Principles of congestion control

Computer Networking: A Top Down Approach
6th edition
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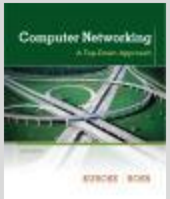
Addison-Wesley



Chapter 3 outline

3.1 Transport-layer services

3.2 Multiplexing and demultiplexing

3.3 Connectionless transport: UDP

3.4 Principles of reliable data transfer

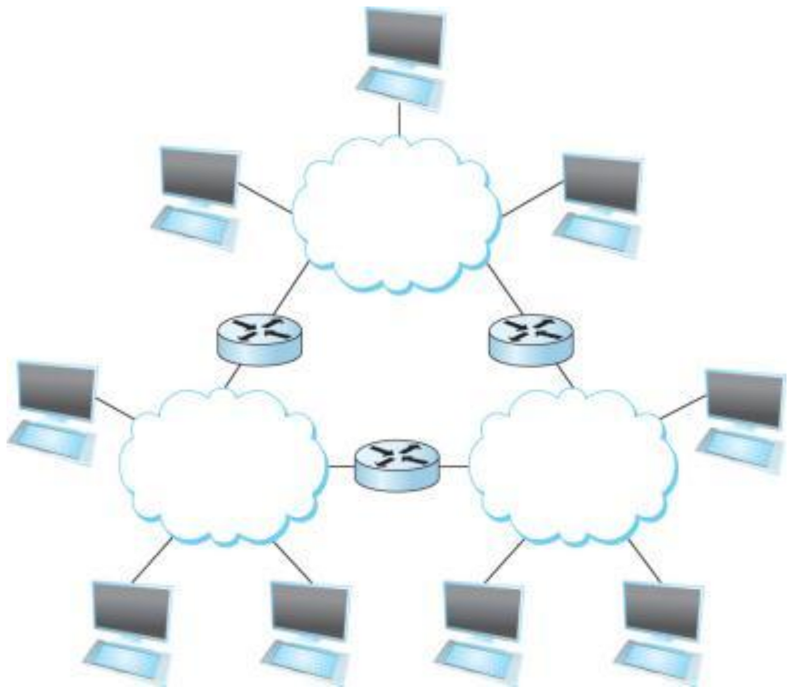
3.5 Connection-oriented transport: TCP
- Segment structure
- Reliable data transfer
- Flow control
- Connection management

3.6 Principles of congestion control

3.7 TCP congestion control

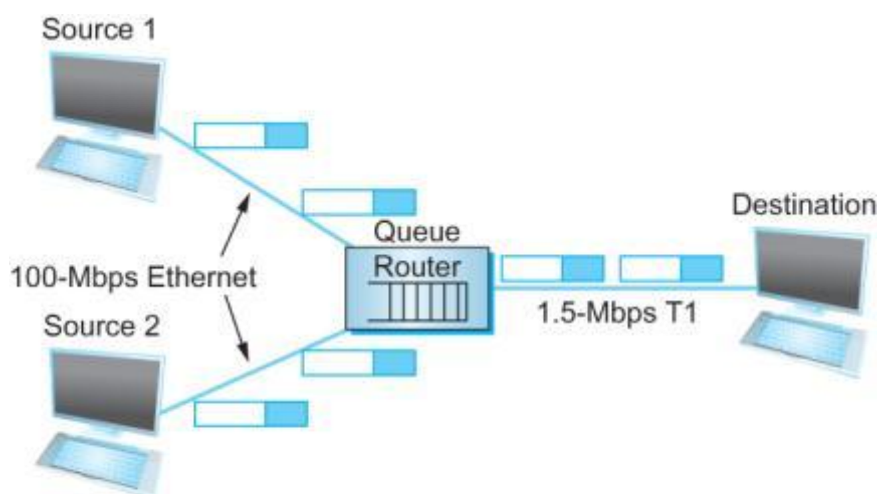
IP best-effort network

- Best-effort model
  - Everybody can send
  - Network does the best it can to deliver
  - Delivery not guaranteed, some traffic may be dropped



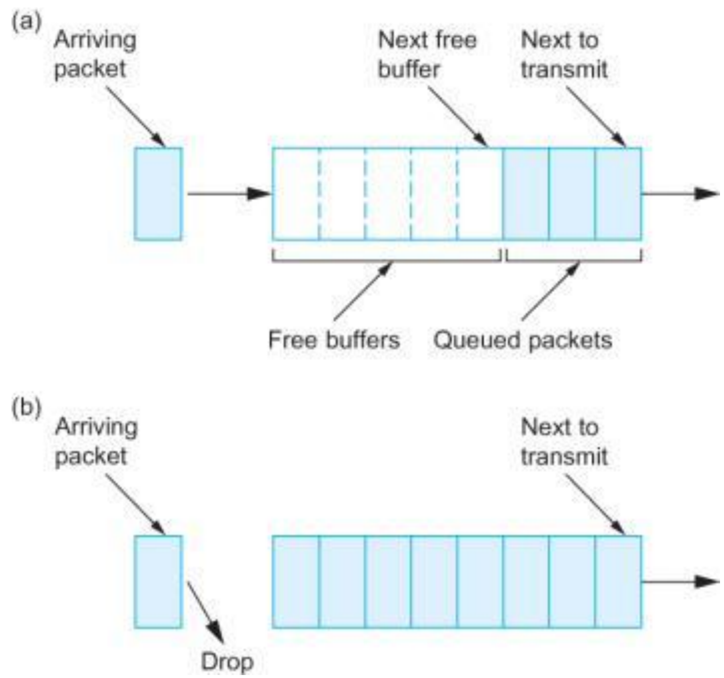
Congestion unavoidable

- Multiple packets arrive at same time
  - Router can only transmit one
  - Router has to buffer remaining
- If too many arrive in a short time window
  - Buffer may overflow
  - Router has to choose some packets to drop



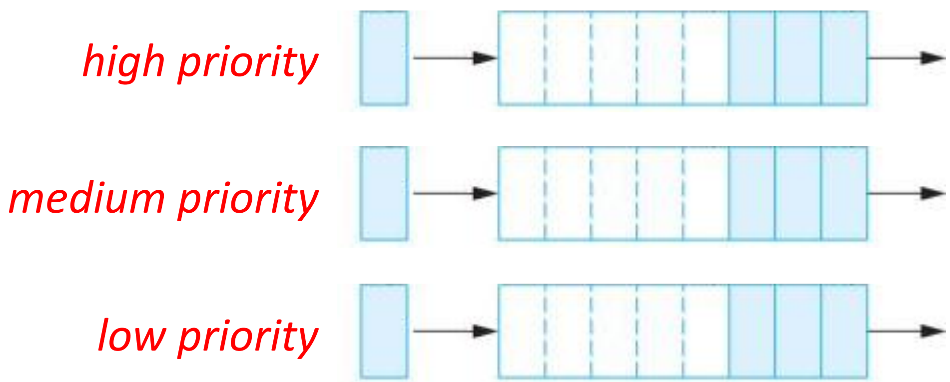
What routers do

- Too many packets arrive too quickly
  - Which packets should we drop?
- First-in first-out (FIFO) with tail drop
  - Simple, drop the new guy that doesn't fit in your buffer



Queuing disciplines

- Priority queuing
  - Packets marked with priority in header
  - Multiple FIFO queues, one for each priority class
  - Transmit high priority queues first
  - Who is allowed to set priority bit?



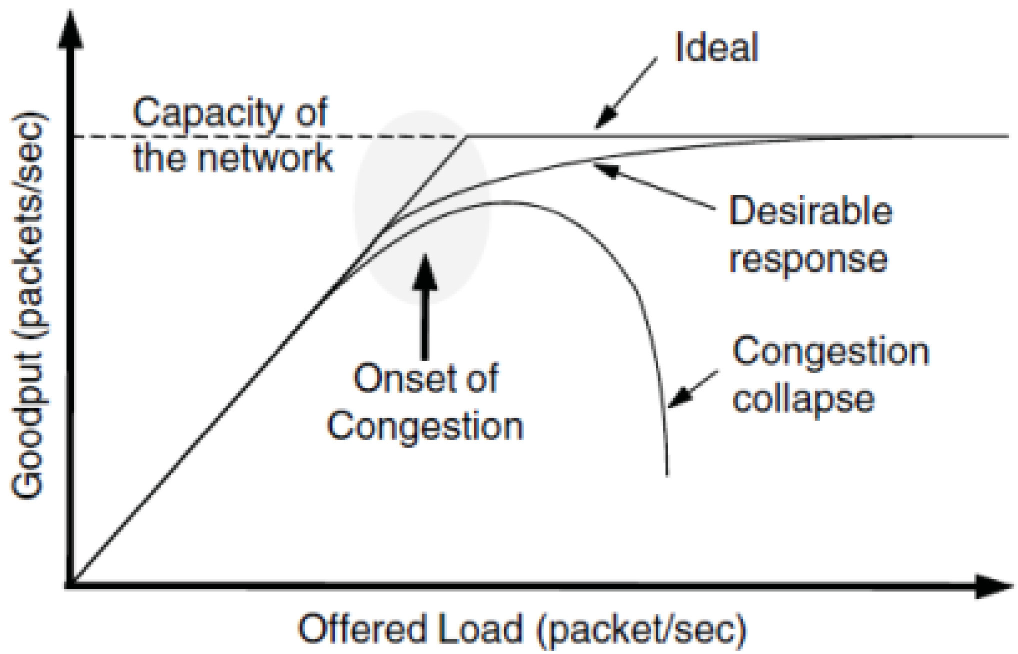
Principles of congestion control

Congestion:

- Informally: "too many sources sending too much data too fast for *network* to handle"
- Different from flow control!
- Manifestations:
  - Lost packets (buffer overflow at routers)
  - Long delays (queueing in router buffers)
- A top-10 problem!

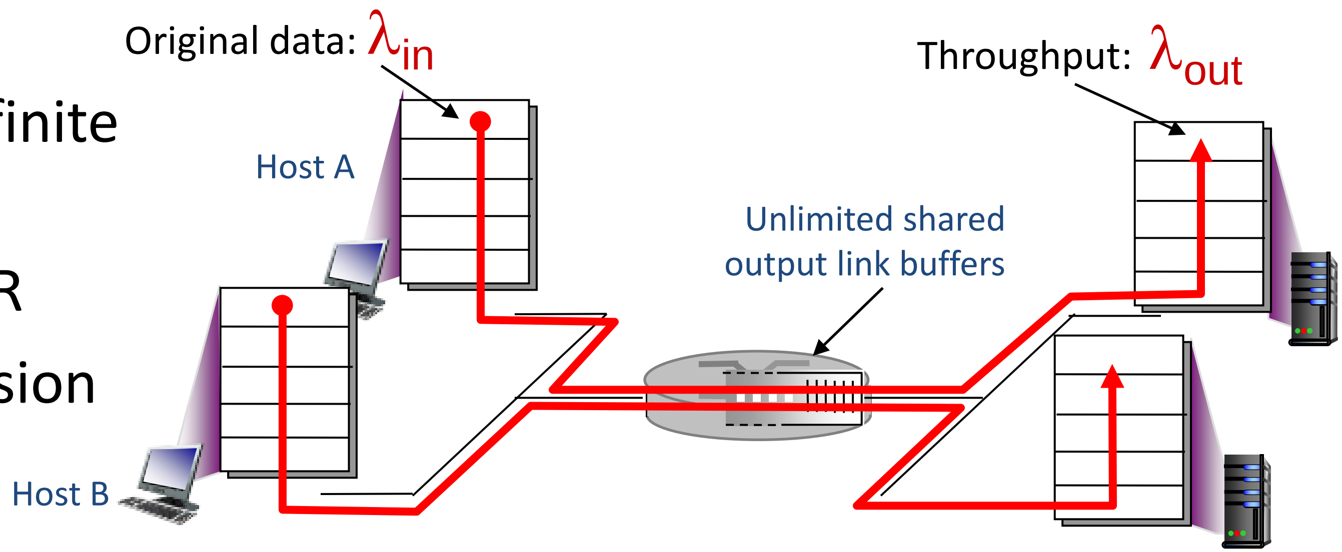
Congestion collapse

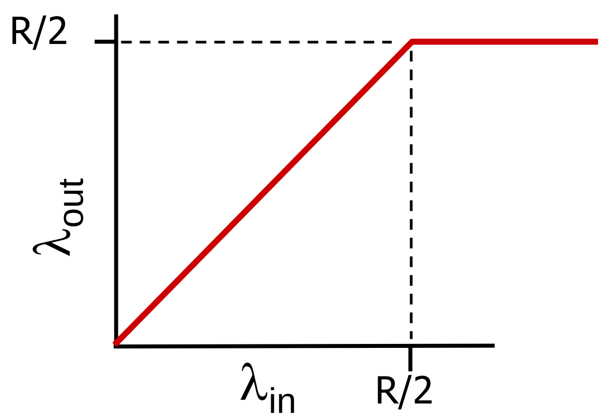
- Congestion collapse
  - 1986, NSF backbone dropped from 32 kbps to 40 bps
    - Hosts send packets as fast as advertised window allowed
    - When packets dropped, hosts retransmit causing more congestion
  - Goodput = useful bits delivered per unit time
    - Excludes header overhead, retransmissions, etc.

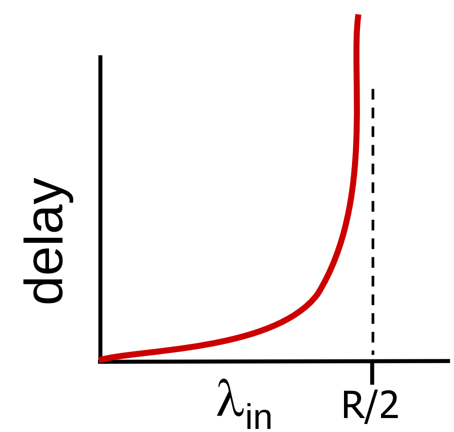


Causes/costs of congestion: scenario 1

- Two senders, two receivers
- One router, infinite buffers
- Link capacity: R
- No retransmission



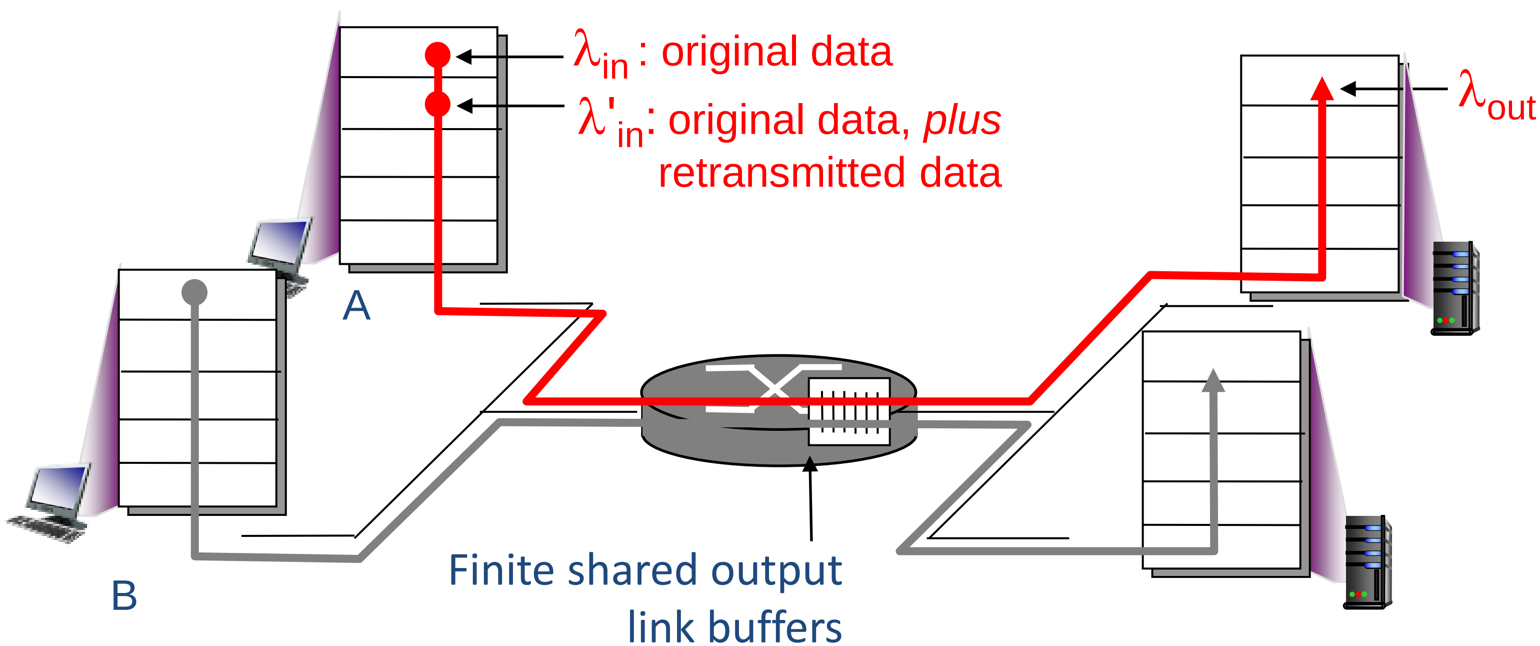




- Maximum per-connection throughput: R/2
- Large delays as arrival rate, λ_{in}, approaches capacity

Causes/costs of congestion: scenario 2

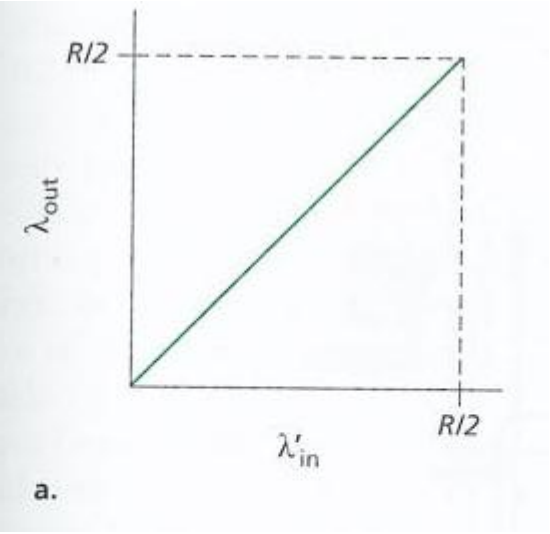
- One router, *finite* buffers, reliable connection
- Sender retransmission of timed-out packet
  - Application-layer input = application-layer output: $\lambda_{in} = \lambda_{out}$
  - Transport-layer input includes *retransmissions* : $\lambda'_{in} \geq \lambda_{in}$
  - λ'_{in} = *offered load*

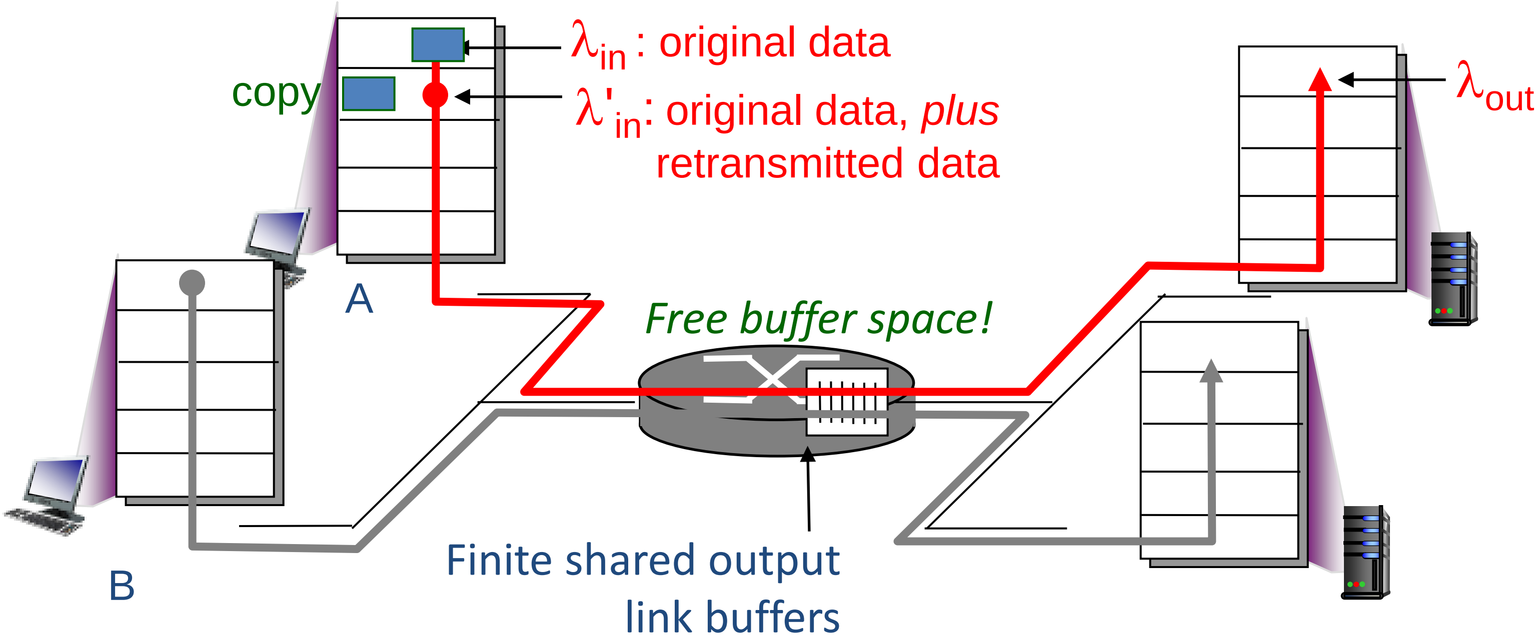


Congestion scenario 2a: ideal case

Idealization: ***perfect knowledge***

- Sender magically sends only when router buffers available
- No loss, $\lambda'_{in} = \lambda_{in}$
- Hosts won't send faster than R/2

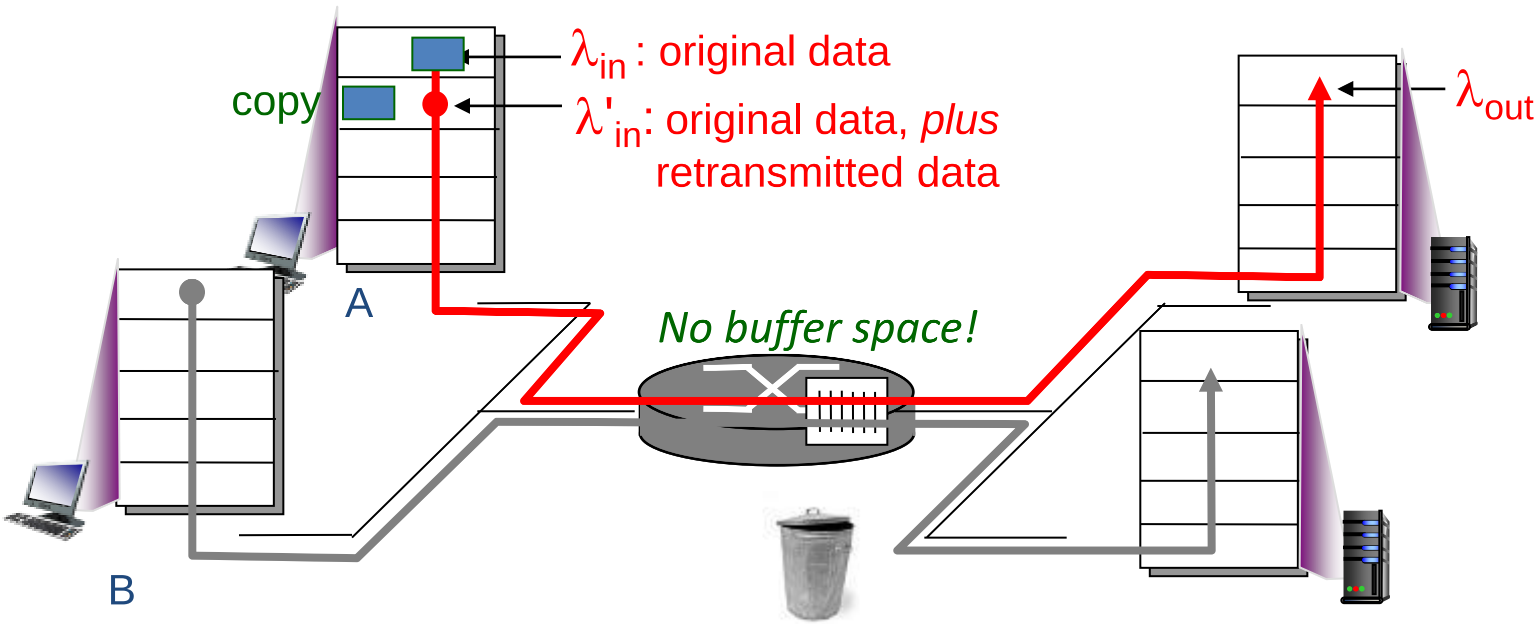




Congestion scenario 2b: known loss

Idealization: *known loss*

- Packets can be lost, dropped at router due to full buffers
- Sender only resends if packet *known* to be lost



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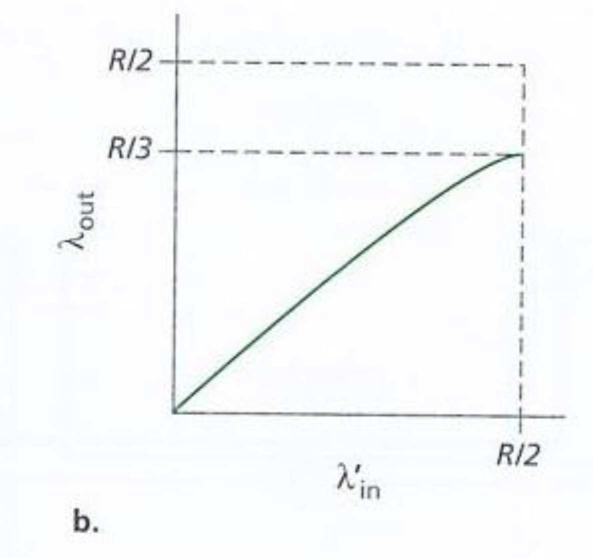
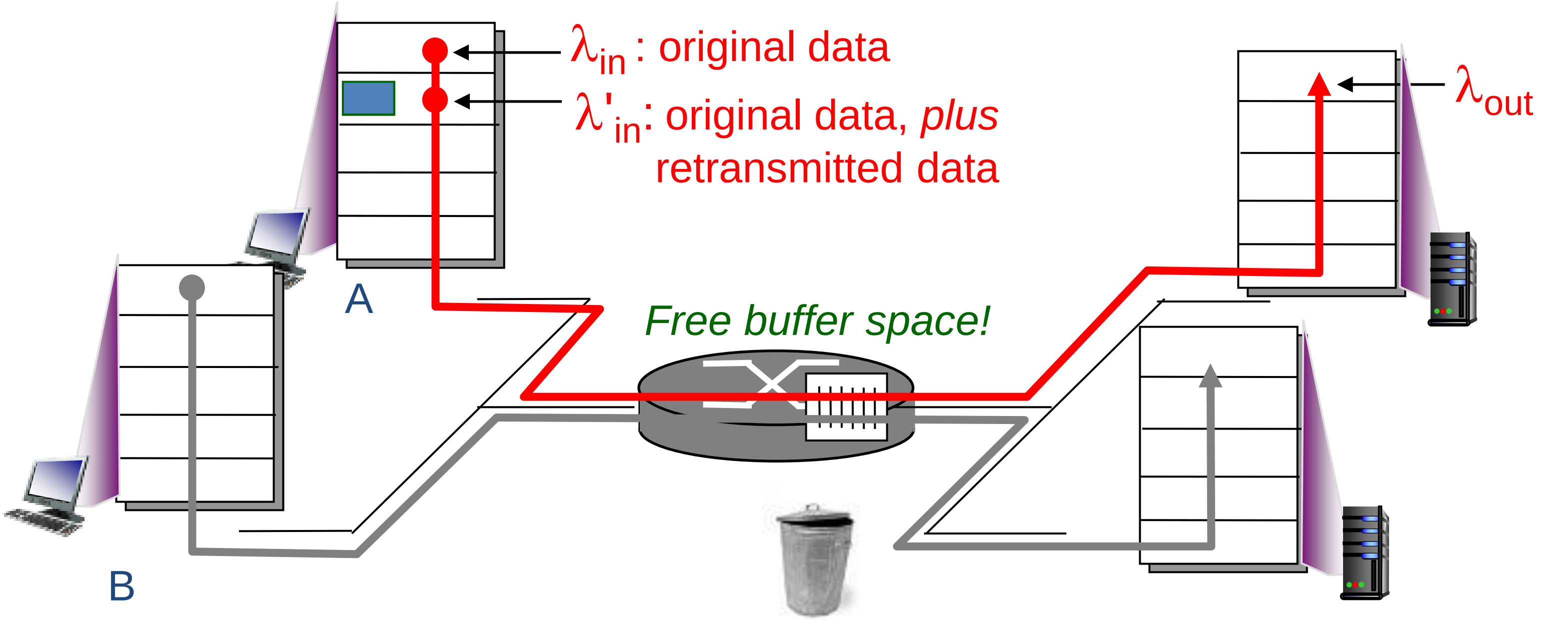
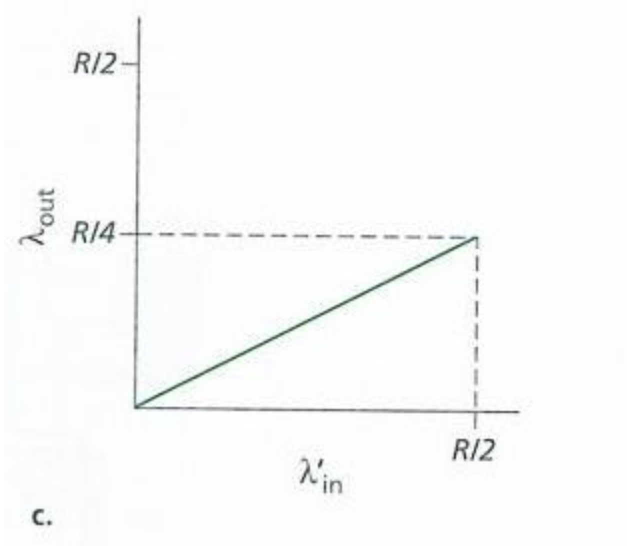


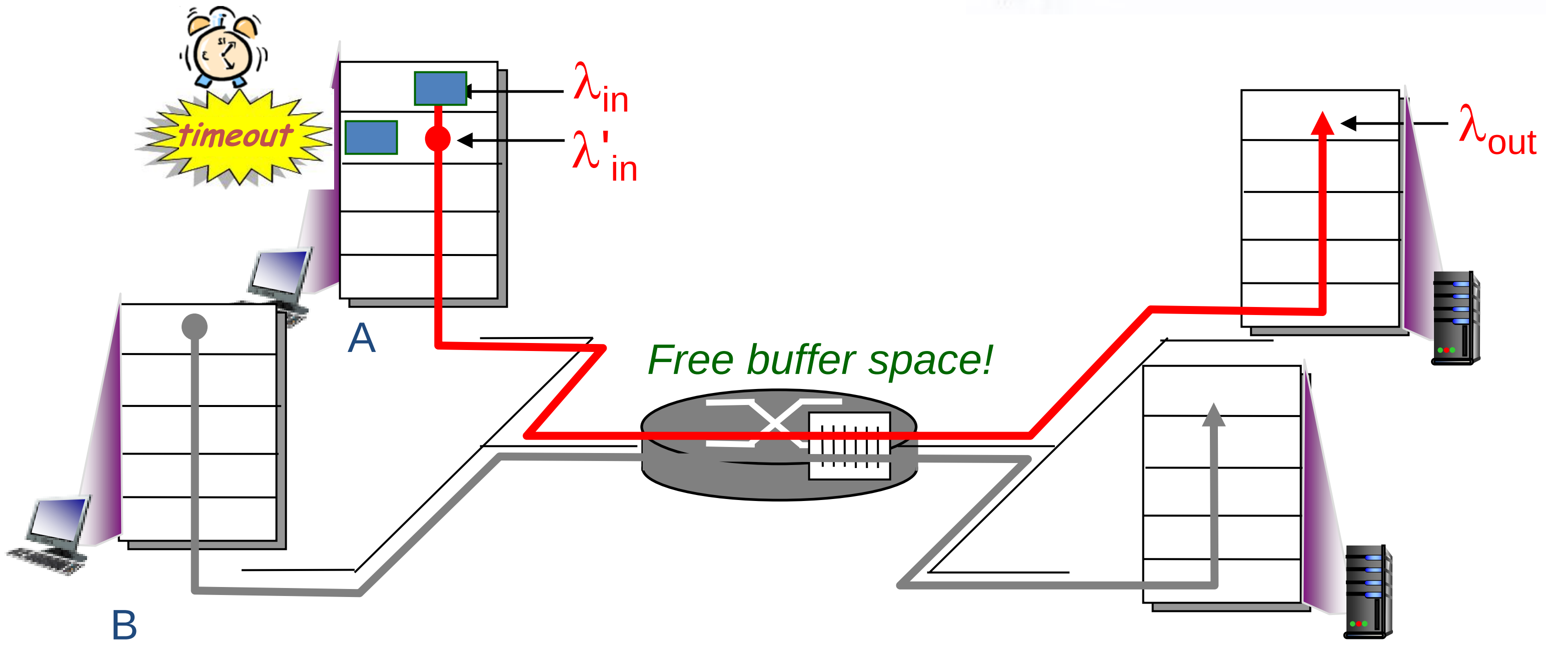


Congestion scenario 2c: duplicates



Realistic: *duplicates*

- Packets can be lost, dropped at router due to full buffers
- Sender times out prematurely, sending *two* copies, both of which are delivered



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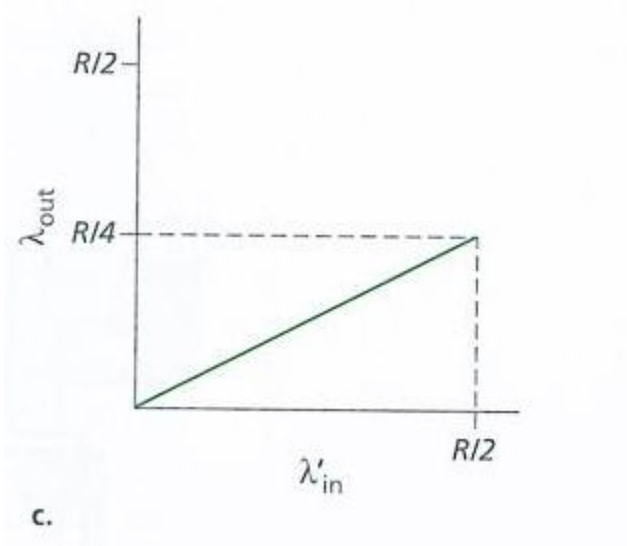


Costs of congestion:

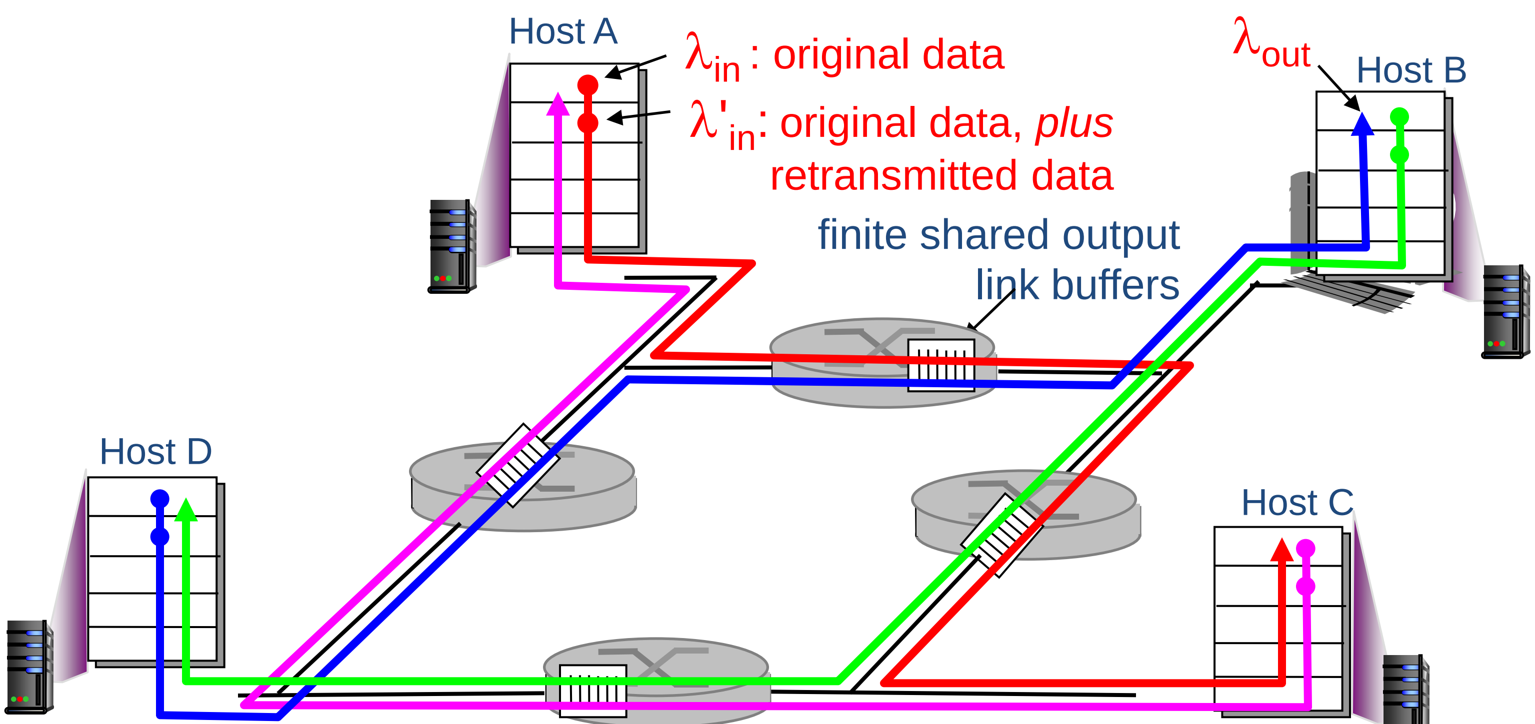
- More work (retransmissions) for given goodput
- Unneeded retransmissions
  - Link carries multiple copies of packet
  - Decreases goodput

Causes/costs of congestion: scenario 3

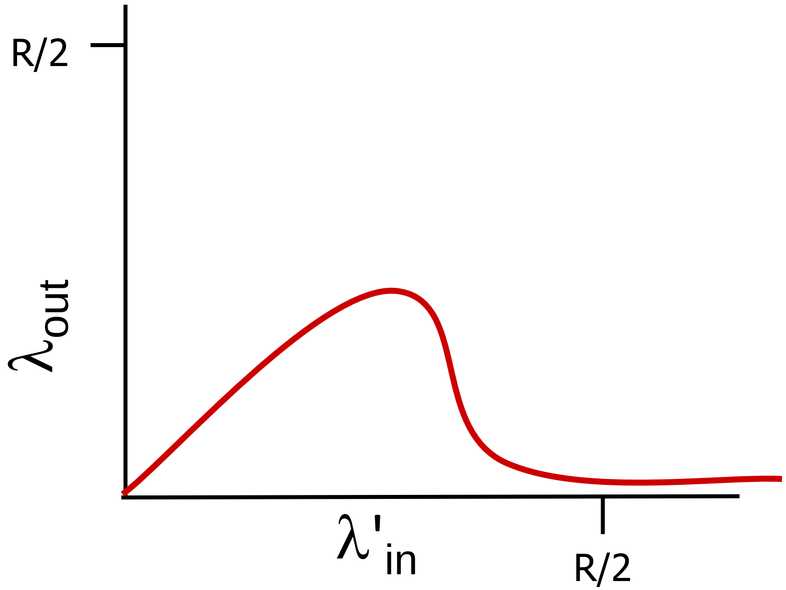
- Four senders
- Multihop paths
- Timeout/retransmit

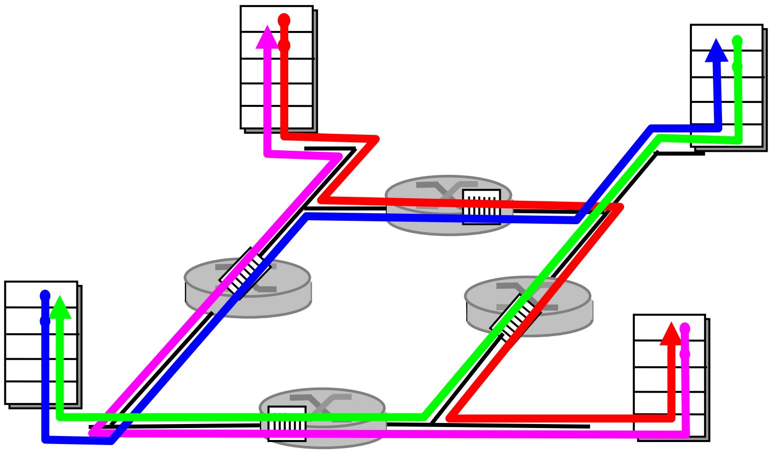
Q: What happens as λ_{in} and λ'_{in} increase?

A: As red λ'_{in} increases, all arriving blue pkts at upper queue are dropped, blue throughput → 0



Causes/costs of congestion: scenario 3





Another cost of congestion:

- When packet dropped, any upstream transmission capacity used for that packet was wasted!

Approaches to congestion control

Two broad approaches towards congestion control:

End-end:

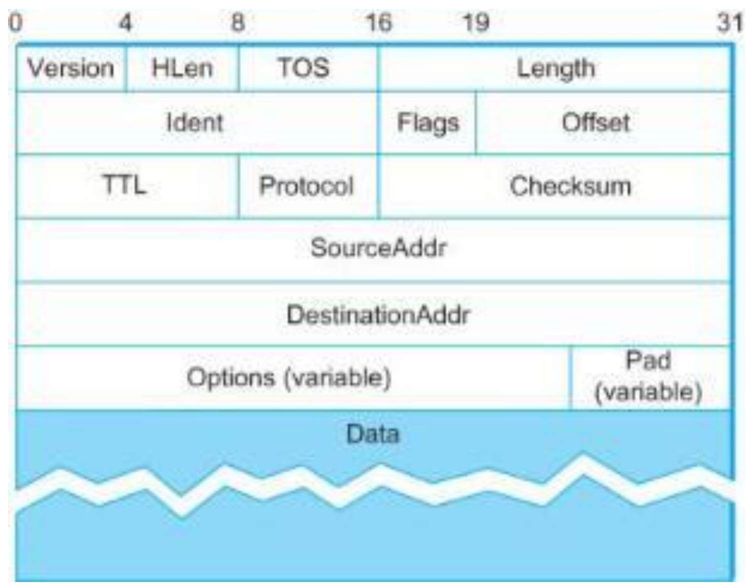
- No explicit feedback from network
- Congestion inferred from end-system observed loss, delay
- Approach taken by TCP

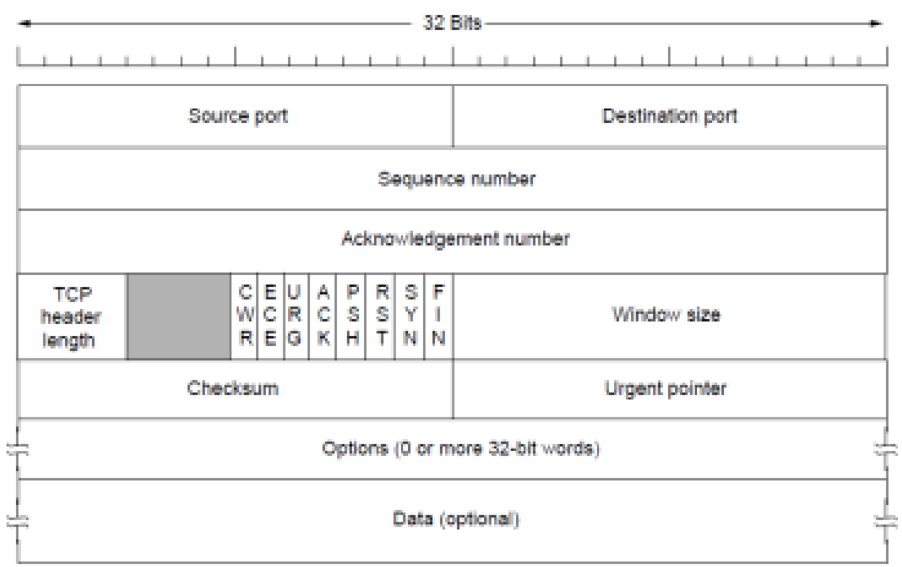
Network-assisted:

- Routers provide feedback to end systems
  - Single bit indicating congestion (SNA, DECbit, TCP/IP ECN, ATM)
  - Explicit rate for sender to send at

Router signaling

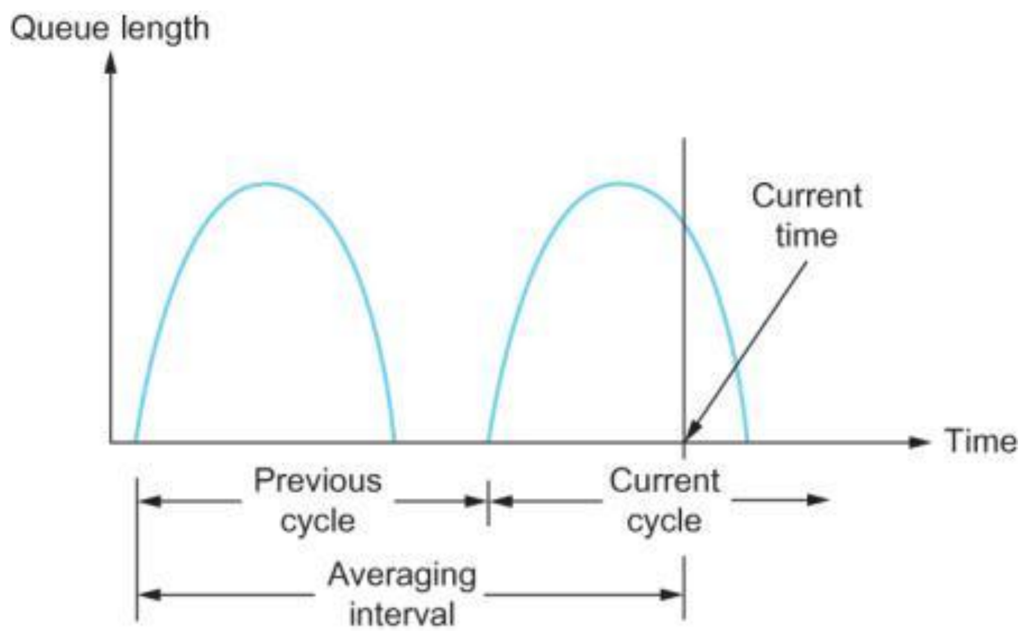
- Explicit Congestion Notification (ECN)
  - Sender sets TOS IP header bit saying it supports ECN
  - If ECN-aware router is congested, marks another TOS bit
  - TCP receiver sees IP congestion bit, informs sender via TCP segment ECN-Echo (ECE) bit
  - TCP sender confirms receipt of ECE with Congestion Window Reduced (CWR) bit





Router signaling

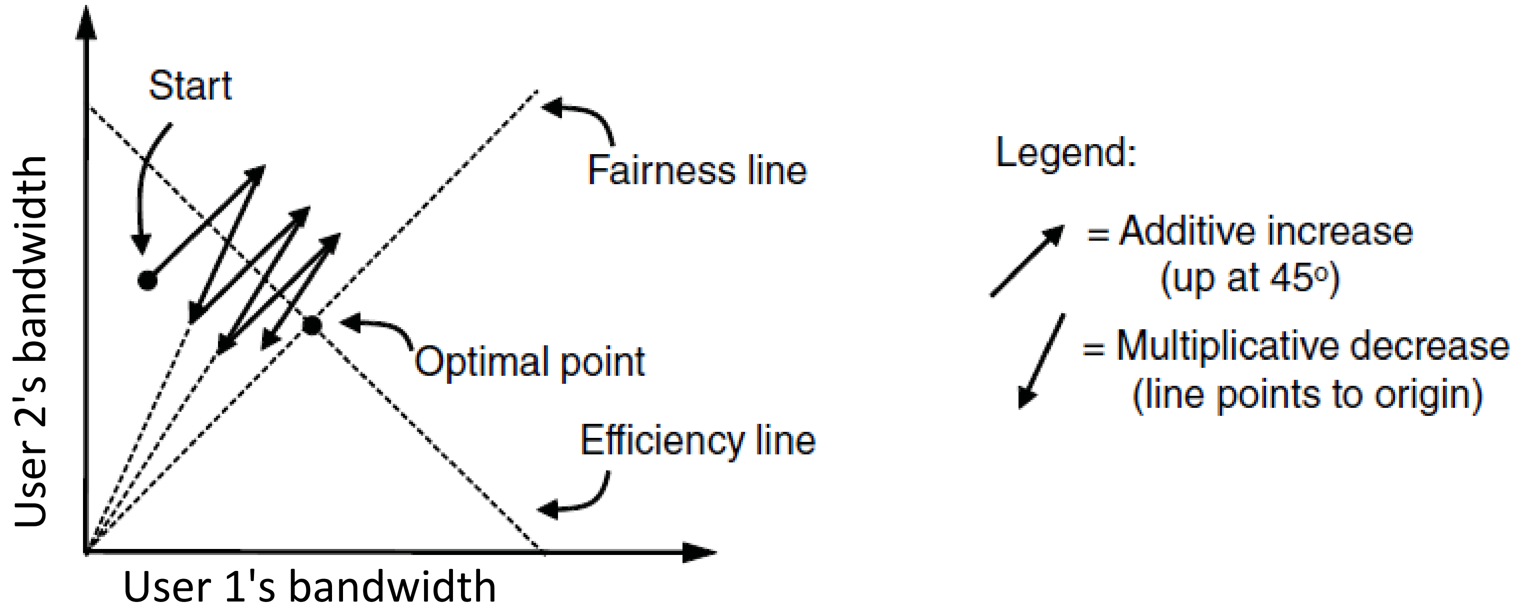
- How does router determine congestion?
  - Checks avg. queue length spanning last busy + idle cycle



- What does TCP sender do with congestion signals?
  - Checks fraction of last window's worth of packets
  - If < 50%, increase congestion window
  - If > 50%, decrease congestion window by 0.875

AIMD principle

- Additive increase, multiplicative decrease (AIMD)
  - Additive increase: On success of last packet, increase number of packets in-flight by one
  - Multiplicative decrease: On loss of packet, divide number of allowed in-flight packets in half



Summary

- Principles of congestion control
  - Too many senders can lead to congestion collapse
    - Links between routers have limited bandwidth
    - Router queues are finite
    - Traffic patterns are unpredictable
  - Goodput = useful bits delivered per unit time
  - Broad approaches
    - End-to-end, no information from routers
    - Network assisted, routers warn when congestion occurring (or about to)
  - AIMD principle
    - Two competing senders achieve efficiency & fairness