Enhanced TCP Congestion Control for Vertical Handover with the RTT inflation and the measured-RTT of the new network

Kwang-il Kim, Jechan Han, and Jaiyong Lee

Department of Electrical and Electronic Engineering Yonsei University
C709 Yonsei Univ. Sinchon-dong Seodaemun-gu Seoul, Korea
E-mail: {kikim71, hjcyy, jyl}@yonsei.ac.kr

Abstract: The recent trend is that the mobile internet service has been offered in the integration of various wireless networks. In such heterogeneous networks, vertical handover is more common and important handover technologies. But during vertical handover, standard TCP has experienced many problems such as multiple packet losses, the packet reordering, the under-utilization due to the drastic change of the Bandwidth Delay Product (BDP) and the network transmission delay (Round Trip Time :RTT).

In this paper, we propose [1,2]“Enhanced TCP congestion control scheme with RTT inflation and the measured-RTT of the new network” for the seamless soft vertical handover and evaluate this by OPNET simulation. We assume the proposed scheme uses the cross-layer design in a TCP receiver and a TCP time-stamp option. OPNET simulation results show that our proposed scheme improves better TCP performance than other handover congestion control schemes such as Freeze-TCP or SS-TCP during the vertical handover.

1. Introduction

The Transmission Control Protocol (TCP) is the most general transport layer protocol used in the internet application services including a web browsing, a file transfer, an e-mail and streaming audio and video. And TCP works well in the wired-line environments, because TCP was originally designed for the congestion control on the wired-line communications when the TCP sender side detects congestion situations such as packet losses by using expiring retransmission timer (RTO) or by receiving triple duplicate acknowledge packets (ACKs). However, the current TCP is well known for the performance degrades in the wired-wireless network environments.

In order to get the seamless handover from one network to another network, the multi-standard capability within MN should be considered. Two primary stages are generally involved in the handover process. The first is at the data-link layer to enable communication through a different access point. If the new access point is within another IP subnet, then a second handover is required at the network layer, to enable use of an IP address recognized as belonging to the new network. Mobile IP provides a standards-based approach to address internetworking handover, and has been widely deployed [6].

There are two categories generally classified during the handover process. The first is the horizontal handover between two similar systems with the similar data transmission configuration on the network and the second is the vertical handover is between two different systems when the mobile node (MN) moves over heterogeneous networks which provide a different type of characteristics such as the access network bandwidth, the cell coverage and the transmission delay (RTT : Round Trip Time).

In the most recent, the wireless internet services have been commonly considered in overlaid wireless networks such as 3rd generation wireless networks (3G) and Wireless Local Area Network (WLAN) or 3G Code Division Multiple Access Evolution Data-Only Network (3G CDMA EVDO) and 4th Generation Long Term Evolution (4G LTE) [1]. 3G or 3G CDMA EVDO network has the low bandwidth and the large coverage and latency and on the other hand WLAN or 4G LTE has the high bandwidth, the small coverage and latency.

$$\boldsymbol{BDP = Estimated\ RTT \times Bandwidth} \qquad (1)$$

Bandwidth-delay product (BDP) is a well-known concept in measuring the capacity of a “network pipe”. When applied to the context of the TCP protocol, the number of outstanding (i.e., in-flight or unacknowledged) data packets cannot exceed the TCP flow’s share of BDP. TCP’s transmission window should be large enough to allow enough in-fight packets to fill the pipe. In fact, the role of TCP’s AIMD (Additive Increase Multiplicative Decrease) congestion control algorithm is to dynamically “probe” the current available bandwidth of the path, in order to reach an optimal congestion window size equaling its share of the BDP.[7]

But when TCP performs the congestion control based the wired network during the vertical handover, TCP has many problems such as multiple packet losses, the packet reordering problem, the under-utilization problem, and the TCP retransmission due to the spurious timeout. These

---

[1] "This research was supported by the MKE(Ministry of Knowledge Economy, Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute of Information Technology Assessment)" **(IITA-2008-C1090-0801-0038)**

[2] "This research was also supported by LG Electronics."

issues are caused by the drastic change of the Bandwidth Delay Product (BDP) and the drastic change of the network transmission delay between the heterogeneous wireless networks. Eventually TCP performance degradation inevitably happens.

There have been many proposed studies to improve TCP performance degradation during handover as like the Freeze-TCP [2] and the Slow Start-TCP (SS-TCP) [3].

Freeze-TCP scheme helps to avoid degrading TCP performance due to multiple packet losses and timeouts while handovers. MN (TCP receiver side) acquainted with handover impending sends a zero window advertisement (ZWA) to the TCP sender side in order to inhibit timeouts at the TCP sender side. And as soon as TCP sender side receives a ZWA from MN, TCP sender side reduces a congestion window (cwnd) by 0 to make itself into the frozen mode that TCP sender freezes all timeout timers and stops the data transmission. After for a while as soon as MN detects the handover is finished, MN sends 3 duplicate ACKs with the available received window size. Then TCP sender side resumes the data transmission with its old cwnd. As the above result, the Freeze-TCP can prevent the drastic diminishment of the cwnd during handover and avoid degrading TCP performance. The Freeze-TCP is designed for a horizontal handover and is well known to work as better as the transmission disconnection time increases during the handover.

In [3], authors proposed a new TCP variation for the vertical handover between heterogeneous networks. In a SS-TCP approach, a TCP sender and receiver side uses the handover option field (HO) in TCP header to recognize an impending handover and a completing handover. After vertical handover, TCP sender side tries to re-adjust its data rate in short time by resuming the data transmission with slow-start mode since the new network has drastically different characteristics in contrast with horizontal handover where keeping the same data rate improves performance.

In this paper, we assume TCP receiver side (MN) uses the cross-layer design [4] and TCP time-stamp option [RFC793 and RFC1323] on the proposed scheme. And we proposed the enhanced TCP congestion control scheme for the seamless soft vertical handover with the RTT inflation and the TCP receiver-based RTT measuring. We evaluated also the TCP performance of the proposed scheme compared with the Freeze-TCP and the SS-TCP with performing the OPNET simulation on the 3G CDMA EVDO - 4G LTE vertical handover. The simulation result shows that the proposed algorithm makes a great improvement in TCP performance during vertical handover in contrast with other proposed algorithms.

2. Proposed Scheme

MN (TCP receiver side) enters a handover situation and then becomes in advance aware of the establishment of the new network layer link for preparing the seamless handover by the cross-layer design [4].

First step : during the handover process, MN measures repeatedly the round-trip time (RTT) in the new network by utilizing the Internet Control Message Protocol (ICMP) [5] and also becomes aware of the new wireless access network bandwidth from the MAC of data-link layer [4]. And then MN can estimate in advance the new network transmission latency (Estimated RTT) and also calculate the estimated BDP for the new network link (2).

$$\mathit{Estimated\_RTT} = \mathit{icmp.RTT} + \mathit{PacketSize}/\mathit{BW}_{BS,AP}$$

$$\mathit{Estimated\_BDP} = \mathit{Estimated\_RTT} \times \mathit{BW}_{BS,AP} \qquad (2)$$

Here, we assume the available bandwidth along a path is the minimum available bandwidth of all traversed links and the TCP end-to-end path has multiple wired links with a wireless link in the network environment deployed. So we can consider the ***Estimated_BDP*** value from (2) as the BDP of the new network since the bandwidth of a wireless link is the most small compared with other large bandwidth of wired links.

With based on the estimated RTT information on the new network, MN can decide whether the handover type is horizontal or vertical handover by comparing with the previous network RTT. If there is the drastic difference of the estimated RTT between the new network and the old network, that shows the vertical handover, otherwise that shows the horizontal handover.

Second step : when MN (TCP receiver side) is aware of the handover impending by the cross layer design, as like the Freeze-TCP and the SS-TCP, MN continues sending ACKs with ZWA in order to make the TCP sender into the frozen mode to avoid degrading performance due to the handover [3]. Furthermore in the case of the downward vertical handover, the proposed scheme will especially operate the RTT Inflation mode by reflecting the estimated RTT of the new network in ACK Timestamp echo reply (ACK.**TSecr**):

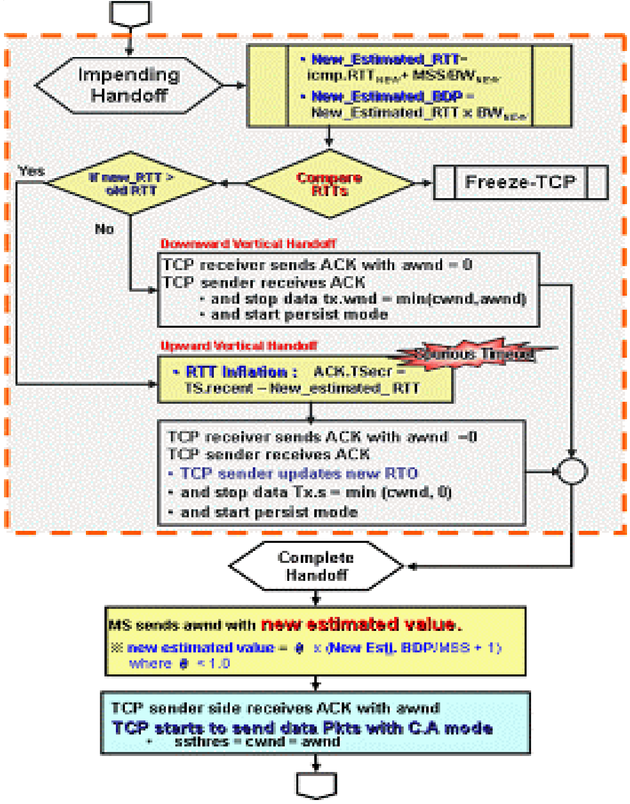

Fig 1. the flow chart of the proposed scheme

Table 1. Simulation Parameters

Parameter	Values
Comparison TCP Protocols	Freeze-TCP, SS-TCP, Proposed Scheme
Data Traffic	FTP Sessions
Simulation Area	1000m x 1000m
# of mobile node	1
Backgrounds	3 FTP connections
TCP MSS	1000 bytes
SACK-enable	ON
Vertical Handoff Duration	10 seconds
Bandwidth(4G LTE eNB)	30Mbps
Queue Size (eNB)	16 packets
RTT(CN-LTE eNB-MN)	100ms
Bandwidth(3G EVDO AN)	1Mbps
Queue Size (AN)	16 packets
RTT(CN-AN-MN)	300ms

$$ACK.TSecr = TS.recent - Estimated\_RTT \qquad (3)$$

MN sends ACK with ACK.**TSecr** as like (3).

Whenever TCP sender side receives ACK with the inflated RTT as the RTT sample, RTO is computed by using the following procedural steps

$$RTTVAR \leftarrow (1-\beta)\cdot RTTVAR + \beta\cdot |SRTT - RTT| \qquad (4)$$

and

$$SRTT \leftarrow (1-\alpha)\cdot SRTT + \alpha\cdot RTT \qquad (5)$$

Where SRTT (Smoothed Round-Trip Time) and RTTVAR (Round-Trip Time Variation) are state variables, and $\alpha = 1/8$ and $\beta = 1/4$. TCP sender updates the RTO as

$$RTO \leftarrow (1-\alpha)\cdot SRTT + \max\{G, k\cdot RTTVAR\}, \qquad (6)$$

Where G is a clock granularity and $k = 4$.

The inflated RTO will be increased to much more the exact RTO value for the new network. When TCP sender side wakes up and resumes the data transmission on the new network link with the newly inflated RTO, TCP sender side can be prevented from producing the early expired the retransmission timeout problem (the spurious timeout problem) after the vertical handover [4].

Third step : TCP sender sustains the frozen mode for a while, and then as soon as MN becomes aware of completing the handover, it sends AWND with the estimated value, not and wakes up the frozen TCP sender side :

$$Estimated\_Value = (Estimated\_BDP/MSS + 1) \times \theta$$

$$\text{where } 0 < \theta <= 1.0 \qquad (7)$$

$$AWND = Estimated\_Value \qquad (8)$$

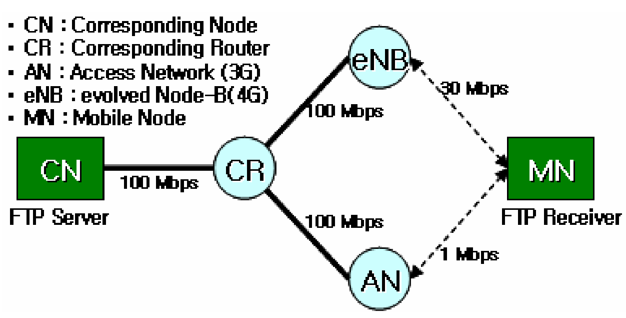

Fig.2. Simulation Topology

So a TCP sender side applies ***Estimated_Value*** to TCP congestion window (cwnd) and slow start threshold (ssthres) for the new network as like (9) and then resumes the data transmission on the new network link with TCP congestion avoidance (CA) mode at the estimated BDP level of the new network.

$$cwnd = ssthresh = AWND \qquad (9)$$

Although there are drastic changes of BDP and the network latency during the vertical handover, By updating the prior estimated BDP information of new network from a TCP receiver side, a TCP sender side can avoid multiple packet losses, the packet reordering, the under-utilization problem and the TCP retransmission due to the spurious timeout on the new network link.

3. Performance Evaluation

A. Simulation Model

We conducted a performance evaluation using the OPNET with the simulation topology shown by Fig.2 for the 3G CDMA EVDO – 4G LTE vertical handover.

we assumed that for LTE which has 30Mbps of the eNB data rate and 100 ms of the network latency (RTT) and for a 3G CDMA EVDO which has 1Mbps of the AN data rate and 300ms of the network latency. The simulation parameters used were shown in Table 1.

B. Simulation Result

Fig.3 and Fig.4 shows the transition of TCP cwnd size respectively during the upward and downward vertical handovers.

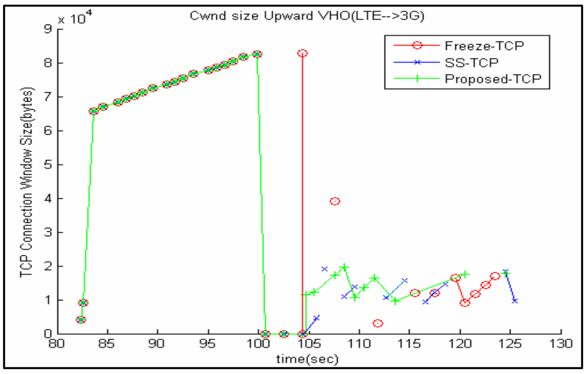

Fig.3. cwnd size vs time on the upward vertical handover

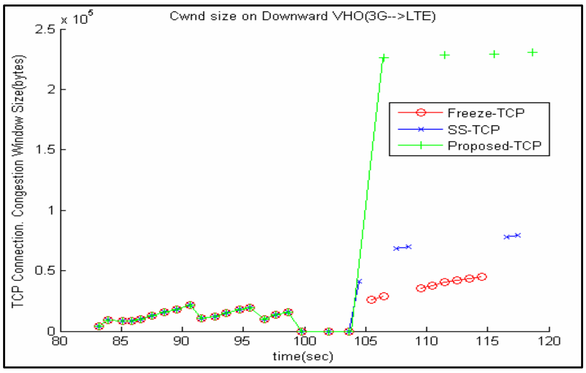

Fig.4. cwnd size vs time on the downward vertical handover

In Fig.3, it is observed that the proposed scheme makes TCP sender side resume the data transmission with not a slow start mode but CA mode at the estimated BDP level for the new network. So we can get the improved performance for the upward vertical handover with avoiding the packet loss problem due to the over-transmission based on the previous network cwnd for the Freeze TCP and In contrast with the slow start mode for the SS-TCP, our proposed scheme also has the better performance by reducing the time of reaching a stable condition.

In the Fig 4, it is observed that the proposed scheme shows the overcome of the under-utilization problem and the spurious timeout retransmission problem. During the downward vertical handover, we can see the great improvement of TCP performance on the proposed scheme from the simulation result in Fig.4 as well

4. Conclusion

We discuss TCP congestion control when the vertical handover occurs. The vertical handover significantly degrades the TCP performance due to the drastic change of BDP and RTT. In this paper we propose a new TCP congestion control scheme for improving TCP performance during vertical handovers.

The soft handover latency may be large since the soft handover needs an authentication process to move into a new mobile network. Freezing the TCP transmission during a handover has an advantage since it prevents packet drops and a backed-off RTO value during the handover. Our proposed scheme obtains improvements in performance by freezing the TCP data transmission during the handover.

And our proposed scheme is receiver driven. Before handover a TCP receiver in advance measures RTTs of the new network repeatedly and calculates the ***Estimated_BDP*** for the new network by (2). After handover TCP sender can avoid packet loss with readjusting its window size by updating a slow-start threshold (ssthresh) and congestion window size (cwnd) by (9) based on the BDP information which a TCP receiver already estimated and sent before handover switchover by (7) and (8). Further more in the downward vertical handoff a TCP receiver in advance conducts the RTT inflation to a TCP sender by (3) ~ (6) so that TCP sender can prevent the premature timeout after handover.

As shown in the OPNET simulation result, our proposed scheme can directly reach a stable condition after handover and have better performance than Freeze-TCP and SS-TCP.

The future work is how to estimate the real time bandwidth during vertical handoff.

References

[1] IntoMobile “Verizon confirms LTE 4G network trials with Vodafone” Nov.29 2007

[2]G.M.T. Da Costa and H.R.Sirisena, "Freeze TCP with Timestamps for Fast Packet Loss Recovery after Disconnections," Proceedings of the International Symposium on Performance Evaluation of Computer and Telecommunication Systems, July 2002.

[3] S. Kim, J. Copeland, "TCP for seamless vertical handoff in hybrid mobile data networks", in Proc. of IEEE GLOBECOM, San Francisco, vol.2, pp. 661-665, Dec. 2003.

[4] Humphrey Rutagemwa, Student Member, IEEE, Sangheon Pack,Member, IEEE, and Jon W. Mark, Life Fellow, IEEE , "Robust Cross-layer Disign of Wireless Profiled TCP Mobile Receiver for Vertical Handover," IEEE Transaction Dec 2007.

[5] A. Conta and S. Deering, "Internet Control Message Protocol(ICMPv6) for the Inter-net Protocol Version 6 (IPv6) Specification," RFC 2463, December 1998.

[6] Yuci Gou, David A. J. Pearce and Paul D. Mitchell, "A Receiver-based Vertical Handover Mechanism for TCP Congestion Control” IEEE Transactions on Wireless Communications, Vol. 5, No. 10. Oct. 2006

[7] W. Stevens, TCP/IP Illustrated (Vol. 1, The Protocols), Addison-Wesley, Reading, MA, USA, 1994