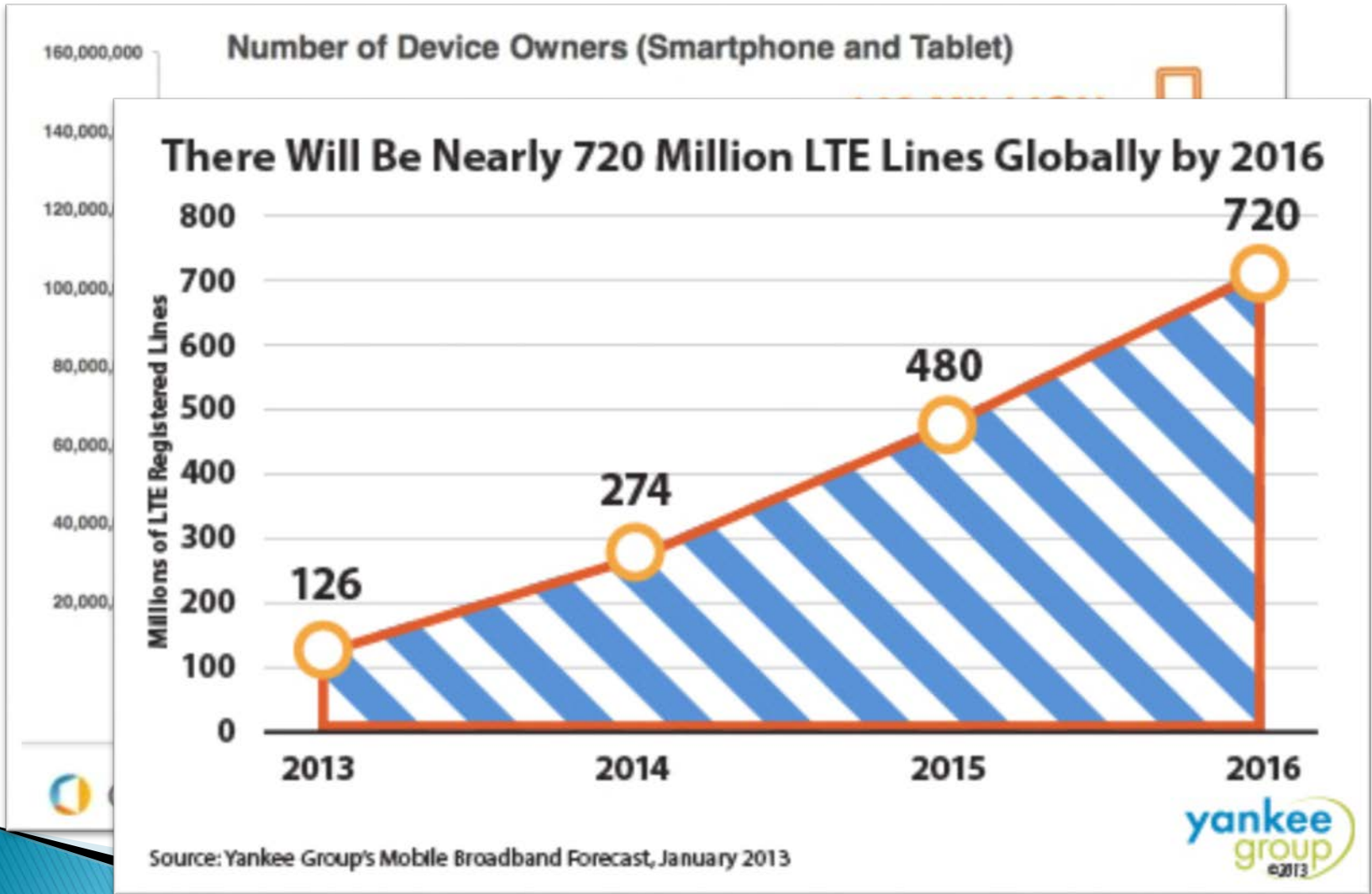# An End-to-End Measurement Study of Modern Cellular Data Networks

Yin Xu, Zixiao Wang**, Wai Kay Leong**, Ben Leong

National University of Singapore

Mobile is the future

Number of Device Owners (Smartphone and Tablet)

There Will Be Nearly 720 Million LTE Lines Globally by 2016

126 · 274 · 480 · 720

Millions of LTE Registered Lines

2013 · 2014 · 2015 · 2016

Source: Yankee Group's Mobile Broadband Forecast, January 2013

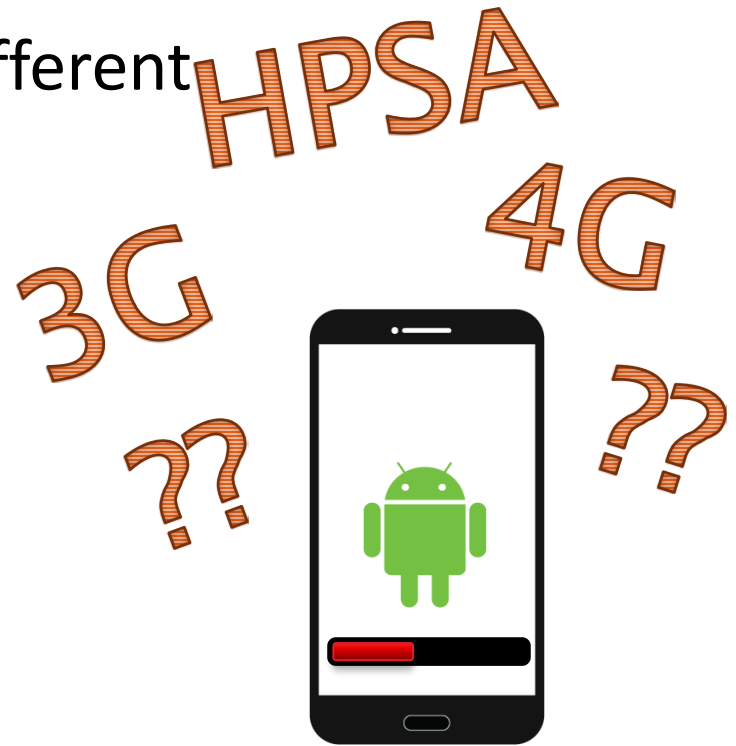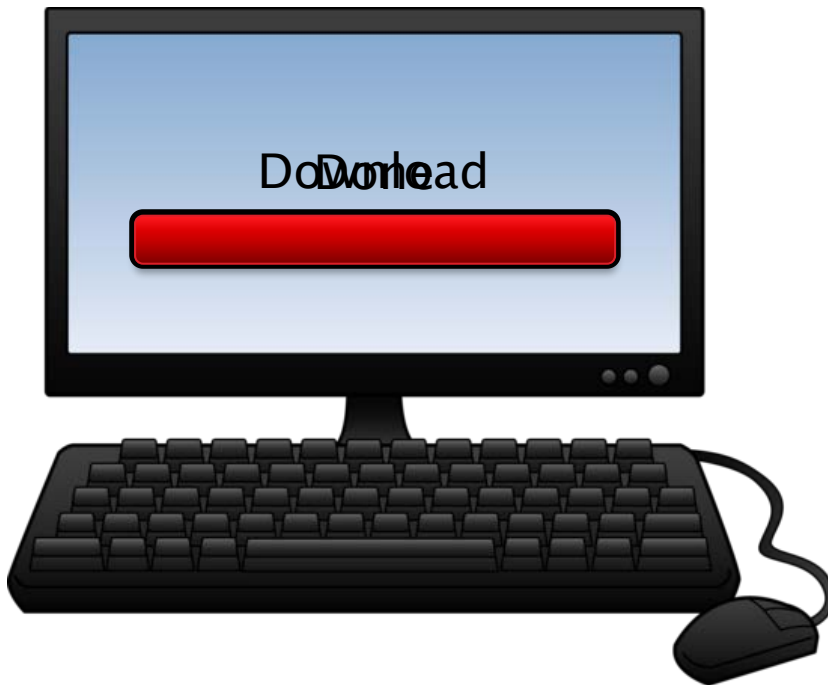yankee group ©2013

Desktop → Mobile

- Mobile Apps are growing
- Increase in Web Apps

Mobile Internet is still new

Mobile Cellular Networks are different

- ◦ Unstable connection
- ◦ Not well understood

HPSA

3G

4G

??

??

Download

Done

Approach

Obtain in-depth understanding of cellular data networks

Understanding	Development	Improvement

Methodology

- **Real** Commercial Networks
  - ◦ 3 Singapore ISPs
- **Real** Users
  - ◦ Crowd-sourced experiments
  - ◦ Users personal devices with Android app
- Laboratory Experiments

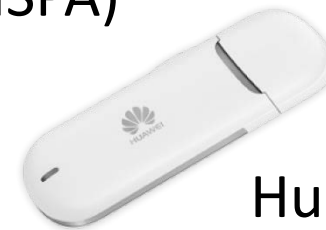# Lab Experiment Set-up

UDP/TCP

Lab Server

HTC Desire
(HSPA)

Galaxy Nexus
(3G HSPA+)

3G/4G data plans

Huawei
USB Modem

Galaxy
S3 LTE

8

Questions

1. Throughput
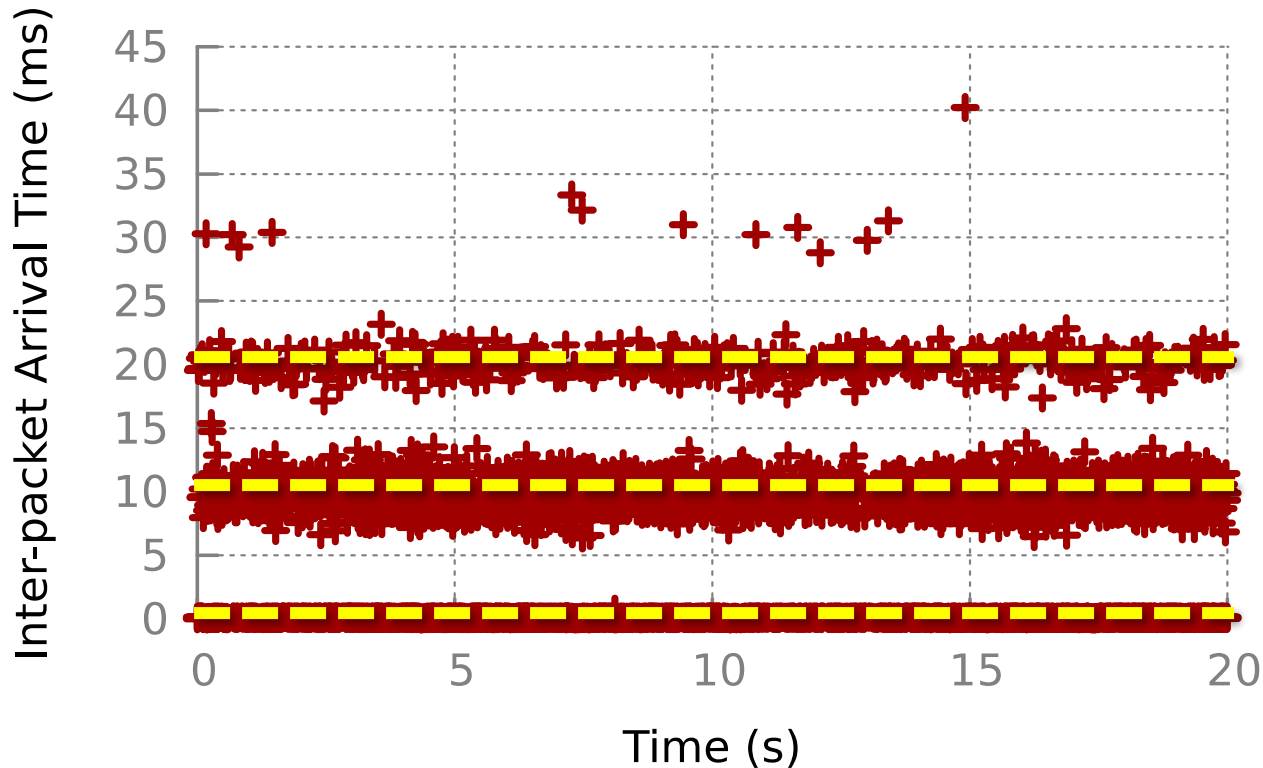   - How to measure instantaneous throughput?
2. Delay
   - Latency? Bufferbloat?
3. Queuing
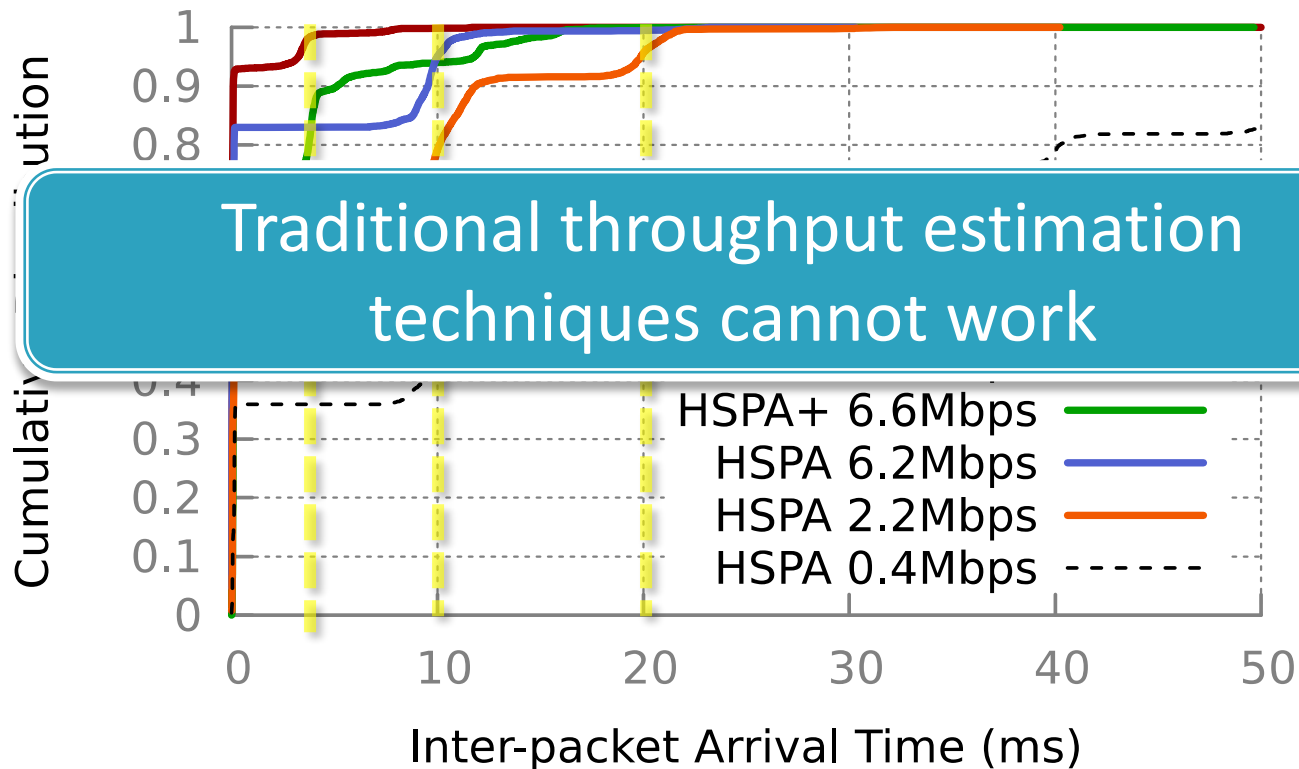   - Queuing schemes?
   - Fairness?

Question 1: Measuring Throughput

▸ Understand arrival pattern
  ◦ Time between consecutive packets
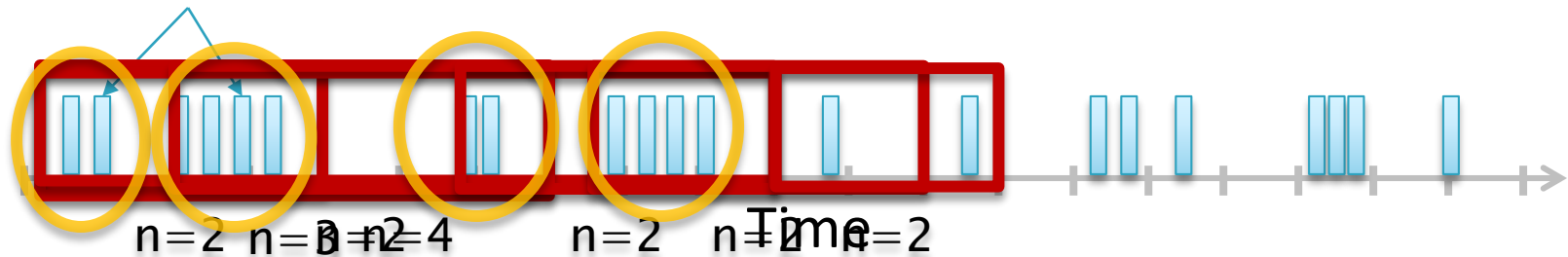▸ Arrivals are bursty

Question 1: Measuring Throughput

▸ Different networks

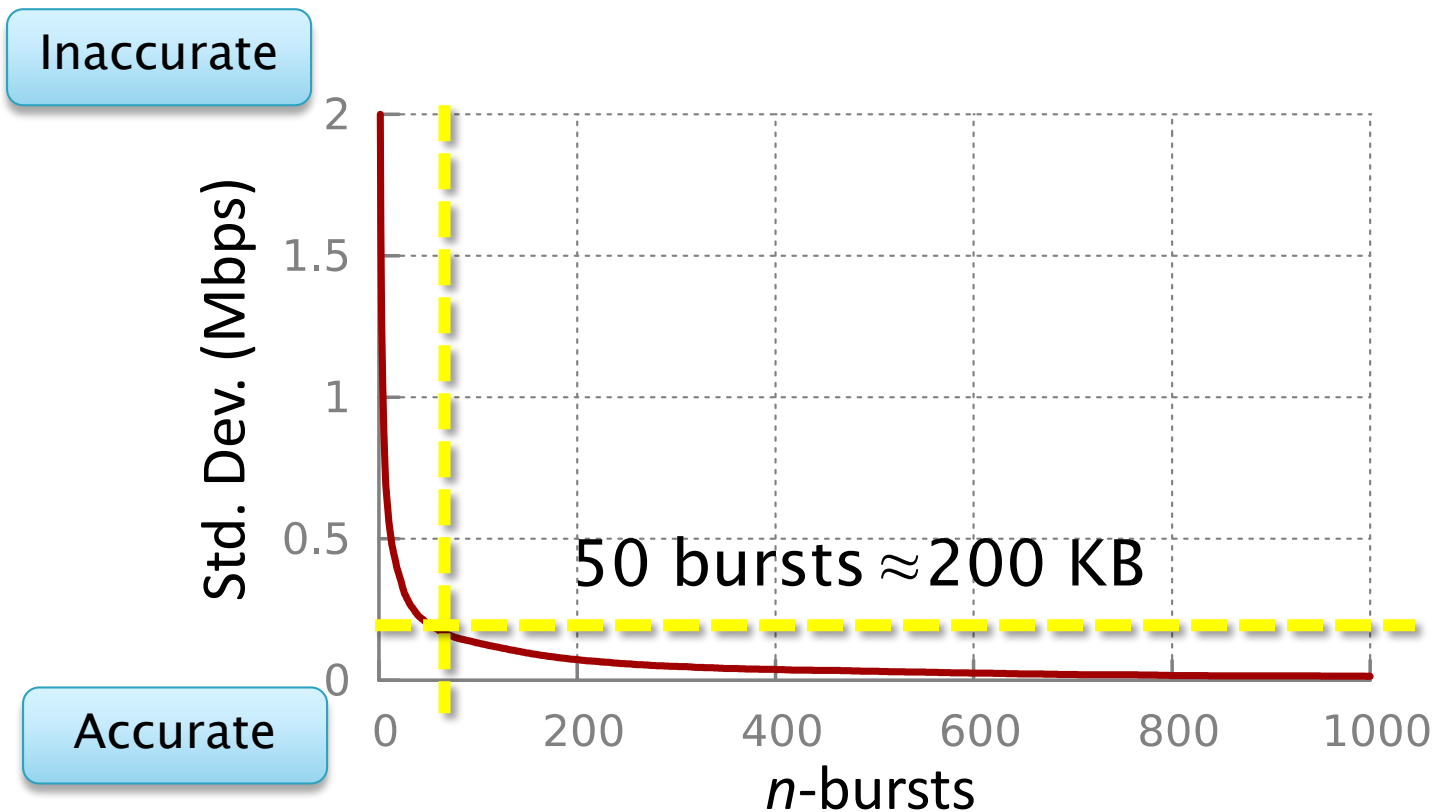Traditional throughput estimation techniques cannot work

HSPA+ 6.6Mbps
HSPA 6.2Mbps
HSPA 2.2Mbps
HSPA 0.4Mbps

Inter-packet Arrival Time (ms)

How to Measure Throughput?

- Took a stable, high speed trace
- Sliding window of size *n* bursts

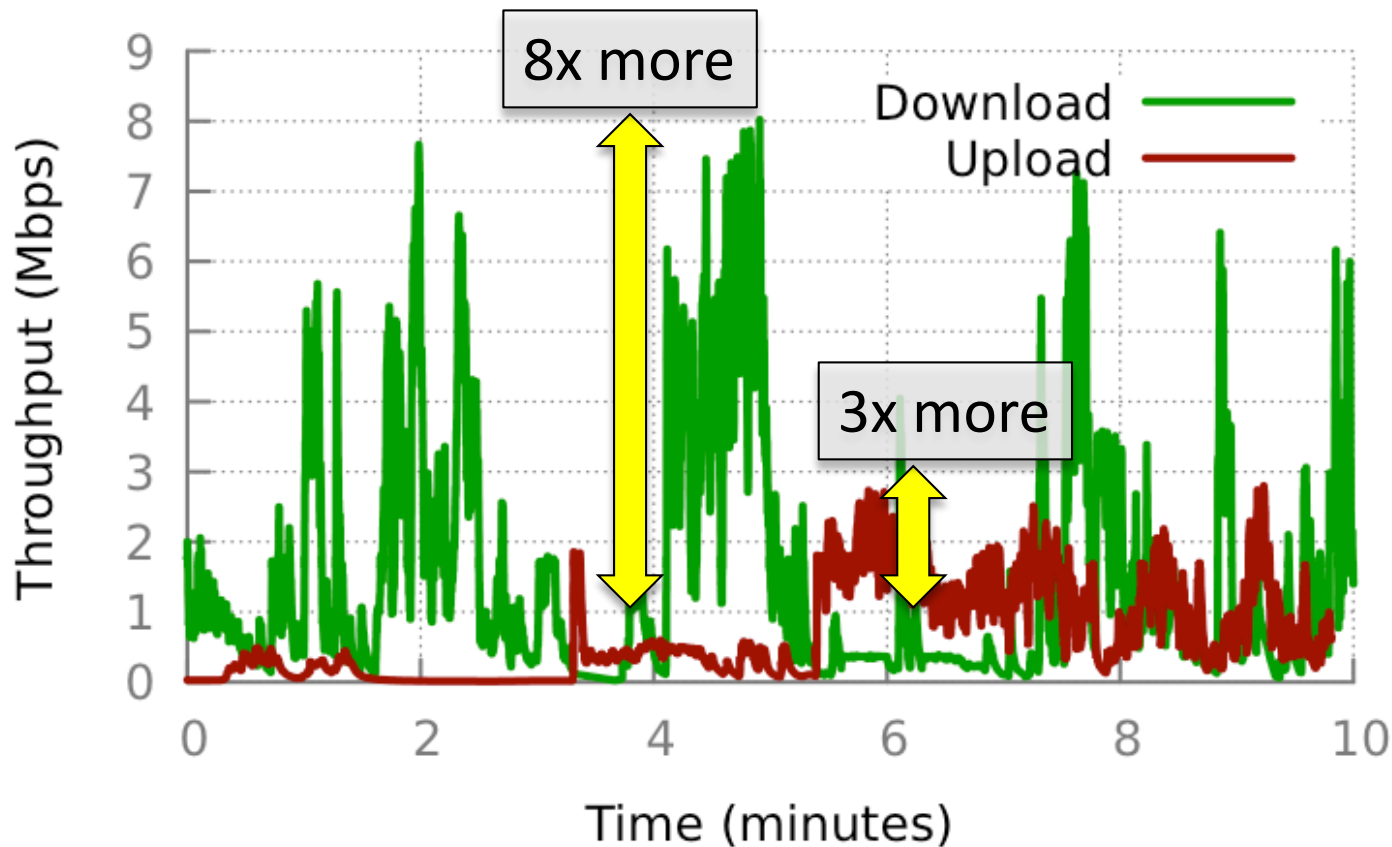Packets received

n=2 n=3 n=4 n=2 n=2 n=4 n=2

Time

Results of sliding window

▸ Total average as ground truth

Significant Throughput Variation

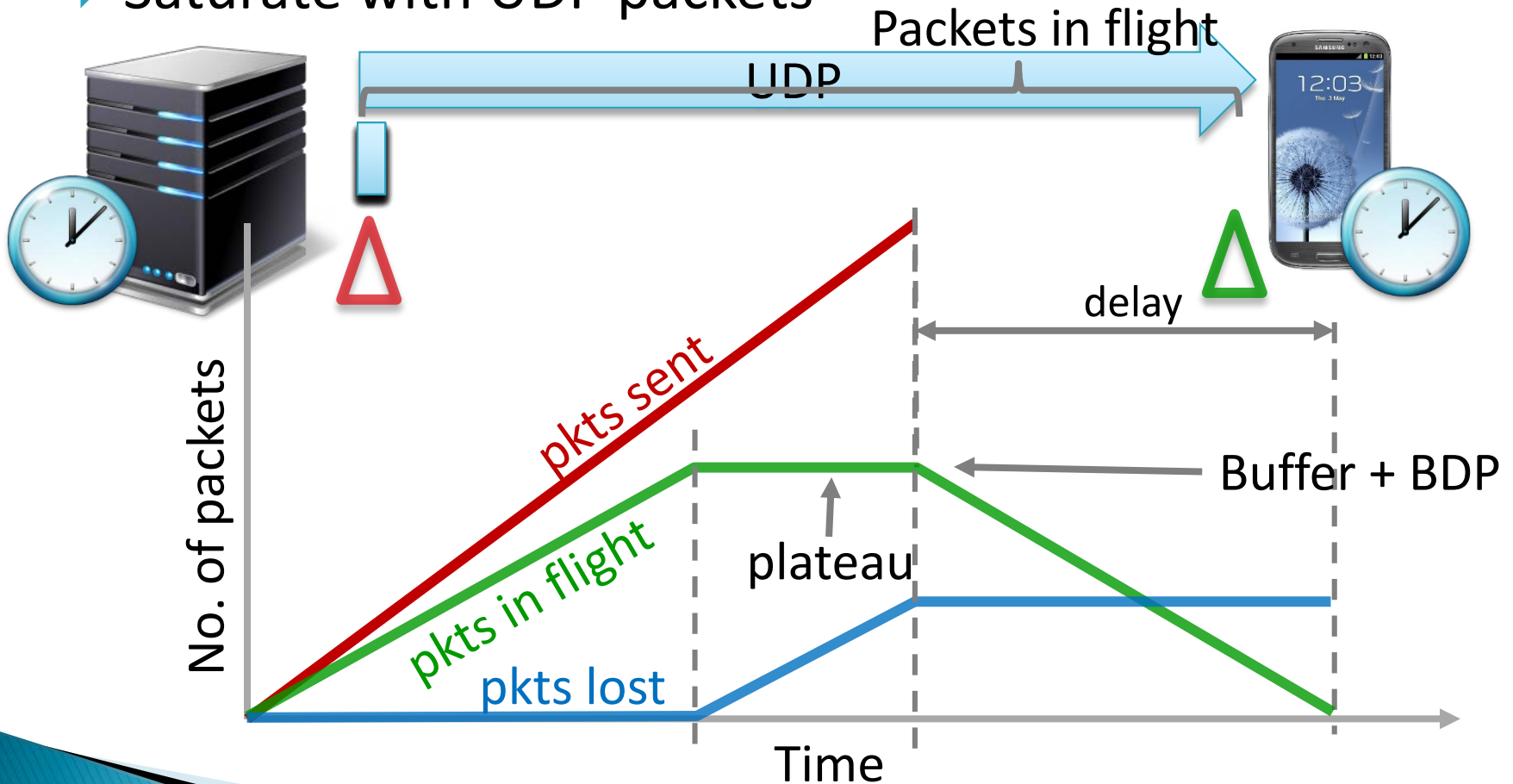▸ At a fixed location

▸ Need to keep measuring to stay updated

Question 2: Understanding Delay

▸ Varying throughput → Queuing
▸ Excessive Buffering → Large delays

Testing Buffer Size

- Saturate with UDP packets

ISP Buffer

Table 1: Downlink buffer characteristics for local ISPs

ISP	Network	Buffer Size	Drop Policy
ISP A	HSPA(+)	4,000 pkts	Drop-tail
	LTE	(≤ 800 ms)	AQM
ISP B	HSPA(+)	400 pkts	Drop-head
	LTE	600 pkts	Drop-tail
ISP C			op-tail
	LTE	2,000 pkts	Drop-tail

Details in the paper

Phone Buffers are different

- Sized in bytes
- Newer phones have additional kernel buffering

Table 2: The radio interface buffer size of different devices

Device Type	Model	Network	Buffer Size
Android Phone	HTC Desire	HSPA	64 KB
	Galaxy Nexus	HSPA+	1.5 MB
	Galaxy S3 LTE[†]	HSPA+	200 KB
		LTE	400 KB
	Galaxy S4[†]	HSPA+	200 KB
		LTE	400 KB
USB Modem	Huawei E3131	HSPA+	300 pkts
	Huawei E3276	LTE	1,000 pkts

[†]These devices have additional buffering of 1,000 packets in the kernel.

Question 3: Queuing Policy & Fairness

▸ ISPs implement fair queuing

▸ UDP vs TCP?
  ◦ Treated equally by our ISPs
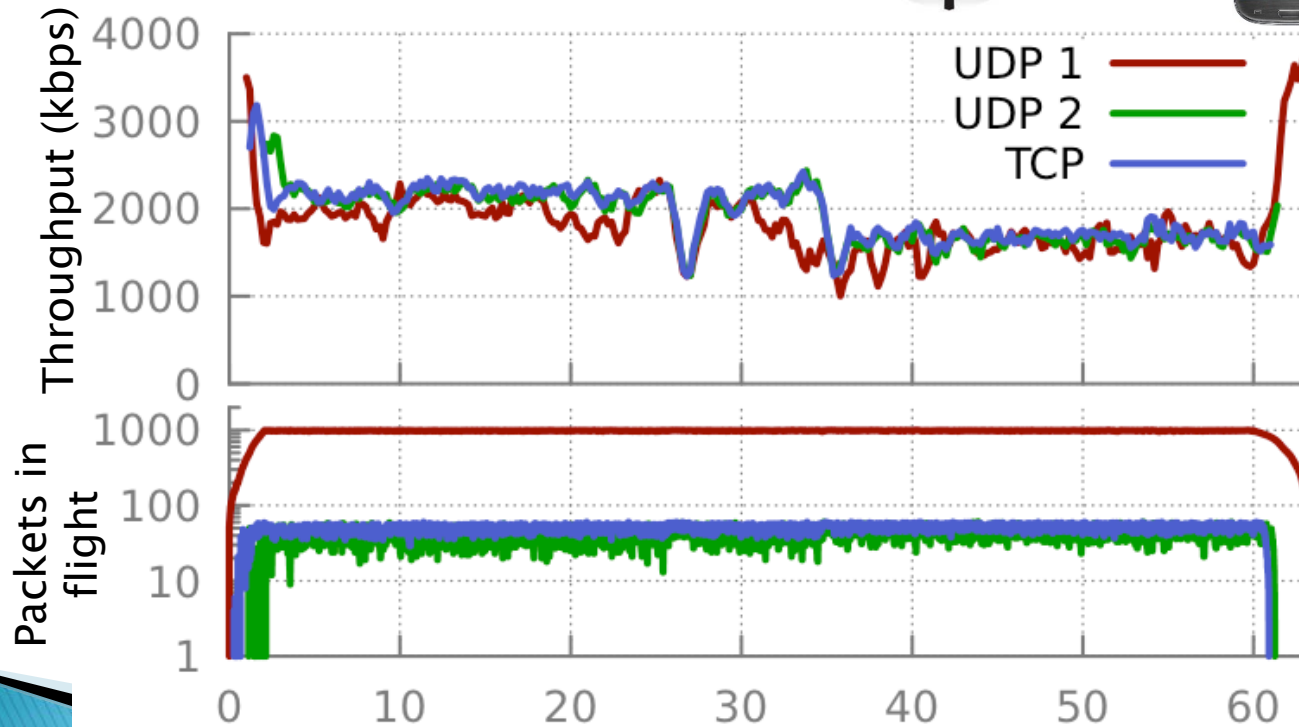
Key Insights

1. ## Throughput
   - Significant variations in throughput over time
   - Hard to measure instantaneous throughput
2. ## Large Buffers can cause delays
   - Buffering scheme vary among ISPs
3. ## Fair Queuing/Scheduling by ISP
   - Congestion control may not be necessary

Thank you

Questions and Comments

Queuing Policy and Fairness

▸ Fair queuing is implemented

▸ UDP and TCP are treated equally in our local ISPs

▸ Add more packets than necessary into the buffer is not useful. Adding more packets than need will only add delay.

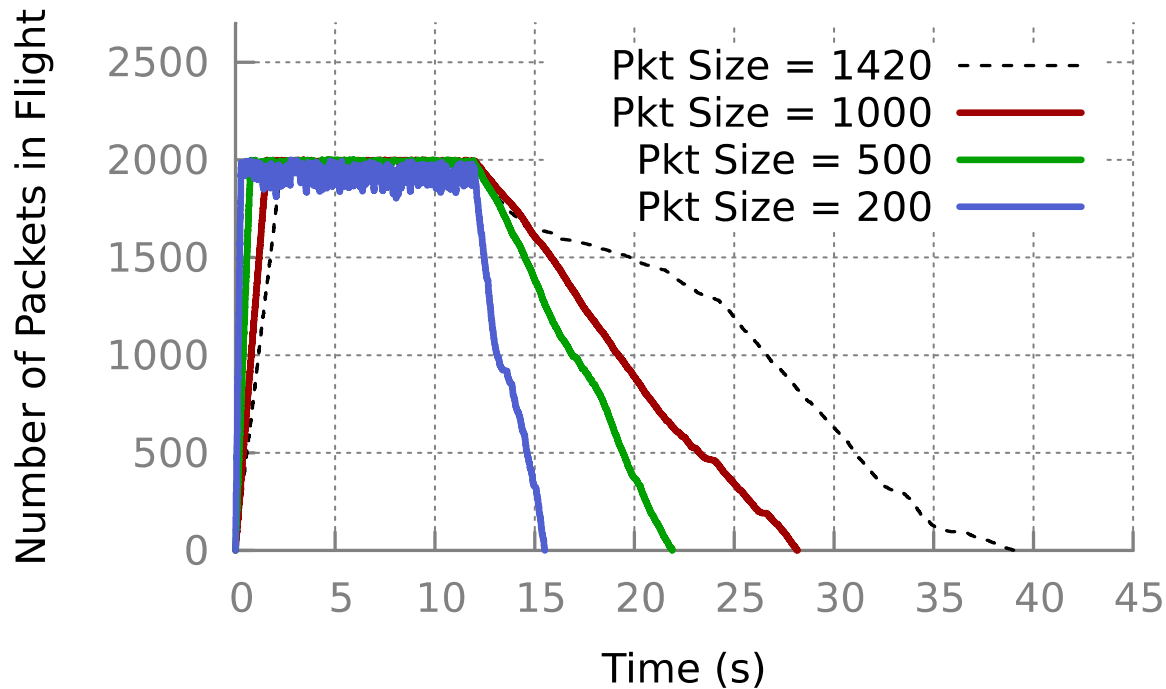▸ More design opportunity. E.g. fairness control may not necessary. [tcp-rre, sprute]
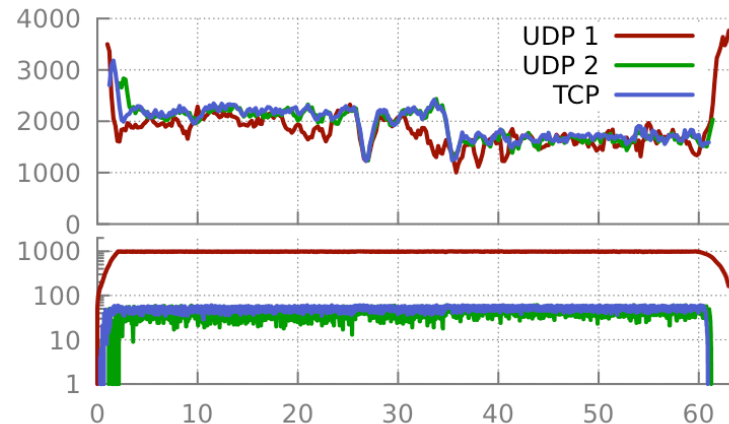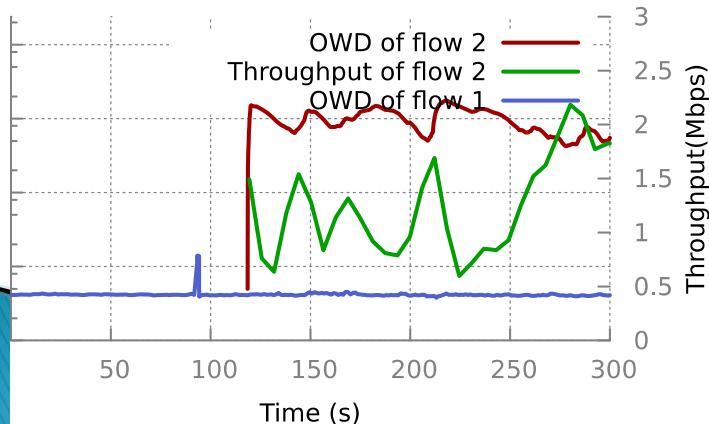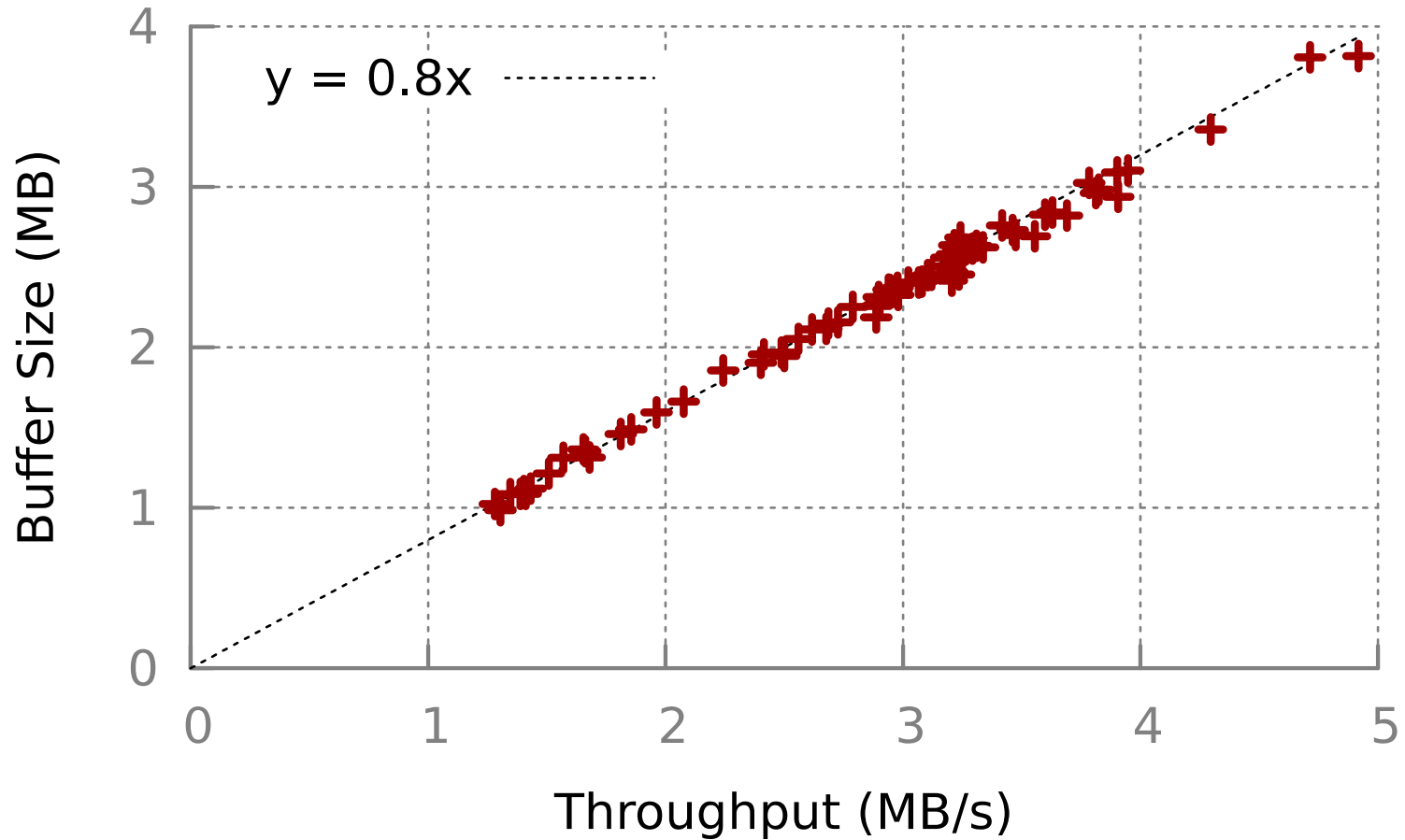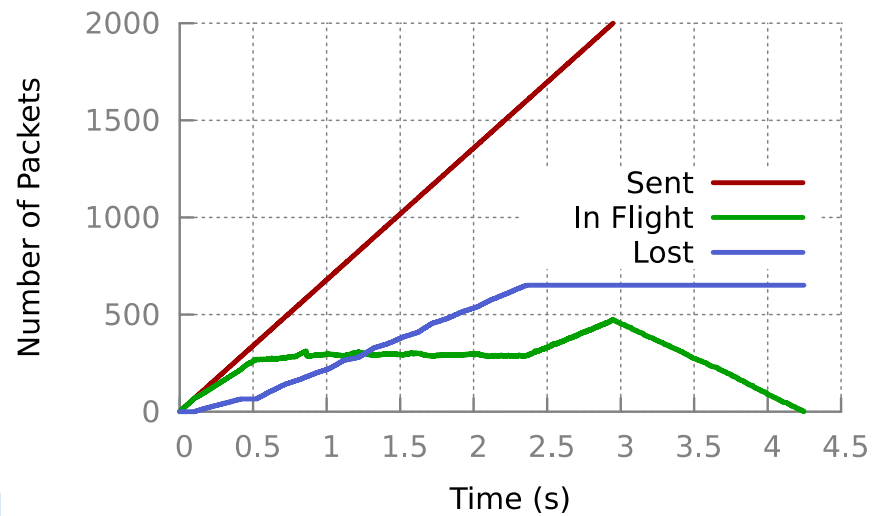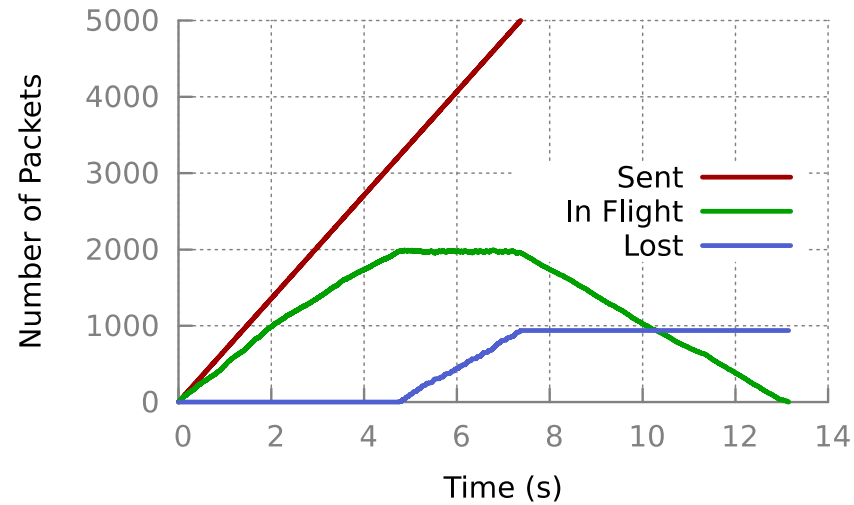
Bursty packet arrival pattern
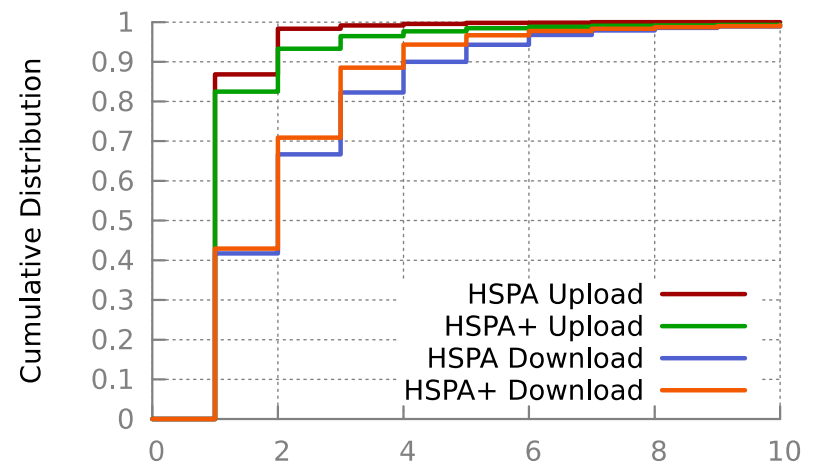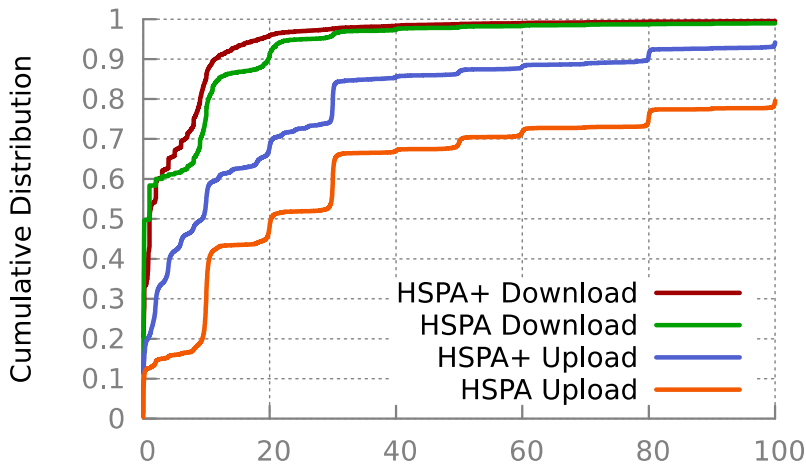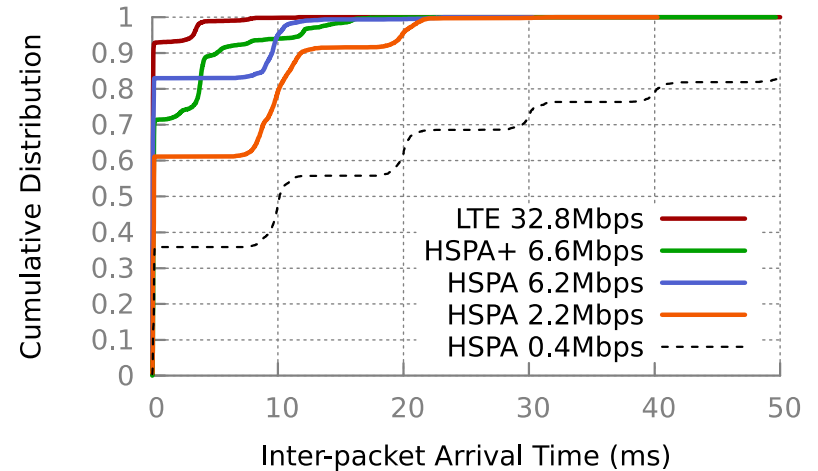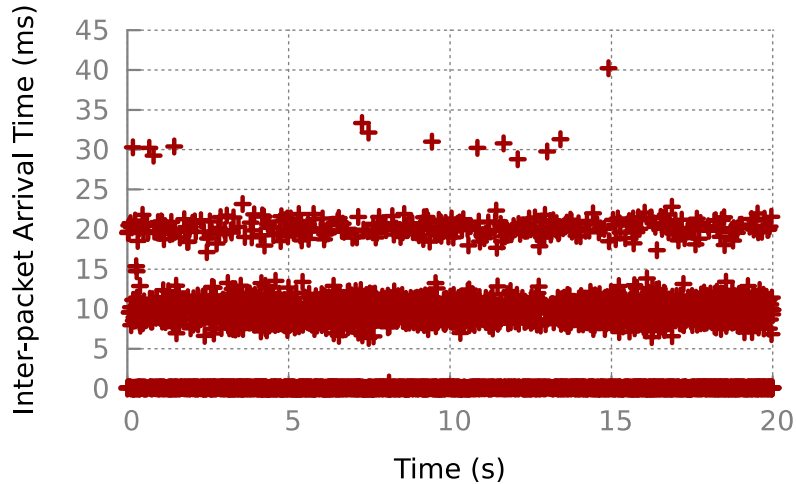
The Downlink buffer

▸ The buffer is sized in packets.

AQM is Found in ISP A's LTE network

y = 0.8x ------------

Buffer Size (MB) vs Throughput (MB/s)

25

Drop-tail VS Drop-head

Uplink Buffer

▸ The phones are sized in bytes, while the Huawei USB Modem are sized in packets.

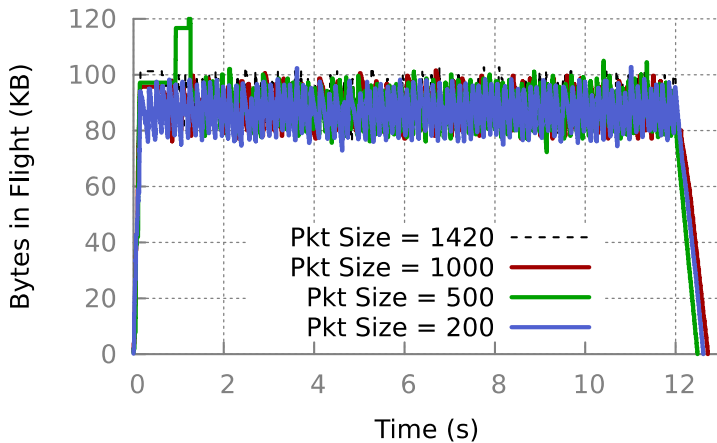Table 2: The radio interface buffer size of different devices

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USB Modem	Huawei E3131	HSPA+	300 pkts
	Huawei E3276	LTE	1,000 pkts

[†]These devices have additional buffering of 1,000 packets in the kernel.

Separate buffer