PCLF: A Practical Cross-Layer Fast Handover Mechanism in IEEE 802.11 WLANs

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***Abstract*—As is known to us, the handover latency of FMIPv6 in its predictive mode is given little concerns. However our previous work [4] shows that FMIPv6 may suffer long handover latency in its predictive mode, and [4] identifies three key issues raising such problems. In this paper, we propose a practical cross-layer fast handover management mechanism (PCLF) to address these issues and improve success rate of mobility prediction. To solve the problem, PCLF includes a smart link layer trigger, a TBScan algorithm, a TBAPS algorithm, a buffering support Bi-Binding scheme and the smart link event notification policy. Experiment results show that our mechanism can achieve reasonable mobility prediction and seamless handover with no interruptions on upper layer applications (VoIP) in IEEE 802.11 WLANs. The average handover latency is less than 50ms, the success rate of mobility prediction is 97.7% and no packet loss is observed.**

Keywords- IEEE 802.11; FMIPv6; fast handover; cross layer;

I. INTRODUCTION

In IEEE 802.11 WLANs, when an MN (mobile node) hands over to an AP in a different IP subnet, both the link layer handover and the network layer handover are needed. Since IEEE 802.11 only supports link layer handovers, MIPv6 is proposed to support network layer handovers. However, MIPv6 suffers long handover latency. To reduce the handover latency, some mobility prediction based schemes have been proposed. FMIPv6 is the most popular one. FMIPv6 reduces the handover latency by conducting the fast handover operations before the link layer handover. Since the time of the link layer handover is hard to control, FMIPv6 has two different modes, the predictive mode and the reactive mode,distinguished by whether the fast handover operations are completed before the link layer handover. There are many works focus on analysis and improvement of FMIPv6 in literature. However, as is known to us, the handover latency of FMIPv6 in its predictive mode is given little concerns relatively. Most of the existing works assume that FMIPv6 can achieve its best performance when the handover prediction is correct and the MN goes into its predictive mode. The link layer factors and the efficiency of interactions between the link layer and the network layer, which may affect the handover latency, are usually ignored.

There are few works based on experiments in real test-bed.Moreover, in most previous experiment works, handovers are triggered through the pre-defined time table, while in practice handovers are actually triggered by link layer events. Focus on analyzing the overhead cost introduced

by FMIPv6 especially when an MN goes into the reactive mode. are conducted by simulation or analytical approaches. There are also existing works on measurement and improvement of FMIPv6 in test-bed. However, handovers are triggered by the pre-defined time table , thus, link layer factors that may impact the handover latency cannot be found or resolved. presents that FMIPv6 may suffer long handover latency in the predictive mode. However, does not identify or solve the inefficiency of interactions between the link layer and the network layer. And the proposed mechanism will suffer bad performance when theMN moves back and forth. Our previous work identifies three key issues affecting handover latencies of the predictive FMIPv6 in IEEE 802.11 WLANs through experiments. In this paper, considering both the link layer and network layer factors and their interaction efficiency, we propose a practical cross-layer fast handover management mechanism –PCLF. Our work focuses mainly on: 1) improve the success rate of mobility prediction; 2) reduce handover latency of FMIPv6 in its prediction mode. PCLF handovers are triggered through smart link layer triggers proposed by us, which allow the MN to start the related network handover operations right after the link layer prediction or the link layer handover.Using TBAPS, an MN can select a target AP through link quality tendency and network layer information, thus, the success rate of mobility prediction can be improved. And we propose TBScan, Bi-Binding and the smart link event notification policy to address the three affecting issues identified by respectively. Experiment results show that our mechanism can achieve reasonable prediction and seamless handover with no interruptions on upper layer applications (VoIP). The average handover latency is less than 50ms, the success rate of mobility prediction is 97.7% and no packet loss is observed through all our experiments.Paper organization: Section II reviews the issues affectingthe predictive handover latency. PCLF is proposed in section III. Section IV and V describe the implementation of PCLF and the experiment results. Section VI summarizes the paper.

II. PROBLEM STATEMENT

This section briefly reviews the phases of the predictive FMIPv6 handover (Fig. 1) and the three key issues that we should address when designing a fast handover management mechanism presented in our previous work . Important parameters are listed in Table. 1. Then we will discuss the design goals and our proposed scheme in the next section

A. Phases of Fmipv6 Predictive Handover Procedure

1) Link Layer Prediction Latency - Tl2Pre

In the link layer prediction phase, the MN has to complete the AP scanning and the target AP selection. And Tl2Pre can be calculated by (1). tscan is the AP scanning delay.

$$T_{l2Pre} = t_1 - t_0 \approx t_{scan} = \mathrm{ChannelNum} \cdot \mathrm{ChannelWaitTime} \quad (1)$$

2) Predictive Network Handover Latency - Tl3Pre

In the predictive network handover phase, the fast handover operations are completed. Tl3Pre can be calculated by (2). During this period, the MN can still send and receive packets.

$$T_{l3Pre} = t_2 - t_1 \quad (2)$$

3) Predictive Tunneling Latency - TPre-T

The MN might still connect with the PAR when the packets are tunneled to the NAR. In this situation, extra handover latency (TPre-T) is introduced, which can be calculated by (3).

$$T_{Pre-T} = t_3 - t_2 \quad (3)$$

4) Link Layer Handover Latency - Tl2

Tl2 is defined as (4). tdisa, tauth and treass denote the delays for the disassociation from the current AP, the authentication and the reassociation with the new AP respectively.

$$T_{l2} = t_4 - t_3 = t_{disa} + t_{scan} + t_{auth} + t_{reass} \quad (4)$$

5) Sender Preparation Latency - TsPre

TsPre is system depended and is defined by (5).

$$T_{sPre} = t_5 - t_4 \quad (5)$$

In summary, all these above phases except the predictive network handover phase can introduce latency to the total handover latency. Thus, the total handover latency of the predictive FMIPv6 can be calculated by (6).

$$T_{total\_handover} = T_{l2Pre} + T_{Pre-T} + T_{l2} + T_{sPre} \quad (6)$$

B. Issues Affecting handover latency of predictive FMIPv6

1) The lack of assistance from the network entities, the key issue affecting Tl2Pre during the link layer prediction phase and Tl2 during the link layer handover phase. Moreover, only instantaneous information of neighbor APs can be obtained during the prediction phase. Handover predictions based on instantaneous information may be wrong at a high probability.

2) The ambiguous link layer triggering time, the key issue affecting TPre-T during the predictive tunneling phase.

3) The inefficient interaction between the link layer and the network layer, the key issue affecting TsPre during the sender preparation phase.

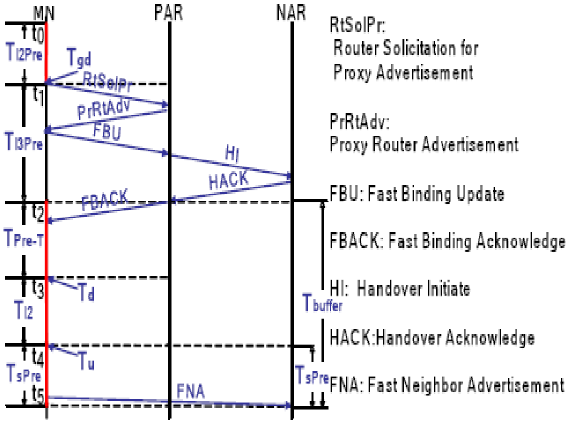


Fig. 1. The Predictive Handover Procedure of FMIPv6. The red solid lines represent periods during which the MN cannot send or receive packets.

III. PROPOSED SCHEMES

A. Our Design Goal

Only when all the three issues above are solved, can we achieve predictive fast handovers in real 802.11 WLANs. Thus, we propose PCLF, a practical cross-layer fast handover management mechanism, includes the following parts:

Smart Link Layer Triggers: provide interaction information between the link layer and the network layer.

TBScan and TBAPS: solve the first issue. TBScan, an AP scanning algorithm, is to reduce Tl2Pre during the link layer prediction phase and Tl2 during the link layer handover phase; TBAPS, a target AP selecting algorithm, is to improve thesuccess rate of mobility prediction.

Buffering Support Bi-Binding Scheme: solve the second issue, reduce TPre-T during the predictive tunneling phase.

Smart Link Event Notification Policy: solve the third issue, reduce TsPre during the sender preparation phase.

B. Overview of PCLF

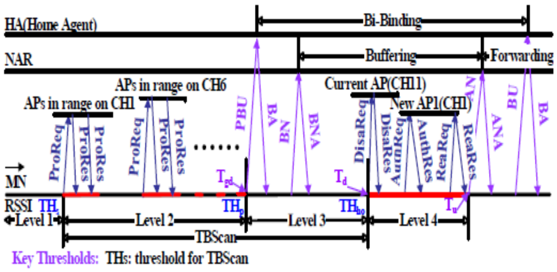
In public WLANs, the engineers should know the neighbor channels (channels on which neighbor APs exist) of each AP as well as the prefix and the MAC address of the attached AR. The information mentioned above can be configured when APs are deployed. And we introduce these information into 802.11 management frames, which will be utilized by the following schemes proposed in this Section.

As is shown in Fig. 2, the MN moves away from its current AP, the RSSI gradually decreases. The main stages of PCLF:

1) ***Mobility Prediction Preparation*****:** When the RSSI goes into Level 2, the MN goes into the TBScan process until the real link layer handover happens. Information such as the neighbor AP's RSSI, the prefix and the MAC address of the attached AR are stored in a data base.

2) ***Predictive Handover*****:** When the RSSI goes into Level 3, the predictive target AP is selected by the TBAPS using information collected by TBScan. If the target AP is in the different subnet from the current AP, a Tgd is sent to the network layer to start the predictive handover procedure. Then the MN sends a PBU and a BN (introduced by Bi- Binding) to the HA and the target AR respectively. Upon receiving the PBU, the HA starts to forward packets to the MN's current and new locations simultaneously. Upon receiving the BN, the NAR starts to buffer packets for the MN.

3) ***Regular Handover*****:** When the RSSI goes into Level 4, the link layer handover occurs; the target AP is selected by the TBAPS using information collected by TBScan. After the MN disassociates with the previous AP, the smart link event notification policy is used to guarantee that the MN can send packets right after it reassociates with the new AP. Once the MN reassociates with a new AP, the Tu is sent to the network layer to start the regular handover procedure. And the MN sends an AN (introduced by Bi-Binding) and a BU (defined instandard MIPv6) to the new AR and the HA respectively. Upon receiving the AN, the NAR starts to forward packets to the MN. Upon receiving the BU, the HA stops forwarding packets for the MN to MN's old location



Key Thresholds: THs: threshold for TBScan
THp: threshold for mobility predictions THho: threshold for link layer handovers
IEEE 802.11 link layer handover related management frames: ProReq: Probe Request
ProRes: Probe Response DisaReq: Disassociation Request DisaRes: Disassociation Response
AuthReq: Authentication Request AuthRes: Authentication Response
ReaReq: Reassociation Request ReaRes: Reassociation Response
Signaling Messages used by Buffering support Bi-Binding Scheme:
PBU: Predictive Binding Update BU: Binding Update BA: Binding Acknowledge
BN: Buffering Notification BNA: Buffering Notification Acknowledge
AN: Access Notification ANA: Access Notification Acknowledge

Fig. 2. link layer perspectives of handover procedure in our scheme. The red solid lines represent periods when the MN can not send or receive packets

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C. Smart Link Layer Triggers

We introduce the prefix and MAC address of the target AR (can be extracted from our extended 802.11 management frames) into Tgd and Tu, so that FMIPv6's RtSolPr can be saved, and the MN need not wait for a RA even if the prediction is wrong. And we introduce Tl2 into Tu. This latency can help the NAR to reduce the duplicated packets the MN may receive, which will be described in subsection F.

D. Topology based Background AP Scanning Algorithm - TBScan

The main idea of TBScan is to divide the long AP scanning phase into small pieces, which is similar to [14]. So that Tl2Pre and Tl2 can be eliminated. The channels are scanned one by one periodically. However, it will take a long time to update the quality of the entire neighbor APs. We improve [14] by introducing the neighbor channels, which can be obtained from AP's association/reassociation response. Thus, the unnecessary channel scanning can be avoided and the MN can update its neighbor APs' quality more quickly, and more information of each neighbor can be obtained. This provides the opportunity to make more reasonable target AP decision. Each channel probing operation is called a TBScan session, and the delay of each TBScan session can be calculated by (7).

$$T_{TBScan} = 2 \cdot T_{CHSwitch} + (1 - p(i)) \cdot T_{MinCHWait} + p(i) \cdot T_{MaxCHWait} \quad (7)$$

Where TCHSwitch is the time to switch channels, p(i) is the probability of one or more AP exist on channel i. TMinCHWait and TMaxCHWait represent the min and max waiting times on each channel defined by 802.11.

E.Tendency based Target AP Selection Algorithm–TBAPS The link quality information obtained during the TBScan is stored in a data base. And thus, the target AP can be selected concerning both the recent updated RSSI and the tendency of RSSI, which is proved to be efficient in . We improve the scheme in by making the final decision with the assistant of the prefix information of each neighbor AP's attached AR.The quality of each neighbor AP is calculated using (8).

$$Q_i = \begin{cases} \alpha \frac{RSSI_i - Th_y}{h_y} + \beta \frac{CN_i}{t_{dw}/(I_a \cdot n)} + \varepsilon & \text{in the same subnet} \\ \alpha \frac{RSSI_i - Th_y}{h_y} + \beta \frac{CN_i}{t_{dw}/(I_a \cdot n)} & \text{else} \end{cases} \quad (8)$$

RSSIi is the most recent updated RSSI of APi, CNi is the number of consecutive RSSI above the Thy of APi. α, β, ε are the weight factors of the current RSSI, the tendency of RSSI and the network prefix. THy is the RSSI threshold, hy denotes hyteresis and tdw denotes the dwelling timer, Ia is the average interval of TBScan, n is the number of the neighbor channels.

F. Buffering Support Bi-Binding Scheme

Since it is impossible for the PAR to know when exactly the MN will reach the NAR, our Bi-Binding scheme (we improve it by provide buffering and duplicated packets reducing support) forwards packets to the PAR and the NAR simultaneously. So that TPre-T can be eliminated. The Bi-Binding is carried out by the HA. New signaling messages are defined, including PBU, BN/BNA and AN/ANA. The PBU is used to notify the HA that both the predictive and previous bindings should be maintained and packets should be forwarded to MN's current and new locations of the MN simultaneously. The NAR sets up a buffer entry and starts to buffer packets for the MN after the exchange of the BN and BNA with the MN, and starts to forward packets to the MN after the exchange of the AN and ANA. The MN records the Tl2 and informs it to the NAR by the AN. To reduce the duplicated packets the MN may receive, the NAR records the time it receives the AN (TAN), then the NAR checks the arrival time (Ti) of each buffered packets, only packets meet the requirement shown in (9) will be forwarded to the MN.

$$T_i > T_{AN} - (T_{l2} + \delta) \quad (9)$$

Where δ is the paths asymmetry adjusting factor, since the paths from the HA to the PAR and the NAR are different.How to adjust δ adaptively will be investigated in our future work. On receiving a regular BU, the HA deletes the previous binding and stops forwarding packets to the MN's previous location. A timer (20s) is used to deal with wrong predictions.

G. Smart Link Event Notification Policy

To eliminate the TsPre of the NM under slow link event processing system (eg, linux-2.6.15), we propose a smart link event notification policy. When the MN disassociates from its current AP, a timer, 30ms is started (the max time for an MN to dissociate, authenticate and reassociate with a new AP observed in our experiments is 27ms). Only when the MN does not connect with a new AP within 30ms, the link down event will be sent to the link-watch module.

IV. CONCLUSIONS

In this paper, we propose a practical cross-layer fast handover management mechanism - PCLF, which can address the three key issues affecting handover latency of predictive FMIPv6. PCLF is consisted of the smart link layer trigger, a TBScan algorithm, a TBAPS algorithm, the smart link eventnotification policy and a buffering support Bi-Binding scheme. Experiment results show that our mechanism can achieve reasonable prediction and seamless handover with no interruptions on upper layer applications (VoIP). The average handover latency is less than 50ms, the success rate of mobility prediction is 97.7% and no packet loss is observed.

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