TCP Westwood and Easy Red to Improve Fairness in High-speed Networks

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PfHsn 2002

Berlin, 22 April 2002

Outline of the presentation

Overview of Reno and Westwood TCP congestion control

Mathematical model of TCP Westwood

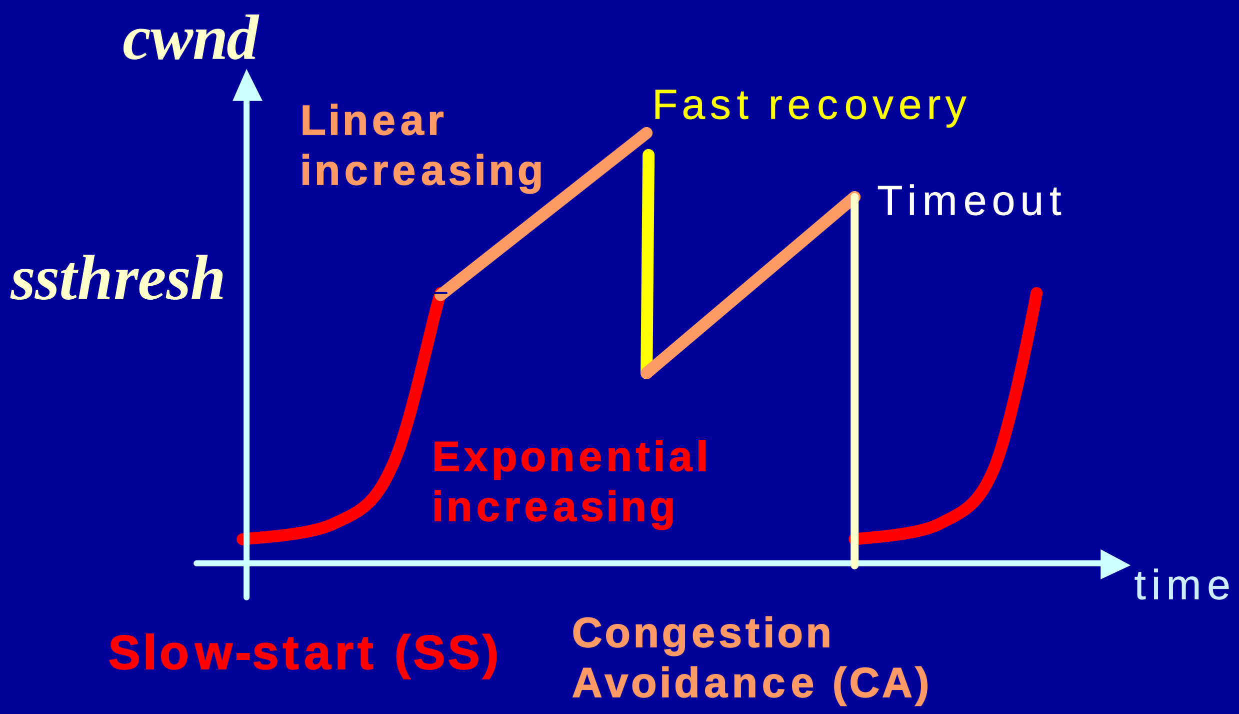
Easy RED

Simulations of Reno, Westwood over drop tail, RED, Gentle Red, & Easy RED

Overview of Classic TCP (Reno)

- Due to fundamental e2e principle the control must follow a trial and error AIMD paradigm with 2 phases:
  - I) A probing phase (additive increase), which aims at discovering the network available capacity
  - II) A multiplicative decrease phase triggered when congestion is signaled via timeout or duplicate ACKs

Reno TCP



Typical *cwnd* dynamics following the AIMD paradigm

Known drawbacks of Reno TCP

- ✍ low throughput over wireless links because losses due to unreliable links are misinterpreted as congestion

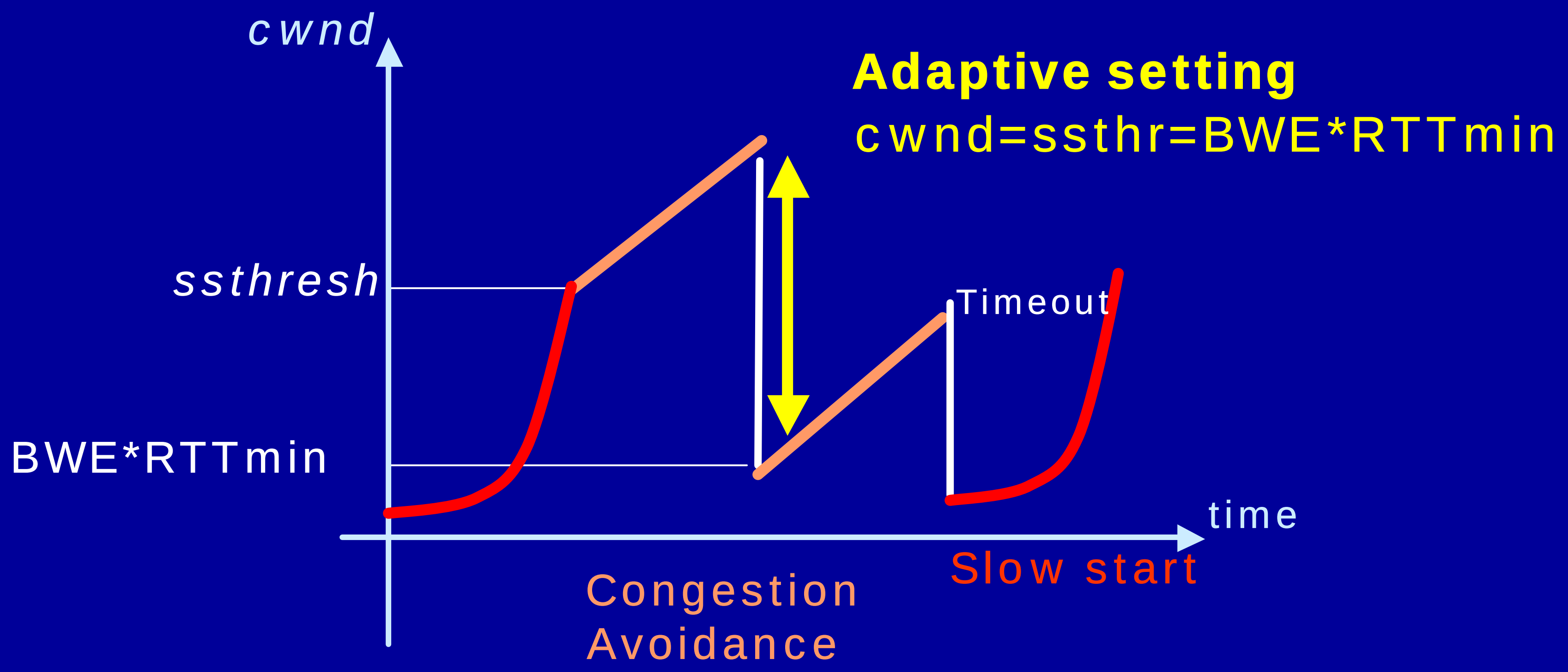
- ✍**Reno throughput proportional to 1/RTT, i.e. it is not that friendly**

Overview of TCP WESTWOOD

TCP Westwood is a sender-side only modification of TCP Reno based on:

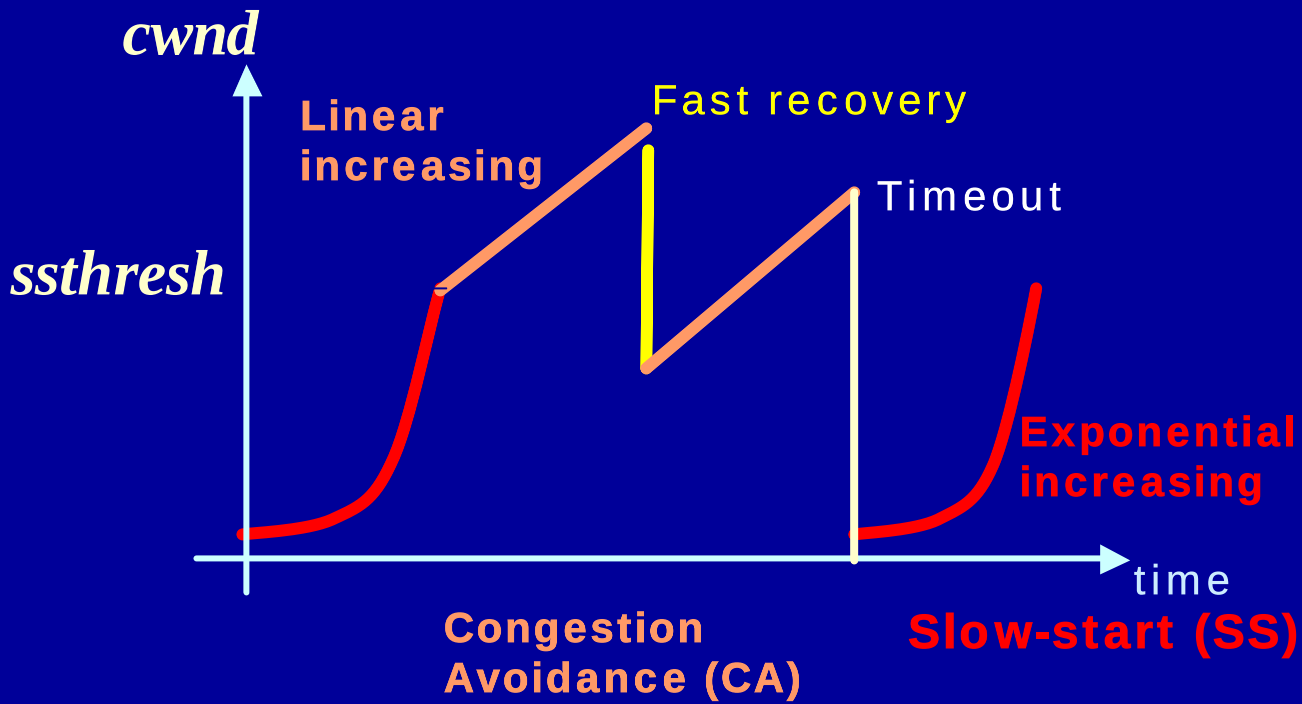
- **window shrinking after congestion based on e2e bandwidth estimation (faster recovery)**
- **E2E estimation of available bandwidth filtering the flow of returning ACK packets**

TCP Westwood



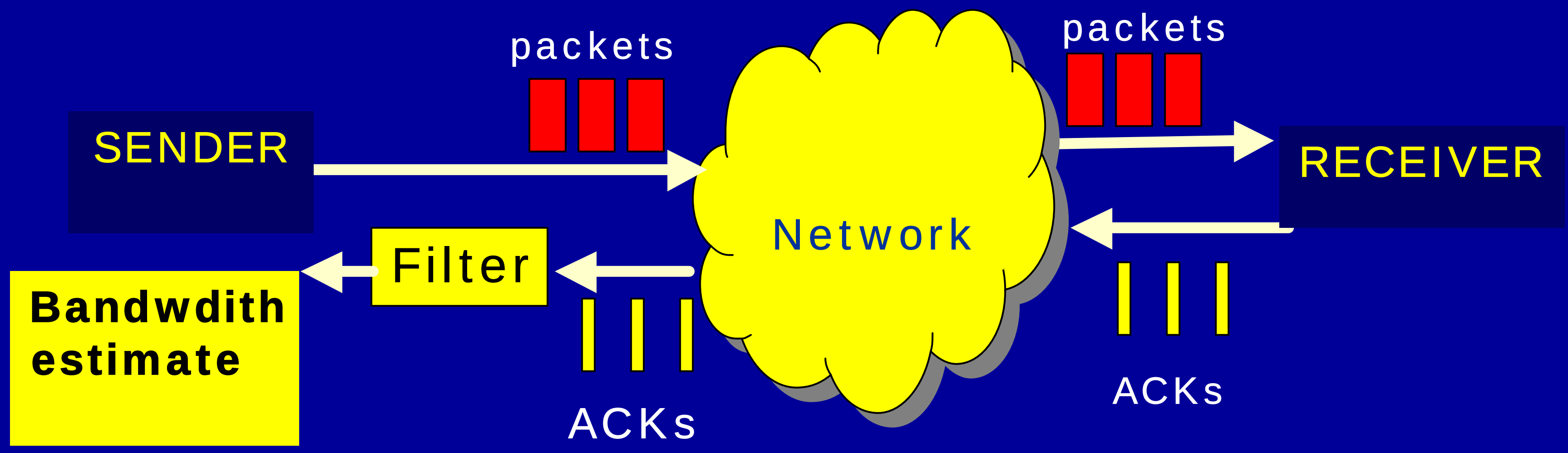
The key point is the AIAD opposed to the AIMD paradigm : window shrinking after congestion is based on available bandwidth

Reno TCP



Typical *cwnd* dynamics following the AIMD paradigm

E2E bandwidth estimation



- The rate of returning ACKS is exploited to estimate the “best-effort” available bandwidth

E2E ESTIMATE USING A TIME-VARYING FILTER

- bandwidth sample $b_j ? \frac{d_j}{?_j}$

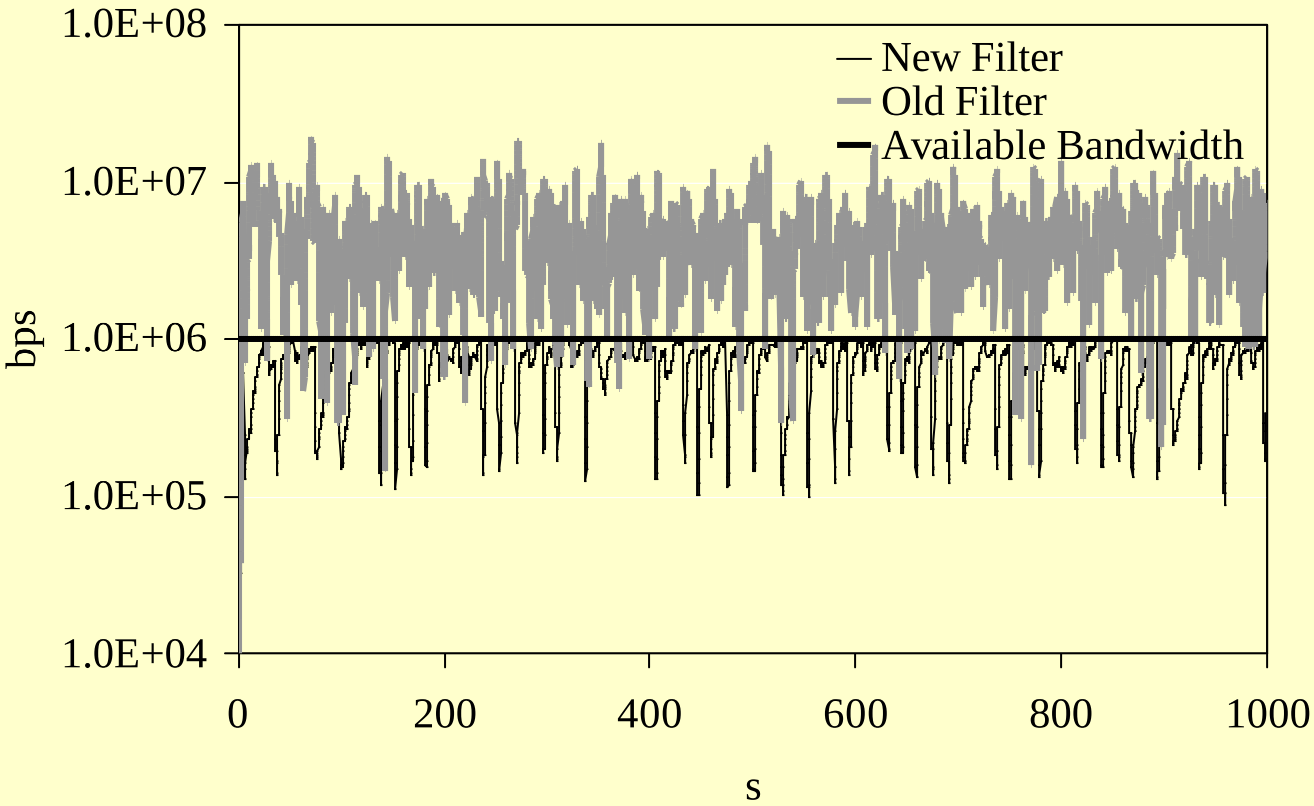
$$? _j ? \textit{Last RTT}$$

$$d_j ? \textit{data acknowledged in the last RTT}$$

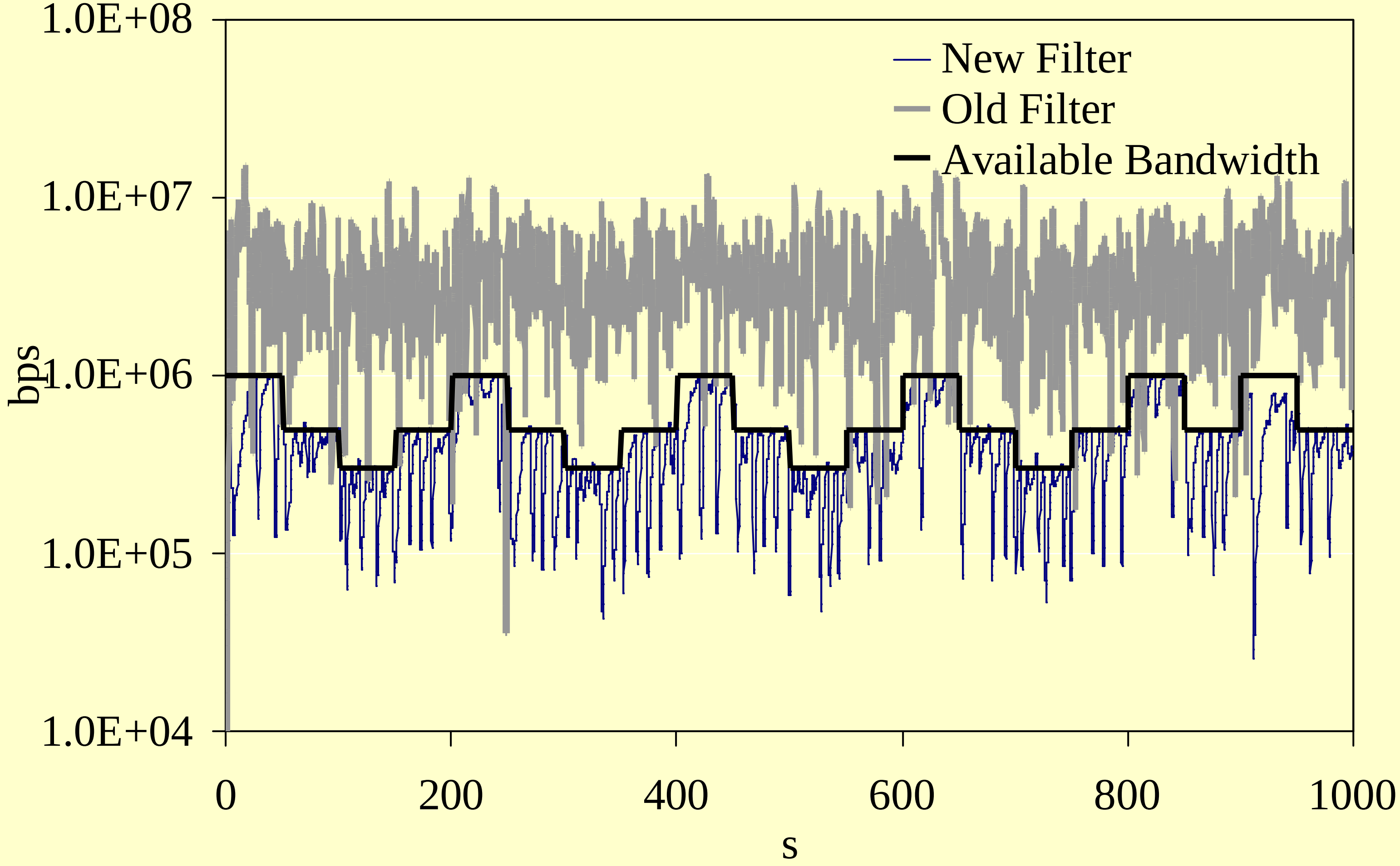
- filtered value $\hat{b}_j ? \frac{2?_f ? ?_j}{2?_f ? ?_j}\hat{b}_{j?1} ? ?_j \frac{b_j ? b_{j?1}}{2?_f ? ?_j}$

1/$?_F$=Cut-off frequency

Bandwidth estimate
A single TCP flow over 1 Mbps link



Bandwidth estimate
1 TCP+1 UDP over 1 Mbps link



in other words...

- Westwood TCP shrinks control windows by taking into account the available bandwidth, whereas TCP Reno performs a "***blind***" multiplicative window reduction

- Adaptive window reduction based on E2E bandwidth estimation makes TCP W robust with respect to wireless loss & increases fairness and throughput

Pseudo-code

- if (3 DUPACKs are received)
  ssthresh=BWE*RTTmin;
  cwnd = ssthresh;
  endif
- if (timeout expires)
  ssthresh=BWE*RTTmin;
  cwnd = 1;
  endif

Equation Model of Westwood

Assuming the following notation:

- B: Bandwidth Estimate
- p: segment loss probability
- RTT_{min}: minimum Round Trip Time
- RTT: Round Trip Time
- ? **cwnd**: change of cwnd on update step

On successfully ACK reception (with probability 1-p) the change in cwnd is (linear phase)

$$? \, cwnd = 1/cwnd$$

On segment loss (with probability p) the change in cwnd is

$$? \, cwnd = B \; ? RTT_{min} - cwnd$$

The expected value of ? cwnd is then

$$E[?\,cwnd\,]\,?\,\frac{1?\;p}{cwnd}\,?\,(B\,?RTT_{\min}\,?\,cwnd\,)\,?p$$

Considering that ? r= ? cwnd/RTT and that the update timestep is RTT/cwnd:

$$\frac{?r(t)}{?t}\,?\,\frac{1?\;p}{RTT^{2}}\,?\;p\,?r(t)\,?\frac{B\,?RTT_{\min}}{RTT}\,?\,r^{2}(t)\,?p$$

By separating variables and solving … … ..

The steady state solution for the throughput is:

$$r^W ? \lim_{t? ?} r(t) ? \frac{B ?RTT_{\min}}{2 ?RTT} ? \sqrt{ ? \frac{B ?RTT_{\min}}{2 ?RTT} ?^2 ? \frac{1 ? p}{p ??RTT ?^2} }$$

Friendliness to Reno

If the loss probability is low, because of the flow conservation principle, the following approximation holds:

$$\boxed{B ? r^{W}}$$

By substituting the approximated bandwidth estimate into the previous Eq. model, we obtain …. … .

The Westwood steady state throughput is :

$$r^{West} = \frac{1}{\sqrt{RTT \cdot T_q}} \cdot \sqrt{\frac{(1 - p)}{p}}$$

The Reno steady state throughput (Kelly's model) is:

$$r_R = \frac{1}{RTT} \cdot \sqrt{\frac{2 \cdot (1 - p)}{p}}$$

Both Westwood and Reno throughputs depend on:

$$1/\sqrt{p}$$

That is:

they are *friendly*

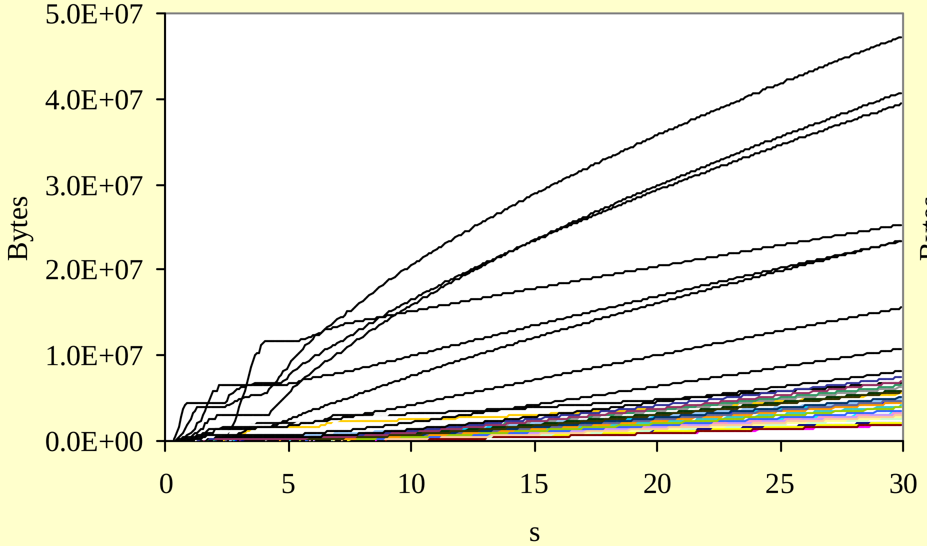
Westwood throughput depends on: $1/\sqrt{RTT}$

Reno throughput depends on: $1/RTT$

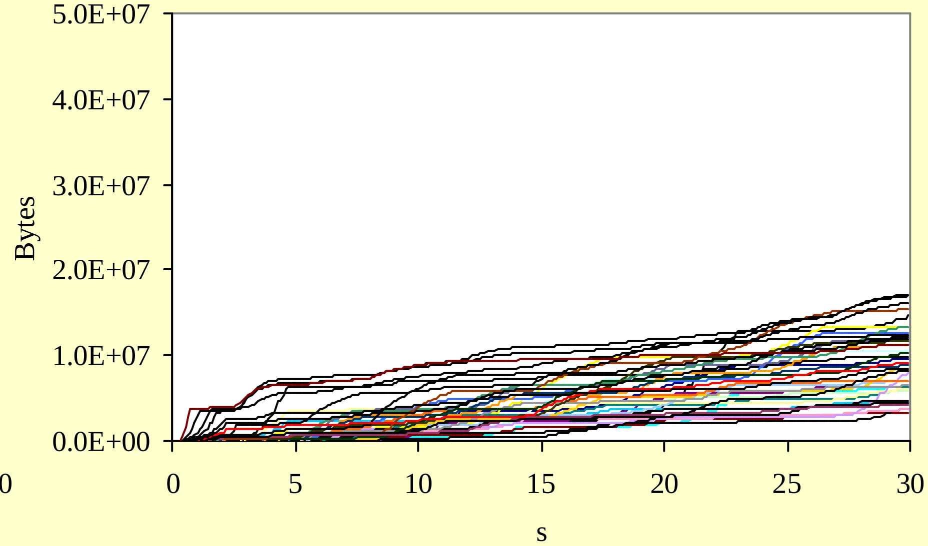
That is:

Westwood improves fair sharing among flows with different RTTs

A “visive”look at fairnes. 40 cnx. over 100Mbps bottleneck link

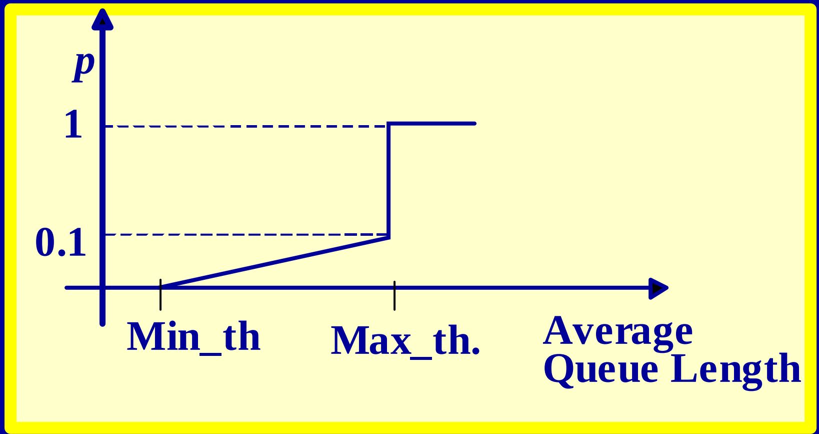


Byte sent by 40 Reno cnx

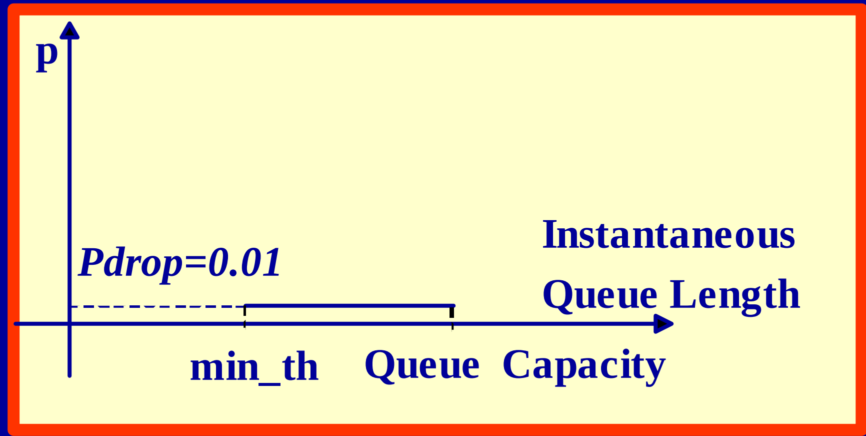


Byte sent by 40 West cnx

RED vs. EASY RED



RED



Easy RED

Average queue vs Istantaneous queue

Varying pdrop vs Constant pdrop

4 parameters vs 2 parameteres

Rationale of Easy RED

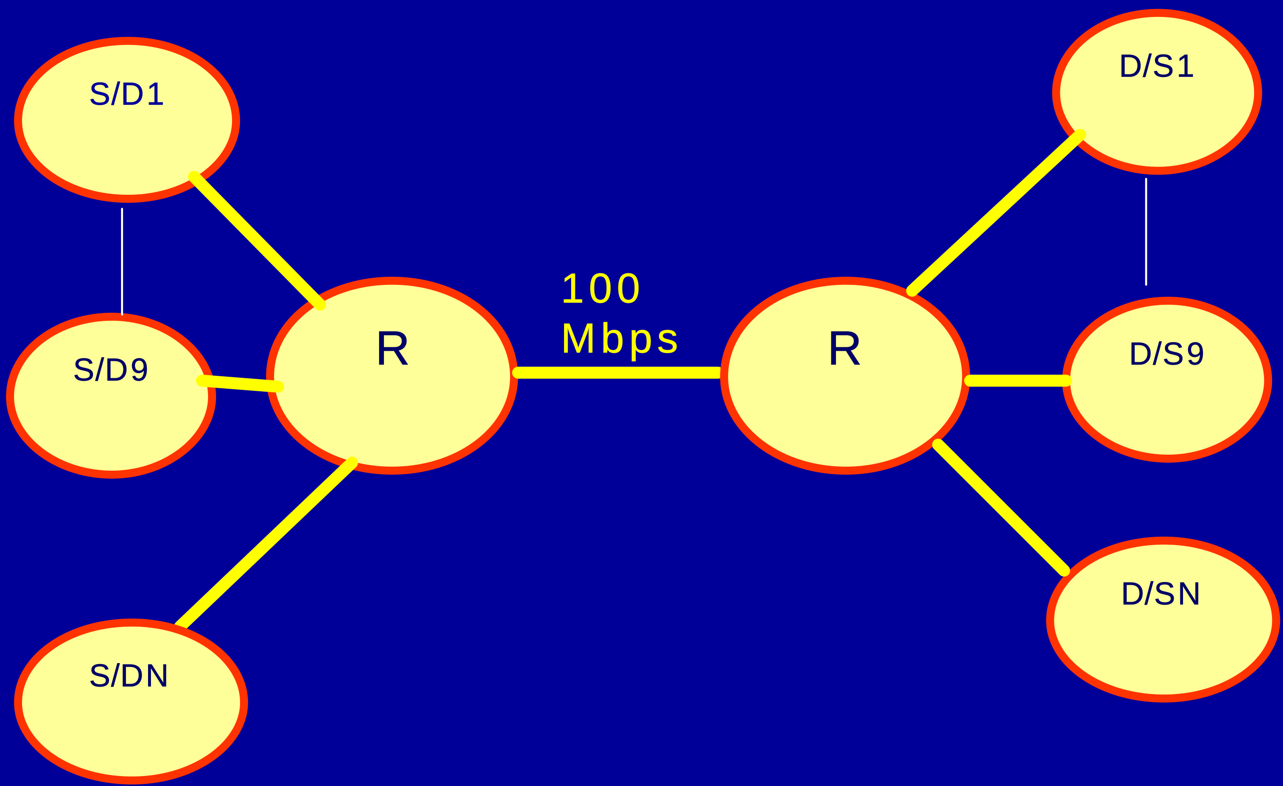
We believe that what the sender needs is just an early drop to promptly react to incipient congestion thus the queue should not be averaged because average introduces delay

It is difficult to influence the sender behaviour via the dropping probability thus a constant dropping probability can be used

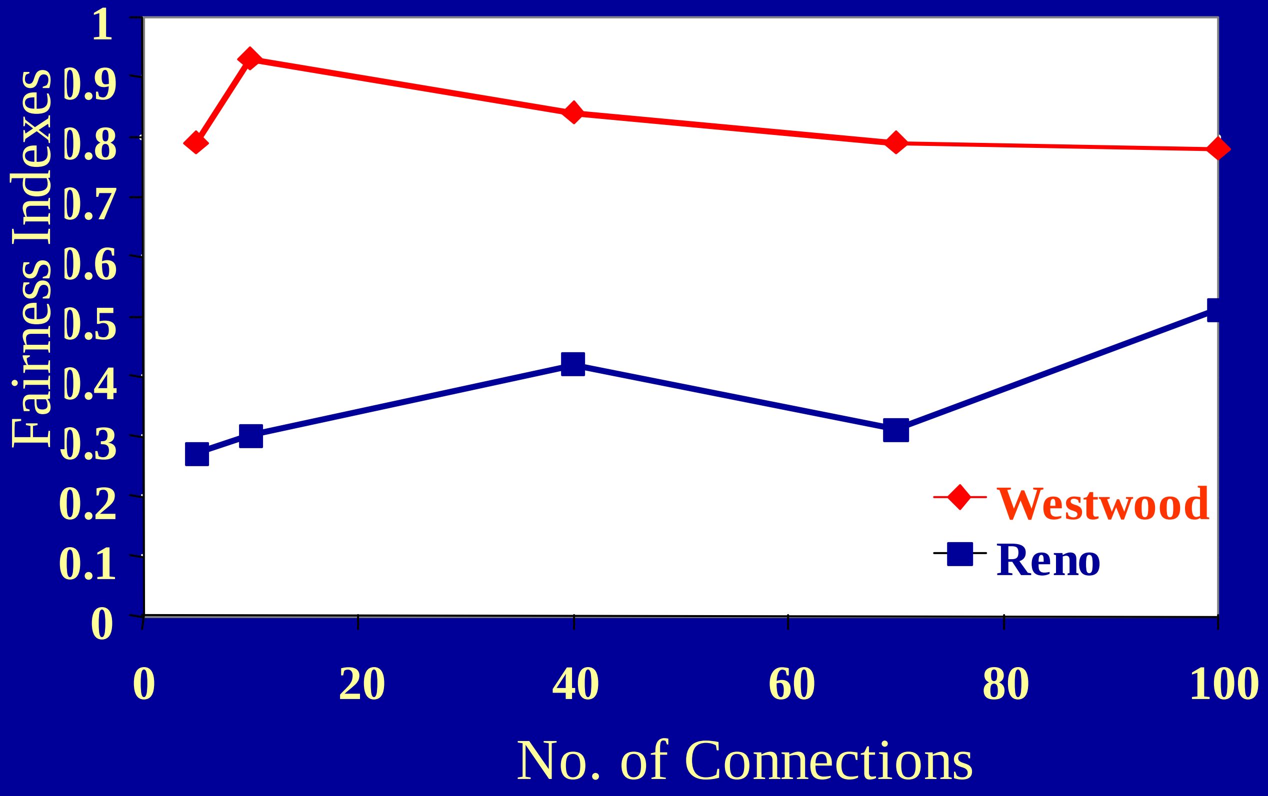
The major gain from early drop can be obtained by changing the sender response to drop, that is using TCP Westwood

Ns-2 simulations

single 100Mbps bottleneck shared by N TCP connections
RTTs ranging from 250/N ms to 250ms

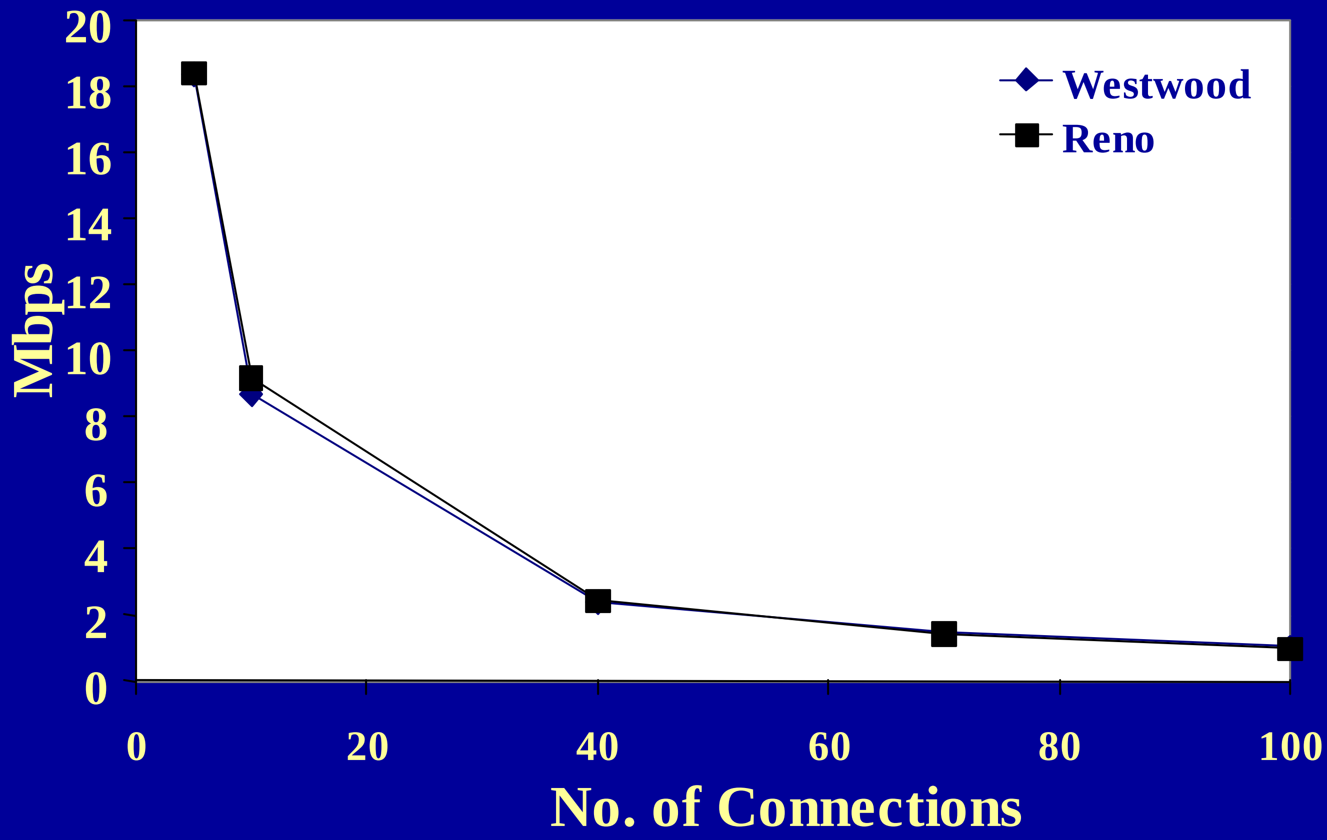


Jain Fairness Index vs. Number of connections sharing a 100Mbps bottleneck with Drop Tail

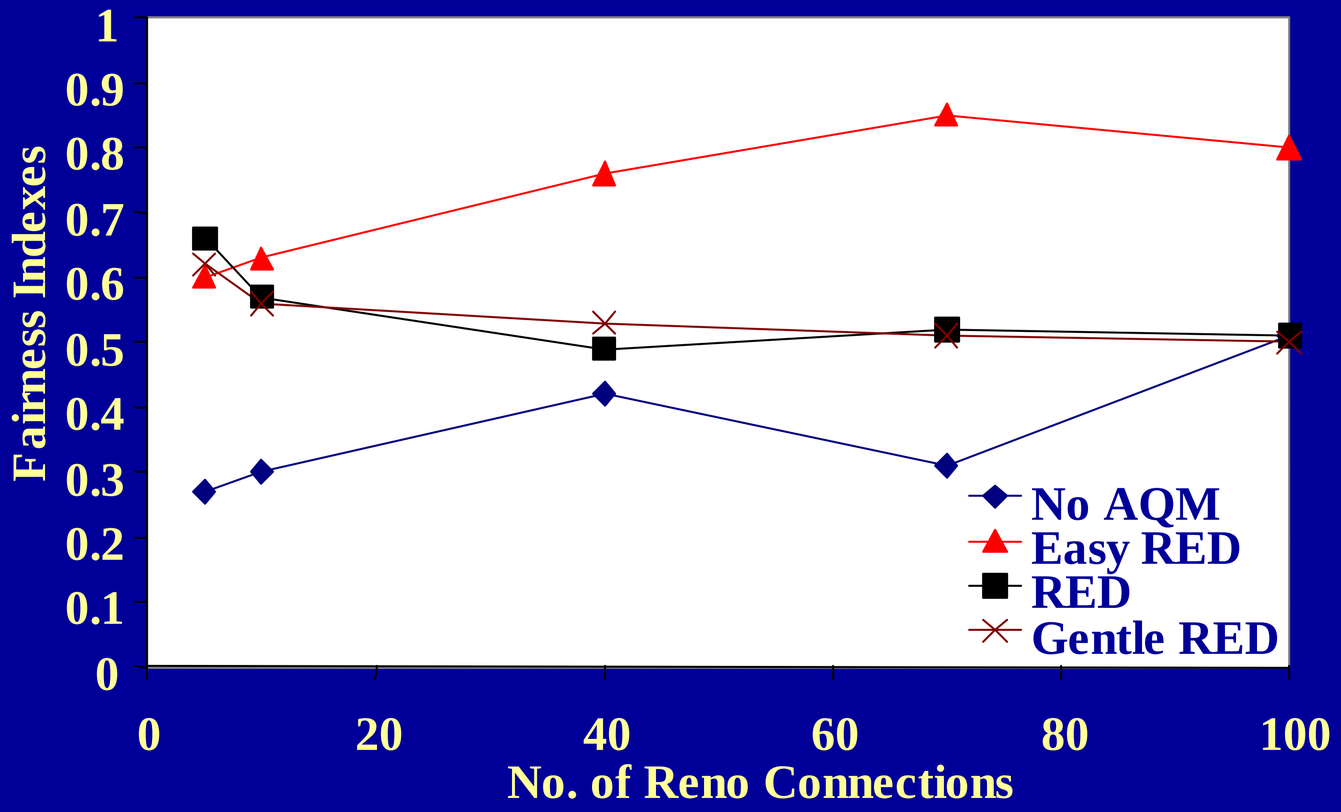


$$Fairness\ Index = \frac{(\sum_{i=1}^{N} b_i)^2}{N \sum_{i=1}^{N} b_i^2}$$

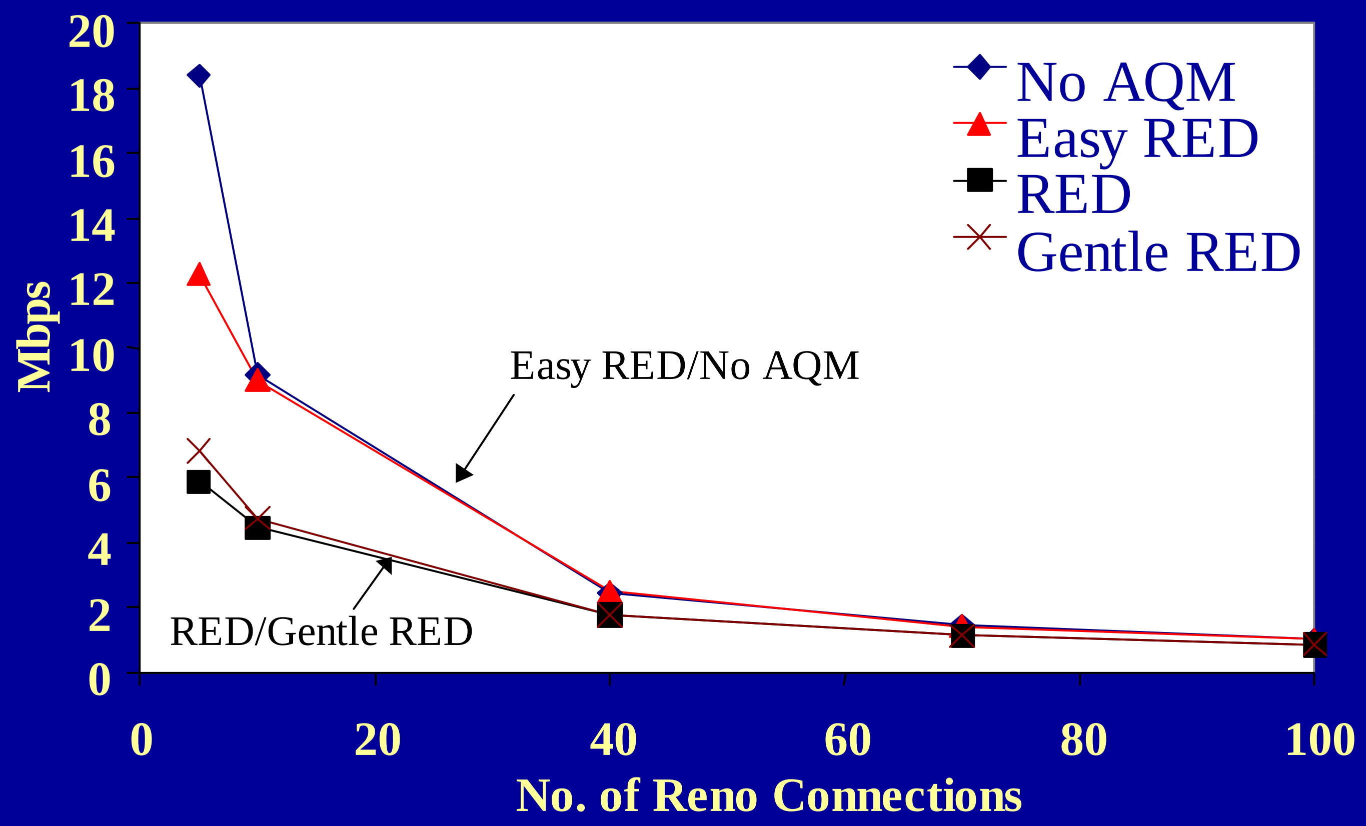
Average Throughput vs. Number of connections sharing the bottleneck (Drop Tail)



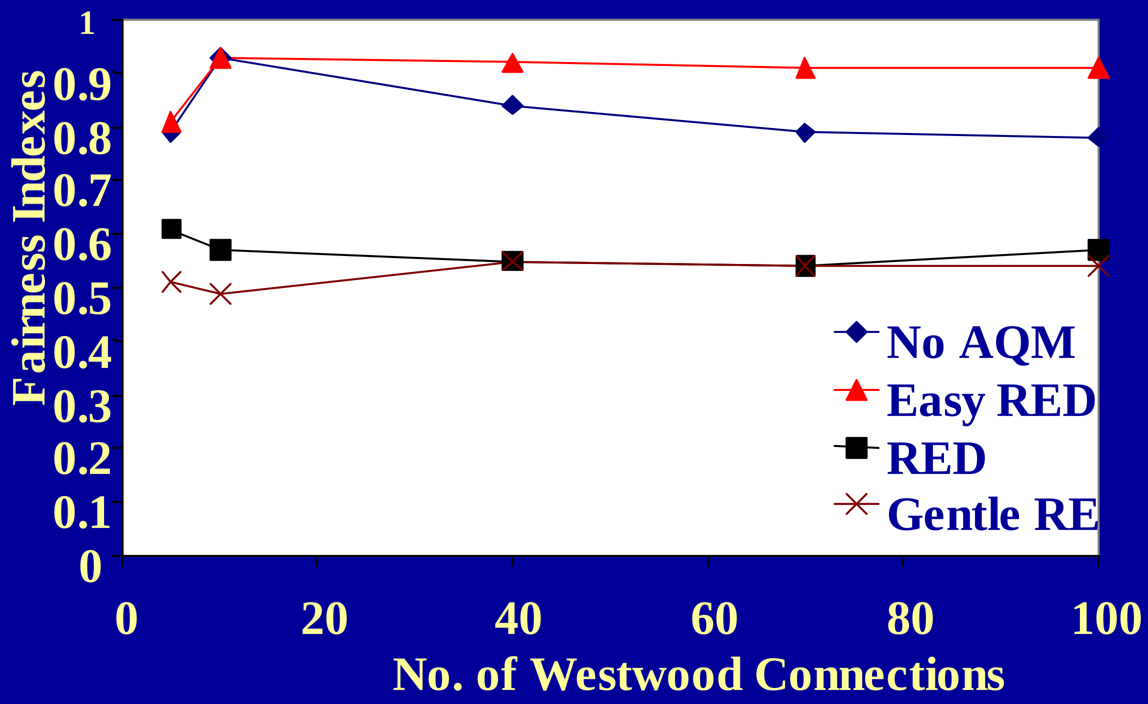
Fairness Index vs. Number of Reno connections sharing the bottleneck with AQM



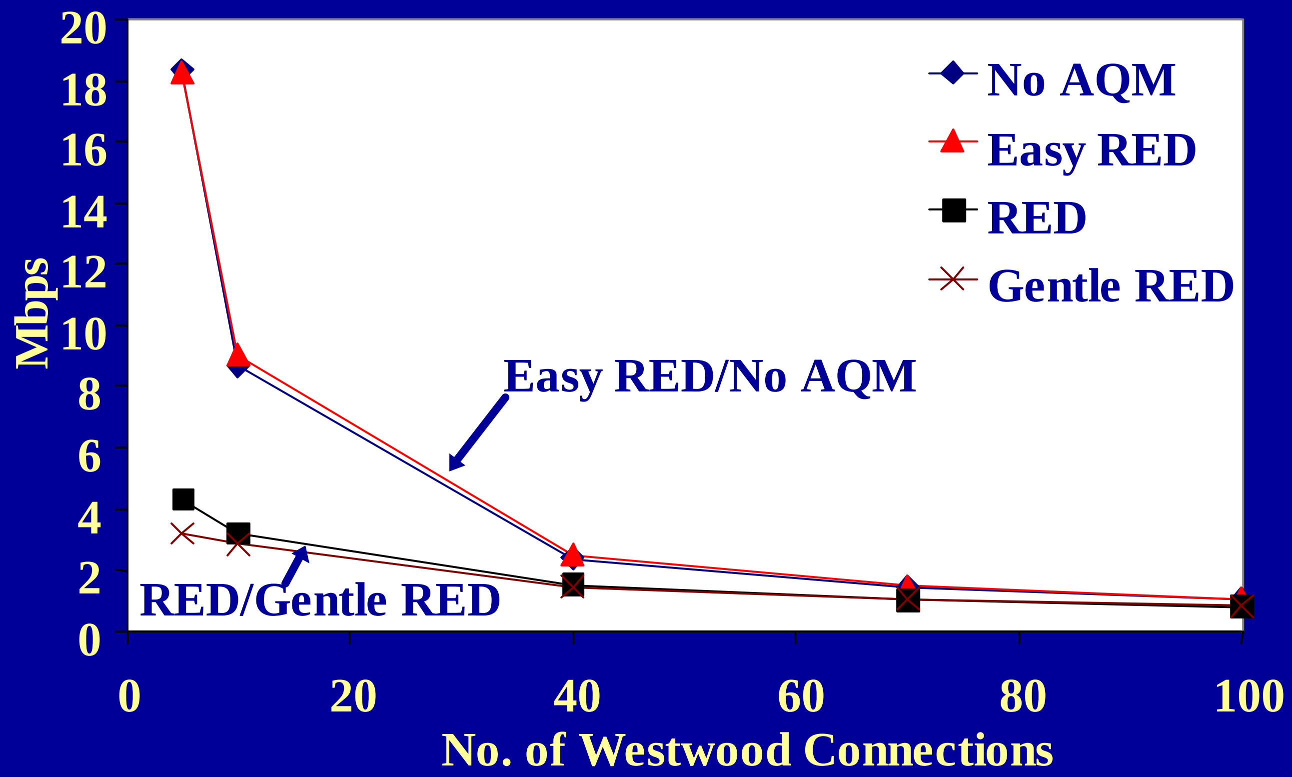
Average Throughput vs. Number of Reno connections sharing the bottleneck with AQM



Fairness Index vs. Number of Westwood connections sharing the bottleneck with AQM



Average Throughput vs. Number of Westwood connections sharing the bottleneck (AQM)



Friendliness

Connections	Fairness Index
100 West	0.78
50W 50Reno	0.64
100 Reno	0.51
70 West	0.79
35W 35Reno	0.66
70 Reno	0.31
40 West	0.84
20W 20 Reno	0.58
40 Reno	0.42
10 West	0.93
5W 5 Reno	0.65
10 Reno	0.3

Conclusions

- ✍ TCP W exploits adaptive vs. multiplicative window reduction
- ✍ Mathematical model of TCP Westwood shows that TCPW is friendly to Reno and provides significant fairness increment in high-speed Internet
- ✍ Easy Red improves the fairness of Reno connections wrt RED and Gentle RED
- ✍ Easy Red improves the fairness of TCPW connections wrt RED and Gentle RED