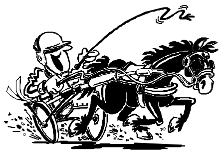
# TCP (Part II)



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- **TCP interactive data flow**
- **TCP bulk data flow**
- **TCP congestion control**
- **TCP timers**
- **TCP futures and performance**

**Ref: Chap 19, 20, 21; RFC 793, 1323, 2001, papers by Jacobson, Karn/Partridge**



## TCP Interactive Data Flow

- **Problems:**
  - **Overhead: 40 bytes header + 1 byte data**
  - **To batch or not to batch: response time important**
- **Batching acks:**
  - **Delay-ack timer: piggyback ack on echo**
  - **200 ms timer (fig 19.3)**
- **Batching data:**
  - **Nagle's algo: Don't send packet until next ack is received.**
  - **Developed because of congestion in WANs**

## TCP Bulk Data Flow

- **Sliding window:**
  - **Send multiple packets while waiting for acks (fig 20.1) upto a limit (W)**
  - **Receiver need not ack every packet**
  - **Acks are cumulative.**
  - **Ack # = Largest consecutive sequence number received + 1**
  - **Two transfers of the data can have different dynamics (eg: fig 20.1 vs fig 20.2)**
- **Receiver window field:**
  - **Reduced if TCP receiver short on buffers**



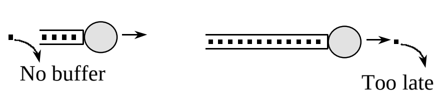
## TCP Bulk Data Flow (Contd)

  - **End-to-end flow control**
  - **Window update acks: receiver ready**
  - **Default buffer sizes: 4096 to 16384 bytes.**
  - **Ideal: window and receiver buffer = bandwidth-delay product**
- **TCP window terminology: figs 20.4, 20.5, 20.6**
  - **Right edge, Left edge, usable window**
  - **"closes" => left edge (snd_una) advances**
  - **"opens" => right edge advances (receiver buffer freed => receiver window increases)**
  - **"shrinks" => right edge moves to left (rare)**

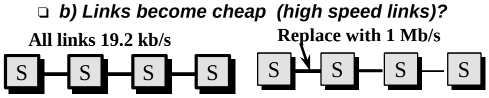


## The Congestion Problem

- ***Problem: demand outstrips available capacity …***
- **Q: Will the "congestion" problem be solved when:**
  - ***a) Memory becomes cheap (infinite memory)?***

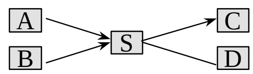



  - ***b) Links become cheap (high speed links)?***




*File Transfer time = **5 mins*** *File Transfer Time = **7 hours***

- ***c) Processors become cheap (fast routers switches)?***




*Scenario: All links 1 Gb/s. A & B send to C.*

Ans: None of the above solves congestion !

- Congestion: Demand > Capacity
  - It is a dynamic problem => Static solutions are not sufficient
  - TCP provides a dynamic solution



# TCP Congestion Control

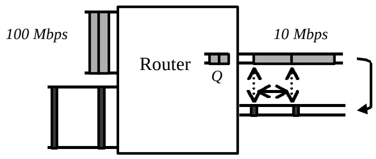
- *Window flow control*: avoid receiver overrun
- *Dynamic window congestion control:* avoid/control network overrun
  - Observation: Not a good idea to start with a large window and dump packets into network
  - Treat network like a black box and start from a window of 1 segment *("slow start")*
  - Increase window size exponentially *("exponential increase")* over successive RTTs => quickly grow to claim available capacity.



- Technique: Every ack: increase *cwnd* (new window variable) by 1 segment.
- Effective window = Min(*cwnd, Wrcvr*)

# Dynamics

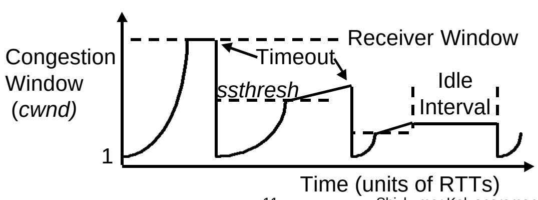

- ❑ Rate of acks = rate of packets at the bottleneck: *"Self-clocking"* property.






# Congestion Detection

- ❑ *Packet loss as an indicator of congestion*.
  - ❑ Set slow start threshold *(ssthresh)* to min(*cwnd, Wrcvr)/2*
  - ❑ Retransmit pkt, set *cwnd* to 1 (reenter slow start)






# Congestion avoidance

  - ❑ Increment *cwnd* by 1 per ack until *ssthresh*
  - ❑ Increment by 1/*cwnd* per ack afterwards *("Congestion avoidance" or "linear increase")*
- ❑ Idea: *ssthresh* estimates the bandwidth-delay product for the connection.
- ❑ Initialization: *ssthresh* = Receiver window or default 65535 bytes. Larger values thru options.
- ❑ If source is idle for a long time, cwnd is reset to one.

## Timeout and RTT Estimation

- Timeout: for robust detection of packet loss
- Problem: How long should timeout be ?
  - Too long => underutilization; too short => wasteful retransmissions
  - Solution: *adaptive timeout: based on RTT*
- RTT estimation:
  - Early method: exponential averaging:
    - $R \leftarrow \alpha$*R + (1 - $\alpha$)*M { M =measured RTT}
    - RTO = $\beta$*R {$\beta$ = delay variance factor}
    - Suggested values: $\alpha$ = 0.9, $\beta$ = 2



## RTT Estimation

- Jacobson [1988]: this method has problems w/ large RTT fluctuations
- New method: Use mean & deviation of RTT
  - A = smoothed average RTT
  - D = smoothed mean deviation
  - Err = M - A { M = measured RTT}
  - $A \leftarrow$ A + g*Err {g = gain = 0.125}
  - $D \leftarrow$ D + h*(|Err| - D) {h = gain = 0.25}
  - RTO = A + 4D
  - Integer arithmetic used throughout. Complex initialization process ...



## Timer Backoff/Karn's Algorithm

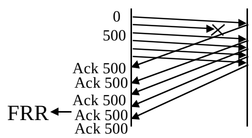
- Timer backoff: If timeout, RTO = 2*RTO {exponential backoff}
- Retransmission ambiguity problem:
  - During retransmission, it is unclear whether an ack refers to a packet or its retransmission. Problem for RTT estimation
  - Karn/Partridge: don't update RTT estimators during retransmission.
    - Restart RTO only after an ack received for a segment that is not retransmitted

## Fast Retransmit and Recovery

- **Goals:**
  - ***Timeout avoidance:* The 500 ms timer granularity can have an adverse performance impact especially for high speed n/ws**
  - ***Selective retransmission:* Especially when packets are dropped due to error or light congestion**
  - ***Fast Recovery:* Converge quickly to a state of congestion avoidance (linear increase) with half-current window -- the assumed ideal window size.**
- Observation: Receivers are required to send an immediate duplicate acknowledgment when they receives out-of-order data segments.



## Fast Retransmit and Recovery




- **3 duplicate acks => assume loss**
- **More duplicate acks => other packets have reached destination safely.**
- **Wait for about 1/2*RTT, and resume transmitting new segments for every subsequent duplicate ack received. Stop this process once the ack for the missing segment received**

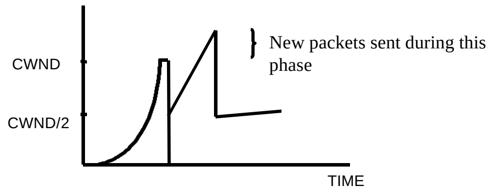


## Fast Retransmit and Recovery

- Fast Retransmit: Received *third duplicate ack*:
  - Set *ssthresh* to 1/2 of current *cwnd*
  - Retransmit the missing segment
  - Set *cwnd* to *ssthresh*+3
- Fast Recovery: For each duplicate ack hence:
  - Increment *cwnd* by 1 MSS
  - New packets are transmitted once *cwnd* grows large enough.
  - [If old cwnd was a pipe of length 1*RTT, the network gets a relief period of 1/2*RTT]

## FRR (contd)

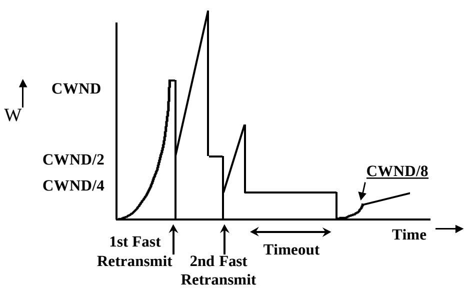
- Upon receiving the next (non-duplicate) Ack:
  - Set *cwnd* to *ssthresh & enter linear growth phase*






## FRR problems

- Burst loss of 3 pkts => Timeout + window shutdown to cwnd/8 !






## TCP Performance Optimization

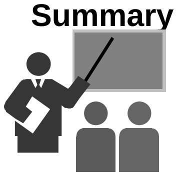
- SACK: selective acknowledgments: specifies blocks of packets received at destination.
- *Random early drop (RED)* scheme spreads the dropping of packets more uniformly and reduces average queue length and packet loss rate.
- *Scheduling* mechanisms protect well-behaved flows from rogue flows.
- *Explicit Congestion Notification (ECN):* routers use a explicit bit-indication for congestion instead of loss indications.

## Congestion control summary

- Sliding window limited by receiver window.
- **Dynamic** *windows*: **slow start (exponential rise), congestion avoidance (linear rise), multiplicative decrease.**
- **Adaptive** *timeout*: **need mean RTT & deviation**
- **Timer back off and Karn's algo during retransmission**
- **Go-back-N or Selective** *retransmission*
- **Cumulative and Selective** *acknowledgements*
- **Timeout avoidance: FRR**
- *Drop* **policies,** *scheduling* **and** *ECN*



## Summary



- **Interactive and bulk TCP flow**
- **TCP congestion control**
- *Informal exercises:* **Perform some of the experiments described in chaps 19-21 to see various facets of TCP in action**