Intelligent Network Selection for Vertical Handover Optimization in LTE-Advanced

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Abstract: - Vertical handover decision (VHD) is a complex strategy in heterogeneous wireless networks because of its significance on network application and performance. The mechanism adopted for the vertical handover utilizes the “break – before – make” phenomenon. However, issue of network availability and the choice of the best available network may be an illusion as the mechanism is subjected to many difficulties in handover decisions, which results in packet drop, high latency and poor network performance. This paper presents an intelligent network selection during vertical handover capable of resolving VHO problems of bandwidth delay (BD) or mismatch and premature timeout by introducing improved TCP proxy in two sub-layers in the radio link layer. The proposed sub-layer interworking network selection mechanism (SLIM) adopts integrated coupling architecture at layer 2 of the eNodeB and UE to provide a smooth handover between 3GPP and WLAN networks. The results obtained demonstrate it adaptability/robustness to various handovers and shows a significant drop in latency during the user equipment (UE) mobility. An improvement in the handover performance with respect to network reliability was eventually achieved when making choice in selecting the optimal network.

Key-Words: - LTE-A, Sub-Layer, eNodeB, VHD, Latency

1 Introduction

Wireless technology holds the promise of the coexistence of different radio access technologies (RAT) as the future next generation networks. The integration of various radio technologies, thus forming a multi-RAT cloud of wireless networks, has the ability to seamlessly roam across the cell boundaries of these heterogeneous networks without disruption. However, traffic on the wireless is expected to be a mix of real-time traffic such as video conferencing, mobile cinema, multimedia gaming (MMG) with users demanding the desired quality of service guarantees for the different types of services. With this kind of traffic mix, mobility management becomes a problem as issues of maintaining data session’s continuity, lengthy handover latency and high packet loss are seriously compromised [1], [2]. Figure 1 shows the architecture of integrated coupling between WLAN (WiMAX) and LTE-A networks, comprising of 3 major coupling stages: loose coupling, tight coupling and the integrated coupling. While loose coupling often suffers from handover latencies, integrated couplings are said to improve better throughput when compared to loose and tight couplings [3]. This becomes evident as the integrated coupling is based on the existing network mobility. The eNodeB performs all radio interference-related functions; MME manages mobility, mobile user equipment (UE) identity and security parameters. The S-GW and a-GW are nodes that interface with the E-UTRAN and Packet Data Network respectively via access routers.

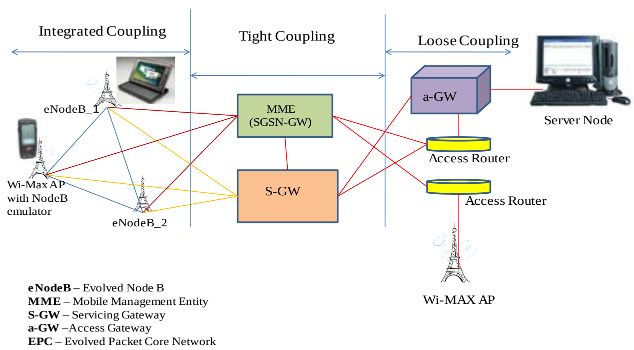

Figure1 System Architecture of Integrated Coupling Networks

Long delays are likely to occur during mobility as handover delays are eminent due to change of the subnets in layer-3 negotiations. The UE accesses data streams from the server by sending UDP dump commands or by pinging the TCP/IP.

The rest of this paper is organized as follows: Section II describes the mechanism of how data is transferred from the source to the target network, while the architecture of the protocol layer is discussed in section III. Sections IV discuss the method of Sub-layer Interworking (IW) mechanism tagged SLIM. The simulation topology and analysis of the results are described in section V. Section VI concludes the paper.

2 Data Transfer Mechanism

2.1 Context Transfer Mechanism

In an attempt to evaluate the performance of the inter-RAT handover, some metrics like handover delays, packet drops, packet blocking rate, and packet loss are easily recognized [3]. Context transfer is one mechanism considered in achieving successful and seamless handover procedure. It is a mechanism that forwards context related data and their parameters to the target network from the source network. Packet Data Convergence Protocol (PDCP) layer, saddled with the responsibility of ciphering and header compression, is equally found to guarantee reliability to data transmission and avoid data loss during data relocation. However, the PDCP is found to be ineffective because the synchronization (sequence number) mechanism of 3GPP differ from that of non-3GPP systems during inter-RAT handover [3]. Therefore, in order to eliminate packet losses at the sub-layer called R-LLC (Remote Link Layer Control), a retransmission mechanism is used [4]. Usually, a retransmission timer is set for a transmitted packet at R-LLC sub-layer in the downlink when a handover is executed. If on the other hand no acknowledgement corresponding to the packet (transmitted) is received before retransmission time (approx. 5-10 sec.) expires, then, retransmission of such unacknowledged packet lost during inter-RAT handover shall be handled by R-LLC. Therefore as a result of unavoidable buffer overflow at the lower layers, the transmission of data eventually stops. During a handover procedure however, data is moved from the source eNodeB (SeNB) to the target eNodeB (TeNB). Here, it is either the protocols are re-initialized after the handover or the whole protocol status is entirely moved to the target eNodeB from the source eNodeB. Since it is assumed that, by resetting the Radio Link Control/Media Access Control (RLC/MAC) protocols after handover, makes it cumbersome and difficult to transfer the whole protocol.

One of the important characteristics of the Wi-MAX system is that it can perform the handover by either the “make-before-break (MBB)” or “break-before-make (BBM)” configuration [6], [10], [11]. Unlike in the WCDMA system, where the Radio Access Network Controller (RANC) controls the user equipment to perform handover, in LTE/LTE-A, such do not exist. Consequently, by default, WiMAX systems incorporate the BBM mechanism. This approach however, introduces long delays which are not acceptable when real-time applications are considered.

2.2 Framework for TCP Handover

Mismatch or bandwidth delay products (BDP), premature timeout, false retransmission, deceptive retransmission timeout (RTO) and burst packet losses are in addition to the TCP traffic specific handover problems in inter-layer procedures [2], [12]. A significantly large number of in-flight data and acknowledgement (ACK) packets get loss in the process of vertical handover (uplink or downlink) that require only timeout mechanism to recover the lost burst packets. Furthermore, these burst losses may lead to unnecessarily stalemating the transmission process where the use of congestion window by TCP to control the number of these in-flight packets is utilized and is said to be equivalent to the bandwidth-delay product of the network path [12].

Comparing the bandwidth of WLAN network to that of the LTE-A networks, it is evident that the bandwidth of the WLAN is relatively higher than the bandwidth of the LTE-A network. Therefore, it is expected that there will be an inrush of data packets transmission into the LTE-A network which may lead to congestion and eventually loss of packet which in turn degrade the TCP performance. A sudden and significant increase in the round-trip time delay will result into TCP having premature timeouts by triggering unnecessary packet retransmission, which degrades the performance of the TCP. Data packet reordering occurs, the result of which data packets transmitted via WLAN happen to arrive at the TCP receiver earlier than the data packets transmitted through the LTE-A network because of the limited bandwidth in the later. The data packets reordering therefore generate sufficiently large number of duplicate acknowledgements which may result in false fast retransmission. In [9], [10] various schemes to combat the effects of burst packet losses due to network disconnections have been proposed for hard vertical handover, while methods to solve network congestion or underutilizations due to BDP (bandwidth-delay product) mismatch are found in [11]-[13]. For dealing with inrush packet transmission [13], and premature timeouts and false fast retransmit due to temporary [8], [14], [15], [18] or permanent [17], [18] increase of round trip time.

To address the performance degradation problems, an effective approach is needed to make available information flow from one layer to the other and to allow decisions (coordinated) take place at each layer. This is the reason why an inter-layer coupling [21] approach is adopted for improving the performance during VHO. It should be noted here that an inter-layer coupling may however lead to unintended interactions that can cause system rigidity and instability [23]. Therefore, it is important to note that, data loss is likely to manifest because of the hard handover approach adopted by the LTE/LTE-A system and the heterogeneous nature of the air interfaces. Figure 2 shows the sketch of the mechanism for the data transfer that can minimize the degree of dependence and exchange information between non-adjacent layers to avoid bottlenecks.

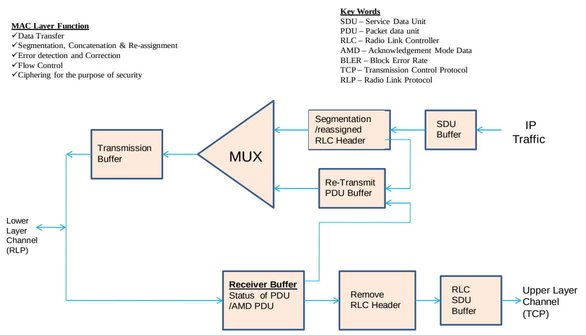

Figure 2 Mechanisms for Data Transfer in LTE/LTE-A Systems

The generated incoming File Transfer Protocol (FTP) traffic is stored in Service Data Unit (SDU) buffer. Segmented (concatenated) into Radio Link Controller PDUs, these SDUs are then added to RLC PDU header before being multiplexed (MUX). Meanwhile, a copy of the PDUs is replicated and stored in the transmission buffer for possible retransmission only when the missing message corresponding to that PDU is received. The multiplexer prioritize the order of retransmitting Packet Data Unit (PDU) first before considering those transmitting for the first time as configured by the RRC. Reassembly is conducted if all PDUs corresponding to a complete SDU is available and the condition of delivery to the upper layer is checked. If one or more SDUs are delivered to the upper (TCP) layer, all performance variables are updated accordingly. If the received PDU is from the correct data type, the header is removed, but if it is a status PDU, then the analysis of the protocol control takes place, and the correspondent actions such as shrinking the retransmission buffer, retransmission of some missing PDUs, etc are performed.

2.3 Network Intelligence based Schemes

Access to multimedia applications in wireless networks are concerned with the performance of handover because of the irretrievable property of real time data delivery. In order to improve the performance of handover (throughput, unnecessary handovers and handover latency), it is very important to make the handover decision intelligently and timely. The concept of network intelligence comes when tackling the issue of information visibility and considering the real-time network traffic. Fuzzy Logic (FL), Artificial Neural Networks (ANN) and intelligent IP-based protocols have been used in the past few years in choosing when and over which network to handover among different available ones [24], [25] in an efficient and intelligent manner.

Similarly, the application of neural networks in handover related issues were used for the estimation of the signal decay [26] and mobile users' profile prediction [27]. Neural networks have been successfully applied to solve complex problems by automatically learning the system behaviour and generalizing it to situations that are not experienced before.

Furthermore, IETF14 proposed Mobile IPv4 (MIPv4) [27] which was altered with the evolution of IPv6 as MIPv6 [28] for dealing with the mobility and its related issues in IP-based networks. This protocol suffered a great deal of problems like maintenance and assignment of the home and care of addresses, latency and packet loss due to lack of network intelligence. Also, it failed completely in the high mobility and user congestion scenarios because immediate multiple binding requests are not entertained in MIP. This resulted in degradation of overall QoS. However, other mobility management protocols such as Hierarchical MIP (HMIP) [30], Proxy MIP (PMIP), Client MIP (CMIP) [31], Fast MIP (FMIP) [32], etc. were proposed by the research community to attain scalability and to make intelligent decisions in the course of high mobility in heterogeneous wireless environments. But these all versions are not without their shortcomings as discussed in [33] too.

Using Stream Control Transmission Protocol (SCTP) [37], Ma et al. discussed the issue of vertical handover at transport layer between networks for efficient service provisioning and continuity by exploiting the multi-homing features of the said protocol [38] [39]. They divided their proposed scheme into two scenarios based on the mapping and configuration of outgoing source and destination IP addresses in the routing table: (1) Single-Homing Fixed Server where, an IP address is added to the routing table, handover is triggered, and the IP address is deleted from the table and (2) Dual-Homing Fixed Server where Mobile user is given the priority for performing IP address management functions like adding, deleting and updating nodes from the routing table.

Both these configurations are compared and dual-homing gives better results in contrast to single-homing in terms of throughput, latency and number of dropped packets. This is because; mobile user spent too much time in the handshake process that affects the arrival of packets into or out of the network. Also, address reconfiguration in single-homing scenario is a time consuming process. To cope with these issues, Ezzouhairi et al. [40] contributed to the field and introduced MSCTP+ (Mobile SCTP+) that reduces the handover latency and packet loss due to dynamic address reconfigurations during a handover procedure. They also extended their works by introducing a hybrid interworking architecture for different protocols in [34]. This architecture incorporates diverse cellular and IP networks, which are considered as peers, around a single IP backbone that hides their respective heterogeneity from one another. This hybrid architecture shows its scalability by treating the real time traffic and by reducing latency, packet loss and handover blocking.

In [35], authors propose Enhanced Mobile IP based handover scheme that uses layer 2 information for handover decision making like RSS, bandwidth and link indicator, etc. as this information is continuously available and can furnish the information about neighboring access networks. Following the same pattern, [41] propose to use inter-domain PMIP for reducing handover latency and packet loss in layer 3 handovers. This mechanism involves some extra messaging between the serving domains and as a result, succeeds to reduce handover latency and packet loss. Munasinghe et al. [36] presented a tight-coupling interworking architecture of WLAN and UMTS employing IMS as a signal arbitrator. They analytically modeled the above scenario by using handover delay, packet loss, jitter and signalling cost; and created the relationships among these parameters too.

Table 1summarizes the network intelligence based vertical handover decision schemes presented in this section and compared with the proposed SLIM.

Table 1 Network Intelligence based Schemes

Network Intelligence	Candidate	Description	Advantage	Disadvantage
Fuzzy	[24] [25]	Handover decision by prioritizing QoS dynamics according to user preferences	-Reduced HO delay - Reduced packet loss - Intelligent network selection -User satisfaction for QoS	-Increased Complexity -Higher decision processing delays
ANN	[33]	Applied to tackle complex problems by learning network behaviour.	-HO Success -Better Network Selection -Lower HO processing delay	-High Latency -Slow training & learning -Resource consumption
Intelligent IP	[29] [32] [34] [35] [36]	Mobility protocols designed for seamlessness and proper HO mechanisms.	-Reduced packet loss -Terminal resource conservation - HO Success -Security	-High latency -Central Control -High signaling overhead
SLIM	Proposed	Mapping between interworking sub-layers of WiMAX and LTE-A networks	-Reduced Latency -Improved HO Performance	-Signalling Delay -Complexity

Thus, if the value of one parameter is changed then it may change the whole set of results like for example, packet loss is directly proportional to the handover delay and its higher values may directly contribute to the behavior of packet loss.

3 Protocol Layer Architecture

Description of the functions and locations of different protocol layers (Control plane protocol stack and the user plane protocol stack) in the LTE/LTE-A architecture are highlighted. At each handover, the user-context (packets) and control plane context are transported from one evolved NodeB (eNodeB) to the other. The movement has to be performed seamlessly and faster without the user perceiving the impact of performance degradation due to the handover scheme in the LTE/LTE-A system.

3.1 Control Plane

The architecture of the control plane simplifies the model by defining triggers and information from lower to upper layers. All the messages from the control plane are coded and guarded by both the UE and MME in which it runs in between them [10], [19]. The UE will transmit neighbouring cells measurement to the eNodeB and this task is facilitated by the Radio Resource Control (RRC) layer. The UE periodically conducts Channel Quality (CQ) measurement to ascertain the condition of the channel which is being monitored by the control plane and temporarily identifies the cell sites for the active UEs. Additionally, during handover, RRC processes the transfer of UE context to the target eNodeB from the source eNodeB, protect the RRC messages and participate in the set-up as well as the maintenance of the radio bearers.

3.2 User Plane

The new feature of the user plane is the introduction of inter system retransmission mechanism that applies the cross-layer mechanism to resolve packet loss and long latency problems. Coding of data in the two Planes (user plane and control plane) are being performed in user plane. Interestingly, as a result of the RRC carrying non-AS messages, they experience double fold ciphering and protection as this was done first at the MME and now repeating at the eNodeB [15].

4 Sub-Layer Interworking Mechanism (SLIM)

The sub-layer interworking mechanism is introduced based on integrated coupling architecture into the protocol stack at both the mobile node and at the eNodeB sides as depicted in Figure 3. It assumes the role of the logical link controller (LLC) sub-layer, like handover support and retransmission mechanism. It is saddled with the responsibility of mapping between the interworking sub-layers of WiMAX and LTE-A networks in the case of inter-RAT handover procedure. Additionally, it also acquires important information such as channel conditions, capacity and MAC addresses of the neighboring networks to facilitate smooth handover. Retransmission, segmentation, re-sequencing as well as retransmission window size adjustment are all part of the retransmission mechanisms of the interworking (IW) sub layer.

During a handover, IW contexts of the source IW sub-layer are then transferred to the target IW sub-layer. The transfer includes received IW ACK messages, yet to be sent and unconfirmed IW blocks and ARQ parameters at the IW sub-layer. There are likely two reasons that might be responsible for considering the ARQ mechanism at IW sub-layer even though PDCP context are transferred.

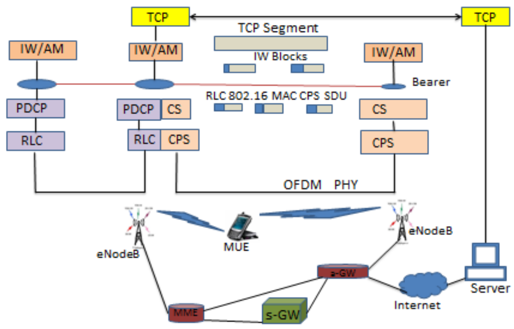

Figure 3 Interworking Sub-Layer Architecture of Integrated Network

i) Cell reselection is supported by WLAN networks in activating traffics for the UE which is not the case in LTE-A networks. After all, the packets lost during cell selection from WLAN to LTE-A might not have been transmitted by the target LTE-A network.

ii) Packet sequence number de-synchronization between the source and target networks may occur in an inter-RAT handover. Therefore it is paramount to have a mechanism to take care of this phenomenon.

In the preparation phase, the UE sends handover request to the source eNodeB to initiate handover to the target eNodeB cell (UE will send measurement reports periodically to the source eNodeB). Depending on the outcome of the report, the source eNodeB will decide to which target eNodeB the UE should handover. The preparation involves exchange of signaling between the source eNodeB and admission control of the UE in the target eNodeB for the handover. The moment the admission control message from the source eNodeB requesting target eNodeB to prepare for handover is received, the target eNodeB will prepare a buffer for the UE. An Interworking ARQ mechanism is depicted in Figure 4, where the window size of the retransmission buffer time is shown. Two retransmission mechanisms are used: IW ARQ and R-LLC [5], [6].

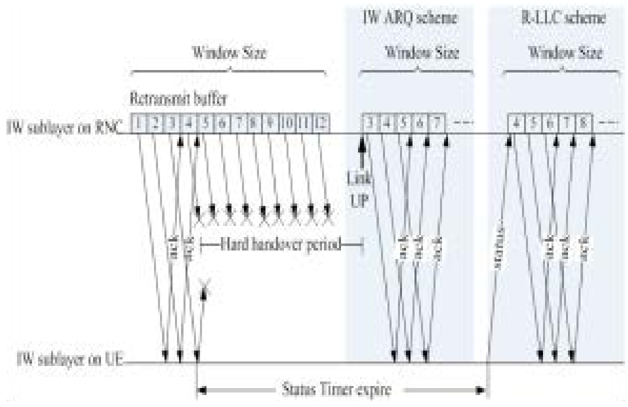

Figure 4 R-LLC Protocols and Interworking (IW) in LTE-A Handover Procedure [5]

However, there are differences between IW ARQ and R-LLC: i) In the R-LLC scheme, the lost IW blocks (Figure 3) are retransmitted at the expiration of time, and ii) in IW ARQ, the retransmit blocks appear on both the status report timeout as well as on a Link Up trigger.

4.1 The TCP Proxy

Many researchers have proposed solutions to the problem of bandwidth delay and premature timeout. Proposals like explicit handover notification [14] where TCP header is added to identify the handover situation. In [3], a scheme that uses MIPv6 mobility management protocol for vertical handover process is proposed. Freeze-TCP [9] was proposed in which it demands the TCP receiver to sense handover prior to disconnection, but needs to compute precise "warning period" to avoid possible delayed ZWA (Zero Window Advertisement). However, in [11] a proposal to delay RTT before a vertical handover is suggested to avoid premature timeout.
Inclusion of TCP proxy is proposed as a solution to these two typical problems. It is assumed that only the downlink traffic is considered as TCP connections encounter bottleneck at the eNodeB and that it is the eNodeB that makes the handover decision. The TCP proxy has the following features:
1) Fixed local congestion window size.
2) TCP proxy works in a transparent way prior to a handover execution and explicitly controls the TCP end-to-end window after a handover.
3) A corresponding ACK timer is then created after the TCP proxy receives a new segment from TCP sender. A locally generated TCP ACK is fed back to the TCP sender for the timeout with calculated advertised window size.
4) In order to avoid deadlock, the last TCP ACK with a new calculated advertised window is resent to the TCP sender.
5) This TCP proxy solution is found useful for the frequent inter-RAT handover process.

5 Simulation

The set up in Figure 5 illustrates the topology used to conduct simulations with ns-2 codes. The simulations were carried out to analyze the interworking sub-layer performance during inter-RAT handover between LTE-A and WiMAX. Data Packets are generated by the FTP server which serve as the transmitter and sent to either the WiMAX or the LTE-A network as the UE receives same as it crisscrosses the borders of these regions that possess enough bandwidth to do so.

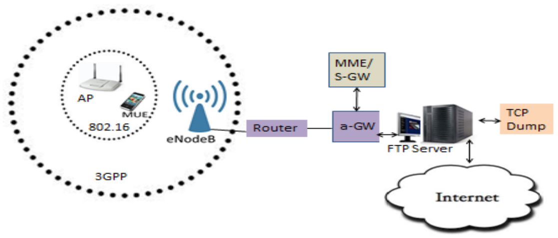

Figure 5 Simulation Topology

The length size of the PDCP in LTE-A radio network is translated as data of 50MB. It is assumed that if the queue length exceeds this value, an excessive buffering may occur which can cause RTT of the TCP traffics to be inflated. However, for the WiMAX module, the bandwidth of WiMAX is much higher than that of LTE-A.

Table 2 Simulation Parameters

Parameters	IW	PDCP	RLC	
Max. Retransmit	10	-	-	LTE-A
Window Size	30 Blocks	-	500 Blocks	
Frame Duration	10 ms	4 ms	-	
TTI	10 ms	-	-	
BLER	1e-6	-	-	
TCP Header Compression & Retransmit	No	No	-	WiMAX
Modulation Type	OFDM	OFDM	OFDM	
ACK Timeout	-	-	50 ms	
FFT	-	-	256	
Number of Sub-carriers used	-	-	200	
RLC Mode	-	-	AM	
Data Rate		Unlimited		TCP
Block Size			20	
Minimum RTO	-	-	0.2 s	
Traffic Type			FTP	

5.1 Simulation Results

5.1.1 Handover from 3GPP to WLAN

The simulation of inter-RAT handover from LTE-A to the WiMAX, starts with an FTP session as the UE begin to perform handover after it enters the coverage region of WiMAX. At about some hundredth of a second, the WiMAX network entry procedure is finished and the IW sub-layer on the eNodeB receives an UpLink trigger. Figure 6 shows the packet flows of context transfer schemes: R-LLC, SDU Reconstruction and the proposed IW ARQ scheme.

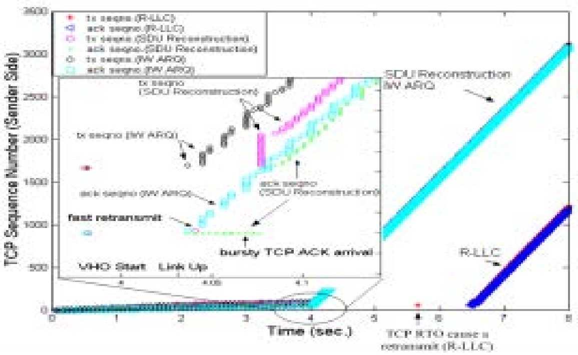

Figure 6 Comparison of Sequence Numbers of TCP connections between LTE-A and WLAN

The R-LLC scheme does not support uplink trigger, so it retransmits the last unacknowledged data packet on the timeout of the retransmission timer. During this period, the TCP RTO timer expires and the congestion window size shrinks. The SDU Reconstruction scheme reconstructs the RLC PDUs that are stored in the RLC retransmission buffer. However, if any PDU of the SDU is successfully transmitted, then it is deleted from the retransmission buffer and the remaining PDUs of this SDU cannot be reconstructed as such are discarded. The remaining RLC SDUs (TCP segments) are then forwarded to WiMAX network after handing over to eNodeB. These packet (out-of-order) arrivals duplicate ACKs which in turn trigger TCP retransmission process faster thereby making the TCP congestion window size to shrink by about half the size of steady state. This phenomenon also leads to the reduction of average throughput as shown in Figure 7.

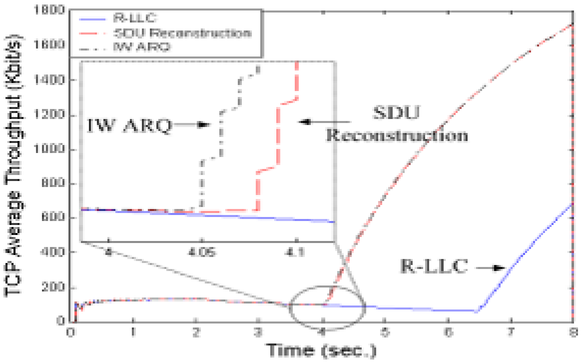

Figure 7 Average Throughput

Furthermore, adjustment of the retransmission window size of IW ARQ scheme is done in line with the queue size of the target network and then forwards the unacknowledged IW data as soon as Uplink trigger is received. After the handover, there will be no packet losses and so the TCP ACK arrivals might not be as bursty as those of SDU Reconstruction scheme. This is as a result of the IW ARQ retransmission window mechanism.

5.1.1 Handover from WLAN to 3GPP

One of the typical problems that do occur during the handover procedure from high-speed WiMAX network to relatively low speed LTE-A network is the buffer overflow, which is caused by the bandwidth delay (BD) mismatch between these two networks. The LTE-A network is likely to undergo buffer overflow when the TCP congestion window size becomes much larger in WiMAX than the buffer allocation for a UE in the LTE-A eNodeB.

In SDU Reconstruction scheme, the buffered packets forwarded from WiMAX to LTE-A may have the probability to overflow the LTE-A buffer, because the buffer in WiMAX is capable of storing more packets than the LTE-A buffer size. Therefore for SDU Reconstruction scheme, in Figure 8, the buffer overflow in LTE-A after handover may lead to TCP retransmission starting a little bit late and cause the TCP congestion window to shrink.

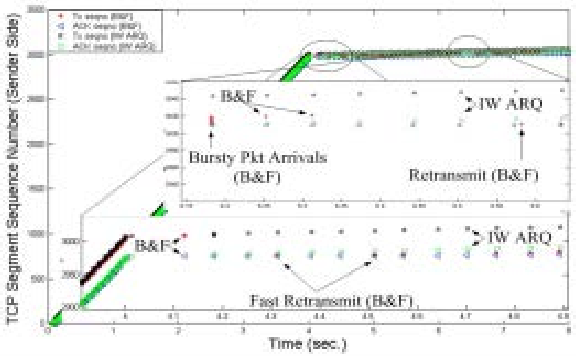

Figure 8 Sequence Number comparison of the TCP connections between WLAN and LTE-A

In R-LLC scheme, the long local retransmission timer period leads to the TCP RTO timer expiration, and the TCP sender retransmits a segment three times before it (local retransmission timer) expires. Regarding IW ARQ scheme, the support of uplink trigger accelerates handover response time, and the robust IW ARQ retransmission window size effectively eliminates buffer overflow in the target network. The side effect of the lossless handover of IW ARQ scheme is clearly seen where the false fast retransmission is eliminated as a result of the packet losses or out-of-order packet arrivals during the handover. Figure 9 shows the average throughput differences for these schemes are not distinct 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 significantly influence the average throughput.

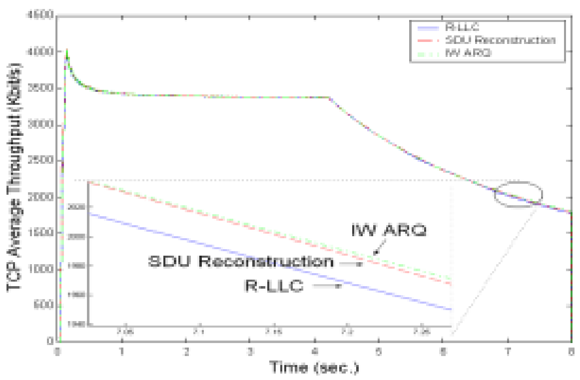

Figure 9 Average Throughput

5 CONCLUSION

The introduction of sub-layer tagged IW which lies on the eNodeB and UE has provided a new phase in the inter-layer handover schemes shown in Figure 4. This paper has chosen a handover scheme on the basis of the integrated coupling architecture for imperceptible (seamless) roaming between WiMAX and LTE-A networks. When IW sub-layer scheme was compared with the other context transfer schemes: RLLC and SDU Reconstruction, it is found to achieve lossless and fast handover procedure for TCP traffics because of the introduction of inter-system retransmission mechanism. The results however prove better handover performances achieved. The introduction of the proposed TCP proxy is found suitable for persistent inter-layer handover scenario as TCP sender's parameters does not need to adjust. Thus, an improvement in the handover performance with respect to network reliability was eventually achieved while considering the choice of selecting the optimal network.

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