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

![Graph showing CDF of payload sizes for downlink and uplink](image)
TCP flow duration
Delayed FIN Packet

- $t=1s$: last payload packet
- $t=11s$: radio turns off (Tail=10s)
- $t=13s$: TCP FIN, radio turns on
- $t=23s$: radio turns off
Distribution of normalized TCP flow rates
Concurrency for TCP flows
Normalized handshake RTT & DNS lookup time
Uplink and downlink RTT

CDF

Ratio of $\text{RTT(M-S)} / \text{RTT(C-M)}$
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

![Diagram showing network behavior of Netflix app](image-url)
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.