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A Receiver-Aided Seamless And Smooth Inter-RAT Handover At Layer-2

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Abstract

The future mobile networks consist of hyper-dense heterogeneous and small cell networks of same or different radio access technologies (RAT). Integrating mobile networks of different RATs to provide seamless and smooth mobility service will be the target of future mobile converged network. Generally, handover from high-speed networks to low-speed networks faces many challenges from application perspective, such as abrupt bandwidth variation, packet loss, round trip time variation, connection disruption, and transmission blackout. Existing inter-RAT handover solutions cannot solve all the problems at the same time. Based on the high-layer convergence sublayer design, a new receiver-aided soft inter-RAT handover is proposed. This soft handover scheme takes advantage of multihoming ability of multi-mode mobile station (MS) to smooth handover procedure. In addition, handover procedure is seamless and applicable to frequent handover scenarios. The simulation results conducted in UMTS-WiMAX converged network scenario show that: in case of TCP traffics for handover from WiMAX to UMTS, not only handover latency and packet loss are eliminated completely, but also abrupt bandwidth/wireless RTT variation is smoothed. These delightful features make this soft handover scheme be a reasonable candidate of mobility management for future mobile converged networks.

Keywords: mobile converged network; multihoming; layer 2; UMTS; WiMAX; vertical handover; inter-RAT handover; soft handover

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1. Introduction

The future mobile systems will consist of hyper-dense heterogeneous and small cell networks [1][2], which may have same radio access technologies (RAT) such as macrocell/picocell/femtocell of LTE-A, or may have different radio access technologies such as UMTS, LTE/LTE-A, WiFi, and WiMAX. Integration and interoperability of these access technologies will be necessary to provide the users with a ubiquitous access to a large range of services. In the next 5G, these heterogeneous networks will be converged into a uniform network, which is named mobile converged network [3]. Since these heterogeneous networks are hyper-dense deployment, mobile converged network shall also provide a good mobility management mechanism to enable Mobile Stations (MS) to cross cell edges frequently. Generally speaking, interoperability of different RATs to implement better mobility management faces more challenges. In this article, we focus on different RAT interworking.

On the other hand, continuous mobile content service is the goal of service convergence or full convergence in converged mobile networks, regardless of user's mobility and connection type [3]. This service convergence requirement is high demanding. For example, interactive applications, such as peer-to-peer multiplayer gaming or video chat, demand high QoS (Quality of Service) requirements. Uncertain handover latency and dramatic network characteristic variations during user mobility among heterogeneous and small cell networks will significantly impact end user's experience, even disrupt his/her connection. Hence, the handover procedure in mobile converged network is expected to be both smooth and seamless. The term "smooth" is referred to the procedure where network characteristics do not change dramatically from application/user perspective, while the term "seamless" is referred to a lossless and no-latency handover procedure.

Two possible convergence solutions for interworking heterogeneous networks are common signaling layer design in [3][4] or high-layer convergence sublayer design [5][6]. Common signaling layer design, i.e., at PHY layer, is applicable to the case where all heterogeneous networks work in the same spectrum band. It needs re-design of future heterogeneous network standards and is very complex. So, it is unacceptable in practice at present. A more feasible solution is high-layer convergence sublayer solution, i.e., a common convergence sublayer above MAC sublayer. It is the only viable option for current MS and network systems, because it minimizes modifications at low layers of heterogeneous networks. In addition, this high-layer convergence solution is applicable to the integration cases where heterogeneous networks work at same or different spectrum bands. Hence, we prefer to propose a mobility management solution on the basis of high-layer convergence design in this article.

Moreover, one of the most promising mobility management solutions based on high-layer convergence solution in mobile converged network is to take advantage of multihoming technologies. A multihomed MS is expected to take its ability of communicating simultaneously on various network interfaces to support better mobility management, for example, to improve horizontal handover or vertical handover (inter-RAT handover) performance (e.g., low packet losses, and short handover latency). Conventional multihoming-based handover solutions can be implemented at IP layer or TCP layer, such as SCTP (Stream Control Transmission Protocol) [7][8], which means they are only applicable to loose coupling or open coupling architectures rather than integrated coupling or tight coupling architectures [9]. As a consequence, their improvements to handover performance are very limited due to long end-to-end round trip time (RTT), or limited cross-layer activities [7], or requirement of accurate RTT calculation [8].

In mobile converged networks, at a common sublayer locating between IP layer and MAC sublayer, multihoming is used to realize soft handover in [5], where a MS can move from LTE network to WiFi network without breaking a session. Unfortunately, how to smooth network characteristic variations when networks switch is not addressed. Another layer 2 multihoming approach in [6] has been proposed for interworking between UMTS and WiMAX in integrated coupling scenario. Handover procedure from low-speed, short wireless RTT WiMAX network to high-speed, long wireless RTT network is seamless, but not for reverse direction. In short, the way towards a seamless service convergence guaranteed by mobility management is still long.

In this article, a novel soft handover scheme is proposed based on the layer 2 convergence solution [6] to realize both seamless and smooth inter-RAT handover when source and target networks have distinct characteristics. Additionally, this soft handover can be applied to frequent handover scenarios. Although this soft handover schemes is described and evaluated on WiMAX-UMTS network scenario in this article, it can be applied to different heterogeneous network combinations, e.g., handover from LTE-A femto-cells to WiMAX macrocells. This benefit is due to the features of high-layer convergence solution, which mask detailed MAC and PHY technologies of underlying heterogeneous networks.

The rest of the paper is structured as follows. The next section summarizes prior work related to vertical handover. These work make us focus on common convergence layer/sublayer solution. Section 3 briefly describes related issues about high-layer convergence solution. The detailed soft handover scheme is discussed in section 4. In section 5, the simulation scenarios, parameters, and results are specified in detail. Finally, conclusions are drawn in section 6.

2. Related Work

Handover among heterogeneous wireless networks has been studied for many years. Wireless network integration architectures and handover solutions are summrized in [9]. Detailed state-of-art of existing vertical handover measurement and decision schemes are categorized in [10]. Since future wireless networks are IP-based networks, in case of loose coupling or open coupling architectures, appling mobile IP [11] and its extensions [12][13][14][15][16] for vertical handover is a natural way. Because mobile IP suffers from trianglar routing and long handover delay problems, [13] optimizes PMIPv6 [12] with a special relay named handover coordinator to reduce handover delay and packet loss. Reference [14] proposes fast handovers for proxy mobile IPv6 (FPMIPv6) to reduce packet delay happening in PMIPv6 handover procedure. In [15], a comparison among various mobility solutions is given. In mobile IPv6 networks, [16] proposes a new resource reservation scheme for different QoS-demanding traffics on basis of collected cumulative delay. Although these extensions can reduce handover latency, packet loss or resouce reservation, to some extent, their handover performance in case of TCP traffics need to be further studied.

Since Media Independent Handover (MIH) framework has been established in 802.21 standard [17] for heterogeneous network interworking, many new handover solutions have been proposed on this MIH basis. In [18], enhanced handover functionality and primitives mapping are proposed on basis of MIH for intergrated Wi-Fi/WiMAX networks. In [19], PMIPv6 handover is optimized by integrating MIH cross-layer ability, which makes mobility functions to be timely triggered. Reference [20] proposes to optimize Fast Mobile IPv6 operations by using MIH services to improve packet loss performance. Reference [21] also carries out a test in real 802.21 heterogeneous integration environments with WiFi, WiMAX and HSPA. Mobility management protocol in [21] is a modified version of MIPv6 and termianl device is a Android smartphone. Test results in [21] indicate avoidable packet loss and handover delay for VoIP, FTP, Video and game. In [22], a cooperative layered architecture, which is a extension of 802.21 MIH, is proposed to exploit mutipath transmission through WiFi and 3G networks for session and service continutiy. Experimental results show that handover latency is shorten and service continuity is improved. These simulations and experiments on [18][19][20][21][22] show that 802.21 MIH can improve handover performance significantly.

Handover mechanism can also be realized at upper application layer. In [23], in the IMS (IP Multimedia Subsystem) integrated architecture for mobile WiMAX and UMTS, the integrated MIP and SIP (Session Intiation Protocol) protocols are used to realize seamless vertical handover with QoS support. However, handover performance metrics are not provided. Reference [24] proposes an application-level approach for vertical handover in the context of Hyper Text Transfer Protocol (HTTP). The random linear network coding is exploited to realize the smoother handover and higher throughput than the normal HTTP, but handover latency is not eliminated.

In case of TCP, [25] takes advantage of cross-layer information to enhance TCP mechanism to improve service continuity. The proposed TCP-CLAH variant in [25] outperforms the TCP NewReno in terms of QoS parameters such as jitter, RTT, and queue size. In [26], for a loosely coupled architecture of WLAN-GPRS, a modified TCP scheme called ISN-TCP is proposed based on intermediate switch network. Although handover performance is improved, e.g., unnecessary timeout due to congestion avoidance when handover from WLAN to GPRS is avoided, its application and deployment are very limited. In order to support vertical handover, a series of adaptation actions are added to original TCP to handle mobility issues in [27]. The improvement over original TCP is also evalutated in this paper. For the purpose of avoiding dramatic TCP throughput reduction due to out-of-order packet delivery during handover procedure, in [28], based on MIH framework, pre-registration is proposed for PFMIPv6 so that handover time is shorten.

Reference [29] examines the impacts of multipath TCP on vertical handover in a WiFi and UMTS live networks. The benefit of multihoming is evident but becomes minor when bandwidth differences are large. Reference [30] compares two multi-homed network mobility protocols: enhanced MIPv6 and SCTP that exploit make-before-break handover for NEMO (NEtwork MObility). Experimental results demostrate that transport layer-based mobility solution outperforms network layer-based protocol. Reference [31] proposes softer vertial handover to deliver packets over all heterogeneous wireless links to maximize TCP throughput. However, packet distribution shall be carefully calculated according to respective link rate. These work indicate that taking advantage of multihoming ability of network is a promising way to improve handover performance.

3. High-layer Convergence Solution Related Issues

3.1 Convergence Sublayer

Adding a common convergence sublayer below IP layer for interworking different RATs is a well-accepted solution in academic and industry societies. For example, in [5], a RAT multiplexing control (RMC) sublayer is added between the IP and MAC layers in a converged base station (CBS) for interworking LTE and WiFi. (Here, the converged base station refers to the cellular station that directly connects WiFi access point.) This common sublayer performs multiplexing/de-multiplexing, resource allocation, scheduling, extension of additional RATs and traffic offloading. Although RMC scheme can smooth handover procedure to some extent by resource provision and QoS mapping in target network, the differences of channel qualities, bandwidths, buffer sizes, user populations etc. of source and target networks still significantly impact handover procedure. In addition, disordered packet arrival problem caused by multiplexing/de-multiplexing through two different RATs at RMC sublayer is not discussed. In other words, besides signaling mechanisms in control plan, convergence sublayer shall have a set of mechanisms in user plan to ensure smooth and seamless handover during MS mobility procedure.

Our soft handover scheme is realized at the IW (InterWorking) sublayer [6][33], which is a layer 2 common sublayer for different interworking scenarios such as UMTS-WiMAX, LTE-WiFi, and LTE-A-WiFi, as shown in **Fig.1**. RNC/eNB of cellular network can be connected with access point of WiFi/WiMAX network directly or through core network. Although IW sublayer is similar to RMC sublayer on protocol stack location, there is a subtle difference between them. IW sublayer focuses on user plan, hence it does not need tight interactions with low sublayers. Only a few cross-layer primitives are used by IW sublayer for handover notification/indication between sublayers. This feature simplifies the application of IW sublayer solution to other heterogeneous network scenarios. In contrast, RMC sublayer focuses on both control and user plans. So, it should be redesigned in case of a new heterogeneous network interworking scenario.

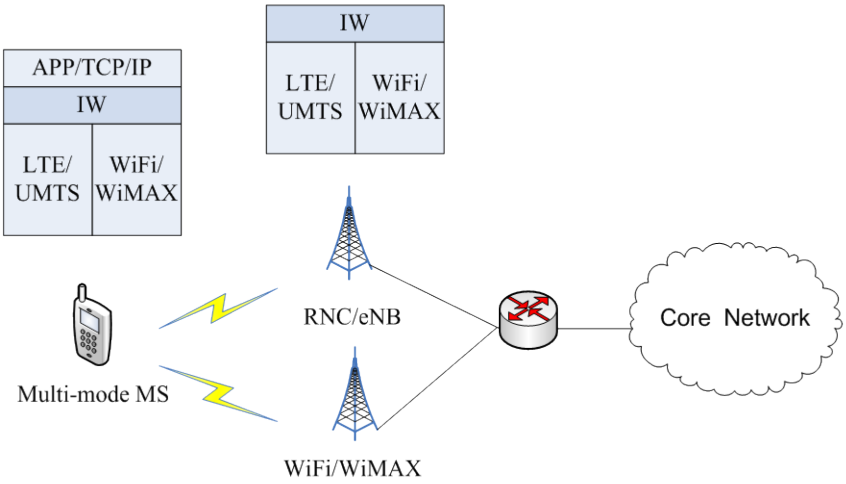


Fig. 1. Common IW sublayer for interworking of LTE/UMTS and WiFi/WiMAX

Another well-known convergence sublayer example is the MIH, which is suggested in 802.21 standard [17] to support different RAT interworking. However, 802.21 only focuses on architecture and signaling design, and does not provide handover solution.

3.2 ARQ Mechanism

ARQ (Automatic Repeat Request) mechanism has been applied at the common IW sublayer to eliminate packet losses for hard handover scenario in [33], to reducing handover latency by simple bi-casting packets over two RATs in [6]. However, these simple ARQ applications cannot eliminate handover latency completely. Furthermore, when handover is from high-speed network to low-speed network, the handover procedure is not smooth and upper applications in MS could suffer from abrupt bandwidth decrease.

3.3 Soft Handover

These problems metioned above motivate us to improve ARQ mechanism to implement a applicable and practicable handover solution for a MS roaming among heterogeneous networks of distinct cell sizes and parameters. Taking advantage of multihoming at common sublayer or layer is a promising way. Reference [7] summaries challenges and issues when SCTP multihoming is implemented. Those problems caused by concurrent multipath transfer (CMT), such as superfluous network traffic, receive buffer blocking, naïve scheduling, are avoided in [8] through accurate RTT calculation of both source and target networks at a sender. However, accurate RTT calculation is not easy to be obtained on sender side. In [5], packets are multiplexed/de-multiplexed at RMC sublayer to realize soft handover. The heterogeneities of two networks are not taken into account. Therefore, this soft handover performance may be not ideal in the case where source and target networks have distinct parameters. Simply duplicating packets and forwarding them to a MS through source and target links simultaneously in [6] could give rise to packet injection problem. When handover is from high-speed network to low-speed network, bi-casting according to source network data rate could inject amount of packets into target network, which may lead to buffer overflow at lower layers or delay new packet transmission after handover. Therefore, make-before-break handover instead soft handover is applied in [6] to avoid packet injection problem.

The reasons for above soft handover problems are summarized as follows: 1) It is better for handover mechanism to be transparent to sender side; 2) Source and target links cannot operate independently during handover procedure; 3) the operations in network side should obtain aids of MS side instead of only estimating MS handover status. For these reasons, we propose a receiver-aided soft handover scheme at layer 2 by utilizing MS multihoming ability.

In the following sections, the terminology handover is referred to inter-RAT handover. The terminologies of link layer and layer 2 are used interchangeably. We only consider downlink traffics. Additionally, we only consider interworking scenario where source and target networks have distinct differences. For example, in case of WiMAX-UMTS interworking, WiMAX stands for high bandwidth, short transmission delay network, while UMTS stands for low bandwidth, long transmission delay network. (We omit WiMAX/WiFi-LTE/LTE-A interworking in the following, because these RATs have similar bandwidths and cannot embody proposed soft handover merits.) We also assume the IW sublayer has the ability to estimate the underlying wireless link bandwidth or allocated data rates (not necessarily accurately) according to information given by lower layers during handover period.

4. Soft Handover Scheme

The new soft handover is implemented on basis of an enhanced ARQ mechanism. Different from ARQ mechanisms in [6][33], its novelties are a dual receiver buffer scheme and receiver-aided ACK-delaying scheme. It should be stressed that ACK-delaying scheme is a conventional RTT adjusting mechanism, but it is first time that ACK-delaying is combined with ARQ mechanism to realize smooth and seamless soft handover to the best of our knowledge.

4.1 Dual Receive Buffer

The ARQ is an error control mechanism and is used at IW sublayer to eliminate packet losses and reduce handover latency. We only summarize its basic operations in [6] to make this article self-contained. At common IW sublayer in a converged base station, (e.g., RNC), every packet from upper layer is encapsulated and assigned a sequence number in its added sub-header. In addition, two retransmission buffers are allocated respectively for source and target wireless interfaces. These encapsulated packets (called IW blocks) are duplicated, stored in two retransmission buffers respectively, and bi-casted over two wireless links. With the help of the sub-headers of IW blocks, disordered blocks are reordered on receiver side, and lost blocks are retransmitted on sender side.

In order to de-couple operations of source and target links in ARQ mechanism in [6], in this article, on the receiver side, two receive buffers are allocated for two wireless links respectively. They operate totally independently. The received blocks from source or target link are firstly stored in respective receive buffers for error detection, reordering and ACK-delaying (see the following section). Then, ACK/NACK (Acknowledge/Negative-acknowledge) for this block is returned through the interface where it is received. In each receive buffer, the first received block is buffered and its subsequent duplicate blocks are omitted.

In addition, in order to avoid deadlock due to ACK/NACK losses during a handover period, a timer is set for each wireless interface on the receiver when the receiver sends an ACK/NACK. When a timer for one interface expires, the receiver sends back a status report (ARQ feedback bitmap) providing the receipt status through this interface. This status report is an ACK or NACK of each IW block.

4.2 Receiver-aided ACK-delaying Mechanism

When handover is from high-speed/short wireless RTT network to low-speed/long wireless RTT network, abrupt wireless RTT decrease may give rise to spurious RTO/premature timeout problems. These problems make TCP sender shrink its congestion window and lead to unnecessary throughput degradation. In order to smooth transmission bandwidth decrease or wireless RTT increase, conventional ACK-delay mechanism is applied on receiver side at IW sublayer for source high-speed wireless network. It is enabled when first block is received on target wireless link. Afterwards, for every new incoming block from source interface, a corresponding ACK-delaying timer is creased. This timer period (SWRTT) is set to wireless RTT (WRTT) of source link plus an incremental change, as follows:

$$\begin{aligned} &SWRTT(i) = i * WRTT * \delta \\ &i \in [1, +\infty] \end{aligned} \quad (1)$$

Where WRTT is the time difference between last sent ACK and new received block. It's a coarse wireless RTT estimation of source link from MS perspective in steady state. Certainly, the more accurate wireless RTT can be given by converged base station to MS when handover is made. The index i is the number of delayed ACK. The constant δ is a constant and set adaptively based on the bandwidth differences of source and target links. Actually, the δ setting is a tradeoff between RTO timer expiration possibility in TCP sender and soft handover duration. How to choose a more proper δ will be our future research task.

When one ACK timer expires, IW sublayer on MS checks whether the corresponding block has bigger sequence number than blocks from target link. If so, this block is de-capsulated and delivered to upper layer. Besides, a corresponding ACK/NACK is fed back to sender through source link. That lagged duplicate block from another wireless link is deleted silently. When a block from target link has bigger sequence number than the last one delivered to upper layer from source link, it means transmission rate of source link has be slowed down to rate of target link. As a consequence, IW sublayer on receiver disables ACK-delaying mechanism and releases receive buffer of source link. Meanwhile, a soft handover completion message is sent to sender side. Upon this message, IW sublayer on converged base station releases buffer resource and retransmission queue for source link. Subsequently, it switches to single-casting mode over target link, or enters into transparent mode after sending all buffered blocks for target link.

In summary, this enhanced ARQ mechanism has the ability of adjusting RTO value of TCP sender to an appropriate value. Besides, dual retransmission queue and dual receive buffer make two link operate totally independently, while receiver-side ACK-delaying mechanism smooth bandwidth/wireless RTT variation. These two mechanisms solve a dilemma in converged mobile network: to eliminate packet losses, to eliminate handover latency and to smooth handover procedure at the same time.

4.3 An Example

In Fig. 2, an example of enhanced ARQ working mechanism for the UMTS-WiMAX integrated coupling architecture is demonstrated. On receipt of IW block no.5 from WiMAX interface, IW sublayer on MS initiates an ACK-delaying timer instead of delivering it to upper layer. The expiration of this ACK-delaying timer not only makes IW sublayer feed back an ACK to RNC through WiMAX link, but also compares its sequence number with blocks from UMTS link. On RNC side, any ACK messages from UMTS link or WiMAX link only make IW sublayer delete corresponding blocks from their respective retransmission queues. Two sets of retransmission queues and local transmission buffers operate totally independently.

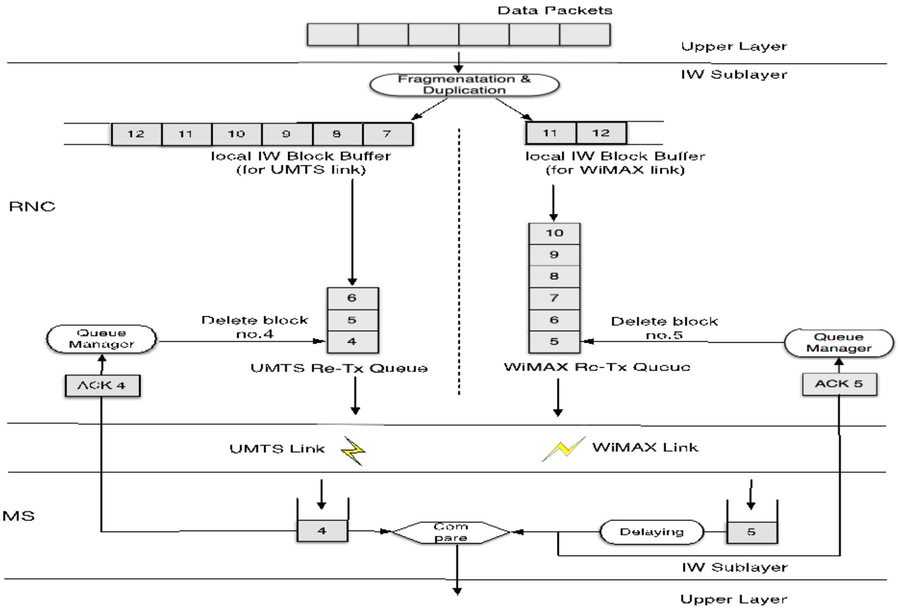


Fig. 2. Enhanced ARQ mechanism

4.4 A Signaling Flow Example

Note that in order to support independent ARQ operations of source and target link, a bi-casting ending signaling is added at IW sublayer. For example, in UMTS-WiMAX interworking, when a block's arrival on UMTS interface is ahead of the ACK-delaying timer expiration of its duplicate block on WiMAX interface, the soft handover completes and IW sublayer on MS sends Soft HandOver Complete message (shown in **Fig.3**) to peer sublayer on RNC. This primitive makes IW stop bi-casting and switch to single-casting through UMTS interface.

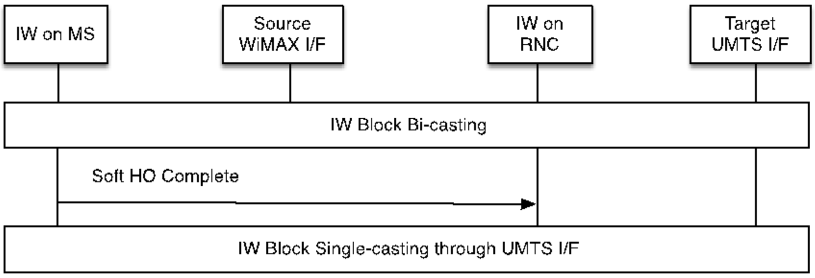


Fig. 3. A signaling flow example

4.5 A Soft Handover Example

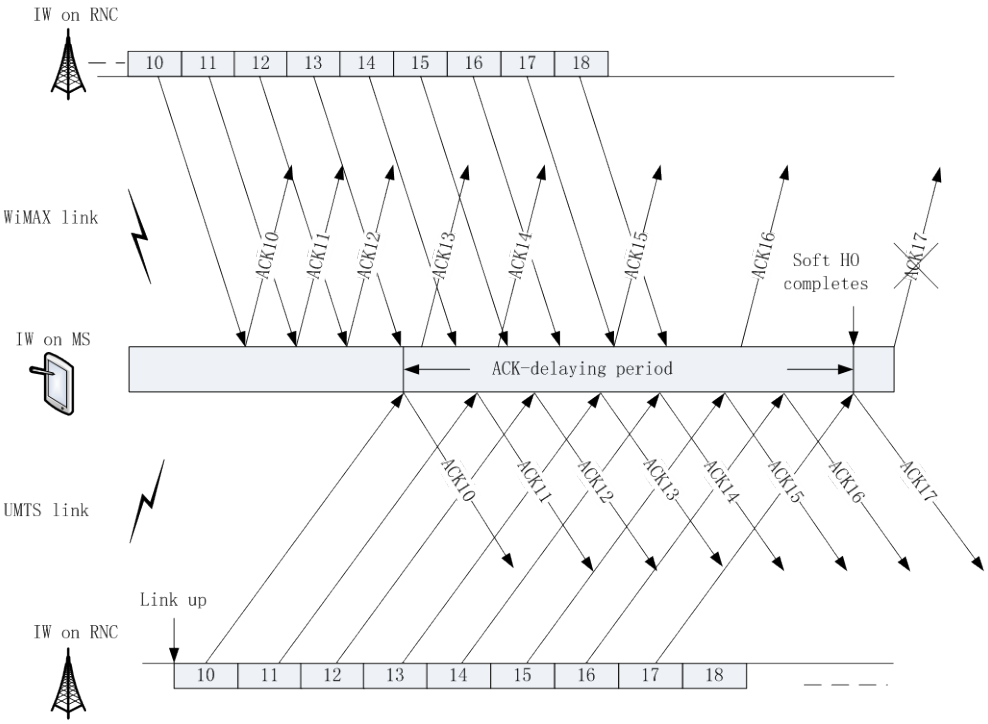


Fig. 4. A soft handover example

In **Fig. 4**, an example of the enhanced ARQ mechanism for soft handover from WiMAX to UMTS is given. Upon receipt of Link_Up trigger from UMTS interface, the IW sublayer on RNC duplicates every block starting from first unacknowledged blocks of WiMAX link (no.10 in this example) and transmits them over two interfaces simultaneously. The first arrived block from UMTS link initiates ACK-delaying mechanism at IW sublayer on MS for blocks from no. 13 from WiMAX link. Afterwards, ACK feedbacks for blocks from no. 13 to no.16 are delayed gradually. When ACK-delaying timers of these blocks expire, their duplicate blocks have not arrived from UMTS interface, so they are delivered to upper layer. The lagged duplicate blocks (from no. 10 to no.16) from UMTS interface will be deleted intelligently at IW sublayer on MS thanks to the enhanced ARQ mechanism. Block no.17 from UMTS link arrives at MS earlier than ACK-delaying timer expiration of its duplicate block on WiMAX link. As a result, the soft handover completes and ACK-delaying mechanism on receiver is disabled.

5. Simulation Results And Analysis

In order to analyze the performance of the enhanced ARQ, we carry out a soft handover simulation on the NS2 [34] platform. Several extensions are made to this simulator, UMTS and WiMAX models, IW sublayer, multi-channel model, enhanced ARQ mechanism and new signaling and primitives. The topology used for simulation analysis is illustrated in **Fig.5**. There is only one MS with two transceivers and there are no other background traffics in this "clean" scenario. The MS always has enough bandwidth to send packets whether it is in WiMAX region or in UMTS region. Note that in this topology, the transmission delay in the wired network is set to a very small value deliberately to minimize its influence on handover procedure. An FTP session is examined, with the CN designated as the sender and the MS designated as the receiver. In UMTS module, a drop-tail policy is applied to radio network queues in PDCP sublayer 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**.

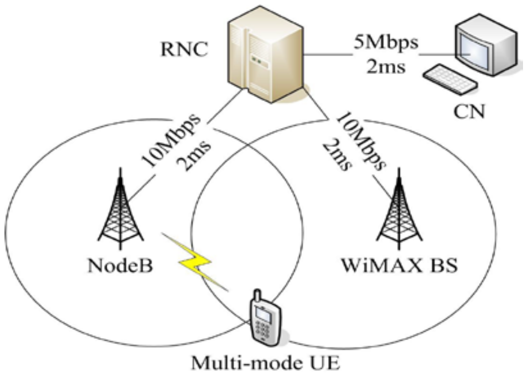


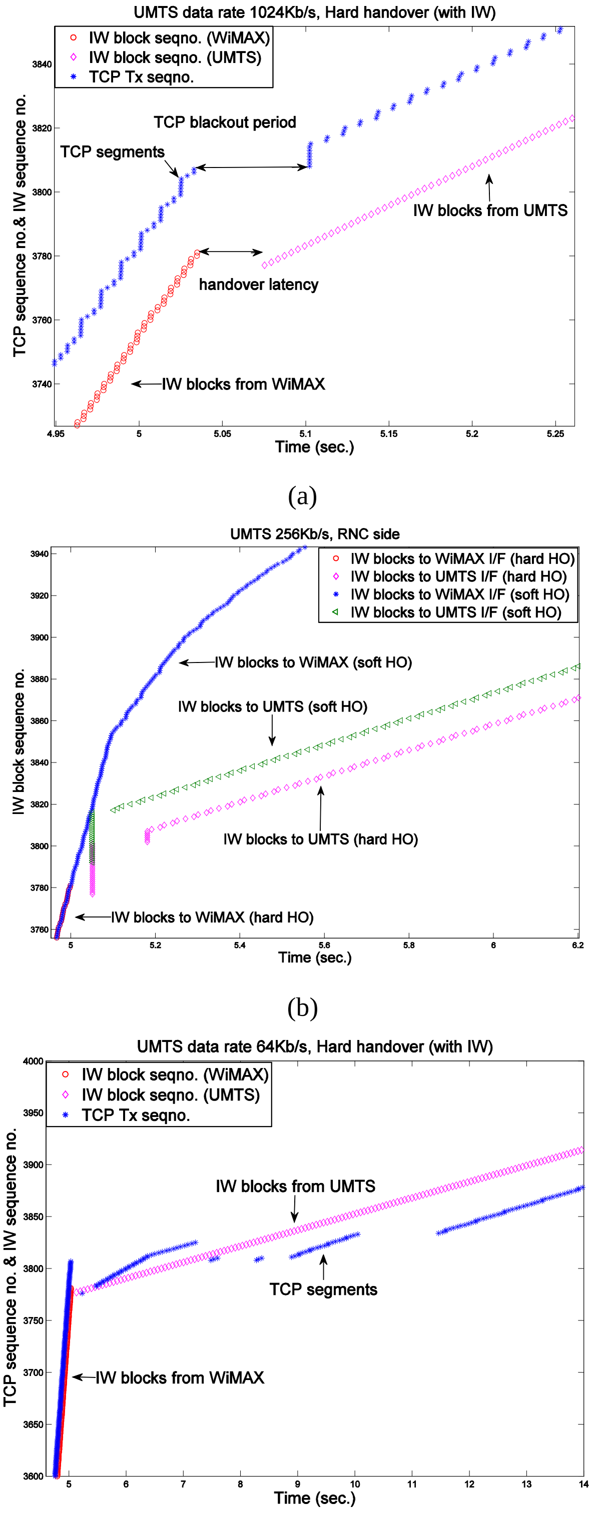
Fig. 5. Simulation topology

Table 1. Simulation parameters

	Parameter	**Value**		**Parameter**	**Value**
IW	Fragment Switch	OFF	UMTS PHY	TTI (ms)	10
				Frame Duration(ms)	10
	Max retransmit count	10		BLER	1e-6
	Default Windows size (block)	30	WiMAX MAC	Allocated data rate	unlimited
				Queue length	50
	Status Report Timer (s)	2.5		Payload Header Suppression	no
PDCP	TCP/IP Header compression,and Retransmission	no		Frame duration (ms)	4
	Allocated data rate	1024/ 2048kb/s,	WiMAX PHY	Modulation	OFDM
	Queue length	25			
RLC	RLC Mode	AM		Interleaving interval (frames)	50
	Windows size (Blocks)	500		FFT	256
	Block size (Bytes)	20		Number of subcarrier used	200
	maxDAT	20	TCP/IP	variant	Reno
	Ack timerout period (ms)	50		MSS (bytes)	512
				default cwnd	32
APP	traffic type	FTP		minimum RTO timer period	0.2s

Handover direction is from WiMAX to UMTS. WiMAX data rate is set to 2Mb/s. Three UMTS data rates are taken into account: 1024Kb/s, 256Kb/s and 64Kb/s, which represents small, medium and huge data rate differences between two links. When a MS is in the coverage region of UMTS network, it performs three kinds of handover: hard handover without any special mechanisms (named hard handover without IW), hard handover with single-homing IW sublayer [33] (named hard handover with IW), and proposed soft handover with multihoming IW sublayer (named soft handover). Handover takes place at 5sec. and link up trigger is issued at about 5.07sec.

In case of hard handover with IW, obliviously there exists a certain handover latency depending on UMTS network entry time, as shown in **Fig.6 (a).** This handover latency leads to TCP blackout period for upper applications, although there are no packet losses. (Here, the figure of UMTS data rate 256Kb/s is omitted due to similar curve as that of 1024Kb/s.)



(a)

(b)

(c)

Fig. 6. TCP segment and IW block number comparisons of hard handover with IW, UMTS data rates are: (a) 1024kb/s; (b) 256Kb/s, RNC side; (c) 64Kb/s

In soft handover case, the MS performs UMTS network entry procedure parallel with IW block transmission on WiMAX interface after handover is made. When UMTS network entry procedure is finished and Link_Up trigger is received, IW sublayer on RNC retransmits unacknowledged blocks of WiMAX interface over UMTS interface. Once the first block is received through UMTS link, the ACK-delaying mechanism is enabled at IW sublayer on MS for WiMAX link. Thereafter, the sequence numbers of IW blocks from WiMAX interface increase in the form of curve instead of straight line, as shown in **Fig. 7**. Once an IW block from UMTS interface arrives earlier than ACK-delaying timer expiration of its duplicate block on WiMAX link, soft handover completes and WiMAX interface is switched off. As a consequence, block transmission rate of WiMAX interface is slowed down gradually from application perspective on MS, and the abrupt bandwidth changes are smoothed by soft handover during this procedure. From the comparisons of **Fig. 6-8**, we can see the advantages of soft handover: *no packet losses* and *no handover latency*. In short, the handover procedure is both seamless and smooth.

Fig. 6(b) shows the IW blocks sent from RNC side on both links in case of hard handover with IW and soft handover when UMTS data rate is 256Kb/s. We can find out that soft handover can continue to transmit blocks over source WiMAX link after handover is made, which makes TCP congestion window size larger in comparison with hard handover with IW, as shown in **Fig. 8**. It should also be stressed that in **Fig. 6(b)**, before the soft handover is finished, IW blocks sent over WiMAX link have higher sequence number than those over UMTS link. This advantage means the soft handover has more amounts of TCP segments sent and received during the whole soft handover period, as also indicated in **Fig.7**.

When UMTS entry procedure is finished at about time 5.07sec in **Fig. 6(b)**, RNC resends unacknowledged IW blocks through UMTS link in both soft handover and hard handover with IW schemes. However, IW blocks resent in soft handover have higher sequence numbers compared with those resent in hard handover with IW. The sequence number difference between two schemes is for the reason that soft handover can transmit blocks during UMTS entry procedure while hard handover with IW cannot. The longer the UMTS entry procedure, the bigger this sequence number difference is. This difference also keeps almost constant until the end of soft handover period. Furthermore, hard handover with IW suffers from block retransmission procedures at 5.2sec in **Fig. 6(b)** due to block losses during two links switch, which also increases the block sequence number difference. Therefore, after soft handover period, this block sequence number difference makes TCP congestion window size of soft handover a bit larger than that of hard handover with IW. (In our simulation scenario, UMTS entry procedure is set to be short. So, this block sequence number difference is not much larger than current TCP congestion window size. Hence, because of linear increase mechanism of TCP congestion window in congestion avoidance phase, the TCP congestion window size difference between two schemes is not very distinct in **Fig. 8** after soft handover period.) In a word, the longer the UMTS entry procedure, the bigger TCP congestion window size difference between two schemes becomes after soft handover period.

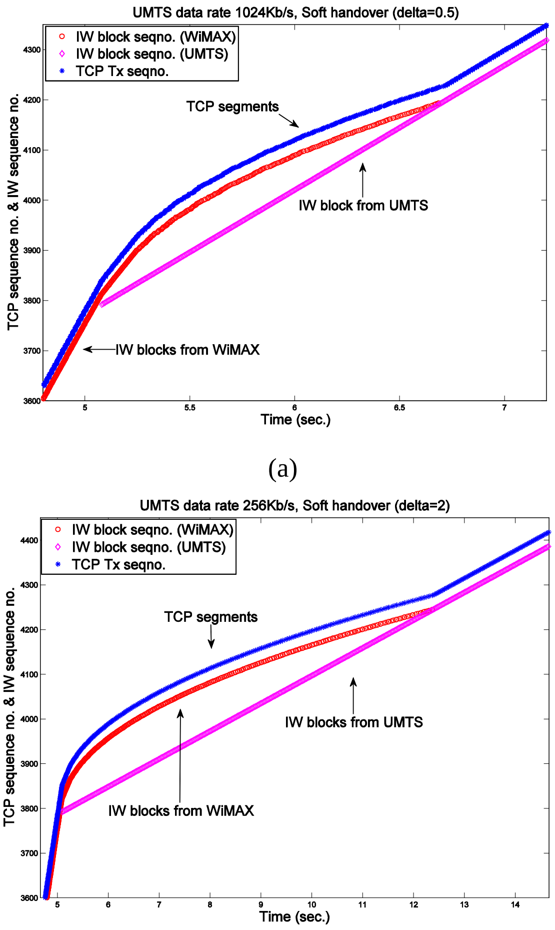
In short, the soft handover has more amounts of TCP segments sent during soft handover period, and has larger TCP congestion window size. This phenomena interestingly indicates that:

- The longer soft handover period is, the more TCP segments can be transmitted, and the faster the file transmission can be finished. The main reason is for the soft handover can take advantage of WiMAX high transmission rate. This result changes our traditional viewpoint: inter-RAT or vertical handover latency shall be as short as possible.
- When a new handover is forthcoming during soft handover period, soft handover is

beneficial for both handover to lower-speed network and handover to higher-speed network. For the former case, soft handover period is just extended. For the latter case, ACK-delaying mechanism is disabled and only simple bi-casting scheme [6] is applied to make IW sublayer catch up with higher speed rate of target network.

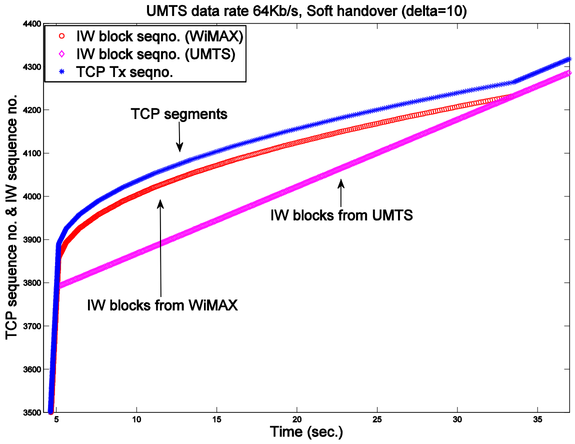
- **Fig. 6(b)** also indicates that although target UMTS network entry procedure is same for both soft and hard handover, IW block transmission over UMTS link is a bit earlier in soft handover than in hard handover with IW. This is because the latter one suffers from disordered blocks' arrivals during two links switch. While in soft handover scheme, two transmission queues and receive buffers are operated totally independently. So disordered block arrival problem in soft handover is not as severe as in hard handover with IW.

Fig. 8(c) shows that when UMTS bandwidth is quite lower than that of WiMAX, hard handover with IW can suffer from more TCP RTO timer expirations than soft handover due to its longer handover latency. In case of hard handover with IW, the longer handover latency makes TCP sender shrink its congestion window and retransmit unacknowledged segments that already have been retransmitted by IW sublayer (see **Fig. 6(c)**). Hence, these duplicate segments could delay new segments' reception on TCP receiver and lead to a second TCP RTO timeout. Hence, performance of hard handover with IW is worse than hard handover without IW, even though it has no packet losses.



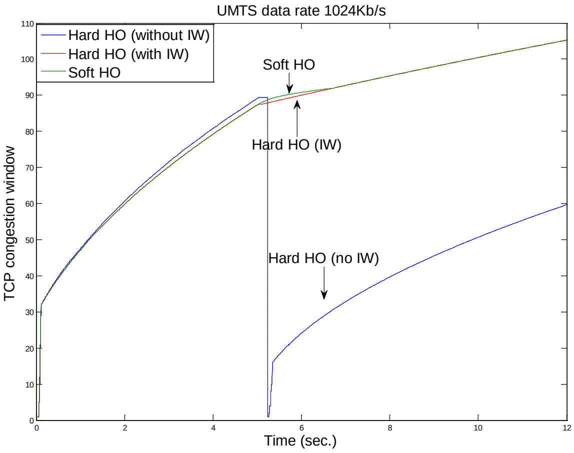
(a)

(b)

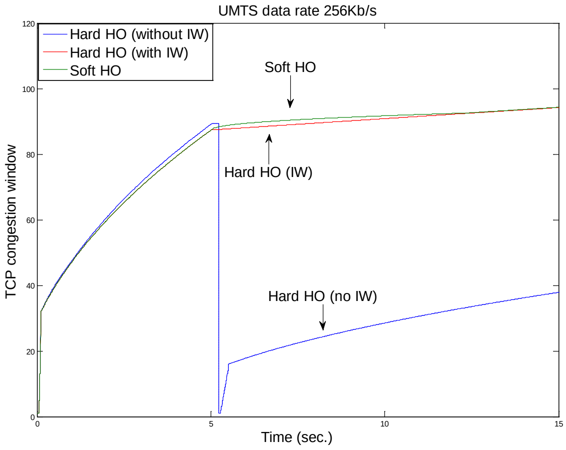


(c)

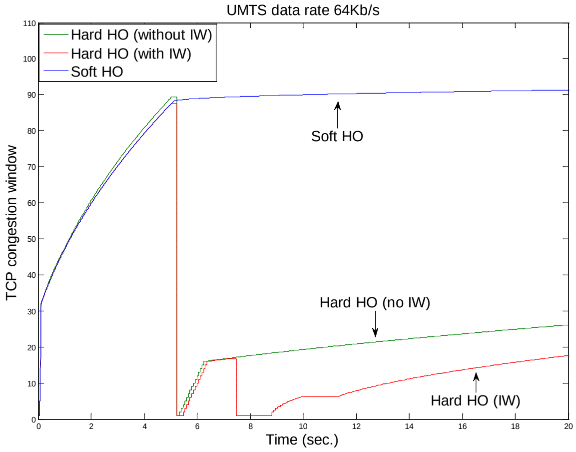
Fig. 7. TCP segment and IW block number comparisons of soft handover, UMTS data rates are: (a) 1024Kb/s; (b) 256Kb/s; (c)64Kb/s



(a)



(b)



(c)

Fig. 8. TCP congestion window comparison, UMTS data rates are: (a)1024Kb/s; (b) 256Kb/s; (c) 64Kb/s

6. Conclusion

In this article, for future mobile converged network, based on the convergence sublayer at layer 2, a seamless and smooth soft inter-RAT handover scheme for handover from high-speed/short wireless RTT network to low speed/long wireless RTT networks is proposed. Compared to existing layer 2 inter-RAT handover schemes, a novel dual receive buffer scheme, and receiver-aided ACK-delaying mechanism are proposed to enable soft handover for better handover performance. The simulation results conducted on UMTS-WiMAX platform show that this soft handover can not only eliminate packet losses and handover latency when handover is from high speed WiMAX network to low speed UMTS network, but also smooth abrupt bandwidth/wireless RTT variation for TCP traffics. In addition, this receiver-aided soft handover can be applicable to frequent handover scenarios. This soft handover approach is a reasonable mobility management candidate for convergence of heterogeneous and small cell networks.

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