A Cross-Layer Scheme for Inter-RAT Handover from WiMAX to UMTS

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Abstract- **In future mobile networks, different radio access technologies, such as GSM, UMTS, WiMAX, WIFI, will coexist. In order to realize a seamless vertical handover (inter-RAT handover) among these technologies, a variety of interworking architectures and inter-RAT handover mobility managements have been proposed. Based on an 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. In addition, an enhanced TCP proxy, which interacts with the IW sublayer, is also introduced to RNC to resolve other two typical inter-RAT handover problems of TCP traffics: BDP mismatch and spurious RTO. Compared with other vertical handover solutions, our novel inter-RAT scheme has the merits of keeping existing TCP protocol stacks unchanged and is robust to different handover scenarios. The simulation results show our total solution not only achieves a lossless and prompt handover procedure, but also accommodates BDP mismatch and prevents spurious RTO of TCP sender.**

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

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 [13], SCTP, inter-RAT (Radio Access Technologies) handover of 3GPP [10]. 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 are 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) [9]. Compared to 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. We propose a novel layer 2 inter-RAT handover scheme by introducing a new common sublayer named IW (InterWorking) sublayer and SR ARQ mechanism to resolve several typical inter-RAT handover problems, such as packet loss, high handover latency, false fast retransmit. In addition, an enhanced TCP proxy is introduced on the RNC (Radio Network Controller) to resolve BDP mismatch and spurious RTO/premature timeout problems. This novel scheme is especially suitable for frequent inter-RAT handover between different systems. To the best of our knowledge, our scheme is the first total solution aimed at resolving several typical inter-RAT handover problems at the same time.

The rest of the paper is structured as follows. Section II describes the IW sublayer and its working mechanisms. In section III, the TCP proxy and its interaction with IW sublayer are specified in detail. In section IV, the simulation scenarios and parameters are specified. The detailed simulation results are given in section V. Finally, conclusions are drawn in section VI.

II. IW SUBLAYER AND TCP PROXY SUBLAYER

The problems about inter-RAT handover have been extensively studied by numerous references [1-5]. These problems, such as long handover latency, BDP (Bandwidth Delay Product) mismatch, delay spikes, packet losses, premature timeout, false fast retransmit and spurious RTO (Retransmission TimeOut) [1], cannot be resolved in total by only one scheme at a time. None of these problems is acceptable for real-time or throughput-sensitive traffics. In order to simplify analysis, we group them into two typical types: *the packet losses/long handover latency, and BDP mismatch/spurious RTO*. As to the first type problems, the most common solution is applying context transfer [12][13] or retransmission mechanism [11] to reduce the amount of data

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loss. However, these solutions have the drawbacks of long handover delay or probable packet loss. For the first type problems, in our project, we add a novel sublayer at layer 2 which is in charge of eliminating packet loss and reducing long handover delay (see section II). The solution for second type problems will be covered in section III.

A. *IW Sublayer Description*

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 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 through Iub interface. IW plays 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 an inter-RAT handover. *3)* SR ARQ (Selective Repeat ARQ) mechanism, including packet segmentation and re-sequencing, retransmission, and retransmission window size adjustment. These IW functions are activated during a handover.

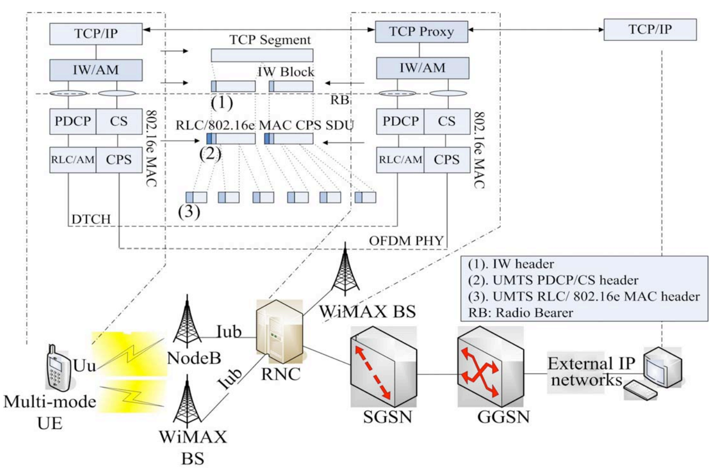

Figure 1. IW sublayer working mechanism

B. *IW ARQ Mechanism*

So as to achieve a 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. In this article, only the downlink traffic is considered. 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. 2). 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 (or to a default value). When an IW block is received by the receiver (the IW sublayer in a UE), 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 acknowledgement (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. (See section III, part B). 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 triggered, the IW ARQ window size is adaptively set to buffer size of the target network.

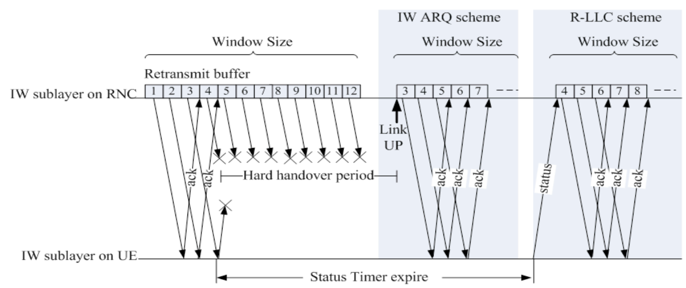

Figure 2. IW ARQ and R-LLC protocol: a example of time evolution

In Fig. 2, 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 [11]. From this figure, we can find out that the difference between IW ARQ and R-LLC solutions is 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 a Link Up trigger.

III. TCP PROXY LAYER

As to the second type, BDP mismatch and spurious RTO/premature timeouts problems, there exist many solutions. Reference [2] proposes to add an explicit handover notification in the option field of TCP header to identify the handoff situation. Evidently, this scheme needs significant modification over the existing TCP protocol stacks. In [3], a receiver based vertical handover scheme is proposed. This scheme uses MIPv6 as a mobility management protocol. As a consequence, the packet loss problem cannot be fixed by this scheme itself but by TCP retransmission mechanism. Freeze-TCP [4] use ZWA (Zero Window Advertisement) packet to make the sender freeze all re-transmit timer and enter into a persist mode. This scheme not only demands the TCP receiver to sense handover prior to disconnection, but also needs to calculate a precise "warning period" to avoid possible delayed

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ZWA (the congestion window has dropped) or early ZWA (which prematurely leads to idle time prior to the disconnection). In [1], the timeout problem during vertical handover is fixed by using timestamp in WP-TCP header, which is not applicable for other existing TCP variants. It should be noted that reference [5] proposes to delay the RTT iteratively to a proper value before a vertical handover to avoid premature timeout. Unfortunately, the RTO algorithm and parameters of TCP sender must be available for TCP receiver.

In our solution, we propose to utilize the TCP proxy architecture to solve these two typical problems. For simplicity, we assume that: *1)* Only the downlink traffic is considered in this article. *2)* The only bottleneck in the path of the TCP connections occurs at the RNC/Nodeb. *3)* It's the RNC that makes the handover decision. *4)* The wireless RTT of WiMAX system is much smaller than that of the UMTS system.

A. TCP Proxy Description

In Fig. 1, the TCP proxy lies on the top of IW sublayer on RNC and has the following features:

1) Fixed local congestion window size.

2) Before a handover, the TCP proxy works in the transparent mode: only forwards segments to the UE and ACKs to the TCP sender.

3) After a handover, the TCP proxy explicitly controls the TCP end-to-end window to maintain a proper local queue length by setting the receiver's advertised window field in the TCP ACK. The advertised window size is calculated according to local queue length, target queue length, estimated network BDP. Denote Wi(t) the calculated value of window size for keeping the queue length in TCP Proxy below a threshold (the BDP of wireless network), and denote rwnd the receiver's advertised window field in a returning ACK or "spoofed" ACK created locally. The TCP proxy checks the ACK and overwrites the its receiver's advertised window field with

   $$Wnew(t) = \min\{ rwnd, Wi(t)\} \quad (1)$$

   We follow the queue management solution provided in [8], and only apply a simple feedback mechanism as:

   $$Wi(t) = W0(t) + a*(Qt - Q(t)) \quad (2)$$

   Where W0(t) is the estimated bandwidth-delay product value based on the measured network RTT (wired and wireless) and data rate, the Qt is target queue length and Q(t) is current queue length, while the parameter "a" is a constant value during a handover process.

4) The TCP proxy sends a TCP ACK with zero receiver window size (ZWA) to the TCP sender when a handover takes place, and triggers TCP sending by feeding back an ACK with non-zero receiver's advertised window size when the handover completes.

5) After a handover, when the TCP proxy receives a new segment from TCP sender, a corresponding "spoofed" ACK timer is created locally. The timer period is set to the former wireless RTT of WiMAX (WRTTwimax). On the timeout, the TCP proxy "spoofs" TCP sender by feeding back a TCP ACK (locally generated) with a calculated advertised window size.

6) If the calculated advertised window size is zero, a ZWA is fed back to the TCP sender and the TCP sender enters into persist mode again. Note that although we utilize Freeze-TCP mechanism [4] to prevent any congestion window shrinking, the "warning period" of [4] does not exist any more thanks to the IW ARQ mechanism (there is no packet loss during the handover period).

7) A local ACK retransmit timer is rescheduled periodically. When it expires, the last TCP ACK with a new calculated advertised window is resent to the TCP sender to avoid any deadlock.

8) This kind of TCP proxy solution is suitable for the frequent inter-RAT handover scenario. For the occasional inter-RAT handover scenario, we will apply ACK Delaying scheme [5] to gradually eliminate the usage of "spoofed" ACK timer and retransmit timer in TCP proxy, which will be specified in detail in a future article.

B. TCP Proxy Algorithm

During or after a handover, whenever a packet (cross-layer primitive or data packet) is received in the TCP proxy, the recv() function is called.

```
recv(){
  If (Handover begin primitive)
    Send ZWA and Set handover flag;
  If (Handover end primitive)
    Send data packets to the UE according to new TCP proxy cwnd;
  If (DATA Packet) {
    If (Downward) {
      If (handover flag) Delete this packet and return;
      else {
        enqueue this packet;
        send packets in the queue to the UE;
        If (need spoofed ACK) trigger a WRTTwimax Timer;
      }}
    If (Upward) {
      If (TCP ACK) {
        Delete corresponding packet in the queue;
        Send packets in queue to UE according to TCP proxy cwnd;
        If (handover flag) {
          If (queue length < = target queue length)
            reset handover flag and sending NZWA to TCP sender;
        }} }} }
```

When a timer expires, the Timeout() is called.

```
Timeout () {
  If (WRTTwimax Timer)  {
    Calculate the advertised windows size (awnd);
```

```
    Create a TCP ACK with corresponding seqno and awnd ;
    Send this TCP ACK to the TCP sender;
    If (awnd == 0)  set handover flag ;
    Reschedule local ACK re-tx timer ; }
  If (ACK re-tx Timer) {
    Calculate the advertised windows size (awnd);
    If (awnd != 0) re-send last TCP ACK
    Reschedule local ACK re-tx timer; }
}
```

C. *Signaling and Primitives between IW and TCP Proxy*

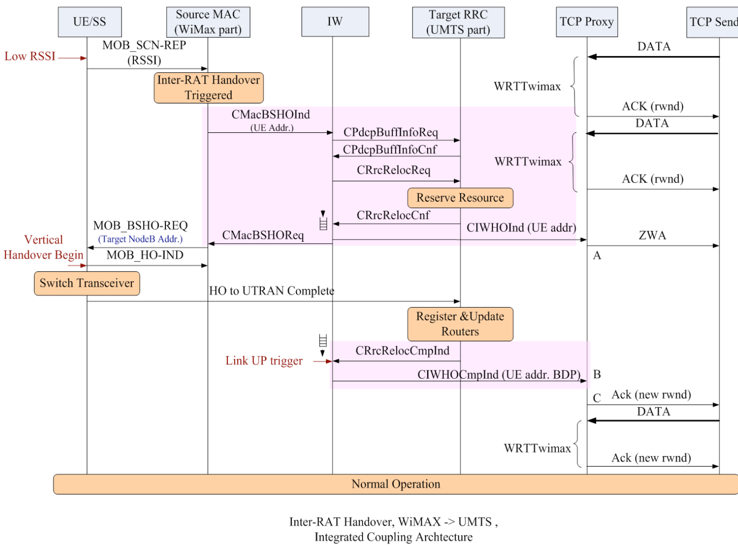

Figure 3. Cross-layer actions between the IW sublayer and the TCP proxy

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 queue length and queue occupation of PDCP sublayer. 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 sending and buffers data packets that require delivery order. *5)* The IW sublayer will inform the TCP Proxy by primitive CIWHOInd. Upon receipt of this primitive, the TCP Proxy sends a ZWA to TCP sender. This ACK freezes the re-transmit timers and congestion window of the TCP sender and makes it enter into persist mode. *6)* The IW sends CMacBSHOReq primitive to inform source MAC that the target network is ready. *7)* The UE performs handover to one of BSs specified in MOB_BSHO-REQ and responds with a MOB_HO-IND message. *8)* UE performs normal UMTS hard handover. *9)* After the UE successfully finishes UMTS radio link setup, the target RRC shall send the CRrcRelocCmpInd primitive to the IW, and the IW restarts data packet forwarding. Here, the primitive CRrcRelocCmpInd is defined as the Link Up triggers. *10)* The IW sublayer informs TCP Proxy of the BDP of the new wireless network by primitive CIWHOCmpInd. The TCP proxy reset it target queue size and local congestion window to this value. Then, it sends the TCP segments stored in its queue to the UE until the queue length is below the target size (draining period). After that, the TCP Proxy sends an ACK with a calculated advertised window size to resume TCP sending, and handover period is complete.

Take a glance at our scheme: after handover, firstly, the periodically "spoofed" ACK in the period of former wireless RTT (WRTTwimax) avoids premature timeout; secondly, the rate-control by feeding back advertised window prevents queue overflow due to BDP mismatch of two systems; thirdly, fixed congestion window of TCP Proxy before or after handover is based on the existence of IW sublayer; finally, the ZWA packet avoids both congestion window shrinking and retransmit timer expiring in TCP sender in case of a long handover period.

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 [15]. Several extensions are made to this simulator, UMTS and WiMAX models, IW sublayer, TCP proxy, multi-channel model, IW ARQ mechanism and new signaling and primitive additions. The topology used for simulation analysis is illustrated in Fig. 4. 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 deliberately set very small 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. In UMTS module, a drop-tail policy is applied to radio network queues in PDCP. This queue length is set as 25 IW blocks, which can accommodate data about 0.5KB*25= 12.5KB (IW block size is almost the same as TCP segment), and is over 3 times the wireless link BDP (about 4KB in our scenario). Therefore this queue length in PDCP is a reasonable size (excessive buffering can cause inflated RTT value for TCP traffics). As to the WiMAX module, the queue length is set 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.

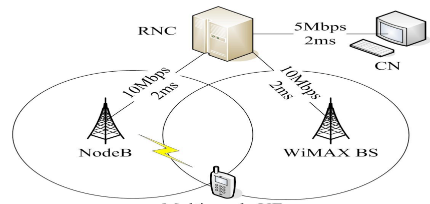

Figure 4. Simulation topology

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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. *Performance Comparison (a=1.5, Qt=25)*

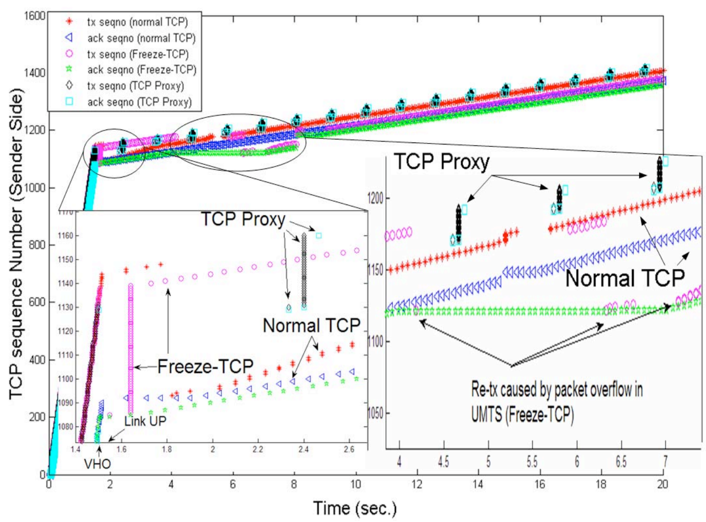
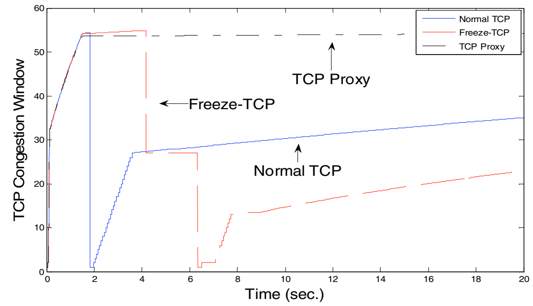
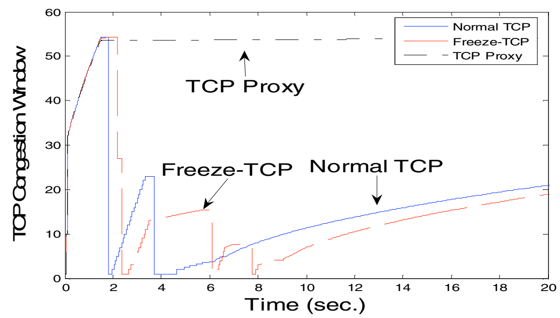


Figure 5. TCP segment number comparison (wimax->umts, sender side) (a=1.5, Qt=25, PDCP queue length 25, UMTS data rate 64kb/s)

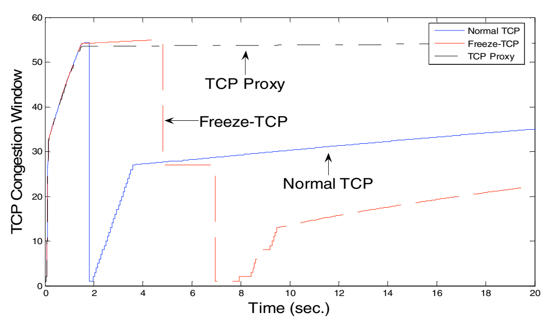
In our simulation of inter-RAT handover from WiMAX network to the UMTS, an FTP session starts at 0.4s, and the UE starts to perform handover at about 1.5s after its entering into the coverage region of UMTS. The handover type is hard handover. At about 1.535s, the WiMAX network entry procedure is finished and the IW sublayer on the RNC informs TCP proxy of the handover completion. Fig. 5 shows the packet flows of three kinds of handover solutions- normal TCP, Freeze-TCP and TCP Proxy. Due to the lack of a mechanism to accommodate BDP mismatch, the Freeze-TCP suffers from buffer overflow and congestion window shrinking. In consequence, Freeze-TCP has a much worse peformance than conventional TCP (see Fig.6 (a)). For TCP proxy scheme, there does not exist packet losses thanks to the IW ARQ mechanism, and the goodput is the largest of three schemes. Note that the TCP proxy has the feature of bursty segment arrivals, but the local queue smooths this kind of burst and the UE still receives packets at a constant data rate.



(a) PDCP queue length 25



(b) PDCP queue length 5



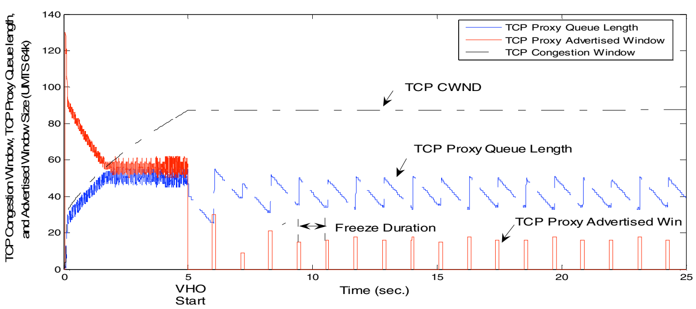
(c) PDCP queue length 45

Figure 6. TCP congestion window (wimax->umts, a=1.5 Qt=25, UMTS data rate 64kb/s)

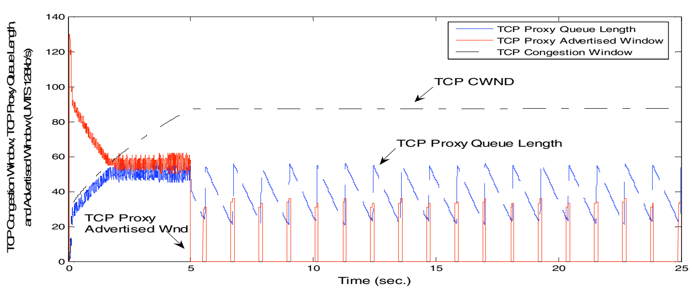
We also change the size of UMTS PDCP queue length to emulate the variation of target network BDP. From Fig.6, we can find out that the Freeze-TCP is not adaptive to the changes of BDP and wireless RTT, therefore it is not suitable for inter-RAT handover. In TCP Proxy solution, the parameter changes of target system do not cause TCP congestion window shrinking and the average goodput is larger than those of two other schemes.

B. Influence of UMTS Data Rate (a=1.5, Qt=25)

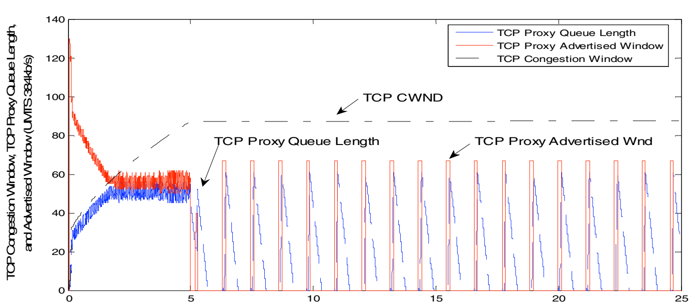
Figure 7 demonstrates the queue length variation in TCP proxy and calculated advertised window size. The queue length increases abruptly and decreases at a constant rate, which makes the queue length look like a "saw-tooth". The interval between two advertised window "pulses" is the freeze period, during which the TCP sender is in the persist mode and its congestion window and retransmit timer are freezed. Compared with the data amount during non-freeze period, the amount of ZWA can be omitted. In the Fig. 7 (c), queue length can reach zero during the freeze period. We call this phenomenon "under-utilization", which can be avoided by reducing the local retransmit timer period to a smaller value (default value is 1.0s).



(a) UMTS data rate: 64kb/s



(b) UMTS data rate: 128kb/s



(c) UMTS data rate: 384kb/s

Figure 7. The variation of local queue length and advertised window size when UMTS data rate changes (a=1.5, Qt=25, PDCP queue length 25)

VI. CONCLUSION

This article provides a novel cross-layer inter-RAT handover scheme on the basis of the integrated coupling architecture for the seamless roaming from the WiMAX to the UMTS network. 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. The IW sublayer can achieve lossless and prompt handover procedure for TCP traffics thanks to the introduction of SR ARQ mechanism. On the top of IW sublayer, a TCP proxy is also introduced on the RNC. In the TCP proxy layer, the combination of queue management and freeze-TCP are used to resolve BDP mismatch and spurious RTO problems that often appear in the inter-RAT handover. The simulation results carried out on the NS2 emulator validate the better handover performances. This kind of TCP proxy is suitable for frequent inter-RAT handover scenario because there is no need to adjust TCP sender's parameters, while for the occasional inter-RAT handover scenario, an enhanced TCP proxy with ACK Delaying scheme will be our future work.

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