IEEE 802.11 Link-Layer Handoff Optimization Scheme

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Abstract: **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. Several simulations illustrate the proposed scheme can reduce the link-layer handoff duration to 24% compared with the IEEE 802.11 standard and achieve power consumption by decreasing the amount of sending messages in the high traffic load environment. Even real time applications can work under an acceptable situation.**

Index Terms: **Handoff, IEEE 802.11, link-layer, performance, wireless.**

I. 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 [2], [11], mobile video conferencing and chat.

The IEEE 802.11 network MAC specification [5] 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 between 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.

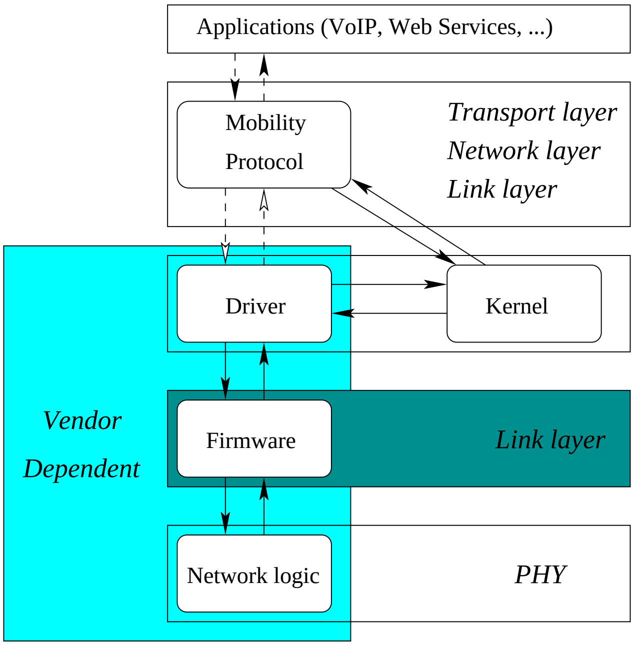


Fig. 1. The overview of handoff relating objects.

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.

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 II summarizes some related Mobility Protocols and makes a brief comparison of them. A detailed experiment of link-layer handoff was made in Section III which indicates that link-layer handoff was becoming the bottleneck to real time applications. Section IV 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 V. In Section VI the compatibility of the proposed scheme and the phase of handoff execution are discussed. Finally, Section VII evaluates the research and the conclusions are presented.

II. 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 [12]. 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) [10]. It provides IP level mobility to allow MNs to roam across wireless LANs without loss of network-layer connectivity and disrupting transport sessions. In MIP, there are home agents (HAs) and foreign agents (FAs) running on the wired network. These MAs periodically broadcast MIP advertisements on the wireless LANs. Whenever a MN migrates from one subnet to another, it will receive MIP 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 its 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 MIP handoff.

	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

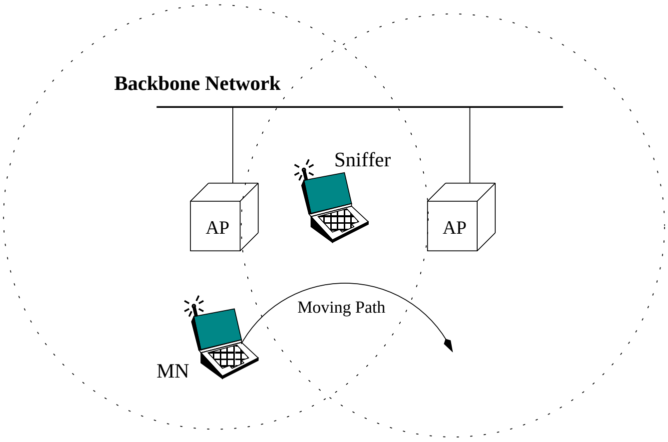
Table 1. Comparison of different Mobility Protocols.

Most of the following Mobility Protocols are referring to MIP. Some of these improving protocols are described as follows. Cellular IP (CIP) [15] 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) [3] is an extension of MIP, it employs a hierarchy of FAs to locally handle MIP registrations. Registration messages establish tunnels between neighboring FAs along the path from the MN to a gateway FA. The method proposed by Yokota *et. al.* [16] 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.* [13] 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.

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.

III. 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.



Node Name	CPU	NIC	OS
AP	AMD K6−2 450MHz	Realtek 8139c(wired) Accton EW−3201(wireless)	RedHat Linux 9.0
Sniffer	Intel Dothan 1.8GHz	SMC−2632W (wireless x 2)	FreeBSD 4.9
MN	Intel Pentium−3 500MHz	*(Selection)*	FreeBSD 4.9

Fig. 2. Experiment network.

A. *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 [4] 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 as average of 30 repetitions. 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.* [8], this paper prefer to provide readers an advanced and a detailed measurement (i.e., without support from the physical layer). 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

	potential	*probe*	*auth*	**Total**
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)

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

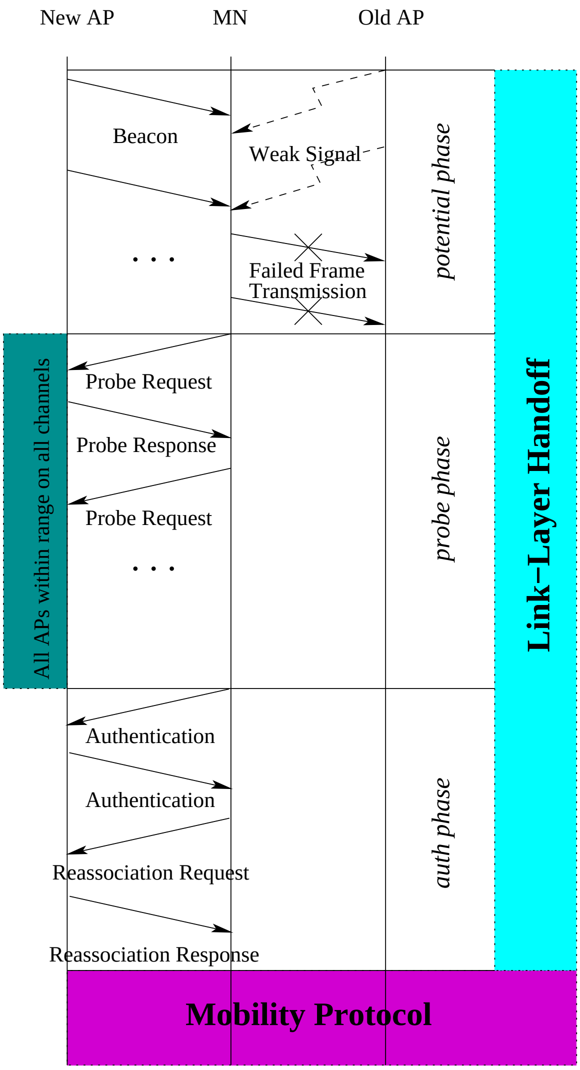


Fig. 3. The link-layer handoff procedure.

B. *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.

B.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 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.

B.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 specifics 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.

B.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.

B.4 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 [7]) 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.

IV. LINK-LAYER OPTIMIZATION SCHEME

A. Preliminary

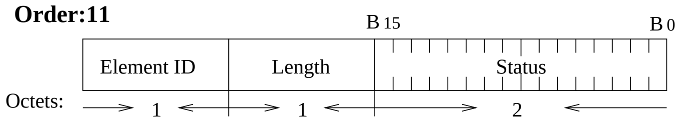
IEEE 802.11-based wireless LANs which consist of APs and WNICs have been set in many places. It may be impractical to make any incompatible modifications with existing devices as the result of doing this may mean an extensive change in the backbone of the networks. The proposed scheme can be achieved through firmware upgrade, no extra cost is needed. Since the *potential* phase can be skipped completely via taking advantage of the information provided by the physical layer 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. With the optimized parameters, whole link-layer handoff latency can be reduced to an acceptable level.

B. Link-Layer Optimization Scheme

B.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.

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_0 to B_{12} are used to represent the status of channel 1 to 13 respectively, and B_{13} to B_{15} are reserved. If AP uses channel



Element ID	*65 (reserved in standard)*
Length	*4*

Status	
B0 ~ B12	*Channel 1~13*
B13 ~ B15	*Reserved*

Fig. 4. The designed field appended to beacon.

n to make communications, it will set B_{n-1} 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.

The previously discussed scheme is demonstrated in Fig. 5. AP_1 and AP_2 use channel 6 and 11. After channel usage status exchanged, they will set B_5 and B_{10} to 1 in their broadcasting beacon respectively.

The detailed actions are described below:

(i) After MN enters the transmission range of AP_1, it can receive periodically broadcasting beacon from AP_1. Then, the WNIC can fetch the field **Order** 11 from received beacon and update its *Channel_Register* with **Status** subfield. After update, the *Channel_Register* will the same as the case in Stage II.

(ii) When MN detects the lack of radio connectivity of AP_1 (from Stage III moves to Stage IV), *probe* phase has been triggered. The WNIC can depend on the records of *Channel_Register* to only send the probe request to channel 6 and 11. This can eliminate the unnecessary channel searching operations in *probe* phase.

(iii) After link-layer handoff completed, MN has associated with AP_2 and reset its *Channel_Register*. Subsequently, MN receives the beacon from AP_2 and sets its *Channel_Register* as the case in Stage IV.

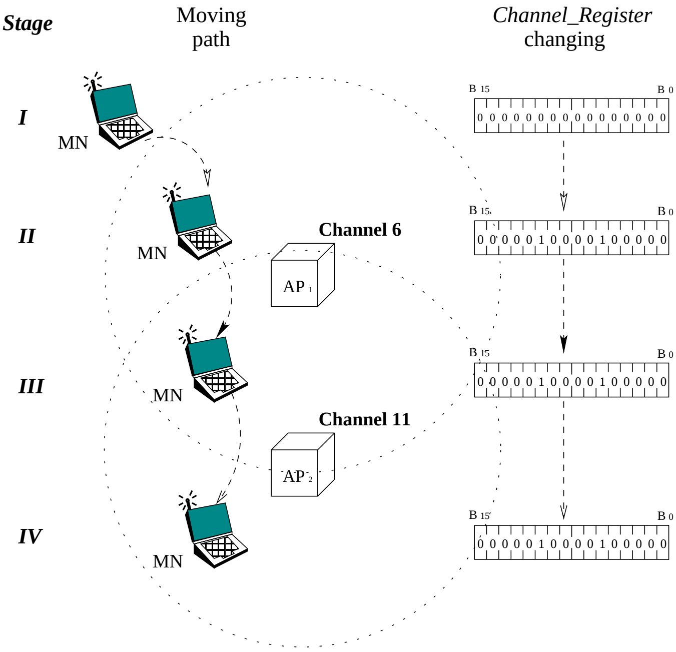


Fig. 5. Link-layer handoff with the proposed optimization scheme.

B.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 μs. 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 following equation.

$$\mathit{MinChannelTime} = \mathit{DIFS} + (\mathit{aSlotTime} \times \mathit{aCWmin})$$

In this equation, *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 μs 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. 6.

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 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 [1], Fig. 6 indicates that 10 TUs would be a reasonable choice for *MaxChannelTime*.

C. *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 follows.

$$T_b = 2T_d + MaxChannelTime$$
$$T_i = 2T_d + MinChannelTime$$

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 following equation.

$$T_p = (n\text{-}o)T_b + oT_i$$

V. 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.

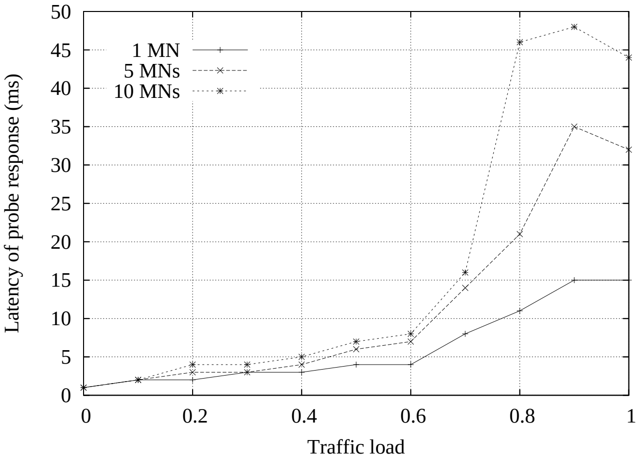


Fig. 6. Latency of probe response.

A. *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. 6 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 10 ms. After analyzed, the proposed optimization scheme defines *MaxChannelTime* as 10 TUs.

B. *Duration of* probe *phase*

In this experiment, the improvements of the proposed optimization scheme can be observed clearly in Fig. 7. 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 10TUs respectively. But these parameters are not specified in the IEEE 802.11 standard. By analyzing the transmission logs generated from the experiments in Section III, 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%.

From Fig. 7, the curves after the number of MNs in the WLAN reached are very stable. It is because MNs have more chances to distribute to the different channels, the possibility of idle channel be distinguished becomes higher when channel searching. But it will different in the actual network environ-

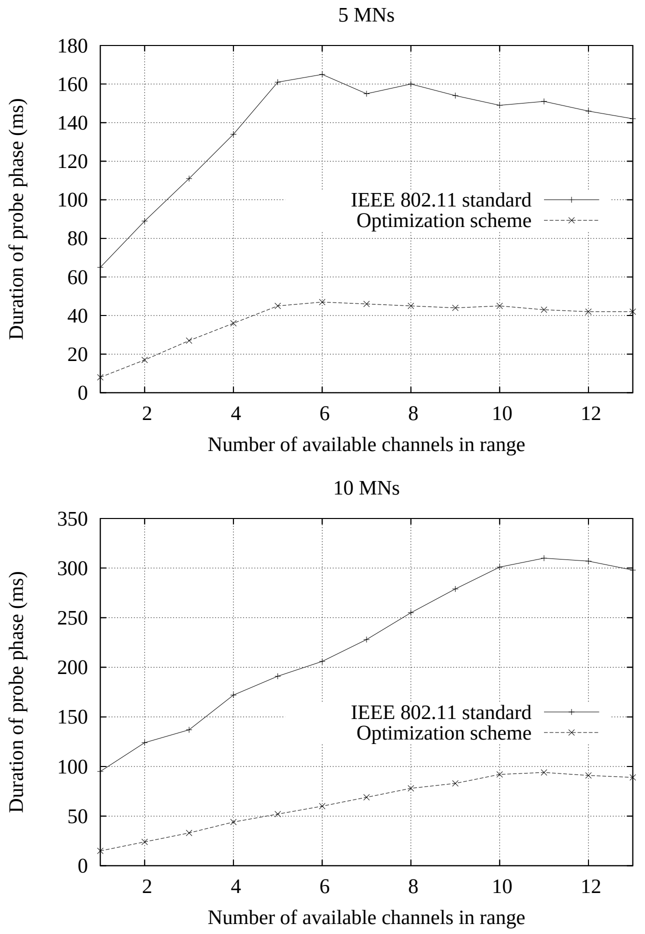


Fig. 7. Duration of probe phase.

ment. The differences between the proposed scheme and IEEE 802.11 standard will become larger. 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. This situation 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 24.1% 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.

C. Power consumption

The power consumption is a key issue in the wireless research area. The less packets transmitted, the more power saved and lower possibility of collision got. The number of probe requests are sent during *probe* phase when the proposed scheme and IEEE 802.11 standard are used is shown in Fig. 8. Since all channels must be searched in the IEEE 802.11 standard, no matter how many busy channels in range the results are the same. The proposed scheme, however, can depend on the records of *Channel_Register* to do a smart search, so the results are increasing with the busy channels in range. In a WLAN with three independent channels, it is 77% less than the one in the IEEE 802.11 standard during *probe* phase.

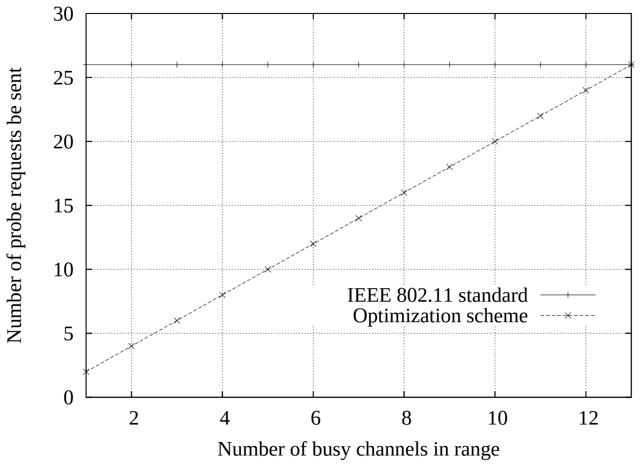


Fig. 8. Number of probe requests be sent.

VI. DISCUSSION

A. 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 [6]. 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.

B. Reduction of auth phase

From the experiments in the Section III, *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 [9] to reduce the handoff latency.

VII. 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.

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