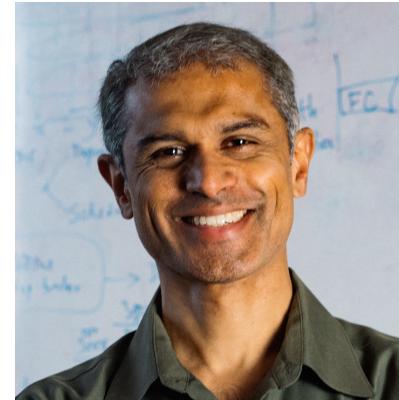


Copa: Practical Delay-Based Congestion Control



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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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Higher bandwidth-delay product

Greater bandwidth \Rightarrow Lower tolerance for non-congestive loss

Greater flow-churn

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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
- 
- Worsens with increasing bandwidth**

Delay-based congestion control?

Benefits

Challenges

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Maintain low delay

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Not competitive with
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Finding true minimum RTT
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If buffer-fillers are present,
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MIN: a more robust statistic for
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Our Solution

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MIN: a more robust statistic for
queuing delay

Empty queues periodically

Basic Goals

Avoid **congestion collapse**

+

Efficient and Fair allocation of bandwidth

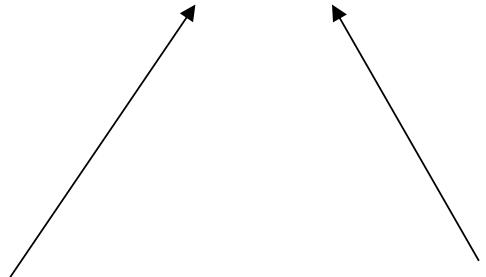
+

Low delay

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

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 \equiv Nash Equilibrium



Unique and Efficient

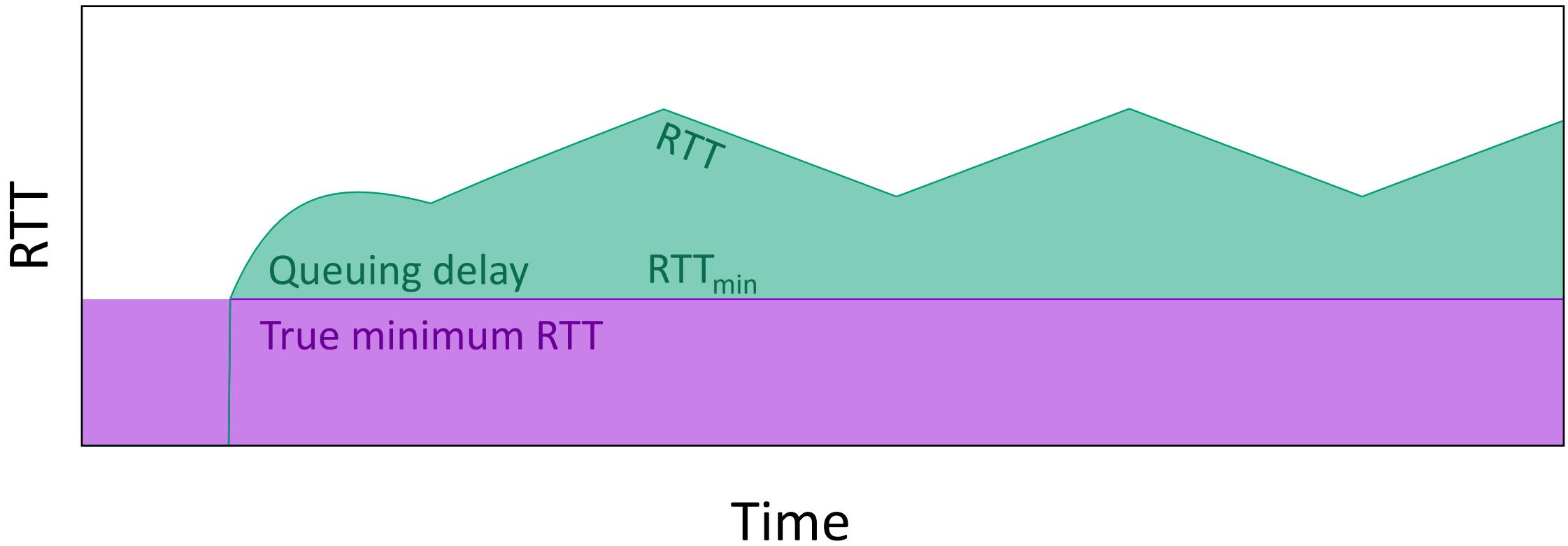
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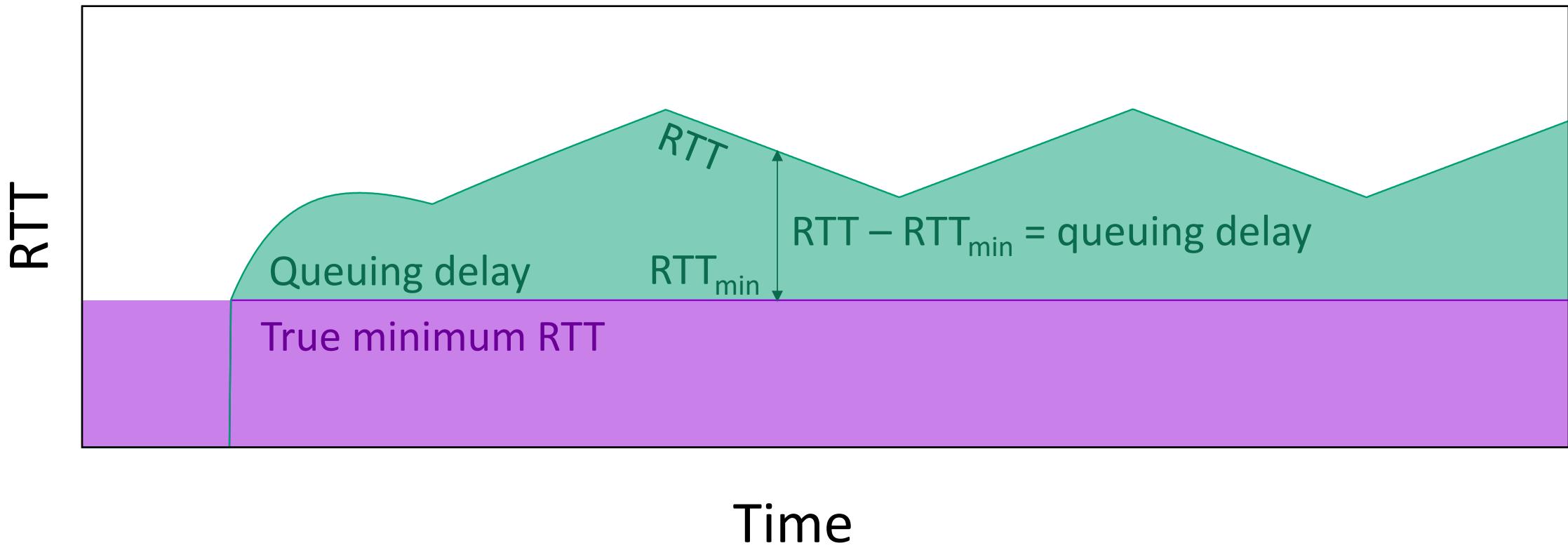
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Computing the Target Rate

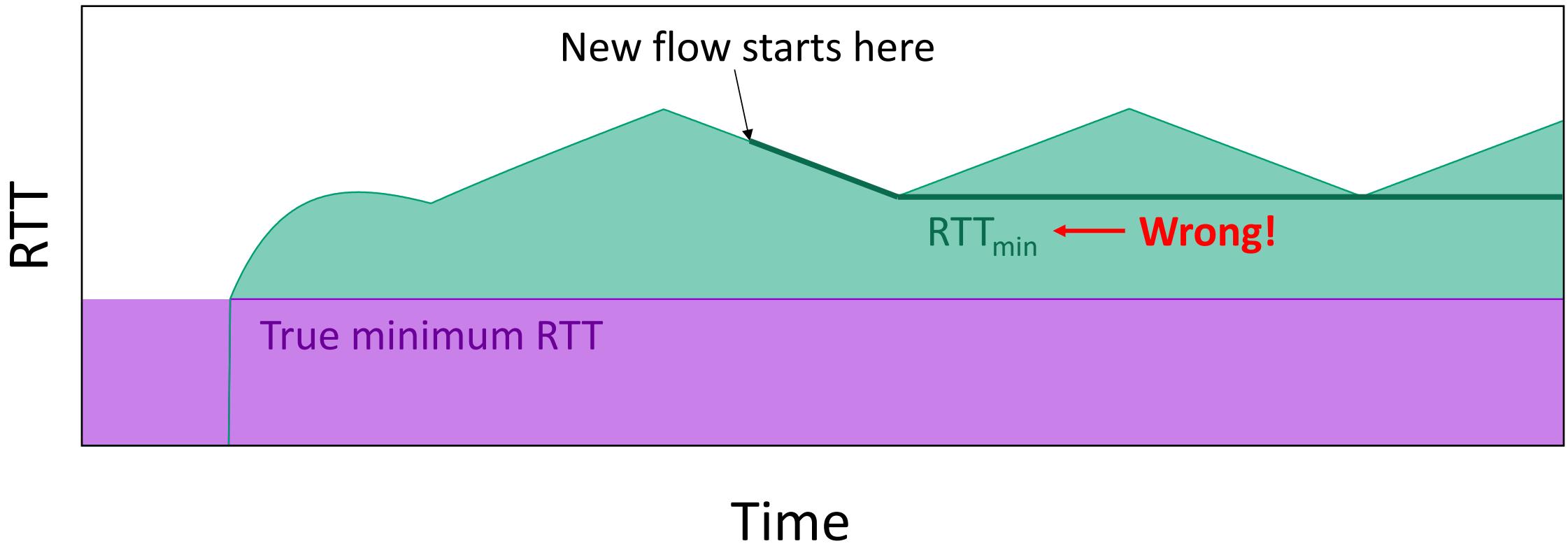
Estimating queuing delay from RTT



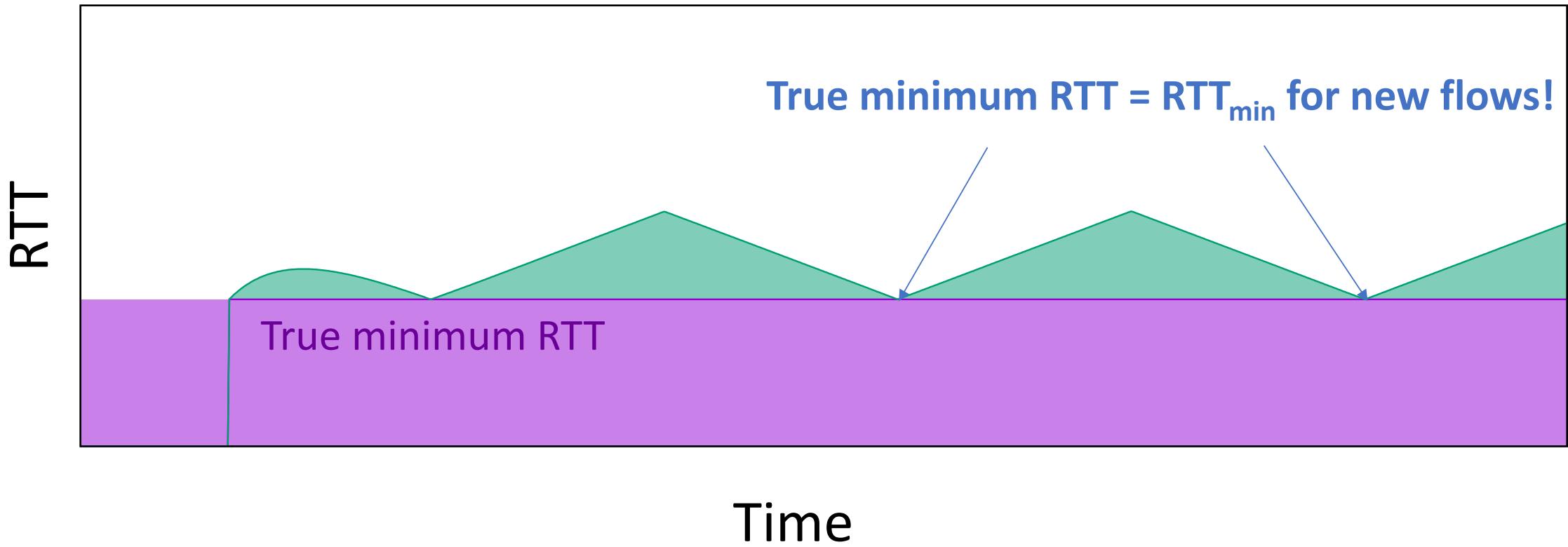
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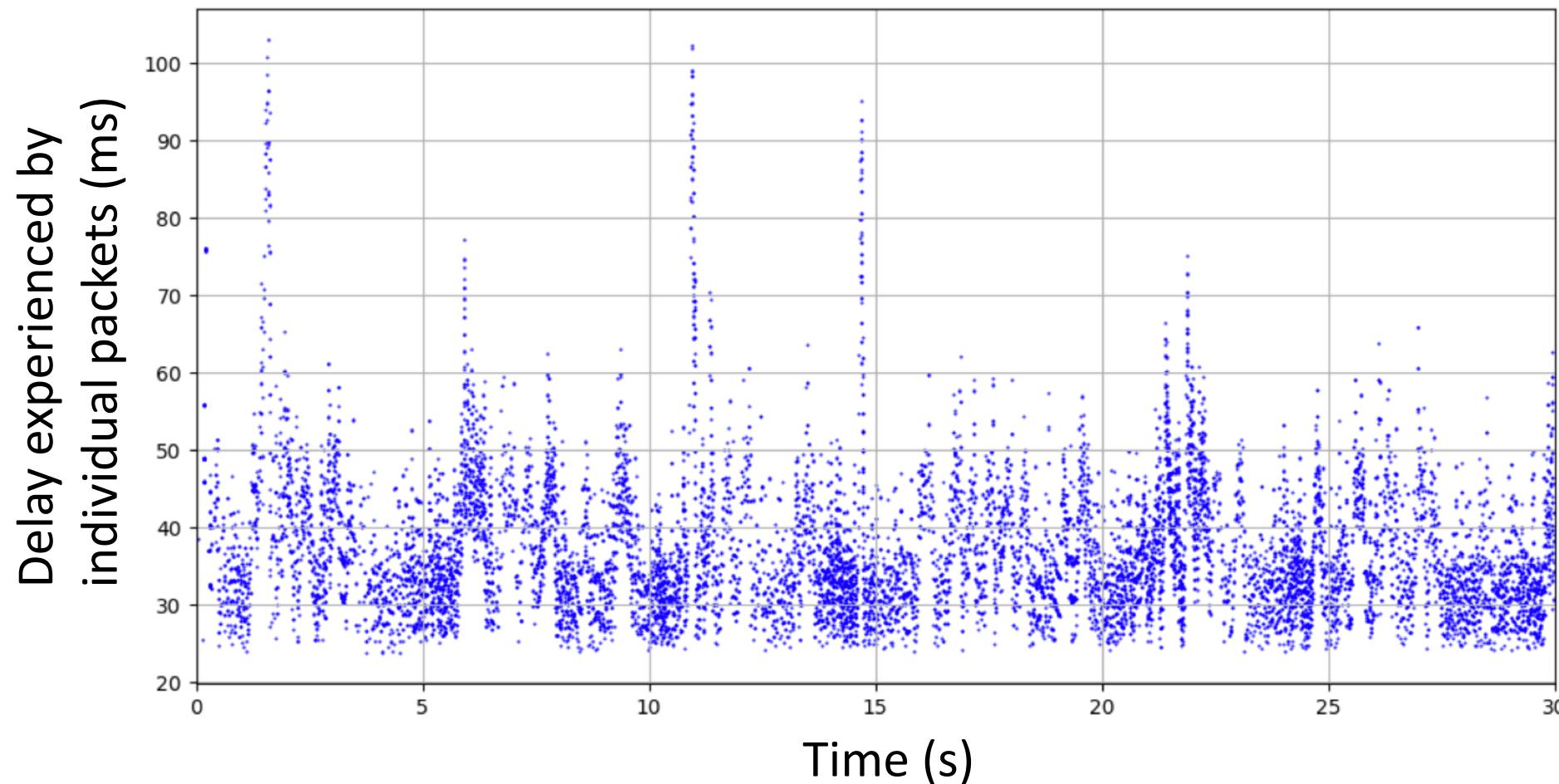
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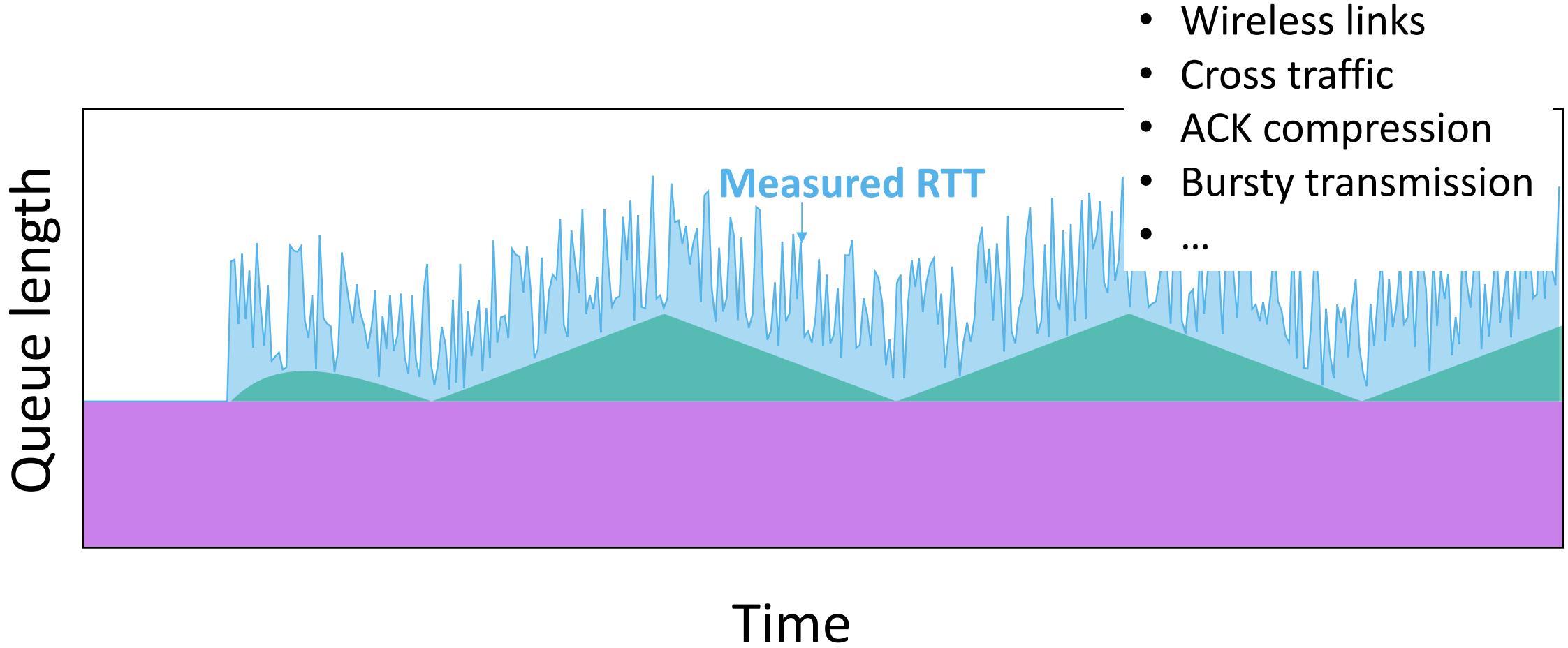
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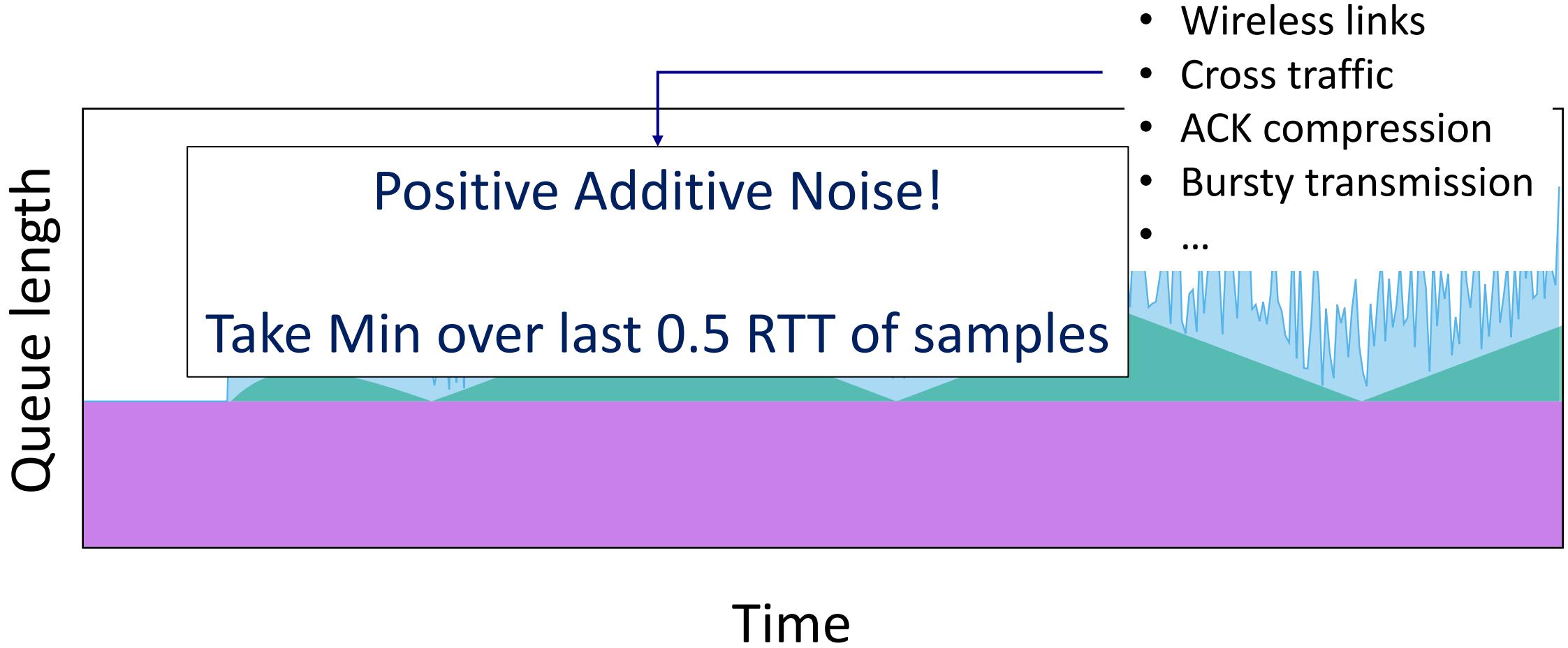
A “noisy” cellular link: Stanford to AWS



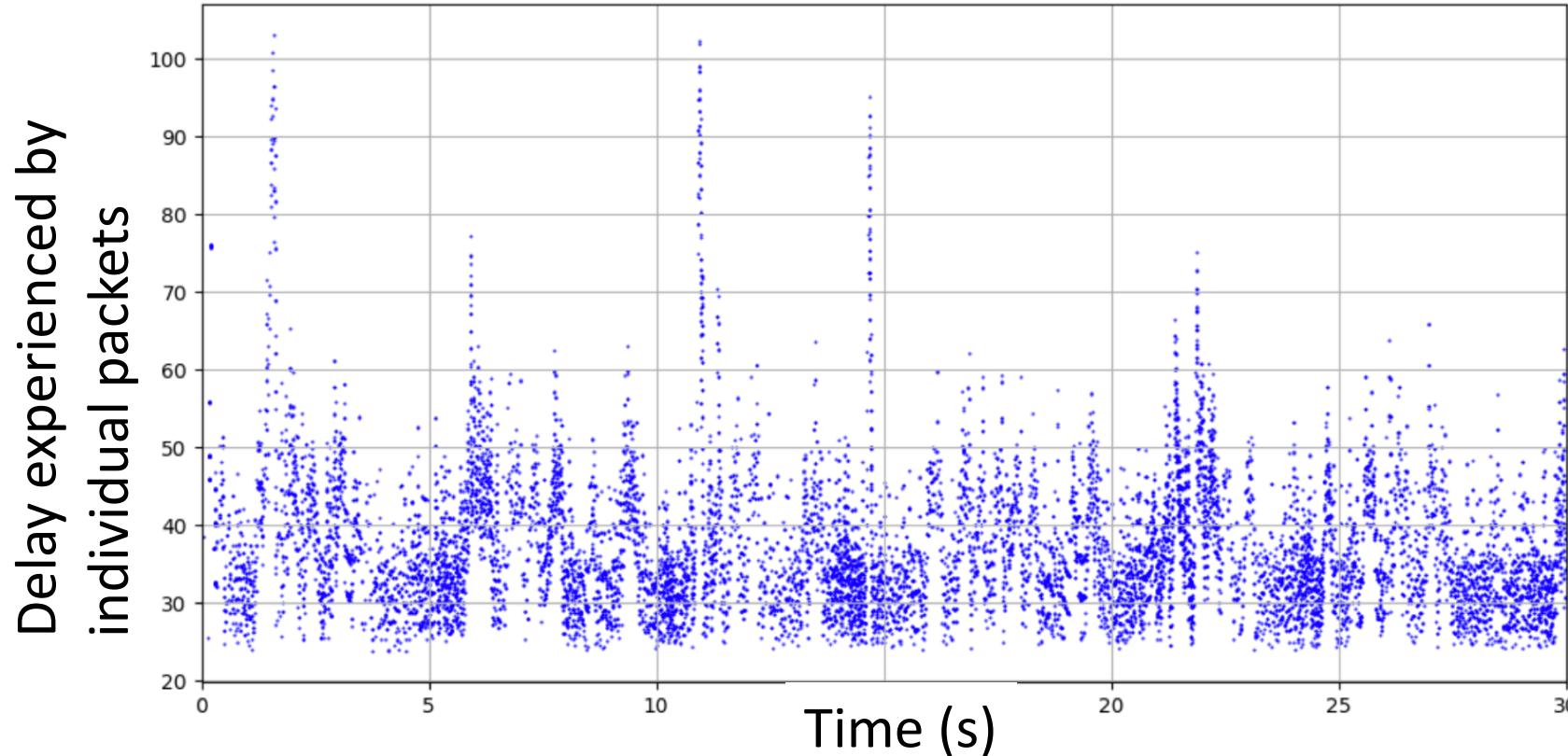
Decoupling queuing delay from other delay variation



Decoupling queuing delay from other delay variation



A “noisy” cellular link: Stanford to AWS



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 < r_t : additively increase by $\frac{\nu}{\delta}$ pkts/RTT

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

The Copa Algorithm

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

Velocity for
faster convergence

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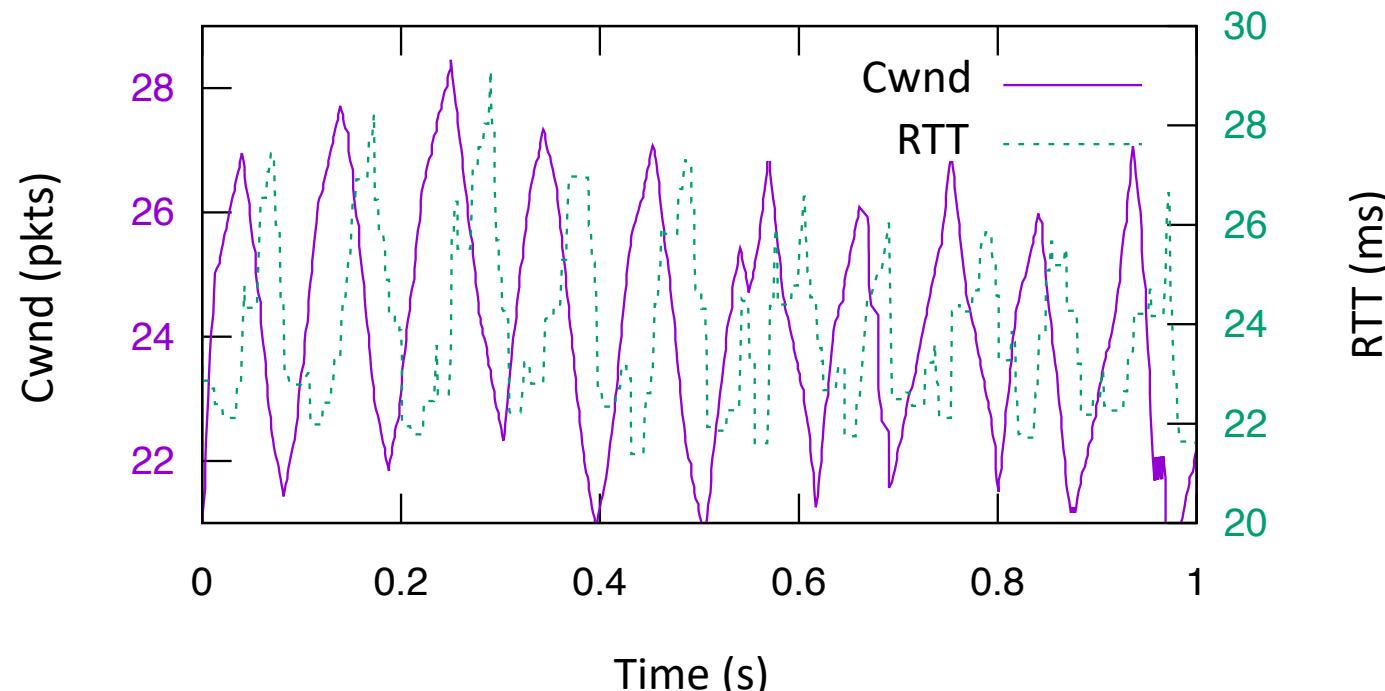
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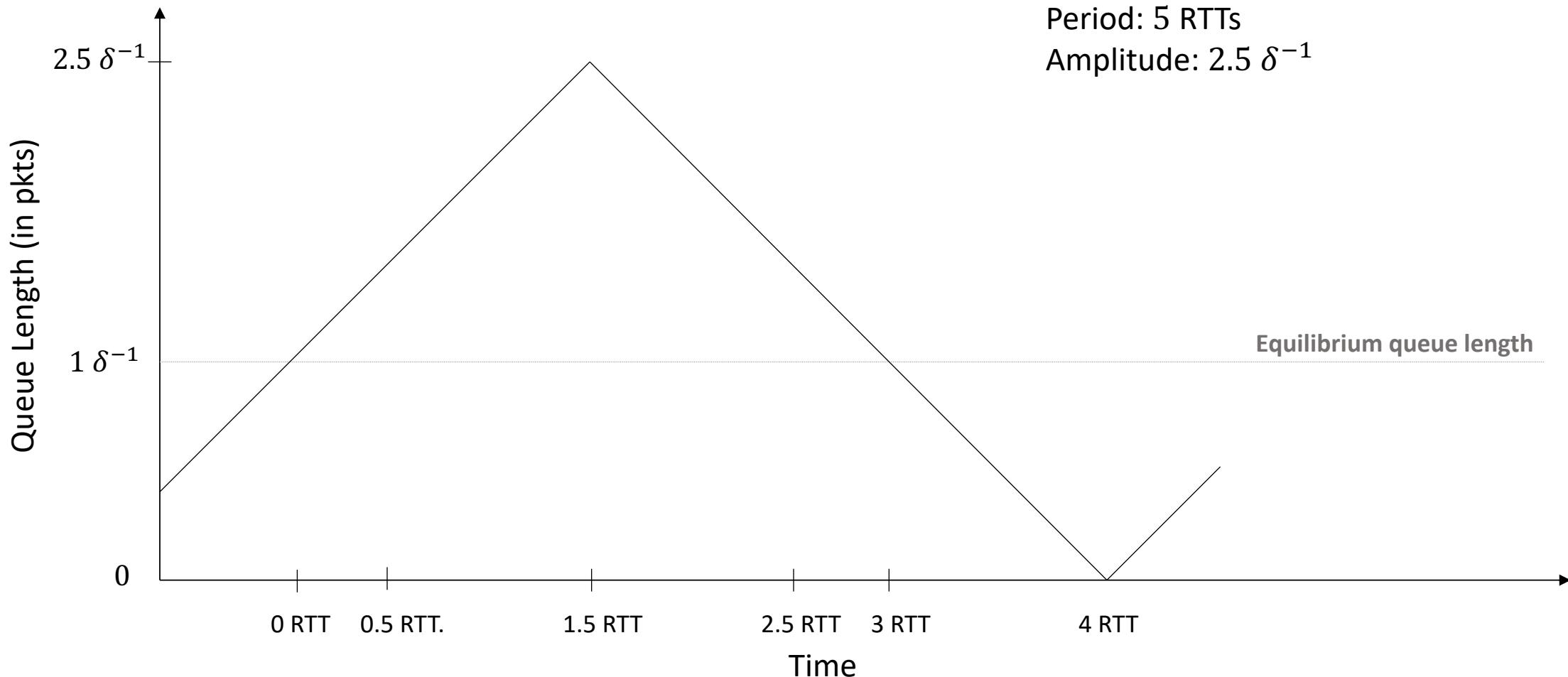
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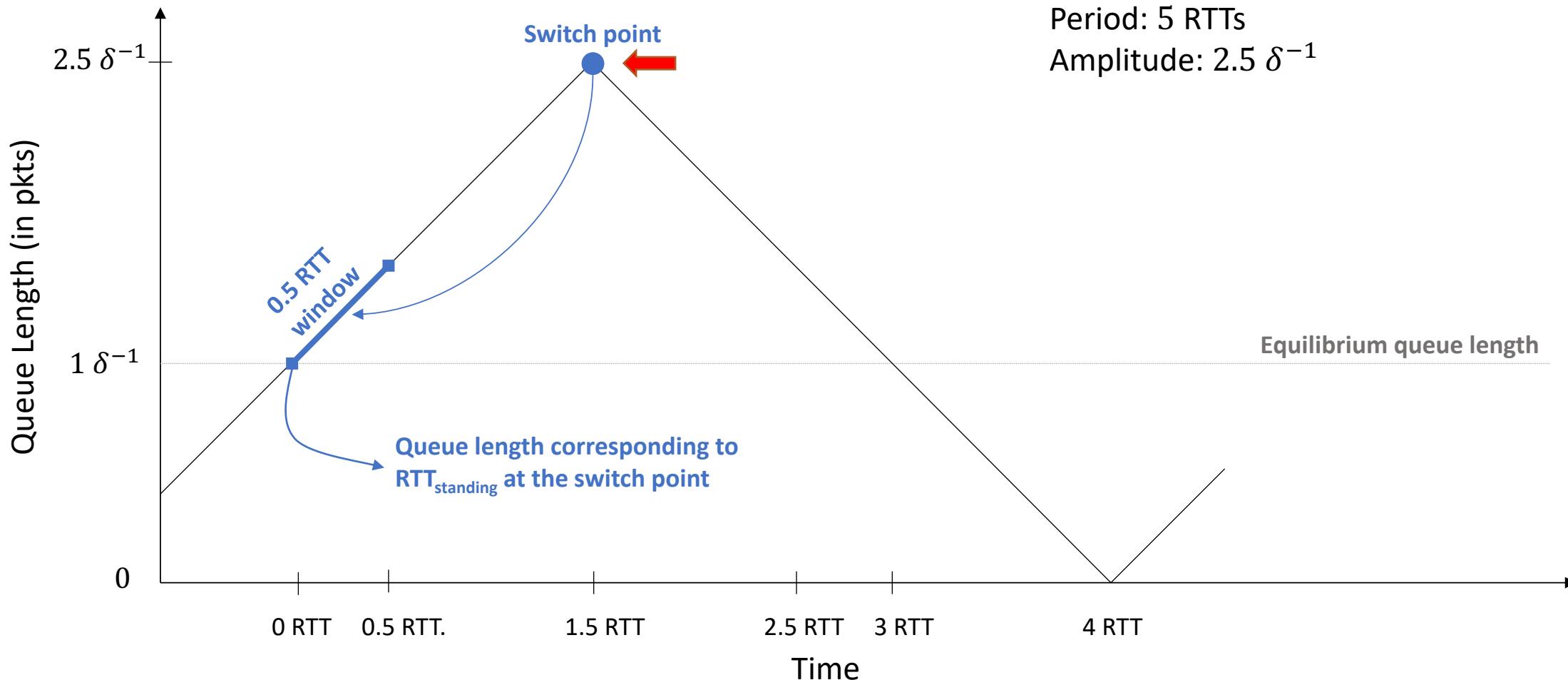
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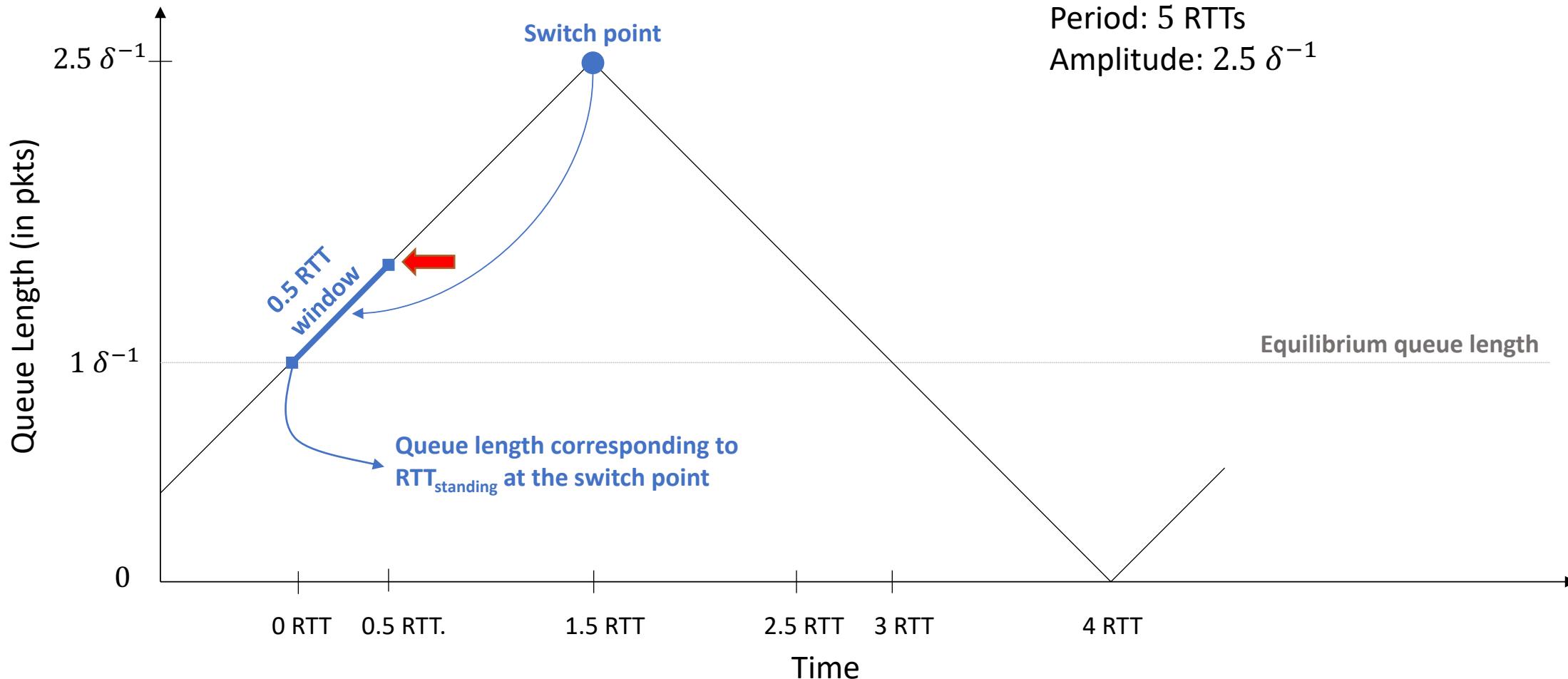
Steady-State Dynamics of Copa



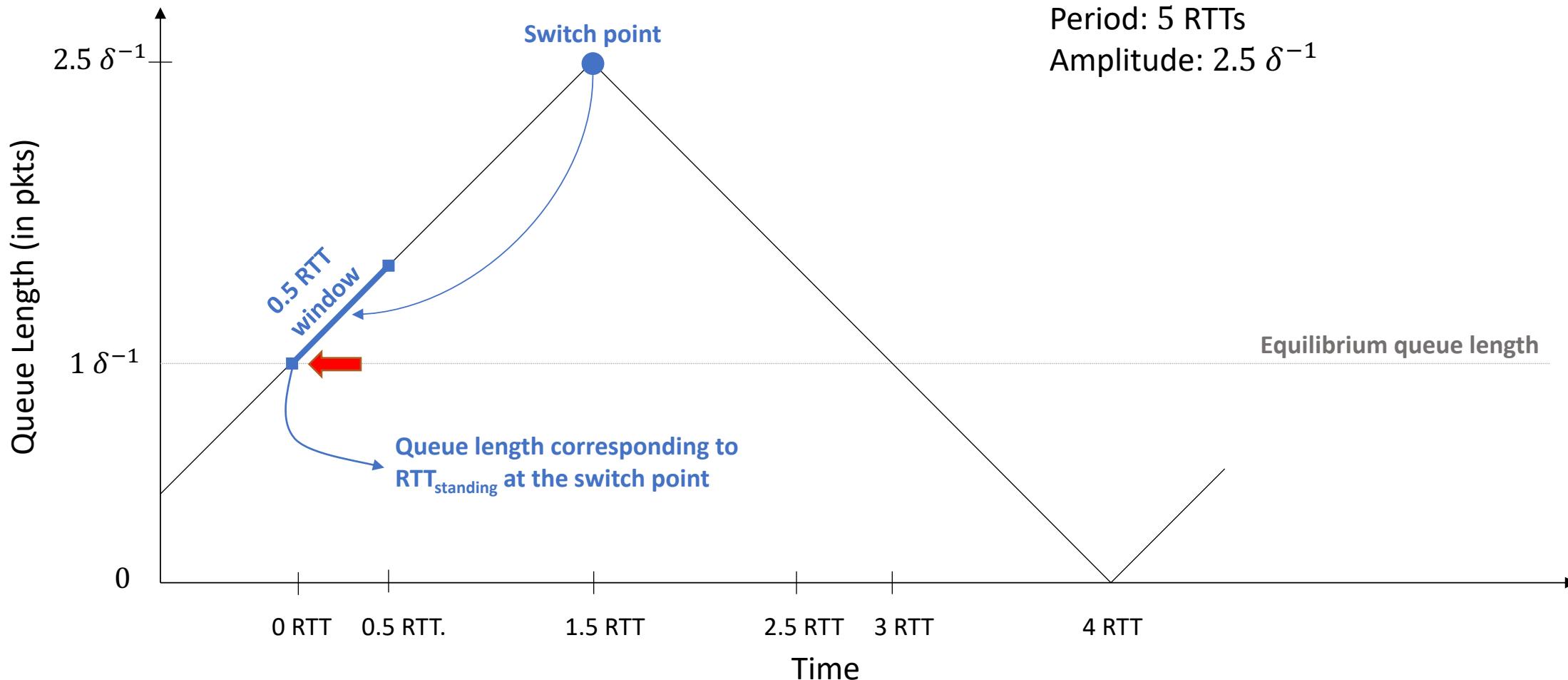
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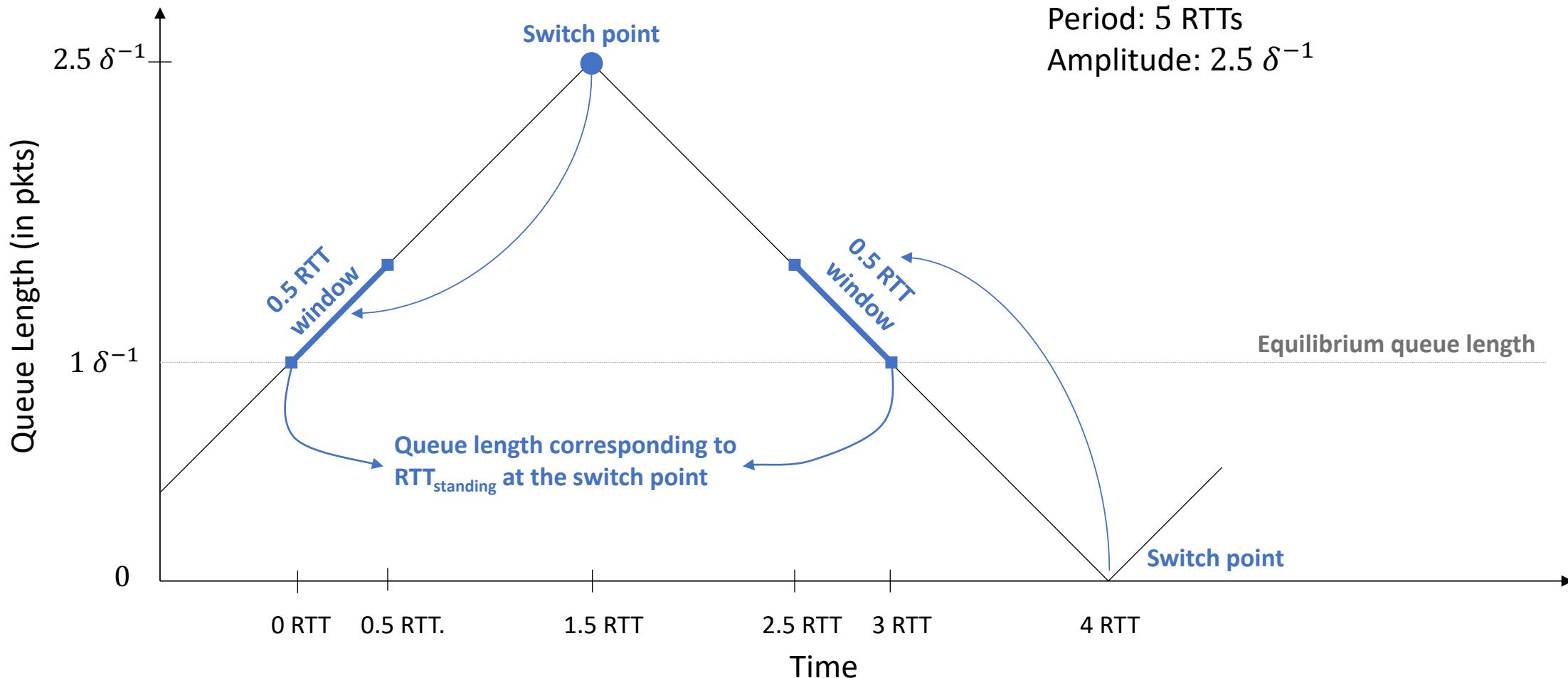
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Queue empties every 5 RTTs! 

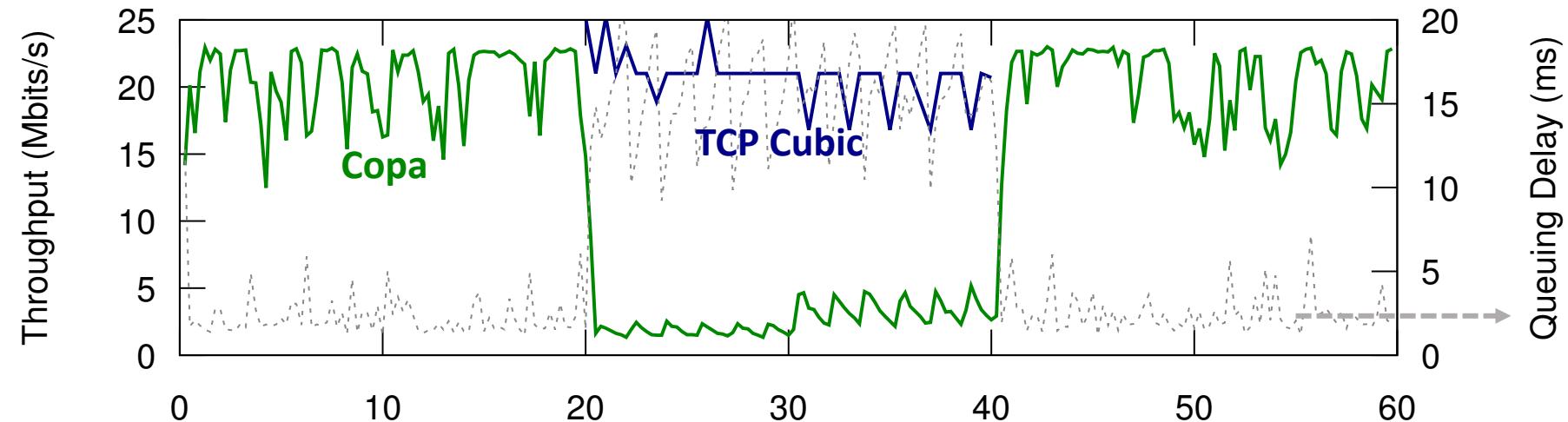
Estimate true minimum RTT

Detect buffer-filling TCP

TCP-Competitiveness

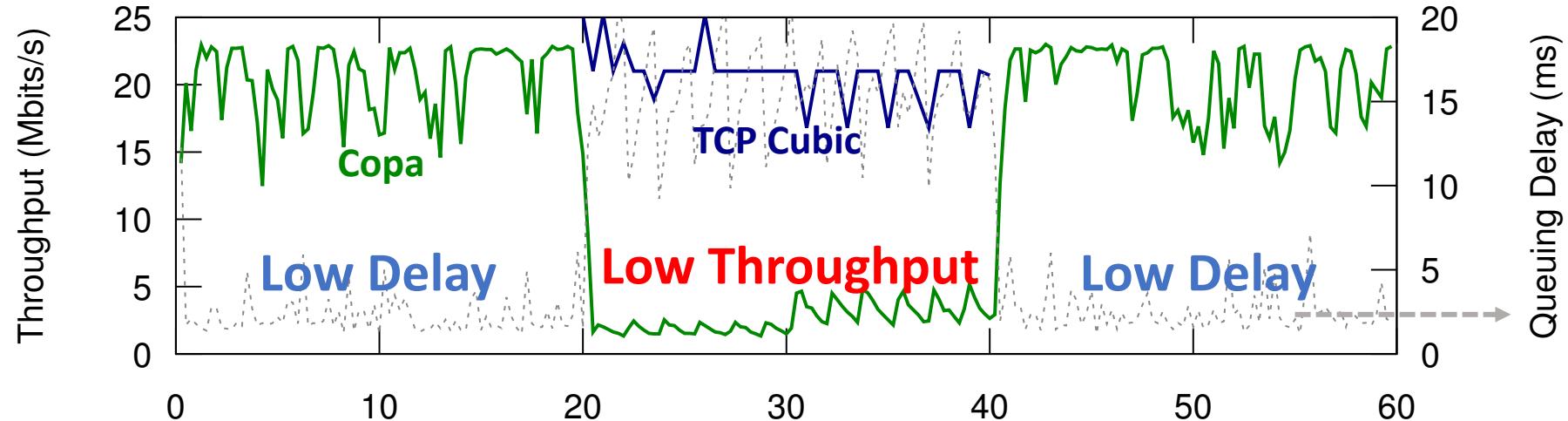
Mode switching for TCP competitiveness

Delay sensitive
 $(\delta = 0.5)$



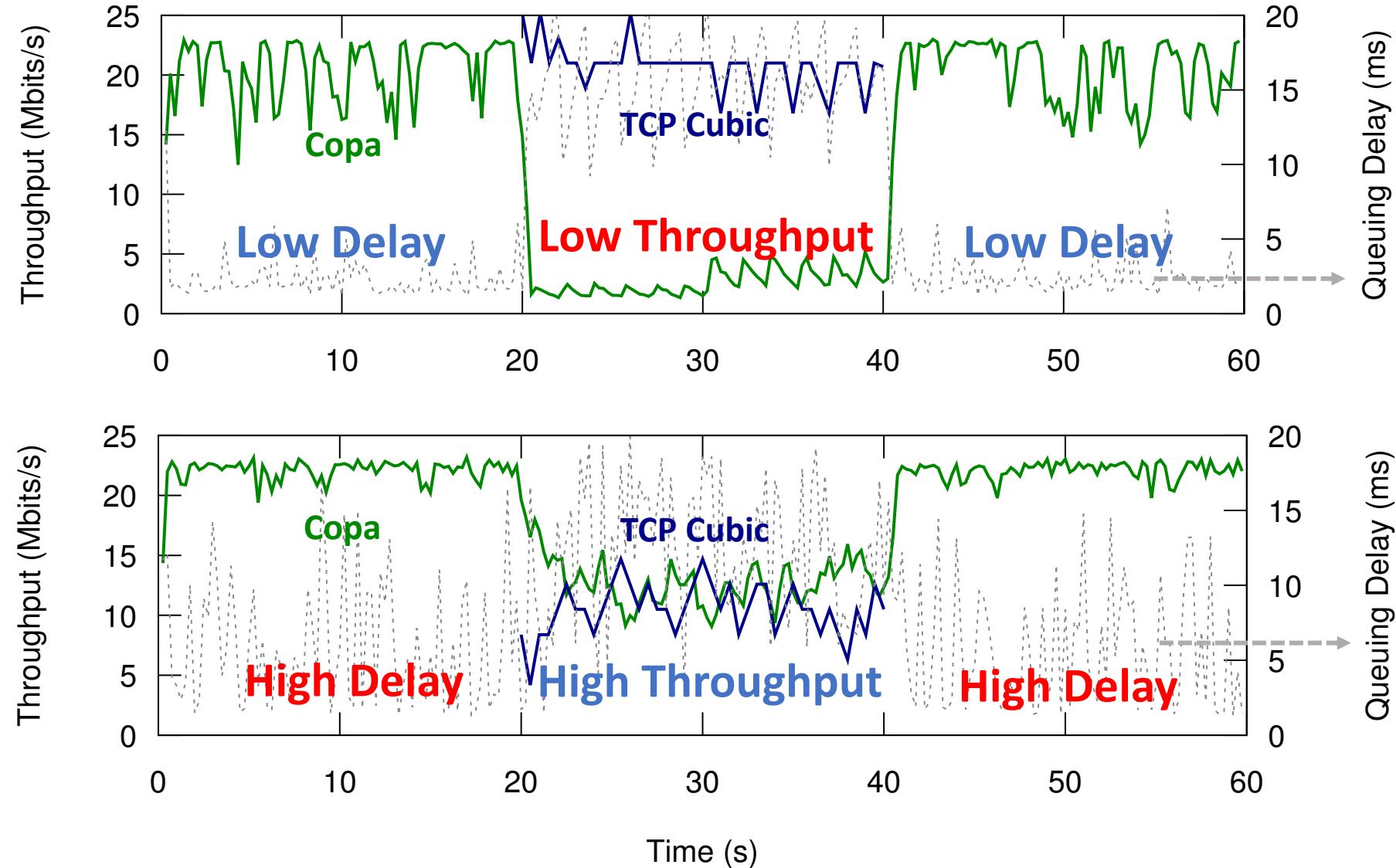
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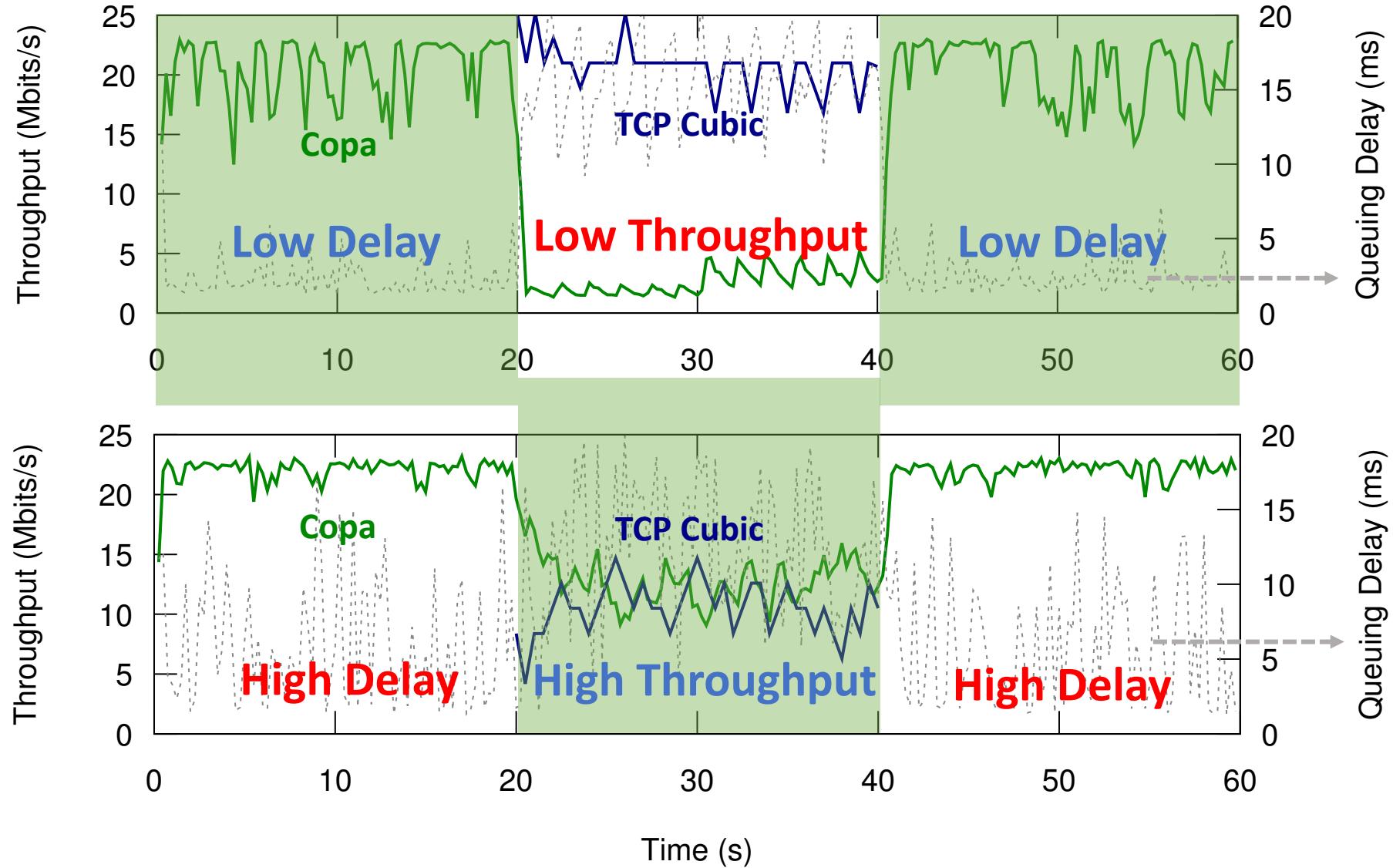
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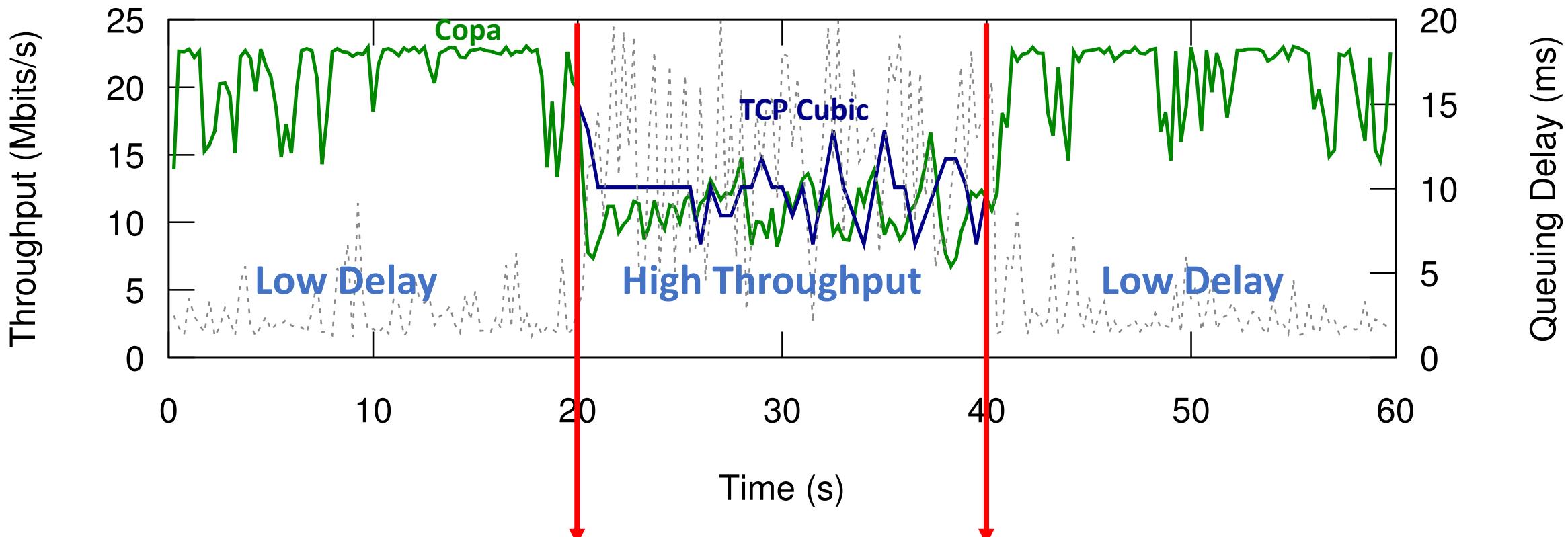
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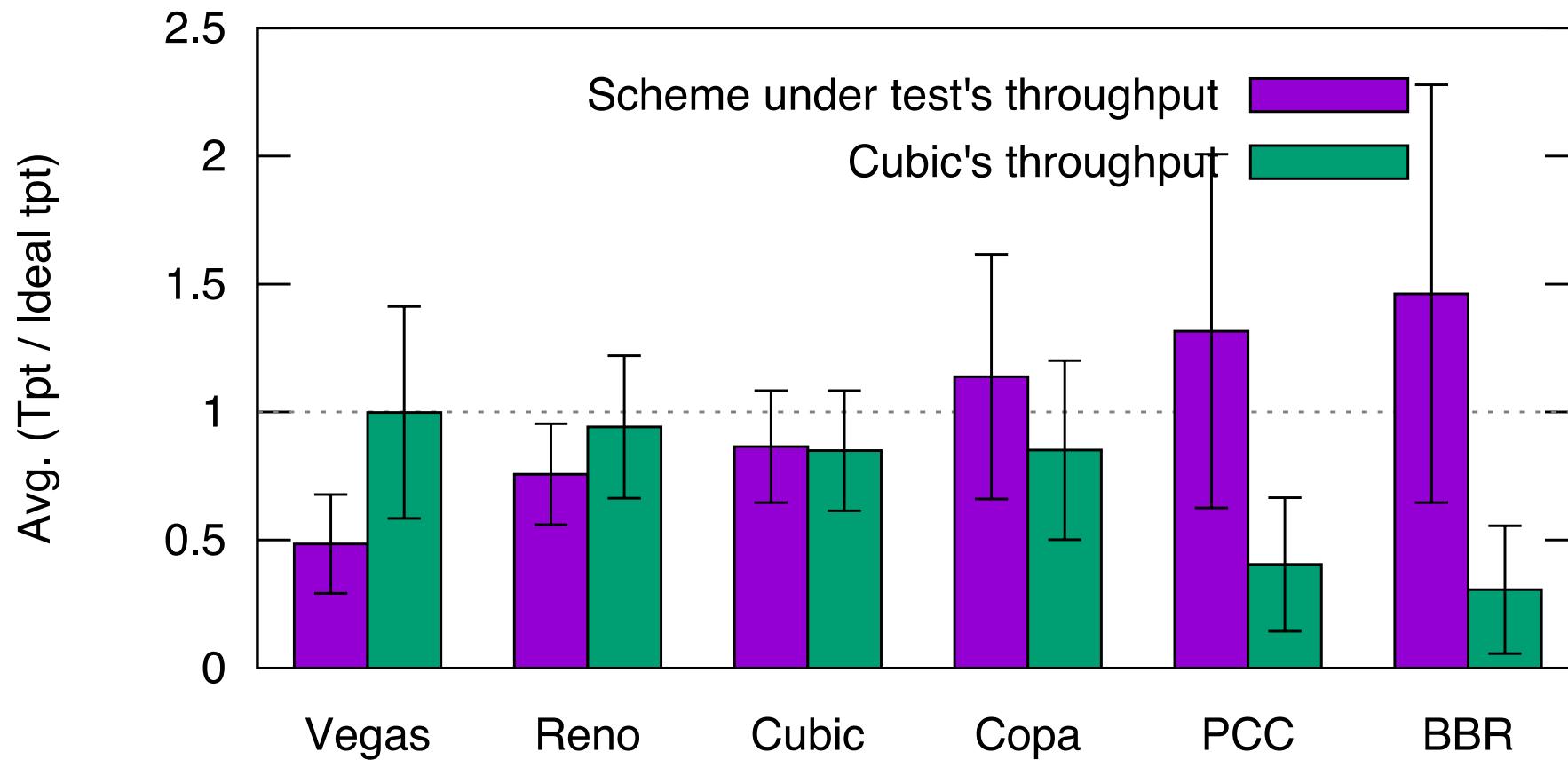
Mode switching for TCP competitiveness

Best of both worlds!

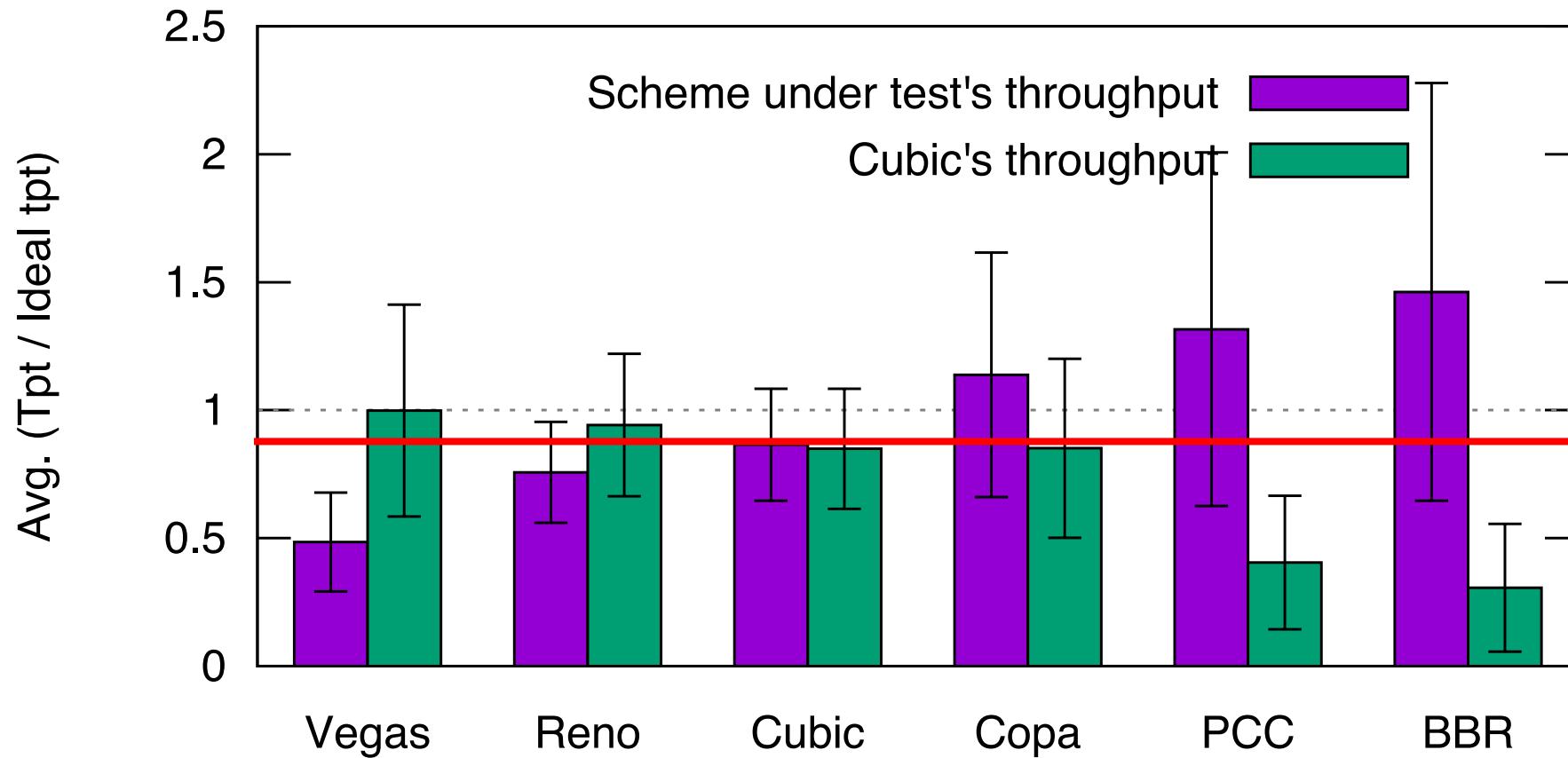


When queue doesn't empty once every 5 RTTs, switch to TCP Competitive mode!

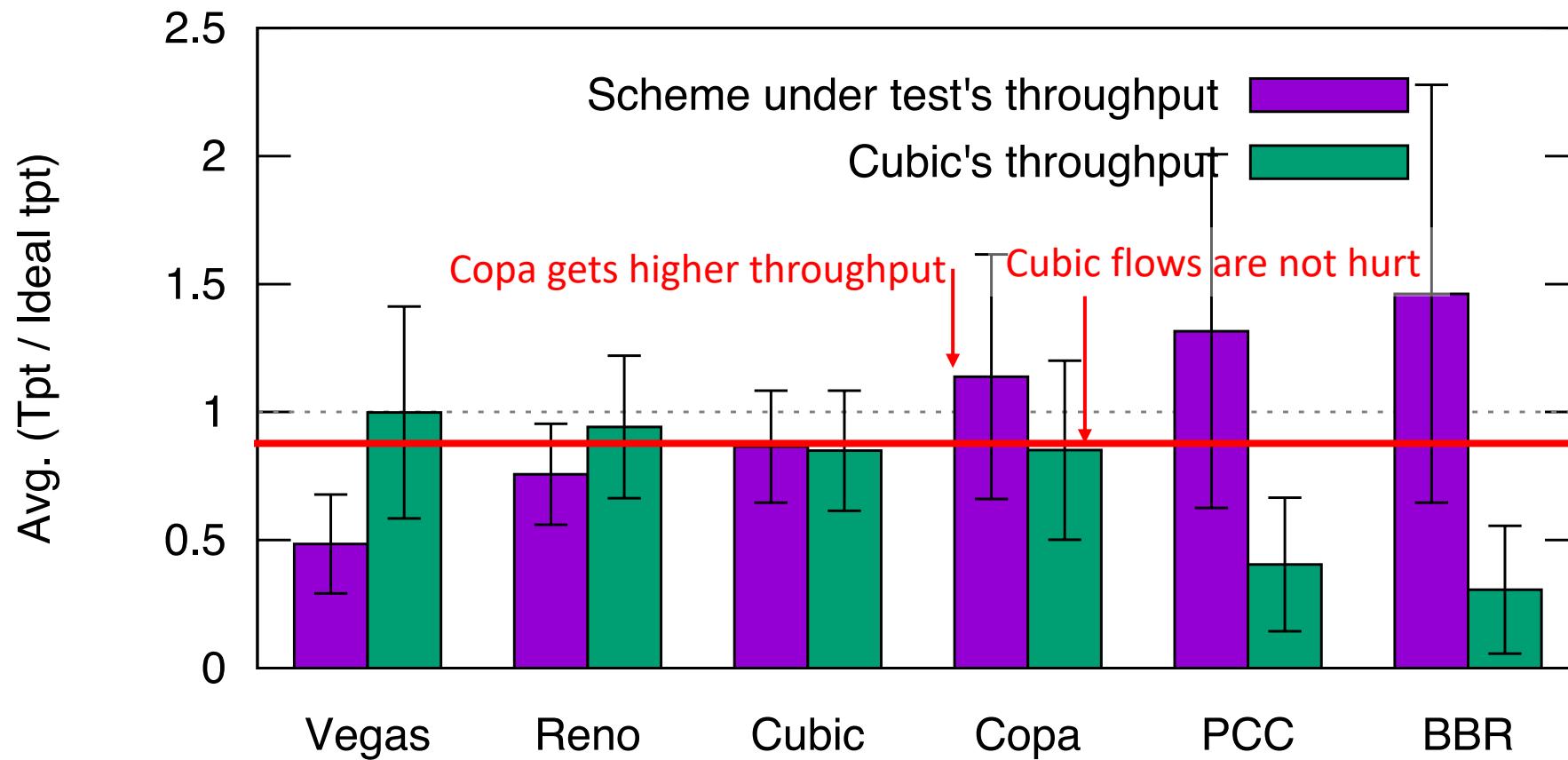
Copa gets higher throughput without hurting TCP Cubic!



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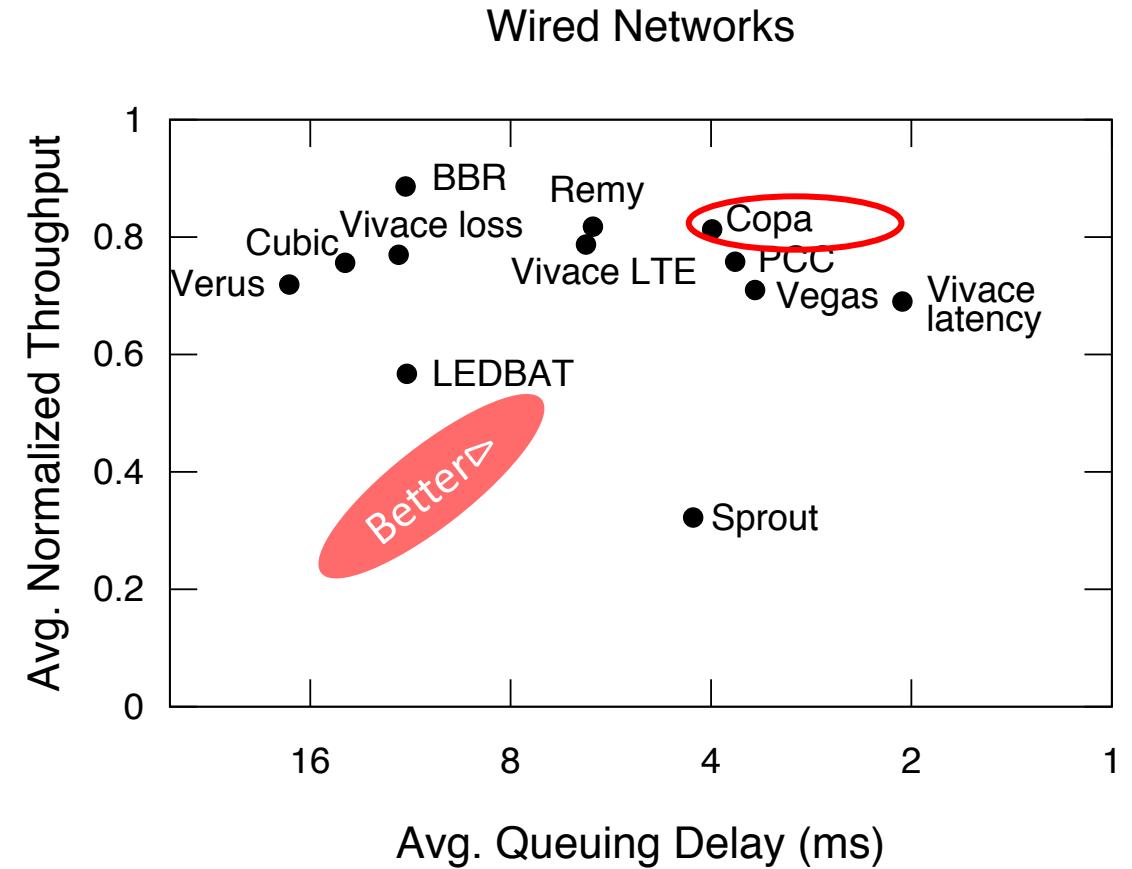
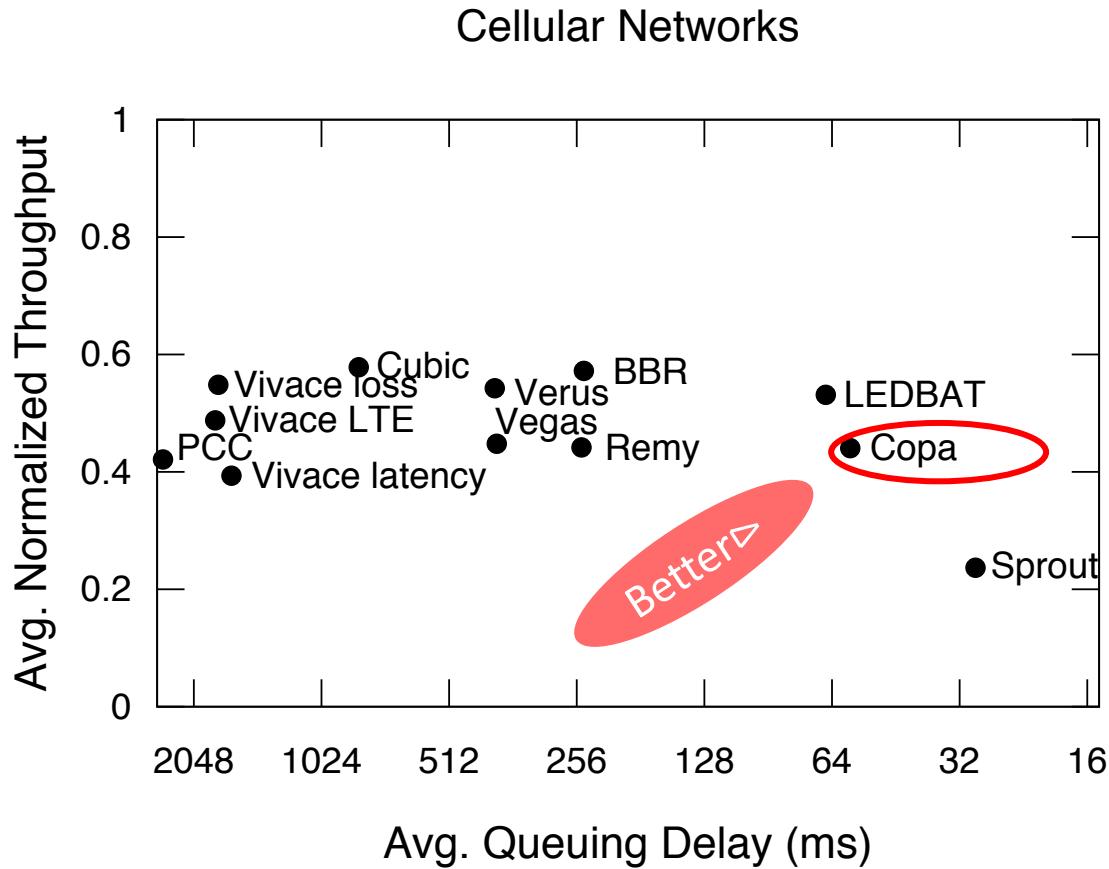
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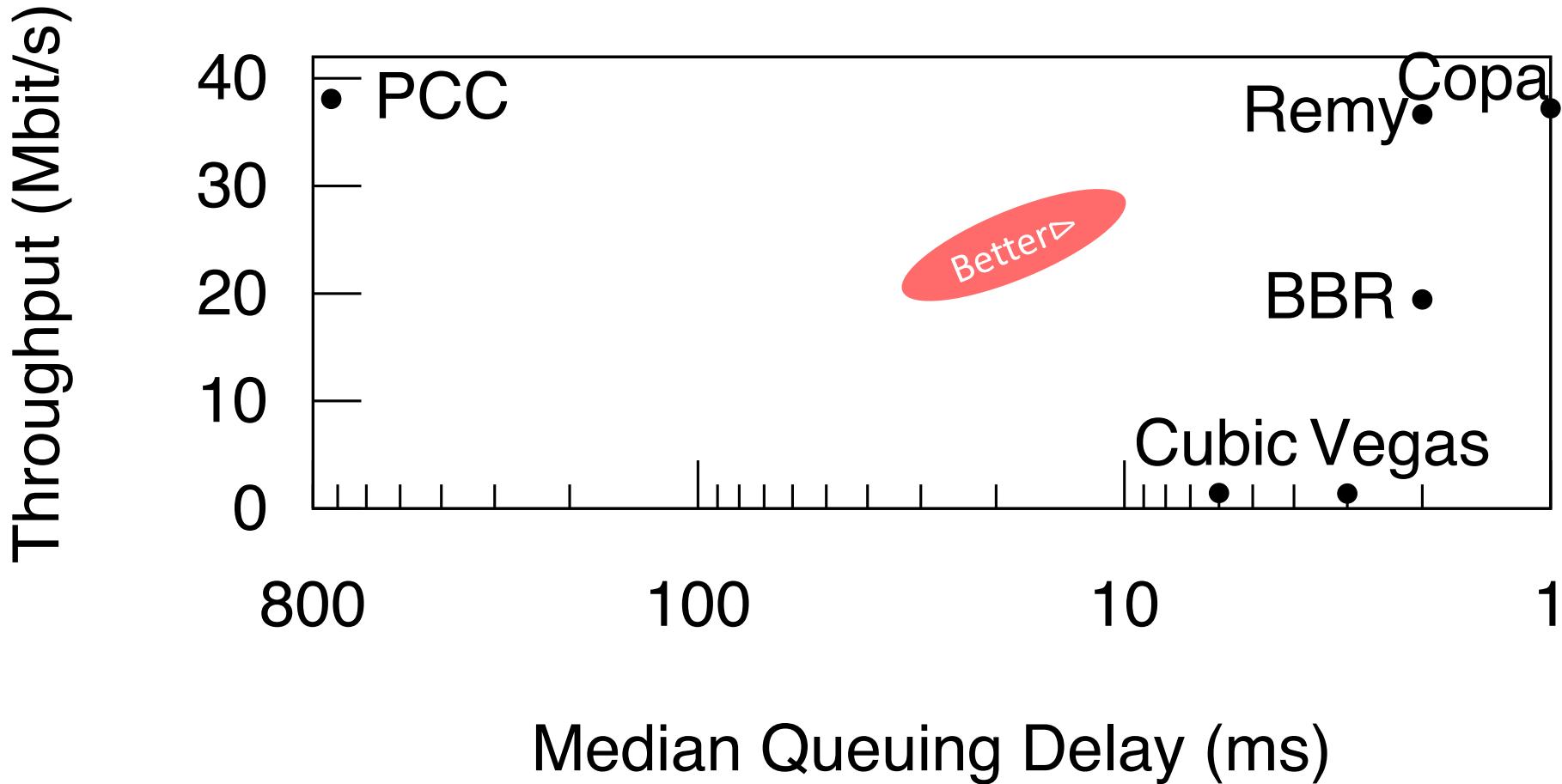
Limitations

- 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

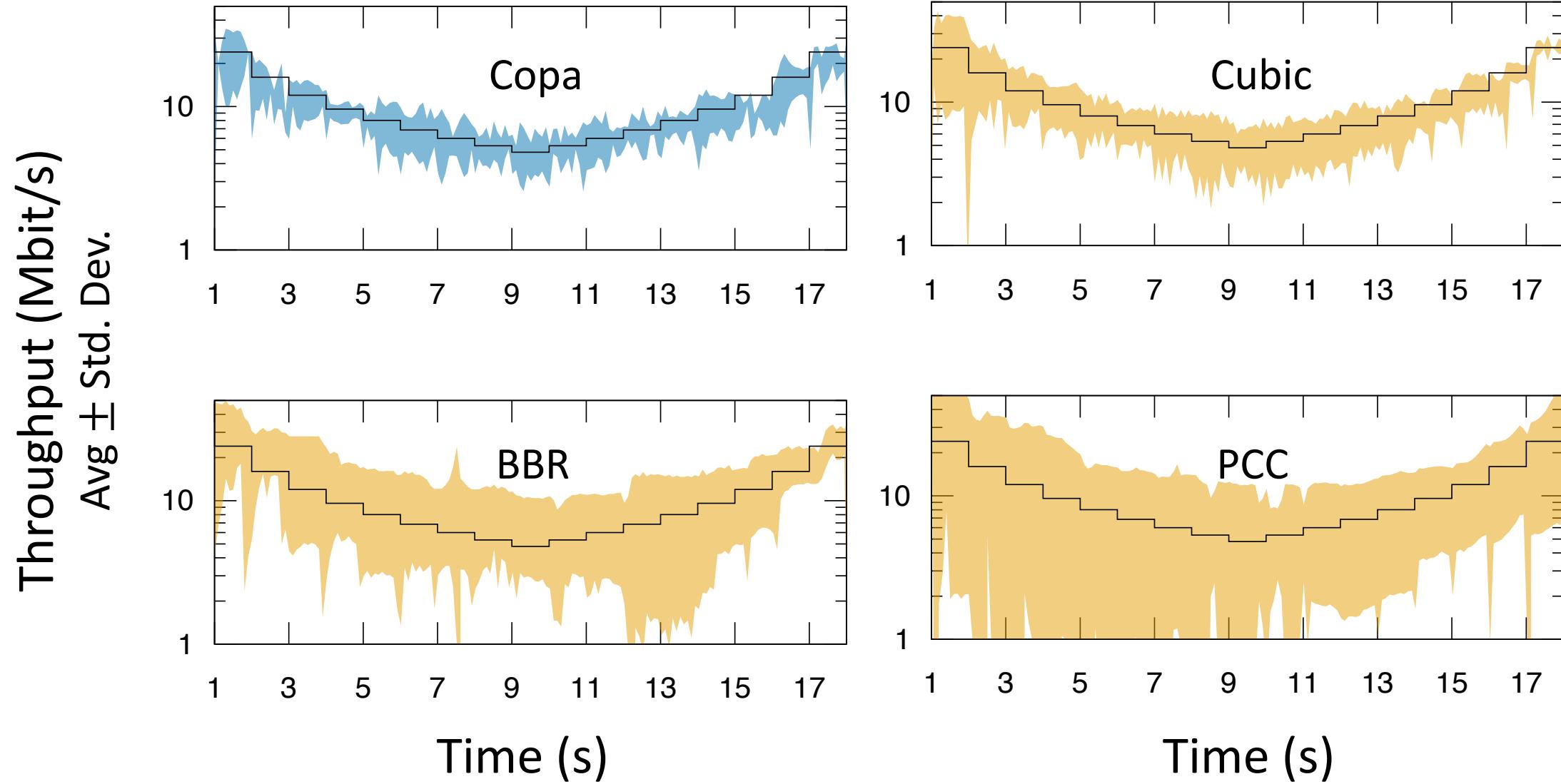
Consistent Performance on Real Paths



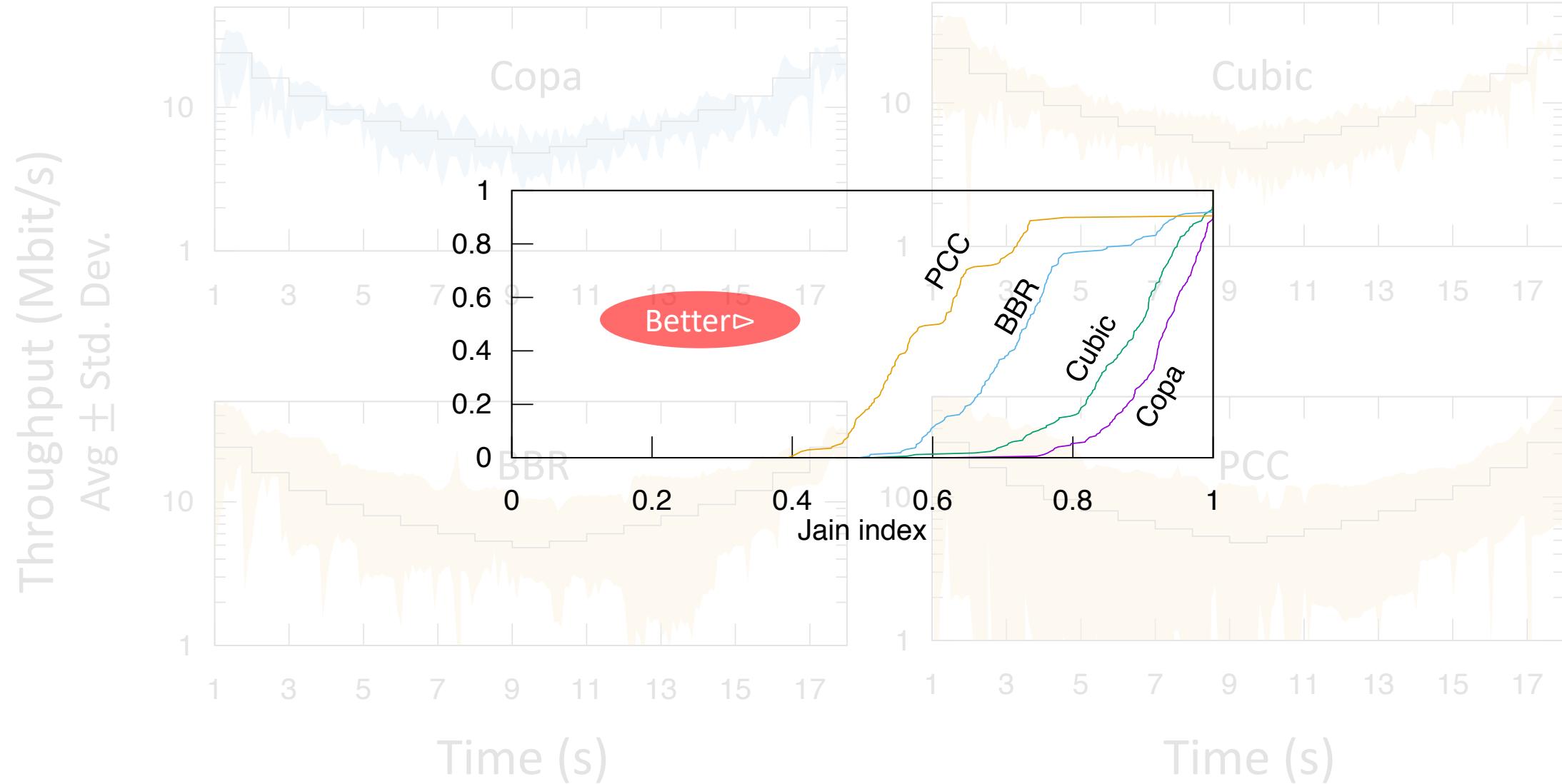
Satellite link: High BDP, high loss



Fairness during flow-churn



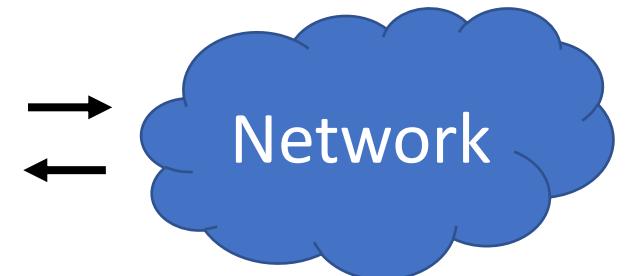
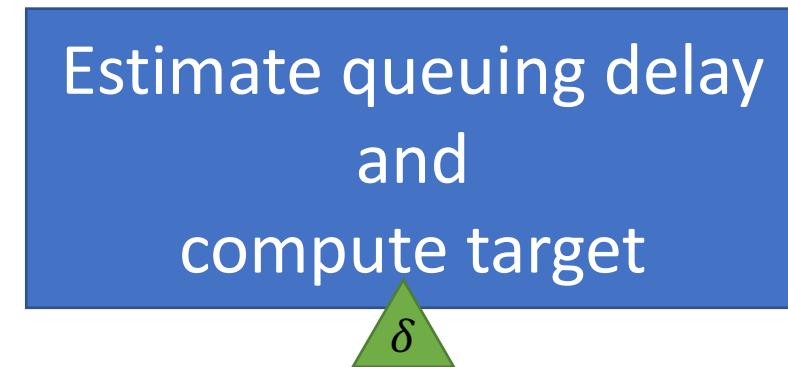
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Summary

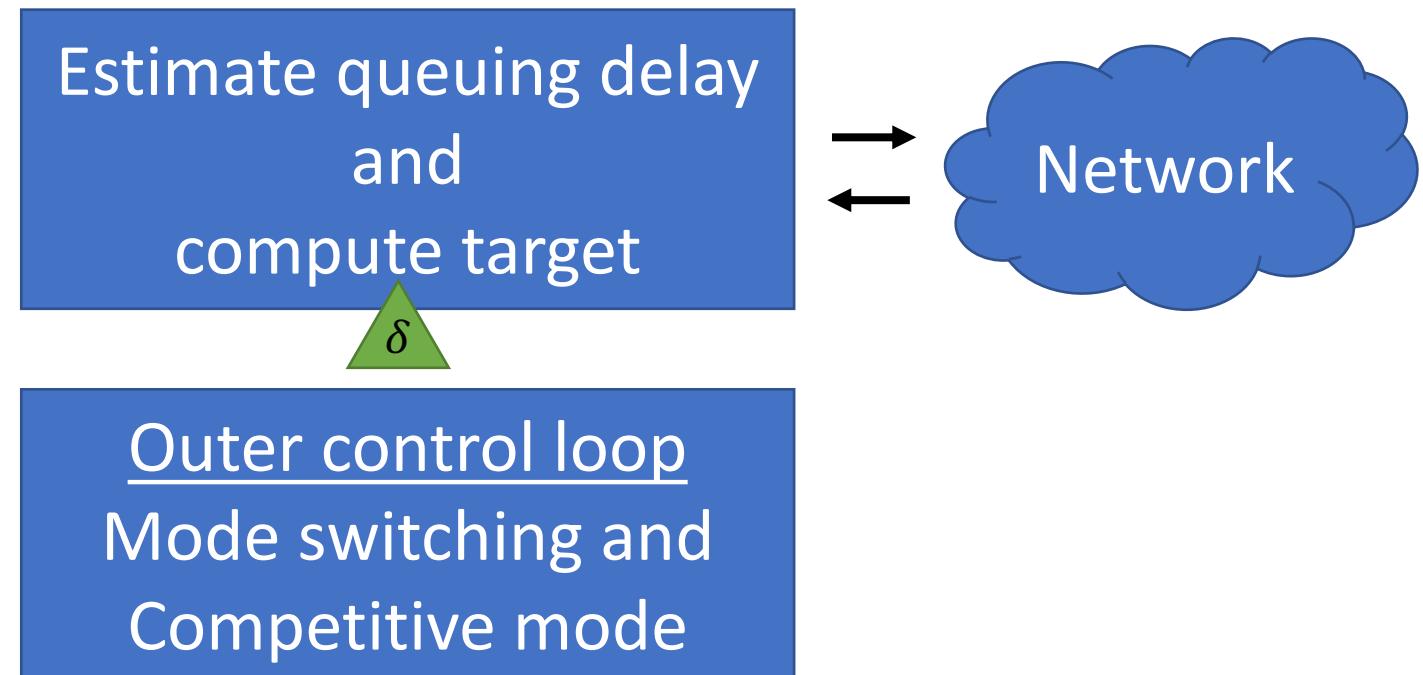
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