Cross-layer Optimized Vertical Handover Schemes between Mobile WiMAX and 3G Networks

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Received July 3, 2008; revised August 14, 2008; accepted August 15, 2008; published August 25, 2008

Abstract

Nowadays, wireless packet data services are provided over Wireless MAN (WMAN) at a high data service rate, while 3G cellular networks provide wide-area coverage at a low data service rate. The integration of mobile WiMAX and 3G networks is essential, to serve users requiring both high-speed wireless access as well as wide-area connectivity. In this paper, we propose a cross-layer optimization scheme for a vertical handover between mobile WiMAX and 3G cellular networks. More specifically, L2 (layer 2) and L3 (layer 3) signaling messages for a vertical handover are analyzed and reordered/combined, to optimize the handover procedure. Extensive simulations using ns-2 demonstrate that the proposed scheme enhances the performance of a vertical handover between mobile WiMAX and 3G networks: low handover latency, high TCP throughput, and low UDP packet loss ratio.

Keywords: Vertical handover, cross-layer optimization, mobile IP, mobile WiMAX, 3G network

This research was supported by the MKE (Ministry of Knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program supervised by the IITA (Institute of Information Technology Advancement) (IITA-2008-(C1090-0801-0002)). Parts of this paper were presented at IEEE IWCMC 2008, Crete Island, Greece, August 6, 2008.

DOI: 10.3837/tiis.2008.04.001

1. Introduction

Recent advances in wireless communication technologies have resulted in the evolution of various wireless networks, and new generations of networks. CDMA's enhanced capabilities and simplified migration path resulted in the 3GPP and 3GPP2 mobile communication systems. Moreover, the number of Internet users has increased rapidly, thus, voice-based services have evolved into data-based services. The CDMA2000 mobile communication system has evolved into 1xEV-DO and 1xEV-DV, for high speed data services, and the UMTS system into HSDPA. As a result of successive successful developments of wireless networks, mobile WiMAX has been developed, for higher bandwidth services [1]. Recently, WiBro (Wireless Broadband), which is another name for mobile WiMAX, has been commercialized in Korea. It has been developed to enable users to achieve high speed, high quality access to the Internet, anywhere and anytime, using portable equipment such as laptops, PDAs, and smart phones. It adopts OFDMA/TDD for multiple-access and duplex schemes, to provide mobility rates as high as 60km/h, and data service rates as high as 50Mbps.

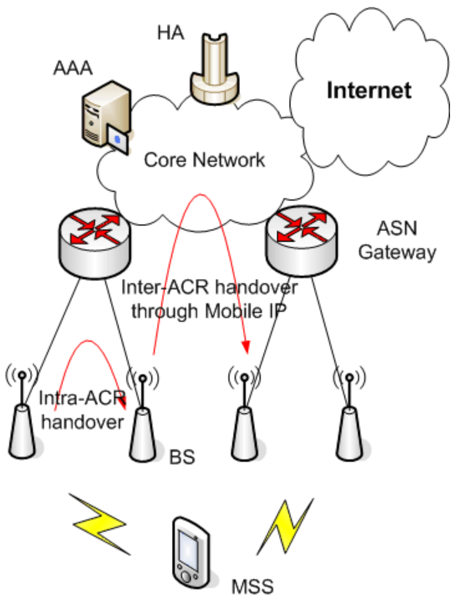


Fig. 1. Network architecture of mobile WiMAX

Fig. 1 shows the architecture of a mobile WiMAX network, in terms of the network elements and their functions [2]. There are four main components in the architecture: MSS (Mobile Subscriber Station), BS (Base Station), ASN (Access Service Network) Gateway, and core network. The MSS communicates with the BS using IEEE 802.16e wireless access technology. The MSS also provides the functions of MAC processing; mobile IP, authentication, packet retransmission, and handover. The BS provides wireless interfaces for the MSS and handles wireless resource management, QoS support, and handover control. The ASN Gateway plays a key role in IP-based data services, including IP packet routing, security, QoS and handover control. The ASN Gateway also interacts with the AAA (Authentication, Authorization, and Accounting) server, for user authentication and billing. To provide the mobility for an MSS, an ASN Gateway supports handover among the BSs, while Mobile IP supports handover among ASN Gateways, as shown in **Fig. 1**.

In order to provide seamless services across heterogeneous wireless networks, efficient handover procedures are essential. For vertical handover procedures, it is possible to use Mobile IP [3], which is generally used for a homogeneous network or its extended version, viz. fast handover [4], which tends to reduce packet loss and delay during the handover. However, since these handover procedures exploit L2 (layer2) and L3 (layer 3) signaling messages sequentially, they can suffer from problems of long handover latency and packet loss. In this paper, we propose a cross-layer optimization scheme for vertical handovers between mobile WiMAX and 3G cellular networks. The proposed cross-layer scheme analyzes and reorders/combines L2 and L3 signaling messages for a vertical handover, thus, we can achieve high handover performance, which is validated via extensive ns-2 simulations.

The remainder of the paper is as follows: Section 2 explains the background behind the paper and related work. In Section 3 we present our cross-layer vertical handover scheme and validate its performance in Section 4. Finally, Section 5 concludes the paper.

2. Related Works

2.1 Mobile IPv6 and fast handovers

Although Mobile IPv6 and its extended version, viz. fast handover, are well known, we briefly introduce their call flows in **Fig. 2** and **Fig. 3**, for ease of understanding of this paper. The procedures and messages in **Fig. 2** and **Fig. 3** are used in our proposed scheme. There is a more detailed explanation in [3][4].

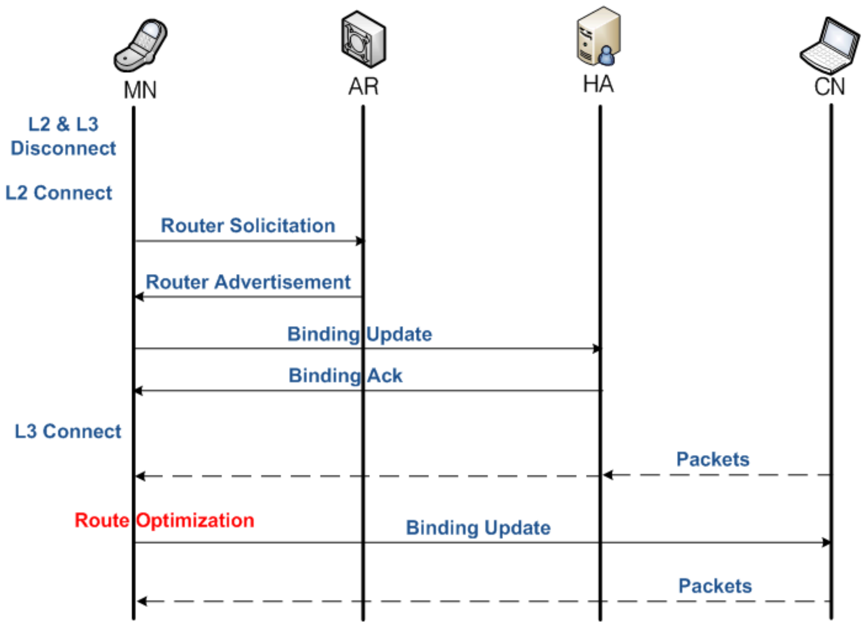


Fig. 2. Mobile IPv6 procedure

2.2 Cross-layer optimization

There are several works related to cross-layer optimization in wireless networks. The authors in [5] proposed a cross-layer horizontal fast handover scheme in mobile WiMAX. This work is an example of an L1 and L2 cross-layer optimization scheme. In [6], another horizontal fast handover scheme in mobile WiMAX was presented, which exploits L2 and L3 cross-layer optimization. However, although this scheme reorders L2 and L3 signaling messages, no reduction in the number of messages is achieved by combining L2 and L3 signaling messages. Mohmoodi et al. proposed a scheme to improve L4 (TCP) performance by exploiting L2 information [7]. These kinds of works are typical examples of cross-layer optimization schemes. However, to the best of our knowledge, there is no vertical handover scheme exploiting cross-layer optimization, thus, this paper is the first approach to cross-layer optimization for vertical handovers.

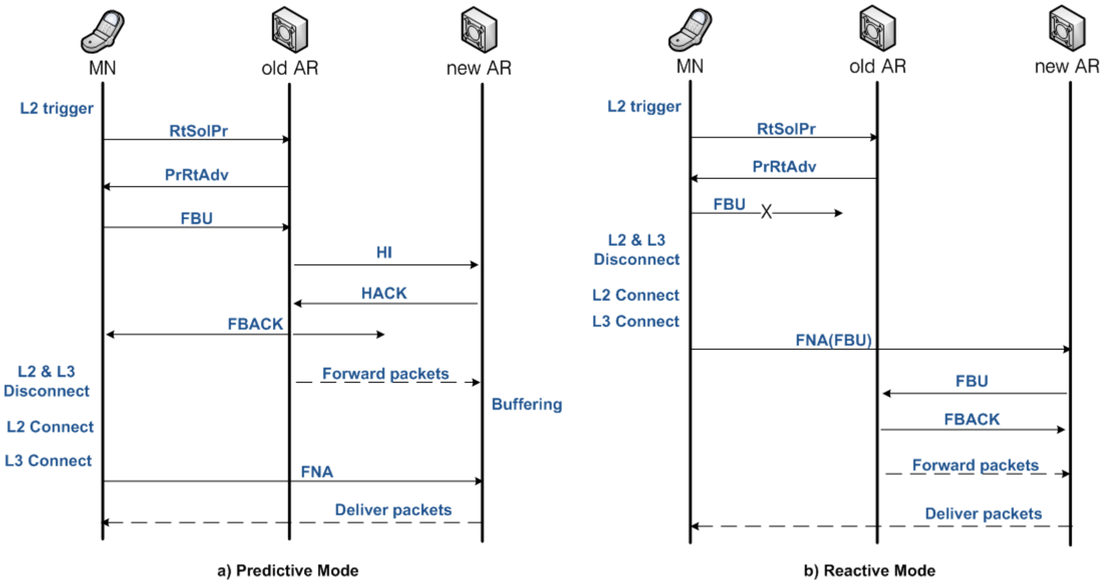


Fig. 3. Fast handover procedures

3. Image Retrieval Approach

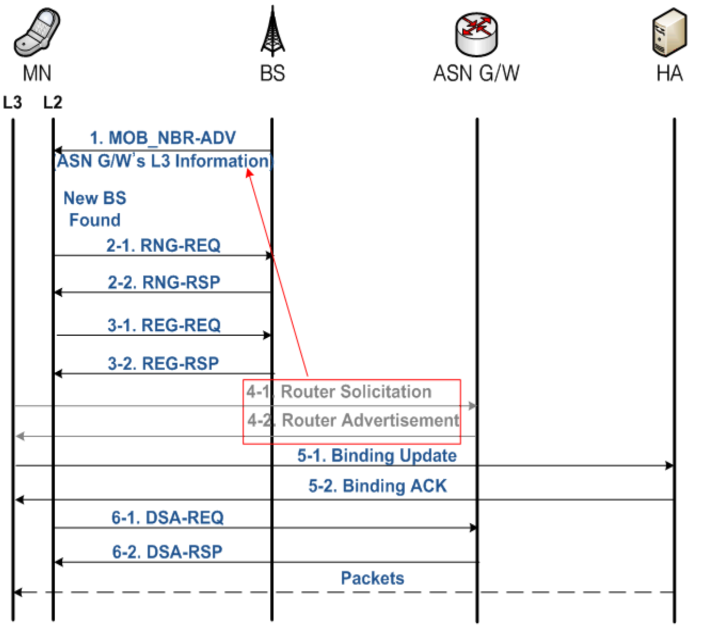
In this section, we propose our vertical handover scheme. The basic concepts behind our scheme are as follows: 1) Reordering and/or parallelizing L2 and L3 signaling messages. 2) Combining L2 and L3 signaling messages. Thus, we achieve shorter vertical handover latency and higher throughput. In the following, Mobile IPv6 and fast handovers are cross-layer optimized according to mobile WiMAX, 3GPP, and 3GPP2 standards [8][9][10][11][12][13].

3.1 Cross-layer optimized Mobile IPv6

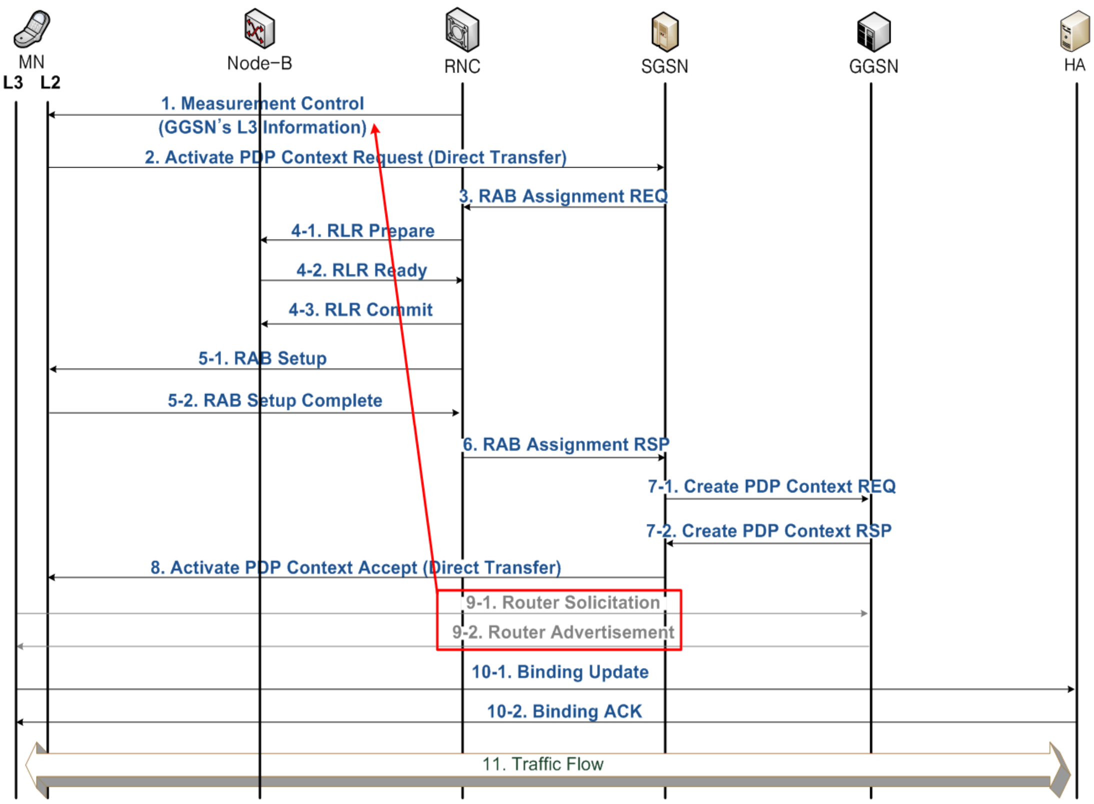
In **Fig. 2**, an MN sends a RtSol message, and receives an RtAdv message, to obtain L3 information about the target network to which the MN moves. If we can pass this information in L2 signaling messages, RtSol/RtAdv messages can be omitted.

Fig. 4(a) depicts the proposed procedure when an MN moves to a mobile WiMAX network. As we previously mentioned, the information about an ASN Gateway to which the MN moves, is passed via an MOB_NBR_ADV L2 message, thus, RtSol/RtAdv messages need not be transmitted. In addition, L2 and L3 messages can be reordered, as shown in **Fig. 4(a)**.

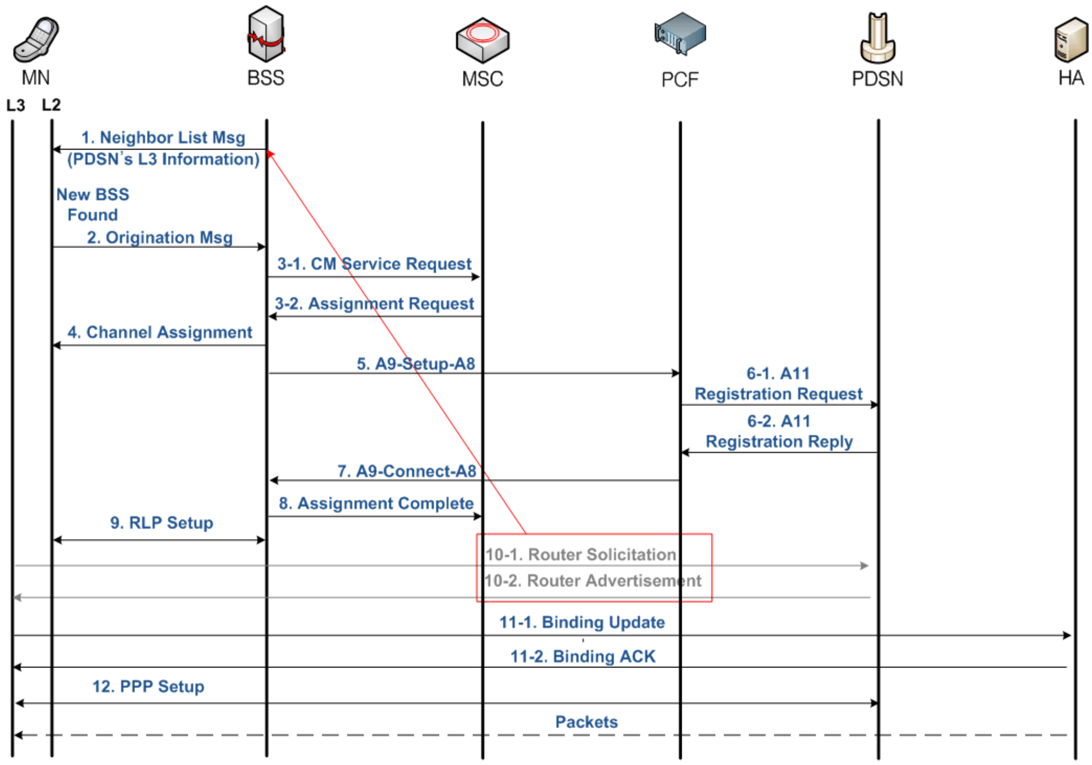
Similarly, this method can be applied to the case where an MN moves to 3GPP and 3GPP2 networks, as depicted in **Fig. 4(b)** and **Fig. 4(c)**, respectively. MeasurementControl L2 message in 3GPP network and NeighborList L2 message in 3GPP2 network contain the L3 information about GGSN and PDSN, respectively, and RtSol/RtAdv messages are omitted.



a) To mobile WiMAX



b) To UMTS



c) To cdma2000

Fig. 4. Cross-layer optimized MIPv6

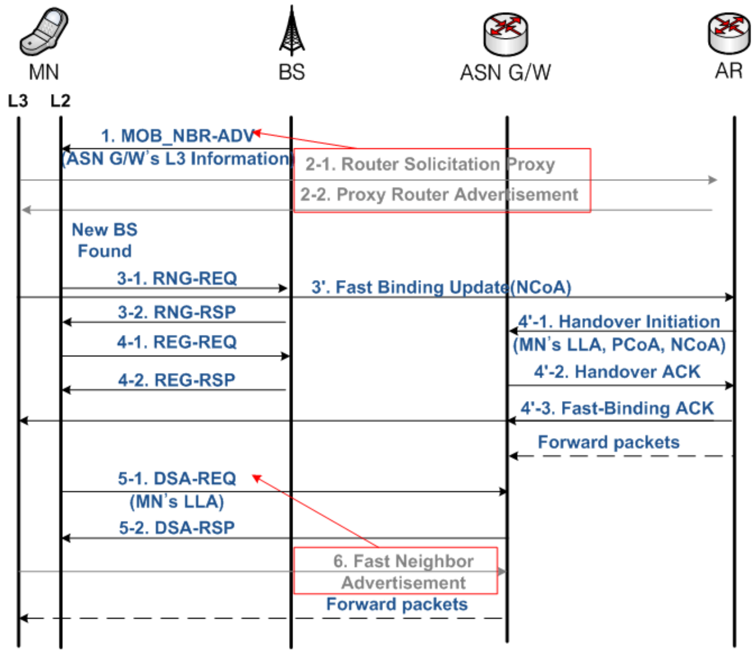
3.2 Cross-layer optimized fast handover

Similar to the Mobile IPv6 cases, if we can pass the L3 information about target networks in L2 signaling messages, RtSolPr/PrRtAdv messages can also be omitted, as shown in **Fig. 3**. In addition, a FastNeighborAdvertisement message in **Fig. 3** plays the role of signaling that all procedures are completed, and buffered packets can be forwarded to MN. So, it can be performed via an L2 signaling message.

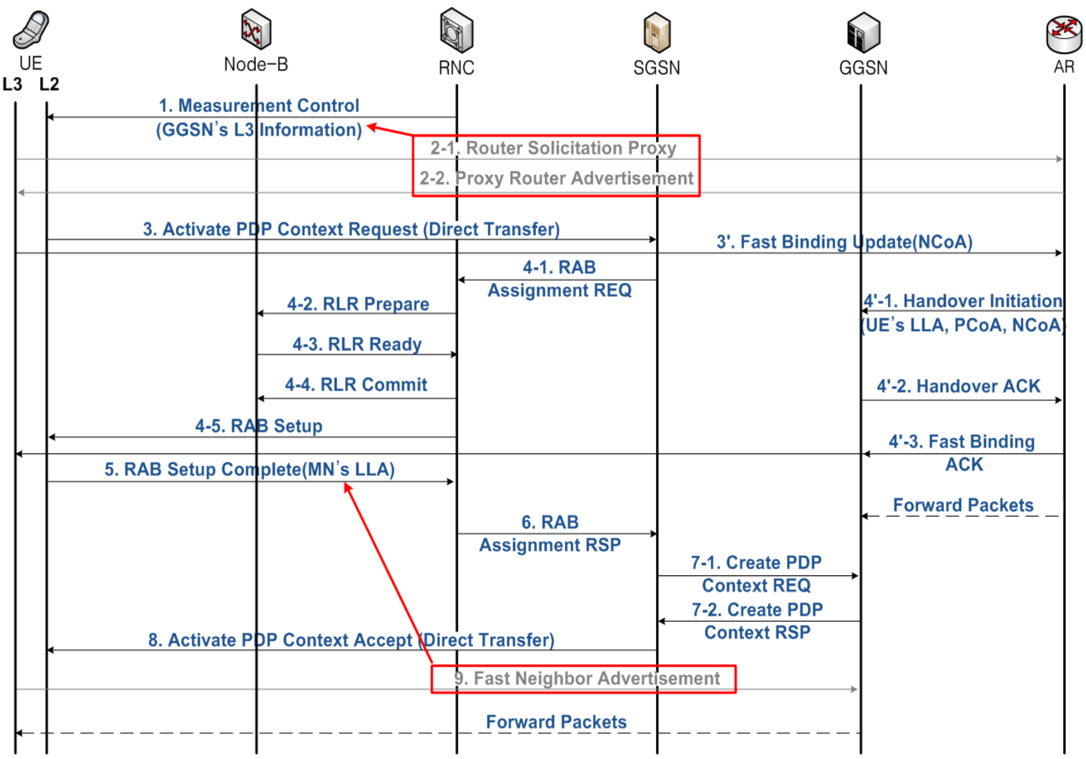
Fig. 5(a) depicts a predictive mode fast handover procedure when a MN moves to a mobile WiMAX network. The information about an ASN Gateway to which an MN moves is passed via an MOB_NBR_ADV L2 message, thus, tRtSolPr/PrRtAdv messages are not transmitted. In addition, DSA-REQ L2 messages contains an MN's LLA (Link Layer Address), enabling us to omit FastNeighborAdvertisement L3 messages. Furthermore, Procedures 3, 4 and 3', 4' in **Fig. 5(a)** can be processed in parallel.

This method can be applied to the case where an MN moves to 3GPP and 3GPP2 networks, as depicted in **Fig. 5(b)** and **Fig. 5(c)**, respectively. MeasurementControl L2 message in 3GPP network and NeighborList L2 message in 3GPP2 network contain the L3 information about GGSN and PDSN, respectively, and RtSolPr/PrRtAdv messages are omitted. In addition, RABSetupComplete L2 message of 3GPP system passes MN's LLA, instead of FastNeighborAdvertisement L3 message, in **Fig. 5(b)**, and LCP/IPCP messages in PPP setup procedures of 3GPP2 system play the same role, in **Fig 5(c)**. Similar to **Fig. 5(a)**, Procedures 3, 4 and 3', 4', in **Fig. 8** and **Fig. 9**, can be processed in parallel.

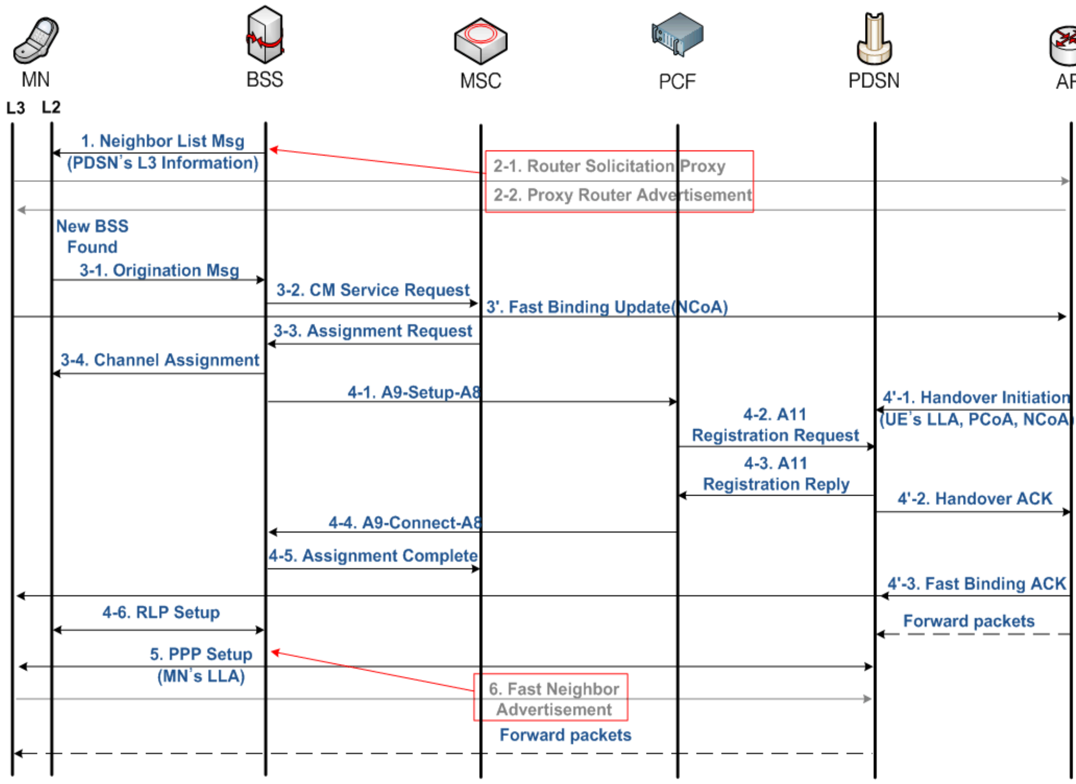
The concept of a predictive mode fast handover can also be applied to a reactive mode fast handover procedure, except for the following: Since FastNeighborAdvertisement L3 message in a reactive mode plays the role of passing a NCoA (New Care-of-Address) of an MN, DSA-REQ, RABSetupComplete, and LCP/IPCP L2 messages in each case should contain the NCoA of an MN, as depicted in **Fig. 6**.



a) To mobile WiMAX

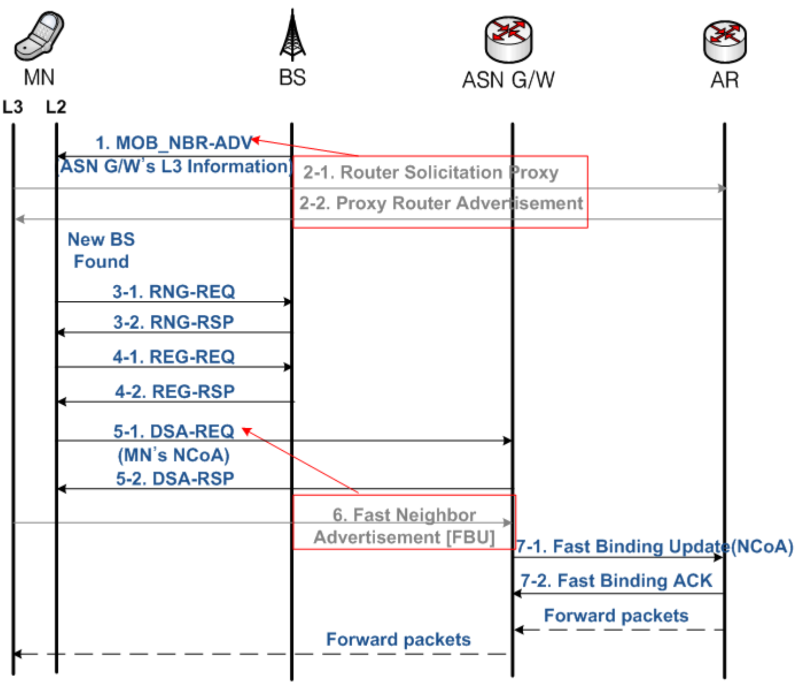


b) To UMTS

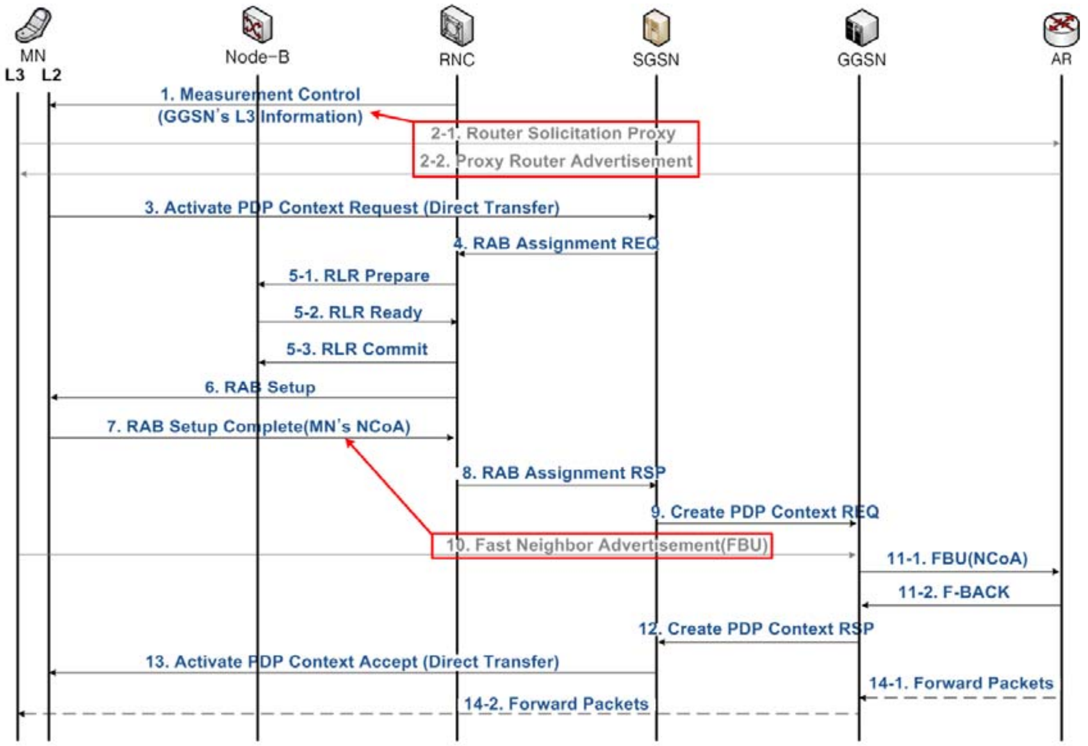


c) To cdma2000

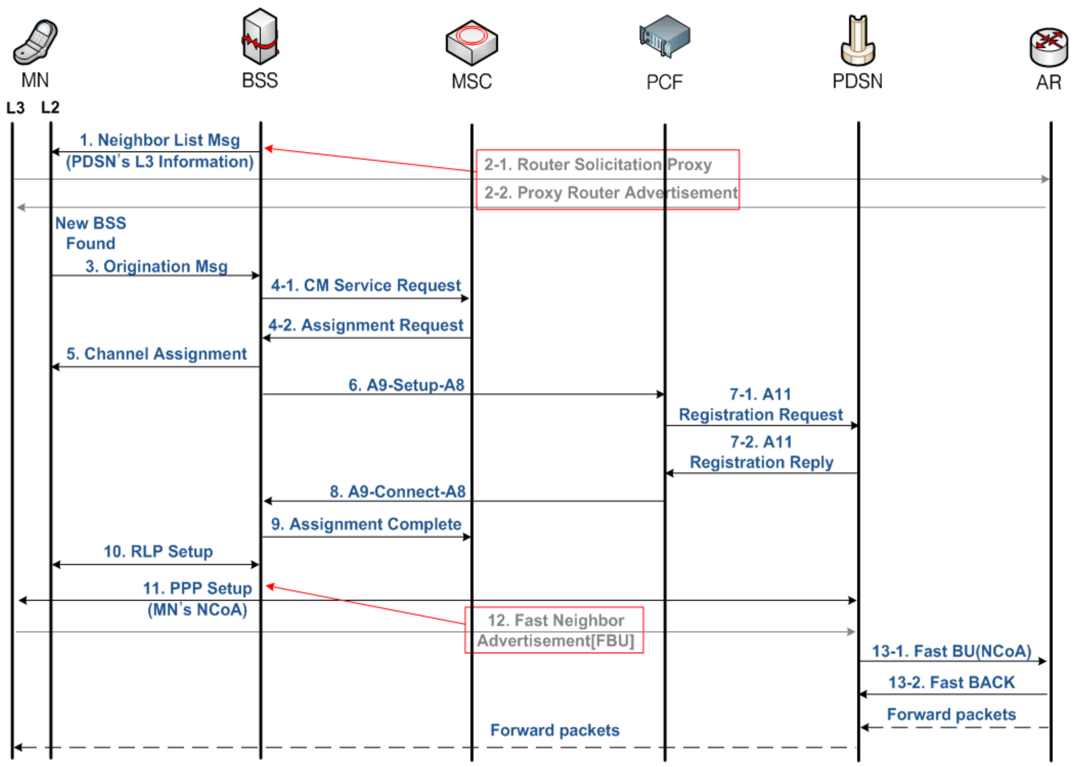
Fig. 5. Cross-layer optimized fast handover: Predictive mode



a) To mobile WiMAX



b) To UMTS



c) To cdma2000

Fig. 6. Cross-layer optimized fast handover: Reactive mode

4. Performance Evaluation

4.1 Simulation model

In this section, we evaluate the proposed scheme, in terms of handover latency, packet delay, and packet loss, compared to the basic Mobile IPv6 and fast handovers, which perform L2 and L3 procedures sequentially. The simulation was executed on ns-2 [14] and **Fig. 7** depicts the simulation scenario and parameters. In **Fig. 7**, the wireless bandwidth means the bandwidth of the air interface, and the wired bandwidth means that of the backbone network.

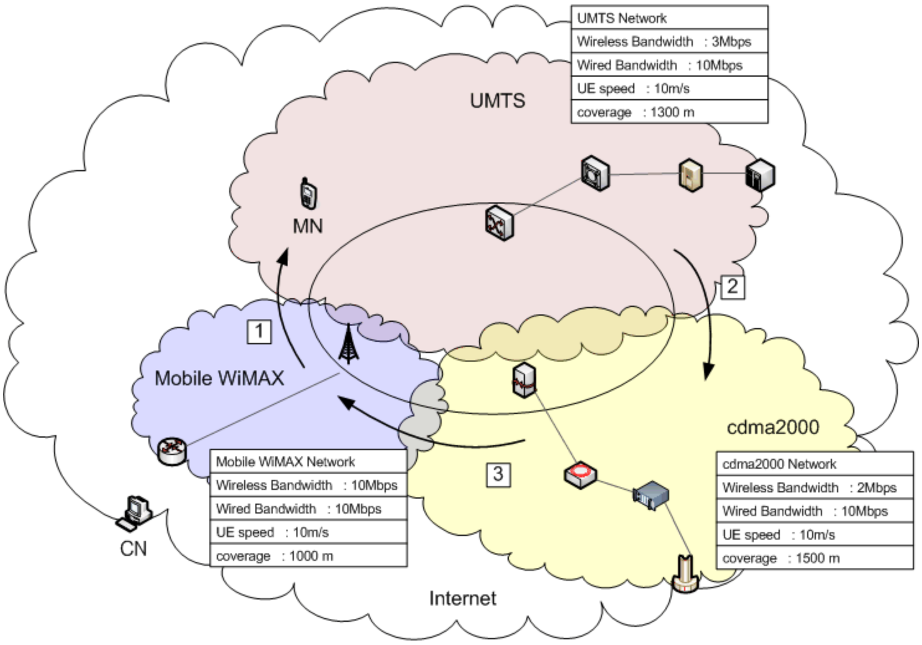


Fig. 7. Simulation scenario and parameters

MNs move around mobile WiMAX, UMTS, and cdma2000 networks, and undergo vertical handovers, while receiving four types of services: conversational (VoIP), streaming (VOD), interactive (Web), and background (FTP). In VoIP services, an 80B packet is transmitted every 50ms, and 3.5KB frames are passed at 5fps in VOD. We assume that a 16KB page is requested every one second in Web services, and the file size is 2.8MB in FTP.

4.2 Simulation result

Firstly, the latency of a vertical handover can be calculated deterministically by summing the delay of L2 and L3 signaling message passing. For example in **Fig. 2** and **Fig. 4**, the handover latencies of the original MIPv6 and the cross-layer optimized MIPv6 handover to mobile WiMAX network are calculated as follows:

$$T_{proposed} = 8d_1 + 4d_2 + 2d_3 \text{ and} \tag{1}$$
$$T_{original} = 10d_1 + 6d_2 + 2d_3, \tag{2}$$

where d_1 denotes the message delay between MN and BS, d_2 is the delay between BS and ASN GW, and d_3 is the delay between ASN GW and HA. From (1) and (2), we can deterministically determine that the proposed scheme reduces the vertical handover latency dramatically. In the following, the simulation results from ns-2 are presented.

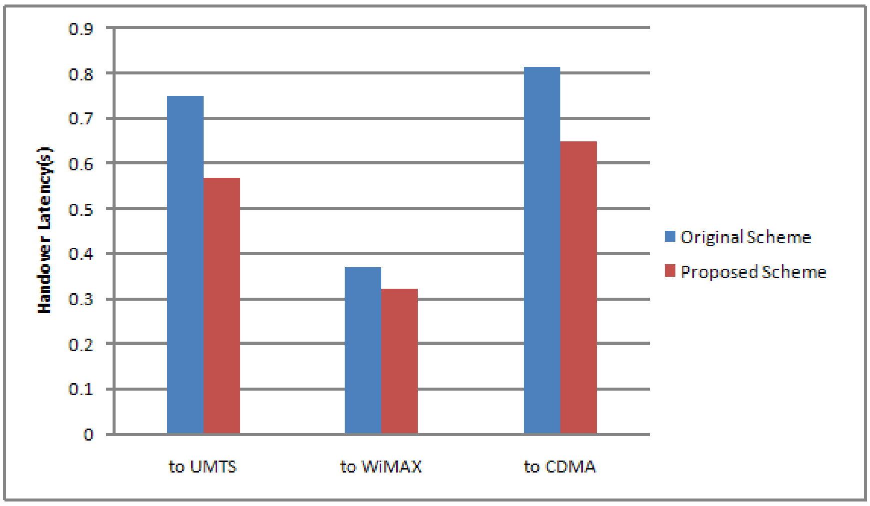


Fig. 8. Average vertical handover latency

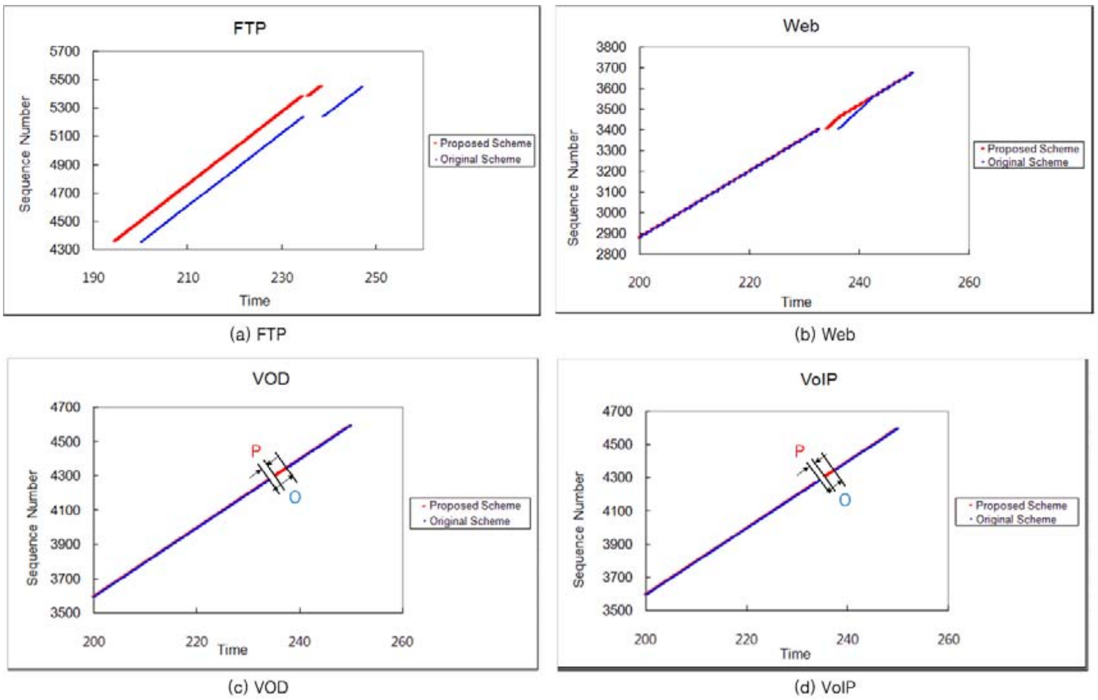


Fig. 9. Packet delay according to sequence number

Fig. 8 shows that the vertical handover latency of the cross-layer optimized scheme is lower than that of the original MIPv6. This is because RtSol/RtAdv messages need not be transmitted, and L2 and L3 signaling messages are suitably ordered for parallelism. In addition, the handover latencies in **Fig. 8** are very close to the values calculated from (1) and (2), which demonstrates the validity of our simulation. Next, we describe the extent to which the handover latency affects the performance of applications.

In **Fig. 9**, the packet delay (i.e. received time of a packet according to sequence number) is depicted, while an MN undergoes a vertical handover to a mobile WiMAX network. As shown in **Fig. 9**, there is no packet loss in Web and FTP services, because Web and FTP employ TCP in the transport layer, and TCP re-transmits lost packets. However, the packet delay of the proposed scheme is much lower than that of the original MIPv6, because of the difference in handover latencies, as shown in **Fig. 8**. In VoIP and VOD applications, which use UDP in the transport layer, it is clear from **Fig. 9** that more packets are lost in the original MIPv6 scheme when there is a vertical handover. In **Fig 9**, we depict the period of packet loss for clarity: P represents the proposed scheme and O represents the original one. In addition, **Fig. 10** shows the average size of lost packets in vertical handovers. As expected, fewer packets are lost in the proposed scheme, which shows the superiority of our cross-layer optimization scheme.

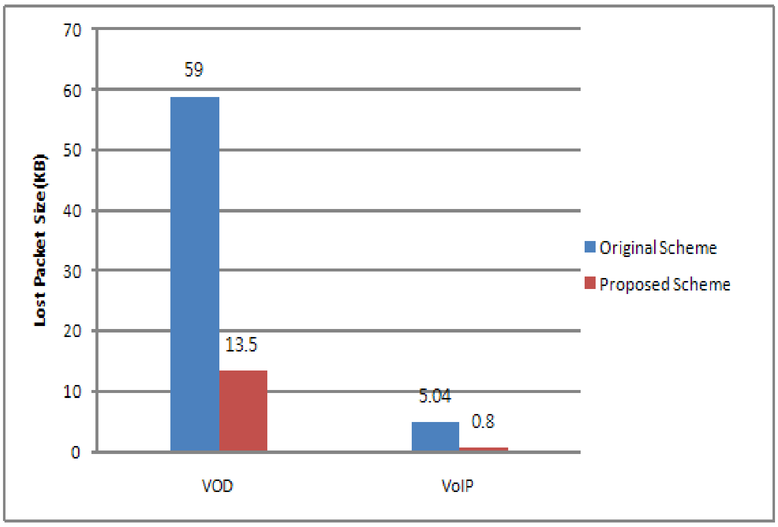


Fig. 10. Average size of lost packets in vertical handover

5. Conclusion

In this paper, we proposed a cross-layer optimization scheme for vertical handovers between mobile WiMAX and 3G cellular networks. Our proposed cross-layer scheme reorders and/or parallelizes L2 and L3 signaling messages, and reduces the number of signaling messages by combining L2 and L3 messages for a vertical handover. Finally, we achieved high handover performance, which was validated via extensive ns-2 simulations.

Since we considered mobile WiMAX, 3GPP, and 3GPP2 standards, these needed to be adapted to our proposed scheme, because we included more functionality in the standard L2 signaling messages. However, to the best of our knowledge, our cross-layer optimization scheme is the first approach handling vertical handovers. The proposed handover latency is a lower bound, because we cannot reduce the number of signaling messages any further.

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