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Inter-Domain Handover in WiMAX Networks Using Optimized Fast Mobile IPv6

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1. Introduction

The most attractive feature of WiMAX is arguable the mobility capability that IEEE 802.16e (IEEE, 2004) standard adds to the previous standard. With mobility support, handover has become one of the most important factors that impact the performance of IEEE 802.16e system. Handover is the process of maintaining active sessions of a mobile station when it migrates from current base station to target base station area. Handover occurs when a mobile station changes its point of attachment on the network. However during hard handover, the mobile station cannot receive or send any packet for a short time interval. This is referred to system disruption time because the services are interrupted or handover latency. In WiMAX, when a mobile node or mobile station changes its location, it moves the point of attachment to the network in two different scenarios;

- The mobile station changes its point of attachment between the base stations which reside in the same Access Services Network (ASN) that is called ASN-anchored, intra, micro, or layer 2 handover. In an ASN-anchored handover, the mobile station resides within previous network address (both current and target base stations located in the same IP subnet). In this scenario, the mobile station does not change its IP configuration, only link layer is re-established.
- The mobile station or mobile node changes its point of attachment between the base stations which reside in different ASN (different IP subnets) that is called Connectivity Services Network (CSN)-anchored, inter, macro, or layer 3 handover. In a CSN-anchored handover, in addition to link layer handover a mobile node must perform a new IP configuration to avoid disconnection.

The intra-domain handover procedure requires support from the physical and MAC layers. IEEE 802.16e has its own MAC layer or layer 2 handover algorithm, but a layer 3 handover algorithm is also required to support the Internet Protocol (IP) addressing, for inter-domain handover. A typical protocol in network layer for mobile terminals is Mobile IP include Mobile IPv4 (MIPv4), (IEEE, 2002) and Mobile IPv6 (MIPv6), (IEEE, 2004) that have been standardized by the Internet Engineering Task Force (IETF). There are many problems associated with MIPv4, such as triangular routing, security and limitation of address space which were solved by using MIPv6. But there still remain some other problems, such as long service disruption time (handover latency), signalling overhead and packet loss.

However, MIPv6 does not solve the handover latency problem which is not negligible for real-time applications such as video streaming and Voice over IP (VoIP). Proxy Mobile IPv6 (PMIPv6), Hierarchical Mobile IPv6 (HMIPv6) and Fast Mobile IPv6 (FMIPv6) have been proposed to decrease long handover latency of MIPv6. The MIPv6 Signalling and Handoff Optimization (MIPSHOP) working group has standardized FMIPv6 (IETF, 2005). FMIPv6 is capable decreasing the handover latency and packet loss by mobility detection and creating new address for the target network and receives data through tunnelling in advance. Because of this, FMIPv6 is used as IP layer protocol in WiMAX. However, due to complexity of handover pattern, designing an impressive handover process to support all mobility scenarios with acceptable latency is still a challenge. There have been many proposals on how to effectively coordinate the FMIPv6 handover algorithm in layer 3 with handover algorithm of the IEEE 802.16e system in layer 2. To overcome some of the shortcomings in the proposed proposals an Optimized Fast Handover Scheme (OFHS) is proposed and presented in this chapter.

This chapter is organized as follows. In section 2, the MIPv6, FMIPv6, IEEE 802.16e handover and related works are described. The proposed scheme is explained in section 3. In section 4, a numerical model is developed to evaluate the performance of OFHS compared with that of RFC5270 (IEEE, 2008). The results and discussion are presented in section 5, and finally, in section 6, conclusions of this chapter are made.

2. Background and previous works

In this section first, some literature that needed to explain proposed method such as mobile IP and the layer 2 handover procedures in IEEE 802.16e or mobile WiMAX are described. Then some related works are introduced which have focused on how apply FMIPv6 over IEEE 802.16e to support inter-domain handover.

2.1 Background

When a host moved to other subnet, the IP address became incorrect for routing and if hosts used new IP address the connections would be terminated because the new IP address was unknown. Mobile IP mechanism works based on a temporary IP address named Care of Address (CoA). The MIPv4 and MIPv6 have introduced for difference IP addressing. In this work IPv6 has been used for addressing. Therefore, in following sections (2.1.1 and 2.1.2) MIPv6 and Fast MIPv6 are described.

The IEEE 802.16e standard supports mobile user in WiMAX network. It supports only intra-domain handover that movement of the mobile station with in same subnet does not affect the IP address. In section 2.1.3, layer 2 handover procedure that has been defined in IEEE 802.16e explained.

2.1.1 Mobile IPv6

The MIPv6 is a protocol to support inter-domain mobility (in network layer) for IPv6 based network. In MIPv6, the packets that are sent to the mobile node from the correspondent node are intercepted and forwarded by a home agent. The MIPv6 has same functions as MIPv4 that is adapted for MIPv6.

In MIPv6 also, each mobile node has two addresses, a static home address under its home network (HoA), and a care of address (CoA) as the mobile node roams to a foreign network for packet routing. The mobile node can create a CoA from a router advertisement message sent by the new visited network. When the mobile node moves to a foreign network, the mobile node sends Binding Update (BU) messages with its CoA to the home agent in order to update the home agent of its current point of attachment. In this way, mobile node's home agent can always detect coming communication packets to mobile node with home address of mobile node, and dispatching these packets to the mobile nodes' CoA via dynamically created IP tunnels. The signalling and data traffic are all transmitted via a unified IP framework, because, all the MIPv6 signalling messages are formed by extending IP protocols with option headers. However the MIPv6 causes a long latency problem. In order to improve handover performance of MIPv6, IETF introduced some IPv6 mobility protocol solutions such as HMIPv6 and FMIPv6.

2.1.2 Fast mobile IPv6

In MIPv6, the movement detection (based on Router Advertisement in IP-layer) and the address configuration procedures cause a long latency problem. FMIPv6 decreases delay of the movement detection and the address configuration phases of MIPv6. It enables the mobile node to provide the target base station identifier (BSID) and detects upcoming entrance to new subnet. It therefore reduces delay of movement detection. For new address configuration, in the FMIPv6 the mobile node obtains the new associated subnet prefix information in advance, while it is still connecting to the current subnet.

After the mobile node select one of the candidate base stations as target base station according to its policy, it sends the Router Solicitation for Proxy (RtSolPr) to the current access router or previous access router and receives Proxy Router Advertisement (PrRtAdv) messages in return. During exchanges of these messages the mobile node obtains the subnet prefix of the target base station. The current base station configures a new IP address (CoA) based on the subnet prefix of the target base station. After that, the mobile node sends a Fast Binding Update (FBU) message to the previous access router. The purpose of FBU messages is to inform the access router that there is a binding between the current CoA at the current subnet and the new CoA (NCoA) at the target subnet. Then, the Handover Initiation (HI) message is sent to the target or new access router by previous access router. The new access router performs duplicate address detection (DAD) to check validity of NCoA. After DAD procedure the new access router reply with handover acknowledge (HAck) message to the current access router. At this instant, a tunnel between the CoA of and NCoA of mobile node is established. The previous access router sends a fast-binding acknowledgement (FBAck) message to new access router. Fig. 1 illustrates the FMIPv6 procedure for Predictive and Reactive mode. If the mobile node receives the FBAck message in the current subnet before the layer 2 handover is started (there is enough time to exchange required messages to establish tunnel), handover occurs in the predictive mode. Otherwise, if the mobile node is forced to move to the new access router without receiving FBAck, FMIPv6 is in reactive mode.

In the predictive mode, the previous access router first store the tunnelled packets in a buffer. After the mobile node attaches to the new link, mobile node sends a Fast Neighbour

Advertisement (FNA) message to the new access router. Upon reception of an FNA message, the new access router delivers the buffered packets to the mobile station.. In reactive mode, mobile node receives packets from the new access router after the packets are rerouted from previous to new access router.

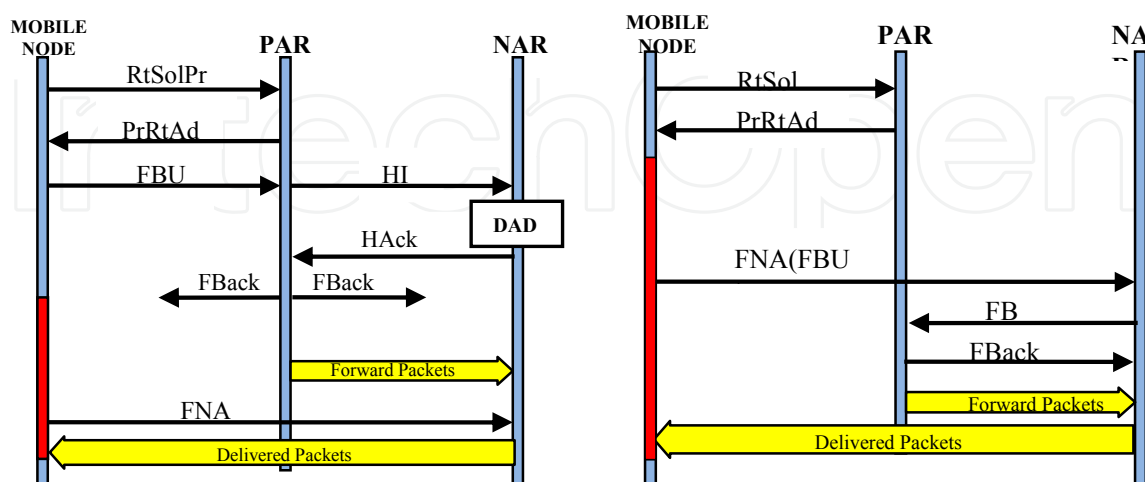


Fig. 1. FMIPv6 Procedure Predictive mode and Reactive Mode

2.1.3 IEEE 802.16e link layer handover

The IEEE 802.16e layer 2 handover procedure can be divided into two steps: handover preparation and handover execution. Fig. 2 illustrates the IEEE 802.16e handover procedure.

The handover preparation can be initiated by either mobile station or base station. During this period, the neighbouring base stations are compared according to its policy. Some metrics such as Quality of Service (QoS) parameters or signal strength are considered to target base station selection. The current base station periodically sends the neighbour advertisement (MOB_NBR-ADV) messages to mobile stations. This message contains information about neighbouring base stations, and the mobile station is capable to select target base stations for a future handover. In order to search for the suitability of neighbouring base stations, mobile station may execute a scanning operation (if necessary). It sends MOB_SCN-REQ to current base station to obtain neighbouring base stations information and the base station reply by MOB_SCN-RSP message. After a mobile station decides to perform handover, it sends a MOB_MSHO-REQ message contain candidate base station identity to the current base station. The current base station negotiates with candidate base stations with exchanges HO-pre-notification and HO-pre-notification-response messages. Then the current base station introduces the recommended base stations by sending an MOB_BSHO-RSP message to mobile station.

The handover execution is started by sending an MOB_HO-IND message from mobile station to the current base station. This message contains selected target base station, and after that packet exchanging between mobile station and current base station is terminate. After IEEE 802.16e network entry process, the mobile station tuned its own parameters to the target base station. The buffered packets are sent to the mobile station from the target base station (it now becomes current base station). If the new base station has a new IP address, a network layer handover mechanism is needed.

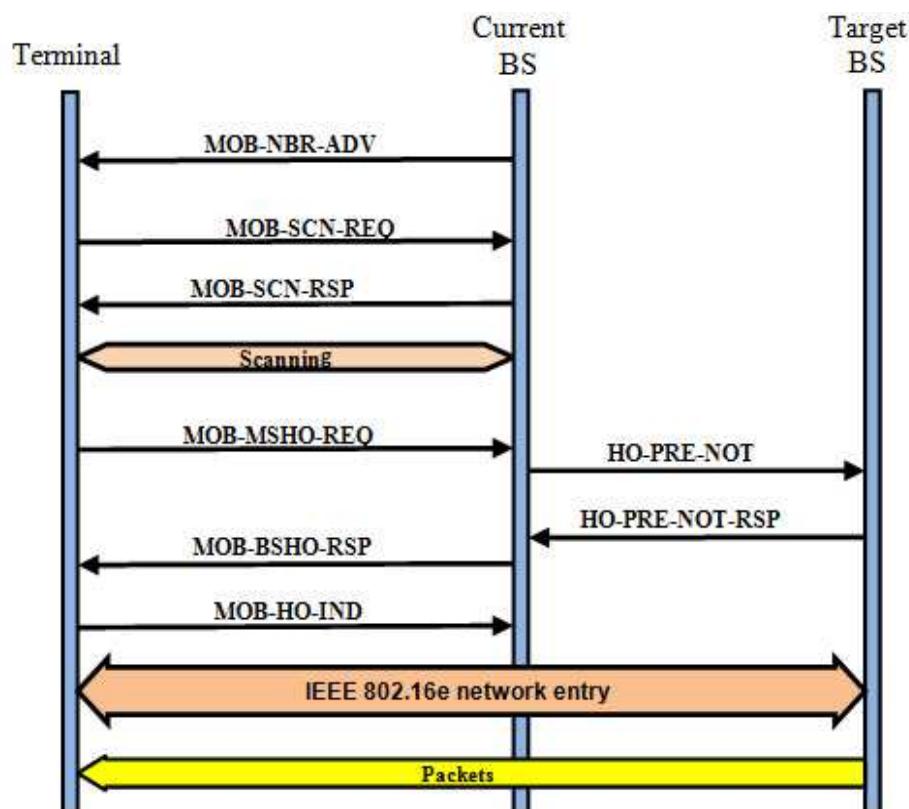


Fig. 2. IEEE 802.16e handover procedure

2.2 Related research works

The reduction of inter-domain handover latency in IEEE 802.16e handover process had been presented in several papers. A link layer optimized scheme that reduces the link-layer handover latency by analyzing and optimizing each step of the procedure is suggested in (Lee, D. et al., 2006). In principle, the overall handover latency does not decrease by simple reduction of the link layer latency. To solve this problem, a cross-layer fast handover scheme for the IEEE 802.16e system is proposed in (Han et al., 2007). It coordinates FMIPv6 with IEEE 802.16e handover procedure to reduce the handover latency. This scheme with a little change is used in RFC5270 (IETF, 2008).

2.2.1 RFC 5270

FH802.16e is a cross layering design for FMIPv6 handover over IEEE 802.16e. One-way signaling is used in the majority of the existing cross layering handovers researches. They usually defined cross layer signals from MAC layer to IP layer. In the Han et al. scheme, two-way signaling between MAC layer and IP layer is defined. This concept helps to achieve faster handover algorithm than previous algorithms. For efficient handovers and reduce the handover latency the authors introduce one command and three events. Some events and command have been proposed in the IEEE 802.21 Media Independent Handover (MIH) (IETF, 2007). They support the interaction between both IP and MAC layers handover procedures. The event are defined as follows:

NEW_CANDIDATE_BS_FOUND: this includes the BSID(s) of candidate base station(s) and is sent by MAC layer to IP layer (FMIPv6) when a new base station(s) is found.

LINK_GOING_DOWN: This is sent by MAC layer to IP layer (FMIPv6) when a mobile node receives an MOB_BSHO-REQ or an MOB_MSHO-RSP message which includes the target BSID. Upon receiving this event, the IP layer of the mobile node performs the handover preparation by sending an FBU message to the current access router.

LINK_SWITCH: This is sent by IP layer (FMIPv6) to MAC layer when the IP layer of a mobile node receives an FBack message. It caused the mobile node MAC layer start handover execution by sending an MOB_HO-IND message to the current base station.

LINK_UP: This is sent by MAC layer to IP layer (FMIPv6) to inform layer 3 that the network re-entry procedure of IEEE 802.16e is terminated. Upon receiving this event, the IP layer of mobile node sends an FNA message.

The scheme proposed in this article provides RFC5270 and the names of triggers change to: New Link Detected (NLD), Link Handover Impend (LHI), Link Switch (LSW), and Link Up (LUP). Fig. 3 and Fig. 4 show the message sequence diagram of the predictive and reactive FMIPv6 handover initiated by the RFC5270. The handover procedure of RFC5270 consists of two stages: handover preparation and handover execution. Just as FMIPv6 that supports all inter-domain handover scenarios, two modes (predictive and reactive) are defined in RFC5270.

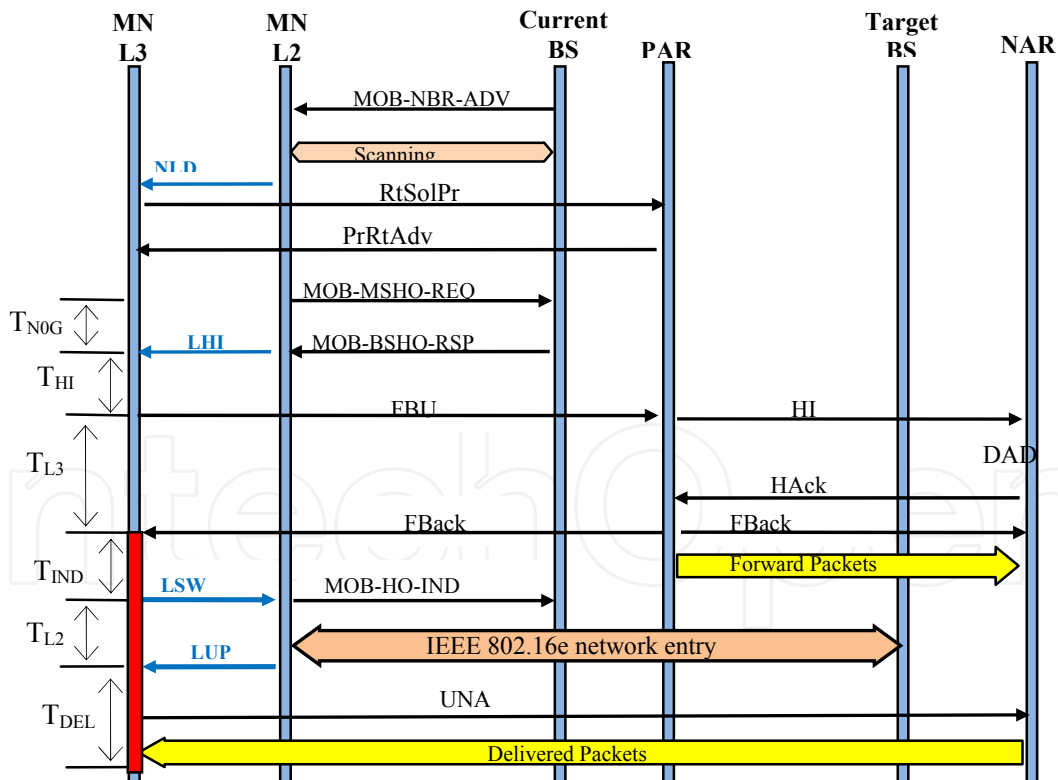


Fig. 3. FMIPv6 over IEEE 802.16e, Predictive Mode

Predictive Mode: Here, the current base station generates and broadcasts a Mobile Neighbor Advertisement (MOB_NBR-ADV) message periodically. It contains the network topology and static link layer information. When the mobile node discovers a new base

station in this message, a scanning may be performed to acquire more dynamic parameters for the new base stations. If the newly found base stations are candidates for the target BSs, the NLD event is delivered to its IP layer from the mobile node MAC layer with the found BSIDs. The Router Solicitation Proxy (RtSolPr) message and Proxy Router Advertisement (PrRtAdv) messages are exchanged between the mobile node and previous access router. The terminal initiates handover by sending a Mobile Handover Request (MOB_MSHO-REQ) message to the current base station and receives a Mobile Handover Response (MOB_BSHO-RSP) message in reply with a target base station in it. The current base station may also initiate handover by sending a MOB_BSHO-REQ message to the mobile node.

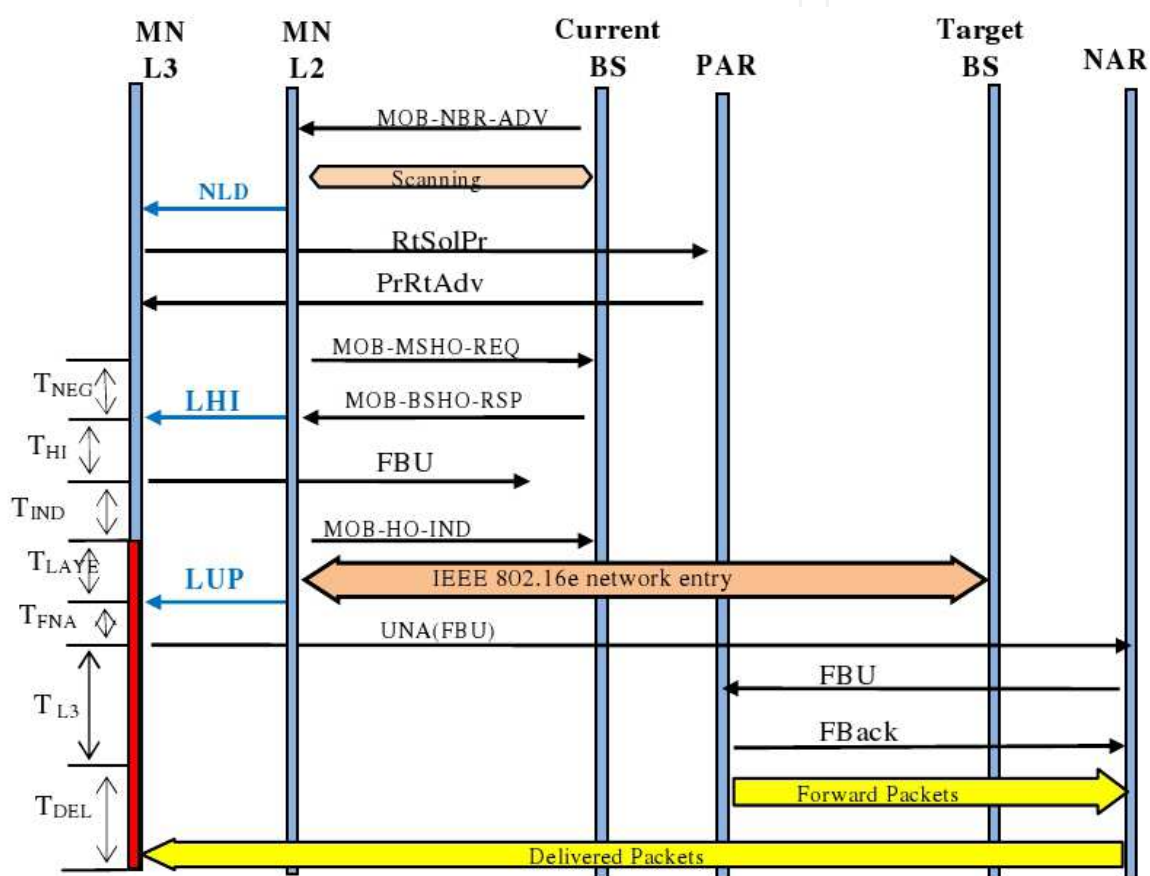


Fig. 4. FMIPv6 over IEEE 802.16e, Reactive Mode

After the mobile node receives MOB_BSHO-REQ or MOB_BSHO-RSP from the base station, the IP layer is triggered by link layer through a LHI to send Fast Binding Update (FBU) to the previous access router. The Handover Indication (HI) and Handover indication Acknowledge (Hack) messages are exchanged between previous and new access routers. The duplicate address detection is performed by new access router (it validates the uniqueness of NCoA in the new subnet, establishes tunnel and sends Fast Biding Acknowledge (FBack) message to the mobile station. Once the tunnel is established, the packets that are destined for the mobile node CoA are forwarded to the NCoA at the new access router through the tunnel. Upon receiving the FBack, the mobile node link layer is signalled by its network layer through a LSW to manage handover by sending a Mobile

handover indication (MOB-HO-IND) message to the target base station. This message starts the 802.16e network re-entry process. After re-entry process, the mobile node link layer triggers its network layer with a LUP to send Unsolicited Neighbor Advertisement (UNA) message to the new access router. When the new access router receives the UNA from the mobile node, it delivers the buffered packets to the mobile node.

Reactive Mode: If the mobile node sends the MOB-HO-IND message to the base station before receiving FBack, the mobile station carries out 802.16e network re-entry process without establishing tunnel with selected NAR. At this instant, the mobile node cannot perform predictive mode so it operates in reactive mode as follows. Upon the network entry procedure completion, the link layer of mobile node sends LUP signal to the IP layer. Then the IP layer identifies that it has moved to the target network without receiving the FBack in the previous link. The mobile node sends an UNA to the new access router by using NCoA as a source IP address and sends an FBU to the previous access router. When the new access router receives the UNA and the FBU from the mobile node, it sends the FBack to the previous access router, and the packets that have been forwarded from the previous access router to new access router are delivered to the mobile node (through NCoA) through the new access router.

2.2.2 Cross Layer Handover Scheme (CLHS)

(Chen & Hsieh, 2007) suggested an integrated design of layer 2 and layer 3 called Cross Layer Handover Scheme (CLHS). The main idea of the CLHS is that if the handover procedures of layer 2 and layer 3 can be coincident, the overall overhead of handover will be decreased. In the CLHS, the correlated messages of IEEE 802.16e and FMIPv6 were integrated. The authors show that some FMIPv6 handover information can be exchanged with the messages of IEEE 802.16e. The messages which have the same characteristics during handover procedure are merged. They are described as follows:

FBU-MOB_HO-IND: The original MOB_HO_IND message are modified to include FBU as a new message. There are 6 reserve bits in the MOB_HO_IND message of link layer. One bit of them is used to indicate that the FBU is enabled or disabled. Upon receiving the FBU-MOB_HO-IND message containing FBU bit, the current base station itself (instead of mobile node) sends FBU message to previous access router.

FNA_RNG_REQ: The RNG_REQ message of 802.16e contains 8 reserved bits. They are used to send the information of FNA message of FMIPv6 in reactive mode.

In addition to the two messages, the neighbour advertisement message of layer 3 and the ranging request message of layer 2 were modified and merged. The MOB_NBR_ADV message in IEEE 802.16e and the PrRtAdv message in FMIPv6 have similar functionality. Hence, the CLHS merges these two messages together. The FBack message of IP layer is combined with the Fast Ranging IE of link layer. Fig. 5 shows message sequence of the CLHS.

2.2.3 Integrated fast handover in IEEE 802.16e (IFH802.16e)

The IFH802.16e proposes a handover scheme for FMIPv6 over the IEEE 802.16e system by integrating FMIPv6 with IEEE 802.16e system. The IFH802.16e used same preparation

concept as the previous works. In the IFH802.16e, the previous access router is informed by base station to imitate IP layer handover on behalf of the mobile node.

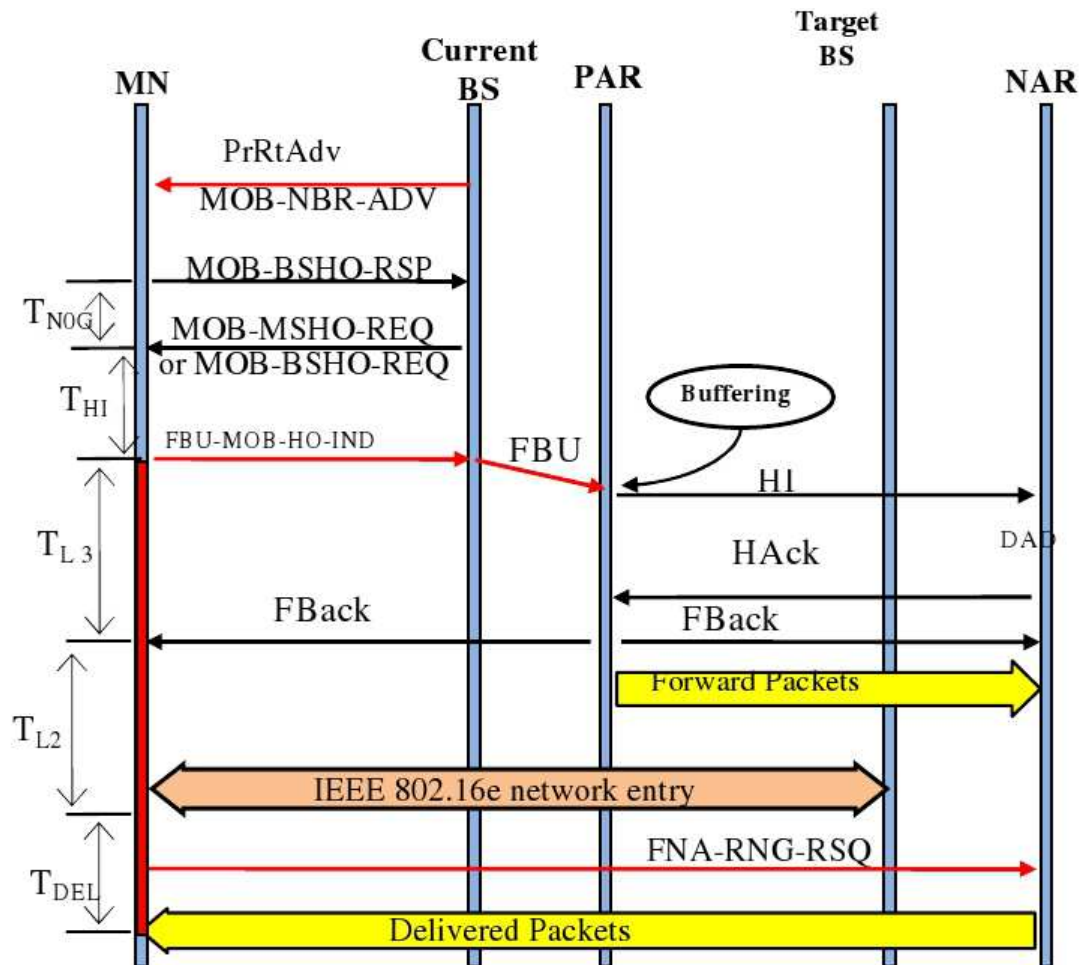


Fig. 5. CLHS procedure

3. Optimized Fast Handover Scheme (OFHS)

In this scheme, pre-established tunnelling mechanism to reduce handover preparation time is used. In addition, a set of messages has been defined to interleave layer 2 and layer 3 procedure. Cross layer design and cross function optimization are used to improve handover performance. The network model is as shown in Fig. 6.

In the OFHS, the serving base station periodically generates and sends the MOB_NBR-ADV message to mobile stations. The MOB_NBR-ADV message of IEEE 802.16e and the PrRtAdv message of FMIPv6 have similar functionality. The information of both messages can be sent through the MOB_NBR-ADV message. Hence, these messages are merged and the PrSolPr message can be eliminated. The mobile station may also perform scanning to obtain link characteristics to evaluate whether to perform handover or otherwise. After the scanning procedure, mobile station selects target base stations among the candidate base stations, based on signal strength, QoS, service price and etc.

If handover is needed, the mobile station sends the MOB_MSHO-REQ message to the possible target base stations that are listed. Then the current base station negotiates with the candidate base stations, and sends the recommended base stations and to mobile station through the MOB_MSHO-RSP message. At the same time the current base station sends the handover notification (HO-NOTIF) message to previous access router. The HO-NOTIF message let the previous access router to start the layer 3 handover. It contains the identities of the recommended base stations and the MAC address of the mobile station. After receiving this message, the previous access router initiates the FMIPv6 handover by sending the handover initiate (HI) message to the next access router associated with target base station. The HI message should contain the NCoA of the mobile station when the stateless address auto-configuration (Thomson et al, 2007) is used. In the OFHS, the NCoA is configured by using the MAC address of the mobile node and the network prefix of new access router. It is performed by previous access router on behalf of the mobile station. The previous access router already knows the network prefix of new access router through some auxiliary protocols (Kwon et al., 2005; Liebsch et al., 2005).

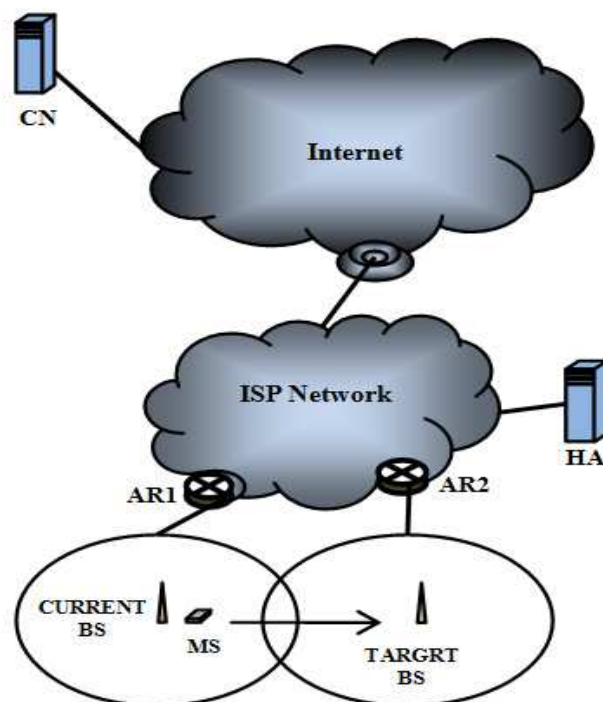


Fig. 6. Network Model

The previous access router exchanges HI and handover acknowledge (HACK) messages with new access router. During this process, a tunnel between the previous and new access routers is set up and the validity of the NCoA is checked with duplicate address detection (DAD). The established tunnel may be more than one based on the recommended base stations. The tunnels are inactive and one of them will be activated only when previous access router receives the handover confirmation (HO-CONFIRM) message that includes the target base station. Once the tunnels are established, previous access router sends an FBack to the mobile station. FBack is applied to inform the status of the configuration of CoA. FBack are sent by the target base station so that the mobile station can be informed that the next CoA is valid. The mobile station can send a MOB-HO-IND message to the target base

station according to the policy and then carry out IEEE 802.16e network re-entry process. If the FBack is received by the mobile station before sending MOB-HO-IND message, handover continues in predictive mode. The MOB-HO-IND message contains selected target base station and the MAC address of the mobile station. The current base station notifies the new access router of the target base station by sending the HO-CONFIRM message. The previous access router obtains the exact target base station and related access router by receiving the HO-CONFIRM message. The previous access router starts forwarding the packets destined to the mobile station through one of the tunnels while the other tunnels that are not selected are discarded.

The new access router buffers the packets during the network re-entry procedures. In this scheme layer 3 handover is initiated at the network side while the mobile station performs the layer 2 handover. Because the mobile station is not involved in formulating the NCoA, it should be informed of NCoA. This can be realized by sending the HO-COMPLETE message from target base station to the new access router after the network re-entry procedures of IEEE 802.16e. The target base station sends the REG-RSP message to mobile station and finalizes the network re-entry procedures of IEEE 802.16e and sends HO-COMPLETE message to confirm the layer 3 handover of mobile station. Upon HO-CONFIRM message received by the next access router, it starts delivering the buffered packets to the mobile station. The HO-COMPLETE message is necessary because after the mobile station performed layer 2 handover the NCoA should be notified to the mobile node. The new access router must send the Unsolicited Router Advertisement with Neighbor Advertisement Acknowledgement option to the mobile node. Fig. 7 shows OFHS predictive mode.

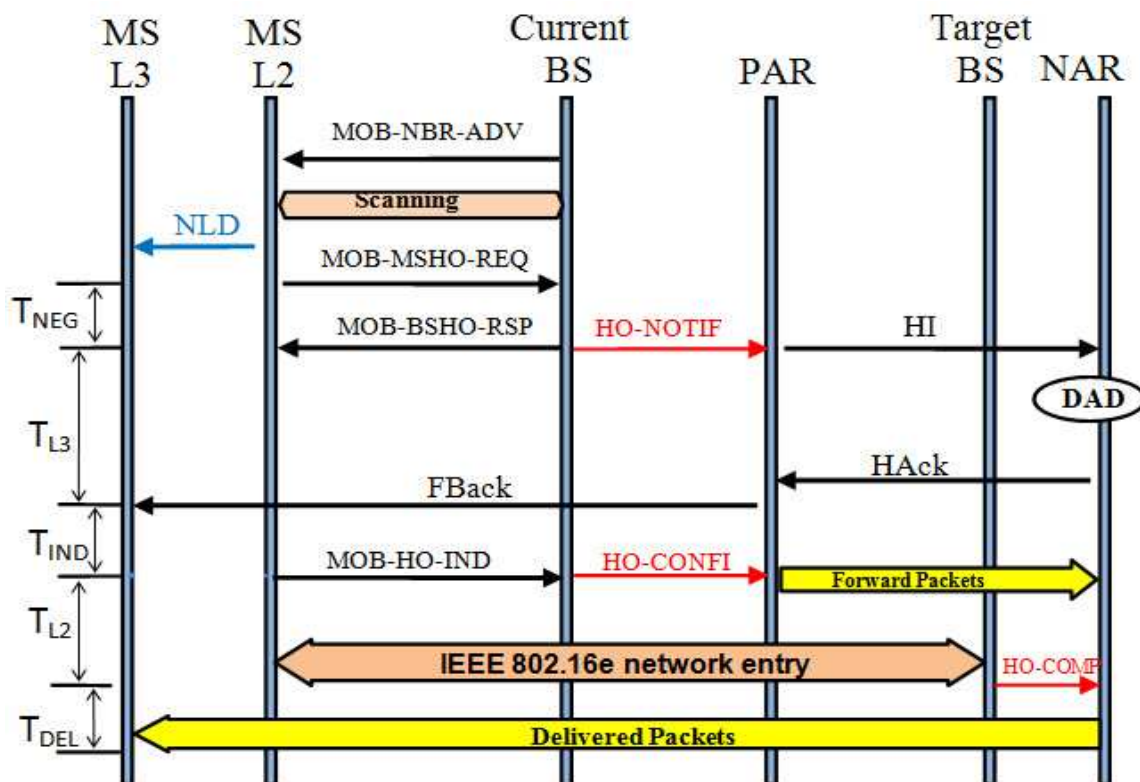


Fig. 7. OFHS Handover Procedure, Predictive Mode

If the mobile node sends MOB-HO-IND message to the current base station before receiving FBack (before establishing tunnel with selected access router), the mobile station starts IEEE 802.16e network re-entry process and the current base station sends HO-CONFIRM message to the previous access router. The previous access router stops sending packets to the mobile node and starts to buffer the packets destined for the mobile station. During the network re-entry procedures of IEEE 802.16e or after that, the previous access router receives the HAck message. There are two scenarios; first, if the previous access router receives HAck messages from the new access router before the end of network re-entry procedures of IEEE 802.16e, the previous access router starts to tunnel the packets destined for the current CoA to the new CoA at the new access router. Then the new access router starts delivering the packets to the mobile station. The previous access router already knows the exact target mobile station and its associated access router, therefore, the previous access router can determine through which tunnel it should start forwarding the packets destined to the mobile station while the other tunnels that are not used will be discarded. The second scenario is that, if the network re-entry procedure of IEEE 802.16e is terminated and the tunnel with selected new access router has not been established yet, the previous access router waits to receive HAck message from the new access router. Upon receiving the HAck message, the previous access router starts to tunnel the packets (destined for the current CoA) to the NCoA at the new access router. Then the new access router starts delivering the tunnelled packets to the mobile node. These two scenarios are called semi-predictive mode defined in OFHS instead of reactive mode defined in the RFC5270. The semi-predictive mode procedure is shown in Fig. 8.

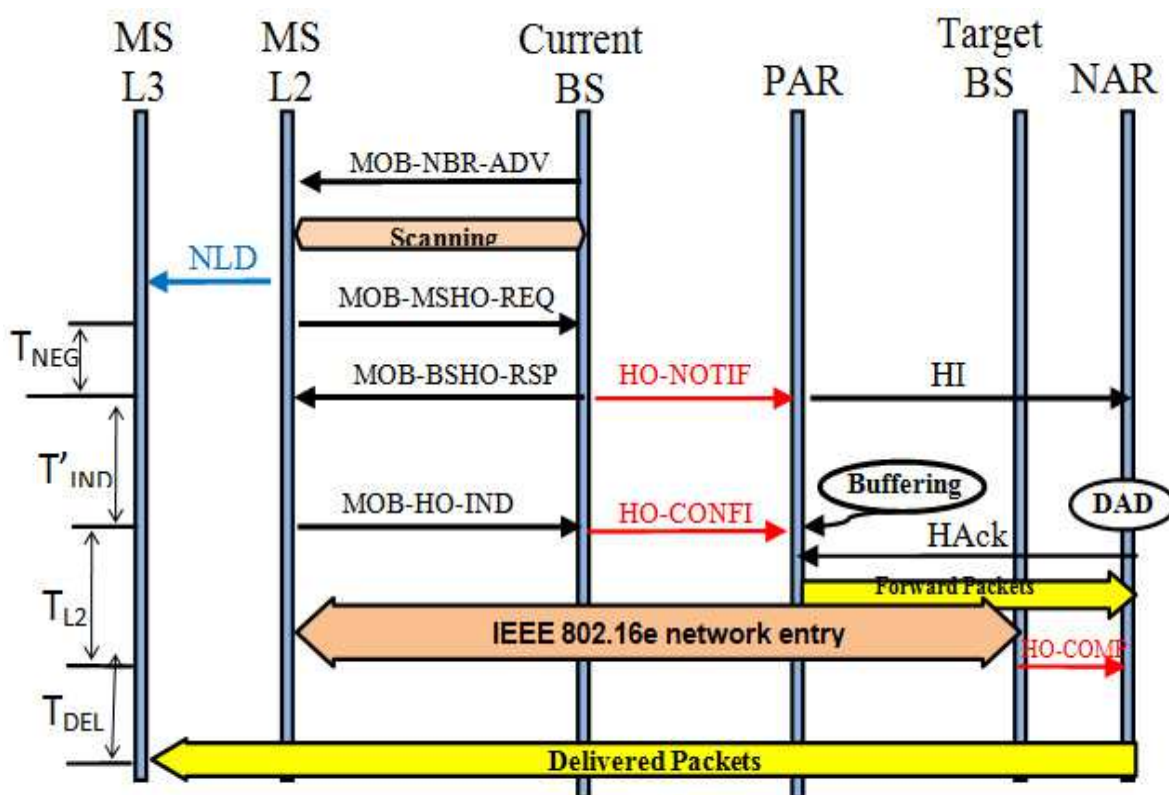


Fig. 8. OFHS Handover Procedure, Semi-Predictive Mode

4. Performance evaluation

In order to evaluate the performance of the proposed method, a numerical model has been developed. In this chapter, the important metrics for evaluating the handover mechanism are total handover procedure time and handover latency respectively. In the evaluation, the OFHS is compared with the RFC5270 as the reference procedure for using FMIPv6 in WiMAX.

To analyze the performance model of the proposed scheme, the duration of each part of the handover procedure are considered. The message interaction is based on the duration of a frame which is an OFDMA type used by IEEE 802.16e air interface. The frame duration is assumed to be at least 1ms and processing time is ignored since it is less than the frame duration. On the other hand, the network nodes message transmission delay is at least a frame long (>1ms). The radio propagation delay is assumed to be smaller than the frame duration, so it is omitted.

4.1 Total handover procedure time

The total handover procedure time (T_{THT}) is defined as the elapsed time between a mobile node sending the MOB_MSHO-REQ message to the current base station and the time the mobile station can receive the first packet through the target access router. $T_{TH-PM-RFC}$ and $T_{TH-PM-OFHS}$ are defined as the total handover time of the predictive mode in RFC5270 and OFHS, respectively. The Equations are defined in term of delay of every routing hop in a wired backbone (T_{HOP}) and frame duration of IEEE 802.16e (T_F). Negotiation between the current base station and the target base station is started by sending MOB-MSHO-REQ. Then the current base station sends handover notification message to target base station and receives handover notification response from it. The procedure is concluded by sending MOB-BS-HO-RSP to current base station. The time lag from the point of sending MOB-MSHO-REQ to receiving MOB-BSHO-RSP or negotiation delay between the current and recommended base stations (T_{NEG}) is given by Equation (1). The time required to perform FMIPv6 in layer 3 from the point of sending FBU to receiving FBack is T_{L3} and the latency of IEEE 802.16e network re-entry procedure is given by T_{L2} . They are expressed in Equations (2) and (3), respectively. $N_{PAR-NAR}$ is the distance between the previous and new access routers in term of number of hops and T_{DAD} is time needed to complete a duplicate address detection procedure. The MAC layer handover time is based on the number of messages exchanged between mobile station and base stations according to the RFC5270. Packet delivery time (T_{DEL}) is the time required from the point of sending the UNA message after IEEE 802.16e handover to receiving the first packet from new access router; this is given by Equation (4).

$$T_{NEG} = 4T_{HOP} + 2N_{PAR-NAR} \times T_{HOP} \quad (1)$$

$$T_{L3-RFC} = 3T_F + 2T_{HOP} + 2N_{PAR-NAR} \times T_{HOP} + T_{DAD} \quad (2)$$

$$T_{L2} = 10T_F + 30 \text{ (ms)} \quad (3)$$

$$T_{DEL-RFC} = 3T_F + 2T_{HOP} \quad (4)$$

The elapse time between receiving MOB-BSHO-RSP and starting layer 3 handover is given by T_{HI} (For RFC5270 procedure $T_{HI} = 2T_F$). T_{IND} is elapse time between receiving FBack and sending MOB-HO-IND. To simplify analysis, fixed delay time for T_{IND} is assumed.

The message interaction is based on the duration of a frame, all times expressed as integer number of frame. Therefore, all non-integer times is rounded to the next nearest integer number (this is shown as $\lceil \cdot \rceil_F$). In OFHS, T_{NEG} , T_{L2} and T_{DEL} are the same as Equations (1), (2) and (3), and T_{L3} is obtained from Equations (5). Hence, the total handover time of the predictive mode in term of T_F for RFC5270 and OFHS are given by Equation (6) and (7), respectively.

$$T_{L3-OFHS} = T_F + 2 T_{HOP} + 2 N_{PAR-NAR} \times T_{HOP} + T_{DAD} \quad (5)$$

$$\begin{aligned} T_{TH-PM-RFC} &= T_{NEG} + T_{HI} + T_{L3-RFC} + T_{IND} + T_{L2} + T_{DEL-RFC} \quad (6) \\ &= \lceil 4T_{HOP} + 2 N_{PAR-NAR} \times T_{HOP} \rceil_F + 18T_F + \lceil 2T_{HOP} \rceil_F + \\ &\quad + \lceil 2T_{HOP} + 2N_{PAR-NAR} \times T_{HOP} + T_{DAD} \rceil_F + T_{IND} + 30(ms) \end{aligned}$$

$$\begin{aligned} T_{TH-PM-OFHS} &= T_{NEG} + T_{L3-POR} + T_{IND} + T_{L2} + T_{DEL-POR} \quad (7) \\ &= \lceil 4T_{HOP} + 2N_{PAR-NAR} \times T_{HOP} \rceil_F + 12T_F + \\ &\quad + \lceil 2T_{HOP} + 2N_{PAR-NAR} \times T_{HOP} + T_{DAD} \rceil_F + \\ &\quad + T_{IND} + 30(ms) + \lceil T_{HOP} \rceil_F \end{aligned}$$

$T_{TH-RM-RFC}$ is the total handover time of the reactive mode of the RFC 5270 and $T_{TH-SPM-OFHS}$ as the total handover time of the semi-predictive mode of the OFHS given by Equations (8) and (9) respectively. In reactive mode, after sending FBU, the mobile node does not receive an FBack from the current access router before the mobile node is forced to move to the target access router. The mobile station must wait for packet rerouting before it can receive any packets from the target access router. T_{FNA} is elapse time between layer 2 handover termination and FNA message, and the time required performing FMIPv6 L3 handover from sending FBU to mobile node receiving FBack is T_{L3-RM} . In reactive mode and semi-predictive mode T_{IND} has various values depending on location, direction and speed of mobile station. Also, T_{DEL} depends on the number of buffered packets and frame duration.

$$\begin{aligned} T_{TH-RM-RFC} &= T_{NEG} + T_{HI} + T_{IND} + T_{L2} + T_{FNA} + T_{L3-RM} + T_{DEL-RFC} \quad (8) \\ &= T_{NEG} + T_{HI} + T_{IND} + T_{L2} + T_{FNA} + T_{L3-RM} + T_{DEL-RFC} \\ &= \lceil 2T_{HOP} + 2N_{PAR-NAR} \times T_{HOP} \rceil_F + T_{IND} + 13T_F + 30(ms) + \\ &\quad + \lceil T_{HOP} \rceil_F + \lceil 2N_{PAR-NAR} \times T_{HOP} \rceil_F + \lceil N_{PAR-NAR} \times T_{HOP} \rceil_F + \lceil T_{HOP} \rceil_F \end{aligned}$$

$$\begin{aligned} T_{TH-SPM-OFHS} &= T_{NEG} + T_{IND} + T_{L2} + T_{DEL-PRO} \quad (9) \\ &= \lceil 2T_{HOP} + 2N_{PAR-NAR} \times T_{HOP} \rceil_F + T_{IND} + \\ &\quad + 11T_F + 30(ms) + 2 \lceil T_{HOP} \rceil_F \end{aligned}$$

4.2 Handover latency

Handover latency (T_{HL}) is defined as the elapsed time between a mobile node receiving the last packet through its current access router and the first packet through the target access

router. After the previous access router sends the FB_{ACK} message to the mobile node, it stops delivering packets to the CoA (sending packets to mobile node). At this time, the current access router re-routes the packets that destined to the CoA to the NCoA in the target access router. Hence, the actual period of handover latency in predictive mode begins when the mobile node receives an FB_{ACK} message. In reactive mode, the actual period of the handover latency begins by sending the MOB-HO-IND message. $T_{HL-PM-RFC}$ is defined as the handover latency of the predictive mode of the RFC 5270 and $T_{HL-PM-OFHS}$ as the handover latency of predictive mode of OFHS given by Equations (10) and (11), respectively.

$$\begin{aligned} T_{HL-PM-RFC} &= T_{IND} + T_{L2} + T_{DEL-RFC} \\ &= T_{IND} + 14T_F + 30(\text{ms}) + [2T_{HOP}]_F \end{aligned} \quad (10)$$

$$T_{HL-PM-OFHS} = T_{L2} + T_{DEL} = 11T_F + 30(\text{ms}) + [T_{HOP}]_F \quad (11)$$

$T_{HL-RM-RFC}$ is the handover latency of the reactive mode of the RFC5270 and $T_{HL-SPM-OFHS}$ is the total handover latency of the semi-predictive mode of the OFHS given by Equations (12) and (13), respectively.

$$\begin{aligned} T_{HL-RM-RFC} &= T_{L2} + T_{FNA} + T_{L3-RM} + T_{DEL} \\ &= 11T_F + 30(\text{ms}) + [2T_{HOP} + 2N_{PAR-NAR} \times T_{HOP}]_F \\ &\quad + [N_{PAR-NAR} \times T_{HOP}]_F + [T_{HOP}]_F \end{aligned} \quad (12)$$

$$\begin{aligned} T_{HL-SPM-OFHS} &= T_{L2} + T_{DEL} + T'_{IND} \\ &= 11T_F + 30(\text{ms}) + [T_{HOP}]_F + T'_{IND} \end{aligned} \quad (13)$$

5. Results and discussion

The parameters of OFHS and RFC570 are compared in this section, based on the previous analysis. Handover parameters are given as in Table 1.

Parameter	Value
T_{HOP}	1 ms
$N_{PAR-NAR}$	2 hops
T_{DAD}	800 ms
$T_{HI} = T_{IND}$	T_F

Table 1. Network Parameters

Fig. 9 shows total handover time of the RFC5270 and OFHS in term of frame durations for predictive, semi-predictive and reactive modes according to Equations (6) to (9), respectively. Handover latency variation in term of frame duration for all modes of the

RFC5270 and the OFHS are depicted in Fig. 10. The numerical values are obtained from Equations (10) to (13). Fig. 8 and Fig. 9 show that, the delay increases with the frame duration increases. The reason is that the base station replies the received message at the next frame because the current frame resource utilization is scheduled in advance. Additionally the response time is lengthened as the frame duration increases. The OFHS shows better total handover time and handover latency than RFC5270.

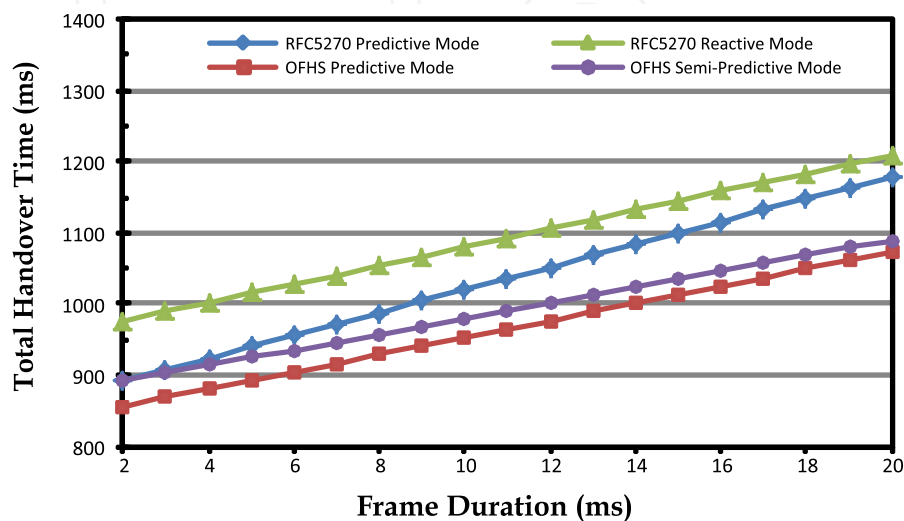


Fig. 9. Total Handover time versus Frame Duration

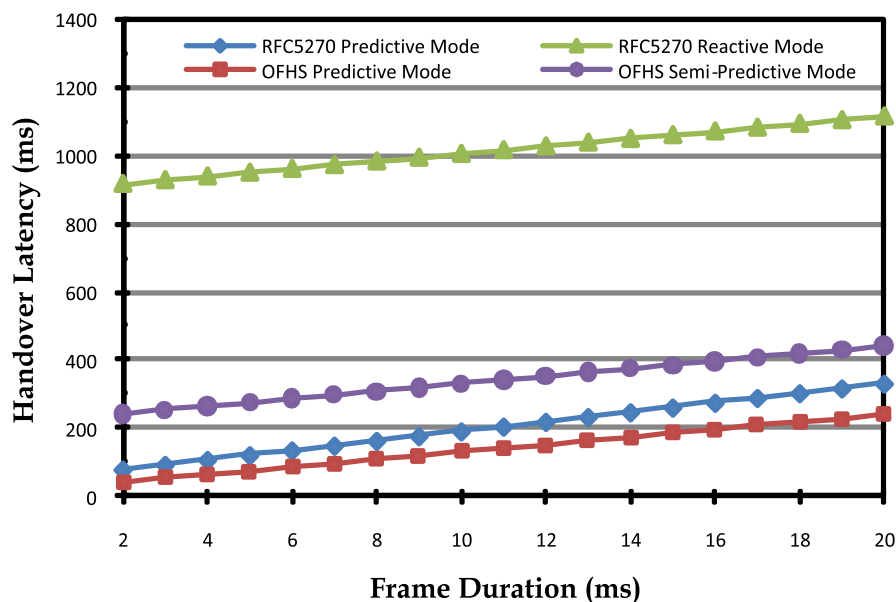


Fig. 10. Handover Latency versus Frame Duration

Usually in IEEE 802.16e, frame duration is considered as 5ms. In Fig. 11 total handover time and handover latency of RFC5270 and OFHS in reactive, predictive and semi-predictive modes for 5ms frame duration are illustrated. When frame duration is 5ms, OFHS decreases total handover time to 47ms for predictive mode, and 90ms for semi-predictive and reactive mode. The OFHS also reduces handover latency to 47ms for predictive mode, and 672ms for

semi-predictive and reactive mode compare with RFC5270. The reason is that our scheme needs less number of messages than that of the RFC5270 when performing handover, and pre-established tunnel concept prepare a mechanism to reduce handover time. Also, the additional anticipation time imposed by FMIPv6 that causes the handover execution start earlier than planned is solved. In OFHS, occurrence probability of reactive mode is lower than that of the RFC5270, because earlier handover preparation provides sufficient time for the mobile node to receive FBack and drive predictive mode.

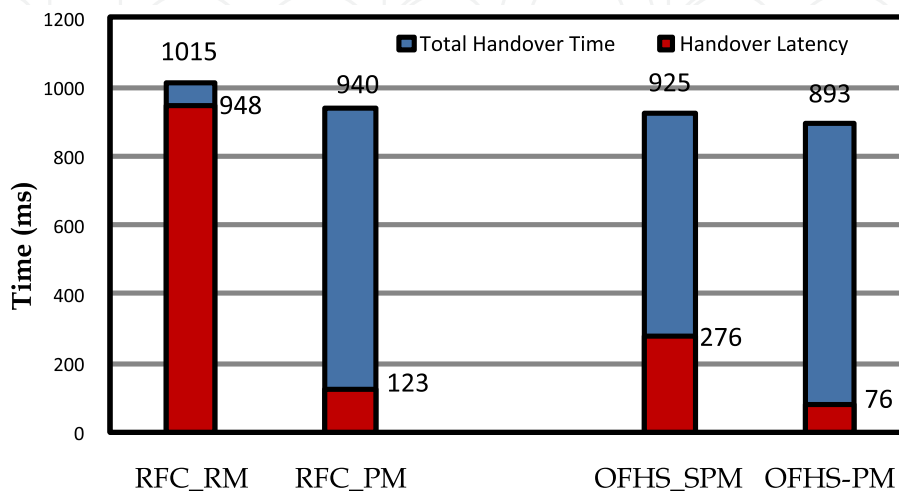


Fig. 11. Handover Latency for Ordinary Frame Duration (5ms)

6. Chapter summary

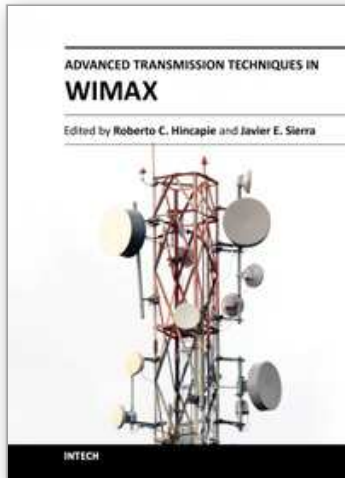
In this chapter an overview of inter-domain handover in WiMAX networks have been presented. The previous solutions for applying FMIPv6 on IEEE 802.16e have long latency that are not acceptable for real time services such as video streaming and voice over IP. In order to reduce handover latency, an optimized fast IPv6 handover scheme (OFHS) have been proposed. The OFHS combined cross layer design and cross function optimization to achieve lower handover latency. A pre-established multi tunnelling concept and a buffered routers mechanism have used to prepare seamless handover. The Layer 2 handover in 802.16e and layer 3 handover in FMIPv6 procedures are interleaved and the correlated messages for both layers are blended and reconstructed, effectively.

The results show that OFHS reduces handover latency and packet losses, and increase probability of predictive mode that has lower handover latency than reactive mode compared with RFC5270. The OFHS reduces handover latency by 38.2% in predictive mode.

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This book has been prepared to present the state of the art on WiMAX Technology. The focus of the book is the physical layer, and it collects the contributions of many important researchers around the world. So many different works on WiMAX show the great worldwide importance of WiMAX as a wireless broadband access technology. This book is intended for readers interested in the transmission process under WiMAX. All chapters include both theoretical and technical information, which provides an in-depth review of the most recent advances in the field, for engineers and researchers, and other readers interested in WiMAX.

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