A Host-based Fast Mobility Scheme (HFMS) in 802.16j Mobile RS Mode

Jun-Li Kuo, Chen-Hua Shih, and Yaw-Chung Chen

Abstract—As technologies for the high quality multimedia application and 4G WiMAX network prevail, one can easily be under services everywhere through WiMAX wireless network. However, the service disruption time (SDT) caused by handover procedure leads to an unacceptable quality of service (QoS) for mobile users, especially in IEEE 802.16j mobile relay station (MRS) mode. Therefore, we proposed a host-based fast mobility scheme (HFMS) in IEEE 802.16j MRS mode to reduce the SDT and solve the packet loss problem during handover via the cooperation between the MRS's link-layer and mobile station's (MS's) IP layer. In the proposed scheme, the MRS's link-layer will notify the MS's IP layer to perform IP layer handover procedure when the MRS performs link-layer handover. The parallel handover reduces the SDT efficiently. On the other hand, the proposed buffering mechanism can avoid packet loss. As a result, the seamless mobility and satisfactory QoE can be achieved for mobile users in IEEE 802.16j MRS mode.

Index Terms—QoS, mobility, mobile IP, relay station, WiMAX.

I. INTRODUCTION

Recent advances in wireless technologies (e.g., 4G WiMAX wireless network) enable users to be under variety of services with any device, anytime, and anywhere. Therefore, providing a satisfactory quality of service (QoS) for mobile users is a critical issue. In the WiMAX network, the mobile users can move freely; however, the handover procedure causes a long service disruption time (SDT) and packet loss, leading to service termination and an unacceptable QoS. Therefore, minimizing SDT is necessary in supporting seamless mobility and satisfactory QoS for mobile users.

In IEEE 802.16e WiMAX network, cross-layering handover procedure has been studied and it can reduce SDT and solve the packet loss problem. Most solutions focus on forcing the mobile station's (MS's) link-layer to cooperate with MS's IP layer, then the link-layer and IP layer handover procedures can be carried out simultaneously. However, these approaches only can be used in IEEE 802.16e WiMAX networks because these protocols assume that the link-layer and IP layer handover procedures are both performed by MS.

In IEEE 802.16j mobile relay station (MRS) mode [1], the MRS and MS perform the link-layer and IP layer handover procedures, respectively because the MSs will still be attached to its associated MRS when the MRS moves from one base station (BS) to the other. Therefore, the previous cross-layer approaches [2]-[5] cannot be applied and only the non-cross-layer schemes such as Mobile IPv6 (MIPv6) scheme [6] or the Proxy Mobile IPv6 (PMIPv6) [7] can be used in MRS mode. The long duplicate address detection (DAD) process and sequential handover procedures in MIPv6 scheme lead to packet loss and long SDT.

In addition, although an outstanding network mobility solution [8] has been proposed for reducing SDT, it is still a challenge to reduce SDT in MRS mode due to different characteristic between the MRS mode and network mobility. The former behaves like a mobile BS while the latter features mobile access router (AR) with IP layer functionality.

In this study, we proposed a host-based fast mobility scheme (HFMS) with cross-layer design to solve the packet loss problem as well as to reduce the SDT in MRS mode. The proposed scheme allows the link-layer handover in MRS to cooperate with the IP layer handover in MS to achieve the parallel handover. The analysis and simulation results show that our proposed scheme can reduce both SDT and packet loss significantly so as to achieve seamless mobility for the MS in IEEE 802.16j MRS mode. As a result, the mobile users can experience the satisfactory QoS.

II. RELATED WORKS

To achieve seamless mobility, MIPv6 [6] provides the fundamental handover methods for mobility management at IP layer. FMIPv6 [2]-[5] provides a strategy of pre-binding process to reduce the SDT. Hierarchical MIP (HMIP) [9] employs hierarchical architecture to perform local mobility management. Unlike these above handover schemes dealing with the mobility in IP layer, Session Initiation Protocol (SIP) deals with the application mobility [10]. On the other hand, Cellular IP [11] imports the mobility management of cellular systems into an IP paradigm.

In the IP layer mobility schemes, the DAD process is necessary and it takes at least one second [12]. Therefore, the SDT in MIPv6 and HMIP is unacceptable. In the FMIPv6 scheme, it utilizes the parallel handover of link-layer and IP layer to perform DAD process in advance. Therefore, it can reduce SDT and solve the packet loss problem efficiently. However, in the MRS mode, the MS and MRS perform the IP layer handover and link-layer handover, respectively. The MS's IP layer does not obtain any triggers from its link-layer. Thus, the previous cross-layer schemes, such as FMIPv6,

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cannot be applied in MRS mode, and only the MIPv6 scheme can be used in MRS mode.

A. MIPv6 Handover Procedure in MRS Mode

In MIPv6, after a link-layer handover of MRS, the MS initiates the IP layer handover by the movement detection. After then, it configures its new Care-of-Address (CoA) and performs the DAD process. Only after completing DAD process, the MS could send binding update to the home agent (HA) for updating the current location of the MS. The sequential handover procedure (Fig. 1) leads to a long SDT and packet loss as previous report [6].

B. PMIPv6 Handover Procedure in MRS Mode

In PMIPv6, the NAR must conduct the IP layer handover on behalf of MSs under an MRS after it receives a router solicitation (RtrSol) message from them. Fig. 2 shows the PMIPv6 handover procedure in MRS mode. The procedure starts when the NAR sends a proxy binding update (PBU) to the MS's HA for updating the current location of the MS. Upon accepting this PBU, the HA sends back a proxy binding acknowledge (PBA) and sets up a bi-directional tunnel to the NAR. The packet loss may occur during the periods of the layer 2 network re-entry process (L2 NR) and PMIPv6 procedure. The SDT is affected by the interval of RtrSol sent from MS. The detailed PMIPv6 procedure can be found in the previous report [7].

III. THE PROPOSED SCHEME

Because the original cross-layer mechanism in FMIPv6 cannot be applied in MRS mode, we proposed a new cross-layer scheme between MRS's link-layer and MS's IP layer. Our proposed cross-layering scheme can reduce SDT by performing the MRS's link-layer and MS's IP layer handover procedures simultaneously, and avoid packet loss by a buffering mechanism. The proposed HFMS enables the MSs to carry out IP layer handover when the MRS performs link-layer handover through exchanging the proposed management messages including MRS_NBR-ADV, MRS_HO-REQ, MRS_HO-RSP, and MRS_HO-CLT between the MS and MRS. The detailed messages are defined as follows.

A. Definition of the Proposed Messages

**MRS_NBR-ADV**: The functionality of MOB_NBR-ADV sent from a BS is to notify the MRS the information about neighboring BSs. The neighboring BSs are the candidates of target BS for MRS, and thus the MSs must obtain the information of the neighboring BSs and then obtain the corresponding AR information for conducting subsequent IP layer handover procedure. Therefore, we designed an MRS_NBR-ADV message which includes the information of neighboring BSs for MRS to send to MSs.

**MRS_HO-REQ**: The MRS can decide the target BS after it receives the MOB_BSHO-RSP message from serving BS. Therefore, the MRS must notify the MSs the information of target BS. After that, the MSs can send an FBU (Fast Binding Update) to current AR for performing IP layer handover procedure. In the proposed scheme, the information of target BS will be sent to MSs by MRS_HO-REQ.

**MRS_HO-RSP**: When the MSs finish the IP layer handover procedure, it has to notify the MRS to conduct subsequent link-layer switch process through MRS_HO-RSP message. The MRS will conduct the subsequent link-layer only when it receives MRS_HO-RSP from all MSs under it or the signal strength of serving BS is less than a threshold.

**MRS_HO-CLT**: When the MRS finishes the layer 2 network re-entry process, it must notify the MSs to send a FNA (Fast Neighborhood Advertisement) message to the new AR for obtaining the buffered packets. This functionality is achieved by the proposed MRS_HO-CLT message.

- **MRS_NBR-ADV [BSID(s)]**
  
<table>
<thead>
<tr>
<th>Sender: MRS</th>
<th>Receiver: MS</th>
<th>Parameter: BSID(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>When triggered: an MRS receives the MOB_NBR-ADV from a BS. Effect of receipt: If the BSID(s) in MRS_NBR-ADV was not resolved to the corresponding AR information, the MRS will exchange RtrSolPv (Router Solicitation for Proxy) and PrRtAdv (Proxy Router Advertisement) with the current AR to get the corresponding subnet information.</td>
<td></td>
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- **MRS_HO-REQ [Target BSID]**

<table>
<thead>
<tr>
<th>Sender: MRS</th>
<th>Receiver: MS</th>
<th>Parameter: Target BSID</th>
</tr>
</thead>
<tbody>
<tr>
<td>When triggered: an MRS receives an MOB_BSHO-RSP and decides which BS (i.e., target BS) it wants to switch. Effect of receipt: The MS will realize the target BS. After then, it sends an FBU to the current AR for performing IP layer handover procedure.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **MRS_HO-RSP**

<table>
<thead>
<tr>
<th>Sender: MS</th>
<th>Receiver: MRS</th>
<th>Parameter: none</th>
</tr>
</thead>
</table>
  | When triggered: an MS receives an FB/Ack (Fast Binding Acknowledgement), indicating that the MS's IP layer handover has
FNA are similar to FMIPv6. The functionalities of RtSolPr, PrRtAdv, FBU, HI, HAck, FBAck, and FNA are similar to FMIPv6.

- **MRS_HO-CLT**
  
  **Sender:** MRS  
  **Receiver:** MS  
  **Parameter:** none

  When triggered: an MRS finishes the layer 2 network re-entry process.

  Effect of receipt: The MS will realize that the link-layer handover is finished. Thus, it sends an FNA to new AR for getting the buffered packets.

B. **The Proposed Handover Procedures**

The HFMS can be divided into predictive and reactive modes as in the FMIPv6. The detailed scheme with predictive mode (Fig. 3) is described as follows.

1. The serving BS (SBS) periodically broadcasts information of neighboring BSs via MOB_NBR-ADV message.
2. Upon receiving MOB_NBR-ADV, the MRS will inform MS about information of neighboring BSs by MRS_NBR-ADV and perform a scanning process for a future handover.
3. The MS may find new BSs from MRS_NBR-ADV. Then, it will request the corresponding subnet information by exchanging RtSolPr and PrRtAdv with the previous AR (PAR).
4. According to either signal strength or QoS parameters, the MRS may initiate handover via MOB_MSHO-REQ. The SBS can choose possible target BSs (TBSS) for MRS via MOB_BSHO-RSP. The MRS will decide the TBS after the process.
5. By MRS_HO-REQ from the MRS, the MS is informed that there is an impending link-layer handover to the TBS.
6. Upon reception of MRS_HO-REQ, the MS finds the corresponding AR and sends FBU, including the new CoA configured by MS, to the PAR for performing IP layer handover. After receiving HI (Handover Initiation) from the PAR, the NAR confirms the new CoA by the DAD process and replies HAck (Handover Acknowledge) to the PAR. Afterward, the tunnel between PAR and NAR is established, and the PAR will copy and forward MS's packets to the NAR. Moreover, the PAR will inform the MS of a successful IP layer handover procedure via FBAck, and the NAR will buffer the packets from PAR for MS to avoid packet loss in the subsequent handover procedures.
7. Since the IP layer handover is finished and tunnel is established, the MS will notify the MRS to conduct subsequent link-layer switch process through MRS_HO-RSP message.
8. The MRS sends MOB_HO-IND to SBS as a final indication of handover and performs the ranging process and layer 2 network re-entry process (L2 NR) after receiving MRS_HO-RSP.
9. The MRS sends MRS_HO-CLT to the MS immediately after finishing the L2 NR. Upon receiving MRS_HO-CLT, the MS realizes that the link-layer handover is finished.

Then, it notifies the NAR to deliver the buffered packets by FNA.

If the MRS moves at a high speed, the MS may not receive FBAck until the MRS conducts L2 NR and sends MRS_HO-CLT to it. Therefore, the MS will consider that IP layer handover procedure may not be finished and it may operate in reactive mode (Fig. 4). In this situation, the MS will send FNA with an encapsulated FBU to the NAR after it receives MRS_HO-CLT. Upon receiving FNA, the NAR verifies the new CoA by DAD and forwards the inner FBU to the PAR for establishing a tunnel. After replying FBAck to the PAR, the NAR starts to forward the packets which are buffered in the old CoA and destined to the new CoA, and the NAR will deliver the packets to MS.

IV. **PERFORMANCE ANALYSIS AND SIMULATION RESULTS**

The SDT is calculated at the MS as the duration started with the reception of the last data packet from the PAR and ended with receiving the first data packet from the NAR. Hence, the SDT can be calculated as follows:

\[
SDT_{PMIPv6} = T_{cont_{read}} + T_{msg} + T_{L2} + T_{SBSA} + T_{DAD} + T_{IPv6BA} + T_f = 14T_{frame} + 7T_{BSA} + 3T_{AR{BA}} + T_{cont_{read}} + T_{msg} + T_{L2} + T_{DAD}
\]

\[
SDT_{PMIPv6} = T_{cont_{read}} + T_{msg} + T_{L2} + T_{BSB{SHO}_{RA/B}} + T_{RS{HOF}BA} + T_f = 6T_{frame} + 3T_{BSA} + 3T_{AR{BA}} + T_{cont_{read}} + T_{msg} + T_{L2} + 1
\]

\[
SDT_{HFMS} = T_{cont_{read}} + T_{msg} + T_{L2} + T_{MRS_HO-CLT} + T_{FNA} + T_f = 5T_{frame} + 2T_{BSA} + 3T_{AR{BA}} + T_{msg} + T_{L2}
\]

\[
SDT_{HFMS} = T_{cont_{read}} + T_{msg} + T_{L2} + T_{MRS_HO-CLT} + T_{FNA} + T_f = 5T_{frame} + 2T_{BSA} + 3T_{AR{BA}} + T_{msg} + T_{L2}
\]

\[
SDT_{HFMS} = T_{cont_{read}} + T_{msg} + T_{L2} + 2T_{RS{HOF}BA} + T_f = 6T_{frame} + 3T_{BSA} + 3T_{AR{BA}} + T_{msg} + T_{L2} + 1
\]

\[
SDT_{HFMS} = T_{cont_{read}} + T_{msg} + T_{L2} + T_{MRS_HO-CLT} + T_{FNA} + T_f = 5T_{frame} + 2T_{BSA} + 3T_{AR{BA}} + T_{msg} + T_{L2}
\]
where $T_{frame}$ is the link-layer frame duration and $t$ is the elapsed time after the MRS finishes L2NR until the MS sends an RtrSol. $T_{BS-AR}$, $T_{AR-HA}$, and $T_{PAR-NAR}$ represent the delay between BS and AR, AR and HA, and PAR and NAR, respectively. $T_{cont\_resol}$ and $T_{nq}$ represent the latency of contention resolution procedure during contention-based ranging process and the ranging process delay, respectively. $T_{olap}$, $T_{DAD}$, and $T_{f}$ correspond to the L2 NR delay, DAD process delay, and packets forwarding delay, respectively. For our analysis, the $T_{frame}$ is assumed to be 5 ms, and other parameters used are: $T_{L2} = 210$ ms, $T_{BS-AR} = 1$ ms, $T_{PAR-NAR} = 4$ ms, $T_{cont\_resol} = 90$ ms, $T_{nq} = 30$ ms, and $T_{DAD} = 1000$ ms. The message transmission time between MS and MRS as well as between MS and BS is $T_{frame}$. Hence, the message transmission time between MS and BS as well as between MS and AR equals twice $T_{frame}$, and $2T_{frame} + T_{BS-AR}$.

![Fig. 5. SDT of all schemes.](image)

Fig. 5 shows the SDT of all schemes. It is worth noting that the SDT of MIIPv6 is substantially larger than that of the HFMS in the predictive mode due to the considerably longer DAD process time (at least one second [12]) relative to the delay caused by other factors affecting SDT. In addition, the SDT in PMIPv6 is affected by $t$ which can be influenced by the interval of RtrSol (4 s [13]). Increasing $t$ would result in growing SDT in PMIPv6. The main factor contributing to the SDT of the HFMS is $T_{L2}$ and $T_{cont\_resol}$.

![Fig. 6. The number of lost packets in all schemes.](image)

The number of lost packets can be represented as $\lambda \times SDT$. The buffered packets for the HFMS equals to $\lambda \times (SDT_{HFMS\_pre} + T_{BS-AR} + 4T_{frame})$ because the PAR will forward MSs' packets to the NAR after receiving HAck. Fig. 6 shows the number of lost packets with the traffic rate of 64 Kbps and packet size of 200 bytes (i.e., $\lambda = 40$). The MIIPv6 and the MIIPv6 with $t \geq 2$ will still experience relatively higher packet loss (more than 55 packets) due to their relatively higher SDT (more than 1,385 ms). Since the HFMS uses a buffering mechanism, the number of lost packets is 0. However, the buffered packets is 13.52 (i.e., 2704 bytes) for the HFMS, which slightly affects AR. Particularly, when the HFMS operates in reactive mode, few packets may be lost.

![Fig. 7. SDT in terms of velocity.](image)

Finally, the comparison in the performance between these three schemes is carried out using network simulator ns-2 [14]. The network topology shown in Fig. 8 indicates that an MRS is mounted on a vehicle and moves from an SBS to a TBS in a different IP subnet. The links between routers and ISP network have 100Mbps bandwidth and 2 ms delay, and the links between BSs and ARs have 100Mbps bandwidth and 1 ms delay. The MS receives downlink traffic with the traffic rate of 64 Kbps and packet size of 200 bytes.

![Fig. 8. Network topology for simulation.](image)

The simulation duration is 6 seconds. At 0th second, constant bit rate (CBR) traffic is sent from the corresponding node (CN) to the MS. The MRS starts to move at 1th second with speed of 100 km/hr or 135 km/hr. For CBR traffic, we check the packet sequence number received by the MS, and...
observe whether a packet is delivered successfully or not. The result of MIPv6 is shown in Fig. 9(a) and the results of PMIPv6 ($t = 0$, $t = 2$, and $t = 4$) are shown in Figs. 9 (b)-(d). The results of HFMS in predictive mode and reactive mode are shown in Figs. 9 (e) and (f), respectively.

![MIPv6 scheme](image)

**Table I: SDT and Packet Loss in All Schems**

<table>
<thead>
<tr>
<th>Protocol</th>
<th>MIPv6</th>
<th>PMIPv6 $t = 0$</th>
<th>PMIPv6 $t = 2$</th>
<th>PMIPv6 $t = 4$</th>
<th>HSMF $pre$</th>
<th>HSMF $re$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDT (ms)</td>
<td>1400</td>
<td>350</td>
<td>2350</td>
<td>4350</td>
<td>350</td>
<td>1350</td>
</tr>
<tr>
<td>#Lost Packets</td>
<td>55</td>
<td>13</td>
<td>93</td>
<td>173</td>
<td>0</td>
<td>53</td>
</tr>
<tr>
<td>Improvement of SDT</td>
<td>-</td>
<td>75%</td>
<td>-67.9%</td>
<td>-210.7%</td>
<td>75%</td>
<td>3.6%</td>
</tr>
<tr>
<td>Improvement of #Lost Packets</td>
<td>-</td>
<td>76.4%</td>
<td>-69.1%</td>
<td>-214.5%</td>
<td>100%</td>
<td>3.6%</td>
</tr>
</tbody>
</table>

The SDT in the HSMF with predictive mode is 350 ms because the cooperation of link-layer and IP layer forces the IP layer handover procedure to be carried out before the MRS switches to TBS. Moreover, packet loss does not occur in the HSMF with predictive mode because the MS’s packets are forwarded to NAR and sent to MS after the NAR receives an FNA. When the HSMF operates in the reactive mode, 53 packets get lost because the bi-direction tunnel will not be established until the MS finishes the IP layer handover procedure. As compared with the MIPv6 approaches, the SDT is reduced by approximately 75% and there is no packet loss in the HSMF with predictive mode.

### V. Conclusions

For supporting mobile users a satisfactory quality of service (QoS) in IEEE 802.16j MRS mode, minimizing the SDT and packet loss is necessary. In this study, we proposed a new cross-layer scheme which allows the link-layer handover in MRS to cooperate with the IP layer handover in MS to achieve the parallel handover. In the proposed scheme, the MRS’s link-layer will notify the MS’s IP layer to perform IP layer handover procedure when the MRS performs link-layer handover. The parallel handover reduces the SDT efficiently. On the other hand, the proposed buffering mechanism can avoid packet loss. As a result, the seamless mobility and satisfactory QoS can be achieved for mobile users in IEEE 802.16j MRS mode.
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