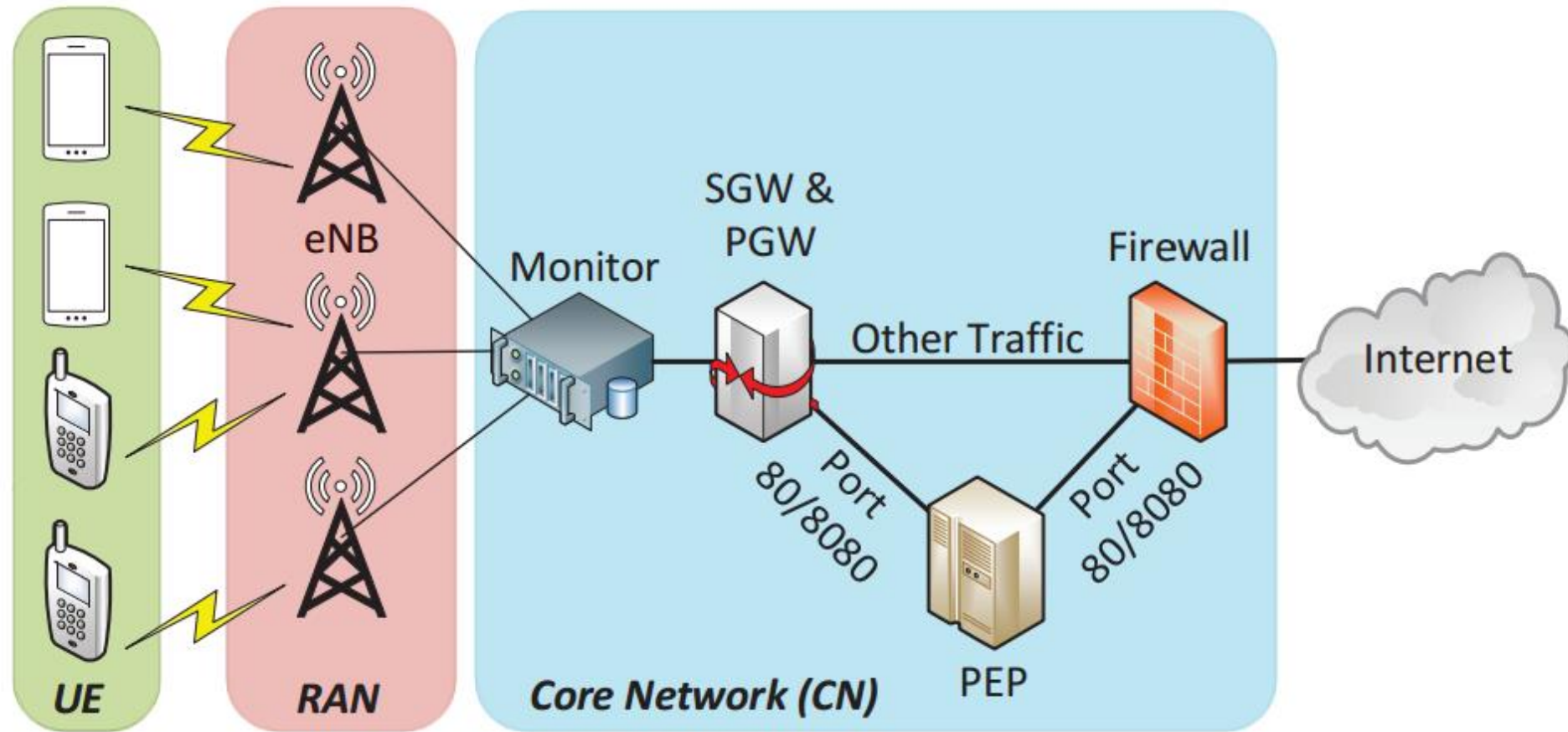


An in-depth study of LTE:
Effect of network
performance and application
behavior on performance

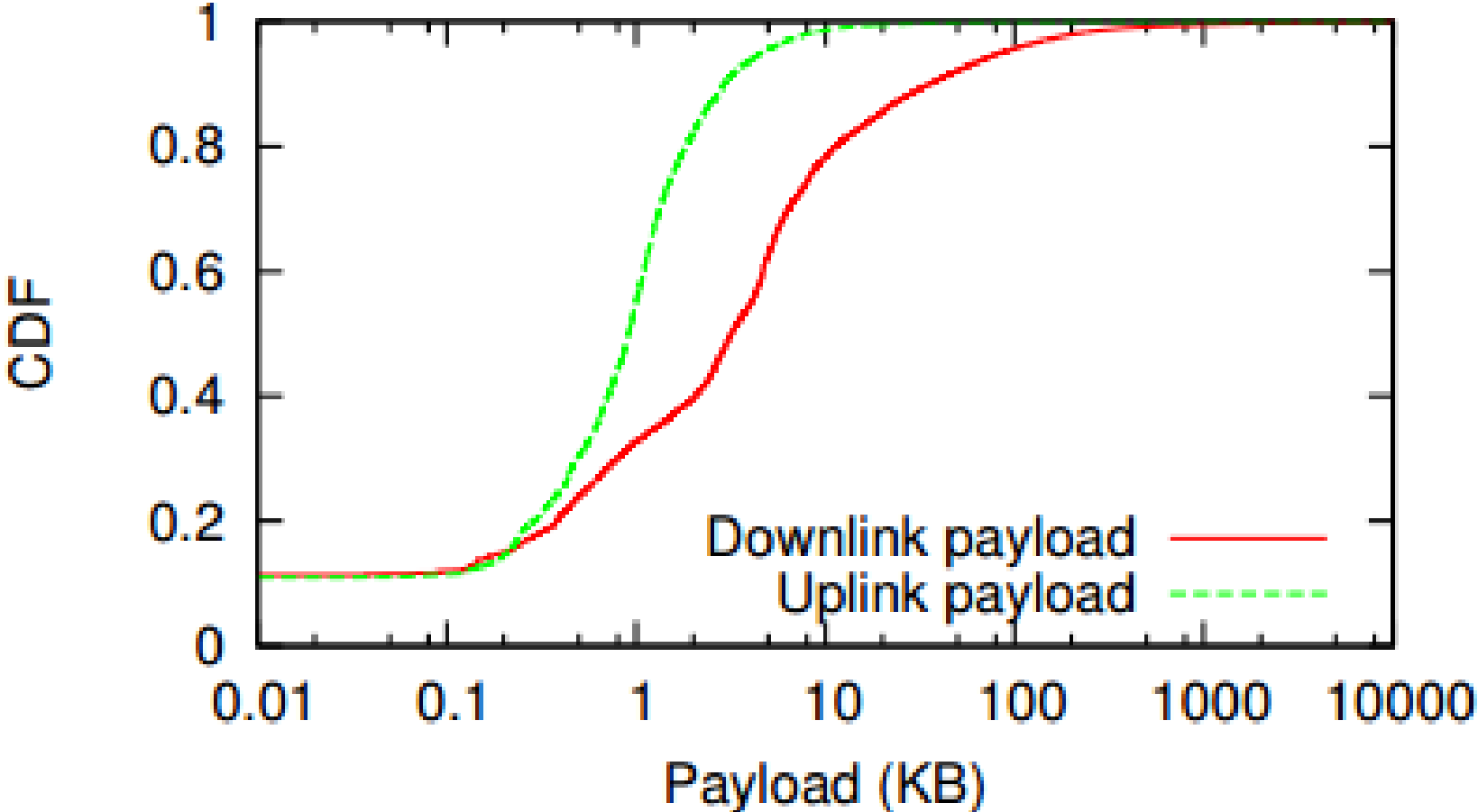
Introduction

- 4G LTE is the latest deployed cellular network that provides high speed data services for mobile devices with advertised bandwidths matching and even exceeding the home broadband network speeds.
- Compared to 3G, 4G LTE is faster

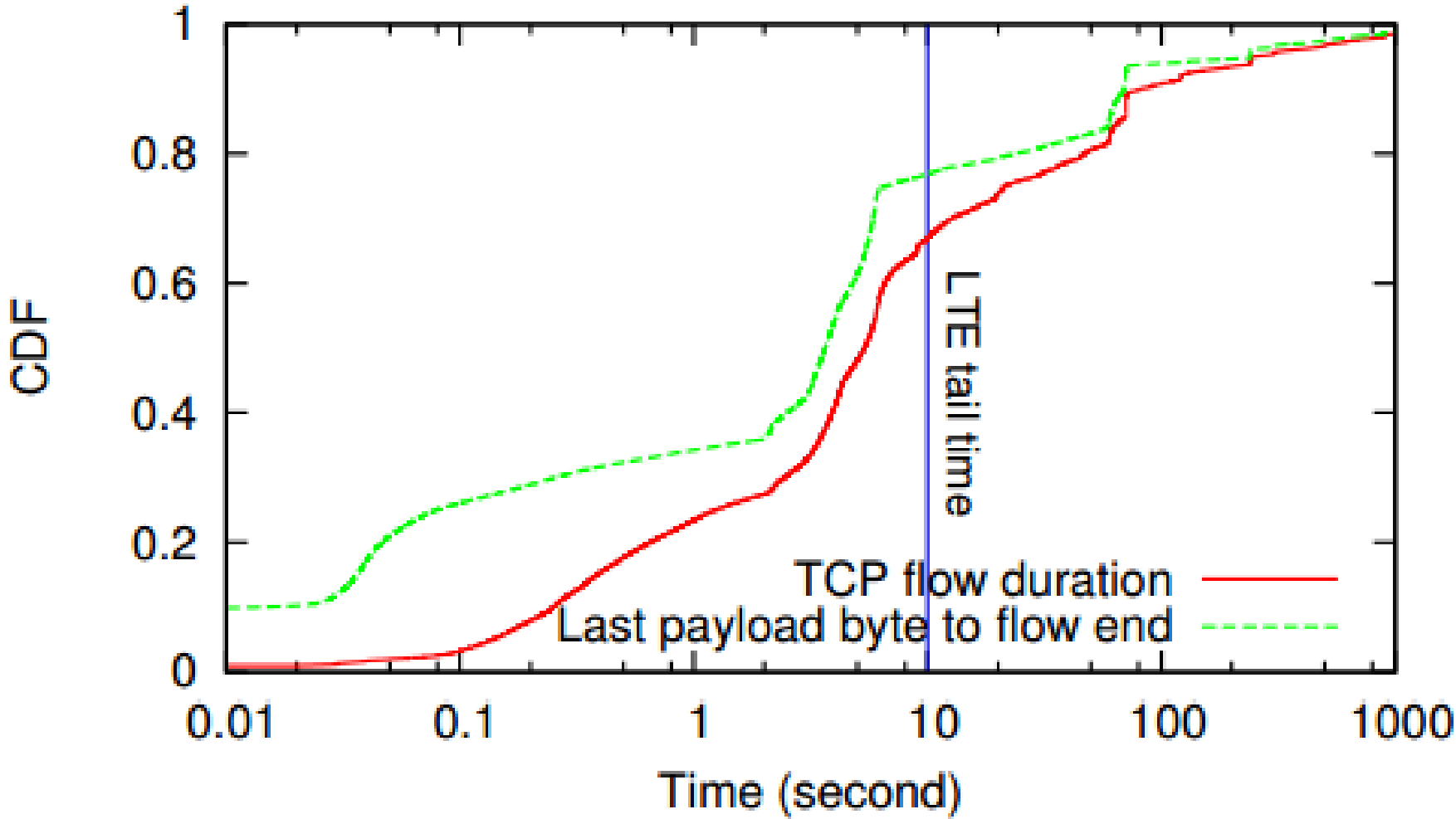
LTE Measurement Data



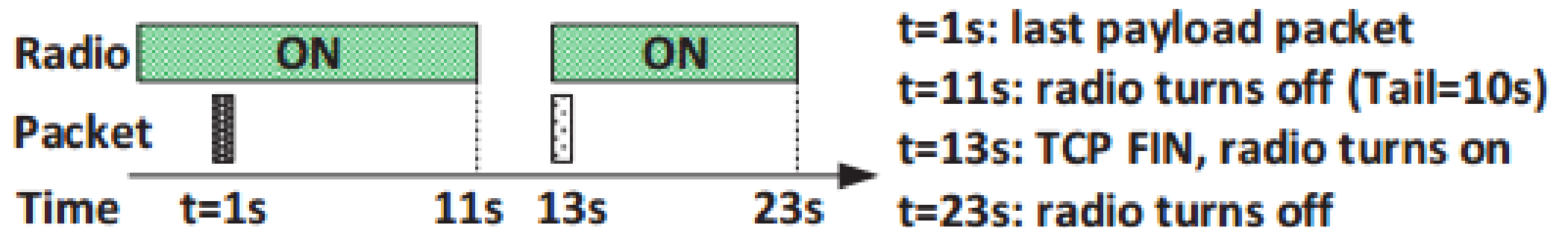
TCP Flow Sizes



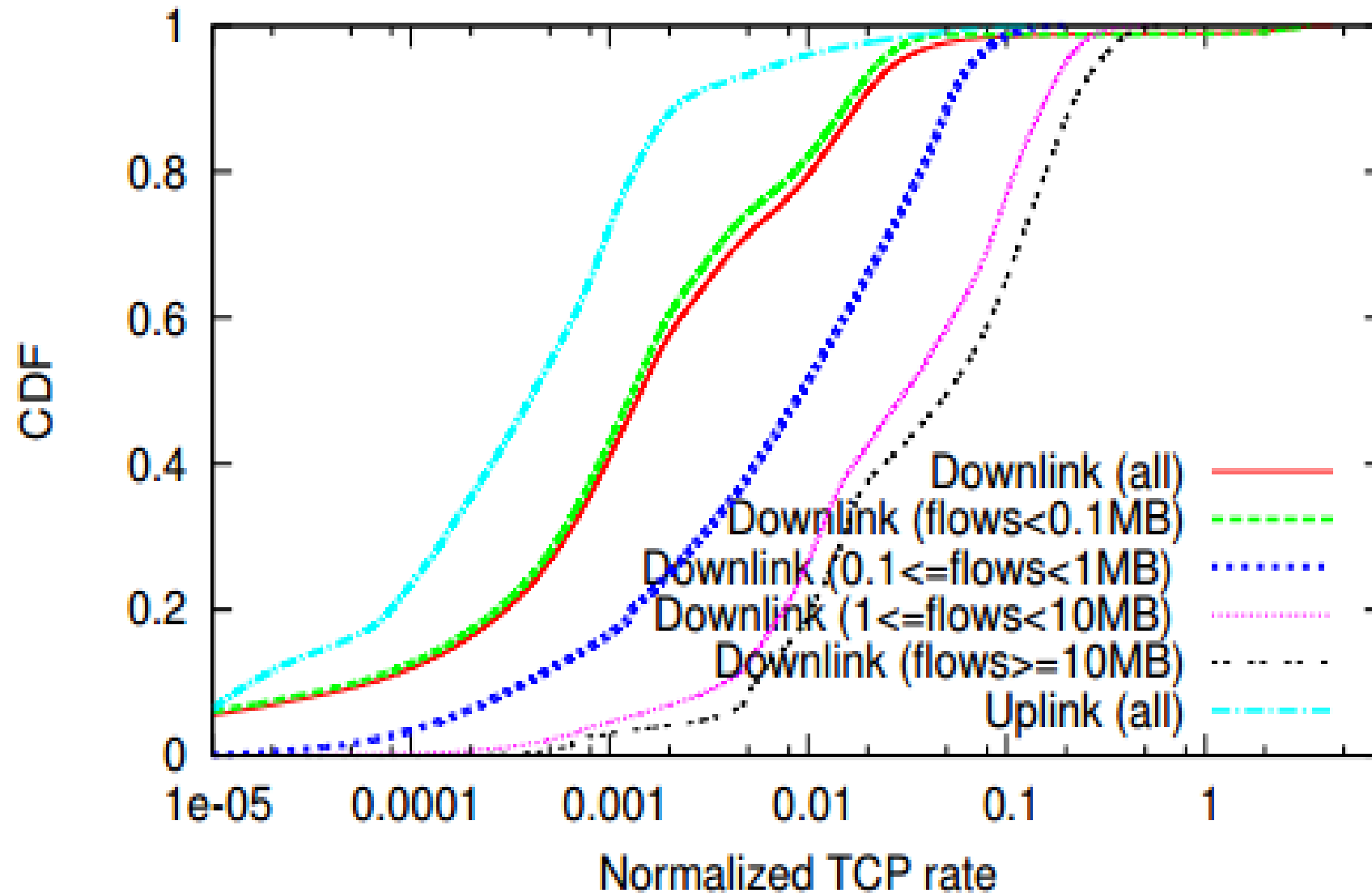
TCP flow duration



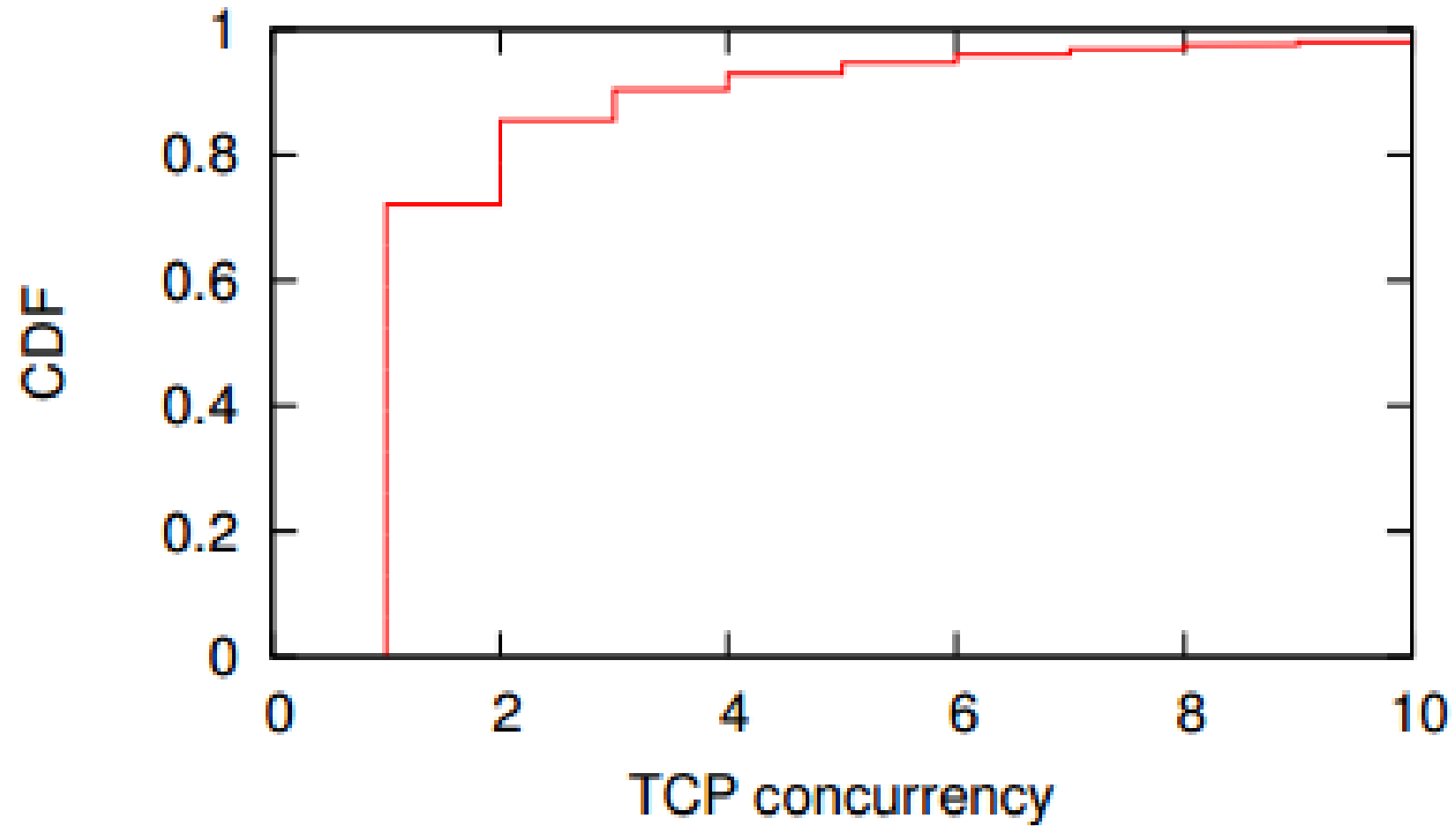
Delayed FIN Packet



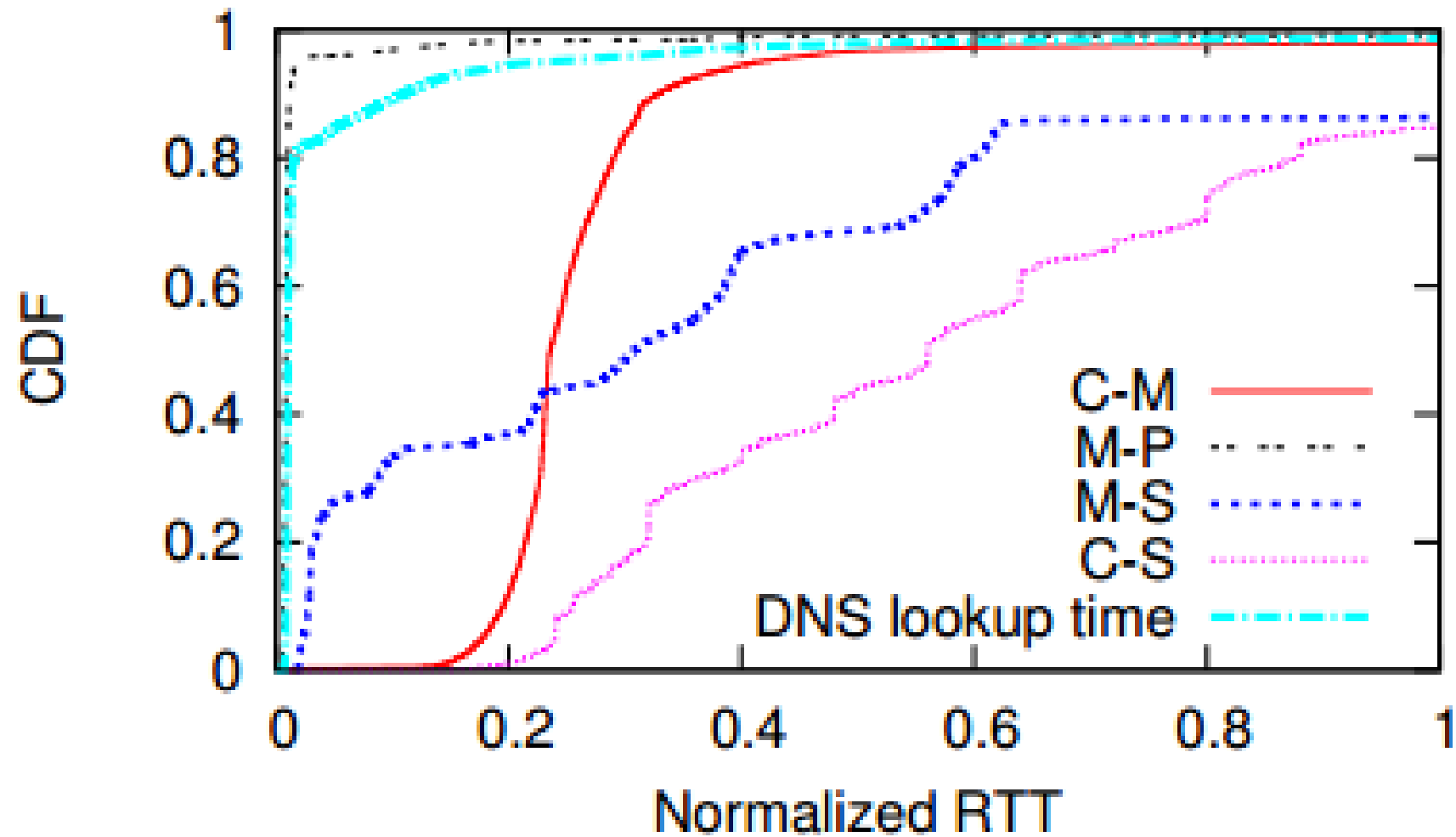
Distribution of normalized TCP flow rates



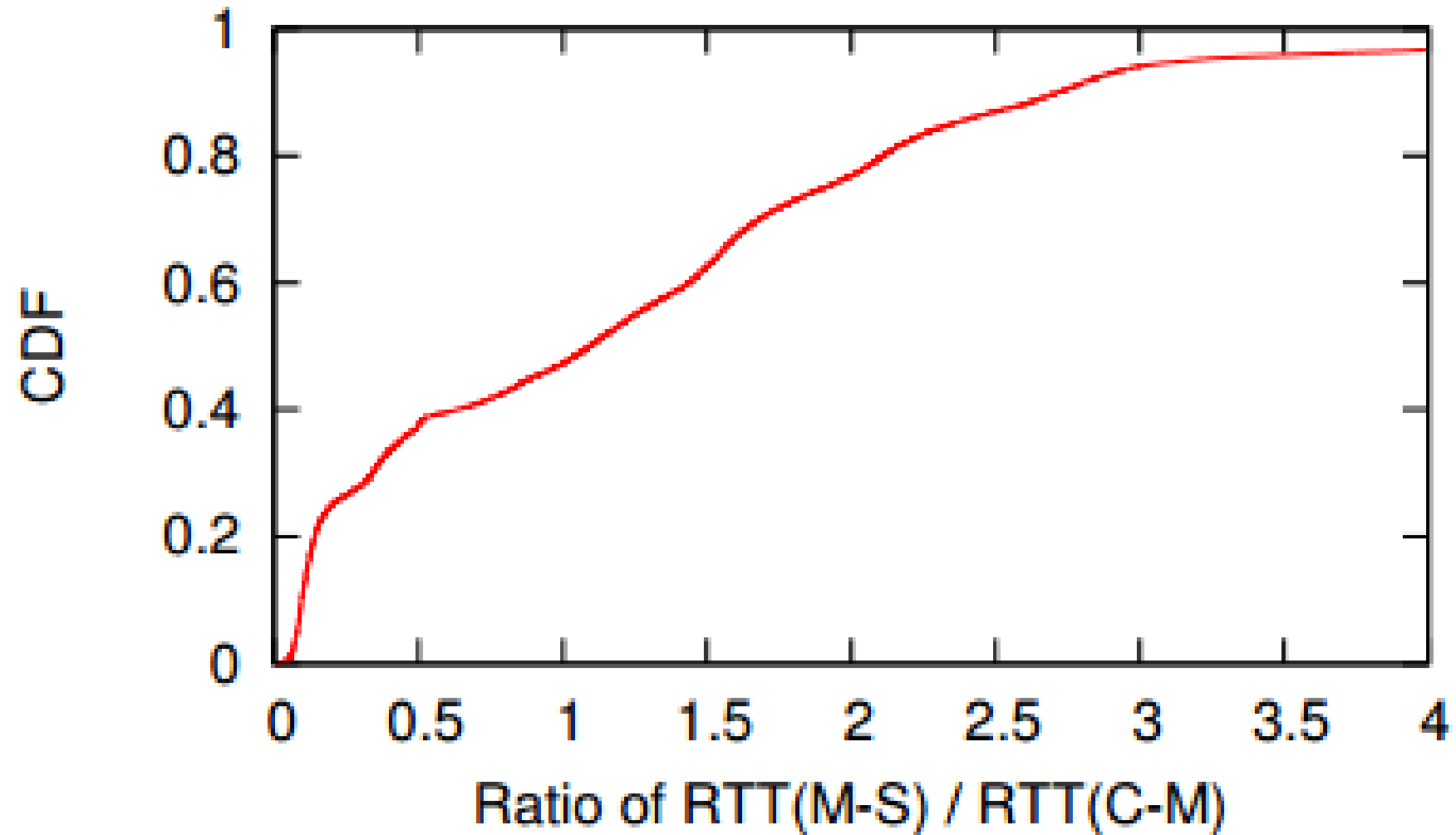
Concurrency for TCP flows



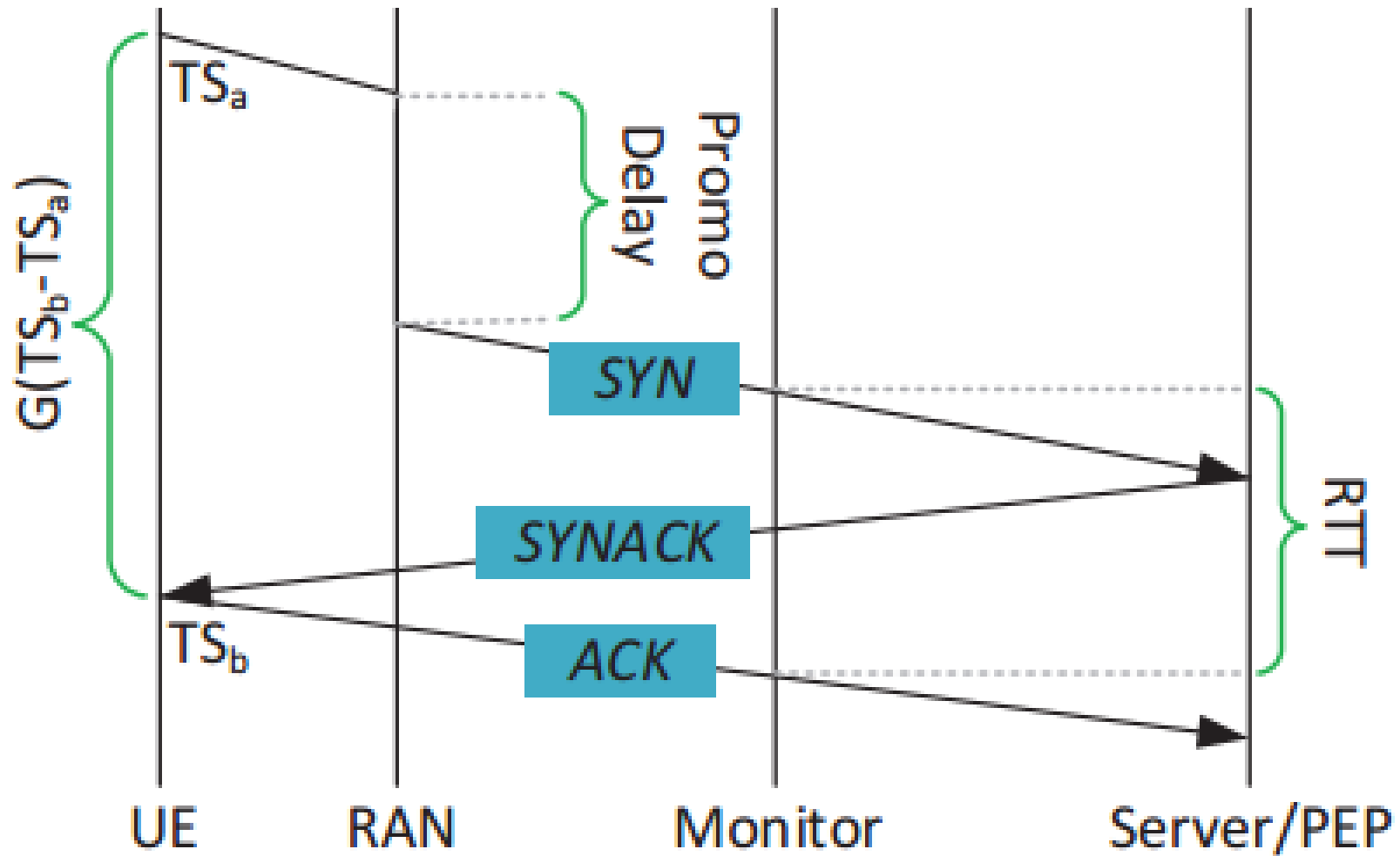
Normalized handshake RTT & DNS lookup time



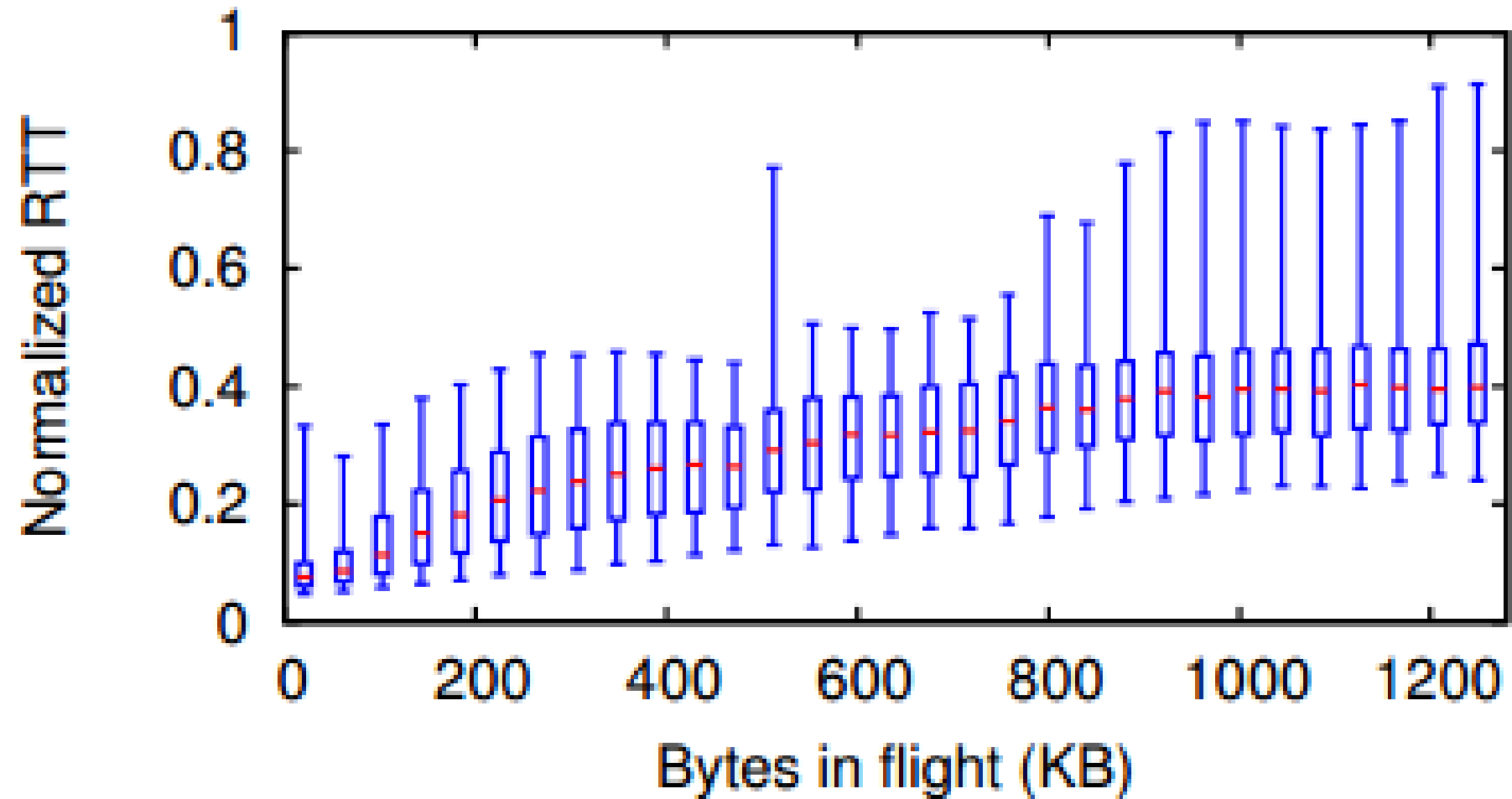
Uplink and downlink RTT

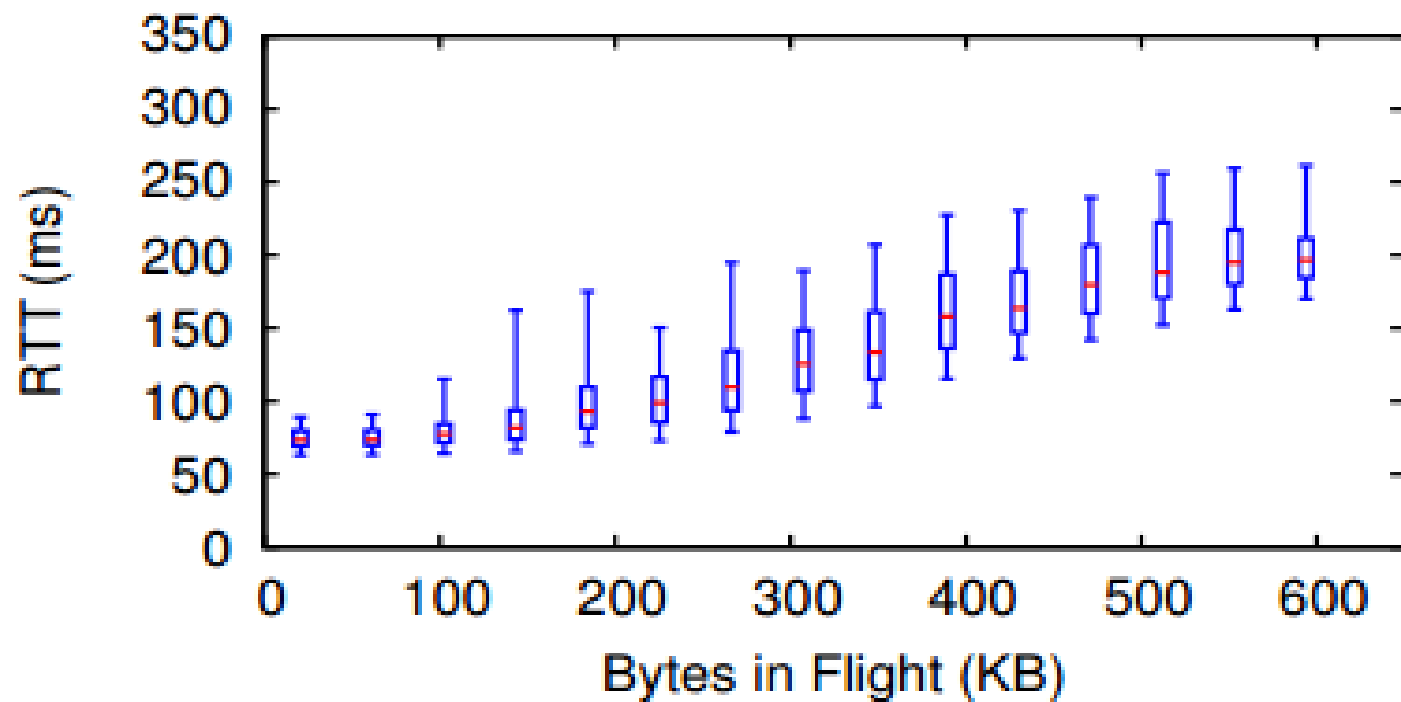
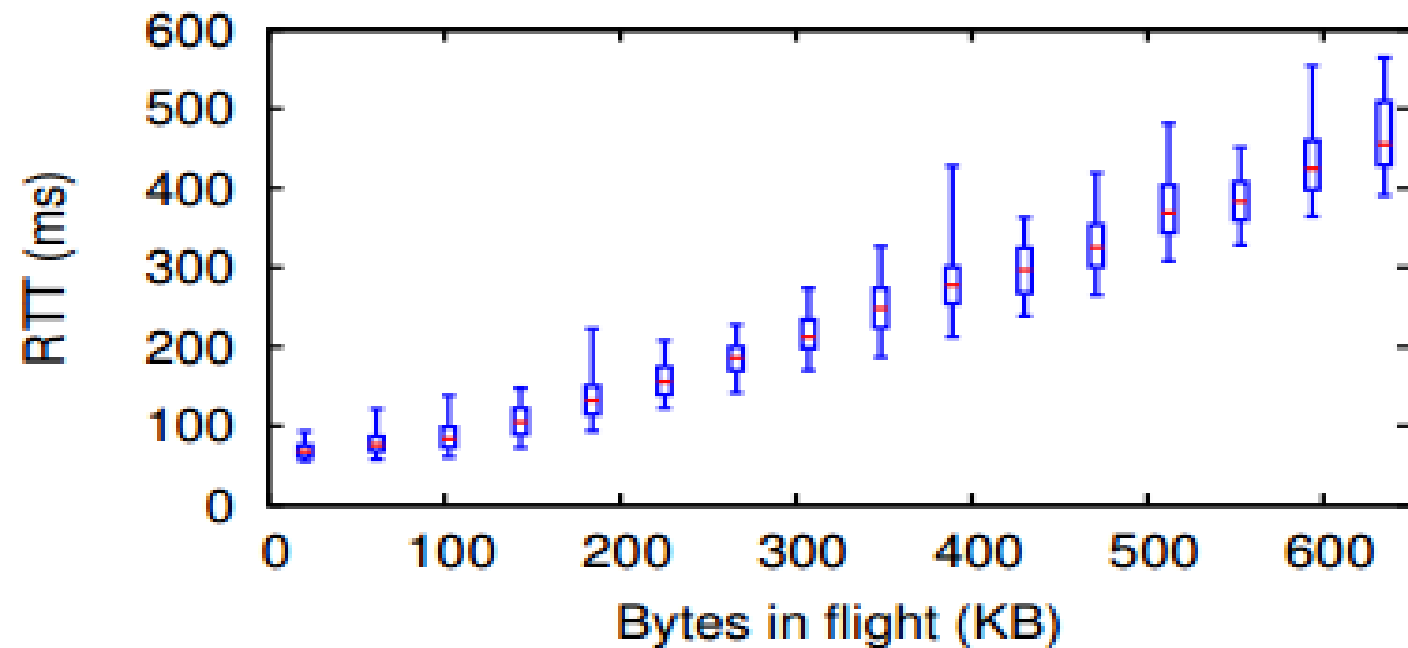


Promotion Delay

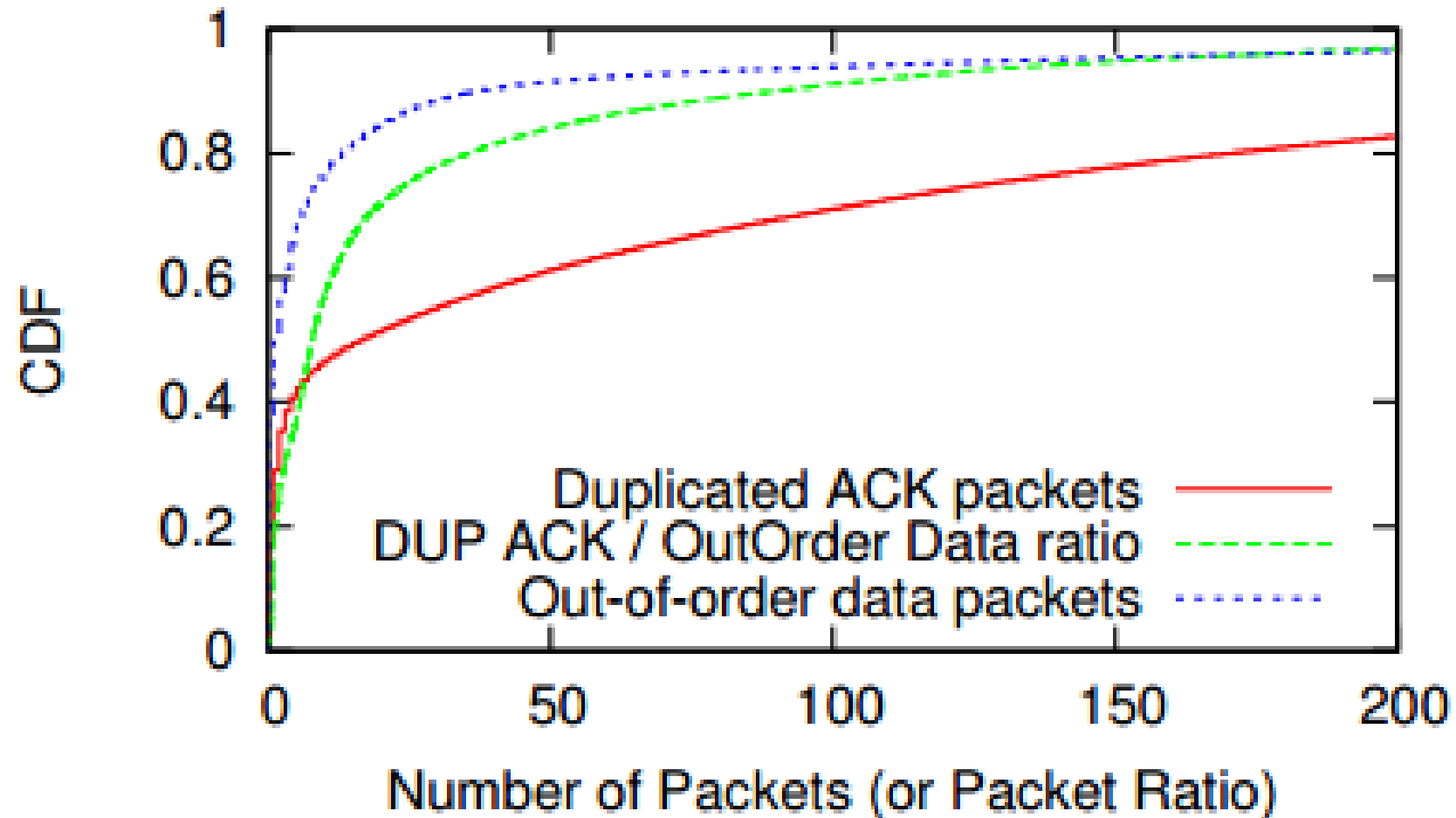


Downlink bytes in flight vs. downstream RTT





Duplicate ACS in reordering of packets



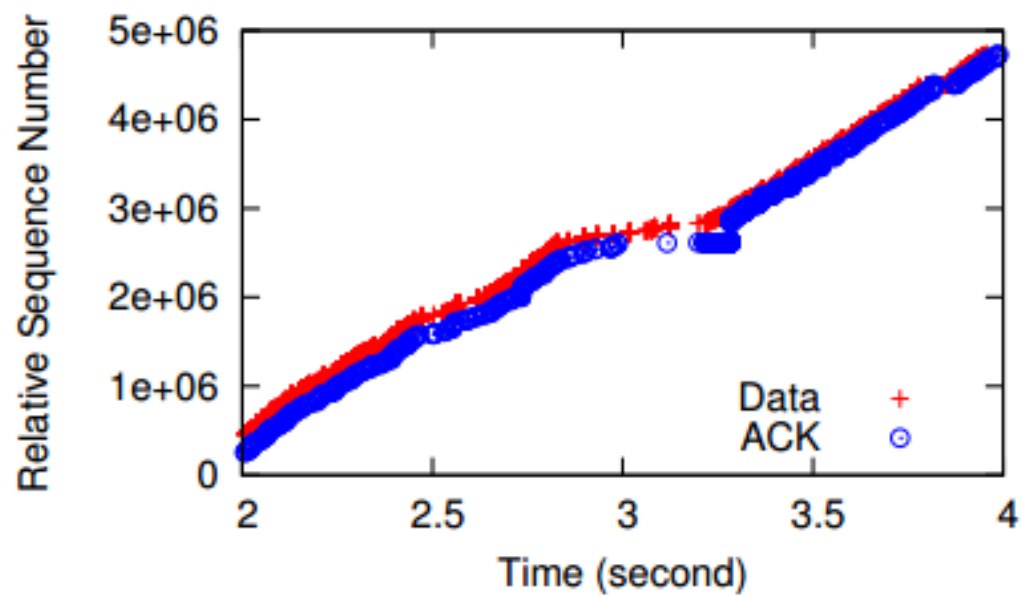


Figure 15: Duplicate ACKs not triggering a slow start.

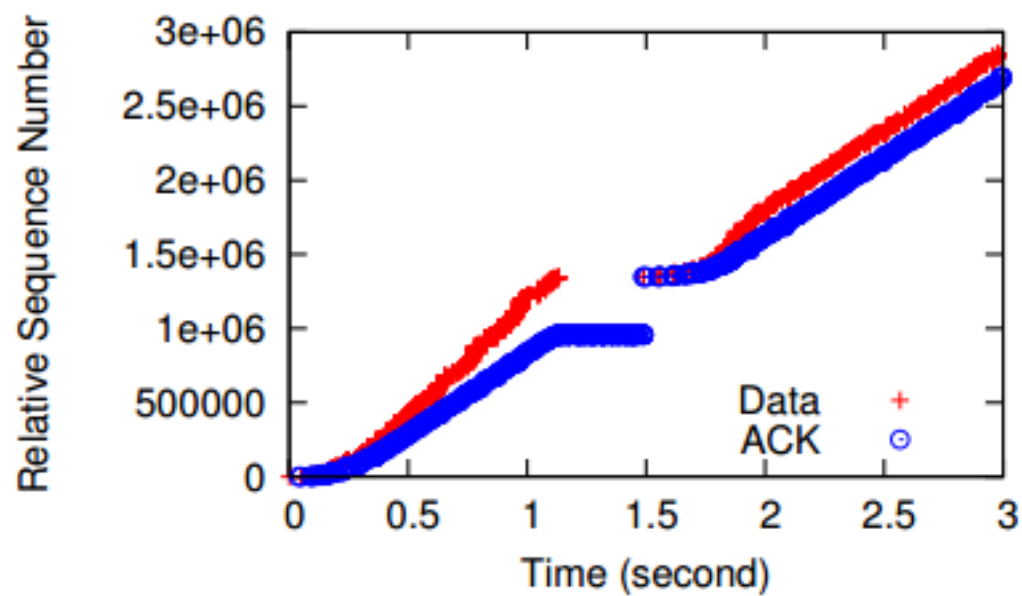
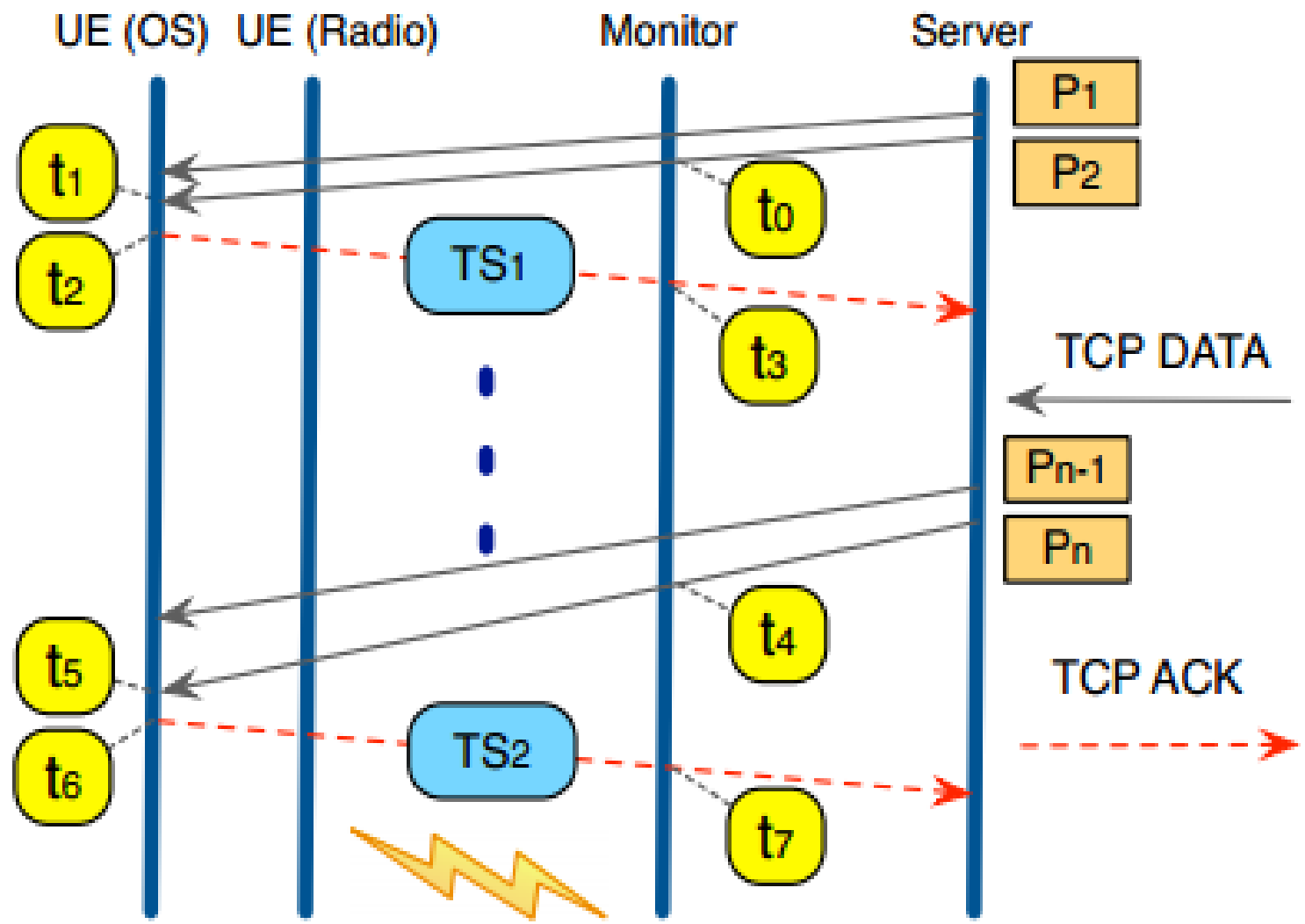


Figure 16: Duplicate ACKs triggering a slow start.

Bandwidth estimation



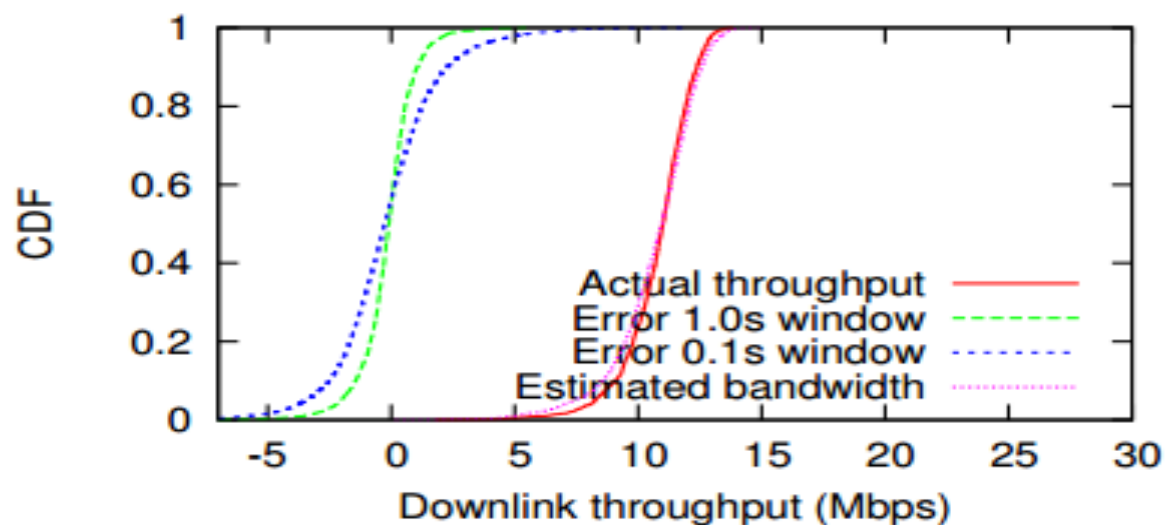


Figure 19: CDF of bandwidth estimation results for LTE network (controlled lab experiments with Carrier A).

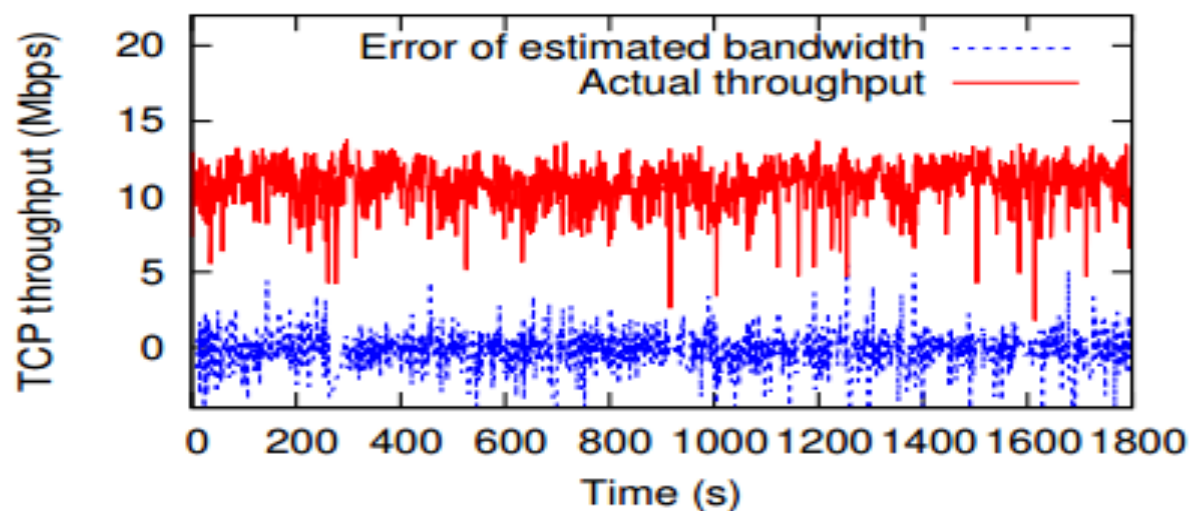


Figure 20: Time series of bandwidth estimation for LTE network (controlled lab experiments with Carrier A).

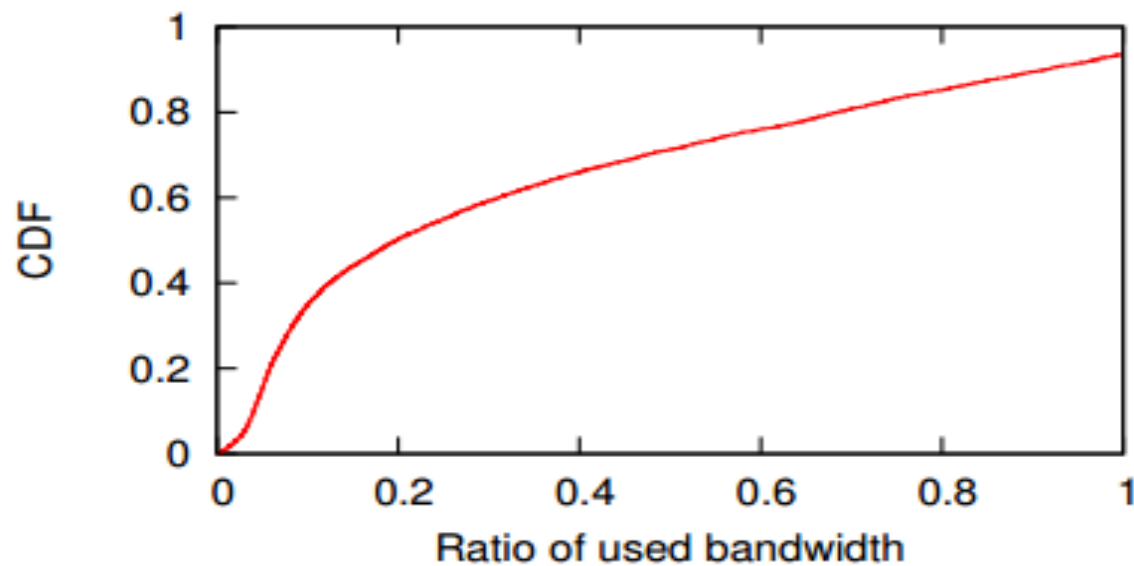


Figure 21: BW utilization ratio for large downlink TCP flows.

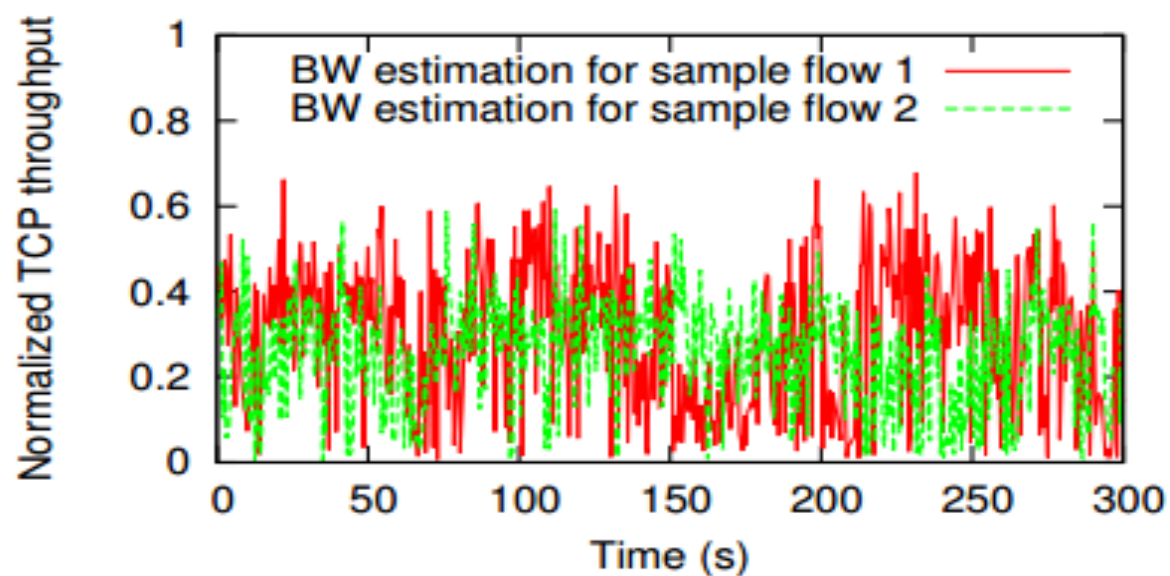
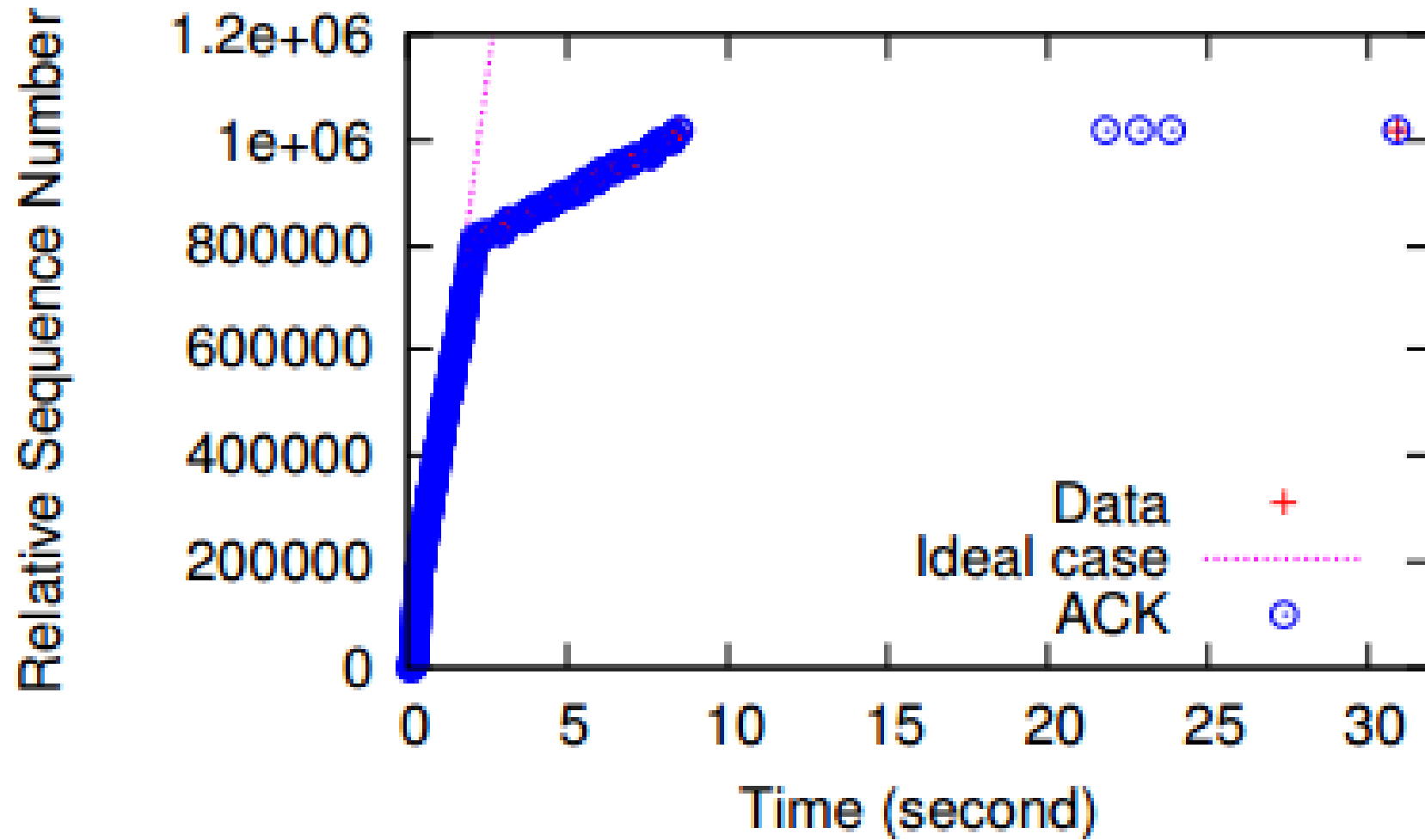
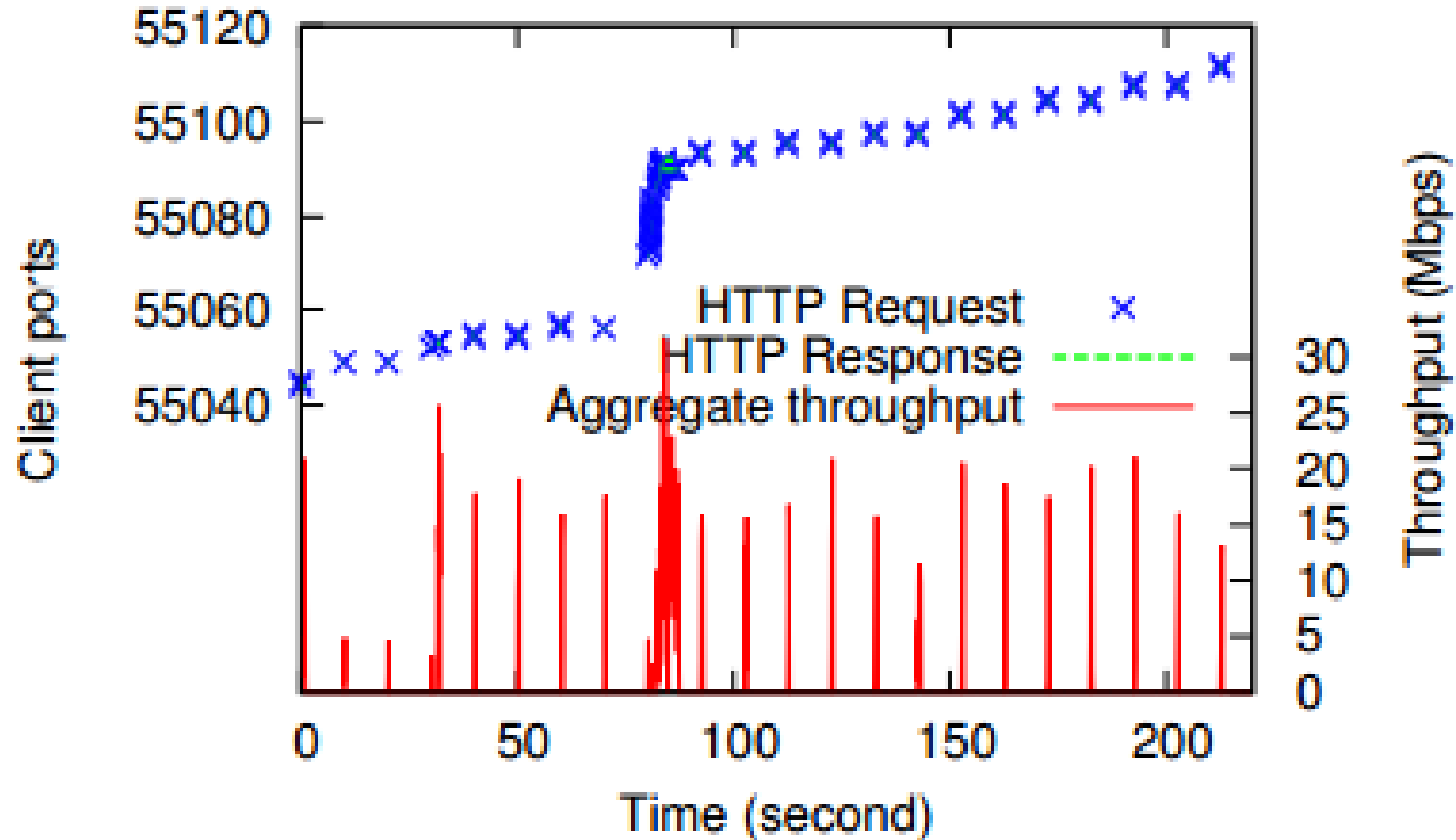


Figure 22: BW estimation timeline for two large TCP flows.

Shazam app downloading music



Network Behavior of Netflix app



Conclusion

- TCP behaviors such as not updating the RTT estimation using duplicated ACKs can cause severe performance issues in LTE.
- Need for developing TCP mechanisms and applications that are more LTE friendly.