An Integrated Handover Scheme for Fast Mobile IPv6 over IEEE 802.16e Systems

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***Abstract*— The IEEE 802.16e system supporting mobility on fixed Wireless-MAN systems is supposed to be a mobile broadband wireless access (BWA) and evolve into 4G mobile communication systems. Although the system already defines its own mobility management algorithm, a network layer handover algorithm should be defined to support the mobility of mobile stations in the Internet. There are many active researches on how to apply the L3 handover protocol over the existing IEEE 802.16e L2 handover scheme, but most of the previous works have focused on the timing of L3 handover messages over the IEEE 802.16e L2 handover messages. In this paper, we propose a new handover scheme for Fast Mobile IPv6 over the IEEE 802.16e system. By integrating FMIPv6 with IEEE 802.16e system efficiently, the proposed scheme can minimize not only L3 handover latency but also packet losses.**

I. Introduction

The IEEE 802.16e [1] extends the IEEE 802.16 Wireless-MAN standard [2] by specifying a system for combined fixed with mobile stations. It has its own link layer (L2) handover algorithm, but, due to Internet Protocol (IP) addressing, a network layer (L3) handover algorithm is also required to support the mobility. To deal with L3 handovers, Mobile IPv6 (MIPv6) [3] has been proposed by Internet Engineering Task Force (IETF). However, MIPv6 is not suitable for delay sensitive application services due to the long latency for movement detection (MD), binding update (BU), and new care-of address (NCoA) configuration.

Fast Handovers for Mobile IPv6 (FMIPv6) [4] is proposed to reduce the handover latency by executing those time-consuming processes when a mobile station (MS) is still present on the current link with the help of timely generated L2-trigger. The L2-trigger is generated from the link layer to indicate that the MS will be likely to perform a L2 handover soon. Upon receiving the L2-trigger, the MS initiates the FMIPv6 procedure and completes a NCoA configuration before the L2 handover. Therefore, the L2-trigger should be generated sufficiently before the L2 handover, but deciding when to generate the L2-trigger is recognized as a difficult problem and left as an implementation specific. During the FMIPv6 handover, if the MS could not receive the FBack message while it is still in the current network due to the imprecise L2-trigger generation time, it should change its handover mode from predictive to reactive, which may significantly degrade the overall handover performance [5].

With the growing interests in IEEE 802.16e systems, how to effectively coordinate the L3 handover algorithm with the L2 handover algorithm of the IEEE 802.16e system has been considered as one of the most important issues to support mobility. For this, several handover schemes over the IEEE 802.16e system have been proposed. The authors in [6] proposed a handover scheme, where the IEEE 802.16e MAC management messages for handovers are coordinated and synchronized with those of FMIPv6 by using three kinds of triggers between L2 and L3. However, this work primarily focuses on the coordination of control messages for handovers between the IEEE 802.16e system and FMIPv6, and only provides a procedural description on how FMIPv6 could be implemented on link layers conforming to the IEEE 802.16e standard.

In this paper, we propose a new handover scheme for FMIPv6 over the IEEE 802.16e system, where the handover operations of FMIPv6 and IEEE 802.16e are integrated to improve the handover performance. To study the handover performance of the proposed scheme, we analyze it in terms of the handover latency and evaluate it by simulation study.

II. Background

A. Handover Procedures over IEEE 802.16e System

In IEEE 802.16e systems, a base station (BS) broadcasts neighbor advertisement (MOB_NBR-ADV) messages periodically to identify the network and inform potential MSs seeking BSs for handovers of the neighbor BSs' characteristics. An MS, which needs to handover possibly due to the degradation of channel quality in the current network, may decode this message and request the time interval for scanning the neighbor BSs to the serving BS. During this scanning interval, the MS may attempt to synchronize with downlink transmissions of each neighbor BS and estimate the quality of the channel.

Based on the scanning results, if the MS decides to handover from the currently serving BS to another BS, it sends a handover request (MOB_MSHO-REQ) message containing

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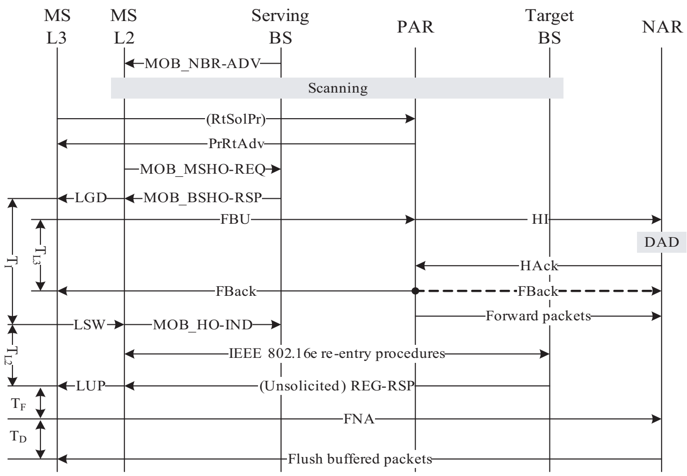


Fig. 1. Message sequence diagram of predictive handover based on [6]

one or more possible candidate BSs. The serving BS receiving a MOB_MSHO-REQ message may send the MS's information to the candidate BSs listed in the MOB_MSHO-REQ message. From the message exchanges between the serving BS and the potential target BSs through the wired backbone network, the serving BS obtains expected MS performance at potential target BSs and indicates one or more recommended target BSs to the MS using a handover response (MOB_BSHO-RSP) message. When the MS selects a target BS, it sends to the serving BS a handover indication (MOB_HO-IND) message including target BSID as a final indication of the handover.

When switching the link, the MS has to execute network re-entry procedures such as synchronization, ranging, re-authentication, and re-registration to the target BS. The MS may omit some of those processes if the target BS has enough knowledge about the MS. For example, if the target BS has already got all MAC state and security information of the MS through the backbone message, it may send an unsolicited registration response (REG-RSP) message. Once the MS receives a REG-RSP message from the target BS, the network re-entry procedures are completed.

B. Mobile IPv6 Fast Handovers over IEEE 802.16e

A scheme that describes how FMIPv6 could be implemented on link layers conforming to the IEEE 802.16e suite of specifications is presented in [6]. It describes both the predictive and reactive handovers of FMIPv6 over IEEE 802.16e, but for brevity, we only describe the predictive handover case. Fig. 1 shows the message sequence diagram of the predictive FMIPv6 handover initiated by the MS in [6]. For efficient handovers, three types of triggers except the original one in FMIPv6 (we refer it as L2-trigger) are used: Link_Going-Down (LGD), Link_Switch (LSW), and Link_Up (LUP).

As shown in the Fig. 1, the LGD trigger is generated when the MS receives the MOB_BSHO-RSP message from the serving BS and used to trigger the corresponding action in L3. When L3 at the MS receives this, it configures a new care-of-address (NCoA) using the network prefix of the target BS and initiates handover by sending Fast Binding Update (FBU) to the previous access router (PAR). Then, as defined in the FMIPv6 standard, the PAR receiving the FBU message sets up a tunnel between the current CoA (PCoA) and the new CoA (NCoA) by exchanging the Handover Initiate (HI) and Handover Acknowledge (HAck) messages with the new access router (NAR) with which the target BS is associated. Before sending the HAck message, NAR should check the validity of the NCoA by duplicate address detection (DAD) procedure [7]. Once the tunnel is set up, PAR sends Fast Binding Acknowledgement (FBack) to the MS and forwards packets destined for the MS to NCoA through tunnel.

When the MS completes the L3 handover by receiving the FBack message, the LSW trigger is generated to signal the L2 of the L3 handover completion. Then, L2 of the MS sends the MOB_HO-IND message immediately, switches its link to the target BS, and starts network re-entry procedures. As soon as completing the network re-entry, L2 of the MS informs the MS L3 of the L2 handover completion and the LUP trigger makes L3 of the MS send the Fast Neighbor Advertisement (FNA) message to NAR. Then, NAR delivers the buffered packets to the MS.

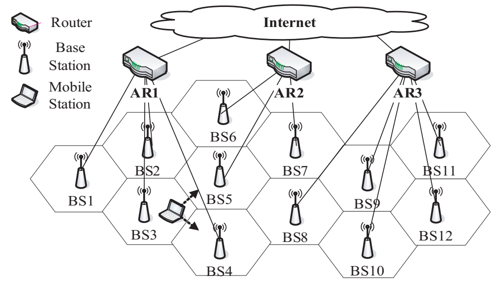


Fig. 2. Network model for the proposed scheme

III. Proposed Scheme

A. Handover Operation

In this section, we describe the proposed scheme. The basic idea of the proposed scheme is that a BS can notify its access router (PAR) of an impending handover based on the MAC management messages exchanged with a MS and make PAR initiate the L3 handover on behalf of the MS. Therefore, the proposed scheme not only can reduce the handover latency but also can solve the problems related to the imprecise L2-trigger generation time, because the L3 handover is always initiated in a predictive manner at the network side and does not require any interventions of the MS. Moreover, the proposed scheme can minimize the packet loss because the PAR buffers the packets destined for the MS until the tunnel is set up. It can be done by synchronizing the PAR with the L2 handover timing using a new control message.

Fig. 2 shows the network model used for the proposed scheme. The handover operation by the proposed scheme is shown in Fig. 3, where three of the new control messages, HO-NOTIF, HO-CONFIRM, and HO-COMPLETE are defined. The purpose of the messages is to synchronize the events

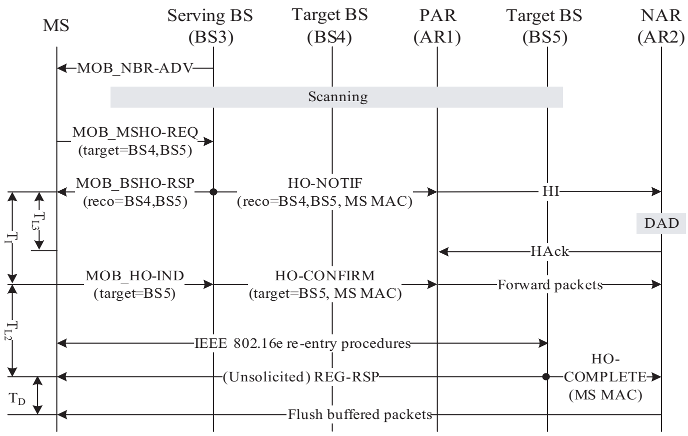


Fig. 3. Message sequence diagram of the proposed scheme (single tunnel)

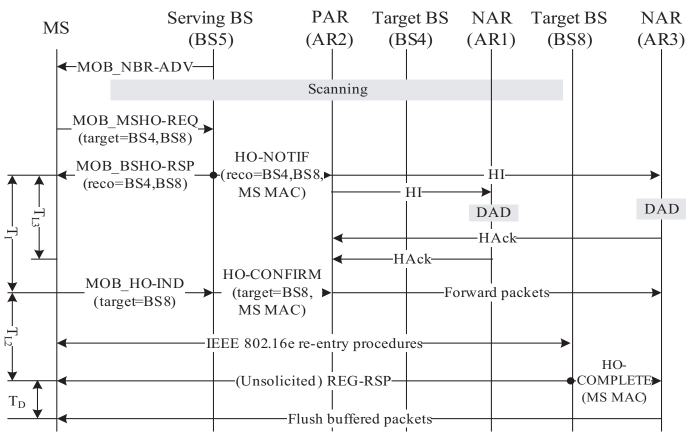


Fig. 4. Message sequence diagram of the proposed scheme (multiple tunnels)

of the L2 (IEEE 802.16e) and L3 (FMIPv6) handovers. Note that some of the existing control messages such as RtSolPr, PrRtAdv, FBU, FBack, and FNA in FMIPv6 are removed in the proposed scheme (see Figs. 1 and 3).

At first, as defined in the IEEE 802.16e standard, the serving BS (BS3 in Fig. 3) transmits the MOB_NBR-ADV message to the MS. When a handover is needed, after the channel scanning, the MS sends BS3 the MOB_MSHO-REQ message, in which BS4 and BS5 are listed as possible target BSs. Then, in response, BS3 transmits the MOB_BSHO-RSP message including a list of the recommended neighbor BSs among the BSs listed in the MOB_MSHO-REQ message. In Fig. 3, BS4 and BS5 are selected by BS3 and they are respectively associated with AR1 (PAR) and AR2 (NAR).

At this moment, BS3 knows the impending handover of the MS. Therefore, BS3 sends the HO-NOTIF message to PAR (AR1). The HO-NOTIF message contains the identities of the recommended BSs and the MAC address of the MS, and its purpose is to let the PAR start the L3 handover. The PAR receiving this message initiates the FMIPv6 handover by sending the HI message to NAR (AR2) associated with BS5. Then, the HI and HAck message exchanged between PAR and NAR, which makes PAR ready to forward the packets bound to the MS to NAR and NAR starts buffering any incoming packets destined to the MS, just like specified in [4]. However, since the HI message should contain the NCoA of the MS if the stateless address auto-configuration [7] is used, in the proposed scheme, PAR configures the NCoA using the MAC address of the MS and the network prefix of NAR on behalf of the MS. We assume that PAR already knows the network prefix of NAR through some auxiliary protocols [8, 9], but the details are omitted since it is beyond the scope of our proposed scheme.

When the MS finally selects BS5 as its target BS and is about to handover to BS5, it sends the MOB_HO-IND message to BS3 as a final indication of handover. We do not discuss the case that the MS selects BS4, because it does not require the L3 handover. The serving BS (BS3) notifies the PAR of the MS's handover by sending the HO-CONFIRM message, which indicates that BS5 is selected as a target BS. Upon receiving this message, PAR starts forwarding the packets for the MS to NAR through the tunnel established during the HI/HAck message exchange. When the MS completes the network re-entry procedures of IEEE 802.16e, which are finalized by receiving the REG-RSP message, the target BS (BS5) also sends the HO-COMPLETE message to NAR (AR2). The purpose of this message is to let NAR confirm the L3 handover of the MS and make NAR send the unsolicited Router Advertisement (RA) with Neighbor Advertisement Acknowledgement (NAACK) option to the MS. This is necessary because the L3 handover is initiated at the network side while the MS performs the L2 handover and the MS is not involved in formulating the NCoA. Therefore, the NCoA formed at the network side (more exactly PAR formulated and NAR validated) should be notified to the MS. Upon this confirmation of the MS's arrival at the NAR's network, NAR starts flushing the buffered packets to the MS.

B. *Buffering and Tunnel Management*

In some cases, the occurrences of handover events shown in Fig. 3 may not follow in that order. First, it is possible that PAR may receive the HO-CONFIRM message before the completion of the HI/HAck message exchange with NAR, because the time needed by NAR to validate the prospective NCoA suggested by PAR through DAD typically requires 1 second. In this case, PAR starts buffering the packets destined for the MS until the completion of the HI/HAck message exchange and forwards them right after the tunnel is set up. On the other hand, if the tunnel is already set up, PAR simply forwards the packets through the tunnel and NAR buffers the packets until the MS completes the network re-entry procedures. Second, the MS may still reside in the current network even after the tunnel is created. PAR can still serve the MS, because the tunnel is inactive and activated only when PAR receives the HO-CONFRIM message, which is generated in response to the MOB_HO-IND message from the MS. In both cases, the pre-configuration of the NCoA and the pre-creation of the tunnel at the network side do not cause any additional overhead. Moreover, the proposed scheme can minimize the packet loss by using the buffering function of

PAR.

Finally, we consider the case that multiple target BSs associated with different ARs are recommended by the serving BS (see Figs. 2 and 4). In the figure, BS4 and BS8, which are respectively associated with AR1 and AR3, are recommended by the serving BS (BS5) through the MOB_BSHO-RSP message. In this case, PAR may formulate multiple NCoAs and set up multiple tunnels as shown in the Fig. 4. However, as discussed earlier, those multiple tunnels remain inactive until PAR receives the HO-CONFIRM message. Upon receiving the HO-CONFIRM message, PAR can know the exact target BS (BS8) and its associated AR (AR3). Therefore, PAR can determine through which tunnel it should start forwarding the packets destined to the MS. In the proposed scheme, all tunnels are maintained in soft-state; if not used for some time, they are destroyed. Therefore, the other tunnels that are not selected will eventually be destroyed.

IV. Performance Evaluation

In this section, we present the performance evaluation results of the proposed scheme. First, we analytically evaluate the proposed scheme in terms of the handover latency. Then, we evaluate and compare the handover performance of the proposed scheme with the protocol in [6] by simulation study.

A. Performance Analysis

In order to analyze the performance of the proposed scheme, we define some parameters (see Figs. 1 and 3) as follows:

- T_{L2}: Time required to perform a 802.16e L2 handover
- T_{L3}: Time required to perform a FMIPv6 L3 handover
- T_I: Time difference from the time receiving MOB_BSHO-RSP to the time sending MOB_HO-IND
- T_F: Time required to send a FNA message after a 802.16e L2 handover
- T_D: Time required to receive the first packet from NAR after NAR recognizes the MS's attachment to the link

The handover latency of the proposed scheme (referred to as $T_{PROPOSED}$) and the scheme in [6] (referred to as T_{DRAFT}) is as follows.

$$T_{PROPOSED} = T_{L2} + MAX((T_{L3} - (T_{L2} + T_I)), 0) + T_D \quad (1)$$

$$= T_{L2} + T_D \quad \text{where } T_{L3} \le (T_{L2} + T_I) \quad (2)$$

$$= T_{L3} - T_I + T_D \quad \text{where } T_{L3} > (T_{L2} + T_I) \quad (3)$$

$$T_{DRAFT} = T_{L2} + T_F + T_D \quad \text{where } T_{L3} < T_I \quad (4)$$

$$= T_{L2} + T_{L3} + T_F + T_D \quad \text{where } T_{L3} \ge T_I \quad (5)$$

If T_I is larger than T_{L3}, the MS can perform a predictive L3 handover. In this case, the handover latency in two schemes can be expressed as (2) and (4) respectively, and the gain of the proposed scheme becomes T_F. On the other hand, when T_I is smaller than T_{L3}, the MS should initiate reactive handover in the target network after the L2 handover following the rules in [6]. However, the proposed scheme initiates the L3 handover as early as T_I and continues the L3 handover during the L2 handover of IEEE 802.16e. Thus, if we subtract (3) from (5), the handover latency can be reduced as much as $T_{L2}+T_I+T_F$ by the proposed scheme. The T_F is dependent on the number of stations contending for uplink opportunity. This will be discussed in the following subsection.

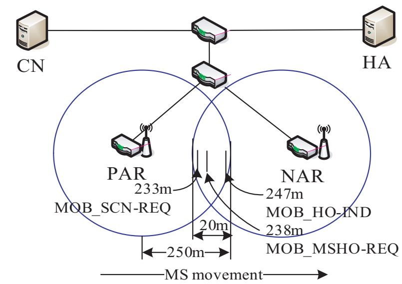


Fig. 5. Network topology for the simulation

B. Simulation Results

For the simulation study, the ns-2 network simulator [10] is used. We have implemented the IEEE 802.16e MAC and an implementation of FMIPv6 from [11] is modified to operate on top of it. The scheme in [6] and the proposed scheme are implemented for performance comparison. To simplify the simulation, we ignore wireless channel errors. The duration of a frame of IEEE 802.16e is set to 5ms.

Fig. 5 shows the network topology used in the simulation study. The radius of a cell and the overlapped range between two adjacent cells are set to 250m and 20m, respectively. The L2 handover latency is chosen from the uniform distribution: [100ms, 115ms] and DAD time is selected from the uniform distribution: [900ms, 1000ms]. The signal strength thresholds for generating MOB_SCN-REQ, MOB_MSHO-REQ, and MOB_HO-IND handover control messages are translated into distances from the center of a cell; each of which corresponds to 233m, 238m and 247m apart from the center. As described in [6], if the MS does not receive the FBack message before the MOB_HO-IND message is generated, we assume that the MS performs the L2 handover without waiting for the FBack message from PAR.

Fig. 6 shows the total handover latency of the two schemes as a function of movement speed. The total handover latency is measured by the time difference from the time when the MS receives the last packet in the serving BS to the time when the MS receives the first packet in the target BS. We assume that there is one downlink constant bit rate (CBR) flow at the rate of 100Kbps from the CN to the MS. When the MS moves at low speeds (less than 9m/s), it has enough time to perform a predictive handover. Therefore, the difference between the scheme in [6] (referred to as DRAFT) and the proposed scheme (referred to as PROPOSED) is less than about 20ms. However, when the MS moves fast, the difference is quite large. In this case, the MS should perform a reactive handover in DRAFT because it cannot receive the FBack message. From the figure, we can clearly see that the proposed scheme always outperforms the DRAFT scheme.

In case that predictive FMIPv6 handover is possible, the performance of both of the schemes is quite comparable with no packet loss. However, as shown in Fig. 7, when the speed

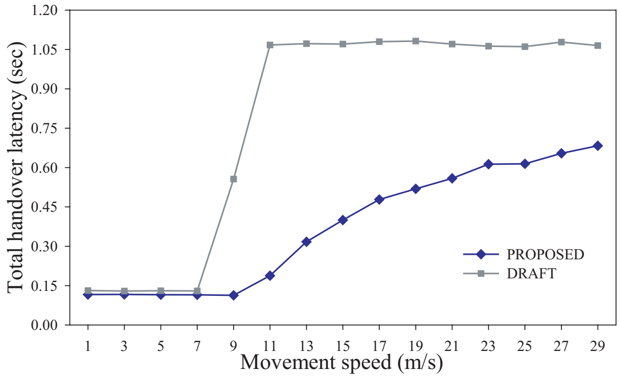
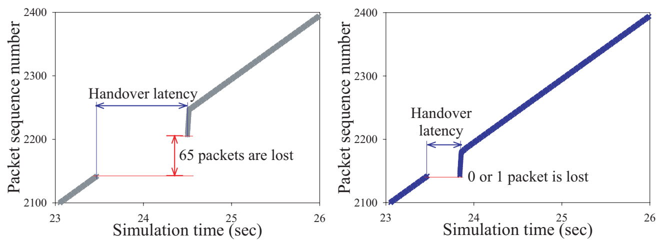


Fig. 6. Total handover latency



(a) DRAFT (b) Proposed scheme

Fig. 7. Reactive handover performance (speed=15m/s)

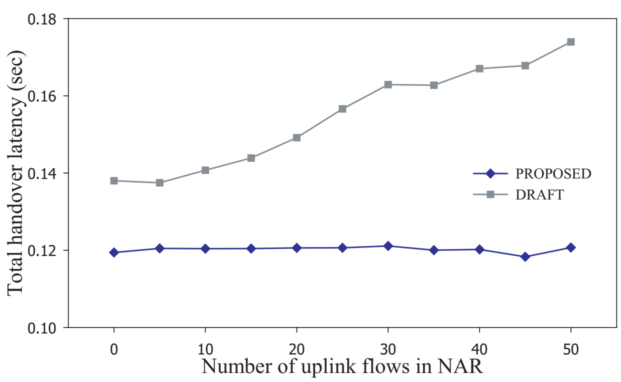


Fig. 8. Predictive handover latency vs. uplink traffic flows

of the MS is high, which forces the MS to perform a reactive FMIPv6 handover, the performance difference between the two schemes is large. In the DRAFT scheme, about 65 packets are lost during the reactive FMIPv6 handover, because the handover operations of IEEE 802.16e and FMIPv6 are not tightly integrated. In this case, PAR keeps forwarding the packets destined for the MS to the serving BS, until the tunnel is established by the FMIPv6 handover operation, even when the MS is in the middle of the L2 handover because PAR does not aware of the MS's handover. At this point, those packets are dropped at the serving BS. On the other hand, in the proposed scheme, the serving BS notifies PAR of the currently on-going L2 handover with the HO-CONFIRM message to make PAR buffer the packets until the tunnel is set up. Therefore, as shown in Fig. 7(b), the packet loss is significantly reduced (less than or equal to 1 packet in multiple runs of simulation) by the proposed scheme.

Fig. 8 shows the influence of the number of uplink flows on the total handover latency (mostly on T_F) when the MS performs a handover in the predictive mode. In this simulation, we assume that there is one downlink flow that experiences a handover while the others are uplink flows sent by other mobile stations. All flows generate CBR traffic at the rate of 100Kbps, and a BS schedules the transmission order of uplink flows as round-robin style because all flows have same characteristic. In this case, when the number of uplink flows in the NAR network is increasing, the MS may experience more latency to acquire bandwidth from the BS for uplink transmissions. The MS in the DRAFT scheme should transmit the FNA message to complete the handover procedure, and it results that the total handover latency is increased in proportion to the number of uplink flows as shown in Fig. 8. However, the MS in the proposed scheme does not need to transmit any uplink message. Therefore, the total handover latency of the proposed scheme is not influenced by the number of uplink flows.

V. Conclusion

In this paper, we propose an integrated Fast Mobile IPv6 handover scheme over the IEEE 802.16e system, where L3 handovers are performed without the intervention of MSs. As the L3 handover is automatically initiated based on the MAC management messages of IEEE 802.16e, it is possible to reduce the handover latency. Also, the proposed scheme is less influenced by the uplink background traffic volume. Moreover, as PAR could acknowledge the exact link switching time and the destination to which a MS performs a handover through the HO-CONFIRM message, the proposed scheme eliminates the packet loss without additional mechanisms such as the BS-level forwarding. By numerical analysis and simulation study, we show that the proposed scheme shows an improved handover performance over the existing scheme.

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