TCP congestion control and vertical handovers (WP2)

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Presentation overview

- TCP congestion control
- Vertical handoff (VHO)
- The problems of TCP with vertical handoff
- Cross-layer assisted enhanced TCP algorithm for vertical handoff
- Future directions

Transmission Control Protocol (TCP)

- TCP is the most widely used transport protocol in the Internet
- TCP guarantees inorder data delivery without loss, duplication and transmission errors
- TCP is a window-based end-to-end protocol
  - TCP behaviour depends on end-to-end path properties
    - Round-Trip-Time (RTT)
    - Bandwidth-Delay Product (BDP)
    - Bit-error rate
    - Bandwidth Asymmetry

TCP congestion control

- The goals of congestion control
  - to fully utilize the bandwidth available in the network
  - operate the network at the ´knee´ corresponding to the maximum of the throughput before the onset of congestion collapse.

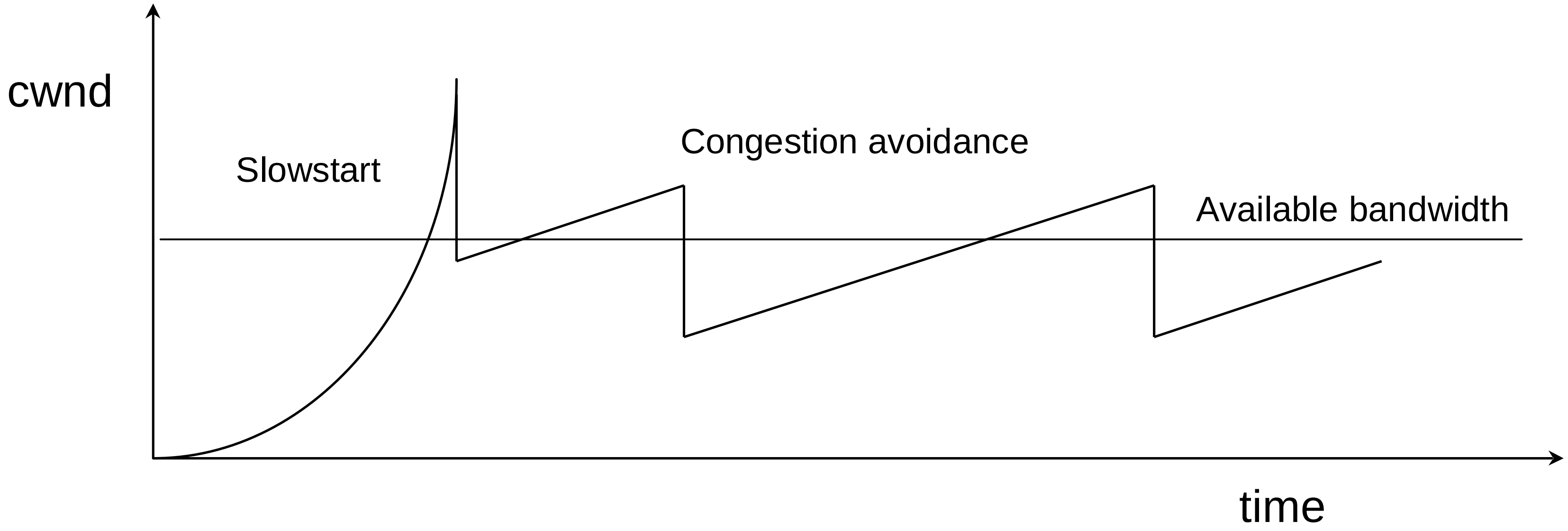
- Additive Increase Multiplicative decrease (AIMD) principle governs the evolution of the window
  - Guaranteed convergence w.r.t efficiency and fairness
  - Easily deployable
  - Fully distributed
  - No need to know full state of system (e.g. number of users, bandwidth of links)

- Jacobson´s paper on congestion control (SIGCOMM '88)
  - The basis of the modern TCP congestion control algorithm

TCP congestion control

- Main algorithms
  - Slow start
  - Congestion Avoidance
  - Fast Retransmit
  - Fast Recovery
  - TCP SACK (Selective Acknowledgement) option

TCP congestion control



Maintains three variables:

- cwnd – congestion window
- rwnd– receiver advertised window
- ssthresh – threshold to determine the congestion avoidance phase

For sending use: win = **min**(rwnd, cwnd)

At steady state, *cwnd* oscillates around the optimal window size.

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Calculation of Retransmission Timeout (RTO)

- Taking the moving average of the RTT samples and their deviation
- Moving average : smoothens the RTT
- Problem: Unable to adapt quickly to the abrupt changes in delay of the end-2-end path

For every RTT measured R' is made

RTTVAR <- (1 - beta) * RTTVAR + beta * |SRTT - R'|

SRTT <- (1 - alpha) * SRTT + alpha * R'

RTO <- SRTT + max (G, K*RTTVAR)

Influence of packet loss on TCP congestion control

A Packet loss is considered as an indication of congestion

- Packet loss is detected
  - Reception of 3 dupacks
  - Expiry of RTO timer
- Upon the reception of 3 dupacks
  - Retransmit the lost packet
  - Congestion window **(cwnd) <- Flightsize/2**
  - Slow-start threshold (ssthresh) <- FlightSize/2
- Upon an Retransmission timeout (RTO)
  - Retransmit the lost packet
  - Slow-start threshold <- FlightSize/2, **cwnd <-1**

If 3 dupacks arrive due to packet reordering or spurious RTOs occur due to delayed ACKs, unnecessary congestion control actions will be taken

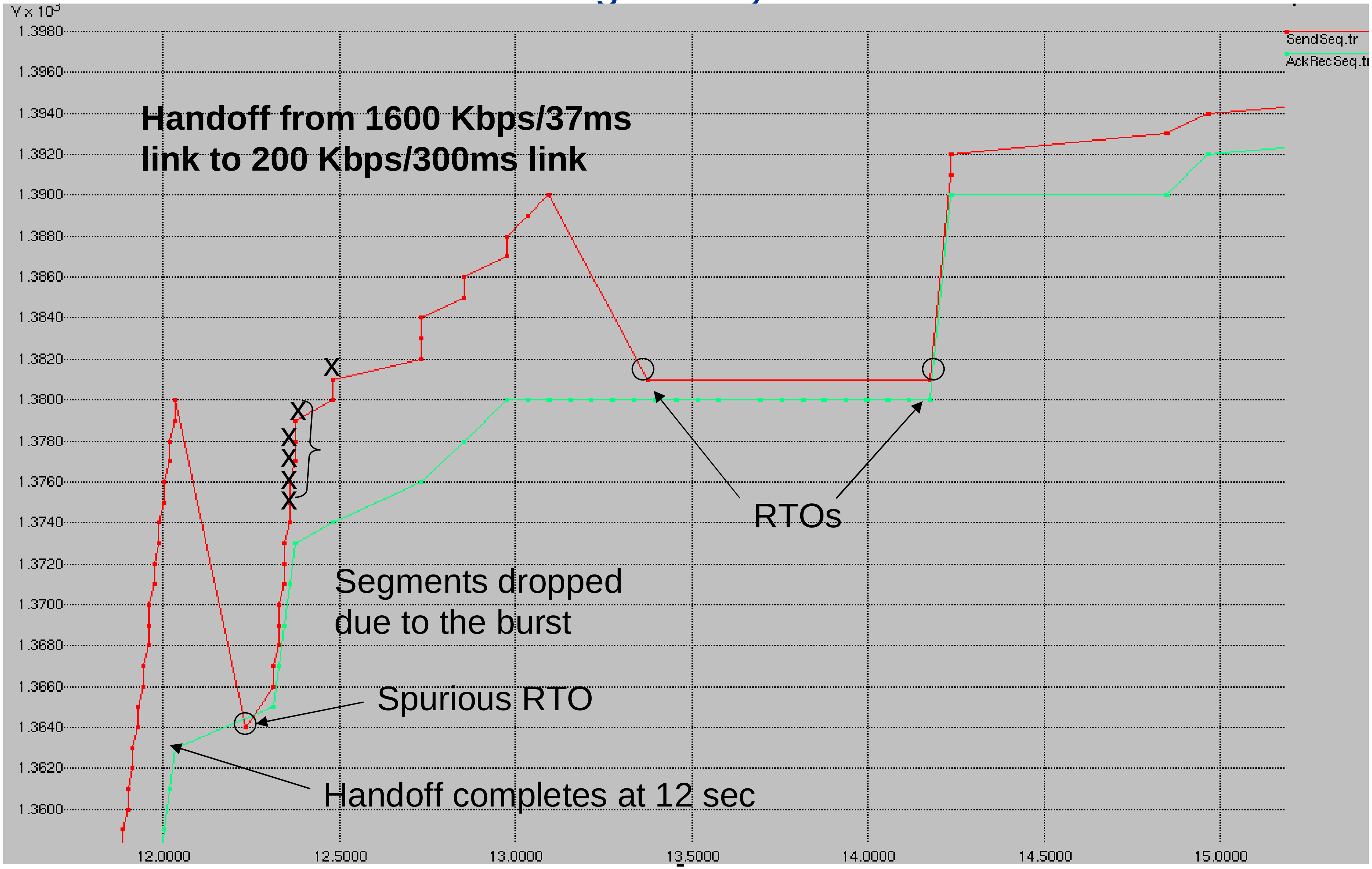
Vertical handoff (VHO)

- Wireless overlay networks
  - Heterogeneous wireless networks forming a overlay structure
- Vertical handoff: Switching between access routers which use a different link level technology
- Vertical handoff results in changes in access link (first-hop/last-hop) characteristics.
  - A significant change in the access link characteristics is likely to change the end-to-end path properties
- Break-Before-Make (BBM)
  - Mobile node's association with the old access router breaks before the connection to the new access router is operational
  - Disruption in connectivity and Packet loss
- Make-Before-Break (MBB)
  - Mobile node's association with the old access router breaks only after the connection to the new access router is operational
  - No disruption of connectivity, no packet loss

Impact of vertical handoff on TCP performance

- **Make-Before-Break Handoff**
  - **Handoff from low-delay to high-delay**
    - **RTO cannot adapt to the sudden increase in RTT after the handoff**
    - **Spurious Retransmission timeouts (RTOs)**
  - **Handoff from high-delay to low-delay**
    - **Packets sent through the fast new link reach the receiver sooner than the packets sent through the slow link**
    - **Packet reordering**
  - **Handoff from high Bandwidth-delay product (BDP) to low BDP / high bandwidth to low bandwidth**
    - **Congestion à Packet losses**
  - **Handoff from high-delay to low-delay**
    - **Slow Convergence to the new RTO value**
  - **Handoff from low bandwidth to high bandwidth**
    - **TCP´s inability to catch up with high bandwidths**

Handoff from high-bandwidth /low-delay link to low-bandwidth/high-delay link -TCP



Impact of vertical handoff on TCP performance

- Break-Before-Make Handoff
  - Disruption in connectivity
    - **Packet losses**
  - RTOs during disconnection
    - **Unused connection time** (the next RTO timer expiry after the connection is up – time at which connection is up)
    - **Prolonged recovery**

      In some implementations if more than one RTO occurs for the same segment, recovery takes long time as it starts in congestion avoidance with smaller ssthresh and cwnd values.

Even if we have seamless handoff, TCP has all possible problems depending on the vertical handoff scenario.
Need to make TCP as well as upper layers aware of vertical handoff

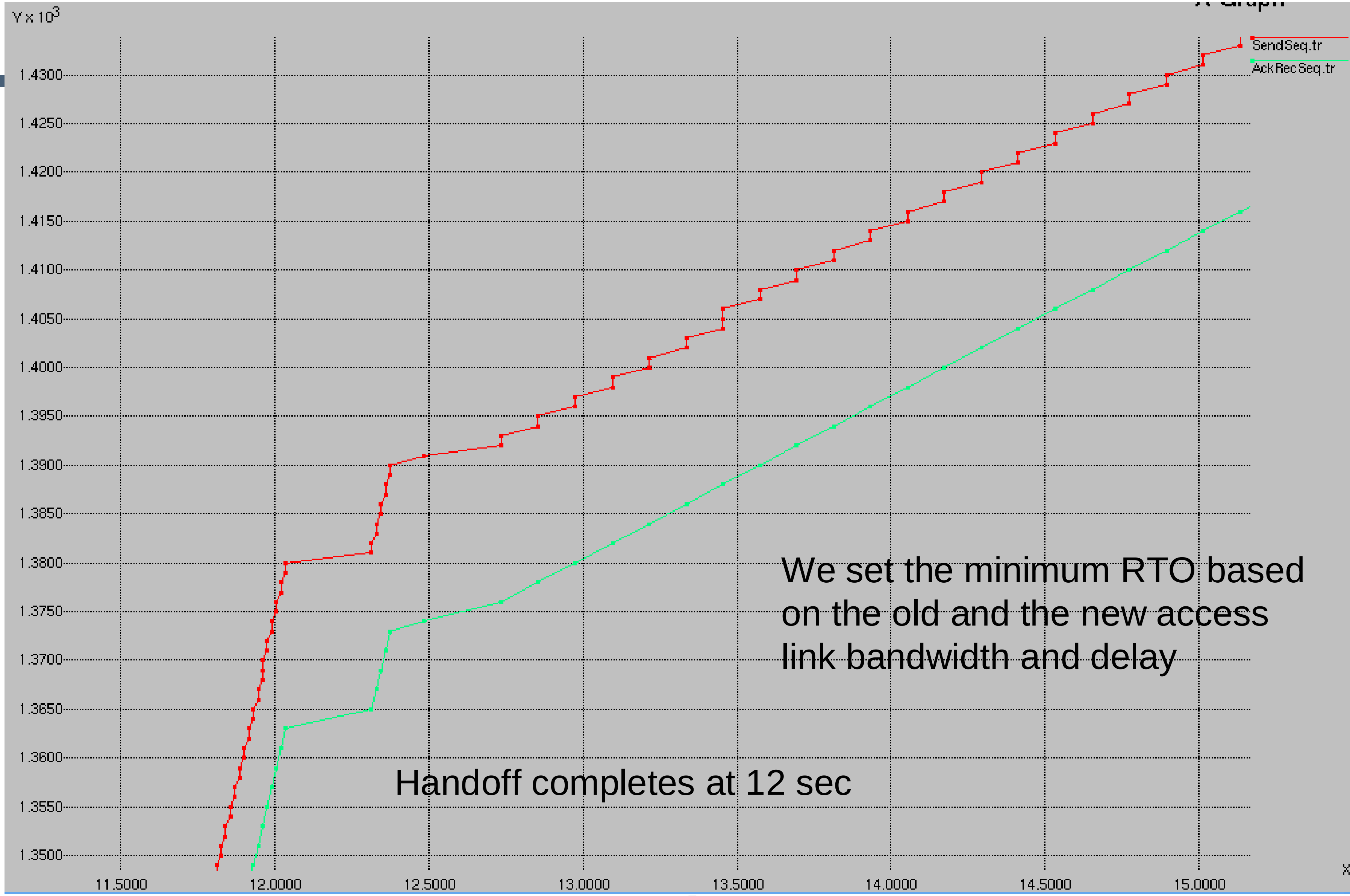
How to make TCP aware of vertical handoff ?

- **By providing cross-layer notifications to TCP**
- How to provide the cross-layer notifications?
  - **Mobile Node (MN) can get the information regarding changes in access link characteristics**
  - **MN can send this information to the other end-host (e.g., as part of mobility signaling – Binding Update message in Mobile IPv6)**
- In our experiments we model
  - **MN sends to the peer end-host link characteristics notifications** :
    - **occurrence of handoff**
    - **bandwidth and delay of the old and the new access links**

Cross-layer assisted enhanced TCP sender algorithm

- **In vertical handoff scenarios cross-layer assisted enhanced TCP is effective in**
  - **Avoiding spurious RTOs**
    - **Set the minimum RTO based on the old and the new access link bandwidth and delay**
  - **Minimizing congestion related packet losses**
    - **Set the cwnd and ssthresh to the new access link BDP**
  - **Making TCP resume after disconnection**
    - **Immediate retransmission if the TCP is in RTO recovery at the time of handoff; reduce the cwnd and ssthresh only once**
  - **Speeding up RTO convergence**
    - **Significant change in the delay after handoff, initialize RTT parameters as in RFC 2988 and update when an ACK arrives for a new data**
  - **Reducing the effects of packet reordering**
    - **Detect reordering using DSACK and access links bandwidth and delay, send new packets through the new link while waiting for the old packets; set the cwnd and ssthresh to new access link BDP**

Handoff from 1600 Kbps/37ms link to 200 Kbps/300ms link- Enhanced TCP



Future directions in WP2

- Enhancements to TCP sender algorithm to mitigate the effects of a vertical handoff is done as a part of MERCoNE and WISEciti projects.
  - **Vertical handoff not the only problem …**
- This background work gives motivation to the **cross-layer based design approach to be used in FI-SHOK**
  - **For designing end-to-end protocols**
    - **Not only TCP**
  - **Distinguishing between congestion and corruption losses**
  - **Determining available network capacity**
    - **Quick-Start for TCP and XCP are earlier examples**

- Currently working on the state-of-the art review of the congestion control

Publications

- L. Daniel, M. Kojo Adapting TCP for vertical handoff in Wireless Networks, LCN 2006
- P. Sarolahti, J. Korhonen, L. Daniel, M. Kojo Using Quick-Start to improve TCP performance with vertical handoffs, LCN2006
- L. Daniel, M. Kojo TCP behaviour with changes in access link bandwidth and delay during vertical handoffs, NGMAST 2007.
- L. Daniel, M. Kojo Using cross-layer information to improve TCP performance with vertical handoffs, Accessnets 2007.
- L. Daniel, M. Kojo. Employing cross-layer assisted TCP algorithms to improve TCP performance with vertical handoffs, accepted for publication in International Journal of Communication Networks and Distributed Systems (IJCNDS).
- L. Daniel, I. Järvinen, M. Kojo Combating packet reordering in vertical handoff using cross-layer notifications to TCP, Wimob 2008

Thank you
for your attention