Congestion Control in Data Center Networks

Overview

- Why is the problem different from that in the Internet?
- What are possible solutions?

DC Traffic Patterns

- In-cast applications
  - Client send queries to servers
  - Responses are synchronized
- Few overlapping long flows
  - According to DCTCP's measurement

Data Center TCP
(DCTCP)

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Data Center Packet Transport

- Large purpose-built DCs
  - Huge investment: R&D, business
- Transport **inside** the DC
  - TCP rules (99.9% of traffic)
- How's TCP doing?

TCP in the Data Center

- We'll see TCP does not meet demands of apps.
  - Suffers from bursty packet drops, Incast [SIGCOMM '09], ...
  - Builds up large queues:
    - ➢ Adds significant latency.
    - ➢ Wastes precious buffers, esp. bad with shallow-buffered switches.

- Operators work around TCP problems.
  - Ad-hoc, inefficient, often expensive solutions
  - No solid understanding of consequences, tradeoffs

Roadmap

- What's really going on?
  - Interviews with developers and operators
  - Analysis of applications
  - Switches: shallow-buffered vs deep-buffered
  - Measurements

- A systematic study of transport in Microsoft's DCs
  - Identify **impairments**
  - Identify **requirements**

- Our solution: **Data Center TCP**

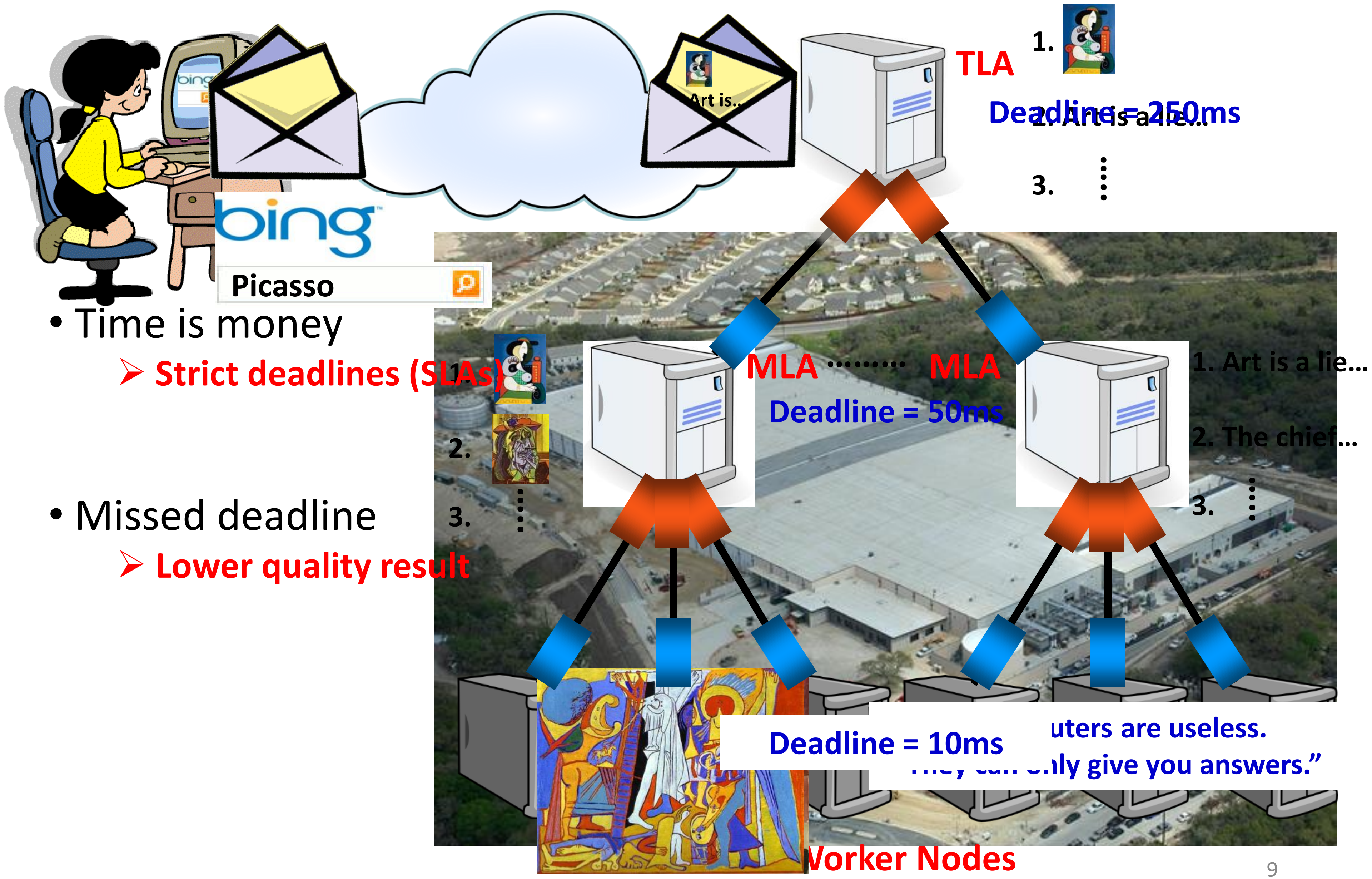
Case Study: Microsoft Bing

- Measurements from 6000 server production cluster

- Instrumentation passively collects logs
  - Application-level
  - Socket-level
  - Selected packet-level

- More than **150TB** of compressed data over a month

Partition/Aggregate Application Structure



- Time is money
  - ➢ Strict deadlines (SLAs)
- Missed deadline
  - ➢ Lower quality result

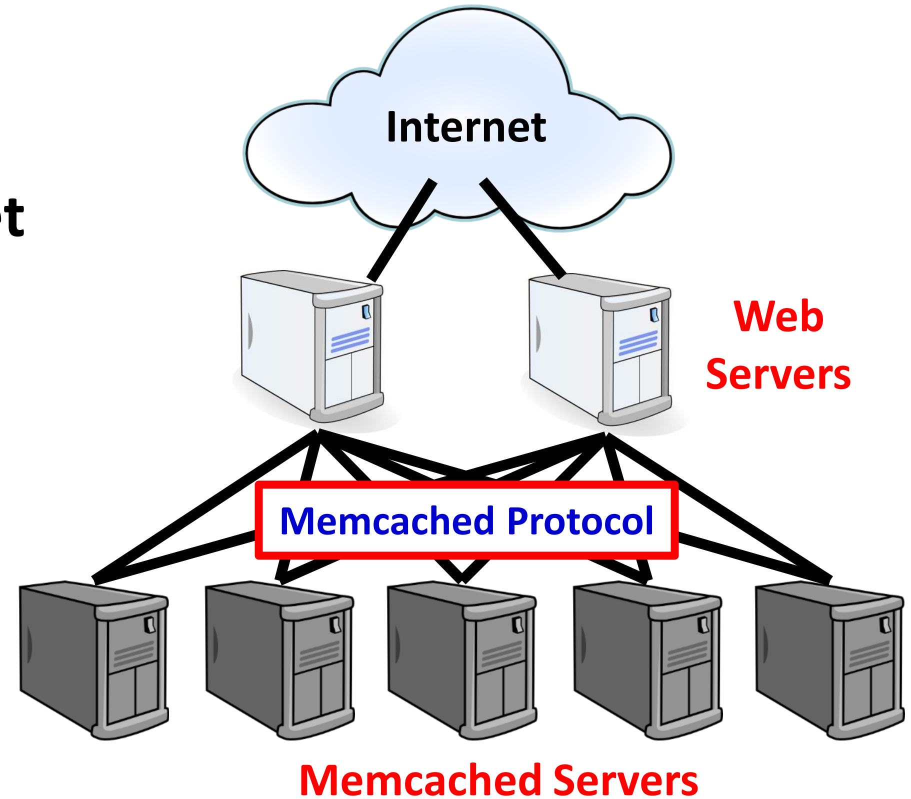
Generality of Partition/Aggregate

- The foundation for many large-scale web applications.
  - Web search, Social network composition, Ad selection, etc.

- Example: **Facebook**

Partition/Aggregate ~ Multiget

- Aggregators: **Web Servers**
- Workers: **Memcached Servers**



Workloads

- Partition/Aggregate
  (Query)

→ Delay-sensitive

- Short messages [50KB-1MB]
  (Coordination, Control state)

→ Delay-sensitive

- Large flows [1MB-50MB]
  (Data update)

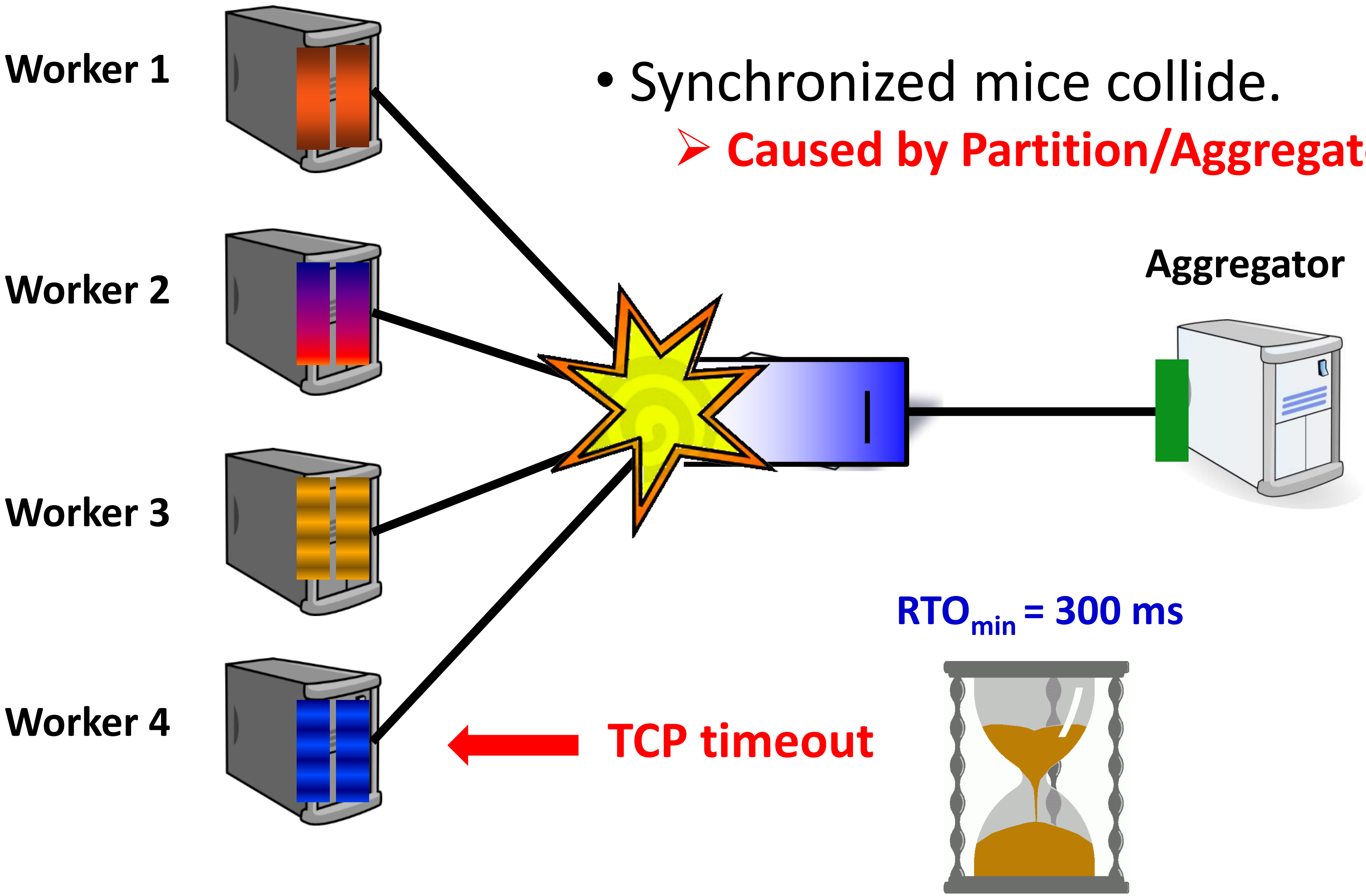
→ Throughput-sensitive

Impairments

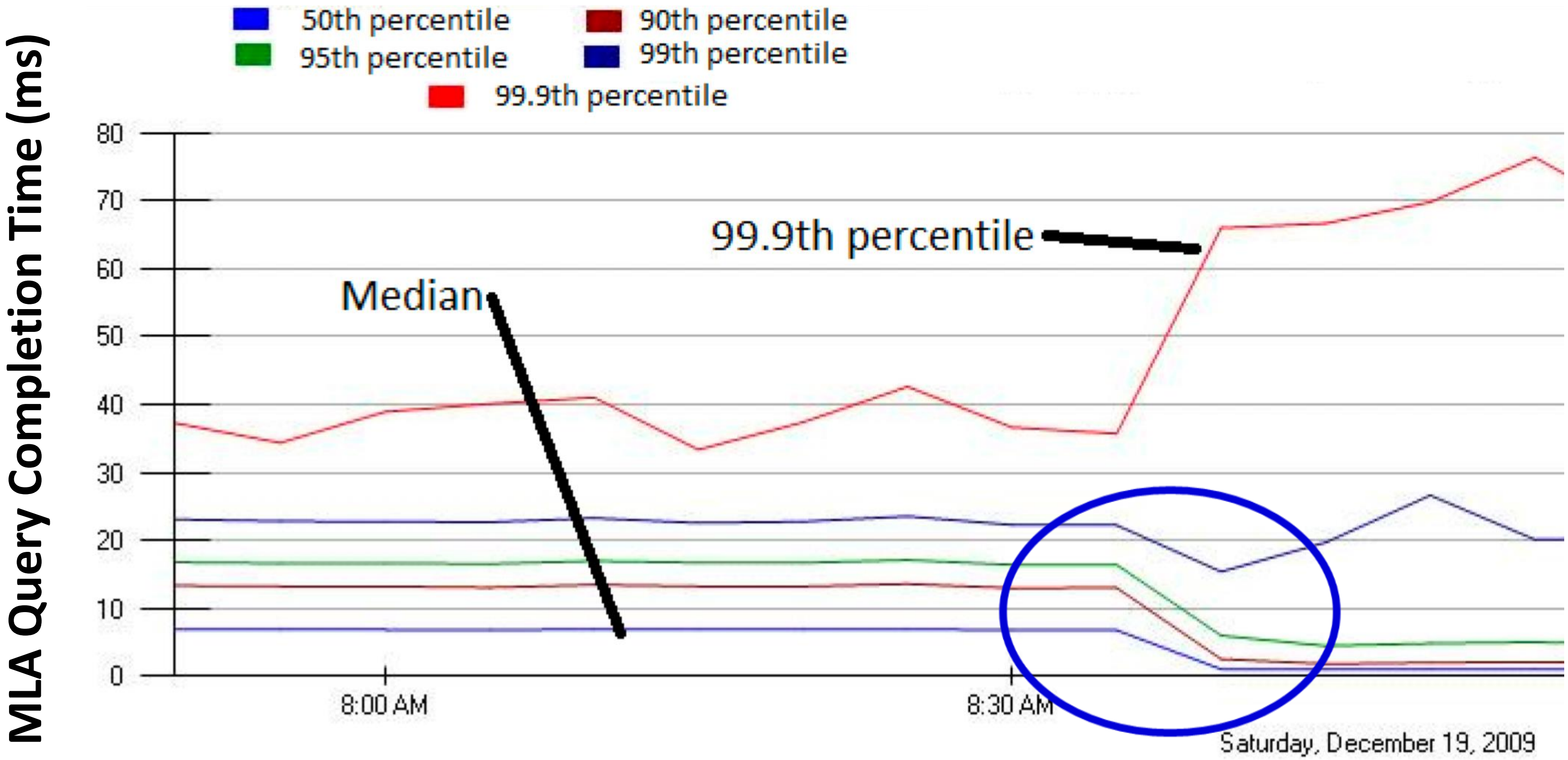
- Incast
- Queue Buildup
- Buffer Pressure

Incast

- Synchronized mice collide.
  - ➢ **Caused by Partition/Aggregate.**



Incast Really Happens



Jittering

99.9th percentile is being tracked.

ntiles.

InCast: Goodput collapses as senders increase

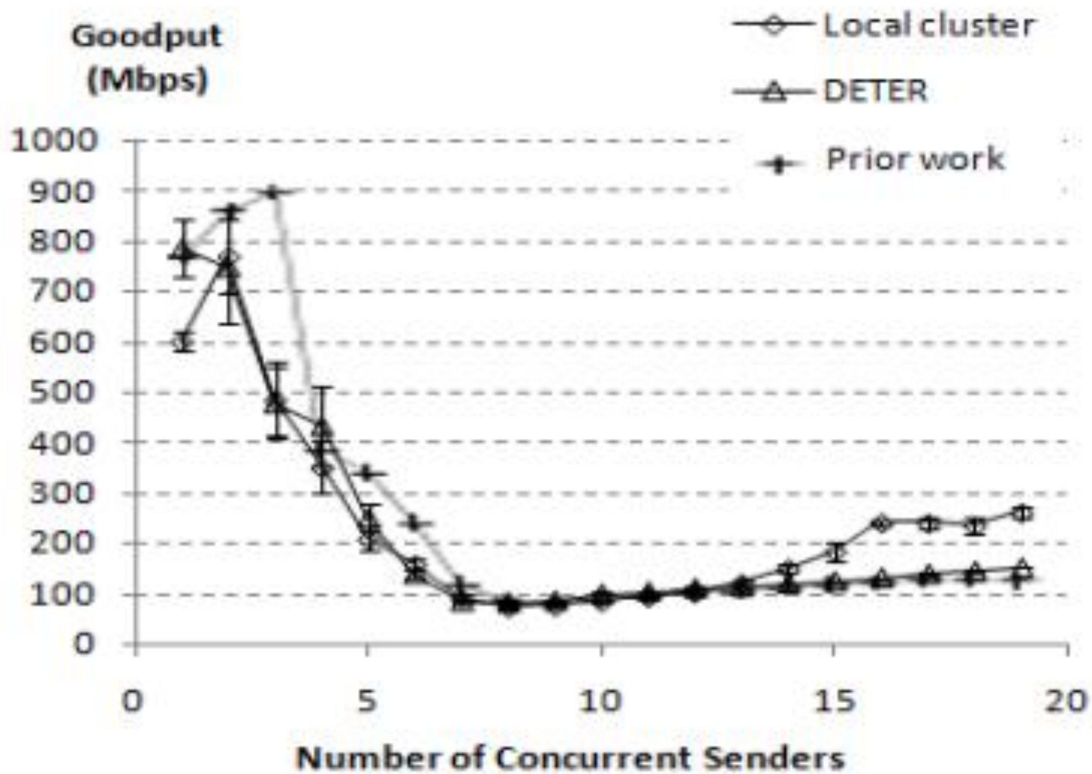


Figure 1: TCP Incast goodput collapse up to 20 senders for three different environments

InCast: Synchronized timeouts

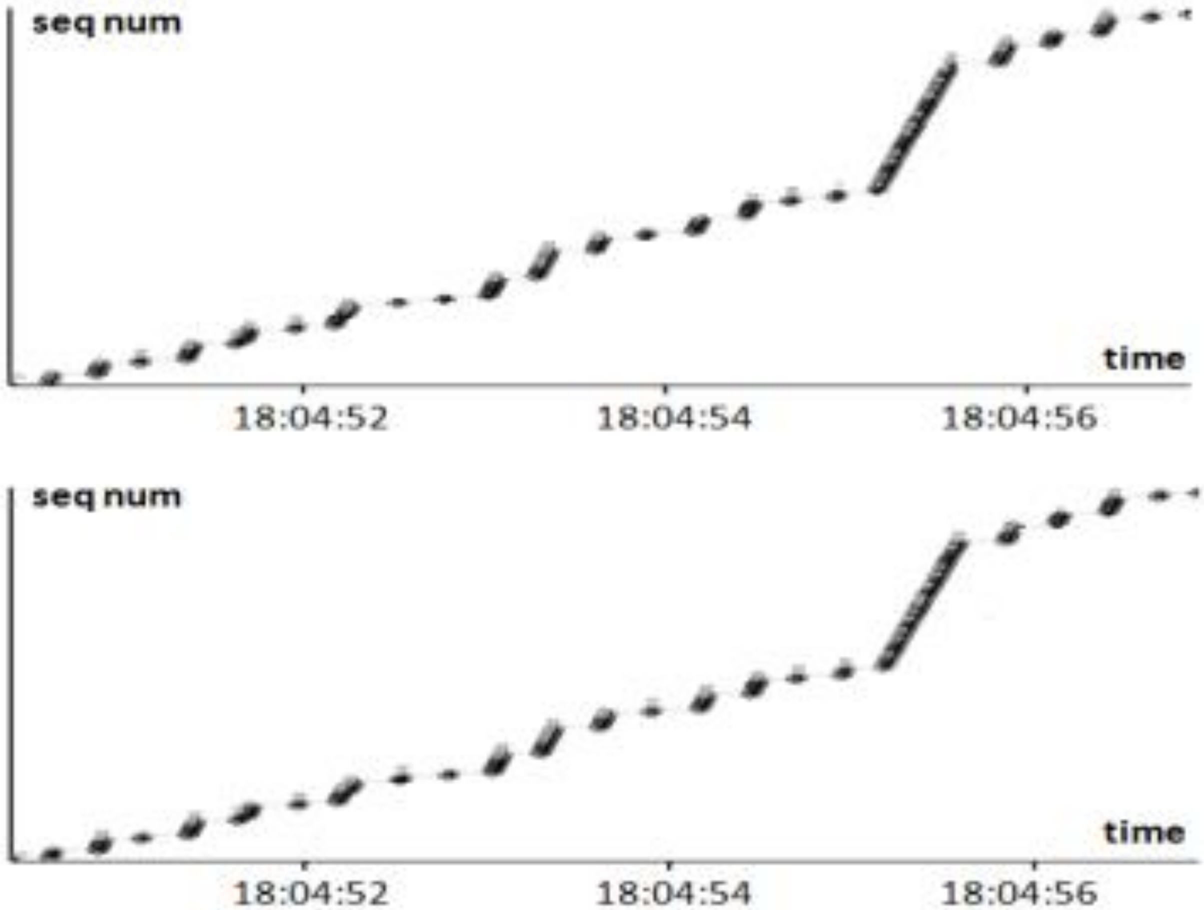
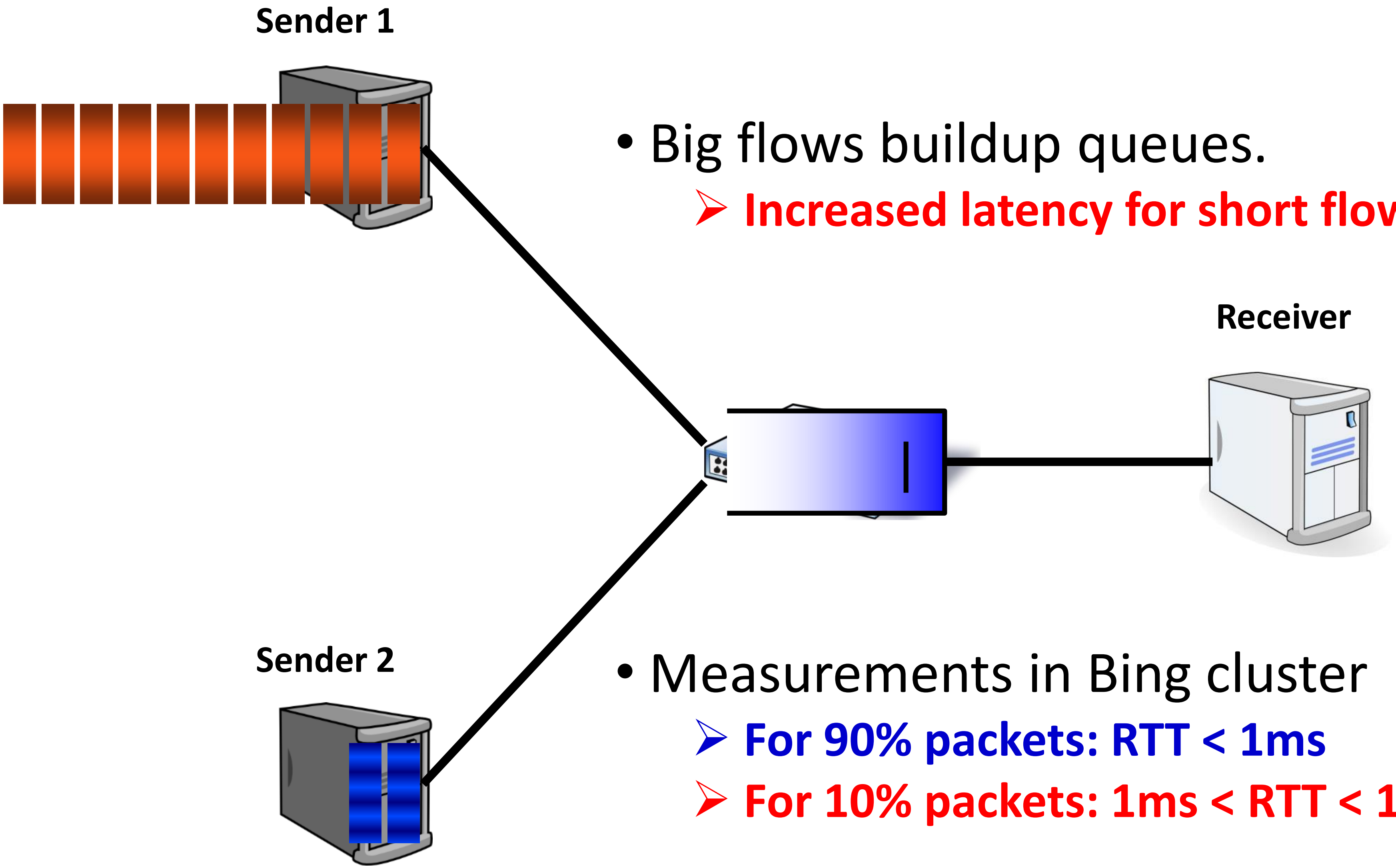


Figure 2: TCP sequence numbers vs. time for two senders in a 5-to-1 setup

Queue Buildup



- Big flows buildup queues.
  - ➢ Increased latency for short flows.

- Measurements in Bing cluster
  - ➢ For 90% packets: RTT < 1ms
  - ➢ For 10% packets: 1ms < RTT < 15ms

Data Center Transport Requirements

1. **High Burst Tolerance**
   - Incast due to Partition/Aggregate is common.

2. **Low Latency**
   - Short flows, queries

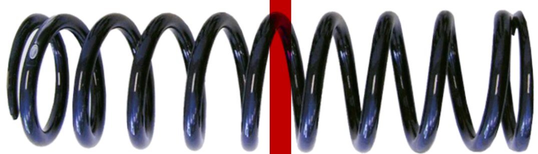
3. **High Throughput**
   - Continuous data updates, large file transfers

The challenge is to achieve these three together.

Tension Between Requirements

High Throughput

High Burst Tolerance



Low Latency

Deep Buffers:

- Qu
  Inc

Shallow Buffers:

&

Objective:

Low Queue Occupancy & High Throughput

Reduced RTO$_{min}$ (SIGCOMM '09)

- Doesn't Help Latency

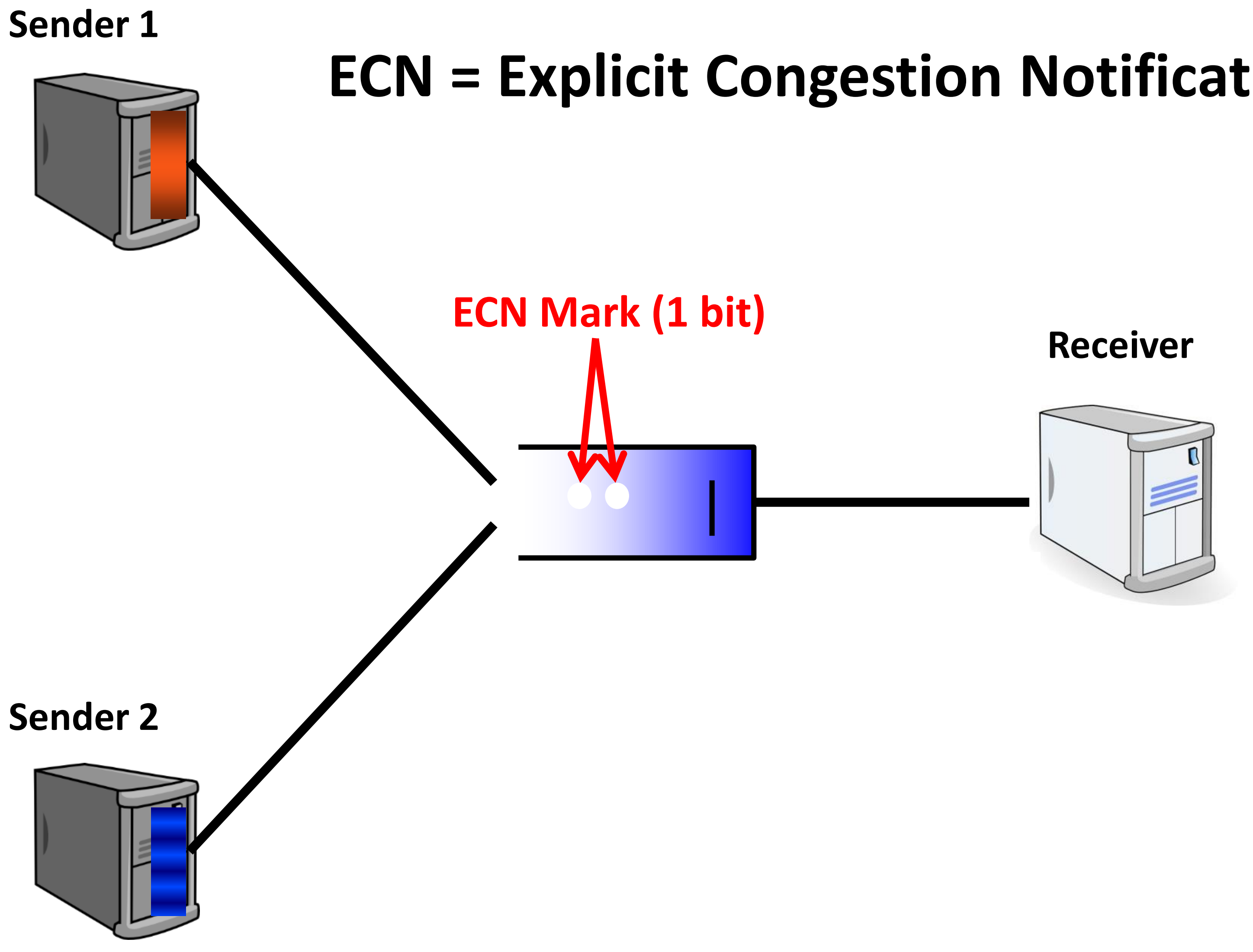
AQM – RED:

- Avg Queue Not Fast Enough for Incast

The DCTCP Algorithm

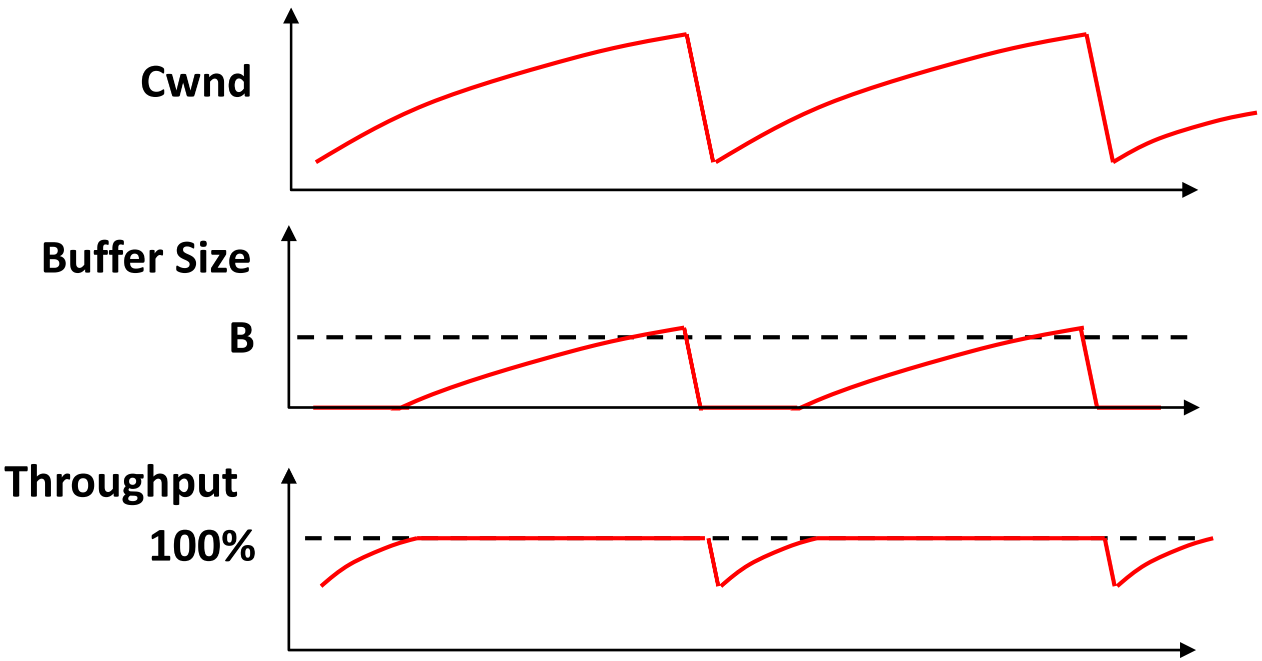
Review: The TCP/ECN Control Loop

ECN = Explicit Congestion Notification



Small Queues & TCP Throughput:
The Buffer Sizing Story

- Bandwidth-delay product rule of thumb:
  - A single flow needs $C \times RTT$ buffers for **100% Throughput.**



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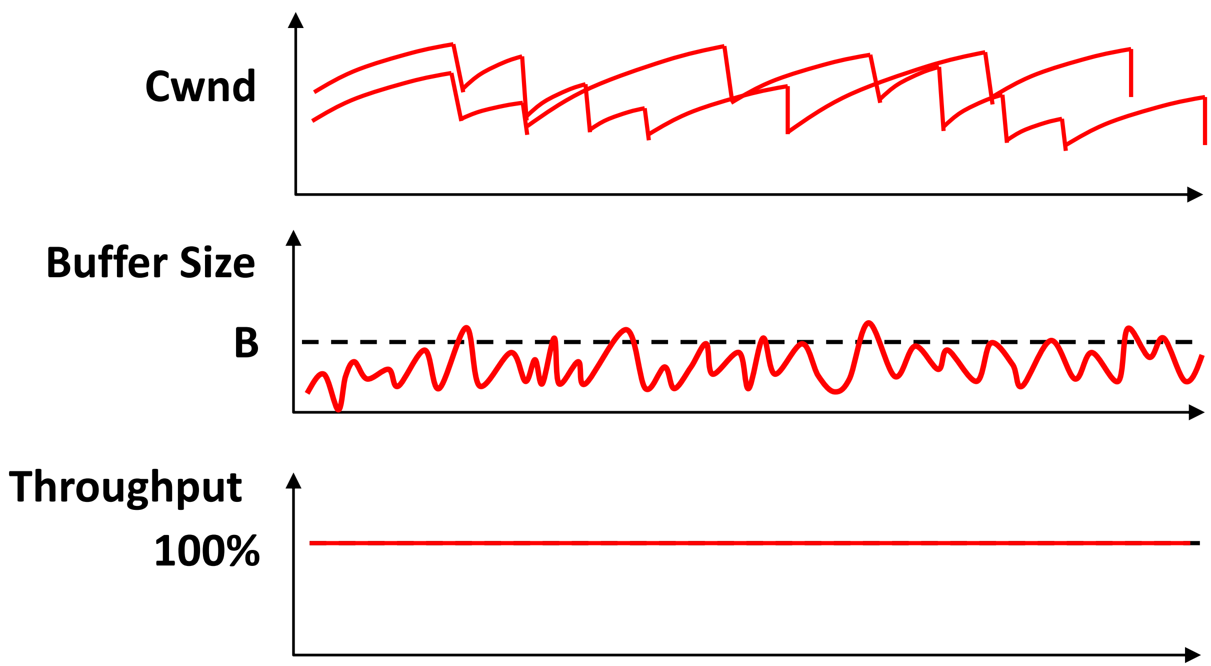

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Real Rule of Thumb:
Low Variance in Sending Rate → Small Buffers Suffice

Two Key Ideas

1. React in proportion to the **extent** of congestion, not its **presence**.
   - ✓ Reduces **variance** in sending rates, lowering queuing requirements.

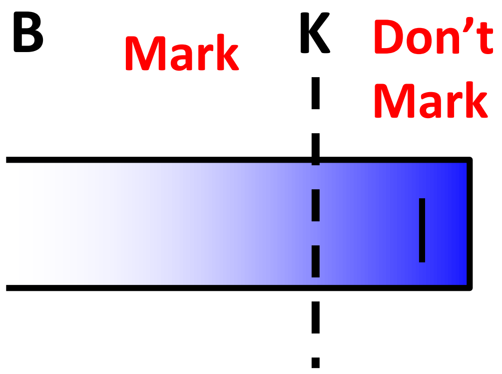
ECN Marks	TCP	DCTCP
1 0 1 1 1 1 0 1 1 1	**Cut window by 50%**	**Cut window by 40%**
0 0 0 0 0 0 0 0 0 1	**Cut window by 50%**	**Cut window by 5%**

2. Mark based on **instantaneous** queue length.
   - ✓ Fast feedback to better deal with bursts.

Data Center TCP Algorithm

Switch side:

– Mark packets when **Queue Length > K.**



Sender side:

– Maintain running average of ***fraction*** of packets marked **(α)**.

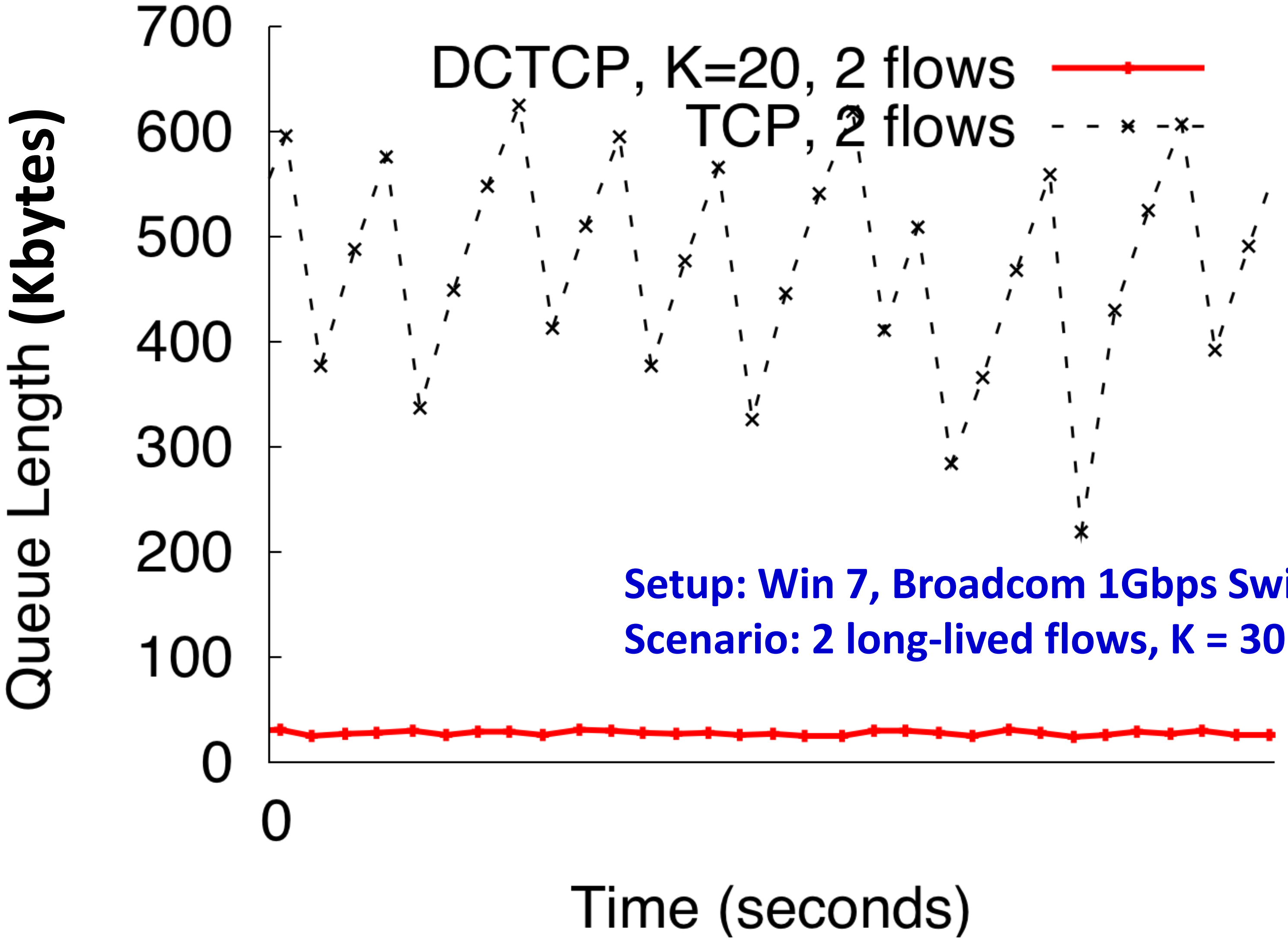
In each RTT:

$$F = \frac{\#\ of\ marked\ ACKs}{Total\ \#\ of\ ACKs} \qquad \alpha \leftarrow (1-g)\alpha + gF$$

➢ **Adaptive window decreases:** $Cwnd \leftarrow (1 - \frac{\alpha}{2})Cwnd$

– Note: decrease factor between 1 and 2.

DCTCP in Action



Setup: Win 7, Broadcom 1Gbps Switch
Scenario: 2 long-lived flows, K = 30KB

Why it Works

1. High Burst Tolerance

- ✓ **Large buffer headroom →** bursts fit.
- ✓ **Aggressive marking →** sources react before packets are dropped.

2. Low Latency

- ✓ **Small buffer occupancies →** low queuing delay.

3. High Throughput

- ✓ **ECN averaging →** smooth rate adjustments, low variance.

Evaluation

- Implemented in Windows stack.
- Real hardware, **1Gbps and 10Gbps** experiments
  - **90 server testbed**
  - **Broadcom Triumph 48 1G ports – 4MB shared memory**
  - **Cisco Cat4948 48 1G ports – 16MB shared memory**
  - **Broadcom Scorpion 24 10G ports – 4MB shared memory**

- Numerous micro-benchmarks
  - **Throughput and Queue Length**
  - **Multi-hop**
  - **Queue Buildup**
  - **Buffer Pressure**
  - **Fairness and Convergence**
  - **Incast**
  - **Static vs Dynamic Buffer Mgmt**

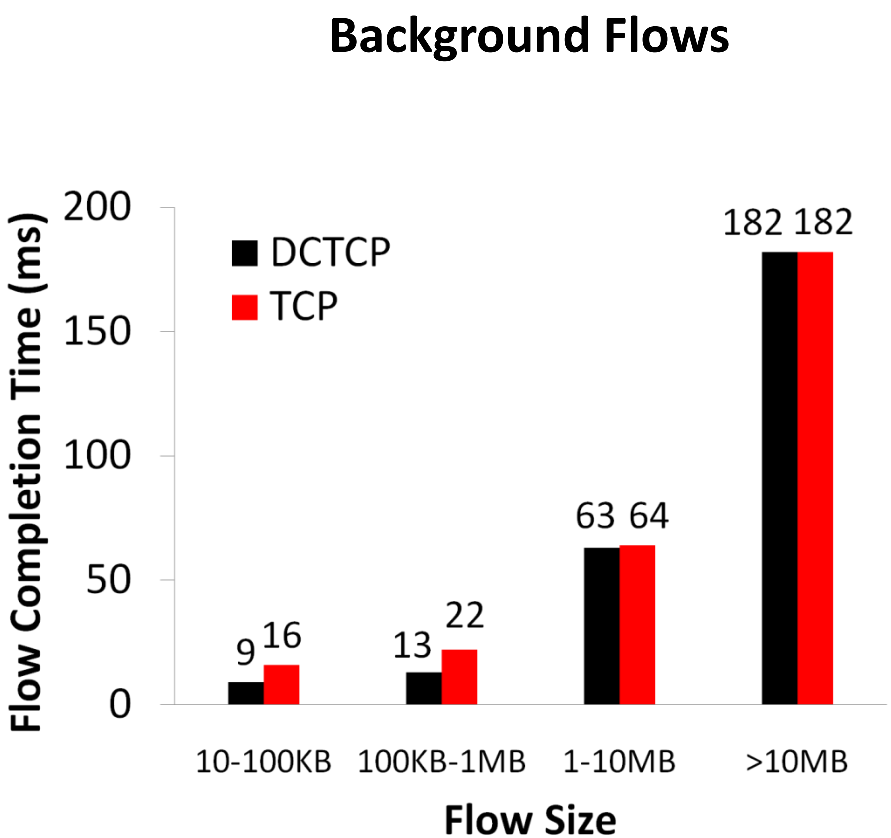
- **Cluster traffic benchmark**

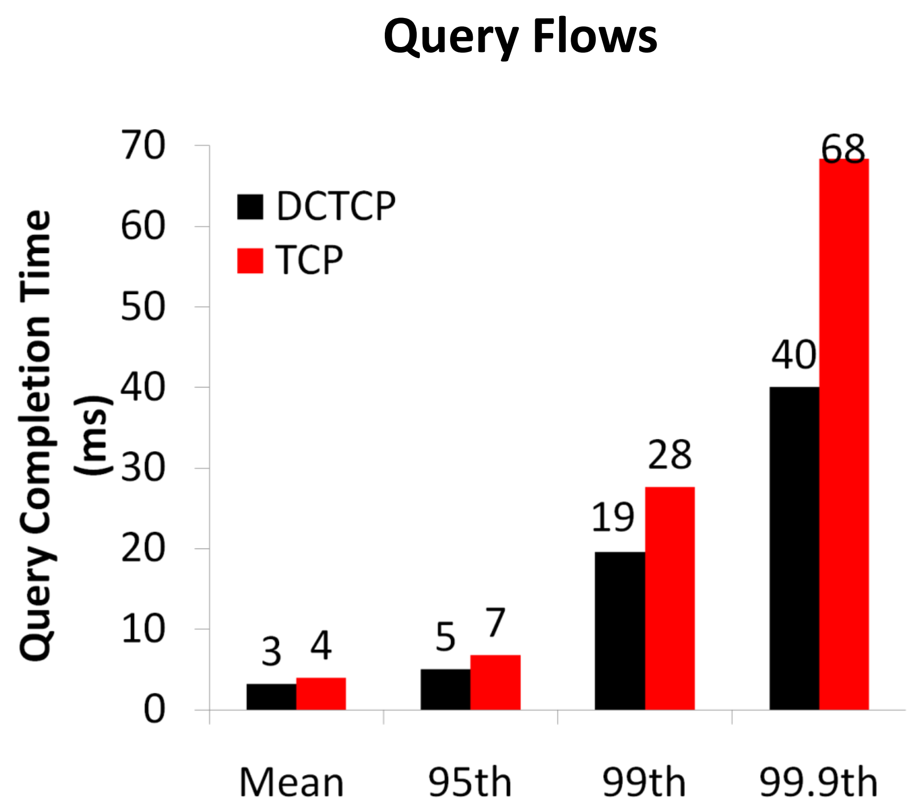
Cluster Traffic Benchmark

- Emulate traffic within 1 Rack of Bing cluster
  - 45 1G servers, 10G server for external traffic
- Generate query, and background traffic
  - Flow sizes and arrival times follow distributions seen in Bing
- Metric:
  - Flow completion time for queries and background flows.

We use RTO_{min} = 10ms for both TCP & DCTCP.

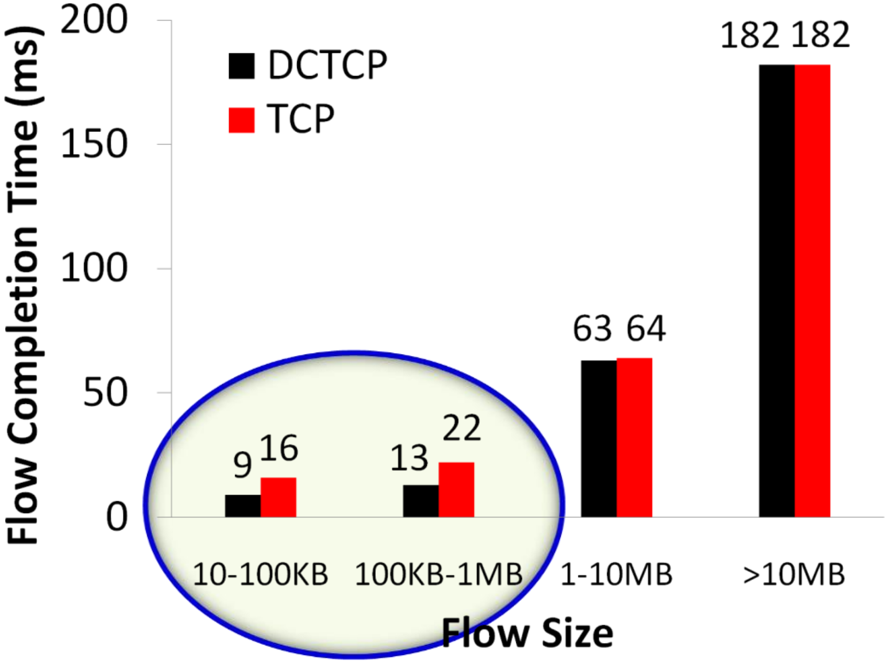
Baseline


Background Flows
Flow Completion Time (ms)
200
150
100
50
0
DCTCP
TCP
9
16
13
22
63
64
182
182
10-100KB
100KB-1MB
1-10MB
>10MB
Flow Size

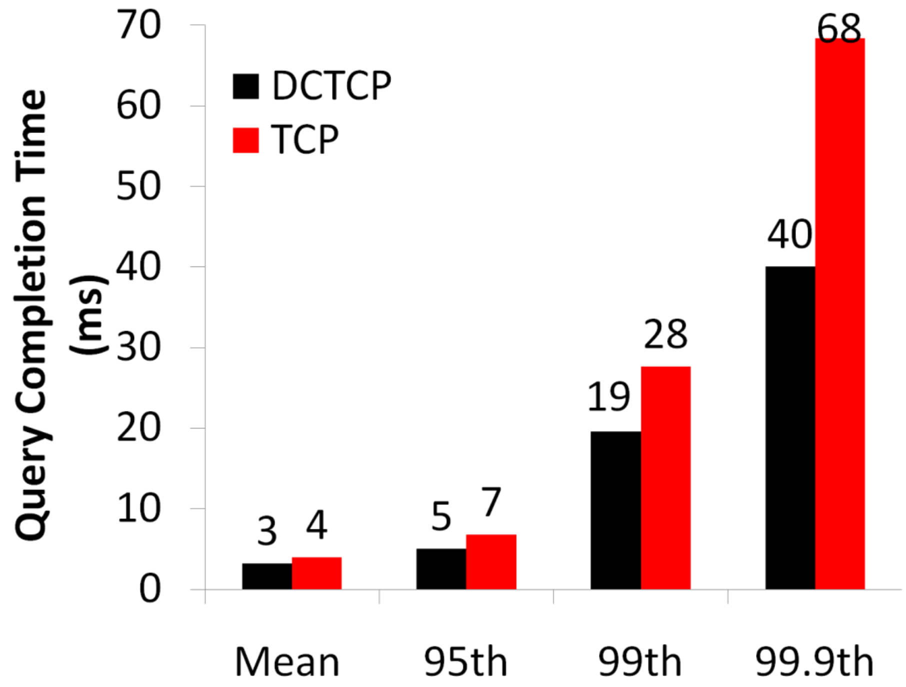

Query Flows
Query Completion Time (ms)
70
60
50
40
30
20
10
0
DCTCP
TCP
3
4
5
7
19
28
40
68
Mean
95th
99th
99.9th

Baseline

Background Flows

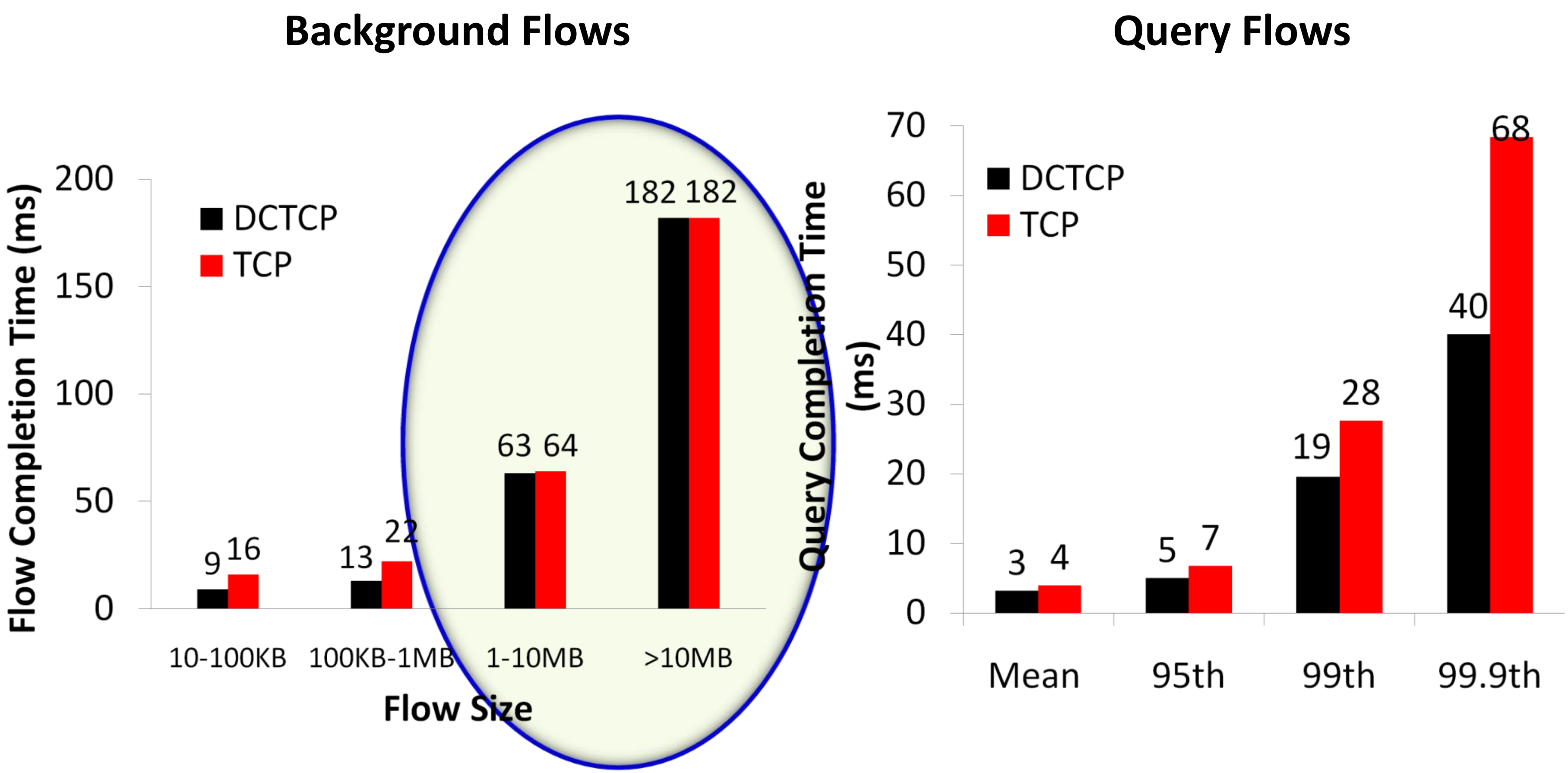


Query Flows



✓ **Low latency for short flows.**

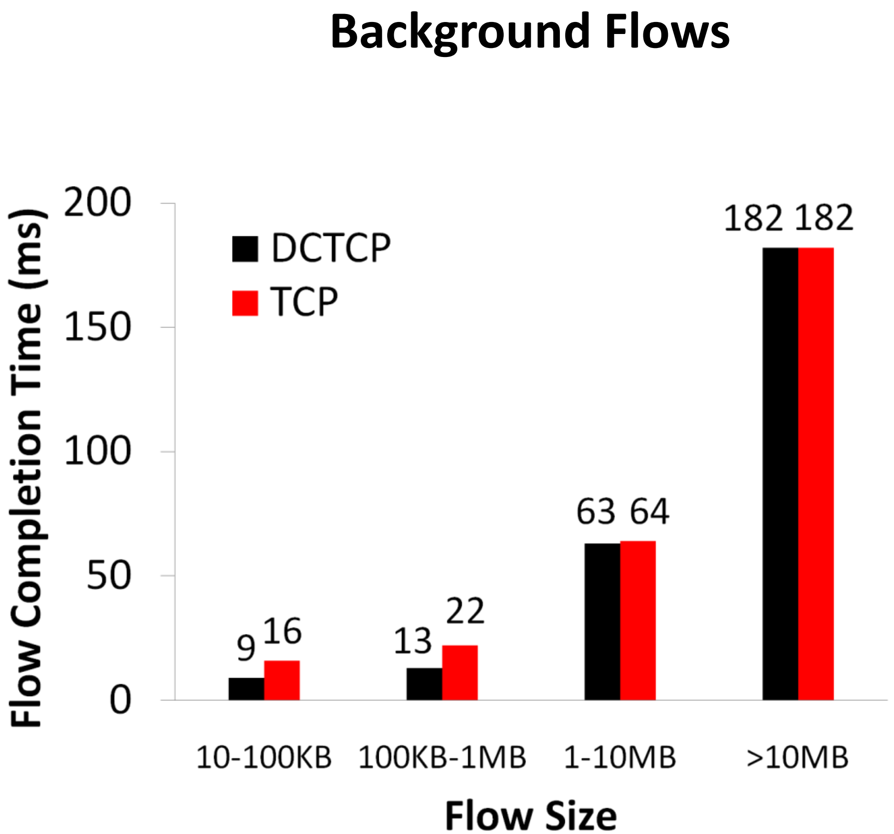
Baseline

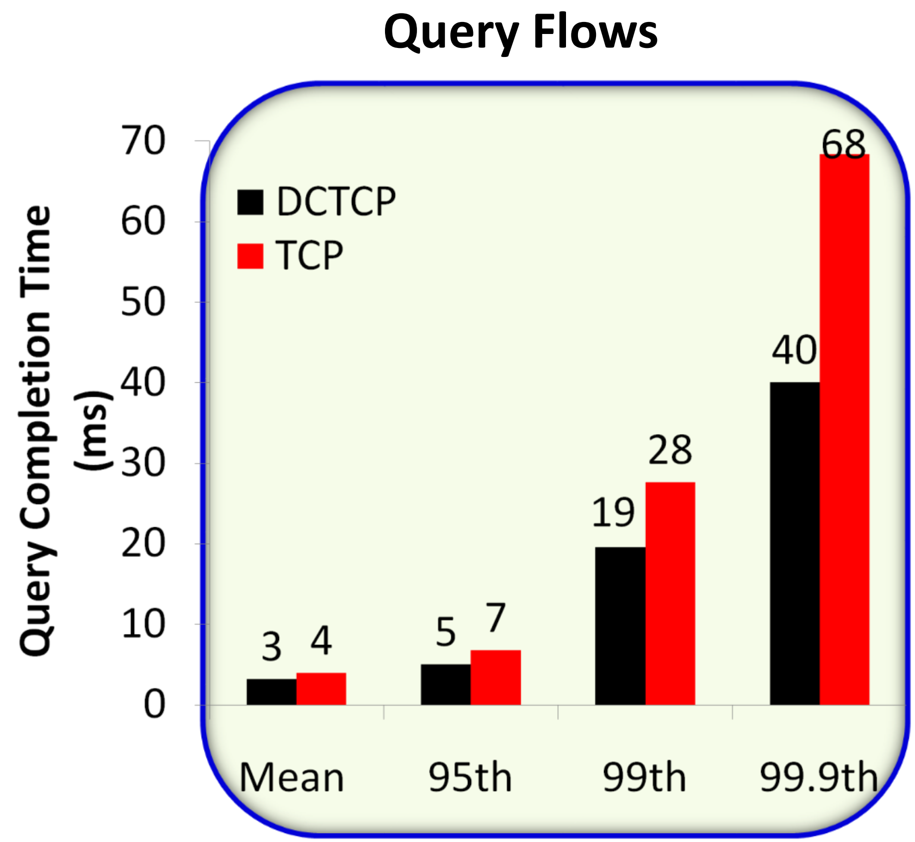


✓ **Low latency for short flows.**

✓ **High throughput for long flows.**

Baseline

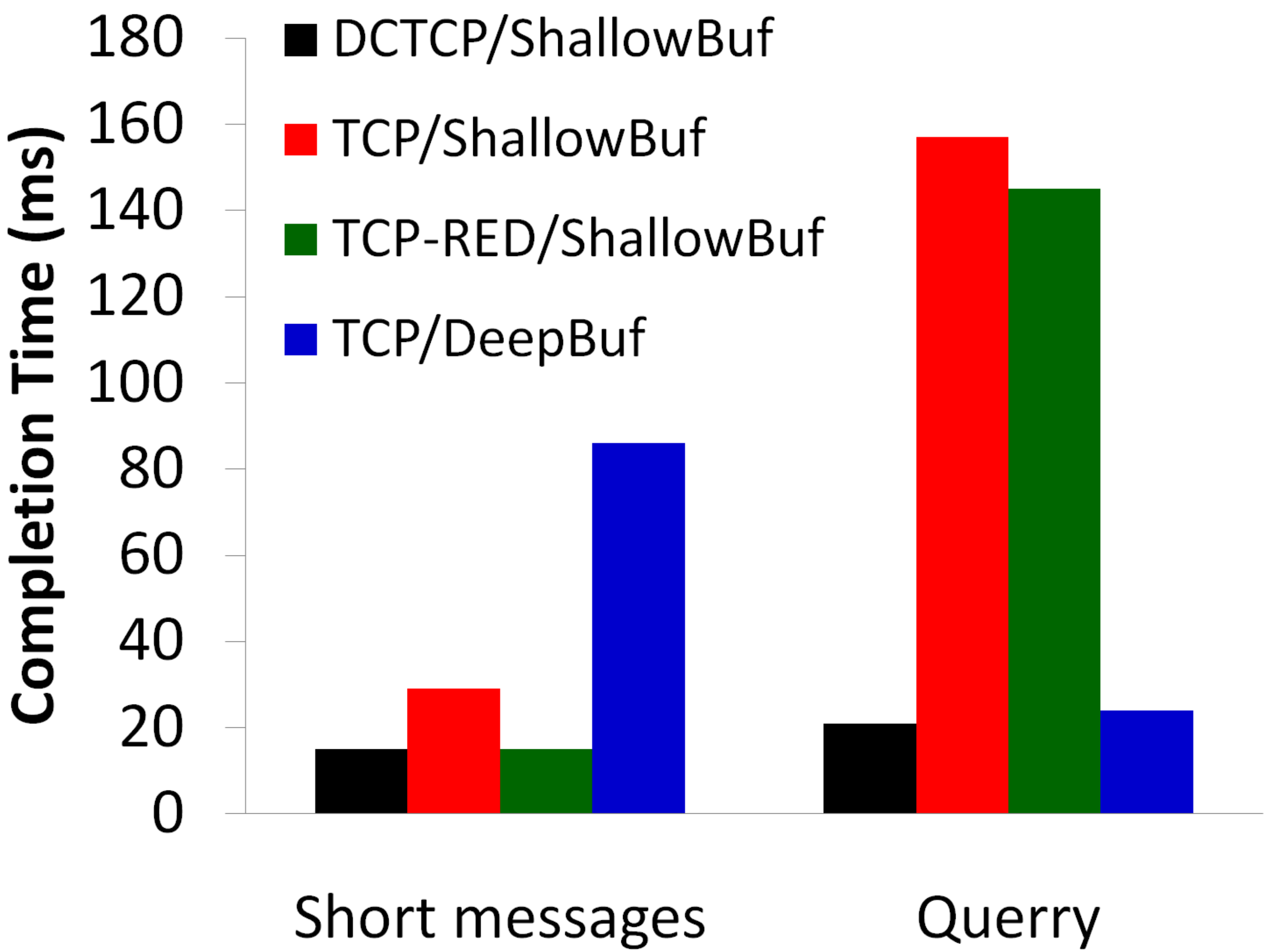




- ✓ Low latency for short flows.
- ✓ High throughput for long flows.
- ✓ High burst tolerance for query flows.

Scaled Background & Query

10x Background, 10x Query



Scalability

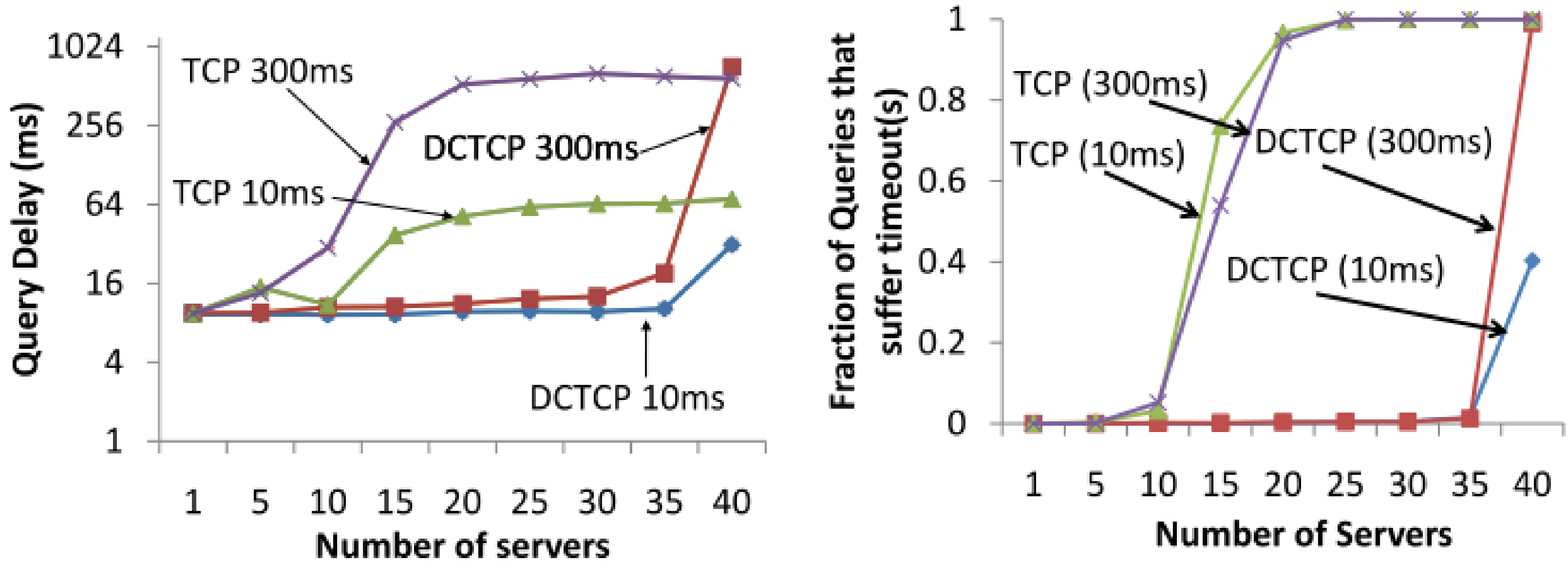


Figure 18: DCTCP performs better than TCP and then converges at 35 senders (log scale on Y axis; 90% confidence intervals for the means are too small to be visible).

Conclusions

- DCTCP satisfies all our requirements for Data Center packet transport.
  - ✓ **Handles bursts well**
  - ✓ **Keeps queuing delays low**
  - ✓ **Achieves high throughput**

- Features:
  - ✓ **Very simple change to TCP and a single switch parameter.**
  - ✓ **Based on mechanisms already available in Silicon.**

Discussion

- What if traffic patterns change?
  - E.g., many overlapping flows

- What do you like/dislike?