Congestion Control

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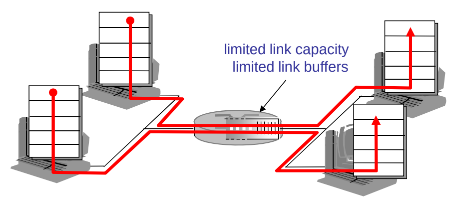
Principles of Congestion Control

Congestion:

- informally: "too many sources sending too much data too fast for the network to handle"
- results of congestion:
  - long delays (e.g. queueing in router buffers)
  - lost packets (e.g. buffer overflow at routers)



Congestion Control

Congestion threatens the growth of the Internet

- tragedy of commons

Two broad approaches towards congestion control:

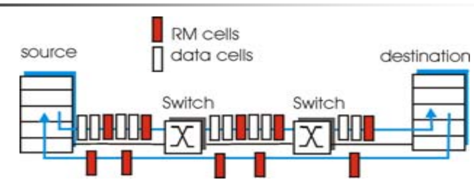
Network-assisted congestion control:

- routers participate in congestion control
- routers provide feedback to end systems that slow down when necessary

End-end congestion control:

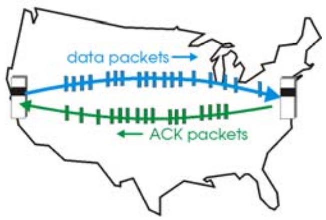
- no explicit help/information from network
- congestion inferred from end-system observed loss, delay

Network-assisted Congestion Control: ATM



- RM (resource management) cells:
  - sent by sender, interspersed with data cells
- bits in RM cell set by switches ("*network-assisted*")
  - NI bit: no increase in rate (mild congestion)
  - CI bit: congestion indication
  - ER (explicit rate) field: congested switch may lower ER value in cell
- RM cells returned to sender by receiver, with bits intact
  - sender control its rate based on information received in RM cells

TCP Congestion Control



- Mechanism: sender controls the sending rate by adjusting the number of packets allowed in flight simultaneously (size of the sliding window)
- Objective: figure out the highest rate that does not cause network congestion

TCP Congestion Control

- **CongWin** is maximum allowed in-flight or un-ACKed bytes
- Roughly:
  - throughput = CongWin/RTT
- dynamically control **CongWin**, based on perceived network congestion
- Goal: maintain a high rate that does not cause congestion

How does sender perceive congestion?

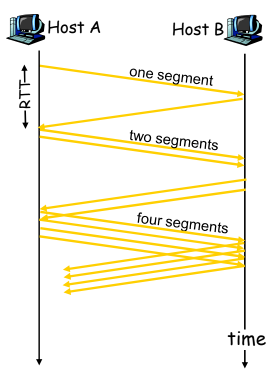
- loss event = timeout *or* triple duplicate ACKs
- timeout before 3 dup ACKs is more alarming
  - 3 dup ACKs indicates network capable of delivering some segments

two phases for TCP congestion control:

- start phase (having little idea of where the good rate is)
- steady state phase (being quite close to the good rate)

"Slow" Start Phase

- At the beginning, **CongWin** = 1 MSS
- Available bandwidth may be >> MSS/RTT
  - Example: MSS = 500 bytes & RTT = 200 msec
    ⇒ initial rate = 20 kbps
  - desirable to quickly ramp up to respectable rate
- Exponential increase: double **CongWin** after every RTT in the absence of loss events
- In this phase, the **CongWin** starts at a slow rate, but it grows fast
- When should we stop exponential growth?



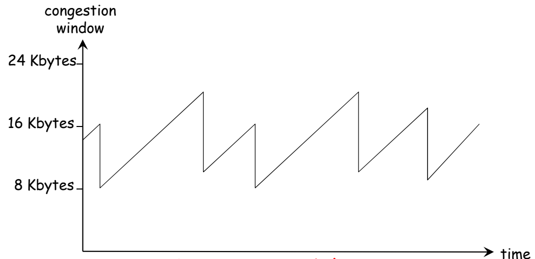
When does Slow Start become Steady State?

- Stop exponential growth:
  - when there is a loss event
  - or when **CongWin** reaches a **Threshold**.
- **Threshold** divides between two states:
  - when you are far away from causing congestion, so you do not need to worry about congestion
  - when you are very close to causing congestion, do need to be very careful
- **Threshold** is maintained based on past history:
  - set to half of **CongWin** at a loss event
  - initially set to a large value so it has no effect

Steady State Phase: AIMD

Additive increase:
increase **CongWin** by 1 MSS every RTT in the absence of loss events

Multiplicative decrease:
cut **CongWin** in half after 3 duplicate ACKs



Long-term stability

Handling Loss Events

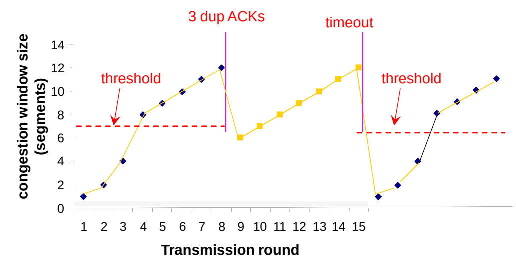
- After 3 dup ACKs:
  - **CongWin** is cut in half, it then grows linearly
- But after timeout event:
  - **CongWin** instead set to 1 MSS, fall back to slow start - the very beginning of the connection

Philosophy:
timeout before 3 dup ACKs is more alarming because 3 dup ACKs indicates network capable of delivering some segments

Summary

- At start phase, window starts at 1 MSS and grows exponentially.
- When **CongWin** is above **Threshold**, sender is in steady state phase, window grows linearly.
- When a triple duplicate ACK occurs, **CongWin** is cut in half.
- When timeout occurs, **Threshold** set to **CongWin/2** and **CongWin** is set to 1 MSS (start again).

Congestion Control in Action



Congestion Control Algorithms

- Reno is what we described.
- Tahoe (a predecessor)
  - does not consider three duplicate ACKs as a loss event.
- New Reno (an enhancement)
  - Congestion is most related to the number of in-flight segments. But Reno send window limits the number of unacked segments, many of which are not in-flight.

  ⇨ send one more segment when receiving a duplicate ACK.
- Vegas
- CUBIC (Linux)
  - More sophisticated slow start, steady state management
  - Window growth based on time, not ACKs

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Heuristics-based Approaches

- Many heuristics-based parameters, little understanding on how good it is compared to alternatives, or how far it is from optimal.

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Outline

- Principles of congestion control
- Congestion control in TCP
- Impact of congestion control on fairness
- Impact of congestion control on TCP efficiency

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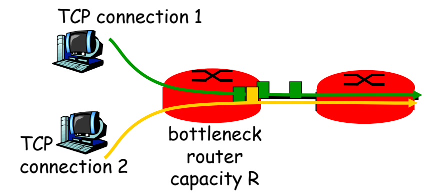
Fairness of TCP Congestion Control

Fairness goal:

if K TCP sessions share same bottleneck link of bandwidth R, each should have average rate of R/K



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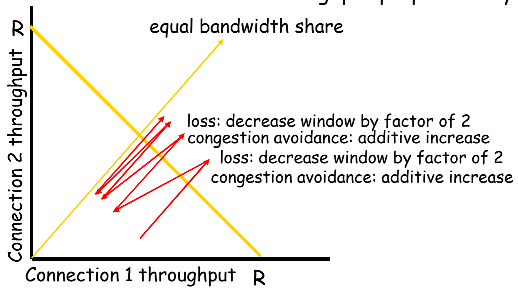
AIMD is Fair

Two competing sessions:

- Additive increase gives slope of 45°, as throughputs of both sessions increase at the same speed
- multiplicative decrease decreases throughput proportionally



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Fairness with UDP

- UDP is not congestion-controlled
  - UDP apps can send data as fast as they want, despite losses (its own losses as well as others)
  - Multimedia applications
- TCP is network friendly while UDP is not
- Regulate UDP traffic within the network

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Fairness with Parallel TCP Connections

- Nothing prevents an app from opening parallel connections between two hosts.
- Example: link of rate R currently supporting 9 connections.
  - new app uses 1 TCP connection, gets rate R/10
  - new app asks for 9 TCP connections, gets R/2 !

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TCP Efficiency

Q: How long does it take to receive an object from a Web server after sending a request?

- data transmission delay
- TCP connection establishment
- congestion control (slow start)

Case study:

- assume fixed congestion window: W segments
- more complicated with full TCP congestion control

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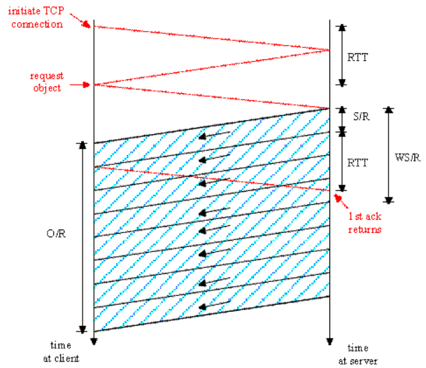
Fixed Congestion Window (1)

Notation, assumptions:
- Link rate: R
- Object size: O
- Fixed window size: WS
- No loss, no corruption



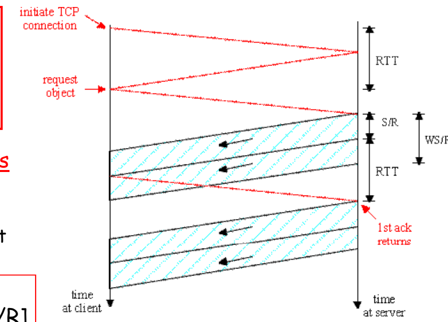
Case 1: congestion window is large

- ACK for first segment in window returns before window's worth of data sent

delay = 2RTT + O/R

Fixed Congestion Window (2)

Notation, assumptions:
- Link rate: R
- Object size: O
- Fixed window size: WS
- No loss, no corruption



Case 2: congestion window is not large

- wait for ACK after sending window's worth of data sent

delay = 2RTT + O/R
+ (K-1)[S/R + RTT - WS/R]
where K = O/WS

TCP Efficiency with Slow Start

- Small window size in the slow start process ⇒ inefficiency
- Inefficiency is amortized over long-running connections
  - persistent connection in HTTP/1.1

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