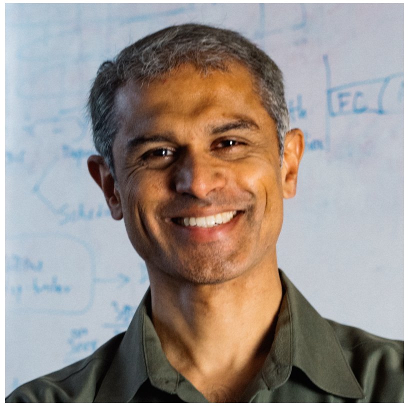
Copa: Practical Delay-Based Congestion Control



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The Internet is more challenging than ever

(Why are we still talking about congestion control in 2018?)

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Greater bandwidth ⇒ Higher bandwidth-delay product; Lower tolerance for non-congestive loss; Greater flow-churn

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Large flows (e.g. video streaming) co-exist with short-flows

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Wireless links with variable bandwidths are commonplace

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Lower tolerance for non-congestive loss

Greater flow-churn

Large flows (e.g. video streaming) co-exist with short-flows

Wireless links with variable bandwidths are commonplace

Simultaneously, users are more sensitive to performance!

Loss-based schemes have long-standing problems

- Buffer-filling
- Vulnerable to non-congestive loss
- Loss is a coarse signal

(last two) Worsens with increasing bandwidth

Delay-based congestion control?

Benefits

Challenges

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Maintain low delay

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Not competitive with buffer-filling schemes

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Finding true minimum RTT is hard

Our Solution

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MIN: a more robust statistic for queuing delay

Delay-based congestion control?

Challenges

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If buffer-fillers are present, give up on low delay

MIN: a more robust statistic for queuing delay

Empty queues periodically

Basic Goals

Avoid **congestion collapse**

+

Efficient and **Fair** allocation of bandwidth

+

Low delay

$$\text{Target rate} = \mathrm{r_t} = \frac{1}{\delta \cdot d_q}$$

Adjustable Parameter
default = 0.5

Queuing delay

Target Rate $\equiv$ Nash Equilibrium

Selfishly optimize for:

$$Utility_i = \log(tput) - \delta_i \log(d_q)$$

Assuming Poisson arrivals (more details in paper)

Target Rate ≡ Nash Equilibrium

↓

Unique and Efficient

Selfishly optimize for:

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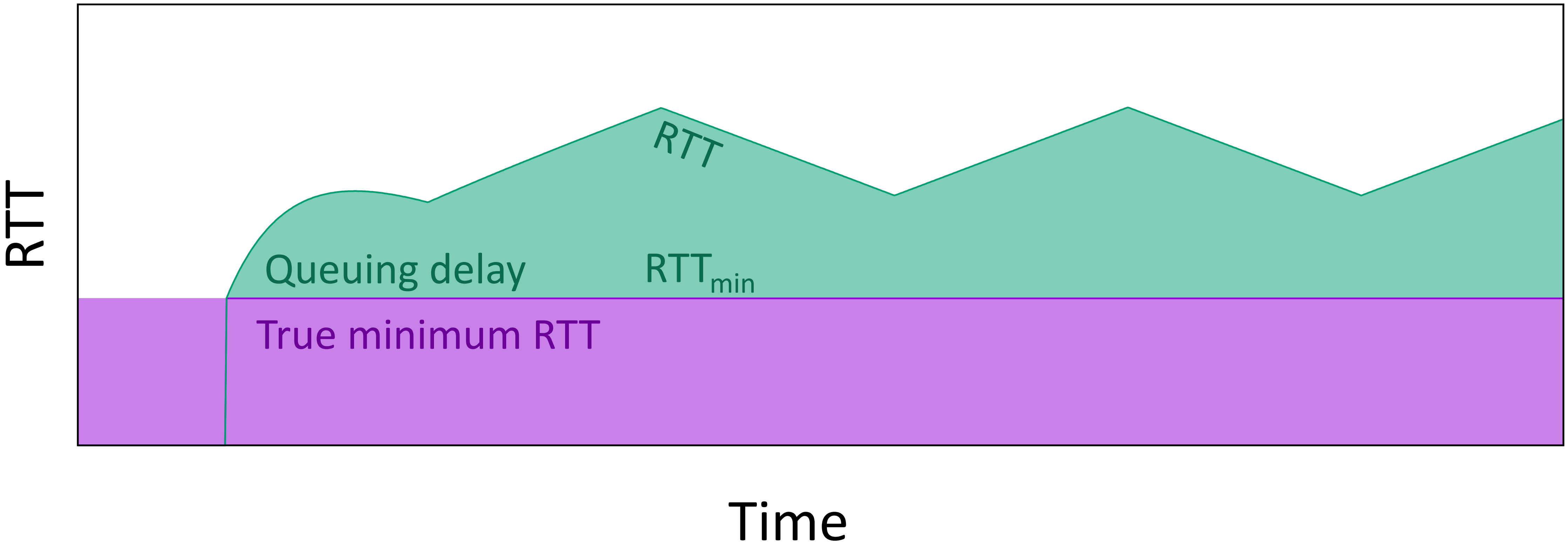
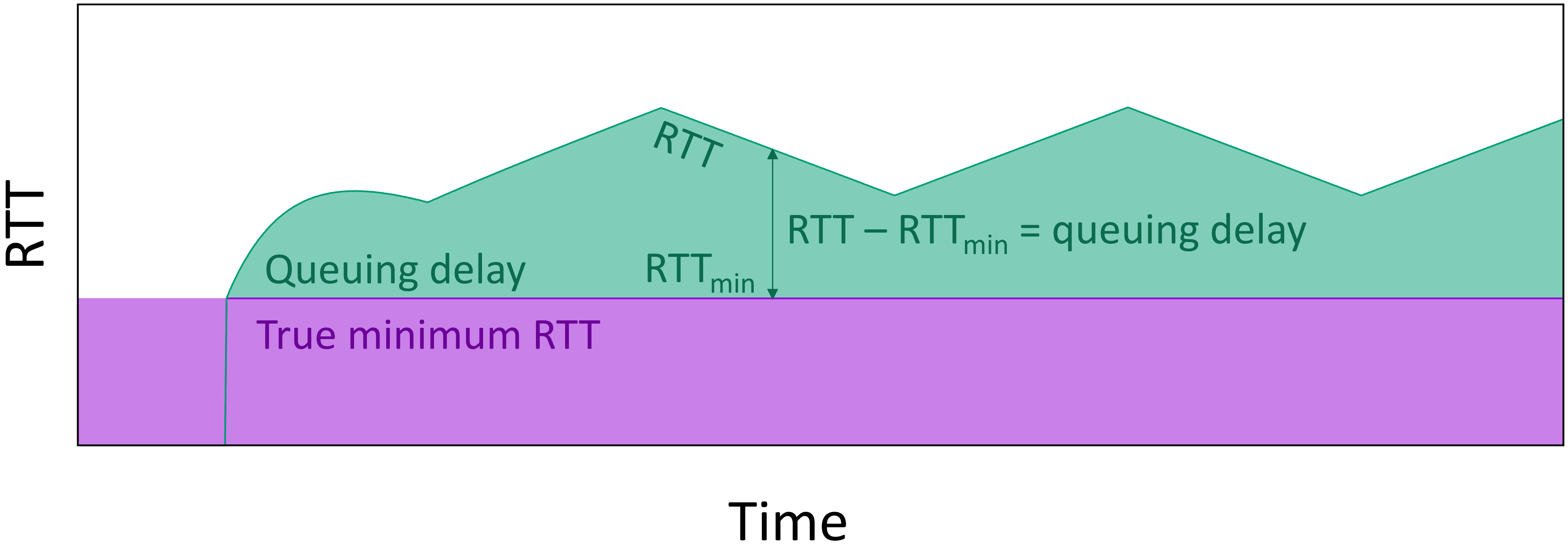
Computing the Target Rate

Estimating queuing delay from RTT



Estimating queuing delay from RTT



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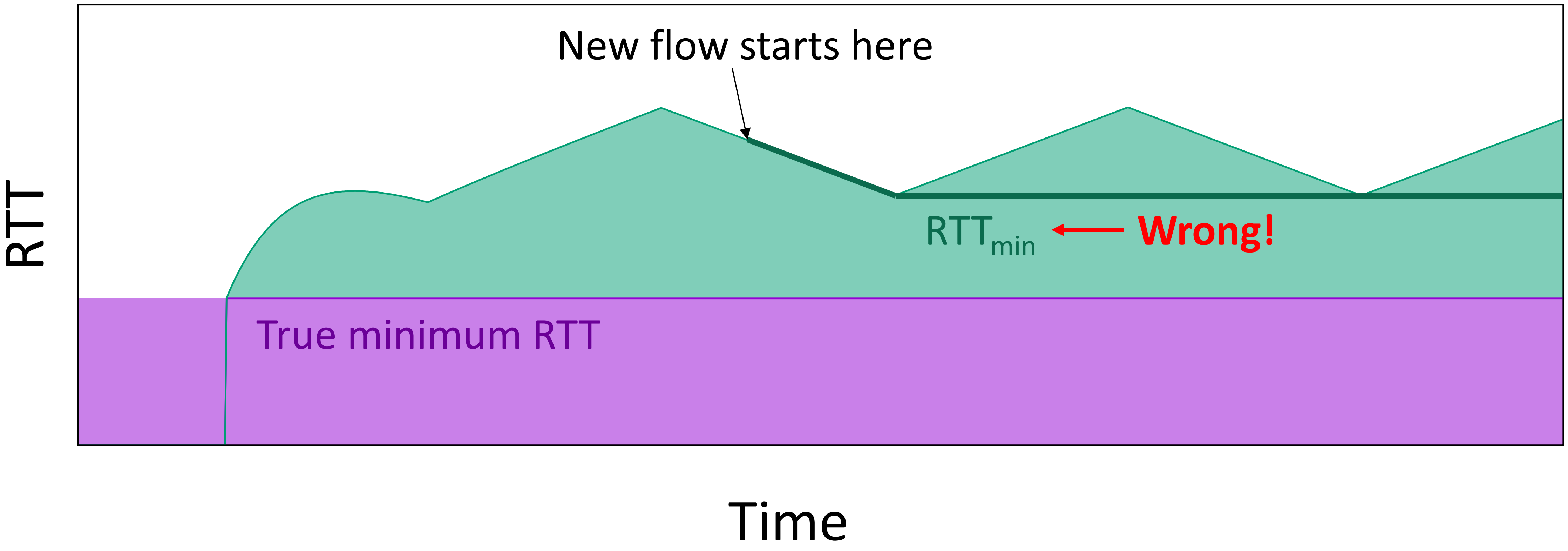

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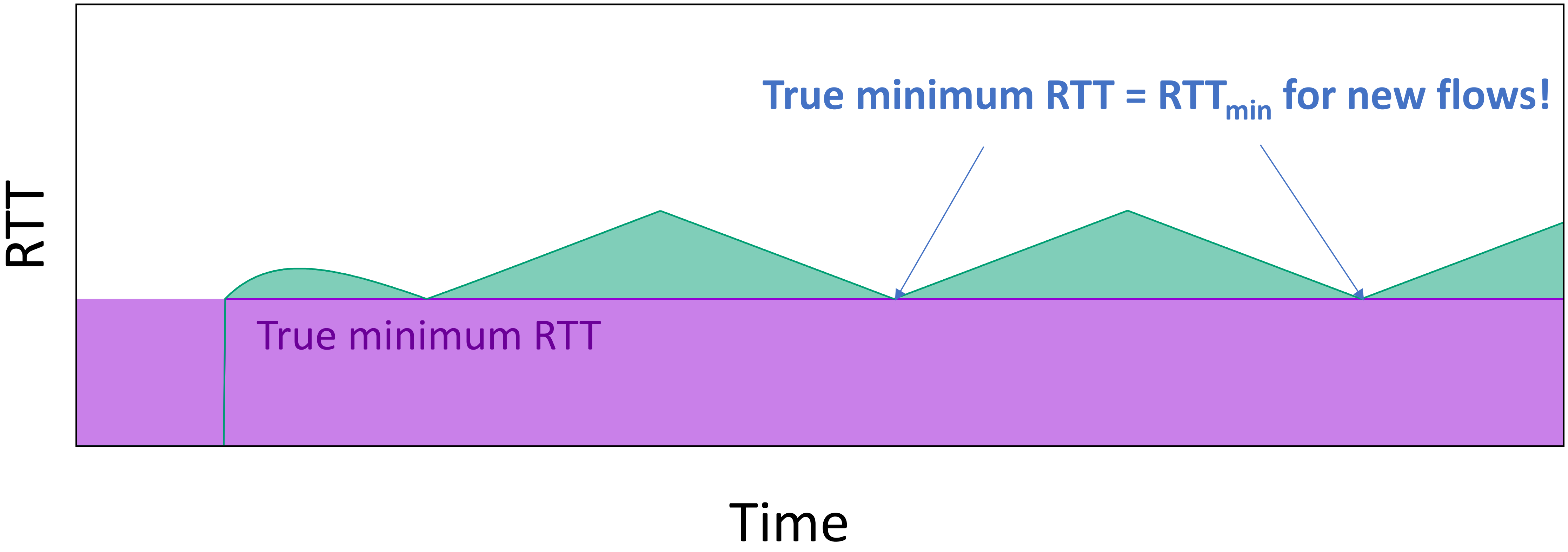
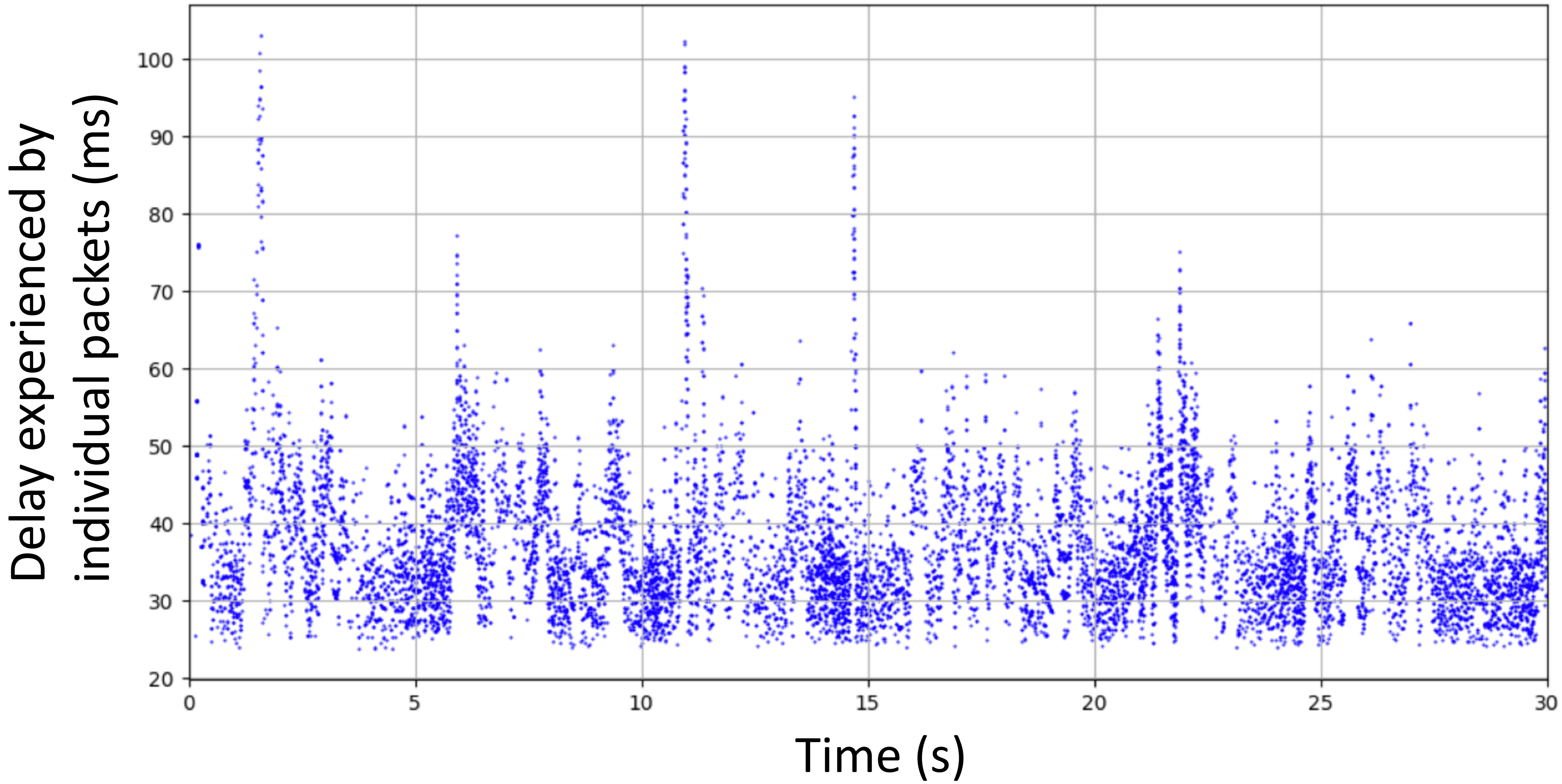
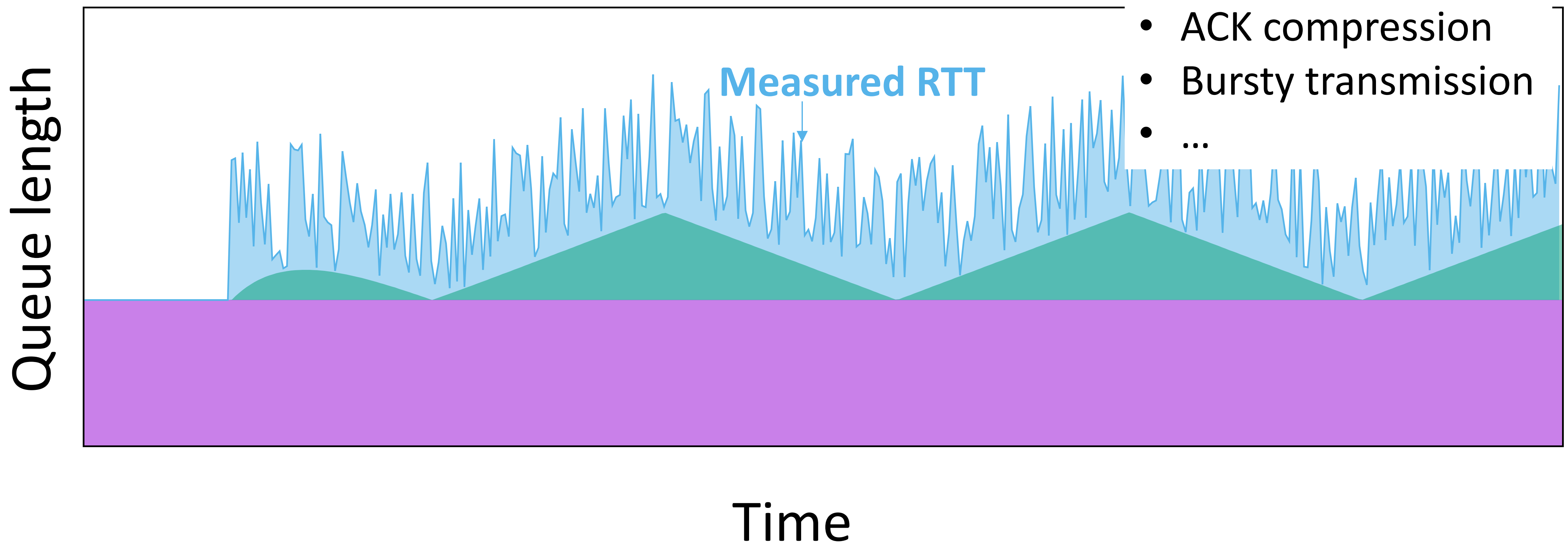


A “noisy” cellular link: Stanford to AWS



Decoupling queuing delay from other delay variation



- Wireless links
- Cross traffic
- ACK compression
- Bursty transmission
- …

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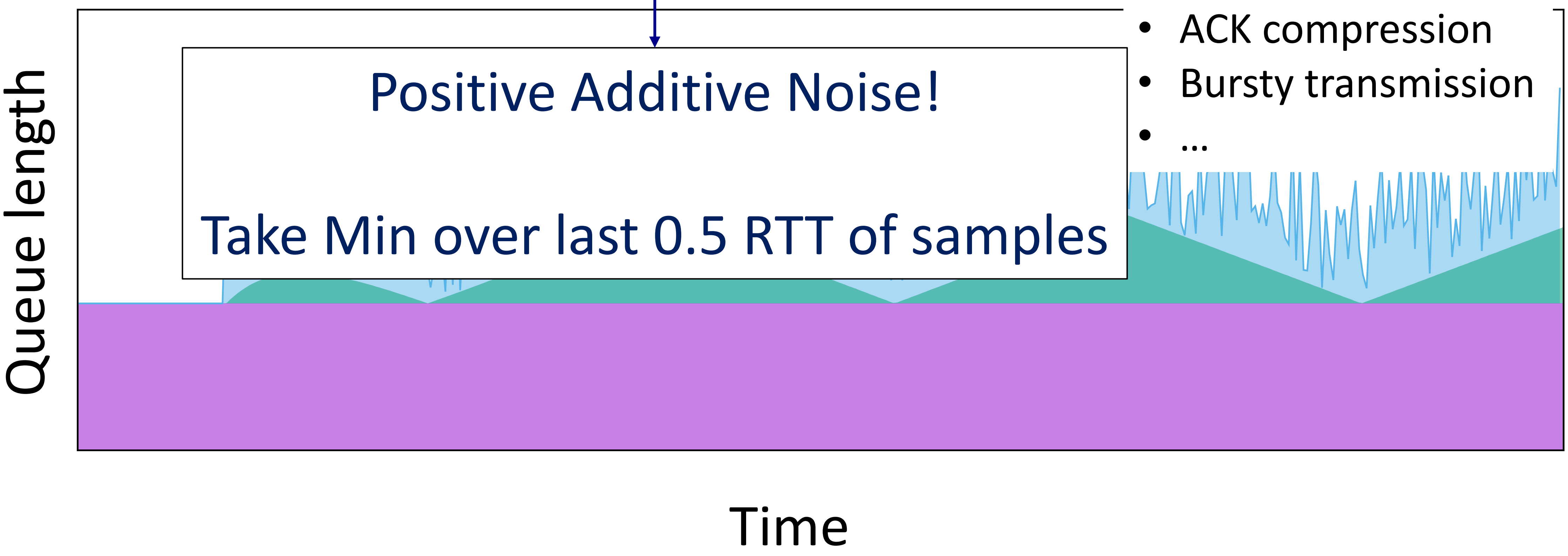

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Positive Additive Noise!

Take Min over last 0.5 RTT of samples

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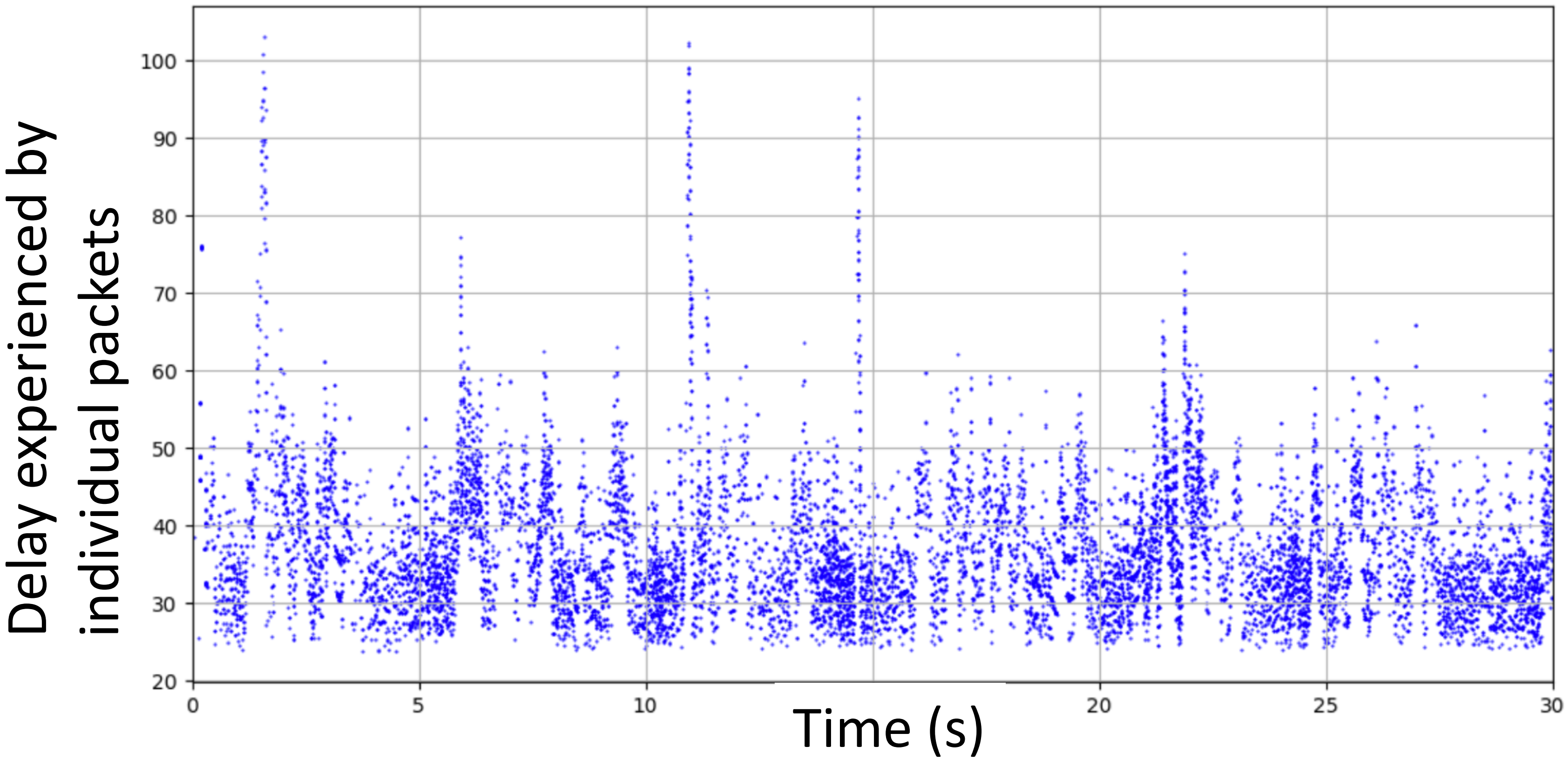

Using the MIN delay estimator improves throughput from **0.5 Mbits/s** to **3.9 Mbits/s**

Attaining the Target

The Copa Algorithm

Calculate target rate $= r_t = \frac{1}{\delta d_q}$

If current rate $< \mathrm{r_t}$: additively increase by $\frac{v}{\delta}$ pkts/RTT

Else: additively decrease by $\frac{v}{\delta}$ pkts/RTT

The Copa Algorithm

Calculate target rate $= r_t = \frac{1}{\delta d_q}$

Velocity for faster convergence

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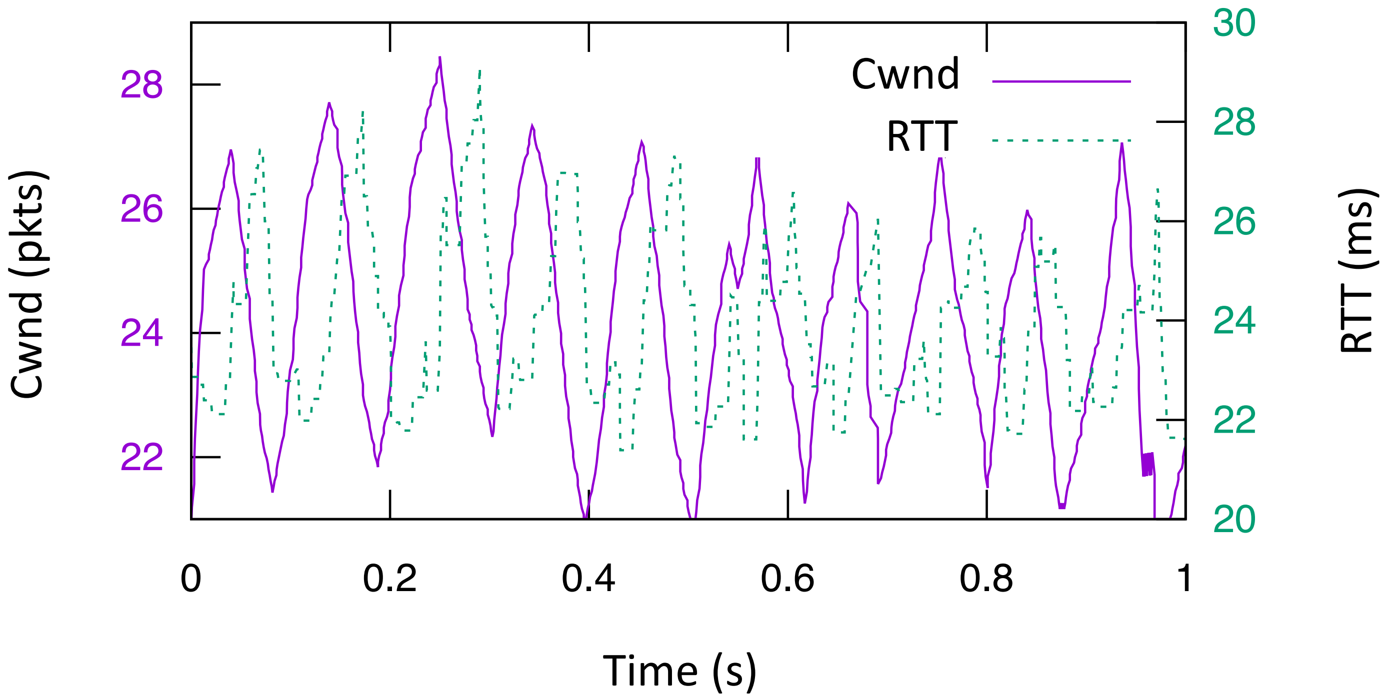
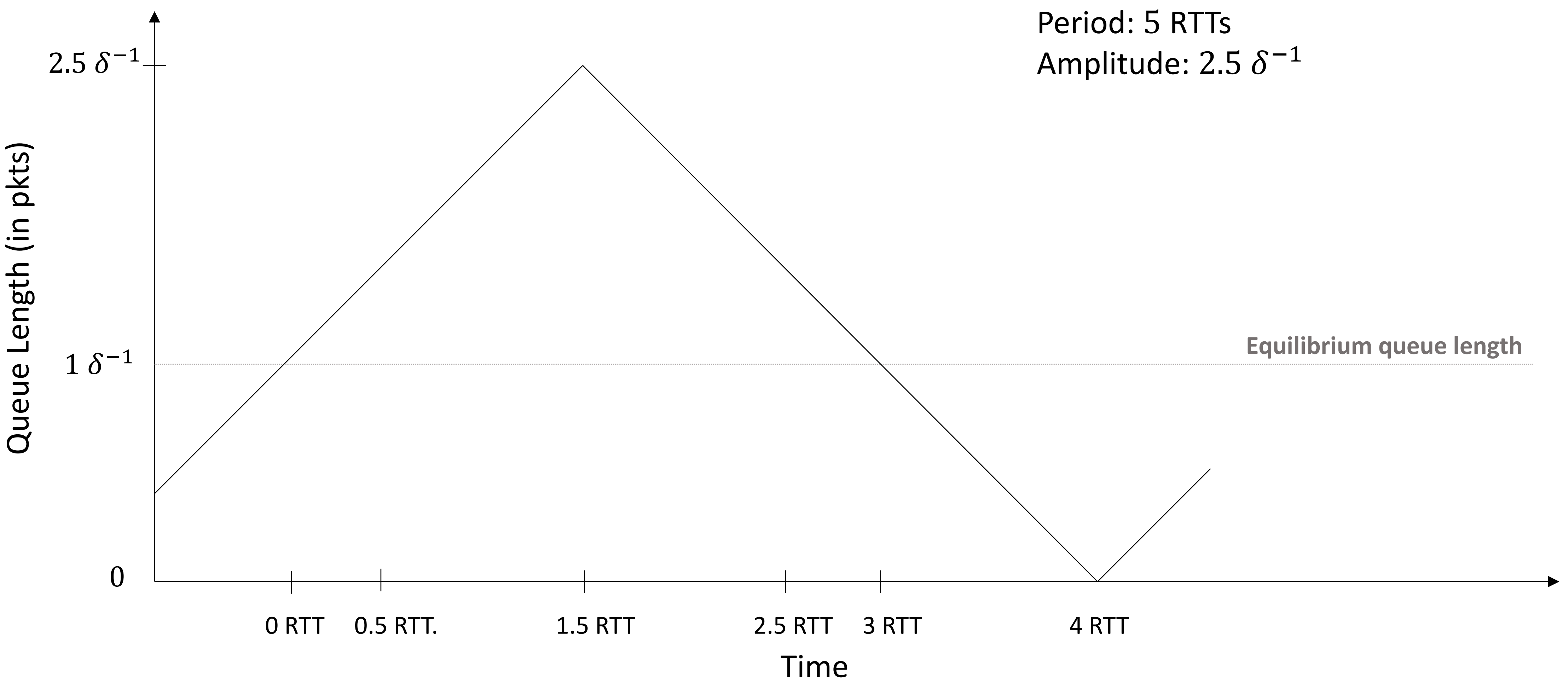


Steady-State Dynamics of Copa



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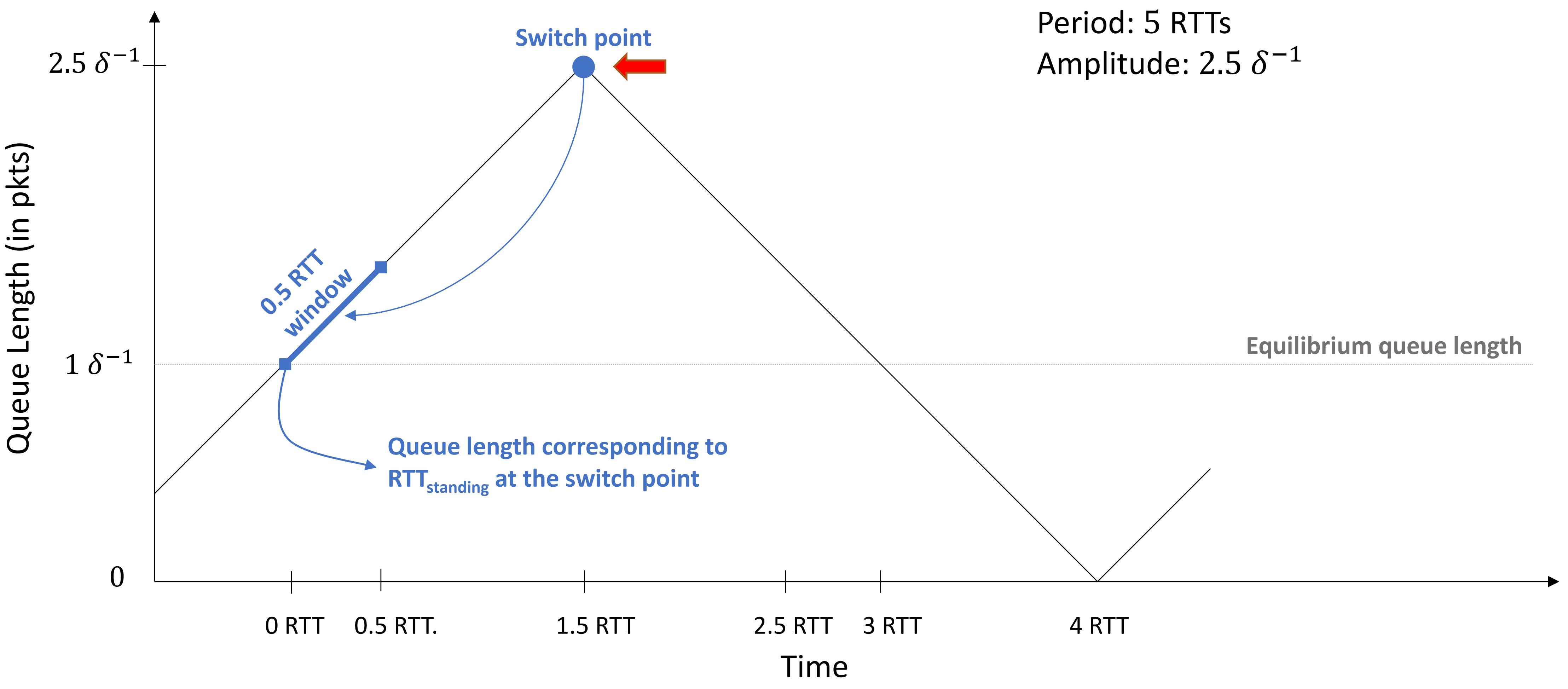

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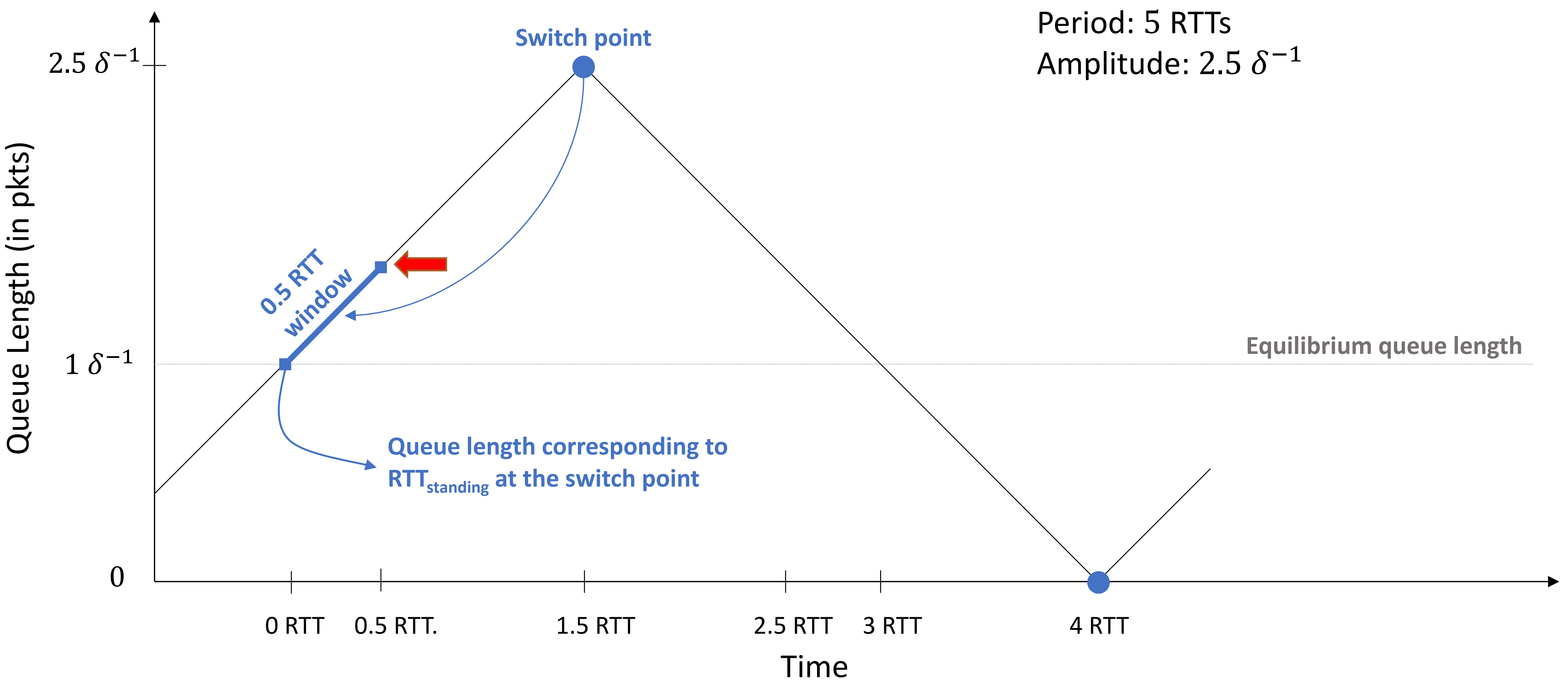

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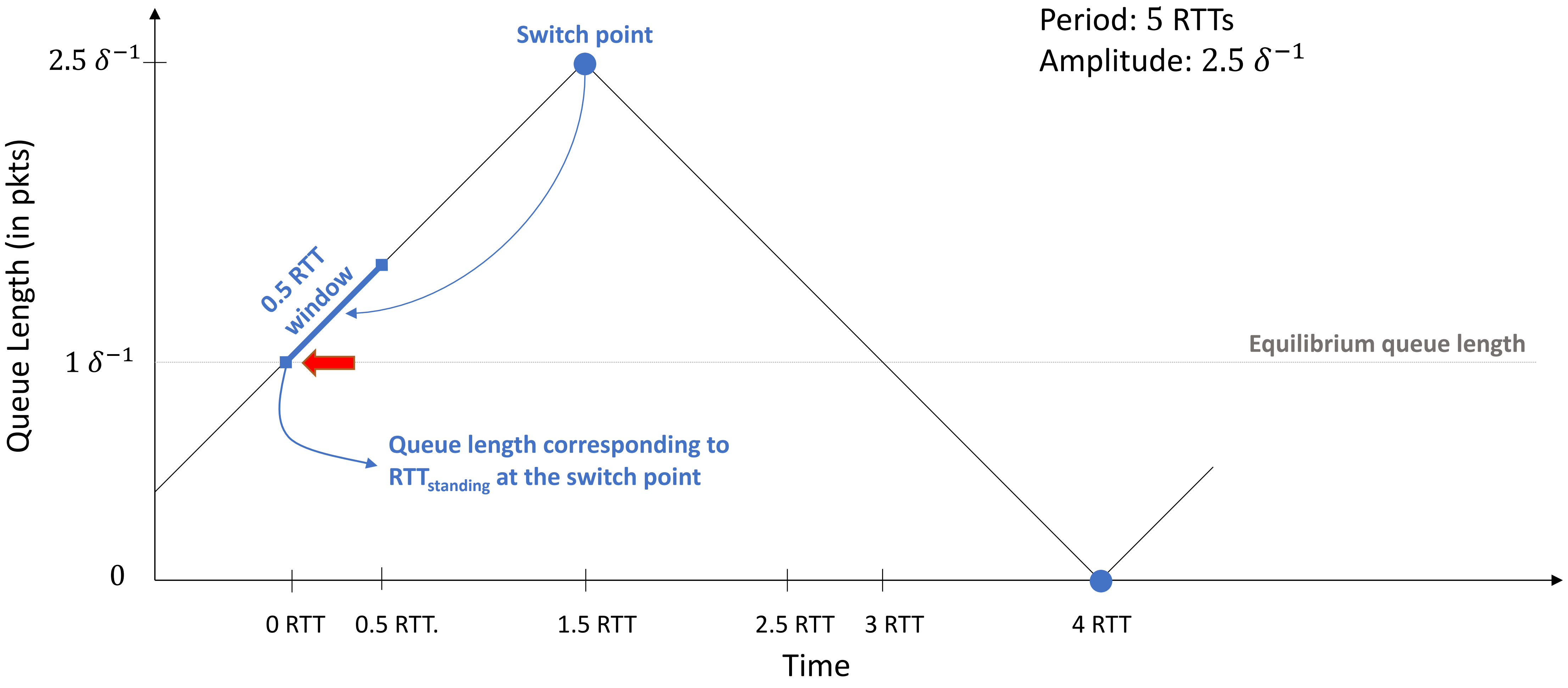

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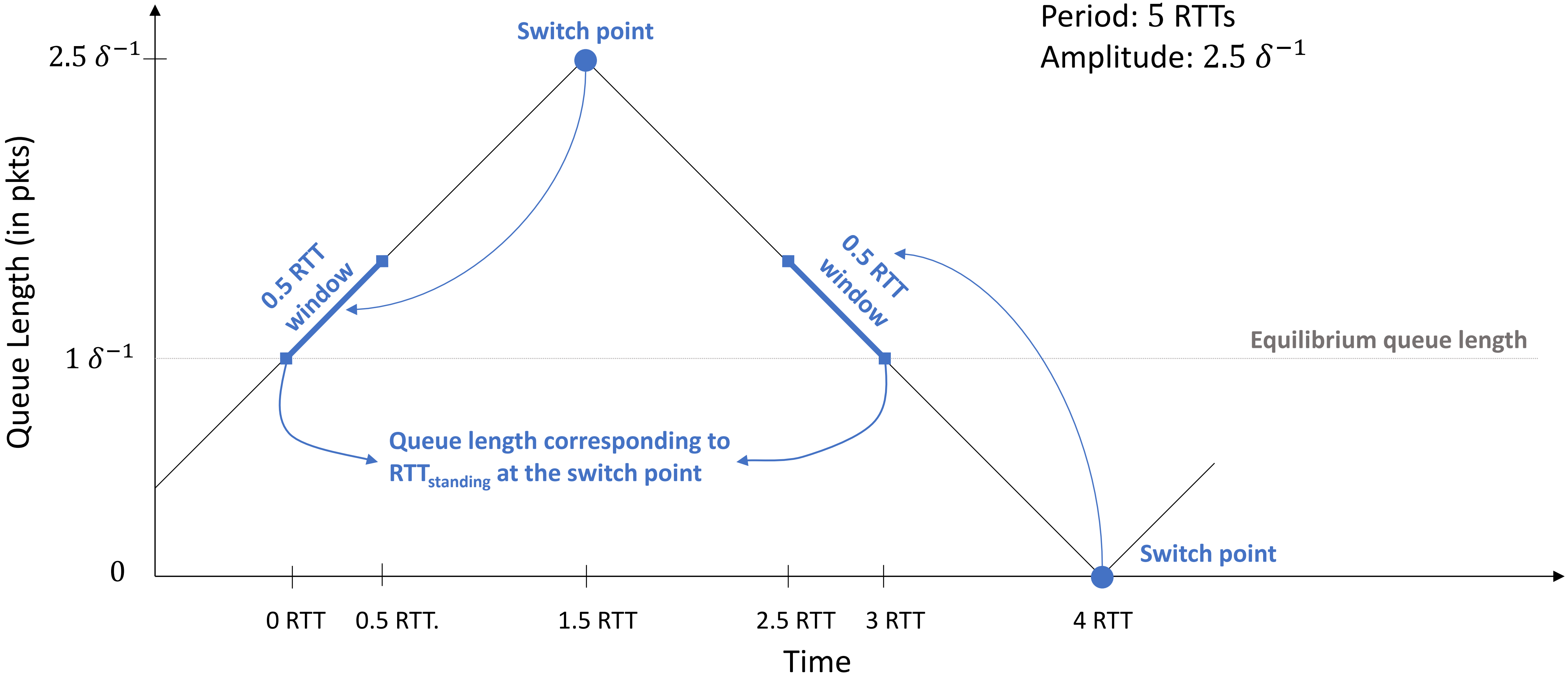


Estimate true minimum RTT

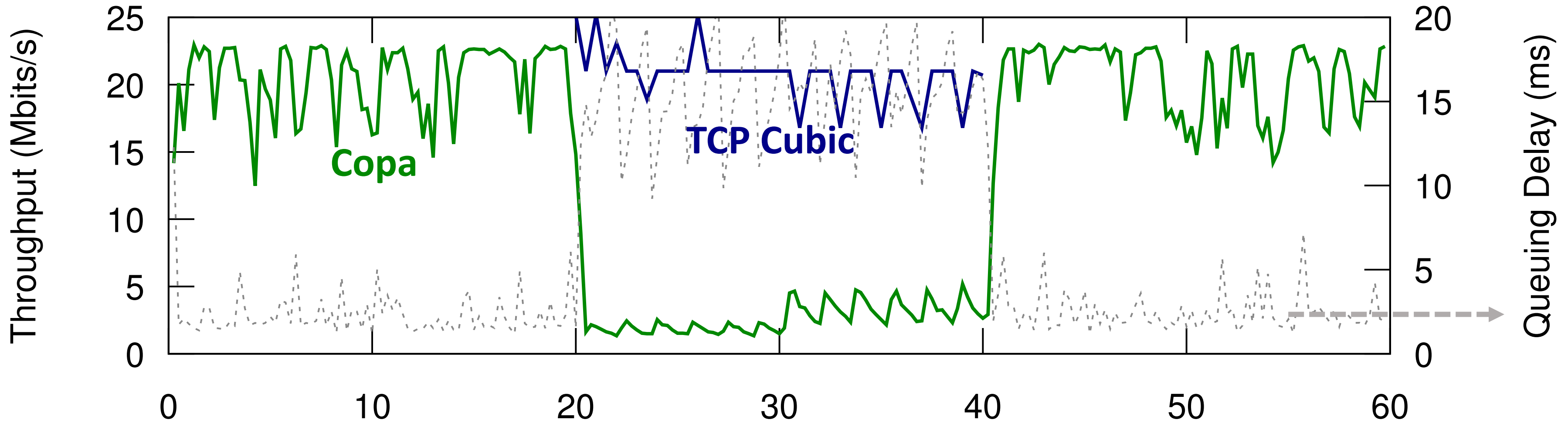
Queue empties every 5 RTTs! ⇒

Detect buffer-filling TCP

TCP-Competitiveness

Mode switching for TCP competitiveness

Delay sensitive
($\delta = 0.5$)



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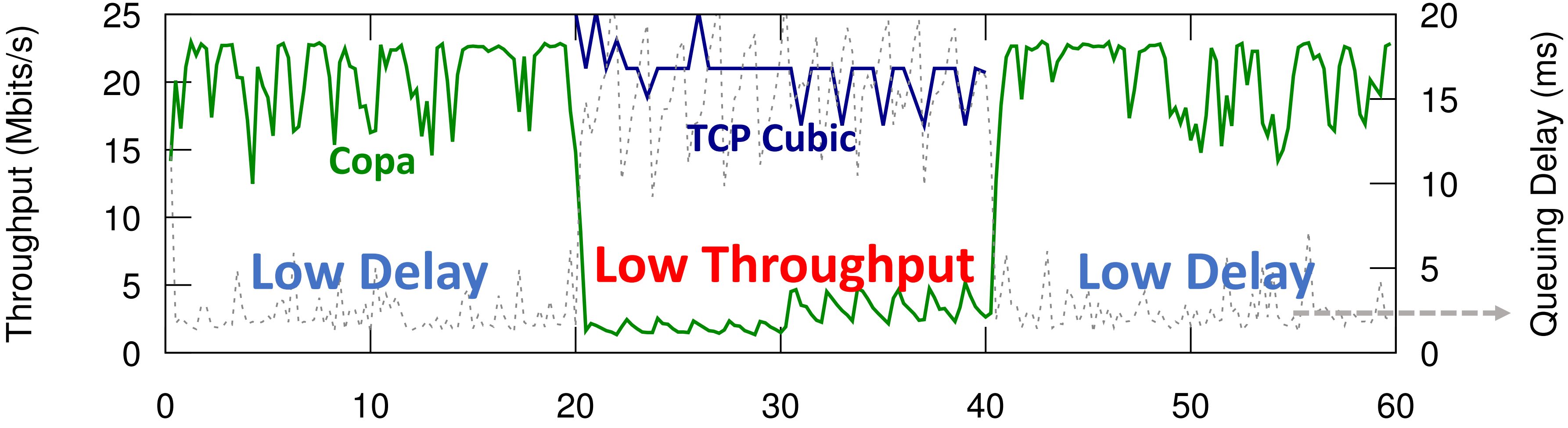

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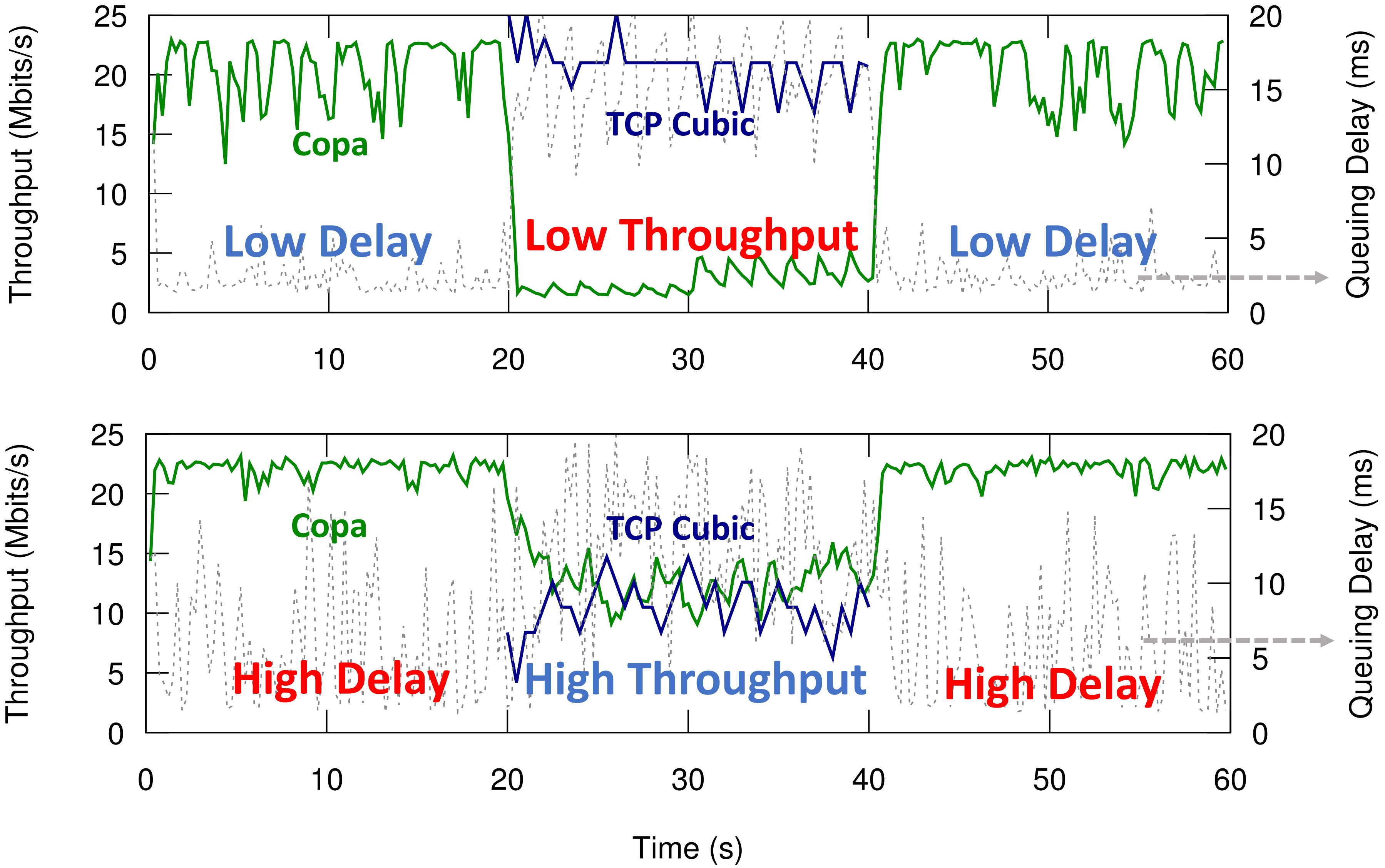

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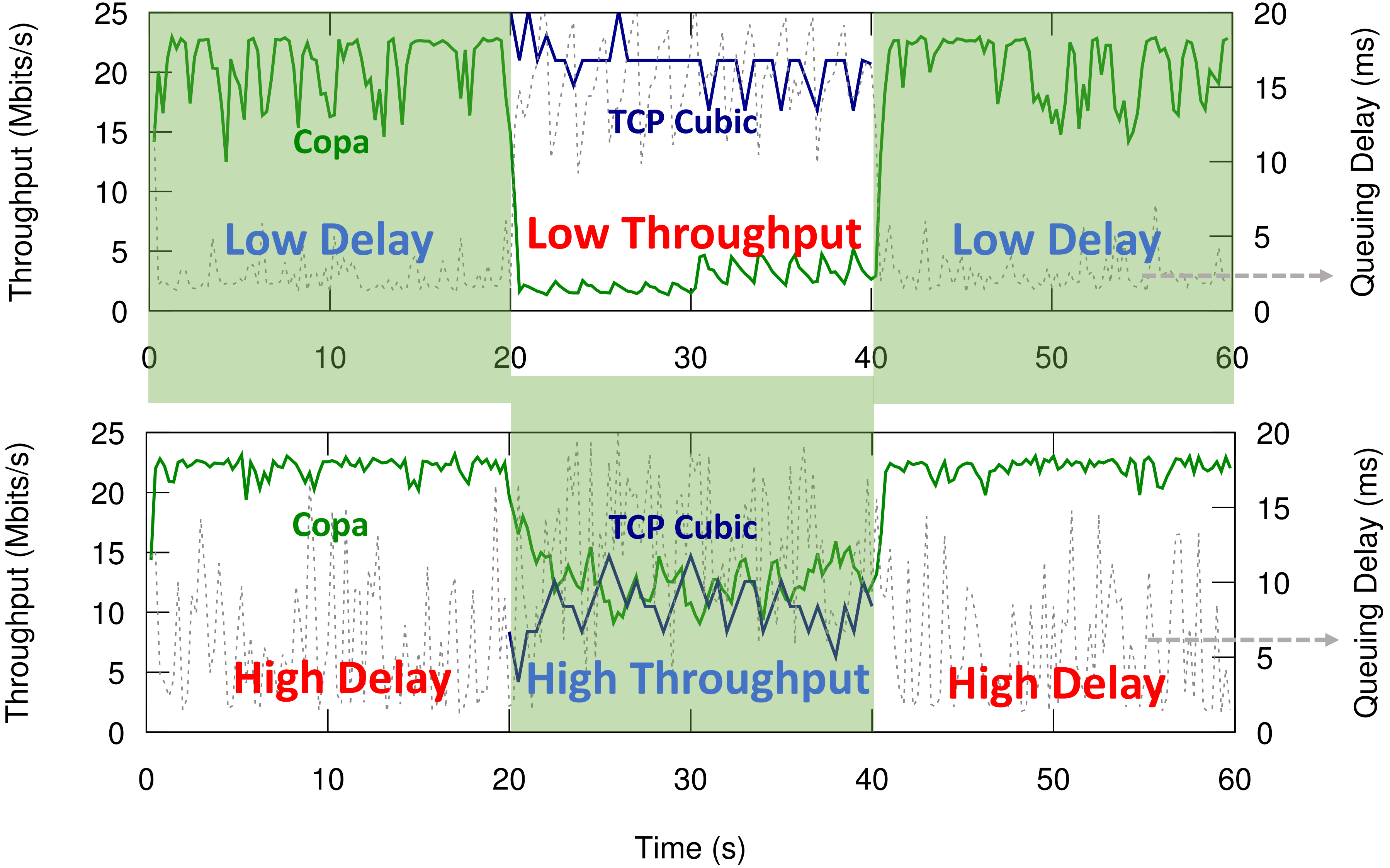

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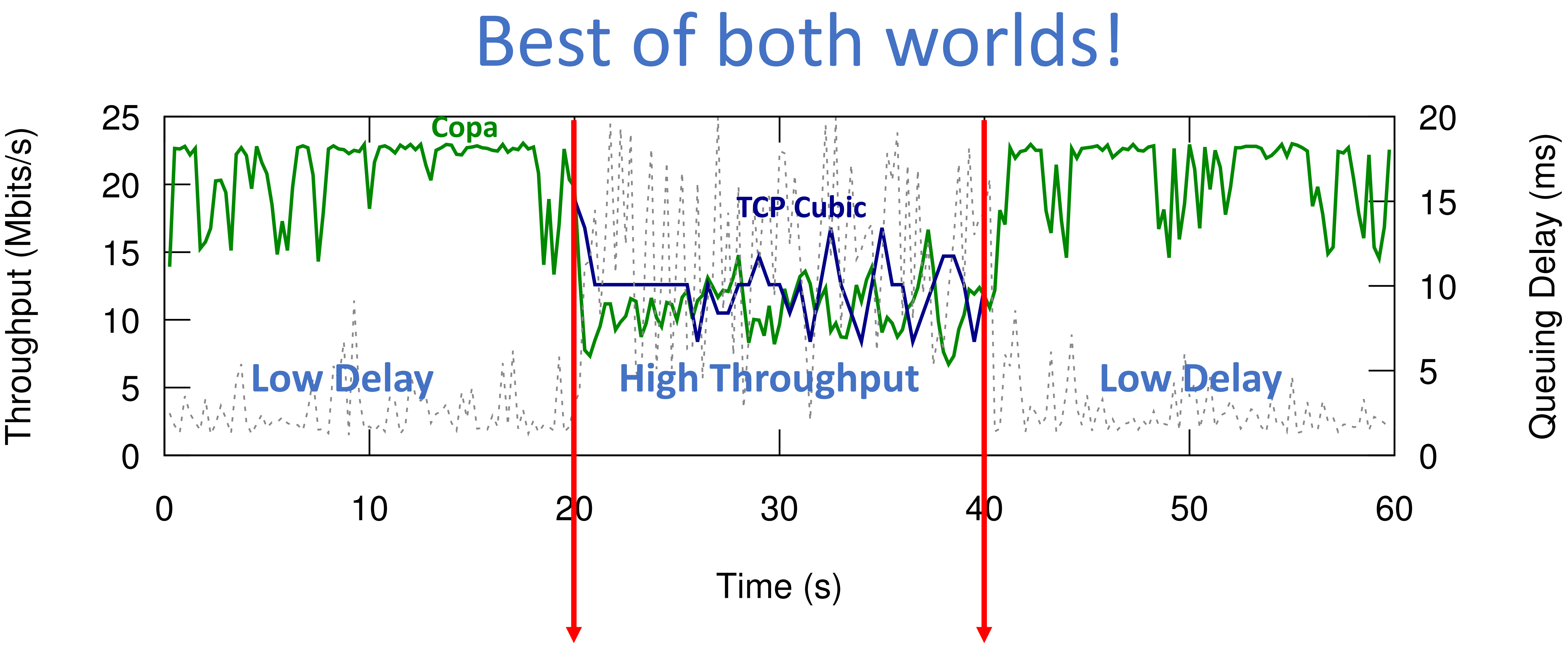
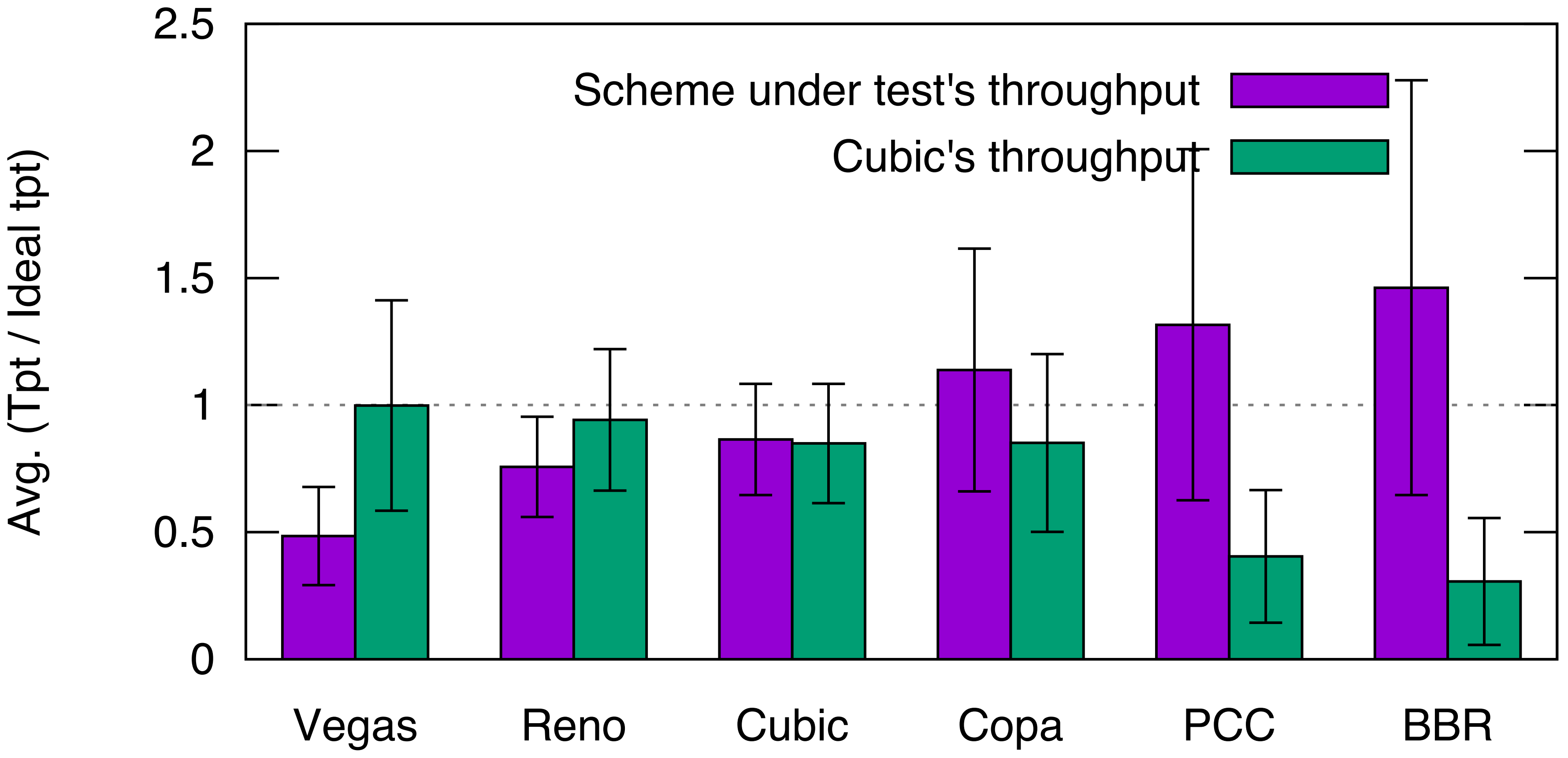


When queue doesn't empty once every 5 RTTs, switch to TCP Competitive mode!

Copa gets higher throughput without hurting TCP Cubic!



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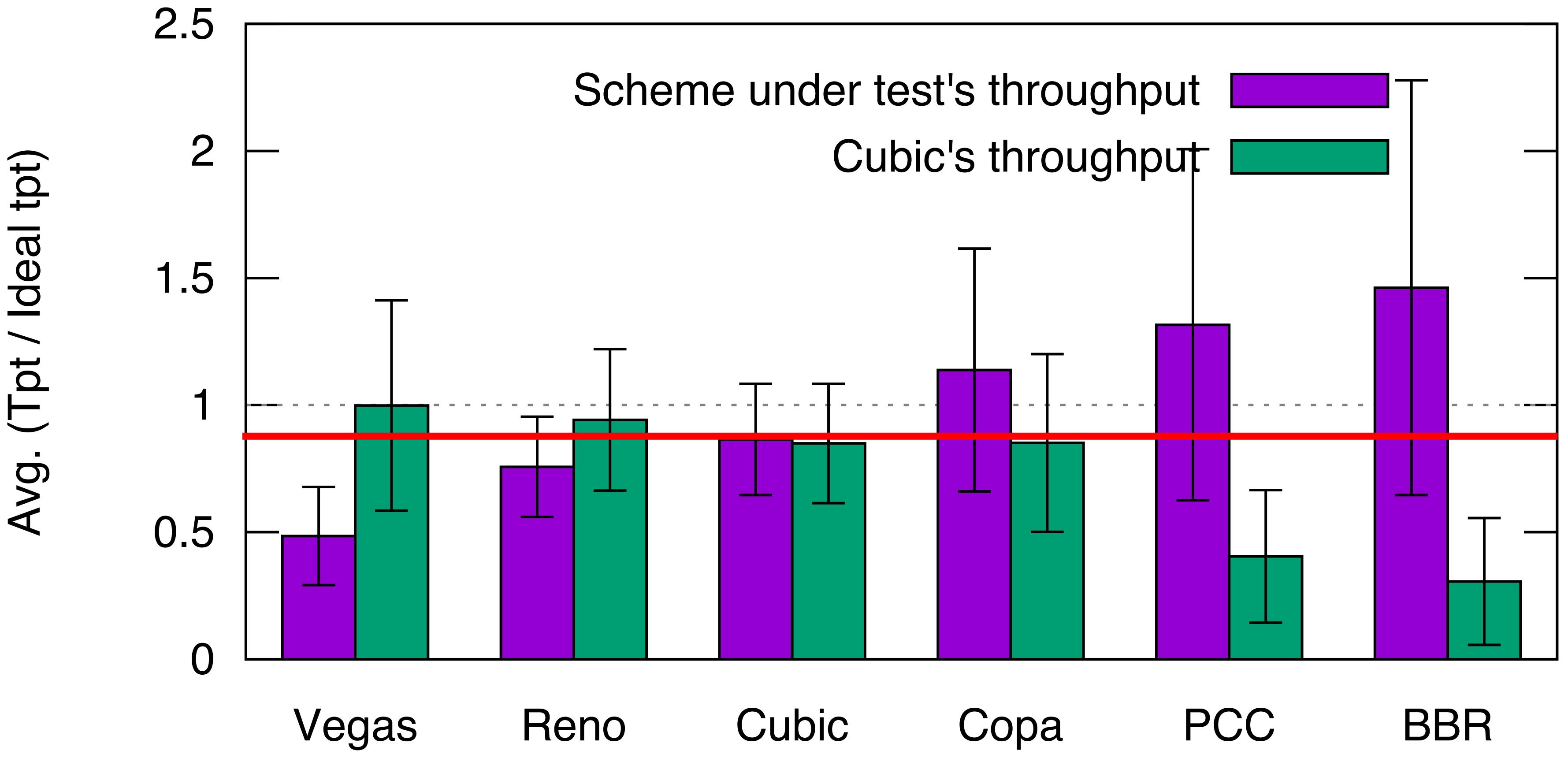

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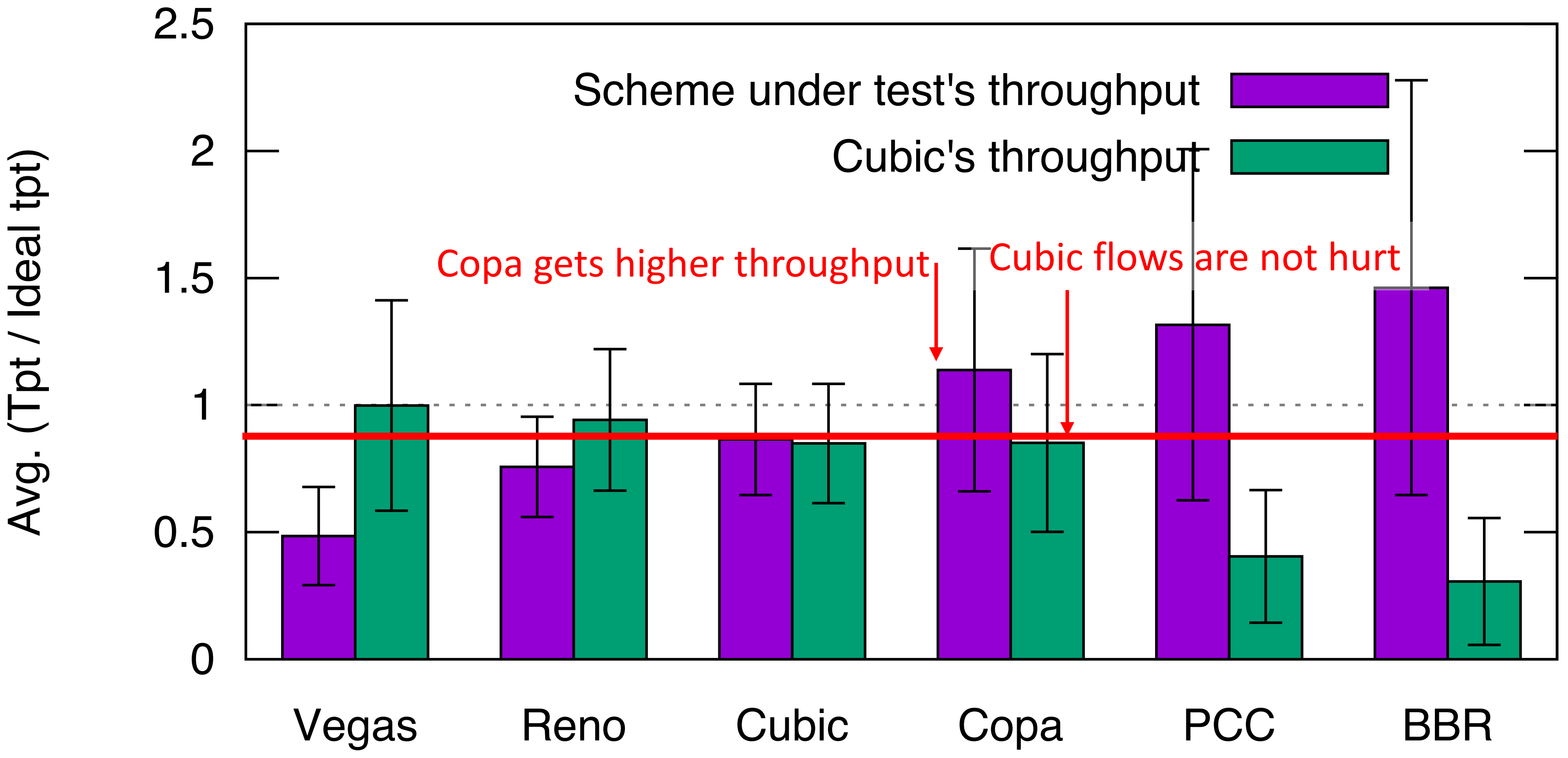
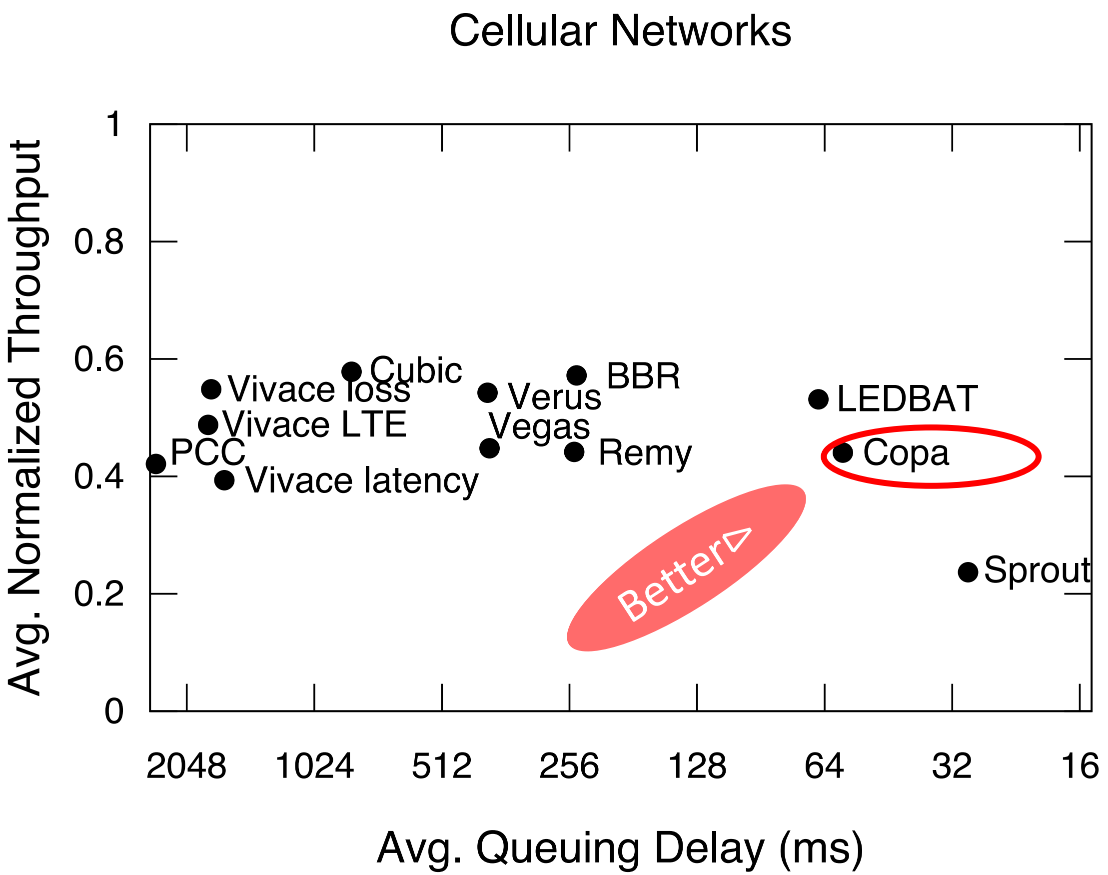
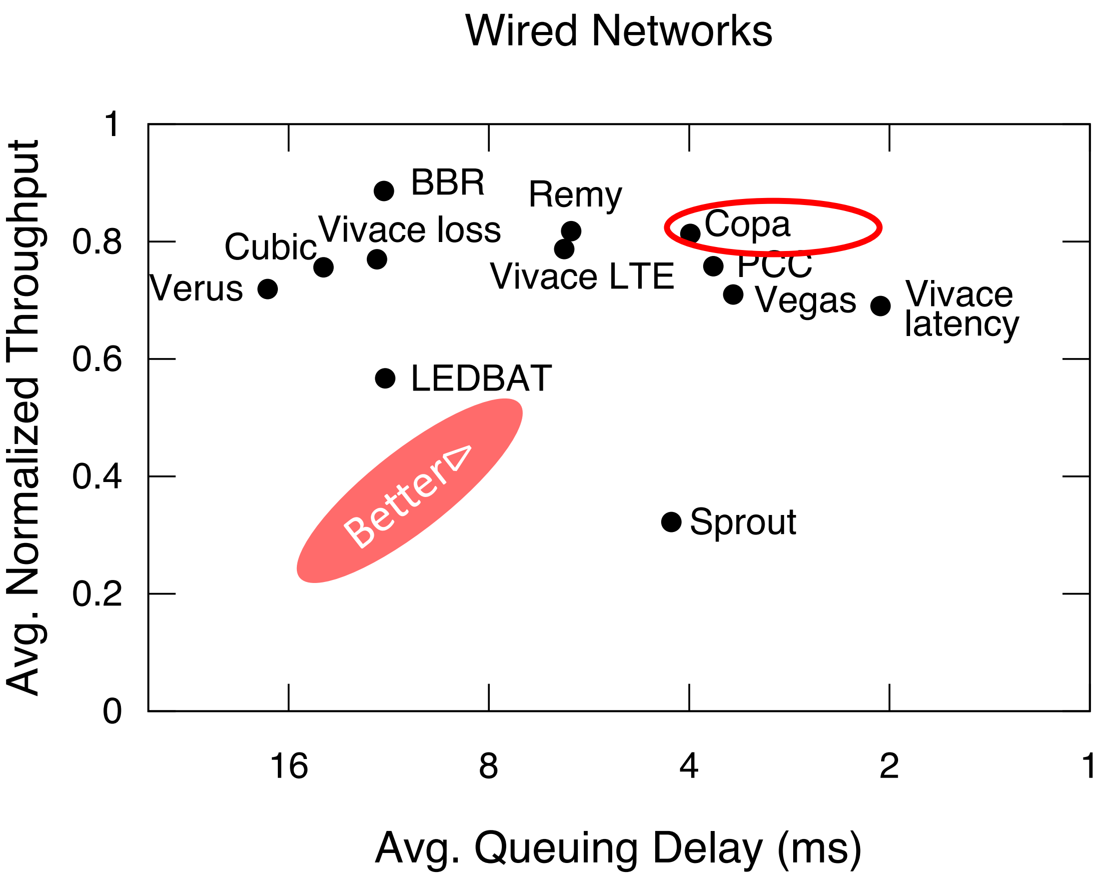


Limitations

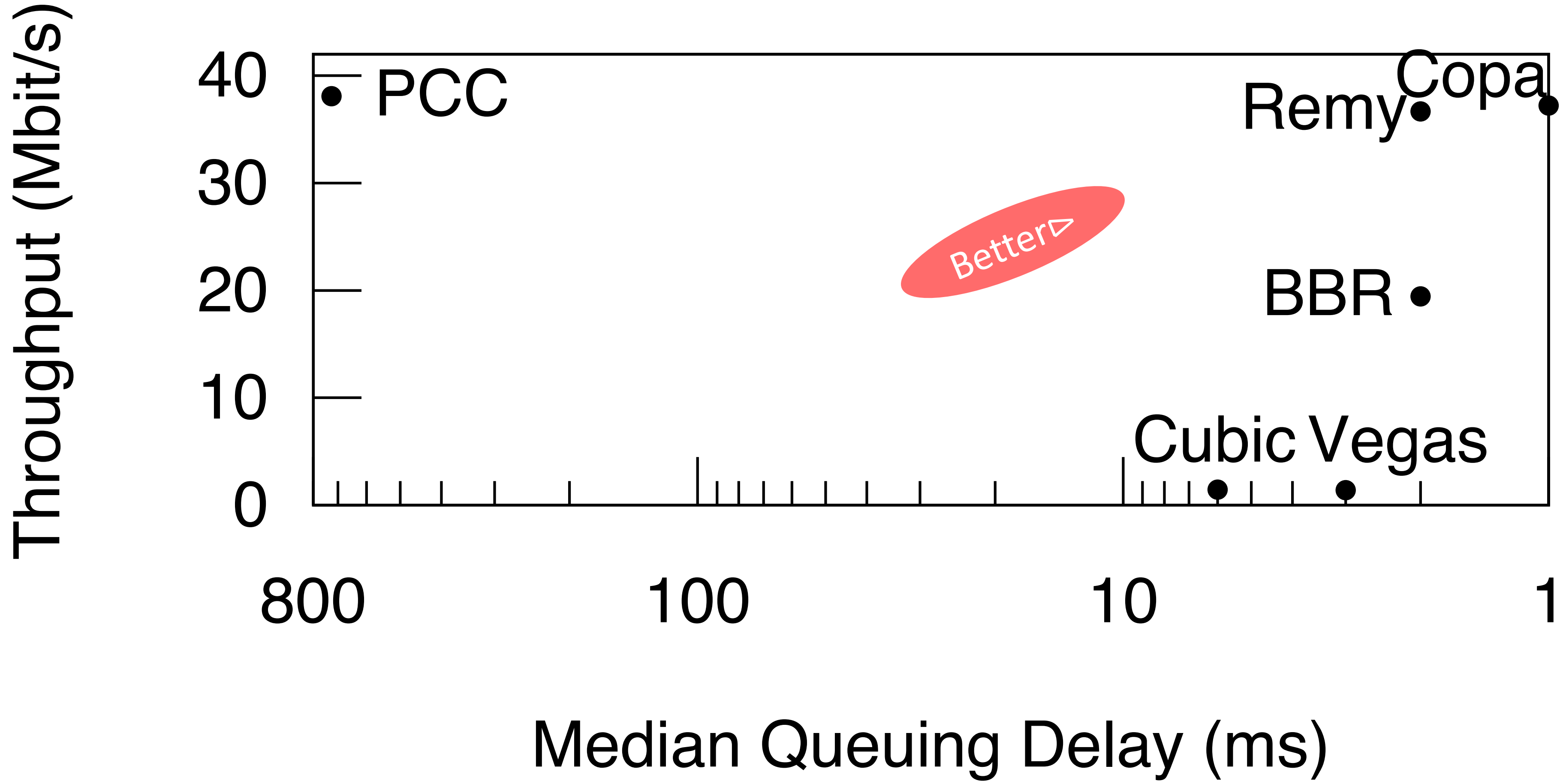
- Cannot ignore low frequency noise
- Queues don’t empty periodically if:
  - Propagation delay is much smaller than queuing delay
  - Flows with very different propagation delays share a bottleneck queue
- Needs precise RTT measurements

Consistent Performance on Real Paths

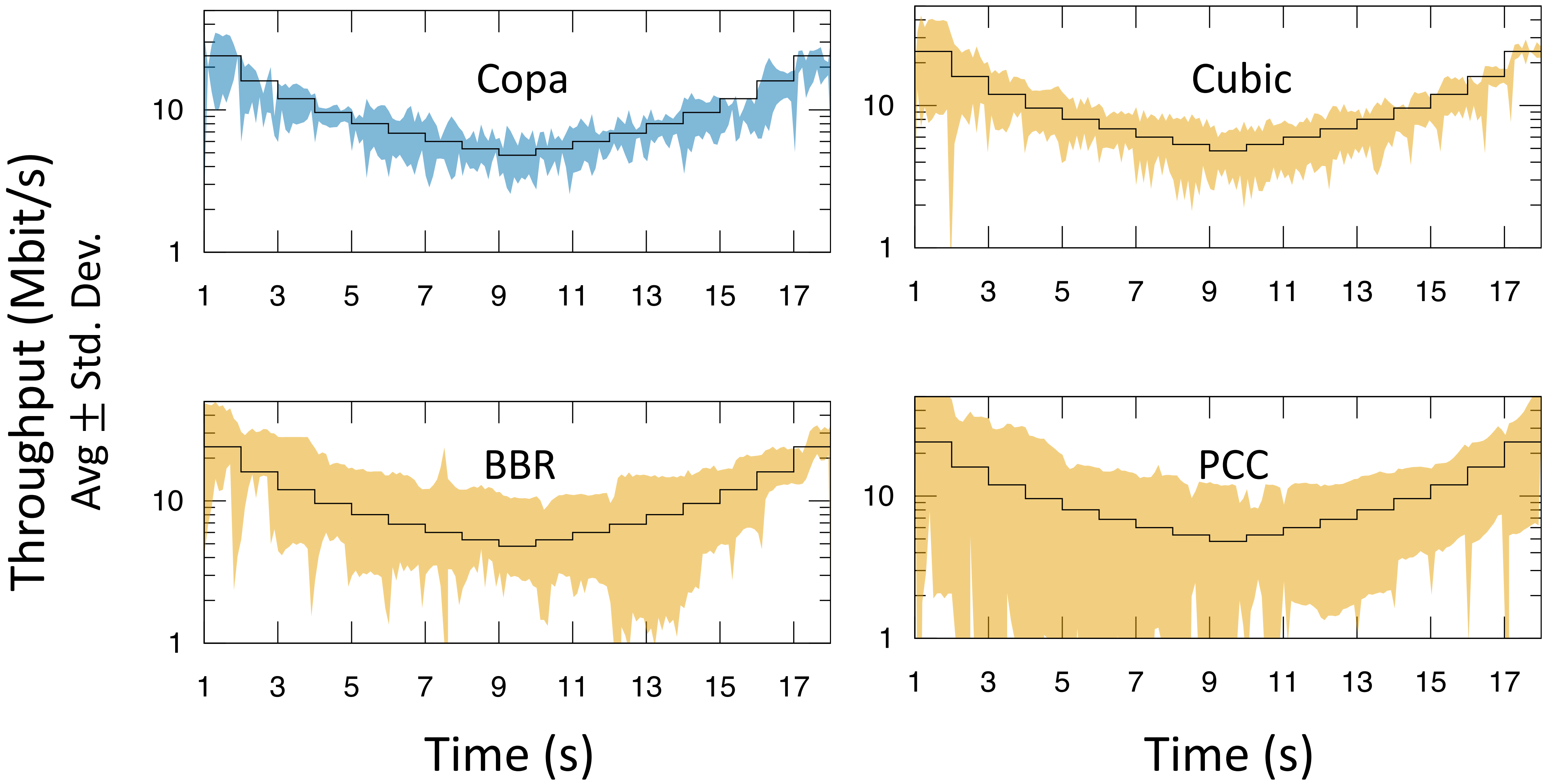




Satellite link: High BDP, high loss



Fairness during flow-churn



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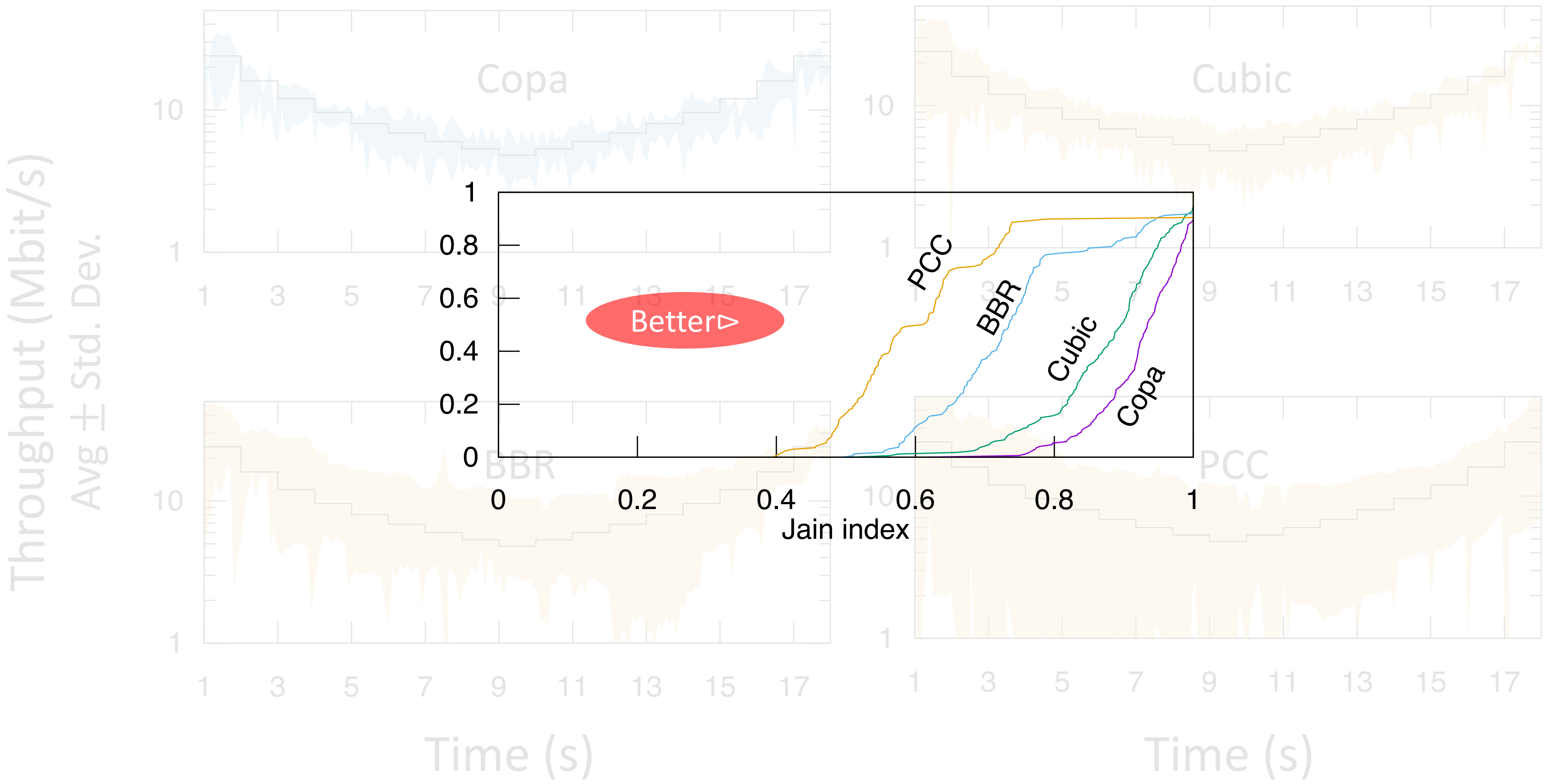
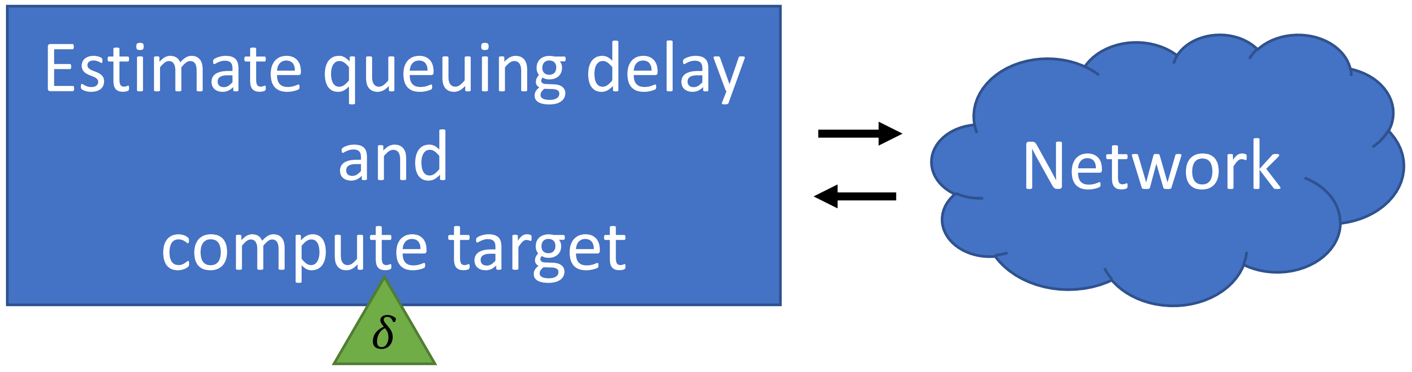


Summary

A ***practical*** delay-based congestion control algorithm

https://web.mit.edu/copa



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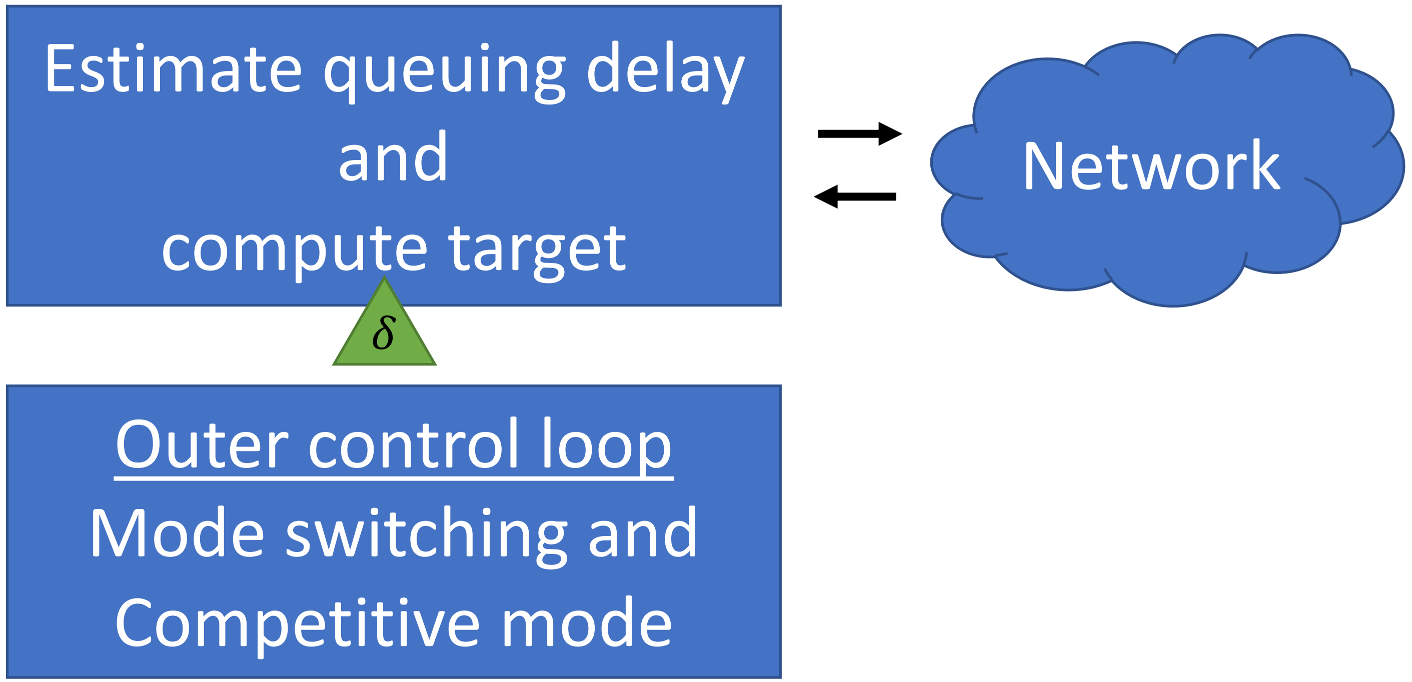

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