The Controlled Delay (CoDel) AQM Approach to fighting bufferbloat

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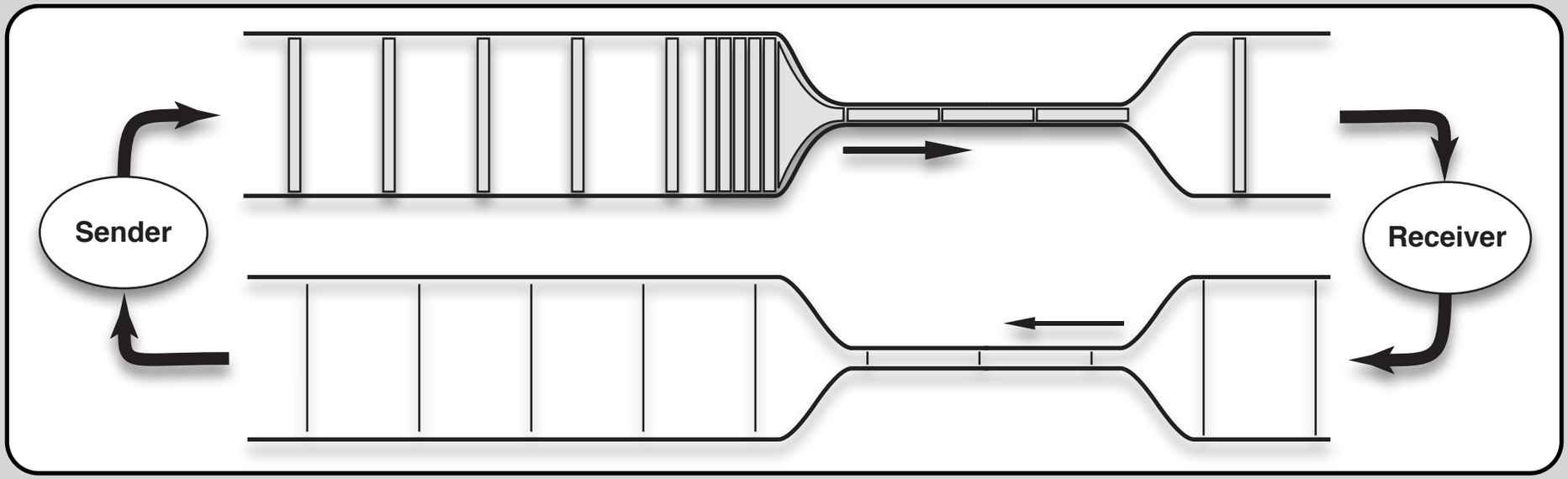
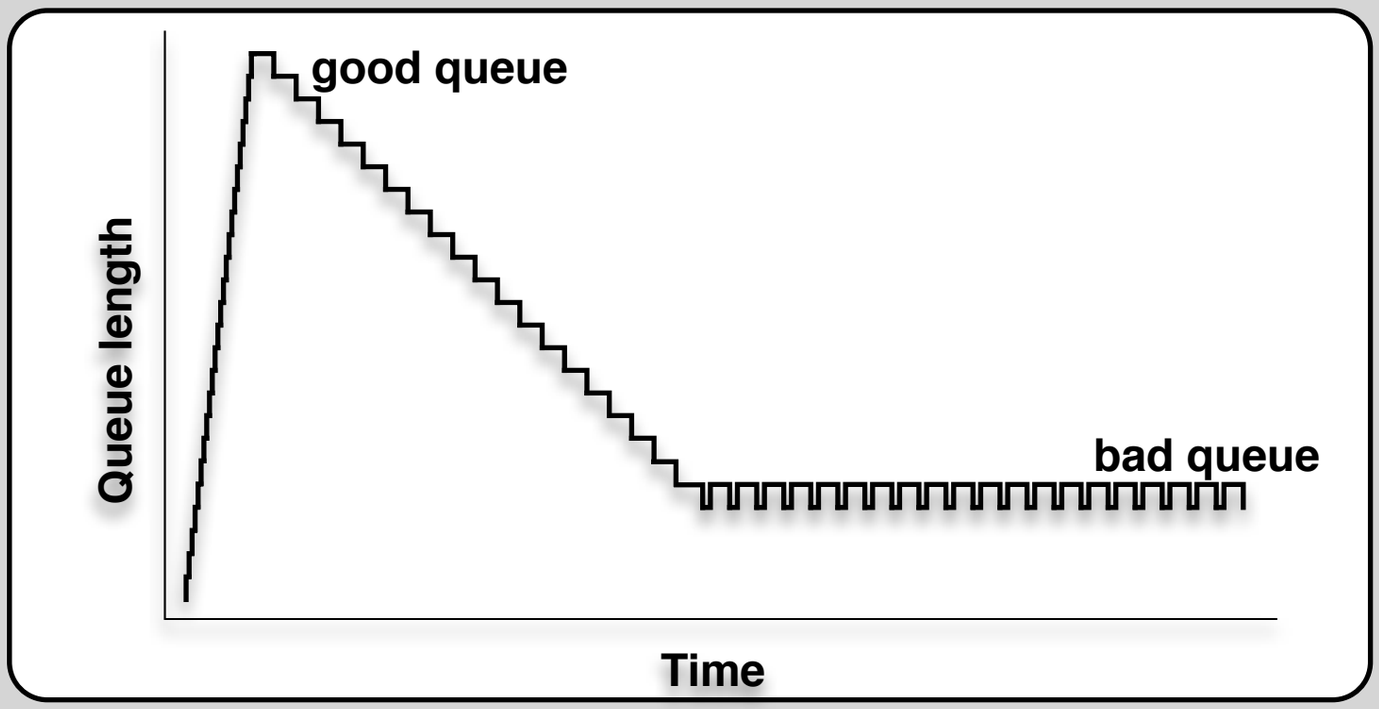
Background

- The “persistently full buffer” problem, now called *bufferbloat,* has been around for 30 years
- The solution, active queue management (AQM), has been known for more than 20 years
  - Unfortunately, the AQMs invented so far only “kind of” work
  - It’s much easier to control long-lived TCPs than mixes
  - A lot of AQMs accept large queue delays
  - Most have many settings and are complex
  - Dynamic link bandwidths are common today
- Using average queue length as a congestion indicator is a big part of the problem

A TCP with a 25 packet window into a connection with an intrinsic pipe size of 20 packets:



After the initial burst of packets, settles into a 5 (+/-1) packet standing queue. The average queue size is the window mismatch to the pipe size, unrelated to the sending rate:



Tracking Bad Queue

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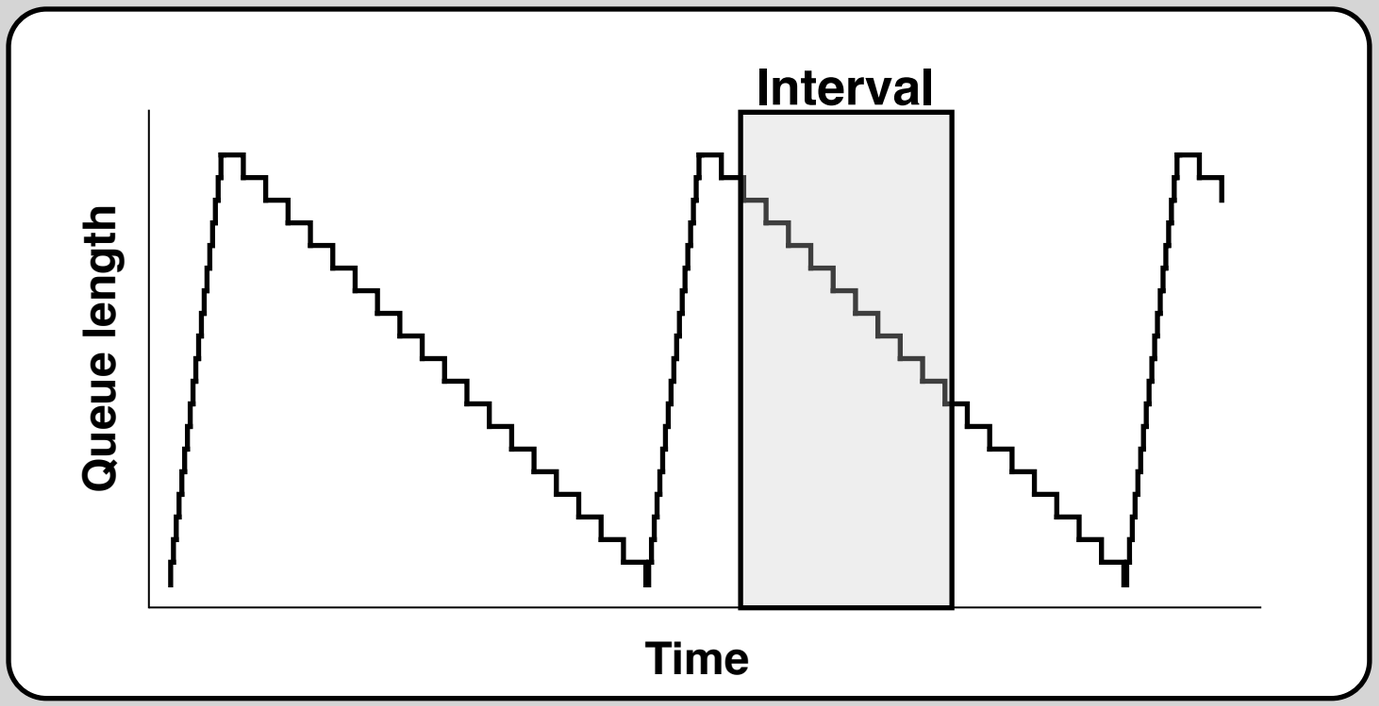


Van made this observation in 2006 (see talk at MIT Lincoln Labs)

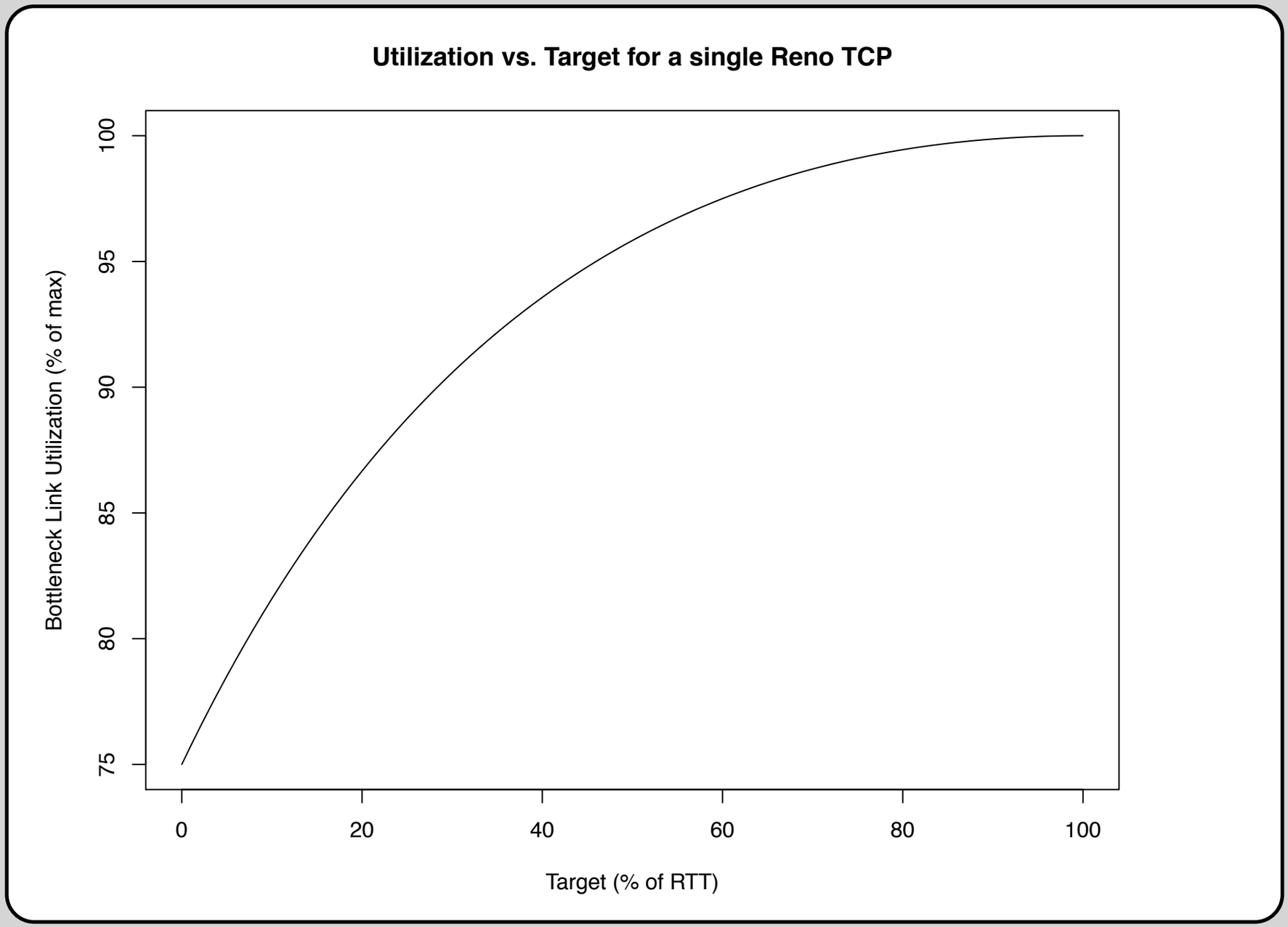
- Good queue goes away in an RTT, bad queue hangs around.

➡ queue length min() during a sliding window interval measures bad queue ...

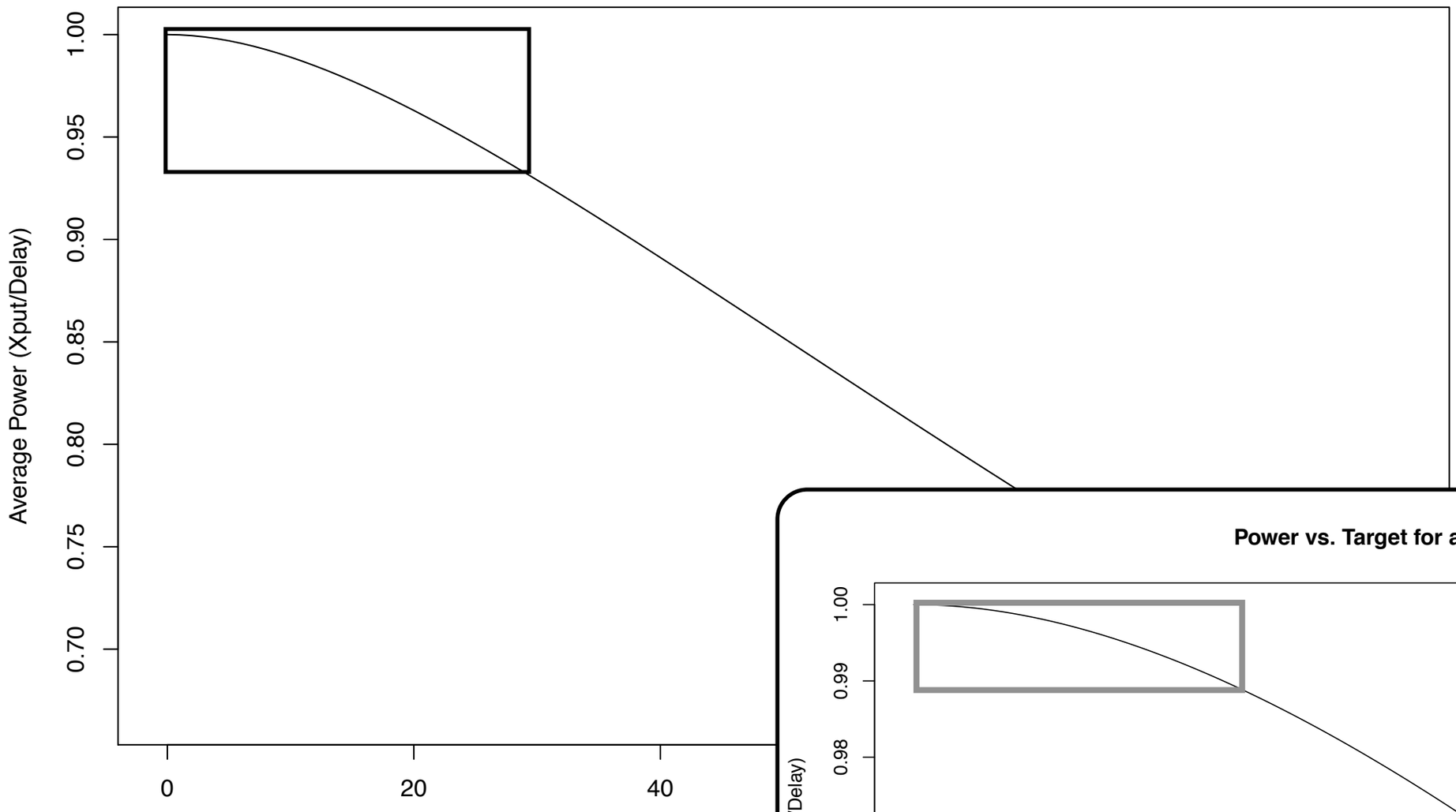
➡ ... as long as window is <u>at least</u> an RTT wide.

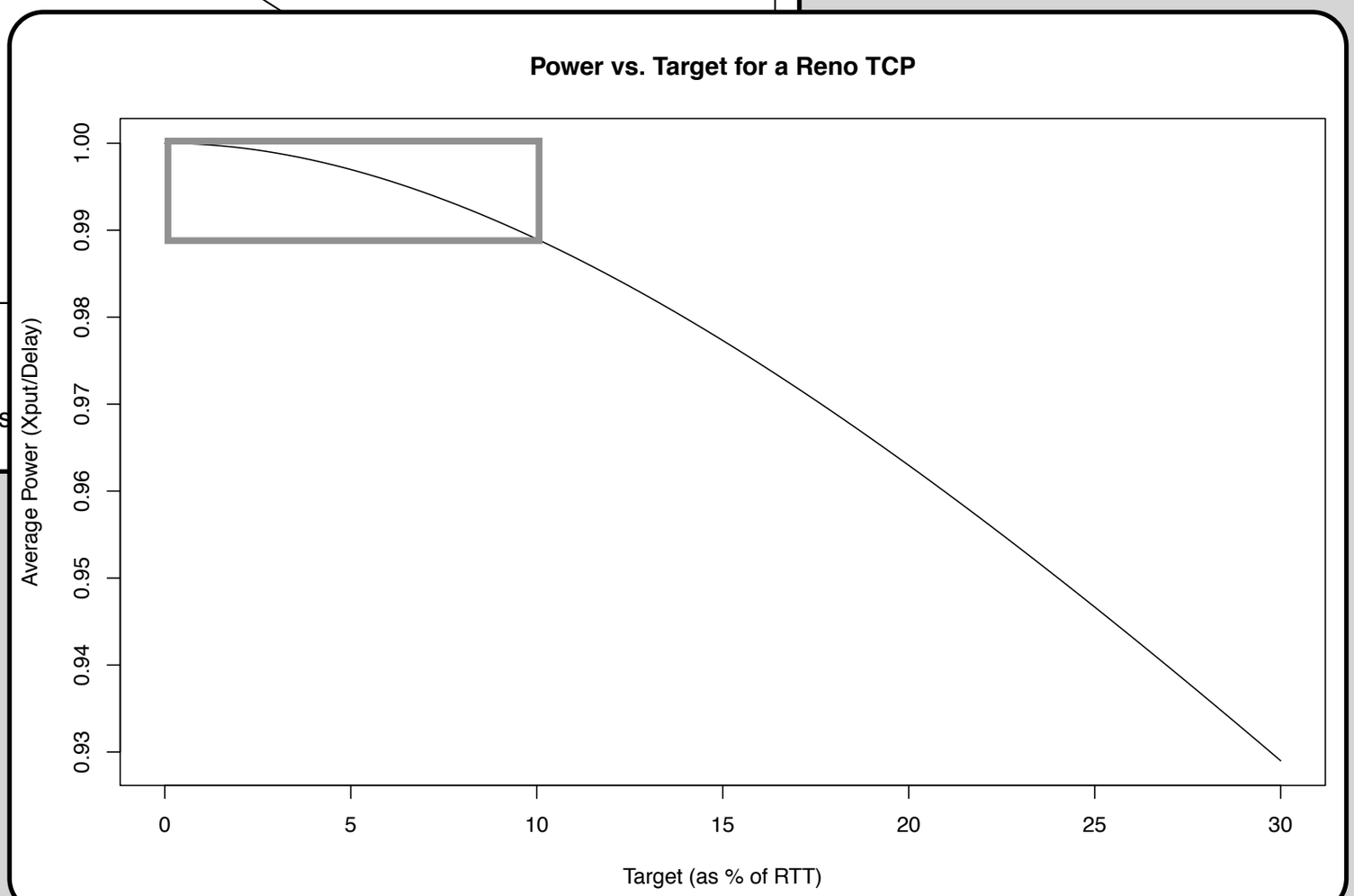
How low should we go?

- As we reduce that “standing queue” of slide 3, don’t want to risk forcing the link to go idle.
- Need to leave an MTU of backlog (i.e., don’t drop if there’s less than an MTU sitting in the buffer).
- A larger backlog can result in higher utilization, particularly where there are a small number (1 to 3) of bulk transfers, but at a cost of higher delay.
- To identify an appropriate range for the backlog, we turn to analysis to find a bandwidth-independent value for this backlog, which we call the *target*



Tolerating some standing queue results in a higher utilization but it reaches 90% with a target that is about 30% of the RTT





This suggests exploring targets in the range from 1 to 15 ms.

Cubic gets better utilizations.

Controlled Delay (CoDel) AQM Goals

- no knobs - parameterless
- separate good queue and bad queue - keep median delays (over time) low while permitting bursts
- insensitive (or nearly so) to RTT, link rates, traffic loads
- adapt to dynamically changing link rates with no negative impact on utilization
- simple and efficient implementation

CoDel Innovations

1. Use the local minimum of queue as the observed statistic

2. The information needed about the local minimum (how long queue has been below/above target) can be kept in a single state variable, no need to keep a sliding window of the actual values

3. Use the packet sojourn time in the queue (the actual packet delay) rather than queue size in bytes or packets as the value observed

Use of minimum means all the work can be done at queue departure time and no locks are needed (the minimum can only change on departure)

CoDel in a nutshell

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- CoDel assumes that a standing queue of *target* is acceptable (as determined by the local minimum) and that it is unacceptable to drop when there are fewer than an MTU worth of bytes in the buffer
- To ensure that the minimum value is not stale, it has to have been experienced in the most recent *interval* (sliding window)
- When the sojourn time has exceeded target for at least an interval, a packet is dropped and a control law used to set the next drop time
- The next drop time is decreased in inverse proportion of the square root of the number of drops since the dropping state was entered (to get a linear change in throughput)
- When the sojourn time goes below target the controller stops dropping.
- Prevented from re-entering dropping state too soon after exiting it and resumes the dropping state at a recent control level if one exists

Target and interval are constants: acceptable queue delay and a time on the order of a worst case RTT of connections through the bottleneck. Experimented with target from 1 to 20ms, but 5ms and interval of 100ms works well for range of RTTs from 10ms to 1sec, with excellent performance in 10ms - 300ms range.

Results

- from the original work last year
- all CoDel runs use exactly the same algorithm
- RED runs each use the link bandwidth to set parameters

Results: Range of static link rates (high)

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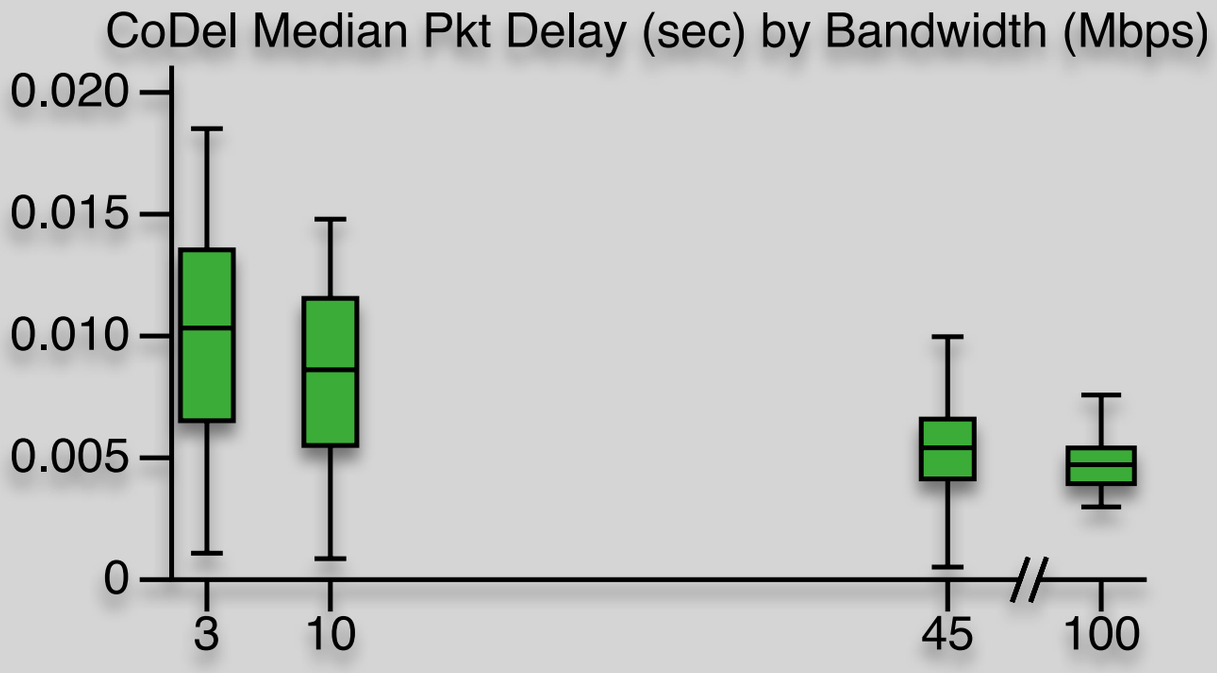

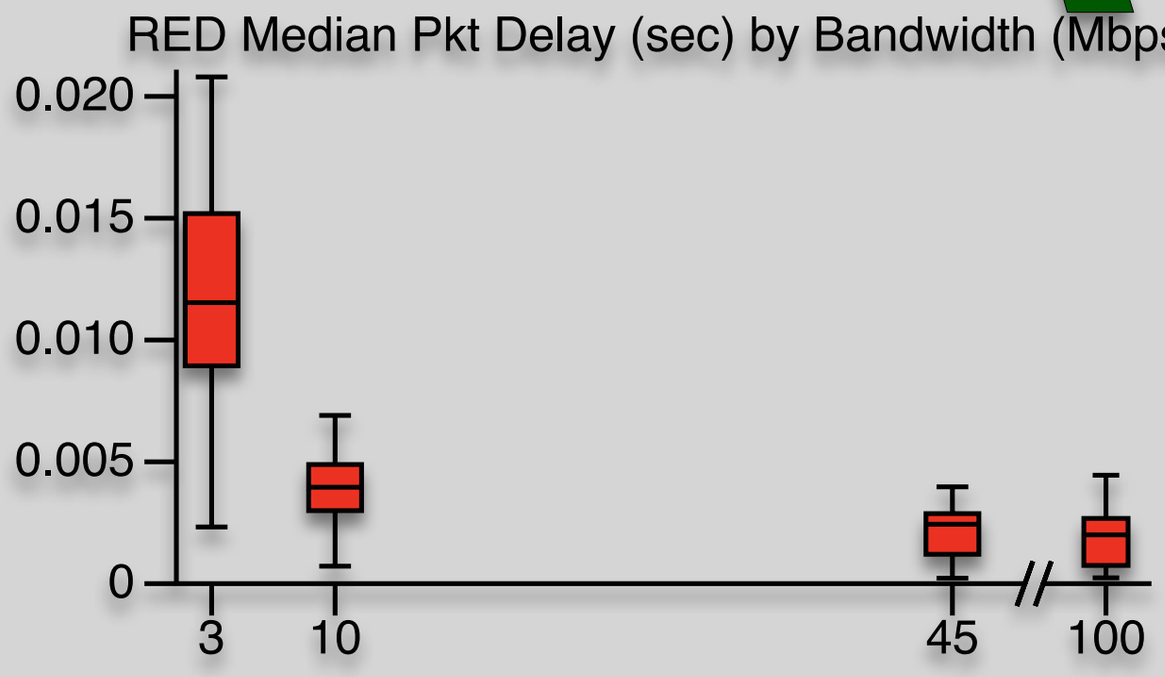

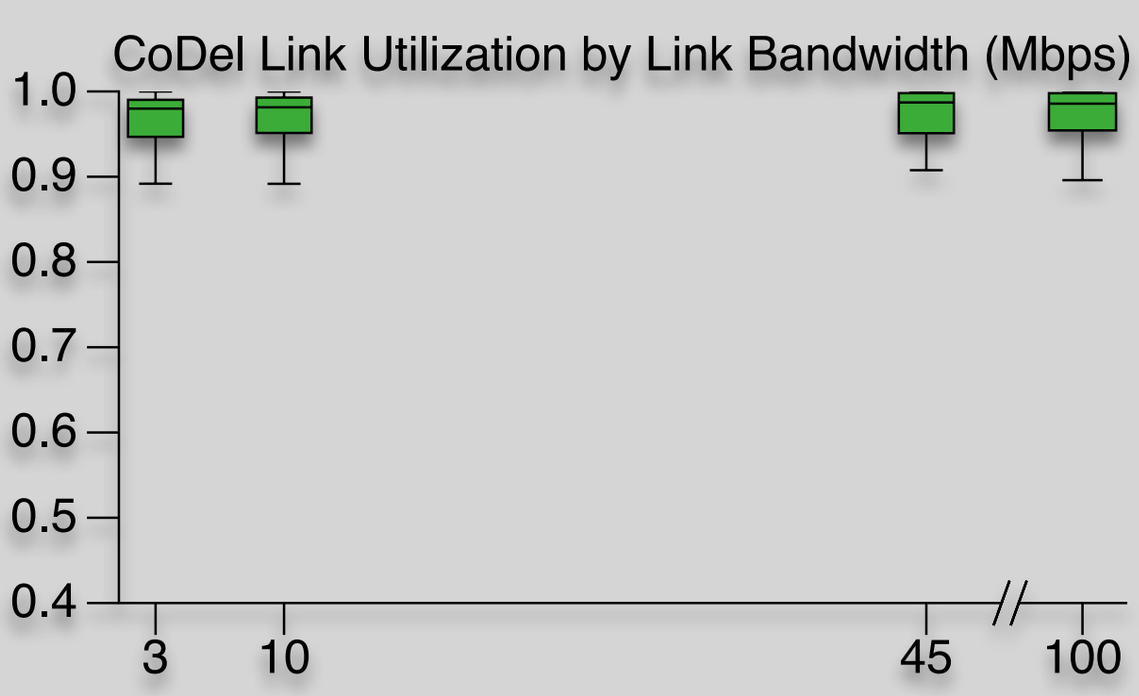

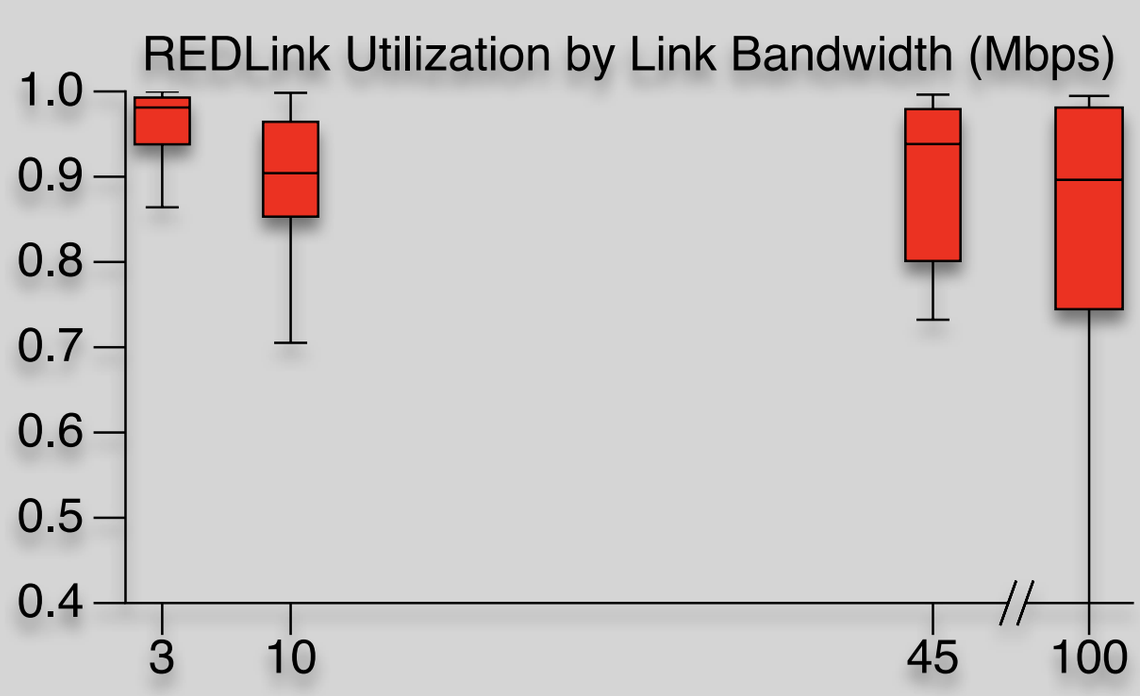

Various loads (FTP, web-browsing, CBR), RTTs from 10ms-500ms sorted by link rate

Results: Range of static link rates (low)

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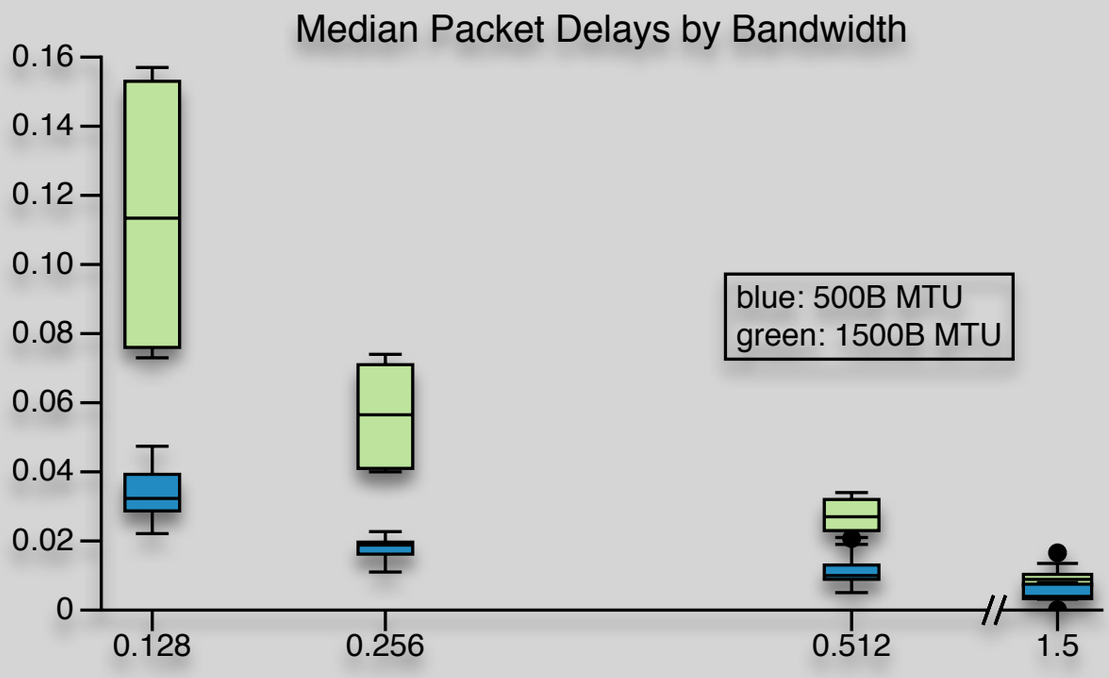

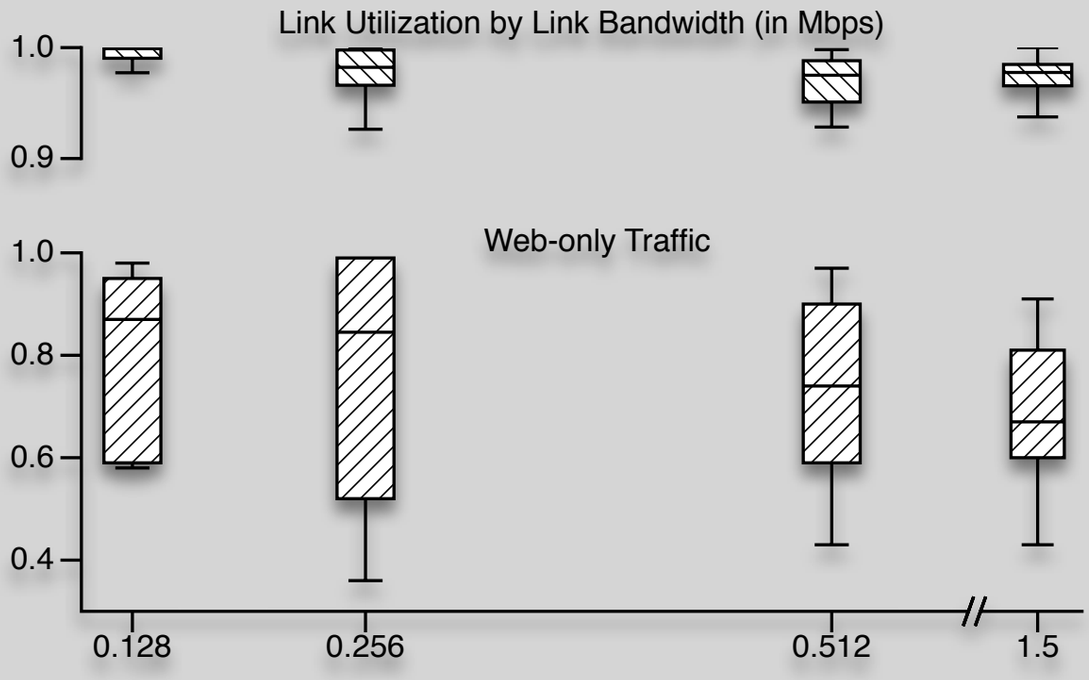

Data for both 500 byte MTU and 1500 byte MTU: the larger MTU increases delays but effect diminishes as bandwidth moved toward 1.5 Mbps. CBRs use 100 byte packets. (The low bandwidths don't work with RED.)

Dynamic Link: the fun stuff

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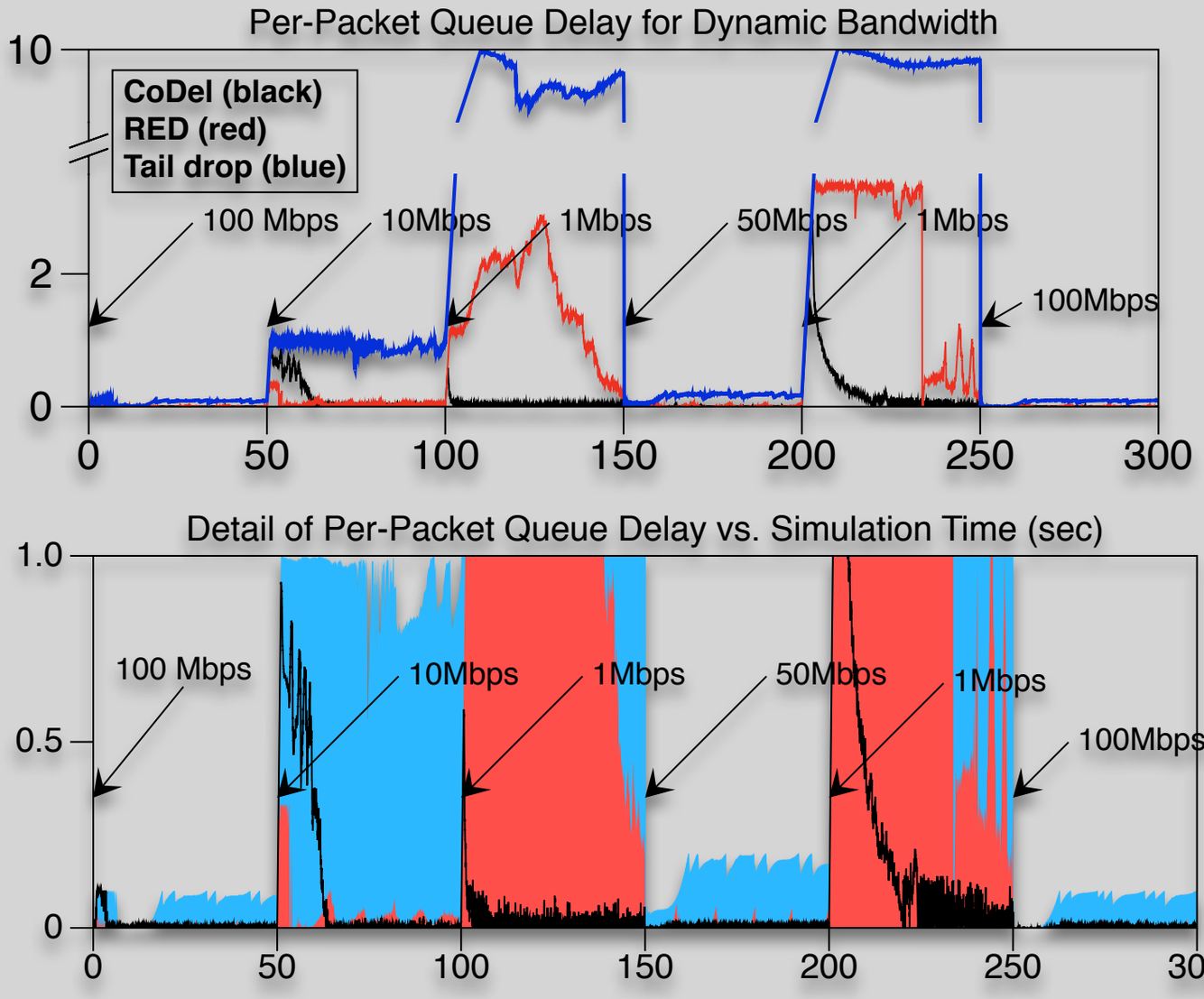

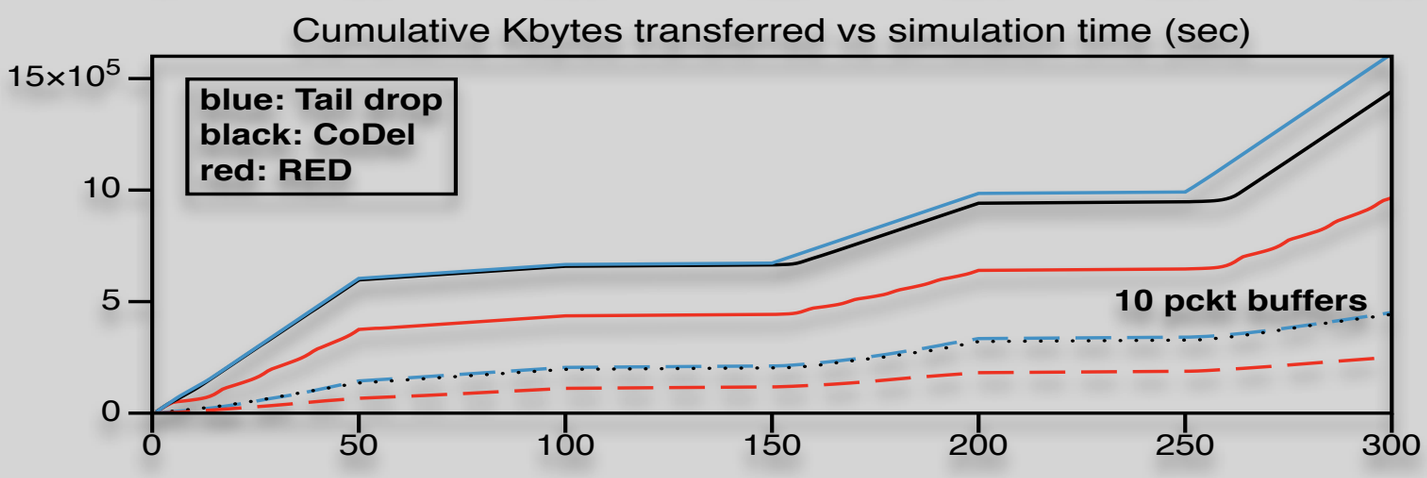

- Nominal 100 Mbps link with rate changes, buffer size of 830 packets
- 4 FTPs, 5 packmime connections/sec
- Note the throughput line for undersized buffer of 10 packets: throughput is about 75% less. CoDel same throughput as tail drop but 2.7ms median delay, 5ms 75th percentile
- Experimentally duplicated by Stanford grad students: http://reproducingnetworkresearch.wordpress.com/2012/06/06/solving-bufferbloat-the-codel-way/

Consumer Edge type example

- Symmetric links
- Load of two-way 64Kbps CBR, infinite FTP download, web browsing at a rate of 2 connections per second, uploads of small FTPs (1MB with 5-15 second idle periods)
- Compared two rates, CoDel and Tail drop
  - CoDel never drops packets at a higher rate (usually less) than Tail drop
  - CoDel keeps a much smaller queue and transfers similar amounts of data

metric	512 Kbps Links						1.5 Mbps Links					
	download			upload			download			upload		
	C	T	C/T	C	T	C/T	C	T	C/T	C	T	C/T
pkt drop %	8	8	100%	1.5	5.8	25%	3.5	4.7	75%	1.4	2.5	56%
median delay (ms)	18	73	25%	9	37	25%	8	49	17%	0	0	100%
total Mbytes	17	18	95%	12.8	13.9	92%	37	40	92%	22	21	103%
fairness of drops	0.87	0.89	98%	0.93	0.89	104%	0.81	0.96	84%	0.6	0.71	85%

Results: Range of RTTs

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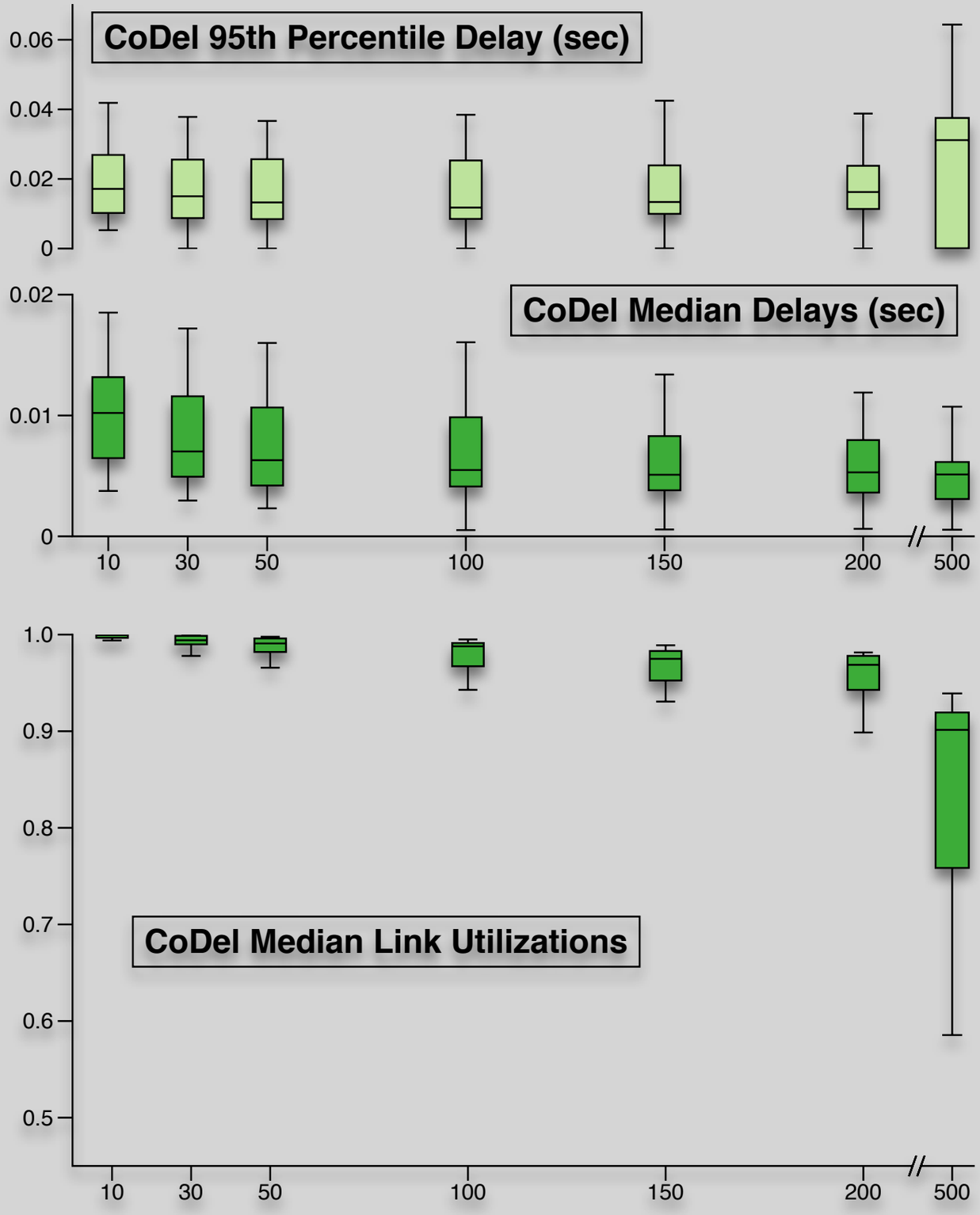

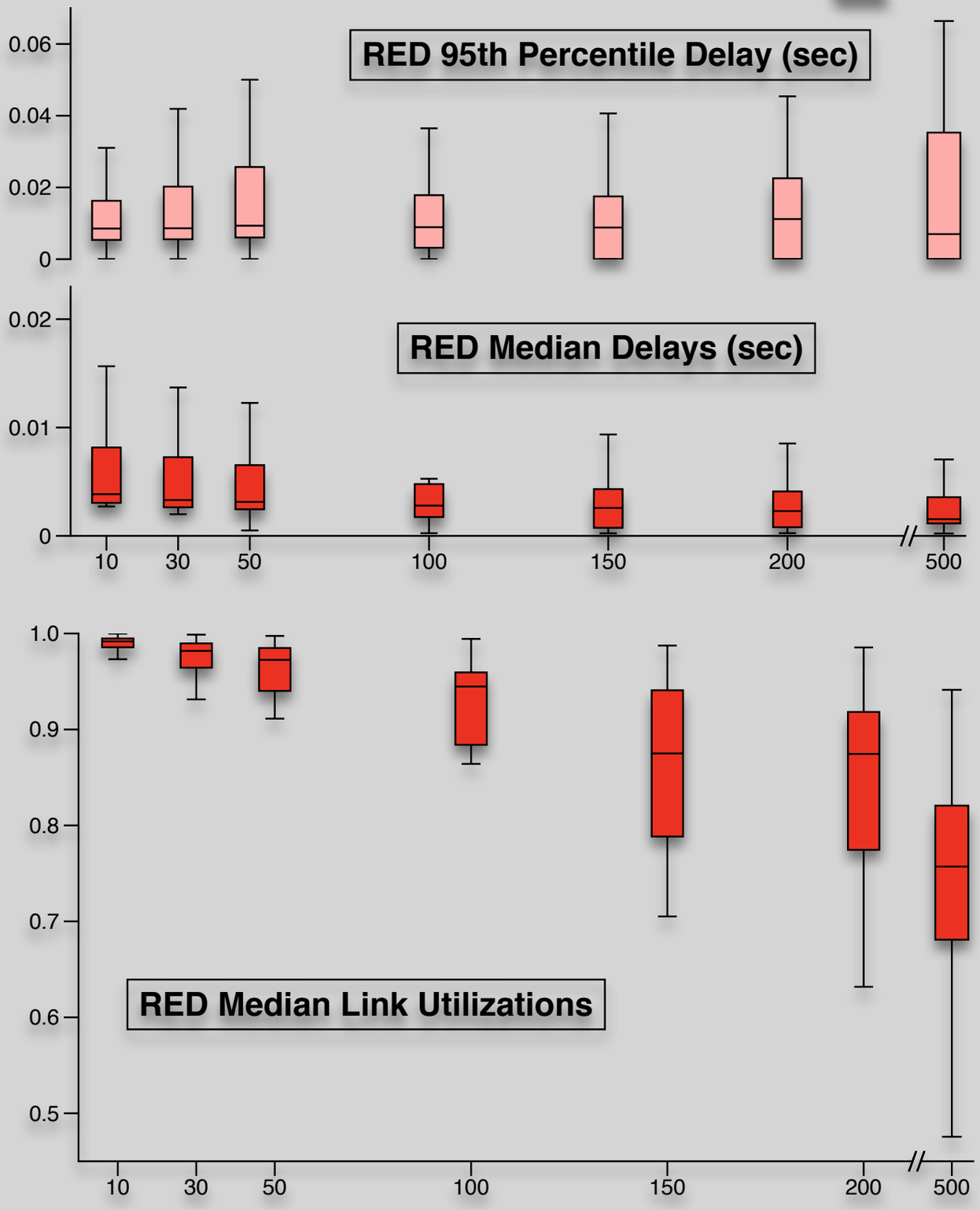

Interesting “Fairness” Results

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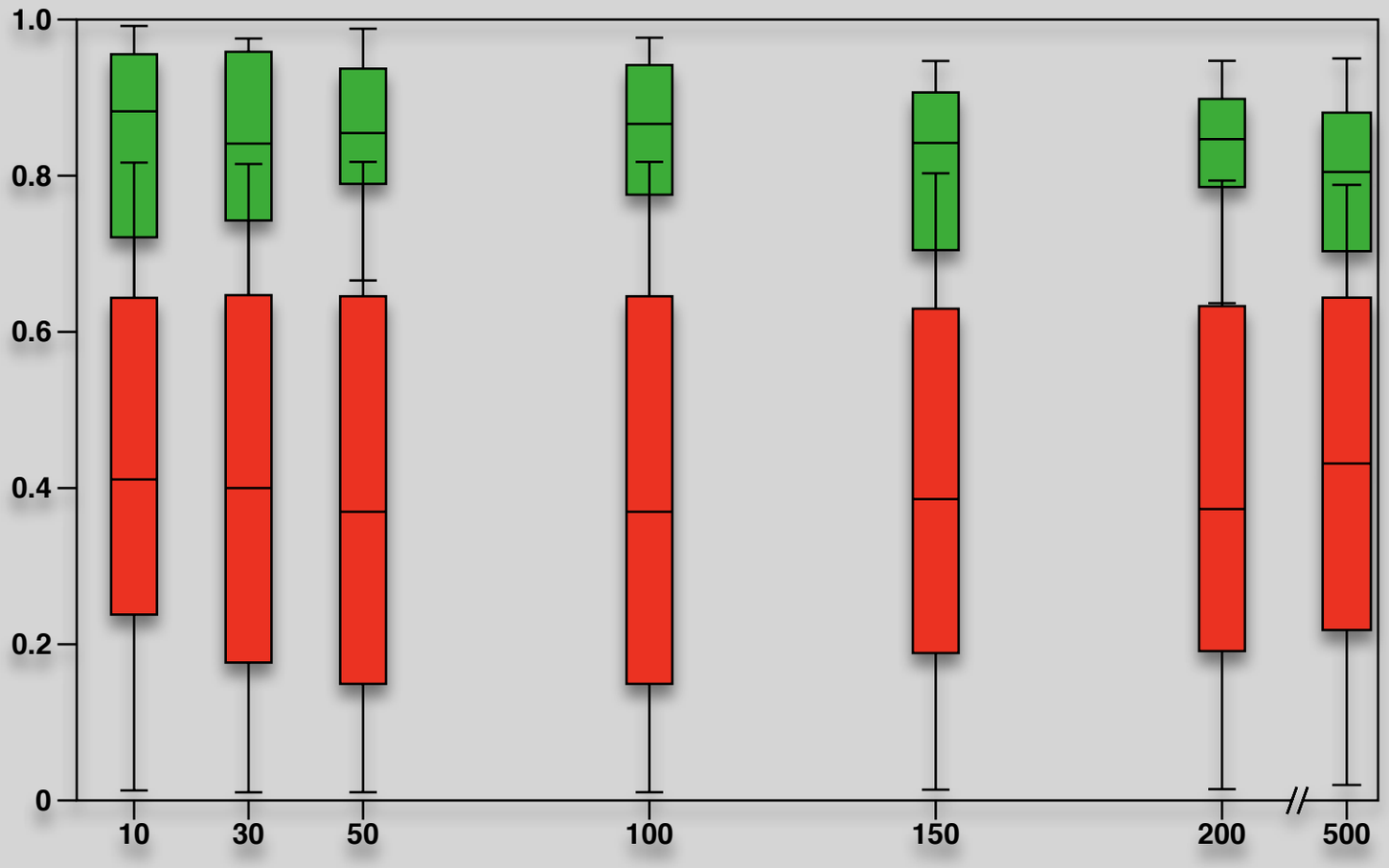
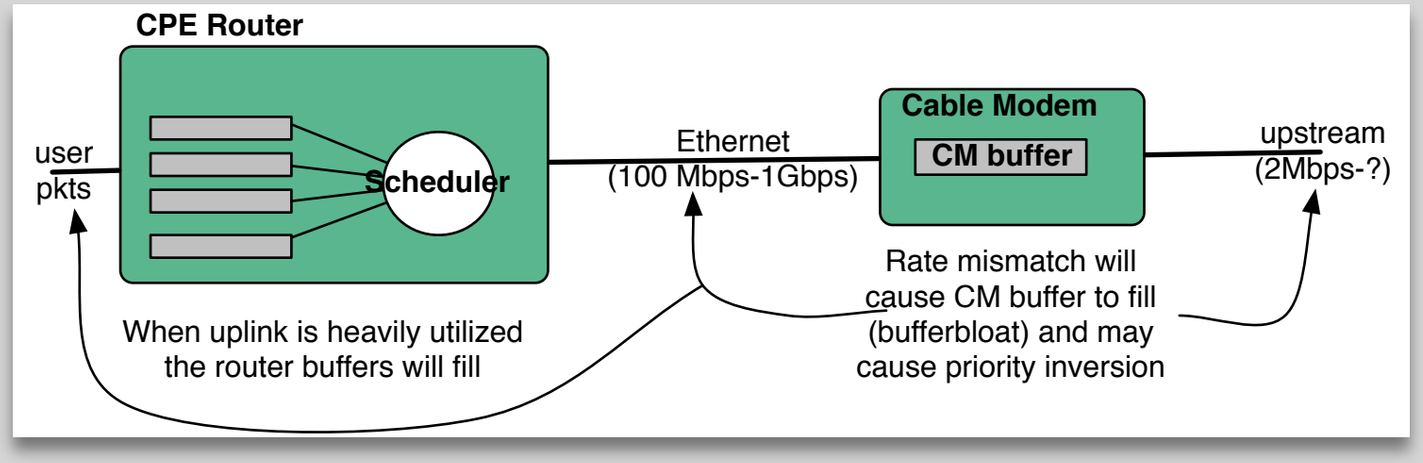


CoDel isn’t really concerned with “fair shares” of the bottleneck bandwidth but we did want to see if the drops were distributed in proportion to the usage of the link. Used the Jain Fairness Index, where 1.0 is best:

$$\frac{(\sum_i x_i)^2}{n \cdot (\sum_i x_i^2)}$$

Issues

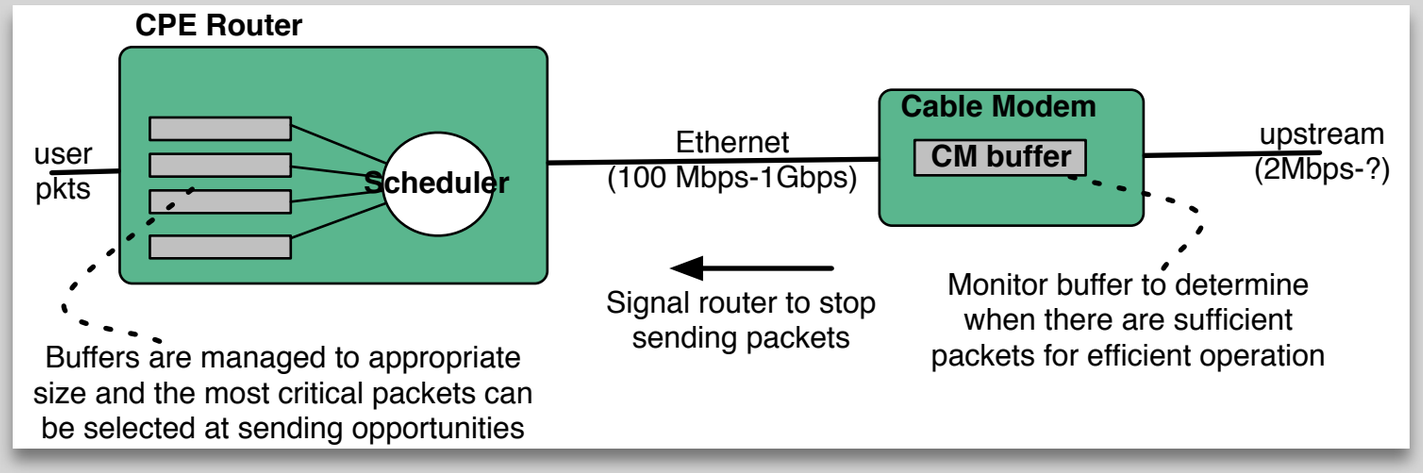
CoDel Can't Fix Concatenated Queues



Solutions:

- rate control
- AQM in CM
- Flow control

Flow control



Traffic-Related Issues

- When “forward” tcp data streams are mixed with “reverse” acks, this has always created problems.
- When long-lived file transfers are mixed with bursty web request streams or VoIP, the latter suffer
- Though running CoDel will help the second problem some due to keeping shorter delays, the real solution lies beyond using an AQM
- The best solution for VoIP is a prioritized queue
- The best solution for creating a better traffic mixing and solving ack compression problems is to run a stochastic flow queue algorithm across a moderate number of bins and then run CoDel on each bin (Dumzaet)

Algorithm Issues

- A more sophisticated Control Law that can recognize a steady state (various “hacks” to mitigate problems)
- Although good results across a range of RTTs have come with a fixed minimum-tracking *interval* of 100-200ms, making the algorithm more robust to RTT is desireable
- An analytic and experimental study of the optimal number of bins for an sfq is needed

Educational Issues

- The meaning of target and interval
- “bursty macs” don’t require larger targets (I wrote a note on this and posted on web site)
- use packet traces to figure out what is really going on
- knowledge is power

Notes, Caveats

- The “second order” parts of CoDel are still being explored.
- We want to keep this algorithm available to anyone and not encumbered by patent stuff: un-encumbered code (BSD/GPL dual-license) available for ns2, ns3, linux
- We have submitted this as in internet draft to the IETF TSV WG and recently updated (draft-nichols-tsv-codel-01)
- We have put our simulator code and other goodies, including links to Van’s talk at www.pollere.net/CoDel.html
- CoDel is in Linux kernels from 3.5 on.
- There is a lot of active experimentation in linux which is tracked by Dave Taht at http://www.bufferbloat.net/projects/codel