## Modeling TCP Throughput: Padhye, Firoiu, Towsley, Kurose [Padhye98a]

(got to slide 18 on 16-Feb-06)

CSci551: Computer Networks

SP2006 Thursday Section

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## Key ideas

- model the throughput of TCP
- why?
  - analysis could give insight
  - can project into future networks
  - maybe this tells how to improve TCP
  - what traffic is NOT like TCP
  - "TCP friendliness"
    - what other transport protocols are *like* TCP so that they can co-exist nicely



## Context

[Mathis97a, eqn 3]

$BW = \frac{MSS}{RTT} \frac{C}{\sqrt{p}}$ $C = \sqrt{3/2}$

- Series of increasingly complete models of TCP steady state performance
  - Floyd, 1991
  - Mathis et al, 1997
  - new contribution: add timeouts
- Parallel line of research: modeling *short* connections:
  - Heidemann, Obrazcka, Touch 1997
  - Cardwell, Savage, Anderson 1998

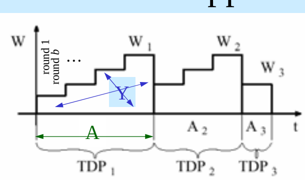


## Basic Approach

- model TCP in *rounds*
  - consider congestion avoidance (ignore slow-start)
  - each round is a flight of packets until their ACKs
  - model window size *W*
- model TDP: series of rounds followed by a drop and a *Triple-Dup-ACK*
- make assumptions where necessary
  - losses are i.i.d., but at end of round all pkts are lost
- solve for mean values using probability



## Basic Approach, pictorially




solve *bandwidth* $B = \frac{E[Y]}{E[A]}$ via solving Y and A

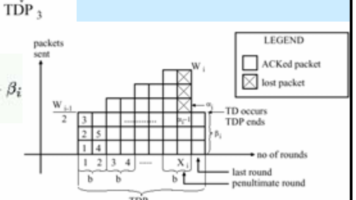
Y: number of segs sent in TDP

A: duration of TDP in seconds

Y:

$$Y_i = \sum_{k=0}^{(X_i/b)-1} \left(\frac{W_{i-1}}{2} + k\right) b + \beta_i$$

A: $E[A] = (E[X] + 1) E[r]$




X: number of rounds in TDP



## Result for Triple-Dup-ACKs

conclusion for triple-dup-ACK steady state (in segments):

$$B(p) = \frac{1}{RTT}\sqrt{\frac{3}{2bp}} + o(1/\sqrt{p})$$

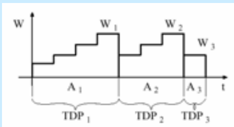
[Padhye98a, eqn 20]

compare to Mathis et al's earlier result (in bytes):

[Mathis97a, eqn 3]

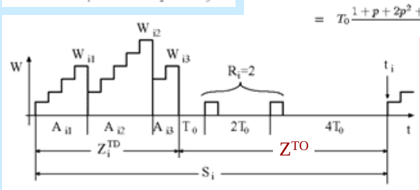
$BW = \frac{MSS}{RTT} \frac{C}{\sqrt{p}}$ $C = \sqrt{3/2}$

## What About Timeouts?




add $Z^{TO}$ to estimate timeouts

$$E[Z^{TO}] = \sum_{k=1}^{\infty} L_k P[R=k] = T_0 \frac{1+p+2p^2+4p^3+8p^4+16p^5+32p^6}{1-p}$$






## Modeling a Limited Window

- Define $W_{max}$ as the window limit
- What is performance if window limited?
  - data sent per round: Wmax
  - rounds until TDP: E[X] (solved for previously)
  - so data sent in TDP = E[Y] = E[X] * Wmax (pkts per round)



## Back to B(p)

with timeouts: [Padhye98a, eqn 29]

$$B(p) \approx \frac{1}{RTT\sqrt{\frac{2bp}{3}} + T_0 \min\left(1, 3\sqrt{\frac{3bp}{8}}\right) p(1+32p^2)}$$

with timeouts and limited windows: [Padhye98a, eqn 32]

$$B(p) \approx \min\left(\frac{W_{max}}{RTT}, \frac{1}{RTT\sqrt{\frac{2bp}{3}} + T_0 \min\left(1, 3\sqrt{\frac{3bp}{8}}\right) p(1+32p^2)}\right)$$