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Research Article

Cross-Layer Handover Scheme for Multimedia Communications in Next Generation Wireless Networks

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In order to achieve seamless handover for real-time applications in the IP Multimedia Subsystem (IMS) of next generation network, a multiprotocol combined handover mechanism is proposed in this paper. We combine SIP (Session Initiation Protocol), FMIP (Fast Mobile IPv6 Protocol), and MIH (Media Independent Handover) protocols by cross-layer design and optimize those protocols' signaling flows to improve the performance of vertical handover. Theoretical analysis and simulation results illustrate that our proposed mechanism performs better than the original SIP and MIH combined handover mechanism in terms of service interruption time and packet loss.

1. Introduction

In next generation wireless system, *access networks* can be carried out by different technologies, such as WiFi, WiMAX and UMTS, while the *core network* infrastructure is established on an all-IP-based network. There have existed a variety of applications for next generation wireless system, in which the multimedia service is one of main applications [1]. However, the characteristics of wireless systems provide a major challenge for reliable transport of multimedia since it is highly sensitive to interference and link or channel change, which may cause delay, packet loss, and jitter. The wireless networks have to cope with this lack of Quality of Service (QoS) guarantees [2]. For improving the QoS, many studies investigate how to optimize the system scheduling scheme of utilizing available network resources [3, 4]. The IP Multimedia Subsystem (IMS) is an architectural framework for delivering IP multimedia services, which applies Session Initiation Protocol (SIP) to controlling multimedia communication sessions. SIP can provide IP mobility by the REINVITE signaling. However, SIP has a longer end-to-end signaling delay which may cause frequent disruption for real-time applications in node motion. Therefore, as the nodes move among heterogeneous wireless networks, one of the greatest challenges is how to provide fast and seamless mobility support.

Media Independent Handover (MIH) standard [5] was proposed for solving the above problem. Some researches (see, e.g., [6, 7]) had been done by using MIH to improve the SIP-based node mobility handover process in vertical handover. In addition, MIH is also used to assist the Mobile IP-(MIP-) based handover process. Fast Mobile IPv6 Protocol (FMIP) is an extension to MIPv6 designed for eliminating the standard MIP handover latencies [8] and is a combined SIP+MIH handover architecture by cross-layer design. A combined FMIP+SIP handover architecture can be found in [9]. However, in fact, the improvement of the handover performance for the previous approaches is limited when only one or two kinds of protocols are combined to solve the handover problem. Hence, a better way to solve the problem is to design a combination of more layer protocols by cross-layer design. In this paper, our interests focus on how to accelerate the handover process.

Handover occurs when a communicating node moves from one network to another. It can be classified into two modes: *make-beforebreak* and *break-beforemake*, in which the former connects to the new network before the node tears down the current connected network, while the latter just does the other way. The make-beforebreak mode is more complicated to be implemented, but have a better performance on end-to-end delay and packet loss. In this paper, an integrated scheme of combining FMIP, SIP and MIH signaling is proposed to optimize the performance of vertical handover on make-beforebreak mode.

The rest of this paper is organized as follows. Section 2 introduces the relevant protocols and related work. The proposed handover mechanism is given in Section 3. Section 4 shows the simulation results and Section 5 concludes this paper. At the end, in order to facilitate the understanding of this paper, some key terminologies used in this paper are listed in the Abbreviations.

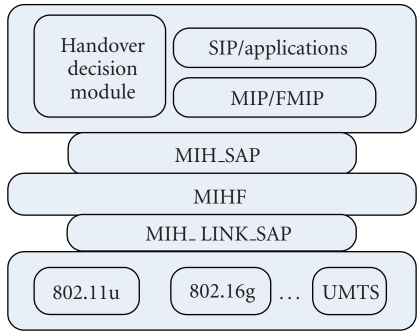

Figure 1: Multiprotocol architecture in heterogeneous networks.

2. Background

2.1. Relevant Protocols. SIP is a signaling protocol, which is widely used for controlling multimedia communication sessions such as voice and video calls over IP. It supports terminal mobility when a mobile node (MN) moves to a different location before a session establishment or during the middle of a session. Before the REINVITE signaling of SIP, the correspondent node (CN) can send data to the MN prior to the registration of MIP. However, even though working with MIP, SIP still needs a *new care of address* (NCoA) whose configuration spends more time.

IEEE 802.21, a.k.a., Media-Independent Handover (MIH), is designed to optimize the handover between heterogeneous networks so that the continuity of transparent services comes true. The MIH consists of a signaling framework and the triggers that make available information from the lower layers (MAC and PHY) to the higher layers of the protocol stack (network layer to application layer). Furthermore, MIH is responsible for unifying a variety of L2-specific technology information used by the handover decision algorithms so that the upper layers can abstract the heterogeneity that belongs to different technologies.

The core idea of MIH is the introduction of a new functional module—Media Independent Handover Function (MIHF), which operates as a glue of L2 and L3 (see Figure 1). MIHF accesses various MAC layers in heterogeneous networks, controls them through different service access points (MIH_LINK_SAP), and provides to up-layer users a media independent service access point (MIH_SAP), such as FMIP, SIP. It is accomplished through three services: media-independent event service (MIES), media independent information service (MIIS), and media-independent command service (MICS).

In MIES, the MIH user can be notified a certain event by the local or remote MIHF. The MIH events are made available to upper layers through the MIH_SAP, such as MIH_Link_Up (the L2 connection is established, and the link is available for the user), MIH_Link_Going_Down (the loss of the L2 connection is imminent), and MIH_Link_Down (the L2 connection is lost). The MIIS is a function for MIHF which discovers the information of available neighboring networks to facilitate the network selection and handover. It provides mostly static information. The MICS gathers the information on the status of connected links and the connectivity decision to the lower layers by offering commands to upper layers (e.g., scanning available networks). Therefore, the MICS commands control, manage, and send actions to lower layers, and can be issued by both local and remote MIH users. There is an IETF workgroup-MIPSHOP, which addresses an L3 transport mechanism for the reliable delivery of MIH messages between different access networks.

MIPv6 was designed to enable MNs to maintain connectivity when they move from one network to another. However, the latency caused by the MIPv6 operation is unacceptable for real-time applications. To overcome this problem, fast handovers for the Mobile IP protocol have been proposed by the Mobile IP working group of the IETF, which enables an MN to connect to a new point of attachment more rapidly. Fast Mobile IPv6 (FMIP) applies an unclearly-defined link layer event to triggering the mobile node's beginning handover process while the MN still connects to the previous link. The MN exchanges the RtsolPr/PrRtAdv (Router Solicitation for Proxy Advertisement and Proxy Router Advertisement) message with the previous access router (PAR) to obtain the target access router's MAC, IP addresses, and valid prefix.

By using the retrieved information, the MN formulates a prospective new care of address (NCoA) and sends a fast binding update (FBU) to the PAR. The purpose of the FBU is to authorize the PAR to bind previous care of address (PCoA) to NCoA, so that arriving packets can be tunneled to the new location of the MN. The PAR sends a Handover Initiate (HI) message to carry the NCoA to the NAR which determines whether NCoA is unique on the new link interface or not by duplicate address detection (DAD). The PAR will return the available address in the FBack. After attaching to the new network, the MN sends an unsolicited neighbor advertisement (UNA) immediately, so that the buffered packets at NAR can be forwarded to the MN right away.

The tunnel created between the two routers remains active until the MN completes the binding update with its correspondent node. Note that the buffer packet to NAR can extremely reduce the packet loss but the service will be interrupted between FBU and UNA. If the FMIP is triggered to begin the handover process timely, the handover delay can be reduced a lot, but the protocol is not specific to the trigger method. This problem can be overcome by introducing MIH. The MIH provides intelligence to the link layer such as the link going down triggers to wake up FMIP.

2.2. Related Work. In [10, 11], some schemes of integrating SIP and MIP have been proposed to optimize the mobility management. For achieving the fast handover procedure, cross-layer schemes have been investigated widely. Among them, some use MIH to facilitate handover while others do not. In [12], an integrated mobility scheme is proposed to combine the procedures of FMIP and SIP. But without MIH, the real-time requirement of L2 trigger is still an unresolved problem. The scheme in [13] suggests to combine MIH and SIP, but, even if it claims to make handover before breaking the link, it does not consider the packet loss while the old link quality becomes poor. The schemes in [14, 15] use existing MIH services to optimize the FMIP. MIH is used to reduce the time of discovering Access Router (AR) by using MIIS to retrieve necessary information of neighboring network without using the RtSolPr/PrRtadv messages. Especially in [15], ARs control the data forwarding (to MN) with the subscribed triggers of MIH events (MIH_Link_Up and MIH_Link_Down). However, additional MIHF operations in handover may increase the system signaling load. Without simulation, it is hard to say that these schemes indeed improve the performance of handover. In [16], a mechanism is proposed to combine SIP, FMIP and MIH. However, the work is limited in 802.16 networks, and there is no comparable simulation result either.

2.3. The OSM. In next generation wireless networks, the network infrastructure is heterogeneous and all-IP. There are multiple protocols and functional modules to support the handover (see Figure 1). Note that the conventional approaches for improving the handover performance are combined by SIP and MIH, while our proposed handover approach is a combination of SIP, FMIP and MIH. For comparison, we briefly describe the *original SIP and MIH combined handover mechanism* (OSM), which is a make-beforebreak handover mechanism. The OSM provides the IP mobility between heterogeneous networks as illustrated in the message flow of Figure 2. Recalling that IP mobility is achieved by the REINVITE signaling of SIP, the MN sends the REINVITE signaling to its corresponding node (CN) to reestablish the communicational session with the new IP address. Before the handover process begins, the MN retrieves the prefix of the NAR through the IS in advance. In order to complete handover process before previous link down, the new IP address configuration and the REINVITE signaling of SIP are triggered by MIH's link going down event (LGD) in OSM. After exchange Router Solicitation (RS) and Router Advertisement (RA) signaling, the MN connects to the NAR.

3. Proposed Mechanism

In order to achieve seamless handover for IP multimedia subsystem in heterogeneous networks, we propose the *FMIP-auxiliary SIP and MIH handover mechanism* (FASM), which is based upon the architecture of Figure 1. The idea behind the FASM is to introduce the FMIP to the SIP and MIH combination architecture. In [17], a handover decision module (HDM) was proposed to handle the network management, which decides a handover target network. Through the MIH_SAP interface, the HDM registers with the local MIHF to become an MIH user. When the link layer event happens, the HDM can obtain the event notification from MIHF. Different from [17], our main concern in FASM is on how to use the cross-layer information to achieve a fast handover, rather than how to select a handover target network any more. Therefore, it is assumed that the link layer handover decision is always valid and the HDM takes charge of choosing the target network.

3.1. Handover Process. In FASM, the fast handover process is achieved by the following three main steps. See also Figure 3 which illustrates the signaling process in FASM. In the first step, the LGD (MIH_Link_Going_Down) event is used to trigger the handover action, while the MIIS is used to tackle the issues related to the discoveries of radio access discovery and candidate AR discovery. The second step is started after the HDM chooses out the target network. In the second step, the FMIP operation is triggered by the LUP (MIH_Link_Up) event. The operations of HI, HAck, FBack and UNA signaling are used not only for the MN to configure its NCoA in advance but also for the ARs to buffer the packets that are forwarded to NCoA. After the NAR receives the UNA signaling, it can serve the MN immediately. The third step is the MIP Bind Update operation mixed with SIP, including SIP REREGISTER and SIP REINVITE signaling. In FASM, the SIP proxy server and the MIPv6 home agent (HA) are mixed together as an integrated logical entity which is the SIP Server (SS) in Figure 3.

3.2. Details of Signaling Flows

3.2.1. Event Registration. At the early beginning, the HDM registers an interesting MIH Event (i.e., L2 triggers) to the local MIHF. This task can be done by the MIH_Event_Subscribe.request/response primitives. According to different MIH Event triggers, the HDM will control FMIP and SIP in different ways as follows: LGD will trigger the HDM to turn on the interface to connect the target network; LUP will trigger the HDM to tell the FMIP to send FBU to PAR and begin the other FMIP handover process sequentially; LD (MIH_Link_Up) will tell the HDM that the make-beforebreak handover is over, and the previous interface can be closed.

3.2.2. Retrieval of Neighboring Network Information from the IS. In FASM, the functions of RtSolPr/PrRtAdv messages in the standard FMIP are replaced by the MIH_Get_Information request/response messages, so the RtSolPr/PrRtAdv messages can be deleted in FASM, and thereby the signaling load can be reduced. The MN obtains the network's neighboring information by the MIH_Get_Information request/response messages, and stores the information

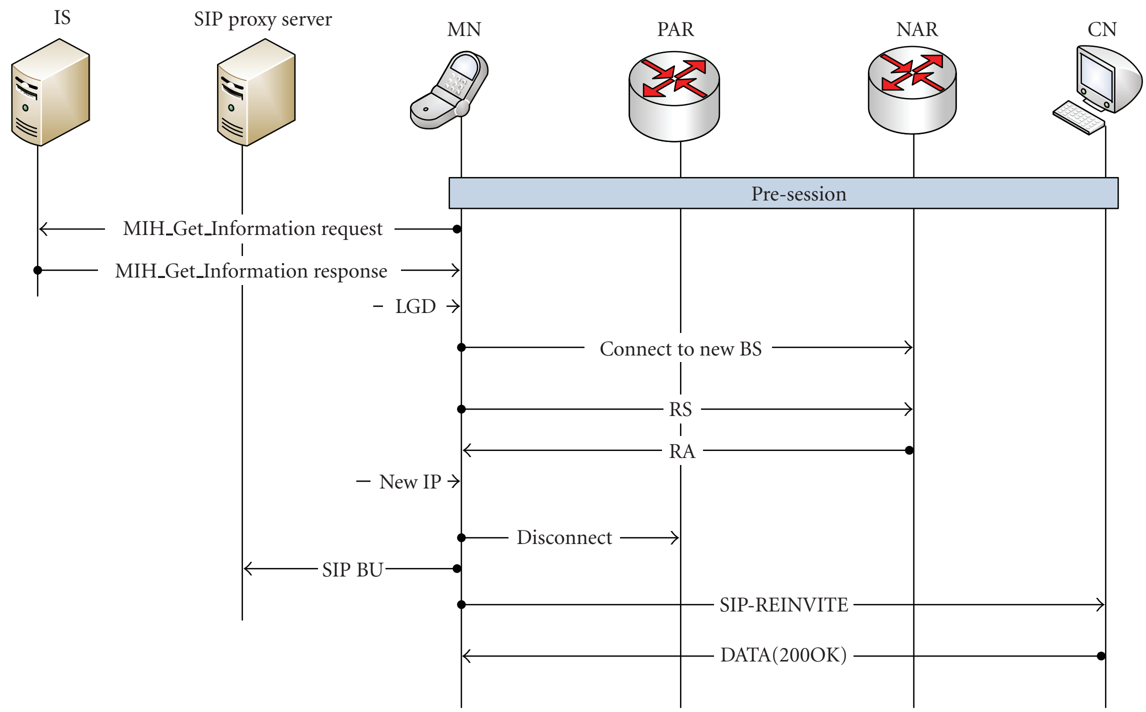

Figure 2: Signaling flows of the OSM.

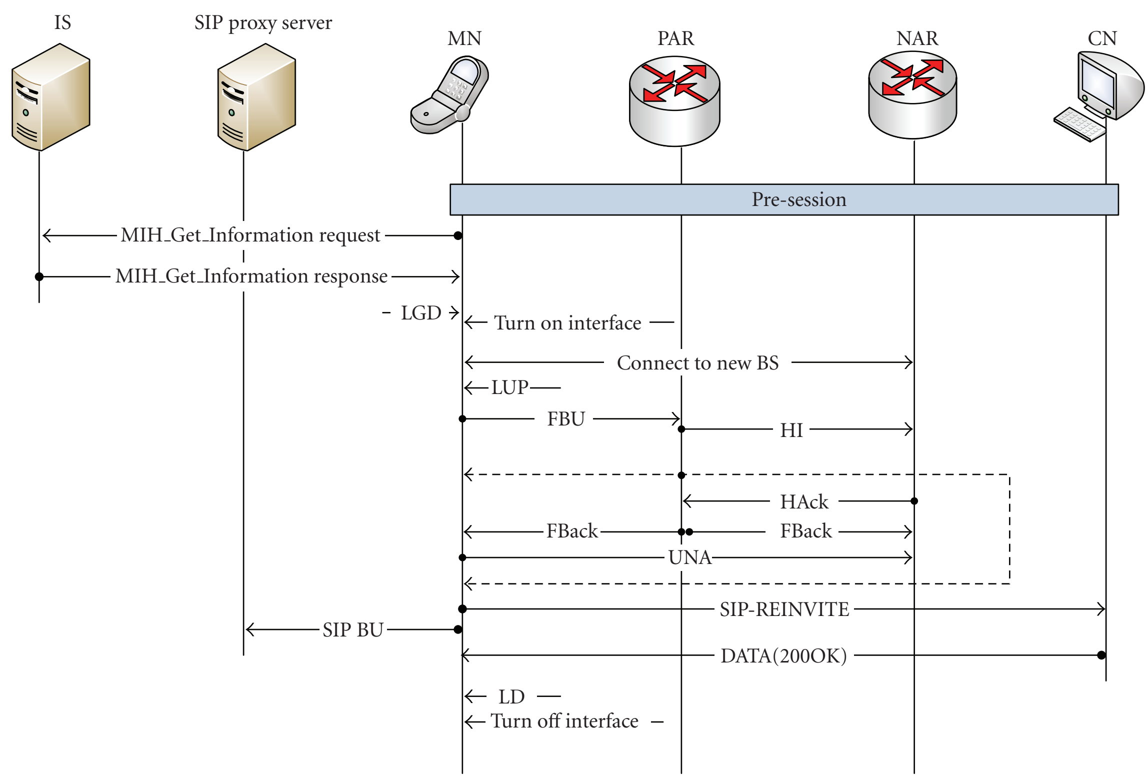

Figure 3: Signaling flows of the FASM. Dotted line depicts buffering and forwarding packets.

about the networks in its cache. The MIH_Get_Information request/response can be done much before the L2 trigger (i.e., MIH_Link_Going_Down), unlike the original FMIP in which the RtSolPr/PrRtAdv only occurs after L2 triggers.

3.2.3. Network Selection and Switching Link. When the signal strength of Base Station (BS) becomes poor, the HDM will be notified that the current connecting link is going down (i.e., LGD event). Then the HDM chooses the target handover network by using the neighboring network information in the MN's cache, and turns on the corresponding interface. Therefore, the MN can connect to the target network rapidly in the L2 layer. After the L2 connection is completed, the HDM is notified by LUP. The target network information stored in the MN's cache will be used to autoconfigure the NCoA. In the FMIP protocol operation, the FBU is sent to the PAR from the prelink. After sending FBU, the MN waits to receive FBack from the prelink. As soon as the MN receives FBack, it sends UNA to the NAR. UNA can be sent successfully because this operation is done after the LUP trigger. After receiving FBU from the MN, the PAR completes the HI/HAck operation to obtain a valid NCoA, and sends it to the MN via FBack. The proposed mechanism implements a bicasting buffering and forwarding policy in which the PAR buffers and forwards the data packet to MN's PCoA and NCoA simultaneously. Note that a cost function approach to the network selection algorithm providing better performance to the multiinterface terminals in the integrated networks can be found in [18].

3.2.4. SIP and MIP Bing Update. After sending UNA to the NAR for announcing its existence, the MN, as an SIP user client, will continue the handover procedure by sending an SIP REINVITE message to the CN. The REINVITE message carries the updated SDP (Session Description Protocol) parameters to the CN. As a result, call parameters are renegotiated on an end-to-end basis. Meanwhile, SIP BU is sent to the MN's SIP server to update the relation between URI and CoA (care of address) as well as the binding of CoA and HA.

3.3. Mechanism Analysis. In OSM, during LGD and 200OK signaling, the link quality of prelink is too poor to receive the packets (see Figure 4). Assume that the probability distribution of data packet loss is $P(x)$, where x is the ratio of the receiving signal power to the BS's sending power of the prelink. During LGD to 200OK, the data packet loss is L_{loss}, which can be determined as follows:

$$L_{\text{loss}} = \int_{R_{\text{lgd}}}^{R_{\text{200OK}}} P(x)dx, \quad (1)$$

where R_{200OK} is the ratio when the MN receives the 200OK signaling, and R_{lgd} is the ratio when the MN receives the LGD event.

The above weakness can be overcome by our proposed mechanism (see Figure 5). During FBU and 200OK, the data packets arrived will be buffered and forwarded to both the MN and the NAR simultaneously, and thus the data packet

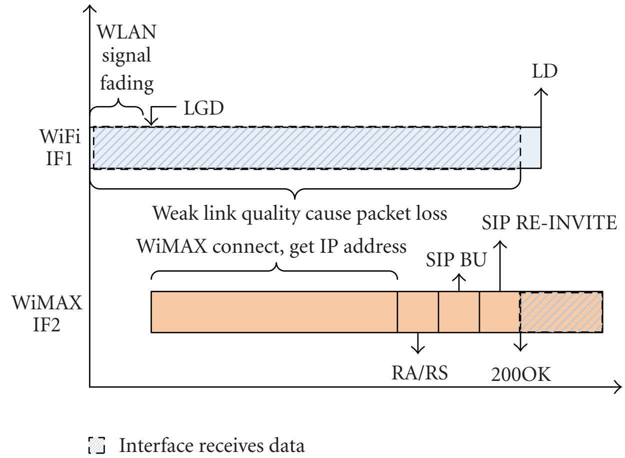

Figure 4: Network switching in OSM.

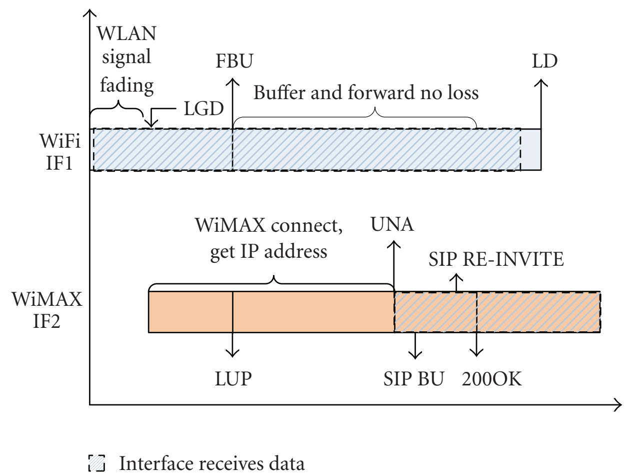

Figure 5: Network switching in FASM.

loss L_{loss} is reduced. When the data packets are bicasted, the MN may receive some packets twice. But the duplicate packets can be handled by the higher layer, for example, the duplicate packets can be found out by a sequence number of the RTP in the higher layer. As soon as the PAR receives FBU, it sends HI to the target NAR specified in the FBU. The NAR does the DAD for the NCoA autoconfigured by the MN, and sends the available address to the PAR. The PAR delivers the available NCoA to the MN in the FBack signal. Therefore, in comparison to the OSM scheme, the probability of successfully using NCoA is improved.

In Figure 3, as soon as the MN receives the FBack, it sends UNA to the NAR for announcing its existence in the new network. This operation makes the network accessing in the FASM faster than the MIPv6's RA and RS mechanism which is used in the OSM. Note that the SIP REINVITE will be sent from new-link, so, if the L3 connection time is decreased by the UNA signaling, the total handover latency will be reduced. The NAR also sends the buffered data packet to the MN as soon as it receives the UNA. The service interruption time is the latency when the MN receives the last packet

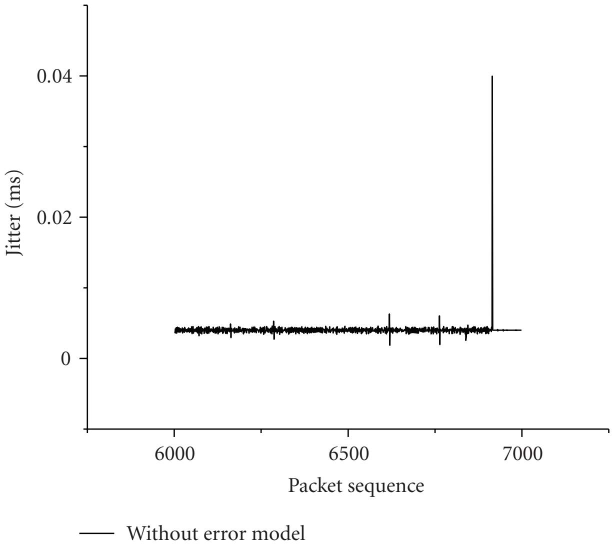

Figure 6: Jitter without error model.

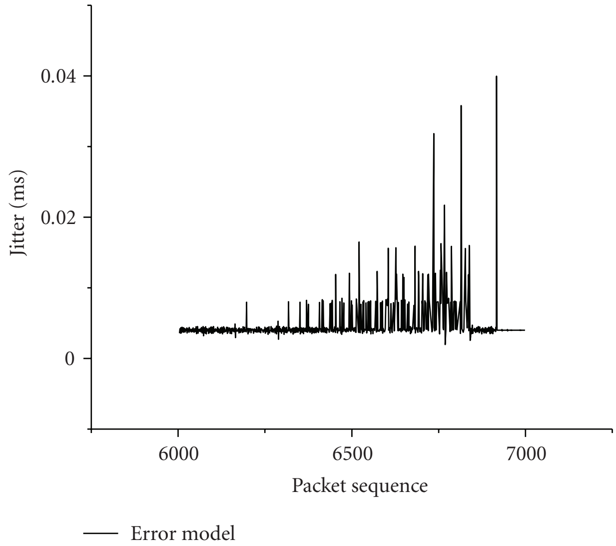

Figure 7: Jitter with error model.

from the old link to the first packet from the new link. As compared with the RA/RS mechanism, the MN can receive data packets earlier in the FASM, so the service interruption time can be reduced as shown in Figure 5.

4. Simulation

4.1. Simulation Design. The NIST seamless and secure mobility software module is used in the NS-2.29 simulator. Note that the NIST software module can support the vertical handover as well as the MIH protocol, but not SIP and FMIP. Hence, the SIP and FMIP modules are implemented in our simulator based on the NIST software module as well as the NIST WiMAX module. For evaluating the performance, we focus on the data packet loss and the service interruption time from CN to MN when the MN hands over between 802.11 and 802.16 networks.

An error model is applied in the simulation, which expresses a relationship of the data packet loss and link quality. The impact of the error model can be observed in FASM in Figures 6 and 7, in which the handover occurs when the time of the MN's receiving the RTP packet sequence is 6000 to 7000, and the jitter means the time interval of successive received packets. Therefore, if there is no error model, there is still no packet loss when the quality of the previous link is poor. On the contrary, the simulation result with the error model added reveals the relationship of the packet loss and the link quality more practically. A larger packet sequence would lead to poorer previous link quality, and greater jitter would lead to more packet loss. The result in Figure 7 has something to cope with the packet loss probability distribution $P(x)$ which is designed for the simulation program.

The simulation topology is illustrated in Figure 8. To evaluate our proposed mechanism, we set up a 2000×2000 simulation area with a WiMAX BS and a WiFi BS. The WiMAX BS has a power radius of 1000 m which covers the WiFi BS that has a power radius of 50 m partly (see Figure 8). The CN connects to the backbone with 100 Mbps data transmission rate. The WiMAX BS and the WiFi BS connect to the backbone also with 100 Mbps. The IS and the SIP proxy servers connect to the backbone with a 10 Mbps data transmission rate. Except that the link delay between BSs and the RT router is 15 ms, the other links' delay is 30 ms. The MN is initialized in the 802.11 BS and moves to the 802.16 BS area in random at the beginning of the simulation. A RTP application data flow is built between CN and MN, and starts at 5 s and ends at 40 s with a rate of 1 Mbps.

Some other parameters also affect the simulation results, such as t21_timeout, which has an effect on the WiMAX L2 handover latency and the maxRADelay that impacts the RA/RS delay. Nevertheless, the aim of our simulation is to evaluate the difference between the FASM and the OSM. Therefore, the simulation program is carried out under the same parameters in FASM and OSM.

4.2. Simulation Results. To evaluate our proposed mechanism, the vertical handover processes of FASM and OSM are simulated, respectively. The simulation results focus on the aspects of the received packet jitter, the data packet loss, the service interruption time, as well as buffer size.

4.2.1. Jitter. In the simulation, the jitter indicates the time interval of two successive packets. As shown in Figure 9, a large jitter is caused by a large packet loss. The FASM scheme shows a remarkable improvement of performance in jitter, as compared to the OSM scheme (see Figures 9 and 10). The improvement is attributed to the FMIP buffering and forwarding mechanism. When the previous link quality is poor, the LGD trigger comes out indicting the beginning of the handover process. Then, the PAR receives FBU and forwards packets to the MN's NCoA in FASM. When the NAR receives UNA, it begins to forward packets to the MN.

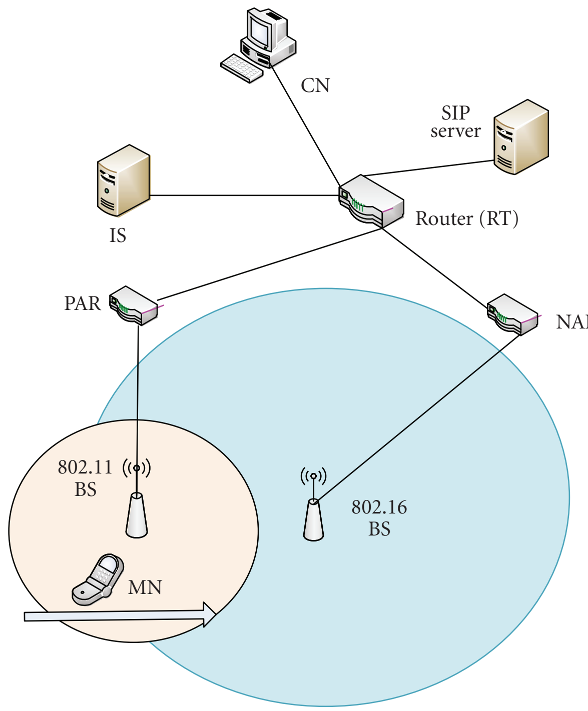

Figure 8: The simulation network model.

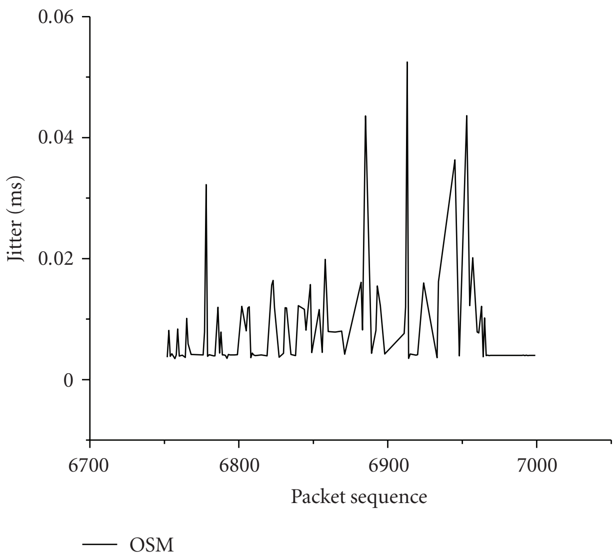

Figure 9: Jitter in OSM with error model.

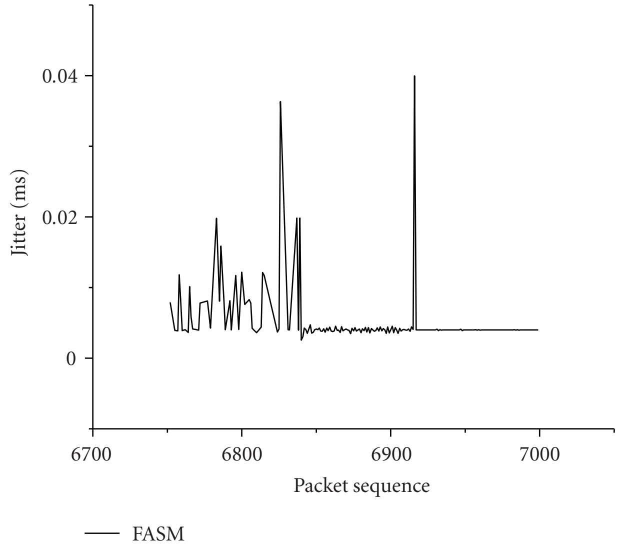

Figure 10: Jitter in FASM with error model.

The MN begins to receive packets when the packet sequence number is 6840. In comparison, in the OSM scheme the MN receives the packets from the PAR until the SIP 200OK is received. Hence, some packets are lost, and the jitter is larger than that of the FASM scheme. The large jitter between 6900 and 7000 in Figure 10 is caused by the SIP REINVITE signaling.

4.2.2. Packet Loss. In Figure 11, the Pr is the ratio of the MN's receiving power of LGD to that of LD which indicates the time interval between LGD and LD. A larger ratio also implies better link quality. Smaller Pr leads to a larger packet loss, because smaller Pr implies that the handover process will begin under poorer link quality and there might be not enough time to complete the FMIP signaling in prelink. While the Pr is greater than or equal to 1.45, the data packet losses of OSM and FASM are almost same. This is because the handover begins when the prelink quality is so good that no packets will be lost. In Figure 11, the data packet loss is reduced from 110 to 41 when Pr is 1.25.

Figure 12 shows the effect of different RTP data rates on the data packet loss. The RTP data rate is varied from 0.1 Mbps to 3 Mbps. With an increasing RTP data rate, both OSM and FASM suffer an increasing packet loss. However, the OSM experiences more severe packet loss than the FASM, because the FASM employs the FMIP for reducing the packet loss when the handover begins. Figure 13 shows the influence of the movement speed of the MN on the data packet loss. The MN's speed is varied from 1 m/s to 20 m/s. The OSM scheme is severely affected by the increase in speed, whereas the FASM scheme suffers a relatively small change. When increasing the movement speed of the MN, the quality of the link becomes poor more quickly (see also Figure 13, in which the packet loss is increased from 48 to 141 in the OSM scheme). In FASM, the average packet loss is 10. This result is also attributed to the FMIP's buffer function. When the packet is buffered by the NAR, no matter how the movement speed is modified, packets will ultimately be forward to the MN, and thus the packet loss is avoided.

4.2.3. Service Interruption Time. The influence of the Pr on the handover service interruption time is investigated as follows. The Pr is varied from 1.05 to 1.5. Both FASM and OSM are severely affected by the increase in Pr. Smaller Pr leads to larger service interruption time, because smaller Pr implies that the handover process will begin under poorer

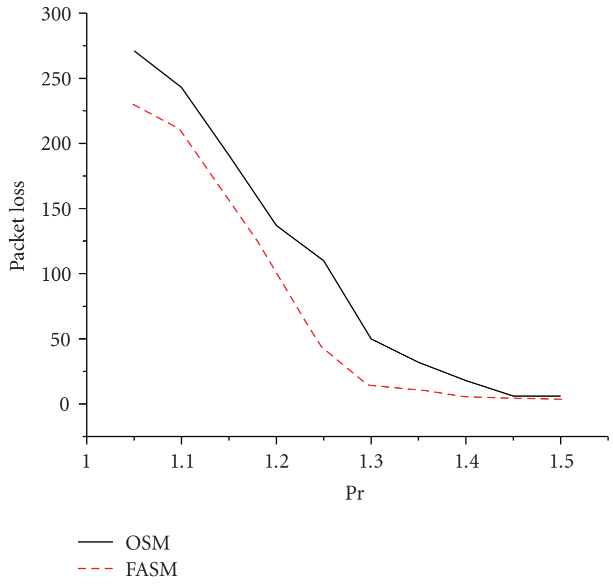

Figure 11: Packet loss versus Pr.

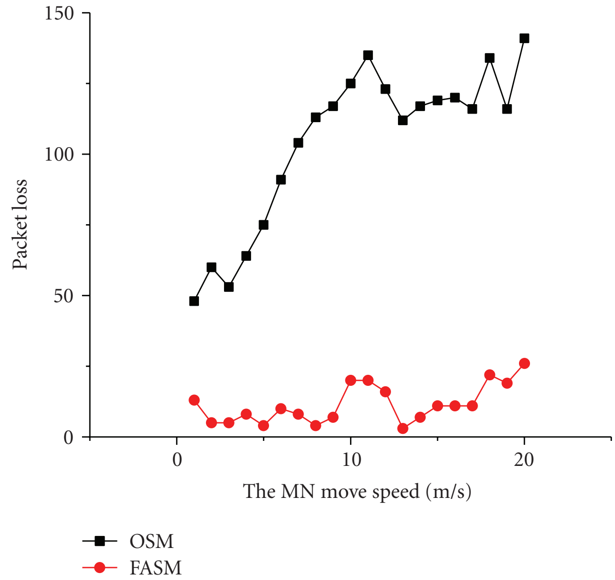

Figure 13: Packet loss versus moving speed of the MN.

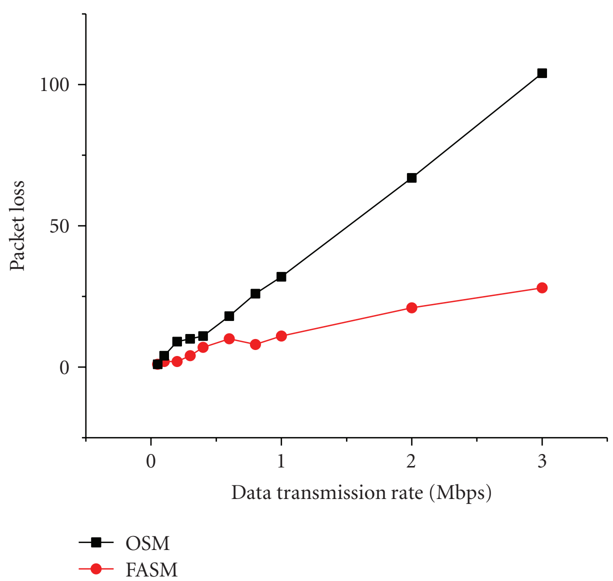

Figure 12: Packet loss versus data transmission rate of the CN.

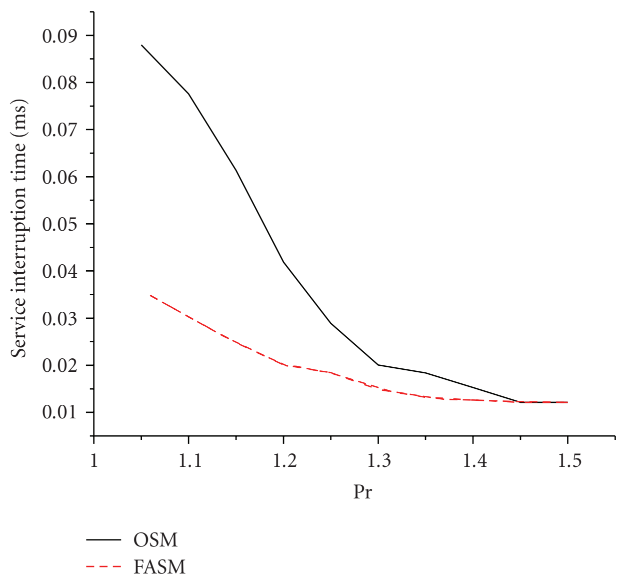

Figure 14: Service interruption time versus Pr.

link quality and there might be not enough time to complete the FMIP signaling in prelink. While the Pr is greater than or equal to 1.45, the service interruption time of OSM and FASM is almost same. This is because the handover begins when the prelink quality is very good. In Figure 14, the service interruption time is reduced from 77 ms to 30 ms when Pr is 1.1. It is obvious that the FASM reduces the service interruption time almost half than the OSM when Pr is smaller than 1.4. The FASM benefits from the FMIP's UNA signaling so that the MN can connect to NAR more quickly. Although the Pr is 1.05, the service interruption time is still less than 100 ms. The phenomenon is caused by not only the make-beforebreak handover mechanism but also by the imperfect of the simulation in NS2.

4.2.4. Buffer Size. The NAR buffers the packets forwarded to NCoA before the MN gets connected to the NAR. The tunnel between PAR and NAR will exist until the MN reinvites CN to send packets to NCoA. The buffer size of the NAR needs to be concerned. Figure 15 shows the relationship of the RTP data rate and the NAR's buffer size. When the RTP data rate is increased, the NAR needs to buffer more packets.

5. Conclusion

In this paper, an integrated handover mechanism, called FASM, combined with SIP, FMIP and MIH protocols in IMS (IP Multimedia Subsystem), has been proposed to achieve the seamless handover in heterogeneous networks.

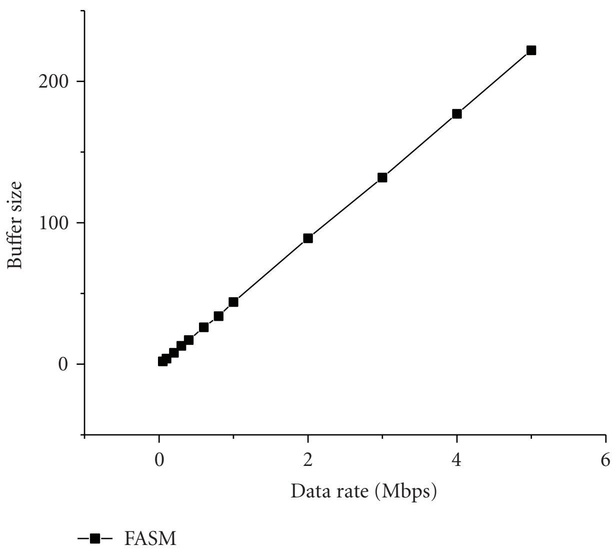

Figure 15: Relationship between the RTP data rate and the NAR's buffer size.

In this scheme, FMIP is introduced into the SIP and MIH combination architecture. By using FMIP, the NCoA can be obtained in advance, and data packets are buffered and forwarded to both NCoA and PCoA while the previous link quality is poor. Hence, our scheme can significantly reduce data packet loss as well as service interruption time. Moreover, our simulation results obtained by the NS2 simulator show that the proposed FASM has better handover performance than OSM, for example, the service interruption time is reduced by about 50 percent when the ratio of the receiving power of LGD to that of LD is 1.1. The proposed mechanism has the ability to achieve the handover of "seamless end-to-end services" in heterogeneous networks.

Abbreviations

BS: Base station
DAD: Duplicate address detection
FASM: FMIP-auxiliary SIP and MIH handover mechanism
FBU: Fast binding update
FMIP: Fast mobile IPv6 protocol
HDM: Handover decision module
IMS: IP multimedia subsystem
IS: Information server
LD: Link down event
LGD: link going down event
LUP: Link up event
MIH: Media independent handover
MIIS: Media independent information service
NAR: New access router
NCoA: New care of address
OSM: Original SIP and MIH combined handover mechanism
RA: Router advertisement
PAR: Previous access router
PCoA: Previous care of address
RTP: Real-time transport protocol
RS: Router solicitation
SIP: Session initiation protocol
UNA: Unsolicited neighbor advertisement
URI: Uniform resource identifier.

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