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.[1] 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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J. L. Kuo is with Computer Science, National Chiao Tung University (NCTU), Taiwan (e-mail: estar.cs95g@nctu.edu.tw).

C. H. Shih and Y. C. Chen are also with Computer Science, NCTU, Taiwan (e-mail: shihch@csie.nctu.edu.tw and ycchen@cs.nctu.edu.tw).

[1] MRS can be mounted on a vehicle, such as a bus or train, connected to a BS via a wireless link. In this case, the MRS provides a access link to end terminals (i.e., MSs) riding on the vehicle.

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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].

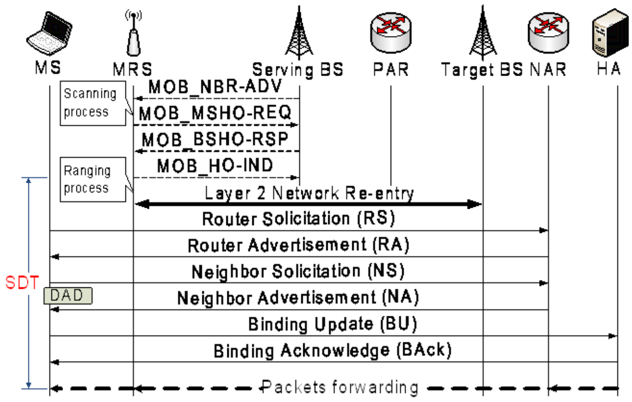


Fig. 1. MIPv6 handover procedure in MRS mode.

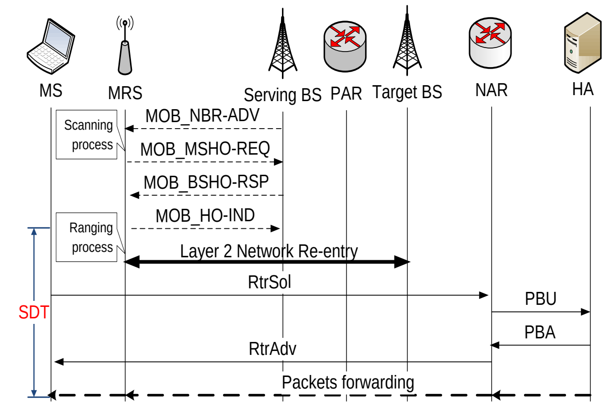


Fig. 2. PMIPv6 handover procedure in MRS mode.

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)]

Sender: MRS	Receiver: MS	Parameter: BSID(s)
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 MS will exchange RtSolPr (Router Solicitation for Proxy) and PrRtAdv (Proxy Router Advertisement) with the current AR to get the corresponding subnet information.		

- MRS_HO-REQ [Target BSID]

Sender: MRS	Receiver: MS	Parameter: Target BSID
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.		

- MRS_HO-RSP

Sender: MS	Receiver: MRS	Parameter: none
When triggered: an MS receives an FBAck (Fast Binding Acknowledgement), indicating that the MS's IP layer handover has		

finished.
Effect of receipt: The MRS will send an MOB_HO-IND to the current BS as a final indication of handover.

- 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)[2].
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 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 notifys the NAR to deliver the buffered packets by FNA.

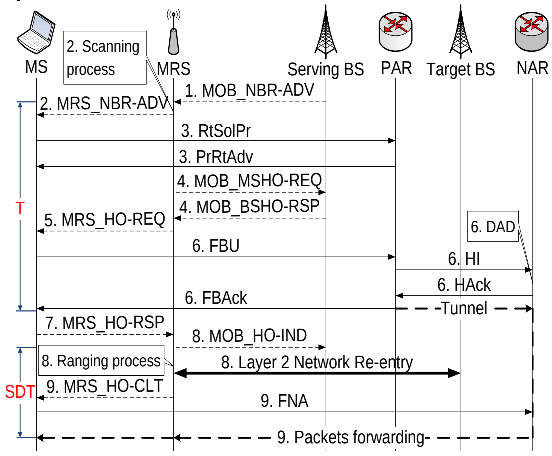


Fig. 3. The HFMS in predictive mode.

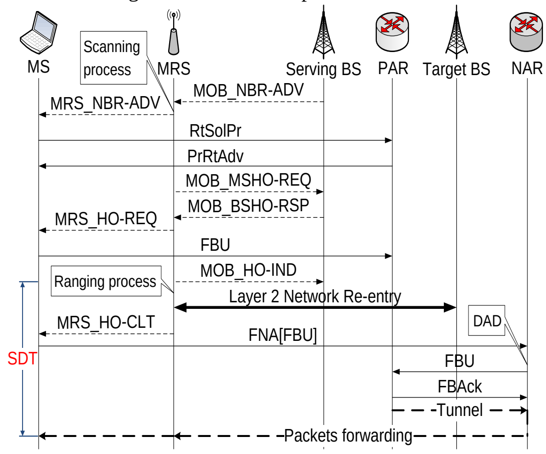


Fig. 4. The HFMS in reactive mode.

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 NAR, the PAR 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:

$$
\begin{aligned}
SDT_{MIPv6} &= T_{cont\_resol} + T_{rng} + T_{L2} + T_{RS/RA} + T_{NS/NA} + T_{DAD} + T_{BU/BAck} + T_F \\
&= 14T_{frame} + 7T_{BS\text{-}AR} + 3T_{AR\text{-}HA} + T_{cont\_resol} + T_{rng} + T_{L2} + T_{DAD} \\
SDT_{PMIPv6} &= T_{cont\_resol} + T_{rng} + T_{L2} + t + T_{RtrSol/RtrAdv} + T_{PBU/PBA} + T_F \\
&= 6T_{frame} + 3T_{BS\text{-}AR} + 3T_{AR\text{-}HA} + T_{cont\_resol} + T_{rng} + T_{L2} + t \\
SDT_{HFMS\_pre} &= T_{cont\_resol} + T_{rng} + T_{L2} + T_{MRS\_HO\text{-}CLT} + T_{FNA} + T_F \\
&= 5T_{frame} + 2T_{BS\text{-}AR} + T_{cont\_resol} + T_{rng} + T_{L2} \\
SDT_{HSMF\_re} &= T_{cont\_resol} + T_{rng} + T_{L2} + T_{MRS\_HO\text{-}CLT} + T_{FNA[FBU]} + T_{DAD} + T_{FBU/FBAck} + \\
&\quad T_F \\
&= 5T_{frame} + 2T_{BS\text{-}AR} + 3T_{PAR\text{-}NAR} + T_{cont\_resol} + T_{rng} + T_{L2} + T_{DAD}
\end{aligned}
$$

[2] The functionalities of RtSolPr, PrRtAdv, FBU, HI, HAck, FBAck, and FNA are similar to FMIPv6.

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. $T_{BS\text{-}AR}$, $T_{AR\text{-}HA}$, and $T_{PAR\text{-}NAR}$ represent the delay between BS and AR, AR and HA, and PAR and NAR, respectively. T_{cont_resol} and T_{rng} represent the latency of contention resolution procedure during contention-based ranging process and the ranging process delay, respectively. T_{L2}, 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, $T_{BS\text{-}AR}$ = 1 ms, $T_{PAR\text{-}NAR}$ = 4 ms, T_{cont_resol} = 50ms, T_{rng} = 30 ms, and T_{DAD} = 1000 ms. The message transmission time between MS and MRS as well as MRS 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 $2T_{frame} + T_{BS\text{-}AR}$.

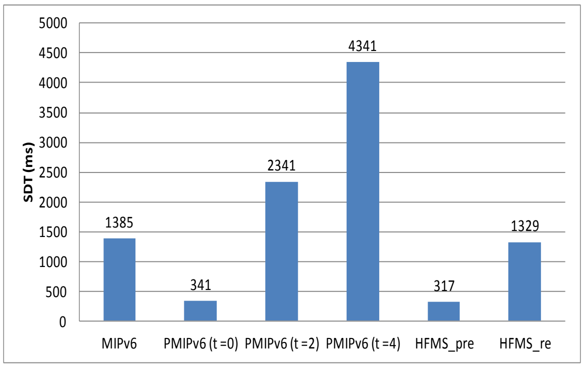


Fig. 5. SDT of all schemes.

Fig. 5 shows the SDT of all schemes. It is worth noting that the SDT of MIPv6 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}.

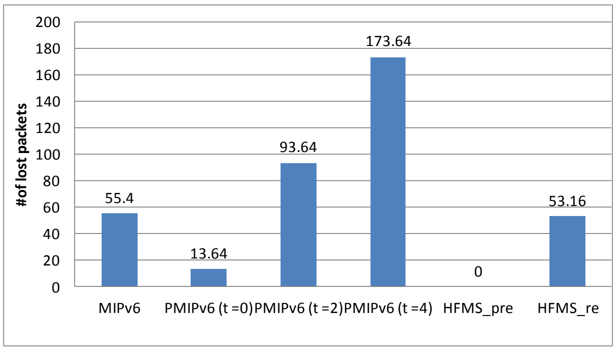


Fig. 6. The number of lost packets in all schemes

The number of lost packets can be represented as $\lambda \times SDT$ where λ is the average packet arrival rate. Besides, the buffered packets for the HFMS equals to $\lambda \times (SDT_{HFMS\_pre} + T_{BS\text{-}AR} + 4T_{frame})$ 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 MIPv6 and the PMIPv6 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.

The SDT and number of lost packets in the HFMS are affected by the velocity of MRS (υ), the overlap distance (D_{olap}) between two BSs, and handover preparation latency (T). When a MRS moves in the overlap area, it performs the handover preparation as well as handover decision and initiation procedures. At the edge of this area, MRS has to execute the handover process. Therefore, the relation between D_{olap}, υ and T can be expressed as $D_{olap} \geq \upsilon \times T$. If velocity of MRS exceeds the threshold (i.e., $\upsilon > D_{olap} / T$), the HFMS will operate in reactive mode. The handover preparation latency for HFMS can be calculated by $T = 13T_{frame} + 4T_{BS\text{-}AR} + 2T_{PAR\text{-}NAR} + T_{scan} + T_{DAD}$ (Fig. 3), where T_{scan} is the scanning process delay. Fig. 7 shows the SDT in terms of velocity. The T_{scan} and D_{olap} are 10 ms and 40 m, respectively. When υ is less than 132.47 km/hr, the SDT of HFMS is 317 ms. The SDT of HFMS will become 1329 ms when υ is more than 132.47 km/hr.

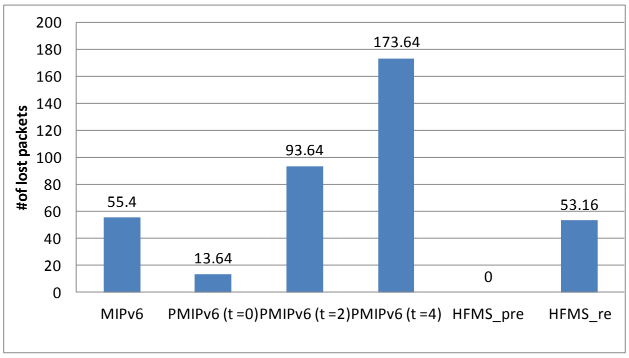


Fig. 7. SDT in terms of velocity.

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.

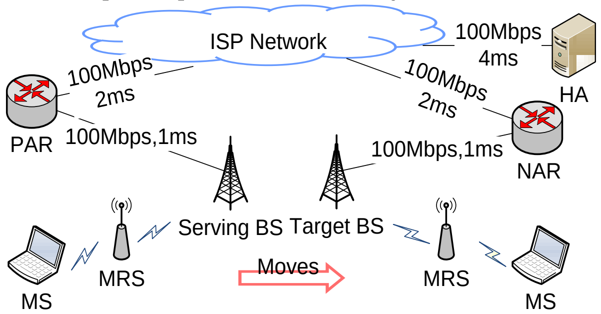
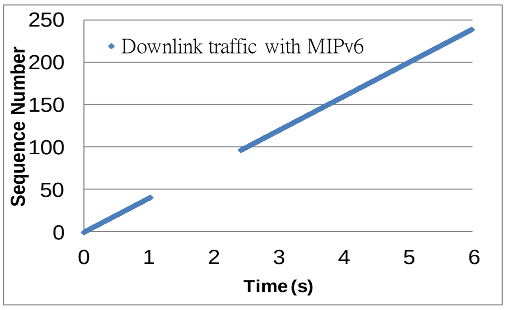
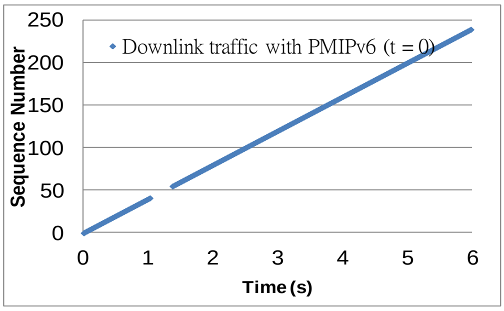


Fig. 8. Network topology for simulation.

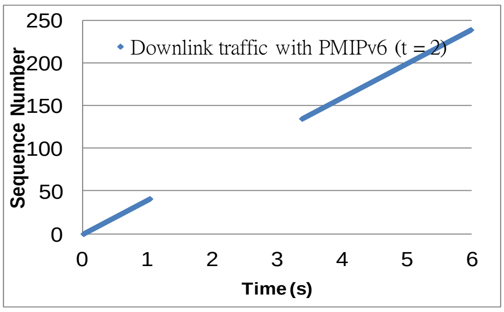
The simulation duration is 6 seconds. At 0th second, constant bit rate (CBR) traffic is sent from the corresponding node (CN) to the MS. The MRS starts to move at 1th second with speed of 100 km/hr or 135 km/hr. For CBR traffic, we check the packet sequence number received by the MS, and observe whether 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.



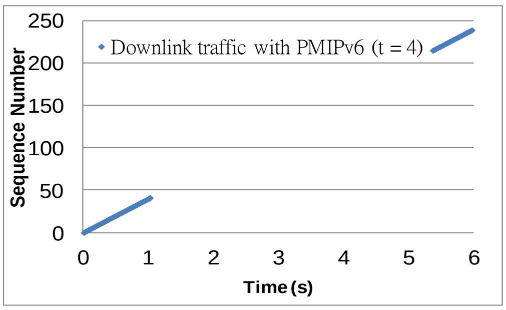
(a) MIPv6 scheme



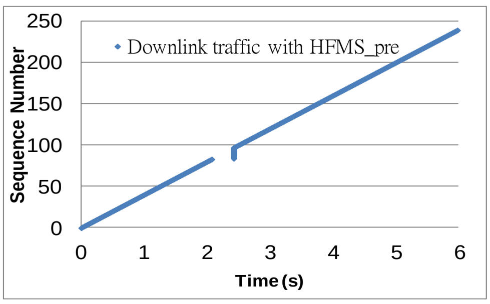
(b) PMIPv6 scheme with t = 0



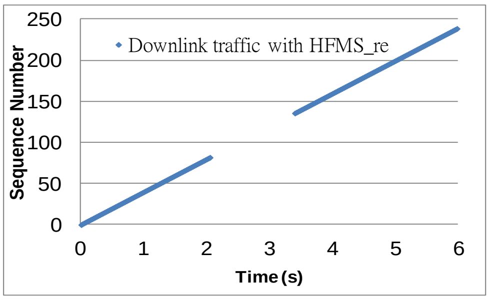
(c) PMIPv6 scheme with t = 2



(d) PMIPv6 scheme with t = 4



(e) The HFMS in predictive mode



(f) The HFMS in reactive mode

Fig. 9. Packet sequence number to receiving time.

Table I illustrates the comparison in the SDT and packet loss between different schemes. In the MIPv6 approach, the SDT is 1,400 ms because the L2NR and IP layer handover procedures are performed sequentially. A higher packet loss (i.e., 55 packets) in the MIPv6 approach is observed because of no buffering mechanism and long SDT. Although the L2NR and IP layer handover procedures are also performed sequentially in PMIPv6 approach, the SDT is reduced to be 350 ms when t = 0 because the MS always uses the home address without DAD process. In addition, 13 packets are lost in PMIPv6 approach due to no buffering mechanism.

TABLE I: SDT AND PACKET LOSS IN ALL SCHEMES

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

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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Jun-Li Kuo is a Ph.D. student in computer science at National Chiao Tung University, Taiwan. His research interests include peer-to-peer network, mobile ad hoc network, cloud computing, and wireless multimedia.

Chen-Hua Shih received his Ph.D. degree in computer science from National Chiao Tung University in Taiwan. His research interests include QoS, mobile IP, wireless networks, and network protocols.

Yaw-Chung Chen received his Ph.D. degree in computer science from Northwestern University, Evanston. Now he is a professor in Computer Science of National Chiao Tung University. His research interests include multimedia communications and wireless networks. He is a member of ACM and a senior member of IEEE.