Adaptive Retransmission: Jacobson/Karels Algorithm

- New calculation for average RTT
  - Difference = SampleRTT - EstimatedRTT
  - EstimatedRTT = EstimatedRTT + (α x Difference)
  - Deviation = Deviation + β (|Difference| - Deviation)
    - where β is recommended to be 0.25
- Consider variance when setting timeout value
  - TimeOut = EstimatedRTT + φ x Deviation
    - where φ = 4

Jacobson/Karels Algorithm

- Fast computation using integer arithmetic
  - scale by α and β, i.e. multiply by 8 (>>3) and 4 (>>2)
  - keep **SampleRTT** and **TimeOut** unscaled
  - Difference = SampleRTT – EstimatedRTT ' >>3
  - EstimatedRTT' = EstimatedRTT' + Difference
  - If (Difference < 0) Difference = - Difference
  - Deviation' = Deviation' + (Difference - Deviation'>>2)
  - TimeOut = EstimatedRTT ' >>3 + Deviation'

TCP Congestion Control

Additive Increase/Multiplicative Decrease

- Objective: adjust to changes in the available capacity
- New state variable per connection: CongestionWindow
  - limits how much data source has in transit

MaxWin = MIN(CongestionWindow, AdvertisedWindow)

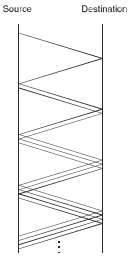
- Idea:
  - increase CongestionWindow when congestion goes down
  - decrease CongestionWindow when congestion goes up
- *Question:* how does the source determine whether or not the network is congested?
- *Answer:* a timeout occurs
  - timeout signals that a segment was lost
  - segments are seldom lost due to transmission error
  - lost segment implies congestion

AIMD

- Algorithm:
  - increment CongestionWindow by one segment per RTT (***linear increase***)
  - divide CongestionWindow by two whenever a timeout occurs (***multiplicative decrease***)
- In practice: increment a little for each ACK

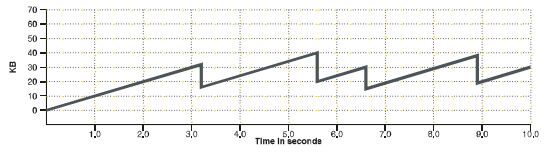
  Increment = (MSS x MSS)/CongestionWindow

  CongestionWindow += Increment



Sawtooth behavior

- Example trace

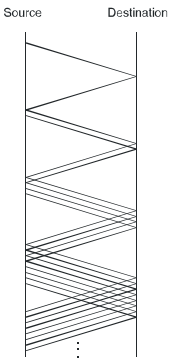


Slow Start

- Objective: determine the available capacity in the first place
  - when first starting connection
  - when connection recovers after a timeout
- Idea:
  - begin with CongestionWindow = 1 segment
  - double CongestionWindow each RTT (increment by 1 segment for each ACK)

Slow Start (cont'd)

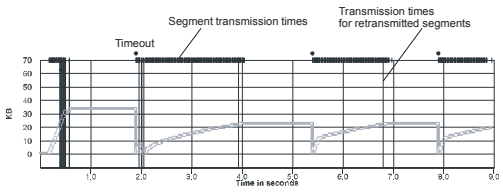
- Exponential growth, but slower than all in one blast



TCP Congestion Algorithm

On a timeout, half the current window size is recorded in ssthresh

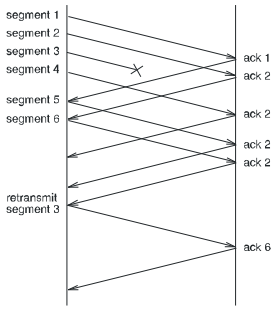
```
if (cwnd < ssthresh) // if we're still doing
        // slow-start, open window exponentially
   cwnd += 1
else // otherwise do Congestion Avoidance
     // linear increase
   cwnd += 1/cwnd
```

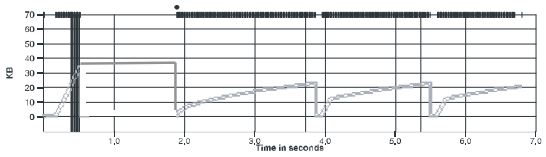



- Example trace
- cwnd stays flat if no ACKs are received
- Problem: lose up to half a CongestionWindow 's worth of data during slow start

Fast Retransmit and Fast Recovery

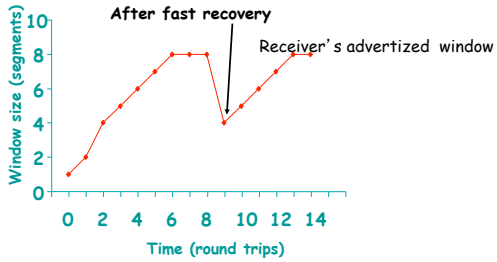
- Problem: coarse-grain TCP timeouts lead to idle periods
- Fast retransmit: use duplicate ACKs to trigger retransmission





- Long periods during which cwnd stays flat are eliminated
- Fast recovery: remove the slow start phase; go directly to half the last successful CongestionWindow
- TCP Tahoe includes all mechanisms *except* fast recovery
- TCP Reno adds fast recovery

Fast Recovery



- After fast retransmit and fast recovery, window size is reduced in half

Putting it Together: TCP Reno

On every ACK

```
if (window < threshold)      // slow start phase
    window += 1              // double window every RTT
else                         // congestion avoidance
    window += 1 / window     // increment by 1 every RTT
```

On timeout

```
    threshold = window / 2
    window = 1
```

On duplicate acknowledgments

```
   threshold = window = window / 2
                 // fast recovery
```