A Layer 2 Scheme for Inter-RAT Handover between UMTS and WiMAX in Tight Coupling Architecture

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***Abstract*-The future B3G or 4G mobile networks will consist of heterogeneous networks, including GSM, UMTS, and WiMAX. In order to realize a seamless vertical handover (inter-RAT handover), a variety of interworking architectures and inter-RAT handover mobility managements have been proposed. In this paper we consider the tight coupling architecture to achieve the interconnection between UMTS and WiMAX systems. A novel common interworking sublayer (IW sublayer) is proposed at layer 2 on RNC, W-RNC and UE to provide a seamless PS inter-RAT handover between UMTS and WiMAX. This IW sublayer scheme, which features SR ARQ mechanism, focuses on eliminating packet loss and reducing handover latency that are common problems for most inter-RAT handover scenarios. The simulation results of the tight coupling architecture show that, compared with other context transfer schemes like buffering-and-forwarding of FMIPv6, the IW sublayer solution can achieve a lossless and prompt handover.**

Keywords - inter-RAT handover; vertical handover; UMTS; WiMAX; TCP; layer 2; tight coupling; FMIPv6

I. INTRODUCTION

The future beyond third generation (B3G) or fourth generation (4G) systems will consist of different radio access technologies (RAT), such as GSM/GPRS, UMTS, WIFI, and WiMAX. Many intensive efforts have been made to identify the unsolved issues about the future mobile system, and one important issue is what the future vertical handover management solution will be. A variety of mobility management solutions have been proposed, such as MIPv6/FMIPv6 [8], SCTP, inter-RAT (Radio Access Technologies) handover of 3GPP [4][5]. Among these solutions, the layer 2 inter-RAT handover solution of 3GPP is a promising way for its high reliable handover procedure. Unfortunately, they do not support inter-RAT handover between WiMAX (Worldwide Interoperability for Microwave Access) and UMTS (Universal Mobile Telecommunications System). Another important issue is the interworking architecture or the coupling scenario that is used to provide an efficient inter-RAT handover management. Depending on where is the coupling point, there are several interworking architectures: no coupling, loose coupling, tight coupling, and very tight coupling (integrated coupling) [1]. The loose coupling and tight coupling architectures, which often use Mobile IP or part of Mobile IP as the handover management protocol, require less complicated modifications to the existing protocol stacks and are more flexible than integrated coupling, although they often suffer from longer handover latencies varying from some hundreds of milliseconds to some seconds. In our project of inter-RAT handover between UMTS and WiMAX, we propose a layer 2 inter-RAT handover framework for the tight coupling architectures. A new common sublayer named IW (InterWorking) sublayer, and an SR ARQ mechanism are introduced to resolve several typical inter-RAT handover problems, such as packet loss, high handover latency, and false fast retransmit. In this article, we will show the advantage of this layer 2 solution in comparison with the FMIPv6 which is often used in the tight or loose coupling architecture.

The rest of the paper is structured as follows. Section II addresses the IW sublayer and its working mechanisms in the tight coupling architecture. In section III, the simulation scenarios and parameters are specified. The detailed simulation results as well as the comparison with the buffering-and-forwarding scheme of FMIPv6 are given in section IV. Finally, conclusions are drawn in section V.

II. IW SUBLAYER AND SR ARQ MECHANISM

A. The IW Sublayer in the Tight Coupling Architecture

In the tight coupling scenario, the WiMAX network may emulate a RNC (Radio Network Controller) or a SGSN (Serving GPRS Support Node). We only consider RNC emulation in our project. Thus, we introduce a new network component called RNC emulator for WiMAX (W-RNC) in the WiMAX access network, which connects with the UMTS CN (Core Network) at the Iu-PS interface shown in Fig. 1. Actually, the W-RNC is an enhanced WiMAX BS with a novel sublayer named IW sublayer, which lies on the top of WiMAX MAC (Medium Access Control) sublayer. The W-RNC with the IW sublayer has the following functions: *1)* Realize Iu-PS interface. *2)* Perform the signaling translation and message exchange between SGSN and WiMAX BS. *3)* Primitive creations between the IW and the UMTS network or between the IW and the WiMAX network in case of an inter-RAT handover. *4)* When an inter-RAT handover takes place, the IW sublayer functions as the LLC sublayer of conventional cellular

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networks by enabling the SR ARQ (Selective Repeat ARQ) mechanism that includes packet segmentation, re-sequencing, retransmission, and retransmission window size adjustment. (In what follows, the SR ARQ mechanism realized in IW sublayer is called IW ARQ.) *5)* When a handover takes place, the IW sublayer transfers context to target RNC or W-RNC where the counterpart sublayer locates. In order to provide a seamless inter-RAT handover between UMTS and WiMAX, a peer IW sublayer shall also be realized on the top of the PDCP sublayer on the conventional RNC; while on the UE, the IW sublayer is a common sublayer on the top of the PDCP sublayer of UMTS and the MAC sublayer of WiMAX (see Fig. 1).

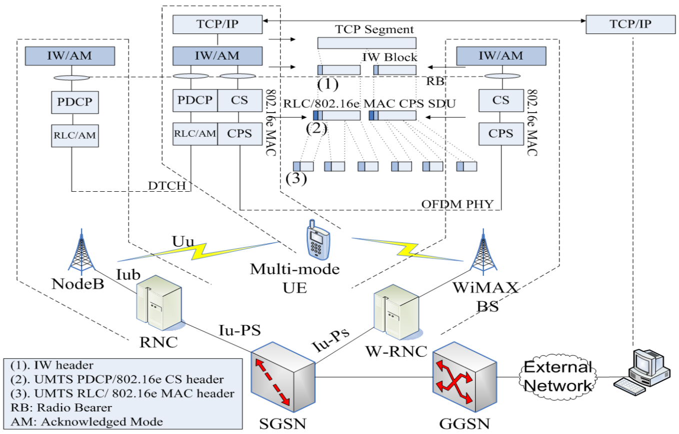

Figure 1. User plane protocol stacks in tight coupling architecture

There are two reasons why add IW ARQ mechanism to W-RNC in addition to SRNS (Serving RNS) context transfer of conventional RNC are in that: *1)* When an inter-RAT handover takes place, there may exist packet sequence number asynchronization between the source RNC and the target WiMAX BS. It is necessarily that there exists a common context transfer mechanism for these two systems to assure a lossless handover. *2)* The second reason is that the WiMAX supports cell reselection initiated by UE for active traffics (dedicated mode in UMTS), which is prohibited in UMTS. Hence the packet lost during cell reselection from WiMAX to UMTS can not be retransmitted by the target network.

B. *Signaling and Primitives*

This section describes the inter-RAT handover signaling procedures and primitives among IW, PDCP, RRC (Radio Resource Control) and WiMAX MAC in the tight coupling architecture, which are implemented in our simulation scenario. (In the following figures, IW/RNC means the function combination of IW sublayer and RNC, so are the IW/W-RNC and MAC/W-RNC). Some newly added cross-layer primitives are augmented to the conventional inter-RAT handover signaling procedures of 3GPP [4][5]. We suggest the future WiMAX and UMTS standards should support these primitives and parameters for the smooth inter-RAT handover.

Generally, the inter-RAT handover consists of handover preparation phase and handover execution phase [5]. In the case of a handover from UMTS to WiMAX, when the inter-RAT handover conditions e.g. low RSSI or load increase, are met, the UE is instructed by the RNC to enter into compressed mode of the handover preparation phase. In the compressed mode, the UE provides the network with its measurement results of the target network using Measurement Reports message. Meanwhile, other important wireless link parameters, such as round trip time (RTT), BDP (Bandwidth Delay Product) are also calculated by the RNC. After that, the inter-RAT handover will enter into execution phase if the RNC makes a positive handover decision. In the case of a handover from WiMAX to UMTS, the scanning period [9] can be considered as the compressed mode of WiMAX.

1) Handover from UMTS to WiMAX

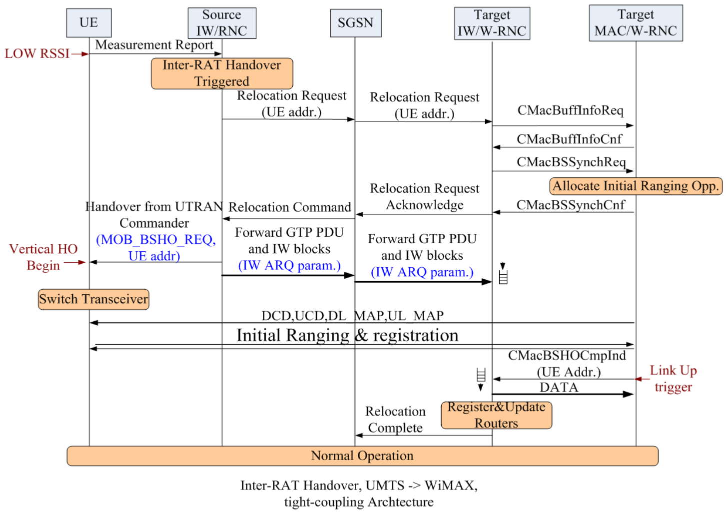

Figure 2. Signaling procedure of the handover from UMTS to WiMAX

Fig. 2 describes the inter-RAT handover from UMTS to WiMAX and shows the exchanged messages. *1)* Based on measurement reports and knowledge of the RAN topology, the RNC, more precisely source RRC decides to initiate an inter-RAT PS handover. *2)* The source RNC sends a Relocation Request (contains target WiMAX cell id) message to the SGSN. The SGSN forwards Relocation Request message to target W-RNC. *3)* Then the IW of target W-RNC sends the CMacBuffInfoReq primitive to the WiMAX MAC to request the buffer characteristics. The WiMAX MAC returns the CMacBuffInfoCnf primitive to inform the IW of the buffer size in its MAC sublayer. According to this information, the target IW adjusts its retransmission window size. (It should be mentioned at this point that current WiMAX MAC does not support this interface, so the IW may adjust its retransmission window size to a default value). *4)* At this stage, the target IW sends the CMacBSSynchReq primitive to the WiMAX MAC to negotiate the location of the dedicated initial ranging transmission opportunity for the UE. This information is returned by primitive CMacBSSynchCnf. *5)* The target W-RNC sends the Relocation Request Acknowledge message to SGSN, and the SGSN continues the handover by sending a Relocation Command to source RNC (including Transparent Container (MOB_BSHO-REQ)). *6)* Upon receipt of Relocation Command message, the IW of source RNC will forward IW context to target IW of W-RNC. The IW context consists of IW ARQ parameters, received IW ACK and remaining IW blocks which have not been transmitted successfully. *7)* The RRC of the source RNC sends the Handover from UTRAN Command message to the UE. *8)* The UE performs hard handover and normal network entry procedure. *9)* After the provisioned service flow is activated, the target WiMAX MAC sends CMacBSHOCmpInd primitive as a Link UP (LU) trigger to the IW sublayer. On this trigger, the IW starts data packet forwarding.

2) Handover from WiMAX to UMTS

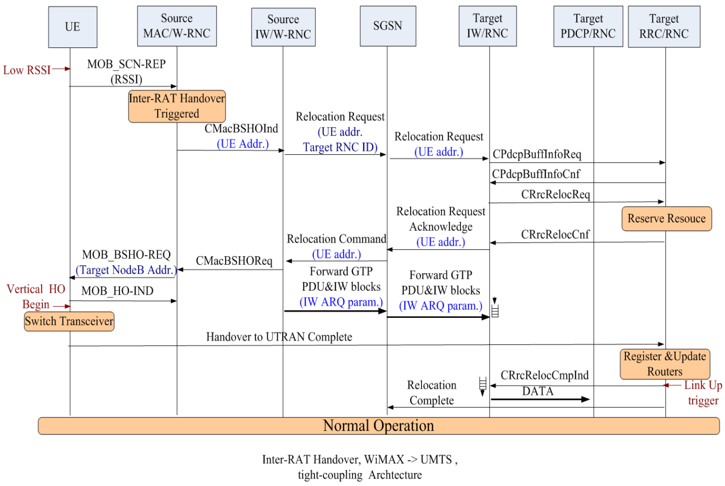

Figure 3. Signaling procedure of the handover from WiMAX to UMTS

The inter-RAT handover from WiMAX to UMTS is described in Fig. 3. *1)* After the scanning interval, the UE sends scanning report to WiMAX serving BS by message MON_SCN-REP which contains physical information such as mean RSSI. *2)* The source WiMAX MAC sends CMacBSHOInd primitive to inform the IW sublayer of handover and target cell id. Then, the source W-RNC sends a Relocation Request (contains target cell id) message to the SGSN. The SGSN forwards Relocation Request message to target RNC. *3)* The IW of target RNC sends CPdcpBuffInfoReq primitive to the RRC sublayer to request the buffer characteristics of the PDCP sublalyer, and RRC returns the CPdcpBuffInfoCnf primitive to inform the IW of buffer size. According to this information, the IW adjusts its retransmission window size. *4)* The target IW sends a CRrcRelocReq primitive to the target RRC to apply for resource allocation. The result is returned in CRrcRelocCnf primitive by the target RRC. *5)* The target RNC sends the Relocation Request Acknowledge message (contains target RNC to source W-RNC transparent Container) to SGSN. The SGSN continues the handover by sending a Relocation Command to source W-RNC. *6)* On receipt of Relocation Command message, the IW of source W-RNC will forward IW context to the IW of target RNC. The IW context consists of IW ARQ parameters, received IW ACK, and remaining IW blocks which have not been transmitted successfully. *7)* The source IW sends CMacBSHOReq primitive to inform MAC that the target network is ready. *8)* The UE performs handover to one of BSs specified in MOB_BSHO-REQ and responds with a MOB_HO-IND message. *9)* UE performs normal UMTS hard handover. *10)* After the UE successfully finishes UMTS radio link setup, the target RRC shall send the CRrcRelocCmpInd primitive to the IW, and the IW starts data packet forwarding.

Note that primitive CMacBSHOCmpInd and primitive CRrcRelocCmpInd are defined as the Link Up (LU) triggers for handover from UMTS to WiMAX, and for handover from WiMAX to UMTS respectively.

C. IW ARQ and Buffering-and-Forwarding (B&F)

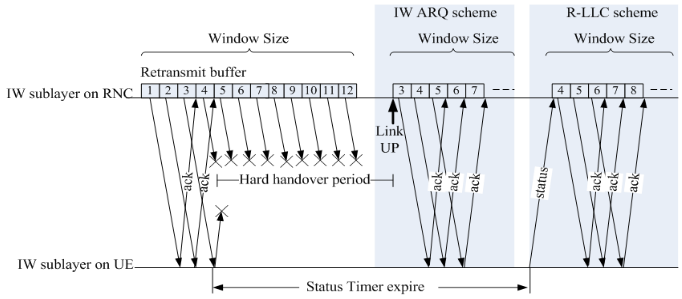

Figure 4. IW ARQ and R-LLC protocol: a example of time evolution

For the sake of achieving lossless inter-RAT handover, a modified Selective Repeat ARQ (SR ARQ) mechanism is applied to the IW sublayer. The ARQ is an error control mechanism that involves error detection and retransmission of lost or corrupted packets. Compared with conventional SR ARQ mechanism of RLC sublayer, the IW ARQ has the following features: *1) Receiver-Driven scheme:* the received status and ACK/NACK are sent back on receipt of an IW block initiatively by receiver without transmitter's polling message. *2) Support Link Up (LU) trigger:* when a handover is finished, the target network will signal the IW sublayer with a link up trigger. On receipt of this trigger, the IW sublayer will retransmit blocks in the retransmit buffer to avoid unnecessary waiting time for a timeout of status report. *3) Adaptive Window Size:* In order to avoid any buffer overflow in the target network, when the packets are retransmitted by the IW sublayer after a handover is over, the IW ARQ window size is adaptively set to buffer size of the target network.

In Fig. 4, an example of the IW ARQ mechanism when the window size is 12 is depicted. The right parts are two retransmission mechanisms: IW ARQ and R-LLC [7]. In this figure, the difference between them is in that the lost blocks are retransmitted when status report timer expires in R-LLC scheme, while IW ARQ retransmits blocks not only on status report timer timeout but also on Link Up trigger.

Another often used context transfer is buffering-and-forwarding (B&F) scheme which has been applied in FMIPv6 [8]. In FMIPv6 protocol, in order to make a handover lossless, previous access router (PAR) will forward buffered packets destined to the UE during the handover period to the new access router (NAR) through an established tunnel, after receiving the new care-of-address (NCoA) of the UE from the NAR. For fairly comparing the inter-RAT handover performance of IW sublayer solution with that of FMIPv6, we also realize the B&F scheme in the IW sublayer in our inter-RAT handover scenario, where the RNC or W-RNC takes the responsibility of buffering and forwarding. This kind of layer 2 realization considers the fact that the conventional IP sublayer terminates on the GGSN in the UMTS network, which suffers from longer transmission delay between the UE and the GGSN. It must be stressed that this layer 2 realization of B&F has better performance than IP layer realization like FMIPv6 thanks to the ability to directly operate layer 2 data packets stored in one RAT. In the simulation section, we will inspect these two kinds of context transfer schemes in the tight coupling architecture. If the handover performance of IW ARQ is better than that of B&F in layer 2, it can be concluded that the IW sublayer solution is much suitable for inter-RAT handover than FMIPv6.

III. Simulation Environment

In order to analyze the performance of the IW sublayer during inter-RAT handover between UMTS and WiMAX, network-level simulations are carried out using NS2 [10] for the tight coupling architecture. Several extensions are made to NS2 simulator, UMTS and WiMAX models, IW sublayer and new signaling and primitive additions. The topology used for simulation analysis is illustrated in Fig. 5. There is only one UE with two transceivers and no other background traffics in this “clean” scenario. The UE always has enough bandwidth to send packet whether it is in WiMAX region or in UMTS region. Note that in this topology, the transmission delay in the wired network is set very small deliberately to minimize its influence to handover procedure. An FTP session with the constant segment size is examined, with the CN designated as the sender and the UE designated as the receiver. In UMTS module, a drop-tail policy is applied to radio network queues in PDCP. This queue length is set to 25 IW block, while the queue length of WiMAX module is set to 50 IW blocks, which considers the fact that generally the bandwidth of WiMAX is much higher. Other important simulation parameters are summarized in Table 1.

TABLE I. Simulation Parameters

	Parameter	value		Parameter	value
IW	Fragment Switch	OFF	UMTS PHY	TTI (ms)	10
	Max retransmit count	10		Frame Duration(ms)	10
	Default Window size (block)	30		BLER	1e-6
	Status Report Timer (s)	2.5	WiMAX MAC	Allocated data rate	unlimited
PDCP	TCP/IP Header compression,and Retransmission	no		Queue length	50
	Allocated data rate	64kb/s		Payload Header Suppression	no
	Queue length	25		Frame duration (ms)	4
RLC	RLC Mode	AM	WiMAX PHY	Modulation	OFDM
	Windows size (Blocks)	500		Interleaving interval (frames)	50
	Block size (Bytes)	20		FFT	256
	maxDAT	20		Number of subcarrier used	200
	Ack timerout period (ms)	50	TCP/IP	variant	Reno
				MSS (bytes)	512
				default cwnd	32

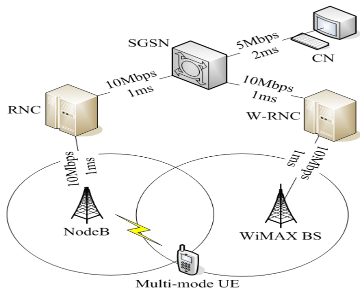

Figure 5. Simulation topology

IV. Simulation Results

A. UMTS to WIMAX Handover

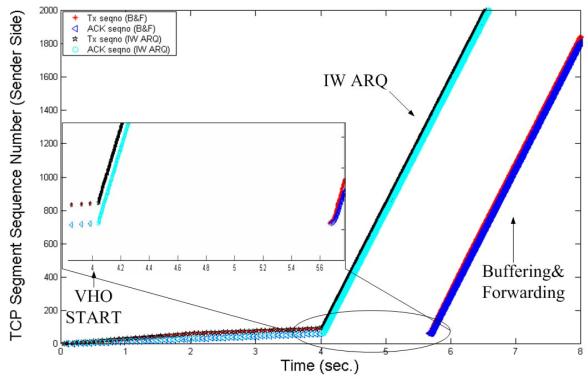

Figure 6. TCP segment number comparison (umts->wimax, sender side)

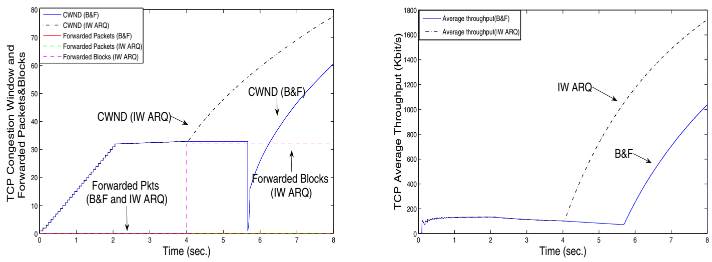

Figure 7. TCP congestion window (left) and average throughput (Kbit/s, right) (umts->wimax)

For the simulation of inter-RAT handover from UMTS network to the WiMAX, an FTP session starts at 0.4s, and the UE starts to perform handover at about 4s after it enters into the coverage region of WiMAX. The handover type is hard handover. At about 4.035s, the WiMAX network entry procedure is finished and the IW sublayer on the RNC receives a Link Up (LU) trigger. Fig. 6 shows the packet flows of two kinds of context transfer schemes: buffering-and-forwarding (B&F) and IW ARQ.

During the handover period, there are no new TCP segment arrivals and consequently no segments are forwarded through the tunnel between RNC and W-RNC for both context transfer schemes (see Fig. 7). One can see in Fig. 7 that, in B&F scheme, the TCP sender retransmits the last unacknowledged segment on the timeout of TCP retransmit timer (RTO) at about 5.7 sec. During this period, the congestion window shrink to one, and throughput reduced significantly. The IW ARQ scheme adjusts its retransmit window according to the target network's queue size, and sends the IW blocks that are forwarded from the source IW on receipt of Link Up trigger. After the handover, there will be no packet losses and TCP congestion window does not shrink thanks to the SR ARQ mechanism. The TCP average throughput is depicted in Fig. 7 (right) and shows that the IW ARQ scheme performs better than B&F scheme.

B. *WiMAX to UMTS Handover*

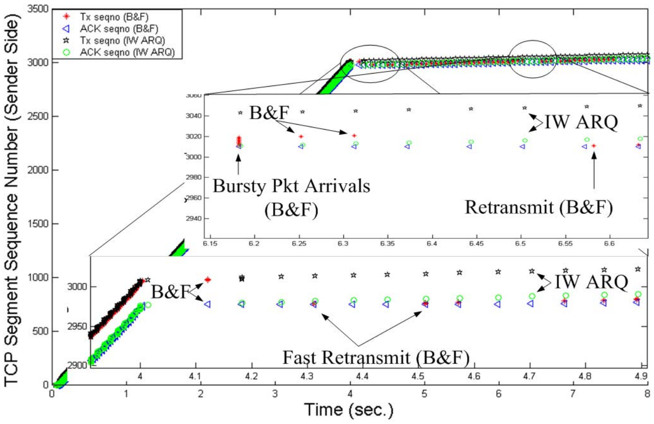

Figure 8. TCP segment number comparison (wimax->umts, sender side)

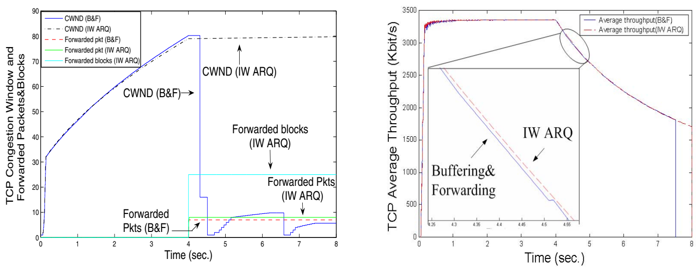

Figure 9. TCP congestion window (left) and average throughput (Kbit/s, right) (wimax->umts)

When a handover from WiMAX to UMTS happens, there exist some TCP segments and IW blocks which are forwarded from W-RNC to RNC through a tunnel for two schemes, shown in Fig.9. For B&F scheme, the arrivals of tunneled segments (about 8 segments) trigger the fast retransmissions twice at time 4.31s and 4.51s for the lost segments during the handover (see Fig. 8), and then congestion window size reduces significantly. From then on, the TCP sender retransmits the segments numbering from the first lost segment to the tunneled packets. The receiver will acknowledge again those segments that have been tunneled before at about 6.18, which herein trigger the bursty segment arrivals. Furthermore, those retransmitted segments that have been tunneled during handover delay the ACK arrivals of new segments, and in consequence lead to a retransmission cause by RTO at 6.58s. We can see that, the B&F scheme degrades the handover performance instead of improving it for TCP traffics due to the lack of a mechanism that recovers the lost packets. For IW ARQ scheme, there is no packet loss during the handover. The support of Link Up trigger accelerates handover response time, and the adaptive IW ARQ window size effectively eliminates buffer overflow in the target UMTS network. The only price for this zero loss handover procedure is that the IW sender may retransmit a couple of IW blocks that possibly has been received by IW receiver but the corresponding ACKs are lost during the handover period. In Fig. 9, the average throughput among two schemes is not apparent in short-term, because the total amount of throughput is dominated by that of WiMAX and the small throughput reduction during handover period does not influence the average throughput significantly.

V. CONCLUSION

This article provides a novel layer 2 inter-RAT handover solution on basis of the tight coupling architecture for the seamless roaming between UMTS and WiMAX networks. In layer 2, a new sublayer named IW sublayer, is added on the top of PDCP (UMTS) and MAC (WiMAX) sublayer on the UE, on the top of PDCP on a RNC, and on the top of MAC (WiMAX) on a RNC emulator for WiMAX (W-RNC). Compared with other context transfer schemes, such as buffering-and-forwarding of FMIPv6, IW sublayer solution can achieve lossless and prompt handover procedure for TCP traffics thanks to the introduction of SR ARQ mechanism. The better handover performance is validated by the simulation results carried out on the NS2 emulator.

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