Cross-Layer Partner-Based Fast Handoff Mechanism for IEEE 802.11 Wireless Networks

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Abstract— **In this paper, we propose a cross-layer partner-based fast handoff mechanism based on HMIPv6, called as PHMIPv6 protocol. Our PHMIPv6 protocol is a cross-layer, layer-2 + layer-3, approach. A new node, called partner node, is adopted in PHMIPv6 protocol. A new layer-2 trigger scheme used in PHMIPv6 protocol is to accurately predict the next AP (access point) and then to invite a possible partner node in the area of the next AP. With the aid of the partner node, CoA can be pre-acquired and DAD operation can be pre-executed by the partner node before the mobile node initialize the handoff request. By the way, PHMIPv6 protocol can significantly reduce the handoff delay time and packet losses. In the mathematical analysis, we verify that our PHMIPv6 protocol offers a better handoff latency than MIPv6, HMIPv6, and SHMIPv6. Finally, the experimental results also illustrate that PHMIPv6 protocol actually achieves the performance improvements in the handoff delay time, and the packet loss rate.**

I. Introduction

A variety of IP based wireless access technologies have been developed for various need; one important need is to provide the seamlessly service switching (handoff) for a mobile node (MN) during an IMS (IP Multimedia Core Network SubSystem) service session between various access networks, where IP convergence has led to the co-existence of several IP based wireless access technologies and the emergence of next generation technologies. Seamless mobility in converged IP centric networks provides the uninterrupted services in pervasive ubiquitous environment.

Using Internet protocol (IP)-based access network is increasing and next generation of network environment is naturally moving toward IPv6-based network [21]. No existing wireless network technology can provide high bandwidth, low latency, low power consumption, and wide-area data service to a large number of mobile users simultaneously [17].

A general handoff problem among WLAN environment is the lack of immediate upper layer awareness when the lower layer has performed a handoff to a new access point (AP) in a different subnet. It usually takes several seconds for the upper layer to detect MN movement and complete the DAD (duplicate address detection) and registration procedures. Many micromobility designs and lower layer supported protocols [1] [4] [13] [2] have been proposed, but there is still room for further improvement. The layer 2 handoff latency [6] is divided into probe, authentication, and reassociation delay time. The probe delay occupies a large amount of the whole layer-2 handoff latency. The layer-3 handoff latency includes the rendezvous time, DAD time, and binding update time [16]. For HMIPV6-based protocols, the DAD duration time occupies a large amount of the layer-3 handoff latency. Existing works have been investigated to reduce the DAD time to significantly reduce the layer-3 handoff latency [16] [17] [20]. Efforts will be made in this work to develop a cross-layer protocol to reduce the total handoff latency of layer-2 and layer-3.

To support the mobility, Mobile IPv6 (MIPv6) [2] [20] is used to inform the binding of its home address and current care-of-address (CoA) to its home agent. MIPv6 suffers a long delay latency and high packet losses because that MIPv6 not support the micromobility. Hierarchical Mobile IPv6 (HMIPV6) [9] is proposed by providing micromobility and macromobility to reduce handoff latency by employing a hierarchical network structure. In this paper, we propose a cross-layer partner-based fast handoff mechanism based on HMIPv6, called as PHMIPv6 protocol. Our PHMIPv6 protocol is a cross-layer, layer-2 + layer-3, approach. A new node, called partner node (PN), is adopted in PHMIPv6 protocol. A new layer-2 trigger scheme used in PHMIPv6 protocol is to accurately predict the next AP (access point) and then to invite a possible partner node in the area of the next AP. With the aid of the PN, CoA can be pre-acquired and DAD operation can be pre-executed by the PN before the mobile node initialize the handoff request. The PHMIPv6 protocol can significantly reduce the handoff delay time and packet losses. In the mathematical analysis, we verify that our PHMIPv6 protocol offers a better handoff latency than MIPv6, HMIPv6, and SHMIPv6. Finally, the experimental results also illustrate that PHMIPv6 protocol actually achieves the performance improvements in the handoff delay time, the packet loss rate.

The rest of this paper is organized as follows. Section 2 discusses related work. Section 3 describes the system architecture and basic ideas. Our proposed PHMIPv6 protocol is presented in section 4. To illustrate the performance achievement, a mathematical analysis is conducted and simulation results are examined in Section 5. Finally, section 6 concludes this paper.

II. Related Work

Following the MIPv6 protocol, Chao *et al.* [14] recently proposed a micro-mobility mechanism in an integrated ad hoc and cellular IPv6 networks to provide a smooth handoff under a high-speed movement. This protocol utilizes *dynamic access routers* to pre-execute the sub-binding operation to CN for a MH. A multicast operation is used to send the same packets to a lot of access points to satisfy the purpose of the smooth handoff in a high speed moving. Unfortunately, the binding update time is still same as the MIPv6 protocol.

To actually improve the binding update time, Hierarchical Mobile IPv6 (HMIPv6) [9] is develop by adding new Mobility Anchor Point (MAP) in foreign domain. Each MH has two sub-CoAs, regional CoA and on-link CoA, to constitute the CoA. The regional CoA is used from CN to MAP, and the on-link CoA is used from MAP to the MN. When a MH under a same MAP, then a local binding update is only performed from MH to MAP. The main time cost of layer-3 handoff latency in HMIPv6 is to perform DAD procedures [12]. After finishing the DAD procedures for LCoA and RCoA, MH then performs binding update using the new generated LCoA and RCoA to HA and CN, respectively.

Lai *et al.* [16] recently proposed a stealth-time HMIPv6 (SHMPv6) protocol to further improve handoff latency. This approach reduces DAD delay time using the pre-handoff notification scheme and reduce the packet loss rate using the buffer technique. The main idea is to use buffer technique in the previous MAP (pMAP) to buffer the data packets from CN. Overall, SHMIPv6 protocol reduces the DAD time for LCoA, but SHMIPv6 still not significantly reduces the DAD time for RCoA.

Lee $et\ al$. [17] more recently proposed a new protocol, called as HMIPv6, by integrated IAPP [3] and access router to reduce the handoff latency. This approach uses the IAPP multicast messages to notify the access router (AR) of new domain to send packets to new access point. This *rendezvous time*, the time to finding a new AR, is reduced by using the IAPP notification. However, this protocol is worked well under all ARs must support the IAPP function. Therefore, this work not compare HMIPv6+ with our new approach.

III. Preliminary

This section first describes the system architecture of PHMIPv6 protocol. The main idea of layer-2 and layer-3 approaches are then introduced, and the idea and advantage of the cross-layer design is finally presented.

A. System architecture

Fig. 1 shows the system architecture of our work. Our work is based on HMIPv6 protocol [9] which is denoted as Partner-based HMIPv6 (or PHMIPv6) protocol. Our PHMIPv6 protocol utilizes a PN to improve the handoff latency during the handoff process.The PN is a mobile node which is located

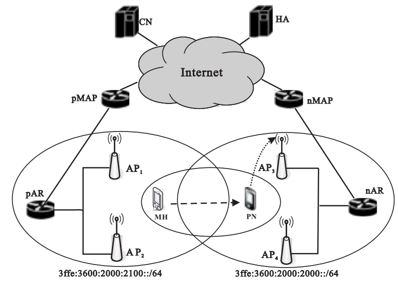


Fig. 1. PHMIPv6 system architecture

with the MN in different MAP domain and can directly communicate with the MN by the using ad hoc network. The main task of PN is to perform the pre-handoff procedure for the MN before MN reach to a new MAP domain. The other functions of the PN are the same as the MN.

Fig. 1 illustrates the PHMIPv6 system architecture which is based on HMIPv6 system architecture [9]. The PHMIPv6 protocol divides the network into two IPv6 subnet domains. MH sends the data packets from the AP and previous AR (pAR) to the CN through the previous MAP (pMAP). That is, CN sends data packets to the RCoA of MH, and MAP then forward the packets to the LCoA of MH. While MH moves into a new MAP (nMAP) domain, MH performs the registration procedure to its nMAP. The macro-mobility is occurred if MH switches from a pMAP to a nMAP domain. Then, MH must acquires a new unique CoA to register the CoA to new access router (nAR) and nMAP. Observe that, in our PHMIPv6 protocol, MH performs the registration procedure with the assistance of PN if PN is existed during the macro-mobility.

B. Cross-layer fast handoff approach

Recently, Chen *et al*. [15] presents a new fast handoff scheme, called the DeuceScan scheme, to further reduce the probe delay for 802.11-based WLANs. The DeuceScan scheme is a pre-scan approach which efficiently reduces the MAC layer handoff latency. Two factors of stable signal strength and variable of signal strength are both used in our developed DeuceScan scheme. DeuceScan scheme [15] is used to act as our layer-2 method. The deuce procedure with signal strength, which is denoted as $D_s(\alpha, \beta)$, where α is the extra number of partial scanning for APs and β is the scan cycles. One key idea of our DeuceScan scheme is the deuce process. The first important property of the deuce process is the partial pre-scanning operation. Observe that, one additional partial pre-scan operations can be done in the time period of one full pre-scan operation.

Figure 2 shows the cross layer idea which is about our scheme. To improve the handoff latency, efforts will be made in this work to reduce the DAD latency by using the PN.The MH and the PN locate in different domains, while MH and PN communicate with each other in ad hoc mode [19]. It is important that the DAD time for LCoA and RCoA can be reduced with the assistance of the PN. This is because that the pre-handoff procedure can be started and performed by

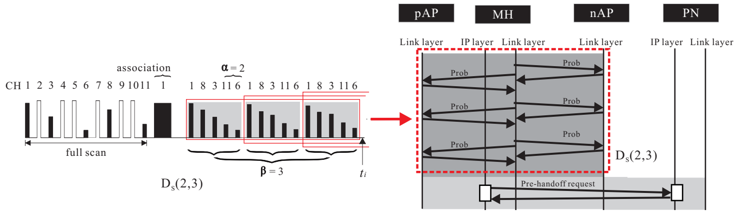


Fig. 2. Cross-layer idea

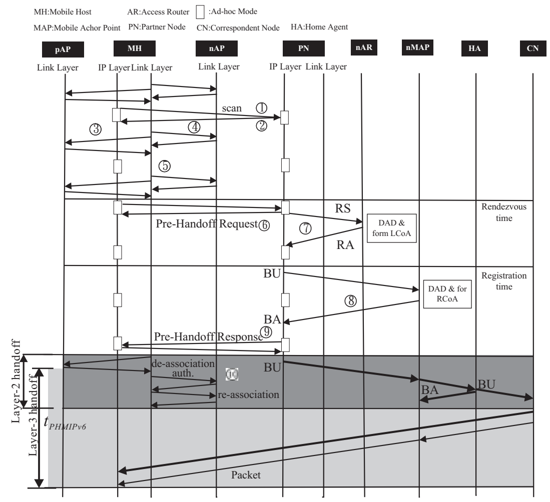


Fig. 3. The successful case of message flow of PHMIPv6 protocol

the PN when the MH is still not switched to the new MAP domain. But when the MH is really switched to the MAP domain, the PN can immediately deliver the LCoA and RCoA to the MH, where the LCoA and RCoA are already checked by performing the DAD operation. One important contribution of this work is the cross-layer design for the fast handoff scheme. Our cross-layer design is a merging of adjacent layers (layer-2 and layer-3) to improve the handoff latency.

IV. Partner-Based HMIPv6 (PHMIPv6) Protocol

The PHMIPv6 protocol is divided into two cases; successful and unsuccessful cases. If no PN is existed in the nMAP domain, MH performs the original HMIPv6 handoff protocol. The successful case is that MH finds a PN in nMAP domain, and then MH switches to the same nMAP domain. The unsuccessful case is that MH finds a PN in nMAP domain, but MH switches to a different nMAP domain. The successful case is focused in this paper.

A. Successful case

The total handoff time, $t_{PHMIPv6}$, and detail message flow of the successful case are given Fig. 3. The detail operations are described as follows.

Step 1 The MH periodically broadcasts message for scanning the PN. The MH moves to the boundary location of serving AP, and uses Network Time protocol (NTP) [7] for synchronization.

Step 2 The PN periodically broadcasts IPv6_Header + Modify_RA + subnet prefix of serving access router (AR). When MH receives IPv6_Header + Modify_RA packet from PN, the information of PN should be kept in MH. Then, MH stores the messages into partner-aware table. A best PN for the MH is identified before layer-2 handoff procedure of MH.

Step 3 $MH \overset{update}{\Longrightarrow} SAT$ (*subnet-aware table*) : MH turns into ad hoc mode, and sends out partner-aware information request message. Then, PN replies partner-aware response message. The MH, then, updates all new information of its own partner-aware table.

Step 4 If the PN still not be found, Repeat execution steps 1-3.

Step 5 By performing deuce procedure $D_s(\alpha, \beta)$, MH can understand the next new AP in a same or different MAP domain. If the AP is in the same pMAP domain, the MH performs the layer-2 handoff and directly connects to the new AP.

Step 6 MH sends out per-handoff request message to the PN.

Step 7 The AR sends the router advertisement message to the PN.

Step 8 The nMAP generates a new RCoA and performs the DAD procedure for RCoA. The nMAP returns the binding ack message to the MH for obtain the new RCoA.

Step 9 The PN replies the per-handoff response message and the MH confirms the message. The MH starts to performs the layer-2 handoff and asks the PN what is the new LCoA and RCoA of MH. the MN, finally, sends out location update message to the CN.

Step 10The CN sends data packets to the new LCoA and RCoA of MH.

V. Performance Analysis

The handoff latency of our PHMIPv6, HMIPv6 [9], and SHMIPv6 [16] protocols are analyzed. The simulation results are then analyzed.

A. Mathematical analysis

In our mathematical analysis, we use the same definitions from [14] [16], the network parameters are given in below.

- BW_w:Bandwidth of the wired backbones
- BW_{wl}:Bandwidth of the wireless link
- L_w:Latency of the wired link
- L_{wl}:Latency of the wireless link
- S_{ctr}:Average size of the control message
- n:Number of hops between the MH and the router
- t_{D_net}:Average delay of packet traveling in the Internet
- t_{D_DAD}:Average delay of the DAD time

Let t_{PN} be the time of PN preforming the pre-handoff procedure, $t_{PN} = t_{PN\_disc.} + t_{rende.} + t_{DAD\_LCoA} + t_{DAD\_RCoA} + t_{B\_CN}$, where $t_{PN\_disc.}$ is the time of a MH finding the PN which is belong to nMAP domain, $t_{rende.}$ is the time of MH finding a nAR, and received the router advertisement message from nAR, t_{DAD_LCoA} is the time of a PN performing DAD operation of LCoA, t_{DAD_RCoA} is the time of a PN performing the DAD operation of RCoA, and t_{B_CN} is is the time of PN sending binding update message to HA, CN if MH is notified the PN for the handoff.

Let S_{ctr} be the average size of the control messages, BW_w be the bandwidth of wired backbones, BW_{wl} be the bandwidth of wireless link, β be the value from layer-2 deuce procedure $D_s(\alpha, \beta)$, t_{D_DAD} be the average delay of the DAD time, and t_{D_net} be the average delay of that a packet traveling in the Internet. First, $t_{PN\_disc.}$ is

$$t_{PN\_disc.} \quad = \quad \frac{n}{\beta}(t_{subnet\_\inf}) \quad \text{, where } n = \beta, 2\beta, ... \quad (1)$$

Then, $t_{rende.} = t_{sol.} + t_{adv.}$, where $t_{sol.}$ is the time of PN sending the router solicitation message, and $t_{adv.}$ is the time of nAR sending the router advertisement message.

$$t_{sol.} = (\frac{S_{ctr}}{BW_{wl}} + L_{wl}) + n(\frac{S_{ctr}}{BW_w} + L_w) + t_{D\_net}, \qquad (2)$$

$$\begin{aligned} t_{PN} \quad = \quad & t_{PN\_disc.} + t_{rende.} + t_{DAD\_LCoA} + t_{DAD\_RCoA} \\ & + t_{B\_CN.} \qquad (3) \end{aligned}$$

$$\begin{aligned} t_{HMIPv6} \quad = \quad & t_{L2} + t_{rende.} + t_{DAD\_LCoA} + t_{DAD\_RCoA} + \\ & t_{B\_CN} \qquad (4) \end{aligned}$$

where t_{L2} is layer-2 handoff delay time. Similarly, $t_{SHMIPv6}$ [16] is derived below.

$$\begin{aligned} t_{SHMIPv6} \quad = \quad & t_{L2} + t_{rende.} + t_{DAD\_LCoA} + \\ & \min(t_{pmap}, t_{bu\_HA}) \qquad (5) \end{aligned}$$

For the successful case, the handoff latency of PHMIPv6 can be represented by

$$t_{PHMIPv6} \quad = \quad t'_{L2} + t_{L3} - t_{overlap} \qquad (6)$$

where t'_{L2} is the layer-2 handoff delay time in our PHMIPv6 protocol. Let t_{Δ_1} be the time difference between $t_{SHMIPv6}$ and t_{HMIPv6}.

$$t_{\Delta_1} \quad = \quad t_{HMIPv6} - t_{SHMIPv6} \qquad (7)$$

Let t_{Δ_2} be the time difference between t_{HMIPv6} and $t_{PHMIPv6}$. Therefore, t_{Δ_2} is the same as t_{Δ_1}

For the unsuccessful case, let $t_{U\_PHMIPv6}$ be the handoff latency of unsuccessful case of PHMIPv6. Thus,

$$t_{U\_PHMIPv6} \quad = \quad t'_{L2} + t_{L3} \qquad (8)$$

Let $t_{\Delta 3}$ be the time difference between t_{HMIPv6} and $t_{U\_PHMIPv6}$.

$$t_{\Delta_3} \quad = \quad t_{HMIPv6} - t_{U\_PHMIPv6} \qquad (9)$$

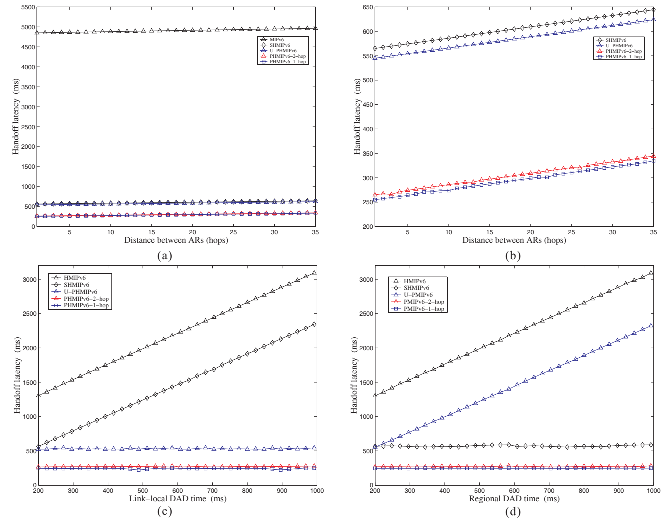


Fig. 4. (a)(b) Handoff latency vs hops, (c) handoff latency vs. link-local DAD time, (d) handoff latency vs. regional DAD time

B. Simulation result

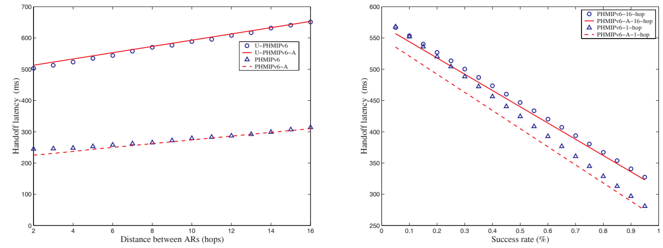
We really implement our PHMIPv6 protocol, MIPv6, HMIPv6, and SHMIPv6. Our testbed system uses the HMIPL and each MAP runs Linux 2.4.20 kernel. We modify the the open source driver ,madewifi [11], to implement the L2 deucescan procedure. Fig. 1 shows our testbed system.

In our simulation, PHMIPv6-x-hop and U-PHMIPv6-x-hop are used to denote PHMIPv6 (successful case) for finding PN.

1) Handoff latency: Fig. 4 illustrates the micro-mobility handoff (vertical handoff) latency vs. distance between ARs (hops) for MIPv6, PHMIP, SHMIPv6, and HMIPv6, and our PHMIPv6 protocols. The time latency is measured by the time from pAR to nAR. The typical wireless-link delay between the MH and nAR is between 10 and 50 ms. Fig. 4 (a) illustrates the fact that MIPv6 protocol has highest latency compared to all existing protocols. Therefore, Fig. 4 (b) drops off the MIPv6 protocol to only compare all other protocols. Our PHMIPv6 protocol has better handoff latency than other protocols. This is because that the overlapping result for our cross-layer partner-based design can significantly reduce the handoff latency.

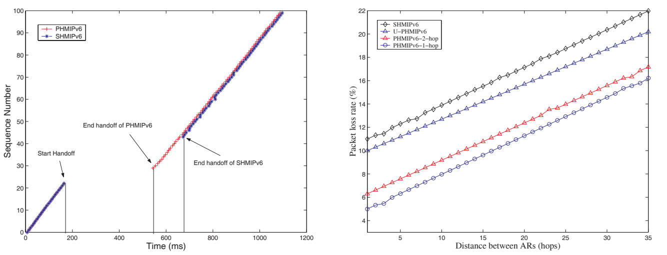
Fig. 4(c) illustrates the HL of the MH under various link-local DAD time. For PHMIPv6 and U-PHMIPv6, the higher link-local DAD time is, the HL doesn't increase, because link-local DAD procedure has been preformed by PN. Fig. 4(d) illustrates the HL of the MH under various regional DAD time. In general, the HL increases as the regional DAD time increases. We observed that the U-HMIPv6 and HMIPv6 increase as the regional DAD time increases. Because U-PHMIPv6 doesn't improve the regional DAD procedure.

Fig. 5(a) displays that using mathematical analysis for our PHMIPv6 scheme. The U-PHMIPv6 is also similar to U-HMIPv6-A. It is nearly from our implementation in low hop counts. Fig. 5(b) shows that using mathematical analysis for our PHMIPv6 scheme under various success rate. The PHMIPv6-16-hop and PHMIPv6-16-hop-A are also similar under higher success rate. Because under higher success rate



(a) (b)

Fig. 5. (a) Handoff latency vs. distance between ARs and (b) handoff latency vs. success rate (%)



(a) (b)

Fig. 6. (a) Sequence number vs. time (b) handoff latency vs. success rate (%)

that MH is successfully switch to nMAP domain in PHMIPv6 scheme.

2) Packet loss: Fig. 6 illustrates the micro-mobility packet (vertical handoff) loss vs. distance between ARs (hops) for SHMIPv6, U_PHMIPv6 and our PHMIPv6 protocols. Fig. 6(a) shows the simulation results of the PL vs. time. We observed that from the start handoff time to handoff time of SHMIPv6 and PHMIPv6, the PHMIPv6 scheme receives the packets from the CN early than the SHMIPv6 scheme. Fig. 6 (b) illustrates the PL of the MH under various distance between ARs (hops). We observed that the PHMIPv6-1-hop, PHMIPv6-2-hop, U_PHMIPv6 and SHMIPv6 increase as distance between ARs (hops) increases. PHMIPv6-1-hop, PHMIPv6-2-hop are increased similar, because the PHMIPv6-2-hop adds one hop discovery range. The U_PHMIPv6 is lower than SHMIPv6, because the U-PHMIPv6 scheme use deuce handoff scheme to decrease the L2 handoff time.

VI. Conclusion

In this paper, we propose a cross-layer partner-based fast handoff mechanism based on HMIPv6, called as PHMIPv6 protocol. Our PHMIPv6 protocol is a cross-layer, L2 + layer-3, approach. With the aid of the partner node, CoA can be pre-acquired and DAD operation can be pre-executed by the partner node before the mobile node initialize the handoff request. By the way, PHMIPv6 protocol can significantly reduce the handoff delay time and packet losses. In the mathematical analysis, we verify that our PHMIPv6 protocol offers a better handoff latency than MIPv6, HMIPv6, and SHMIPv6. Finally, the experimental results also illustrate that PHMIPv6 protocol actually achieves the performance improvements in the handoff delay time, the packet loss rate, and the handoff delay jitter.

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VII. Acknowledgement

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