A Cross-Layer Partner-Assisted Handoff Scheme for Hierarchical Mobile IPv6 in IEEE 802.16e Systems

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***Abstract*—In this paper[1], a new approach is proposed to reduce handoff operation in IEEE 802.16e network. Traditional mobile approaches, such as mobile IPv6 (MIPv6) and hierarchical MIPv6 (HMIPv6), can support smoothly handoff. These approach, ,unfortunately, suffer large handoff delay and packet lost in macro mobility for mobile users. With the aid of the partner node, DAD operation can be pre-executed by the partner node before the mobile node initialize the handoff request. we propose a cross-layer partner based fast handoff mechanism based on HMIPv6 in IEEE 802.16e network, called as P_HMIPv6 protocol. The P_HMIPv6 protocol is a cross-layer, layer 2 and layer 3, approach. The partner station (PS), which is a new component with relay ability and adopted by our protocol, is a static mobile station (MS). With the aid of the PSs, care-of address (CoA) can be pre-acquired and DAD operation can be pre-executed by the PS before the MS initials the layer 2 handoff. The simulation results show that P_HMIPv6 protocol actually achieves the performance improvements in the handoff delay time and the packet loss.**

I. Introduction

With the rapid development of wireless technologies, the wireless networks have become more and more popular. By connecting to any wireless access network, users can get many kinds of internet services out of doors. In wireless networks, mobility management provides mobile users to continuously get the internet service when they move between different subnets. When a mobile station (MS) moves from one subnet to another, the MS performs layer 2 handoff to establish new link to the new base station or access point. The mobile users also need an handoff mechanism to maintain network connectivity in order to obtain the internet service. Users suffer large handoff latency and packet loss if no proper handoff mechanism is exploited.

A new wireless technology, called WiMAX (Worldwide Interoperability for Microwave Access), which is defined by the WiMAX Forum [3], has been specified in IEEE 802.16 standards for metropolitan networks. The IEEE 802.16-2004 standard [4] defines physical and Medium Access Control (MAC) layer operations of broadband wireless access (BWA) systems which supports last mile connectivity at high data rate and large transmission range in wireless metropolitan area networks. The IEEE 802.16-2004 standard is only for fixed wireless connections, a further amendment, the IEEE 802.16e standard [5], is specified to support mobility for mobile devices. Every BS exchanges channel information and Mobile station's (MS) handoff parameters over the backbone network to speed up L2 handoff. The MSs are advertised by their serving BSs of neighbor BSs' information to support MS scanning and handoff procedures. Because of large transmission range, resource scheduling algorithm and good support for the MS mobility, WiMAX may become one of the most important wireless technologies.

In IP mobility, a MS can move and attaches arbitrarily itself to another subnet. a new IP address could be assigned since the MS wants into the new subnet. With this change of IP address, all existing connections to the MS are unable to deliver the data to the correct endpoint. Therefore, a network layer handoff algorithm is also required to deal with IP mobility. Mobile IPv6 (MIPv6) [11] is a protocol developed as a subset of IPv6 to support mobile connections, which allows an IPv6 node to remain reachable regardless of its location on an IPv6 network and whether the nodes with which the Mobile IPv6 node is communicating also support Mobile IPv6. In MIPv6, each MS is always identified by its home address. While situated away from its home network, a MS is also associated with a care-of address (CoA), which provides information about the MS's current location. The protocol enables IPv6 nodes to cache the binding of a MS's home address with its CoA, and then to send any packets destined for the MS directly to it at this CoA. MIPv6 offers a solution to solve the IP mobility, but due to intolerable high data lost rate and long handoff latency. A new protocol, called Hierarchical Mobile IPv6 has been proposed by the RFC 4140 [15] document, which

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extends Mobile IPv6 to allow for both micro mobility and macro mobility handling. Hierarchical mobility management for Mobile IPv6 is designed to reduce the amount of signaling between the Mobile Node, its Correspondent Nodes (CN), and its Home Agent (HA). The Mobility Anchor Point (MAP) which is defined to improve the performance of Mobile IPv6 in terms of handoff speed.

In this paper, we propose a cross-layer partner-assisted handoff mechanism based on HMIPv6 in 802.16e wireless system, termed P_HMIPv6 protocol. Our P_HMIPv6 protocol is a cross-layer, layer 2 + layer 3, approach, which is based on HMIPv6. The basic idea of the partner node performing pre-handoff procedures is based on [8]. The partner station (PS) [9], defined in this protocol, is a static MS which has relay ability defined in 802.16j. With the PS's assistances, the MS detects the neighbor BSs' exist early and then to request some possible PSs in the coverage of the next BS to perform layer-3 mobility before the actual layer 2 handoff. The PS also performs the duplicate address detection (DAD) operation of the MS's new care-of address (CoA) before the MS initials the handoff request. In order to reach the goal, some control messages of layer 3 are combined into layer 2. By the way, P_HMIPv6 protocol can significantly reduce the handoff delay time and packet losses. In the simulation results illustrates that P_HMIPv6 protocol actually achieves the performance improvements in the handoff delay time, packet loss, and the handoff delay jitter.

The rest of this paper is organized as follows. Session 2 discuss related work. Session 3 describes the system architecture and basic ideas. The proposed protocol is presented in session 4. The analysis and simulation results are shown in session 5. Finally, session 6 concludes the paper.

II. Related Work

In this section, we first discuss some IP mobility solutions. Many active researches are proposed to apply the layer-3 handoff protocol over the existing IEEE 802.16e layer 2 handoff. Most of the previous researches, [14] [9] [10], focus on integrating the layer 3 handoff messages into layer 2 messages. Those researches are described in the following paragraphs.

Jang *et al*. [10] first proposed FMIPv6 protocol in IEEE 802.16e systems. The handoff procedures in IP layer and the original FMIPv6 procedure are all the same. The proposed scheme only use four triggers, named New_BS_Found (NBF), Link_Going_Down (LGD), Link_Up (LUP) and Link_Switch (LSW), defined in IEEE 802.21 [6] to control the timing of mobility procedures in IP layer and link layer.

Minsik Shim *et al*. [14] proposed a FMIPv6 based scheme in WiBro system. According to combine several layer 3 messages with layer2 message, the handoff latency is reduced. In WiBro system, the Radio Access Station (RAS) has ability to do packet buffering. When the Portable Subscriber Station (PSS) switches its access link, both the new streams and undelivered packets may be delivered at the same time. Thus, the out-of order problem has occurred. To solve this problem, the scheme uses previous Access Control Router (pACR) buffering for preventing out-of-order packets.

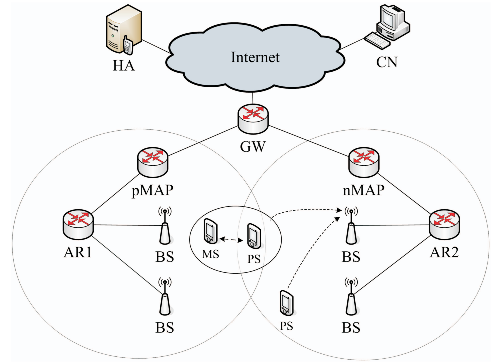


Fig. 1. P_HMIPv6 network architecture in IEEE 802.16e system

Chen *et al*. [9] also proposed an FMIPv6 based scheme in IEEE 802.16e systems. The proposed scheme also combine layer 3 messages to layer 2 message and also used PAR (previous Access Router) to do data buffering. The main difference in this paper is the timing to do the DAD and tunnel between PAR and NAR (new Access Router). By overlapping the layer 2 handoff delay time and FMIPv6 procedure, the MS precisely knows the actual target BS which the MS wants to switch and the handoff delay time is reduced.

III. Preliminary

In this section, we describe system architecture of our proposed scheme will be described. In subsection B, we describe the challenge of our protocol in IEEE 802.16e and compare it with [8]. Finally, we introduce the basic idea of our approaches.

A. System architecture

Fig. 1 shows the network architecture of our proposed scheme. Our proposed method is based on HMIPv6 so our network architecture is similar to that of HMIPv6. The only difference is a new component has been specified in our architecture. When the MS wants to perform handoff due to the lack of the signal strength but the MS is still not in the neighbor BSs' coverage area, we can try to find some the appropriate MSs in the neighbor BSs coverage area in nMAP domain. We call this component "partner station" (PS). The PS assists another MS to deal with partial impending mobility procedures in advance. The detail of the PS is defined as follow.

Definition 1: Partner Station (PS): Given a MS, any neighbor MSs of this MS in different MAP domain can become the PSs. The function of the PS is to assist the MS in performing the partial work of the layer 3 handoff which is defined in the macro mobility of the HMIPv6. The MS should obtain the DCD and UCD information which from the PS if the MS needs the assistance of the PS. To maintain backwards compatibility, a PS acts like a BS from the view point of the attached MSs so the any serving BS also broadcasts neighbor

PSs' information using the MOB_NBR-ADV message. Any MS who wants to become a PS needs to satisfy the following conditions:

- The RSSI of the BS downlink to the MS must less than $RSSI_{thr}$ to ensure that the MS is nearly in the boundary of the neighbor BS's coverage.
- The MS must perform neighbor BS scanning to ensure its locality and report the scanning result to its serving BS.

After satisfying the above conditions, the MS can register with its serving BS. The purpose of the MS registration procedure is to inform the MS's serving BS that the MS satisfy the above conditions and it want to be a PS. The scanning results of PSs are also reported to the serving BS in the registration procedure. Because the PSs need to connect to IP network through their serving BS and communicate with the MSs at the same time, we need to assume any MSs who want to become PSs have relay station's (RS) functions defined in IEEE 802.16j [1].

B. Challenge

Our handoff mechanism is based on the [8] which is a partner-based HMIPv6 protocol in IEEE 802.11. The mobile node gets partner node's assistance to perform the pre-handoff procedure. Due to the results of [7], the MS can decides the target access point (AP) to switch to before the mobile node finds appropriate partner node. Therefore, the MS can choose one PS in the target AP to get the partner node's assistance using the ad-hoc mode communication. However, in our network scenario, when the MS wants to perform layer 2 handoff, the MS may not in neighbor BSs' coverage if the overlap coverage area of two BSs is too small. The MS needs to find PSs before the target BS is selected. The unpredictable target BS results in unpredictable target PS. Moreover, due to no ad-hoc mode is defined in IEEE 802.16e, we assume every MS has relay station's functions defined in IEEE 802.16j [1] to support the communication between the MS and the PS.

C. Basic idea of our handoff scheme

The main object of PSs is to assist the MS in performing partial layer 3 handoff procedures before the MS actually reaches to a target BS coverage which is in a new MAP domain. As described in RFC-2461 [12], any MS needs to wait the Router Advertisement messages (RA) for receiving network prefix or sends Router Solicitation messages (RS) actively to query the prefix. The DAD procedure is described in RFC-2462, the MSs send Neighbor Solicitation (NS) messages which target Address is set to the address being checked to other MSs in the same domain to ensure that this address is unique, and wait the Neighbor Advertisement Messages (NA) at least one second. If no response, the address can be assigned into the interface. Therefore, for the handoff latency, the Neighbor Discovery and DAD procedures are a key bottleneck in MIPv6 [11] based scheme. The latency of macro mobility in HMIPv6 is more serious because the handoff procedures include the DAD procedures of the RCoA and LCoA. However, the PS can assist the MS to obtain the RCoA and LCoA address and execute the DAD procedure for proving the unique. The MS can still transmit data to the CN during the pre-handoff procedure. If the MS receives the reply address information from the PS, the MS performs the layer 2 and layer 3 handoff procedure except DAD and switches into new WiMAX network. Therefore, the latency of handoff in the P_HMIPv6 protocol is less than the HMIPv6 and MIPv6.

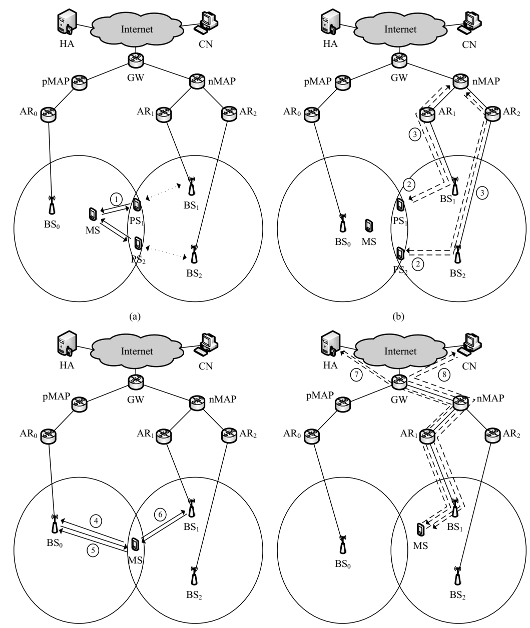


Fig. 2. Scenario of successful case of P_HMIPv6 protocol

IV. PARTNER-ASSISTED HMIPV6 PROTOCOL

This section presents our partner-assisted handoff mechanism based on HMIPv6 in IEEE 802.16e systems. The P_HMIPv6 protocol is a cross-layer design by merging layer 2 and layer 3.

First of all, the MS needs to find appropriate PSs to perform the pre-handoff procedures. Then the protocol operation of P_HMIPv6 is divided into three cases: successful case and unsuccessful case 1 and case 2. In successful case, the MS finally handoffs to the target BS in which the MS finds a PS to assist the pre-handoff procedures during the scanning with association procedures. In unsuccessful cases 1, the MS can not discover any PSs to perform pre-handoff procedures in nMAP domain. In unsuccessful case 2, the MS discovers PSs in nMAP domain but those PSs are not in the nAR's subnet.

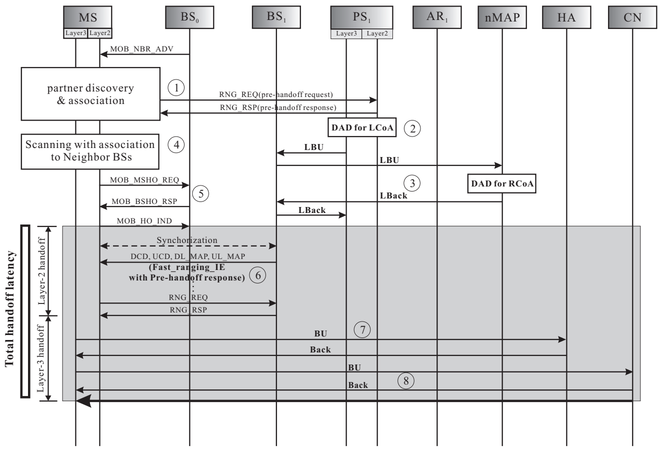


Fig. 3. Flowchart for successful case of P_HMIPv6 protocol

For the paper length limiting, we do not show the unsuccessful case in this work.

To explain the operation of the P_HMIPv6 protocol, let $X \overset{forward}{\longrightarrow} Y$ indicates that *X* forwards data message to *Y*, $X \overset{broadcast}{\longrightarrow} Y$ implies that *X* broadcast the message to *Y* within a one-hop transmission range and $X \overset{multicast}{\longrightarrow} Y$indicates that *X* multicasts messages to *Y*. In addition, let $X \overset{action}{\Longrightarrow} Y$ denotes that *X* executes a *communication action* to *Y*, where *X* and *Y* = $\{MS, BS, PS, MAP, HA, CN\}$, and *communication action* = $\{scan, assoc, HO{-}REQ, SCN{-}REQ, L2{-}HO, NBR{-}ADV, packet, LBU, DAD, BU\}$. Basically, $X \overset{action}{\Longrightarrow} Y$ is achieved by one or many $X \overset{forward}{\longrightarrow} Y$, $X \overset{broadcast}{\longrightarrow} Y$.

A. Handoff procedure in P_HMIPv6

Fig. 2 shows the handoff procedure of the P_HMIPv6. Fig. 3 shows more details of the handoff procedure. We assume that the PS can be discovered and the MS can associate with it.

Step 1:$MS \overset{assoc}{\Longrightarrow} PS$: After finishing the partner discovery procedures, the MS then finds PSs to perform pre-handoff procedures in every subnets of $nMAP$ domain. The PS_1 in AR_1's subnet and PS_2 in AR_2's are all in the nMAP domain. The MS requests the two PSs to perform pre-handoff procedures.

Step 2:$PS \overset{DAD}{\Longrightarrow}$ *All nodes in* nAR: After receiving the RNG-REQ with pre-handoff request which includes the MS's MAC address. The PSs then send the RNG-RSP to the MS and form the LCoAs based on the MS's MAC address to perform the DAD procedures for those LCoAs in those possible subnets to confirm the two LCoAs is unique.

Step 3:$PS \overset{LBU}{\Longrightarrow} nMAP$: After confirmed the MS 's LCoAs to be unique, those PSs send local binding update messages to bind the LCoAs and RCoA. In original HMIPv6, one RCoA only binds one LCoA. In our P_HMIPv6, we bind an RCoA with multiple LCoAs temporarily in modified LBU message. A new flag is added in modified LBU message, the p flag, which indicates that this message is sent from the PS. When the modified LBU message is set, the RCoA can bind multiple LCoA included in this binding update message. Another change of this message is that mobility option includes the MS's old LCoA. The old LCoA is to confirm the multiple binding messages are sent for the same MS. After receiving the LBU of the PSs, the $nMAP$ performs the RCoA DAD for one of the two binding updates and sends two LBack messages to the two PSs. The LBack results are also stored in the BSs which the PSs connect to.

Step 4:If the MS still moves to the target BS, the MS continuously scans the neighbor BSs with association procedure to find the appropriate target BS and gets the ranging parameters of those candidate BSs to reduce layer 2 handoff latency.

Step 5:$PS \overset{HO-REQ}{\Longrightarrow} MS$: After getting the results of the neighbor BSs' RSSI, CINR and related delay parameters, the MS then sends the MOB_MSHO-REQ to the serving BS the candidate BSs and the serving BS negotiates its service capability with those BSs through backbone network to find the target BS. The BS_0 finally decides that the MS's target BS is BS_1. The MS then sends MOB_HO-IND to notify the serving BS the start of handoff.

Step 6:$MS \overset{L2-HO}{\Longrightarrow} BS$: The MS starts synchronize to target BS and get the downlink and uplink parameters (DCD, UCD, DL-MAP, UL-MAP) and then perform ranging procedures to adjust the uplink power and offset to the serving BS. The UL-MAP message includes Fast_Ranging_
IE to provide the MS a non-contention based initial ranging opportunity to accelerate the ranging procedure. We modify this message to include the LBack result of the MS to notify the MS if the LCoA and RCoA are valid.

Step 7:$MS \overset{BU}{\Longrightarrow} HA$: After finishing the layer 2 handoff procedure, the MS also got the validation of the LCoA and RCoA and the local binding update is finished by the PS in target BS's subnet. The MS only needs to bind the RCoA with its home address (HoA) by sending the binding update (BU) message to HA and wait for binding ACK message to reply the result. The example is shown in Fig. 2(d).

Step 8:$MS \overset{BU}{\Longrightarrow} CN$: The MS sends BU message to the CN to notify CN its RCoA. This can optimize the route between MS and CN.

V. Performance Analysis

In this section, the handoff latency of P_HMIPv6 and HMIPv6 [15] is analyzed by the simulation.

A. Simulation result

To simulation our P_HMIPv6 and HMIPv6 protocol in IEEE 802.16e network, two ns-2 modules, NIST wimax module [13] and mobiwan [2], are also required to be installed. Fig. 4 shows simulation evitonment of our P_HMIPv6 and HMIPv6. For simplifying the scenario, every BS supports access router functions, which denotes that one BS presents a different subnet. The CBR traffic is established from CN to MS, and the bandwidth and latency for every link between every two components are also specified in this scenario.

In our simulation, P_HMIPv6 and U_P_HMIPv6 are used to denote successful case and unsuccessful case 2 of P_HMIPv6 protocol. The unsuccessful case 2 is that the DAD procedure of RCoA is down by PS in an AR's subnet different from the nARs' in the same MAP domain. Some performance metrics to be analyzed from simulation result are:

- **Handoff latency:** The handoff latency is defined as the time interval from last packet received form serving BS to and new packet received from target BS.
- **Packet loss:** The packet loss counts from the MS disconnecting to serving BS to receiving new packets from the target BS.

1) Handoff latency: Fig. 5 illustrates the sequence number vs. time for P_HMIPv6 and HMIPv6 protocols. In our P_$HMIPv6$, two layer 2 handoff trigger is used. The first trigger is for the PS discovery to get the assistance of the PSs to finish DAD procedures of LCoA and RCoA and the binds between the two addresses. The second trigger is the actually layer two handoff trigger, which is used two start the target BS's selection. The scanning interval and interleaving interval are set to be 50 frames and the scanning iteration is set to be 2. Therefore, in the scanning interval, the MS does not receive the incoming packets which are buffered in BS and the interleaving interval is a rendezvous time which is used to receiving packets from the BS and separates the latency of scanning. As shown in Fig. 5, the handoff latency of P_HMIPv6 much less than HMIPv6 because the MS has finished the DAD procedures of LCoA and RCoA and local binding update between LCoA and RCoA.

Fig. 6(a) illustrates the handoff latency of the MS under various LCoA DAD time. In general, the handoff latency increases as the LCoA DAD time increases. For each case, the higher the LCoA DAD time is, the higher the handoff latency will be. We observed that the U_P_HMIPv6 and HMIPv6 increase as the LCoA DAD time increases. For U_P_HMIPv6, the PS performs DAD procedure in wrong subnet in the target MAP domain so the MS needs to get the new LCoA and perform the LCoA DAD. For P_HMIPv6, the increasing LCoA DAD time does not affect the handoff latency because LCoA DAD procedure has been preformed by the PS in the target subnet.

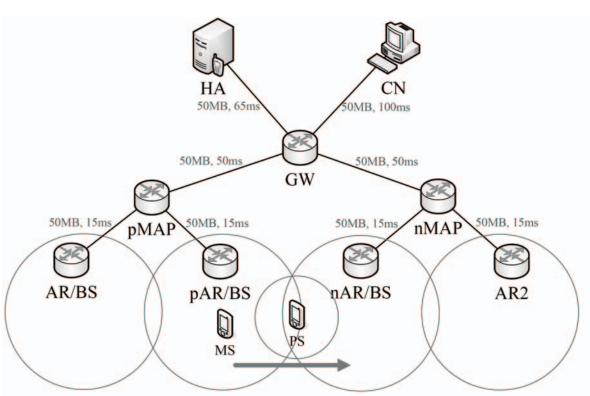


Fig. 4. Simulation Environment

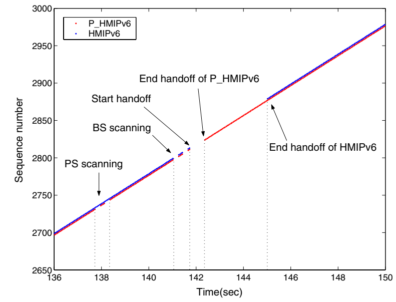
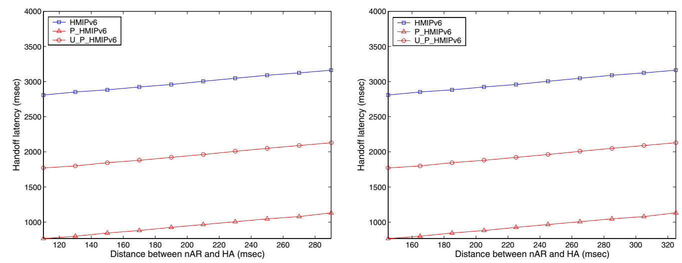


Fig. 5. sequence number vs. time

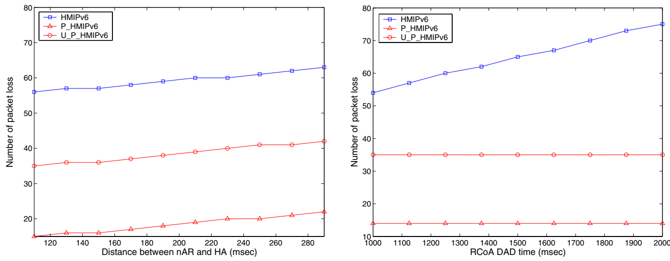


(a) (b)

Fig. 6. (a) Handoff latency vs. distance between nAR and HA, (b) Handoff latency vs. distance between nAR and CN

Fig. 6(b) illustrates the handoff latency of the MS under various RCoA DAD time. In general, the handoff latency increases as the RCoA DAD time increases. We observed that the HMIPv6 increase as the RCoA DAD time increases. However, for U_P_HMIPv6 and P_HMIPv6, the higher regional DAD time is, the handoff latency does not increase. The RCoA DAD procedure has been preformed by the PS in P_HMIPv6. In U_P_HMIPv6, the MS sends the local binding update message to bind the new LCoA and RCoA. If the binding cache in the MAP has a binding between the RCoA and another LCoA, the MAP then checks the the binding update message and the binding in the binding cache is from the same MS by using p flag and old LCoA. If the MAP confirms that the two binding updates are sent from the same MS, the MS directly binds the new LCoA and the RCoA in the binding cache.

2) Packet loss: Fig. 7(a) shows the simulation results of the packet loss vs. distance between HA and nAR. Note that the packet loss number does not include the packet loss in scanning procedures of PS and BS as shown in Fig 5. The reason is that the serving BS buffers the incoming packets to the MS when the MS in scanning status. We observe that the results of



(a) (b)

Fig. 7. (a) Packet loss vs. distance between nAR and HA, (b) Packet loss vs. RCoA DAD time

P_HMIPv6 and HMIPv6 are all affected by the factor because the global binding update message (to HA and CN) are sended after the actual layer 2 handoff. However, the difference of the packet loss between the P_HMIPv6 and HMIPv6 are almost the same when the distance between HA and nAR is increasing. Therefore, The curves of P_HMIPv6 (16 ˜22) is lower than that of HMIPv6 (35 ˜42) and U_P_HMIPv6 (56 ˜63). The average packet loss of P_HMIPv6 is < that of the U_P_HMIPv6 which is < that of the HMIPv6 under various distance between nAR and HA.

Fig. 7(b) illustrates the packet loss of the MS under the increasing RCoA DAD time. In general, the packet loss increases as the RCoA DAD time increases. However, the results show that the P_HMIPv6 and U_P_HMIPv6 do not increase as the RCoA DAD time increases because the RCoA DAD procedure is finished by the PSs in the nMAP domain. The average packet loss of P_HMIPv6 is < that of the U_P_HMIPv6 which is < that of the HMIPv6 under various DAD time. Therefore, the average packet loss of P_HMIPv6 is < that of the U_P_HMIPv6 which is < that of the HMIPv6 under various DAD time.

VI. Conclusion

In this paper, we propose a cross-layer partner-assisted handoff mechanism based on HMIPv6 in IEEE 802.16e systems, called P_HMIPv6 protocol. A new station, termed PS, is adopted in P_HMIPv6 protocol. By scanning the neighbor BSs and PSs with association in the 802.16e handoff procedure, the MS can request the PS to perform the DAD procedure and get the LCoA and RCoA in advance before the mobile node initialize the layer 2 handoff. P_HMIPv6 protocol significantly reduces the handoff delay time and packet losses. The experimental results also illustrate that P_HMIPv6 protocol actually achieves the performance improvements in the handoff delay time and the packet loss.

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