CSE/EE 461 Lecture 15
TCP Congestion Control

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Peterson, Chapter 6

RPC Failure Models

- How many times is an RPC done?
  - Exactly once?
    - Server crashes before request arrives
    - server crashes after ack, but before reply
    - server crashes after reply, but reply dropped
  - At most once?
    - If server crashes, can't know if request was done
  - At least once?
    - Keep retrying across crashes, but may be done multiple times
    - Example: NFS idempotent ops (ex: read/write file block)

Exactly Once RPC

- Example: buy something over Ebay, Amazon
  - want exactly one widget, book, 100 shares of kozmo
- Want RPC to be
  - done exactly once
  - done completely or not at all
  - done atomically with respect to other requests
  - once done, stays done (independent of later crashes)
- Analogous to distributed database transactions

Exactly Once RPC

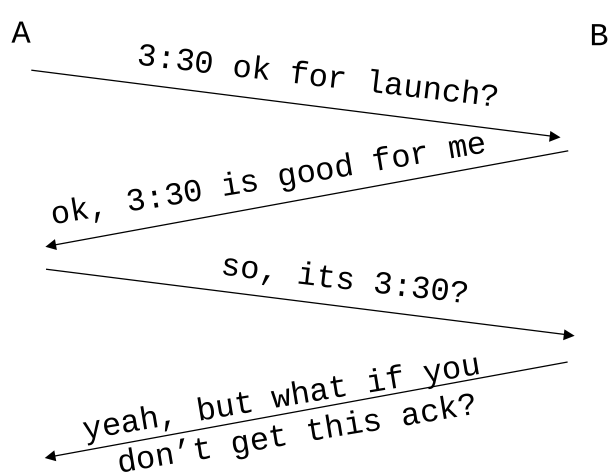
- Can implement using disk on both ends
  - client writes “about to make request” to disk
    - – keep retrying until there is a reply (done/abort)
  - client sends request
  - server gets request; computes result
  - server writes “about to reply” to disk
    - – along with contents of reply message
  - server sends reply
  - client writes “got response” to disk
    - – to remove request; if crash, don’t want to retry

General’s Paradox

Can we use messages and retries to synchronize two machines so they are guaranteed to do some operation at the same time?

- No.

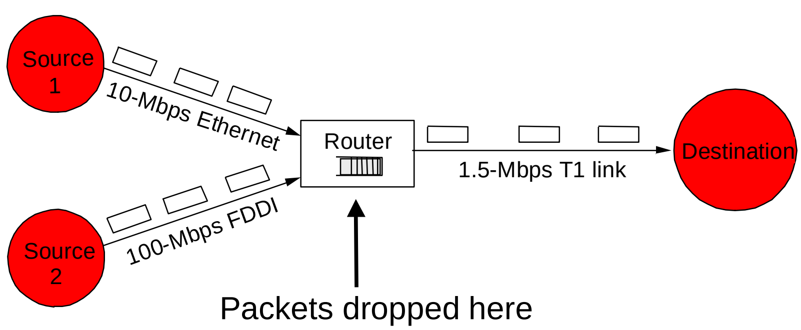
General’s Paradox Illustrated



Bandwidth Allocation

- How do we efficiently share network resources among billions of hosts?
  - Congestion control
    - Sending too fast causes packet loss inside network -> retransmissions -> more load -> more packet losses -> …
    - Don't send faster than network can accept
  - Fairness
    - How do we allocate bandwidth among different users?
    - Each user should get fair share of bandwidth

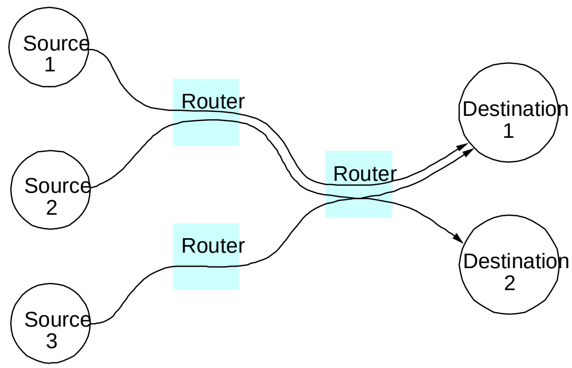
Congestion



- Buffer absorbs bursts when input rate > output
- If sending rate is persistently > drain rate, queue builds
- Dropped packets represent wasted work

Chapter 6, Figure 1

Fairness



- Each flow from a source to a destination should get an equal share of the bottleneck link … depends on paths and other traffic

Chapter 6, Figure 2

The Problem

- Original TCP sent full window of data
- When links become loaded, queues fill up, and this can lead to:
  - *Congestion collapse:* when round-trip time exceeds retransmit interval -- every packet is retransmitted many times
  - Synchronized behavior: network oscillates between loaded and unloaded

Jacobson Solution

- Modify retransmission timer to adapt to variations in queueing delay
  - Timeout based on measured RTT and variance
- Infer network bandwidth from packet loss
  - drops => congestion => reduce rate
    - drops also caused by link noise!
  - no drops => no congestion => increase rate
- Limit send rate based on network bandwidth in addition to receiver buffer space
  - minimum of what network and receiver can accept

TCP Congestion Control

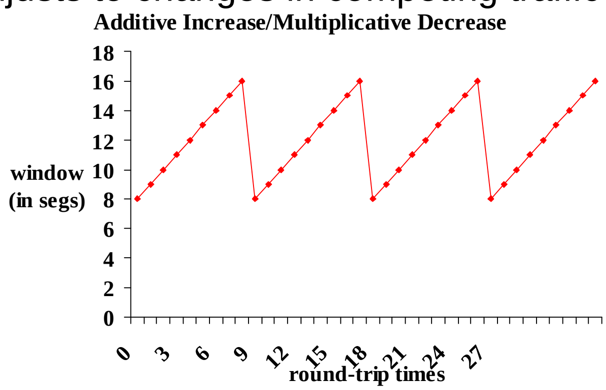
- Adjust rate to match network bandwidth
  - Additive increase/multiplicative decrease
    - oscillate around bottleneck capacity
  - Slow start
    - quickly identify bottleneck capacity
  - Fast retransmit
  - Fast recovery

Tracking the Bottleneck Bandwidth

- Sending rate = window size/RTT
- Multiplicative decrease
  - Timeout => dropped packet => cut window size in half
    - and therefore cut sending rate in half
- Additive increase
  - Ack arrives => no drop => increase window size by one packet/window
    - and therefore increase sending rate a little

TCP "Sawtooth"

- Oscillates around bottleneck bandwidth
  - adjusts to changes in competing traffic

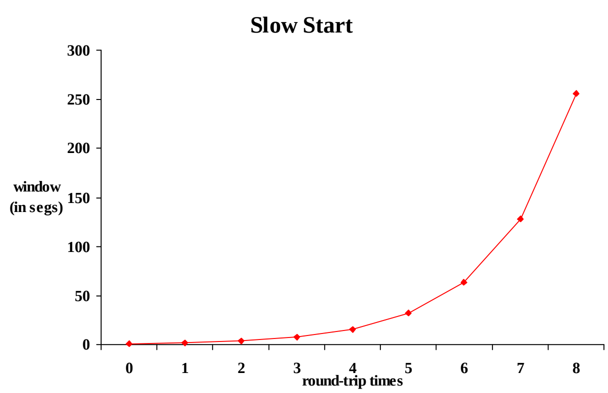


Slow start

- How do we find bottleneck bandwidth?
  - Start by sending a single packet
    - start slow to avoid overwhelming network
  - Multiplicative increase until get packet loss
    - quickly find bottleneck
  - Remember previous max window size
    - shift into linear increase/multiplicative decrease when get close to previous max ~ bottleneck rate
    - called “congestion avoidance”

Slow Start

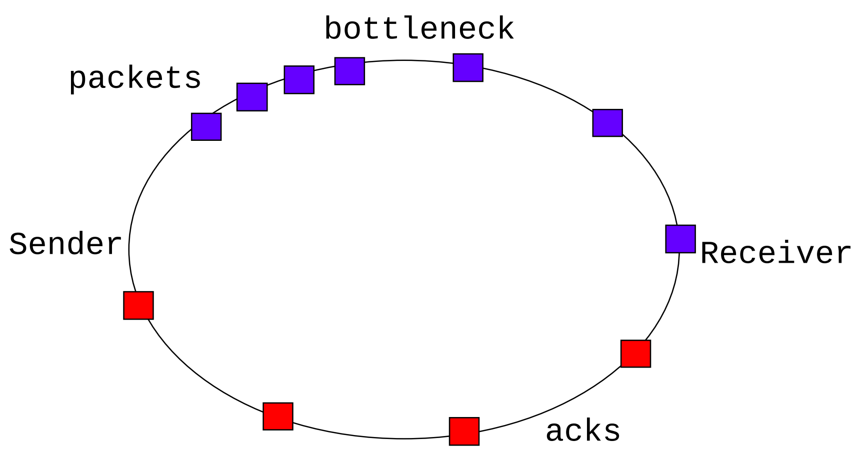
- Quickly find the bottleneck bandwidth



Slow Start Problems

- Bursty traffic source
  - will fill up router queues, causing losses for other flows
  - solution: ack pacing
- Slow start usually overshoots bottleneck
  - will lose many packets in window
  - solution: remember previous threshold
- Short flows
  - Can spend entire time in slow start!
  - solution: persistent connections?

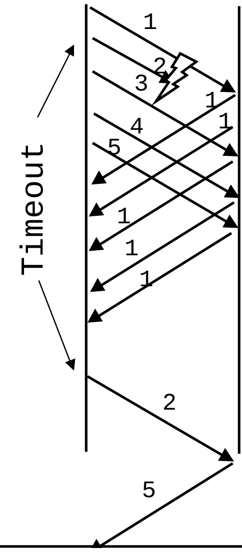
Avoiding burstiness: ack pacing



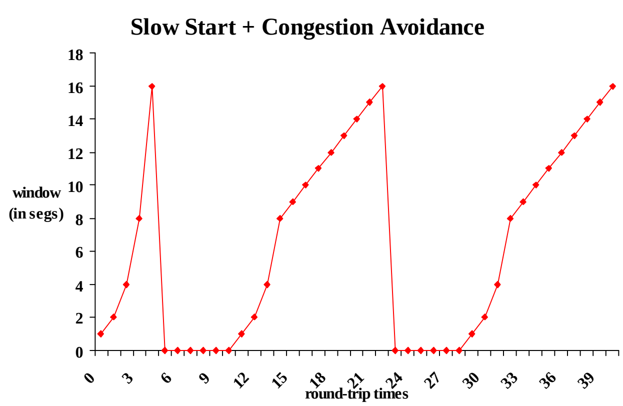
Window size = round trip delay * bit rate

Ack Pacing After Timeout

- Packet loss causes timeout, disrupts ack pacing
  - slow start/additive increase are *designed* to cause packet loss
- After loss, use slow start to regain ack pacing
  - switch to linear increase at last successful rate
  - "congestion avoidance"



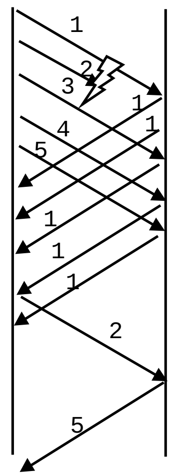
Putting It All Together



- Timeouts dominate performance!

Fast Retransmit

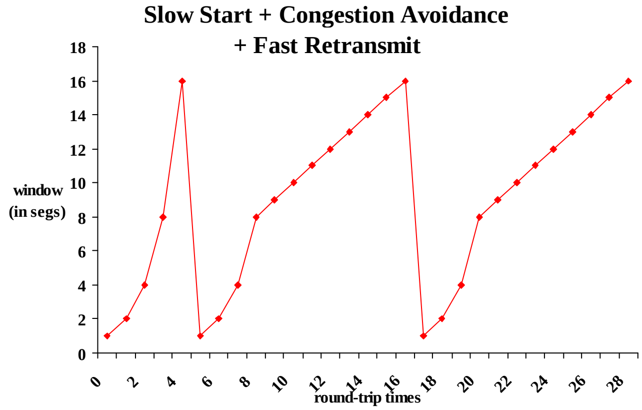
- Can we detect packet loss without a timeout?
  - Receiver will reply to each packet with an ack for last byte received in order
- Duplicate acks imply either
  - packet reordering (route change)
  - packet loss
- TCP Tahoe
  - resend if sender gets three duplicate acks, without waiting for timeout



Fast Retransmit Caveats

- Assumes in order packet delivery
  - Recent proposal: measure rate of out of order delivery; dynamically adjust number of dup acks needed for retransmit
- Doesn’t work with small windows (e.g. modems)
  - what if window size <= 3
- Doesn’t work if many packets are lost
  - example: at peak of slow start, might lose many packets

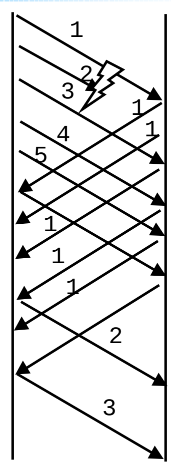
Fast Retransmit



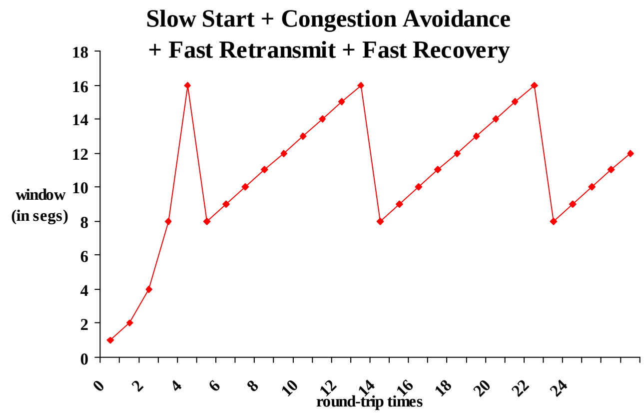
- Regaining ack pacing limits performance

Fast Recovery

- Use duplicate acks to maintain ack pacing
  - duplicate ack => packet left network
  - after loss, send packet after every other acknowledgement
- Doesn't work if lose many packets in a row
  - fall back on timeout and slow start to reestablish ack pacing



Fast Recovery



Delayed ACKS

- Problem:
  - In request/response programs, server will send separate ACK and response packets
    - – computing the response can take time
- TCP solution:
  - Don't ACK data immediately
  - Wait 200ms (must be less than 500ms)
  - Must ACK every other packet
  - Must not delay duplicate ACKs

Delayed Ack Impact

- TCP congestion control triggered by acks
  - if receive half as many acks => window grows half as fast
- Slow start with window = 1
  - ack will be delayed, even though sender is waiting for ack to expand window