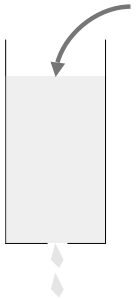
TCP
Tahoe, Reno, NewReno,
SACK, and Vegas

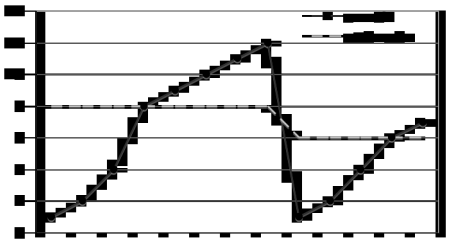
cwnd: congestion window
swnd: usable sending window
rwnd: advertised receiver's window
ssthresh: slow-start threshold

RFC793

No cwnd
On timeout: retransmit
swnd = rwnd

TCP Tahoe





new ack:
if (cwnd < sstresh)
  cwnd += 1
else
  cwnd += 1/cwnd

timeout/3rd dup ack:
retransmit all unacked
ssthresh = cwnd/2
cwnd = 1

Improving TCP Tahoe:

Packets still getting through in dup ack -- no need to reset the clock!

TCP Reno

new ack:
if (cwnd < sstresh)
  cwnd += 1
else
  cwnd += 1/cwnd

timeout:
retransmit 1st unacked
ssthresh = cwnd/2
cwnd = 1

3rd dup ack:
retransmit 1st unacked
ssthresh = cwnd/2
cwnd = cwnd/2 + 3

Fast Recovery:
the pipe is still almost full -- no need to restart

subsequent dup ack:
cwnd++

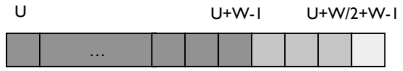
new ack:
cwnd = ssthresh

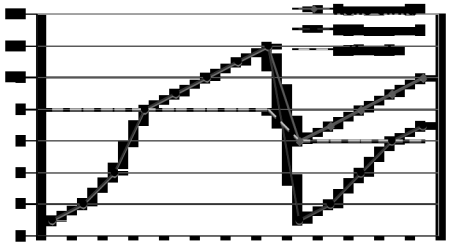
Suppose U is lost (oldest unacked) and all other packets are not. At time t, cwnd is W, and packets [U, U+W-1] are in the pipe.

Between time t and t+RTT, we would have retransmitted U and received W-1 duplicate ACK.

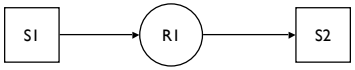
Between time t and t+RTT, the cwnd becomes W/2 + W-1. So we get to send W/2 new packets during the time. (Soon cwnd is going to become W/2 anyway..)

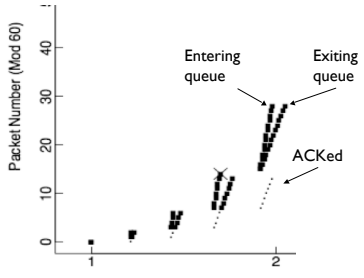
At time t+RTT, we receive ACK for packets [U,U+W-1], set cwnd to W/2.

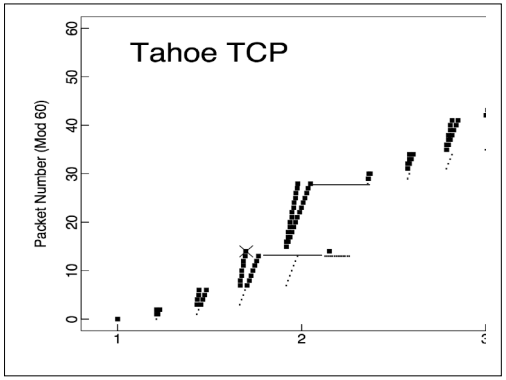


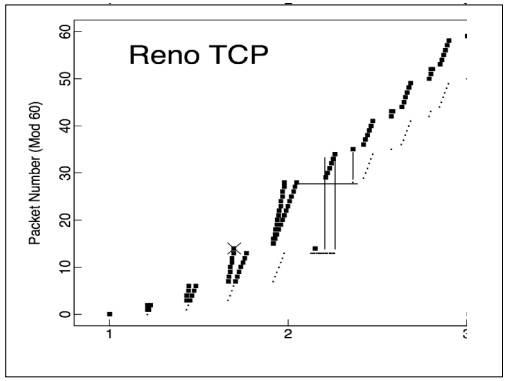


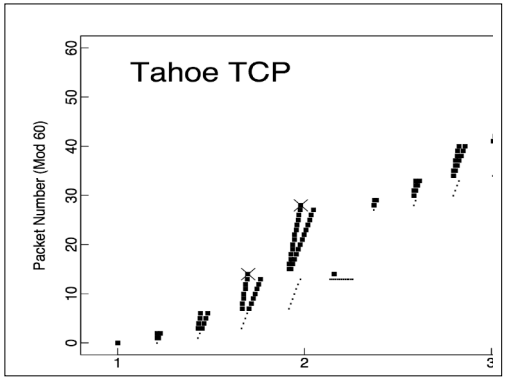
Simulation of TCP Tahoe/Reno

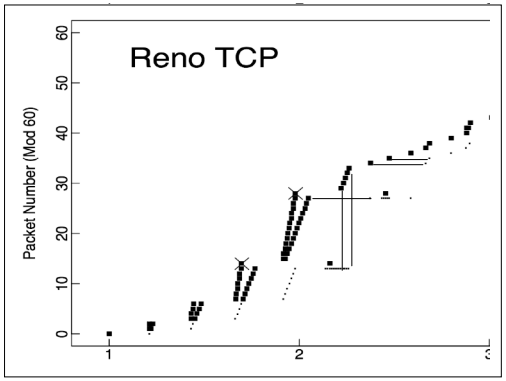


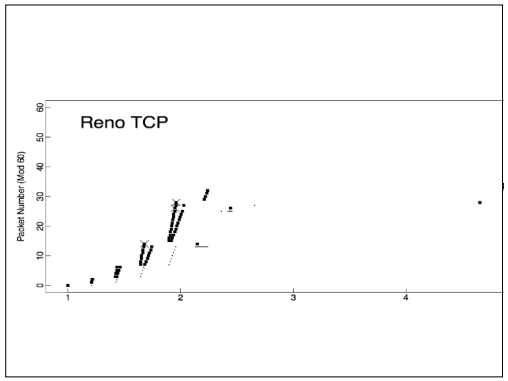


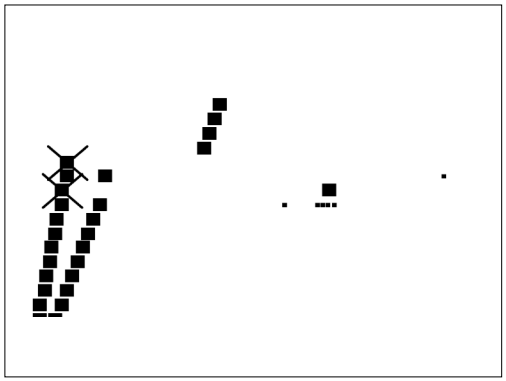

Tahoe TCP
Packet Number (Mod 60)


Reno TCP
Packet Number (Mod 60)


Tahoe TCP
Packet Number (Mod 60)


Reno TCP
Packet Number (Mod 60)


Reno TCP
Packet Number (Mod 60)

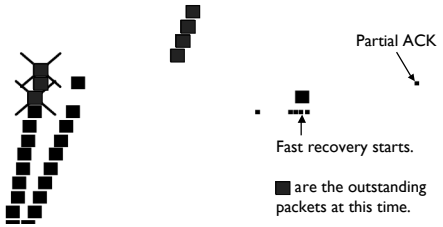


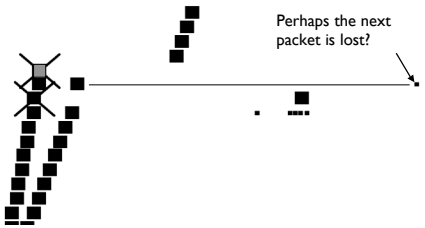
Improving TCP Reno:

Timeout if multiple losses in a window

TCP NewReno

Idea: stays in fast recovery until all ■ have been ACKed.



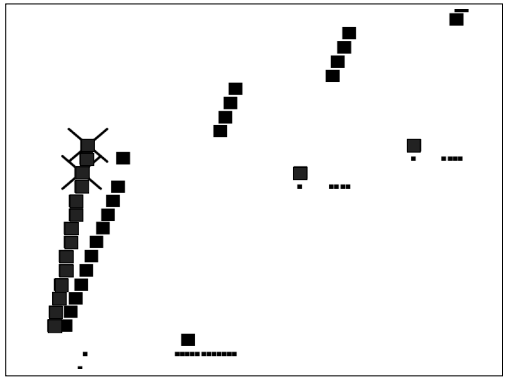


3rd dup ack:
retransmit 1st unacked
ssthresh = cwnd/2
cwnd = cwnd/2 + 3
remember highest ■

subsequent dup ack:
cwnd++

"complete" ack:
(all ■ are acked)
cwnd = ssthresh

“partial” ack:
retransmit
cwnd = ssthresh (?)



Note: RFC2581/RFC2582 give the accurate/gory details. Simplified version is presented here (eg. cwnd vs FlightSize, update of cwnd upon partial ACK).

TCP SACK

Coarse Feedback

Go-Back-N
vs
Selective Repeat

Use TCP header options to report received segments.

SACK Blocks:

1st block - report most recently received segments

subsequent blocks - repeat most recent previous blocks

pipe: num of outstanding packets in the path.

send only if pipe < cwnd

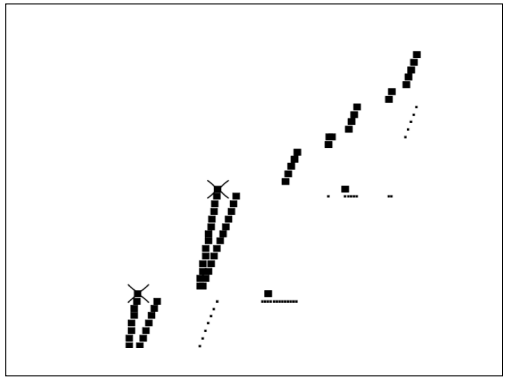
scoreboard: which packets have been received?

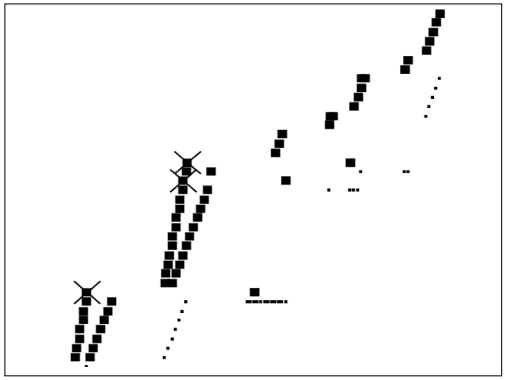
3rd dup ack:
pipe = cwnd - 3
retransmit 1st unacked
ssthresh = cwnd/2
cwnd = cwnd/2 + 3

subsequent dup ack:
cwnd++
pipe--

(if send new packet, pipe++)

“partial” ack:
retransmit
cwnd = ssthresh
pipe -= 2





Power of SACK:
Which packet has left the network?
Where is the gap?
Decouple *when* to send and *what* to send.

TCP Vegas

So far,
packet loss as signal of congestion.

But, already **over congested** when packets are dropped

What other signals are there?

Expected Sending Rate

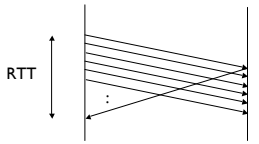
E = cwnd/BaseRTT

BaseRTT: RTT when no congestion

(take min measured RTT in practice)

Actual Sending Rate

A = cwnd/RTT



If (E-A) < alpha
  cwnd++
else if (E-A) > beta
  cwnd--

Intuition:
(E-A) x BaseRTT represents extra buffers occupied in the network

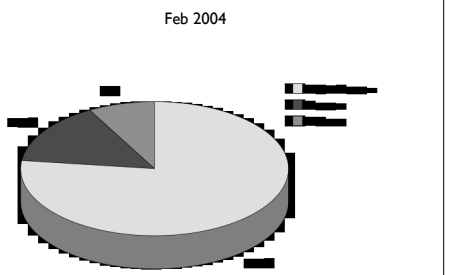
Picking alpha/beta

alpha: small but non-zero to take advantage of available bandwidth immediately. (= 1/BaseRTT)

Picking alpha/beta

beta: beta-alpha should not be too small to prevent oscillation.
(= 3/BaseRTT)

Deployment



70%
SACK capable

Where is TCP Vegas?

Problem 1.
Can't compete with TCP Reno.

Problem 2.
Sensitive to RTT estimation.

TCP BIC/CUBIC
Linux 2.6.x

Compound **TCP**
MS Windows Vista