Congestion Avoidance and Control

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

Fixes to TCP in BSD

Handwaving arguments

Less rigorous math

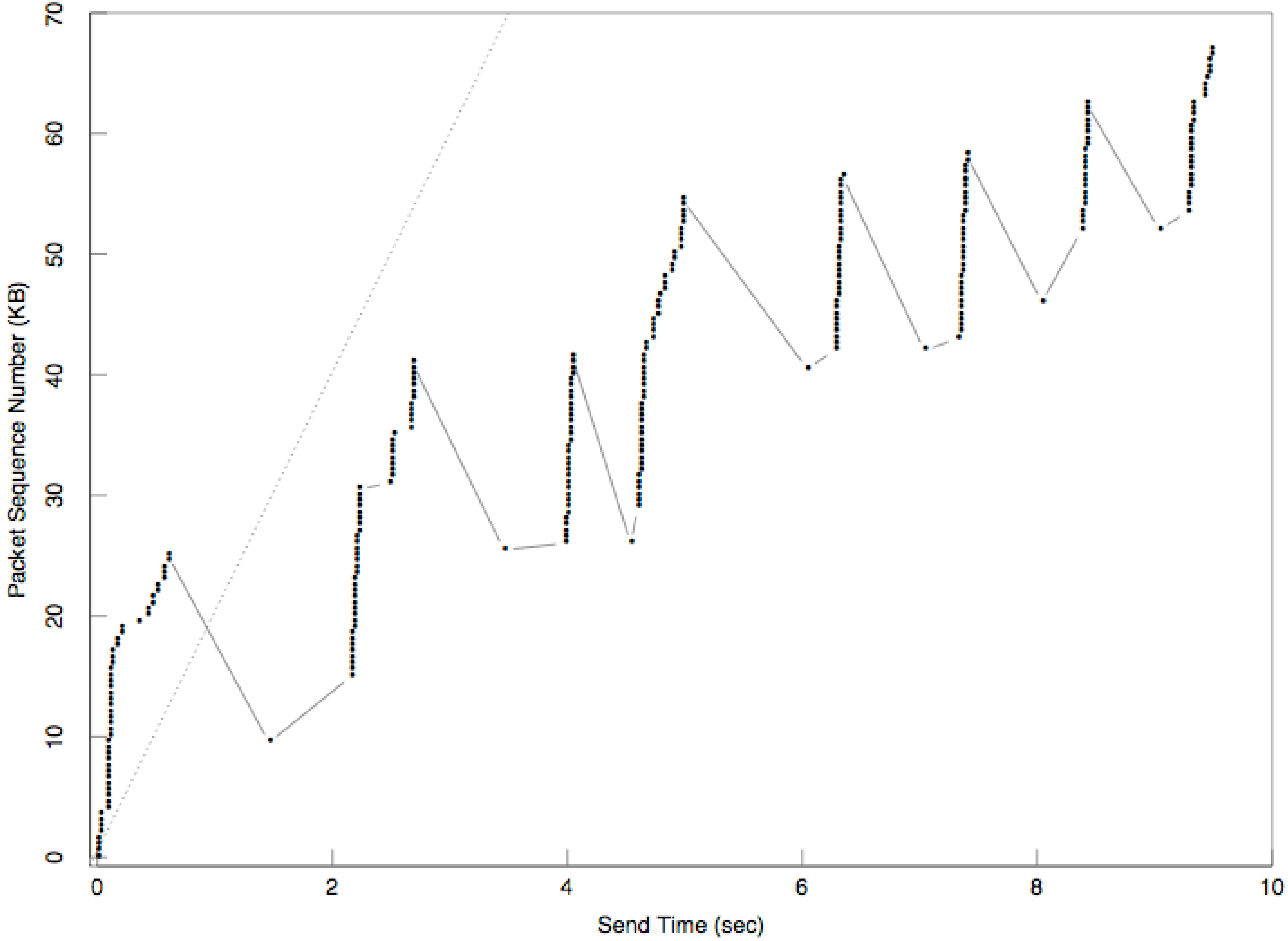
Lots of “magical” hacks

1986

Argentina won the World Cup.
Challenger exploded.
Internet had a congestion collapse!

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

Congestion Collapse:
sender sends too fast
routers delay/drop packets
sender retransmit
no useful data getting through



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

Observation: a TCP connection should obey

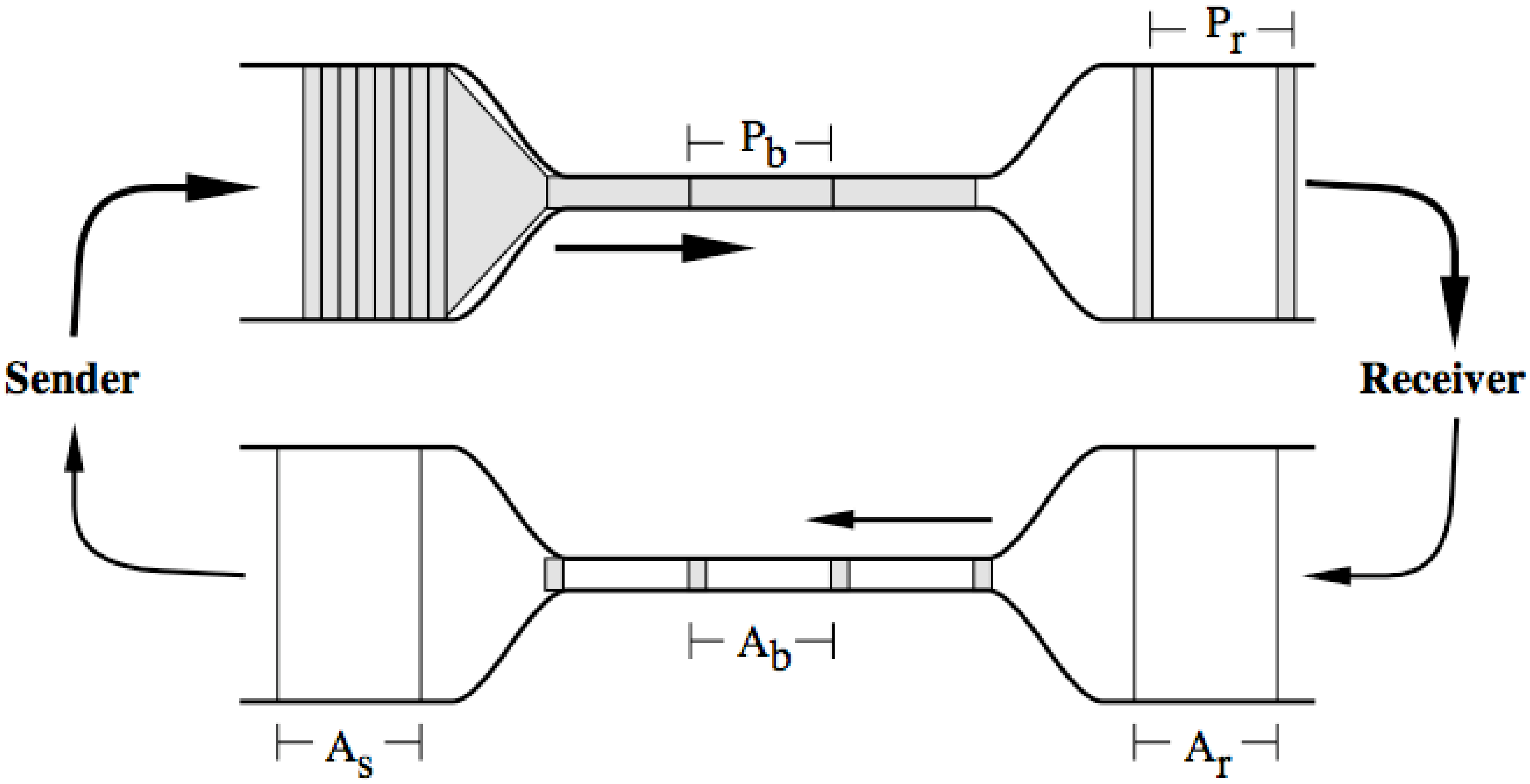
Conservation of Packets

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

1. Getting to the equilibrium state

Equilibrium state: self-clocking

Figure 1: Window Flow Control 'Self-clocking'



How to start the ‘clock’?

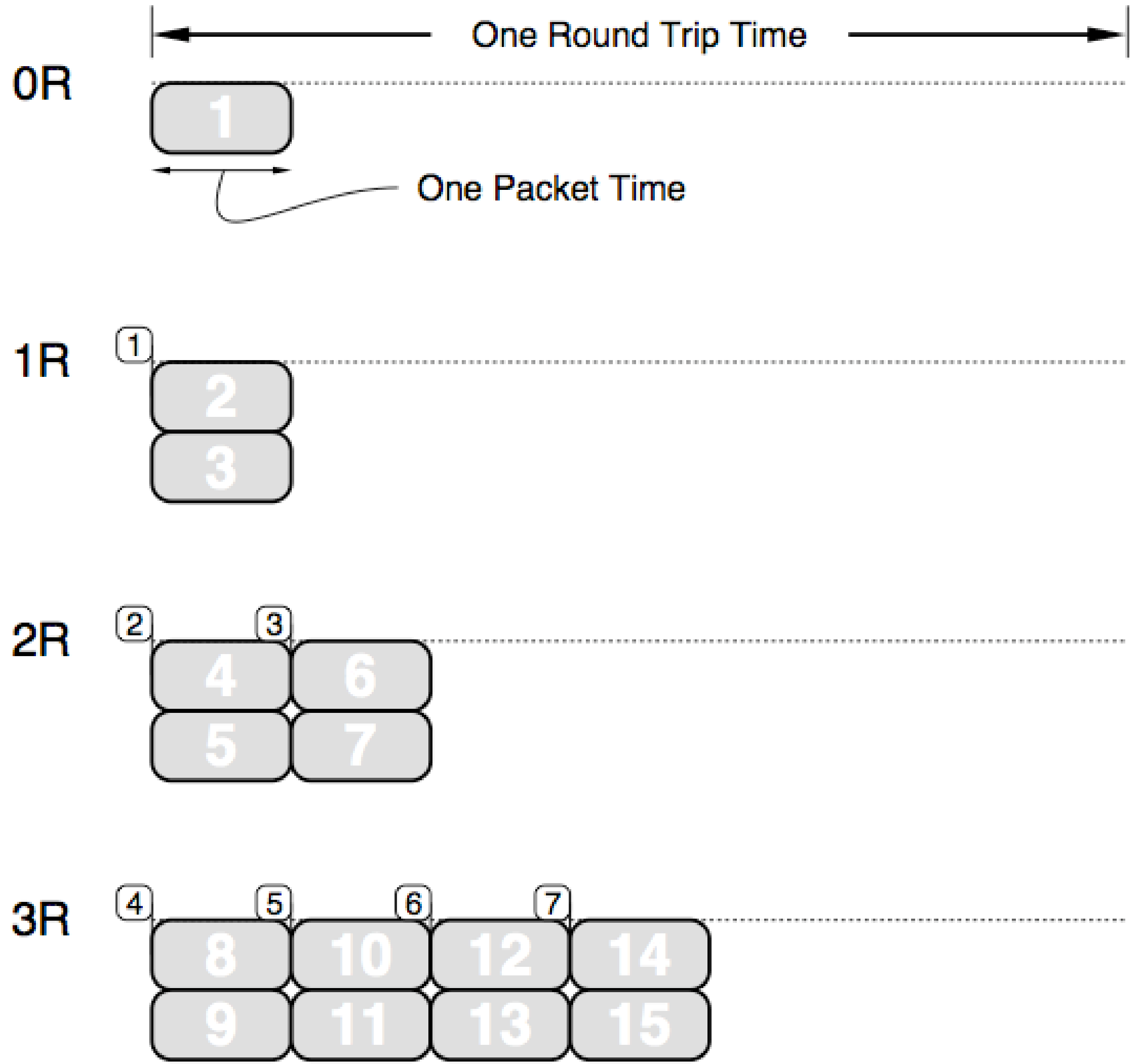
Slow Start

Add a new variable *cwnd*.

Start/Restart: *cwnd* = 1.

Upon receiving ACK, *cwnd*++.

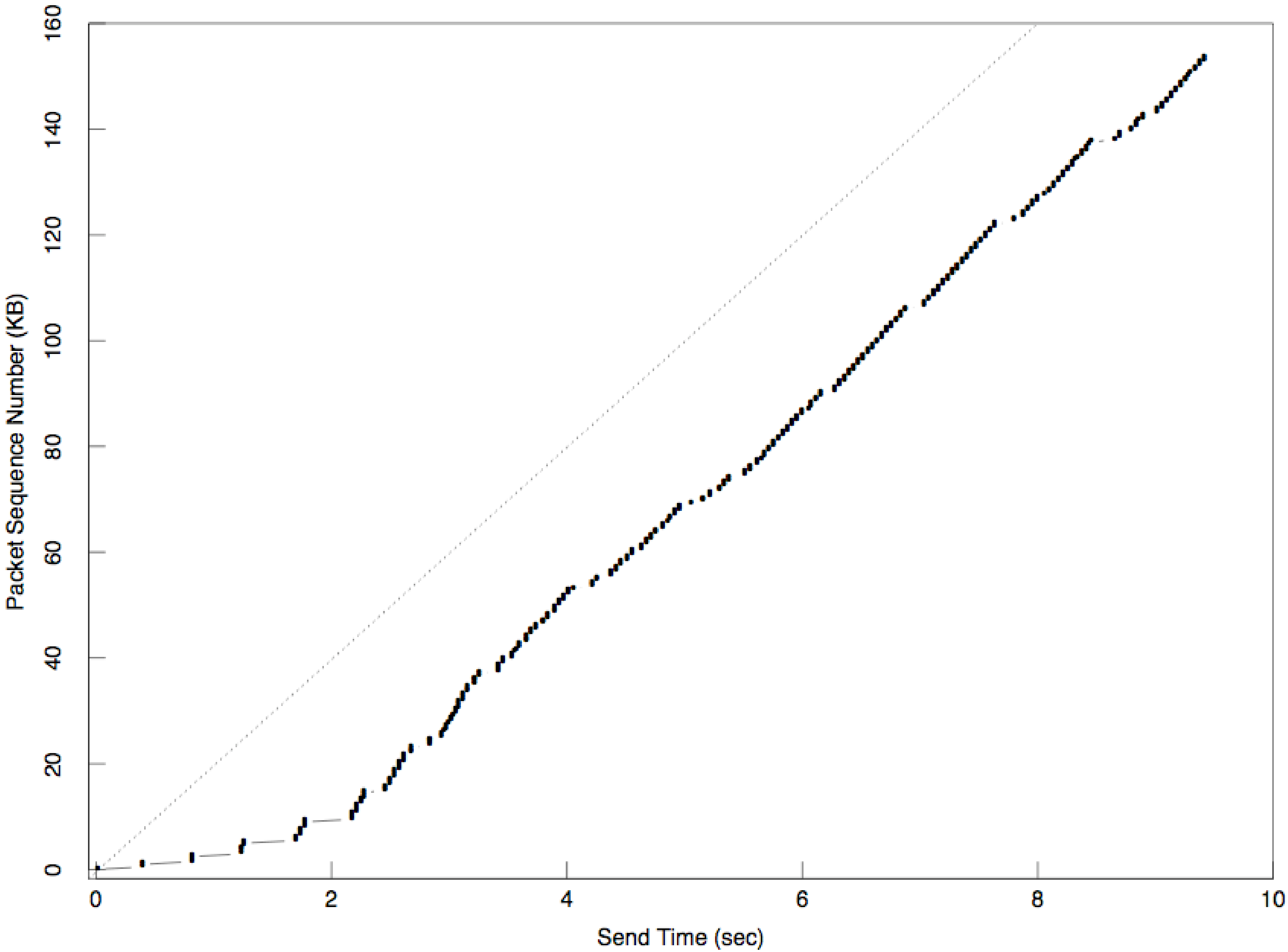
Send at most *min(cwnd,rwin)*.


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



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

2. Conservation at Equilibrium

Something's wrong with TCP timer

TCP (RFC793)

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

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

Variation in RTT is inversely proportional to (1 - load)

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

Idea: estimate the variation and use in calculating RTO

Measuring Variation

variance:
    costly (need to square)
mean error:
    simpler

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

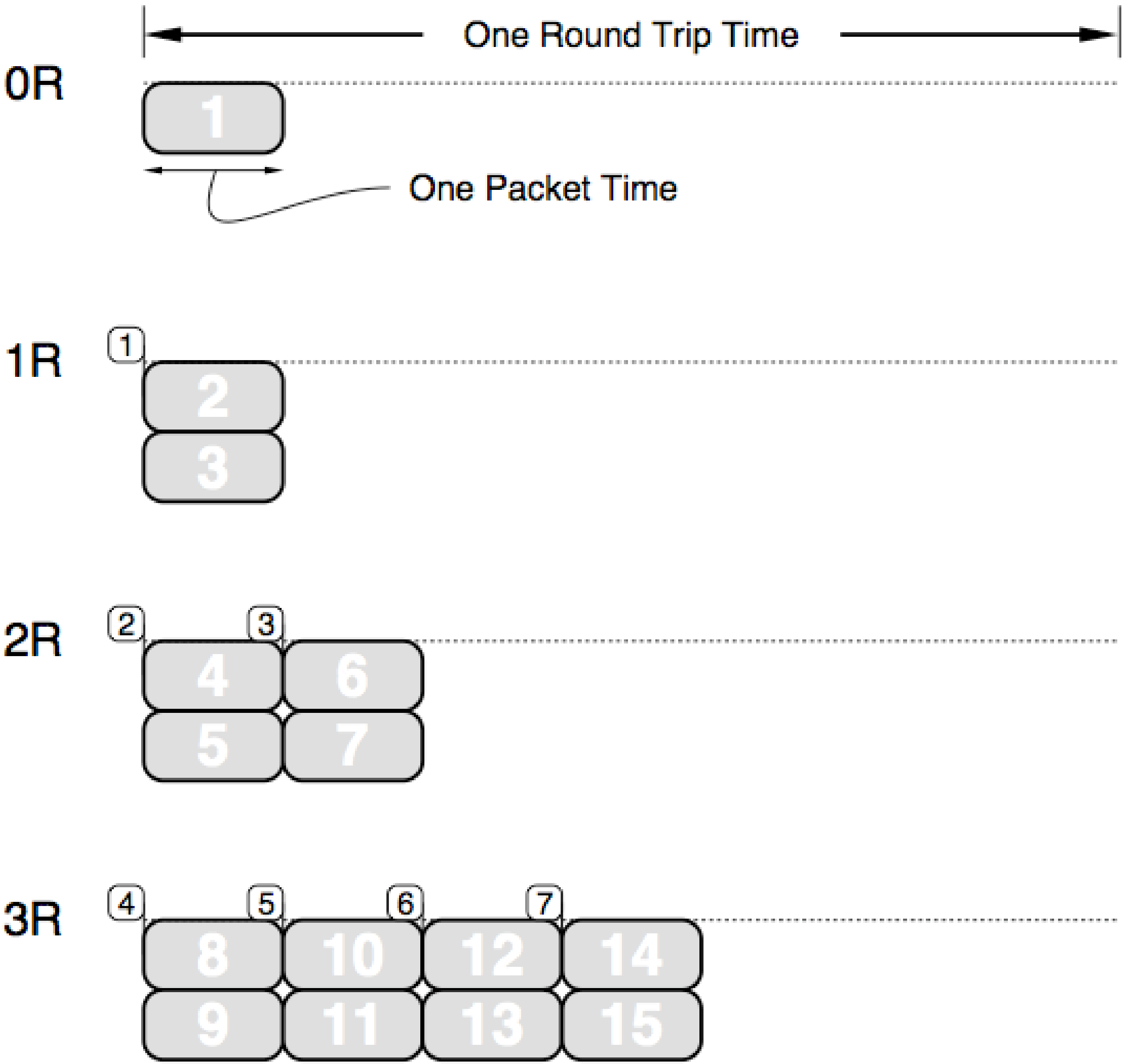
$$
\begin{aligned}
R_i &\leftarrow (1-\alpha)R_{i-1} + (\alpha)M_i \\
R_i &\leftarrow R_{i-1} + \alpha(M_i - R_{i-1}) \\
V_i &\leftarrow V_{i-1} + \alpha(|M_i - R_{i-1}| - V_{i-1})
\end{aligned}
$$

$$RTO_i \leftarrow R_i + kV_i$$

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 5: Performance of an RFC793 retransmit timer

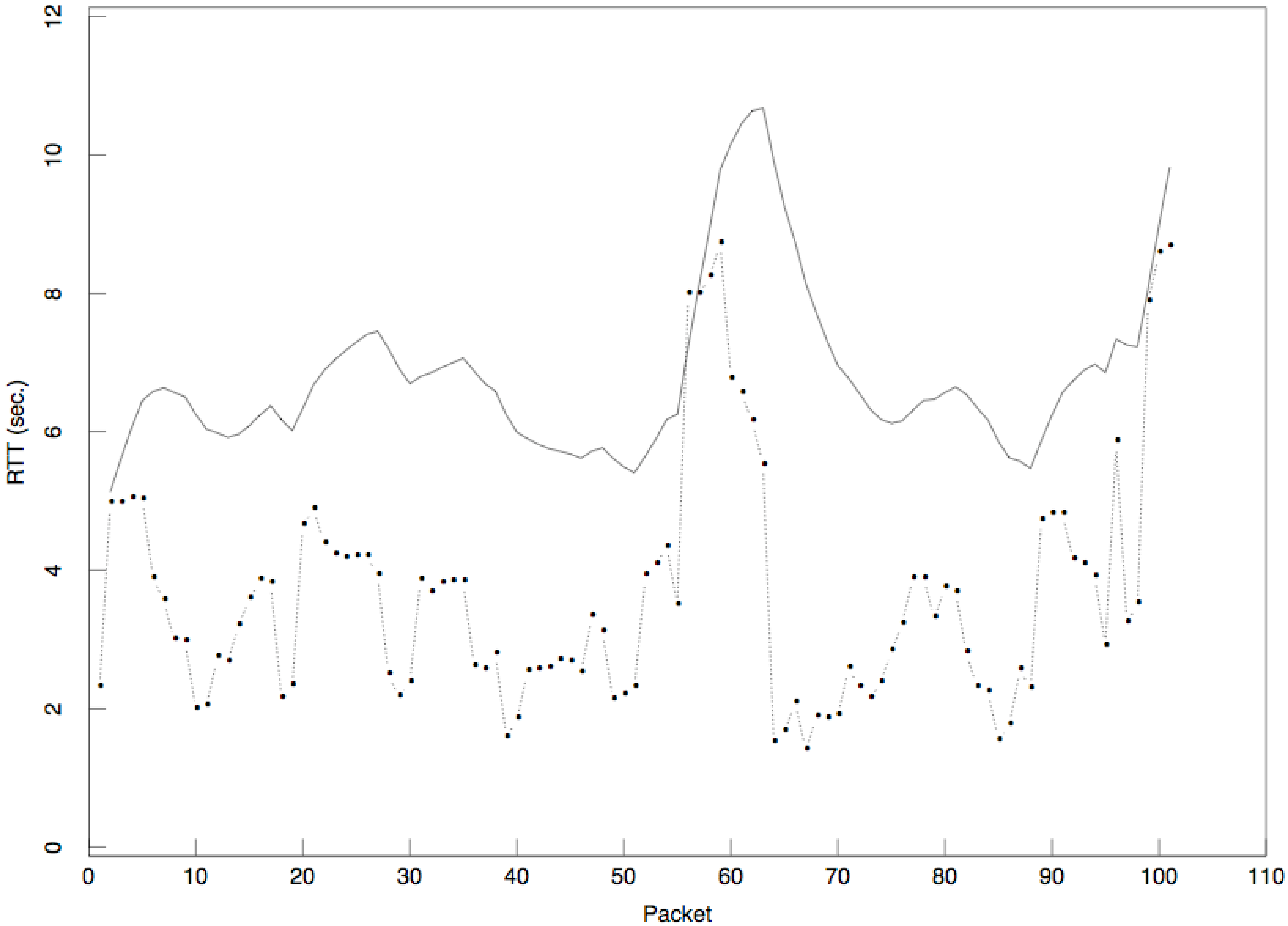
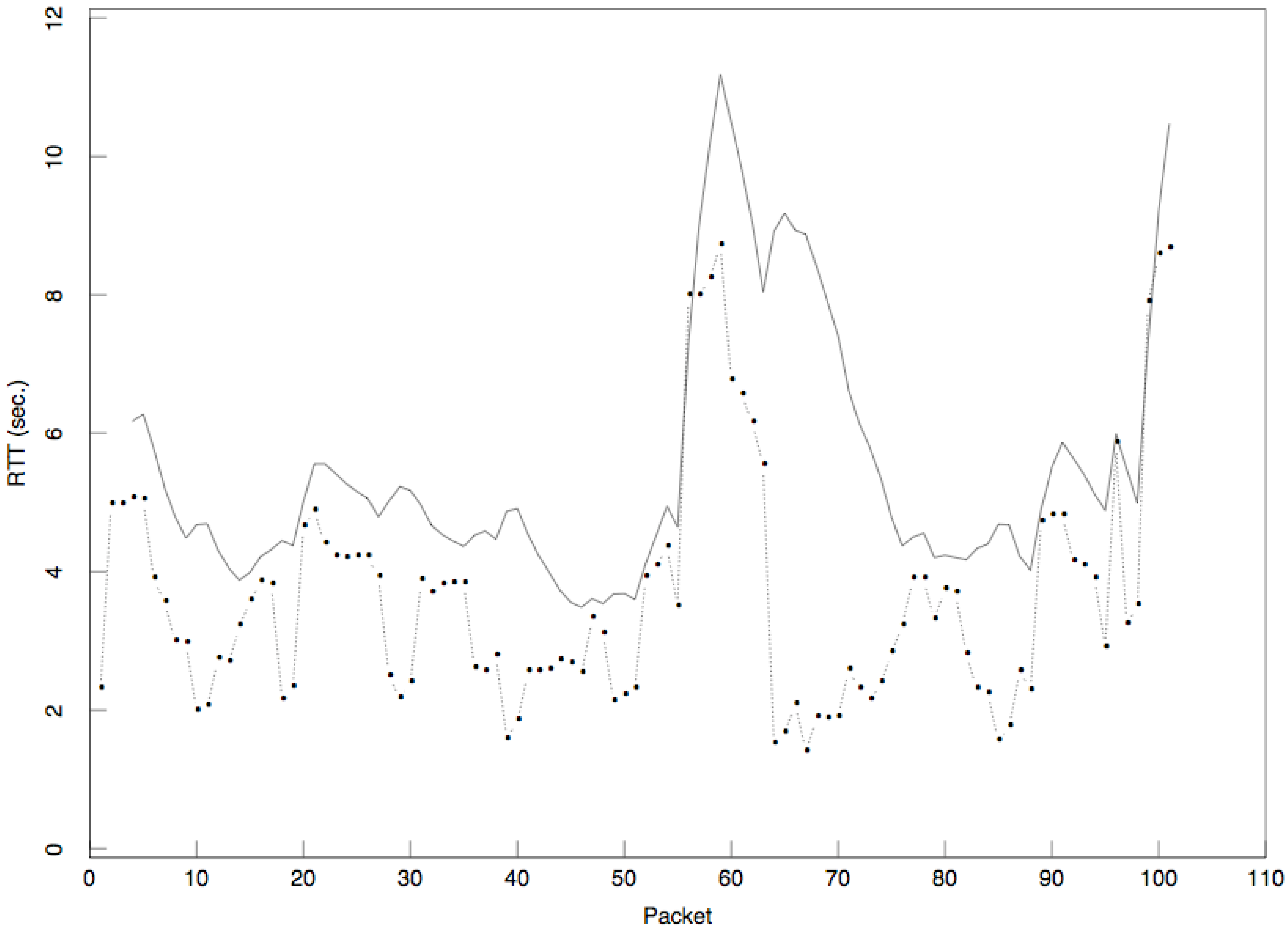


Figure 6: Performance of a Mean+Variance retransmit timer



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?

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