

A Layer 2 Scheme of Inter-RAT Handover between UMTS and WiMAX

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Abstract—The future B3G or 4G mobile networks will consist of heterogeneous networks, including GSM, UMTS, WiMAX and WIFI. 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. Based on the integrated coupling architecture, we propose a novel common interworking sublayer (IW sublayer) at layer 2 on RNC and UE to provide a seamless PS inter-RAT handover between UMTS and WiMAX systems. This IW sublayer scheme focuses on eliminating packet loss and reducing handover latency which are common problems for most inter-RAT handover scenarios. Compared with other context transfer schemes, the simulation results show the IW sublayer with ARQ mechanism can achieve a lossless and prompt handover procedure. In addition, this IW sublayer scheme can eliminate false fast retransmit of TCP traffics which is usually caused by packet losses or out-of-order packet arrivals.

Keywords- *inter-RAT handover; vertical handover; UMTS; WiMAX; TCP; layer 2; integrated coupling*

I. INTRODUCTION

The future beyond third generation (B3G) or fourth generation (4G) systems will consist of different radio access technologies, 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 [9], SCTP [13], 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, the 3GPP inter-RAT solutions only support inter-RAT handover between cellular networks, and 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 and 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, very tight coupling (integrated coupling) [1]. Compared with tight and loose coupling

architectures, the integrated coupling generally achieves better handover performance at expense of adding complex modification to existing network protocol mechanism. In our project on inter-RAT handover, we adopt it as the base interworking architecture for integrating UMTS with WiMAX. Moreover, we propose a novel layer 2 inter-RAT handover scheme by introducing a new common sublayer named IW (InterWorking) sublayer and SR ARQ (Selective Repeat ARQ) mechanism to resolve several typical inter-RAT handover problems, such as packet loss, long handover latency and false fast retransmit.

The rest of the paper is structured as follows. Section II addresses the problems which often appear during an inter-RAT handover, and presents some existing solutions. The IW sublayer and its working mechanisms are described in detail in section III. In section IV, the simulation scenarios and parameters are specified. The detailed simulation results are given in section V. Finally, conclusions are drawn.

II. CONTEXT TRANSFERS FOR INTER-RAT HANDOVER

The problems about inter-RAT handover have been extensively studied in [1-3][7-9], such as long handover latency, BDP (Bandwidth Delay Product) mismatch, delay spikes, packet losses, premature timeout, false fast retransmit. Among these problems, the packet losses and long handover latency are in particular not desirable for real-time and throughput-sensitive traffics. The most common solution is applying context transfer [8][9] or retransmission [7] mechanism to accelerate the handover process or reduce the amount of data loss.

J. Sachs [8] proposes the SDU (Service Data Unit) reconstruction scheme. In order to make a handover lossless, a data packet that is already segmented and stored in the PDU (Packet Data Unit) buffer of source link is first reconstructed back to a SDU and then forwarded to the target link as well as the SDUs from the SDU buffer. When these proposals are applied to the inter-RAT handover from UMTS to WiMAX or from WiMAX to UMTS for TCP traffics, the traffic performance may still degrade, for the following reasons: 1) If a PDCP (Packet Data Convergence Protocol) PDU sequence number asynchronization takes place just before a inter-RAT handover from UMTS to WiMAX, the asynchronization problem can not be resolved by WiMAX system. This leads to

an unreliable handover procedure. 2) A RLC (Radio Link Control) SDU whose corresponding RLC PDUs have not been successfully transmitted in total, can not be reconstructed and will be discarded locally. In [7] a novel sublayer called R-LLC (Link Layer Control) locating on the BTS is proposed. This R-LLC sublayer takes the role of conventional LLC, and retransmits packets lost during inter-RAT handover when the retransmission timer expires. The simulation results in [7] demonstrate zero packet loss for handover and cell reselection procedures. However, the packet loss is only indicated by retransmission timer timeout which is set to 5 sec. Such a long period is unfavorable to keep TCP congestion window from shrinking. In addition, the configuration of retransmission window is not specified. In our project, we will provide a more applicable inter-RAT handover scheme at layer 2 for TCP traffics.

III. IW SUBLAYER

A. IW Sublayer Description

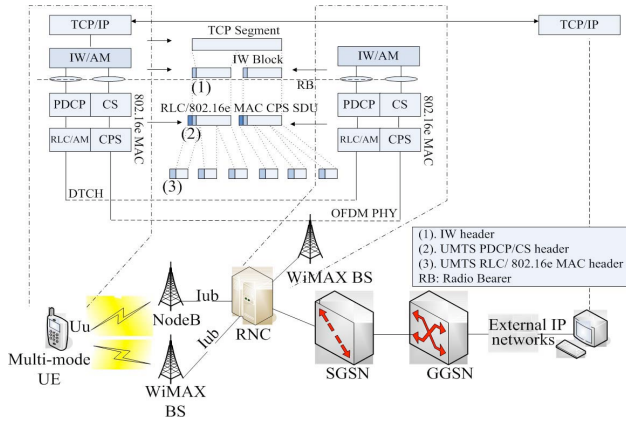


Figure 1. IW sublayer working mechanism of integrated coupling

As stated above, our inter-RAT scheme is based on the integrated coupling architecture. A novel common network entity named interworking sublayer (IW) is introduced on the top of PDCP (Packet Data Convergence Protocol) sublayer of UMTS and the Medium Access Control (MAC) CS sublayer of 802.16e on the RNC and UE, shown in Fig. 1. The WiMAX BS is integrated with the RNC (Radio Network Controller) through Iub interface. IW takes the role of LLC sublayer of conventional cellular networks, such as retransmission mechanism and handover support. The main functions of IW sublayer are: 1) Determination of a suitable target network. 2) Primitive creation between the IW and the UMTS network or between the IW and the WiMAX network in case of inter-RAT handover. 3) SR ARQ (Selective Repeat ARQ) mechanism, including packet segmentation and re-sequencing, retransmission, and retransmission window size adjustment.

B. Signaling and Primitives

In order to have insight into IW sublayer working mechanism, this section describes the inter-RAT handover signaling procedures and primitives among IW, PDCP, RRC (Radio Resource Control) and WiMAX MAC, which are implemented in our simulation scenario. Some newly added

cross-layer primitives are added 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. During 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 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 [10] can be considered as the compressed mode of WiMAX.

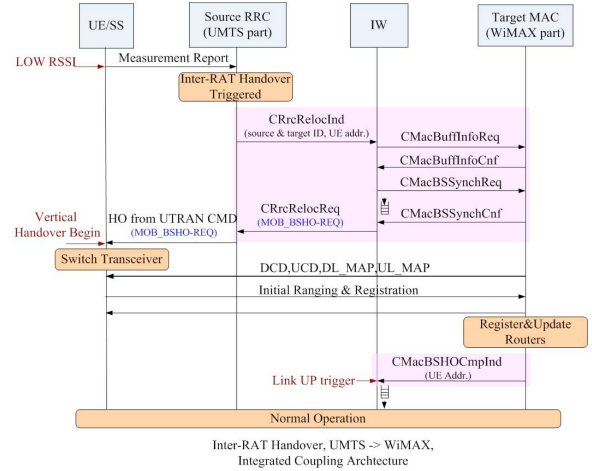


Figure 2. Handover signaling procedure from UMTS to WiMAX

Fig. 2 describes the inter-RAT handover from UMTS to WiMAX and shows the exchanged messages and primitives. 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 RRC sends the CRrcRelocInd primitive (contains target WiMAX cell id) to the IW. 3) Then the IW sends the CMacBuffInfoReq primitive to the target WiMAX MAC to request the buffer characteristics. The WiMAX MAC shall return the CMacBuffInfoCnf primitive to inform the IW of the buffer size in its MAC sublayer. According to this information, the IW adjusts its retransmission window size. (Note 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 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) After that, the IW begins to buffer data packets that require delivery order and sends a CRrcRelocReq primitive (including Transparent Container (MOB_BSHO-REQ)) to the source RRC. 6) The RRC sends the Handover from UTRAN Command message to

the UE, which includes a MOB_BSHO-REQ. 7) The UE performs hard handover and normal WiMAX network entry procedure. 8) After the provisioned service flow is activated [10], the target WiMAX MAC sends CMacBSHOCmplInd primitive as a Link UP (LU) trigger to the IW sublayer. On this trigger, the IW shall restart data packet forwarding.

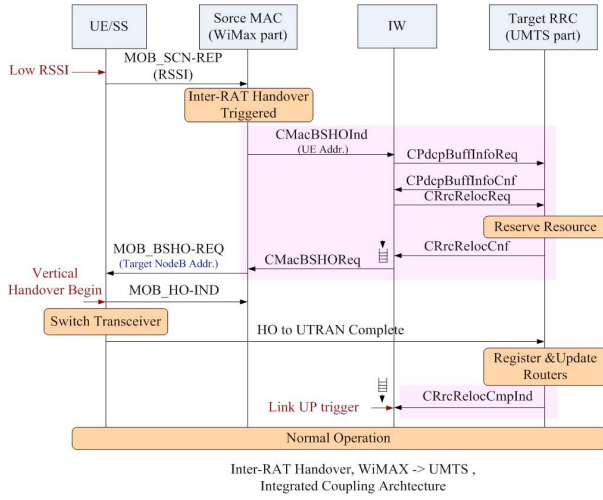


Figure 3. Handover signaling procedure from WiMAX to UMTS

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 target cell id. The IW then sends CPdcpBuffInfoReq primitive to the target RRC of the UMTS network. The RRC shall return the CPdcpBuffInfoCnf primitive to inform the IW sublayer of buffer size and buffer occupation. According to this information, the IW adjusts its retransmission window size. 3) The IW sublayer sends a CRrcRelocReq primitive to the target RRC to apply for resource allocation. The result is returned in CRrcRelocCnf primitive by the target RRC. 4) Upon receipt of the CRrcRelocCnf, the IW suspends and buffers data packets that require delivery order. 5) IW sends CMacBSHOREq primitive to inform source MAC that the target network is ready. 6) The UE performs handover to one of BSs specified in MOB_BSHO-REQ and responds with a MOB_HO-IND message. 7) UE performs normal UMTS hard handover. 8) After the UE successfully finishes UMTS radio link setup, the target RRC shall send the CRrcRelocCmplInd primitive to the IW, and the IW restarts data packet forwarding.

Note that primitive CMacBSHOCmplInd and primitive CRrcRelocCmplInd 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 Mechanism

For the sake of achieving lossless inter-RAT handover, a modified Selective Repeat ARQ (SR ARQ) mechanism is applied to the IW sublayer during the handover period. The ARQ is an error control mechanism that involves error

detection and retransmission of lost or corrupted packets. When a packet is accepted from upper layer, it is segmented into smaller IW blocks, each of which is assigned a sequence number (see Fig. 4). This new IW sub-header is used for block loss detection and block re-sequencing in the receiver to guarantee in-sequence delivery. Afterward, each IW block is transmitted through the UMTS or the WiMAX interface. These IW blocks are also queued in the retransmit buffer in order to be scheduled for retransmission. The IW ARQ transmitter maintains an adaptive window size which is set to target network buffer size. When an IW block is received by the receiver, a positive or negative acknowledgement (ACK/NACK) is sent back immediately for the purpose of reducing handover latency. In addition, in order to avoid dead lock due to IW ACK/NACK losses during a handover period, a timer is set when the receiver sends an ACK/NACK. When this timer expires, the receiver sends back a status report (ARQ feedback bitmap) providing the receipt status. This status report is an acknowledgement (ACK) or negative acknowledge (NACK) of each IW block within the window. Compared with conventional SR ARQ mechanism of RLC, 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 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 retransmit buffer to avoid unnecessary waiting 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.

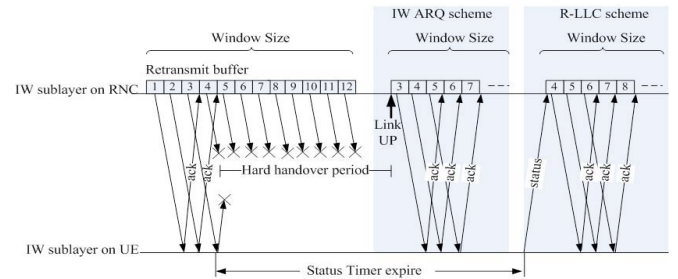


Figure 4. IW ARQ and R-LLC protocol: a example of time evolution

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. 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 this timer but also on Link Up trigger.

IV. 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 [12]. Several extensions are made to this simulator, UMTS and WiMAX models, IW sublayer, multi-channel model, IW ARQ

mechanism and new signaling and primitives. 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 is examined, with the CN designated as the sender and the UE designated as the receiver. We focus on the problems of packet loss and handover latency, while BDP mismatch, spurious RTO problems for the TCP traffics are our future work. In UMTS module, a drop-tail policy is applied to radio network queues in PDCP and this queue length is set to 25 IW blocks. As to the WiMAX module, the queue length 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.

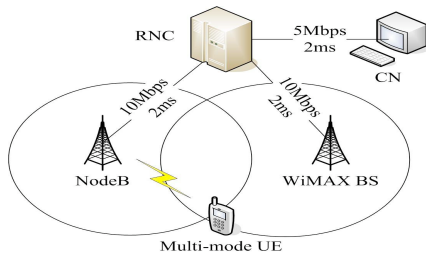


Figure 5. Simulation topology

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 Windows 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

V. SIMULATION RESULTS

A. UMTS to WiMAX Handover

For the simulation of inter-RAT handover from UMTS network to the WiMAX, an FTP session starts at 0.4 sec., and

the UE starts to perform handover at about 4 sec. after it enter into the coverage region of WiMAX. The handover type is hard handover. At about 4.035 sec. 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 three kinds of context transfer: R-LLC, SDU Reconstruction and our scheme IW ARQ.

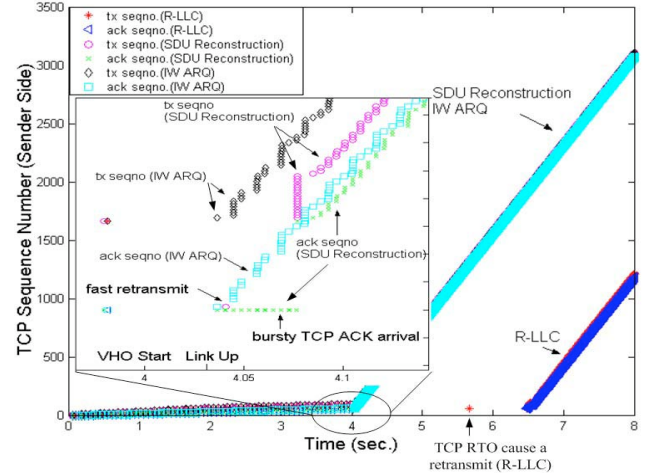


Figure 6. TCP segment number comparison (umts->wimax, sender side)

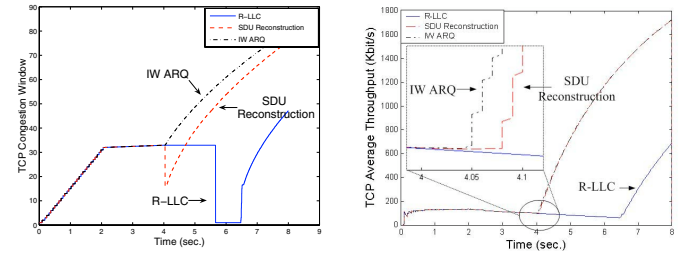


Figure 7. TCP congestion window (left figure) and average throughput (Kbit/s, right figure) (umts->wimax)

The R-LLC scheme does not support LU trigger, so it retransmits the last unacknowledged IW block on the timeout of status report timer. During this period, the TCP timer expires and the congestion window shrink to one, shown in Fig. 7. There is a retransmitted TCP segment at about 5.7 sec. The SDU Reconstruction scheme reconstructs the RLC PDUs stored in the RLC retransmit buffer. However, if one PDU of a SDU is successfully transmitted, this PDU is deleted from retransmit buffer and the remaining PDUs of this SDU cannot be reconstructed and are discarded locally. The remaining RLC SDUs (TCP packets here) are forwarded to WiMAX network after handover on RNC. These arrivals of out-of-order packets generate several duplicate ACK and trigger TCP's fast retransmit process. The TCP congestion window shrinks to half of congestion window of steady state, and the average throughput is also reduced (see Fig. 7). The IW ARQ scheme adjusts its retransmit window according to the target network's queue size and forwards the IW blocks in its retransmit buffer on receipt of Link Up trigger. After handover is over, there will be no packet losses and the TCP ACK arrivals are not as bursty

as those of SDU Reconstruction scheme thanks to the IW ARQ window mechanism (see Fig. 6 between 4 and 4.1 sec.).

B. WiMAX to UMTS Handover

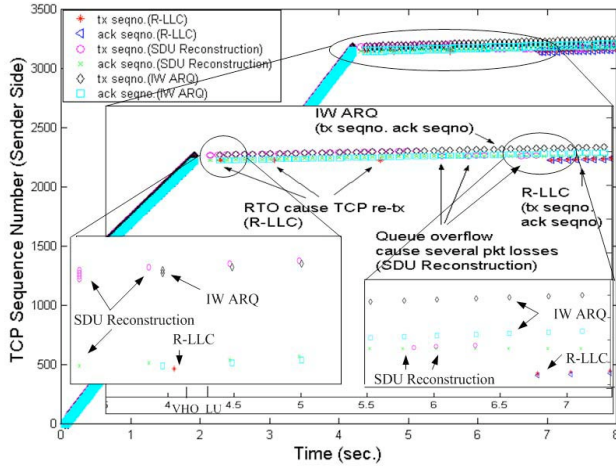


Figure 8. TCP segment number comparison (wimax->umts, sender side)

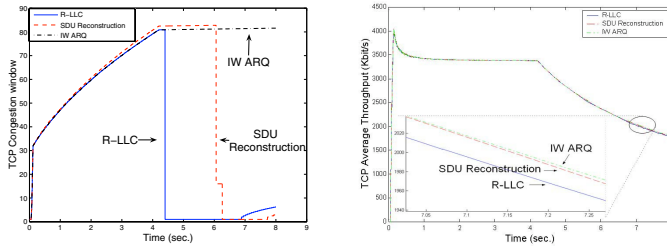


Figure 9. TCP congestion window (left figure) and average throughput (Kbit/s, right figure) (wimax->umts)

A typical problem during handover process from high bandwidth data network WiMAX to relative low bandwidth network UMTS is buffer overflow, which is caused by BDP mismatch between these two networks. The UMTS network is likely to undergo buffer overflow when a TCP congestion window for WiMAX is much larger than the buffer allocation per mobile in UMTS. For SDU Reconstruction scheme, even TCP congestion window is not larger than buffer size of UMTS, the buffered packet forwarded from WiMAX to UMTS still may have the probability to overflow the UMTS queue, because queue in WiMAX may buffer more packets than the queue size of UMTS due to inflated transmission time. For SDU Reconstruction scheme, in Fig. 8, the buffer overflows in UMTS after handover lead to TCP retransmission starting at about 6.0 sec. The corresponding TCP window shrinks, shown in Fig.9. For R-LLC scheme, the long status report period leads to TCP RTO and a segment is retransmitted by TCP sender three times before a status report timer timeout (2.5sec. in our scenario). Whereas for IW ARQ scheme, 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. It can be seen that the

lossless handover of IW ARQ mechanism has a “side effect”: eliminate the false fast retransmission caused by packet losses or out-of-order packet arrivals during a handover. In Fig. 9, the average throughput among three 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.

VI. CONCLUSION

This article provides a novel layer 2 inter-RAT handover scheme on basis of the integrated coupling architecture for the seamless roaming between UMTS and WiMAX networks. In layer 2, a new sublayer, named IW sublayer which lies on the RNC and UE, is added on the top of PDCP (UMTS) and MAC (WiMAX) sublayer. Compared with other context transfer mechanisms, such as R-LLC and SDU Reconstruction, IW sublayer can achieve lossless and prompt handover procedure for TCP traffics thanks to the introduction of SR ARQ mechanism. The better handover performances are validated by the simulation results carried out on NS2 emulator. In addition, this novel IW sublayer scheme also eliminates the false fast retransmission which is due to packet loss or out-of-order packet arrivals during a handover period.

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