Mobile IP 지원 무선 랜 상에서 링크 계층의 지원을 통한 연속적인 미디어 스트리밍

(Link-layer Assisted Seamless Media Streaming over Mobile IP-enabled Wireless LAN)

이철호 [†] 이동욱 [††] 김종원 [†††]
(Chul-Ho Lee) (Dongwook Lee) (JongWon Kim)

요 약 Mobile IP를 지원하는 무선 랜 환경에서 링크 계층 핸드오프와 Mobile IP의 IP 계층 핸드오프로 인해 데이터 전송이 일시적으로 중지되며 이는 스트리밍 클라이언트의 버퍼 언더플로우를 유발하고 다량의 패킷 손실을 발생시킨다. 이들은 연속적인 미디어 스트리밍을 제공함에 있어서 치명적인 문제점으로 작용한다. 아직까지 실시간을 요하는 스트리밍 미디어 응용프로그램에 대한 핸드오프 방식에 따른 실제적인 영향을 고려한 실험적 연구들이 거의 없었기 때문에 그 필요성이 제기되고 있다. 본 논문에서는 Mobile IP를 지원하는 무선 랜 환경에서 사전 버퍼링의 적용을 통하여 핸드오프 시에 발생하는 핸드오프 지연을 보상하는 미디어 스트리밍 구조를 소개한다. 추가로 L2 (layer 2) 트리거 기반의 패킷 버퍼링과 포워딩 기능의 구현과 스트리밍 클라이언트에서의 핸드오프를 인지하는 사전 버퍼링의 적용을 통하여 핸드오프 시에 발생하는 핸드오프 지연 및 패킷 손실을 극복한다. 실험을 통해 제안된 방식이 핸드오프 시에 발생하는 핸드오프 지연 및 패킷 손실을 극복하고 연속적인 미디어 스트리밍을 가능하게 함을 확인한다.

키워드 : Wireless LAN, Mobile IP, link-layer trigger, smooth handoff, MPEG-4 video streaming, and pre-buffering estimation

Abstract In Mobile IP-enabled wireless LAN (WLAN), packet flows are corrupted due to the handoff of a mobile node (MN) at the link and network layers, which results in burst packet losses and can cause temporary buffer underflow in a streaming client at the MN. This transient behavior hurts time-sensitive streaming media applications severely. Among many suggestions to address this handoff problem, few studies are concerned with empirical issues regarding the practical validation of handoff options on the time-sensitive streaming media applications. In this paper, targeting seamless streaming over Mobile IP-enabled WLAN, we introduce a seamless media streaming framework that estimates accurate pre-buffering level to compensate the handoff latency. In addition, we propose a link-layer (L2) assisted seamless media streaming system as a preliminary version of this framework. The proposed system is designed to reduce the handoff latency and to overcome the playback disruption from an implementation viewpoint. A packet buffering and forwarding mechanism with L2 trigger is implemented to reduce the handoff latency and to eliminate burst packet losses generated during the handoff. A pre-buffering adjustment is also performed to compensate the handoff latency. The experimental results show that the proposed approach eliminates packet losses during the handoff and thus verify the feasibility of seamless media streaming over Mobile IP-enabled WLAN.

Key words : Wireless LAN, Mobile IP, link-layer trigger, smooth handoff, MPEG-4 video streaming, and pre-buffering estimation

---

† 비 회 원 : 노스캐롤라이나 주립대학 전기 및 컴퓨터공학과
clee4@ncsu.edu
†† 비 회 원 : 삼성전자 Digital Media & Communications 부분 무선사업부
dwmax.lee@samsung.com
††† 종신회원 : 광주과학기술원 정보통신공학과 교수
jongwon@nm.gist.ac.kr

논문접수 : 2007년 4월 25일
심사완료 : 2009년 7월 8일

정보과학회논문지: 컴퓨팅의 실제 및 레터 제15권 제9호(2009.9)

1. Introduction

Mobile devices such as PDAs and laptop computers come into wide use and the demand for IP-based multimedia services on mobile devices over wireless networks increases rapidly. Mobile IP is a protocol to provide IP mobility [1].[1] In Mobile IP-enabled wireless LAN (WLAN), a mobile node (MN) can communicate with correspondent nodes regardless of their locations. The MN can also move to another network while accessing one network. To provide this IP mobility, Mobile IP defines the handoff procedure between different sub-networks.

Mobile IP was originally designed without any assumption about underlying link layer and thus the handoff procedure of the MN consists of both link-layer (L2) and IP-layer (L3) handoffs. In Mobile IP-enabled WLAN, when the MN changes its associated access point (AP) to another one, it suffers some latency caused by the scanning, authentication, and association processes for the L2 handoff [2]. Moreover, in L3 handoff, it also spends time to discover a new foreign agent (nFA) and to perform the registration process. These handoff latencies interrupt packet transport and thus packets are not delivered to the MN during the handoff, causing temporary buffer underflow in a streaming client at the MN. This transient behavior hurts time-sensitive streaming media applications since the playback of streaming media can be temporarily stopped. To date, a number of solutions have been suggested to address this handoff-related problem. However, only few studies are concerned with empirical issues regarding the practical validation of handoff options on the time-sensitive streaming media applications.

In this paper, targeting seamless streaming over Mobile IP-enabled WLAN, we introduce a seamless media streaming framework based on the estimation of accurate pre-buffering level to compensate the handoff latency. We also propose a L2 assisted seamless media streaming system as an initial version of this framework by extending the previous work in [3]. The proposed system supports the following features. First of all, a L2 trigger (event) about the change of AP association by a wireless network interface is utilized to reduce the agent discovery time of L3 handoff. A packet buffering and forwarding mechanism (a.k.a., smooth handoff [5]) is also implemented to eliminate burst packet losses during the L2/L3 handoffs. Note that we are discussing the causes of packet losses during the handoff and related solutions from the viewpoint of implementation. Moreover, a pre-buffering adjustment scheme is performed based on the suggested estimation of handoff latency, which effectively combines the operational measurement and the transient time analysis of [4]. With the appropriate latency estimation, all forwarded packets through the packet buffering and forwarding can be ready in time for the continuous playback of streaming media. Finally, the performance of the proposed system is validated with the MPEG-4 video streaming over Mobile IP-enabled WLAN. The experimental results show that the proposed approach can eliminate packet losses during the handoff and thus validate the feasibility of seamless media streaming.

The rest of the paper is organized as follows. Section 2 describes the handoff-related problems of time-sensitive streaming media applications and related work. In Section 3, we introduce the proposed seamless media streaming framework. In Section 4, we explain the proposed system to overcome handoff-related problems for seamless media streaming over Mobile IP-enabled WLAN. Next, the implementation of the proposed system is detailed in Section 5. We also present experimental results and discussions. Finally, we conclude this paper in Section 6.

2. Media Streaming over Mobile IP-enabled WLAN

For the time-sensitive streaming media applications, media streams have to be transported continuously, overcoming the fluctuations of network resources and system limitations. In general, the media streaming over wireless networks experi-

---

[1] Note that, although specific discussions in this paper are based on Mobile IPv4, the proposed seamless media streaming framework can be applied to both Mobile IPv4 and IPv6 environments.

ences time-varying delay, loss, and bandwidth due to the following reasons. First, the available bandwidth is relatively scarce and limited compared to wired networks. Moreover, time-varying delay and jitter happen due to the wireless channel variation and the channel contention to access shared wireless medium. Channel errors caused by fading and shadowing effects are not deterministic and lead to packet losses. Hence, it causes poor match with traditional transport-layer protocols. In addition, the mobility issues (including the handoff-related problems) raise transient packet losses and transport disruptions. There are other limitations such as security and power consumption of the wireless terminals. Among these challenges, in this paper, we concentrate upon the handoff-related problems in Mobile IP-enabled WLAN. Note again that the transient behavior during the handoff is critically related to the success of seamless streaming media applications.

2.1 Problem Statement

Handoff latency: In Mobile IP-enabled WLAN, when a MN moves to another foreign network, it experiences handoff latency due to the following reasons. First, IEEE 802.11 L2 handoff is *hard* and *forward*, which means that the connection with an old AP (oAP) is terminated before the connection with a new AP (nAP) is established, and that the L2 handoff is not predicted and initiated by the nAP instead of the oAP, respectively. Thus, the MN can communicate with only one AP at each time and cannot communicate with an old FA (oFA) during the L2 handoff. This L2 handoff latency is caused by the time taken to perform the scanning, authentication, and re-association processes. In addition, Mobile IP is independent of any underlying link-layer. Thus, the link and IP layers are clearly separated and L3 handoff begins only after the L2 handoff is completed. Without explicit L2 notifications (i.e., L2 triggers[2]), the IP and upper layers cannot catch the occurrence of the L2 handoff immediately. Hence, the MN should spend time (i.e., agent discovery time) before discovering changes of the network attachment by receiving an *Agent Advertisement* message from a nFA. It depends on the sending interval of the *Agent Advertisement* message. In Mobile IP specification [1], the maximum limit of this sending interval is recommended as 1 *sec*. That is, the agent discovery time varies between 0 *sec* and 1 *sec* and the worst case is set to 1 *sec*. Note that this agent discovery time is one of the longest in total handoff latency. Subsequently, the registration process of L3 handoff also takes some time to be completed, since the registration messages should propagate to a home agent (HA). Therefore, besides L2 handoff latency, L3 handoff latency is caused due to the agent discovery and registration process. The overall handoff procedure and required handoff latencies are depicted in Fig. 1.

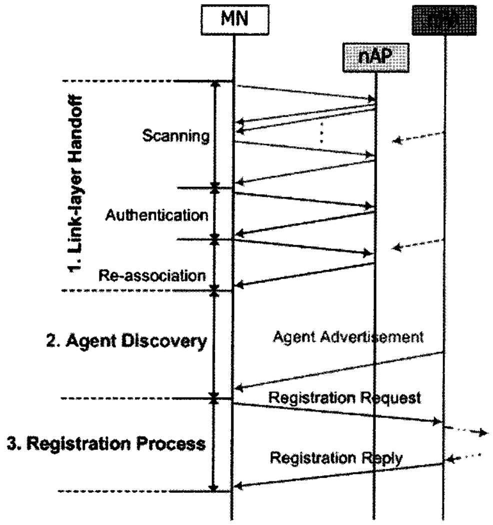


Fig. 1 Handoff procedure and involved latencies in Mobile IPv4

Packet loss: When a MN visits a foreign network, its HA handles packets, destined to the home address of the MN, as a proxy. It then sends these packets through IP-in-IP tunneling to a care-of address (CoA) that indicates the termination point of a tunnel toward the MN side. If the MN moves (i.e., performs L2/L3 handoffs) to another foreign network, it cannot receive any packet. Since these packets are destined to an old CoA and the MN

---

[2] The L2 trigger is described as the information from the link layer that informs to the network (i.e., IP) layer about particular events before and after the L2 handoff [10]. The description of L2 trigger is not specific to any particular link layer.

cannot communicate with an oFA during the handoff, there exist burst packet losses. To the time-sensitive streaming media applications, the interruption of packet transport and burst packet losses during the handoff can cause temporary buffer underflow at a streaming client. Buffer underflow results in the starvation of the playout process, which causes video frame and audio playback to be frozen and interrupted, respectively. Buffer underflow is especially critical for the video since the decoding of current frame usually requires the successful decoding of previous frames. A single missing packet may therefore prevent successful decoding of several subsequent frames. When the buffer underflow happens, the streaming media application typically freezes the last frame and wait for the next re-synchronization frame (I-frame) before resuming the playout. To achieve seamless media streaming, we should avoid (or reduce) this transient behavior.

2.2 Related Work

To mitigate the negative impact of handoffs, several handoff ideas have been suggested to reduce the handoff latency and to minimize packet losses in Mobile IP [5]-[11]. A packet buffering and forwarding mechanism (a.k.a., smooth handoff) in [5] can eliminate packet losses during the handoff. It is either a required component or complementary with several handoff schemes [8]-[11]. However, in the time-sensitive streaming media applications, occasionally forwarded packets (through the packet buffering and forwarding) cannot arrive in time for continuous playback. In [6], WLAN ad-hoc mode is assumed to realize a fast handoff scheme. This scheme may not be applied to WLAN hot spots, since WLAN is usually operated in an infrastructure mode for performance and management reasons. Another handoff scheme in [7] is limited since special arrangements such as a media access control (MAC) bridge, additional resource, and corresponding signaling are needed. Instead of L2 trigger, in [8], by periodically checking the accessed MAC address of an associated AP, a fast detection for L2 handoff is proposed at the cost of polling overhead. Also, although smooth handoff scheme in [8] can be used with a HA to eliminate packet losses, this approach can cause excessive processing load on the HA. Note that it should process, buffer, and send whole packets separately which are destined to each home address of several MNs. In addition, another L2 trigger-based handoff scheme is proposed in [9]. Since we need to modify management frames of IEEE 802.11 and to implement a WLAN AP with Mobile IP FA functionality, it is hard to realize this scheme with legacy IEEE 802.11 WLAN devices. Also, they describe the importance of estimating the required amount of buffering at FA, without suggesting a practical solution. On the other hand, pre- and post-registration methods are proposed for low-latency Mobile IPv4 handoff in [10], which rely on several types of L2 triggers. However, since this L2 handoff for WLAN is *hard* and *forward* as discussed before, the required L2 triggers are not easy to be realized. Similarly, for Mobile IPv6, a fast handoff scheme [11] is recently finalized in IETF RFC 4068. However, it also depends on special types of L2 triggers. In the context of IEEE 802.11 WLAN [12], deployment examples are discussed for Mobile IPv6 fast handoff and limitations of existing devices (i.e., lack of required triggers for predictive handoff) are mentioned.

Even with smooth and low-latency handoff options, seamless media streaming (i.e., without any playback disruption due to the handoff) is not easy to achieve in a practical situation. Since no packet will be delivered to a MN during the handoff, this can cause temporary buffer underflow at a streaming client of the MN. Thus, to avoid buffer underflow, one has to pre-buffer the packets sufficiently before the handoff. Note that the required level of pre-buffering depends on the efficiency of adopted L2/L3 handoff options. So far, few studies are concerned with empirical issues regarding the practical validation of these handoff options on the time-sensitive streaming media applications.

3. Proposed Seamless Media Streaming Framework

In this section, we introduce a proposed seamless media streaming framework in Mobile IP-enabled WLAN, where IEEE 802.11 WLAN devices are

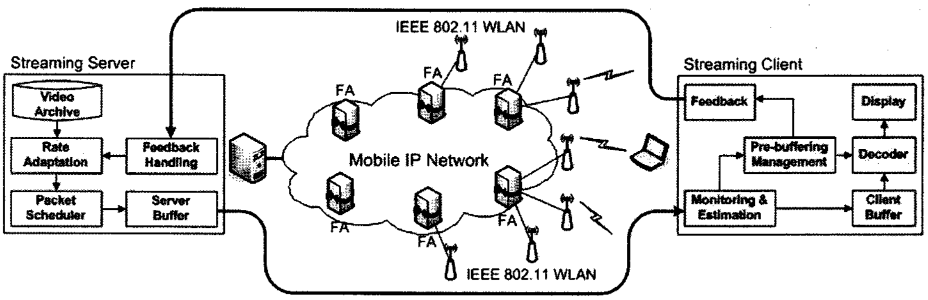


Fig. 2 Proposed seamless media streaming framework in Mobile IP-enabled WLAN

configured in an infrastructure mode. It is depicted in Fig. 2. A streaming client on a MN receives packets from a media server while keeping appropriate amount of packets to overcome network fluctuations such as available bandwidth, delay, jitter, and packet loss. The streaming server reacts to the feedback from the streaming client and performs quality adaptation and packet scheduling. The streaming client periodically sends its status information to the server, which includes current buffer occupancy, receiving rate, and error rate. Many studies on the relationship between feedback and reaction have been reported in [13].

In the proposed framework, handoff latency is estimated before a handoff occurs. To estimate the handoff latency, the MN monitors network conditions such as link delay, flow rate, and queue status of the neighbor FAs. In addition, the handoff protocol and related signaling procedure are analyzed to get the handoff latency. After estimating the handoff latency, the streaming client tries to prepare sufficient level of pre-buffered packets to compensate the estimated interruption time of possible handoff while keeping playback of the received media packets. There are two choices to boost the target per-buffering level, which is decided based on the estimated handoff latency. One may increase the sending rate at the streaming server or decrease the playback speed at the streaming client. The choice depends on the policy of pre-buffering management module. Since the network conditions (e.g., link delay, flow rate, and queue status of the neighbor FAs) change over time, the estimated handoff latency will vary. Thus, the target pre-buffering level should be estimated and adjusted periodically to match the network fluctuations and to cover up the handoff latency.

In addition, since the burst packet losses exist during the L2/L3 handoffs as mentioned above, FAs need a packet buffering and forwarding mechanism (smooth handoff) [5] in which FAs maintain copies of incoming packets destined to each MN for a sufficient amount of time (i.e., pre-buffering level in FAs), and then forward them to next neighbor FA (nFA) if the MN moves and make a connection with nFA. Here, FAs also need to have an appropriate pre-buffering level due to the similar reasons of changing target pre-buffering level in the MN. The detailed procedure of the packet buffering and forwarding mechanism will be explained in the following Section.

4. Link-layer Assisted Seamless Media Streaming System

To address the handoff-related problems mentioned above and achieve seamless media streaming, we propose and implement a L2 assisted streaming system as a preliminary version of the aforementioned framework. It mainly consists of *a packet buffering and forwarding mechanism with L2 trigger* in FAs and *a pre-buffering adjustment* in a streaming client at a MN.

4.1 Packet Buffering and Forwarding Mechanism with L2 Trigger

As discussed above, a MN should discover the change of network attachment to perform the agent discovery process of L3 handoff. It is one of the most time-consuming procedures in L2/L3 handoffs. At this point, if the MN supports L2 trigger about the change of an AP association, it can quickly

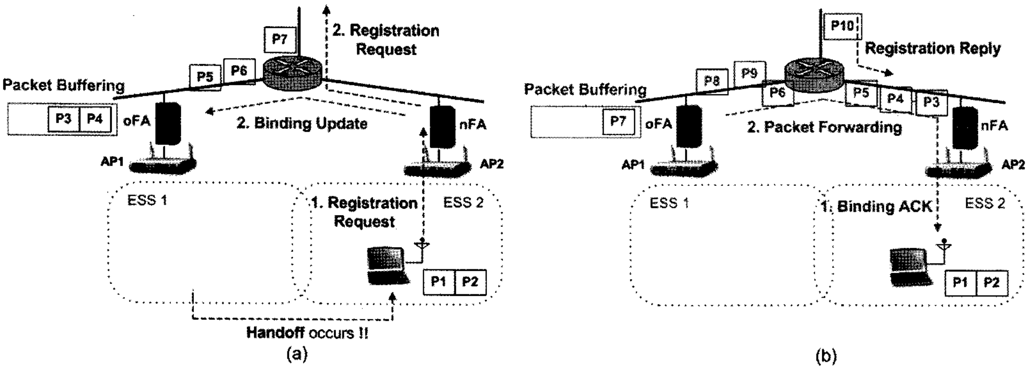


Fig. 4 The procedure of a packet buffering and forwarding mechanism in FAs

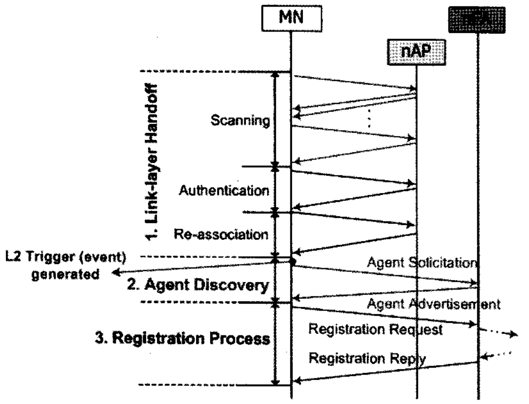


Fig. 3 Handoff latency in Mobile IPv4 with L2 trigger

detect the change of network attachment by sending an *Agent Solicitation* message instead of waiting for an *Agent Advertisement* message from the nFA. When the MN senses the change of network attachment by receiving an *Agent Advertisement* message as the response of the *Agent Solicitation* message, it can immediately initiates the registration process. Therefore, the agent discovery time can be reduced at about the round-trip time (RTT) in the wireless link and thus the total handoff latency can be considerably reduced. Fig. 3 shows the handoff latency with the L2 trigger.

To avoid burst packet losses during the handoff, a packet buffering and forwarding mechanism (smooth handoff) in FAs is proposed in [5]. Fig. 4 indicates the relevant procedure of the packet buffering and forwarding mechanism after the agent discovery process. First, an oFA de-capsulates and sends packets toward the MN, and also caches these packets in a local circular buffer. When the MN moves to another foreign network, it appends a *Previous Foreign Agent Notification* extension to a *Registration Request* message and sends them to a nFA. The nFA then sends a *Binding Update* message to the oFA as well as the *Registration Request* message to a HA. When the oFA receives the *Binding Update* message, it validates the message. If validated, the oFA updates its binding cache and sends a *Binding ACK* message to the MN through the nFA. Then, the oFA re-tunnels buffered packets, along with any future packets tunneled to the oFA, to the MN's a new CoA (i.e., nFA). Thus, the implemented packet buffering and forwarding mechanism in FAs can recover the burst packet losses during the handoff.

The MN cannot anticipate and notify the movement to another foreign network before the handoff is actually initiated.[3] Therefore, the oFA cannot know the exact moment when the MN disconnects its current association. Thus, the oFA should continuously buffer packets for the MN in the circular buffer. Now, how many packets should be buffered at the oFA is an important issue. It is evident that, to prevent packet losses, the circular buffer should be filled enough to cope with the worst handoff latency. The size estimation of the circular buffer is related with the pre-buffering adjustment in the streaming client, which is to be discussed below.

4.2 Pre-buffering Adjustment

---

[3] As discussed, the L2 hadoff is *hard* and *forward* in Mobile IP-enabled WLAN.

In general, pre-buffering techniques can partially or fully compensate the network jitter and delay in the streaming environment. With properly configured pre-buffering, we expect that a streaming client at a MN should be able to play streaming media without playback disruption. If the amount of pre-buffering is not sufficient to overcome the transport interruption of handoff, the playback disruption will happen. However, over-sized pre-buffering will cause memory waste and undesired latency overhead. It is important to decide the effective amount of required pre-buffering. Note that, this decision needs to take into account the timing related with the handoff itself as well as the timing related with forwarded packets from an oFA during the handoff.

As discussed, a dispatched (i.e., moved to another AP) MN consumes time for the L2 handoff and L3 handoff (i.e., the combination of agent discovery and the end-to-end messaging for binding update among oFA/nFA/MN). Thus, based on the handoff transient time analysis suggested in [4], the pre-buffering time is approximated as a function of L2 handoff latency, the propagation delay of wireless link, the link delay between an oFA and a nFA, and the processing and queueing delays in FAs and APs.

Fig. 5 indicates the total handoff latency (t_{total}), which is utilized to estimate the pre-buffering time. It reflects the time difference between the last received packet from the old foreign network and the following packet forwarded via a nFA from an oFA. Note that the forwarded packets may include packets which a MN already has received because of enough buffering at the circular buffer in the oFA. Thus, the additional time consumed to receive the duplicated packets should be taken into account for the total handoff latency.

We denote L2 handoff latency, agent discovery time, binding update time, and additional latency as t_{L2}, t_d, t_{BU}, and t_{add} respectively. In addition, agent discovery time (t_d) and binding update time (t_{BU}) can be denoted by

$$t_d = 2t_w, \quad (1)$$

$$t_{BU} = 2t_f + 2t_w, \quad (2)$$

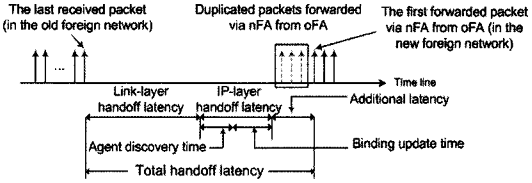


Fig. 5 The transmitted packets of old stream before/after handoff

where t_w is the propagation delay of wireless link and t_f is the forward link (between the oFA and the nFA) delay. As mentioned above, we consider the additional latency (t_{add}), which is the consumed time taken to receive duplicated packets transmitted via the nFA from the oFA. To simply estimate the pre-buffering time, we do not consider processing and queueing delays in FAs and APs. In addition, the packets of new stream via the nFA should be decoded only after forwarded packets via the nFA from the oFA are decoded. Thus, the packets of new stream is not needed in estimating the pre-buffering time. Therefore, we have the total handoff latency (t_{total}) and the estimated pre-buffering time ($t_{pre-buffering}$), which can be denoted by

$$\begin{aligned} t_{total} &= t_{L2} + t_d + t_{BU} + t_{add} \\ &= t_{L2} + 2t_f + 4t_w + t_{add}, \quad (3) \end{aligned}$$

$$\begin{aligned} t_{pre-buffering} &= t_{total} + t_{margin} \\ &= t_{L2} + 2t_f + 4t_w + t_{add} + t_{margin}, \quad (4) \end{aligned}$$

where t_{margin} is the margin time for smooth playback in the streaming client. Here, t_{margin} is required to overcome the unexpected network fluctuations, as the time-varying jitter and delay occur (e.g., due to the wireless channel variation and the channel contention to access the wireless shared medium) in wireless networks.

In addition, the circular buffer size in the oFA should be large enough to store the packets, which will be forwarded to the nFA to eliminate burst packet losses during the L2/L3 handoffs. In other words, it should be long enough to cover $t_{total} - t_{add}$ (L2/L3 handoff latencies) because the MN cannot receive any packet during this handoff latency. Thus, the actual circular buffer size will be larger than ($t_{total} - t_{add}$) times the *sending rate* of streaming server.

5. Implementation and Experiments

5.1 Implementation Details

A experimental environment to provide seamless media streaming over Mobile IP-enabled WLAN is depicted in Fig. 6. Machines used in experiments are shown in Table 1. In addition, Cisco Aironet 350 series APs and client adapters supporting IEEE 802.11b are used and operated in an infrastructure mode. The HUT Mobile IP and the MPEG4IP implementations for Linux are adopted for Mobile IP system and MPEG-4 clients, respectively [14], [15]. In the experiment environment, FA and AP entities are distinctively separated. We also adopt Apple Darwin Quicktime streaming server as a streaming server [15].

On top of these, we utilize L2 trigger that notifies the change of AP association with a wireless NIC. The device driver of wireless NIC supports *Linux Wireless Extension*[4]. This extension makes it possible to signal Mobile IP software for L2 triggers (in particular about the change of AP association). These triggers can be received through the *rtnetlink* socket.[5]

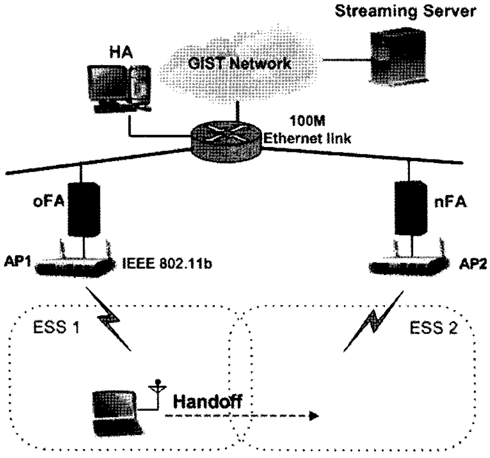


Fig. 6 A Mobile IP-enabled WLAN evaluation environment

Table 1 Machines used in experiments

	Machine	OS
MN	Pen III - Mobile 733MHz RAM - 256MB	Linux 2.4.20-8
HA	Pen III - 700MHz RAM - 512MB	Linux 2.4.18-3
oFA	Pen III - 800MHz RAM - 256MB	Linux 2.4.18-3 (Divert socket)
nFA	Pen III - 500MHz RAM - 128MB	Linux 2.4.20-8 (Divert socket)
Streaming Server	Pen IV - 1.5GHz RAM - 512MB	Linux 2.4.19

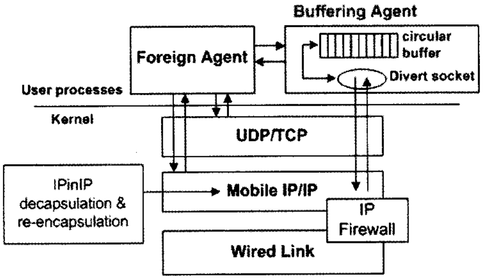


Fig. 7 FA architecture for the packet buffering and forwarding mechanism

In addition, we implement the packet buffering and forwarding mechanism based on the FA architecture depicted in Fig. 7. We also extend the related messages such as *Previous Foreign Agent Notification* extension, *Binding Update*, and *Binding ACK* [5] messages. To transparently capture packets passing through FAs and store them into a local circular buffer, *Linux Divert* socket[6] [17] is used. It is also used to forward the buffered packets to the nFA, since it can enable IP packet interception and injection on the end nodes as well as on the routers. Also, to make the tunnel between an oFA and a nFA for packet forwarding, we utilize the routing and IP-in-IP tunneling capabilities of the Linux operating system. As of now, in this paper, the circular buffer size and related buffering parameters are based on the worst-case estimate on the duration of L2/L3 handoffs.

5.2 Experimental Results and Discussion

We test the performance of MPEG-4 video streaming with the implemented prototype system. The

---

4) The Linux Wireless Extension is a generic application program interface (API) that allows the driver to expose the user space configuration and statistics specific to common wireless LANs [16].

5) The *rtnetlink* is a Linux IPv4 routing socket, which can be used to communicate with the user level processes, to setup programs and kernel, and to communicate internally between kernel subsystems.

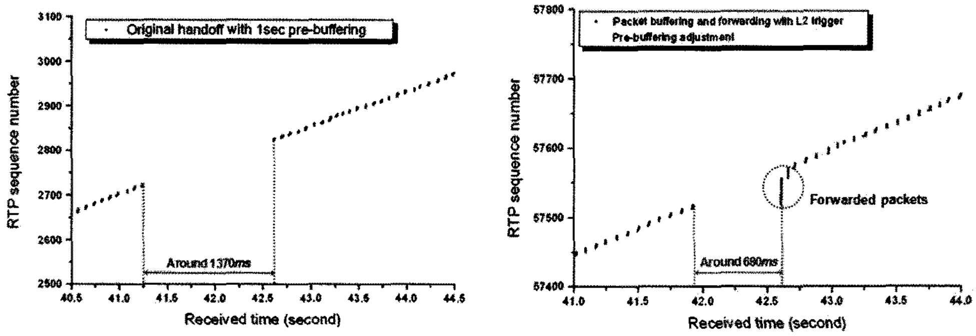
6) Through the *Linux Divert* socket, packets can be intercepted in the IP-layer and made available for user level processes outside the kernel via a modified version of raw sockets. The *Linux Divert* socket relies on the IP firewall mechanism for packet filtering.

experimental testbed is depicted in Fig. 6. We set the period of *Agent Advertisement* broadcasting to 1 *sec*. We also consider that the radio coverage of the APs between adjacent sub-networks can be overlapped. Handoff latency is computed as the time interval between last packet transferred from the oFA and the first packet transferred from the nFA (except for Mobile IP signaling). To accurately measure the handoff latency, additional monitoring computers are used to capture L2 management frames from the used wireless channels. To measure the required link delays of propagation delay of wireless link (t_w) and the link delay between the oFA and the nFA (t_f), we add the probing packet measurement functions in the HUT MN and agent implementation. The pre-buffering time can be estimated and applied to the streaming client before the playback of streaming media. In the testbed, we measure each delay several times and take the maximum value among them: t_{L2} = 600*ms*, t_f = 2.21*ms*, t_w = 4.86*ms*, and t_{add} = 100*ms*. According to Eq. (4), the pre-buffering time is estimated at 1023.86*ms*, where we set t_{margin} = 300*ms*. Also, we simply use a fixed buffering time of 700*ms* to the circular buffer in the oFA, which is set by considering the measured maximum L2 handoff and safe margin. However, in order to fully realize the seamless media streaming framework introduced in Section 3, this pre-buffereing estimation should be done adaptively to time-varying handoff situations, accordingly the streaming server should adjust the sending rate or the client should decrease the playback speed to maintain the appropriate pre-buffering level. We leave this as a future work.

To evaluate the quality improvement for streaming media, we experiment MPEG-4 video streaming with the sending rate of about 1 Mbps and the frame rate of about 25 *frames/sec*. The pre-buffering time is fixed to 1 *sec* in original Mobile IP system case. To verify the seamless playback of streaming, we measure the sequence number of RTP packet and the decoded frame sequence.

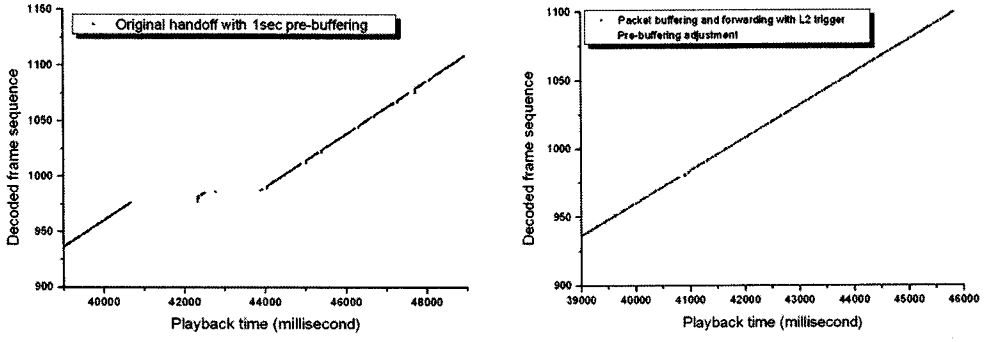
The trace of sequence number of received RTP packets is depicted in Fig. 8. From the comparison between Fig. 8(a) and Fig. 8(b), we can verify that the handoff latency is reduced by using the L2 trigger. Also, burst packet losses during the handoff is canceled out by the packet buffering and forwarding mechanism. In particular, in Fig. 8(a), the handoff latency is around 1370*ms* including L2/L3 handoff latencies. Without the L2 trigger, there exist burst packet losses, especially around 100 RTP packets during the handoff. However, in Fig. 8(b), the handoff latency is reduced to around 680*ms*. We can also observe that lost packets are eliminated by the packet buffering and forwarding mechanism.

The trace of decoded frame sequence is depicted in Fig. 9. From Fig. 9(a), we can know that the media playback is blocked by the burst packet losses generated during around 1370*ms*. This is probably because the pre-buffering is smaller than required. Additionally, the end-to-end video quality



(a) (b)

Fig. 8 Received RTP sequence: (a) Original handoff with 1 sec pre-buffering and (b) Link-layer assisted seamless media streaming system



(a) (b)

Fig. 9 Decoded frame sequence: (a) Original handoff with 1 sec pre-buffering and (b) Link-layer assisted seamless media streaming system

is also degraded after the handoff. The streaming client does not recover the smooth playback and does not synchronize between audio and video of the streaming media for a long time. However, in Fig. 9(b), there does not exist playback disruption during the handoff because forwarded packets can be applied to playback with sufficient pre-buffering in place. Then, the MPEG-4 streaming client at the MN is not faced with buffer underflow. Thus, we can know that applying our measurement results to the pre-buffering time is reasonable.

6. Conclusions

In this paper, we have presented a seamless media streaming framework over Mobile IP-enabled WLAN and corresponding prototype realization for the handoff from the implementation perspective. The experiment results showed that the handoff aware streaming has no playback discontinuity while keeping a minimal pre-buffering size and validated the feasibility of seamless media streaming.

References

[1] C. Perkins, "IP mobility support for IPv4," RFC 3344, Internet Engineering Task Force, August 2002.

[2] A. Mishra, M. Shin, and W. Arbaugh, "An empirical analysis of the IEEE 802.11 MAC layer handoff process," *ACM Computer Communications Review*, vol.33, no.2, pp.93-102, April 2003.

[3] C.-H. Lee, D. Lee, and J. Kim, "Link-layer assisted seamless MPEG-4 streaming over mobile IP-enabled wireless LAN," in *Proc. SPIE ITCOM '2004: Multimedia Systems and Applications VII*, Philadelphia, PA. USA, October 2004.

[4] D. Lee and J. Kim, "Transient time period analysis of smooth handoffs in mobile IP networks and its application to media streaming," in *Proc. SPIE Applications of Digital Image Processing XXVI*, San Diego, CA, August 2003.

[5] C. Perkins and K-Y. Wang, "Optimized smooth handoffs in mobile IP," in *Proc. IEEE Symposium on Computers and Communications*, Egypt, July 1999.

[6] D. Forsberg, J. T. Malinen, J. K. Malinen, and H. H. Kari, "Increasing communication availability with signal-based mobile controlled handoffs," in *Proc. IP based Cellular Networks (IPCN '00)*, Paris, France, May 2000.

[7] H. Yokota, A. Idoue, T. Hasegawa, and T. Kato, "Link layer assisted mobile IP fast handoff method over wireless LAN networks," in *Proc. ACM MobiCom '02*, Atlanta, Georgia, September 2002.

[8] S. Sharma, N. Zhu, and T. Chiueh, "Low-latency mobile IP handoff for infrastructure-mode wireless LANs," *IEEE Journal on Selected Areas in Communications*, vol.22, no.4, pp.643-652, May 2004.

[9] P. De Cleyn, N. V. den Wijngaert, L. Cerda, and C. Blondia, "A smooth handoff scheme using IEEE 802.11 triggers - design and implementation," *Computer Networks*, vol.45, issue 3, pp.345-361, Elsevier, June 2004.

[10] K. El Malki, "Low latency handoffs in mobile IPv4," draft-ietf-mobileip-lowlatency-handoff-v4-11.txt (work in progress), Internet Engineering Task Force, October 2005.

[11] R. Koodli, Ed., "Fast handovers for mobile IPv6," RFC 4068, Internet Engineering Task Force, July 2005.

[12] P. McCann, "Mobile IPv6 fast handovers for 802.11 networks," RFC 4260, Internet Engineering Task Force, November 2005.

[13] G. J. Conklin, G. S. Greenbaum, K. O. Lillevoid, A. F. Lippman, and Y. A. Reznik, "Video coding for streaming media delivery on the Internet," *IEEE Trans. on Circuits and Systems for Video Technology*, vol.11, no.3, pp.269-281, March 2001.

[14] (2001) Dynamics - HUT mobile IP, [Online] Available: http://dynamics.sourceforge.net.

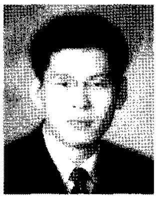
[15] (2003) MPEG4IP - Open streaming video and audio, [On-line] Available: http://www.mpeg4ip.net/.

[16] (2003) Wireless tools for linux, [Online] Available: http://www.hpl.hp.com/personal/Jean_Tourrilhes/Linux/Tools.html.

[17] W. Kellerer, E. Steinbach, P. Eisert, and B. Girod, "A real-time Internet streaming media testbed," in *Proc. International Conference on Multimedia and Expo (ICME '02)*, Lausanne, Switzerland, August 2002.

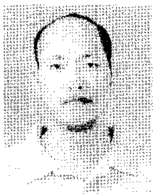
이철호

2003년 2월 한국항공대학교 정보통신공학과 학사. 2005년 2월 광주과학기술원 정보통신공학과 석사. 2005년 11월~2006년 4월 광주과학기술원 정보통신공학과 연구원. 2006년 8월~현재 노스캐롤라이나 주립대학 전기 및 컴퓨터공학과 박사과정. 관심분야는 Wireless and Mobile Networks



이동욱

1997년 2월 충북대학교 컴퓨터공학과 학사. 1999년 2월 광주과학기술원 정보통신공학과 석사. 2004년 2월 광주과학기술원 정보통신공학과 박사. 2004년 9월~2007년 2월 오하이오 주립대학 컴퓨터과학공학과 박사후연수. 2007년 3월~현재 삼성전자 Digital Media & Communications 부분 무선사업부 책임연구원. 관심분야는 Multicast/Broadcast over Wirless Network, Wireless Mesh Network, Network-adaptive Media Delivery, Linux Mobile (LiMo), and End-to-end QoS



김종원

1987년 2월 서울대학교 제어계측공학과 학사. 1989년 2월 서울대학교 제어계측공학과 석사. 1994년 2월 서울대학교 제어계측공학과 박사. 1994년 3월~1999년 6월 공주대학교 전자공학과 조교수. 1997년 7월~2001년 6월 University of Southern California, EE-Systems Dept. 방문연구 및 연구조교수. 2001년 9월~현재 광주과학기술원 정보통신공학과 교수. 관심분야는 유무선 IP 네트워크상의 일체화된 실감형 멀티미디어의 견실하고 유연한 전달을 위한 네트워크미디어 시스템 개발 및 이를 이용한 서비스 실현