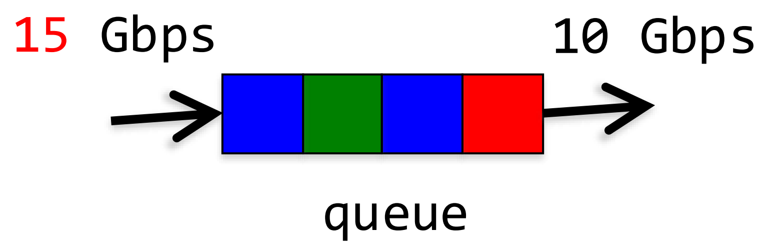
Congestion Control

COS 316: Principles of Computer System Design
Lecture 7

Wyatt Lloyd

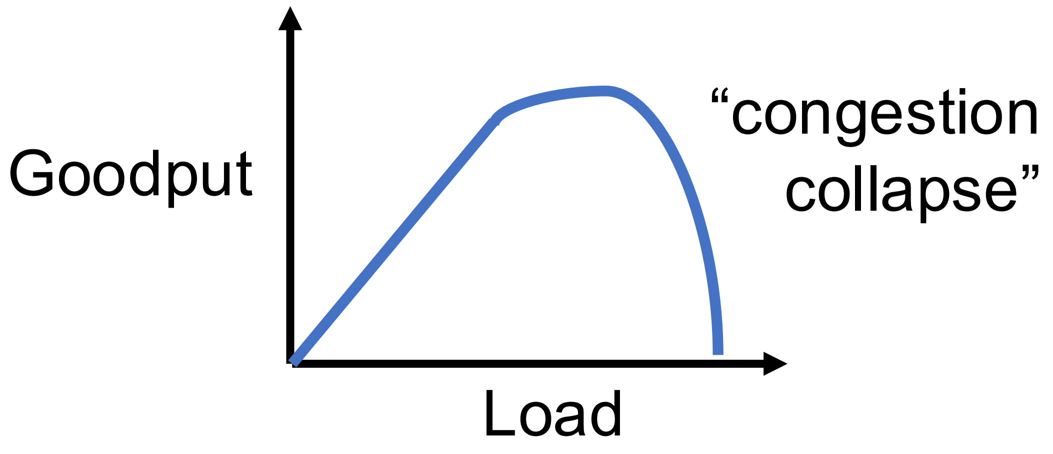
Congestion

- Best-effort network does not "block" calls
  - So, they can easily become overloaded
  - Congestion == "Load higher than capacity"
- Examples of congestion
  - Link layer: Ethernet frame collisions
  - Network layer: full IP packet buffers
- Excess packets are simply dropped
  - And the sender can simply retransmit



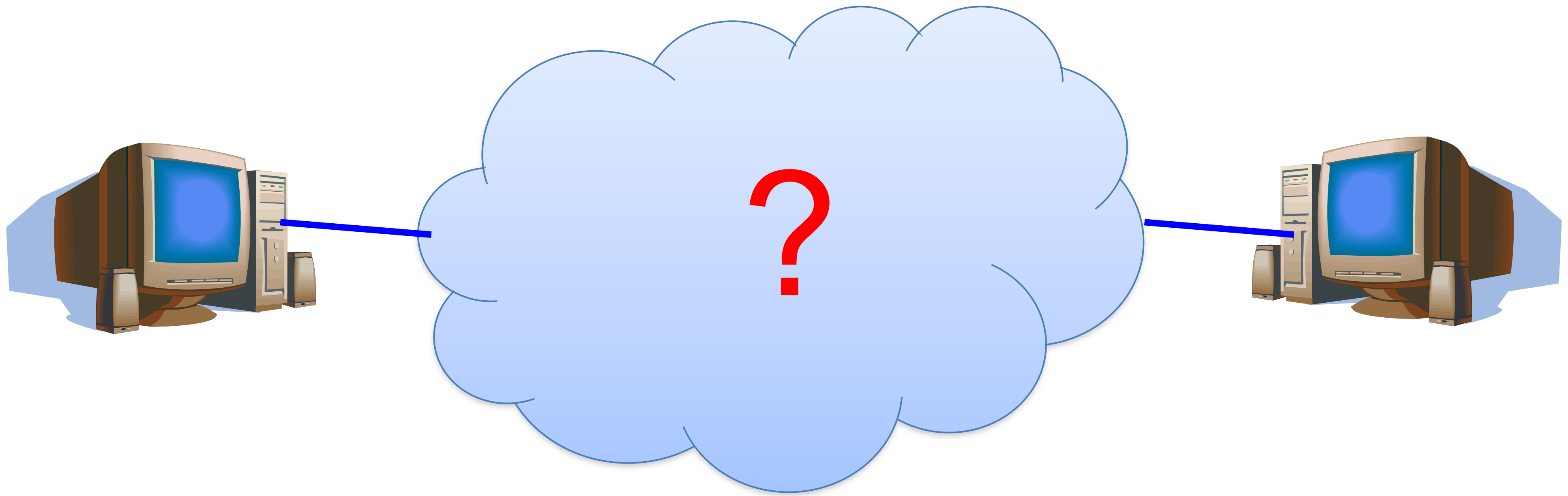
Congestion Collapse

- Easily leads to *congestion collapse*
  - Senders retransmit the lost packets
  - Leading to even *greater* load
  - … and even *more* packet loss



Increase in load that results in a decrease in useful work done.

Detect and Respond to Congestion



- What does the end host see?
- What can the end host change?

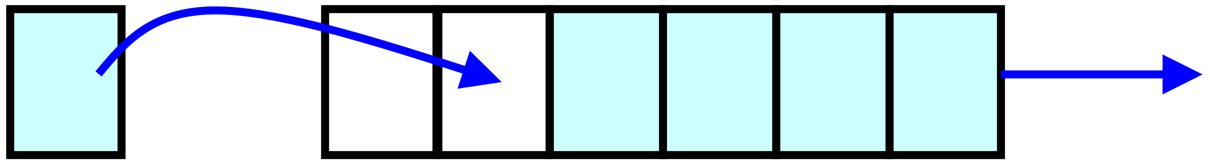
Detecting Congestion

- Network layer
  - Observing end-to-end performance
  - Packet delay or loss over the path

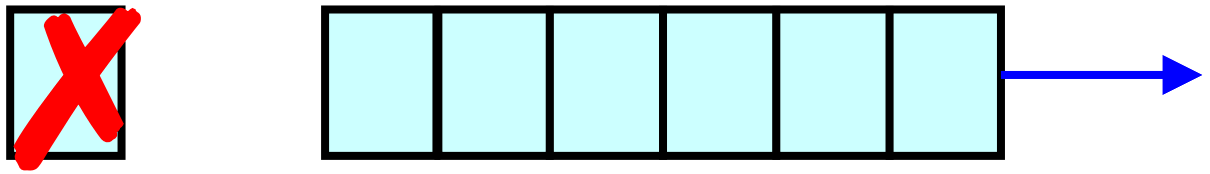
TCP Congestion Control

Congestion in a Drop-Tail FIFO Queue

- Access to the bandwidth: first-in first-out queue
  - Packets transmitted in the order they arrive



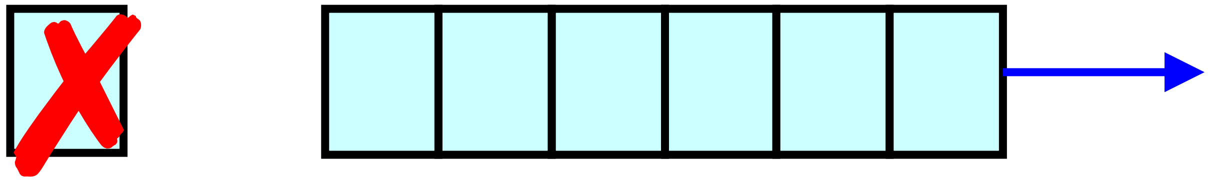
- Access to the buffer space: drop-tail queuing
  - – If the queue is full, drop the incoming packet



How it Looks to the End Host

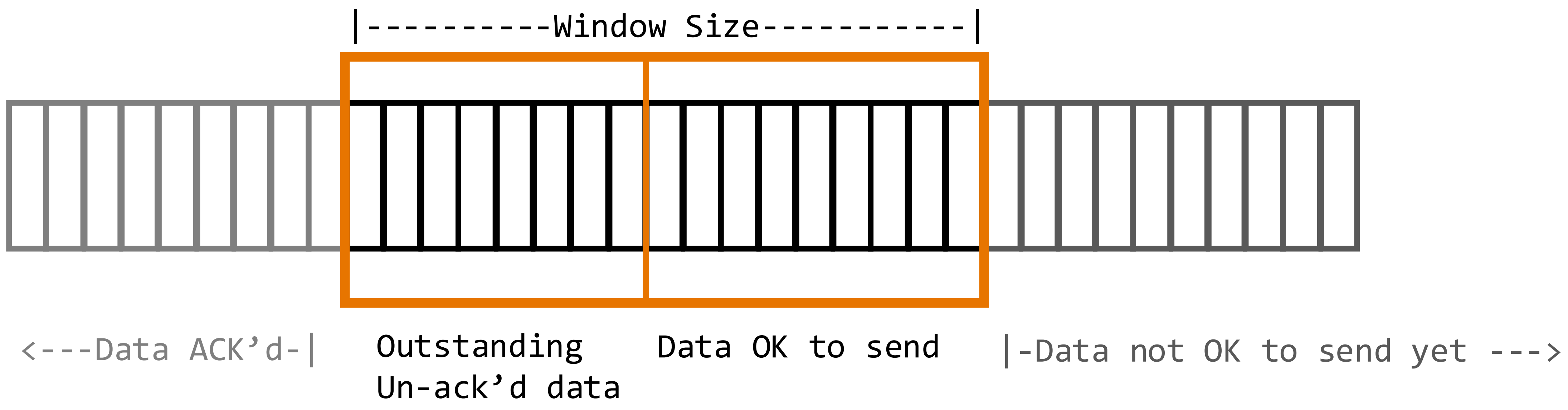
- Delay: Packet experiences high delay
- Loss: Packet gets dropped along path

- How does TCP sender learn this?
  - Delay: Round-trip time estimate
  - Loss: Timeout and/or duplicate acknowledgments



TCP Congestion Window

- Each TCP sender maintains a congestion window
  - Max number of bytes to have in transit (not yet ACK'd)


|----------Window Size-----------|
<---Data ACK'd-|
Outstanding
Un-ack'd data
Data OK to send
|-Data not OK to send yet --->

- Limits the sending rate of traffic

Receiver Window vs. Congestion Window

- Flow control
  - Keep a **fast sender** from overwhelming a **slow receiver**
- Congestion control
  - Keep a **set of senders** from overloading **the network**
- Different concepts, but similar mechanisms
  - TCP flow control: receiver window
  - TCP congestion control: congestion window
  - Sender TCP window = min { congestion window, receiver window }

TCP Sender Adjusts the Congestion Window

- Packet loss (fail!)
  - Suspect an overutilized network (congestion)
  - Pessimistically decrease the congestion window

- Packet delivery (succeed!)
  - Suspect an underutilized network
  - Optimistically increase the sending rate

- Always struggling to find the right rate
  - Pro: avoids the need for explicit feedback
  - Con: continually under-shooting and over-shooting

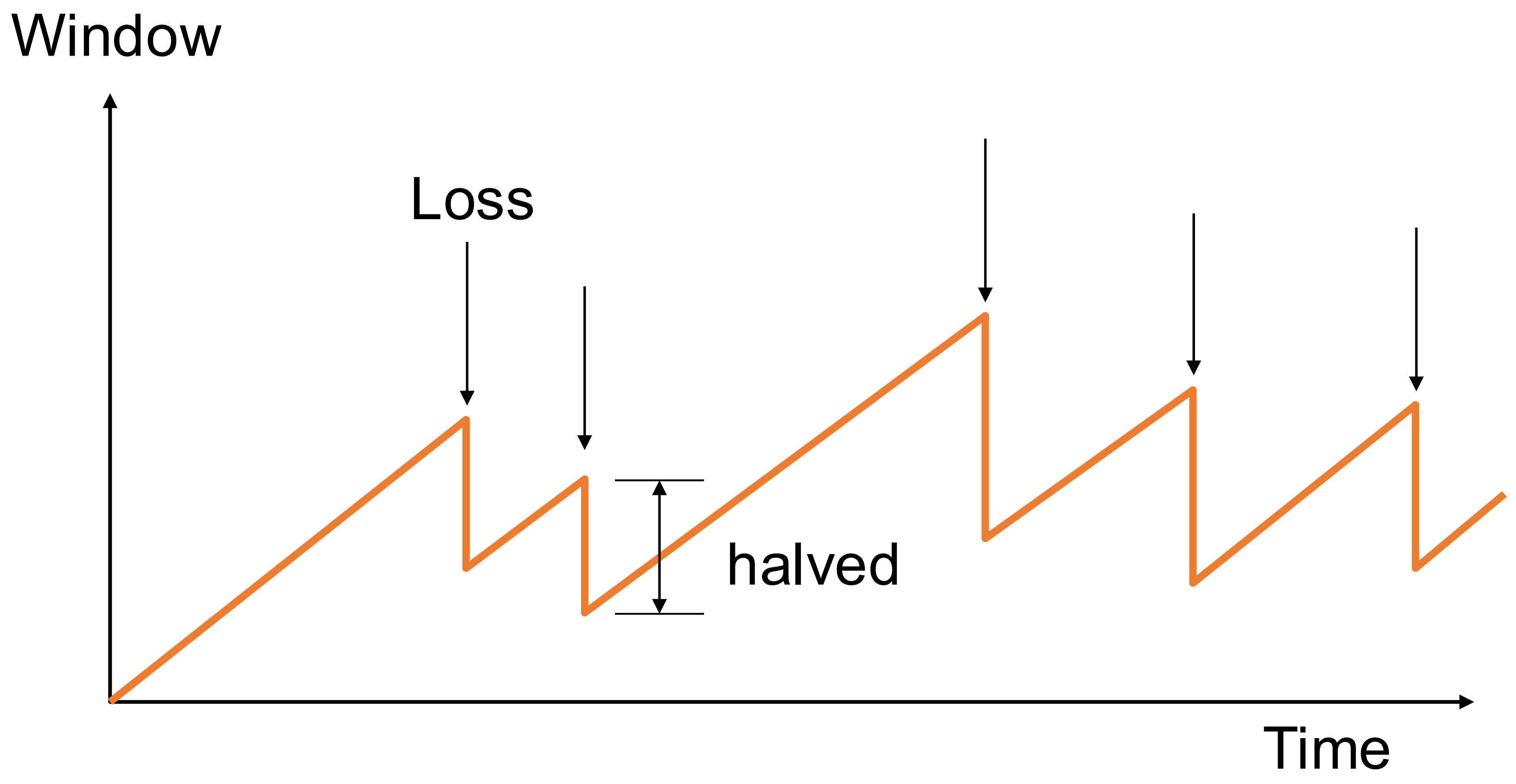
How Much Should the Sender Adapt?

- Additive increase (AI)
  - Cautious to avoid triggering congestion
  - On success of last window of data, increase congestion window by 1 packet

- Multiplicative decrease (MD)
  - Aggressive to respond quickly to congestion
  - On the loss of packet, divide congestion window in half

- Much quicker to slow down than speed up?
  - Over-sized windows (causing loss) are much worse than under-sized windows (causing lower throughput)

Leads to the TCP “Sawtooth”



Sources of Poor TCP Performance

- The below conditions *may* primarily result in:

(A) Higher packet latency (B) Greater loss (C) Lower throughput

1. Larger buffers in routers
2. Smaller buffers in routers
3. Smaller buffers on end-hosts
4. Slow application receivers

TCP seeks “Fairness”

Fair and Efficient Use of a Resource

- Suppose 3 users share the bandwidth on a single link
  - E.g., link has total of 30 Gbps
- What is a fair allocation of bandwidth?
  - Suppose user demand is unlimited
  - Allocate each a 1/n share (e.g., 10 Gbps each)
- But, “equality” is not enough
  - Which allocation is best: [5, 5, 5] or [18, 6, 6]?
  - [5, 5, 5] is more “fair”, but [18, 6, 6] more efficient
  - What about [5, 5, 5] vs. [22, 4, 4]?

Fair Use of a Single Resource

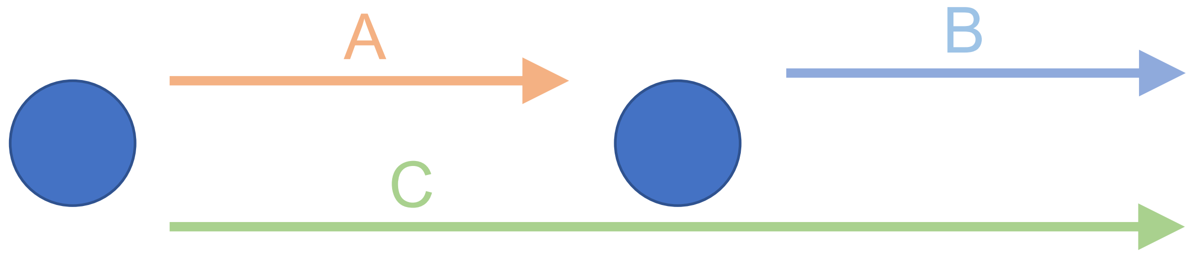
- What if some users have limited demand?
  - E.g., 3 users where 1 user only wants 6 Gbps
  - And the total link capacity is 30 Gbps
- Should we still do an “equal” allocation?
  - E.g., [6, 6, 6]
  - But that leaves 12 Gbps unused
- Should we allocate in proportion to demand?
  - E.g., 1 user wants 6 Gbps, and 2 each want 20 Gbps
  - Allocate [4, 13, 13]?
- Or, give the least demanding user all they want?
  - E.g., allocate [6, 12, 12]?

Potential Goal: Max-Min Fairness

- The allocation must be "feasible"
  - Total allocation should not exceed link capacity
- Can't be any better for the 'min'
  - Any attempt to increase the allocation of one user
  - ... necessarily decreases for another user with equal or lower allocation

- Benefit: Fully utilize a "bottlenecked" resource
  - If demand exceeds capacity, the link is fully used
- How: Progressive filling algorithm
  - Grow all rates until some users stop having demand
  - Continue increasing all remaining rates until link is full

Resource Allocation Over Paths

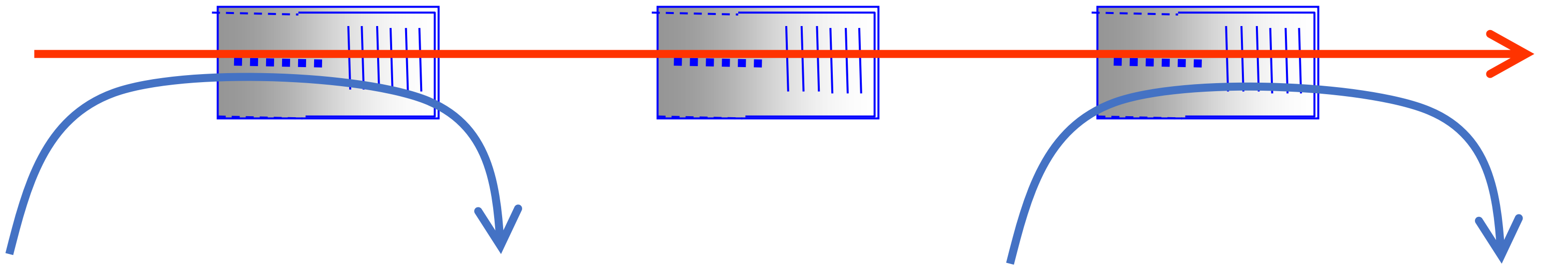


Three users A, B, and C
Two 30 Gbps links

- Maximum throughput: [30, 30, 0]
  - Total throughput of 60, but user C starves
- Max-min fairness: [15, 15, 15]
  - Equal allocation, but throughput of just 45
- Proportional fairness: [20, 20, 10]
  - Balance trade-off between throughput and equality
  - Throughput of 50, and penalize C for using 2 busy links

TCP Achieves a Notion of Fairness

- Effective utilization is not only goal
  - We also want to be *fair* to various flows
- Simple definition: equal bandwidth shares
  - N flows that each get 1/N of the bandwidth?
- But, what if flows traverse different paths?
  - Result: bandwidth shared in proportion to RTT



Conclusions

- Congestion is inevitable
  - Internet does not reserve resources in advance
  - TCP actively tries to push the envelope

- Congestion can be handled
  - TCP sender limits traffic to a congestion window
  - Additive increase, multiplicative decrease

- Fairness
  - TCP congestion control is a distributed algorithm that achieves “fairness”
  - ... well, as long as TCP end-points don’t cheat!