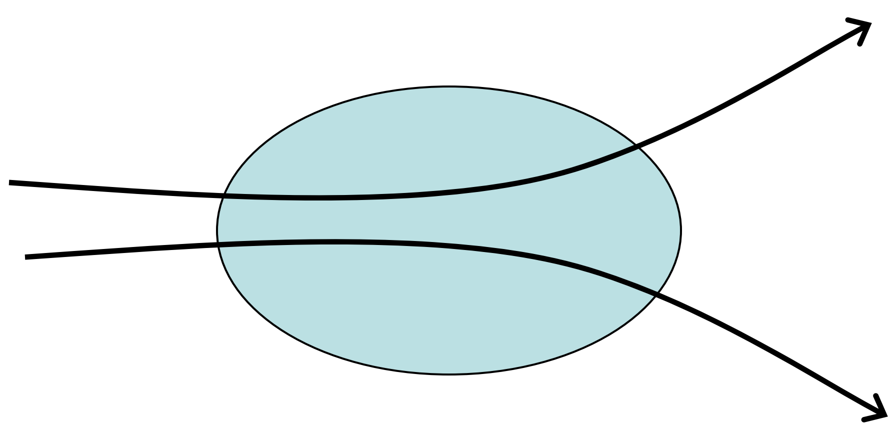
Van Jacobson's Congestion Avoidance and Control

presented by Leon Poutievski

Problem: Congestion

- Congestion
  - Load exceeds the capacity of the network
  - Overflow at router queues
- ATM: channel is reserved during the connection setup
- IP: if queue is full, packets are dropped



Problem: Congestion

- Problem
  - Wasted bandwidth (retransmission required)
  - Unpredictable delay
- October 1986: first “congestion collapse”
  - Caused by TCP retransmissions
- Scenario:

  TCP sends a window's worth of data

  Some of it gets lost; the rest sits in queue

  Sender times out, retransmits everything

  Result: Multiple copies of same data in queue! (REPEAT)

Problem: Congestion

- Crux of the problem:
  - When the router is congested (i.e. its queue is full), retransmitting data all at once is exactly the wrong thing to do
  - But this is what TCP spec said to do
    - Go-back-N protocol
  - Send window is the only constraint on sending rate

$$\text{sending rate} = \frac{\text{send window}}{\text{RTT}}$$

Extremely important concept!

Problem: Congestion

- Thus: *send window* controls how fast sender x-mits
- Original TCP (flow control):

  send window := rcv window

- Conclusion: sender should also consider the network capacity
- Idea: reduce send window to reduce rate under congestion
- Solution: add congestion window

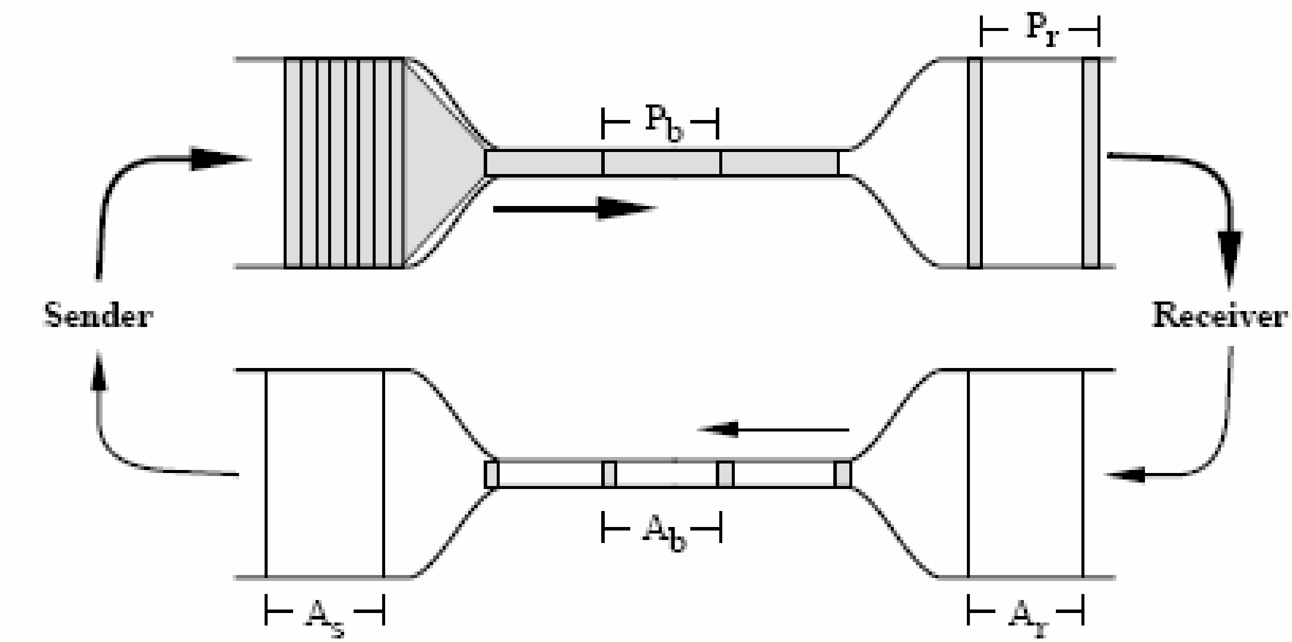
  send window := min (rcv window, congestion window)

"Conservation of packets" principle

- Equilibrium = “stable,
  full window of data in transit”
- “Conservative” packet flow
  - New is not put into network until an old leaves
- Possible problems with packet conservation
  1. Didn’t get to equilibrium
  2. Sender ejects new packets before old has exited
  3. Equilibrium can’t be reached

Getting to Equilibrium: Slow-start

- Self-clocking system
  - Automatically adjusts to BW & delay variations
  - Sender uses ACK as a ‘clock’
  - Hard to start



- Packet size (area) = BW x time

Slow-start algorithm

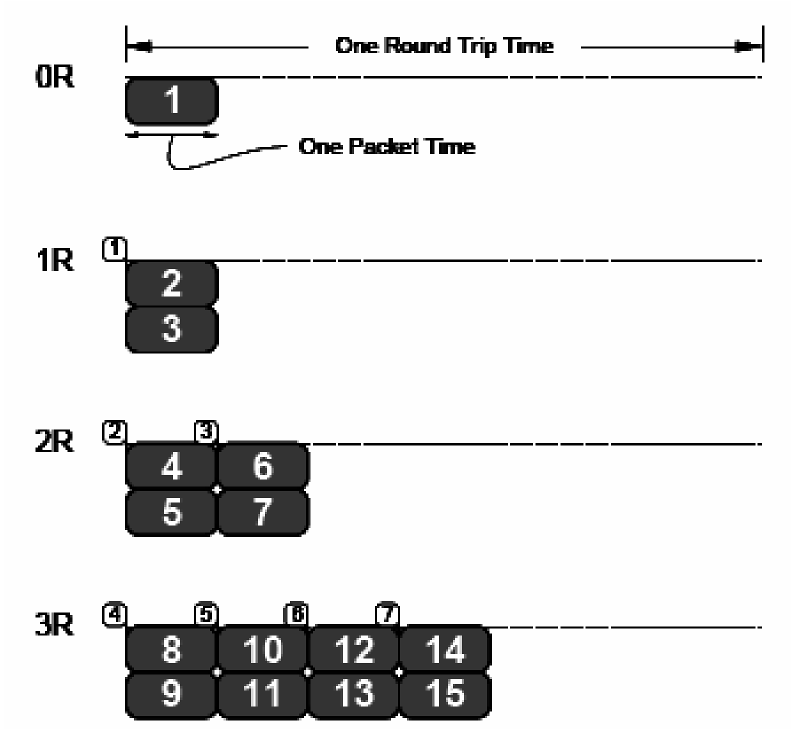
- Add "congestion window" to algorithm
  - send window := min (rcv window, cwnd);
- When starting (restarting)

  cwnd := 1 packet;
- On ACK for new data

  cwnd += 1 packet;

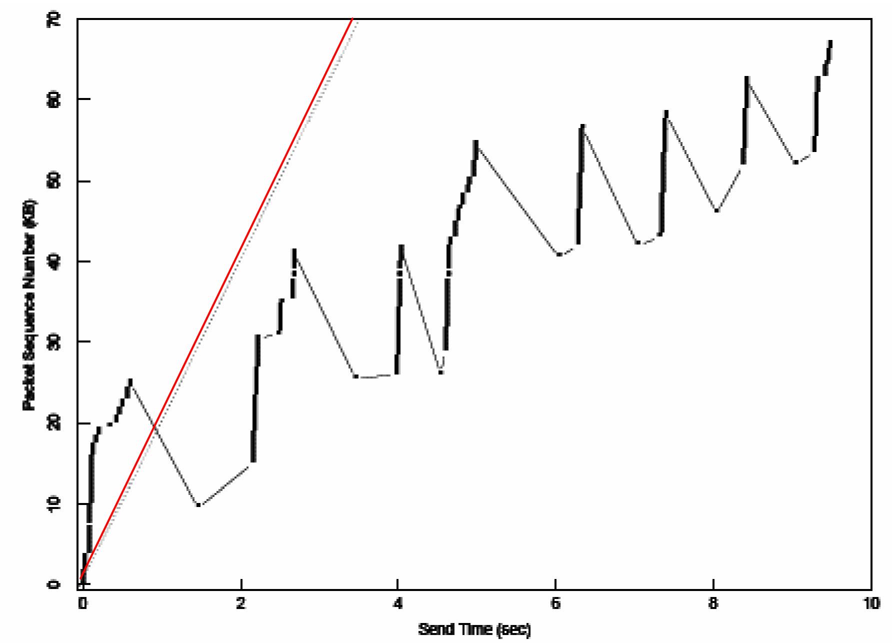
Slow-start, analysis

- "Slow" is misnomer:
  - rate grows exponentially
  - On each ack 2 pkts are sent
    - one for the packet acked (left n/w)
    - one to increase the window
  - So SWS doubles every RTT

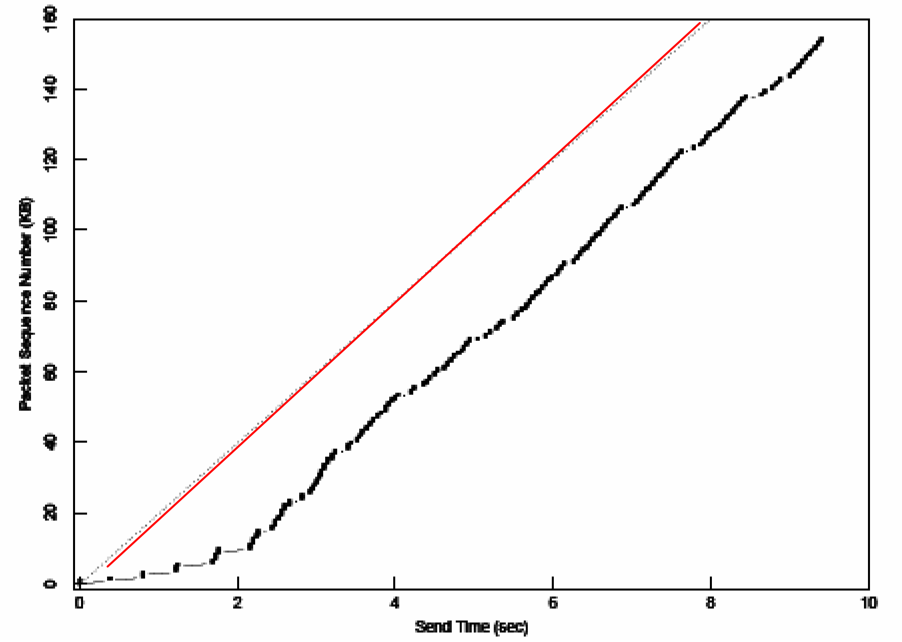


- It takes $R \log_2 W$
    - R: round trip time
    - W: window size in packets

Slow-start, analysis



Without Slow-start



With Slow-start

Conservation at Equilibrium (round-trip timing)

- Need good estimate of
  - RTT mean estimate
  - RTT variation estimate
    - It increases quickly with load

  for retransmit timeout interval (rto) (described later)

- Exponential backoff after retransmit
  - Reasoning: linear systems

Congestion avoidance (adapting to the path)

- Assumption:
  – Losses are due to congestion
    - Losses due damage are rare (<< 1%)
- Strategy
  – If congestion, network must signal to endpoints so that endpoints decrease utilization
  – If no congestion and thus no signals, endpoints increase network utilization

Congestion avoidance Multiplicative decrease

- $L_i = N + \lambda L_{i-1}$,

  L_i – load at interval i, average queue length

  N – constant
- $\lambda \approx 0$, no congestion
- $\lambda > 1$, congestion
  - $L_n = \lambda^n L_{0,}$, grows exponentially
- System stabilizes only if traffic is reduced as quickly as queues are growing

Congestion avoidance: Multiplicative decrease

- On congestion: $W_i = d\ W_{i-1}$ $(d < 1)$
- Take $d = 0.5$, $W_i = W_{i-1} / 2$
  - Motivation: give up ½ BW for a new connection, everybody adapts to new situation

- Congestion detection
  - Did not receive any ack (timeout)
  - Received 3 duplicate acks

Congestion avoidance Additive increase

- Also known as "Additive Increase, Multiplicative Decrease" (AIMD)
  - Refers to change in cwnd per RTT
- If no congestion detected:

  $W_i = W_{i-1} + u \quad (u << W_{max})$

  - Take u = 1, so $W_i = W_{i-1} + 1$

Congestion avoidance Algorithm

- On timeout:

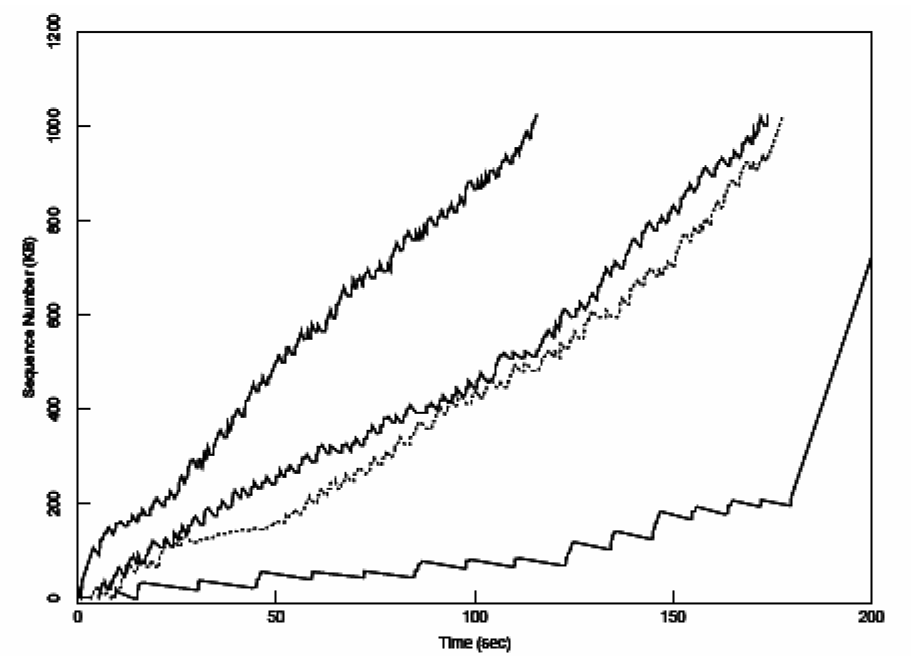
  cwnd = send window / 2; //multiplicative decrease

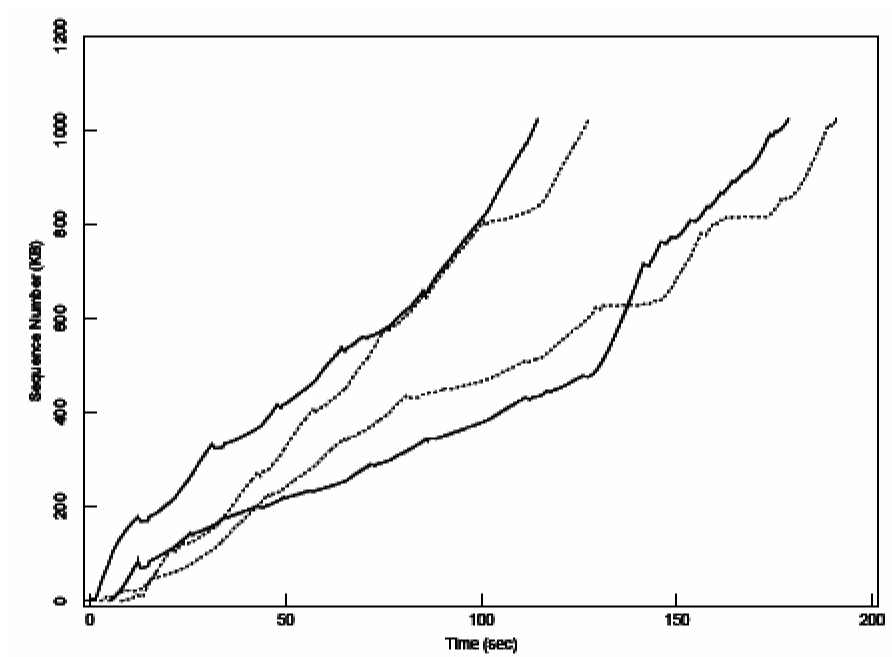
- On ack:

  cwnd += 1 / cwnd; //additive increase

- send window := min (rcv window, cwnd);

Congestion avoidance, Analysis (sequence numbers)





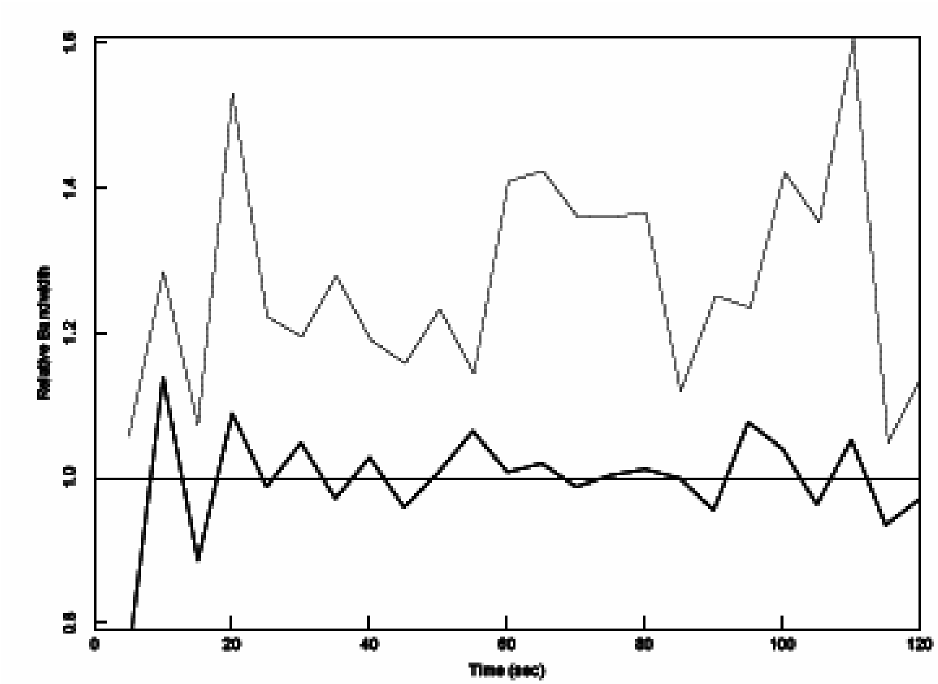
No congestion avoidance

With congestion avoidance

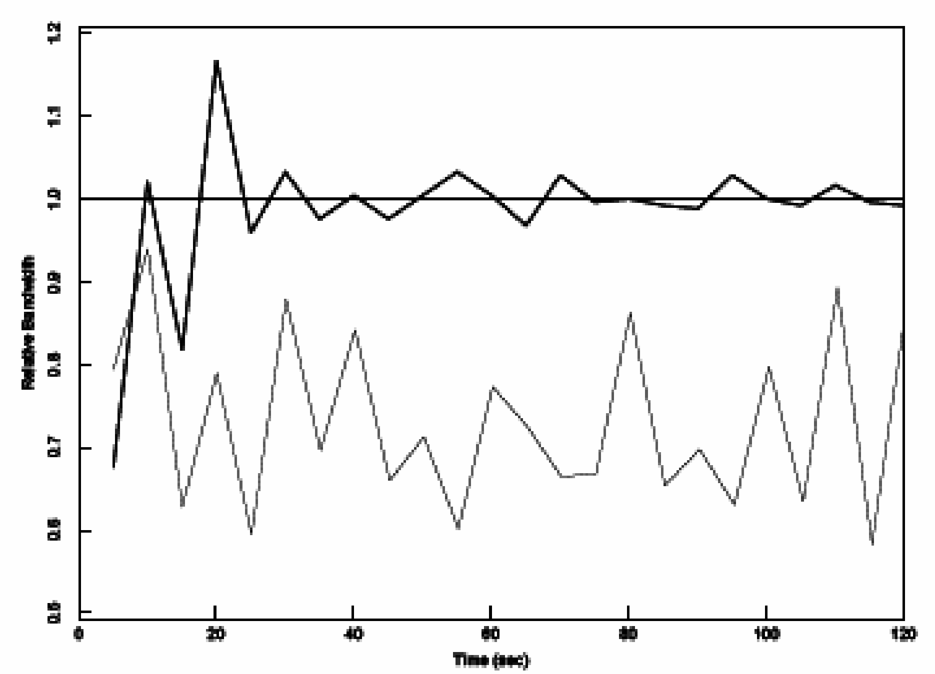
Congestion avoidance, Analysis (relative BW)

No congestion avoidance

With congestion avoidance



Total BW



Delivered BW

Combined algorithm

(slow start + congestion avoidance)

- cwnd = congestion window
- ssthresh = threshold, to switch between algs
- send window = min (rcv window, cwnd);
- On timeout:

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ssthresh = send window / 2;  //mult. decrease, cong. avoid.
cwnd = 1;                    //start slow start
```

- On ack on new data:

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if (cwnd < ssthresh)
  cwnd += 1                  //slow start
else
   cwnd += 1/cwnd;           //congestion avoidance
```

Conservation at Equilibrium

- Need good
  - RTT mean esimate (R)
  - RTT variation esimate (b)

  for retransmit timeout interval (rto)
- RFC793: use low pass filter

  R = aR + (1-a)M, M – new measurement

- RFC813 suggests: rto = bR = 2R

RTT estimation, theory

- A := (1-g)A + gM, 0 < g < 1

after rearranging:

- A := A + g(M-A)
  M-A = Er + Ee, where
  Er (random error): due to noise in measurement
    random kick, they will cancel out
  Ee (estimation error): due to bad choice of A
    kick in the right direction
- A := A + gEr + gEe, we want large g to get most of Ee, but small g to reduce Er
- Usually take 0.1 ≤ g ≤ 0.2

RTT estimation, practice

- Goal: estimate variance of M
- $\sigma^2 = \sum |M\text{-}A|^2$
  - Squaring can cause overflow
  - Use mean deviation instead
  - mdev = $\sum | M – A |$
- $mdev^2 = (\sum | M – A |)^2 \leq \sum | M – A |^2 = \sigma^2$
- For normal distribution:

  mdev = sqrt(π/2) sdev ≈ 1.25 sdev

RTT estimation, practice

- Err = M – A
- A := A + gErr
- D := D + g(|Err| - D)

- M -= (SA >> 3);
- SA += M;
- If (M < 0)

  M = -M;
- M -= (SD >> 3);
- SD += M;

- $g = 1/2^n$
- $SA = 2^nA$
- $SD = 2^nD$

RTT estimation, final

- Err = M – A
- A := A + gErr
- D := D + g(|Err| - D)
- rto := A + 2D

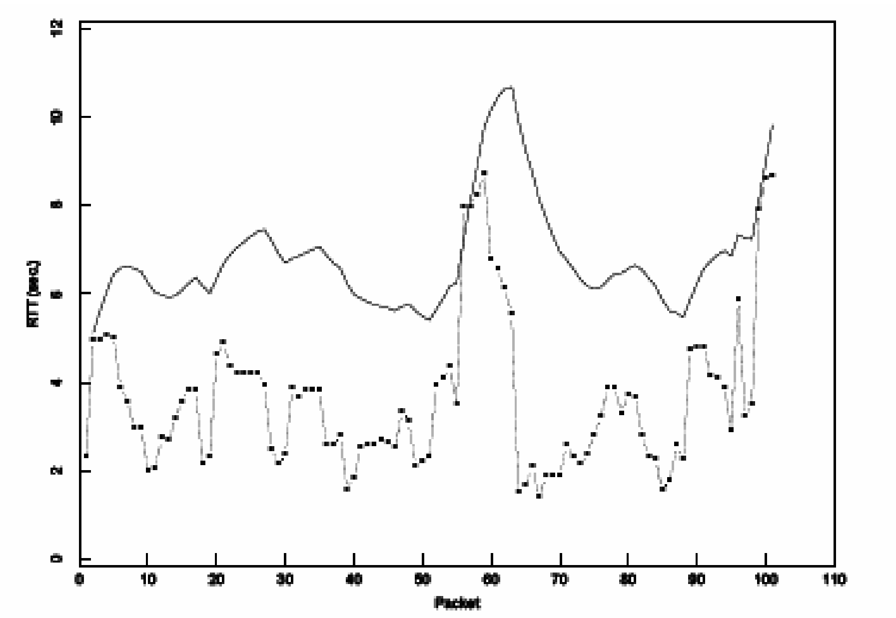
- M -= (SA >> 3)
- SA += M;
- If (M < 0)

  M = -M;
- M -= (SD >> 2);
- SD += M;
- rto = ((SA >> 2) +SD)>>1

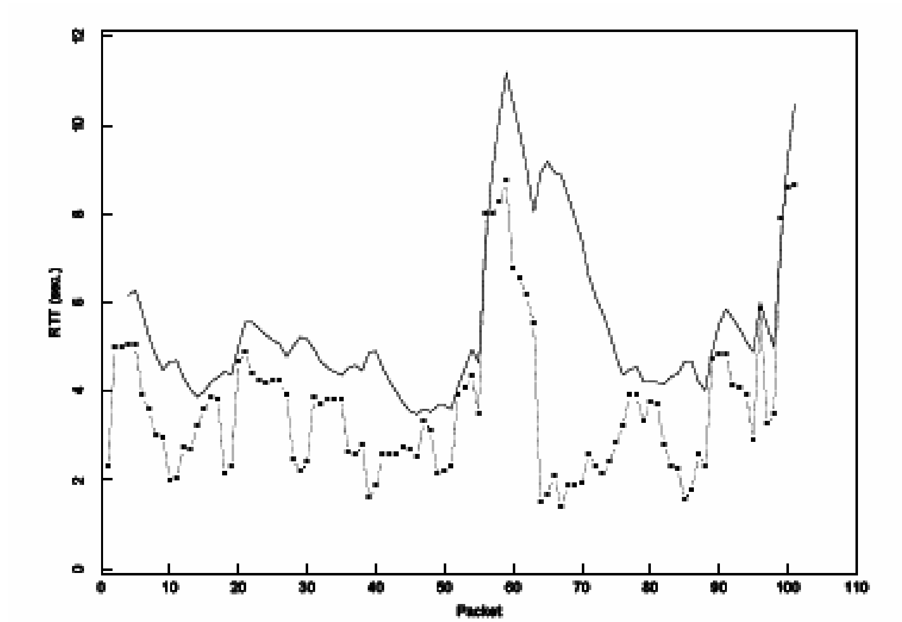
- $g_A = 1/2^3$ $SA = 2^3A$
- $g_D = 1/2^2$ $SD = 2^2D$

Analysis

y – time from send till reception of ack by sender



Old TCP



New mean + variance