

Chapter 3

Transport Layer

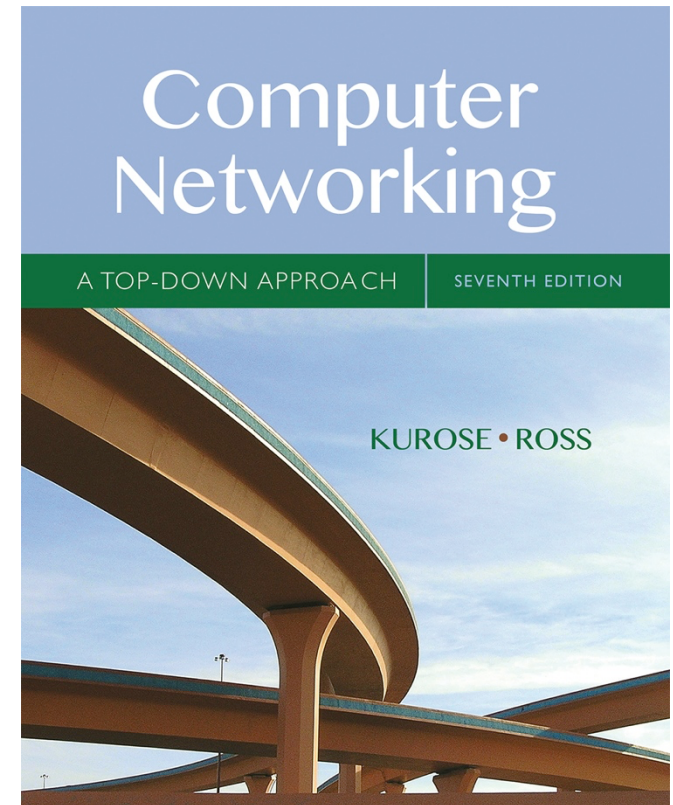
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Computer Networking: A Top Down Approach

7th edition

Jim Kurose, Keith Ross

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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

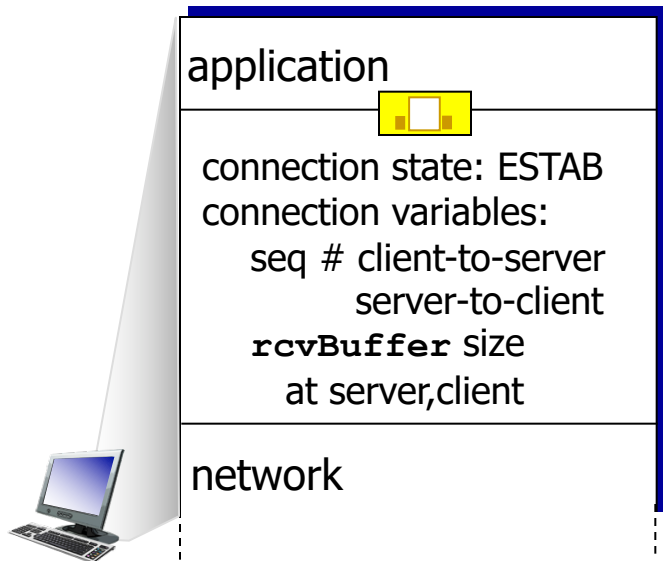
3.6 principles of congestion control

3.7 TCP congestion control

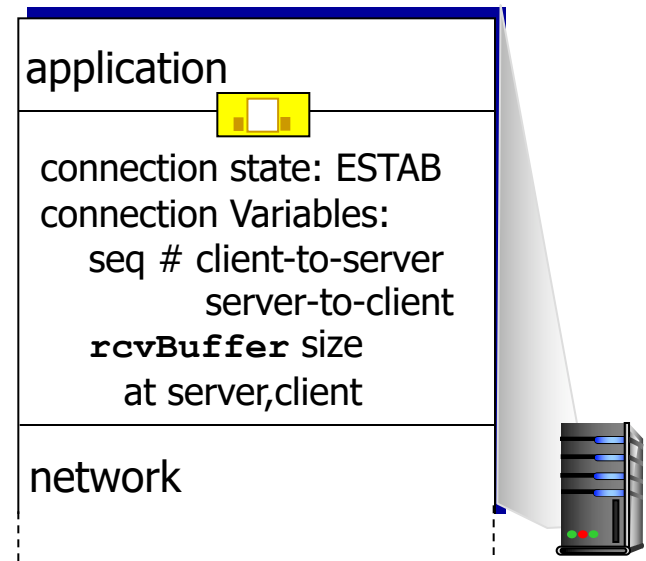
Connection Management

before exchanging data, sender/receiver “handshake”:

- agree to establish connection (each knowing the other willing to establish connection)
- agree on connection parameters



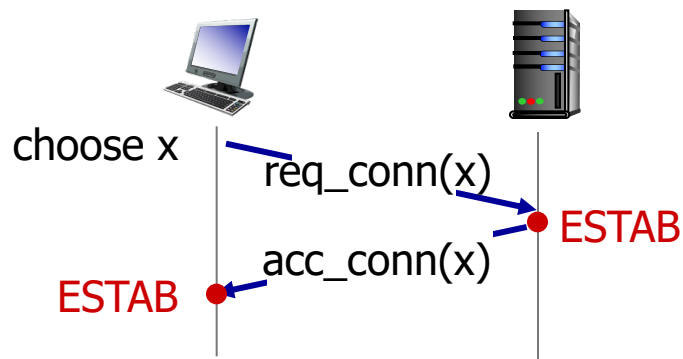
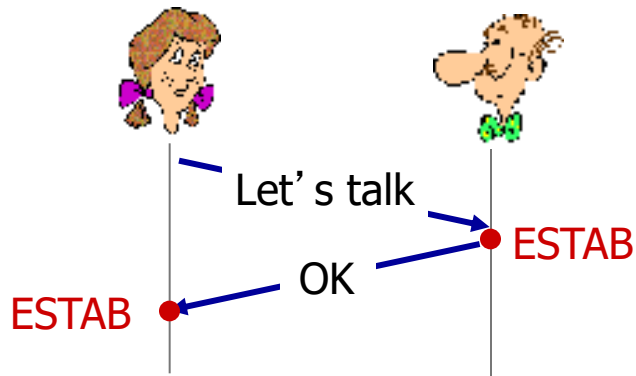
```
Socket clientSocket =  
    newSocket("hostname", "port  
    number");
```



```
Socket connectionSocket =  
    welcomeSocket.accept();
```

Agreeing to establish a connection

2-way handshake:

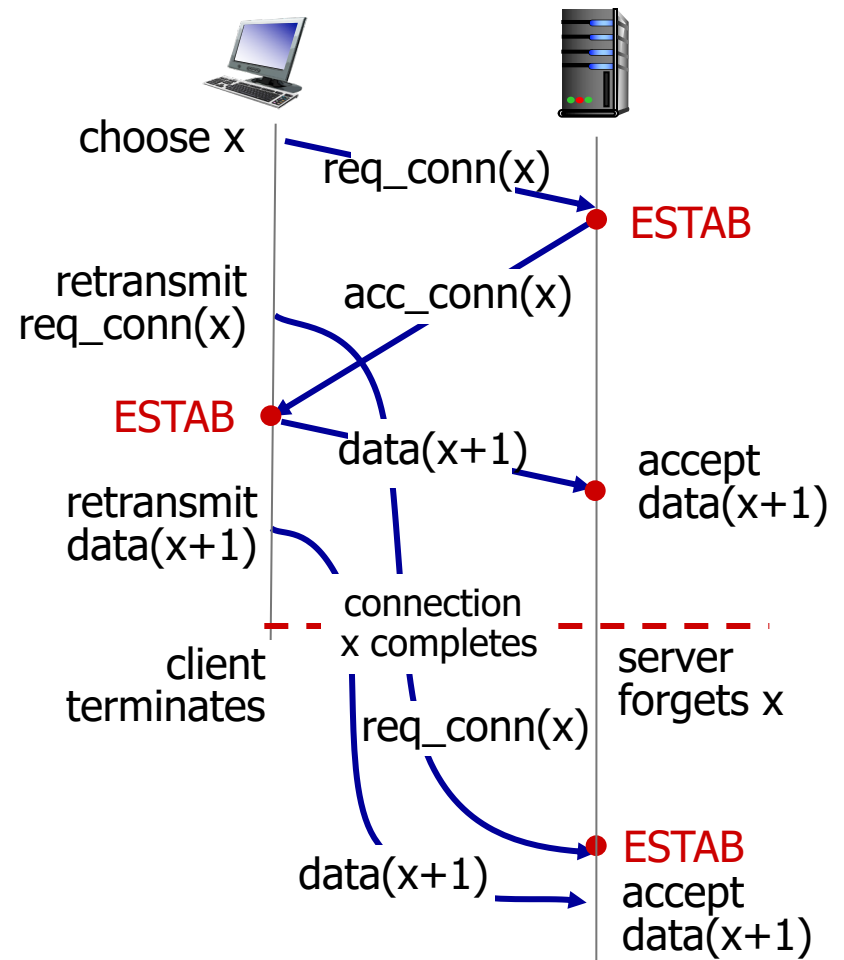
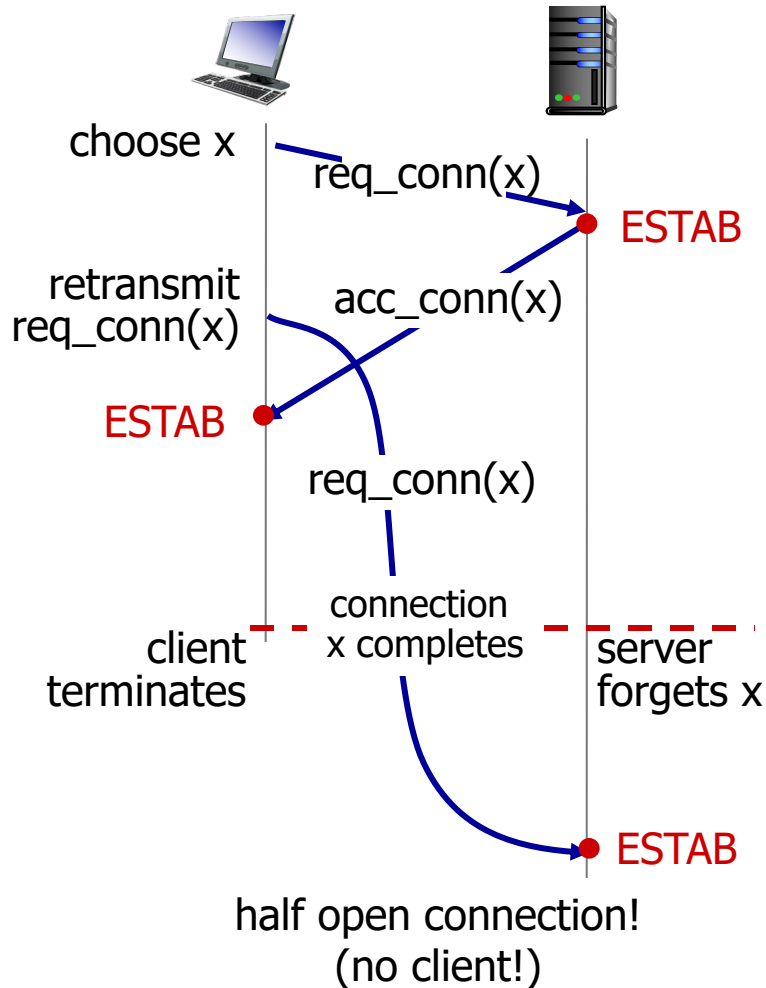


Q: will 2-way handshake always work in network?

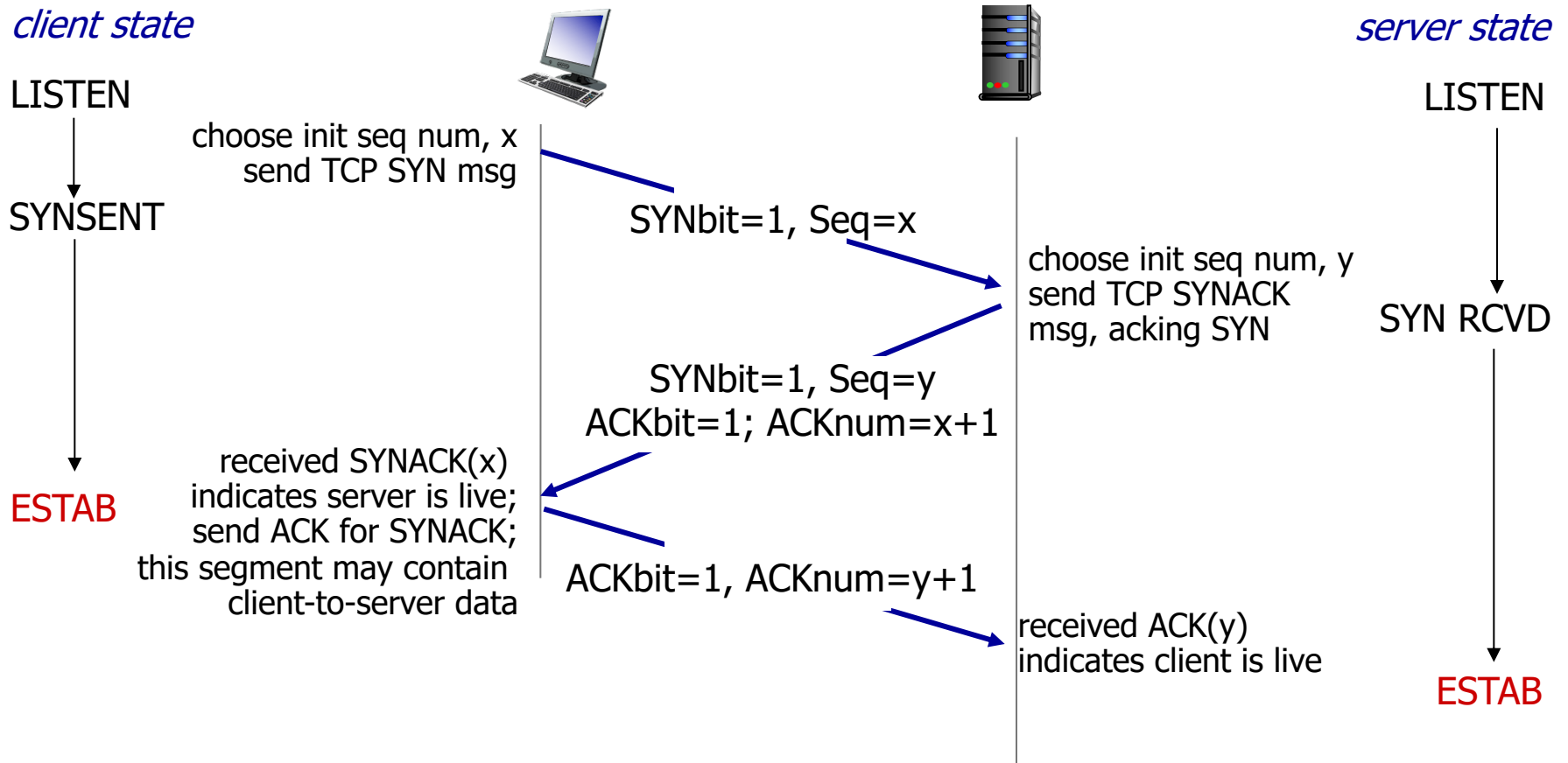
- variable delays
- retransmitted messages (e.g. req_conn(x)) due to message loss
- message reordering
- can't "see" other side

Agreeing to establish a connection

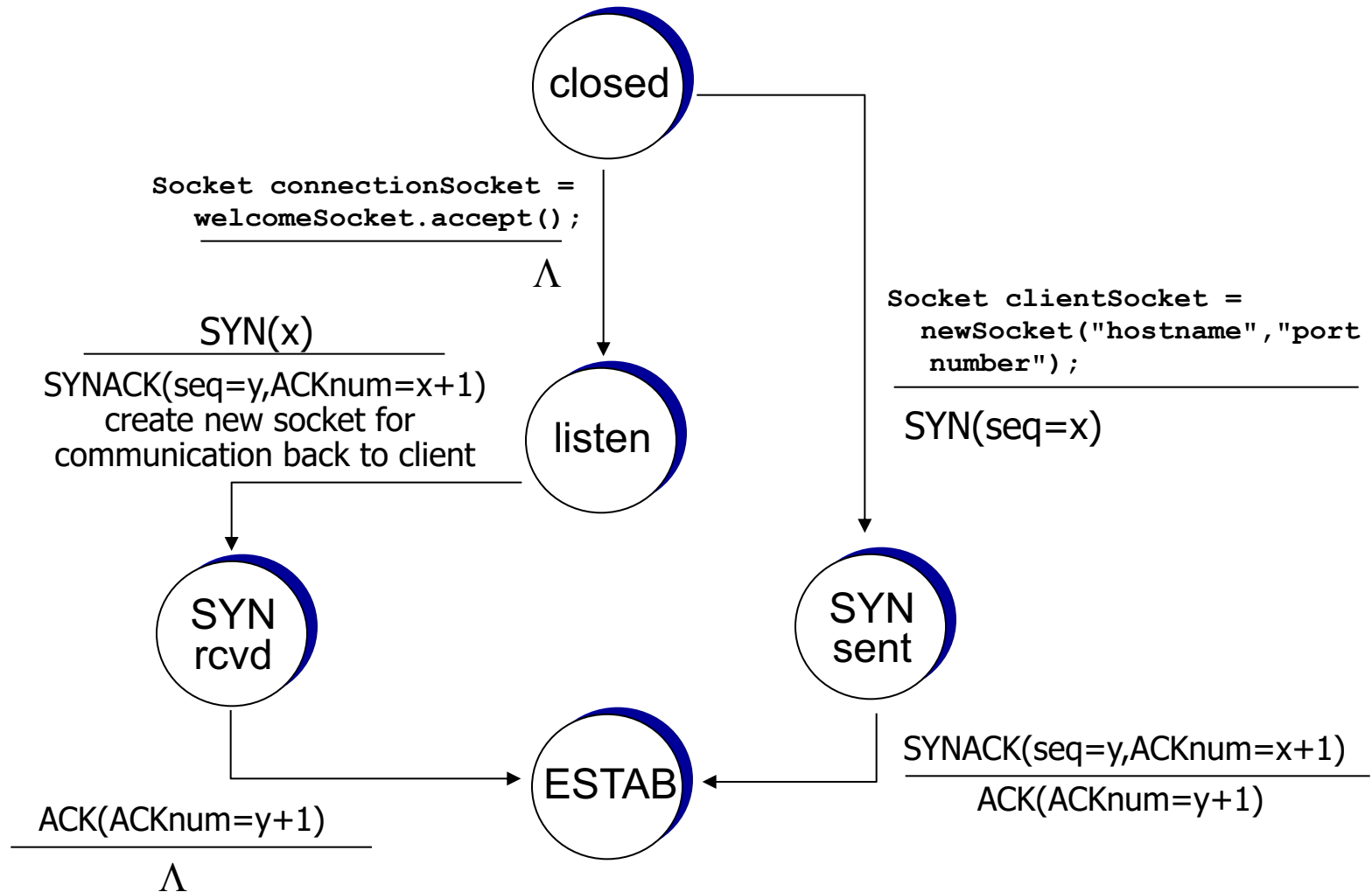
2-way handshake failure scenarios:



TCP 3-way handshake



TCP 3-way handshake: FSM



TCP: closing a connection

- client, server each close their side of connection
 - send TCP segment with FIN bit = 1
- respond to received FIN with ACK
 - on receiving FIN, ACK can be combined with own FIN
- simultaneous FIN exchanges can be handled

TCP: closing a connection

client state

ESTAB

`clientSocket.close()`

FIN_WAIT_1

can no longer
send but can
receive data

FIN_WAIT_2

wait for server
close

TIMED_WAIT

timed wait
for $2 * \text{max}$
segment lifetime

CLOSED



FINbit=1, seq=x

ACKbit=1; ACKnum=x+1

FINbit=1, seq=y

ACKbit=1; ACKnum=y+1

can still
send data

can no longer
send data

server state

ESTAB

CLOSE_WAIT

LAST_ACK

CLOSED

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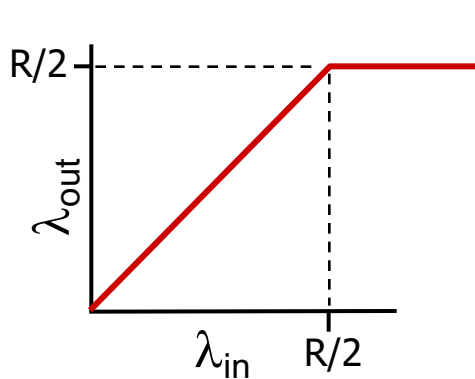
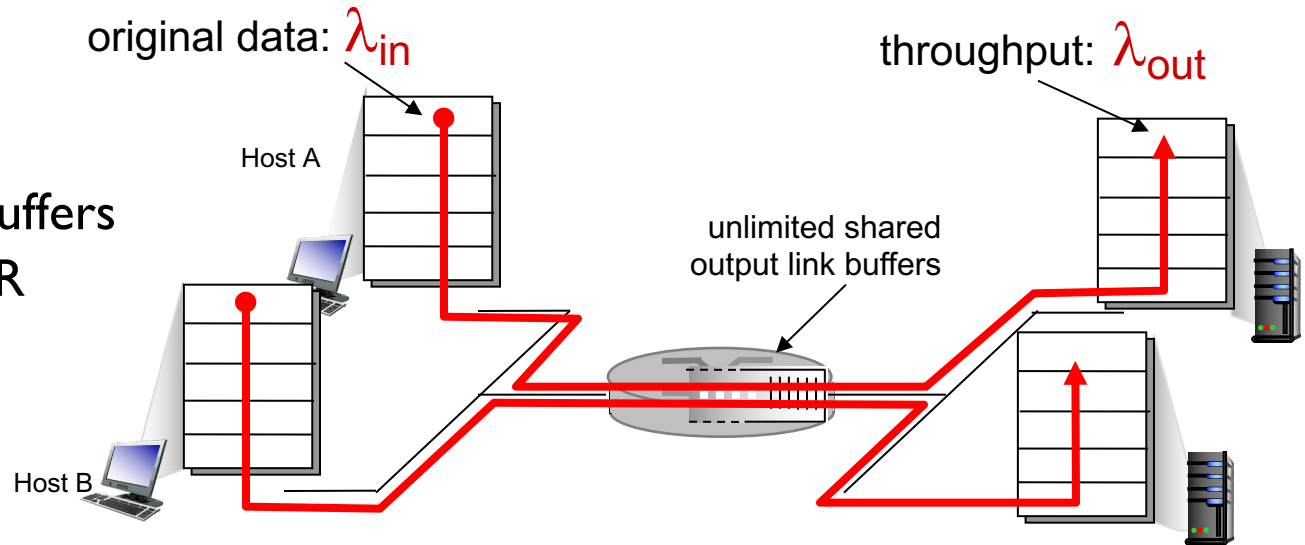
Principles of congestion control

congestion:

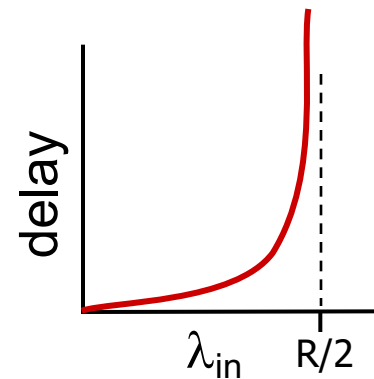
- informally: “too many sources sending too much data too fast for *network* to handle”
- different from flow control!
- manifestations:
 - lost packets (buffer overflow at routers)
 - long delays (queueing in router buffers)
- a top-10 problem!

Causes/costs of congestion: scenario I

- two senders, two receivers
- one router, infinite buffers
- output link capacity: R
- no retransmission



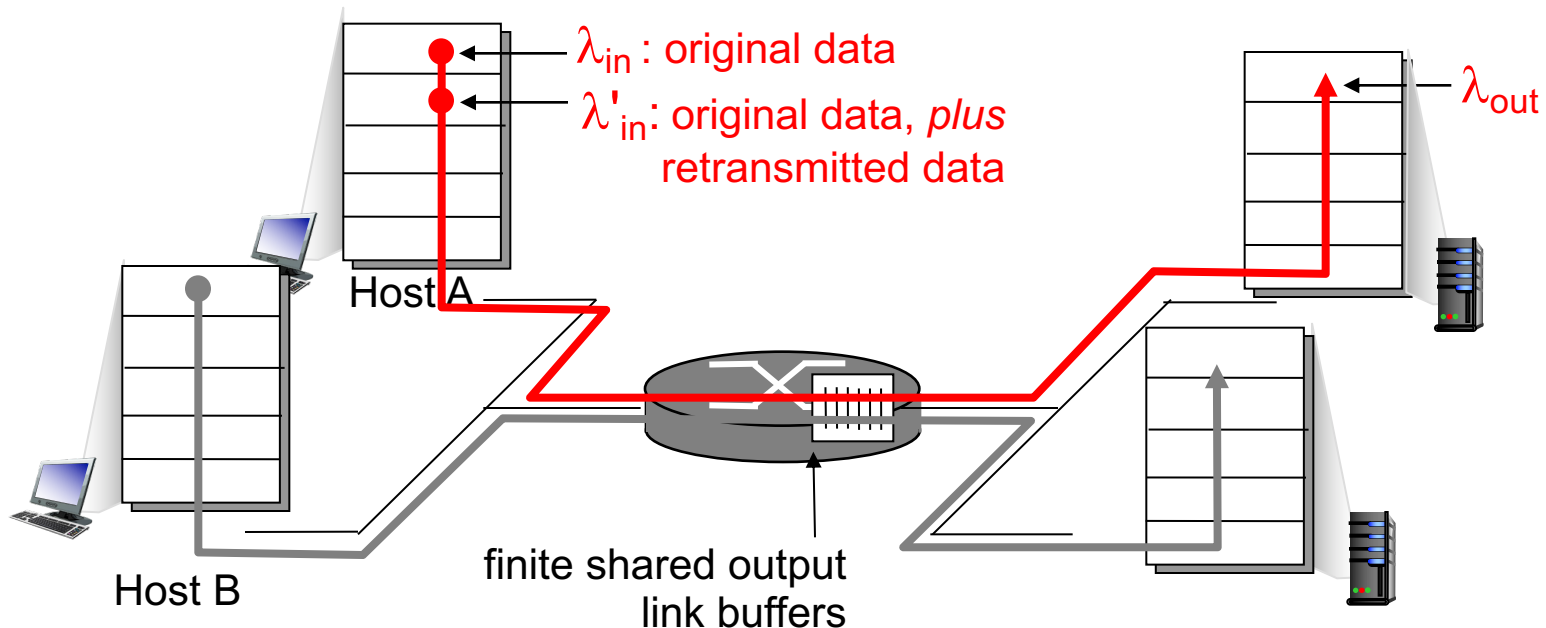
- maximum per-connection throughput: $R/2$



- ❖ large delays as arrival rate, λ_{in} , approaches capacity

Causes/costs of congestion: scenario 2

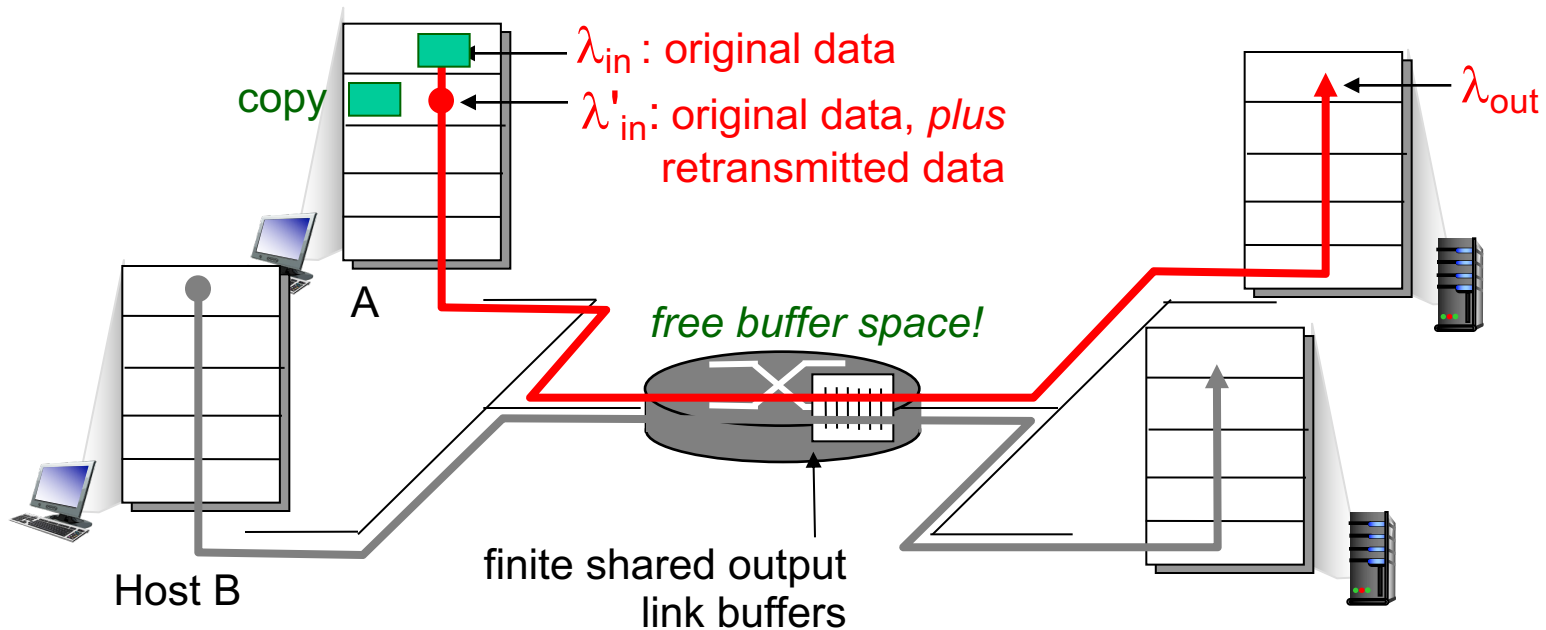
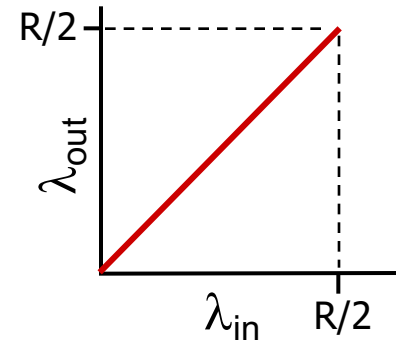
- one router, *finite* buffers
- sender retransmission of timed-out packet
 - application-layer input = application-layer output: $\lambda_{in} = \lambda_{out}$
 - transport-layer input includes *retransmissions* : $\lambda'_{in} \geq \lambda_{in}$



Causes/costs of congestion: scenario 2

idealization: perfect knowledge

- sender sends only when router buffers available

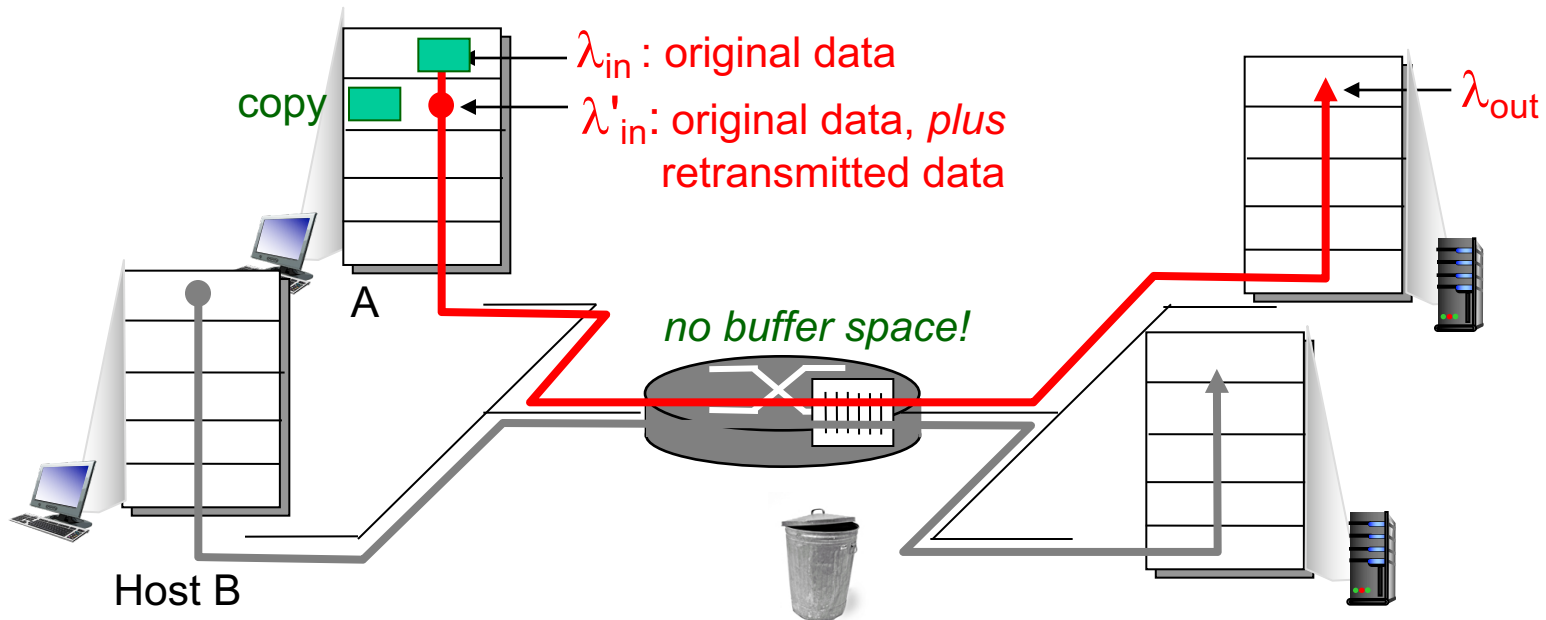


Causes/costs of congestion: scenario 2

Idealization: known loss

packets can be lost,
dropped at router due
to full buffers

- sender only resends if
packet *known* to be lost

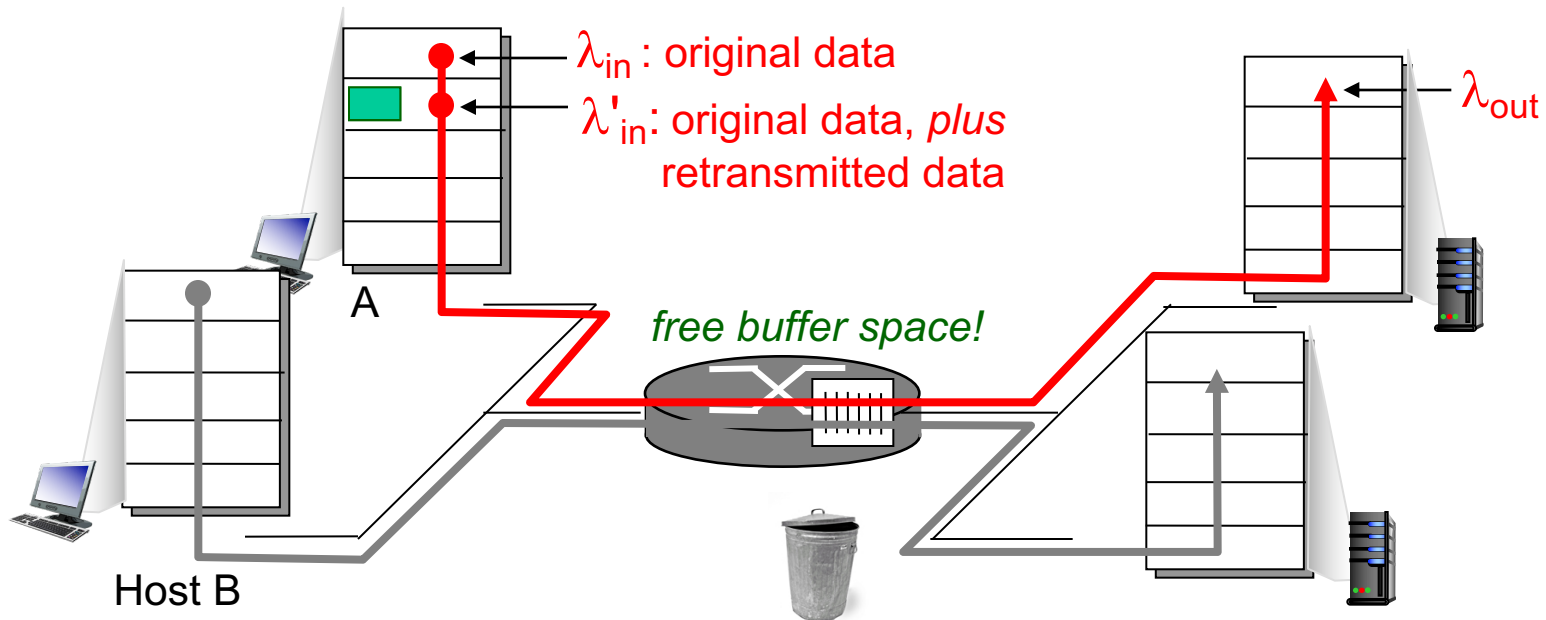
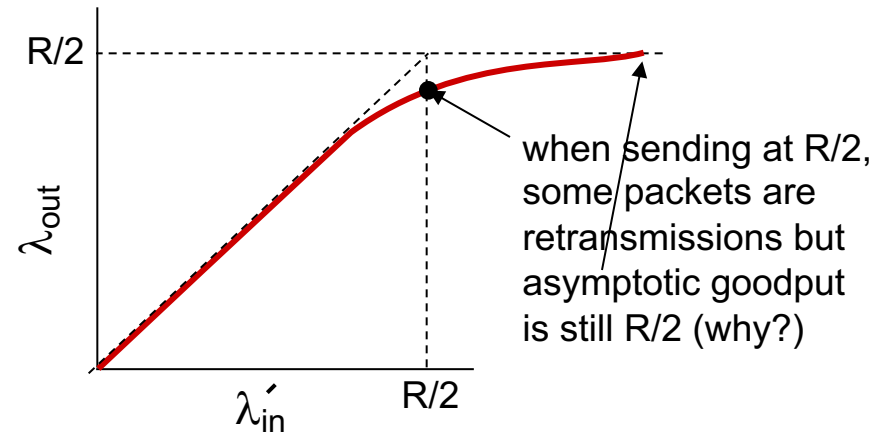


Causes/costs of congestion: scenario 2

Idealization: known loss

packets can be lost,
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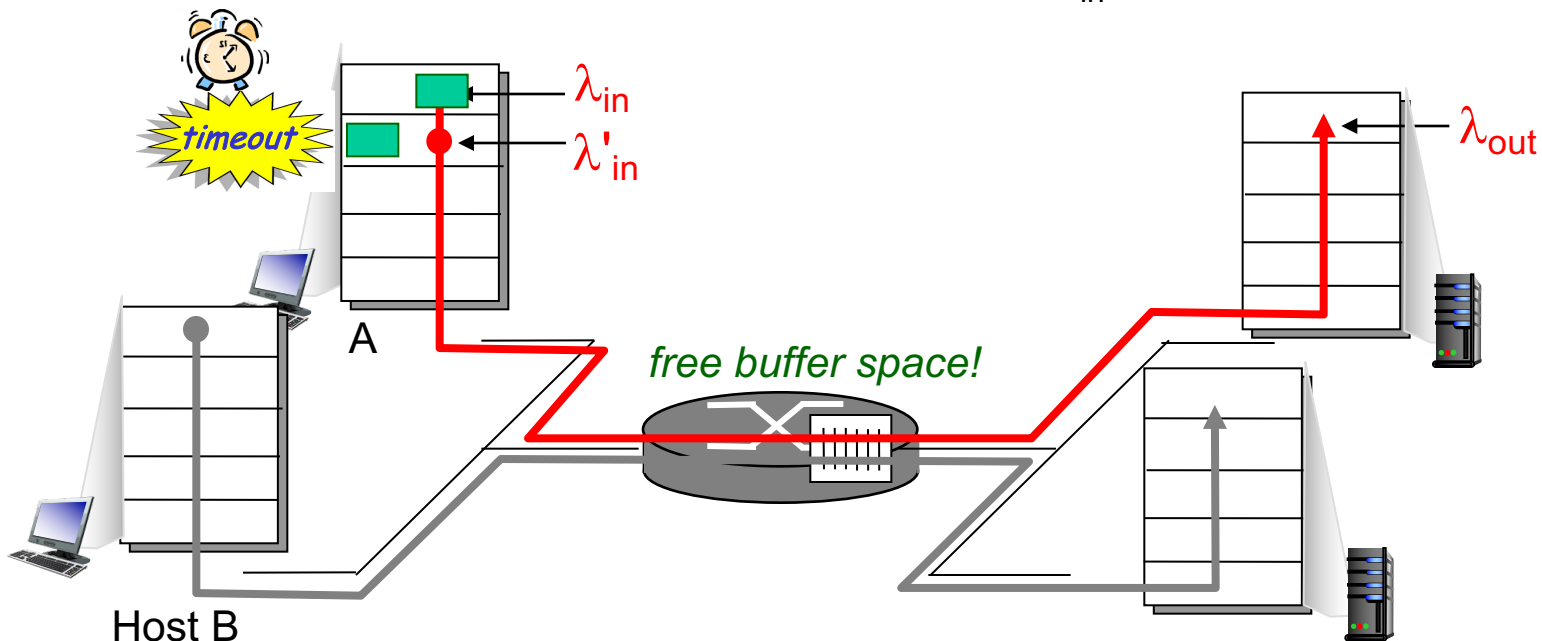
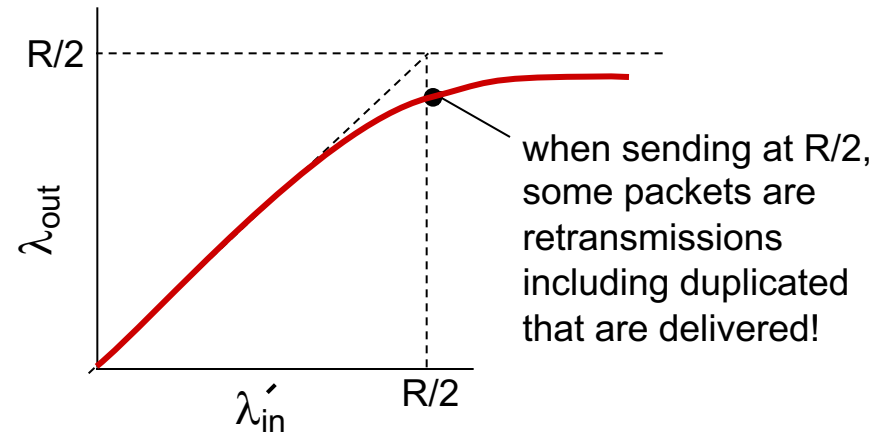
- sender only resends if
packet *known* to be lost



Causes/costs of congestion: scenario 2

Realistic: *duplicates*

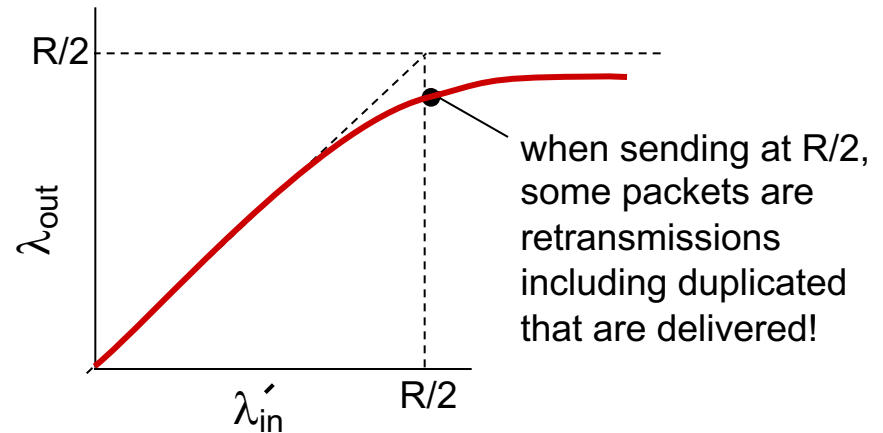
- packets can be lost, dropped at router due to full buffers
- sender times out prematurely, sending *two* copies, both of which are delivered



Causes/costs of congestion: scenario 2

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



“costs” of congestion:

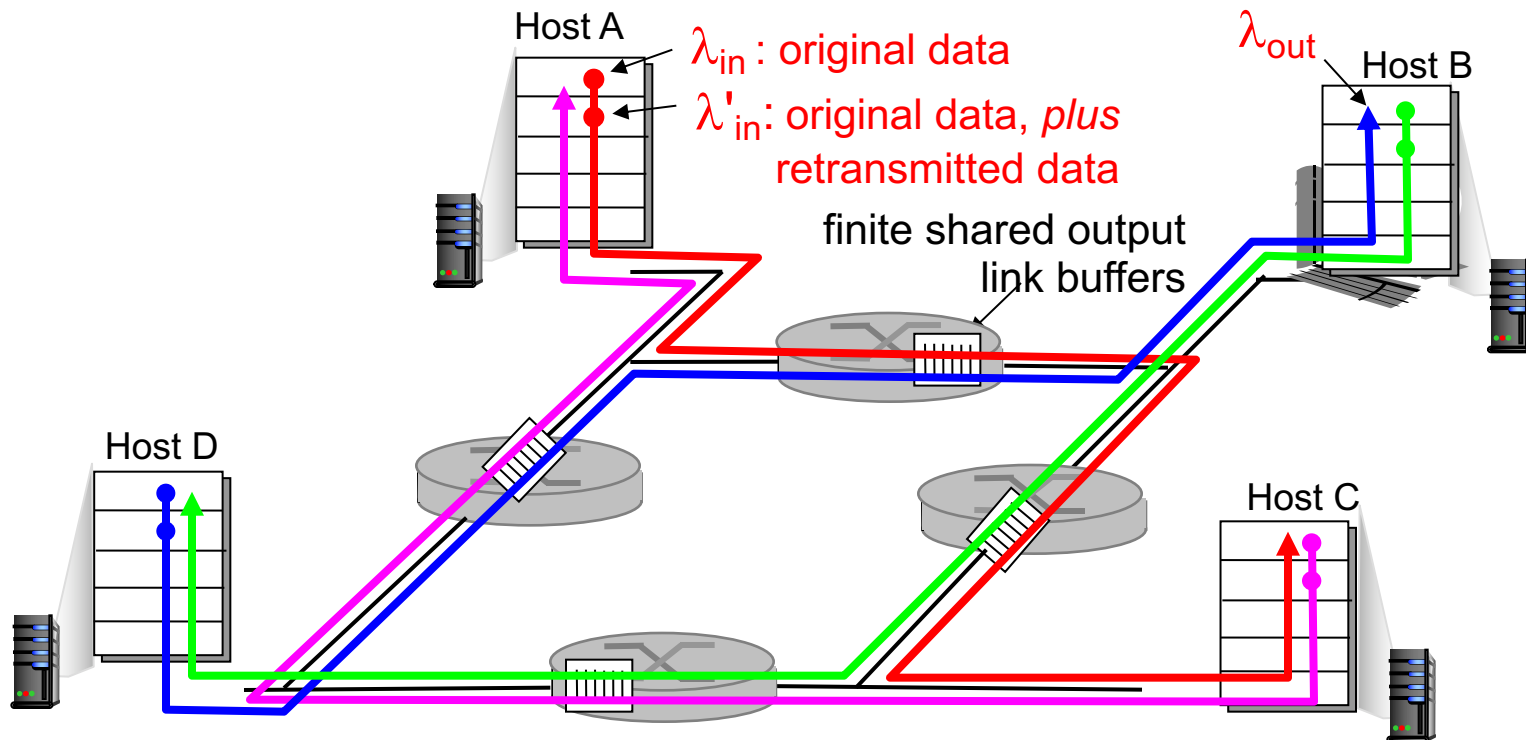
- more work (retrans) for given “goodput”
- unneeded retransmissions: link carries multiple copies of pkt
 - decreasing goodput

Causes/costs of congestion: scenario 3

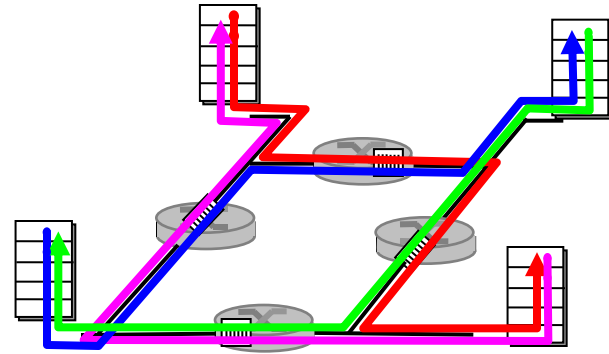
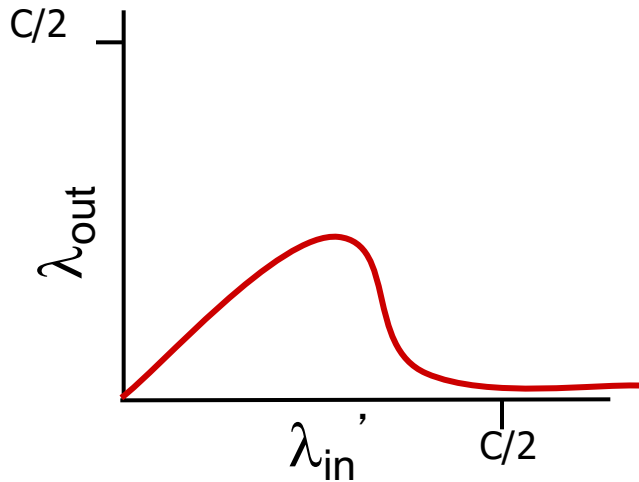
- four senders
- multihop paths
- timeout/retransmit

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 $\rightarrow 0$



Causes/costs of congestion: scenario 3



another “cost” of congestion:

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

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