國立交通大學

網路工程研究所

碩 士 論 文

一個在 IEEE 802.16j 行動式中繼站模式上

基於網路的快速行動交遞機制

A Network-based Fast Handover design over IEEE 802.16j

Mobile RS mode

研 究 生：姚祺昉

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中 華 民 國 一〇〇 年 七 月

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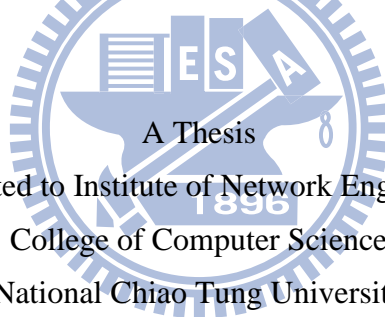Mode

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摘要

近年來無線網路之技術快速的發展，其中之一便是 IEEE 802.16 (WiMAX)。在此類無線寬頻系統如此迅速的發展之下，如何在行動 all-IP 網路服務中達成無接縫的交遞(基地台交換)顯得非常重要。現今的網路 IP 層交遞機制可分為兩種範疇，其一為基於行動裝置的機制，例如 Mobile IPv6 (MIPv6)；其二為基於網路的機制，例如 Proxy Mobile IPv6 (PMIPv6)。其中 PMIPv6 擁有較 MIPv6 更優良的表現，並很有希望是下一世代行動 all-IP 網路服務的選擇。然而，在 IEEE 802.16j 行動式中繼站模式之上，PMIPv6 並無法避免封包遺失以及較長的服務中斷時間。因此在這篇論文中，我們提出了一個在 IEEE 802.16j 行動式中繼站模式之上，基於網路的、並且跨網路分層的行動交遞機制。由於使用新提出的控制訊息還有通道路由器的緩衝暫存功能，所提出的機制可以讓資料聯結層與網路 IP 層的交遞同時進行，並且避免封包的遺失。最後，數學分析與模擬的結果顯示出本機制在效能表現上有顯著的提升。

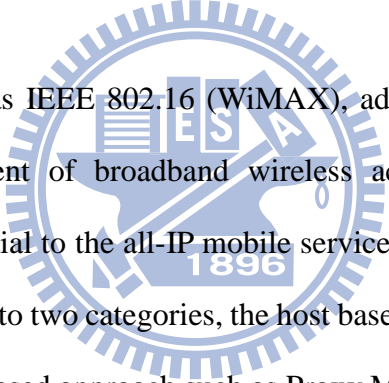A Network-based Fast Handover Scheme over IEEE 802.16j Mobile RS Mode

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Abstract

Wireless technology, such as IEEE 802.16 (WiMAX), advances quickly in recent years. With the rapid development of broadband wireless access system, how to achieve seamless handover is essential to the all-IP mobile services. Nowadays IP layer handover schemes can be classified into two categories, the host based approach such as Mobile IPv6 (MIPv6), and the network-based approach such as Proxy Mobile IPv6 (PMIPv6). PMIPv6 outperforms MIPv6 and is a promising option for next-generation all-IP mobile networks. However, PMIPv6 may not prevent packet loss and long service disruption time (SDT) problems in IEEE 802.16j mobile relay station (MRS) mode. In this thesis, a network-based cross-layering handover mechanism was proposed for IEEE 802.16j MRS mode. With the newly introduced control message and buffering mechanism in Access Router, the Data-Link layer and IP layer handover are processed concurrently and packet loss is prevented. Finally, both numerical analysis and simulation results show remarkable improvement of performance.

誌謝

　　隨著這篇論文的完成，我的學生生涯也接近尾聲。在交通大學資訊工程學系大學部四年、網路工程研究所碩士班兩年，交大給予我的專業訓練濃縮成精華展現於這篇論文中。這六年來，有歡笑、有淚水，有失落、有得著，點點滴滴的往事也隨著這篇論文幻化成回憶，當然，更有說不盡的感謝。

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　　接下來我要感謝本多媒體通訊實驗室裡最尊敬也最優秀的學長姐們，博班的施振華學長、林冠宇學長、郭俊利學長、許育嘉學長，碩班的林振全學長、黃紀寰學長、周吟珊學姐、章瑋芸學姐、簡嘉瑋學長，你們在研究領域中的卓越表現與指導永遠是我的楷模。尤其是施振華學長對本論文的直接指導，您不厭其煩的提點讓我沒齒難忘。還有同學們王銘慶、陳閔煌、王博謙，我們互相扶持砥礪，切磋學業，是我學生生涯中充實進步的時刻。雖然只有短短兩年的緣份相處，相信我們都能是一輩子的好朋友、好夥伴。

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中華民國一○○年八月

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Chapter 1 Introduction

Broadband Wireless Metropolitan Area networks, such as the IEEE 802.16 standards (Worldwide Interoperability for Microwave Access, WiMAX) [1], are developing very rapidly in recent years. The standards aim to provide low-cost, high bandwidth and scalable solution for multimedia services from backbone networks to wireless users. Moreover, it has potential to provide portable mobile broadband connectivity across cities and country sides through a variety of devices. In order to support connectivity in such large area, portability and mobility have become major issues in IEEE 802.16. And when it comes to mobility, the process of handover plays an important role to provide continuous service.

1.1 IEEE 802.16e and 802.16j standards

IEEE 802.16e is a significant milestone in the developing history of WiMAX. In PHY (physical layer), the IEEE 802.16e uses scalable Orthogonal Frequency Division Multiplexing (OFDMA) to carry data supporting bandwidth between 1.25MHz and 20MHz. Other features include using Adaptive Antenna System (AAS), Multiple Input Multiple Output (MIMO), Multicast and Broadcast service (MBS), and allocating specific Quality of service (QoS) class to each connection. In addition, terminal is allowed to move while receiving wireless traffic and so that the terminals can maintain the same IP sessions during Data-link layer handover. Therefore the IEEE 802.16e, which is published in December 2005, is the first one to add mobility support to the original WiMAX standard [2].

In June 2009, IEEE 802.16j was published as an amendment by Relay Task group [3].

One of the main features of 802.16j is multi-hop relay which is added into the network structure to enhance the function of 802.16e. By deploying the new equipment, which is called Relay Station (RS), the coverage of Base Station (BS) can be extended and capacity of a specific area can be increased. And at the same time, there is no need to modify the end user equipment in 802.16e [4][5]. The new standard solved some problems in the older one, for example: the limitation of BSs deployment, high cost of backbone networks, and lack of network infrastructure in newly developed area.

There are two main types of RS: fixed and mobile (FRS and MRS). The FRS is permanently installed at the same place whereas the MRS is usually implemented into moving vehicles, such as bus, train, etc. The main functions of FRS provide additional capacity to areas and extend coverage at cell edge, indoor users, and coverage holes in which the signal from BS is blocked by buildings. Also, the FRS can provide access for clusters of users outside the BS's coverage area, without directly construct a new BS for those users. On the other hand, the MRS provides its functions in two modes, the moving BS mode and the moving RS mode.

In moving BS mode, the MRS behaves like a small BS with the IP layer functionality and thus it can assign IP addresses and connection identifiers (CID) to end terminals connected to it. However, the MRS should be modified and cost more hardware enhancement in moving BS mode because it must provide both layer 2 and IP layer handover functions. As a matter of fact, the IEEE 802.16j would basically perform the other mode described below. In moving RS mode, when the MRS is placed on a vehicle, it is connected to BS via mobile link, and it provides a coverage area for all end terminals riding on the vehicle as a fixed access link. In addition to the main two types of RS, there are another one called Nomadic RS (NRS), which work as a temporary RS to extent coverage and capacity in areas which need emergency signal enhancement [6]. Different

kinds of RS and their functions are shown in Figure 1.1.
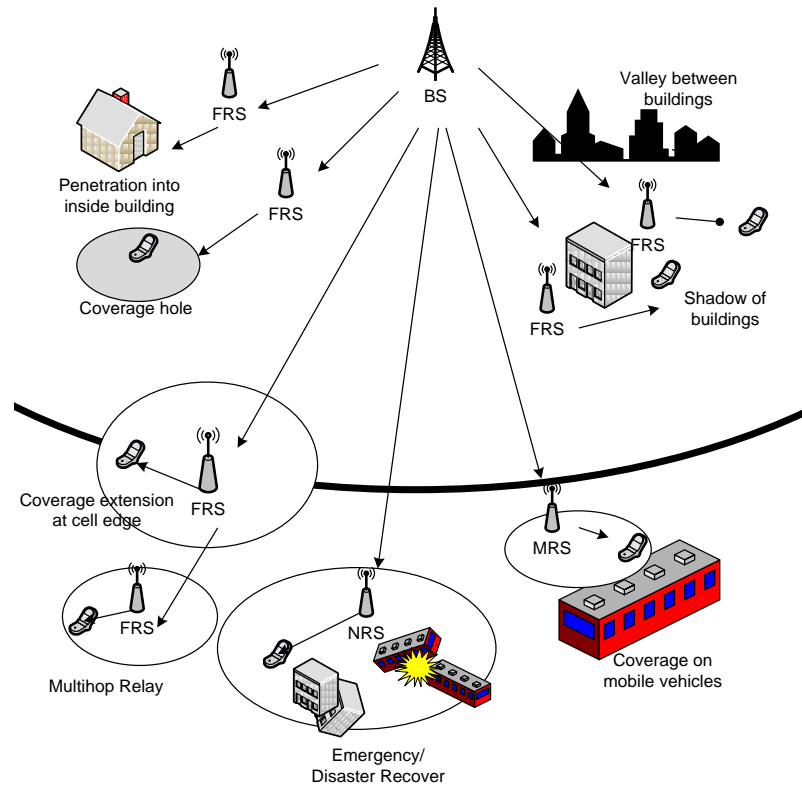
Figure 1.1   Three types of relay stations

1.2 Mobile IPv6 and Proxy Mobile IPv6

Mobile IP (MIP) is a standard published by Internet Engineering Task Force (IETF) [7] which defines a communication protocol that allow a mobile node (MN, or Mobile Station, MS) to retain its home address on moving from network to another. While MS uses MIP moving between networks, there is no need to modify the intermediate routing nodes.

In MIP, each MS has two network addresses – the permanent home address (HoA) and the Care-of-Address (CoA), which is calculated and reassigned while MS travels to another network. In MS's home network, the Home Agent (HA) is responsible for keeping the information about MS's permanent address. The HA also keeps being aware of which MNs are under the home network, and which MNs are visiting a foreign network.

Normally when MS is under the home network, a node wanting to communicate with the MS, which is called Correspondent Node (CN), uses the permanent address of MS as the destination address in IP datagram to send packets to the MS. When MS travels to a foreign network, it tries to connect to internet through the local router, which is called access router (AR), and generally AR also works as Foreign Agent (FA). The AR advertises the address every time an MS moves into its network. And then the AR would assign a newly calculated CoA to MS. And afterwards, the MS would register this CoA information to the MS's HA and CN. Now the packets from CN to MS are still routed by standard IP routing mechanisms, so the packets are forwarded to the HA. The HA would establish an IP tunnel to AR according to MS's registered CoA, and redirect the packets through this tunnel. While sending packets back to CN, the MS directly passes packets back to CN through the AR without sending them through the HA [8]. The two direction have different routing is called triangular routing, and it may causes lower efficiency. Figure 1.2 shows an overview of MIP.
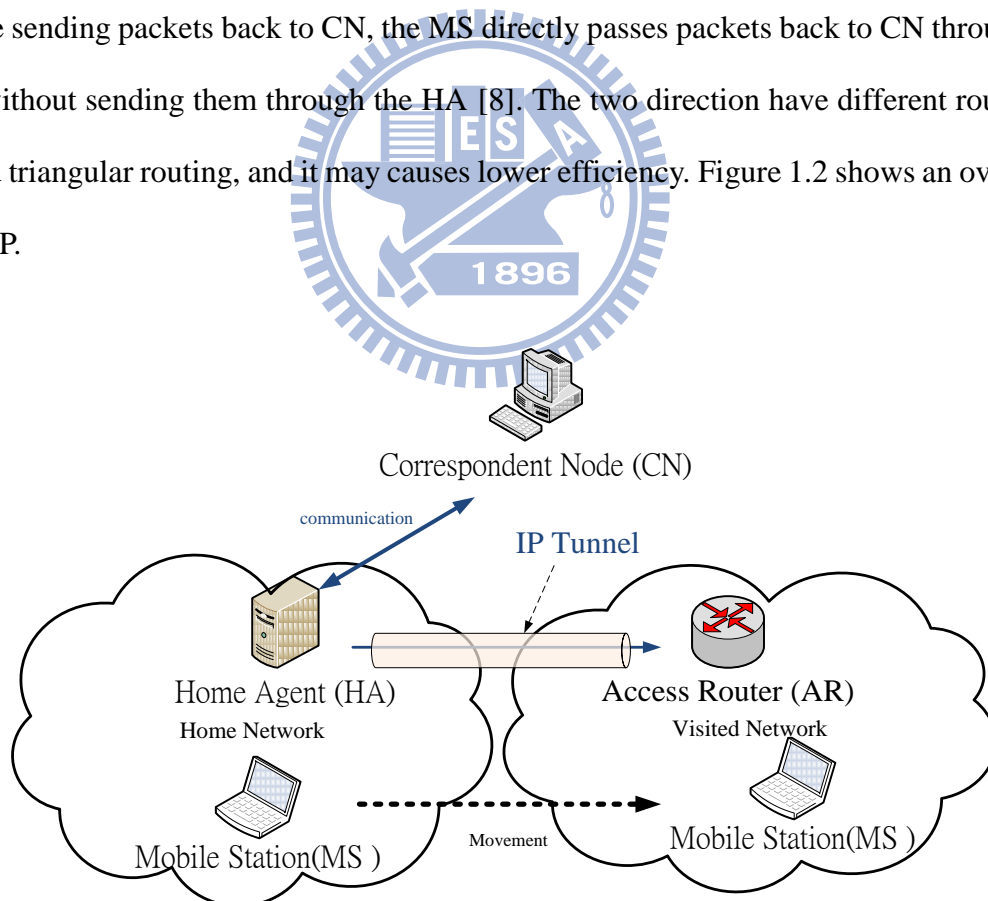
Figure 1.2   Overview of Mobile IP

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Mobile IPv6 (MIPv6) is an enhancement of Mobile IPv4 and is developed to improve mobile communications in some circumstances. MIPv6 uses various methods to solve many problems in MIPv4, for example, the triangular routing, weaker security, and the limitation of address space [9]. There are some optimization steps which are triggered by the MS to improve the routing efficiency. In the route optimization process, after the MS switches to AR's subnet, it registers this binding to the CN. By finishing this process, the CN can directly send packets to MS, instead of sending packets through HA continuously [10].

Although MIPv6 provide better solution than MIPv4, there still remain some problems, such as packet loss, handover latency, and signaling overhead. Furthermore, handover latency would seriously affect QoS but MIP does not offer any guarantee to it. As a result, another standard mentioned in following paragraph is developed to improve the performance of MIPv6.

Proxy Mobile IPv6 (PMIPv6, or PMIP) is designed as a network-based IP mobility management protocol and is also published by IETF. Just as MIP, PMIPv6 has the same mobile functions and there is no need to modify the host's TCP/IP protocol stack. The main difference between them is that with PMIPv6, the MS can travel to another point-of-attachment (PoA) to the internet without MS participated in any mobility-related signaling. Unlike the MIP, the function that allows the MS to maintain the same IP address in different networks is implemented by the network but not triggered by MS. Therefore it is not necessary to modify MS's mobility functions (It seems like remain in the same network on MS's point of view) [11]. Other benefits of PMIPv6 include supporting both IPv4/IPv6, making better use of wireless resources, and improving handover performance [12].

In PMIPv6, there are two main network devices involved in the mobility

management − Local Mobility Anchor (LMA) and the Mobile Access Gateway (MAG). The LMA is similar to HA in MIP, and it maintains the MS's address is reachable while MS moves around within a PMIPv6 domain. The LMA also includes a binding cache entry for each currently registered MS, which stores more information than those in MIPv6's HA. The additional information includes MS-Identifier, the MS's home network prefix, a flag indicating a proxy registration, and the interface identifier of the bi-directional tunnel between the LMA and MAG. On the other hand, the MAG which usually runs on an AR, detects the movement of MNs and takes charge of managing mobility related signaling for MNs attached to MAG's access link. In this thesis, when it comes to PMIPv6, we use the term AR to represent the MAG, and HA to represent LMA, so that we can unify the equipments' names in different protocols.

The following is how PMIPv6 works (Figure 1.3). When a MS attaches to certain MAG, the MAG first performs the authentication procedure and obtains the profile of the MS. Then the MAG sends a proxy binding update (PBU) message include the MS-Identifier to the MS's LMA on behalf of the MS. Once the LMA receives the PBU message, it allocates an appropriate home network prefix for the MS and encapsulates this prefix into proxy binding acknowledgment (PBA) message, and sends PBA back to MAG. Now the LMA and MAG have enough information and create a bi-directional tunnel for enabling the MS to use an address from its home network prefix and the MAG emulates the MS's home network on the access network for the MS. After the bi-directional tunnel is successfully established, all traffic sent by the MS would be routed to its LMA through the tunnel. And packets from CN to MS would send to the LMA in advance, and then the LMA forwards them to the MAG through the tunnel. Finally, the MAG removes the outer header of the packets and forwards them to the MS.
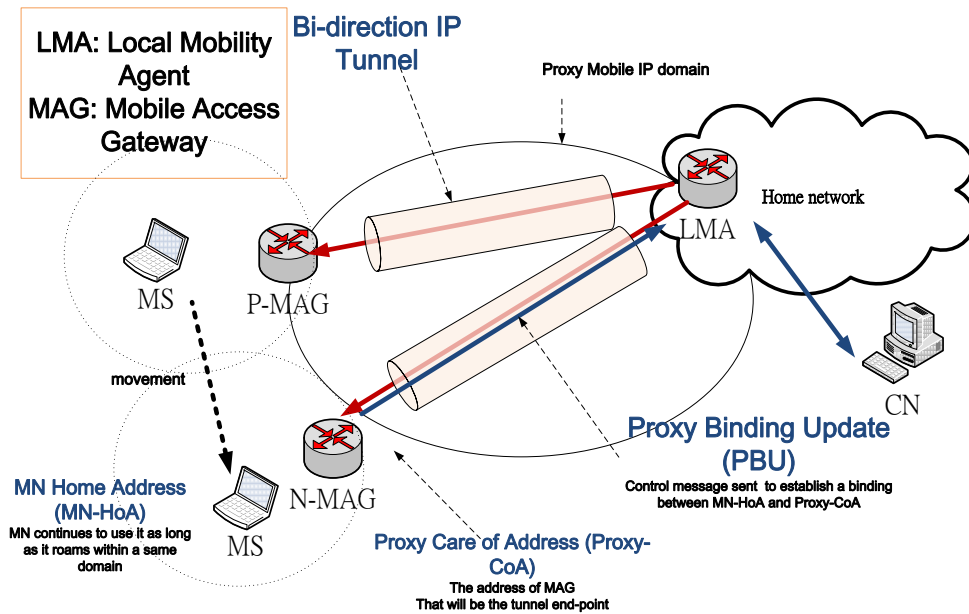
Figure 1.3   Overview of PMIPv6.

1.3 Motivation and purpose

From the above description, we can see that IEEE 802.16j is one of the latest WiMAX standards, which provides good coverage extension with low cost. In this standard, the MRS with moving RS mode is an efficient method to provide internet access for passengers aboard. IEEE 802.16j defined the handover procedures in Data-Link layer (MAC layer, or layer 2); however, when IEEE 802.16j combines the mobile mechanisms in network layer (IP layer, or layer 3) there are still some problems to be solved, including packet loss and long service disruption time (SDT). In many real time applications such as video streaming and VoIP (Voice over IP), these problems may seriously affect the performance and user's experience. As a result, achieving seamless handover in IEEE 802.16j with MRS mode has become the main purpose of this thesis.

The two main IP layer handover schemes mentioned above can be classified into two categories. One, MIPv6 belongs to the host based approach, which requires modification to the protocol stack of the mobile node MS. And the other one, PMIPv6 belongs to the

network-based approach, in which the serving network controls IP mobility management on behalf of the MS. Although PMIPv6 outperforms MIPv6 in the aspects of deployment, performance, and management of network service provider [13], problems of packet loss and long SDT still occurs. Thus, several works [14] [15] proposed the cross-layer based scheme to improve SDT and packet loss. However, enhanced schemes for PMIPv6 can't be applied in IEEE 802.16j MRS mode because the layer 2 handover procedures in MRS mode are different from common situation. In common situation, MS performs layer 2 handover procedures whereas MRS performs layer 2 handover procedures in MRS mode since the MNs under the MRS still attach to it when MRS migrates from one BS to another one. The enhanced schemes for PMIPv6 assume that the layer 2 and IP layer handover are performed by MS and new access router (NAR), respectively, and then lead layer 2 in MS and IP layer in NAR to cooperate and result in reduced SDT. Hence these schemes can't be applied and only the MIPv6 or PMIPv6 schemes can be used in MRS mode.

In this thesis, in order to achieve seamless mobility for MS in IEEE 802.16j MRS mode, we proposed a network-based cross-layering handover scheme to solve the packet loss problem and to reduce the SDT. There are several new control messages proposed and defined in chapter 3, and by exchanging these messages, the layer 2 handover in MRS can cooperate with the IP layer handover in NAR. The rest of this thesis is organized as follows. In chapter 2, the layer 2 handover procedure of IEEE 802.16j, and the handover procedures of MIPv6/PMIPv6 with IEEE802.16j are described. In chapter 3, the definition of new messages and the proposed handover procedure are described. In chapter 4, we analyze the proposed scheme. Then in chapter 5, the simulation results show how much progress in packet loss and reduced SDT by our method. Finally chapter 6 concludes this thesis.

Chapter 2 Related Work

In this chapter, the Data-link layer (layer 2) handover procedures defined in IEEE 802.16j standard will be described first. And then we will present the handover procedures in Mobile IPv6 and Proxy Mobile IPv6, and show how the two IP layer mobile mechanisms cooperate with IEEE 802.16j.

2.1 IEEE802.16j MRS Handover

IEEE 802.16j defines the MS handover process in layer 2. The MS/MRS keeps aware of the information of neighbor BSs while moving. A handover occurs when MS/MRS needs to change the BS to higher signal quality or higher QoS. The whole procedure of MRS handover can be divided into three phases: Handover preparation, Handover decision and initiation, and Handover execution [4]. Figure 2.1 shows an overview of MRS layer 2 handover.
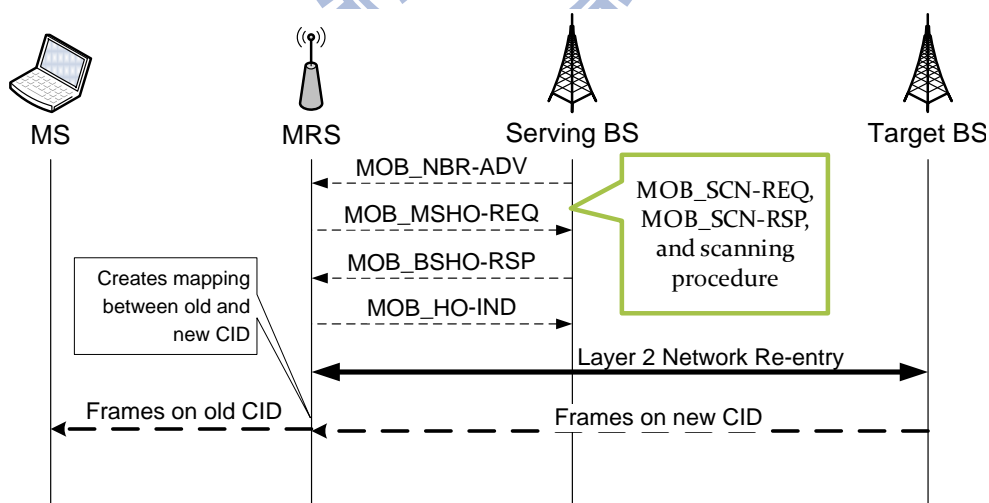

Figure 2.1   MRS layer 2 handover procedure

First, the handover preparation phase takes place. Three procedures are included - network topology advertisement, scanning, and association procedure. During network

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topology advertisement procedure, a BS periodically broadcasts MOB_NBR-ADV (Mobile Neighbor Advertisement) which contains information about the network topology MAC management message. This message tells the MRS the information about the network identification, provides information about neighboring BSs, and facilitates MRS synchronization with neighboring BSs. After obtaining information from this message, the MRS can make an immediate decision for a future handover. In the scanning procedure, MOB_SCN-REQ (Mobile Scanning Interval Allocation Request) and MOB_SCN-RSP (Mobile Scanning Interval Allocation Response) messages are exchanged. Through these two messages the MRS and the BSs it wants to scan can coordinate for the scanning. The MRS scans the neighboring BSs to seek and monitor one that is suitable for a handover candidate. The last one – the association procedure is an optional ranging procedure occurring during the scanning interval with respect to one of the neighbor BSs.

Secondly in handover decision and initiation phase, the MRS selects one or more candidate BSs. The MRS may make a decision to initiate the handover and sends a MOB_MSHO-REQ (Mobile MS Handover Request) message to current serving BS. Before replying MOB_BSHO-RSP message with recommended target BSs to the MRS, the serving BS may send the MAC addresses and CIDs of the MSs under MRS to neighbor BSs over the backbone. The handover can also initiated by the serving BS which would send MOB_BSHO-REQ (Mobile BS Handover Request) message to the MRS.

The last phase is handover execution. The MRS chooses a target BS and then sends MOB_HO-IND (Mobile Handover Indication) message to indicate a handover to the serving BS. After this message, the serving BS officially terminates the connection to MRS so that no packet would be delivered by serving BS. And then the MRS switches to

target link and performs downlink synchronization, raging, and network re-entry to the target BS. Next, the target BS sends RNG-RSP (ranging response) message to MRS to assign new CIDs for MSs, then MRS creates mapping between old and new CIDs for each MS. Once the handover execution is done, the target BS, which has become the serving BS, can start forwarding packets to the MRS and provide services.

2.2 Handover procedures with MRS in Mobile IPv6

In this section we will describe how MIPv6 works with IEEE 802.16j MRS mode. While MRS enters a different subnet, the MSs connected to it must re-configure a CoA address, new IP address, and re-establish its IP connection based on the new IP address. However, MSs cannot realize that they are under another network in the first place until they receive the router advertisement (RtrAdv) message periodically sent by the NAR. The MS can also request the NAR to send router advertisement by sending router solicitation (RtrSol) message. Next, the MS uses information exchanged in these messages to create a new CoA and confirms this CoA by sending neighbor solicitation message. After the CoA confirmation is done by the NAR (the confirmation is called duplicate address detection, DAD), the MS sends a binding update message to its HA, which updates the binding cache upon receiving this message [9].

To sum up the procedure in MIPv6, after finishing the layer 2 handover of MRS, the MS performs the IP layer handover procedures including movement detection, new care of address (CoA) configuration and DAD. And binding update is sent by the MS to officially start connection to the NAR. We can see that the two layer handover mechanism operate sequentially, therefore this handover procedures lead to a long SDT and packet loss. Figure 2.2 shows the detail handover procedure using MIPv6.
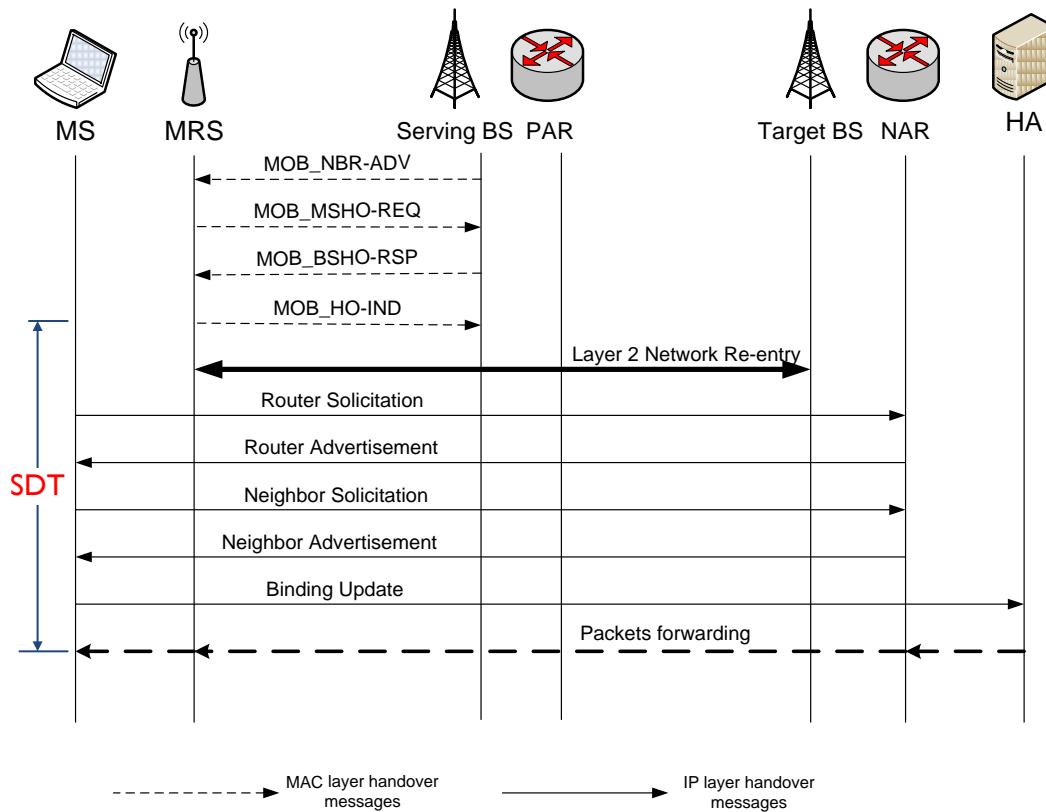
Figure 2.2   Mobile IPv6 handover procedure in MRS mode

2.3 Handover procedures with MRS in Proxy Mobile IPv6

PMIPv6 is a network-based IP layer handover approach where the serving network controls IP mobility management on behalf of the MS. Hence, when PMIPv6 is used over IEEE 802.16j network, the IP layer mobility management is done by the AR so the MS never knows about the subnet changing and the occurrence of IP layer handover. The new AR (NAR) will start to perform the IP layer handover procedures on behalf of the MS via PMIPv6 after it receives the RtrSol (Router Solicitation) periodically sent by MS, which may arrive at any time after the MRS's attachment. Note that we use the term "HA" and "NAR" instead of "LMA" and "MAG" for the reason of consistency..

Figure 2.3 shows the PMIPv6 procedure [11]. After NAR detects the new MS is under its subnet by RtrSol message, it sends a PBU (Proxy Binding Update) to the MS's home

HA. The HA obtain the MS's identifier form PBU and then allocates an appropriate home network prefix for the MS. Afterwards, the prefix is encapsulate in PBA (Proxy Binding Acknowledgement) message and sent back to NAR. At the same time the bi-directional tunnel is created between HA and NAR. Now the NAR sends RtrAdv (Router advertisement) message to the MS as a response of prior RtrSol message, and start forwarding data packets tunneled from HA. In PMIPv6 scheme, the packets forwarding from the PAR is not allowed since MOB_HO-IND message is exchanged, so the packet loss may occur during the periods of the layer 2 network re-entry (L2 RN) of MRS and the following PMIPv6 handover procedures. Since the IP layer handover of MSs are done one by one in this scheme, the SDT is affected by the amount of MSs under the MRS. In addition, because RtrSol is not sent upon layer 2 handover is done but is sent periodically, the interval of RtrSol also affect SDT. We can see that the NAR does not start handover procedure until it receives RtrSol, so the longest possible idle time is the whole interval time of RtrSol.
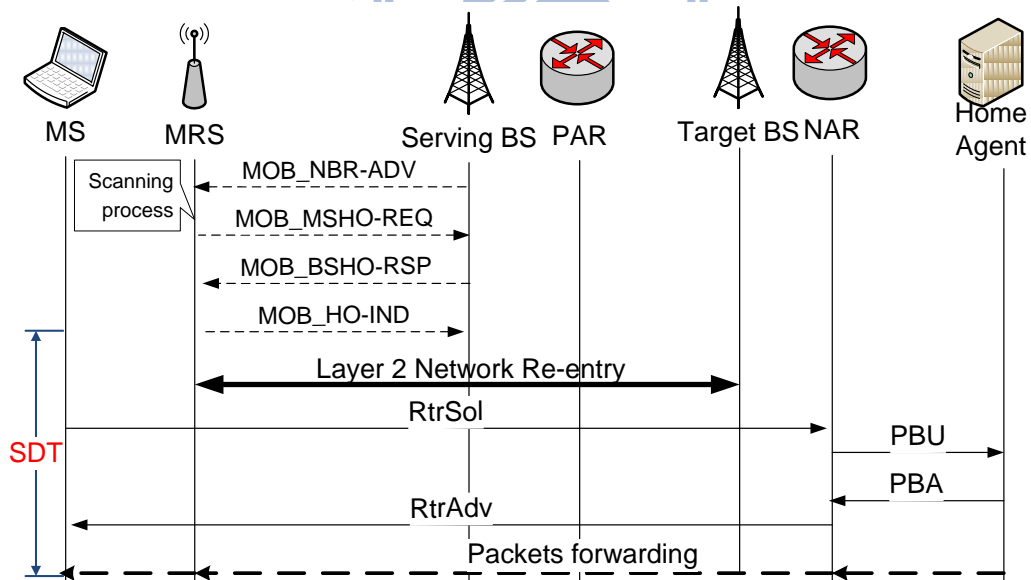
Figure 2.3   Proxy Mobile IPv6 handover procedure in MRS mode

Chapter 3 Proposed Scheme

3.1 Network scenario

In this thesis we proposed a cross-layer handover mechanism over IEEE 802.16j network, and the detail network scenario will be described below. The typical deployment of IEEE 802.16j is to let a MRS mounted on a public transportation vehicle, such as a bus or a train. The passengers' mobile devices, like a notebook or a cell phone, link to the BS through MRS instead of direct link to the BS. The MRS and MSs travel together as long as the passengers are on board.
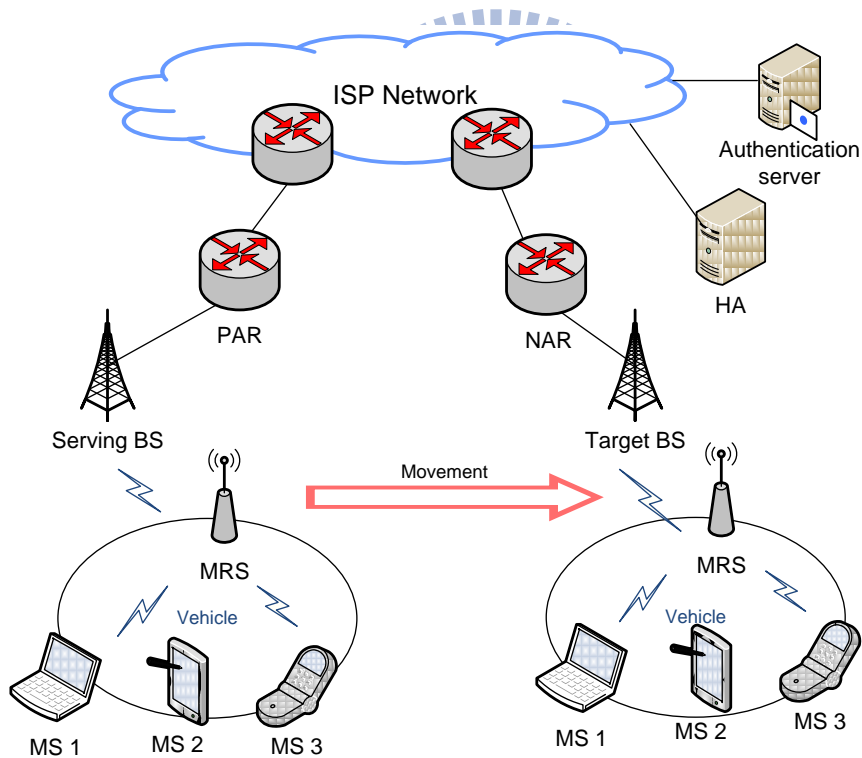
Figure 3.1   Vehicular network scenario.

In this scenario, the MRS works in mobile RS (MRS) mode and support link access for MSs. When the MRS switches from the serving BS to target BS belonging to a different subnet, the MSs attached to it should involve IP layer handover. The MRS itself

performs layer 2 handover to the target BS, at the same time it continuously provide fixed access link for MSs. As a result, the MSs attached to the MRS retain connections and do not have to perform a layer 2 handover. In MIP and PMIPv6 mentioned in Section 2.2 and 2.3, the MS or NAR conducts IP layer handover after the MRS finished the layer 2 handover.

Our proposed handover procedure is based on PMIPv6, but after the MOB_BSHO_RSP message is exchanged, there are several new messages added to improve the performance. Distinct from PMIPv6, the layer 2 and IP layer handover are not performed sequentially. In fact, the NAR tries to start the IP layer handover for all the MSs under the MRS before the MRS conduct the layer 2 handover. The detail of the proposed method is described in following sections.

3.2 Definition of proposed messages

In this section, we explain the format and purpose of messages we proposed. In Section 3.2.1, three wireless messages, which are exchanged between the MRS and BSs, are defined according to WiMAX standard. In Section 3.2.2, three messages transferred in wired network between BSs and ARs are explained. Finally in Section 3.2.3, there are some modifications in the original PBU and PBA messages in order to match our demands.

3.2.1 Proposed messages in WiMAX network

First we define the MRS_HO-REQ (Mobile Relay Station Handover Request) message. After MRS receives MOB_BSHO-RSP (Mobile Base Station Handover Response) message from the serving BS with recommended target BS, the MRS chooses one from the candidates and sends the MRS_HO-REQ. The main function of this

message is to inform the serving BS which target BS is the MRS going to switch to. Upon receiving MRS_HO-REQ, serving BS can find the target BS's identifier, and do further information exchange with the serving AR (previous AR, PAR). The MRS_HO-REQ message format is shown in Table 3.1.

Table 3.1   MRS_HO-REQ message format

Syntax	Size	Notes
MRS_HO-REQ_Message_format() {	—	—
Management Message Type = 100	8 bits	—
N_Recommended	8 bits	—
For (j=0 ; j<N_Recommended ; j++) {	—	—
Neighbor BSID	48 bits	—
Preamble index/ Preamble Present and Subchannel Index	8 bits	For the SCa and OFDMA PHY this parameter defines the PHY specific preamble for the neighbor BS.
Service level prediction	8 bits	—
HO process optimization	8 bits	—
Network Assisted HO supported	1 bit	Indicates that the BS supports Network Assisted HO.
HO_ID_included_indicator	1 bit	Indicates if the field HO_IND is included.
if (HO_ID_included_indicator == 1) {	—	—
HO_ID	8 bits	ID assigned for use in initial ranging to the target BS once this BS is selected as the target BS.
}	—	—
HO_authorization policy indicator	1 bit	To indicate if authorization negotiation is used in HO procedure.
Reserved	4 bits	Shall be set to zero.
if (HO_authorization policy indicator == 1) {	—	—
HO_authorization_policy_support	8 bits	Signed Integer from –128 to 127 in unit of dBm.
}	—	—
}	—	—
TEMP_BSID_Anchor	3 bits	Temp BSID for Anchor BS.
AK Change Indicator	1 bit	To indicate whether the AK being used should change when switching to a new Anchor BS.
}	—	—

Second, we propose MRS_HO-RSP (Mobile Relay Station Handover Response) message, which is used to notify MRS that the subsequent layer 2 link switch process can be started. The MRS_HO-RSP is sent after the serving BS receives HO-RSP, which is

newly defined in next section. Upon receiving this message by the MRS, it is suggested that the previous AR (PAR) and new AR (NAR) has completed some of the IP layer handover preparation. This will be explained in following sections. Note that if the reactive mode is triggered due to high speed movement of MRS, the MRS_HO-REQ and MRS_HO-RSP may not be sent. Table 3.2 shows the MRS_HO-RSP message format.

Table 3.2   MRS_HO-RSP message format

Syntax	Size	Notes
MRS_HO-RSP_Message_format() {	—	—
Management Message Type = 101	8 bits	—
}	—	—

The third WiMAX MAC management message we defined is the MRS_HO-CLT (Mobile Relay Station Handover Complete). After the layer 2 network re-entry process is done by the MRS, it immediately sends the MRS_HO-CLT message to the successfully attached target BS. By this message, the target BS realizes that the layer 2 handover is done, and it can inform the new AR to start packet delivery. Table 3.3 shows MRS_HO-CLT message format we defined.

Table 3.3   MRS_HO-CLT message format

Syntax	Size	Notes
MRS_HO-CLT_Message_format() {	—	—
Management Message Type = 102	8 bits	—
RS MAC address	48 bits	—
}	—	—

3.2.2 Proposed messages in wired network

We proposed the HO-REQ (Handover Request) message which is sent after the

serving BS receive MRS_HO-REQ. The HO-REQ message is delivered from serving BS to PAR in order to notify the PAR that there is a MRS handover about to happen. In addition to MRS's MAC address, this message also contains target BS's identifier and MAC addresses of MSs attached to the MRS. The serving BS acquires these information and encapsulates them into PBU which will pass to the NAR latter. Note that the amount of MS attached to the MRS is uncertain, so there is 8 bits "Number of MSs" to indicate how many MSs are there. The format of HO-REQ is shown in Table 3.4.

Table 3.4　HO-REQ message format

Syntax	Size	Notes
HO-REQ_Message_format() {	—	—
Wired Message Type = 00	8 bits	—
RS MAC address	48 bits	—
Target BS ID	48 bits	The BS which MRS is about to switch to
Number of MS	8 bits	—
For(I = 0;I < Number of MS; I++) {		
MS MAC address	48bits	—
}		
}	—	—

Another message we propose in wired network is HO_RSP (Handover Response) message. This message is delivered from PAR to serving BS after the PAR receives PBA and established the tunnel to the NAR. The function of HO_RSP is to let serving BS to inform the MRS that the layer 2 handover can start operating. The format of HO_RSP is shown in Table 3.5.

Table 3.5　HO-RSP message format

Syntax	Size	Notes
HO-RSP_Message_format() {	—	—
Wired Message Type = 01	8 bits	—
}	—	—

The other wired message proposed is HO-CLT (Handover Complete) message. After the target BS receives MRS_HO-CLT, which means the layer 2 network re-entry of MRS is completed, the target BS forward HO-CLT to inform the NAR. The main information contains in this message is the MAC address of MRS which complete the handover. Once the NAR receive HO-CLT, it can start forwarding packets to the MS. Table 3.6 shows the format of HO-CLT.

Table 3.6   HO-CLT format

Syntax	Size	Notes
HO-CLT_Message_format() {	—	—
Wired Message Type = 02	8 bits	—
RS MAC address	48 bits	—
}	—	—

3.2.3 Modified Proxy Binding Update and Proxy Binding Acknowledgement

In our proposed procedure, the NAR requires knowing the information about the MRS and MSs connected to it, so that it can conduct IP layer handover for MSs. We encapsulate this information in PBU, including MRS's MAC address, the home network prefixes and home addresses of all MSs. As a result, the original PBU which is defined in RFC 5213 [11], should be modified to support our scheme. The modified PBU format is shown in Table 3.8. Two flags are included in the reserved part of the message. If the F flag (stands for Fast handover scheme) is turned on, it means that our proposed fast handover scheme is used. On the other hand, when O flag (stands for handover mOde) is set to 0, it indicates that the predictive mode is in progress; when O flag is set to 1, it is in the reactive mode. In predictive mode, the information of MRS and MSs is carried in mobility options; while in reactive mode, PBU functions as a request so that the mobility

options carry less information. The format of mobility options is shown in Table 3.8.
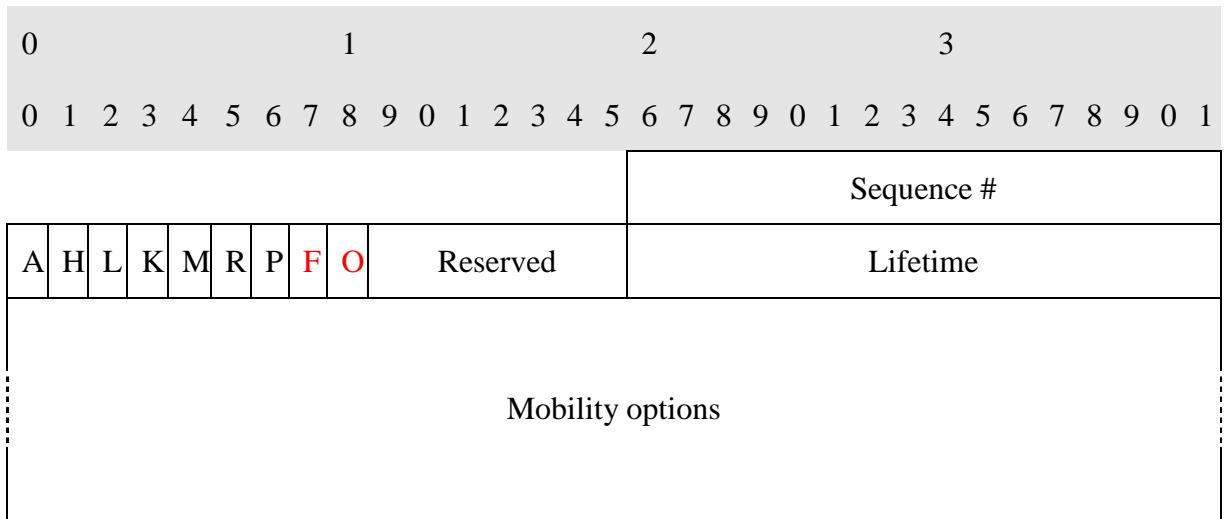
Table 3.7   Modified PBU message format

0										1										2										3	
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1

																	Sequence #														
A	H	L	K	M	R	P	F	O	Reserved							Lifetime															
Mobility options																															

Table 3.8   Mobility options for modified PBU message format

Syntax	Size	Notes
PBU_mobility_options_format() {	—	—
RS MAC address	48 bits	—
If (O flag == 0) {	—	Predictive mode processing
IP version	1 bit	Ip version used by MSs, 0 for v4 and 1 for v6
Number of MS	8 bits	—
If (IP version == 0) {	—	IPv4
For (I = 0; I < Number of MS; I++) {	—	—
MS IP address	32 bits	—
Home prefix	32 bits	—
HA address	32 bits	—
}	—	—
}	—	—
If (IP version == 1) {	—	IPv6
For (I = 0; I < Number of MS; I++) {	—	—
MS IP address	128 bits	—
Home prefix	128 bits	—
HA address	128 bits	—
}	—	—
}	—	—

The PBA message in [11] should also be modified. The F and O flags are also added into the reserved part of PBA. As mentioned above, PBA is replied by NAR as PBU's return message in predictive mode. However in active mode, PBA is sent by PAR and it includes the information of MRS and MSs in its mobility options. The format of modified PBA and its mobility options are shown in Table 3.9 and Table 3.10, respectively.
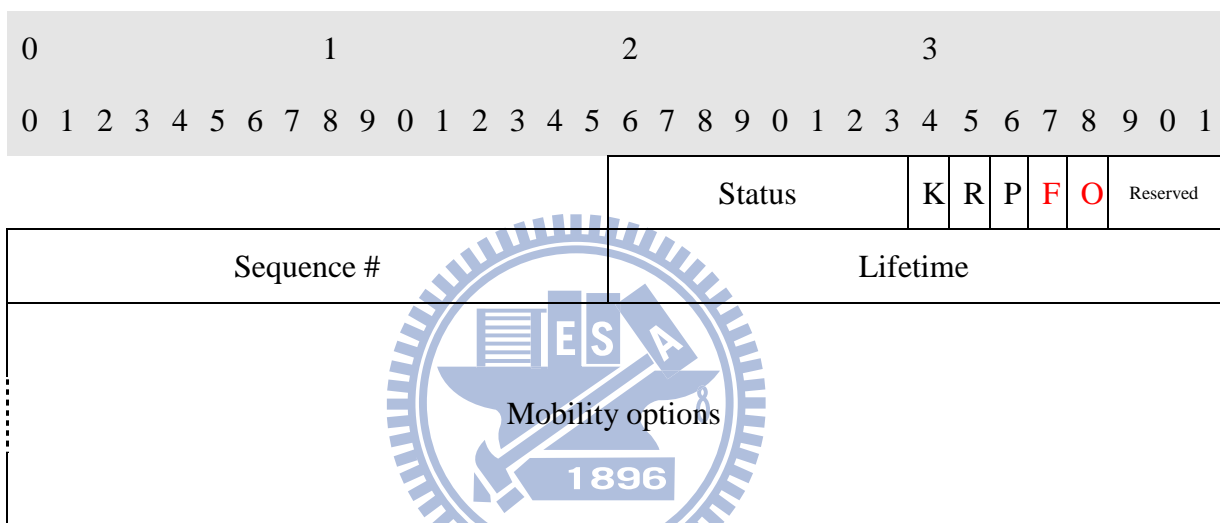
Table 3.9   Modified PBA message format

0	1	2	3
0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1 2 3 4 5 6 7 8 9	0 1

	Status	K R P F O Reserved
Sequence #	Lifetime	
Mobility options		

Table 3.10   Mobility options for modified PBA message format

Syntax	Size	Notes
PBA_mobility_options_format() {	—	—
RS MAC address	48 bits	—
If (O flag == 1) {	—	Reactive mode processing
IP version	1 bit	Ip version used by MSs, 0 for v4 and 1 for v6
Number of MS	8 bits	—
If (IP version == 0) {	—	IPv4
For (I = 0; I < Number of MS; I++) {	—	—
MS IP address	32 bits	—
Home prefix	32 bits	—
HA address	32 bits	—
}	—	—

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}	—	—
If (IP version == 1) {	—	IPv6
For (I = 0; I < Number of MS; I++) {	—	—
MS IP address	128 bits	—
Home prefix	128 bits	—
HA address	128 bits	—
}	—	—
}	—	—

3.3 Proposed handover procedures

3.3.1 Predictive mode

In our proposed scheme, SDT is reduced by a network based cross-layering scheme in which the layer 2 and IP layer handover procedures are performed simultaneously, while packet loss can be avoided by a buffering mechanism. The proposed scheme enables the AR to conduct IP layer handover on behalf of all MSs under the MRS when the MRS performs layer 2 handover by exchanging management messages, including *MRS_HO-REQ/RSP*, *HO-REQ/RSP*, *MRS_HO-CLT*, and *HO-CLT* between the BS, AR, and MRS. The detailed scheme is described as follows (Figure 3.2).
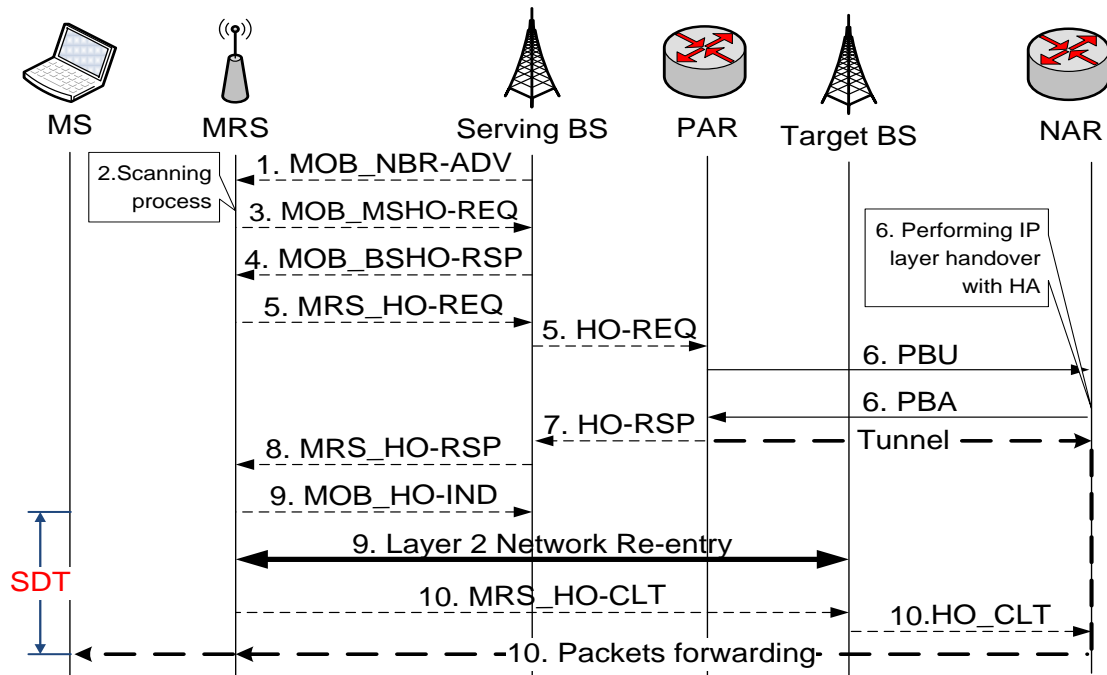
Figure 3.2   Predictive mode of proposed scheme

1. The serving BS (SBS) periodically broadcasts information about neighboring BSs using MOB_NBR-ADV (Mobile Neighbor Advertisement) message.

2. Upon receiving MOB_NBR-ADV, the MRS may perform a scanning process to monitor and measure the radio condition of neighbor BSs for a future handover.

3. Based on the signal strength or QoS parameters, the MRS may initiate handover by sending MOB_MSHO-REQ (Mobile MS Handover Request).

4. Through MOB_BSHO-RSP, the SBS can indicate one or more possible target BSs (TBSs) for MRS.

5. The MRS notifies the SBS that there is an impending layer 2 handover to the TBS through *MRS_HO-REQ*. By means of *HO-REQ* from the SBS, the previous AR (PAR) is informed that the MRS will move to the TBS.

6. Upon receiving *HO-REQ*, the PAR finds information of all MSs under the MRS, and sets up tunnel for all MSs by exchanging PBU/PBA messages with the NAR. Note that in PMIPv6 it requires one PBU per MS, but in the proposed scheme, the modified

PBU is responsible for all MSs. Afterwards, the PAR copies and forwards MSs'
packets to the NAR. Moreover, the home network prefixes and home addresses of all
MSs are included in PBU, and the NAR will perform IP layer handover on behalf of
those MSs with HAs.

7. Since IP layer handover is in progress and the tunnel is established, the PAR will
notify the SBS to conduct further handover procedures through *HO-RSP* message.
Moreover, the NAR will buffer packets coming from PAR for MSs to avoid packet
loss in the subsequent handover procedures.

8. After receiving *HO-RSP*, the SBS notifies the MRS to conduct subsequent layer 2
switch process by *MRS_HO-RSP*.

9. The MRS sends MOB_HO-IND as a final indication of handover and performs the
layer 2 HO procedure.

10. The MRS sends *MRS_HO-CLT* to the TBS immediately after finishing the Layer 2
HO process. Upon reception of *MRS_HO-CLT*, the TBS will notify the NAR of the
MRS's arrival by *HO-CLT*. When the NAR receives *HO-CLT* from the TBS, it will
deliver the buffered packets to all MSs.

3.3.2 Reactive mode

If the MRS moves at high speed, the NAR may not receive PBU and set up tunnel
with the PAR before the MRS conducts L2 RN process, therefore the packet loss may
occur. In this situation, the NAR will exchange PBU/PBA with the PAR to set up
bi-direction tunnel after it receives *HO-CLT*, and we call this reactive mode hereafter.
Figure 3.3 illustrate a typical situation that reactive mode is triggered, and the whole
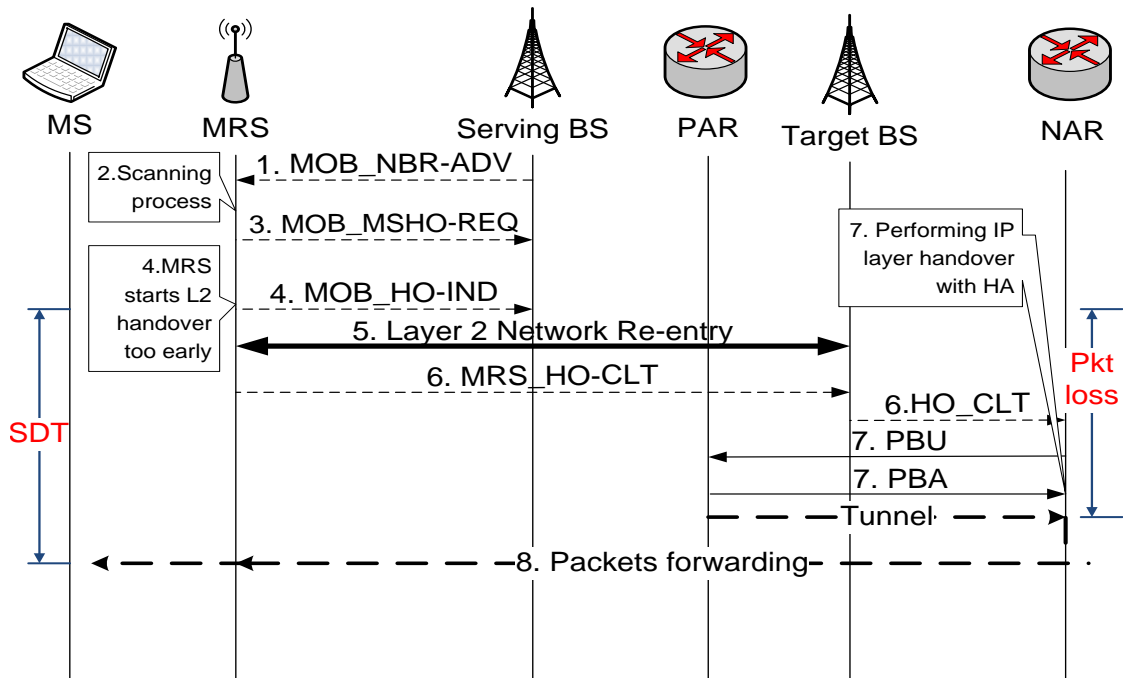procedure described as follows.

Figure 3.3   Reactive mode of proposed scheme

1. ~ 3. As explained in predictive mode, MOB_NBR-ADV is periodically broadcasted by SBS. After the possible scanning process, the MRS initiates the handover by sending MOB_MSHO-REQ message to SBS.

4. Due to the fast movement of MRS, there is no enough time for the PAR acquiring information to create PBU message. At this point, the MRS decides to start switching to the TBS. The MRS sends MOB_HO-IND and terminates the connection to SBS.

5. The MRS performs layer 2 network re-entry to the TBS without PAR and NAR establishing a tunnel.

6. Once the MRS complete layer 2 network re-entry, it send MRS_HO-CLT message to the newly connected TBS. Then by sending HO_CLT message, the TBS informs the NAR that the MRS has connected to the new network.

7. The NAR requests information of MSs which is attached to the MRS by sending PBU to PAR. IP addresses, home network prefixes and HA addresses of MS are

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encapsulated in PBA and sent back to NAR. Upon receiving PBA, the tunnel between PAR and NAR is established. At the same time, the NAR performs IP layer handover for all MSs. Note that the PBA and PBU have opposite functions compared with those in predictive mode.

8. The packets which are still sent to PAR are forwarded to NAR through the tunnel, and then the NAR forwards them to the MS. After the IP layer handover is finished, the bi-directional tunnels between the NAR and the HAs is created and the packets can be directly sent to the NAR.
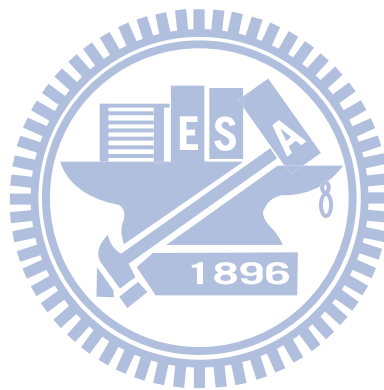
Chapter 4 Numerical Analysis

In this chapter, we use mathematical calculation to analysis the performance of our proposed scheme as well as the schemes using Mobile IPv6 and Proxy Mobile IPv6. Next, we point out some parameters that affecting the performances and explain the benefit of proposed scheme over conventional ones.

4.1 Numerical calculation

In order to measure the processing time of mobile messages participate in all schemes, we design an experiment by developing a C++ program and executing on a layer 2 wireless access point device (WL-320gE). The messages measured include the original IEEE 802.16j messages (i.e. MOB_NBAR-ADV, MOB_MSHO-REQ, MOB_BSHO-RSP, and MOB_HO-IND) and the messages we proposed (i.e. MRS_HO-REQ, MRS_HO-RSP, and MRS_HO-CLT). Each message is executed 1 million times and the average processing time is calculated. The experiment results show that all the processing time is less than 10^{-2}ms. In IEEE 802.16j, the layer 2 data is transferred frame by frame, thus the interaction of mobile messages is based on the frame duration. The common IEEE 802.16j frame duration is about 5ms, which is absolutely longer than the processing time of mobile messages. Therefore, we can assume that all transmission delay of mobile messages equals to one frame duration time (represent as T_{frame}). In other words, it is assumed that it takes T_{frame} for messages exchanging between two wireless devices. Besides, the radio propagation delay is too small (about 10^{-2}ms) that we omit it in the calculation.

Some other parameters used in the calculation are described as follows. T_{BS-AR}, T_{AR-HA}, and $T_{PAR-NAR}$ represent the delay between BS and AR, AR and HA, and PAR and NAR,

respectively. t is the average elapsed time from the MRS finishes L2 RN process to the MS sends a RtrSol. T_{L2}, T_{DAD}, and T_F represent the L2 RN process delay, DAD process delay, and packets forwarding delay, respectively. The delay between MS and BS equals twice T_{frame}. The main factors contributing to the whole SDT are T_{AR-HA}, T_{L2}, and T_{DAD}. All the parameters are listed in Table 4.1.

Table 4.1   Parameters for calculation

parameter	Description	Used scheme
T_{frame}	Frame duration of IEEE 802.16j	All
T_{L2}	Latency of IEEE 802.16j network re-entry procedure	All
T_F	Forwarding delay of the first packet from NAR	All
T_{HO-IND}	Latency of the HO-IND message	All
T_{BS-AR}	Latency between BS and AR	All
T_{AR-HA}	Latency between AR and HA	All
T_{DAD}	DAD process delay	MIPv6
$T_{RS/RA}$	Latency of Router Solicitation plus Router Advertisement	MIPv6/PMIPv6
$T_{NS/NA}$	Latency of Neighbor Solicitation plus Neighbor Advertisement	MIPv6
$T_{BU/Back}$	Latency of Binding Update plus Binding ACK	MIPv6
t	Time elapsed from L2 re-entry finished to RtrSol is sent	PMIPv6
$T_{PBU/PBA}$	Latency of Proxy Binding Update plus Proxy Binding Ack	PMIPv6/proposed
T_{MRS_HO-CLT}	Latency of the MRS_HO-CLT message	Proposed
T_{HO_CLT}	Latency of the HO_CLT message	Proposed
$T_{PAR-NAR}$	Latency between PAR and NAR	Proposed
D_{olap}	Overlap distance between Serving and Target BS	All
v	Velocity of MRS	All

The SDT is calculated at the MS from the reception of the last data packet from the PAR to the reception of the first data packet from the NAR . Hence, the SDT of using MIPv6, PMIPv6, and the proposed scheme can be calculated as follows:

(1) In MIPv6, there are six messages exchanged after the MRS finishes the layer 2 handover, including Router Solicitation, Router Advertisement, Neighbor Solicitation, Neighbor Advertisement, Binding Update and Binding ACK. The first four messages above are exchange between the MS and the NAR, which takes $2T_{frame} + T_{BS-AR}$. The other two messages exchanged by the MS and HA take $2T_{frame} + T_{BS-AR} + T_{AR-HA}$, so the total of them is $12T_{frame} + 3T_{BS-AR} + 2T_{AR-HA}$. The T_{HO-IND} equals $1T_{frame}$ and T_F equals $2T_{frame} + T_{BS-AR} + T_{AR-HA}$. Besides, the DAD processing time done by NAR and layer 2 re-entry processing time should be added. As a result, the SDT in MIPv6 can be expressed as follows.

$$SDT_{MIPv6} = T_{HO-IND} + T_{L2} + T_{RS/RA} + T_{NS/NA} + T_{DAD} + T_{BU/Back} + T_F$$
$$= 15T_{frame} + 7T_{BS-AR} + 3T_{AR-HA} + T_{L2} + T_{DAD}$$

(2) In PMIPv6, after the MRS finishes layer 2 handover, the process idles for an uncertain time until the RtrSol periodically broadcast by NAR is received. The factor t which represent the above elapse time must be considered. The latency of RtrSol plus RtrAdv, which are exchanged between the MS and NAR equals $4T_{frame} + 2T_{BS-AR}$. PBU and PBA are exchange between NAR and HA, so the latency is $2T_{AR-HA}$. Finally, the T_{HO-IND} equals $1T_{frame}$ and T_F equals $2T_{frame} + T_{BS-AR}$. The SDT in PMIPv6 ca n be expressed as follows.

$$SDT_{PMIPv6} = T_{HO-IND} + T_{L2} + t + T_{RS/RA} + T_{PBU/PBA} + T_F$$
$$= 7T_{frame} + 3T_{BS-AR} + 3T_{AR-HA} + T_{L2} + t$$

(3) In the predictive mode of proposed scheme, after the MRS completes layer 2 handover, there are only MRS_HO-CLT message and HO-CLT message delivered from MRS to target BS then to NAR. Thus, the latency of the two messages is $1T_{frame} + 1T_{BS-AR}$. The T_{HO-IND} equals $1T_{frame}$ and T_F equals $2T_{frame} + T_{BS-AR}$. So the SDT of predictive mode can be expressed as follows.

$$SDT_{Proposed} = T_{HO-IND} + T_{L2} + T_{MRS\_HO-CLT} + T_{HO\_CLT} + T_F$$
$$= 4T_{frame} + 2T_{BS-AR} + T_{L2}$$

(4) If the reactive mode is triggered in proposed scheme, the PBU and PBA messages are exchanged between PAR and NAR during the SDT. Therefore, $2T_{PAR-NAR}$ should be added into the equation. In addition, the latency of first packet delivered by tunnel should also be added, which equals $1T_{PAR-NAR}$. The following is the expression of reactive mode.

$$SDT_{Proposed\_re} = T_{HO-IND} + T_{L2} + T_{MRS\_HO-CLT} + T_{HO\_CLT} + T_{PBU/PBA} + T_F$$
$$= 4T_{frame} + 2T_{BS-AR} + T_{L2} + 3T_{PAR-NAR}$$

For our analysis, the T_{frame} is assumed 5 ms, and the other parameters used are: $T_{L2} = 220$ ms, $T_{BS-AR} = 1$ ms, $T_{PAR-NAR} = 4$ ms, and $T_{DAD} = 1000$ ms.

4.2 Numerical analysis results

Figure 4.1 shows the impact of T_{AR-HA} on SDT. It can be observed that both MIPv6 and PMIPv6 are affected by the change in delay between AR and HA because they need to exchange messages including BU/BAck or PBU/PBA to/from the HA. In contrast, the

proposed scheme is not affected because the HA is not involved in mobility-related signal after MRS finishes L2 RN procedure. In particular, it is worth noting that the SDT of MIPv6 is significantly larger than that of the proposed scheme due to the considerably longer DAD process time relative to the delay caused by other factors affecting SDT. In addition, the SDT in PMIPv6 is affected by t which can be affected by the interval of RtrSol (4 seconds [16]). Increasing t would result in growing SDT in PMIPv6. The main factor contributing to the SDT of the proposed scheme is T_{L2}; however, the T_{L2} can be reduced to less than 220 ms depending on whether L2 RN optimization defined in the standard is used or not.
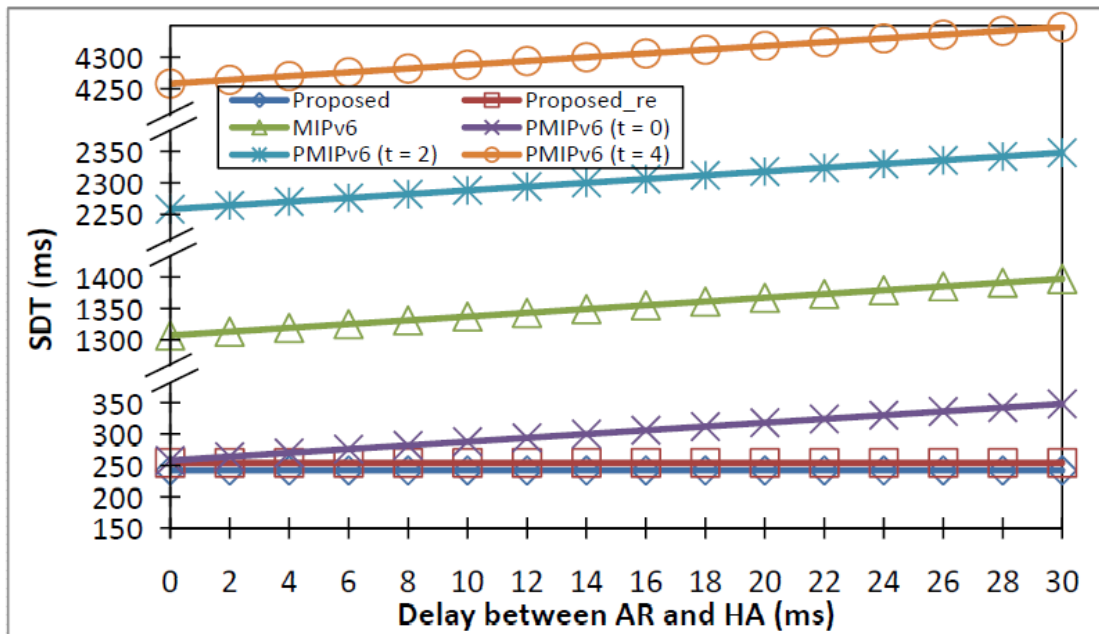
Figure 4.1   Impact of AR-HA delay on SDT

The number of lost packets and the required buffer size for proposed scheme can be represented as $\lambda \times SDT$ and $\lambda \times (SDT_{Proposed} + T_{BS-AR} + T_{frame})$, respectively, where λ is the average packet arrival rate. Since the number of lost packets is affected by SDT which can be affected by the T_{AR-HA}. Figure 4.2 shows the impact of T_{AR-HA} on packet loss with the traffic rate of 64 Kbps and packet size of 200 bytes, indicating that all schemes are slightly

influenced by the $T_{AR\text{-}HA}$. Since the proposed scheme uses a buffering mechanism, the number of lost packets is 0. Particularly, when the proposed scheme operates in the reactive mode, few packets may be lost. In addition, the MIPv6 and PMIPv6 experienced higher packet loss due to their higher SDT as shown in Figure 4.2.
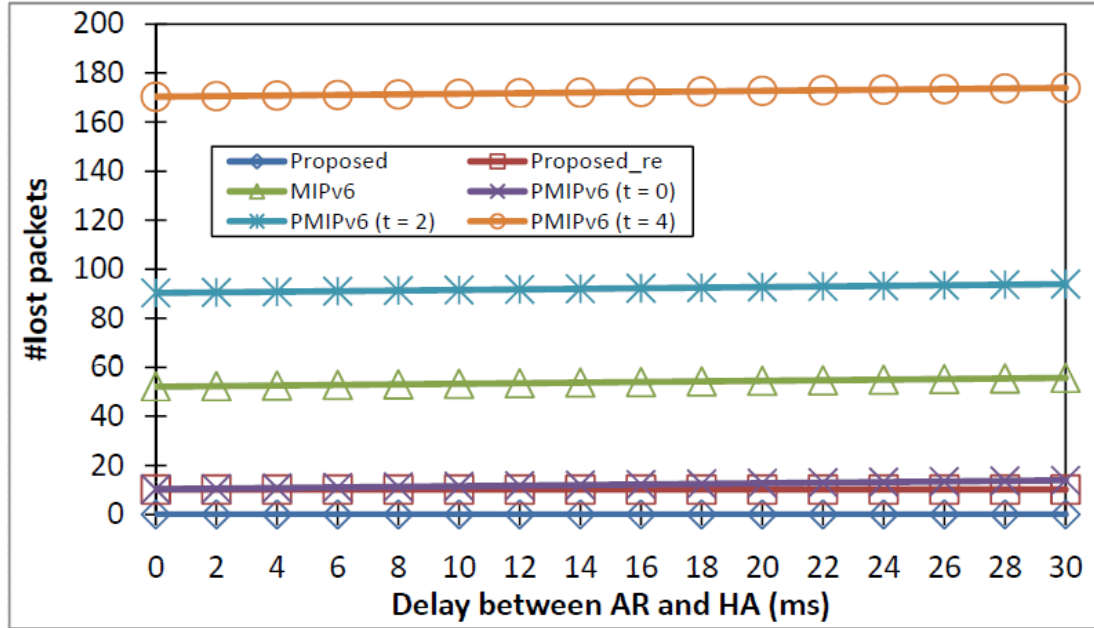

Figure 4.2   Impact of AR-HA delay on #lost packets

The SDT and number of lost packets in the proposed scheme are affected by the velocity of MRS (v), the overlap distance (D_{olap}) between two BSs, and handover preparation latency (T). When MRS moves in the overlap area, it performs the handover preparation as well as handover decision and initiation procedures. At the edge of this area, MRS must execute the handover process (Figure 4.3). Therefore, the relation between D_{olap}, v, and T can be expressed as $D_{olap} \geq v \times T$. If velocity of MRS exceeds the threshold (i.e., $v > D_{olap}/T$), the proposed scheme will operate in reactive mode.
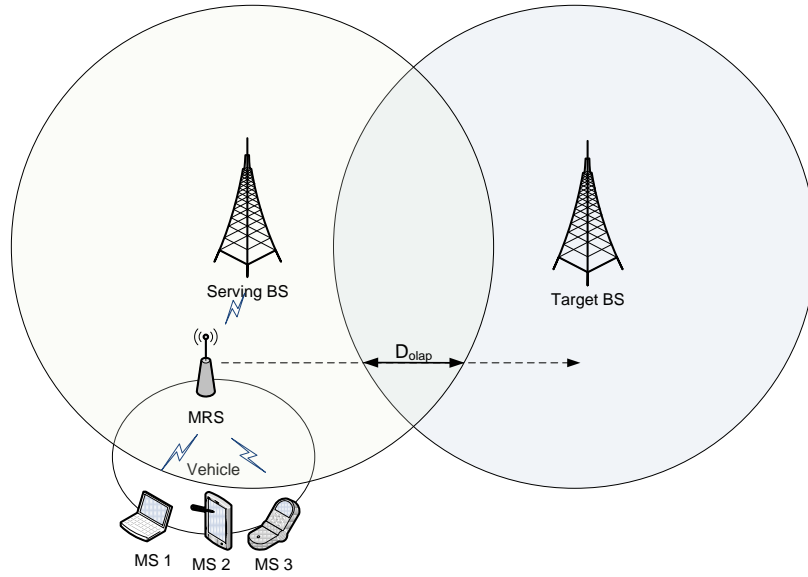
Figure 4.3   Overlap between two BSs

The handover preparation latency can be calculated as $T = 5T_{frame} + 2T_{BS\text{-}AR} + 2T_{PAR\text{-}NAR} + T_{scan}$, where T_{scan} is the scanning process delay.   Figure 4.4 shows the impact of T_{scan} on the proposed scheme with different D_{olap}, it indicates that even with $D_{olap} = 10$ m and $T_{scan} = 400$ ms, the proposed scheme is still in nonreactive mode when v is no larger than 82 km/hr. Since usually the D_{olap} will be larger than 10 m and T_{scan} will be less than 400 ms, the proposed scheme will be in nonreactive mode with common vehicle speed.
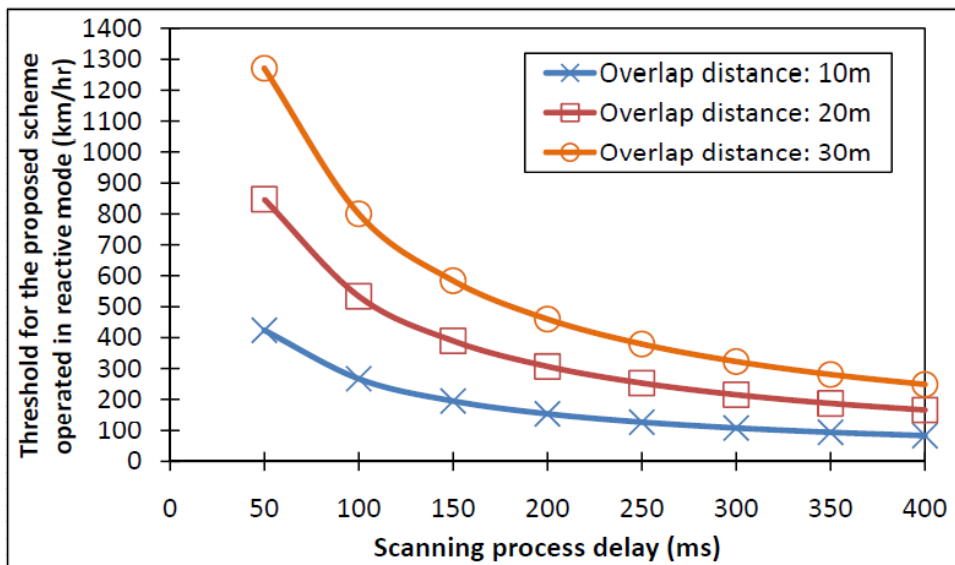

Figure 4.4   Impact of T_{scan} on the proposed scheme

Chapter 5 Simulation and Results

5.1 Simulation environment

In this chapter, we develop a simulation environment based on NS-2 (version 3.31) network simulator [17]. In order to match our network scenario, we install two additional modules on the NS-2, which are Secure Mobility Module designed by National Institute of Standards and Technology (NIST) and Light WiMAX Simulator (LWX) Module [19]. LWX can support IEEE 802.16 and IEEE 802.16j standards. Also, LWX provides 802.16 MAC functionalities with QoS, different modulation coding rates, and traffic relay supports are mainly used for bandwidth allocation and relay link selection researches. LWX also provides several bandwidth allocation algorithms for 802.16 and 802.16j networks including strict priority and round robin bandwidth algorithms for basic 802.16 network and round robin bandwidth algorithm for 802.16j relay network [19].

We modify the above program and add the proposed control messages to implement our proposed handover scheme. The detail of simulation network topology is shown in Figure 5.1, in which a MRS is mounted on a vehicle and moves from a SBS to a TBS in a different IP subnet. Note that the links between routers and ISP network have 100Mbps bandwidth and 3ms delay, and the links between BSs and ARs have 100Mbps bandwidth and 1ms delay.
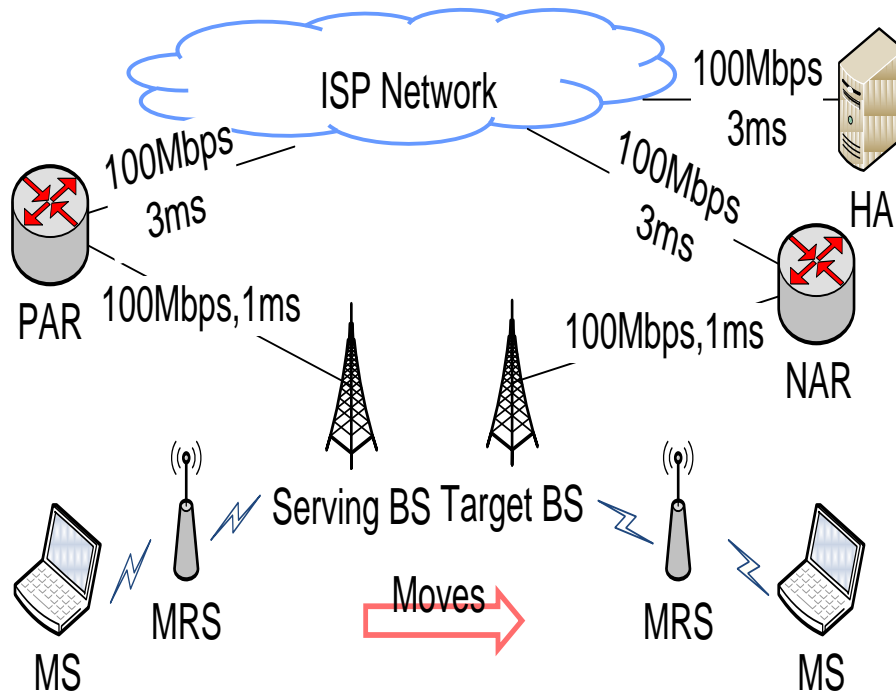
Figure 5.1 Network topology for simulation.

In order to observe the performance of proposed scheme, we choose VoIP as our simulation target, because VoIP is a typical real time application people usually use on public transportation system. We set the traffic source parameters according to general VoIP, in which the MS receives downlink traffic that has 64 Kbps of constant bit rate and 200 bytes of packet size. All the parameters we used in NS-2 are shown in Table 5.1.

Table 5.1 Simulation parameters

Parameter	Value
Channel type	WirelessChannel
Radio propagation model	TwoRayGround
Network interface type	WirelessPhy
MAC type	LWX

Interface queue type	PriQueue
Link layer type	LL
Antenna model	OmniAntenna
Max packet in ifq	50
Routing protocol	AODV
Bandwidth allocation algorithm	Round Robin for Relay
Framd duration	5 ms
Traffic type	UDP/CBR
Packet size	200 bytes
Bit rate	64Kbps

5.2 Simulation results

In the simulation, the traffic starts at 0 second and each packet of it is assigned a sequence number. We record the receiving time of each packet in the simulation program, so that we can indicate which packets are lost and can also find out the period that packets cannot be delivered. After the results are obtained, we draw charts to show the relationship of packet's sequence number and receiving time in all schemes. The result of MIPv6 is shown in Figure 5.2. And the results of PMIPv6 ($t = 0$, $t = 2$, $t = 4$) are shown in Figure 5.3, 5.4, and 5.5. Next, the results of proposed scheme in predictive mode and reactive mode are shown in Figure 5.6 and 5.7 respectively. Finally, we give a comparison of all schemes in a Table 5.2 and analysis the simulation result.
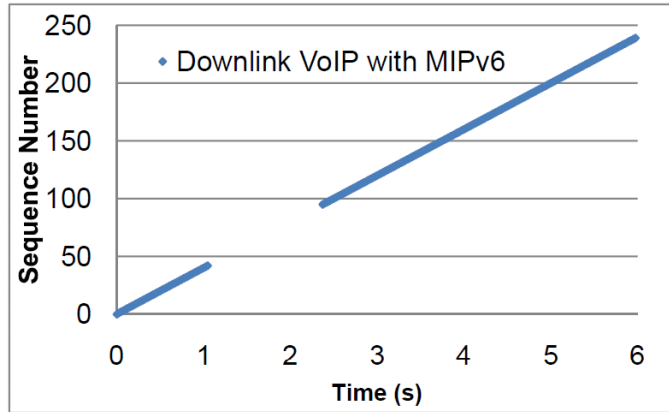
Figure 5.2   Packet sequence number to receiving time in MIPv6 scheme
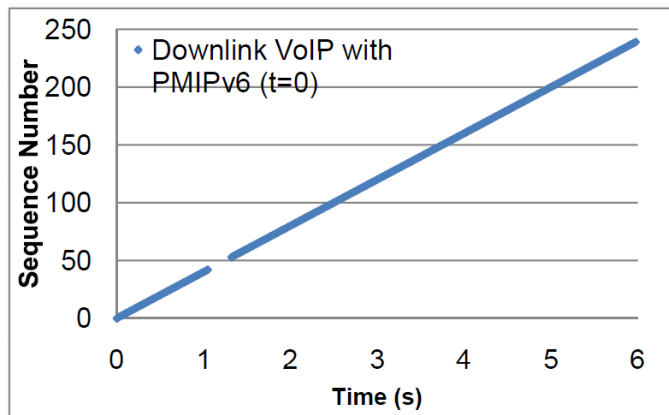

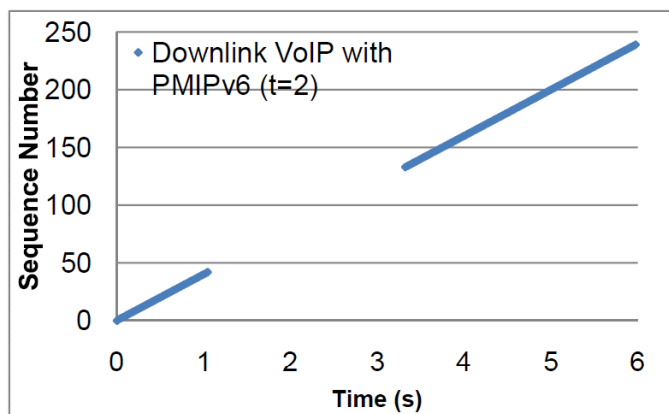Figure 5.3   Packet sequence number to receiving time in PMIPv6 (t=0) scheme

Figure 5.4   Packet sequence number to receiving time in PMIPv6 (t=2) scheme
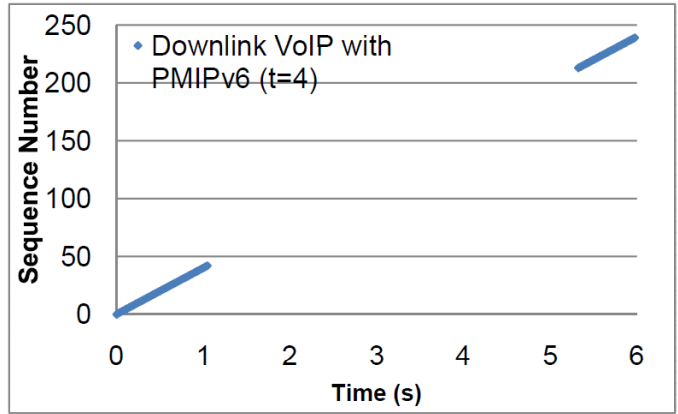
Figure 5.5　Packet sequence number to receiving time in PMIPv6 (t=4) scheme
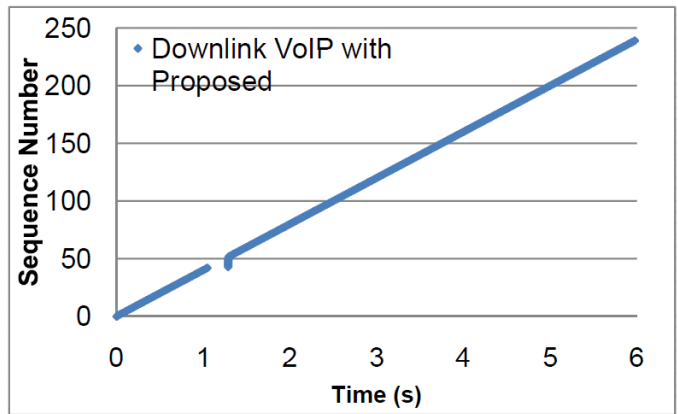

Figure 5.6　Packet sequence number to receiving time in proposed scheme (predictive mode)
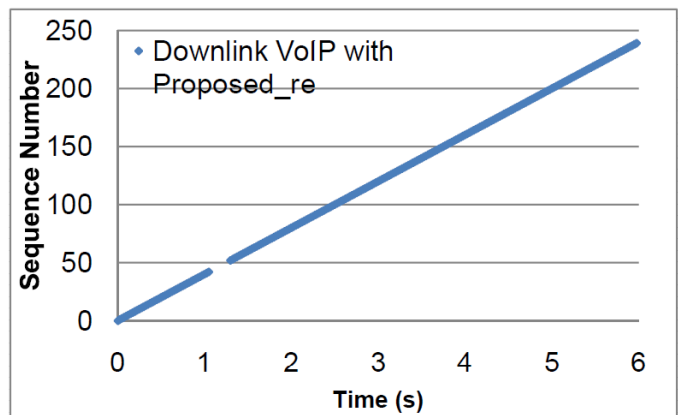

Figure 5.7 Packet sequence number to receiving time in proposed scheme (reactive mode)

Table 5.2   SDT and packet loss in all schemes

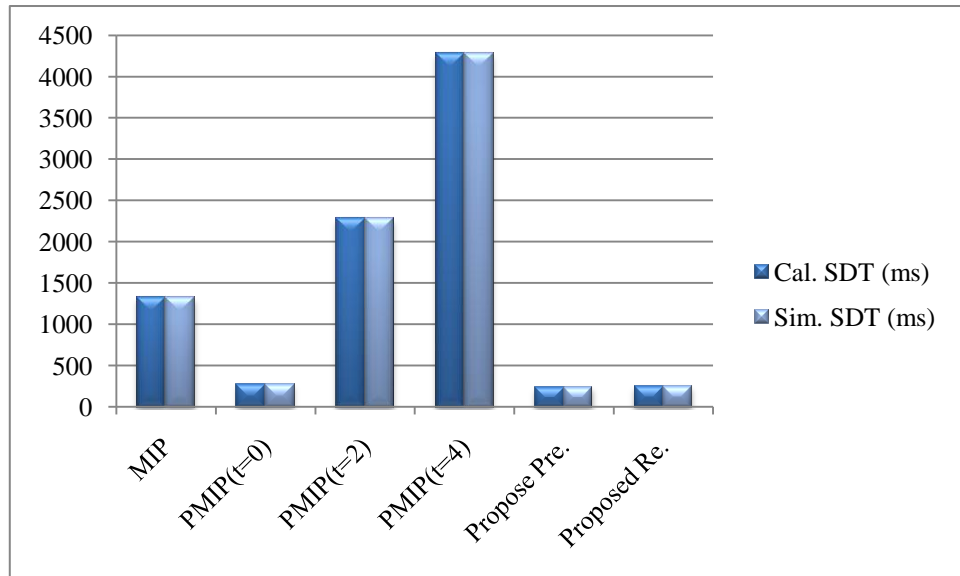| Protocol	MIPv6	PMIPv6			Proposed Scheme	
		t = 0	t = 2	t = 4	Pre.	Re.
Cal. SDT (ms)	1320	276	2276	4276	242	254
Sim. SDT (ms)	1325	275	2275	4275	240	255
#Lost Packets	52	10	90	170	0	9
Improvement of SDT	81.9%	12.7%	89.5%	94.4%	-	-

Figure 5.8   Comparison of SDT in calculation and simulation

In Table 5.2, the first and second rows show the SDT results by calculation and simulation respectively. We can observe that compared with the numerical results calculated in Chapter 4, the simulation result in each scheme has similar value (less than 5 ms). Moreover, as can be seen in Figure 5.8, the trends of all schemes are approximately identical in calculation and simulation. Therefore, we can say that the

calculation and simulation results confirmed each other.

In the MIPv6 approach, the SDT is 1325 ms because the layer 2 network re-entry and IP layer handover procedures are performed sequentially. A higher packet loss (i.e., 52 packets) in the MIPv6 approach is observed because of no buffering mechanism and long SDT. Although layer 2 network re-entry and IP layer handover procedures are also performed sequentially in PMIPv6 approach, the SDT is reduced to 275 ms when $t = 0$ because the MS always uses the home address without DAD process. In addition, 10 packets are lost in PMIPv6 approach because there is no buffering mechanism.

The SDT in the proposed scheme is less than 255 ms because the cooperation of layer 2 and IP layer forces IP layer handover procedures to be performed before the MRS switches to TBS. Moreover, packet loss did not occur in the proposed scheme with nonreactive mode because the MSs' packets are forwarded to NAR and sent to MSs after the NAR receives a *HO-CLT*. When the proposed scheme operates in the reactive mode, 9 packets are lost because the bi-direction tunnel won't be established until the MRS finishes the L2 RN process. As compared with the MIPv6 and PMIPv6 approaches, the SDT is reduced by approximately 81.9% and 89.5%, respectively and there is no packet loss in the proposed scheme under nonreactive mode.

Chapter 6 Conclusions

In this thesis, we first point out the defects of MIPv6 and PMIPv6. In IEEE 802.16j MRS mode, When a MRS and MSs attached to it handover to another BS, high packet loss rate and long SDT may occurs in both scheme. Although there are some amendments of PMIPv6 which improve the performance, these methods cannot apply to IEEE 802.16j in MRS mode. Therefore, we proposed a network-based fast handover mechanism which uses cross-layering design to solve the above problem.

In the proposed scheme, there are some control messages added in order to let the IP layer handover and the layer 2 handover to cooperate. By the mathematical calculating, we can see that the proposed method has shorter SDT and less packet loss than those in MIPv6 and PMIPv6. The main reasons are that there is no DAD process time, and the delay between AR and HA does not influence performance of the proposed handover scheme. Next, we develop a NS-2 network environment to observe the performance of all schemes. The results show that the proposed scheme has 0 (or very less) packet loss and the SDT is reduced by approximately 81.9% and 89.5% compared to MIPv6 and PMIPv6.

In spite of the remarkable achievement of our proposed scheme, there are some future works to improve the performance even more. For example, we can design a optimize layer 2 re-entry process. Besides, packet loss still occurs in reactive mode, so a mechanism to optimize the reactive mode may be necessary. Furthermore, we plan to do some in depth research on practically deploying our proposed scheme on the current WiMAX system, and come up with some experiments to test the real user experience when using the proposed scheme.

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