Cellular Network Measurements: A Study of Four Swedish HSDPA+ and LTE Networks

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Outline

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- Measurement setup
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- TCP protocol efficiency
- Conclusions

Background

- Delays typically directly impact user service perceptions
- Most TCP flows in cellular networks are short (90% $<$ 36KiB)
- Per-user queuing are employed in cellular networks, but concurrent user flows can interact
- Access technology that may be prone to buffer bloat
  - Large buffers used to accommodate varying data rates over time-varying wireless channels, and to conceal link frame errors/retransmissions
- Limited impact in the past due to per user buffering and low level of user multitasking. This is changing due to
  - Increased use of cellular broadband connections for residential Internet access
  - Sharing of such access in homes, hotels, small businesses
  - Emergence of more and more powerful smartphones

Examined Problems

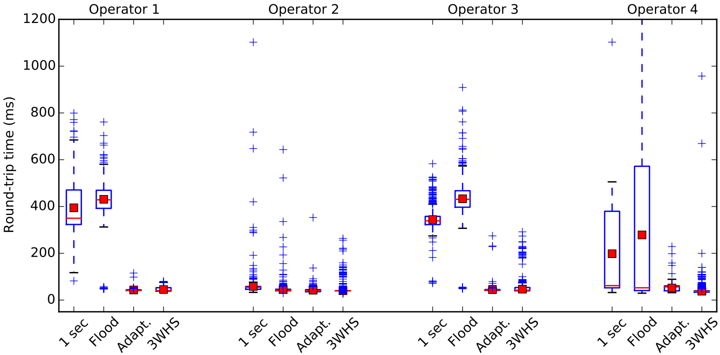
- Ongoing measurements (in various forms) since summer 2012
- How does bufferbloat affect application performance
- What is the impact of congestion control
- Which is the "best" approach to measure network layer delay?
- What is the impact of concurrent traffic on measured delay?
- How well does empirical measurements follow an analytical model?
- What is the TCP protocol efficiency in cellular networks?
- What is the impact of time-of-day effects?

Measurement Setup

- Networks of 4 leading Swedish providers
  - Tre
  - Telia
  - Telenor
  - Tele2
- Technologies
  - 3.5G (HSPA+)
  - 4G (LTE)

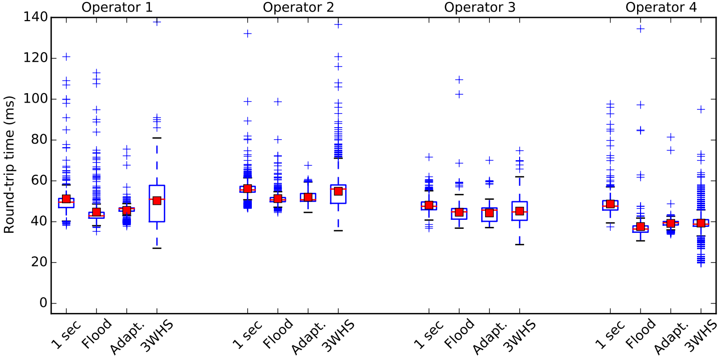
- Applications
  - Ping, various types (1s intervals, flood, adaptive)
  - Bulk download (20 MiB transfer)
  - Short flows, 1388 - 327568 bytes (11 steps)
  - Web transfer (DN.se webpage)
  - VoIP traffic
  - Impact of background traffic, one long TCP flow

3.5G Different RTT Measurement Approaches



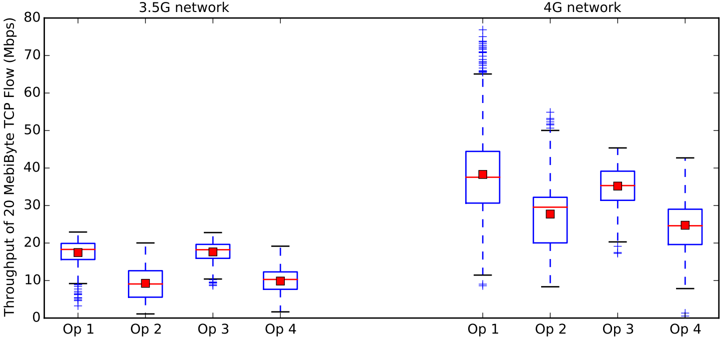
Differences in link state timeout configuration between operators likely cause of observed differences

4G Different RTT Measurement Approaches



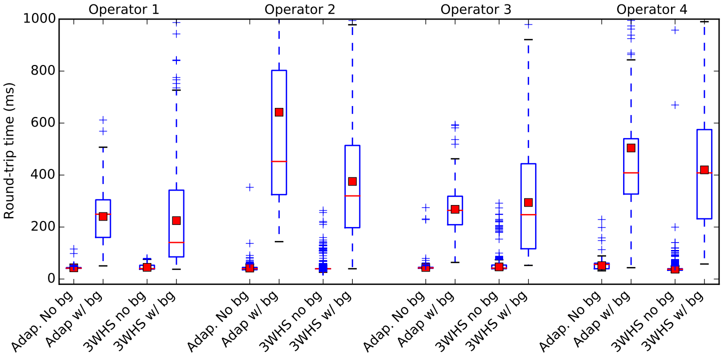
No operator differences: 4G link state handling different from 3.5G

Throughput of long flows



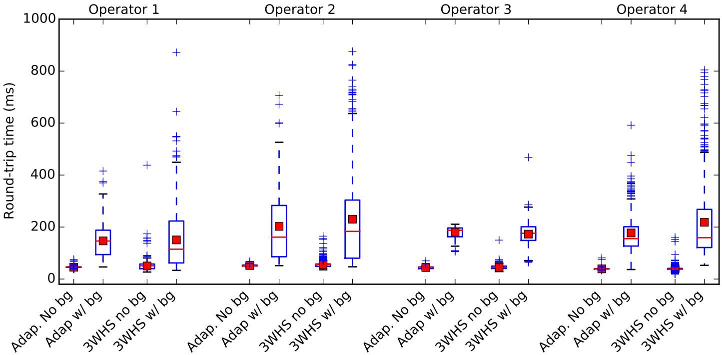
As expected, the 4G network obtains better throughput for long TCP flows

3.5G Effect of Background Flows



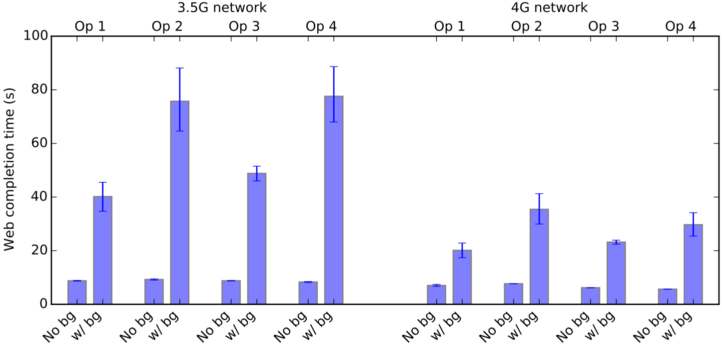
Delays are considerably increased when a background TCP flow is present

4G Effect of Background Flows



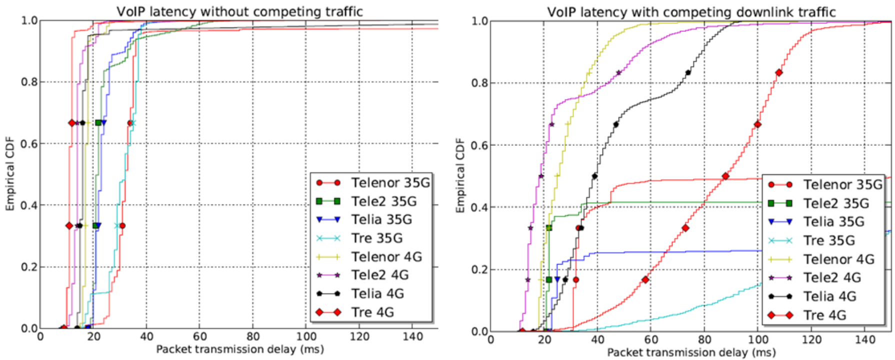
Delays in 4G are also considerably increased when a background TCP flow is present

Web page completion times without and with bg flows



Effect of background traffic visible also at the application layer

VoIP performance without and with bg flows



VoIP considerably damaged by the presence of competing bulk traffic

Analytical model

Analytic expression for the estimated flow completion time $\hat{L_S}$:

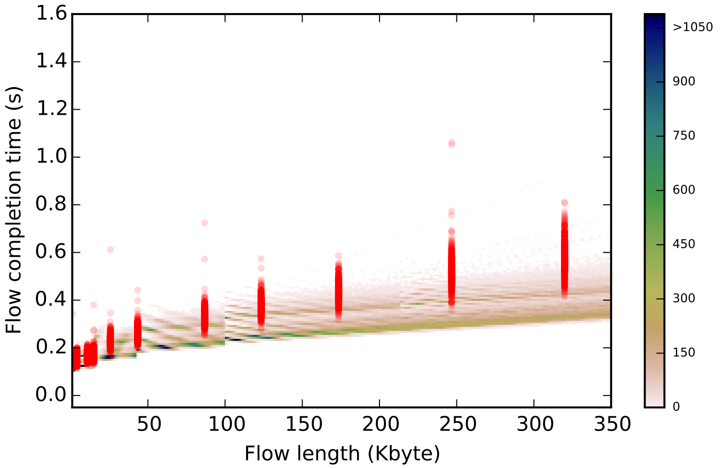
$$\hat{L_S} = 2R_S + \frac{O}{C} + P\left(R_S + \frac{S}{C}\right) - \left(2^P - 1\right)\frac{IS}{C} + R_S$$

where

$$P = \min\left(\max\left(\left\lceil log_2\left(\frac{R_S + S/C}{IS/C}\right)\right\rceil, 0\right), \left\lceil log_2\left(1 + \frac{O}{IS}\right)\right\rceil - 1\right)$$

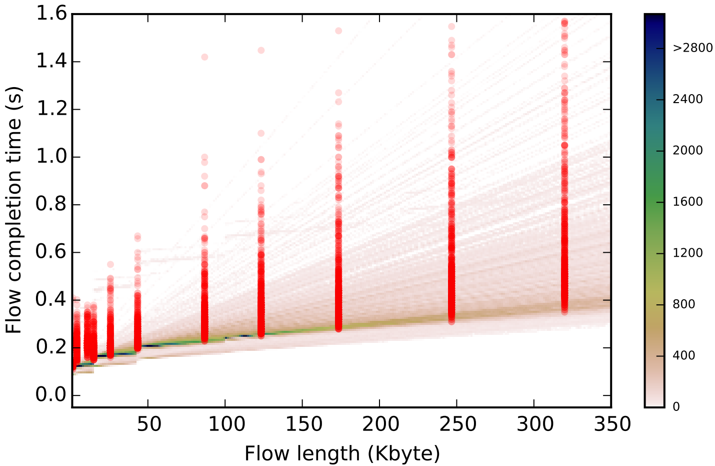
L	Flow completion time	(s)	S	Segment size	(bits)
R_S	RTT seen by short flow	(s)	I	Initial window	(segs)
O	Flow size	(bits)	P	Rounds with idling	-
C	Available capacity	(bits/s)			

3.5G Op 1: Analytical Model vs Empirical Measurements



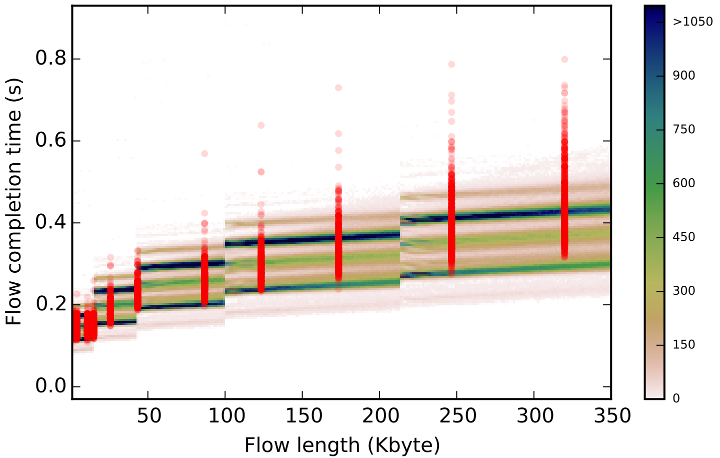
Heatmap: Monte-Carlo Simulation based on empirical 3WHS RTT and TCP Throughput distributions
Red dots: Measured flow completion times

3.5G Op 2: Analytical Model vs Empirical Measurements



Heatmap: Monte-Carlo Simulation based on empirical 3WHS RTT and TCP Throughput distributions
Red dots: Measured flow completion times

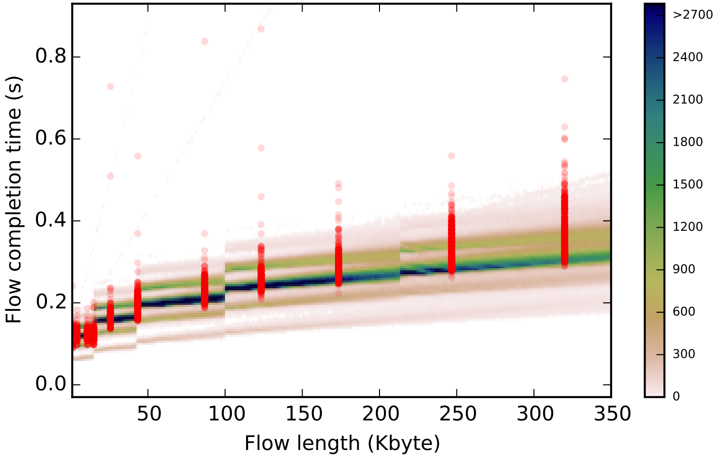
4G Op 1: Analytical Model vs Empirical Measurements



Heatmap: Monte-Carlo Simulation based on empirical 3WHS RTT and TCP Throughput distributions

Red dots: Measured flow completion times

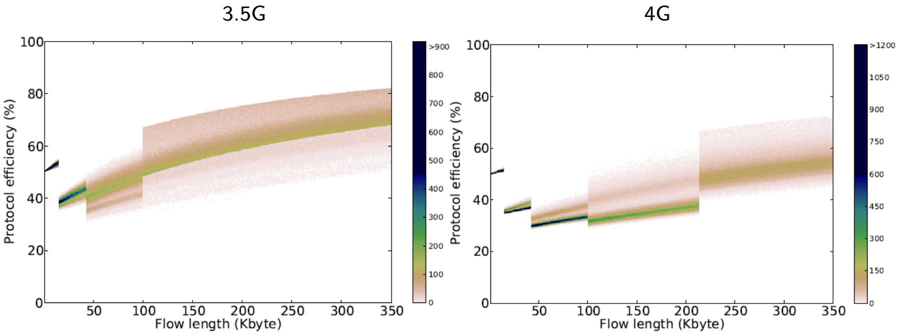
4G Op 4: Analytical Model vs Empirical Measurements



Heatmap: Monte-Carlo Simulation based on empirical 3WHS RTT and TCP Throughput distributions

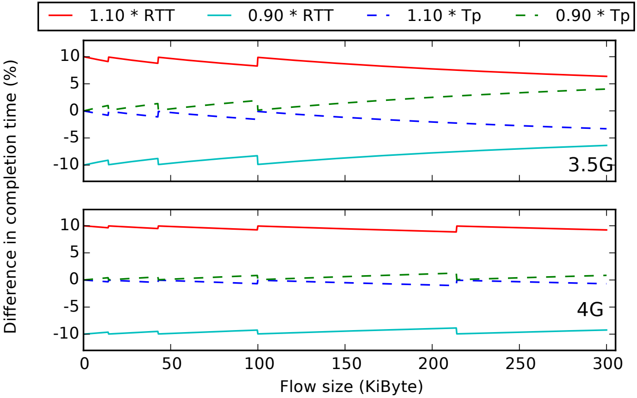
Red dots: Measured flow completion times

3.5G/HSPA+ vs 4G/LTE TCP Protocol Efficiency



4G has worse protocol efficiency than 3.5G

Relative impact of Throughput and RTT on short flow completion time



Mean values for RTT and throughput from the measurements are used as baselines. The figure shows the relative impact of a 10% change in RTT and throughput.

The completion time is much more sensitive to variation in RTT than throughput.

Conclusions

- Different network layer delay metrics have been examined
  - 3WHS and Adaptive ping gave most consistent results
- Effects of concurrent traffic has been examined
  - Concurrent traffic increases delay at all layers
  - Web page completion times increased by up to an order of magnitude
  - VoIP performance severely impacted
- Analytical model presented and evaluated against empirical measurements
  - Network layer performance metrics can serve as useful predictors to transport layer performance
  - Can be used for evaluating protocol efficiency

Related Publications

- J. Garcia, S. Alfredsson, and A. Brunstrom. Delay metrics and delay characteristics: A study of four Swedish HSDPA+ and LTE networks. In Proc. EuCNC, June 2015.
- J. Garcia, S. Alfredsson, and A. Brunstrom. Examining TCP Short Flow Performance in Cellular Networks Through Active and Passive Measurements. In Proc. ATC SIGCOMM Workshop, August 2015.
- J. Garcia, S. Alfredsson, and A. Brunstrom. A Measurement Based Study of TCP Protocol Efficiency in Cellular Networks. In Proc. WiOpt, May 2014.
- S. Alfredsson, G. Del Giudice, J. Garcia, A. Brunstrom, L. De Cicco, and S. Mascolo. Impact of TCP Congestion Control on Bufferbloat in Cellular Networks. In Proc. IEEE WoWMoM, June 2013.