Congestion Control in the *Real* World

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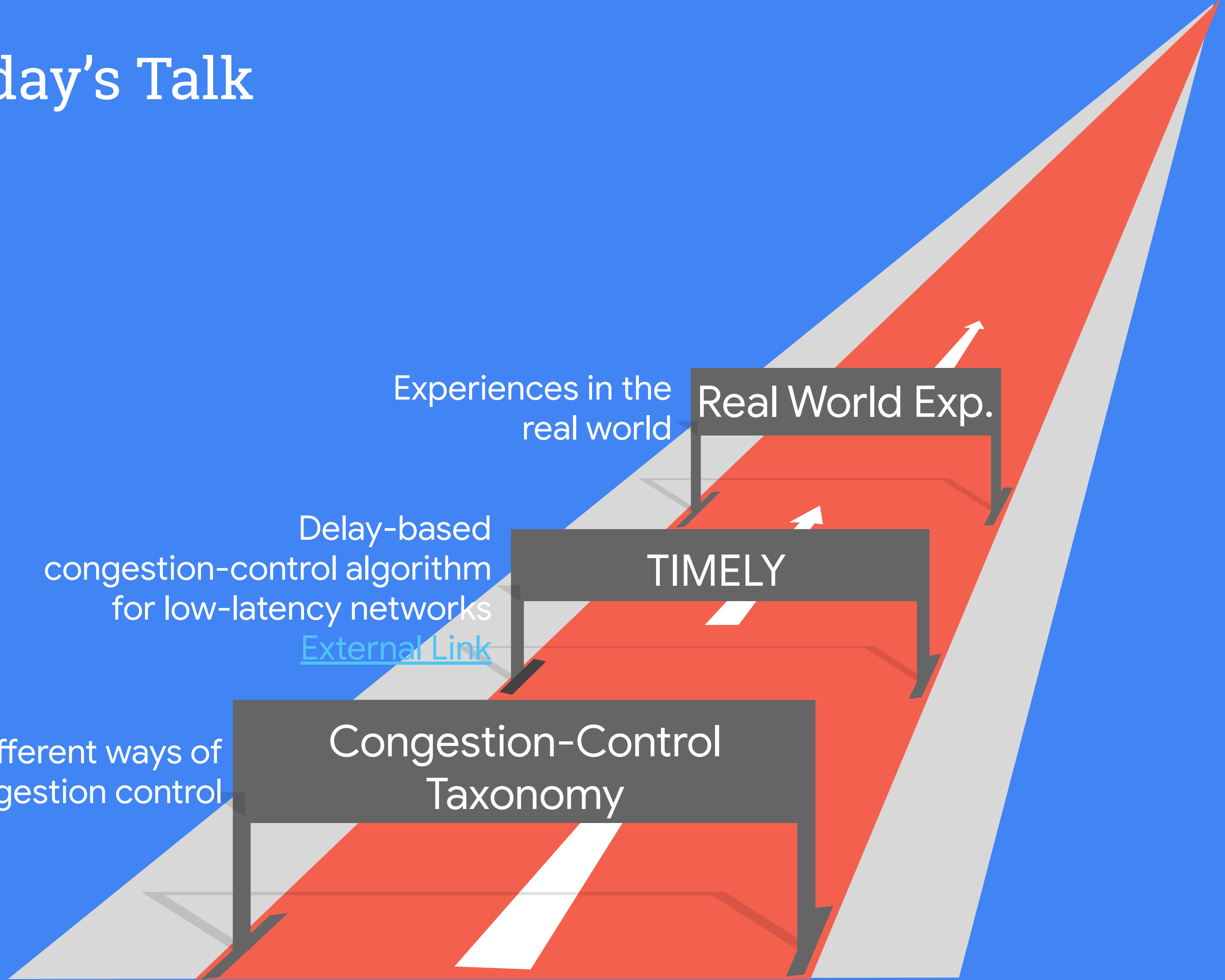
Today's Talk



Experiences in the real world

Delay-based congestion-control algorithm for low-latency networks
[External Link]

Many different ways of congestion control

Many different ways to signal Congestion

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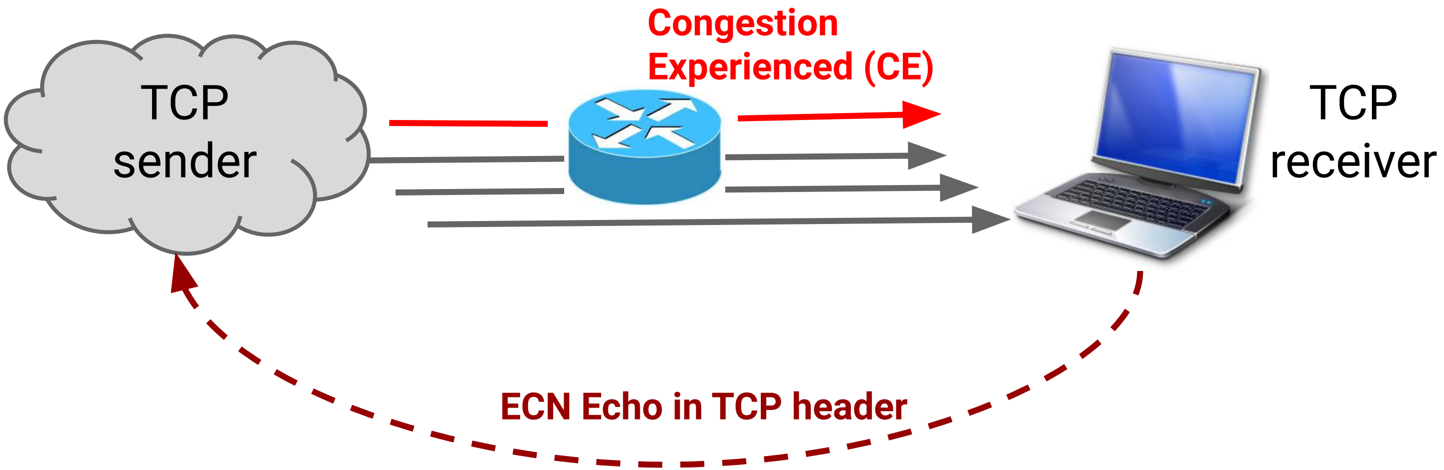
Congestion Control Taxonomy

Loss	New Reno, Cubic TCP
Delay	TCP Vegas, TIMELY, BBR
Explicit Feedback	DCTCP, XCP, RCP

[1] TIMELY: RTT-based Congestion Control for the Datacenter, SIGCOMM 2015
[2] DCTCP: Data Center TCP (DCTCP), SIGCOMM 2010
[3] BBR: Congestion-based Congestion Control, ACM Queue, 2016
[4] TCP Vegas: new techniques for congestion detection and avoidance, SIGCOMM 1994

Explicit Congestion Notification (ECN)

- Switches set “Congestion Experienced” bit on packets if the queue grows too large as per the IETF ECN standard.
- Switches inform receiver, which in turn can inform sender of congestion marks.



Datacenter TCP (DCTCP)

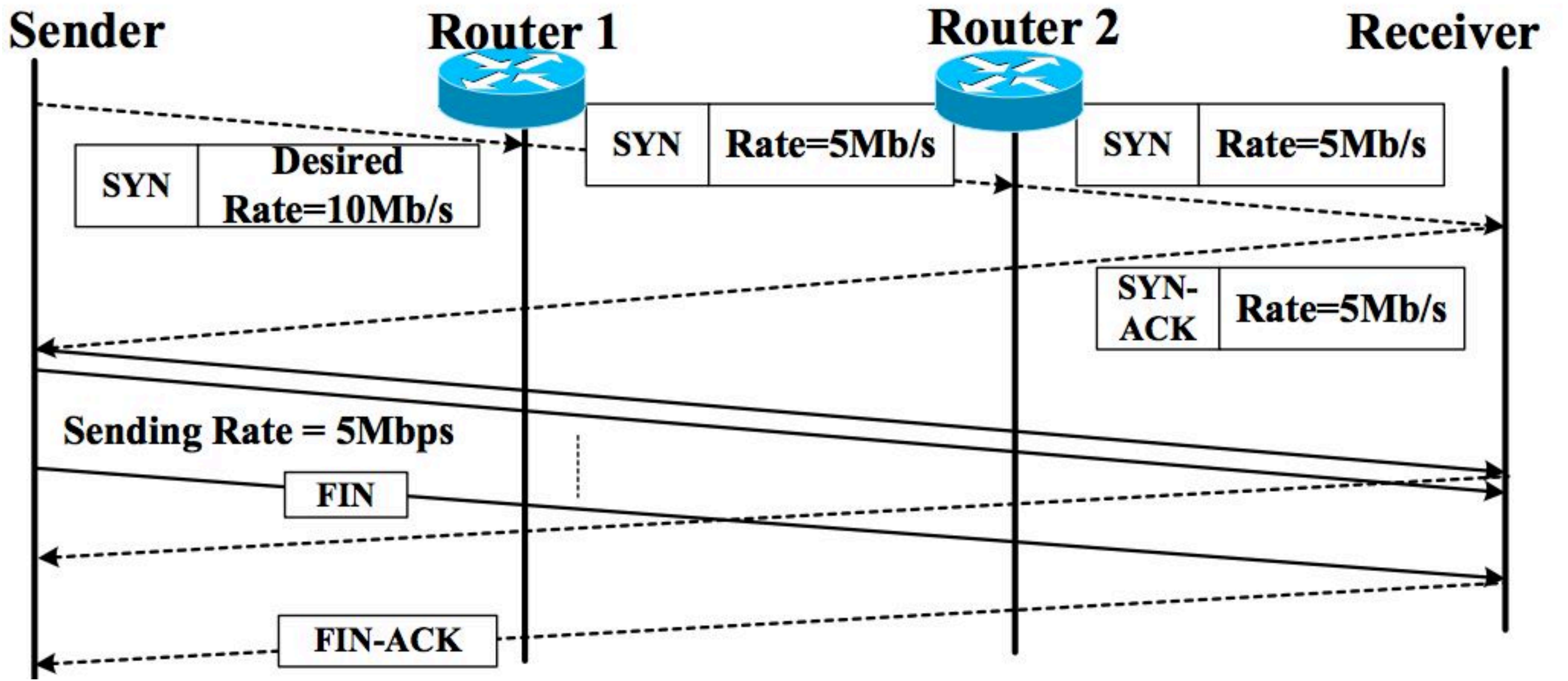
- Datacenter DCTCP (SIGCOMM 2010) uses ECN marks.
- Switches mark CE bit in IP header if queue > 65KB.
- Receivers reflect marks to senders (via TCP flags).
- Sender slows down according to proportion of marked packets each RTT.

Rate Control Protocol (RCP)

RCP motivation

- Uses flow completion time as the primary metric for congestion control.
- Should work well for short flows that don't have an opportunity for continual incremental rate updates.
- No complex per-packet computations in switches.

RCP uses min. supported rate along the path



RCP Algorithm

Link Capacity

Aggregate Traffic

queue

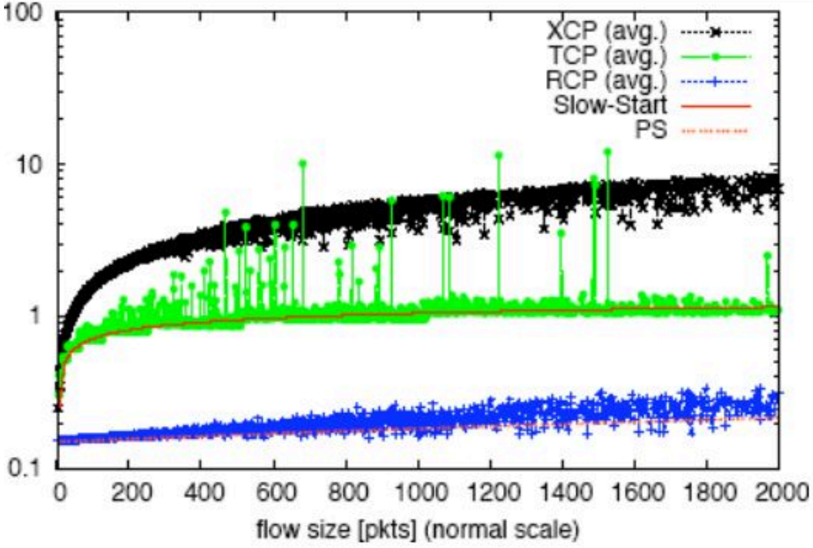
Average RTT

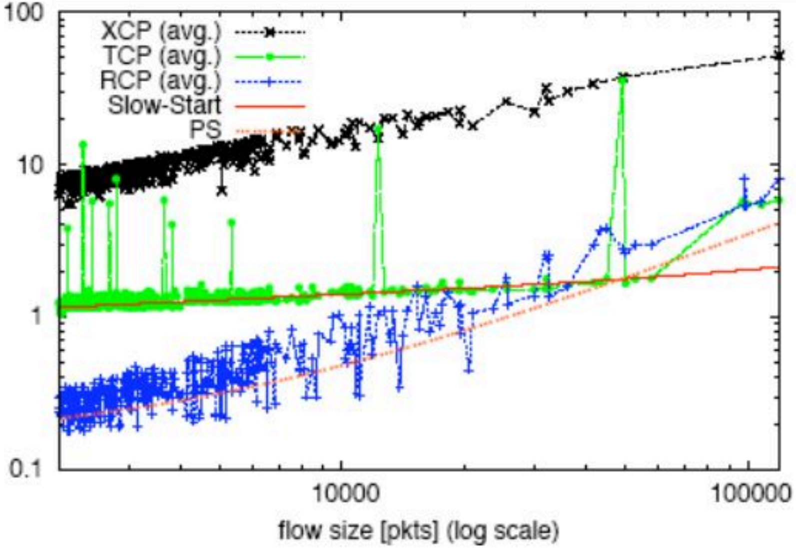
$$R(t) = R(t - d_0) + \frac{\alpha(C - y(t)) - \beta \frac{q(t)}{d_0}}{\widehat{N(t)}}$$

Estimate of # flows

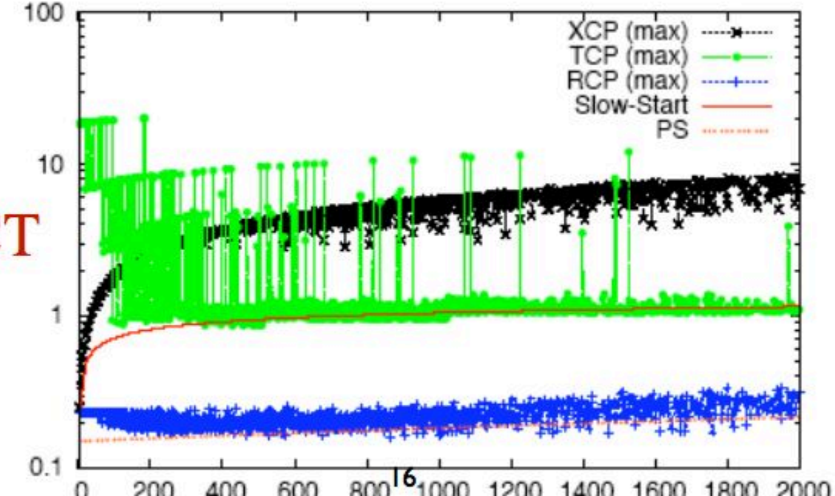
$$\widehat{N(t)} = \frac{C}{R(t - d_0)}$$

$$R(t) = R(t - T)[1 + \frac{\frac{T}{d_0}(\alpha(\gamma C - y(t)) - \beta \frac{(q(t) - q_0)}{d_0})}{\gamma C}]$$


XCP (avg.)
TCP (avg.)
RCP (avg.)
Slow-Start
PS
100
10
1
0.1
0 200 400 600 800 1000 1200 1400 1600 1800 2000
flow size [pkts] (normal scale)


XCP (avg.)
TCP (avg.)
RCP (avg.)
Slow-Start
PS
100
10
1
0.1
10000
100000
flow size [pkts] (log scale)

Max. FCT


XCP (max)
TCP (max)
RCP (max)
Slow-Start
PS
100
10
1
0.1
0 200 400 600 800 1000 1200 1400 1600 1800 2000

Explicit feedback is a game changer for CC

E2E congestion control has a hard time with:

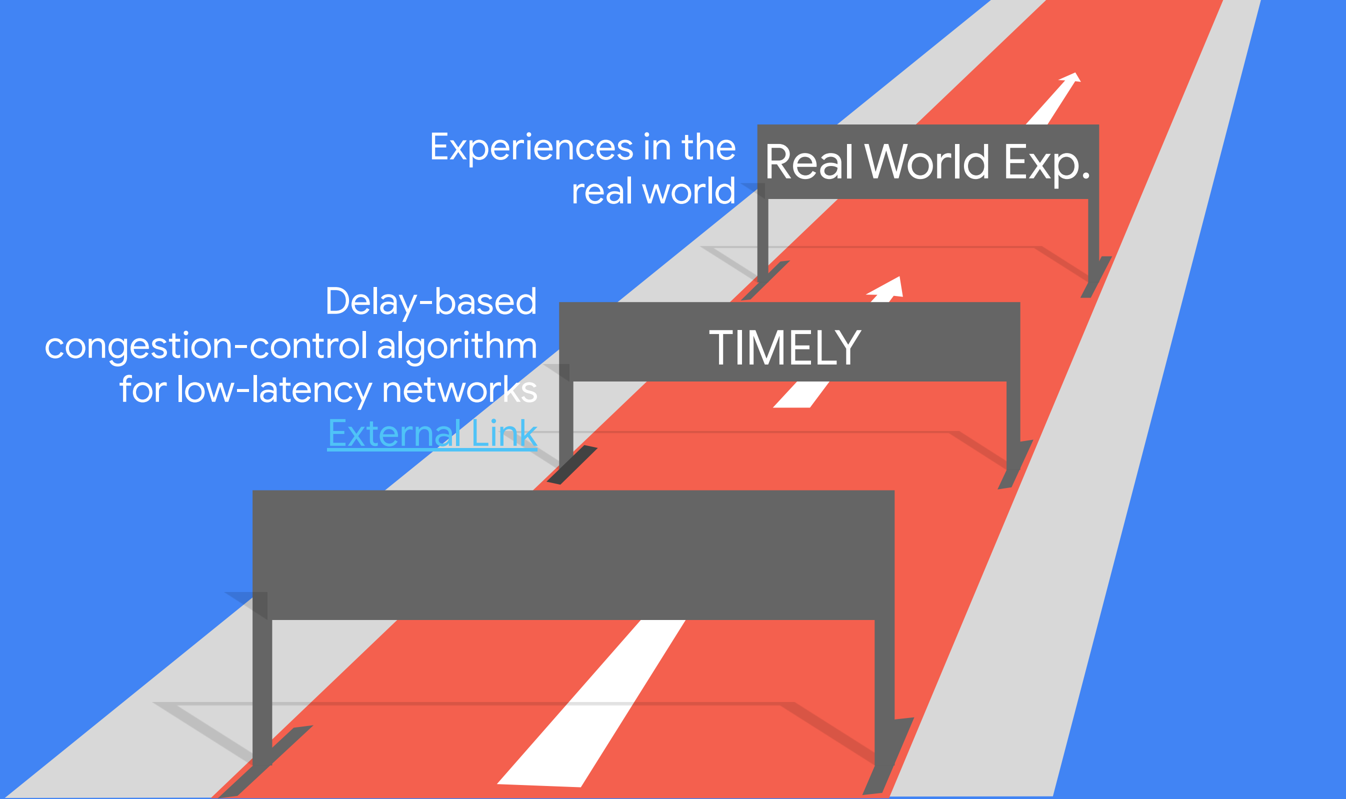
- Discerning between incidental losses/delay or persistent congestion.
- Disambiguating between forward and reverse path congestion.
- Figuring out which hop along the network path is contributing to delay.
- Applications starting up large number of connections, e.g., O(10K).
- Reconciling between LAN/WAN congestion.
- <and several others here>.

TIMELY: RTT-based Congestion Control for the Datacenter

Experiences in the real world

Delay-based congestion-control algorithm for low-latency networks

External Link



Datacenter Congestion Control
High Level Goals

Low-Latency for RPCs
Provides low RPC completion times for short and long RPCs.

End-to-end network performance isolation
Performance isolation at every congested point along the path.

Bandwidth Efficiency
Provides high-throughput even under heavy-incasts.

CPU Efficiency
Uses constructs that use less CPU (e.g., doesn’t require too many locks).

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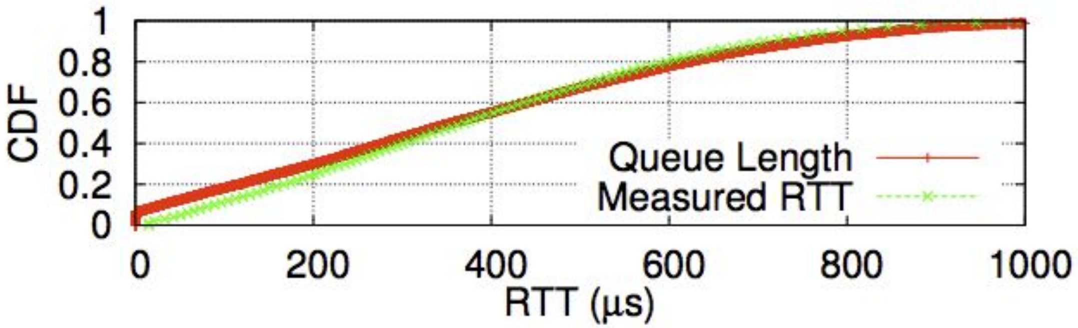
Delay as a Congestion Signal

- Can be measured accurately using NIC hardware timestamps.
- Is a rapid, multibit signal that correlates extremely well with queuing.



- Is an end-to-end congestion signal and directly ties with latency-guarantees, congestion control is trying to provide.
- Is decomposable - can provide isolation at different congestion-points.

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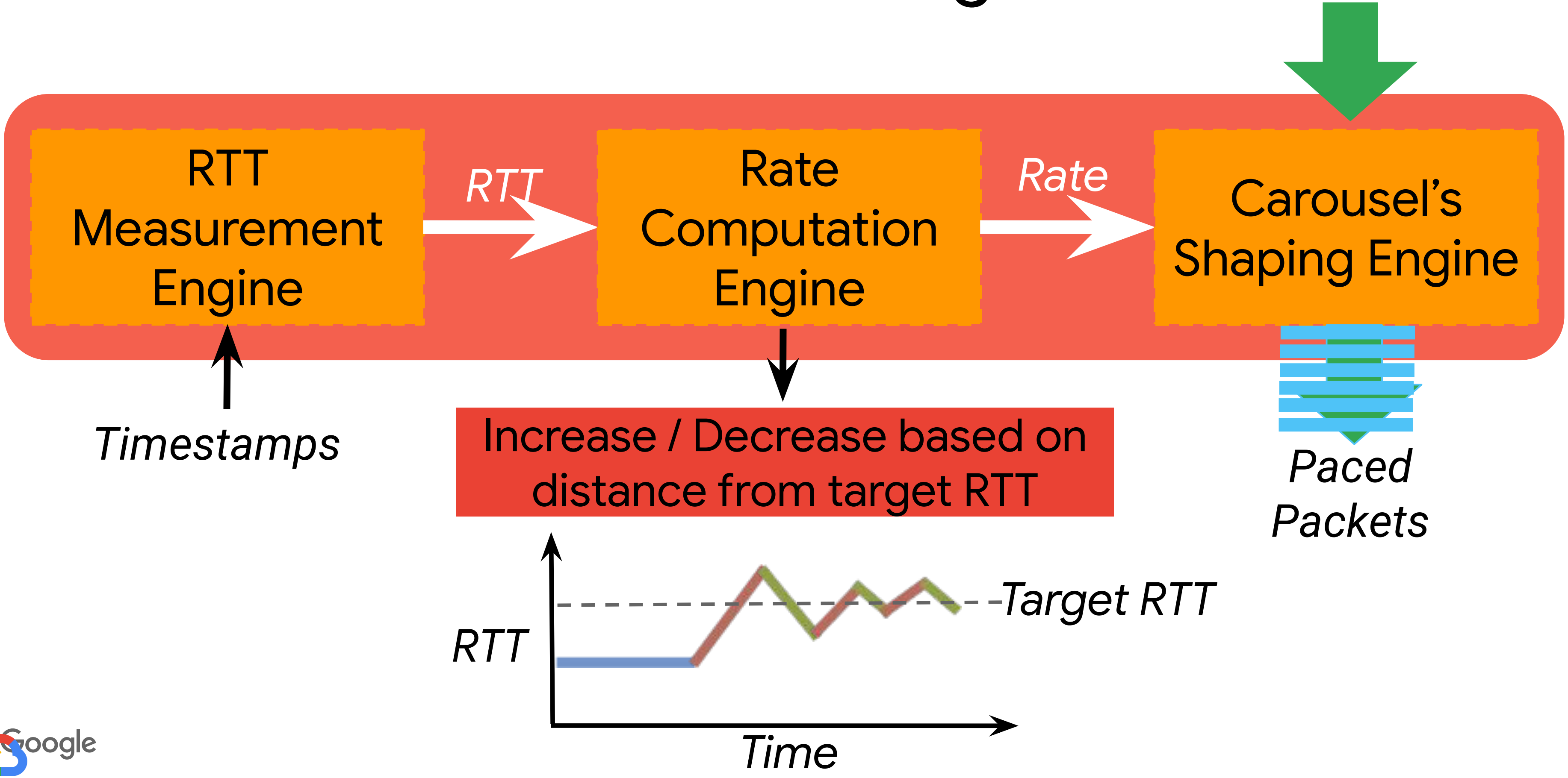
TIMELY Framework and Algorithm



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Predictable Low-Latency

TIMELY adjusts sending rate based on measured delay

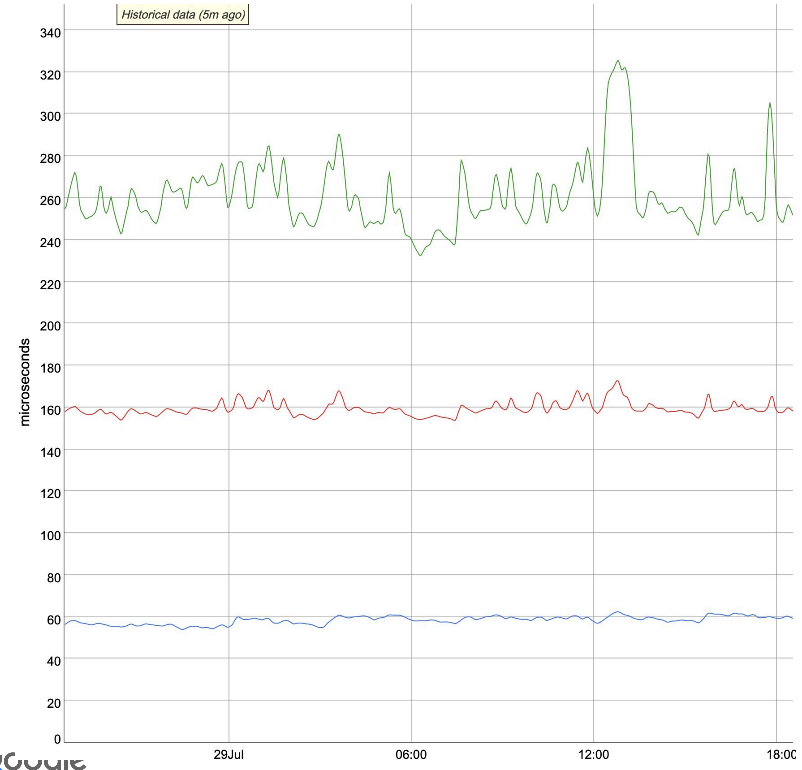
- Sender tracks a congestion-window (cwnd) to determine the rate to send at.
- If measured delay < target, increase the cwnd, otherwise decrease the cwnd.
- Additive-increase Multiplicative-decrease (AIMD) to ensure fairness b/w senders.

Target-delay allows fine-grain control over latency

- Experimental and production data shows that RTTs hover around the specified target.

Takeaway 1: TIMELY controls delay to be around the specified target

RTTs in a large setting



Median RTT ~59us

99th-p RTT ~ 158us

99.9th-p RTT ~ 251us

Even tail RTTs are much lower compared to traditional congestion-control algorithms

High Fan-In Traffic Patterns

TIMELY's cwnd can fall below 1 when a large number of flows send to the same host

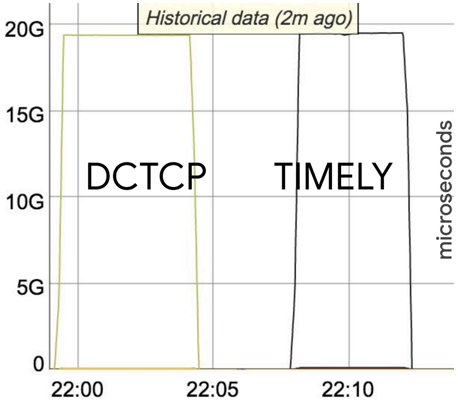
- This enables TIMELY to keep its promise of low-latency and zero loss, while still providing maximum throughput

cwnd < 1 is enabled via pacing packets using a Timing Wheel

- TIMELY moves seamlessly between a rate-based and window-based protocol

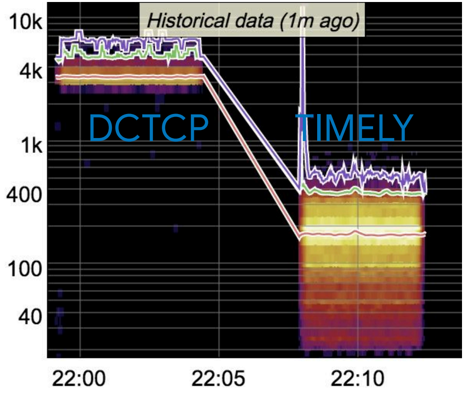
Takeaway 2: TIMELY supports extremely small cwnds to handle bursts efficiently, maintaining high-throughput, low-latency, and almost zero loss

Large Incast - 1000 flows sending to 1



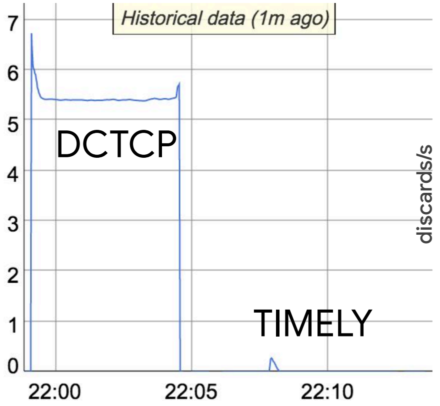
Throughput

TIMELY is able to provide line-rate throughput (NIC speed = 20G).



RTT

TIMELY’s median RTT is 172us whereas DCTCP”s median RTT is 3310us.
At 99th-p, TIMELY’s RTT is 370us while DCTCP’s is 4900us.



Retransmissions

DCTCP has 5.5% retransmissions whereas TIMELY has ~0%.

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Real World Experience

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Special Switch Queues for TIMELY

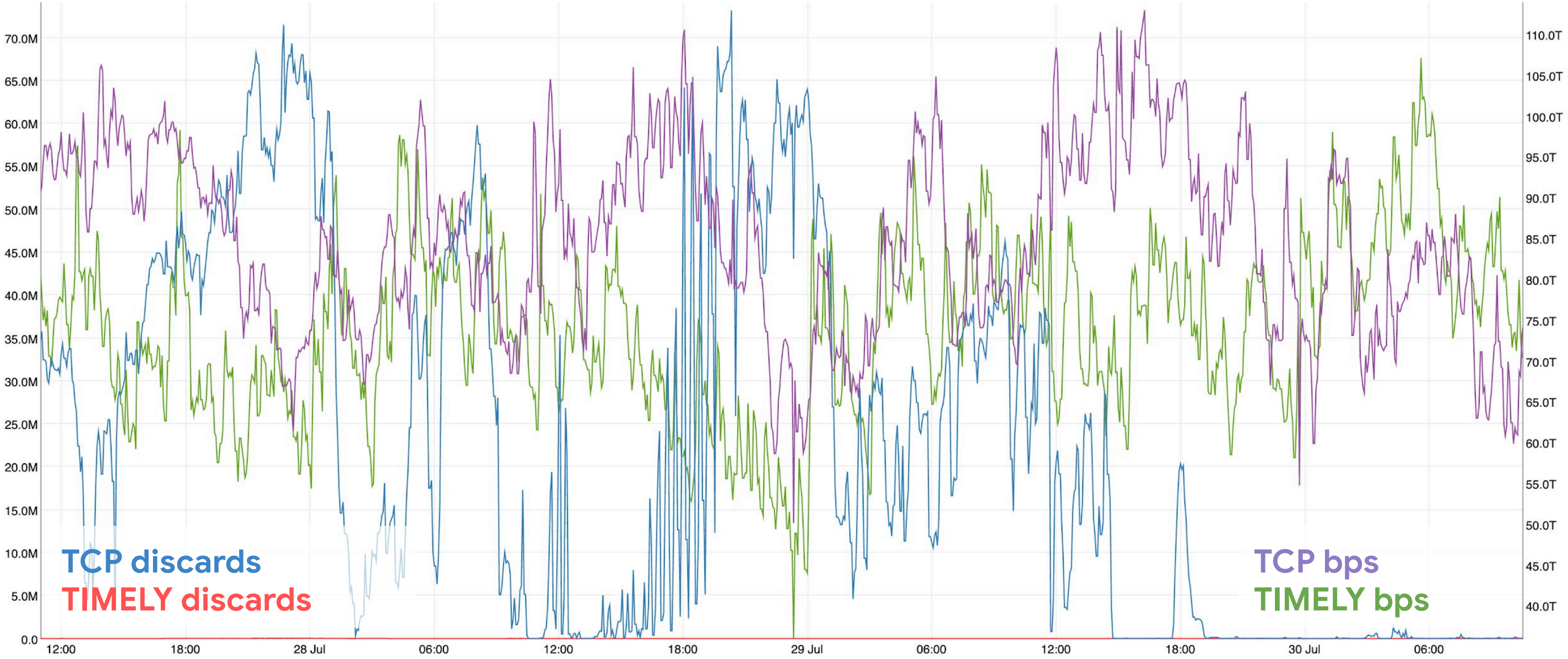
TIMELY is non-TCP-compatible and requires its own network-queue

Separate queues provide isolation vs TCP traffic

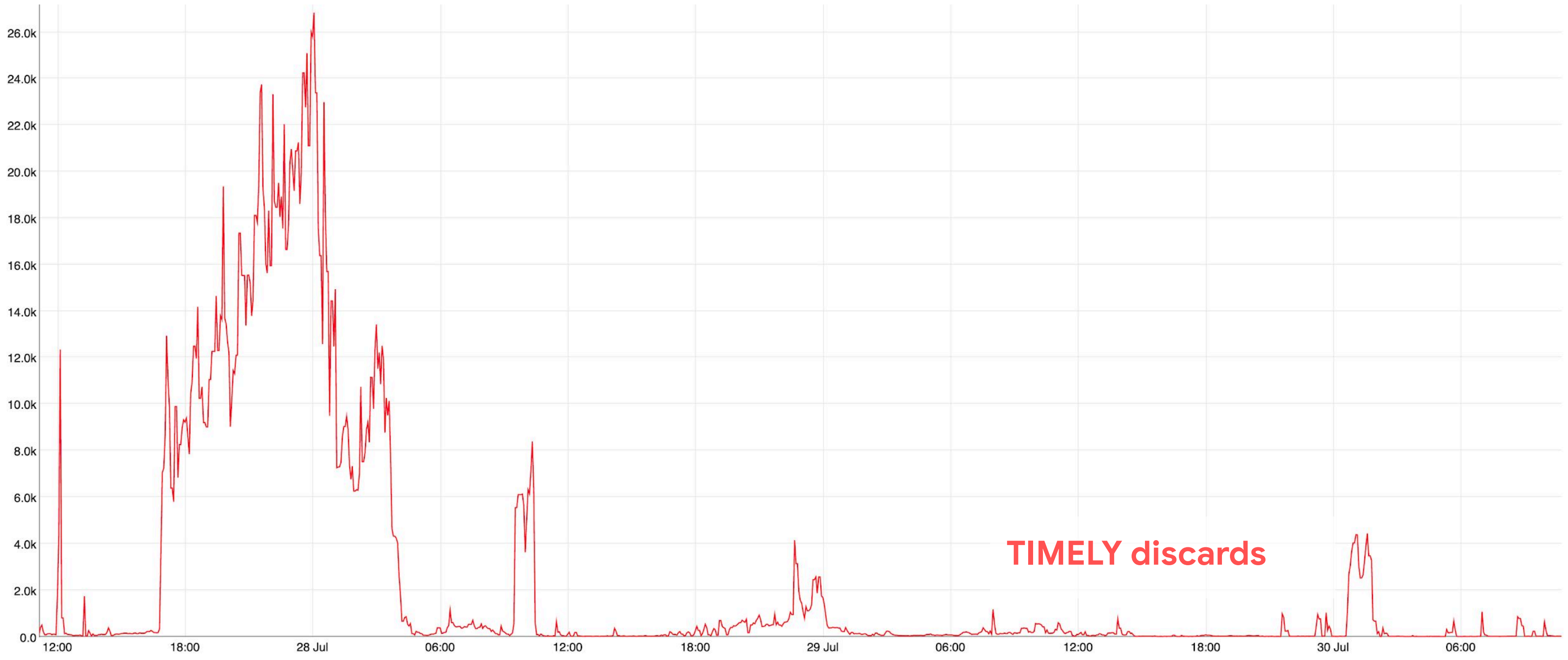
- If TIMELY shared queues, latency, loss, throughput will be affected by TCP, since TCP typically requires more buffers.

Takeaway 3: TIMELY runs on it's own network queues which enables it's promise of low-latency and almost-zero loss.

Substantially lower discards at similar throughputs



XXXbps on TIMELY and almost 0 loss



CPU constrained Networks

Congestion is not limited to the fabric, can also occur at endpoints.

Networking doesn't have infinite CPU: OS-bypass/User-Space packet-processing gives a CPU-efficient alternative, but packet-processing engines can get overloaded and queues can build up.

Endpoint congestion behaves differently than Fabric congestion

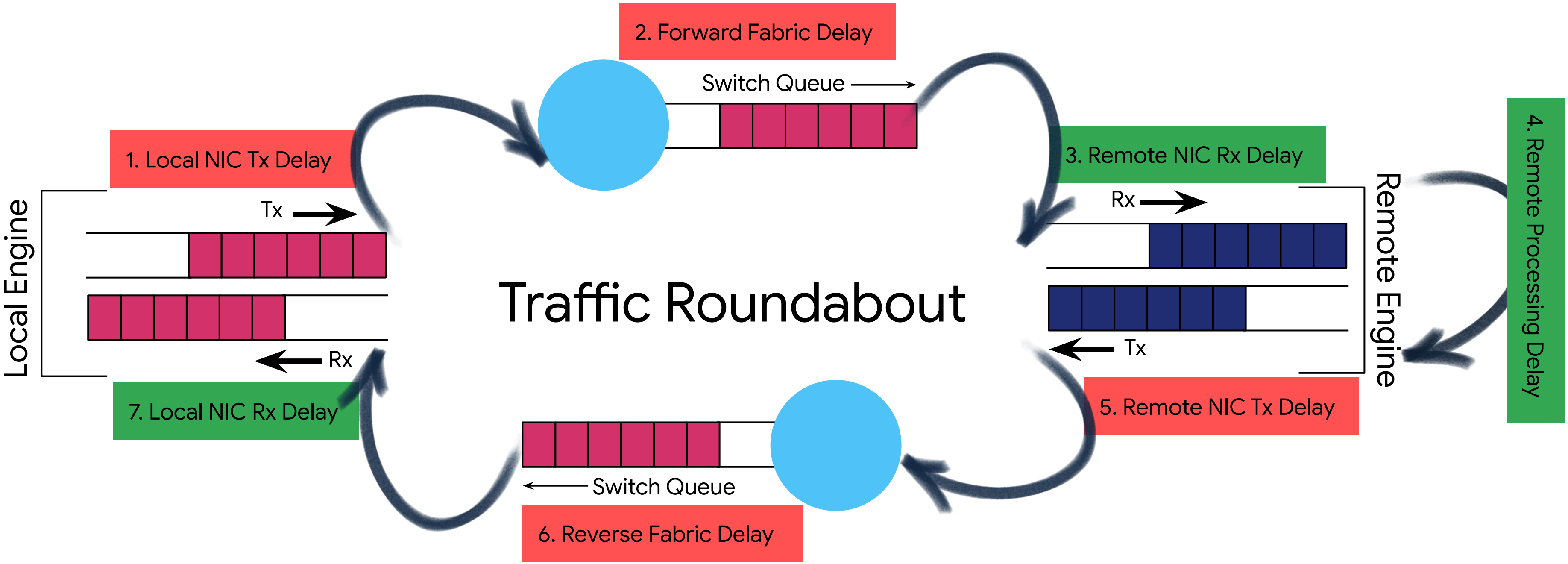
Think more volatile, transient queue build-ups - not just depend on incoming pps but also host-specific attributes, e.g., cache locality.

Takeaway 4: Two congestion-windows instead of one

One to track available capacity in the fabric, and one to track available capacity at the endpoints.

$cwnd = min\ (fcwnd, ecwnd)$

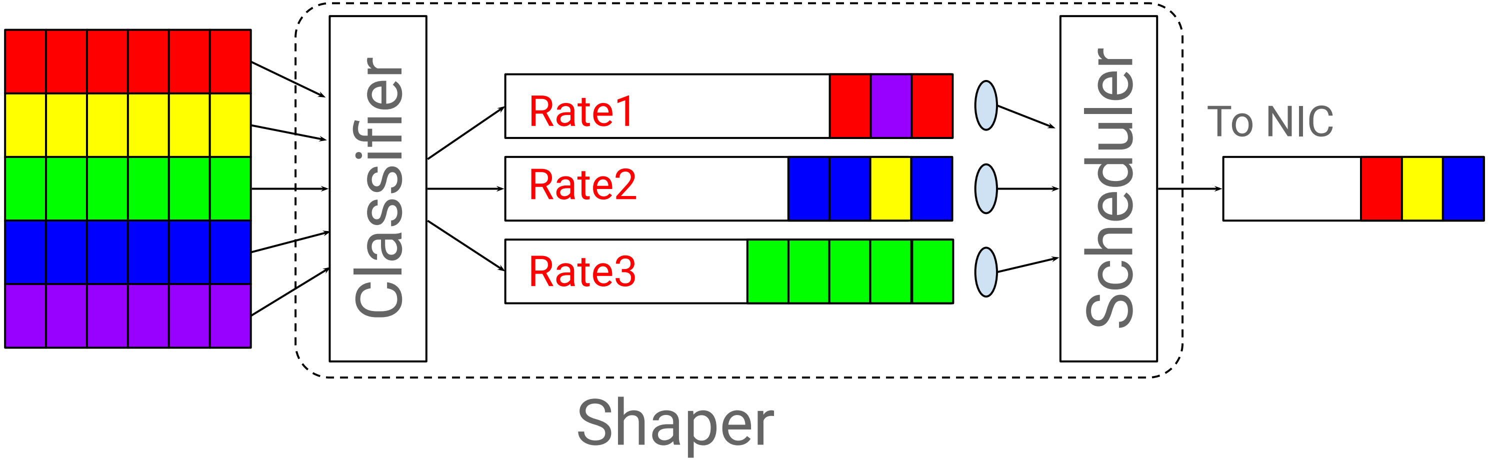
Delay sources in SNAP[1]



1. High-performance Host-Networking stack supporting RDMA (**Snap: a Microkernel Approach to Host Networking**)

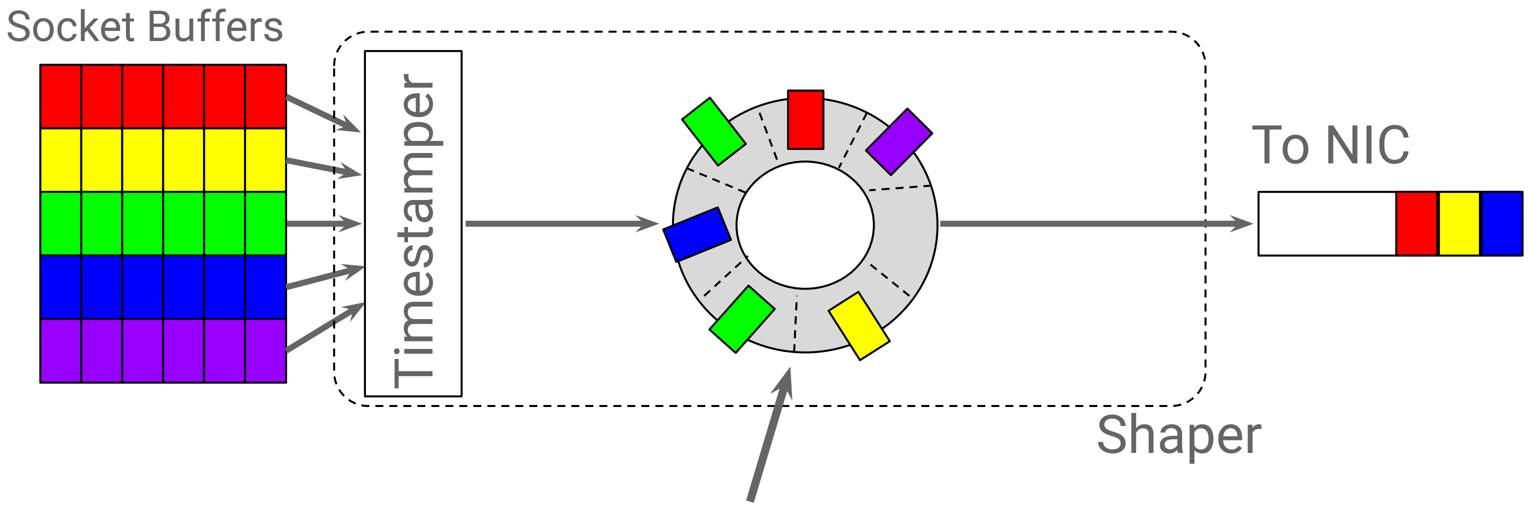
Traffic Shapers in Practice

Packet Sources: Socket Buffers
in Host OS or Guest VM

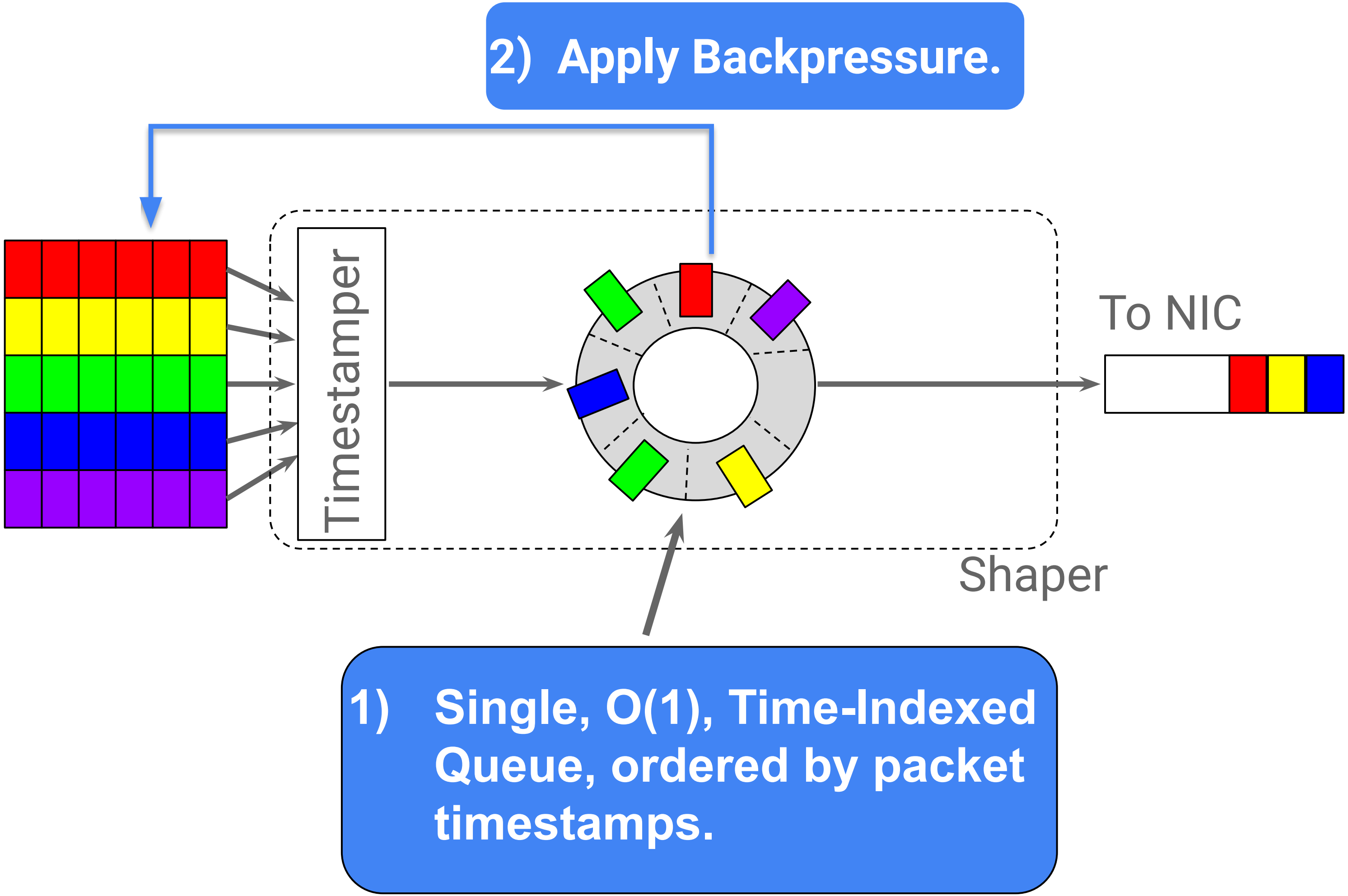


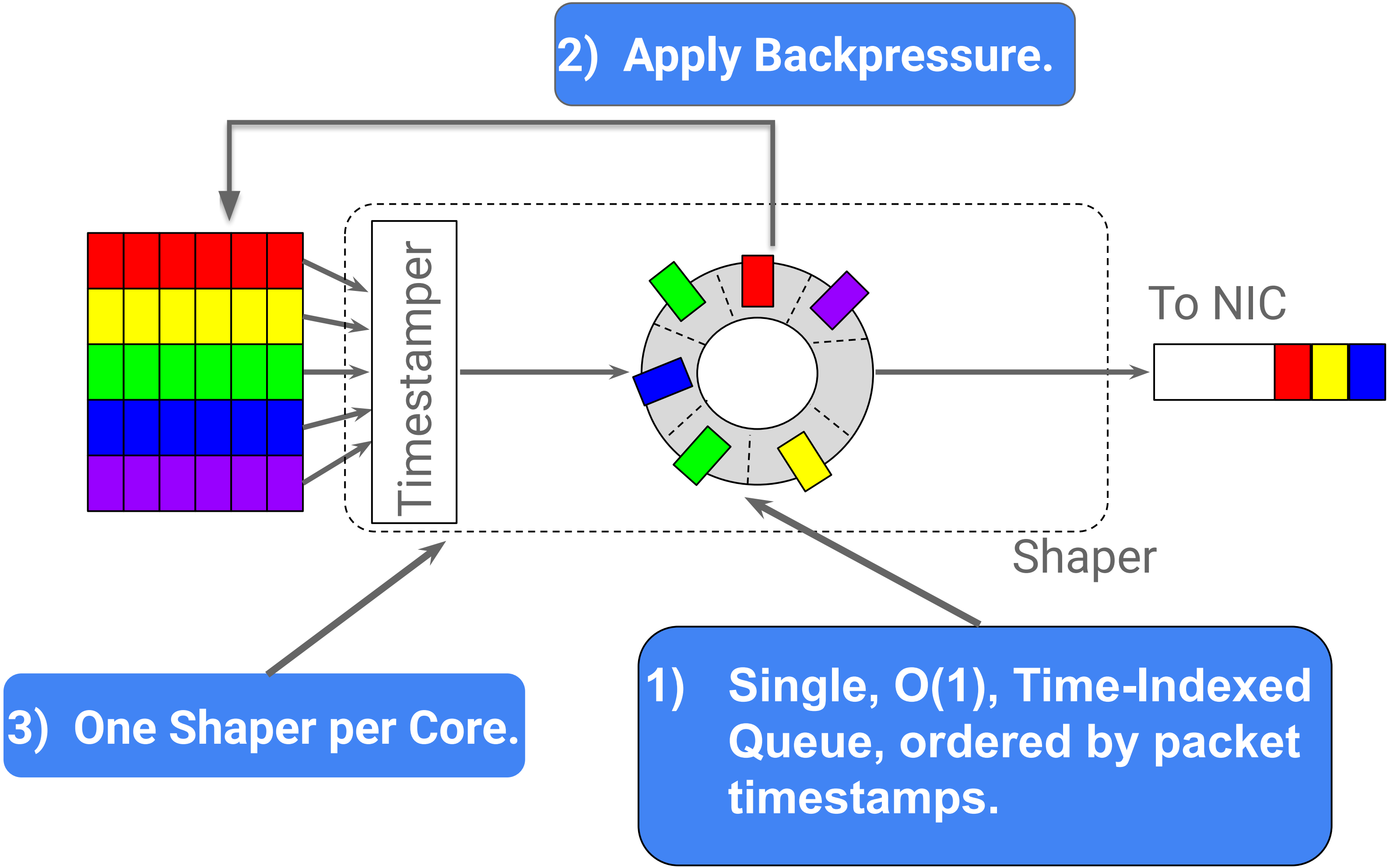
Pre-filtering with Multiple Token Bucket Queues.

Design Principles of Carousel

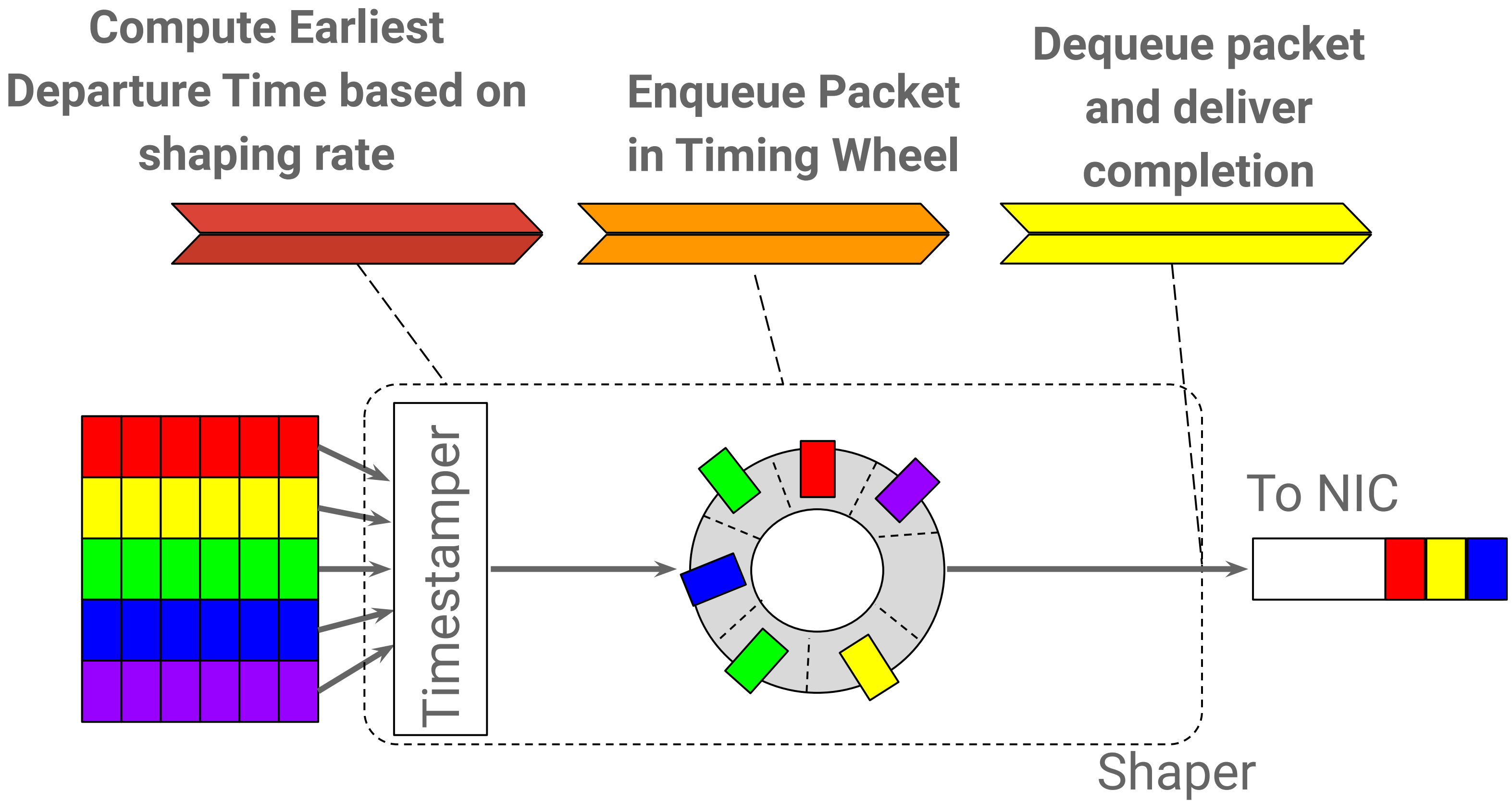


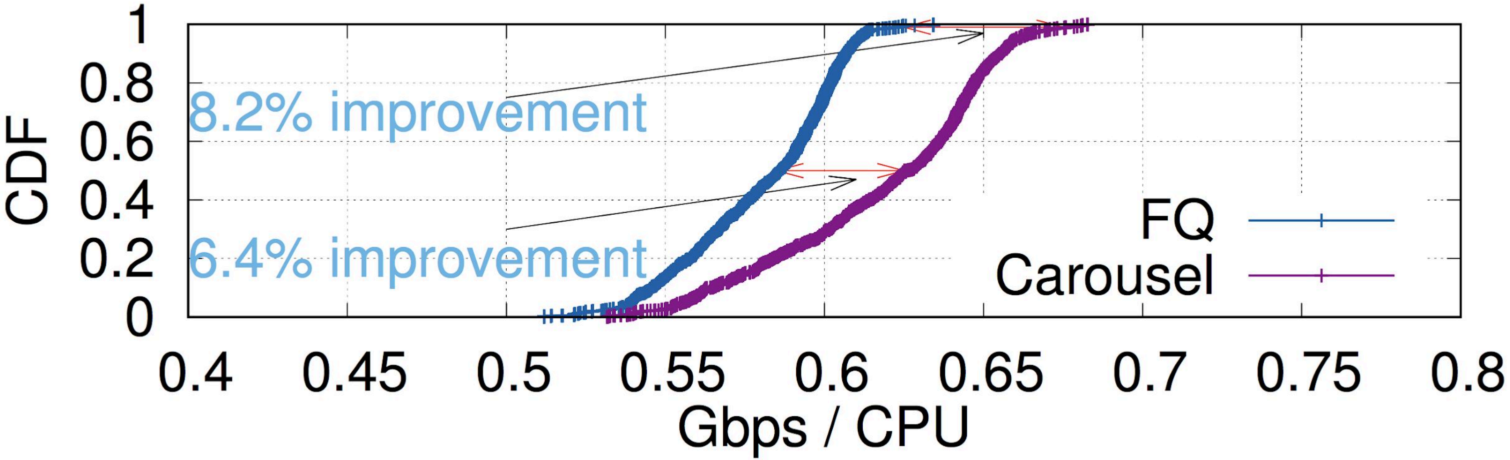
1) **Single, O(1), Time-Indexed Queue, ordered by packet timestamps.**


2) Apply Backpressure.
Timestamper
To NIC
Shaper
1) Single, O(1), Time-Indexed Queue, ordered by packet timestamps.


2) Apply Backpressure.
Timestamper
To NIC
Shaper
3) One Shaper per Core.
1) Single, O(1), Time-Indexed Queue, ordered by packet timestamps.

Life of a Packet in Carousel





Carousel saves up to 8.2% of overall CPU utilization.
(5.9 cores on a 72 core machine)

Concluding Remarks

Congestion control is a systems problem with broad applications:

- Resource allocation.
- Efficiency.
- Isolation.
- Directly impacts the performance of applications.

Acknowledgments

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