PAPER

Media-Independent Handover Design for Seamless Mobility in Heterogeneous WiMAX/Wi-Fi Networks

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SUMMARY As we are moving toward next generation wireless networks, we are facing the integration of heterogeneous access networks. The main challenge is to provide mobile users moving freely across different radio access technologies with satisfactory quality of services for a variety of applications. Consequently, the seamless roaming over heterogeneous networks is an important concern. To minimize the disruption to the ongoing session when a mobile user is moving from one access network to another, we propose a framework that integrates IEEE 802.11 WLANs and IEEE 802.16 WMANs based on the IEEE 802.21, so-called Media Independent Handover (MIH), to facilitate both homogeneous and heterogeneous handovers. Both numerical analysis and simulation results show that seamless roaming between WLAN and WMAN can be achieved and much better performance can be obtained compared with the IEEE 802.21 standard approach.
key words: media independent handover, mobility, heterogeneous networks, mobile IP, WiMAX

1. Introduction

Recent advances in wireless technologies (e.g., Wi-Fi, WiMAX, CDMA, GSM, GPRS, and UMTS) enable users to access the Internet with any device, at anytime and anywhere. As a result, next generation networks such as 4G will be the overlay across heterogeneous networks. One of the main purposes of 4G networks is to allow mobile users to use always best connect (ABC) session through heterogeneous networks [1], representing that the integration is an essential issue. The main concerns of heterogeneous networks integration include quality of services (QoS) and seamless mobility. The former regards QoS mapping between heterogeneous networks because the QoS definition varies between different networks, and how to choose the best network candidate within heterogeneous networks. The latter regards the handover latency and service disruption time (SDT) caused by handover.

Handovers can be classified into horizontal handover and vertical handover. The horizontal handover only occurs in the homogeneous network while the vertical handover occurs in heterogeneous networks. The vertical handover can be further classified into make-before-break (soft) and break-before-make (hard) handover. For the make-before-break (soft) handover, user traffic flows are continuously available while the services may be disrupted for short durations for the break-before-make (hard).

In general, there are two types of time interval in a handover procedure, handover latency and SDT. The handover latency starts when a mobile node (MN) initiates a handover and ends because of the complete of the handover. On the other hand, the SDT is the time period during which the MN is unable to receive any packets from the serving network. It is mainly caused by the hard handover and network layer handover. A long SDT may lead to service termination, thus minimizing the SDT is necessary in supporting seamless mobility.

Regarding the QoS problem between heterogeneous networks, [2] proposed the vertical handoff translation center architecture (VHTC), including packet translation, QoS mapping, bandwidth borrowing management, and vertical handoff protocol, to enhance the transmission of QoS guarantees. To achieve seamless mobility in homogeneous network, mobile IPv6 (MIPv6) [3] provides the fundamental handover methods for mobility management at network layer (i.e., layer 3, L3). Fast MIPv6 (FMIPv6) [4], [5] provides a strategy of pre-binding process to reduce the handover latency. Hierarchical MIP (HMIP) [6] employs hierarchical architecture to perform local mobility management. In addition, the authors in [7] proposed a fast intra-network and cross-layer handover (FINCH) for the mobile WiMAX and other IEEE 802-series standards.

For assisting the integration of heterogeneous networks, the IEEE 802.21 defines media-independent handover standard which can facilitate handover decision by providing link layer network related information (i.e., L2 triggers) to network and upper layers between heterogeneous networks. Based on IEEE 802.21, [8] proposed a scheme to provide the QoS resources in the target network during the handover preparation phase; [9] proposed the network decision algorithm and network selection algorithm to choose the most suitable target network; [10], [11], and [12] proposed seamless mobility schemes in UMTS-WLAN, LTE-WLAN, and WIBRO-HSDPA, respectively. For providing seamless mobility in WiMAX/Wi-Fi networks, [13] indicated a handover scheme using FMIPv6 with IEEE 802.21 to reduce handover latency. However, reducing the SDT and preventing high packet loss still remain as challenges.

In this article, we propose a new handover scheme by IEEE 802.21 for supporting seamless mobility for WiMAX/Wi-Fi environment. The proposed scheme consists of three mechanisms (i.e., pre-DAD procedure, parallel handover, and buffer mechanism) that ensure the continuous on-

going session during handover, leading to reduced handover latency and SDT.

The rest of the present study is organized as follows. In Sect. 2, we present the IEEE 802.11 [14] and 802.16 [15], [16] handover procedure based on the IEEE 802.21 media-independent handover standard [17]. In Sect. 3, the proposed scheme was discussed in detail. Numerical analysis and simulation results based on ns-2 simulator are presented in Sect. 4. We conclude the work in Sect. 5.

2. Related Works

In this section, we briefly introduce the IEEE 802.21 standard including the information services, event services, and command services as well as illustrate relevance of them on the IEEE 802.21 framework. We also present the handover procedure between WiMAX/Wi-Fi networks. The abbreviations used in this article are listed in Table 1.

2.1 IEEE 802.21 Framework

The 802.21 framework is also called media-independent handover (MIH), which includes a signaling framework and triggers. It provides link layer network related information (i.e., L2 triggers) to network and upper layers, and unifies the diverse L2 technology-specific information to support the handover decision so that the upper layers can abstract the heterogeneity aspects belonging to different technologies. The MIH functionality can facilitate both *mobile-initiated* and *network-initiated* handovers for improving the user experience [17]. The standard consists of three elements: MIH user, service access point (SAP), and MIH function (MIHF). The MIH user is functional entities that use the services provided by the MIHF. The details of SAP and MIHF are described as follows:
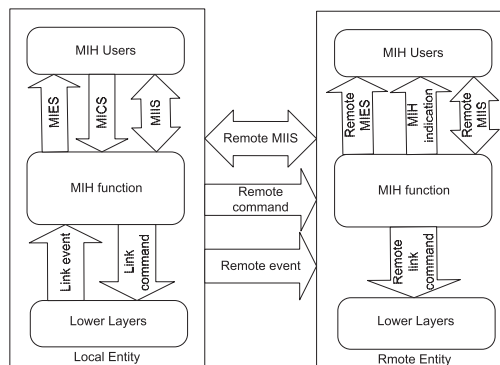
- **Service Access Points (SAPs):** The MIHF interfaces with other layers and functional planes using SAPs. Each SAP consists of a set of service primitives that specifies the interactions between the service user and service provider, and it defines both media-independent and media-dependent interfaces. The SAPs are depicted in Fig. 1.
- **Media Independent Handover Function (MIHF):** The MIHF is a logical entity that supplies the unified interface to the upper layers and independent of the underlying access technology. MIH services can use either local operation occurring within a protocol stack or remote operation occurring between two MIHF entities (Fig. 2). MIHF includes three main services that assist handovers across heterogeneous networks: media independent event services (MIES), media independent command services (MICS), and media independent information services (MIIS).

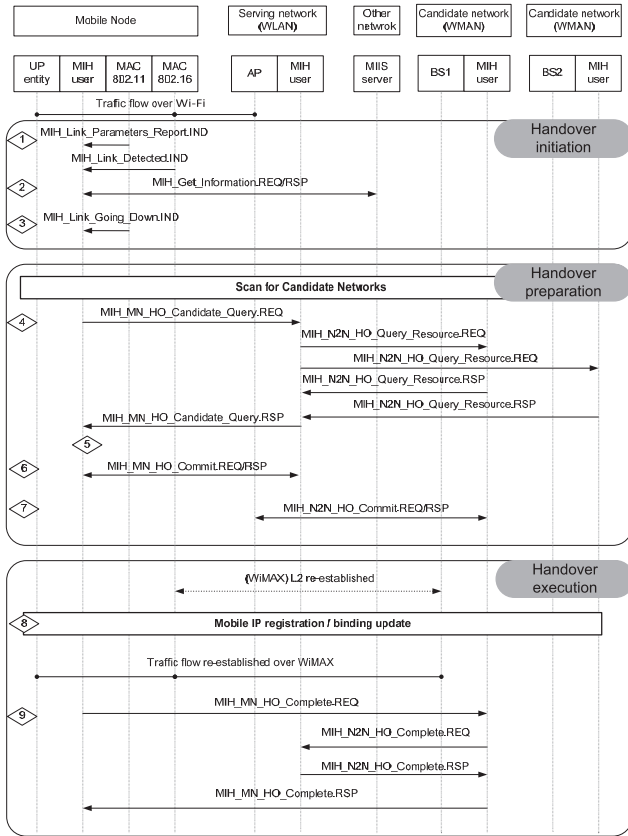### 2.2 Handover Procedure on WiMAX/Wi-Fi Networks

The handover procedure includes three steps: initiation, preparation, and execution. In initiation, it configures old devices to report measurements when specific thresholds are crossed. In preparation, the MN starts scanning for the neighbor networks. The QoS context must be transferred to the new network in a resource availability check process.
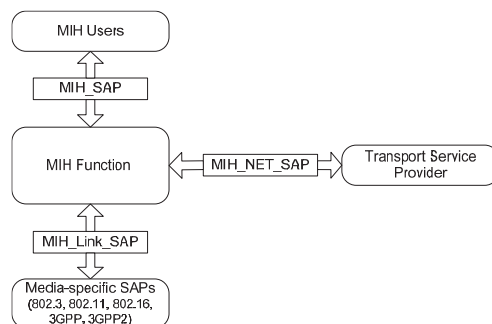
Fig. 1 Relationship between different MIHF SAPs.

Fig. 2 Communication between local and remote MIHF entities.

Table 1 Abbreviations used in this article.

Abbreviation	Full text	Abbreviation	Full text
MN	mobile node	QoS	quality of service
BS	base station	SDT	service disruption time
T-AR	target access router	CBR	constant bit rate
S-AR	serving access router	CAC	call admission control
HA	home agent	RS	router solicitation
CN	correspondent node	RA	router advertisement
NCoA	new care-of-address	NS	neighbor solicitations
DAD	duplicate address detection	BU	binding update
PoA	point of attachment	BAck	binding acknowledge
MIH	media-independent handover	FBU	fast binding update
MIHF	MIH function	HI	handover initiate
SAP	service access point	HAck	handover acknowledge
MIES	media independent event services	FBAck	fast binding acknowledge
MICS	media independent command services	FNA	fast neighborhood advertisement
MIIS	media independent information services	RtSolPr	router solicitation for proxy
F-MIP	FMIPv6-based	PrRtAdv	proxy router advertisement

Fig. 3 Message flow between Wi-Fi and WiMAX in IEEE 802.21 standard.

Furthermore, radio resource must be reserved over the selected network. Handover execution includes L2 signaling and higher layer signaling, which are beyond the scope of the standard. We present two handover approaches, one is provided in IEEE 802.21 standard, and the other is proposed in the [13].

• **The approach in IEEE 802.21 standard**

The handover procedure can be initiated by a mobile device or a wireless network. In the mobile-initiated handover procedure of dual radio node, both radios involved in handover can transmit/receive at the same time as shown in Fig. 3. Each message is formed as MIH_XXX.YYY, where XXX denotes its functionality and YYY denotes its purpose. The MN is connected to the Wi-Fi network and the handover procedure includes the following steps:

(1) The MN receives the 802.11 link measurement reported from the MIH_Link_Parameters_Report.IND event. When the MN receives a mobile_neighbor_ advertisement message from the WiMAX base stations (BSs) followed by a MIH_Link_Detected.IND event from the MAC layer toward the MIH user through MIHF, the MN becomes aware of a new connectivity opportunity.

(2) The MN gathers information about neighbor point of attachments (PoAs) and their characteristics by exchang-

ing the MIH_Get_Information.REQ/RSP with the MIIS.

(3) When the MIH_Link_Going_Down.IND event occurs on the current Wi-Fi network, the MN enters the handover preparation process and performs the MIH_Link_Actions.REQ to scan the link status of the candidate networks.

(4) The MN checks the resource availability status of the candidate networks by sending the MIH_MN_HO_ Candidate_Query.REQ message to the serving PoA (Wi-Fi AP). After serving PoA received the message from the MN, it sends MIH_N2N_HO_Query.REQ message toward the candidate PoAs to retrieve resource information from candidate networks. As a consequence, the candidate PoAs may perform their call admission control (CAC) to confirm whether they can support the MN session requirements without degenerating the existing sessions in the candidate networks. The CAC result (session totally, partially, or not at all supported) is sent back by MIH_N2N_HO_Query_Resources.RSP message that is followed by a MIH_MN_HO_Candidate_Query. RSP message.

(5) In the following, MIH user can perform the handover decision considering both the resource available at the candidate PoAs and the user's preferred selection of the target network.

(6) The MN sends MIH_MN_HO_Commit.REQ to the serving PoA to indicate the decided target network information.

(7) Through MIH_N2N_HO_Commit.REQ/RSP, serving PoA reserves the resource at the target network for MN. The WiMAX L2 re-establishment can happen in parallel with resource reservation process, because the MN equips with two interfaces. Moreover, the handover procedure already proceeded to handover execution.

(8) After completing WiMAX L2 re-establishment, the L3 handover procedure will be performed by using MIPv6. The MN will detect that it has moved to a new network via receiving router advertisement (RA) message from target access router (T-AR). The MN can also send a router solicitation (RS) for requesting the T-AR to send a RA back. The MN can create a new care-of-address (NCoA) via either stateless [18] or stateful [19] address auto-configuration based on the new network prefix information in RA message. The NCoA must be verified for uniqueness on the new network by duplicate address detection (DAD) procedure. To execute DAD, the MN has to send several neighbor solicitations (NS) message(s) to its NCoA and wait for a response for at least one second. After the confirmable NCoA is available, the MN must send a binding update to update the binding cache in its home agent (HA) and its correspondent nodes (CNs).

(9) The target PoA exchanges the MIH_N2N_HO_Complete messages with the serving PoA to release the resource for the MN on the original network after receiving the MIH_MN_HO_Complete.REQ from MN.
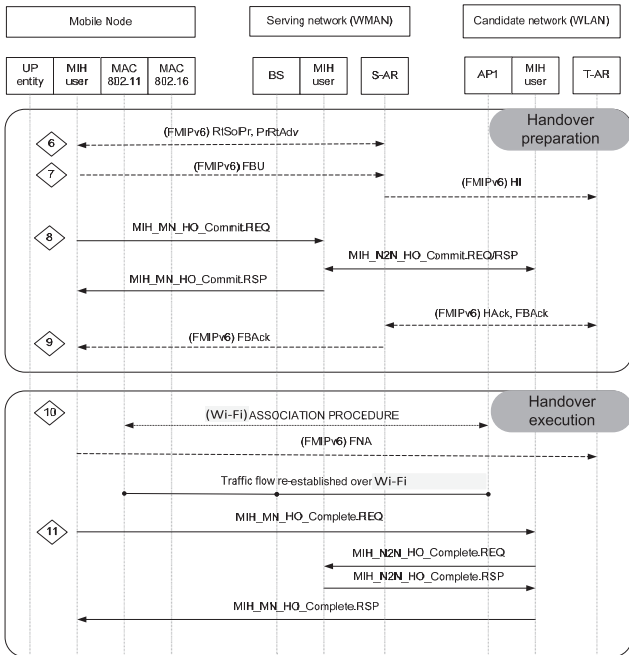
Fig. 4 Message flow from WiMAX to Wi-Fi in the F-MIP approach.

Fig. 5 Comparison of the standard with the F-MIP approach.

- **The FMIPv6-based (F-MIP) approach**

In [13], it addressed mobile-initiated handover and used FMIPv6 to reduce handover latency. The handover procedure operates as in Fig. 4.

(1)∼(5) The steps are almost same as the standard approach.

(6) After making the handover decision, the MN exchanges the router solicitation for proxy (RtSolPr) and proxy router advertisement (PrRtAdv) messages with the serving AR (S-AR) to get the new network prefix of the T-AR. After receiving a PrRtAdv message, the MN configures NCoA.

(7) The MN sends a fast binding update (FBU) message to the S-AR. Upon receiving this message, the S-AR sends a handover initiate (HI) message to the T-AR. The T-AR executes DAD procedure to verify the uniqueness of NCoA and responds with handover acknowledge (HAck) message to the S-AR. At this time, the tunnel between the MN's old CoA and its NCoA at the T-AR is established. The T-AR stores the tunneled packets in a buffer until it receives a fast neighborhood advertisement (FNA) message from the MN.

(8) Because a DAD procedure needs a long execution time, the L3 handover execution is interlaced simultaneously with MIH_Handover_Commit (MN Request, N2N Request/Response, and MN Response).

(9) When the S-AR receives a HAck message, it responses fast binding acknowledge (FBAck) messages to the MN and the T-AR. If the MN receives the FBAck message in the serving network before the L2 handover takes place, it will operate in the predictive FMIPv6 procedure, and MN can quickly receive packets from the T-AR after it moves to the target network. If the MN does not receive
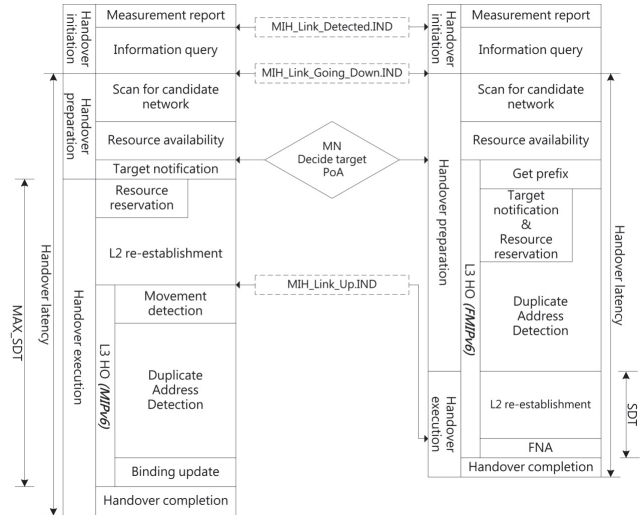
any FBAck message from the S-AR before the MN's disconnection from the serving network, the FMIPv6 will operate in reactive mode in which the MN must wait for the L2 handover to complete and restart partially the L3 handover procedure.

(10) After the MN receives an FBAck message, the MIH user activates the Wi-Fi interface by using MIH_Link_Action.REQ message to initiate the L2 handover. When the L2 handover is completed, the MN sends a FNA message to the T-AR to start forwarding the traffic to the MN.

(11) The step is like step (9) in the IEEE 802.21 standard.

The F-MIP approach only provides a make-before-break approach that the MN's session can benefit from seamless handover, but it doesn't take account of the FMIPv6 in reactive mode and may cause session disruption and packet loss.

- **Comparison of the standard and the F-MIP approaches**

The standard approach is different from the F-MIP approach which uses the FMIPv6 to execute the IP layer handover. There are two mechanisms in the FMIPv6, anticipated and tunnel-based handover [20]. In anticipated handover, the MN receives these L2 triggers indicating that it is about to perform an L2 handover. In tunnel-based handover, the S-AR can tunnel packets to the T-AR and store them in the T-AR's buffer during the L2 handover procedure to reduce packet loss rate.

Figure 5 shows the comparison of the standard with the F-MIP approach. Our discussion focuses on handover latency and SDT. The handover latency starts when the MN received MIH_Link_Going_Down.IND from the MIHF and ends when the Handover_Complete message is received. For the handover latency, the spent time in the standard is similar to that in the F-MIP because they both count the time elapsed for L2 and L3 handover. For the SDT, there is a

special condition in the standard, when the MN finishes L3 handover and its connection to the serving PoA is still active, such as make-before-break approach, the SDT is negligible. If the MN moves fast, it may cause the handover break-before-make, and the maximum SDT will be the total time of both L2 and L3 handovers.

In the F-MIP approach, the SDT is the duration from that MN received an FBAck message from the S-AR to that it received a forwarded packet from T-AR. The maximum SDT in the F-MIP approach is the total time of L2 handover, FNA message transmission, and packet forwarding from the S-AR. In the F-MIP approach, authors only illustrated that the handover is make-before-break, but it may be break-before-make handover in which the FMIPv6 is in reactive mode and packet loss may happen. In make-before-break handover, the approach in the standard is better than the F-MIP approach regarding the SDT, but the MN must move slowly. Further, the predictive mode of FMIPv6 supports tunnel-based mechanism and stores packets in buffer to avoid packet loss.

3. The Proposed Scheme

Both SDT and packet loss rate are key factors in supporting seamless handover for real-time applications. We account MN's speed influencing the packet loss rate and SDT. Another factor is the overlap distance between the serving PoA and target PoA. In studies [21]–[24], MIH services are used for improving the SDT to offer the 4G always best connected vision. Our intention is providing seamless handover in either low or high speed moving of the MN. We proposed a scheme for handover in WiMAX/Wi-Fi heterogeneous networks, and introduce three mechanisms in our scheme which can reduce the SDT as well as achieve seamless handover in heterogeneous WiMAX/Wi-Fi networks.

3.1 Proposed Handover Procedure

The handover procedure of our proposed scheme is presented in Fig. 6 and the difference between our proposed scheme and F-MIP approach has been indicated (in italic and boldface). Our three mechanisms to reduce the SDT include pre-DAD procedure, parallel handover, and buffer mechanism explained as follows.

● **Pre-DAD procedure**

The DAD execution time takes at least one second. It causes the L3 handover much longer than the L2 handover. However, we observed that the time elapsed from the MN's receiving a MIH_Link_Detected.IND event to the trigger by MIH_Link_Going_Down.IND is dependent of the MN's speed and overlap distance between the serving PoA and the target PoA. In general, this time is longer than the duration from that MN received a MIH_Link_Going_Down.IND event to the service disruption. Therefore, we try to start DAD process before receiving a MIH_Link_Going_Down.IND event by using a mech-
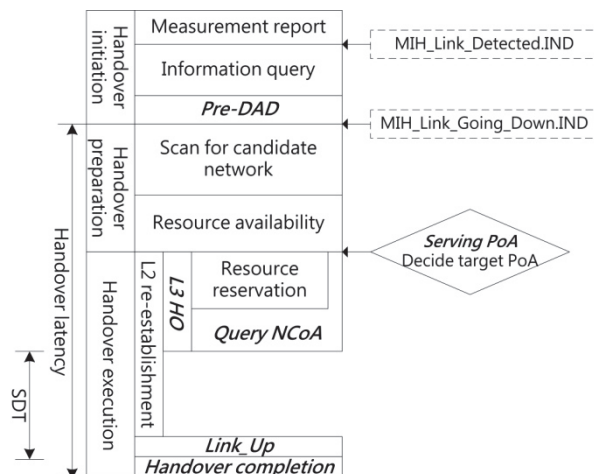

Fig. 6 The proposed scheme in handover procedure.

anism called pre-DAD procedure. When the MN detects a new link, it can query the MIIS about the new PoA information and forward the interface address to the S-AR by Pre-DAD.REQ messages. Upon receiving the message from the MN, the S-AR will reply a Pre-DAD.RSP message and configure a new IPv6 address for the MN with all S-AR neighbor network prefixes. Since address configuration can be done stateless or stateful in IPv6 networks, the S-AR can assist the MN to generate a new IPv6 address with stateful configuration. The 128 bits IPv6 address can be configured with a 64-bit suffix combined with the new network prefix. The number of NCoAs configured by S-AR depends on the number of AR's neighbors. There are two conditions in our mechanism: (1) The S-AR must configure these NCoAs with the new network prefix and the interface address from the MN. These NCoAs created by the S-AR are already unique and won't be verified by the DAD procedure. Therefore, the required time for the pre-DAD execution is the latency of exchanging Pre-DAD.REQ and Pre-DAD.RSP. (2) the S-AR must configure NCoAs with the new network prefix based on either the interface address from the MN or a randomly generated address. These NCoAs must be confirmed with the DAD procedure. Therefore, the required time for the pre-DAD execution takes ca. one second because that the DAD procedure takes at least one second.

● **Parallel handover**

The L2 handover may occur in parallel with the L3 handover. When an MIH user knows the target PoA, it can instruct target interface of the MN to perform the L2 handover procedure and send a Query_NCOA.REQ message to the S-AR through the MN interface in order to do partial L3 handover process. The Query_NCoA.REQ message includes target PoA information to inform the S-AR that the MN intends to handover under its PoA and applies for NCoA. Since the L2 handover procedure can be simultaneously executed with the partial L3 handover process, we only select the longer handover process, the L2 handover in our scheme, to calculate the latency.
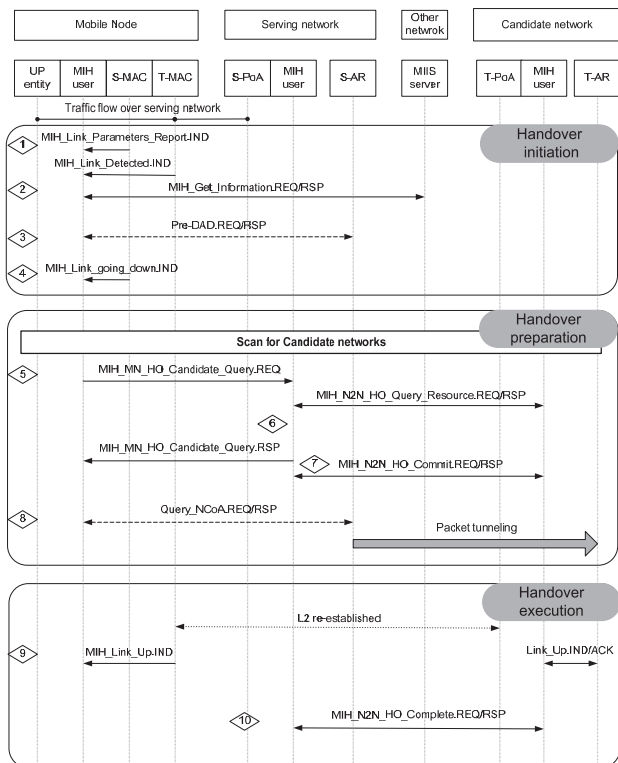
Fig. 7 The proposed message flow in WiMAX/Wi-Fi networks.

• **Buffer mechanism**

When the S-AR receives a Query_NCoA.REQ message from the MN, the S-AR assigns an NCoA to the MN based on MN's target PoA and establishes a tunnel between the MN's current CoA and its NCoA at the T-AR. The T-AR intercepts the tunneled packets and stores them in a buffer until it receives a Link_Up.IND message. Upon receiving the message, the T-AR replies a Link_Up.ACK message to the target PoA and forwards the buffered packets to the MN.

• **Message flowchart**

Our proposed scheme is illustrated in Fig. 7 and uses FMIPv6 in the L3 handover procedure. The MIH messages are depicted by solid lines, while FMIPv6 and technology-specific messages are indicated by dashed and dotted lines, respectively. The handover procedure operates as follows:

(1) The MN receives the MIH_Link_Parameters_Report. IND event from serving interface that called S-MAC and it includes link measurement report. The message can be sent periodically for informational reasons. When the T-MAC of the MN detects a new link from new PoA, it triggers a MIH_Link_Detected.IND event to inform the upper layer.

(2) The MN periodically queries MIIS via the MIH_Get_Information.REQ/RSP message to gather information about neighbor PoAs and their characteristics.

(3) When the MN detected a new link, it can query the MIIS about the new PoA information and forward the interface hardware address to the S-AR via Pre-DAD.REQ

messages. Upon receiving the message from the MN, the S-AR responds a Pre-DAD.RSP message to the MN and configures some NCoA for the MN with all S-AR neighbor network prefix. As mentioned above, we use the second method to create address, the S-AR configures these NCoAs with the new network prefix and based on either the interface hardware address from the MN or generated randomly. Moreover, these NCoAs must be confirmed with DAD procedure and be stored both in the S-AR and the corresponding T-AR.

(4) Upon reception of the MIH_Link_Going_Down.IND event from the S-MAC, the MN initiates handover preparation process and sends a MIH_Link_Actions. REQ message for scanning the link status of the candidate networks.

(5) The MN sends a MIH_MN_HO_Candidate_Query. REQ message to the serving PoA and two parameters of this message are CandidateLinkList and QosResourceRequirements. The first parameter instructs the serving PoA to check resource availability status for the list of candidate PoAs. The second parameter is the minimal QoS resources required at the candidate network. After the serving PoA received the message from the MN, it retrieves resource information from candidate networks by sending a MIH_N2N_HO_Query.REQ message to the candidate PoAs. As a consequence, the candidate PoAs may perform their CAC to confirm whether they support the MN's session requirements without degenerating the existing sessions in the candidate networks. The CAC result is sent through the MIH_N2N_HO_Query_Resources.RSP message for replying to the serving PoA.

(6) Upon receiving the MIH_N2N_HO_Query_Resources.RSP message, the serving PoA selects the target PoA based on CAC result. In our scheme, the target PoA is selected by the serving PoA in order to omit the MIH_MN_HO_Commit.REQ/RSP messages as well as to enter resource reservation process quickly. The serving PoA sends a MIH_MN_HO_Candidate_ Query.RSP message to notify the MN regarding the selected target PoA.

(7) When the serving PoA selects the target PoA, it can reserve the resource in the target network via MIH_N2N_HO_Commit.REQ/RSP messages.

(8) When the MN receives the MIH_MN_Candidate_ Query.RSP message, the MN sends a Query_NCoA. REQ message to the S-AR to acquire an NCoA for the MN and L2 re-establishment can be performed in parallel because the MN is equipped with two interfaces. The S-AR assigns an NCoA to the MN via a Query_NCoA.RSP message and establishes the tunnel between the MN's old CoA and NCoA at the T-AR. The T-AR stores the tunneled packets in a buffer until it receives a Link_Up.IND from the target PoA, and the S-AR deletes other unused NCoA for the MN by sending the Cancel_Unused_NCoA.IND/ACK messages to other neighbor ARs.

(9) When L2 handover is completed, the T-MAC of the MN triggers a MIH_Link_Up.IND event to MIH user and informs that the MN attaches to the new link. In our scheme, the target PoA informs the T-AR directly instead of exchanging FNA message twice between T-AR and MN, thus the SDT could be reduced.

(10) When the MN attaches to the target PoA, MIH_N2N_HO_Complete.REQ/RSP messages are exchanged between the target PoA and the serving PoA to release the resource of serving PoA.

4. Performance Analysis and Simulation Evaluation

4.1 Performance Analysis

Table 2 shows parameters for performance analysis of three approaches, $RTT_{MN\text{-}TAR}$ and $RTT_{MN\text{-}SAR}$ values are depending on whether the MN is in WiMAX or Wi-Fi network environment, other parameters are referred to NIST publisher [25]. Note that the handover latency is the total time of handover preparation and handover execution. It could be expressed in Eq. (1).

$$T_{HO\_Latency} = T_{HO\_pre} + T_{HO\_exe} \qquad (1)$$

Before calculating the handover latency, we calculate the handover procedure time of the MIPv6 and FMIPv6 for the standard and the F-MIP approach respectively. The MIPv6 consists of three operations: movement detection, DAD process, and binding update. In movement detection, the MN uses MIH mechanism to detect movement through L2 trigger events, and it gets the network prefix by exchanging Router Solicitation/Router Advertisement messages with T-AR. During DAD process, the MN sends neighbor solicitation (NS) message to its NCoA and waits at least one second for a response. Then, the MN must perform the binding update process by exchanging the binding update (BU) and binding acknowledge (BAck) with its home agent (HA) and correspondent node (CN) to announce its new location. The total time for MIPv6 process can be

Table 2 Parameters used in mathematical analysis.

Parameter	Value (ms)	Description
T_{frame}	5	Frame duration of IEEE 802.16j
$T_{Wi\text{-}Fi}$	2	Time for transmitting a frame in Wi-Fi
T_{scan_WiMAX}	85	Scan for 802.16 candidate network
$T_{scan\_Wi\text{-}Fi}$	120	Scan for 802.11 candidate network
T_{WiMAX_L2}	287	Latency of IEEE 802.16 network re-entry procedure
$T_{Wi\text{-}Fi\_L2}$	195	Latency of IEEE 802.11 network re-entry procedure
T_{DAD}	1000	Time needed to perform a DAD process
$T_{AP\text{-}AR}$	1	The transmission time between AP and AR
$T_{BS\text{-}AR}$	1	The transmission time between BS and AR
$RTT_{MN\text{-}TAR}$	--	The round-trip time between the MN and target AR
$RTT_{MN\text{-}SAR}$	--	The round-trip time between the MN and serving AR
$RTT_{TAR\text{-}HA}$	2	The round-trip time between target AR and home agent
$RTT_{SAR\text{-}TAR}$	2	The round-trip time between serving AR and target AR

expressed as Eq. (2).

$$\begin{aligned} T_{MIPv6} &= T_{RS/RA} + T_{NS} + T_{DAD} + T_{BU/BAck} \\ &= T_{DAD} + 3RTT_{MN\text{-}TAR} + RTT_{TAR\text{-}HA} \end{aligned} \qquad (2)$$

For the FMIPv6, the MN exchanges the Rt-SolPr/PrRtAdv messages with serving AR in order to get the new network prefix of the T-AR. Before the DAD process, the MN exchanges FBU/FBAck with the S-AR, and S-AR exchanges HI/HAck with the T-AR to perform DAD process. When the MN completes the L2 handover, it sends a FNA message to notify the T-AR forwarding packets to the MN. Then, the time elapsed for FMIPv6 process can be expressed in Eq. (3).

$$\begin{aligned} &T_{FMIPv6} \\ &= T_{RtSolPr/PrRtAdv} + T_{FBU/FBAck} + T_{HI/HAck} + T_{DAD} + T_{FNA} \\ &= T_{DAD} + 2RTT_{MN\text{-}SAR} + RTT_{SAR\text{-}TAR} + RTT_{MN\text{-}TAR} \end{aligned} \qquad (3)$$

There are two handover conditions, WiMAX → Wi-Fi and Wi-Fi → WiMAX. We analyze the handover latency and SDT of three approaches individually.

• WiMAX → Wi-Fi

Based on the values in Table 2, we can calculate Eqs. (2) and (3) as follows.

$$\begin{aligned} T_{MIPv6} &= T_{DAD} + 3RTT_{MN\text{-}TAR} + RTT_{TAR\text{-}HA} \\ &= T_{DAD} + 3 \times (2 \times (T_{Wi\text{-}Fi} + T_{AP\text{-}AR})) + RTT_{TAR\text{-}HA} \\ &= 1020 \,(ms) \end{aligned}$$

$$\begin{aligned} T_{FMIPv6} &= T_{DAD} + 2RTT_{MN\text{-}SAR} + RTT_{SAR\text{-}TAR} + RTT_{MN\text{-}TAR} \\ &= T_{DAD} + 2 \times (2 \times (T_{frame} + T_{BS\text{-}AR})) + RTT_{SAR\text{-}TAR} \\ &\quad + 2 \times (T_{Wi\text{-}Fi} + T_{AP\text{-}AR}) = 1034 \,(ms) \end{aligned}$$

Specifically, T_{FMIPv6} is a little larger than T_{MIPv6}, because the MIPv6 is executed in Wi-Fi network and the FMIPv6 is accomplished in WiMAX network. The handover latency involves operations such as scan, resource availability check, and target notification. We can calculate the handover latency of three schemes based on Fig. 5 and Fig. 6. In our proposed scheme, we calculate the L2 re-establishment time instead of the partial L3 handover process time in handover execution. In Link_Up process, it comprises the time of sending Link_Up.IND/ACK messages and forwarding packet from the T-AR to the MN. The handover latency based on Eq. (1) can be calculated as follows:

$$\begin{aligned} T_{Standard} &= T_{HO\_pre} + T_{HO\_exe} \\ &= (T_{Scan\_Wi\text{-}Fi} + \text{Resource availability} \\ &\quad + \text{Target notification}) \\ &\quad + (T_{Wi\text{-}Fi\_L2} + T_{MIPv6} + \text{Handover completion}) \\ &= 1371 \,(ms) \end{aligned}$$

$$\begin{aligned} T_{F\text{-}MIP} &= T_{HO\_pre} + T_{HO\_exe} \\ &= (T_{Scan\_Wi\text{-}Fi} + \text{Resource availability}) \\ &\quad + (T_{FMIPv6} + T_{Wi\text{-}Fi\_L2} + \text{Handover completion}) \\ &= 1375 \,(ms) \end{aligned}$$

$T_{Proposed} = T_{HO\_pre} + T_{HO\_exe}$

$\quad = (T_{Scan\_Wi\text{-}Fi} + \text{Resource availability})$

$\quad\quad + (T_{Wi\text{-}Fi\_L2} + Link\_Up + \text{Handover completion})$

$\quad = 341\,(ms)$

On the other hand, the SDT for standard, F-MIP, and proposed schemes in WiMAX → Wi-Fi can be calculated as below:

$MAX\_SDT_{Standard} = T_{Wi\text{-}Fi\_L2} + T_{MIPv6} = 1215\,(ms)$

$SDT_{F\text{-}MIP\_pre} = T_{Wi\text{-}Fi\_L2} + T_{FNA} = 201\,(ms)$

$SDT_{F\text{-}MIP\_re} = T_{Wi\text{-}Fi\_L2} + T_{FNA} + T_{FBU} + T_{DAD} + T_{FBAck}$

$\quad\quad = 1203\,(ms)$

$SDT_{Proposed} = T_{Wi\text{-}Fi\_L2} + Link\_Up = 199\,(ms)$

$MAX\_SDT_{Standard}$ is the maximum SDT in the standard approach when the MN performs a break-before-make handover. In addition, $SDT_{F\text{-}MIP\_pre}$ and $SDT_{F\text{-}MIP\_re}$ mean the SDT in the F-MIP approach with predictive and reactive mode respectively.

- **Wi-Fi → WiMAX**

Similarly, we calculate Eqs. (2) and (3) as follows:

$T_{MIPv6} = T_{DAD} + 3RTT_{MN\text{-}TAR} + RTT_{TAR\text{-}HA}$

$\quad = T_{DAD} + 3 \times (2 \times (T_{frame} + T_{BS\text{-}AR})) + RTT_{TAR\text{-}HA}$

$\quad = 1038\,(ms)$

$T_{FMIPv6} = T_{DAD} + 2RTT_{MN\text{-}SAR} + RTT_{SAR\text{-}TAR} + RTT_{MN\text{-}TAR}$

$\quad = T_{DAD} + 2 \times (2 \times (T_{Wi\text{-}Fi} + T_{AP\text{-}AR})) + RTT_{SAR\text{-}TAR}$

$\quad\quad + 2 \times (T_{frame} + T_{BS\text{-}AR}) = 1026\,(ms)$

The handover latency based on Eq. (1) can be calculated as follows:

$T_{Standard} = T_{HO\_pre} + T_{HO\_exe}$

$\quad = (T_{Scan\_WiMAX} + \text{Resource availability}$

$\quad\quad + \text{Target notification})$

$\quad\quad + (T_{WiMAX\_L2} + T_{MIPv6} + \text{Handover completion})$

$\quad = 1440\,(ms)$

$T_{F\text{-}MIP} = T_{HO\_pre} + T_{HO\_exe}$

$\quad = (T_{Scan\_WiMAX} + \text{Resource availability})$

$\quad\quad + (T_{FMIPv6} + T_{WiMAX\_L2} + \text{Handover completion})$

$\quad = 1424\,(ms)$

$T_{Proposed} = T_{HO\_pre} + T_{HO\_exe}$

$\quad = (T_{Scan\_WiMAX} + \text{Resource availability})$

$\quad\quad + (T_{WiMAX\_L2} + Link\_Up + \text{Handover completion})$

$\quad = 395\,(ms)$

On the other hand, the SDT for standard, F-MIP, and proposed schemes in Wi-Fi → WiMAX can be calculated as below:

$MAX\_SDT_{Standard} = T_{WiMAX\_L2} + T_{MIPv6} = 1325\,(ms)$

$SDT_{F\text{-}MIP\_pre} = T_{WiMAX\_L2} + T_{FNA} = 299\,(ms)$

Table 3 Theoretical performance comparison.

	Scheme	WiMAX→ Wi-Fi	Improve- ment	Wi-Fi→ WiMAX	Improve- ment
Handover latency	Standard	1371	--	1440	--
	F-MIP	1375	-0.29%	1424	1.11%
	Proposed	341	75.13%	395	72.57%
SDT	Standard	1215	--	1325	--
	F-MIP_pre	201	83.46%	299	77.43%
	F-MIP_re	1203	0.99%	1301	1.81%
	Proposed	199	83.62%	294	77.81%
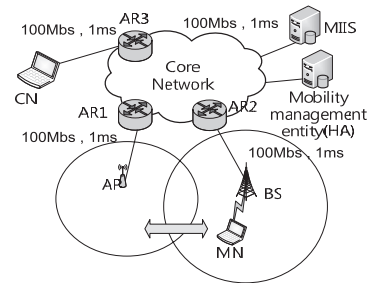
Fig. 8 Simulation network topology.

$SDT_{F\text{-}MIP\_re} = T_{WiMAX\_L2} + T_{FNA} + T_{FBU} + T_{DAD} + T_{FBAck}$

$\quad\quad = 1301\,(ms)$

$SDT_{Proposed} = T_{WiMAX\_L2} + Link\_Up = 294\,(ms)$

- **Performance comparison**

The result of mathematical analysis is depicted in Table 3. It shows that our scheme outperforms other two methods. Due to pre-DAD process, our scheme reduces the handover latency and SDT significantly. The L2 re-establishment is also the factor of the handover latency and SDT. In particular, it is worth noting that the handover latency from Wi-Fi to WiMAX is longer than that from WiMAX to Wi-Fi because the required time for performing the L2 re-establishment and scan process in WiMAX network is longer than in Wi-Fi network.

4.2 Simulation and Numerical Results

In this section, we compare the performance of three approaches by using the network simulator ns-2 [26] with mobility module [27]. Two scenarios are used to measure the performance. In scenario I, the MN moves from WiMAX to Wi-Fi network. While in scenario II, it redirects from Wi-Fi to WiMAX network. Figure 8 shows the network topology. Each wired link features 100 Mbps bandwidth, 1 ms propagation delay time, and drop tail queuing policy. The WiMAX cell is overlapped with the coverage area of Wi-Fi AP. The data rate in Wi-Fi is set to 11 Mbps because 11 Mbps is a common data rate in practice. It is assumed that the MN has two interfaces. The simulation duration is 110 seconds, and at 9th second constant bit rate (CBR)

Table 4   Parameters of simulation.

Parameter	Value	Parameter	Value
Network Topology		**WiMAX Configuration**	
WiMAX cell coverage	1000m	Dcd/Ucd_interval	5s
Wi-Fi cell coverage	100m	Default modulation	OFDM_16QAM_3_4
Coverage area	40m	Frame duration	5 ms
Mobility Model		**CBR traffic**	
Velocity	10(m/s)	VoIP — Packet size	200 bytes
Path	Straight line	Data rate	64 Kbps
Wi-Fi Configuration		Streaming — Packet size	1500 bytes
Data rate	11Mbps	Video — Data rate	1 Mbps

Fig. 9   The result I in standard scheme.

Fig. 10   The result I in the F-MIP scheme.

Fig. 11   The result I in our proposed scheme.

traffic was sent from the CN to the MN. The MN started to move at 10th second with speed 10 meter per second. For CBR traffic, we use VoIP and streaming video and check the packet sequence number received by the MN, we can observe whether a packet is delivered successfully or gets lost. Parameters of the simulation are listed in Table 4.

● **Scenario I: Moving from WiMAX to Wi-Fi**

Figures 9 to 11 show the simulation results in standard approach, F-MIP approach, and the proposed scheme with VoIP traffic respectively. In Figs. 9 to 11, the horizontal width of the gap in the curve represents the SDT during which the MN is unable to receive packets from the serving network. On the other hand, the vertical width of the gap in the curve represents the packet loss.

In Fig. 9, the handover started at about 94.53 s when the MN received a MIH_Link_Going_Down.IND message. At about 95 s, the MN service was disrupted before Wi-Fi connection was established. The SDT is about 903.03 ms. During this period, the MN is unable to receive any packet from CN and packets sent to MN got lost because no mechanism is available to buffer and forward those packets. Hence, the packet loss rate is high and the performance is degraded seriously.

In Fig. 10, the method of F-MIP approach is used. The MN moves at 10 m/s, it results in that MN can neither receive FBAck message in time nor perform the handover procedure in FMIPv6 predictive mode. Therefore, when MN finished L2 re-establishment of Wi-Fi interface, it must send an FNA message to T-AR with an encapsulated FBU message and complete DAD process. The SDT starts at 95 s and ends at 96.2 s, so the SDT is 1206.79 ms.

Figure 11 shows the result of our scheme. The T-AR forwards the buffered packets to the MN when it receives the Link_Up.IND. The MN received Query_NCoA.RSP message and the forwarded packets at about 94.66 s and 94.86 s, respectively, and the total SDT is 195.38 ms.

● **Scenario II: Moving from Wi-Fi to WiMAX**

The parameters of scenario II is same as that in scenario I, but the MN is under Wi-Fi AP and handover is from Wi-Fi to WiMAX. Figures 12 to 14 represent the results of the handover from Wi-Fi to WiMAX. The profiles of simulated results are similar to the profiles in scenario I, but the time of
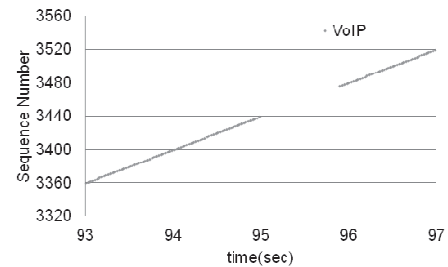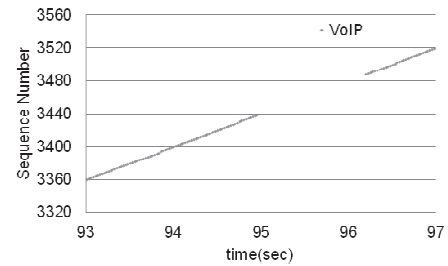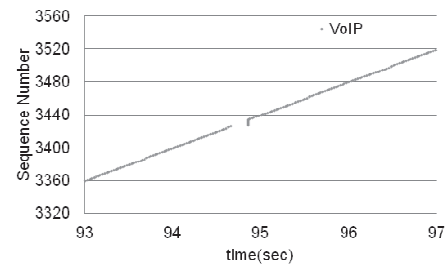
WiMAX connection re-establishment is longer than that of Wi-Fi. The handover begins at about 15.6 s and we use VoIP traffic to observe the arrived sequence number sent by CN. The SDT is 1004.634 ms, 1298.37 and 289.87 in the standard scheme, the F-MIP approach and our proposed scheme, respectively.

We change the moving speed of MN from 1 m/s to 30 m/s and perform simulation for every 5 m/s speed change, and compare our proposed scheme with other two in the situation of MN moves from WiMAX to Wi-Fi. Figure 15 illustrates the relation between the SDT and speed. Obviously, our proposed scheme keeps a stable SDT value. Although the performance of our proposed scheme in low speed is worse than that in the standard, our scheme outperforms the standard when moving speed exceeds 5 m/s. Because of buffer mechanism, we can store packets during the SDT which is around 195 ms in our scheme. The F-MIP approach with MN speed 1 m/s executes in predictive mode and has buffer mechanism like ours. On the other hand, when MN's moving speed exceeds 5 m/s, the F-MIP approach executes in reactive mode, and MN has to re-establish Wi-Fi connection and perform DAD process once the original connection is disrupted.
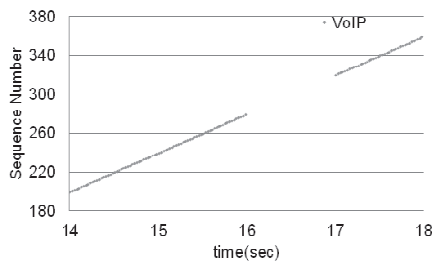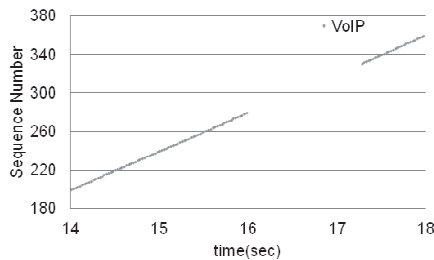
Fig. 12   The result II in standard scheme.

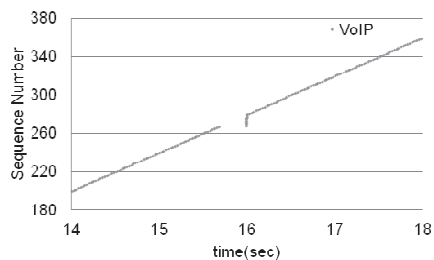**Fig. 13**   The result II in the F-MIP scheme.
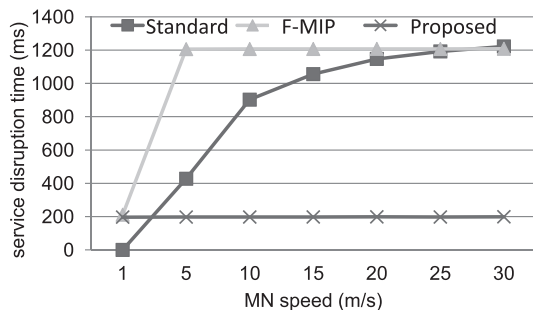

Fig. 14   The result II in our proposed scheme.

Fig. 15   Simulation results of Wi-Fi to WiMAX handover in our proposed scheme.

Table 5   Performance comparison of simulation results.

	Scheme	WiMAX→ Wi-Fi	Improve- ment	Wi-Fi→ WiMAX	Improve- ment
Handover latency	Standard	1364.24	--	1426.2	--
	F-MIP	1370.76	-0.48%	1419.51	0.47%
	Proposed	338.6	75.18%	393.34	72.42%
SDT	Standard	903.3	--	1004.63	--
	F-MIP	1206.79	-33.6 %	1298.37	-29.24%
	Proposed	195.38	78.36%	289.87	71.18%

dover latency by 75.18% and 72.42% from the WiMAX → Wi-Fi and Wi-Fi → WiMAX respectively.

According to Table 3 and Table 5, we can compare the mathematical analysis with the simulation results. As we can see, the simulation results correspond with the mathematical analysis.

5.   Conclusions

In this article, we proposed three main mechanisms to enhance the handover procedure. First, Pre-DAD procedure can anticipate the accomplishment of the DAD process. Second, parallel handover can perform both L2 and L3 handovers simultaneously. Finally, buffer mechanism can avoid packet loss during handover. According to the simulation result, the handover latency and the SDT is reduced more than 70% and the result well matches the data from mathematical analysis.

Specifically, the F-MIP approach does not improve the SDT, because it changes to reactive mode when the speed of MN exceeds 5 m/s. So, it needs more time than the standard scheme to complete handover procedure. We use pre-DAD and parallel handover mechanism to improve the method of the F-MIP approach and achieve good performance in both handover latency and SDT.

Voice services can tolerate a maximum delay between 150 and 200 ms. When the MN handovers from Wi-Fi to WiMAX, the current voice delay can't be accepted, but when the MN handovers from WiMAX to Wi-Fi, it is just acceptable. It is necessary to further reduce the delay in the future study. For video on-demand service, we may set a video buffer in the MN to solve the out-of-order packets problem. But still some problems, such as QoS mapping and DoS attacks against MIIS, need to be studied.

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In Table 5, we compare the handover latency and SDT of three schemes in both scenarios. We can observe clearly that, comparing with the standard scheme, the SDT is reduced by approximately 78% and 71% in WiMAX → Wi-Fi and Wi-Fi → WiMAX respectively. The F-MIP approach performs in reactive mode and it doesn't get any improvement. Also, we compare the handover latency of three schemes when the MN's speed is 1 m/s. In that situation, the F-MIP approach will operate in predictive mode. The simulation results show that our approach reduces the han-

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