TCP Performance with Vertical Handoffs

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Vertical Handoff (VHO)

Vertical handoff refers to the switching between access routers which use different link level technologies.

A vertical handoff may result in significant changes in the access link (first-hop/last-hop) characteristics such as link bandwidth and delay which are likely to affect the end-to-end path properties of a TCP connection.

As TCP behaviour depends on the end-to-end path properties, it is affected by a vertical handoff.

Problems of TCP with Vertical handoff

Event	Problem	Enhancements
Handoff from low delay link to high delay link	Spurious Retransmission Timeout (RTO)	Increase RTO value based on the bandwidth and delay of the new access link **
Handoff from high delay link to low delay link	Packet reordering Slow convergence of RTO	Set the *dupthresh* based on the delay and bandwidth of the old and the new links, use limited transmit. Use DSACK information to determine the *cwnd* and *ssthresh* Initialize Round-trip time (RTT) Variables and update RTO **
Handoff from high bandwidth-delay product (BDP) link to low BDP link	Packet losses	Set the *cwnd* and *ssthresh* to the BDP of the new link / number of flows **
Handoff from low BDP link to high BDP link	Inability to catch up with high bandwidth	Quick-Start to set the *cwnd* and *ssthresh*
RTOs during disconnection	Unused connection time	Retransmit immediately If TCP is in RTO recovery

** Initialize RTT variables as recommended by RFC 2988 and update RTO when all packets before handoff are acknowledged.

Solution via a Cross-layer approach

A TCP sender gets a cross-layer notification from the lower layers regarding the occurrence of a handoff along with the bandwidth and delay values of the new and the old access links. A mobile node can deliver this information to the TCP sender at the correspondent node by piggybacking in the mobility signalling messages, for example, by incorporating it in the binding update message in Mobile IPv6. We have designed a TCP sender side algorithm that uses the handoff notifications to improve TCP performance in vertical handoff.

Results

A comparison of the performance of TCP enhanced by our proposed VHO-algorithms and TCP SACK for a wide range of access link bandwidths and delays has been carried out using ns-2 simulations. The results obtained show that the proposed VHO algorithms are effective in different vertical handoff scenarios and reduce the transfer time up to 40 % for a single TCP flow.

With the increase in the number of flows, the problems of TCP in a vertical handoff due to spurious RTOs, unnecessary retransmissions and packet reordering have a diminishing effect due to a decrease in the size of the TCP window of each flow. However, the effectiveness of our algorithm is especially visible when the TCP window size is sufficiently large as it can mitigate the aforementioned problems of TCP in a vertical handoff.

Future work

Improving the VHO-algorithm by estimation of end-to-end bandwidth and round trip time

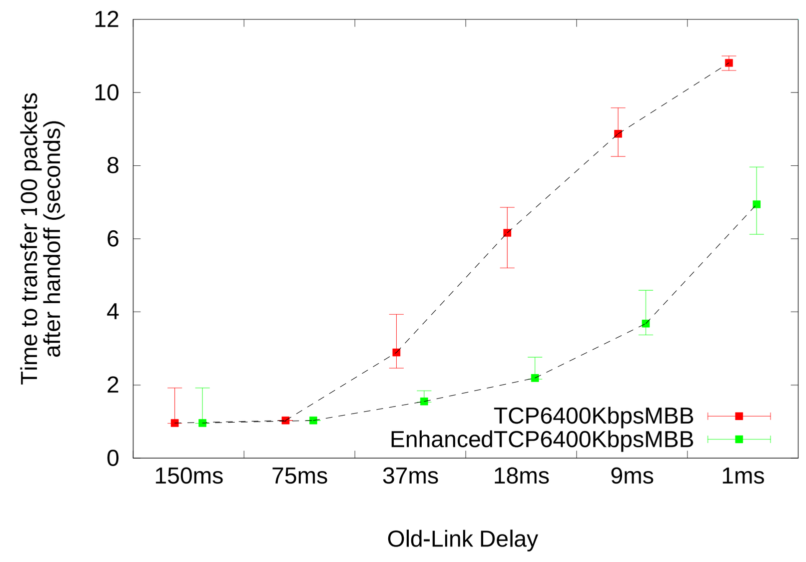
Evaluation of the algorithm in real network environments.

Publications

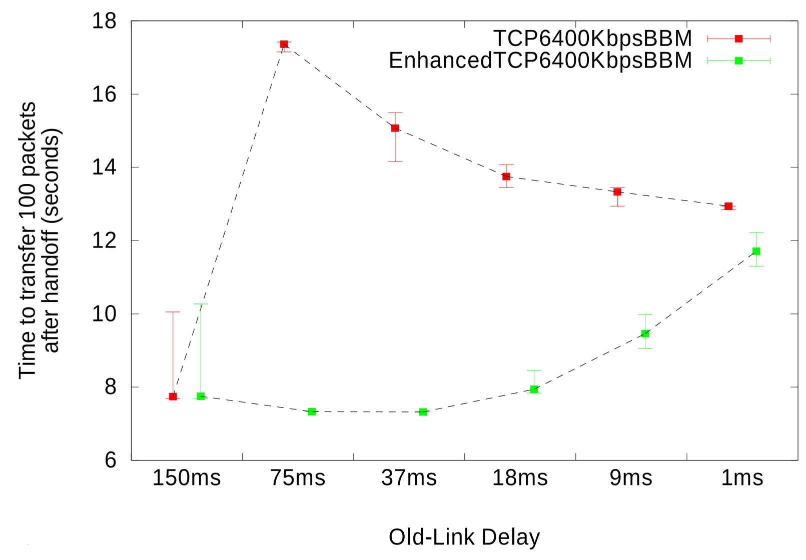
1. L. Daniel, M. Kojo. Adapting TCP for Vertical Handoff in Wireless Networks, In Proc. Proc. 31st IEEE Conference on Local Computer Networks (LCN'06), 2006
2. P. Sarolahti, J. Korhonen, L. Daniel, M. Kojo. Using Quick-Stat to improve TCP performance with Vertical Handoffs, In Proc. 31st IEEE Conference on Local Computer Networks (LCN'06), 2006
3. L. Daniel, M. Kojo. TCP Behaviour with Changes in Access Link Bandwidth and Delay During Vertical Handoffs, In Proc. International Conference on Next Generation Mobile Applications, Services and Technologies (NGMAST 2007), 2007.
4. L. Daniel, M. Kojo. Using Cross-layer Information to Improve TCP Performance with Vertical Handoffs, In Proc. 2nd International Conference on Access Networks (Accessnets 2007), 2007.
5. L. Daniel, M. Kojo. Employing Cross-layer Assisted TCP Algorithms to Improve TCP Performance with Vertical Handoffs, International Journal of Communication Networks and Distributed Systems (IJCNDS), 2008.
6. L. Daniel, I. Järvinen, M. Kojo. Combating packet reordering in vertical handoff using cross-layer notifications to TCP, In Proc. 4th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob 2008) , 2008
7. L. Daniel, M. Kojo. The performance of multiple TCP flows with vertical handoff, 7th ACM International Symposium on Mobility Management and Wireless Access, October 2009

Performance Evaluation of the VHO Algorithms

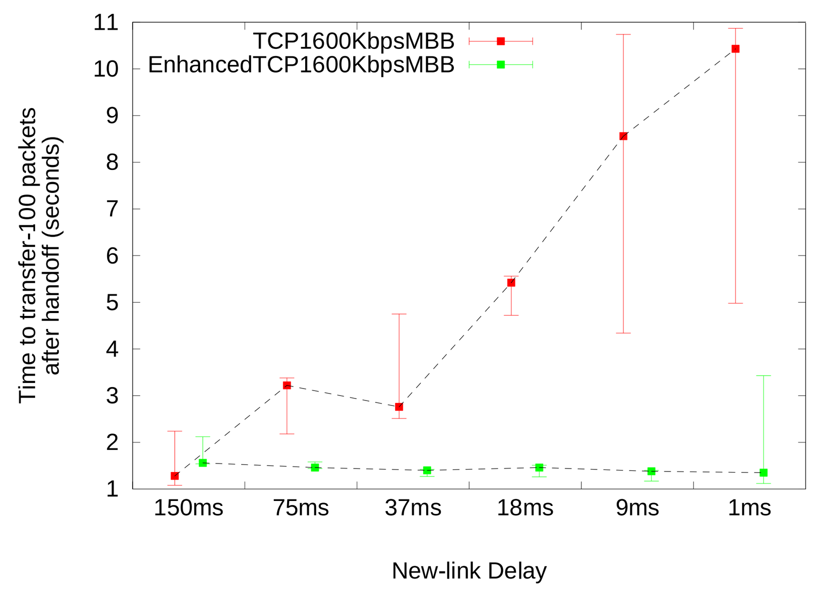
Single TCP flow



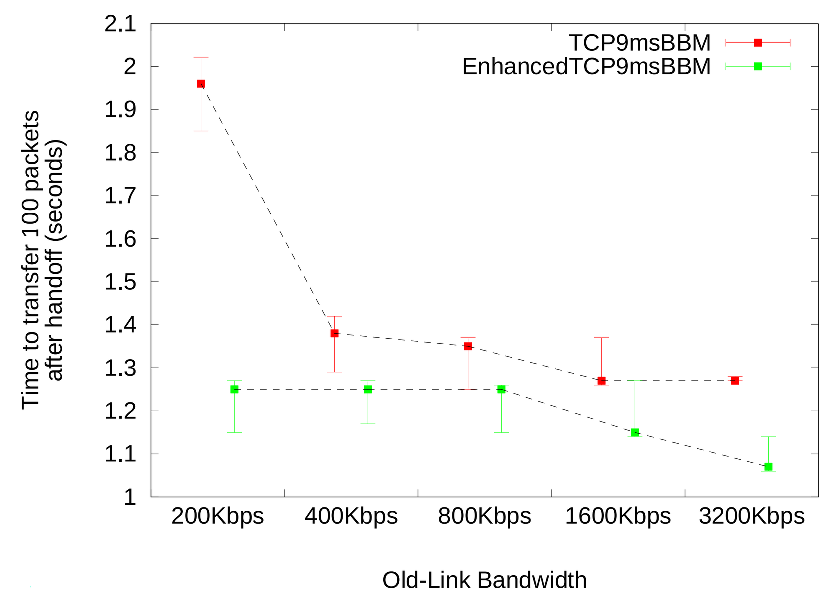
Make-before-break handoff from a low-delay link to a high-delay link with bandwidth of the links fixed at 6400 Kbps. The delay of the new link is fixed at 300 ms.



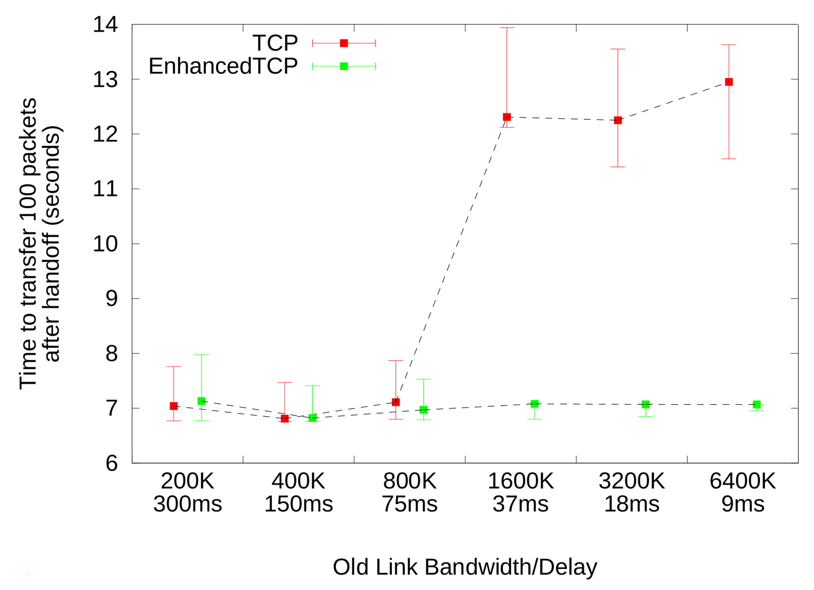
Break-before-make handoff from a low-delay link to a high-delay link with bandwidth of the links fixed at 6400 Kbps. The delay of the new link is fixed at 300 ms.



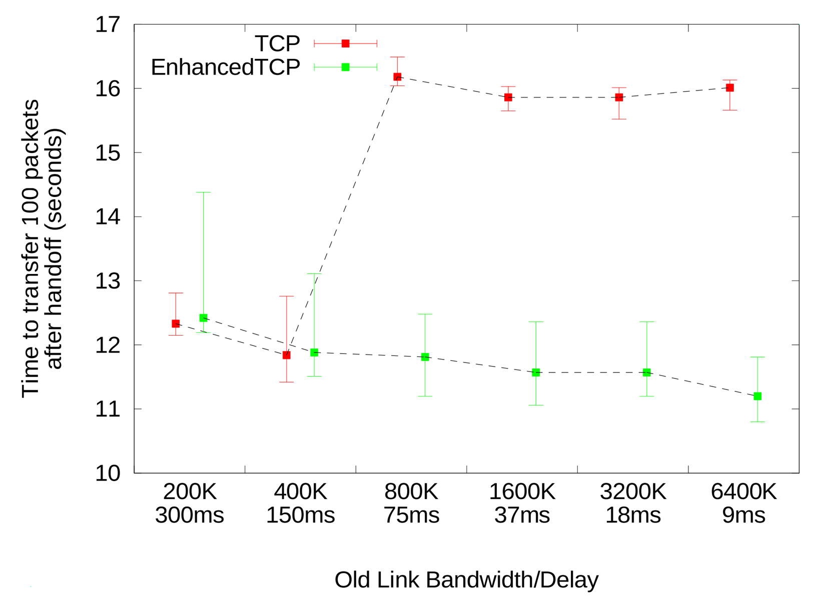
Make-before-break handoff from a high-delay link to a low-delay link with bandwidth of the links fixed at 6400 Kbps. The delay of the old link is fixed at 300 ms.



Break-before-make handoff from a low-bandwidth link to a high-bandwidth link with delay of the links fixed at 9 ms. The bandwidth of the new link is fixed at 6400 Kbps.

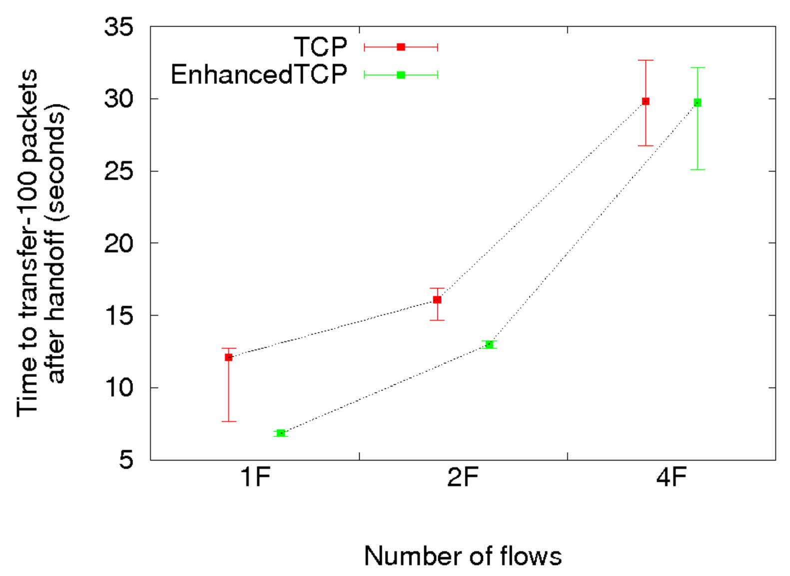


Make-before-break handoff from a low-delay/high-bandwidth link to a high-delay/low-bandwidth link with BDP of the links fixed at 10 packets. The new link has 200 Kbps/300 ms.

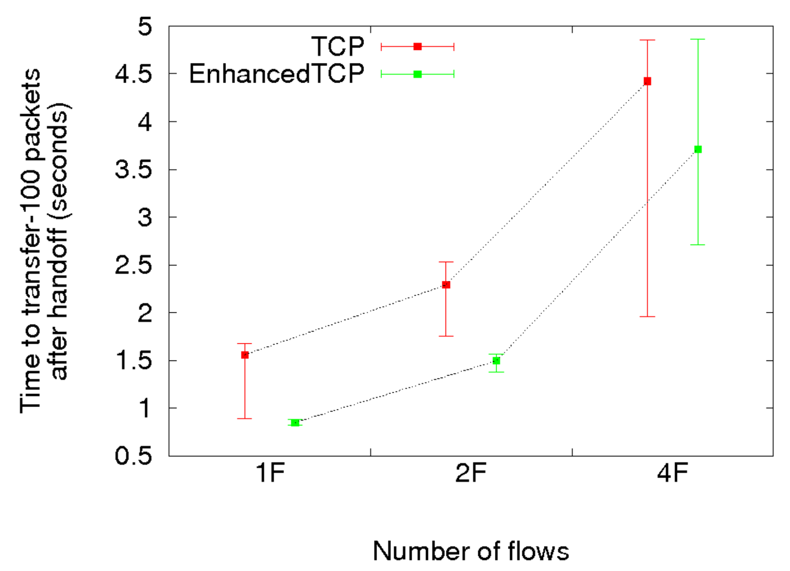


Break-before-make handoff from a low-delay/high-bandwidth link to a high-delay/low-bandwidth link with BDP of the links fixed at 10 packets. The new link has 200 Kbps/300 ms.

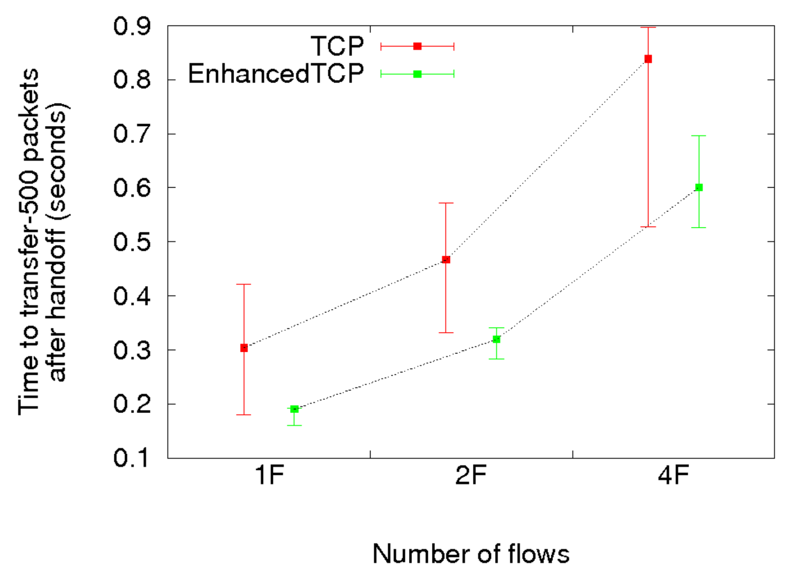
Multiple TCP flows



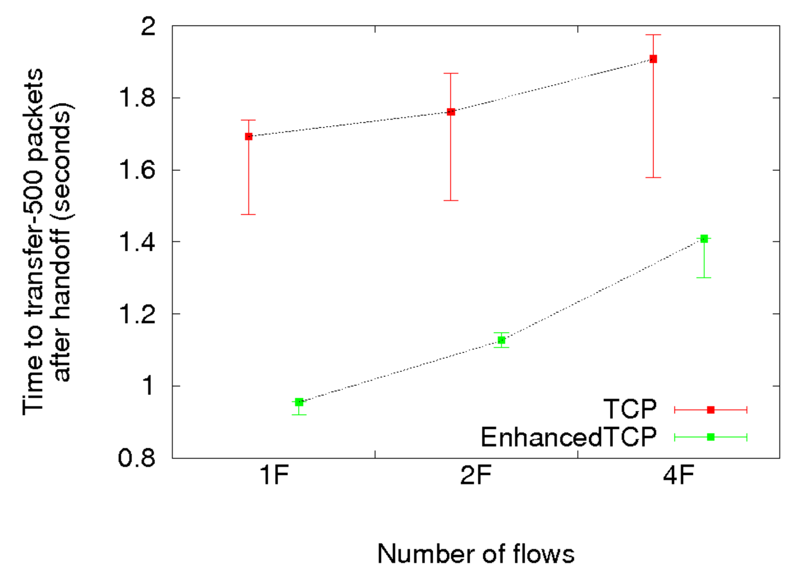
Make-before-break handoff from a 6400 Kbps/9 ms link to a 200 Kbps/300 ms link, the BDP of the links fixed at 10 packets.



Make-before-break handoff from a 54000 Kbps/2 ms link to a 2000 Kbps/50 ms link. The BDP of the links fixed at 18 packets.



Make-before-break handoff from a 6000 Kbps/ 50 ms link to a 54000 Kbps/4 ms link.



Break-before-make handoff from a 6000 Kbps/ 50 ms link to a 54000 Kbps/4 ms link.

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