TCP Throughput Improvement over Vertical Handover between 3G LTE and WLAN

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Abstract. We address TCP throughput degradation over vertical handover between 3G-LTE and WLAN. 3G-LTE link layer tries to recover packet loss and deliver recovered packets in-order. This may involve link layer holding packets before later arriving packets arrive, causing spurious timeout. A state-of-the-art scheme holds fast retransmit/recovery for one RTT waiting for packets arriving at TCP layer out of order. We show this wait is unnecessary and costs TCP throughput. Our scheme is also able to improve TCP throughput by loss differentiation with parameters adapted to new network on vertical handover, considering link layer characteristics of 3G LTE which supports in-order delivery. Simulation result shows improved TCP throughput under various scenarios with TCP Reno and TCP SACK.

Keywords: 3G LTE, Vertical handover, throughput optimization.

1 Introduction

The variety of Internet links with different properties has increased and has led to the integration of a variety of wireless networks such as cellular networks(e.g., 3G WCDMA/LTE) and wireless LAN(e.g., 802.11x). A process where a mobile node switches from one network to a different type of network is called vertical handover. However, TCP which is the most prevalent protocol used on the Internet runs under the basic assumption that any packet loss is the indication of congestion, not including wireless part. TCP over wireless network may involve high packet loss rate or delay from link-layer retransmission or vertical handover between heterogeneous wireless networks. As a result, TCP interprets them as an indication of congestion, falsely triggers fast retransmit or timeout and reduces its transmission rate. Therefore, TCP throughput is gradually degraded.

Previous researches[5,6] for packet losses over wireless network have addressed differentiation of congestion losses from wireless losses, but have paid little attention to real features of commercial wireless link layers. Some known researches[1,2,3] on vertical handover have handled the difference in bandwidth-delay products between two different types of networks or the communication across layers to adapt the propagation delay of new network.

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In this paper, we consider the real features of 3GPP network local functions previous schemes have overlooked. It delivers the packets to the upper protocol layers in-order and may cause the spurious TCP RTO since local communication by link layer blocks the later arriving packets until the preceding packets arrive successfully to deliver packets in-order to upper layer. Vertical handover from slow wireless link to fast wireless link may introduce this case since the following packets may overtake preceding packets.

We introduce a new TCP congestion control scheme to solve this problem which adapts to the link layer transmission schemes involved in vertical handover, specifically, between 3G LTE and WLAN. Our schemes uses the loss differentiation to improve throughput and the parameter adaption of LD to new network on vertical handover. The proposed loss differentiation is a modification of loss differentiation (LD) scheme [7] over vertical handover between 3G LTE and WLAN. The proposed LD deals with wireless/wireless handover problem and tunes key parameters of LD over time to the network, while the original LD differentiates wireless loss from congestion loss over wired/wireless networks. We also employ the F-RTO [9] to detect vertical handover and to adjust the parameter of LD to new wireless network.

There has been a scheme [5] which tries to improve throughput with similar approaches on vertical handover between 3G WCDMA and WLAN. However, it assumes that wireless link layer supports local recovery and may generate out-of-order packets, while commercial 3G-LTE networks have the strict link-layer ordering even in handover procedures. As a result, fast retransmit/recovery algorithms of TCP are triggered one RTT after the first receipt of duplicate ACK on previous scheme [5].

Our scheme addresses this problem by triggering fast retransmit/recovery algorithm without the one RTT delay, and thus improves throughput of TCP during vertical; handover 3G-LTE and WLAN.

Our scheme is not a mere enhancement of previous scheme [5]. First, we solve a new problem of TCP throughput degradation over vertical handover between 3G-LTE and wireless LAN, while the previous scheme deals with vertical handover between 3G WCDMA and WLAN.

Second, our scheme significantly improves throughput more than the previous scheme [5] as well as F-RTO[9]. Data behavior in Fig.2 shows that the lost packets are retransmitted faster and Fig.3 shows TCP throughput under various scenario with TCP Reno and TCP SACK.

The rest of this paper is organized as follows. We provide a detailed description of proposed scheme in section 2. Section 3 presents the comparison of data behavior between previous schemes [5] and proposed scheme. The performance evaluation of our schemes is provided in Section 4.

2 Proposed TCP Modification

In this section, we provide a detailed description of proposed scheme which affects the TCP sender behavior only in congestion avoidance phases.

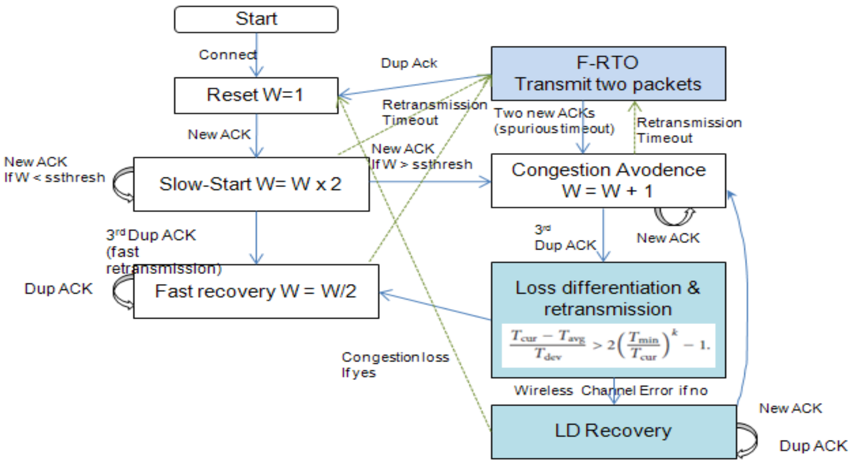


Fig. 1. State Transition Diagram of Proposed Scheme

2.1 Implementation Details of Loss Differentiation

As shown in Fig.1, the proposed scheme includes three states, i. e. Loss Differentiation, LD Recovery and F-RTO states. Loss Differentiation (LD) and LD Recovery states are involved in the loss differentiation scheme to improve TCP throughput, identifying the cause of packet losses over old and new wireless network. On three-duplicate ACKs, the LD determines the packet loss types as wireless packet loss or congestion packet loss using Equation (1) [5].

$$\frac{Tcur - Tavg}{Tdev} > 2\left(\frac{T_{\min}}{Tcur}\right)^k - 1 \quad (1)$$

Tcur denotes the RTT measured immediately before the current packet loss, *Tavg* and *Tdev* denote an exponentially weighted moving average of RTT and the deviation,respectively. A flag indicating congestion is set to true if the inequality in Equation (1) is satisfied, and then it goes to the fast recovery state which follows the operation of conventional TCP. Otherwise, the flag is set to false, and it retransmits a packet which triggered three duplicate ACKs, and it waits for new ACK on the LD recovery state to avoid unnecessary multiple retransmits on congestion avoidance. On the LD recovery, TCP sender transmits three new packets in response to three duplicate ACKs with one new packet per each duplicate ACK as far as the congestion window allows it. This is similar to the proposed standard limited transmit algorithm [11]. The LD recovery state ensures that LD state remains ack-clocked and new packet is put on the network only on indication that one of the previously sent packets has left the network. If a new ACK arrives, it enters congestion avoidance, retaining the current congestion window size. On retransmission timeout event in LD recovery phase, it goes to the Reset state, because LD recovery phase already sent new three packets for three duplicate ACKs and waits for new ACK. On slow start state, congestion avoidance, and fast recovery, it goes to F-RTO state.

2.2 Delay Adaptation to New Network

3G-LTE which supports local recovery with in-sequence delivery to the upper layer. Vertical handover between different networks can cause the delay of the ACKs and lead to RTO which can greatly degrade TCP throughput, even though there is no congestion packet loss.

The F-RTO state is for the TCP sender to keep the congestion window with detection of delay spike due to vertical handover or wireless network delay from local functions. This state retransmits the packet that triggered timeout on entering retransmission timeout and waits for the ACK. The sender's receipt of two new ACKs allows the sender to cancel the TCP timeout retransmission procedure and transmit new packets continuously in congestion avoidance, retaining the current congestion window. However, on receiving one or two duplicate ACKs, the state goes to Reset state. When TCP receives ACK for the first newly transmitted packet, $T_{\min}$ and T_{avg} is set to new measured RTT and T_{dev} is set to a half of the new measured RTT. This reset operation of parameters allows the modified loss differentiation scheme to adapt itself to the change in propagation delay due to vertical handover to new wireless network as in [5].

3 Behavior Comparison of Proposed LD Implementation

In this section, we show the data behavior of proposed scheme and previous scheme [5]. It is assumed that the round trip time is T20.

Packet losses can be categorized into link level recoverable wireless packet loss, link level unrecoverable wireless packet loss, and congestion packet loss. The link level recoverable packet losses over 3G LTE are hidden to the TCP layer since recovered packets are delivered in-order to the TCP layer as shown in the top of Figure 2, while previous schemes [5] [7] assume that local recovery in wireless network results in out-of-order packet to TCP layer. For link level unrecoverable wireless packet loss previous scheme [5] and proposed scheme show the same behavior. However, if wireless L2 sub-protocols decides it is unrecoverable, they show different behavior, as shown in middle and bottom of Figure 2. The TCP sends packets 1 through 5, and packet 2 is lost on the wireless radio. If wireless L2 sub-protocols in UE decide it unrecoverable, they deliver packet 3 through 5 to upper layers and then TCP receiver in UE sends duplicate ACKs for packet 2 on receiving packet 3 through 5 in proposed scheme. In case of previous scheme [5], TCP receiver starts the delayed response timer of one RTT at T28 at the first duplicate ACK, and retransmits the lost packet 2 on expiration of delayed response timer at T48. For proposed LD, TCP sender detects three duplicate acknowledgement for packet 2 and retransmits packet 2 at T30 as conventional TCP does. The delayed retransmission of previous scheme [5] affects the cwnd update time which is updated when new ACK is received and results in the delayed transmission of new packets. Likewise, the congestion packet losses can have the same impact on lost packet retransmission for the previous scheme [5].

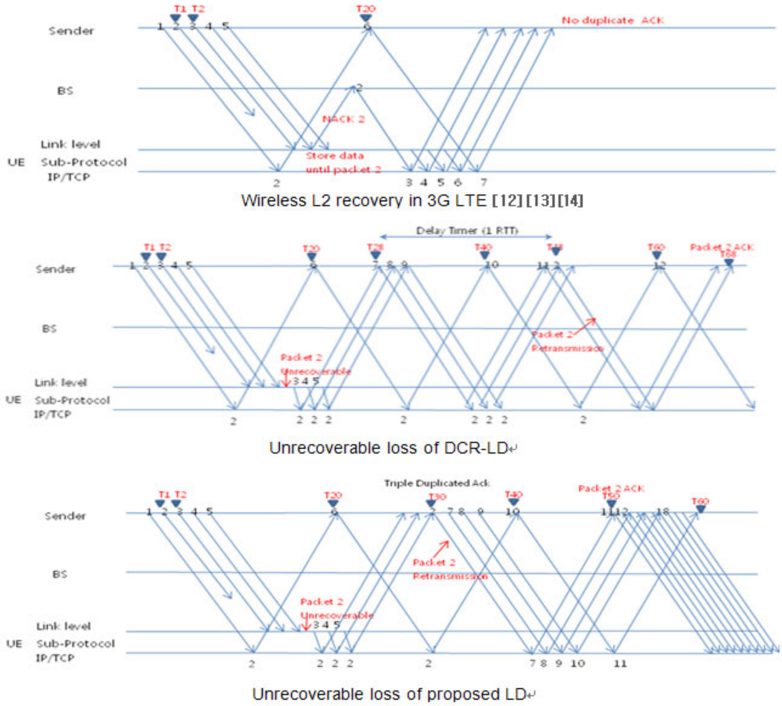


Fig. 2. Data Behaviors

In conclusion, previous scheme [5] delay the retransmission of the lost packet falsely expecting local recovery function. However, 3G LTE link level sub-protocol supports not only local recovery but also in-order delivery service and previous scheme always delays the TCP recovery time on packet losses on 3G-LTE as well as WLAN. Proposed scheme gets rid of this unnecessary delay, thus improving TCP throughput during vertical handover between 3G-LTE and WLAN.

4 Simulation Results

In this section, we present simulation results which evaluate the TCP throughput performance of TCP connections during lifetime for previous LD [5] and the proposed LD when TCP-Reno and TCP-SACK are used, respectively. This simulation is based on the ns-2 simulator (version 2.34) [15]. Previous scheme [5] and proposed scheme agents are implemented by modifying the TCP-Reno agent and TCP-SACK agent in ns-2.

In this simulation, two different losses, wireless losses as well as congestion losses are considered for TCP throughput evaluation. For each situation, we also consider two different environments, WLAN and 3G LTE, respectively. We compare the TCP throughput comparison for various scenarios, the congestion packet loss with wired/WLAN, wireless packet loss over WLAN, congestion packet loss with wired/3G-LTE, and wireless packet loss over 3G-LTE when TCP-Reno and TCP-SACK are used respectively.

The simulated wireless link has a bandwidth of 1Mbps for 3G LTE and of 10Mbps for WLAN. For wired network, 20Mbps of bandwidth is used. For congestion loss model, we set the loss rate to be as high as 1% with uniform distribution for wired/WLAN and wired/3G-LTE. 5% of uniform loss rate is set with 200ms delay for 3G LTE wireless packet loss. WLAN wireless packet loss is set to 1% with 20ms delay. The diagram is shown below.

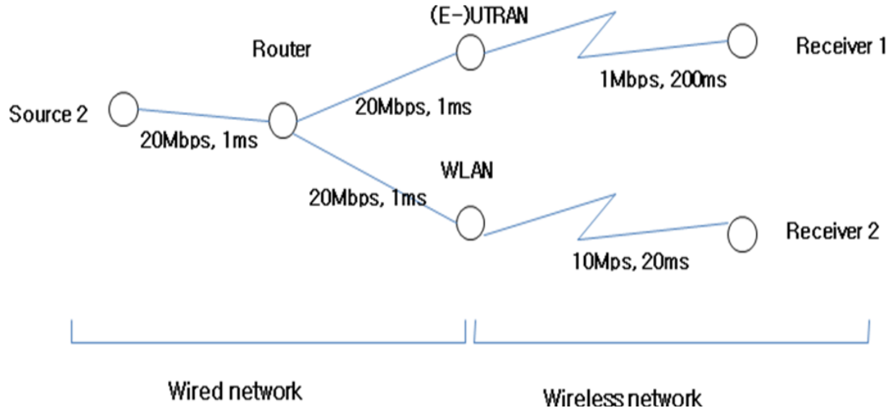
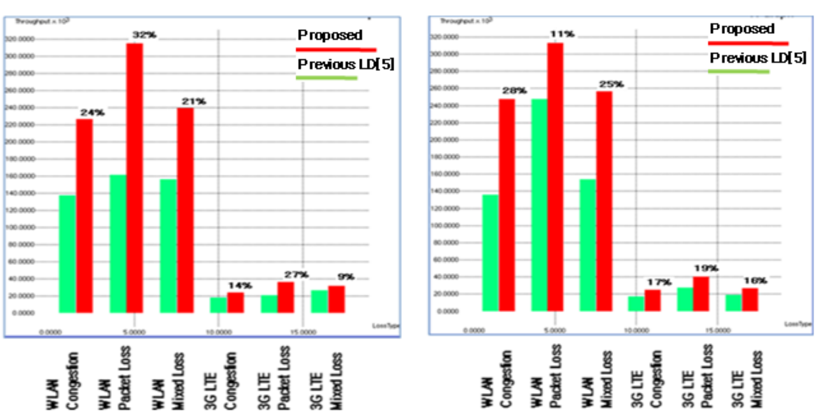


Fig.3 show the average throughput for the schemes of previous LD[5] and proposed LD when TCP-Reno(left part of Fig. 3) and TCP-SACK(right part of Fig. 3) are used, over WLAN and 3G LTE. The simulation evaluates the throughput various cases where there are congestion packet losses only, wireless packet losses only and mixed packet losses over WLAN and 3G LTE. The green bars represent previous LD while red bar represents proposed LD. For mixed packet loss, we assumed 20% of the total packet loss rate (1%) is wireless loss. The simulation runs for 200 seconds. The average throughput is on the y-axis. The x-axis shows the packet loss type. It can be seen from the graph that average throughput of proposed LD is better than that of previous LD in both TCP-Reno and TCP-SACK.



TCP-Reno throughput TCP-SACK Throughput

Fig. 3. Throughput Comparison

5 Conclusion

Vertical handover from 3G LTE to WLAN may involve TCP throughput degradation. A state-of-the-art scheme to address this problem is not suitable for commercial 3G-LTE network which reveal features different than those assumed in the previous scheme. Our contribution lies in removing unnecessary wait for one RTT after handover by previous scheme, enhancing throughput. Simulation is performed using ns-2 for various scenarios involving TCP Reno and TCP SACK to verify improvement of TCP throughput over previous approach.

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