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

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

I. INTRODUCTION

Recent advances in wireless communication technologies have been evolving various wireless networks and new network generations. CDMA's enhanced capabilities and simplified migration path enabled the 3GPP and 3GPP2 mobile communication systems. Moreover, the number of Internet users has increased rapidly so that voice-centric services have changed into data-centric services. The cdma2000 mobile communication system has been evolved into 1xEV-DO and 1xEV-DV for high speed data services and UMTS system into HSDPA. As a result of the consecutive successful development of wireless networks, mobile WiMAX has been defined for higher bandwidth services [1]. Recently WiBro (Wireless Broadband) which is another name of mobile WiMAX has been commercialized in Korea. It has been developed to enable users to access the Internet anywhere anytime with high speed and good quality using the portable equipments such as laptops, PDAs, and smart phones. It adopts OFDMA/TDD for multiple-access and duplex schemes, and aims to provide mobility rates up to 60km/h and data service rates up to 50Mbps.

Fig. 1 shows the architecture of 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

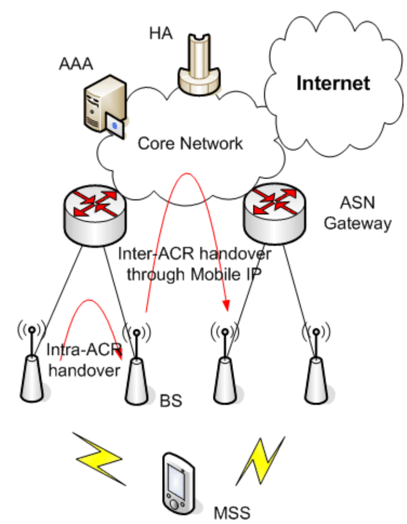

Figure 1. Network architecture of mobile WiMAX

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 takes care of 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 mobility for the MSS, a ASN Gateway supports handover among the BSs while the mobile IP provides handover among ASN Gateways as shown in Fig. 1.

In order to provide seamless services across heterogeneous wireless networks, efficient handover procedure is essentially required. As for vertical handover procedure, it is possible to use Mobile IP [3] which is generally used in for homogeneous network or its extended version, so called 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,

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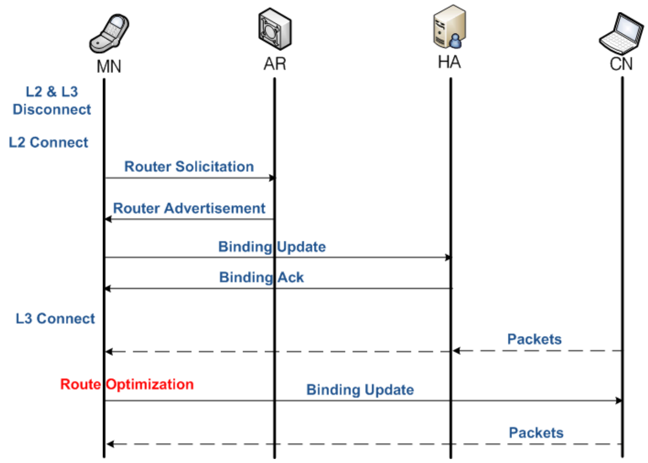

Figure 2. Mobile IPv6 procedure

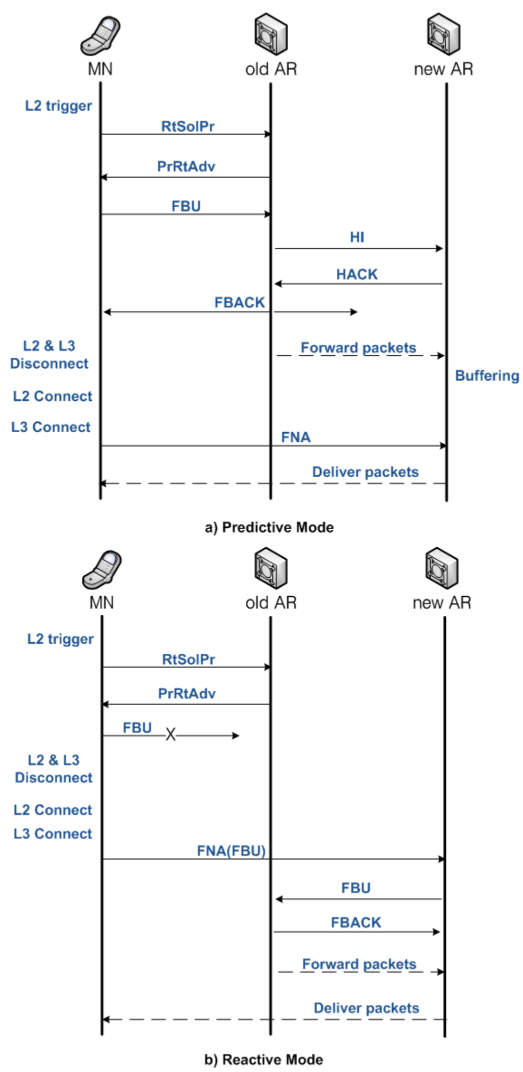

Figure 3. Fast handover procedures

they have a problem that handover latency may be quite long and packet loss can occur. In this paper, we propose a cross-layer optimization of vertical handovers between mobile WiMAX and 3G cellular networks. The proposed cross-layer scheme analyzes and reorders/combines L2 and L3 signaling messages for vertical handover so that we can obtain high handover performance which has been validated through 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.

II. Related Work

A. Mobile IPv6 and fast handovers

Although Mobile IPv6 and its extended version, so called fast handover, are well known already, we briefly introduce their call flows for understandability of this paper in Fig. 2 and Fig 3. The procedures and messages in Fig. 2 and Fig. 3 will be used in our proposed scheme. The readers can refer to [3, 4] for more detailed explanation.

B. Cross-layer optimization

There are several works related with cross-layer optimization in wireless networks. The authors in [5] proposed a cross-layer horizontal fast handover in mobile WiMAX. This work is an example of L1 and L2 cross-layer optimization. In [6], another horizontal fast handover in mobile WiMAX was presented which exploits L2 and L3 cross-layer optimization. However, this scheme reorders L2 and L3 signaling messages but there is no message reduction by combining L2 and L3 signaling messages. Mohmoodi et al. proposed a scheme to improve L4 (TCP) performance with help of L2 information [7]. These kind of works are typical examples of cross-layer optimization.

To the best of our knowledge, however, there is no vertical handover scheme exploiting cross-layer optimization and thus this paper is the first approach to the cross-layer optimization for vertical handovers.

III. Proposed Scheme

In this section, we propose our vertical handover scheme. The basic idea behind our scheme is as follows: 1) Reorder and/or parallelize L2 and L3 signaling messages. 2) Combine L2 and L3 signaling messages. Thus we can get shorter vertical handover latency and higher throughput. In what follows, Mobile IPv6 and fast handovers are cross-layer optimized according to mobile WiMAX, 3GPP, and 3GPP2 standards [8, 9, 10, 11, 12, 13].

A. Cross-layer optimized Mobile IPv6

In Fig. 2, a MN sends a `RtSol` message and receives a `RtAdv` message to get an L3 information of target network which the MN moves to. If we can deliver the information in L2 signaling messages, `RtSol/RtAdv` messages can be omitted.

Fig. 4a) depicts the proposed procedure when a MN moves to mobile WiMAX network. As we mentioned earlier, the information of ASN Gateway which the MN moves to is delivered through `MOB_NBR_ADV` L2 message, so that the

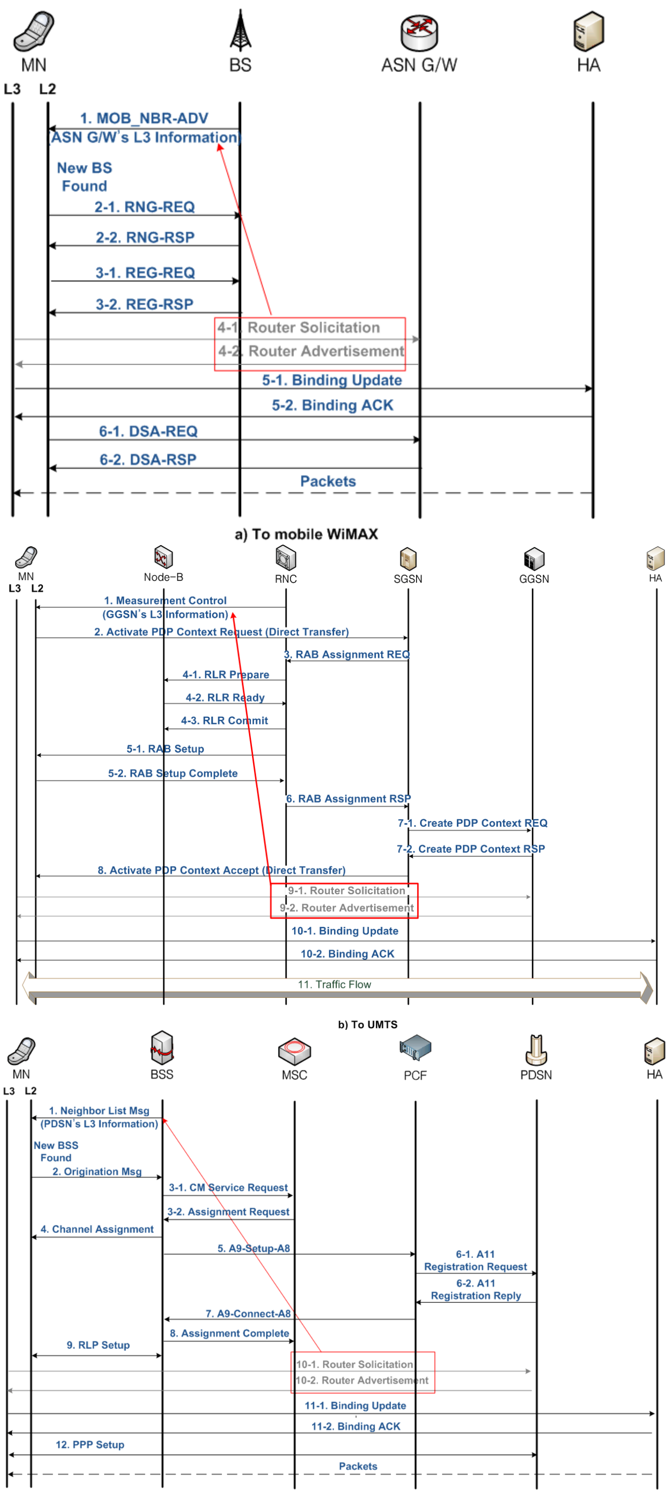

Figure 4. Cross-layer optimized MIPv6

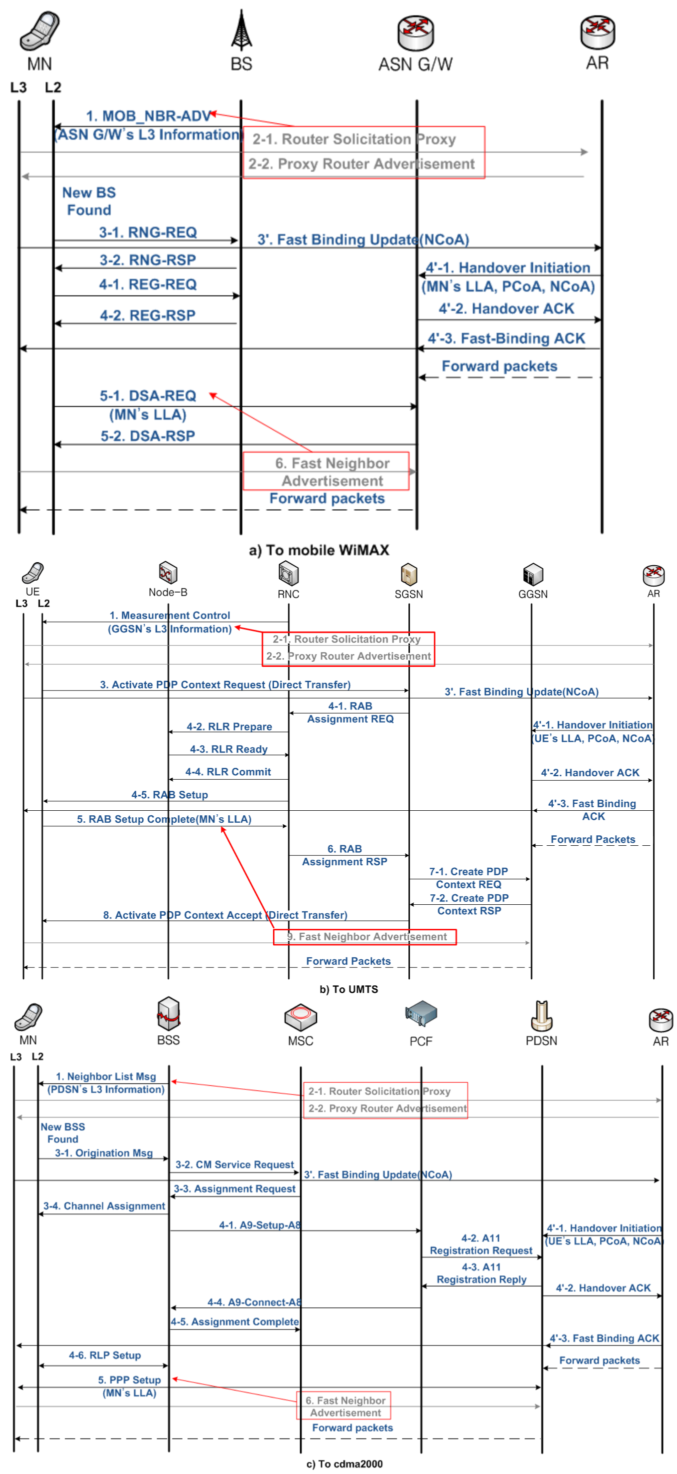

Figure 5. Cross-layer optimized fast handover: Predictive mode

RtSol/RtAdv messages need not be transmitted. In addition, L2 and L3 messages can be reordered as shown in Fig. 4a).

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

B. *Cross-layer optimized fast handover*

Similar to the Mobile IPv6 cases, if we can deliver the L3 information of target network in L2 signaling messages, `RtSolPr/PrRtAdv` messages can be also omitted in Fig. 3. In addition, `FastNeighborAdvertisement` message in Fig. 3 plays a role which indicates all the procedures are done and buffered packets can be forwarded to MN. So it can be performed through a L2 signaling message.

Fig. 5a) depicts the predictive mode fast handover procedure when a MN moves to mobile WiMAX network. The information of ASN Gateway which the MN moves to is delivered through `MOB_NBR_ADV` L2 message and thus the `RtSolPr/PrRtAdv` messages are not transmitted. In addition, `DSA-REQ` L2 message contains MN's LLA (Link Layer Address) to omit `FastNeighborAdvertisement` L3 message. Furthermore, procedures 3, 4 and 3', 4' in Fig. 5a) can be processed in parallel.

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

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

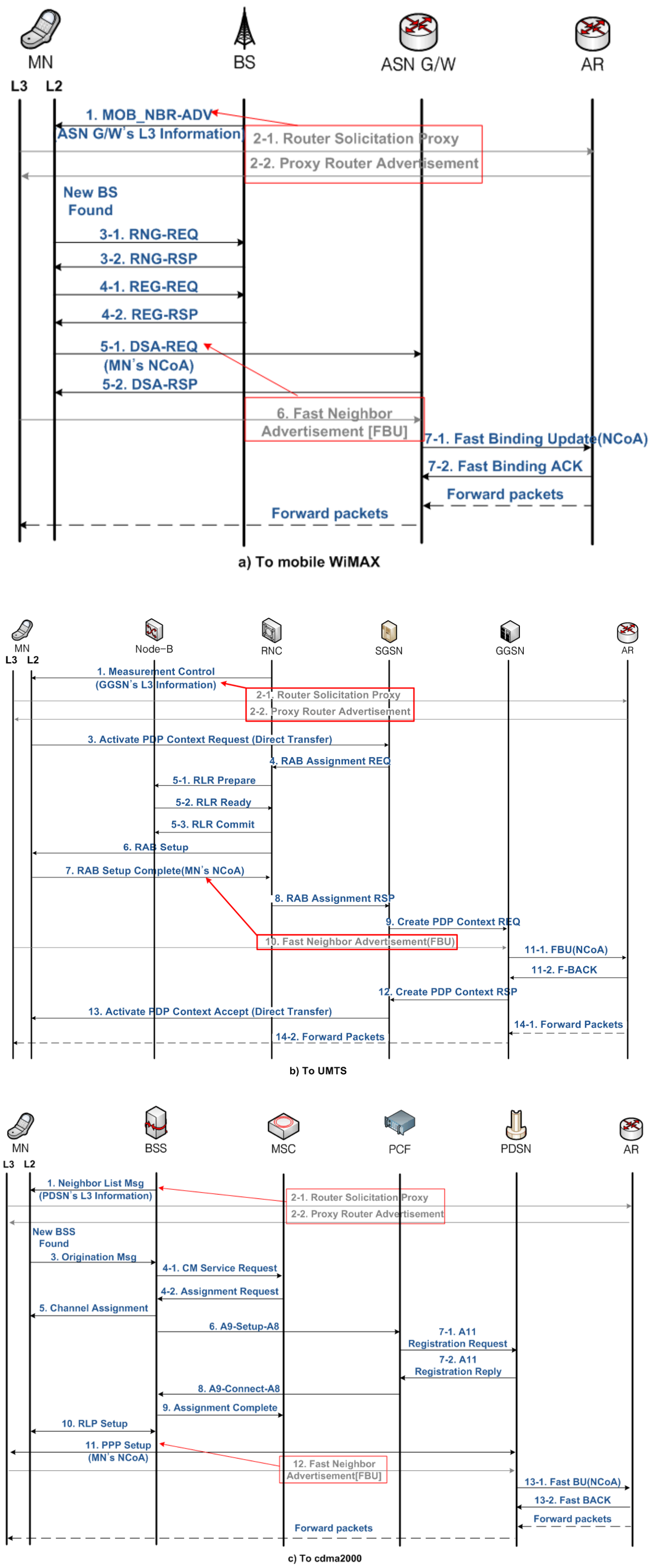

Figure 6. Cross-layer optimized fast handover: Reactive mode

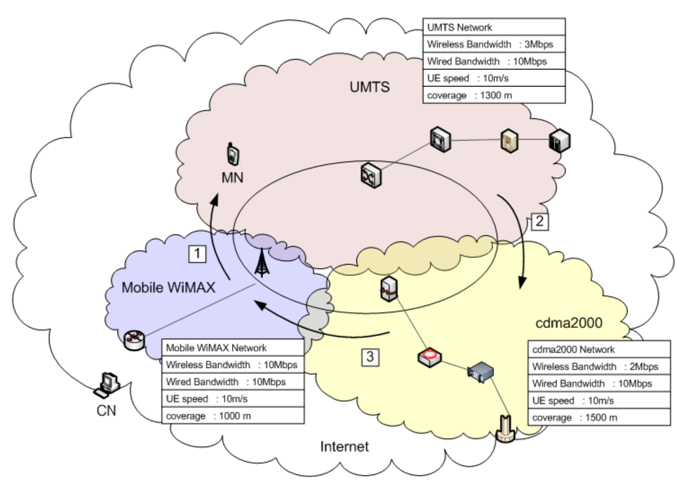

Figure 7. Simulation scenario and parameters

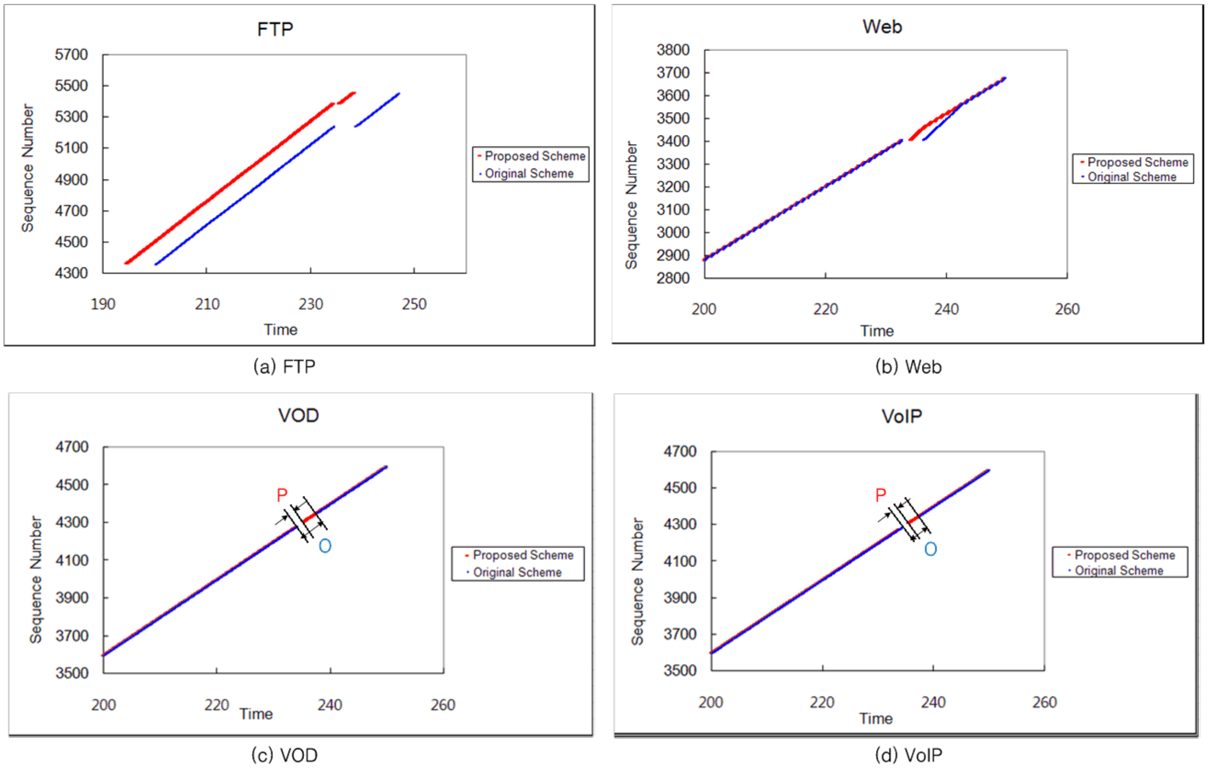

Figure 9. Packet delay given the sequence number

IV. Performance Evaluation

A. Simulation model

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

MNs move around mobile WiMAX, UMTS, and cdma2000 networks and experience vertical handovers while getting the following 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 delivered with 5fps in VOD. We assume a 16KB page is requested every one second in Web services and the file size is 2.8MB in FTP.

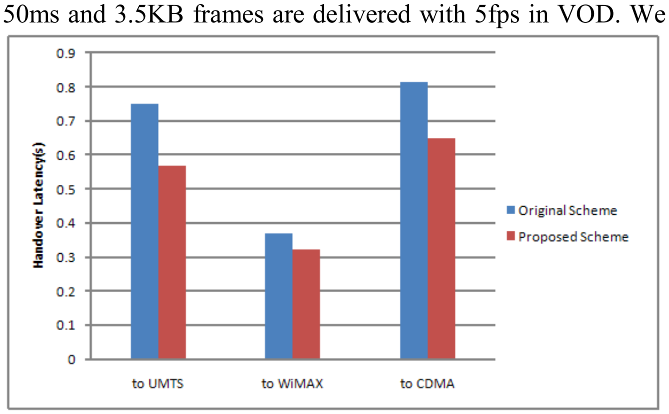

Figure 8. Average vertical handover latency

B. Simulation result

First of all, the latency of vertical handover can be calculated deterministically by summation of the delay of L2 and L3 signaling message delivery. 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:

$$T_{proposed} = 8d_1 + 4d_2 + 2d_3 \quad \text{and} \tag{1}$$

$$T_{original} = 10d_1 + 6d_2 + 2d_3\,, \tag{2}$$

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

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

In Fig. 9, the packet delay (i.e. received time of a packet given the sequence number) is depicted while a MN experiences a vertical handover to mobile WiMAX network.

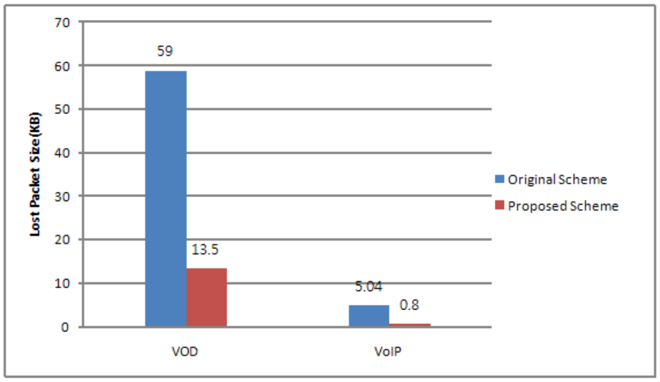

Figure 10. Average size of lost packets on vertical handover

As shown in Fig. 9, there is no packet loss in Web and FTP services because Web and FTP employ TCP as transport layer and TCP retransmits the lost packets. However, the packet delay of the proposed scheme is much smaller than that of the original MIPv6 because of the difference of handover latencies as shown in Fig. 8. In VoIP and VOD applications which use UDP as transport layer, we can find from Fig. 9 that more packets are lost in the original MIPv6 scheme when a vertical handover occurs. In Fig 9, we depict the period of packet loss for clarity: `P` for the proposed scheme and `O` for the original one. In addition, Fig. 10 shows the average size of lost packets in vertical handovers. As expected, less packets are lost in the proposed scheme, which shows the superiority of our cross-layer optimization.

V. CONCLUSION

In this paper, we have proposed a cross-layer optimization of 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 vertical handover. After all we can obtain high handover performance which has been validated through extensive ns-2 simulations.

Since we consider mobile WiMAX, 3GPP, and 3GPP2 standards, some modifications are required on them for our proposed scheme because we add more functionality in the standard L2 signaling messages. However, we believe our cross-layer optimization is the first approach to vertical handovers and the proposed handover latency is the lower bound because we cannot reduce the signaling messages any more.

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