Lecture 6:
Congestion Control

Project 1a due MONDAY
Lecture 6 Overview

- Finish TCP connections
  - Connection establishment
  - Connection teardown

- Congestion control
  - Bandwidth Allocation
  - Congestion Collapse
  - TCP Bandwidth Probing
Connection Establishment

- Both sender and receiver must be ready before we start to transfer the data
  - Sender and receiver need to agree on a set of parameters
  - Most important: sequence number space in each direction
  - Lots of other parameters: e.g., the window size

- Handshake protocols: setup state between two oblivious endpoints
  - Need to deal with delayed and reordered packets
Two-way handshake?

Active participant (client)  Passive participant (server)

SYN, SequenceNum = x
SYN, SequenceNum = y
+data

What’s wrong here?
Two-way handshake?

Active participant (client)

Old SYN, SequenceNum = x
New SYN, SequenceNum = q
SYN, SequenceNum = y

Passive participant (server)

Delayed old SYN
Rejected

+data
Three-Way Handshake

- Opens both directions for transfer

SYN, SequenceNum = x

SYN + ACK, SequenceNum = y,
Acknowledgment = x + 1

ACK, Acknowledgment = y + 1

+data

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Connection Teardown

- Orderly release by sender and receiver when done
  - Delivers all pending data and “hangs up”

- Cleans up state in sender and receiver

- TCP provides a “symmetric” close
  - Both sides shutdown independently
TCP Connection Teardown

Web server

FIN

ACK

FIN

ACK

TIME_WAIT

CLOSED

Web browser

CLOSED
The TIME_WAIT State

- We wait \(2\times\text{MSL}\) (maximum segment lifetime of 60 seconds) before completing the close
  - Why?

- ACK might have been lost and so FIN will be resent
  - Could interfere with a subsequent connection

- Real life: Abortive close
  - Don’t wait for \(2\times\text{MSL}\), simply send Reset packet (RST)
  - Why?
Some Comments

- We could abbreviate this setup, but it was chosen to be robust, especially against delayed duplicates
  - Three-way handshake from Tomlinson 1975

- Choice of changing initial sequence numbers (ISNs) minimizes the chance of hosts that crash getting confused by a previous incarnation of a connection

- How to choose ISNs?
  - Maximize period between reuse
  - Minimize ability to guess (why?)
CC Overview

- How fast should a sending host transmit data?
  - Not to fast, not to slow, just right…

- Should not be faster than the sender’s share
  - Bandwidth allocation

- Should not be faster than the network can process
  - Congestion control

- Congestion control & bandwidth allocation are separate ideas, but frequently combined
Bandwidth Allocation

- How much bandwidth should each flow from a source to a destination receive when they compete for resources?
  - What is a “fair” allocation?
Congestion

- Buffer intended to absorb bursts when input rate > output
- But if sending rate is persistently > drain rate, queue builds
- Dropped packets represent wasted work; goodput < throughput

Packets dropped here

Source 1
10-Mbps Ethernet

Source 2
100-Mbps FDDI

Router

1.5-Mbps T1 link

Destination

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Drop-Tail Queuing

Throughput vs. Arrival rate

Latency vs. Arrival rate

Loss due to Congestion

Congestion collapse

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Congestion Collapse

- Rough definition: “When an increase in network load produces a decrease in useful work”

- Why does it happen?
  - Senders send faster than bottleneck link speed
  - Packets queue until dropped
  - In response to packets being dropped, senders retransmit
  - All hosts repeat in steady state…
Mitigation Options

- Increase network resources
  - More buffers for queuing
  - Increase link speed
  - How big should buffers be for a given speed?

- Reduce network load by adapting sending rate
  - Send data more slowly
  - How much more slowly?
  - When to slow down?
Designing a Control

- Open loop
  - Explicitly reserve bandwidth in the network in advance

- Closed loop
  - Respond to feedback and adjust bandwidth allocation

- Network-based
  - Network implements and enforces bandwidth allocation

- Host-based
  - Hosts are responsible for controlling their sending rate
Proactive vs. Reactive

- **Congestion avoidance**: try to stay to the left of the knee
- **Congestion control**: try to stay to the left of the cliff
Challenges to Address

- How to detect congestion?
- How to limit sending data rate?
- How fast to send?
For Next Time

- Read 6.3-6.4 in P&D

- Discussion this evening (HW solutions and Project help)

- (Keep) going on the project…