Introduction to Computer Networks

TCP Congestion Control (III)

CS640

https://pages.cs.wisc.edu/~mgliu/CS640/S26/index.html

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Outline

- Last
  - TCP Congestion Control (II)
- Today
  - TCP Congestion Control (III)
- Announcements
  - Quiz 4 in-class 04/23
  - Lab 4 due date 04/30/2026

Recap

- Key Questions:
  - How does TCP Reno work?

- Terminology
  - Reaction point (RP), congestion point (CP), and notification point (NP)
  - Slow start, AIMD, Fast retransmit/recovery, Per-ACK adjustment

TCP Reno

- Congestion control is a window adjustment algorithm
  - #1: Reaction point (RP) or sender
  - #2: Congestion point (CP) or switch/router
  - #3: Notification Point (NP) or receiver

} Adjust window

} Issue implicit feedbacks

- TCP Reno
  - One of many congestion control algorithms
  - #1: Slow start
  - #2: AIMD
  - #3: Fast retransmit/recovery
  - #4: Per-ACK adjustment

TCP is the dominant transport protocol in data centers.

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The Problem

- TCP cannot satisfy data center application demands
  - Throughput drops under burst
  - High tail latency
  - Inferior fairness guarantees
  - …

Limitations of Prior Solutions

- #1: Ad-hoc, inefficient, and expensive solutions
  - E.g., Work for app A, not app B

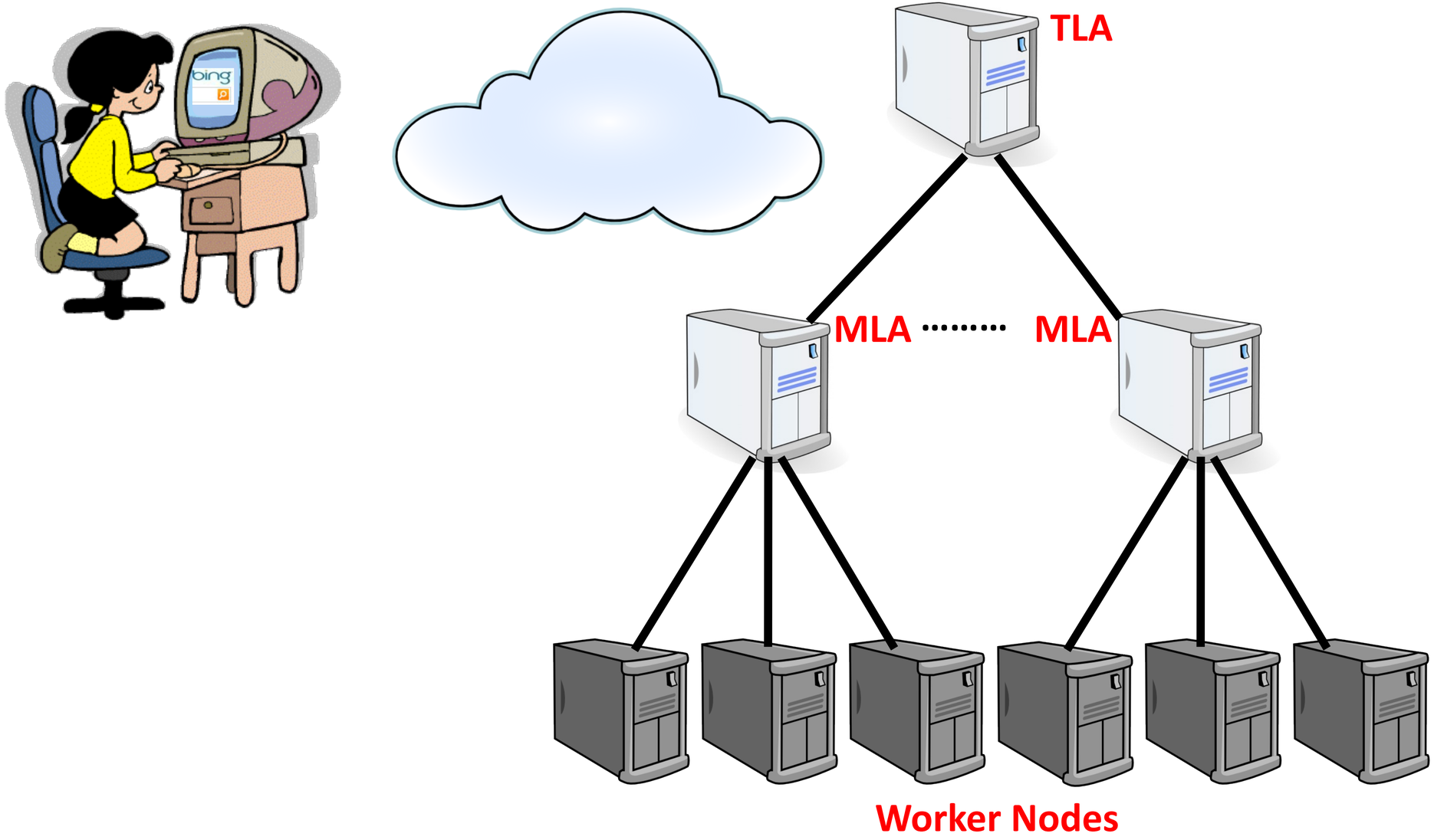
- #2: No solid understanding of consequences and tradeoffs
  - Not capture data center application characteristics
  - Not capture data center network characteristics

Microsoft Bing Search

- Large scale
  - Measurements from 6000 server production cluster
  - Collect more than 150TB of compressed data over a month

- Extensive instrumentation
  - Application-level
  - Socket-level
  - Selected packet-level

Partition/Aggregation Application Structure



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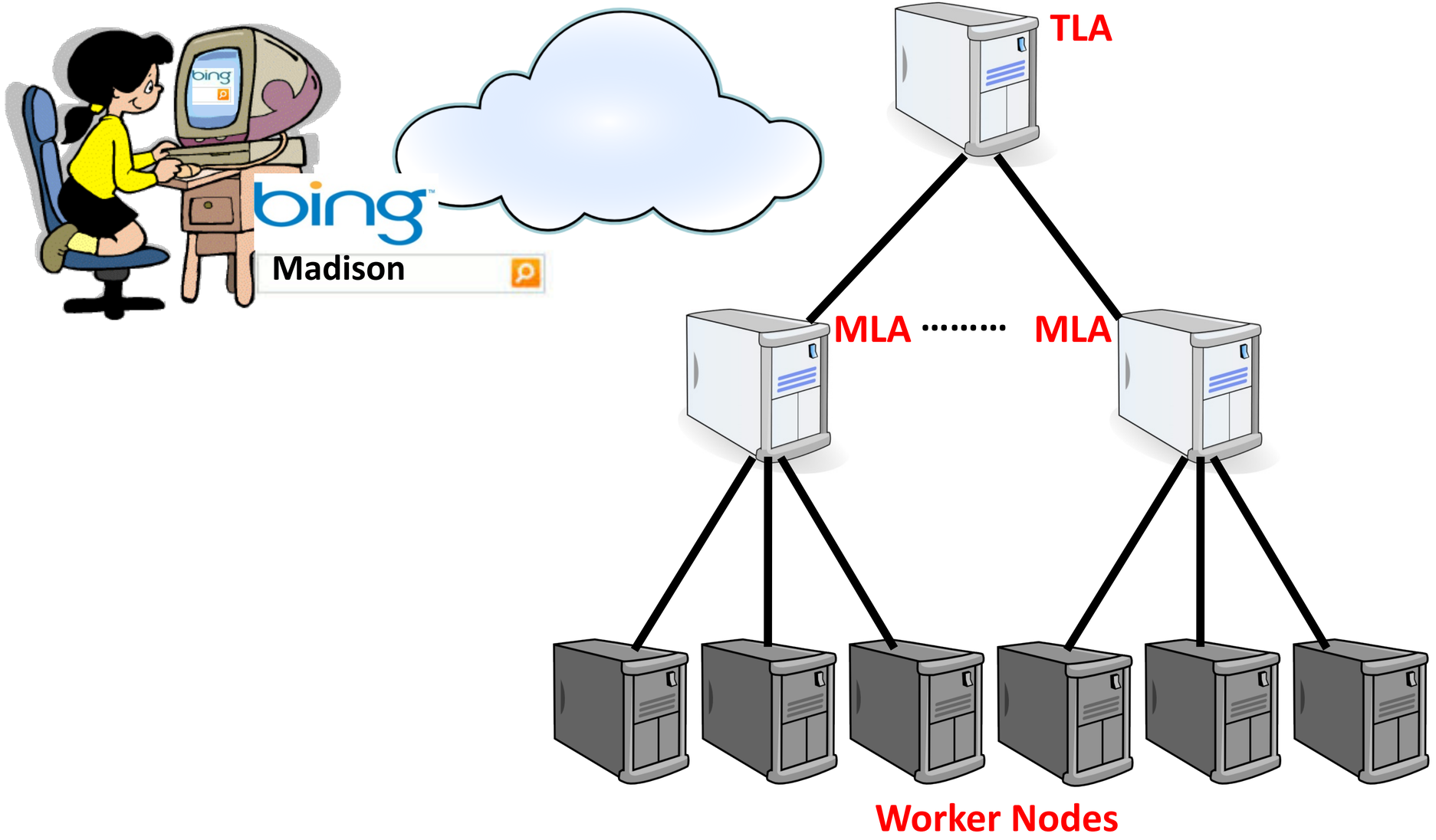

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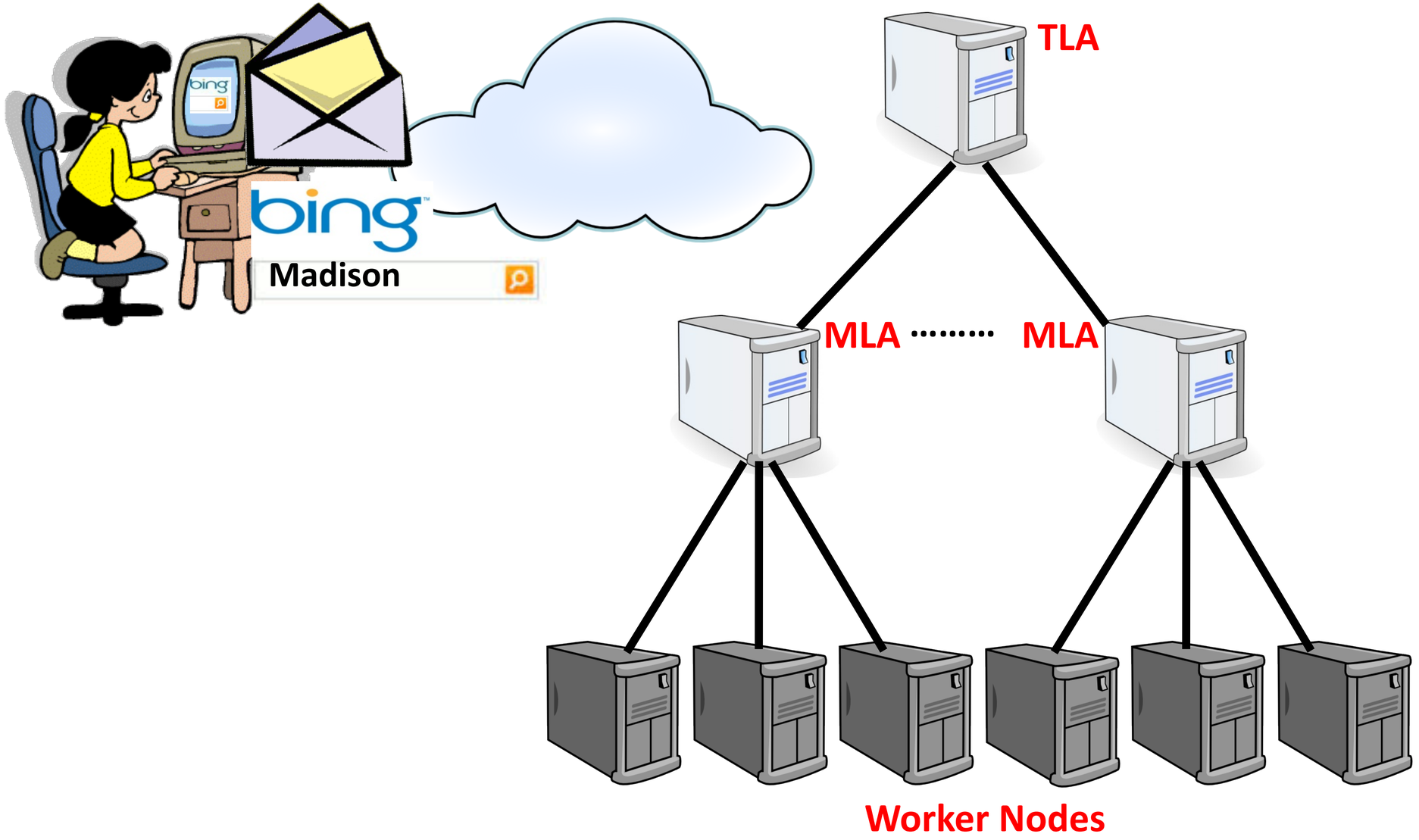

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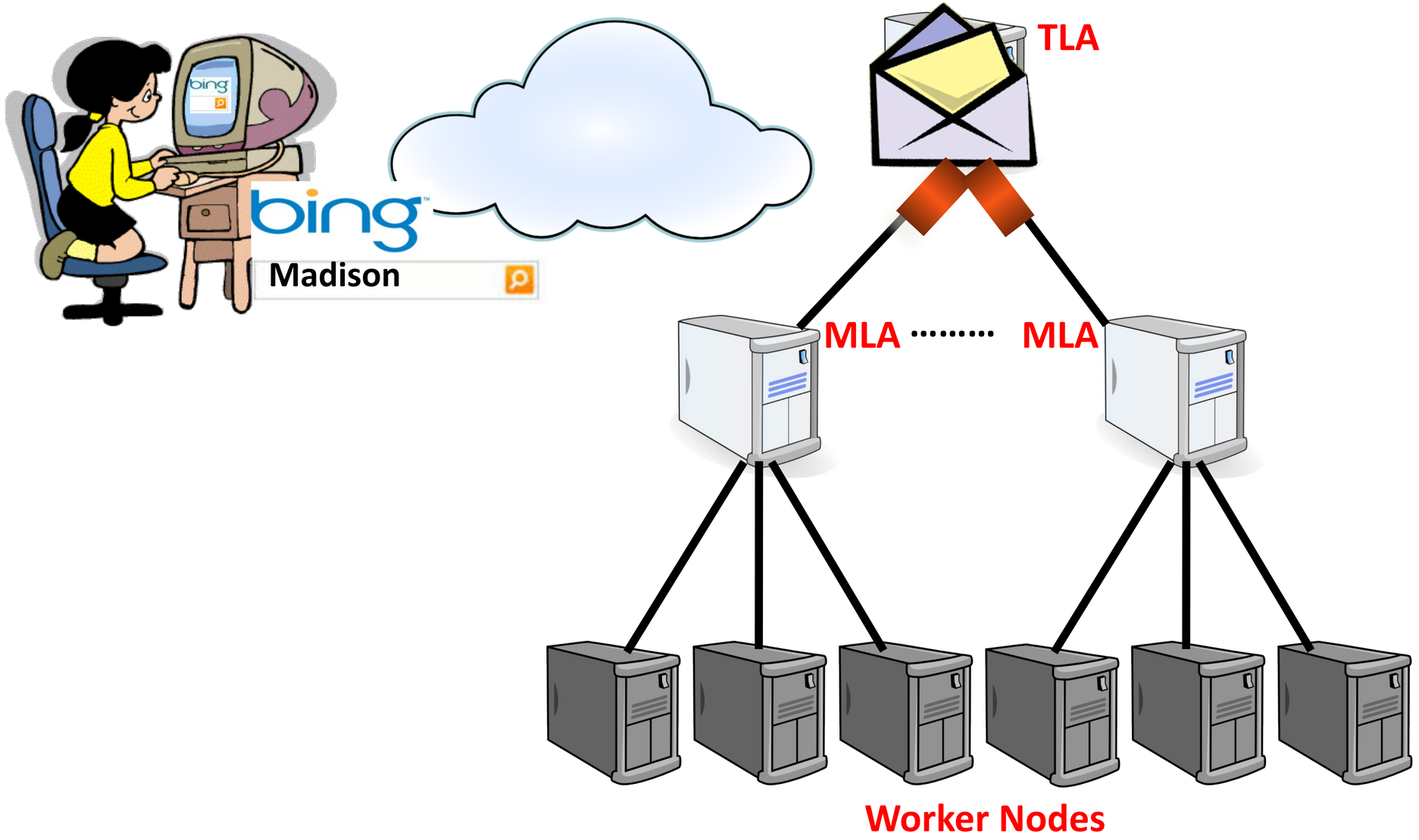

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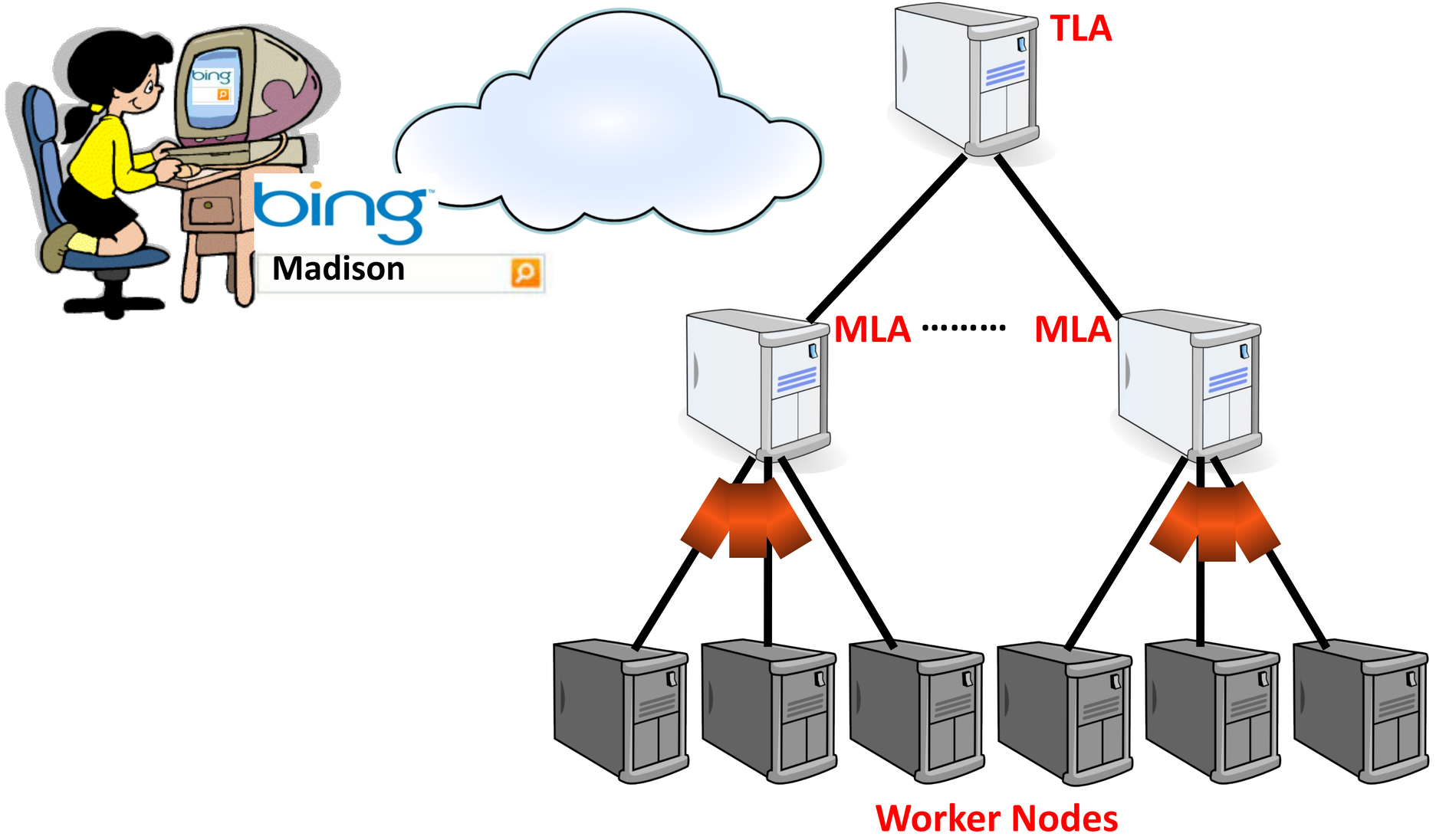

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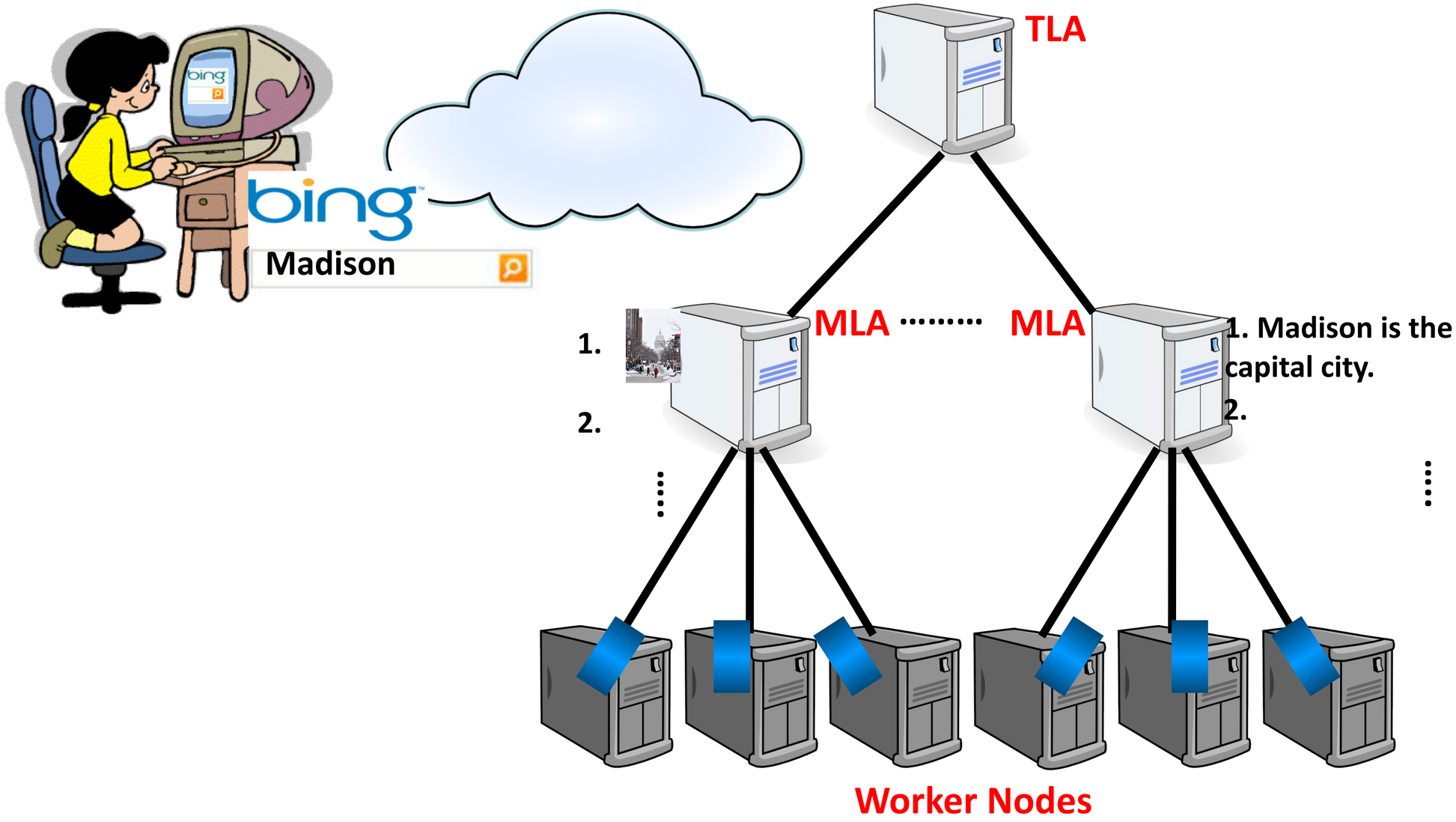

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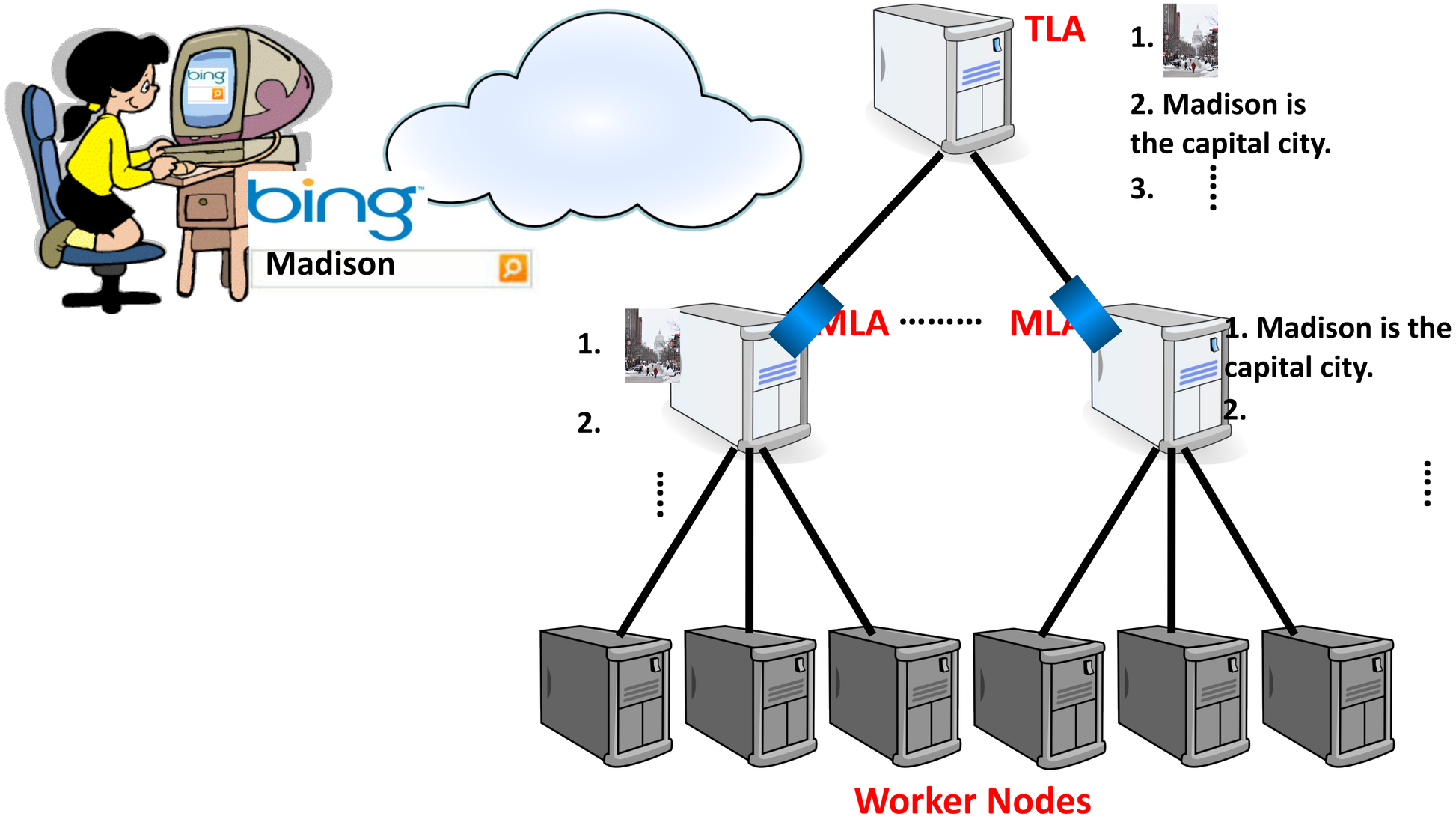

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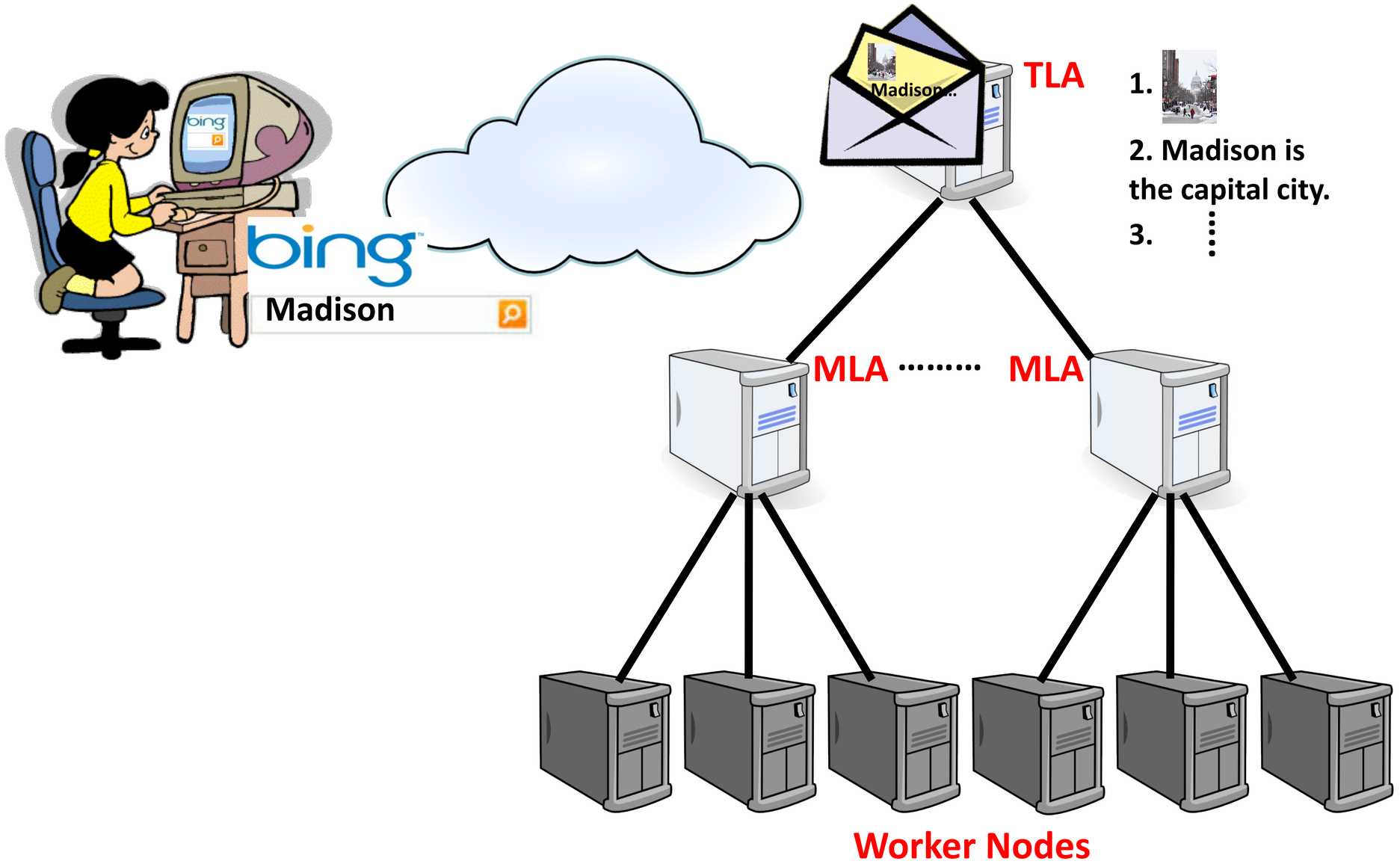

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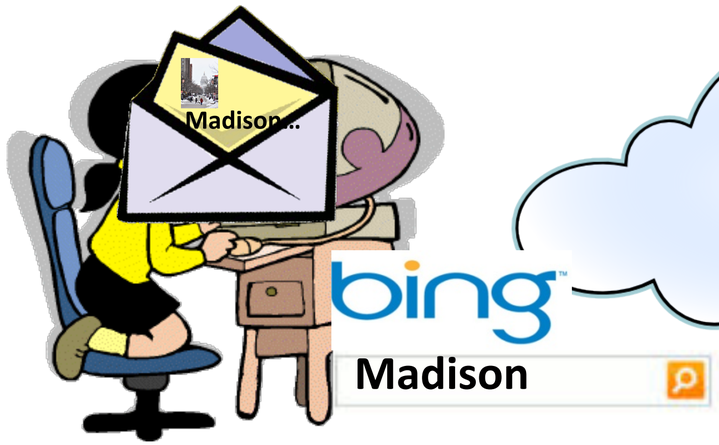

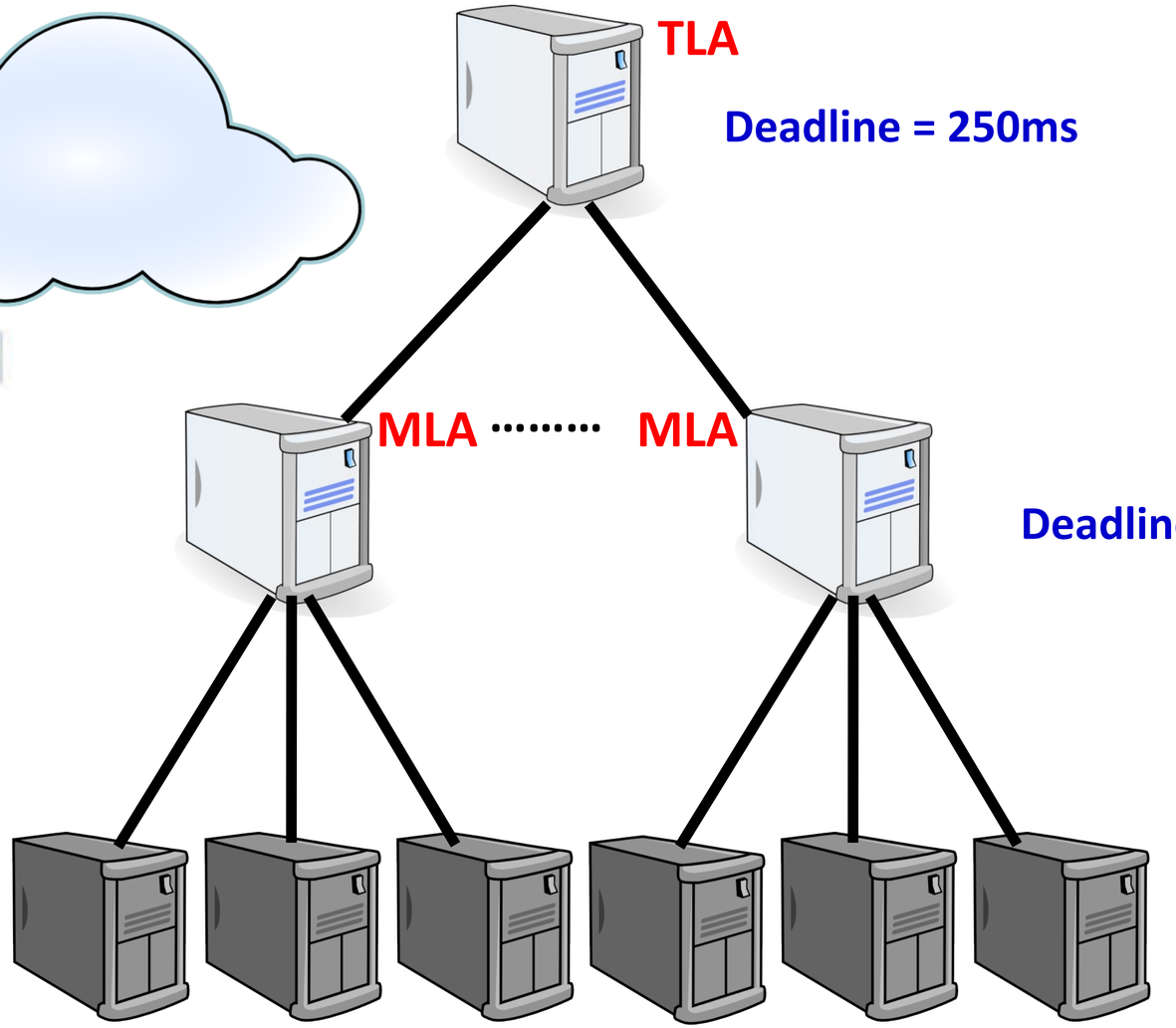

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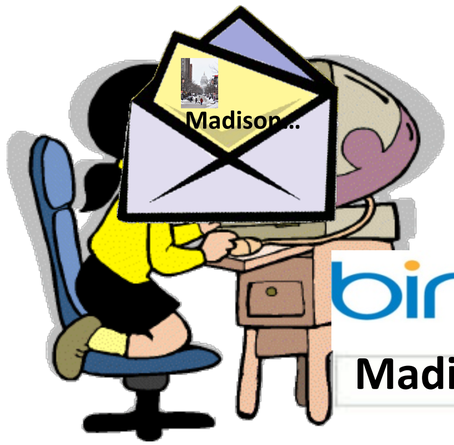


bing

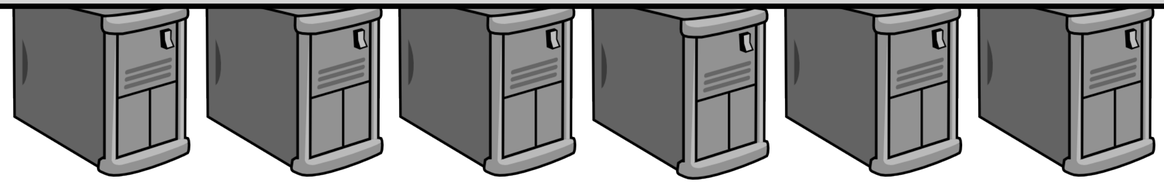
Madison

TLA

Deadline = 250ms

MLA ..... MLA

- Time is money => Strict deadline (SLAs)
- Missed deadline => Lower quality results



Deadline = 10ms

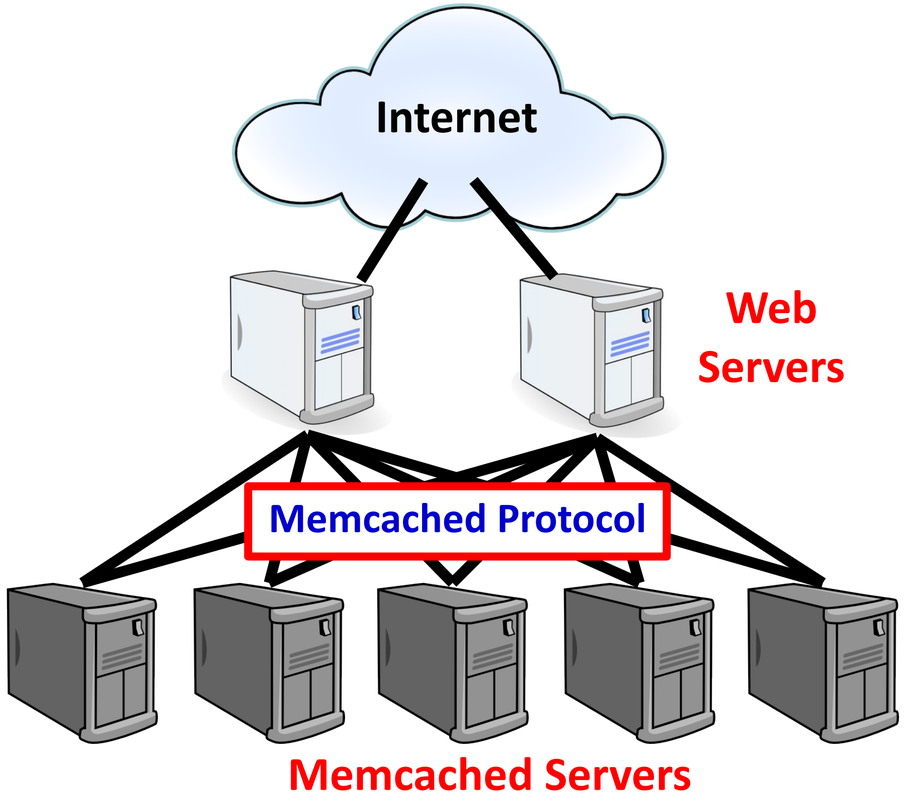
Worker Nodes

Partition/Aggregation application structure is everywhere!

Generality of Partition/Aggregation

- The foundation for many large-scale web applications.
  - Social network, ad selection/recommendation, AI inference,…

- Example: Facebook
  - Aggregators: Web servers
  - Workers: Memcached servers



Workload Characteristics

- #1: Split/Merge
  - Query-like execution model
- #2: Short message [50K-1MB]
  - Coordination, control state,…
- #3: Large flows [1MB-50MB]
  - Data retrieval and update

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  - Query-like execution model

→ Delay-sensitive

- #2: Short message [50K-1MB]
  - Coordination, control state,…

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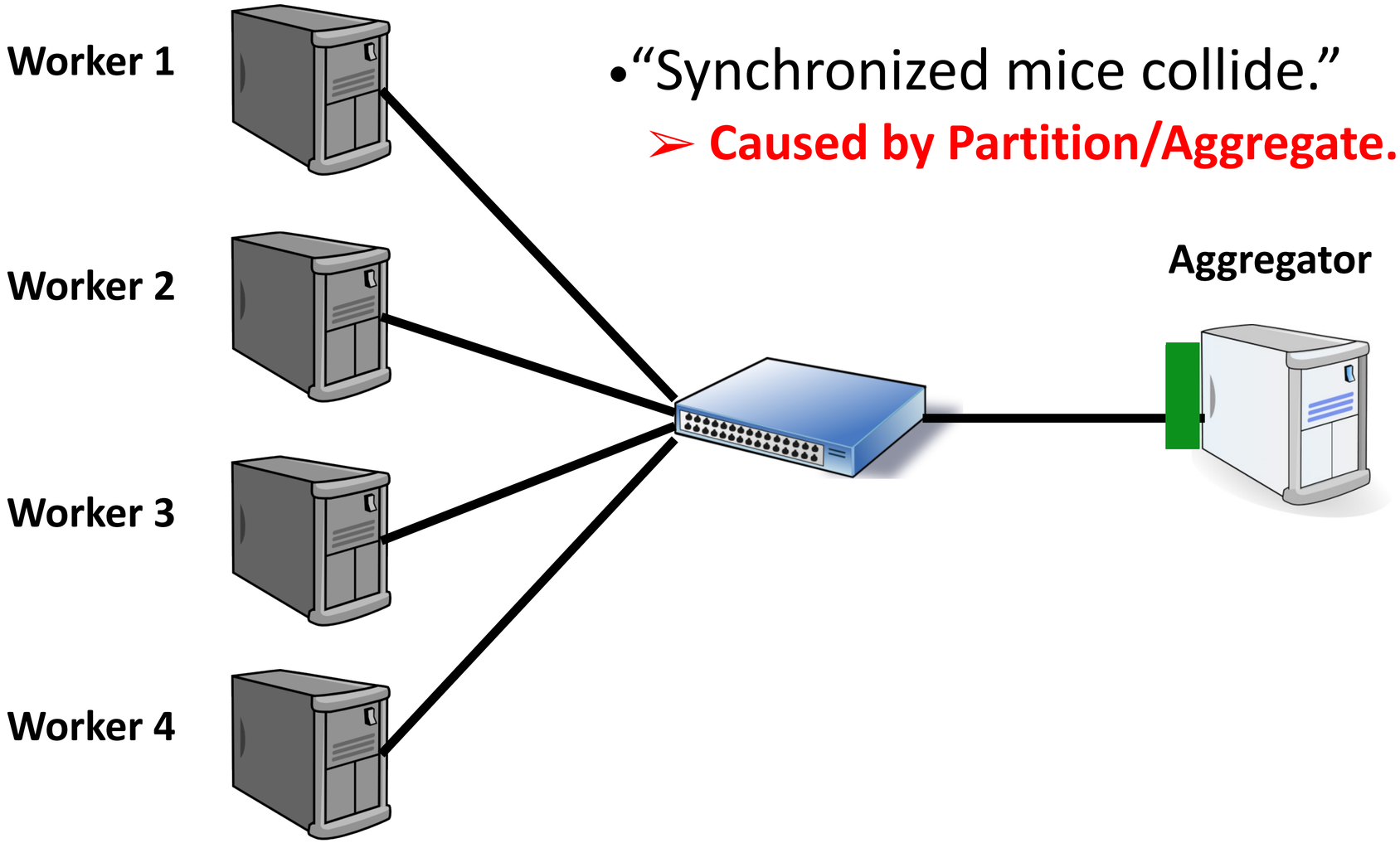
- #3: Large flows [1MB-50MB]
  - Data retrieval and update

→ Throughput-sensitive

Given these, what are the performance abnormalities?

Issue #1: Incast



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

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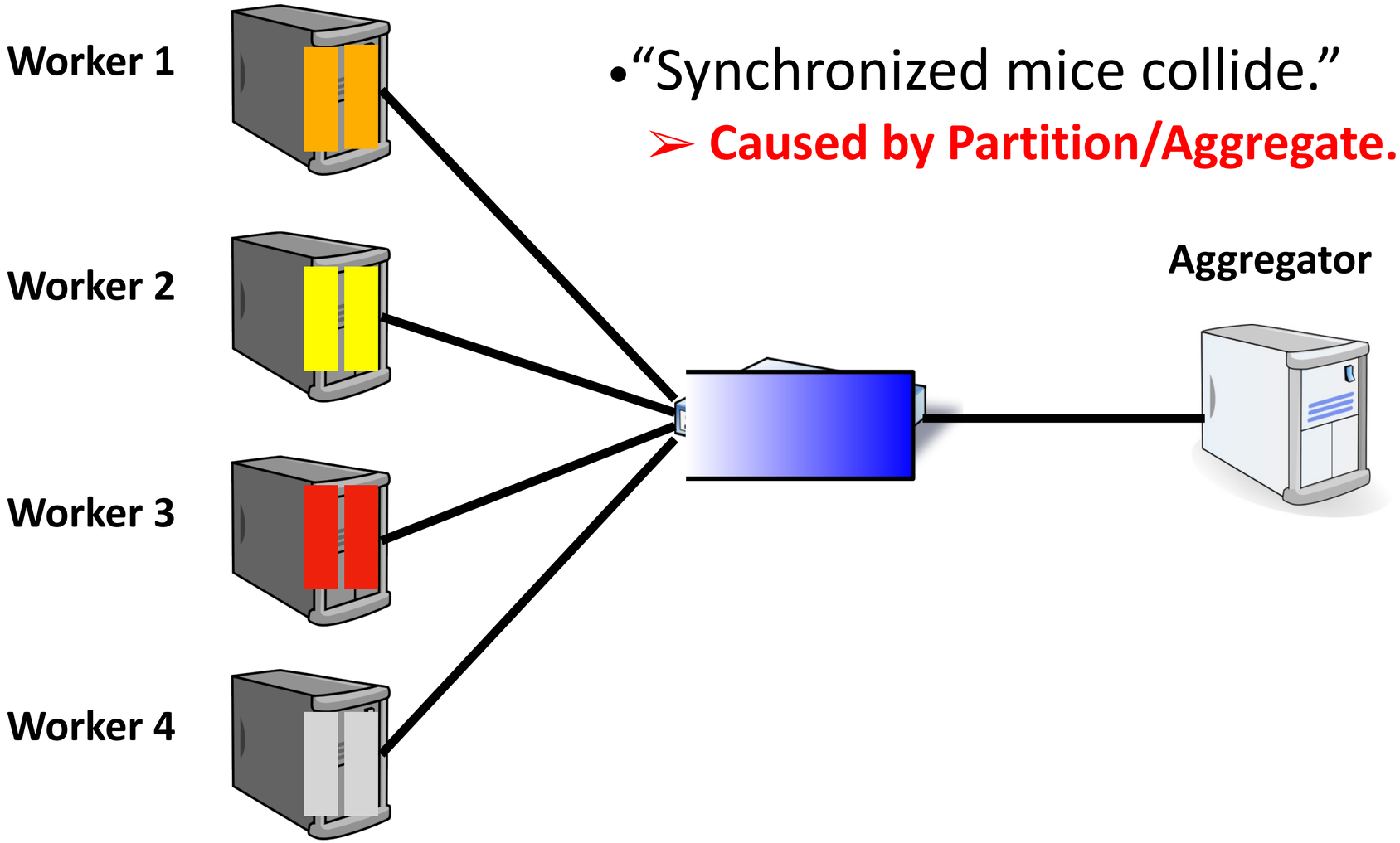

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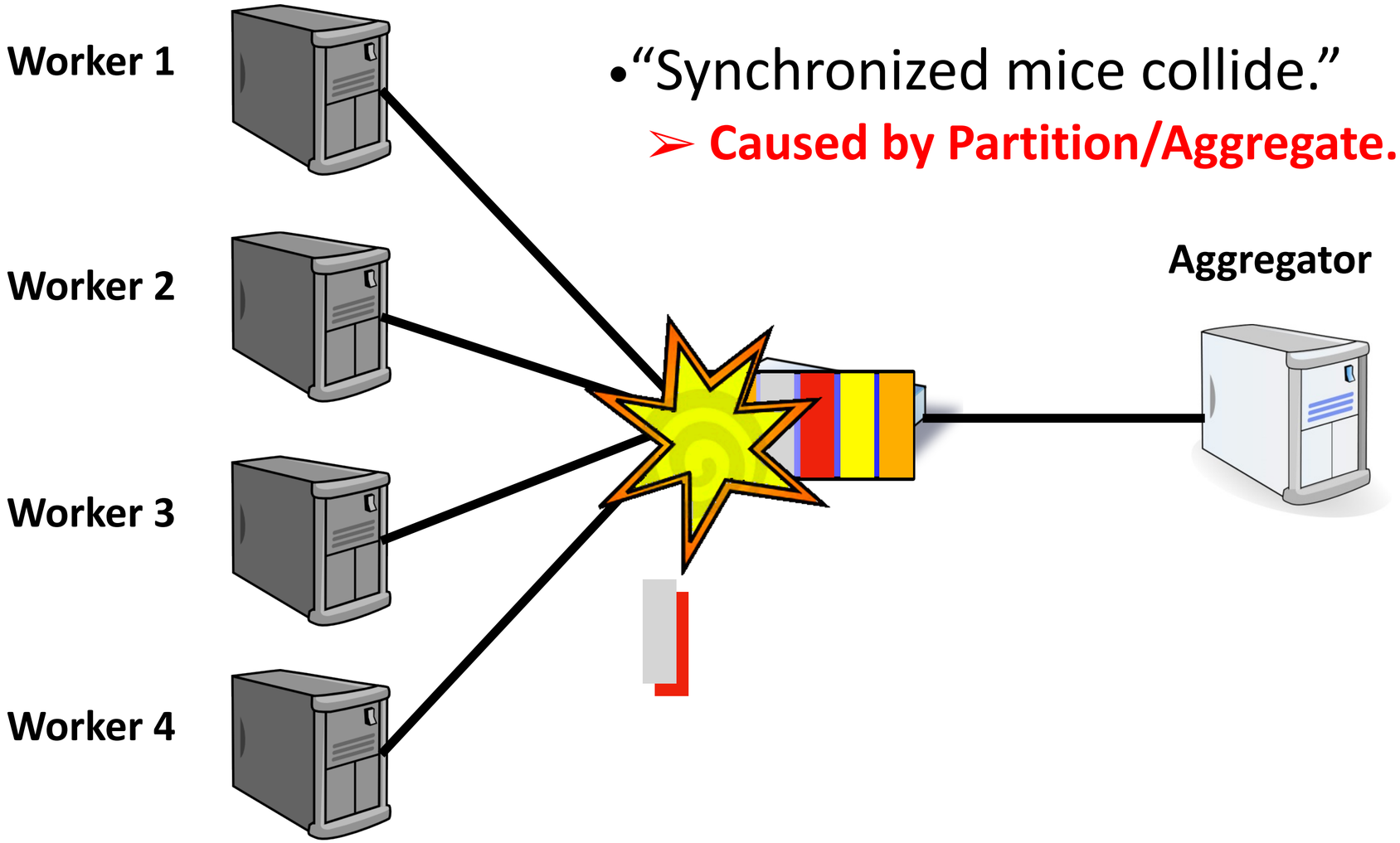

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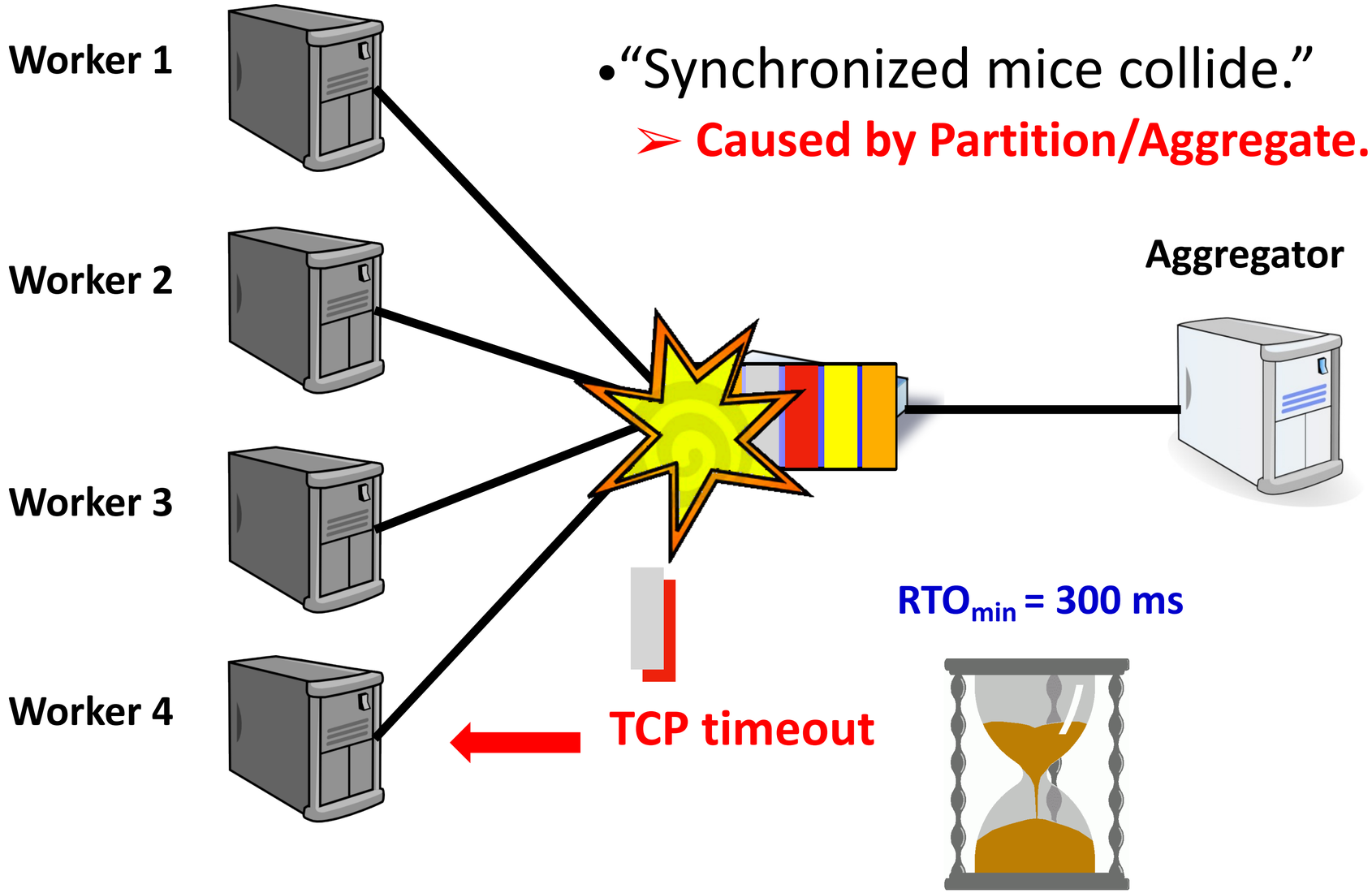

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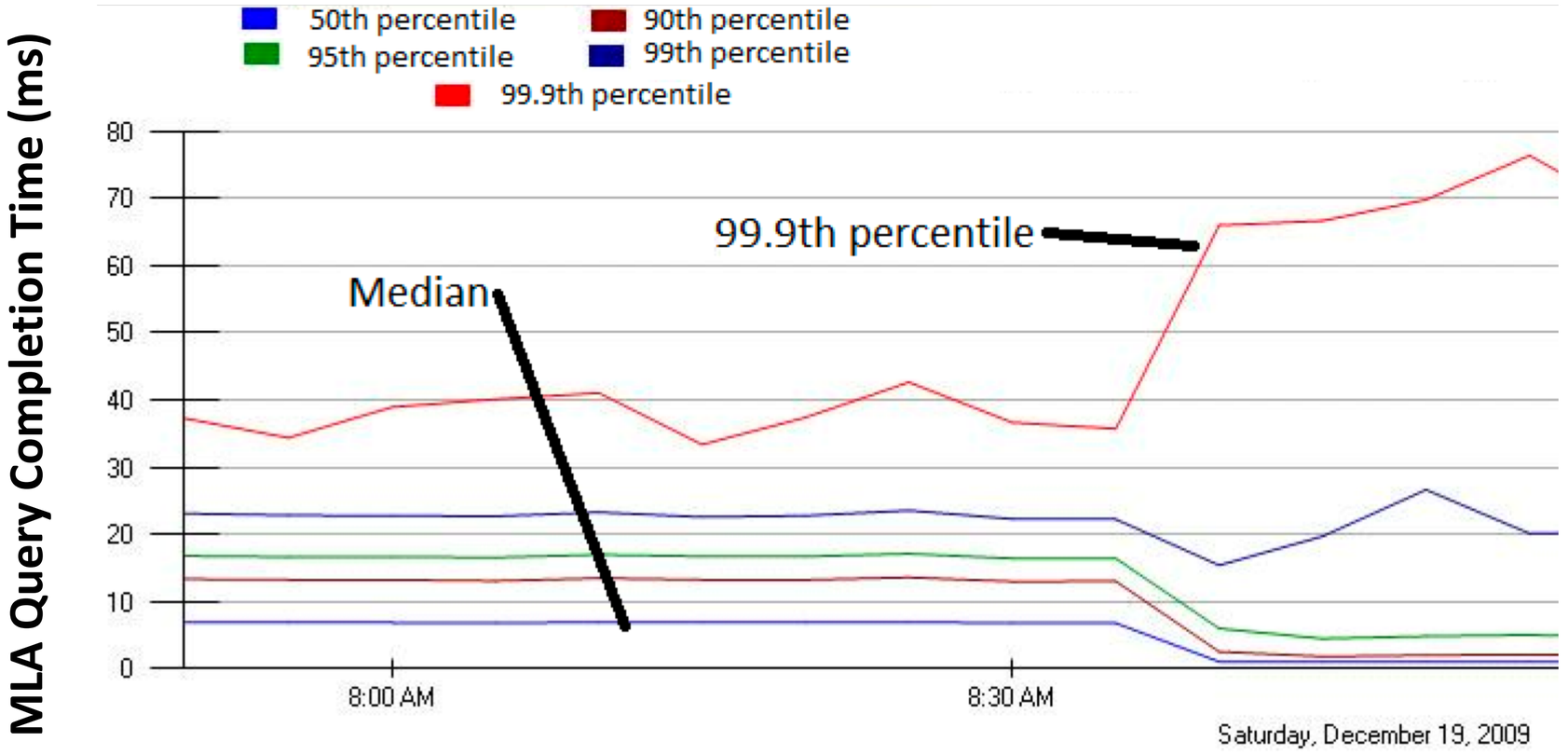
Performance under Incast



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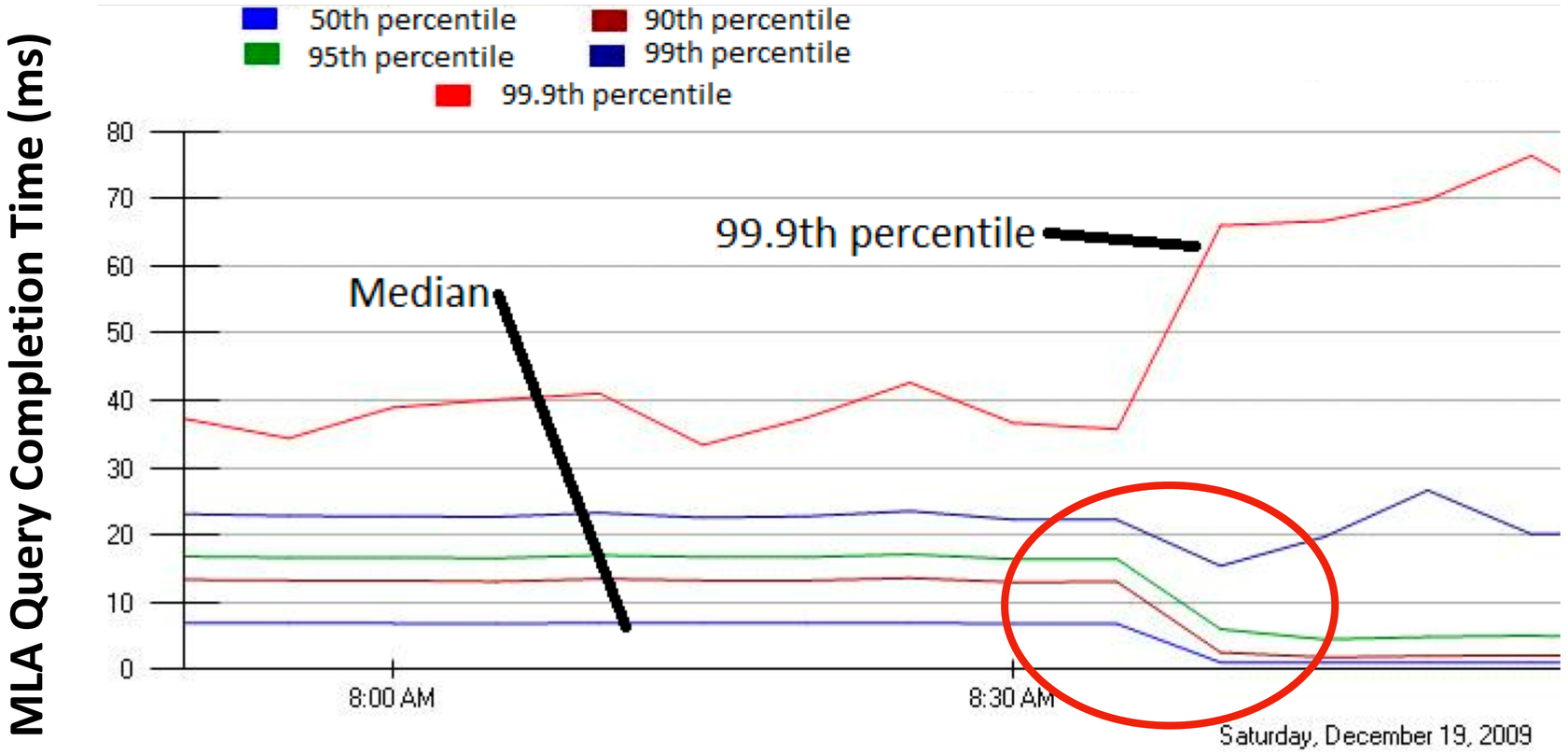
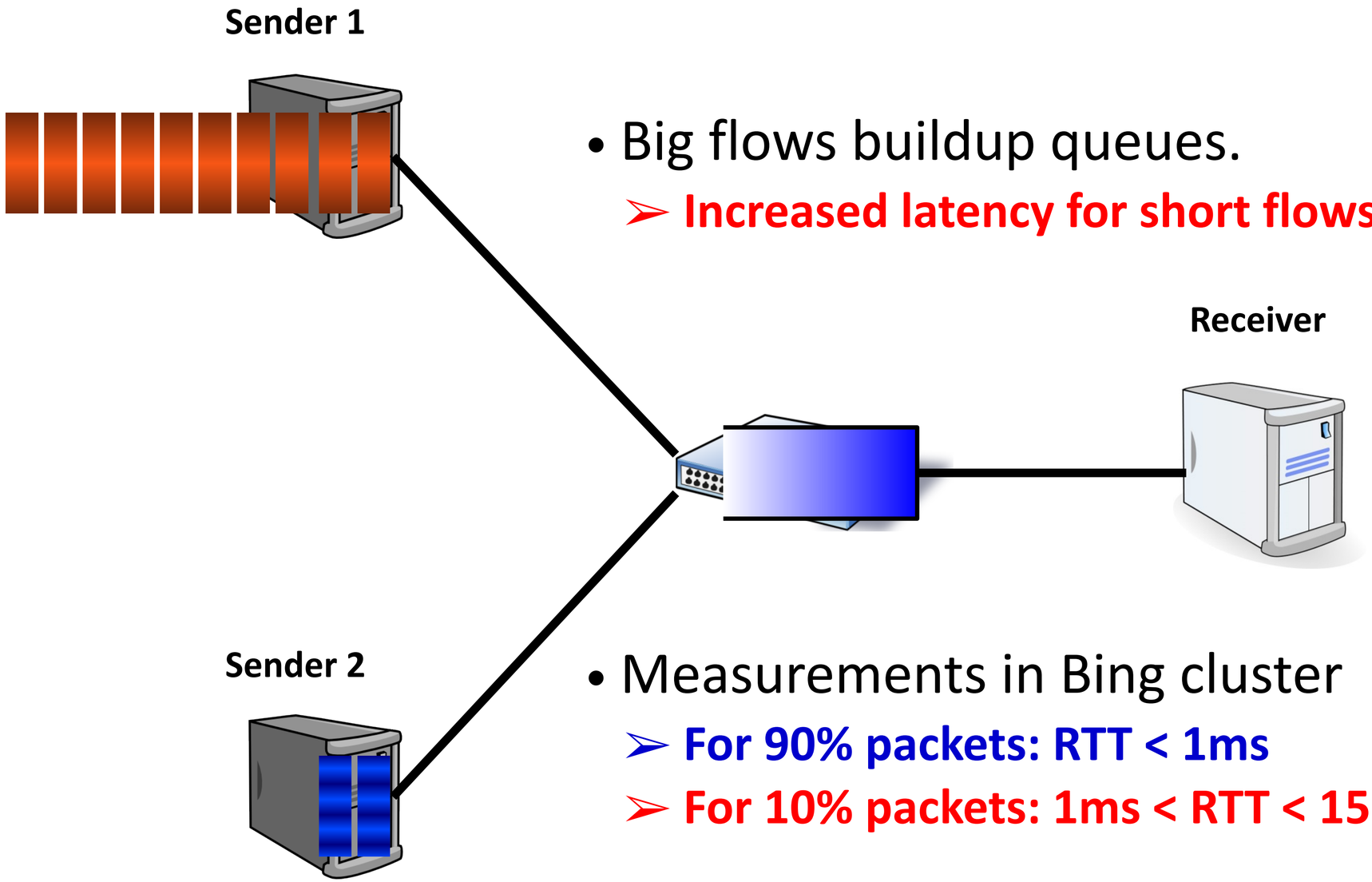


- Requests are jittered over 10ms windows
- Jittering switched off around 8:30am

Issue #2: Queue Buildup



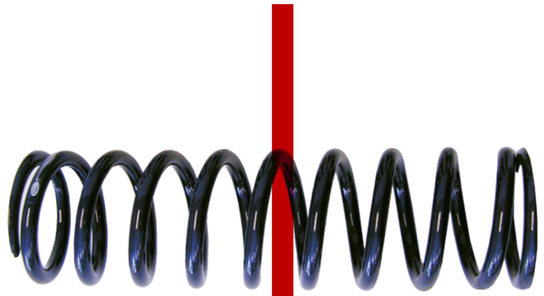
- Big flows buildup queues.
  - ➢ **Increased latency for short flows.**
- Measurements in Bing cluster
  - ➢ **For 90% packets: RTT < 1ms**
  - ➢ **For 10% packets: 1ms < RTT < 15ms**

Design Goals of the “Enhanced” TCP

- #1: High burst performance
  - Tolerate the incast due to partition/aggregation
- #2: Low average/tail latency
  - Short flows
- #3: High throughput
  - Continuous data updates and large file transfers

Tension Between Requirements

High Throughput
High Burst Tolerance



Low Latency

Deep Buffers:
➢ Queuing Delays & Increase Latency

Reduced RTO_{min} (SIGCOMM '09)
➢ Doesn't Help Latency

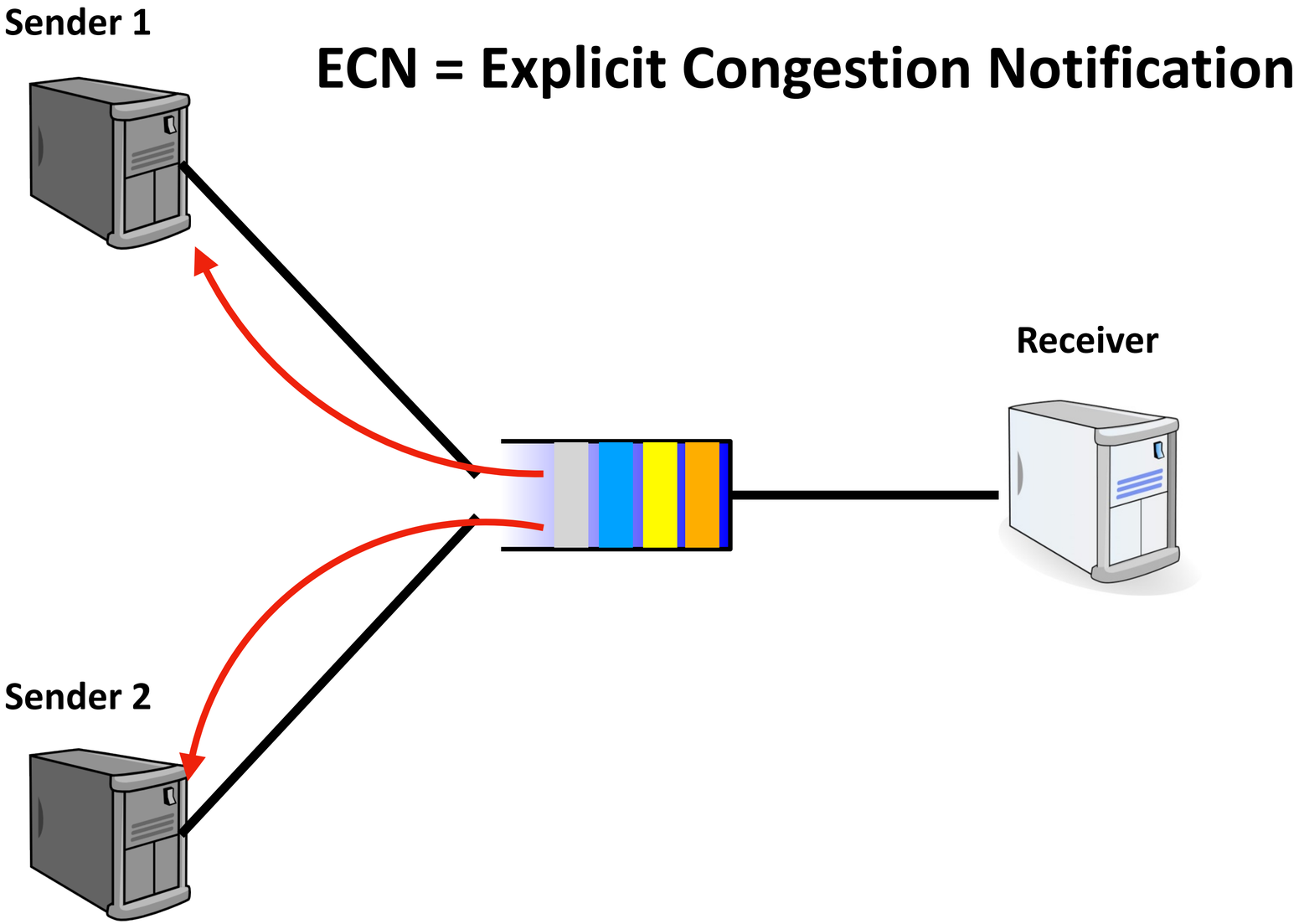
Shallow Buffers:
➢ Bad for Bursts & Throughput

AQM – RED:
➢ Avg Queue Not Fast Enough for Incast

Objective:
Low Queue Occupancy & High Throughput

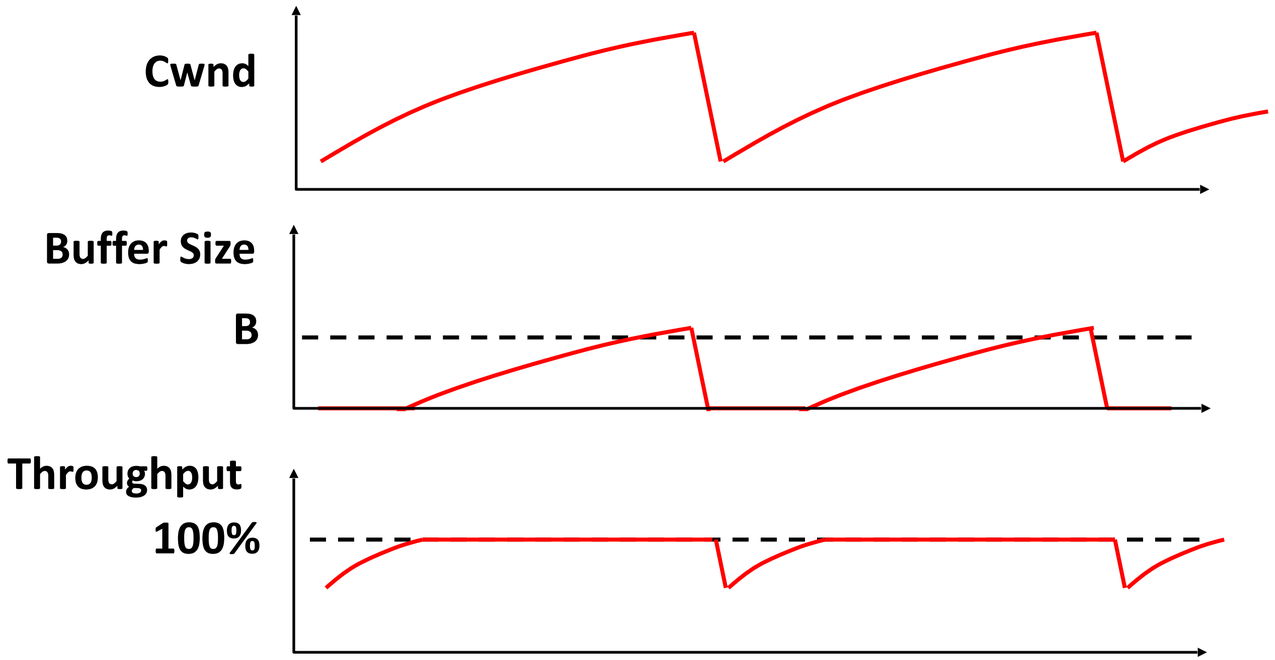
How does DCTCP solve the problem?

TCP/ECN Control Loop



Buffer Sizing: Small Queue

- Bandwidth-delay product rule of thumb:
  - A single flow needs `C x RTT` buffers for 100% throughput



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

Key Ideas of DCTCP

- #1: React proportional the extent of congestion, not its presence
  - Reduce variances in sending rates, lowing queue requirement

ECN Marks	TCP	DCTCP
1 0 1 1 1 1 0 1 1 1	Cut window by 50%	Cut window by 40%
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- #2: Mark based on instantaneous queue length
  - Fast feedback to better deal with bursts

DCTCP Algorithm

DCTCP Algorithm

Sender side:

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

$$F = \frac{\#\ of\ marked\ ACKs}{Total\ \#\ of\ ACKs}$$

$$\alpha \leftarrow (1-g)\alpha + gF$$

$$Cwnd \leftarrow (1 - \frac{\alpha}{2})Cwnd$$

DCTCP Algorithm

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Switch

Receiver

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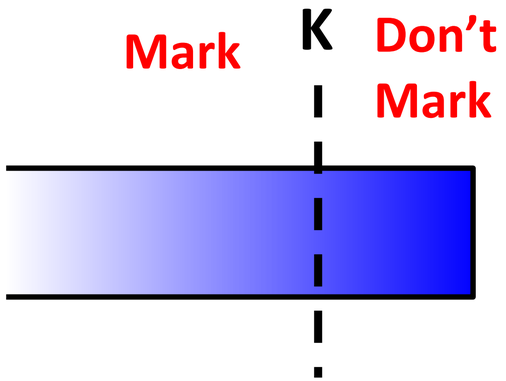

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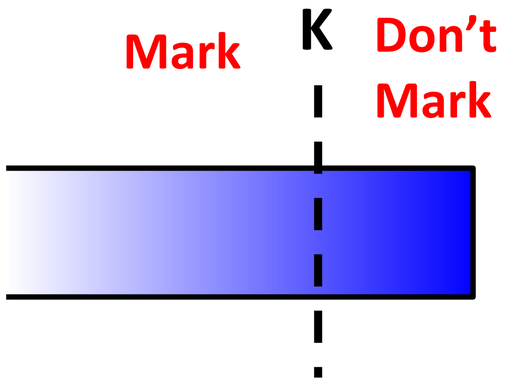
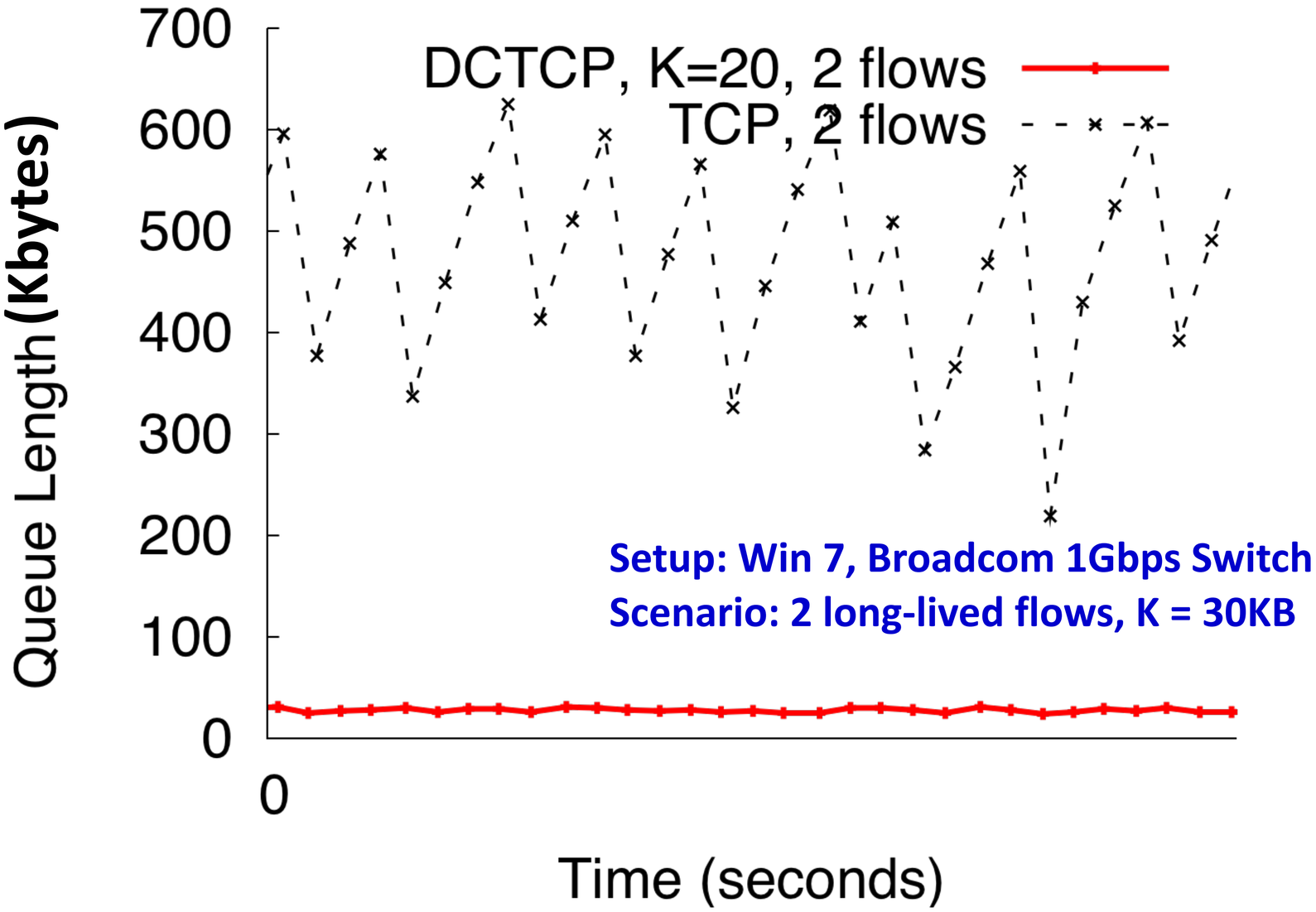


Receiver side:

- Piggyback

DCTCP Effect



Why does DCTCP work?

Efficiency of DCTCP

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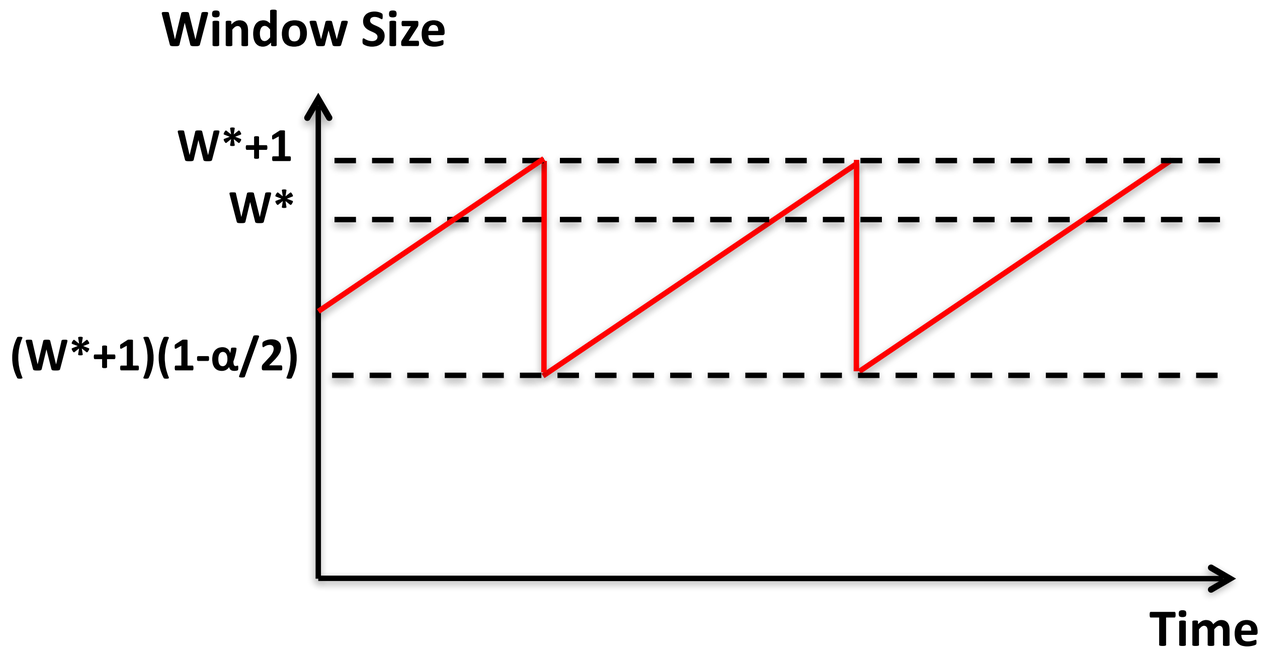
ECN averaging —> smooth rate adjustment, low variance

DCTCP Analysis

- How long can DCTCP maintain queues without throughput drop?



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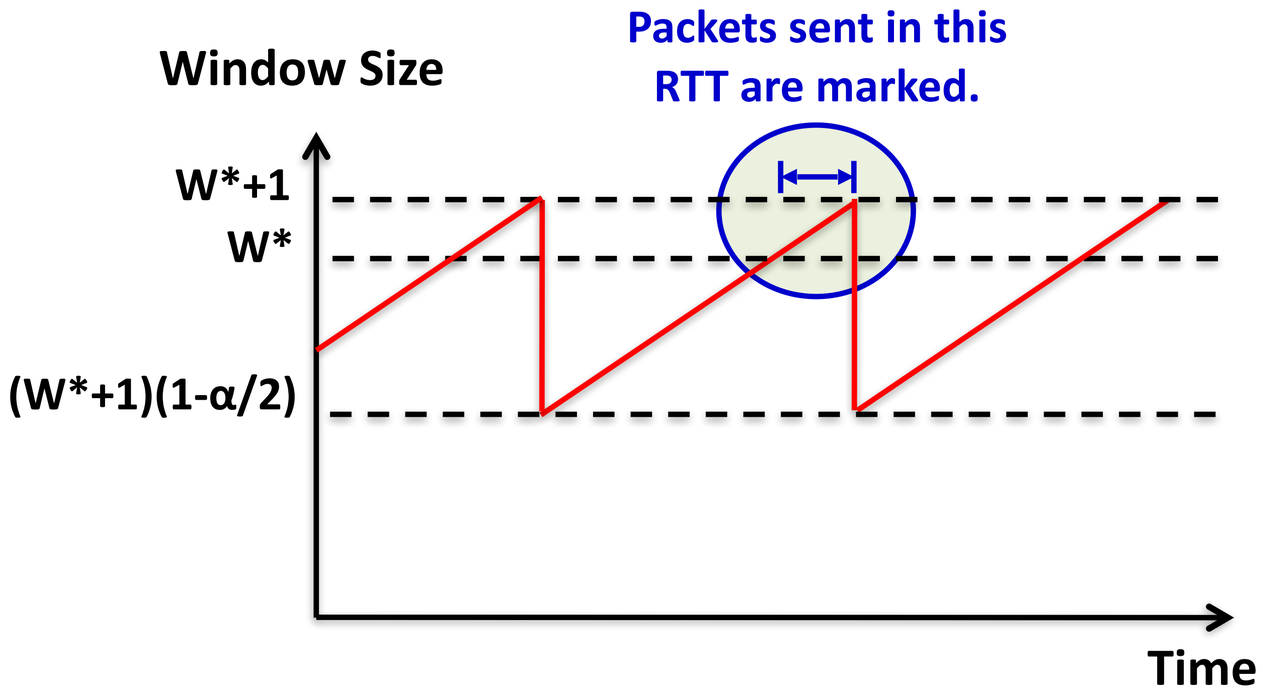

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Need to quantify queue size oscillations (stability)

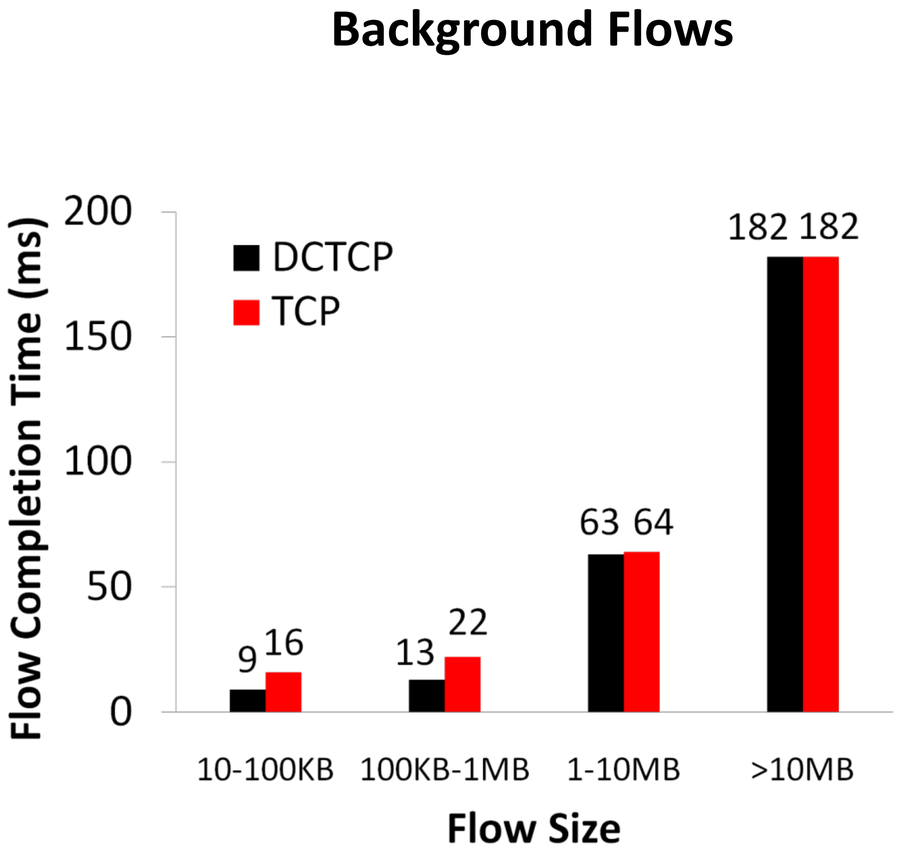
DCTCP Analysis

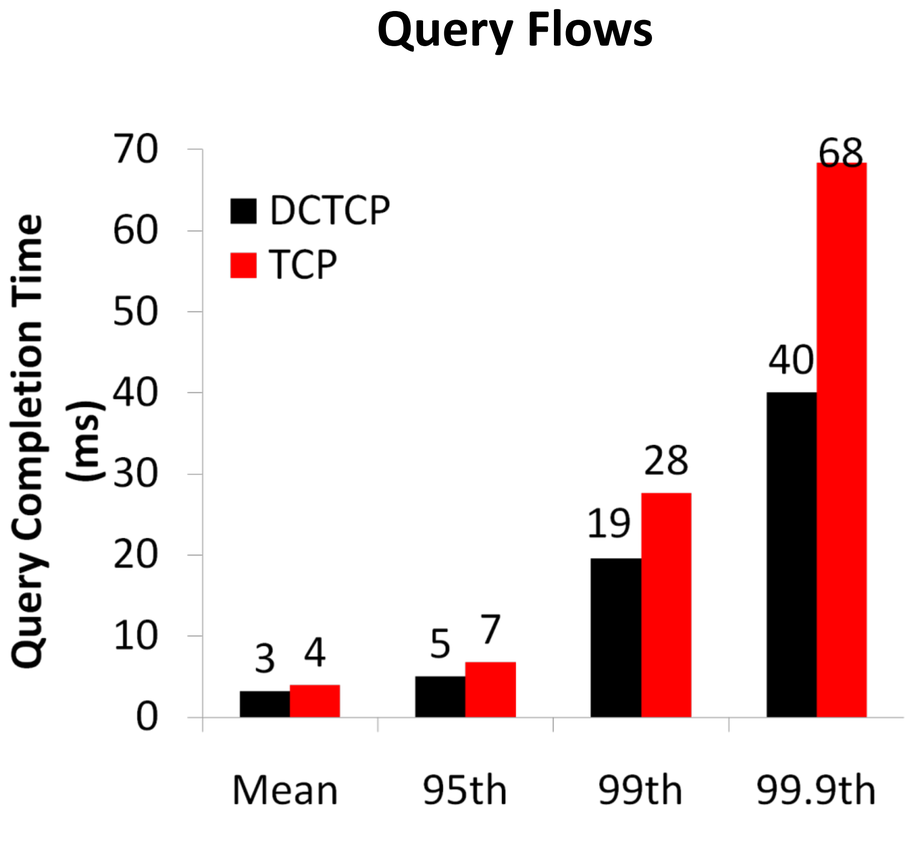
- How long can DCTCP maintain queues without throughput drop?
- How do we set the DCTCP parameters?

$$K > \frac{1}{7} C \times RTT$$

85% Less Buffer than TCP

DCTCP Performance





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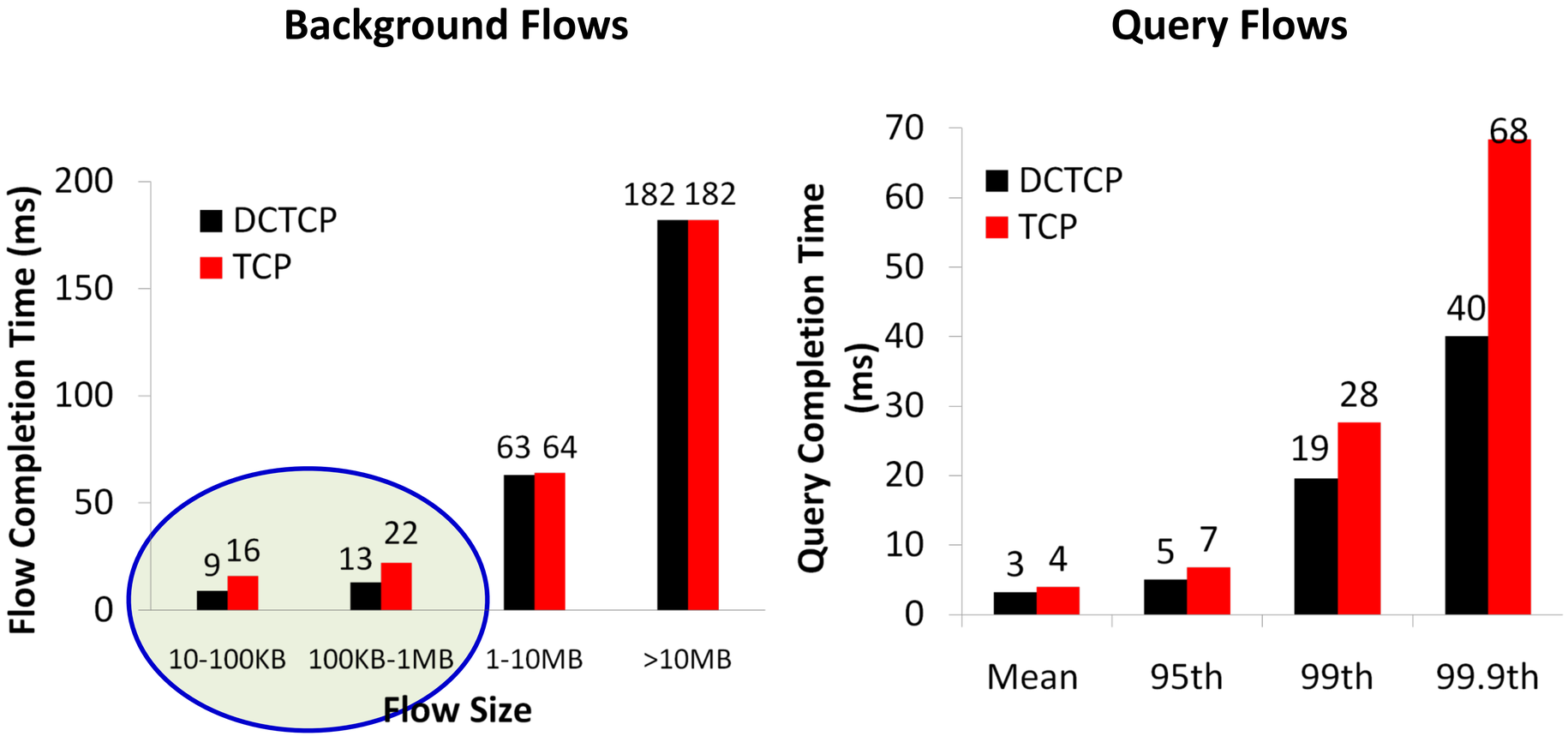
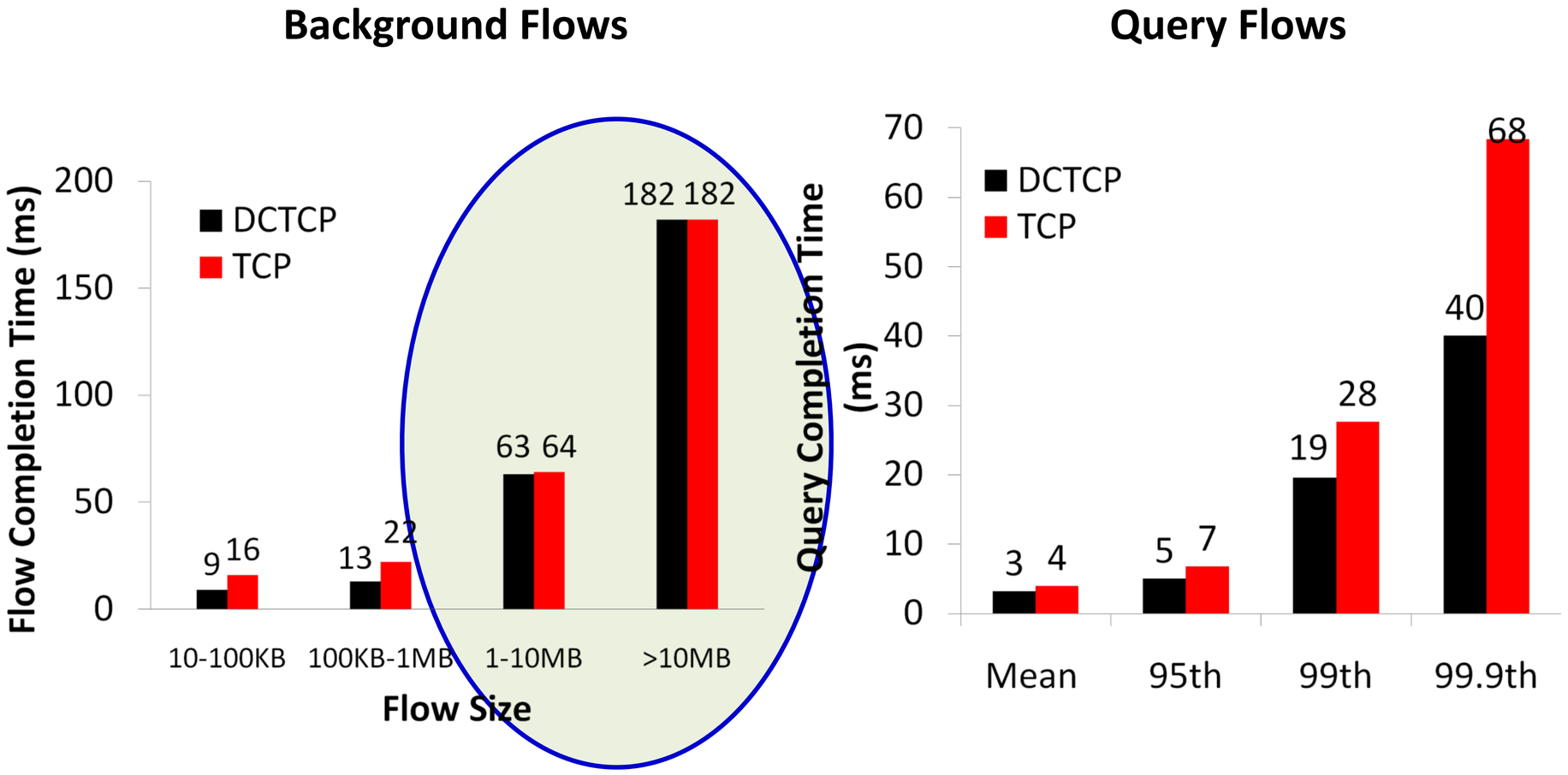


✓ **Low latency for short flows**

DCTCP Performance



✓ Low latency for short flows

✓ High throughput for long flows

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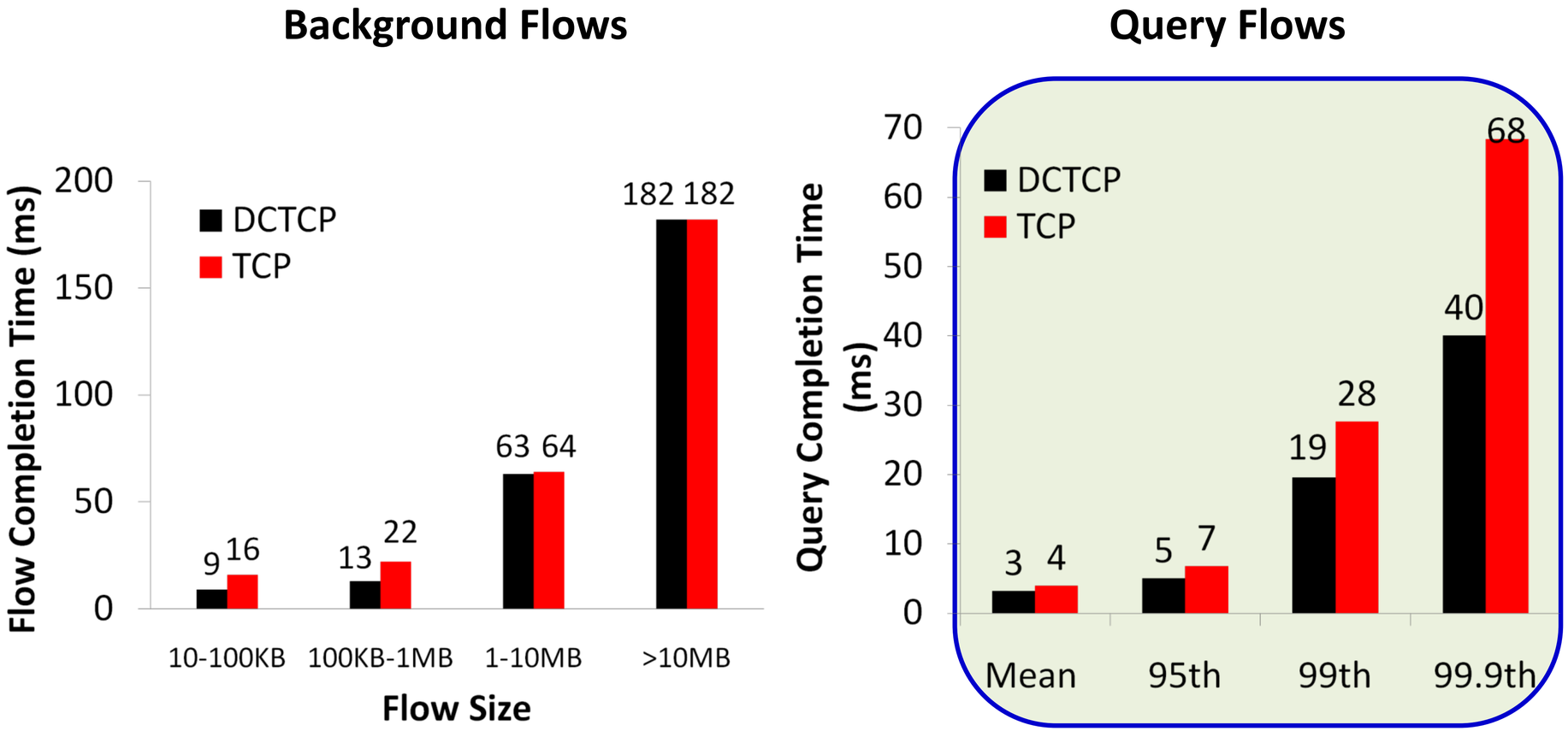

✓ Low latency for short flows

✓ High throughput for long flows

✓ High burst tolerance for query flows

Summary

- Today
  - TCP Congestion Control (III)

- Next
  - TCP in-network support