Computer Networks COL 334/672

Congestion Control

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Slides adapted from KR

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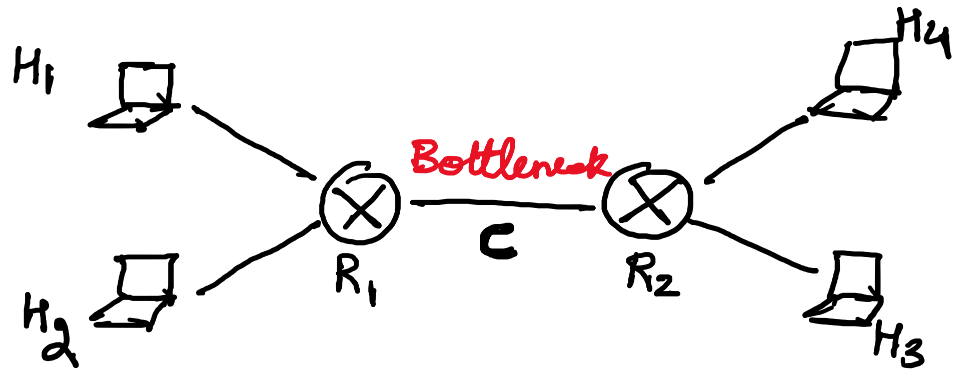
Recap: TCP Congestion Control

- **What:** Adjust sending rate at end-host to avoid congestion in the network
- **Why:** congestion → wasted network resources
- **How:**
  - **Design Space:** Multiple approaches possible. TCP chose:
    - End-to-end
    - Distributed
    - Window-based



  - **General approach:**
    1. Probe b/w by increasing window
    2. Detect congestion
    3. Backoff by decreasing window
  - **Multiple ways:** AIMD is chosen (desirable stability properties, provides fairness)

Window Update in AIMD

$0 < \beta < 1$

AIMD: AI: $cwnd = cwnd + \alpha$, MD: $cwnd = \frac{cwnd}{\beta}$

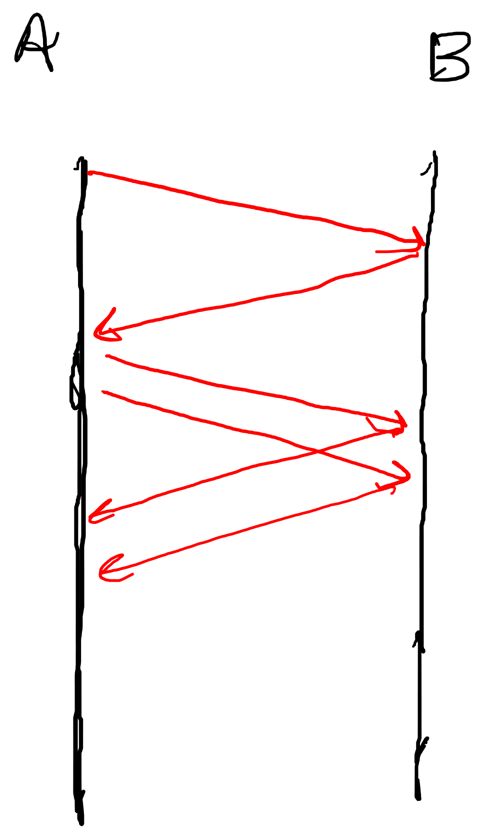
cwnd max $\alpha > 1$ $= 1$

- **Goal**: For additive increase, update window size by 1 every RTT. But when?

$cwnd = cwnd + 1/cwnd$

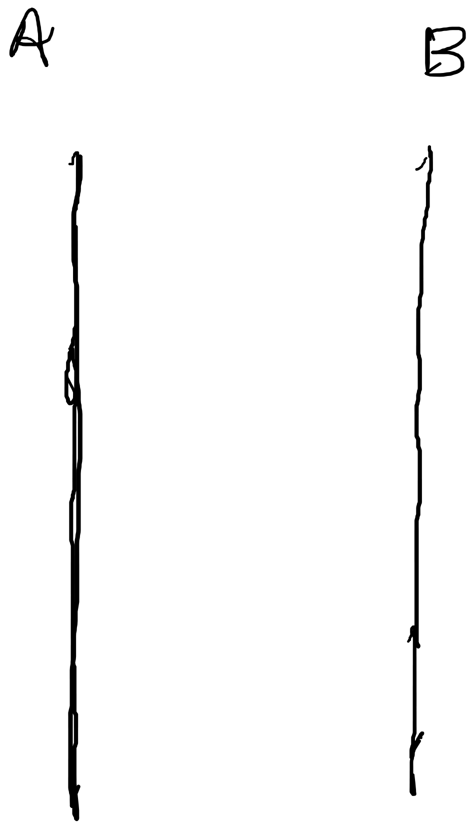
goal 1 MSS ↑ per RTT

$cwnd = cwnd + \left(\frac{MSS}{cwnd}\right) \times MSS$



Window Update in AIMD

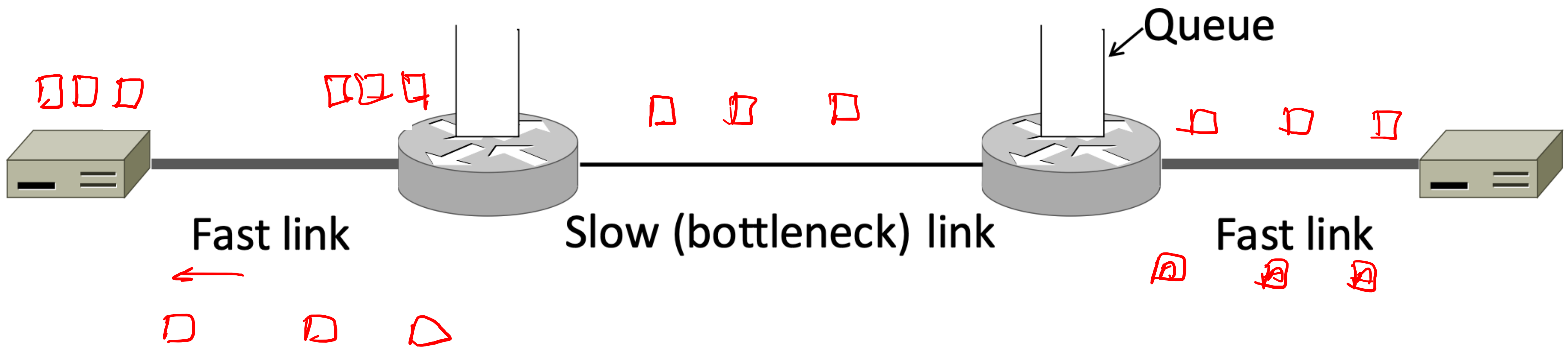
- **Goal**: For additive increase, update window size by 1 every RTT. But when?
  - Window updated as ACKs arrive
- How much should be the update?



- Because TCP updates based on ACKs, TCP is self-clocking Benefit: Self-clocking smooths packet sending rate

TCP Self Clocking

- ACK clocking smooths packet sending rate



1 RTT后

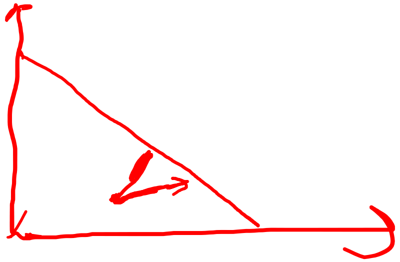
AIMD is TCP Fair

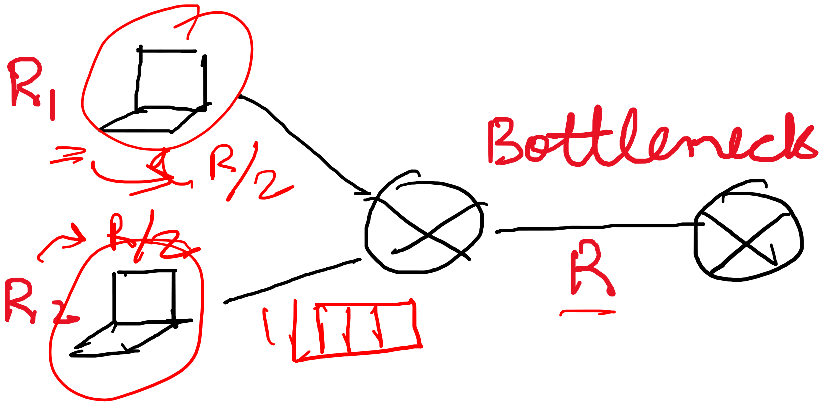
Active queue Management (AQM)
↳ Random Early Drop (RED)

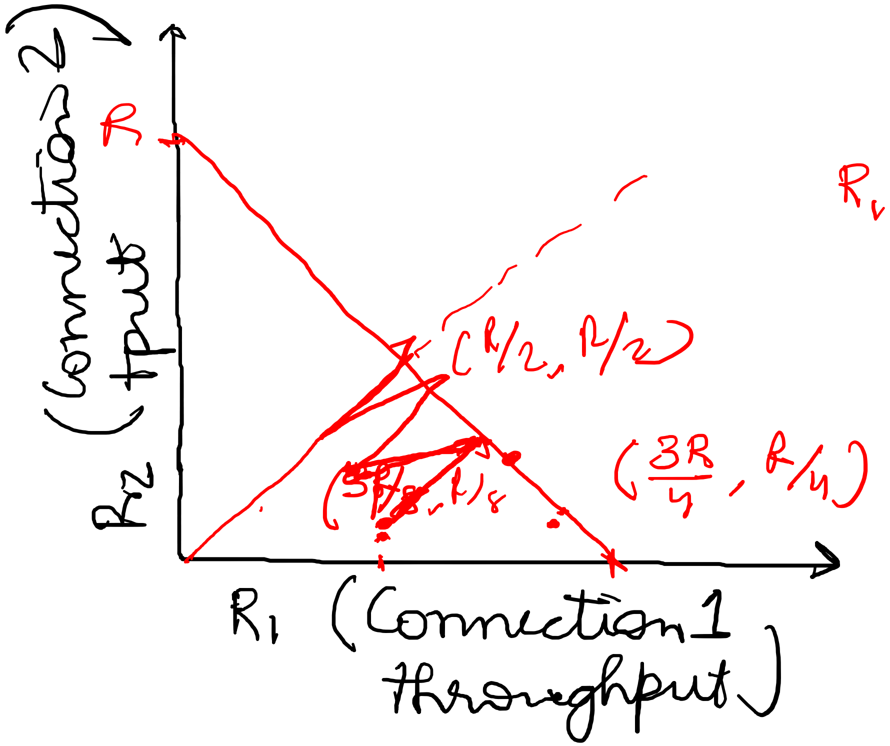
Example: two competing TCP sessions:

② . Is this mechanism TCP in all scenarios?

AIMD: is not RTT-fair







$R_1 + R_2 \le R$

Beginning of the Connection

cwnd = 10^4 IW = 1

RTT = 10^{-2} s

How much time

= 10^2

- What *cwnd* size should we start with?
  - **Goal**: We want to quickly near the *right* rate.
  - A linear increase with a small value of cwnd is painfully slow!

exponential

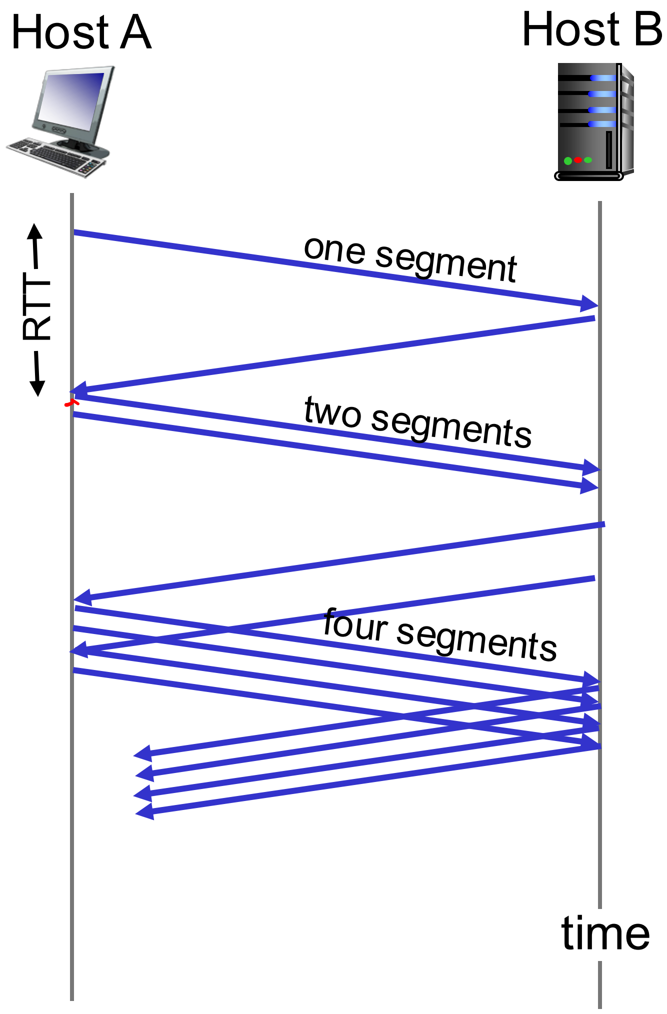
start w/ a large value ?

- What are the options?
  - Start with a large value of cwnd
  - Start with a small value of cwnd but increase it faster

Start with a large IW : Rwnd

TCP slow start

- when connection begins, increase rate exponentially until first loss event:
  - initially **cwnd** = 1 MSS
  - double **cwnd** every RTT
  - done by incrementing **cwnd** for every ACK received
- *summary:* initial rate is slow, but ramps up exponentially fast

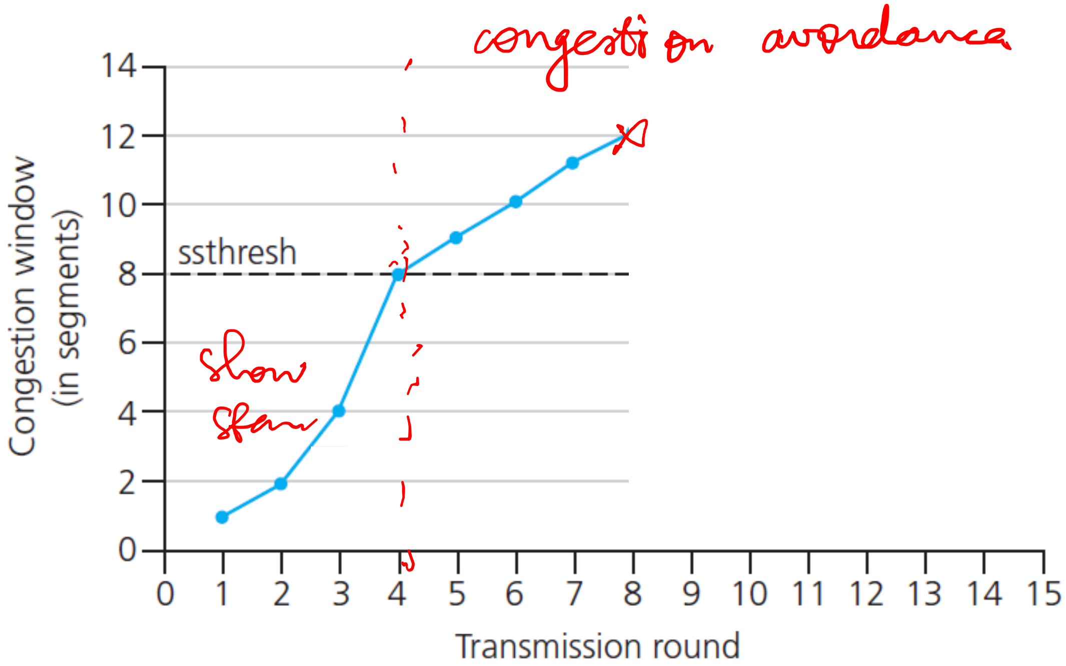


Until when?

TCP Slow Start and Congestion Avoidance

- Uses a threshold, $\boxed{\textit{ssthresh}}$, after which TCP enters congestion avoidance

- *What happens when a loss occurs?*



Timeout — Fast Retransmit

Triple dup ACK

What happens when a loss occurs?

→ ssthresh = 6

cwnd = 6

- When loss is due to triple duplicate ACK: congestion is not severe!
  - Set *ssthresh to cwnd/2*
  - On receipt of another duplicate ACK, send 1 new segment
  - Once a new ACK arrives, set *cwnd = ssthresh (or cwnd/2)*
  - Enter congestion avoidance phase

Fast Recovery Phase

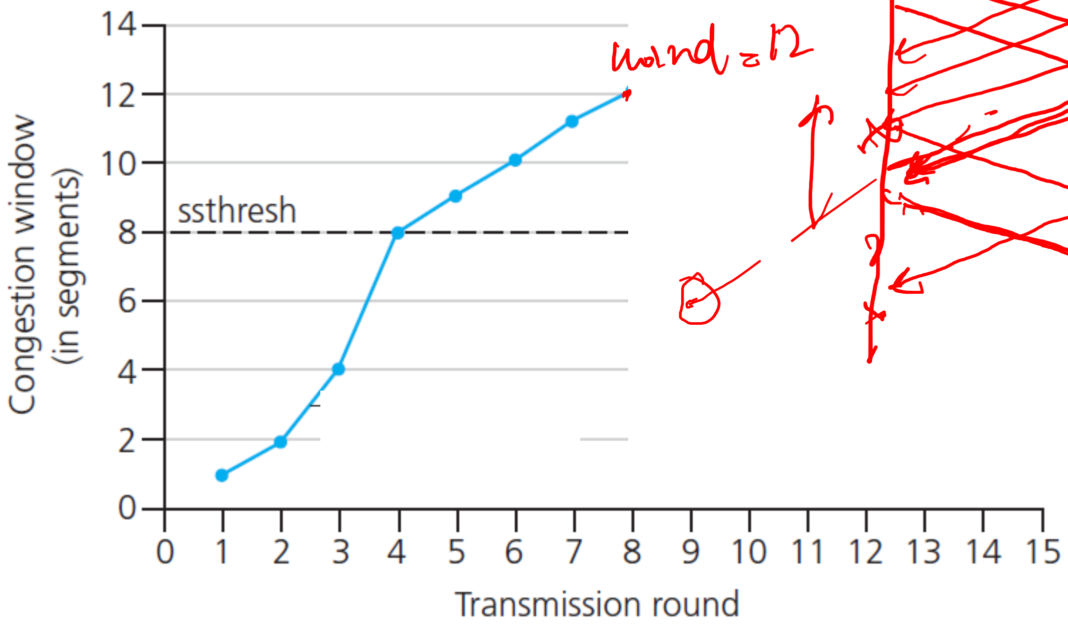
Congestion avoidance

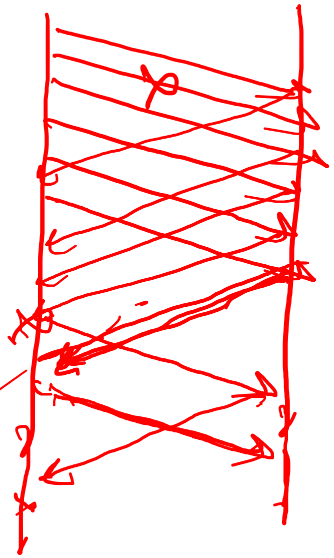
congestion avoidance

TCP Reno: Fast retransmit, fast recovery!

TCP Tahoe :

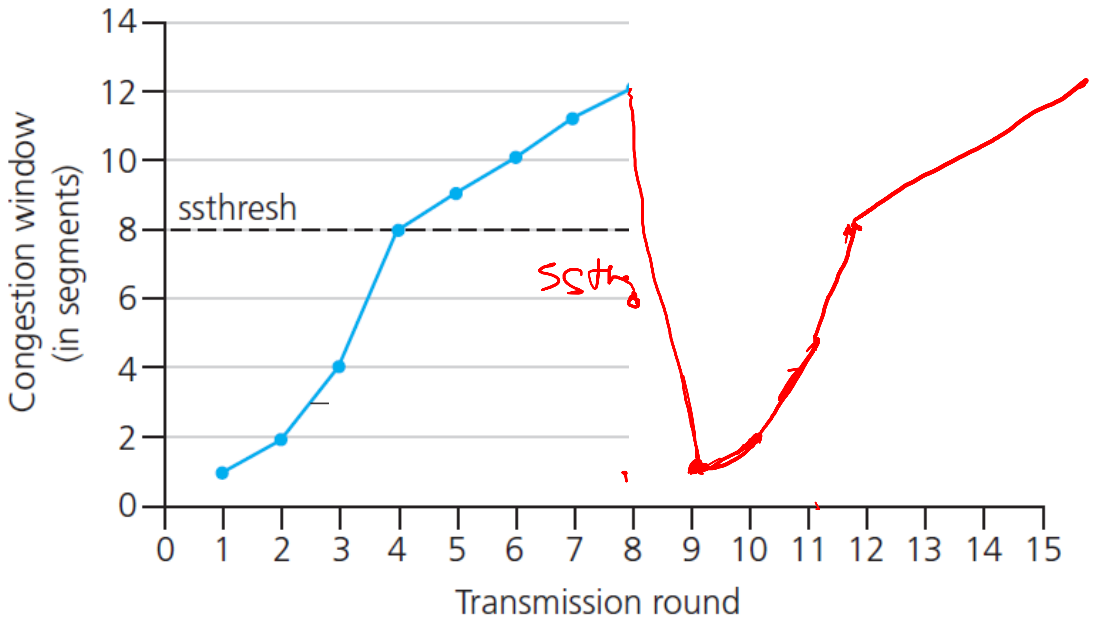
cwnd = 12





What happens when a loss occurs?

- When loss is due to timeout: ssthresh = 6
  severe congestion!!
  - Set *ssthresh to cwnd/2*
  - Reset cwnd to 1 , IW
  - Enter slow start phase



What happens when a loss occurs?

- Loss is due to timeout: severe congestion!!
  - Set *ssthresh to cwnd/2*
  - Reset cwnd to 1
  - Enter slow start phase
- Loss is due to triple duplicate ACK: congestion is not severe!
  - Set *ssthresh to cwnd/2*
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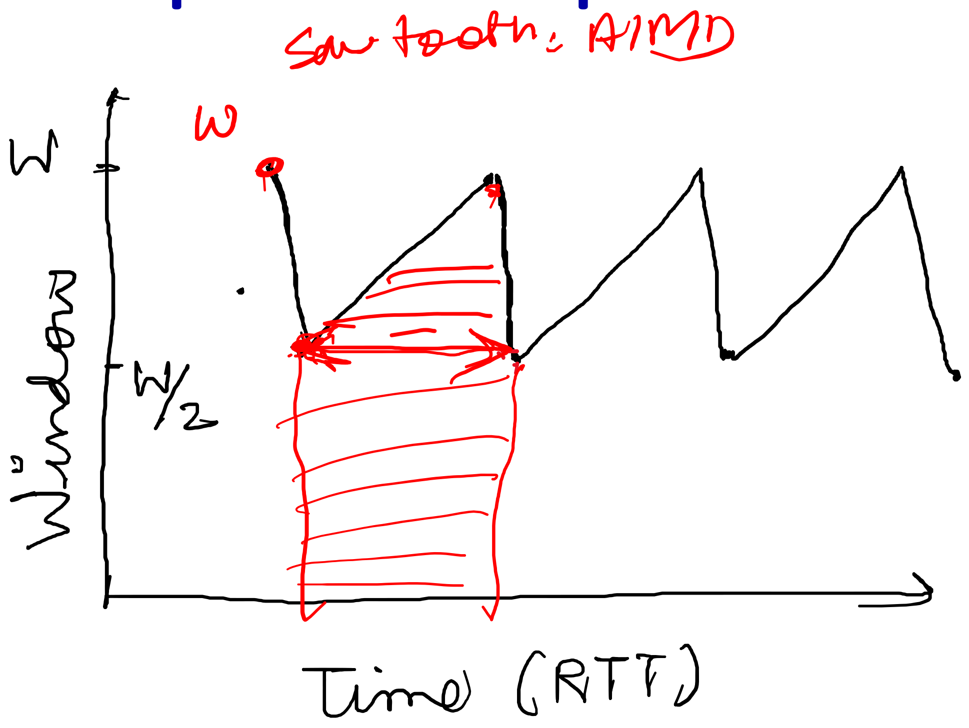
TCP Reno Throughput: Macroscopic Description

- Throughput: area under the curve

Average Tput : $\frac{3W}{4}$

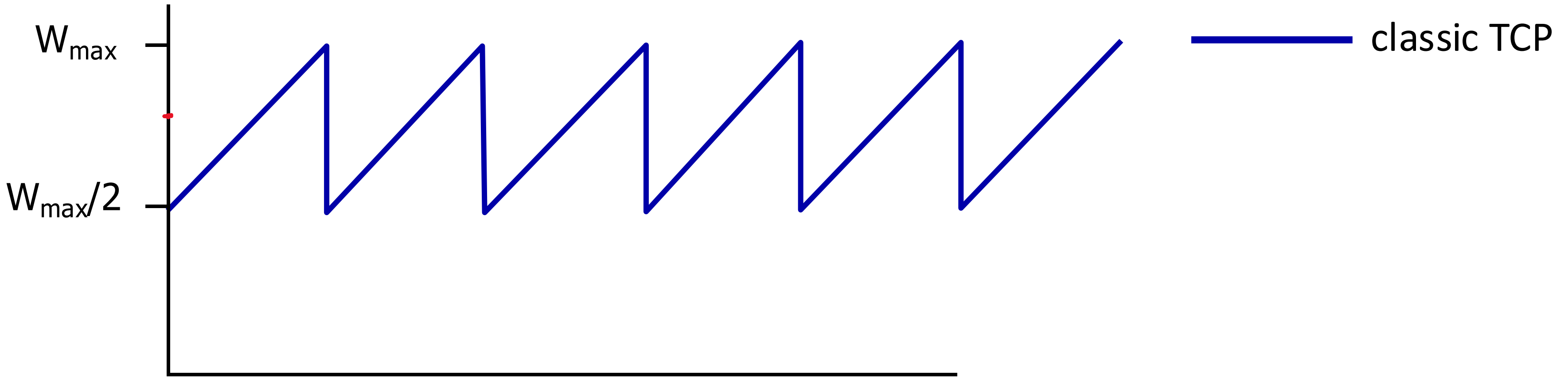


Inefficient for networks with high bandwidth delay product!

Can we do faster?

Is there a better way than AIMD to "probe" for usable bandwidth?

- Insight/intuition:
  - W_{max}: sending rate at which congestion loss was detected
  - congestion state of bottleneck link probably (?) hasn't changed much
  - after cutting rate/window in half on loss, initially ramp to to W_{max} *faster*, but then approach W_{max} more *slowly*



TCP CUBIC

- K: point in time when TCP window size will reach W_{max}
  - K itself is tunable
- increase W as a function of the *cube* of the distance between current time and K

$$W(t) = C(t - K)^3 + W_{max}$$

$$K = \sqrt[3]{\frac{W_{max}\beta}{C}}$$

- TCP CUBIC default in Linux, most popular TCP for popular Web servers

Attendance