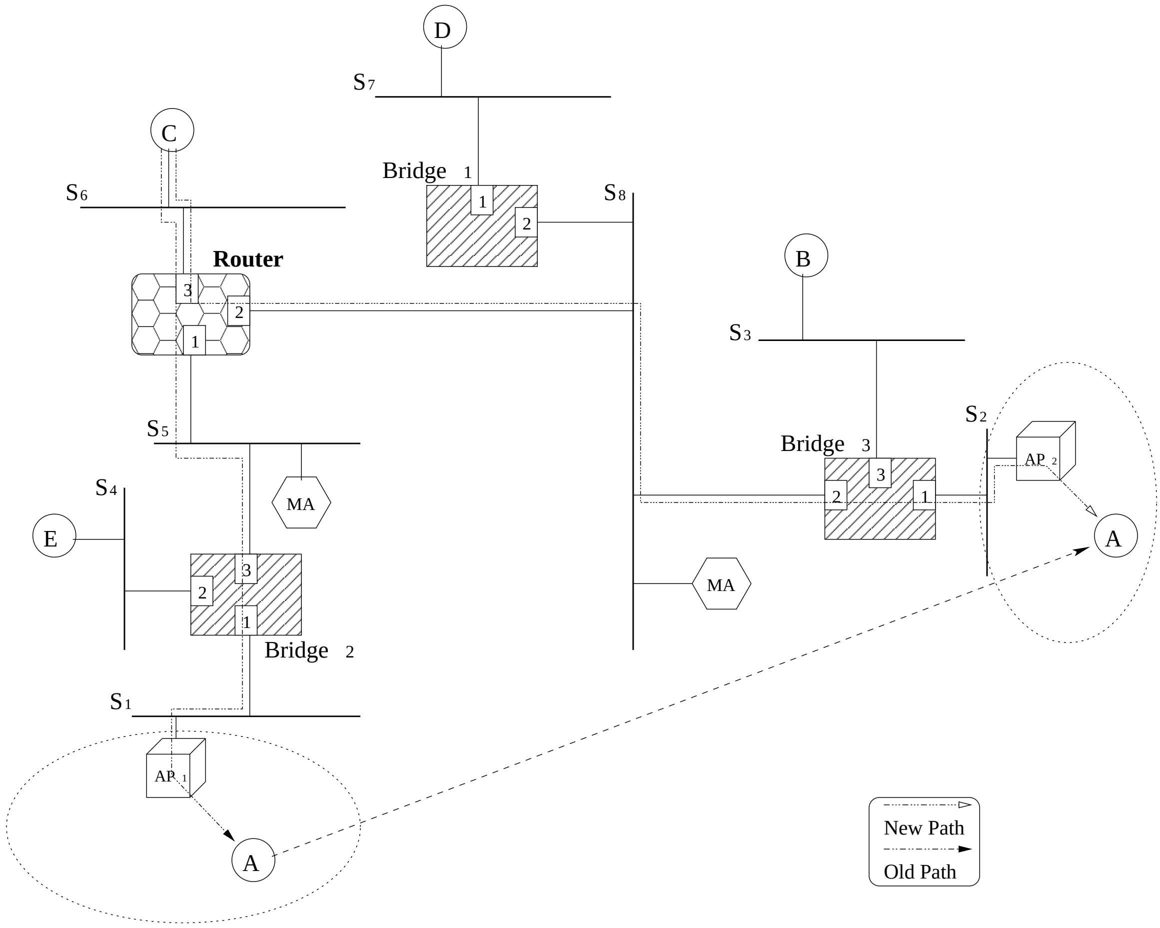
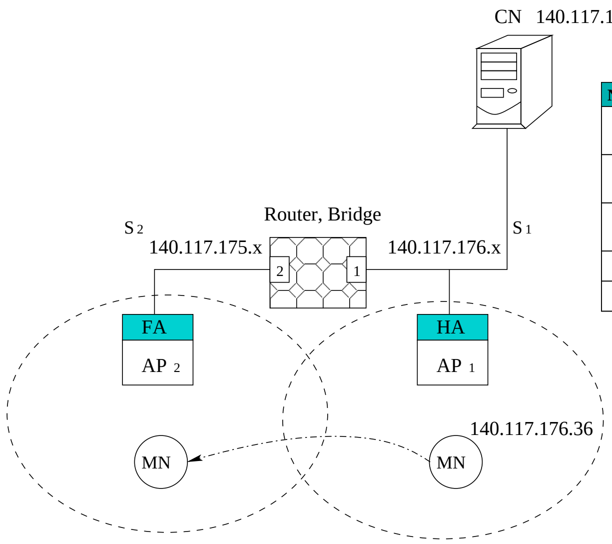


Fig. 3. A network with Large Extended LANs.



Node Name	CPU	NIC	OS
AP_1, HA	AMD K6−2 450MHz	Realtek 8139c(wired) Accton EW−3201(wireless)	FreeBSD 4.9
AP_2, FA	AMD K6−2 450MHz	Realtek 8139c(wired) Accton EW−3201(wireless)	FreeBSD 4.9
Router, Bridge	VIA C3 1GHz	VIA VT6103(Port1) D−Link DFE−530TX(Port2)	FreeBSD 4.9
CN	AMD K6−2 450MHz	Realtek 8139c	RedHat Linux 9.0
MN	Intel Pentium−3 500MHz	Orinoco 802.11b Silver	FreeBSD 4.9

Fig. 4. Experiment Network.

B. UDP Transmission Experiment

The Corresponding Node (CN) is made to transmit 64 bytes of UDP packets to the MN at 50 ms intervals to measure the handoff period, the results are shown in Fig. 6. The Fig. 6(a) shows the case where only the Mobile IP is used and it can be seen that 2.4 seconds of disruption occurs during handoff and 47 packets are lost. It can also be seen that the transmission times of the 20th, 98th and the 184th packets in the same figure are larger than those of the other packets. This is thought to have been caused by retransmission on the wireless link. After

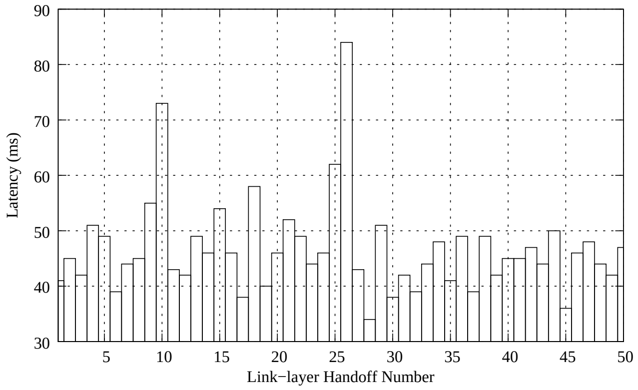
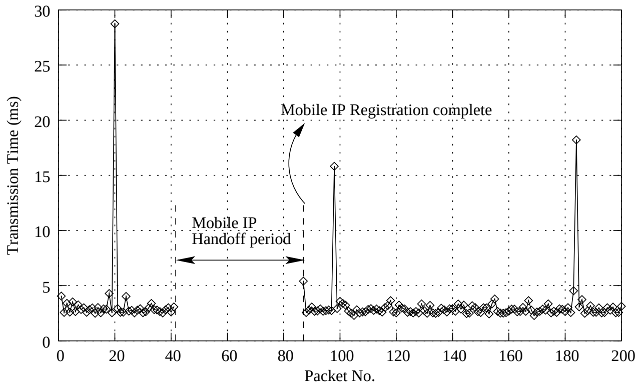
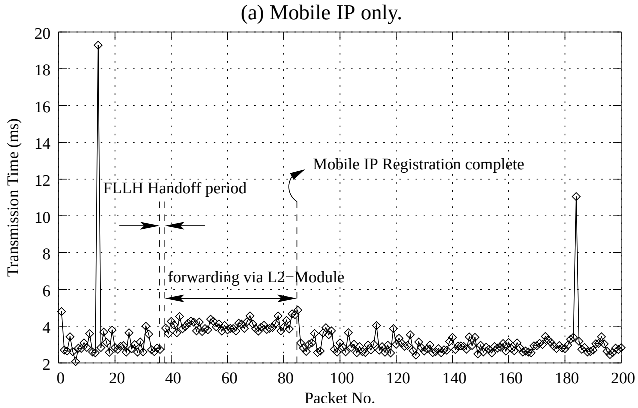


Fig. 5. Link-layer Handoff Latencies.



(a) Mobile IP only.



(b) Mobile IP with FLLH.

Fig. 6. UDP Packet Transmission Experiment.

Mobile IP registration is completed, the transmission times of the first packet (87th) received by the MN is 3 ms more than the other packets. This is caused by updating of the routing table.

Fig. 6(b) shows the case where the FLLH has been used. In this figure, it can be seen that the FLLH takes about 60 ms to establish a new forwarding path and causes only one packet to be lost. Although the FLLH still causes a packet to be lost, it can forward UDP packets to the correct destination before Mobile IP registration complete. About 1 ms is added to the transmission time due to the processing in the L2-Module. The results show that the proposed method can make the data continue to be received by the roaming MN before completing its Mobile IP registration process and reduce the influence caused by handoff effectively. The real-time applications such as audio and video (e.g., QuickTime Player [2]) usually have a buffer to eliminate the lag. If the proposed method is used and the player keeps few buffers, then the lag can be eliminated completely.

C. TCP Transmission Experiment

To be able to evaluate the TCP transmission experiment the CN was used as the File Server and the MN was used to download a 15 mega byte file from the CN through a File Transfer Protocol (FTP). The sender follows Reno TCP [4] and the receiver uses the delayed ACK. On the receiver side the buffer is 16K bytes (the default setting). During the file transmission the handoff is made by moving the MN from the communication range of AP_1 to AP_2. The evaluation of the results is shown in Fig. 7.

The cases where only the Mobile IP is used are shown in Fig. 7(a) and 7(b), it can be seen that the 3.35 and 7.56 seconds of disruption occurs respectively. Fig. 7(c) shows the case where the FLLH method is used and 1.02 seconds of disruption occurs. In the following section the reason for this difference will be discussed. In the before mentioned statement, it is known that if the connection is bi-directional (e.g., TCP) it will cause a larger communication disruption compare to the unidirectional one (e.g., UDP). In Table 4, the static MN is used to be the base of the measurement and then it is compared with the three situations in Fig. 7. From this table, it is known that the handoff degrades the transmission performance and the result of the comparison shows that the proposed method can substantially eliminate the harm caused by the handoff.

Comparison data	Transmission rate (KB/s)	Transmission time (s)	Performance ratio
Static MN	573.10	26.8	100%
Fig. 7(a)	514.41	29.86	89.76%
Fig. 7(b)	453.64	33.86	79.16%
Fig. 7(c)	549.39	27.96	95.86%

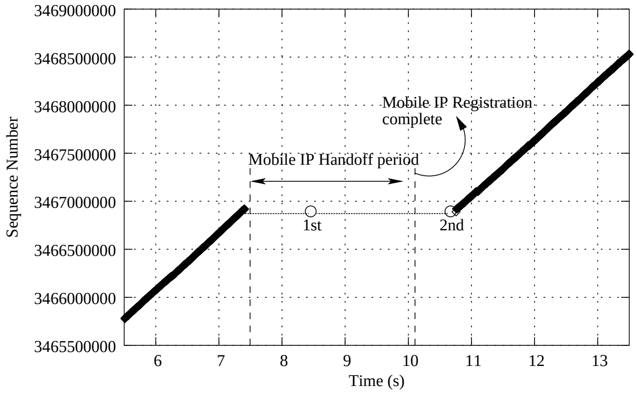
Table 4. Transmission performance comparison.

VI. DISCUSSION

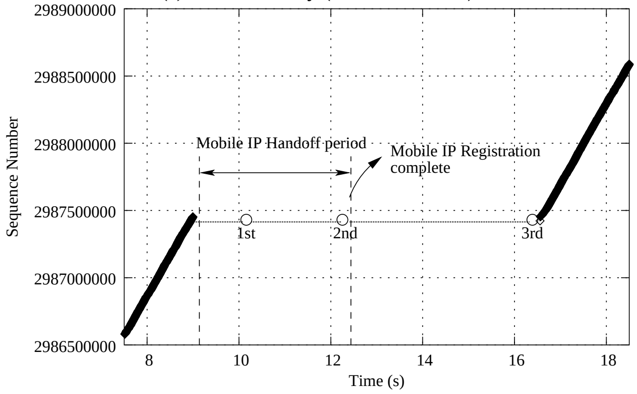
A. TCP retransmission

The TCP retransmission policy is responsible for retransmitting lost packets to guarantee the reliability of the transmission data. But it will degrade the throughput if the handoff has occurred. Fig. 7(a) shows that packet loss occurs at the 7.4th second when the MN started to move. The Mobile IP handoff is completed by the 10.1st second; however the MN is not able to receive packets again until the 10.75th second. Therefore there is a space 0.65 seconds of silent time which is caused by TCP retransmission.

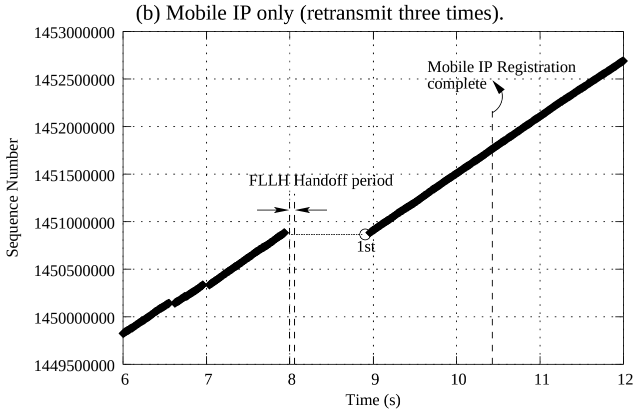
In Fig. 7(b), the throughput degradation is more serious. The packet loss occurs at the 9.1st second and the Mobile IP handoff is completed at the 12.4th second, however it is not until the 16.56th second that the MN continues to receive packets again.



(a) Mobile IP only (retransmit twice).



(b) Mobile IP only (retransmit three times).



(c) Mobile IP with FLLH.

Fig. 7. TCP Packet Transmission Experiment.

The silent time duration is 7.46 seconds. The TCP retransmission causes the extra 4.16 seconds of silent time which is much larger than the condition in Fig. 7(a). The condition in Fig. 7(a) is evaluated in a very low loading network environment (only the necessary connections exist). The experiment network environment in Fig. 7(b) has some other data transmissions and is close to the real network environment; therefore it will be discussed below.

In a typical TCP implementation, the lower and upper bound of the retransmission timer are 1 second and 64 seconds, respectively [18]. The retransmission timer was set to 1 second (the minimum value) at the 9.1st second. The retransmission timer expires during the MN handoff then approximately 1 second later (at the 10.15th second) the lost packet was then retransmitted. At this time, the retransmission timer is multiplied by an element of the array for the exponential backoff $\{\mathbf{1, 2, 4, ..., 64}\}$, and is set to 2. At the 12.2nd second, the packet is retransmitted for the second time and the retransmission timer is set to 4, therefore the third retransmission is invoked at the 16.3rd second. It can be seen in the Fig. 7(b), that the packet is retransmitted three times. Since the Mobile IP handoff may occupy 3 seconds, retransmission could occur 2 to 3 times, so that the interruption of the data transmission due to handoff may be between 3 to 7 seconds.

The fast forwarding data path is established in 60 ms when the proposed method is used as shown in Fig. 7(c). Since the minimum value of the TCP retransmission timer is 1 second, so the packet will be retransmitted at the 8.96th second. The duration of time that data transmission is interrupted does not depend on the Mobile IP handoff, and its maximum value is always 1 second. Even in a network with Large Extended LANs, the FLLH handoff period only increased with the number of network segments which the *RUM* went through. This proves that the lost packet is being retransmitted for the first time and will reduce the degradation of transmission performance substantially, only if the moving speed of the MN is less than the transmission rate of electric signal.

When noting that multiple packets could be lost during handoff, Reno TCP terminates the fast retransmit as soon as one packet is lost and subsequent packets lost causes a slow start making it more difficult to reduce the influence of interruptions in data transmission [7]. In this case of multiple packets lost during handoff, the NewReno TCP [5] or the SACK option [10] will effectively improve the situation.

B. Buffer Agent

To achieve seamless handoff, the packet lost of bidirectional connection (e.g., TCP) should be eliminated. Some proposals suggest using a network device to buffer the connection data, but with no further discussions on how many packets should be cached. In this paper, a network device called *Buffer Agent (BA)* is proposed to solve the problem and is described as follows.

(i) *BA* should be added to each network segment intended to provide wireless communication.
(ii) *BA* is not necessarily an independent network device. It could be bound with MA or any other devices on the WLANs.
(iii) All frames sending out from *BA* after receiving a *RUM* will use the MAC address in the *RUM* as their destination.
(iv) There is a reference table in *BA* to record each IP address and its corresponding MAC address.
(v) Since a bidirectional connection could be identified by its socket pairs, *BA* will buffer only one packet for each direction of the connection. After receiving a *RUM*, *BA* will
    (1) Check its reference table to find the corresponding IP address of the MAC address in *RUM*.
    (2) Search in the buffer for the packet with the IP address as its destination.
    (3) Send the packet to the IP address.
(vi) *BA* will also cache the latest ICMP router advertisement and send it out upon receiving a *RUM*. The recipient of

the ICMP router advertisement will then change its default router setting and then be able to send packets out.

Considering an example in Fig. 4, BA_1 and BA_2 are added to S_1 and S_2 respectively. After MN detects AP_2 and sends a *RUM*, the *RUM* will be received by BA_2. BA_2 will then respond by sending the latest ICMP router advertisement it cached to MN. The *RUM* will also be received by BA_1. BA_1 will then respond by sending all the buffered packets with destination address same with MN's IP address to MN. Since the *RUM* has changed the forwarding data path of all routers and bridges, the packets responded from BA_1 can reach MN without any problem. Therefore, no packet lost will occur in this method.

Since there is no packet lost, TCP retransmission policy will not start. The factors causing performance degradation such as slow start will also be eliminated. The transmission time in Table 4 can reduce to 26.89 seconds and achieve a high performance ratio as 99.67%.

VII. CONCLUSIONS

In this paper the Fast Link Layer Handoff method which is completely independent of network layer has been discussed; therefore, no matter Mobile IPv4 or Mobile IPv6 is used, the proposed method can work correctly. A software probing mechanism is used to detect the link-layer handoff and trigger a control message. A *routing update message (RUM)* is used to change the forwarding path in a bridge and router. These can help the data be delivered to the correct destination before all Mobile IP registrations are completed. This method can be used in either a simple wireless network or the network with Large Extended LANs. The enhanced version can further solve the problem within the message delay. By using the proposed method, the packet transmission interruption due to Mobile IP is reduced to the same time as a FLLH handoff. The TCP retransmission times can be reduced only once. Furthermore, a buffer agent designed can eliminate the packet lost of bidirectional connection completely. Therefore the communication quality can be kept at a reasonable level. Even real-time applications can also work under an acceptable situation.

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