

## Short Paper

---

# An Optimization Scheme for the IEEE 802.11 Link-Layer Handoff Process

GUO-YUAN MIKKO WANG AND CHUNHUNG RICHARD LIN

*Department of Computer Science and Engineering*

*National Sun Yat-Sen University*

*Kaohsiung, 804 Taiwan*

A growing number of IEEE 802.11-based wireless LANs have been set up in many public places in the recent years. These wireless LANs provide convenient network connectivity to users. Although mobile nodes allowed roaming across wireless LANs, handoff latency becomes an obstacle when mobile nodes migrate between different IP networks. Advanced, the link-layer handoff process disrupts the association when a mobile node moves from one access point to another. Without discussing the latency of Mobility Protocols, this link-layer handoff latency already made many real time applications can not meet their requirements. Several actual network experiments are made to proof this point. In this paper, it is proposed that a link-layer optimization scheme is designed to reduce the latency of link-layer handoff procedure. No violation to the existing specifications in the IEEE 802.11 standard and compatible with existing devices. Since the proposed optimization scheme is worked in the base of whole handoff procedure, whatever which Mobility Protocol is used in the upper-layer, it can take the benefit from the proposed scheme. Even real time applications can work under an acceptable situation.

**Keywords:** handoff, IEEE 802.11, link-layer, performance, wireless

## 1. INTRODUCTION

IEEE 802.11-based wireless local area networks (LANs) have seen immense growth in the last few years, and are becoming an important part in the networking environment. A growing number of wireless LANs have been set up in public places such as campus and airport as access networks to the Internet. These wireless LANs provide not only convenient network connectivity but also a high speed communication. Because of the mobility-enabling nature of wireless LANs, there is opportunity for many promising multimedia and peer-to-peer applications such as VoIP [1, 2], mobile video conferencing and chat.

The IEEE 802.11 network MAC specification [3] allows for two operating modes namely, the *ad hoc* and the *infrastructure* mode. In the *ad hoc* mode, two or more MNs recognize each other and establish a peer-to-peer communication without any existing infrastructure. In *infrastructure* mode, it uses Access Point (AP) to bridge all data be-

---

Received August 16, 2005; revised November 21, 2005; accepted November 24, 2005.

Communicated by Yu-Chee Tseng.

tween the MNs associated to it. In this paper, it is concerned with the network that sets with *infrastructure* mode which is widespread use in most of public places.

The Mobility Protocol allows a MN to migrate between different IP networks without breaking network-layer connectivity and disrupting transport sessions. When a MN moves from one network-level point of attachment to another, a Mobility handoff takes place. This handoff is composed of a sequence of stages that includes the detection of a MN's movement to the new network, registers at corresponding Mobile Agents (MAs) and updates MN's location. After Mobility handoff, MN can continue its data transmission.

But in whole handoff procedure, Mobility handoff is just a part of it. Before the Mobility handoff, the link-layer handoff will take place first. Fig. 1 gives a simple view of the objects and protocol that handle these handoff procedures. In all known commercial wireless network interface cards (WNICs), the link-layer handoff is controlled by the firmware which is located in the Link layer of OSI network architecture. Mobility Protocol that worked on the upper-layer must depend on the results from Link layer to move its next action. So the link-layer handoff procedure becomes a bottleneck of whole handoff procedure.

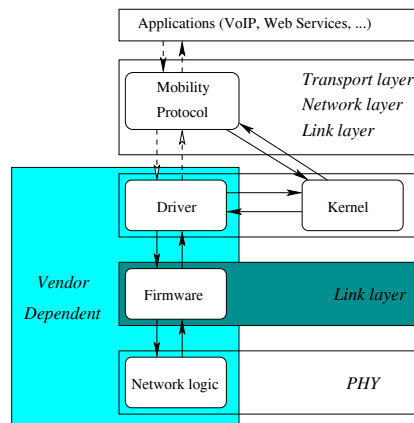


Fig. 1. The overview of handoff relating objects.

In this paper, it is proposed that a link-layer optimization scheme is designed to reduce the latency of link-layer handoff procedure. No violation to the existing specifications in the IEEE 802.11 standard. Since the proposed scheme is worked in the base of whole handoff procedure, whatever which Mobility Protocol is used in the upper-layer, it can take the benefit from the proposed scheme.

The remainder of this paper is arranged as follows. Section 2 summarizes some related Mobility Protocols and makes a brief comparison of them. A detailed experiment of link-layer handoff was made in section 3 which indicates that link-layer handoff was becoming the bottleneck to real time applications. Section 4 introduces the proposed optimization scheme to reduce the latency of link-layer handoff procedure. The comparisons with IEEE 802.11 standard to evaluate performance enhancement are presented in section 5. In section 6 the compatibility of the proposed scheme and the phase of handoff

execution are discussed. Finally, section 7 evaluates the research and the conclusions are presented.

## 2. MOBILITY PROTOCOL

In the last few years, several Mobility Protocols have been proposed to support mobility-enabling nature of wireless LANs. It can be broadly classified into three categories: *Micromobility (intrasubnet mobility)*, *Macromobility (intradomain mobility)* and *Global mobility (interdomain mobility)* due to its administrative domain [4]. In general, the primary goal of Mobility Protocol is to ensure continuous and seamless connectivity between *micromobility* and *macromobility*, which occur over short timescales. *Global mobility* involves longer timescales, where the goal is to ensure that MNs can reestablish communication after a move rather than provide continuous connectivity.

In a cellular environment there are two kinds of handoff: *intracell* and *intercell*. *Intracell* handoff occurs when a user, moving within a cell, changes radio channels to minimize interchannel interface under the same network. On the other hand, *intercell* handoff occurs when an MN moves into an adjacent cell. *Intercell* handoff may be performed in two ways: *soft* and *hard*. If two networks simultaneously handle the interchange between them while performing the handoff, it is a *soft* handoff. *Soft* handoff is achieved by proactively notifying the new network before actual handoff. Thus, it minimizes packet loss, but delay incurred may be more. In *hard* handoff, one network takes over from another in a relay mode, so delay as well as signaling is minimized, but it does not guarantee zero packet loss.

In *infrastructure* mode wireless LANs, the handoff is *hard* since a MN can communicate with exactly one AP before and after a handoff. And it is *forward* since the MN cannot communicate with the old MA during the handoff and has to carry out the handoff by reestablishing a connection with the new MA in the new network. **These limits make many proposed Mobility Protocols cannot be implemented correctly or achieve the performance it expects in the actual network environment.**

The earliest Mobility Protocol is Mobile IP (MIP) [5]. It provides IP level mobility to allow MNs to roam across wireless LANs without loss of network-layer connectivity and disrupting transport sessions. Most of the following Mobility Protocols are referring to MIP. Some of these improving protocols are described as follows. Cellular IP (CIP) [6] 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. Hierarchical MIP (HMIP) [7] is an extension of MIP, it employs a hierarchy of MAs to locally handle MIP registrations. Registration messages establish tunnels between neighboring MAs along the path from the MN to a gateway MA. The method proposed by Yokota *et al.* [8] named LLAMIP is use an AP and a dedicated MAC bridge to reduce packet transmission interruptions in both the forward and reverse directions. Another improvement proposed by Sharma *et al.* [9] named LMIP use some information from network card driver to speed up the movement detection. It also designed a MIP advertisement caching and relay proxy to reduce the handoff time. Table 1 makes a brief comparison of these different Mobility Protocols.

**Table 1. Comparison of different mobility protocols.**

|                     | MIP     | CIP         | HMIP                | LLAMIP | LMIP           |
|---------------------|---------|-------------|---------------------|--------|----------------|
| Protocol Layer      | Network | Network     | Network & Transport | Link   | Link & Network |
| Mobility Management | Global  | Macro/Micro | Global/Macro        | Macro  | Global/Macro   |
| Handoff Control     | Hard    | Hard/Soft   | Hard                | Hard   | Hard           |
| Latency             | ~2.4s   | ~250ms      | ~900ms              | ~200ms | ~100ms         |

From Fig. 1, it presents that Mobility Protocol is transparent to applications. Although some Mobility Protocols can reduce handoff by took advantage from driver directly, most of them must be triggered by the information provided from system kernel. No matter which layer the Mobility Protocol operated, it cannot break away from the influence of firmware since the firmware controls the link-layer handoff in the lower-layer. Thus, if there is a scheme can reduce the latency of link-layer handoff, all Mobility Protocols should get advantage from it. Next section will describe the influence of link-layer handoff in detail.

### 3. LINK-LAYER HANDOFF

To analyze the link-layer handoff procedure, it is split into three sequential phase: *potential*, *probe* and *auth*. The goal of the *potential* phase is the detection of the need for the handoff. Following, the *probe* phase collects the acquisition of the information necessary for the handoff. Finally, the handoff is performed during the *auth* phase.

#### 3.1 Experiment

In this subsection, the duration of each handoff phase was measured in an experimental network environment as shown in Fig. 2. The wired LAN portion was constructed with 100Base-T and the wireless LAN portion was constructed with 802.11b. The version 0.3.9 of Host AP driver [10] was used in each AP to make them have AP functions and set their channel as 1 and 6 respectively. Host AP driver also installed on Sniffer to make it has a monitor mode which enables a designed program to read raw IEEE 802.11 frames on one particular channel. Thus by capturing traffic from two WNICs (on channel 1 and 6) on Sniffer, it is able to sniff all frames transmitted by participating entities in the common RF medium. The open system was used to be the default authentication algorithm. During the experiment, the only traffic in the network was a flow of packets generated by the MN which was transmitting 64 bytes of UDP packets at 100 ms intervals.

Four commercial IEEE 802.11b WNICs with different chipsets were selected to measure their handoff time. From the experiments, it is noted that all commercial WNICs take advantage of the information provided by the physical layer and completely skip the *potential* phase. These cards start the *probe* phase when the strength of the received radio signal degrades below a certain threshold. Since the handoff measurements using physical layer information have already been reported by Mishra *et al.* [11], this paper prefer

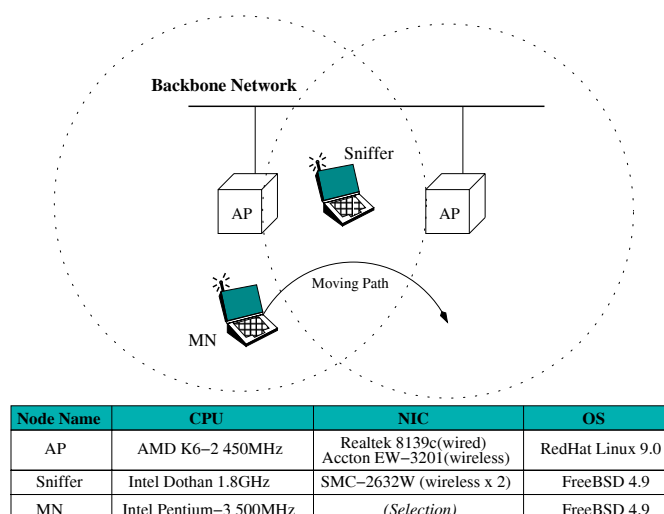


Fig. 2. Experiment network.

Table 2. The duration of link-layer handoff for selected cards.

|                        | <i>potential</i> | <i>probe</i> | <i>auth</i> | <b>Total</b> |
|------------------------|------------------|--------------|-------------|--------------|
| Orinoco 802.11b Silver | 1021             | 71           | 1           | 1093         |
| D-Link DWL-520         | 1702             | 273          | 2           | 1977         |
| ZoomAir 4100           | 894              | 265          | 2           | 1161         |
| Symbol LA-2400         | 1267             | 102          | 3           | 1372         |

(ms)

to provide readers an advanced and a detailed measurement (*i.e.*, without support from the physical layer). To measure the *potential* phase, the handoff was forced by abruptly switching off the radio transmitter of the AP to which the MN was connected. This allows assessing the importance of using the signal strength in deciding to start the handoff. Thus, the handoff time in the experiments was measured from the first non-acknowledged data frame until the transmission of the first frame via the new AP. The measuring results are presented in Table 2.

### 3.2 Analysis

The Fig. 3 illustrates the common case of link-layer handoff procedure. The analyses of experiment are divided into three parts depending on the definition of handoff phase and detailed below.

#### 3.2.1 *potential* phase

The handoff can be classified into two categories due to which one initiated the handoff. The actions during the *potential* phase vary depending on which entity initiated the handoff. When the handoff is initiated by network, the *potential* phase consists of a

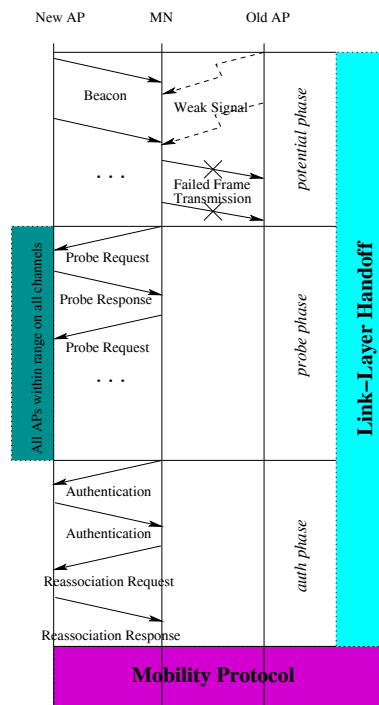


Fig. 3. The link-layer handoff procedure.

single disassociation message sent by an AP to the MN. However, the most common handoff is the one initiated by the MN due to its mobility-enabling nature, in which MNs have to detect the lack of radio connectivity based on weak received signal reported by the physical layer or failed frame transmissions. The observed results were quite startling – none of the analyzed cards used the lack of beacon reception to discover that the AP was not in range. All cards decide the need for the handoff by failed frame transmissions. From Table 2, it shows the duration of *potential* phase is the longest in all cases and widely varies among different cards. This was expected since the IEEE 802.11 standard only specifies the mechanisms to implement the handoff, but their combination and duration are left unspecified. The purpose was to allow the manufacturers some freedom to balance between different tradeoffs such as fast reaction or low power consumption.

The main factor in controlling the duration of *potential* phase is the number of allowed failed frames. It varies with each card because when a frame is not acknowledged, the MN can not differentiate whether the reason was a collision, congestion in the cell or the AP being out of range. Different cards use different assumptions depending on their purpose. For instance, the D-Link DWL-520 is designed for a desktop PC, thus it assumes that the AP is always in range and retransmits for a longer period than the ZoomAir 4100 designed for laptops.

### 3.2.2 probe phase

The *probe* phase consists of serial actions performed by the MN to find the APs in

range. Since the IEEE 802.11 standard specifies that APs can operate in any channel of the allowed set, all allowed channels must be searched in *probe* phase. There are two methods to search a channel, *active* and *passive* searching. In *passive* searching, MNs listen to each channel for the beacon frames from APs. The main problem of this method is how to calculate the time to listen to each channel. This time must be longer than the beacon period, but the beacon period is unknown to the MN until the first two beacons are received. Another problem is its performance. Since the whole set of allowed channels must be searched, MNs need over a second to discover the APs in range with the default 100 ms beacon interval. There are 11 and 13 allowed channels in USA and most of Europe respectively, thus it would take 1.1 and 1.3 seconds in *probe* phase when MNs perform *passive* searching. If the faster searching is needed, MNs must perform *active* searching.

From analyzing captured frames, all cards performed *active* searching. It means that MNs will broadcast a probe request frame on each allowed channel and wait for the corresponding probe response generated by the AP. The variance of duration in experiment is due to the different number of probe requests sent per channel and more significantly due to the time to wait for probe responses. The reason to make this is the same as the one in *potential* phase – The IEEE 802.11 standard left the combination and duration of the mechanisms unspecified.

### 3.2.3 *auth* phase

The *auth* phase is the execution of the handoff. To perform the handoff, the MN must exchange authentication frames with the new AP first. Authentication consists of two or four consecutive frames depending on the authentication method used by the AP. Since the open system used in the experiment, there are only two authentication frames exchanged between the MN and the AP.

Following, the MN sends a reassociation request to the new AP to associate with the new AP. After AP confirms the reassociation, it will send a reassociation response to the MN. Upon successful *auth* phase, the handoff is completed and the Mobility Protocol can take over the following handoff progress.

## 3.3 Conclusions of Experiment

From the experiments, the following conclusions can be drawn. First, the *potential* phase is the primary contributor to the overall link-layer handoff latency. Fortunately, all cards can take advantage of the information provided by the physical layer to skip it completely. Second, different cards presented different performance, but none matched the delay requirements of real time applications during handoff (*e.g.*, the guidelines for jitter in VoIP applications is recommended the overall latency not to exceed 50 ms [12]) even though the *potential* phase can be ignored. The *probe* phase becomes the bottleneck in link-layer handoff process. An optimization scheme is needed to reduce the latency of link-layer handoff within acceptable bounds. Then, the whole handoff latency (*i.e.*, includes link-layer and Mobility Protocol) can have a chance to reach the requirements of real time applications.

## 4. LINK-LAYER OPTIMIZATION SCHEME

### 4.1 Preliminary

IEEE 802.11-based wireless LANs which consist of APs and WNICs have been set in many places. It may be impractical to make any incompatible modifications with existing devices. The proposed scheme can be achieved through firmware upgrade, no extra cost is needed. Since the *potential* phase can be skipped completely and the latency in *auth* phase is not significant, the *probe* phase becomes the main contributor to the overall link-layer handoff latency. A designed field is used to optimize the interactions between AP and WNIC.

### 4.2 Link-Layer Optimization Scheme

#### 4.2.1 Optimizing operations

To optimize the operations of link-layer handoff, the proposed scheme focuses on *probe* phase and designs a novel field. This field has been appended to the beacon which AP broadcasts usually to avoid all channels being searched in *probe* phase. The details of this field are presented in Fig. 4.

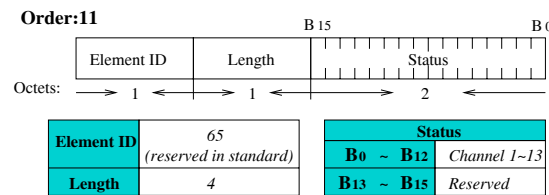


Fig. 4. The designed field appended to beacon.

The **Order** of this field in beacon is set to 11 which is unused in the IEEE 802.11 standard. The **Element ID** is 65 and the **Length** is 4. The **Status** is used to represent the channel usage status. **B<sub>0</sub>** to **B<sub>12</sub>** are used to represent the status of channel 1 to 13 respectively, and **B<sub>13</sub>** to **B<sub>15</sub>** are reserved. If AP uses channel *n* to make communications, it will set **B<sub>n-1</sub>** to 1 and keep other subfields to 0.

On AP, there is a message exchange mechanism must be implemented to overcome the physical limitation of signal receiving when different channels are used on AP and MN. The **Status** subfield should include the channel usage status of neighboring APs. This can be done by a centralize server that periodically exchanges channel usage status with all APs in a regional network (*e.g.*, in a building). Since the position of AP usually is fixed, the interval of this message exchange can be set to large (*e.g.*, 5 minutes). In addition, the size of exchange message is very small. Therefore, no observable traffic load will appear in the network.

On WNIC, there is a 2-bytes register – *Channel Register* used to collect the received channel usage status of APs in range. The register upgrade can be completed in a very short time since the WNIC can take the received **Status** subfield to make a simple

logic instruction “OR” with *Channel\_Register* to renew, no significant load generated. In *probe* phase, the WNIC can depend on the records of *Channel\_Register* to send probe request to specific channels. After link-layer handoff completed, the WNIC will reset its *Channel\_Register* to avoid the influences from expired information. For the compatibility reason, a special case must be considered. If all subfields in the *Channel\_Register* are 0 or there are no responses from the recorded channels, the WNIC should send the probe request following the IEEE 802.11 standard. Since it may mean there is no AP supports the proposed scheme in range.

#### 4.2.2 Tuning parameters

Besides optimizing operations, there are two parameters (*MinChannelTime* and *MaxChannelTime*) must be tuned to speed up the *probe* phase. Since after MN broadcasts probe request to specific channels, it still needs to wait for the probe response generated by the AP. The time to wait for responses depends on the channel activity after the probe request sent. If the channel is idle during *MinChannelTime* (*i.e.*, there is neither response nor any kind of traffic in the channel), the searching is finished and the channel is declared idle. If there is any traffic during this time, the MN must wait *MaxChannelTime*. Note that searching MNs might not be able to sense other MNs communicating with the AP, but they will always receive the acknowledgement sent from the AP and thus they will wait *MaxChannelTime* for probe responses.

The IEEE 802.11 standard does not define the values of *MinChannelTime* and *MaxChannelTime* even they control the duration of the channel searching. Both parameters are measured in Time Units (TUs) and the IEEE 802.11 standard defines a TU to be 1024  $\mu$ s. To minimize them, the proposed scheme finds out the reasonable values for them. First, *MinChannelTime* which is the maximum time an AP would need to answer given that the AP and channel are idle is calculated. If the probe response generation time and the propagation time are ignored, the IEEE 802.11 medium access function establishes that the maximum response time is given by the Eq. (1).

$$\text{MinChannelTime} = \text{DIFS} + (a\text{SlotTime} \times a\text{CWmin}) \quad (1)$$

In Eq. (1), *DIFS* is the Distributed InterFrame Space, *aSlotTime* is the length of a slot, and *aCWmin* is the maximum number of slots in the minimum contention window. These values are defined in the IEEE 802.11 standard. After inserting them in the equation, the value 670  $\mu$ s can be obtained. Since *MinChannelTime* must be expressed in TU, its value could be concluded to be 1 TU.

The definition of *MaxChannelTime* is more complicated. Since *MaxChannelTime* is the maximum time to wait for a probe response when the channel is busy, it should be large enough as to allow the AP to compete for the medium and send the probe response. This time is a variable since it depends on the cell load and number of MNs competing for the channel. In order to find a reasonable value for *MaxChannelTime*, a simulation was ran to measure the time to transmit the probe response. The simulation results are presented in Fig. 5.

The results confirm that the transmission time of a probe response depends on the traffic load and the number of MNs. In addition, they also show that *MaxChannelTime* is

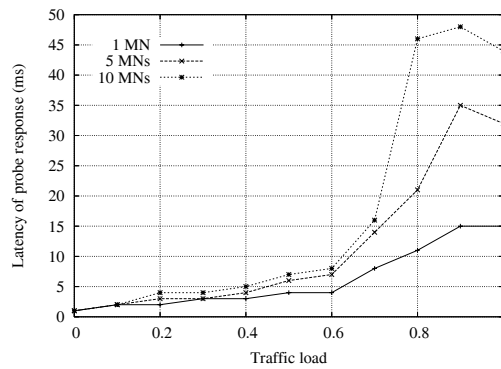


Fig. 5. Latency of probe response.

not bounded as long as the number of MNs can increase. A value for *MaxChannelTime* that would prevent overloaded AP to answer in time is suggested. Since 10 MNs per cell seems to be an appropriate number to achieve a good cell throughput [13], Fig. 5 indicates that 8 TUs would be a reasonable choice for *MaxChannelTime*.

### 4.3 Optimized Results

When a channel is searched, a probe request is broadcasted and then the MN waits for the probe response. Since the probe request is sent to the broadcast address, there is no acknowledgement responded. Therefore, at least two consecutive probe requests must be sent to reduce the influence of possible collision. Each probe request must follow the same channel access procedure as the data packets, thus they will experience the transmission delay. Let  $T_d$  be the transmission delay,  $T_b$  be the time needed to search a busy channel (*i.e.*, with traffic) and  $T_i$  be the time to search an idle channel. Then,  $T_b$  and  $T_i$  can be calculated as Eqs. (2) and (3) respectively.

$$T_b = 2T_d + \text{MaxChannelTime} \quad (2)$$

$$T_i = 2T_d + \text{MinChannelTime} \quad (3)$$

Each channel searching operation spent  $T_b$  or  $T_i$ . Let  $n$  be the number of nonzero subfields in *Channel\_Register*, and  $o$  be the number of APs which are already out of range. With the proposed optimization scheme is used, the WNIC does not need to search all channels in *probe* phase. The optimized duration of *probe* phase  $T_p$  could be concluded by the Eq. (4).

$$T_p = (n - o)T_b + oT_i \quad (4)$$

## 5. SIMULATION AND ANALYSIS

Since the proposed optimization scheme must modify the firmware of WNIC and AP to achieve, no real devices experiments could be made without vendors' support.

Simulations are performed by ns-2 2.28 [14] with some necessary modifications (*e.g.*, beacon transmission and designed field processing were added to IEEE 802.11 module). In this section the simulations of the proposed optimization scheme are presented and compared with the IEEE 802.11 standard. The wireless link speed is based on IEEE 802.11b. The effect on radio interference of closed channels in the IEEE 802.11 standard is more obvious than in the proposed optimization scheme. This is because the proposed scheme can prevent unnecessary probe requests being sent, so the possibility of collision could be reduced. Therefore, for the reason that the results can be compared clearly, the effect on radio interference of closed channels is ignored in this simulation. The channel switching delay is neglected in the simulations.

**5.1 Latency of Probe Response**

The purpose of this experiment is to find out a reasonable value for *MaxChannelTime*, the number of MNs 1, 5, and 10 are simulated. Fig. 5 illustrates the results. The probe response time shown is the average of 30 transmissions for each load level with channel bit rate set to 2Mbps, the maximum possible rate for the probe response in IEEE 802.11b. In the most situations, the probe response can be responded in 8 ms. After analyzed, the proposed optimization scheme defines *MaxChannelTime* as 8 TUs.

**5.2 Duration of probe Phase**

In this experiment, the improvements of the proposed optimization scheme can be observed clearly in Fig. 6 The IEEE 802.11 standard is compared with the proposed scheme when there are 5 and 10 MNs in the WLAN. After tuning parameters, *MinChannelTime* and *MaxChannelTime* used in the proposed scheme are 1 TU and 8 TUs respectively. But these parameters are not specified in the IEEE 802.11 standard. By analyzing the transmission logs generated from the experiments in section 3, the parameters of Orinoco 802.11b Silver are 3 TUs and 30 TUs for *MinChannelTime* and *MaxChannelTime*, respectively. This experiment takes these two parameters of Orinoco card as the parameters in the IEEE 802.11 standard and sets the traffic load to 50%.

In Fig. 6, the increments of the durations become less after the number of available channels reached the number of MNs in the WLAN. It is because MNs have more

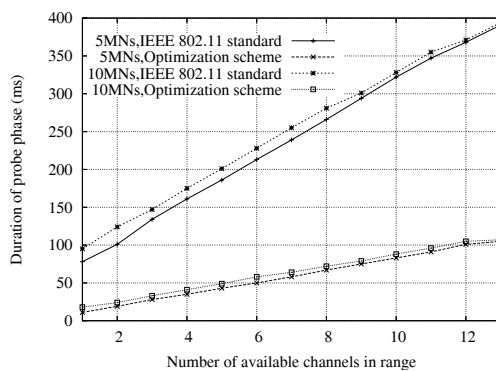


Fig. 6. Duration of probe phase.

chances to distribute to the different channels, the possibility of collision could be reduced when channel searching. The probe request and probe response frames, therefore, can prevent delaying due to follow the Distributed Coordination Function (DCF) rules.

The differences between the proposed scheme and IEEE 802.11 standard will become larger in the actual network environment. Since the closed channels will interfere in radio signal transmission of each other. In the IEEE 802.11 standard, a channel searching operation must spend *MaxChannelTime* even the searching channel is idle if there are any signal transmission during *MinChannelTime* in the closed channel. In addition, there is a channel switching delay existing when WNICs switch to a new frequency, resynchronize and start demodulating frames. The switching times are fixed in the IEEE 802.11 standard but flexible in the proposed scheme. These situations can be eased since not all channels must be searched in the proposed scheme.

In an arranged WLAN, there are usually three independent channels which should not interfere with each other be set (*e.g.*, channel 1, 6 and 11). By observed the simulation results, the proposed scheme could reduce the duration of *probe* phase to only 33 ms which is only 22.4% of the one in the IEEE 802.11 standard even there are 10MNs in the high traffic load WLAN. This makes whole handoff latency has a chance to meet the high requirements of real time applications. The design goal of the proposed scheme is accomplished.

## 6. DISCUSSION

### 6.1 Compatibility

When a novel scheme presented, the compatibility is another important thing besides its contributor. The proposed optimization scheme endeavors to reduce the latency of link-layer handoff and make compatible with existing devices. It can be achieved through firmware upgrade which supported by the most of commercial products. The signaling to perform the link-layer handoff is specified in the Medium Access Control protocol of the IEEE 802.11 standard and is common to the IEEE 802.11a/b/g supplements. Therefore, the proposed optimization scheme can apply to all of them in general.

In AP, a designed field is appended to the broadcasting beacons. This 4-bytes attachment will not cause the beacon be fragmented. AP only needs to depend on its channel usage status to set the corresponding subfield before encapsulation of beacon. The main problem is on WNIC, since it needs an extra register as *Channel\_Register*. Fortunately, most of devices reserved some free registers when leave the factory. Take ADM8262 which is a controller of WLAN Base Band Processor/Medium Access Control (BBP/MAC) as an example [15]. There are two 4-bytes registers **RR\_CSR13A** and **TOFS\_CSR17** reserved in its data sheet. Each of them can be used to as the *Channel\_Register* in the proposed scheme.

### 6.2 Reduction of *auth* Phase

From the experiments in the section 3, *auth* phase is the shortest phase in the whole link-layer handoff procedure. The measurements show that the *auth* phase using open

system authentication is 3 ms at most for an empty cell, thus reducing the *auth* phase will not obviously reduce the overall link-layer handoff time. Furthermore, there are more complicated authentication schemes which are not the researching ambit in this paper that require querying an external agent. In these cases, the authentication must be completed before the handoff execution [16] to reduce the handoff latency.

## 7. CONCLUSIONS

In this paper, an optimization scheme which can reduce the latency of link-layer handoff has been presented. To analysis the details of link-layer handoff procedure, a real environment experiment is made. It concludes that the requirements of real time applications are not meet and points out where the bottleneck is. The proposed optimization scheme endeavors to reduce link-layer handoff latency and make it more acceptable. A novel designed field is appending to the beacon AP broadcasts usually and wireless interface card can depends on the records of its special register to search specified channels. Two important parameters during *probe* phase are also being tuned. These modifications can be achieved through firmware upgrade in the existing devices, and no compatibility problems occurred. By using the proposed scheme, no matter which Mobility Protocol is used in the upper-layer, it can be triggered early and the duration of handoff procedure can be reduced.

## REFERENCES

1. R. Caceres and V. N. Padmanabhan, "Fast and scalable wireless handoffs in support of mobile internet audio," *Mobile Networks and Applications*, Vol. 3, 1998, pp. 351-363
2. J. Rosenberg, *et al.*, "SIP: session initiation protocol," IETF, RFC 3261, 2002.
3. IEEE Std 802.11 – Part11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 1999.
4. D. Saha, A. Mukherjee, and M. Chakraborty, "Mobility support in IP: a survey of related protocols," *IEEE Network*, Vol. 18, 2004, pp. 34-40.
5. C. Perkins, "IP mobility support for IPv4," IETF, RFC3344, 2002.
6. A. G. Valkó, "Cellular IP: a new approach to internet host mobility," *ACM SIGCOMM Computer and Communication Review*, Vol. 29, 1999, pp. 50-65.
7. E. Gustafsson, A. Jonsson, and C. Perkins, "Mobile IP regional registration," Internet Draft, draft-ietf-mobileip-reg-tunnel-09.txt, 2004.
8. H. Yokota, A. Idoue, T. Hasegawa, and T. Kato, "Link layer assisted mobile IP fast handoff method over wireless LAN networks," in *Proceedings of ACM MOBICOM*, 2002, pp. 131-139.
9. S. Sharma, N. Zhu, and T. Chiueh, "Low-latency mobile IP for infrastructure-mode wireless LANs," *IEEE Journal on Selected Areas in Communication*, Vol. 22, 2004, pp. 643-652.
10. "Host AP driver," <http://hostap.epitest.fi>.
11. A. Mishra, M. Shin, and W. Arbaugh, "An empirical analysis of the IEEE 802.11 MAC layer handoff process," *ACM SIGCOMM Computer Communication Review*,

- Vol. 33, 2003, pp. 93-102.
12. International Telecommunication Union, "General characteristics of international telephone connections and international telephone circuits," ITU-TG. 114, 1988.
  13. G. Bianchi, "Performance analysis of the IEEE 802.11 distributed coordination function," *IEEE Journal on Selected Areas in Communication*, Vol. 18, 2000, pp. 535-547.
  14. "The network simulator – ns-2," <http://www.isi.edu/nsnam/ns/>.
  15. Infineon Technology, "ADM8262 PCI/Cardbus/Mini-PCI WLAN MAC/BBP controller preliminary data sheet, Rev. 1.1," 2005.
  16. S. Pack and Y. Choi, "Pre-authenticated fast handoff in a public wireless LAN based on IEEE 802.1x Model," in *Proceedings of the IFIP TC6/WG 6.8 Working Conference on Personal Wireless Communications*, 2002, pp. 175-182.

**Guo-Yuan Mikko Wang (王國淵)** was born in Taichung, Taiwan, in 1979. He received his B.S. degree from the Department of Information Engineering and Computer Science, Feng Chia University, in 2002. Currently, Mr. Wang is working toward the Ph.D. degree in the Department of Computer Science and Engineering, National Sun Yat-Sen University. His research interests focus on the design and analysis of computer network protocols, mobile host mobility, and the implementation of embedded operating systems.

**Chunhung Richard Lin (林俊宏)** was born in Kaohsiung, Taiwan. He received the B.S. and M.S. degrees from the Department of Computer Science and Information Engineering, National Taiwan University, in 1987 and 1989, respectively, and the Ph.D. degree from Computer Science Department, University of California, Los Angeles (UCLA), in 1996. Dr. Lin joined National Chung Cheng University in Taiwan in 1996. Since August 2000, he has been with the Department of Computer Science and Engineering, National Sun Yat-Sen University, Kaohsiung, Taiwan. His research interests include the design and control of personal communication networks, protocol design and implementation for differentiated/integrated services in mobile wireless networks, mobile Internet, distributed simulation, and embedded operating system design and implementation. Dr. Lin is an ACM member. He received the 2001 Junior Professor Research Award from National Sun Yat-Sen University and the 2000 Investigative Research Award from the Pan Wen Yuan Foundation, Taiwan, R.O.C.