Congestion Avoidance and Control

Van Jacobson,
"Congestion Avoidance and Control",
SIGCOMM 1988

Fixes to TCP in BSD

Handwaving arguments

Less rigorous math

Lots of “magical” hacks

We assume

- the sender always has data to send
- each packet is of the same size
- TCP is message-oriented

1986

TCP throughput from LBL to UC Berkeley (two hops) dropped from **32K** bps to **40** bps.

RFC793

Sending window = receiving window

No congestion control

Retransmit only when timeout

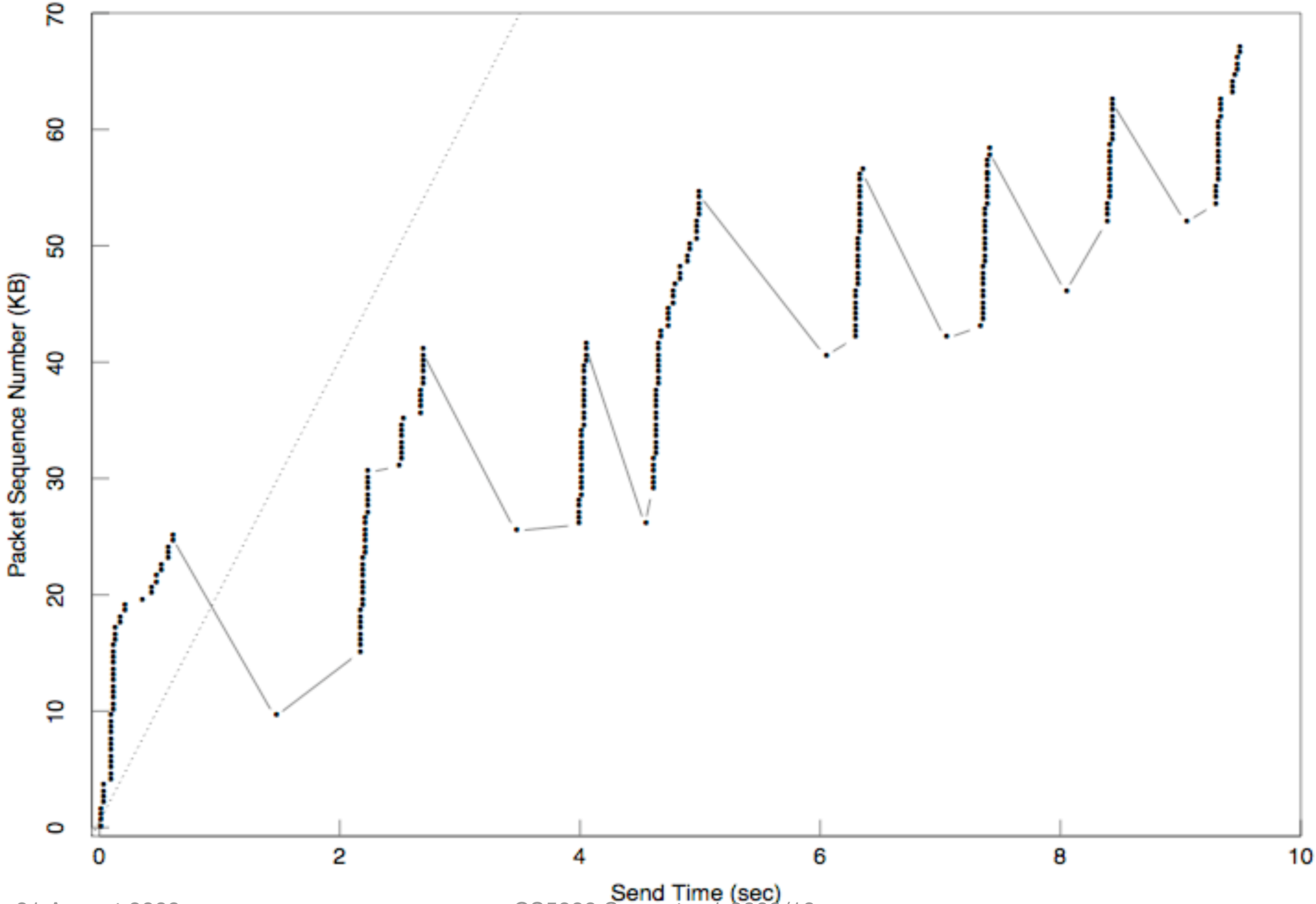
Congestion Collapse:

sender sends too fast

routers delay/drop packets

sender retransmit

no useful data getting through

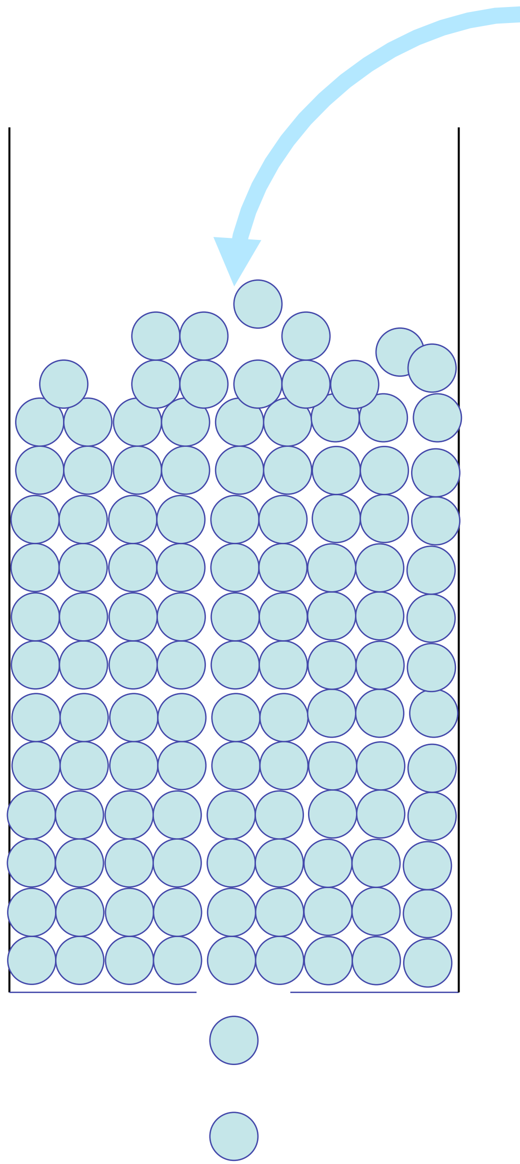


Packet Sequence Number (KB)
70
60
50
40
30
20
10
0
0
2
4
6
8
10
Send Time (sec)

Observation: a TCP connection should obey

Conservation of Packets

In equilibrium state, a new packet is not inserted until an old packet leaves.



How could this principle be violated?

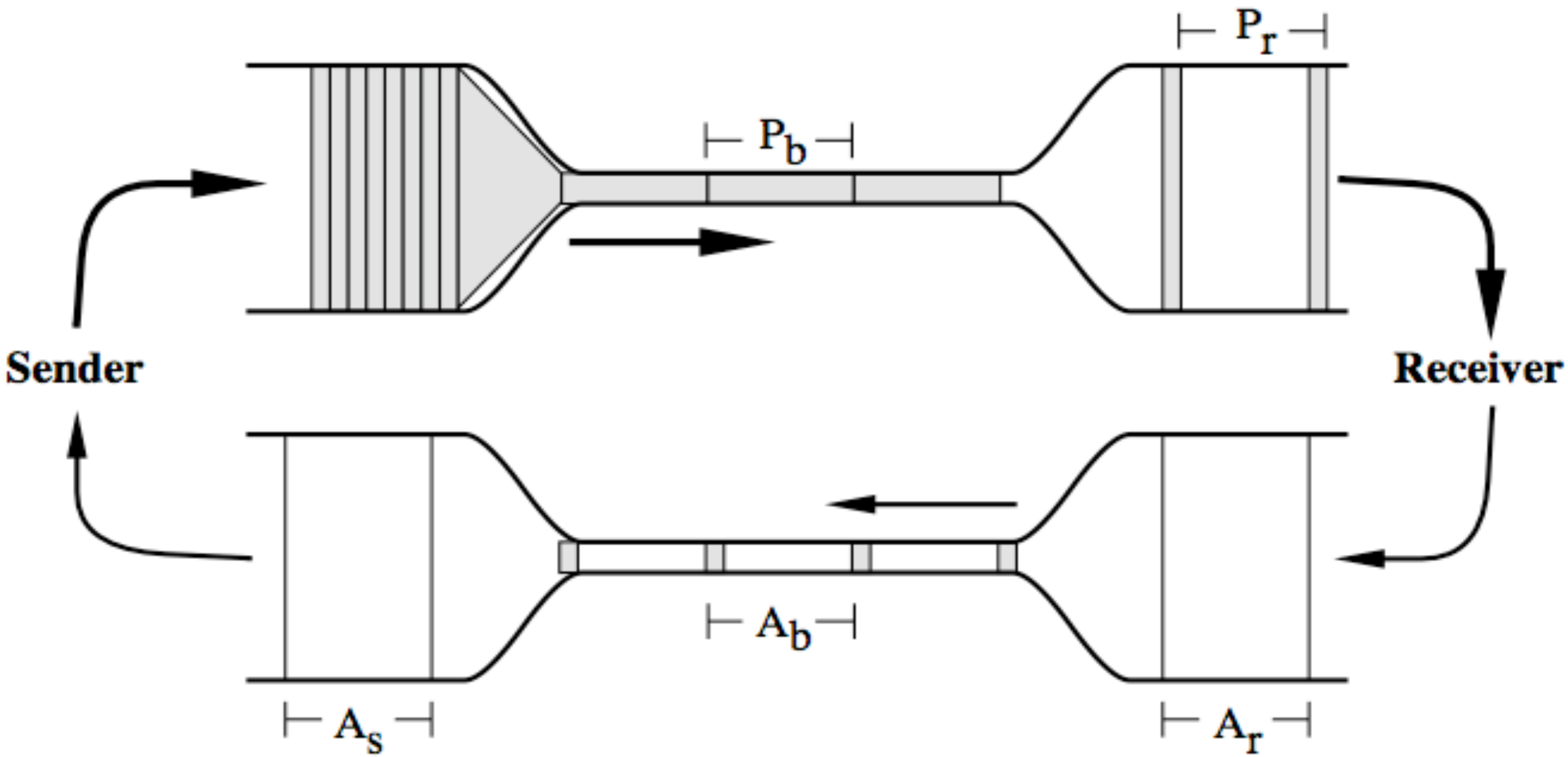
1. Never reaches equilibrium

2. Inject a packet before the next packet leaves

1. Getting to the equilibrium state

Equilibrium state: self-clocking

Figure 1: Window Flow Control 'Self-clocking'



How to start the ‘clock’?

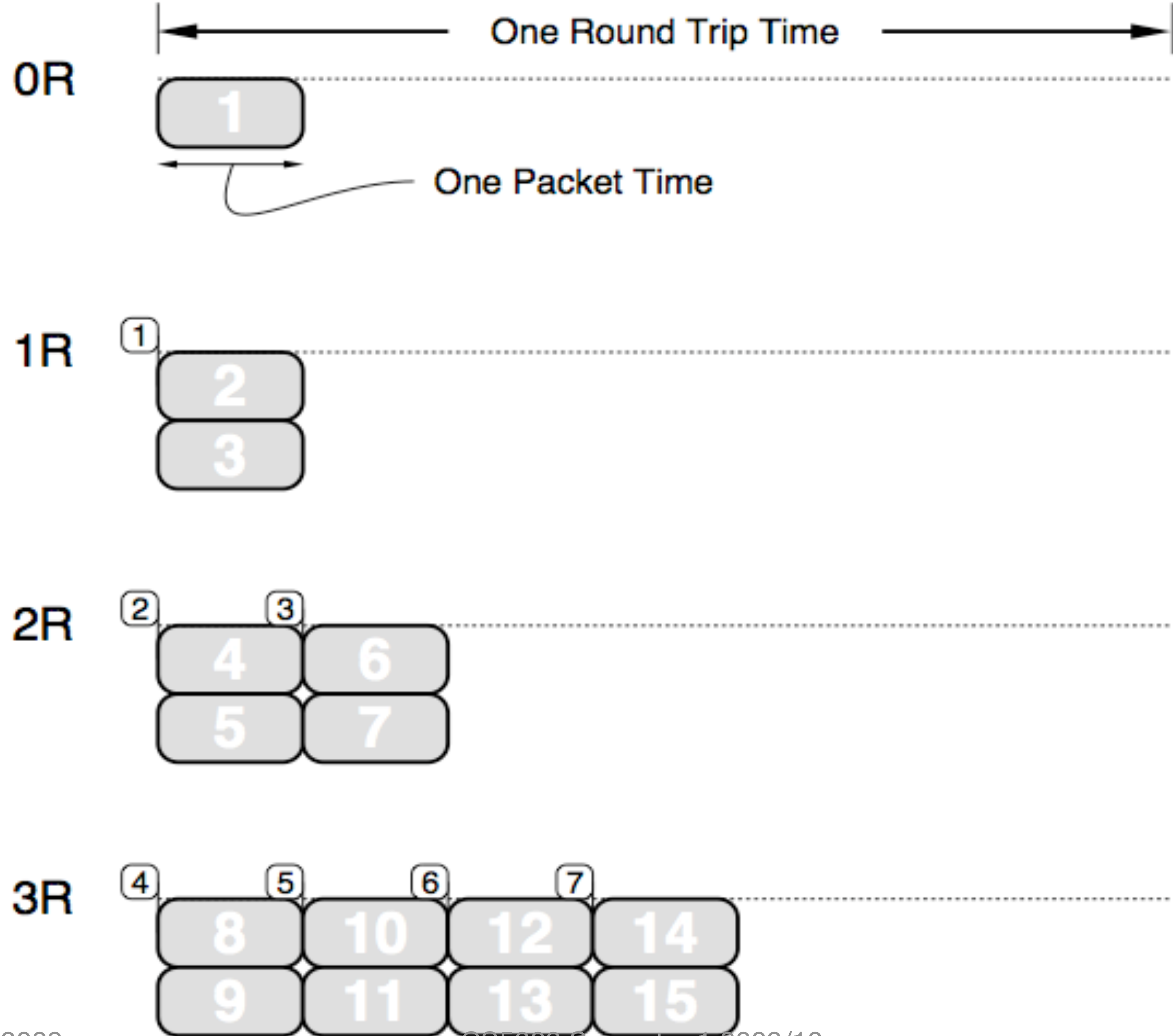
Slow Start

Add a new variable *cwnd.*

Start/Restart: *cwnd* = 1.

Upon receiving ACK, *cwnd*++.

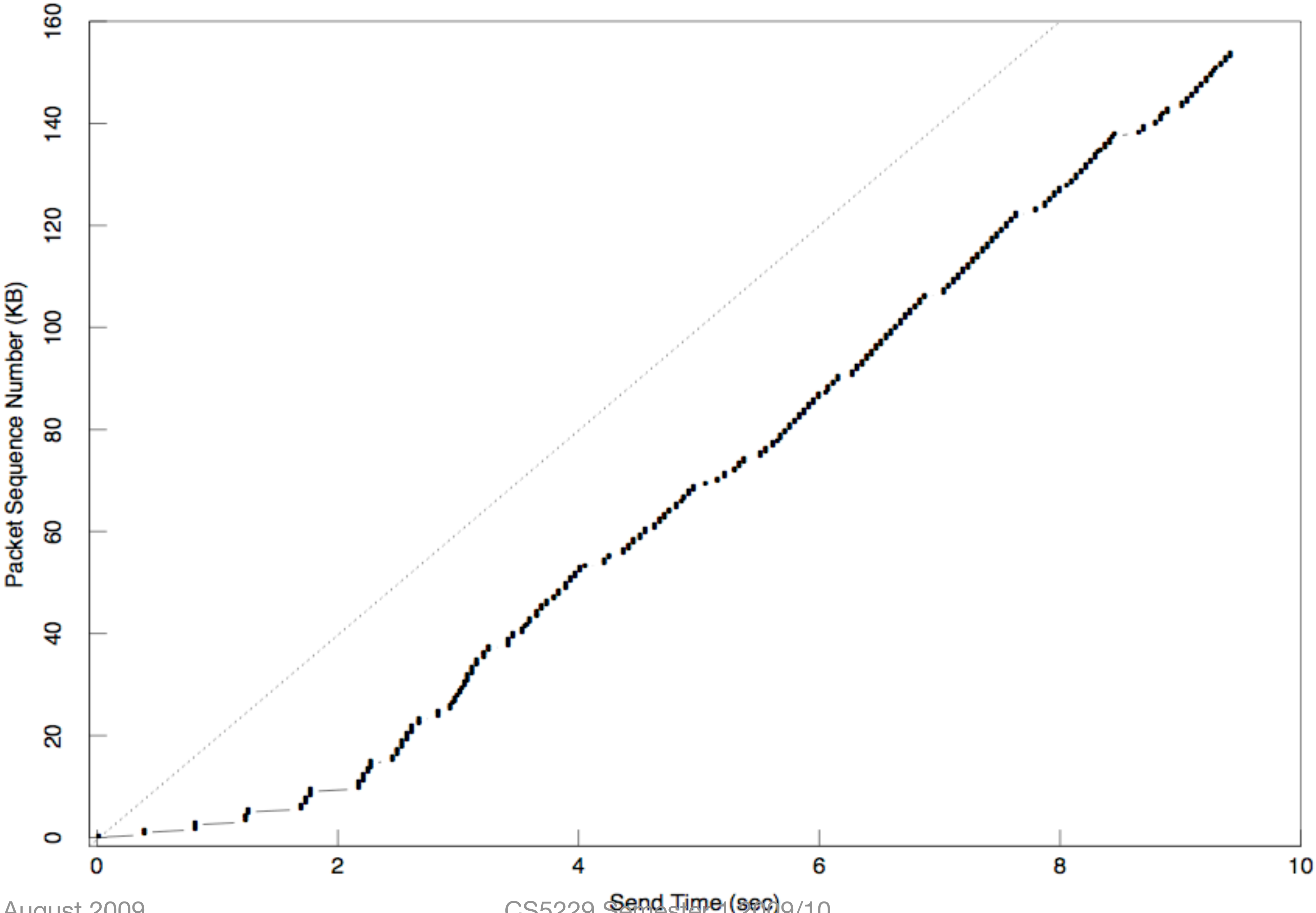
Send at most *min(cwnd,rwin)*


One Round Trip Time
0R
1
One Packet Time
1R
1
2
3
2R
2
3
4
6
5
7
3R
4
5
6
7
8
10
12
14
9
11
13
15

Never send more than 2x the max possible rate.

(previously 200x is possible!)

Figure 4: Startup behavior of TCP with Slow-start

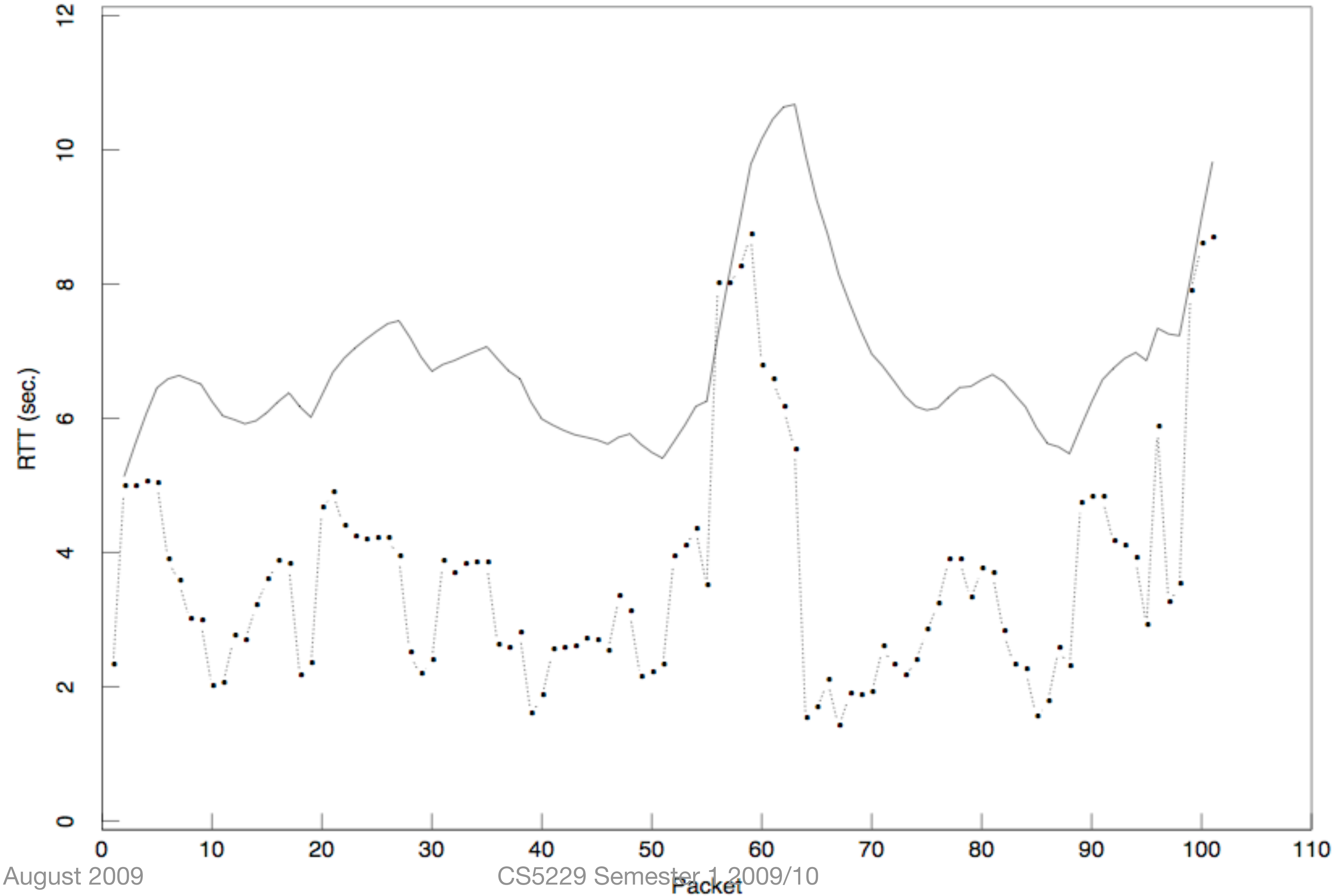


2. Inject a packet before the next packet leaves

2. Conservation at Equilibrium

Something's wrong with TCP timer

Figure 5: Performance of an RFC793 retransmit timer



TCP (RFC793)

$$
\begin{aligned}
R_i &\leftarrow (1-\alpha)R_{i-1} + (\alpha)M_i \\
RTO_i &\leftarrow \beta R_i
\end{aligned}
$$

R_i : smoothed RTT
M_i : measured RTT
RTO : timeout value

Variation in RTT when network is loaded

$\beta = 2$ (recommended)
tolerates only **30%** load

Idea: estimate the variation and use in calculating RTO

Measuring Variation

variance:

costly (need to square)

mean error:

simpler

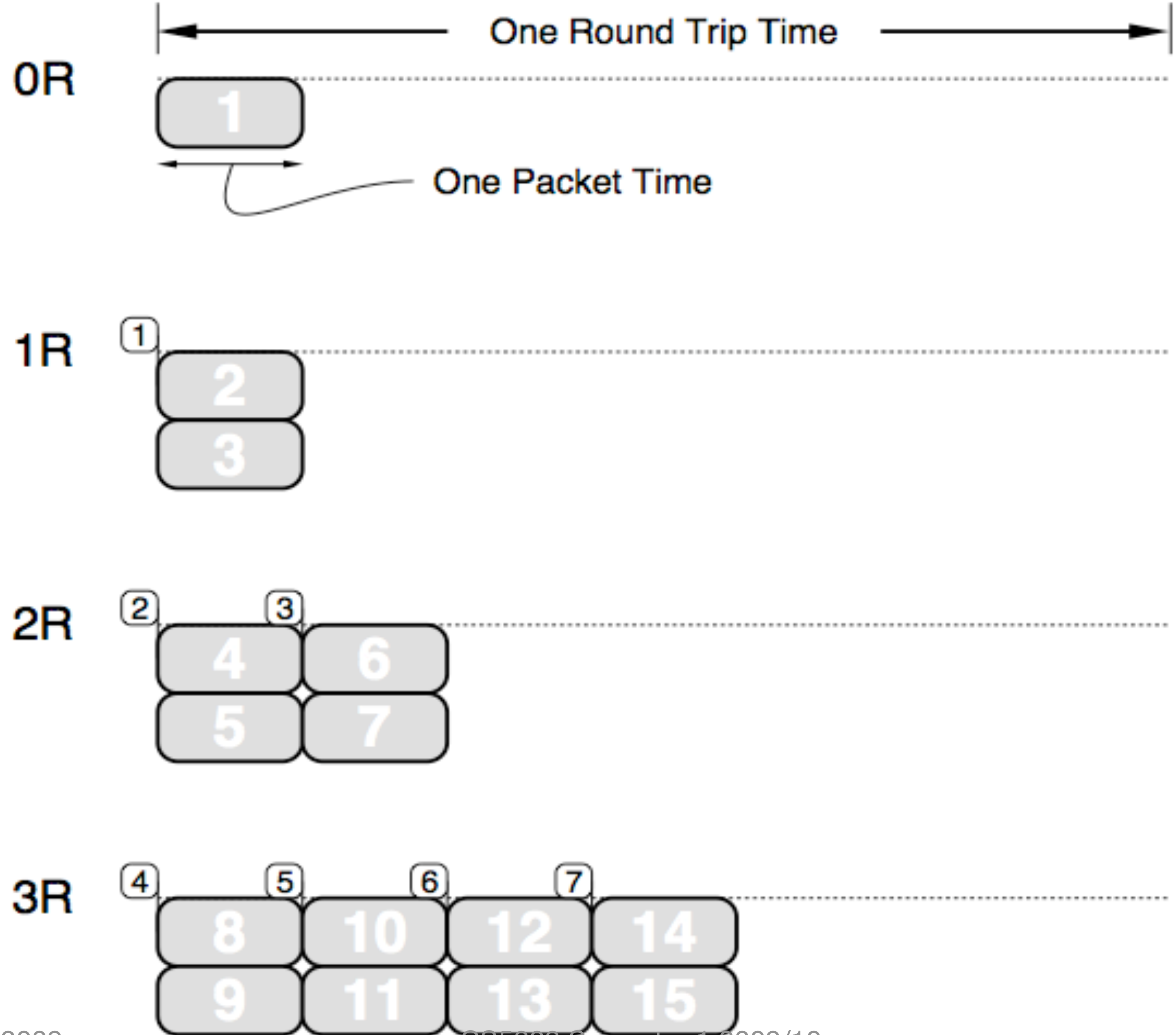
$$
\begin{aligned}
R_i &\leftarrow (1-\alpha)R_{i-1} + (\alpha)M_i \\
R_i &\leftarrow R_{i-1} + \alpha(M_i - R_{i-1}) \\
V_i &\leftarrow V_{i-1} + \alpha(|M_i - R_{i-1}| - V_{i-1})
\end{aligned}
$$

$$RTO_i \leftarrow R_i + kV_i$$

To prevent spurious timeout,

$$RTO_i > R_{i+1}$$

To pick a value of k, consider bandwidth-dominated link.


One Round Trip Time
0R
1
One Packet Time
1R
1
2
3
2R
2
3
4
6
5
7
3R
4
5
6
7
8
10
12
14
9
11
13
15

R doubles each round during slow-start.

$$
\begin{aligned}
RTO_i &> R_{i+1} \\
R_i + kV_i &> 2R_i \\
R_i + k(R_i - R_{i-1}) &> 2R_i \\
R_i + k(R_i - \frac{1}{2}R_i) &> 2R_i \\
k(\frac{1}{2}) &> 1 \\
k &> 2
\end{aligned}
$$

$$RTO_i = R_i + 4V_i$$

Figure 6: Performance of a Mean+Variance retransmit timer

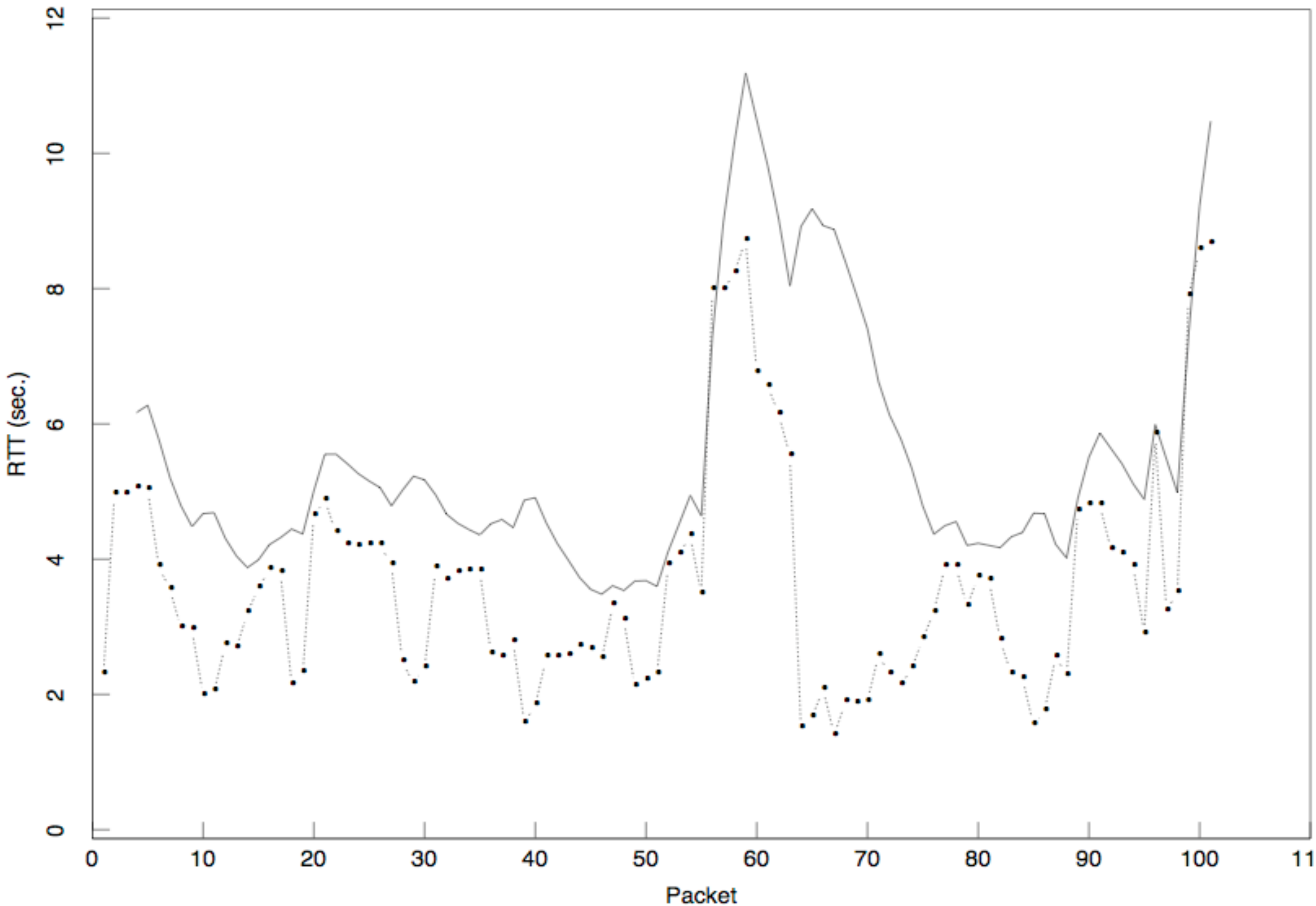
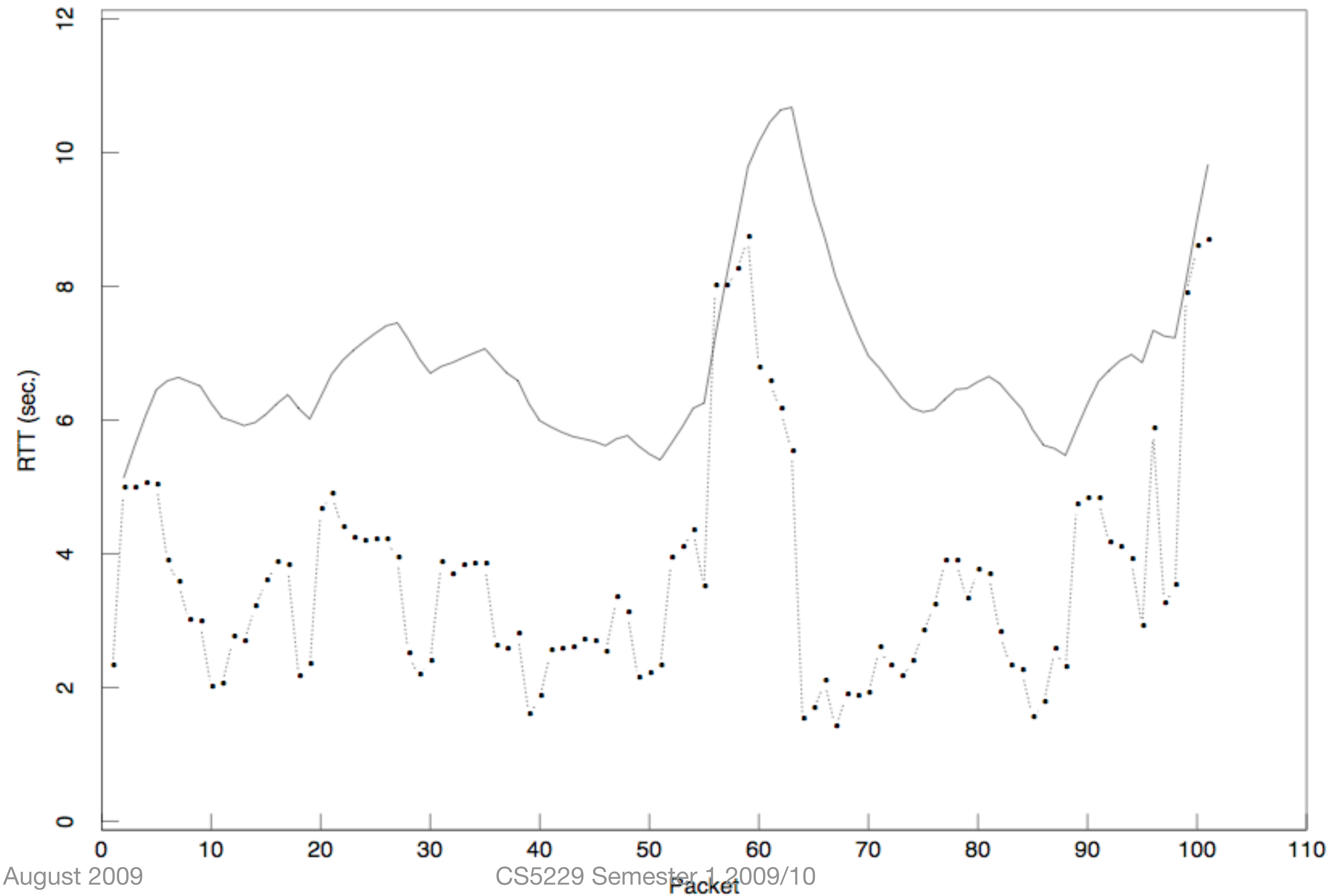


Figure 5: Performance of an RFC793 retransmit timer



3. Moving towards new equilibrium when path changes

Idea: adjust *cwnd* when congestion happens

Assume: congestion leads to packet loss, leads to timeout.

On timeout, cwnd /= 2

On ACK, cwnd += 1/cwnd

Why drop by half ?

1. Slow-start:

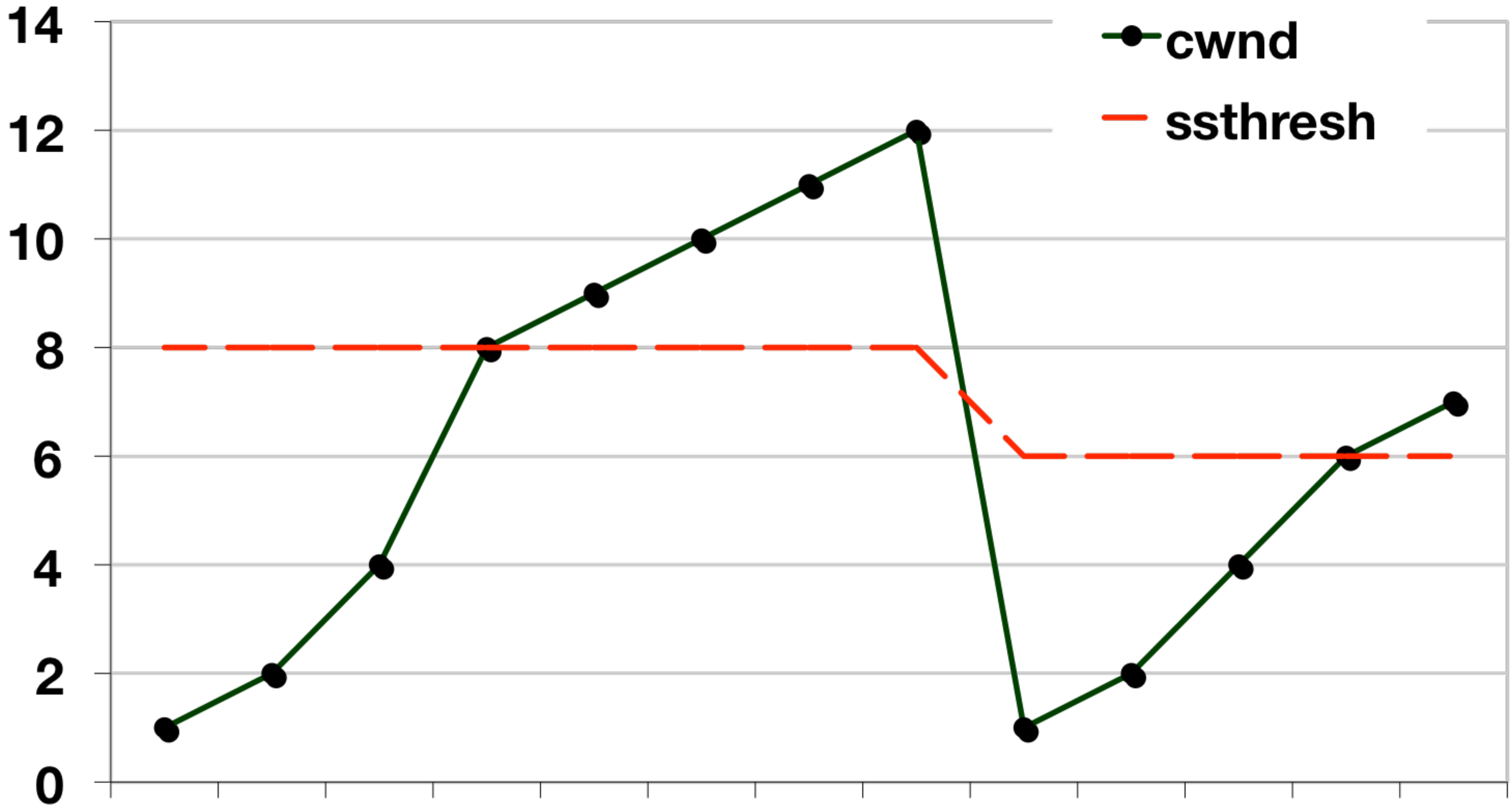
we know R/2 works

2. Steady state:

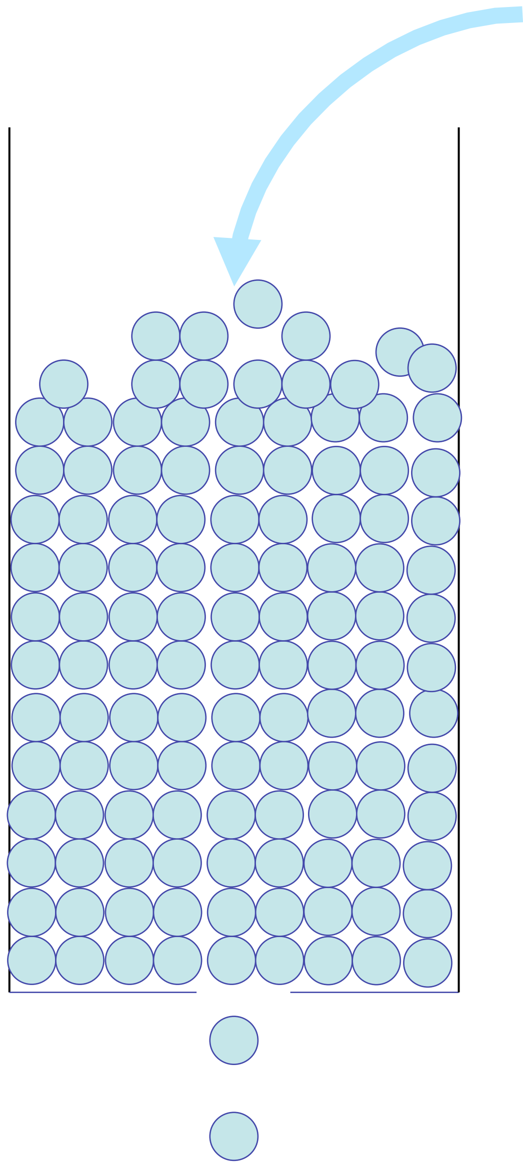
a new flow probably?

Combining slow-start and congestion avoidance

TCP Tahoe



14
12
10
8
6
4
2
0
cwnd
ssthresh



cwnd:

“pipe size” probed

ssthresh:

“pipe size” during equilibrium

new ack:

```
if (cwnd < ssthresh)
   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

timeout:

retransmit all unacked

ssthresh = cwnd/2

cwnd = 1

3^{rd} duplicate ACK:

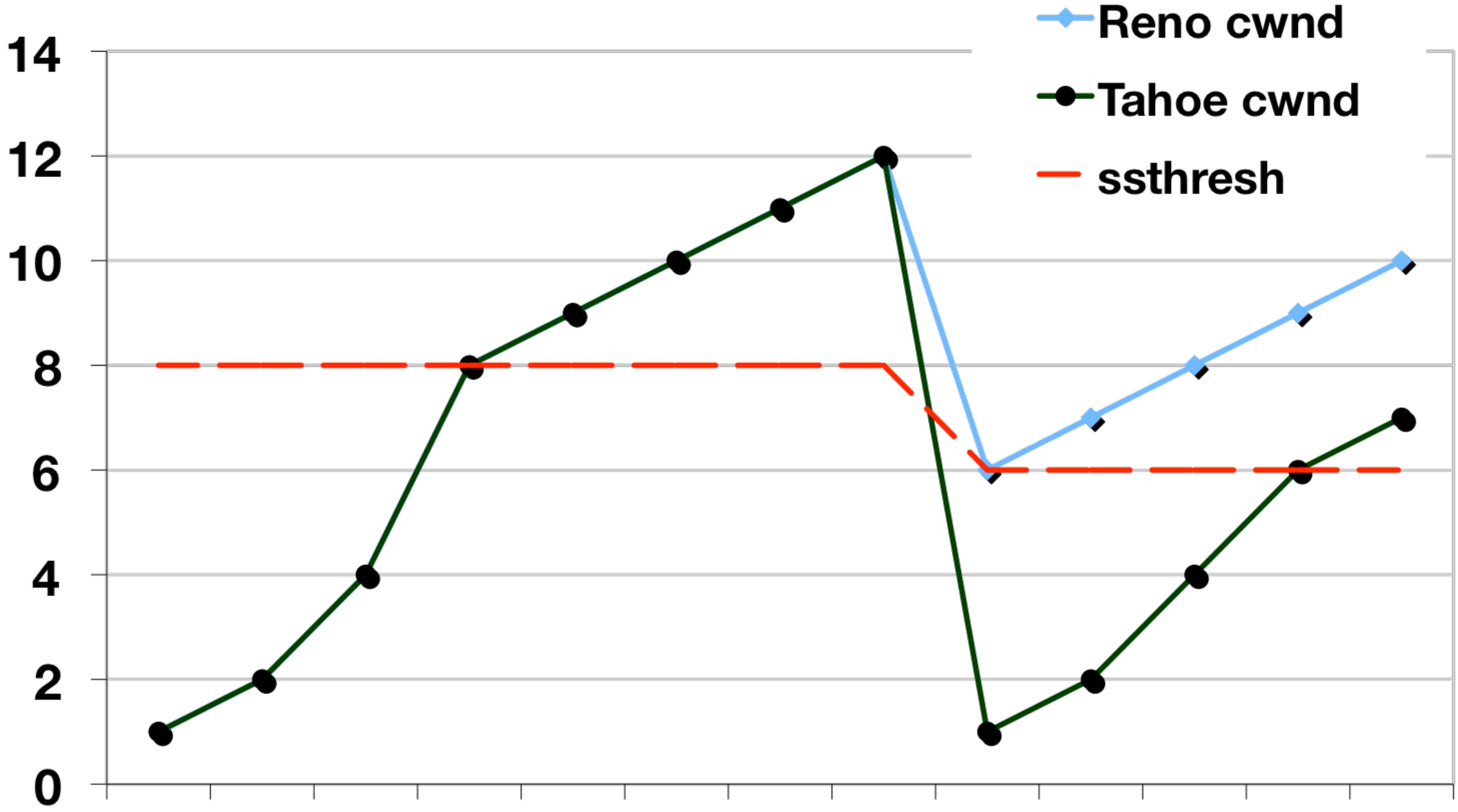
fast retransmission

(ie, retransmit 1^{st} unack)

fast recovery

(details in Week 4)

ssthresh = cwnd = cwnd/2



Reno cwnd
Tahoe cwnd
ssthresh
14
12
10
8
6
4
2
0

AIMD

additive increase
multiplicative decrease

Chiu and Jain, "Analysis of Increase and Decrease Algorithms for Congestion Avoidance in Computer Networks", Comp. Net. & ISDN Sys. 1989