Delay, loss, and throughput

CE 352: Computer Networks

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Lecture 2

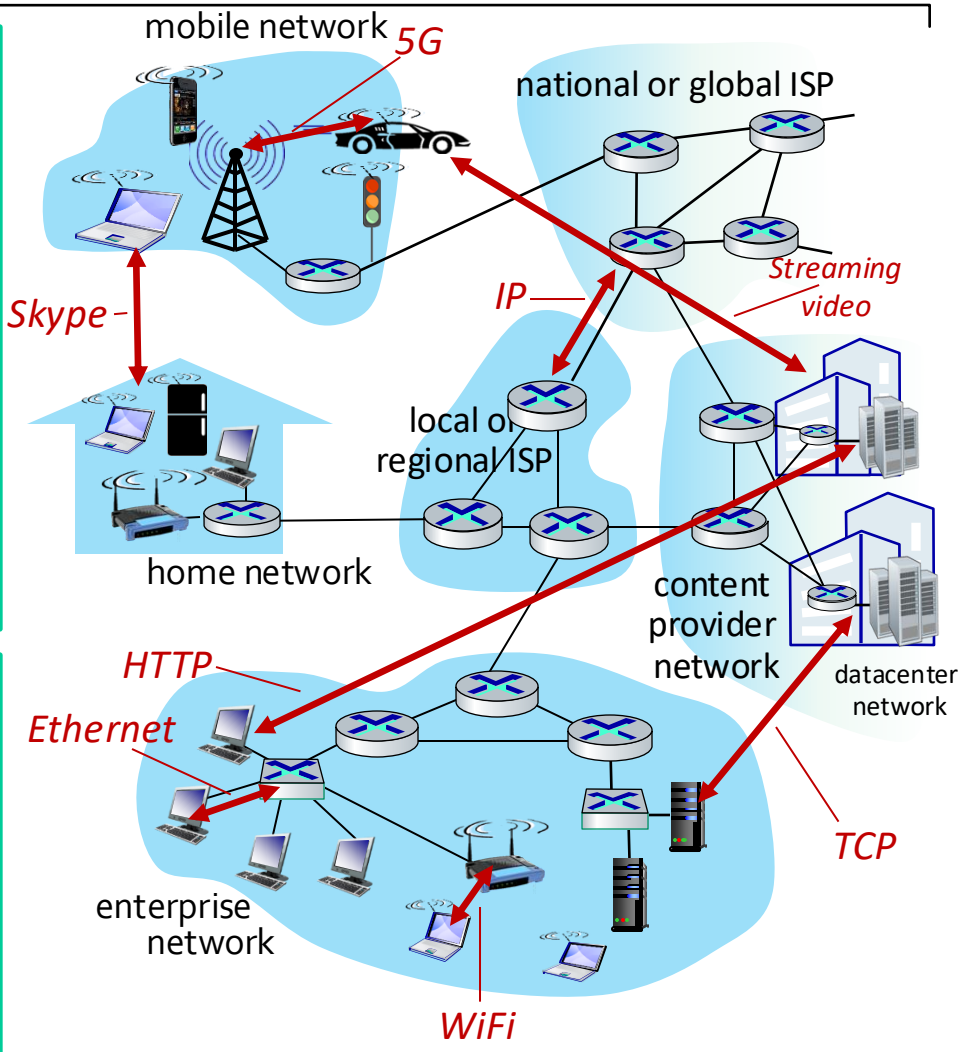
Recap (The Internet : Interconnected networks)

General view:

- Internet: "network of networks"
  - Interconnected ISPs
- Protocols: control sending, receiving of messages e.g., TCP, IP, HTTP, Skype, 802.11
- Standards: RFC: Request for comments, IETF: Internet Engineering Task Force

Service view:

- Infrastructure that provides services to applications: Web, email, VoIP
- Provides programming interface to applications



Recap (Network structure)

Network edge:

- hosts: clients, servers (data centers)

Access networks:

- Home, enterprise, datacenter, mobile

Physical media:

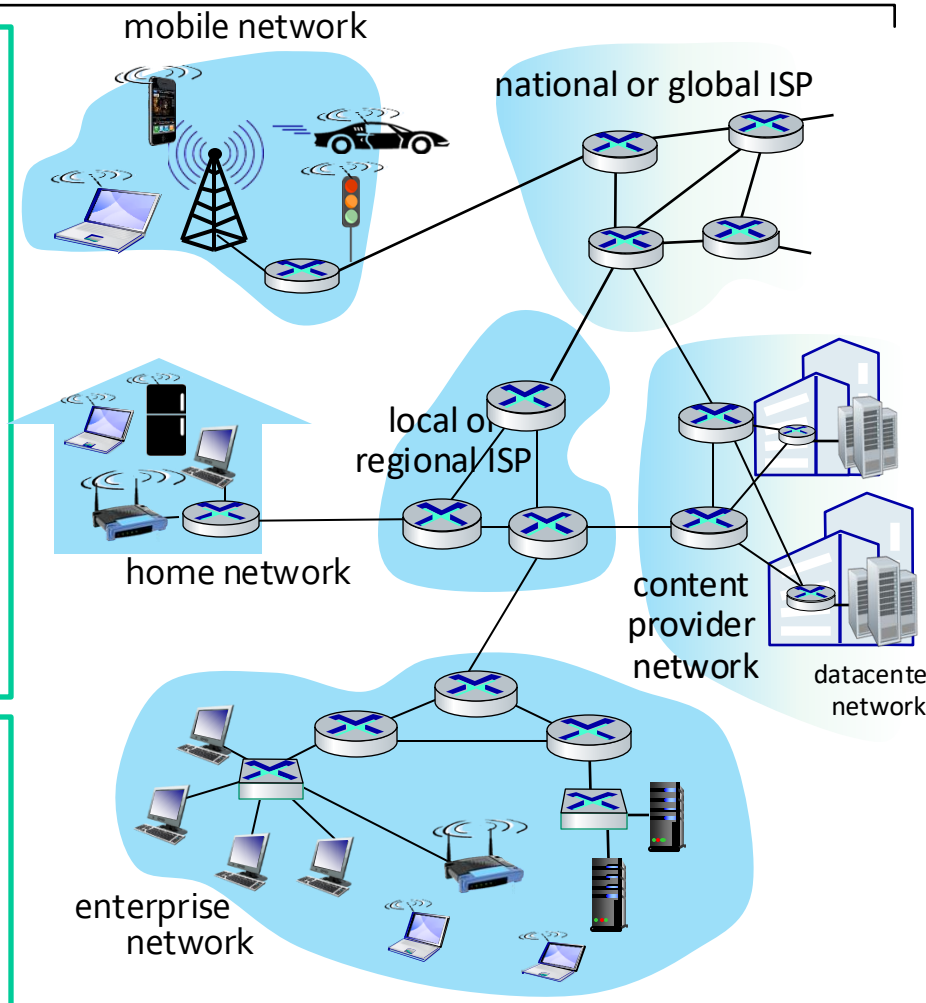
- wired, wireless communication links

Network core:

- interconnected routers
- network of networks

How to connect end systems to edge router? (bits per sec, shared/ dedicated)

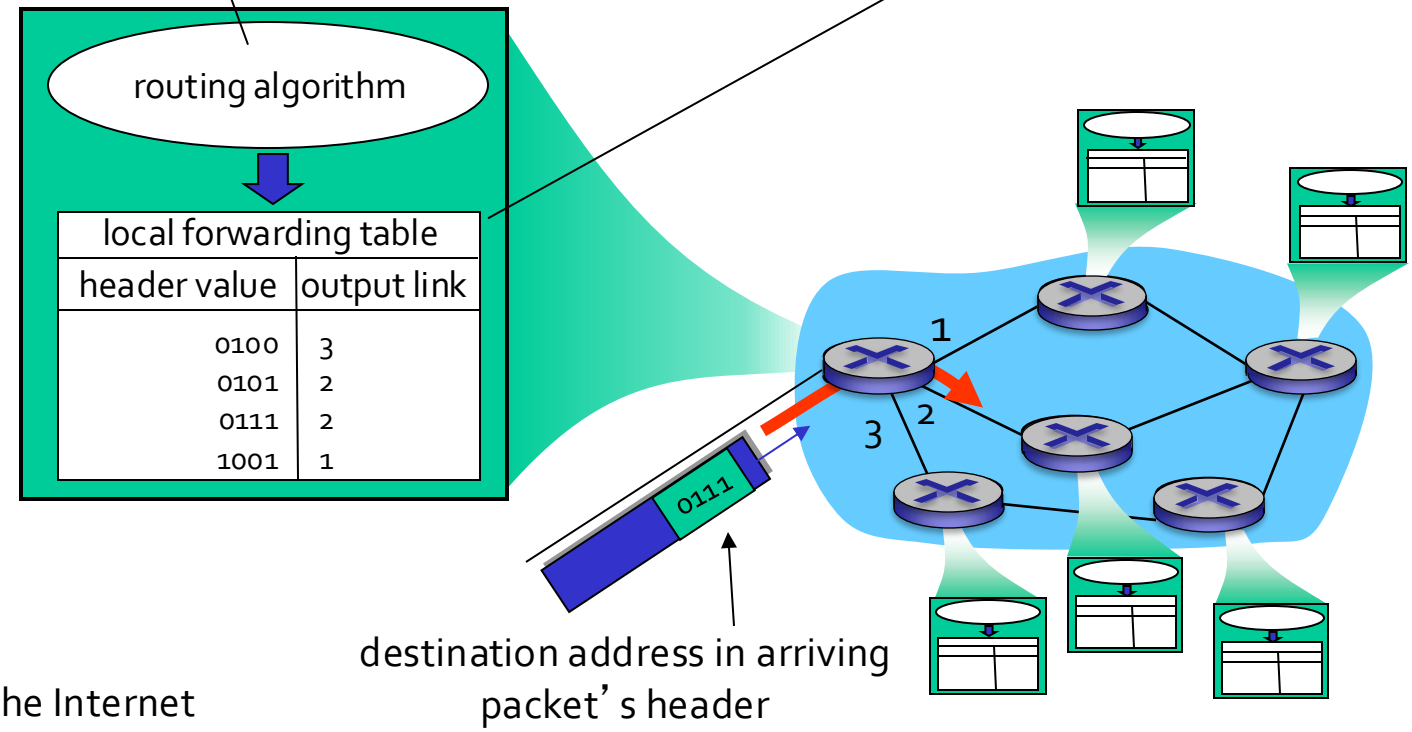
- Access and core networks
- Layers: Application, Transport, Network, Data link, Physical



Recap (Packet switching - key functions)

routing: determines source-destination route taken by packets
- *routing algorithms*

forwarding: move packets from router's input to appropriate router output

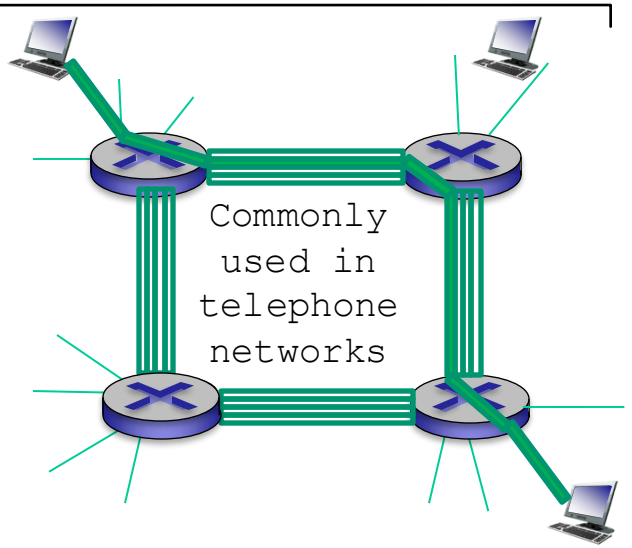


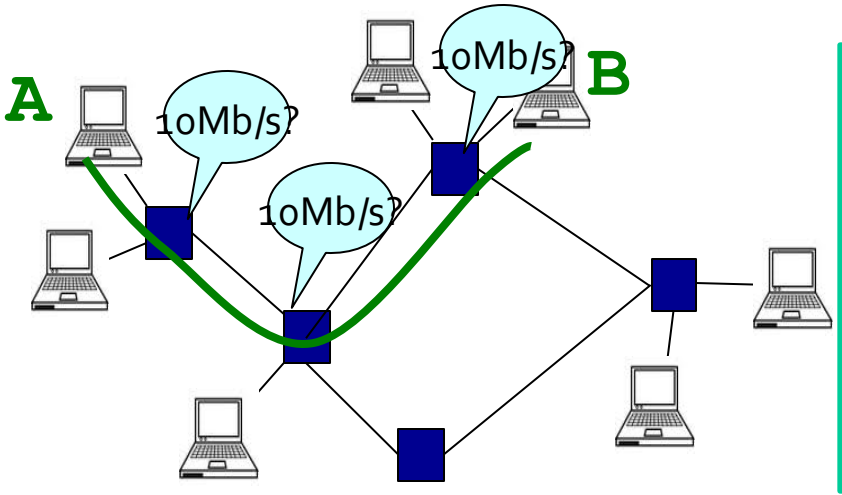
Example: The Internet

Recap (Circuit switching)

end-to-end resources allocated to, reserved for "call" between source and destination

- e.g. each link has four circuits. call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*

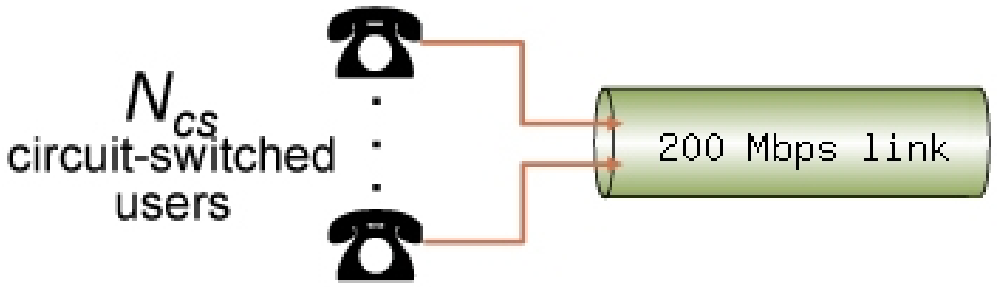




- source reserves network capacity along a path
  - Node A sends a reservation request
  - Interior switches establish a connection – "circuit"
  - A starts sending data
  - A sends a "teardown circuit" message

Example: Research and Education Networks (CalREN, Internet2, ESnet …)

Example – Circuit Switching

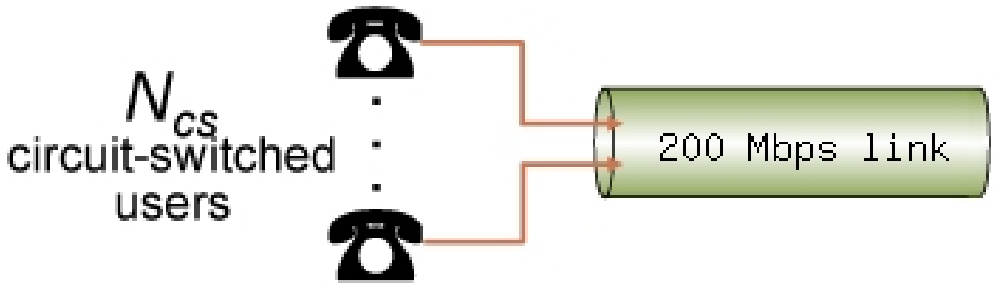


Each user:

- 20 Mb/s when "active"
- active 10% of time

- How many users can be served at most?

Example – Circuit Switching



Each user:

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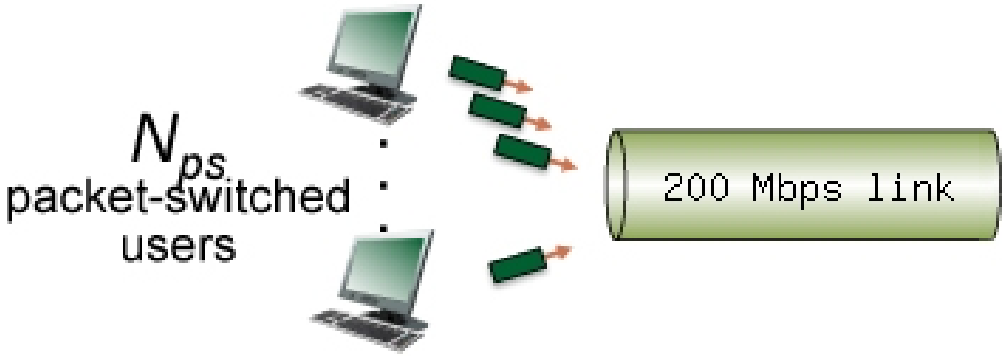
- How many users can be served at most?
  - 200 Mbps / 20 Mbps = 10 circuit-switched users

Example – Packet Switching



Each user:

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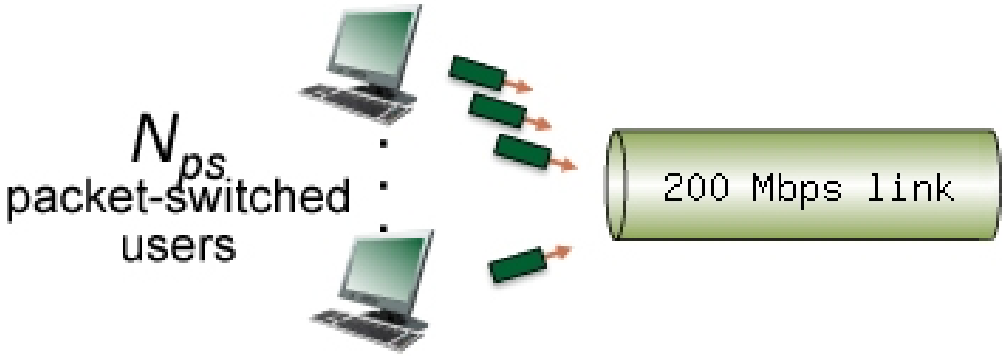
19 packet-switching users (i.e., Nps = 19)

- Probability (specific) user is busy transmitting is _____
- Probability one specific other user is not busy transmitting is _____
- Probability all of other N_{ps}-1 users are not transmitting is _____

Example – Packet Switching



Each user:

- 20 Mb/s when "active"
- active 10% of time

19 packet-switching users (i.e., Nps = 19)

- Probability (specific) user is busy transmitting is p= 0.10
- Probability one specific other user is not busy is (1-p)
- Probability all of other N_{ps}-1 users are not transmitting is $(1-p)^{Nps-1}$

Example – Packet Switching

- Probability that one specific user is busy transmitting, and the remaining users are not transmitting is _____
- The probability that exactly one (anyone) of the N_{ps} users is busy transmitting is _____
- Probability that 10 specific users of 19 users are transmitting and the other 9 users are not transmitting is _____
- Probability any 10 of 19 users are busy transmitting is _____
- Probability more than 10 of 19 users are busy transmitting is _____

https://en.wikipedia.org/wiki/Binomial_distribution
http://gaia.cs.umass.edu/kurose_ross/interactive/

Example – Packet Switching

- Probability that one specific user is busy transmitting, and the remaining users are not transmitting is $p^1(1-p)^{Nps-1}$
- The probability that exactly one (anyone) of the N_{ps} users is busy is $Nps * p^1(1-p)^{Nps-1}$
- Probability that 10 specific users of 19 users are transmitting and the other 9 users are not transmitting is $p^{10}(1-p)^9$
- Probability any 10 of 19 users are busy transmitting is

Binomial Coefficient

$$\binom{19}{10} p^{10}(1-p)^9 = \frac{19!}{10!(19-10)!} p^{10}(1-p)^9$$

- Probability more than 10 of 19 users are busy transmitting is

$$\sum_{i=11}^{19} \binom{19}{i} p^i(1-p)^{19-i}$$

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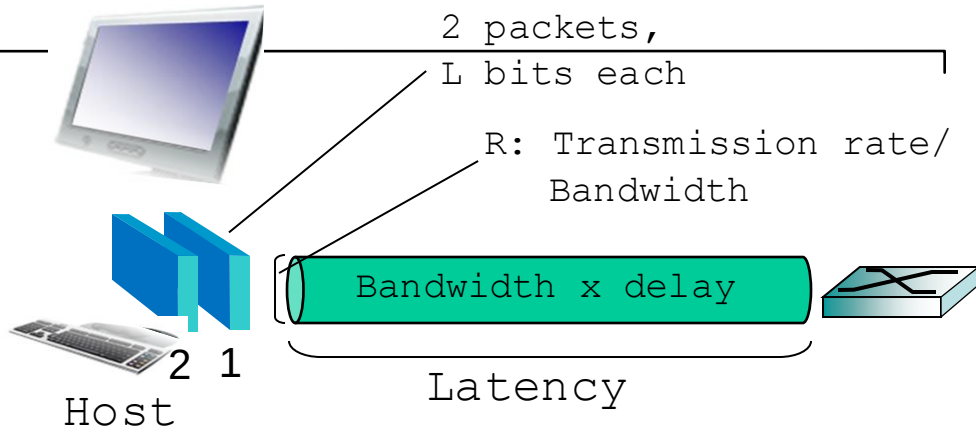
Topics of today

- Sending packets
- Packet delay and loss
- Throughput of a link
- Linux network commands

Sending packets

Host takes application message, breaks into smaller chunks, known as *packets*, of length *L* bits, and transmits at *rate R*



Bandwidth (capacity): "width" of the link?

Transmission - Delay: "size" of the packet?

Propagation - Delay: "length" of the link?

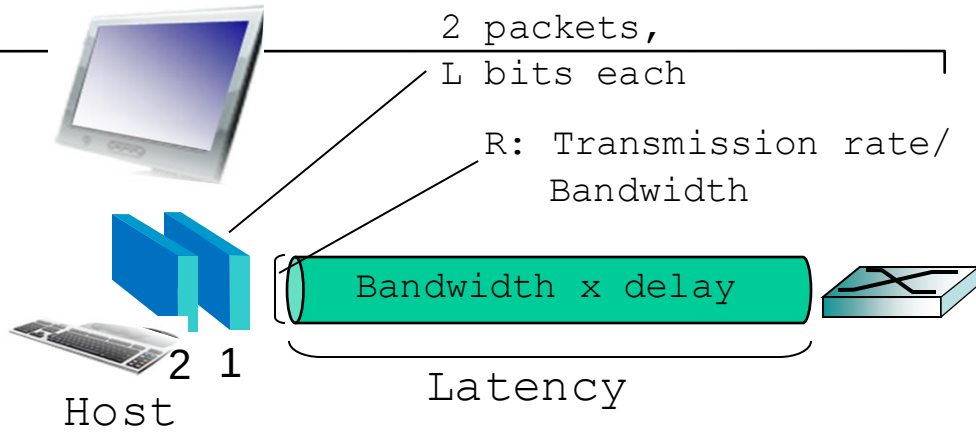
Bandwidth-Delay: "volume" of the link?

Example: Transmitting data over a cross boarder fast transmission link:

- Bandwidth = 10Gbps
- Delay = 10msec
- Volume = _____

Sending packets

Host takes application message, breaks into smaller chunks, known as *packets*, of length *L* bits, and transmits at *rate R*



Bandwidth (capacity): "width" of the link

number of bits sent (or received) per unit time (bits/sec or bps) → transmission rate *R*

Transmission - Delay: → L (bits)/ R(bps)

Probagation - Delay: "length" of the link

transmission time of data (L-bit packet) to travel along the link (seconds) = distance (m)/ $3*10^8$(mps)

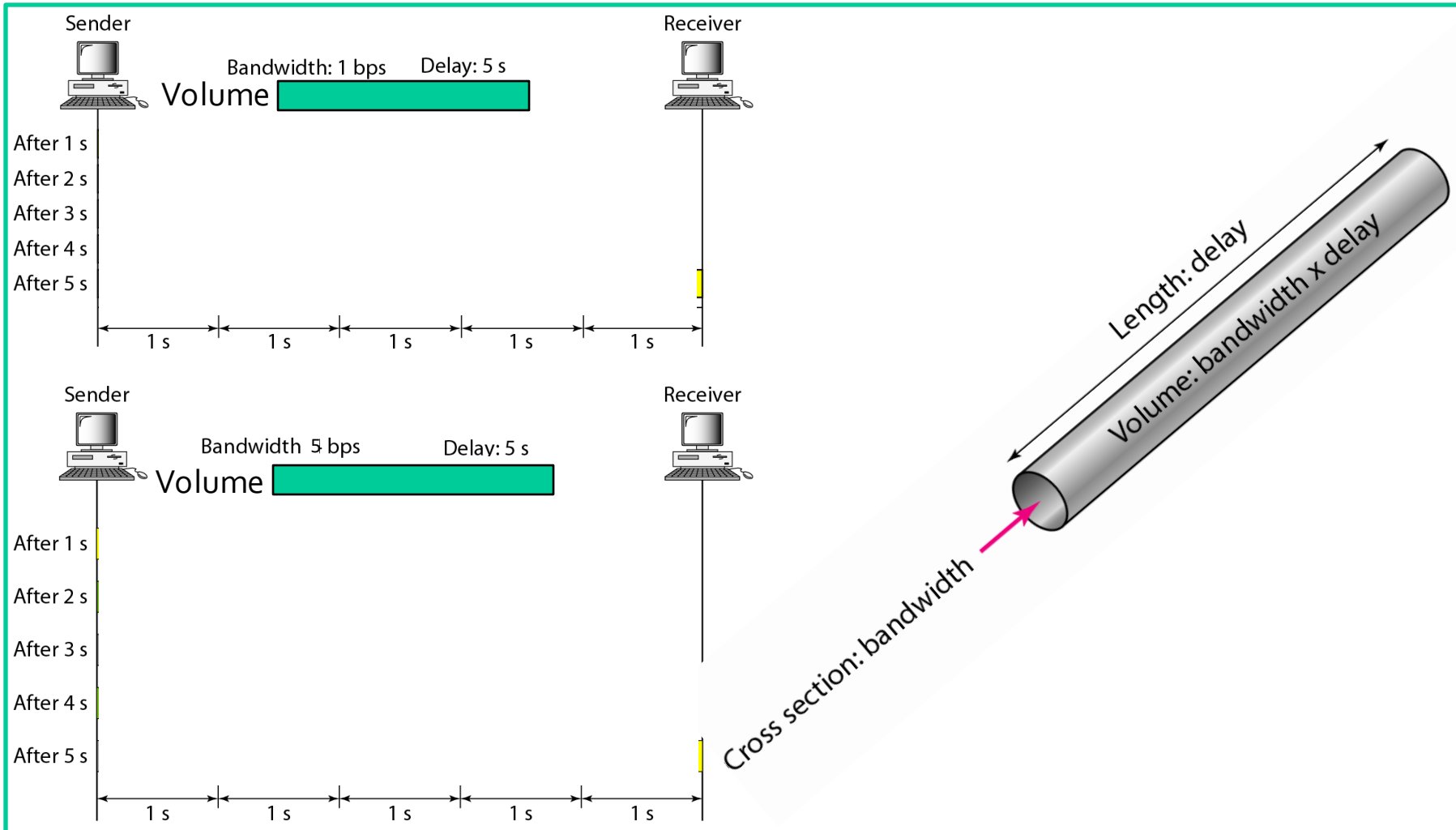
Bandwidth-Delay: "volume" of the link

amount of data that can be in link at any time (bits in link) = bits/time x propagation delay

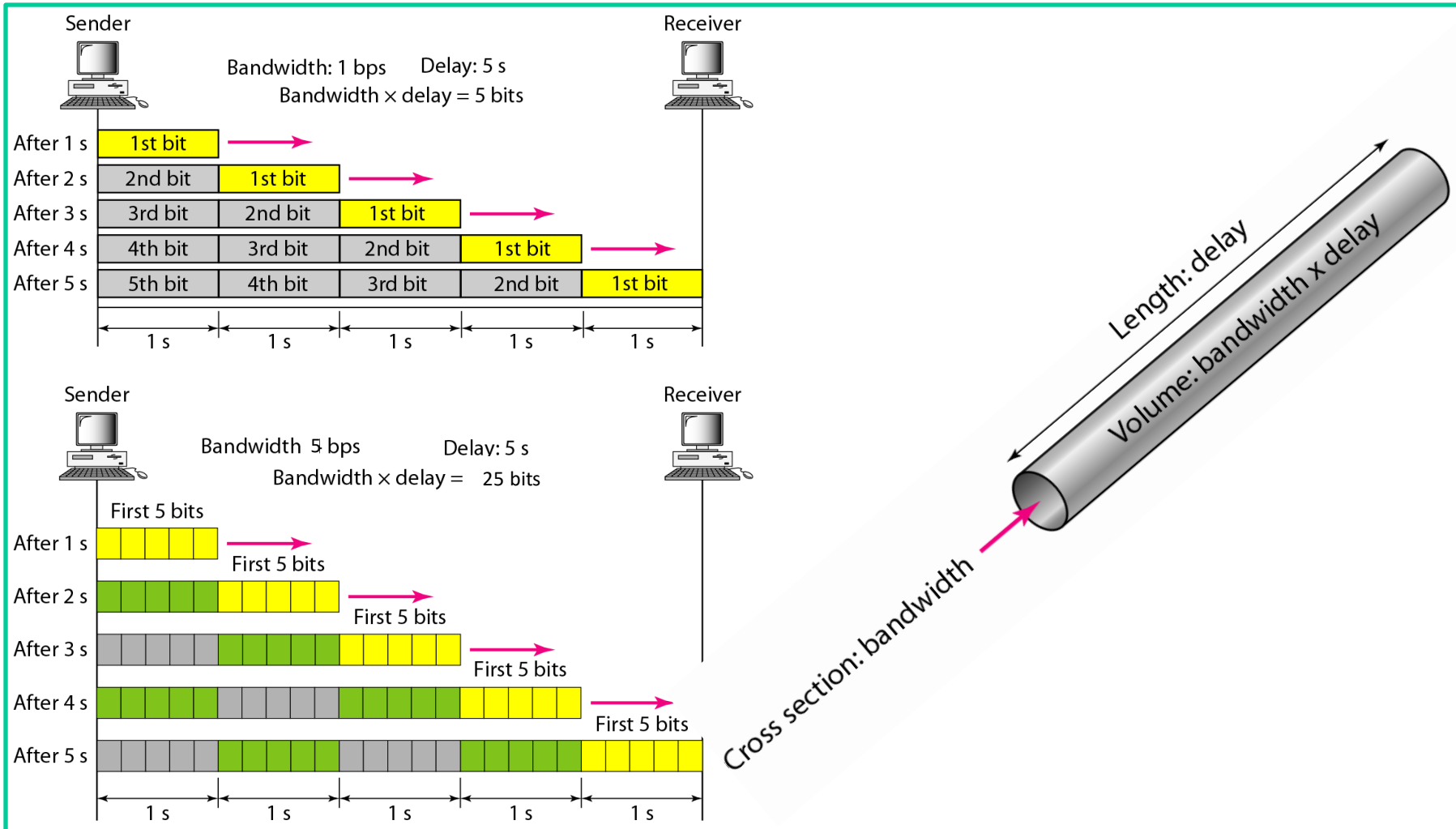
Example: Transmitting data over a cross boarder fast transmission link:

- Bandwidth = 10Gbps
- Delay = 10msec
- Volume = $10^{10} \times 10^{-2} = 10^8$bits = 12.5MBytes

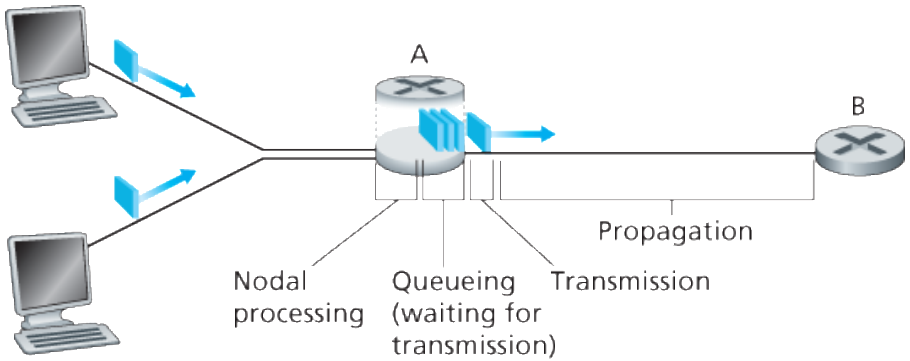
Example: sending packets

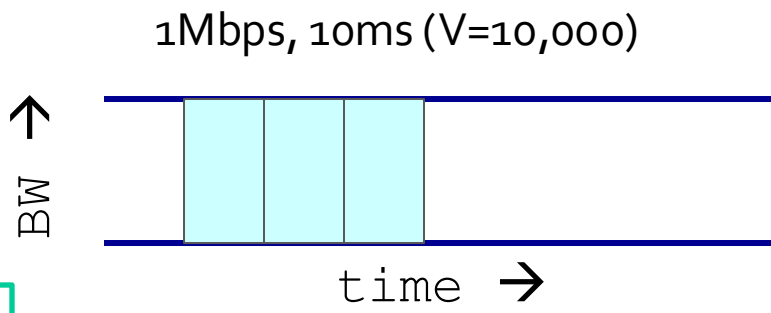


Example: sending packets

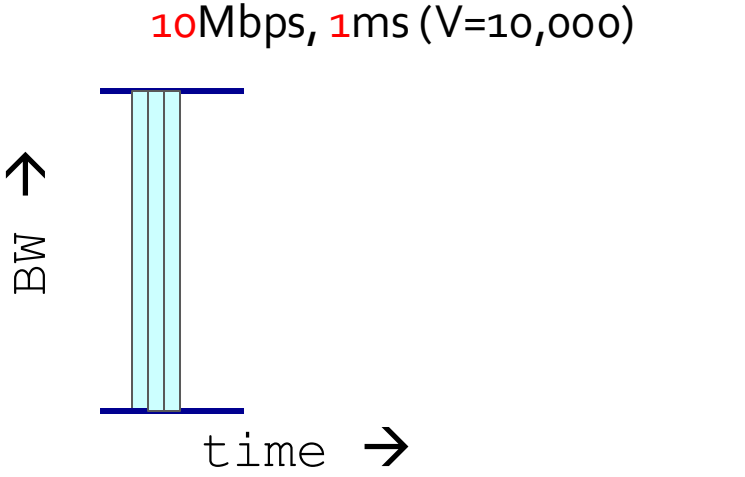


Packet delay

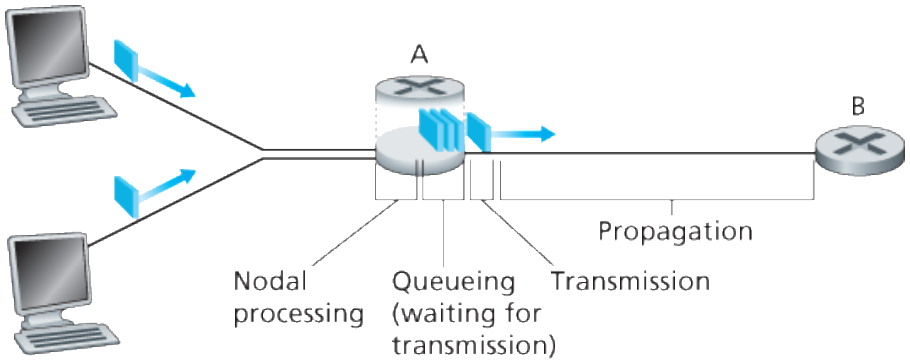




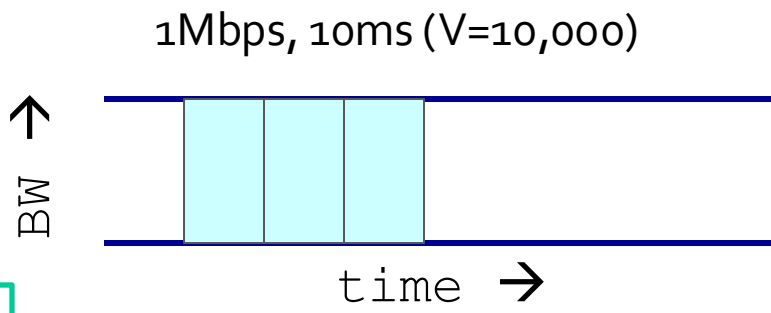
- Nodal Processing Delay:
- Queuing Delay:
- Transmission Delay:
- Propagation Delay:

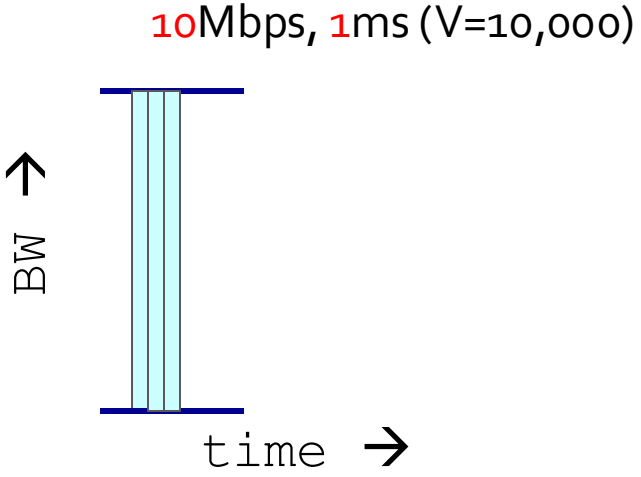


Packet delay

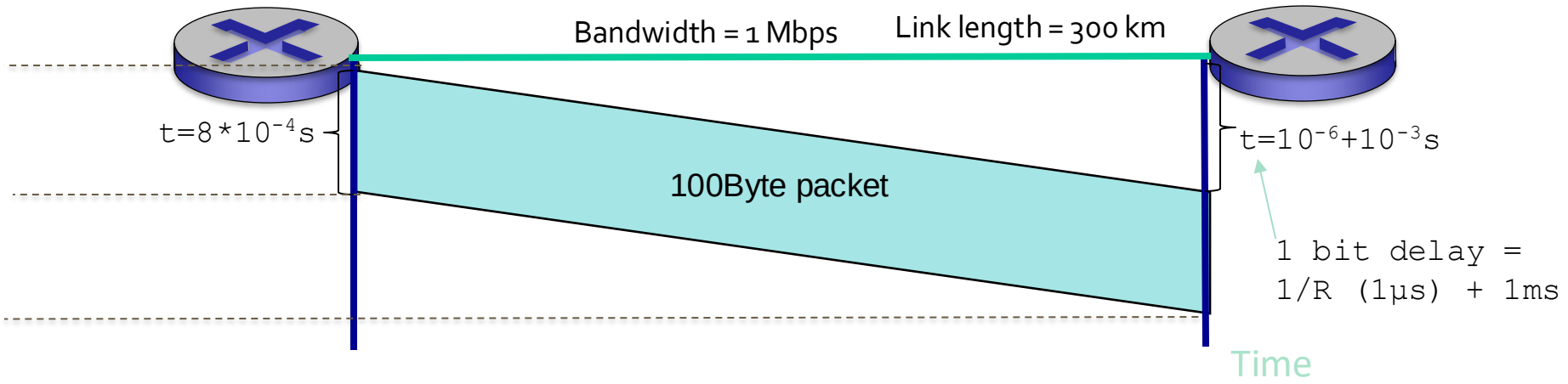


- Nodal Processing Delay: The time required to examine the packet's header and determine where to direct the packet
- Queuing Delay: The time a packet waits to be transmitted onto the link
- Transmission Delay: This time required to push (that is, transmit) all of the packet's bits into the link, L (packet size)/R (bandwidth)
- Propagation Delay: The time required to propagate from the beginning to the end of the link.





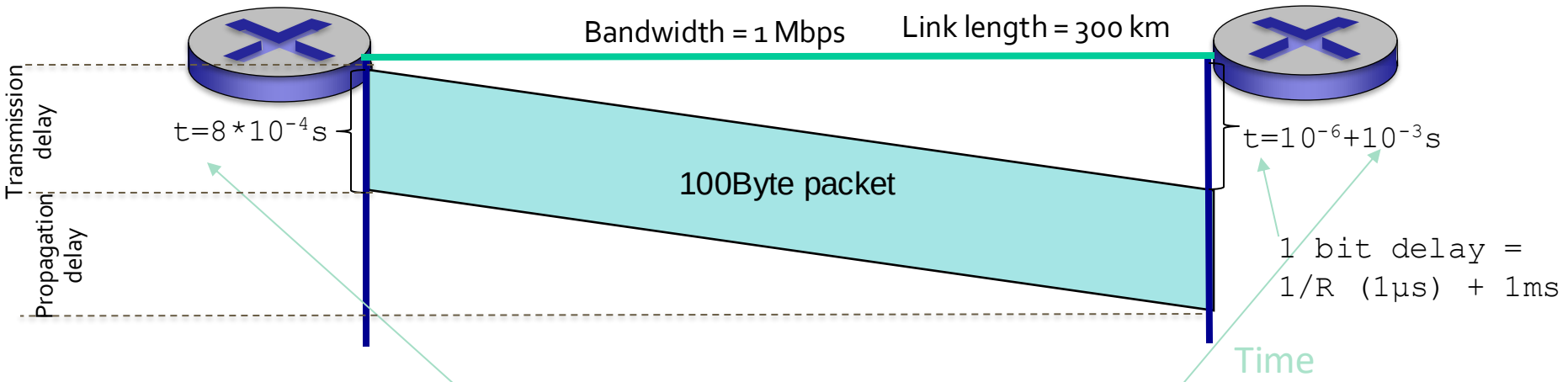
Example: Transmission/ propagation Delay



- Transmission Delay:

- Propagation Delay:

Example: Transmission/ propagation Delay



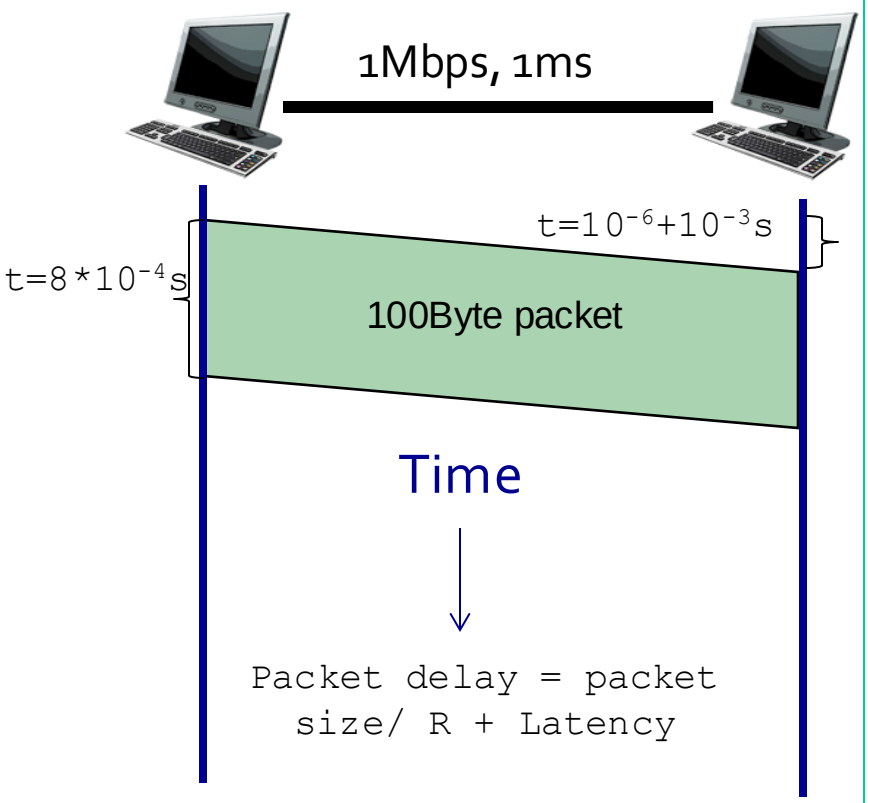
- Transmission Delay: This time required to push (that is, transmit) all of the packet's bits into the link
  - = L (packet size)/R (bandwidth) --> 100 bytes * (8 bits/1 byte)/ 1 Mbps
    --> 800 bits/ 1 x 10^6 bits/second = $8x10^{-4}$ seconds
    --> 0.8 ms
- Propagation Delay: The time required to propagate from the beginning to the end of the link, bits travel at the speed of light
  - = distance / speed of light --> 300 km/$3x10^8$m/second --> $3x10^5/3x10^8$m/s = $1x10^{-3}$ s
    --> 1 ms

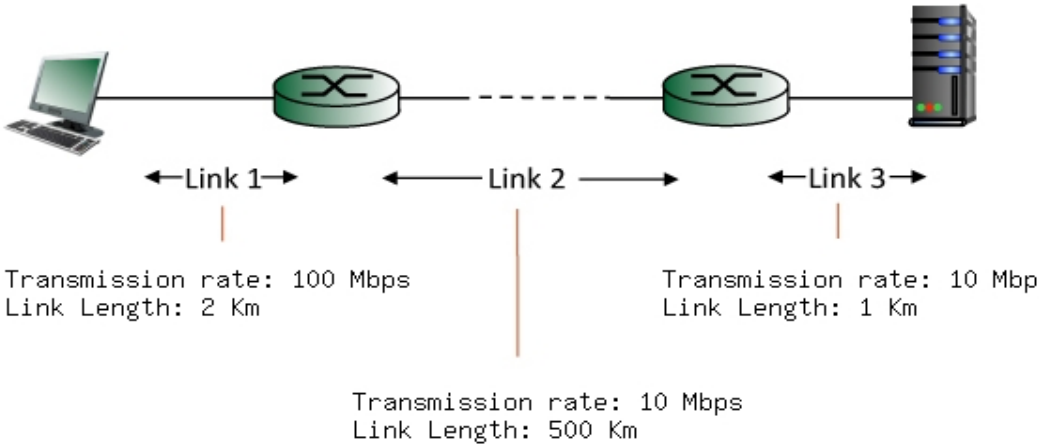
Capacity (Bytes) and Speed (Bits per Second)

- Units of size (memory, disk, data, etc.)
- Bits and bytes (1 byte = 8 bits)

Term	Abbrev	Binary Size	Speed (bits per second - bps)	Decimal Compare
Byte	B	8 bits		
Kilobyte	KB	2^{10} bytes	Kbps	10^3
Megabyte	MB	2^{20} bytes	Mbps	10^6
Gigabyte	GB	2^{30} bytes	Gbps	10^9
Terabyte	TB	2^{40} bytes	Tbps	10^{12}
Petabyte	PB	2^{50} bytes		10^{15}
Exabyte	EB	2^{60} bytes		10^{18}

Example: end-end delay





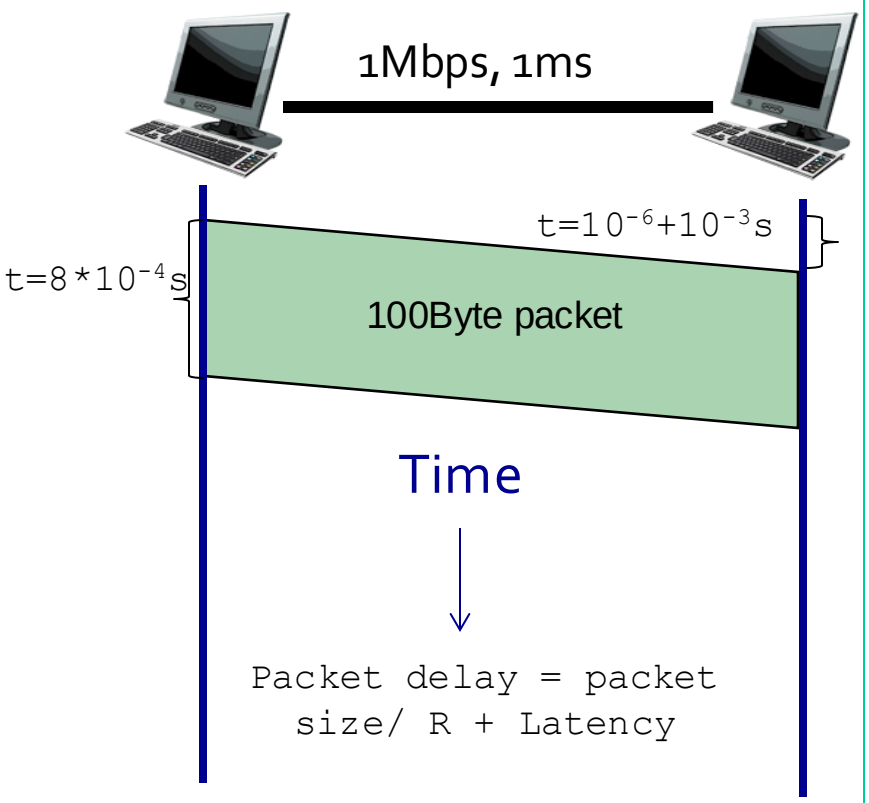
packet length of **12000** bits

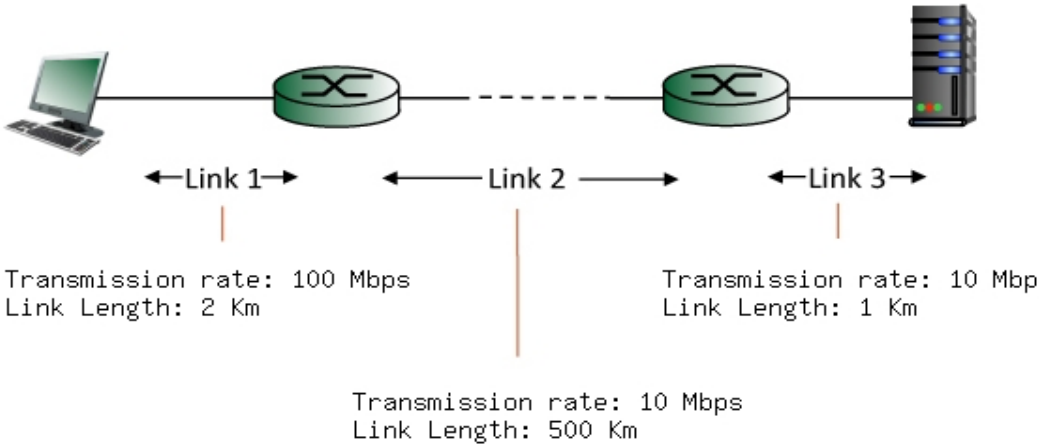
Bits travel at speed of light $3x10^8$ m/sec

Link 1 transmission delay =

Link 1 propagation delay =

Example: end-end delay





packet length of **12000** bits

Bits travel at speed of light $3x10^8$ m/sec

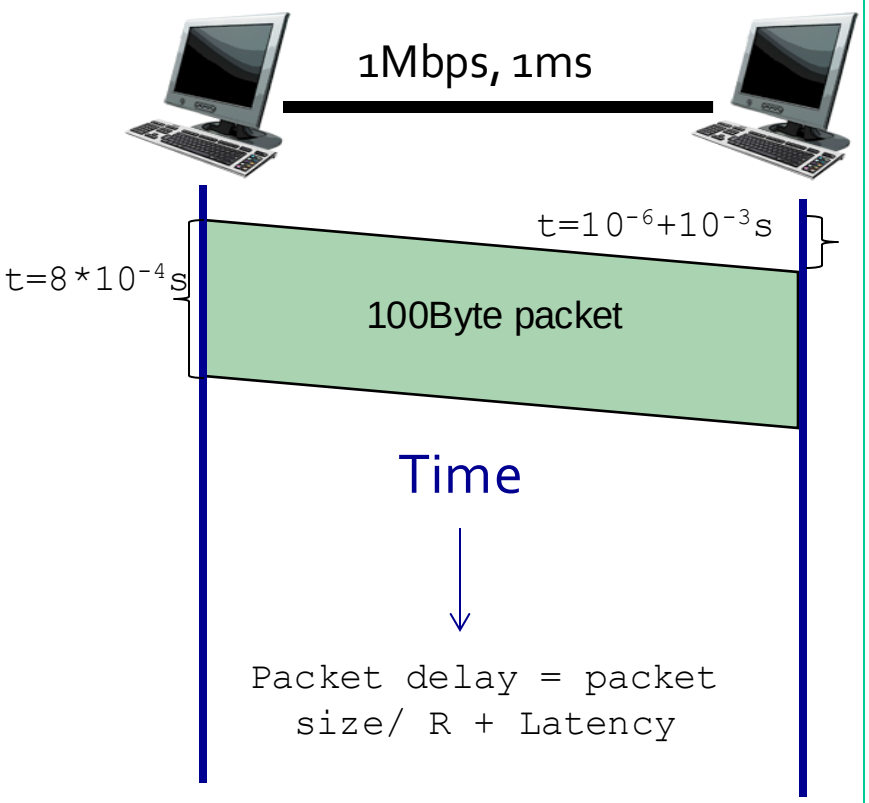
Link 1 transmission delay = L/R = 12000 bits / 100 Mbps → 0.12 ms

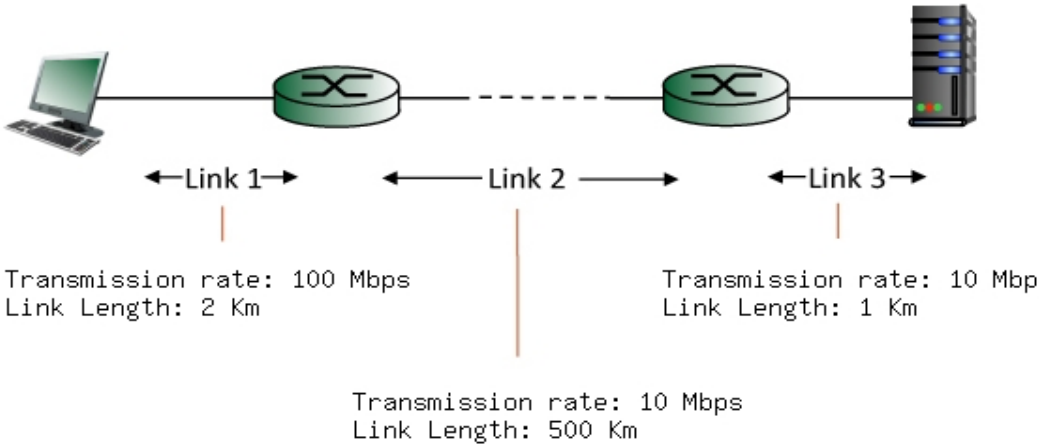
Link 1 propagation delay = d/s = 2 Km / 3*10**8 m/sec → 0.0067 ms

Link 2 transmission delay =

Link 2 propagation delay =

Example: end-end delay





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Link 1 propagation delay = d/s = 2 Km / 3*10**8 m/sec → 0.0067 ms

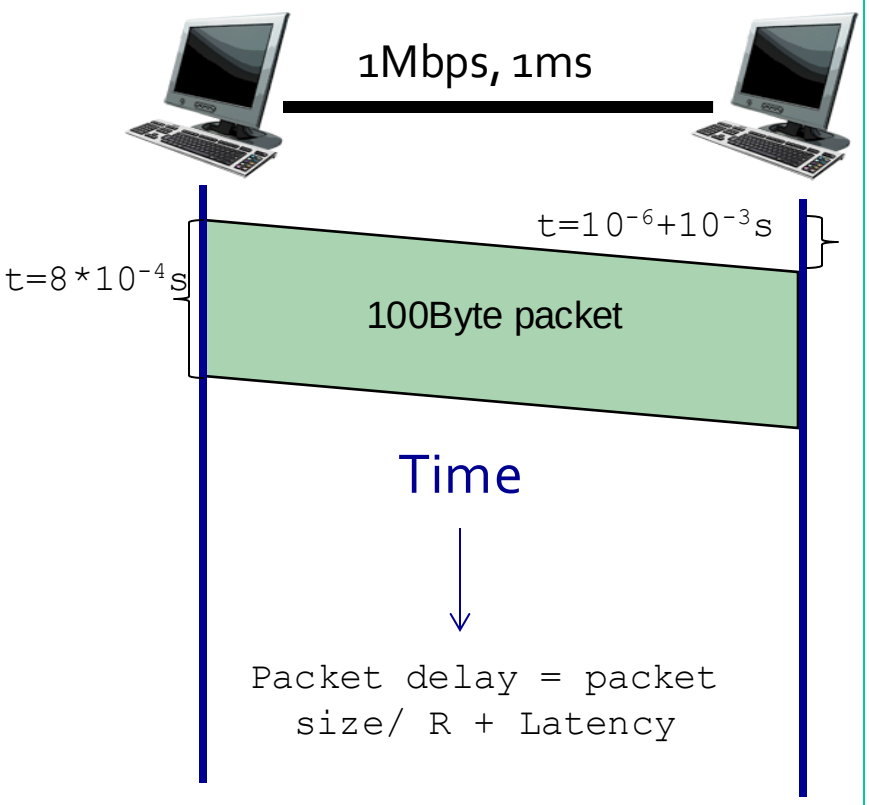
Link 2 transmission delay = L/R = 12000 bits / 10 Mbps → 1.2 ms

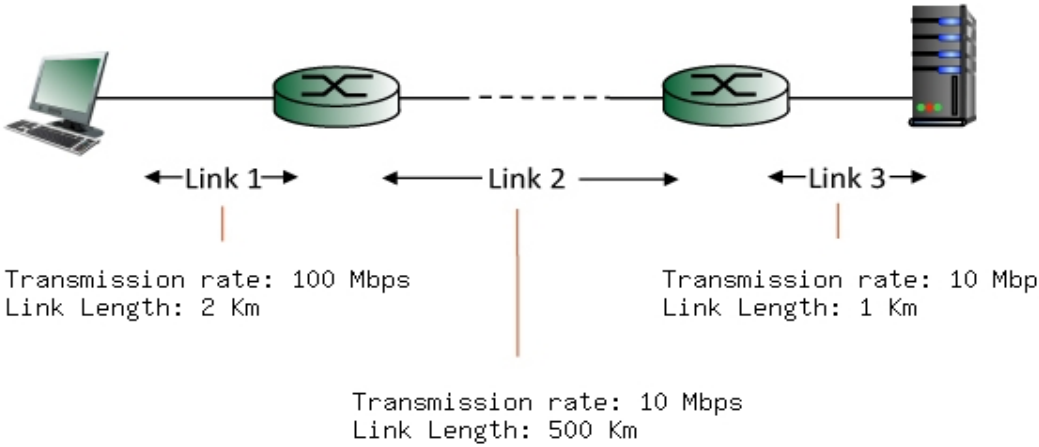
Link 2 propagation delay = d/s = 500 Km / 3*10**8 m/sec → 1.667 ms

Link 3 transmission delay =

Link 3 propagation delay =

Example: end-end delay





packet length of **12000** bits

Bits travel at speed of light $3x10^8$ m/sec

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Link 1 propagation delay = d/s = 2 Km / 3*10**8 m/sec → 0.0067 ms
Link 2 transmission delay = L/R = 12000 bits / 10 Mbps → 1.2 ms
Link 2 propagation delay = d/s = 500 Km / 3*10**8 m/sec → 1.667 ms
Link 3 transmission delay = L/R = 12000 bits / 10 Mbps → 1.2 ms
Link 3 propagation delay = d/s = 1 Km / 3*10**8 m/sec → 0.0033 ms

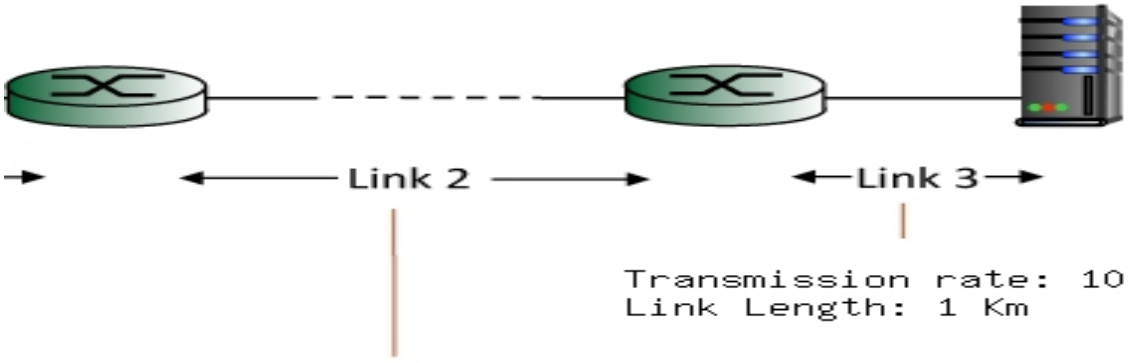
Total end-to-end delay = 4.196667 msecs.

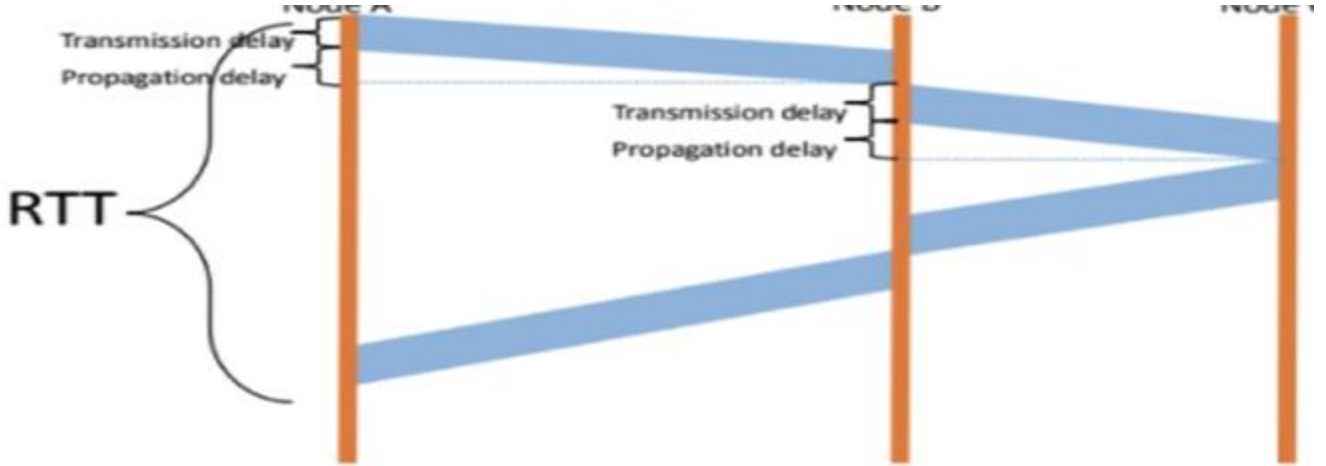
Example: round trip time (RTT)

Packet length
of **12000** bits
Bits travel at $3x10^8$ m/sec
Link 2 d_{trans} = 1.2 ms
Link 2 d_{prop} = 1.667 ms
Link 3 d_{trans} = 1.2 ms
Link 3 d_{prop} = 0.0033 ms

4.0703 ms

RTT = ?

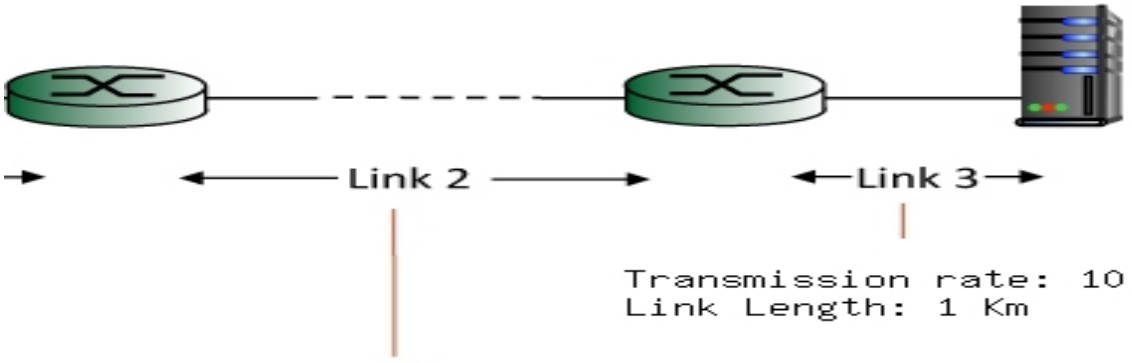


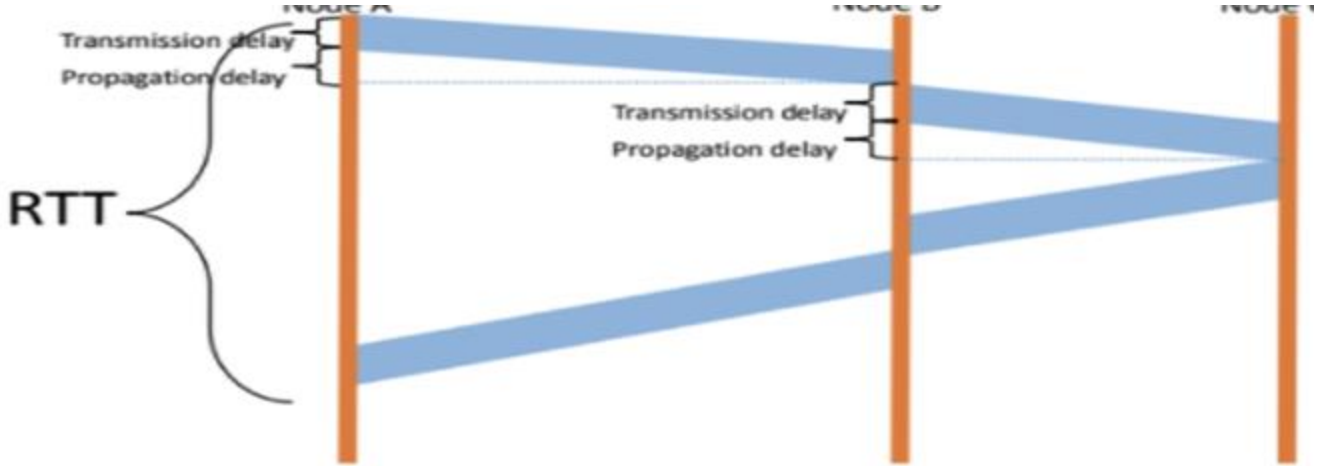


Example: round trip time (RTT)

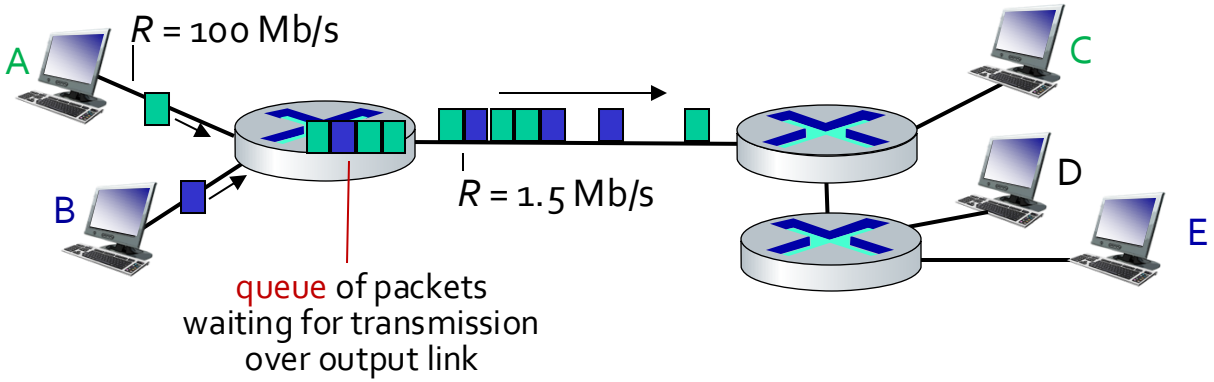
Packet length
of **12000** bits
Bits travel at $3x10^8$ m/sec
Link 2 d_{trans} = 1.2 ms
Link 2 d_{prop} = 1.667 ms
Link 3 d_{trans} = 1.2 ms
Link 3 d_{prop} = 0.0033 ms

RTT = 2*(4.0703) = 8.14 ms





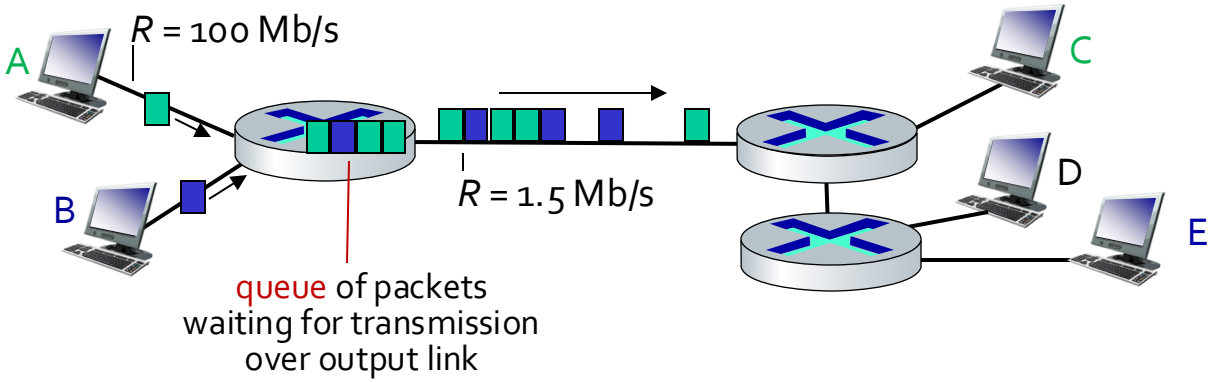
Packet-switching: queueing and loss



Queueing

Packet queuing and loss

Packet-switching: queueing and loss



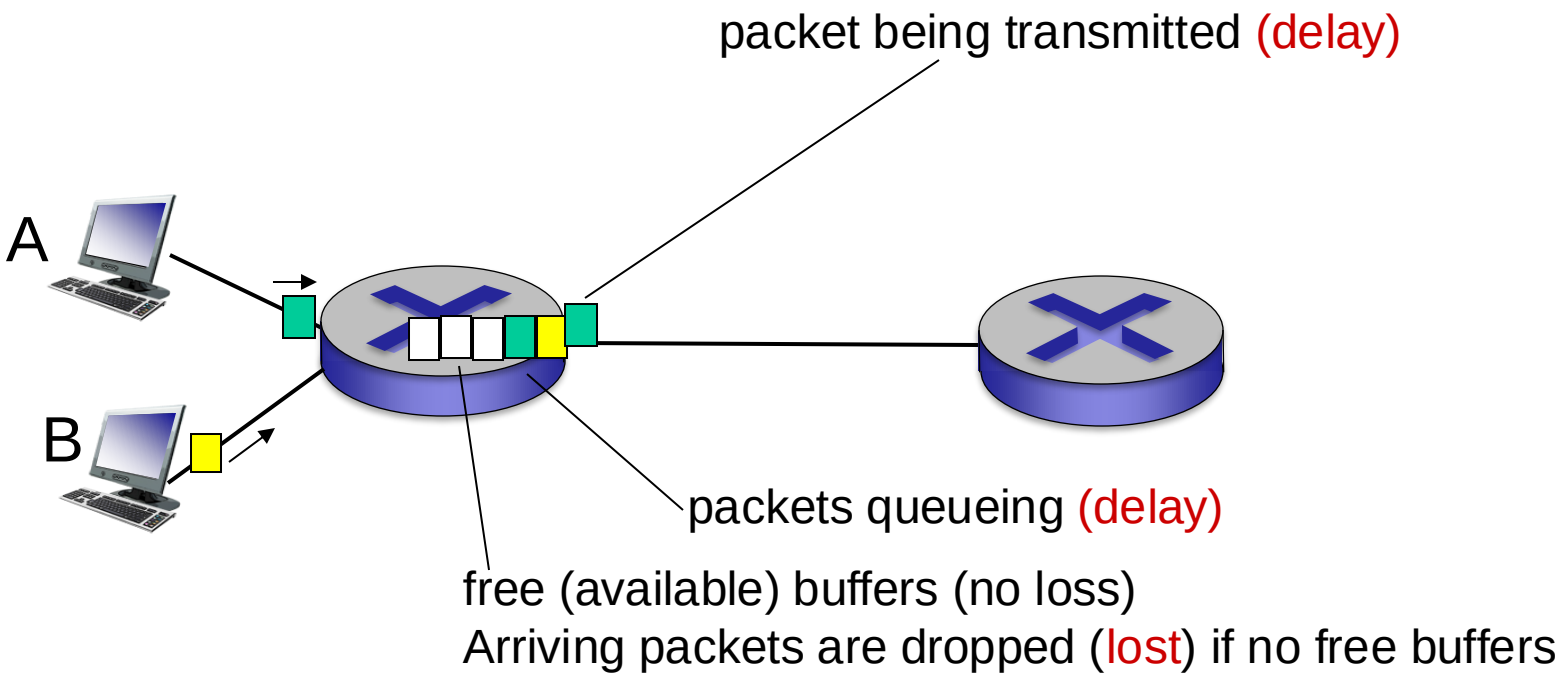
Queueing occurs when packets arrive faster than can be serviced:


Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

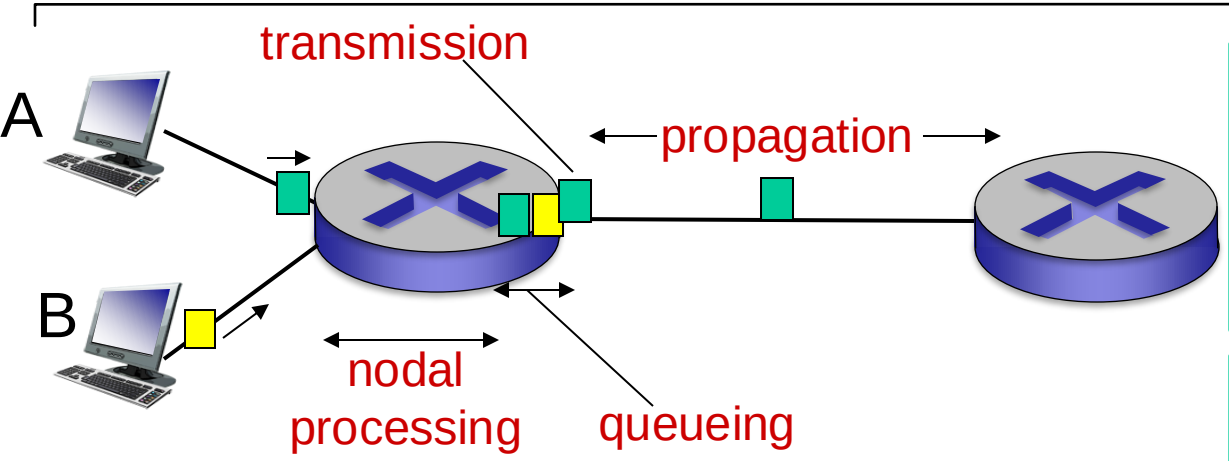
- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

How do loss and delay occur?

- packets *queue* in router buffers
- packet arrival rate to link (temporarily) exceeds output link capacity
- packets queue, wait for turn



Four sources of packet delay



d_{trans}: transmission delay:
- L: packet length (bits)
- R: link *bandwidth (bps)*
  - $d_{trans} = L/R$

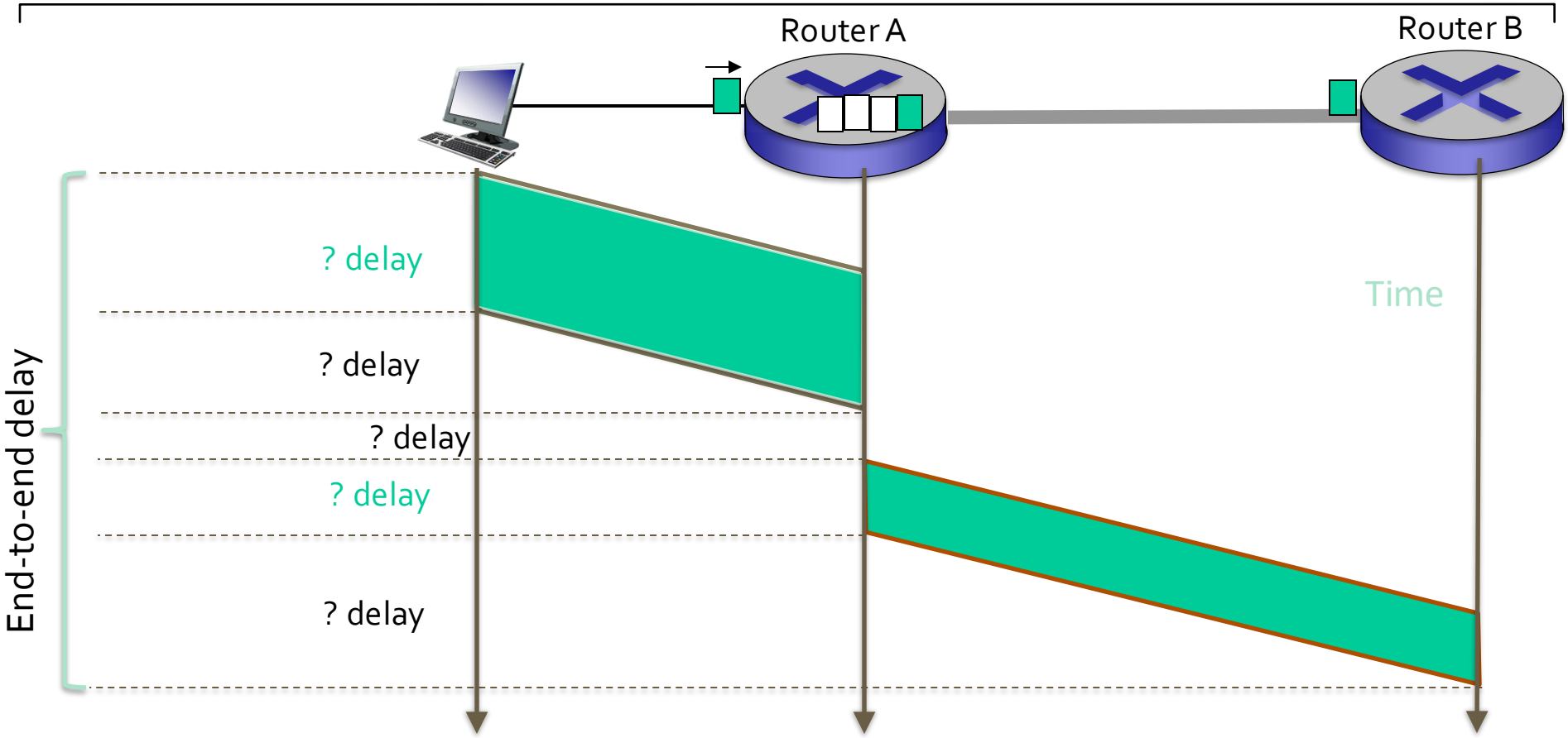
d_{prop}: propagation delay:
- d: length of physical link
- s: propagation speed (~$3x10^8$ m/sec)
  - $d_{prop} = d/s$

$$d_{total} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

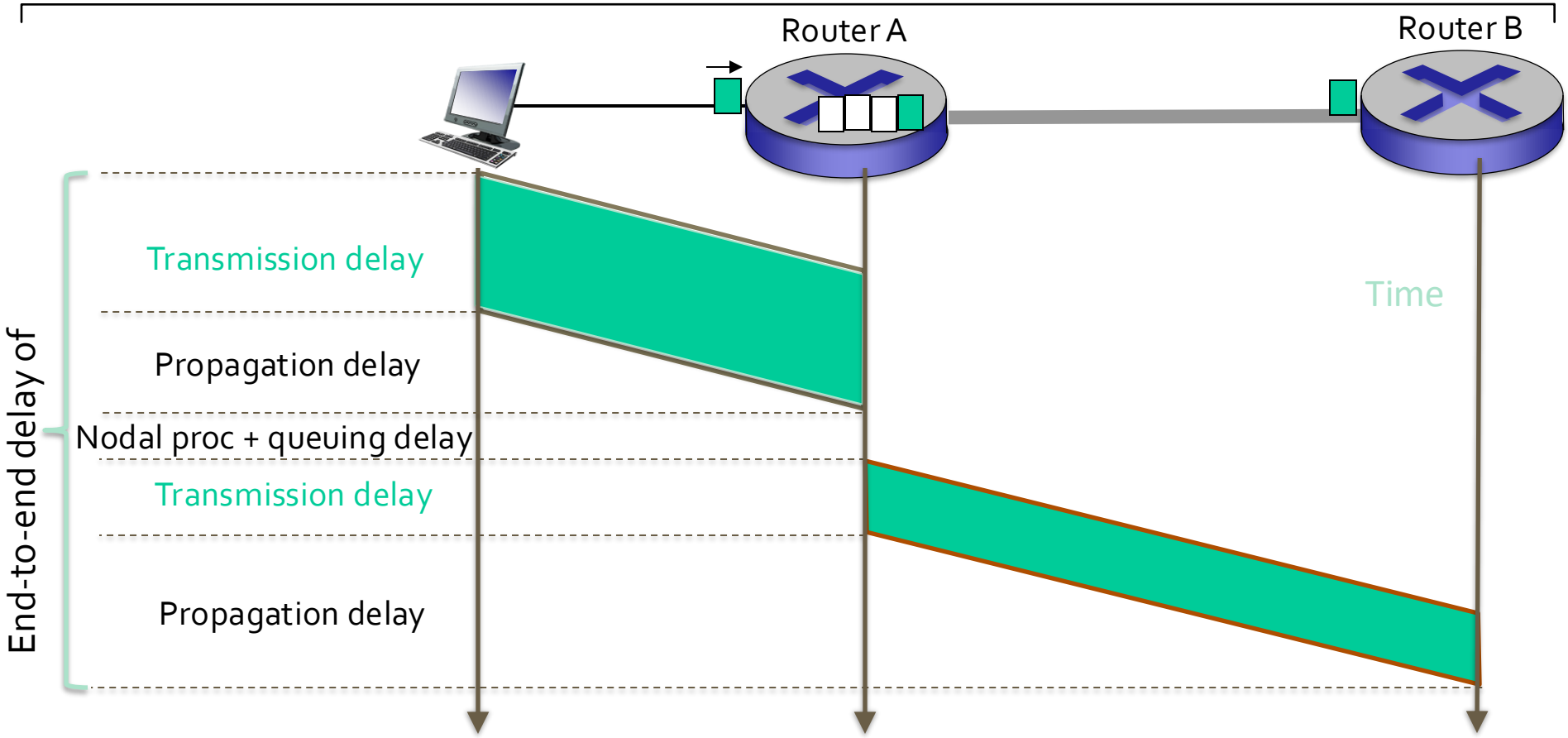
d_{proc}: nodal processing
- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay
- time waiting at output link for transmission
- depends on congestion level of router

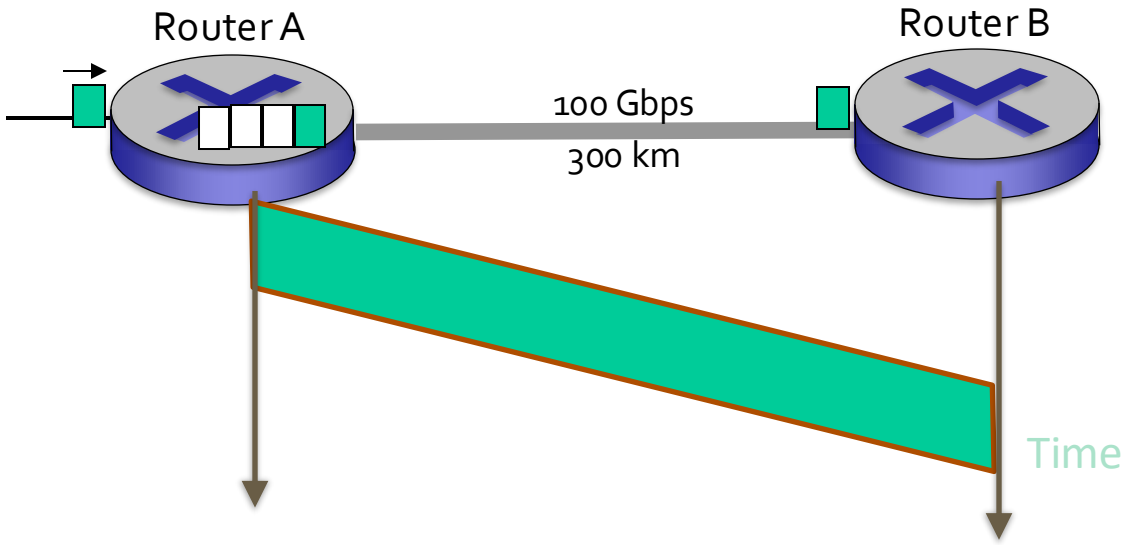
Illustrating packet end – end delay



Illustrating packet end – end delay



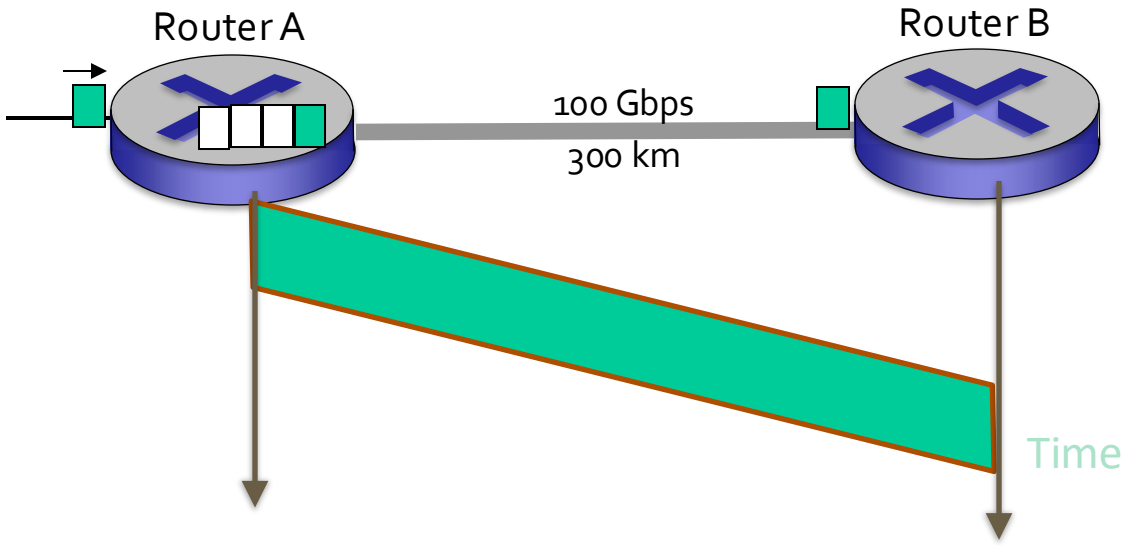
Illustrating packet end – end delay



- When A-B link (300km) has 100 Gbps bandwidth and transmitting files:
- 1 KByte? → d_{trans} =
- 1TByte? → d_{trans} =
- d_{prop} =

SO?

Illustrating packet end – end delay



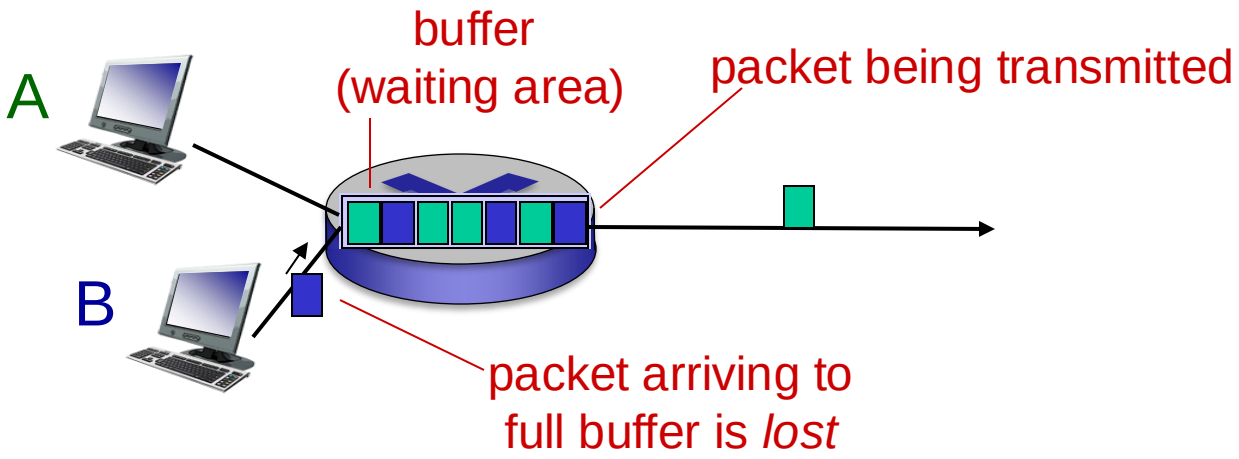
- When A-B link (300km) has 100 Gbps bandwidth and transmitting files:
- 1 KByte? → $d_{trans} = 8x10^3/1x10^{11} = 80$ ns
- 1TByte? → $d_{trans} = 8x10^{12}/1x10^{11} = 8x10^1 = 80$ s
- $d_{prop} = 300x10^3/3x10^8 = 1x10^{-3} = 1$ ms

SO

- d_{prop} dominates d_{trans} when trasmitting 1 Kbyte,
- d_{trans} dominates d_{prop} when transmitting 1TByte

Packet loss

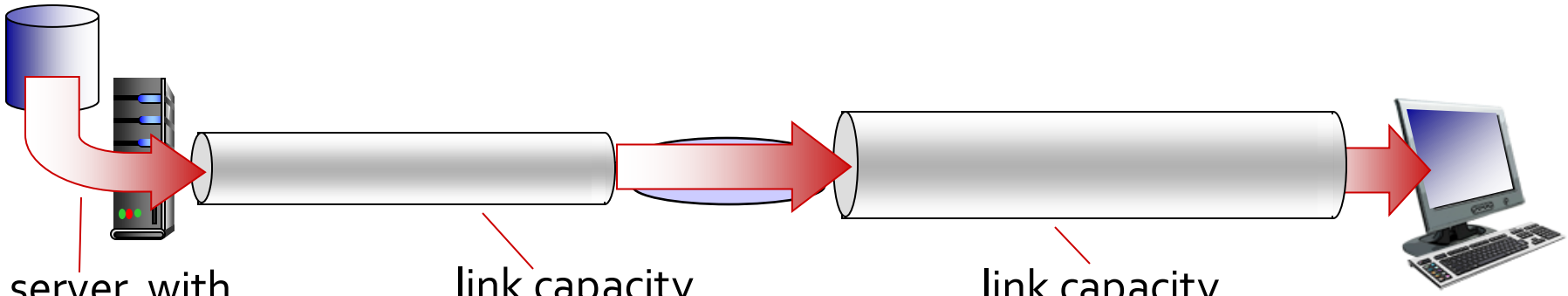
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all



Throughput

throughput: rate (bits/time unit) at which bits transferred between sender/receiver

- *instantaneous:* rate at given point in time
- *average:* rate over longer period of time



server, with file of F bits to send to client

server sends bits (fluid) into pipe

link capacity R_s bits/sec

pipe that can carry fluid at rate R_s bits/sec)

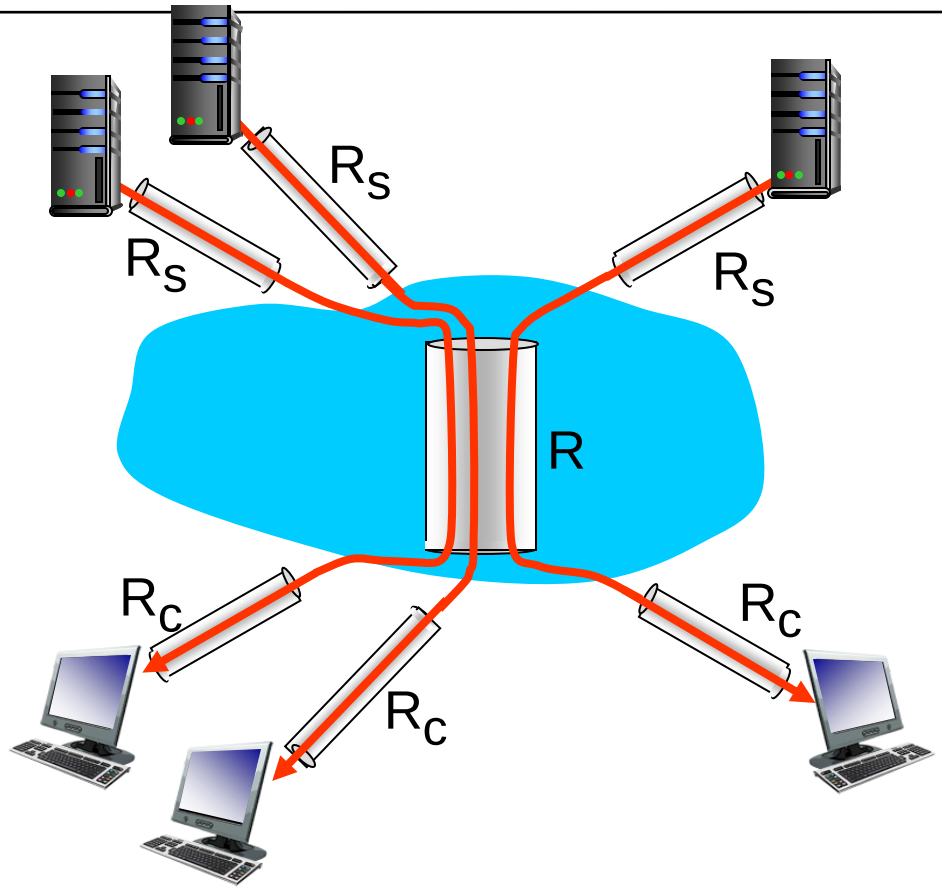
link capacity R_c bits/sec

pipe that can carry fluid at rate R_c bits/sec)

Throughput: Internet scenario

per-connection end-end throughput:
- *?*

in practice:
- R_c or R_s is often bottleneck



10 connections (fairly) share backbone bottleneck link *R* bits/sec

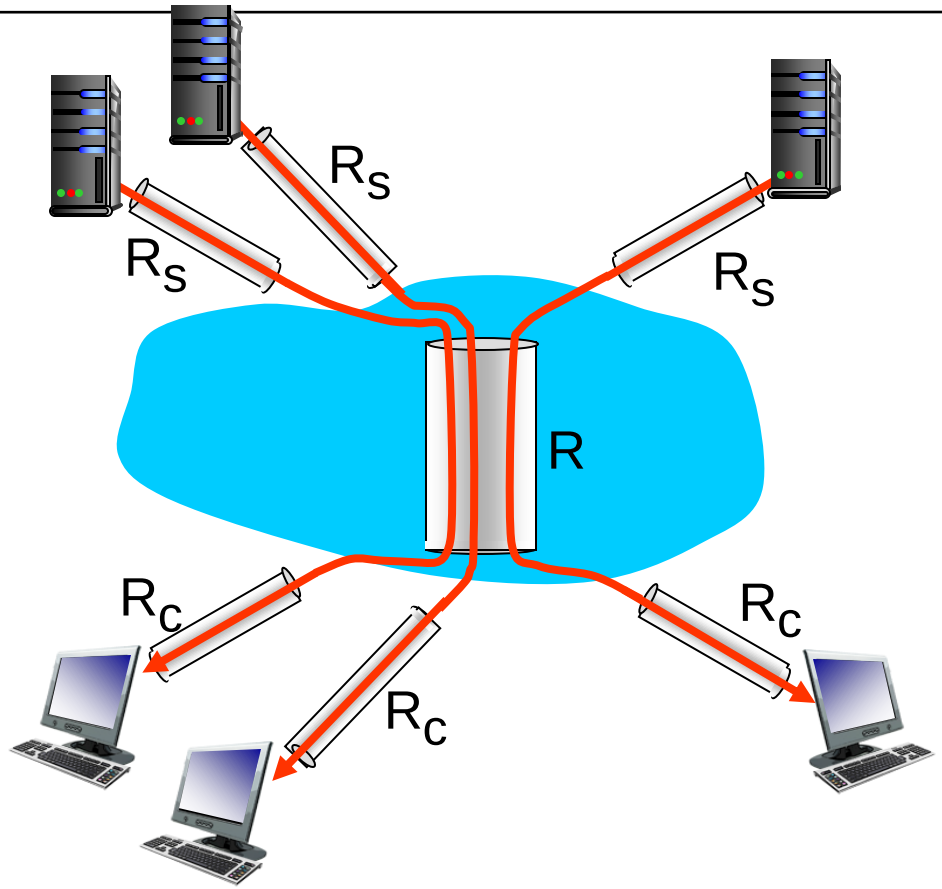
Throughput: Internet scenario

per-connection end-end throughput:

- *min(R_c, R_s, R/10)*

in practice:

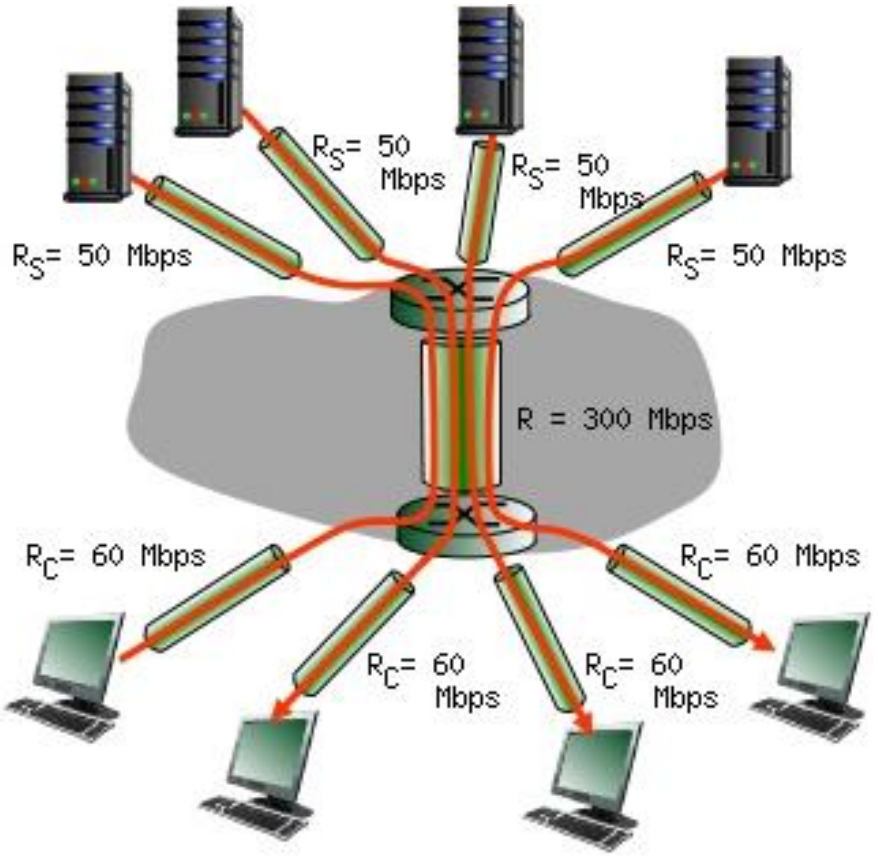
- R_c or R_s is often bottleneck



10 connections (fairly) share backbone bottleneck link *R* bits/sec

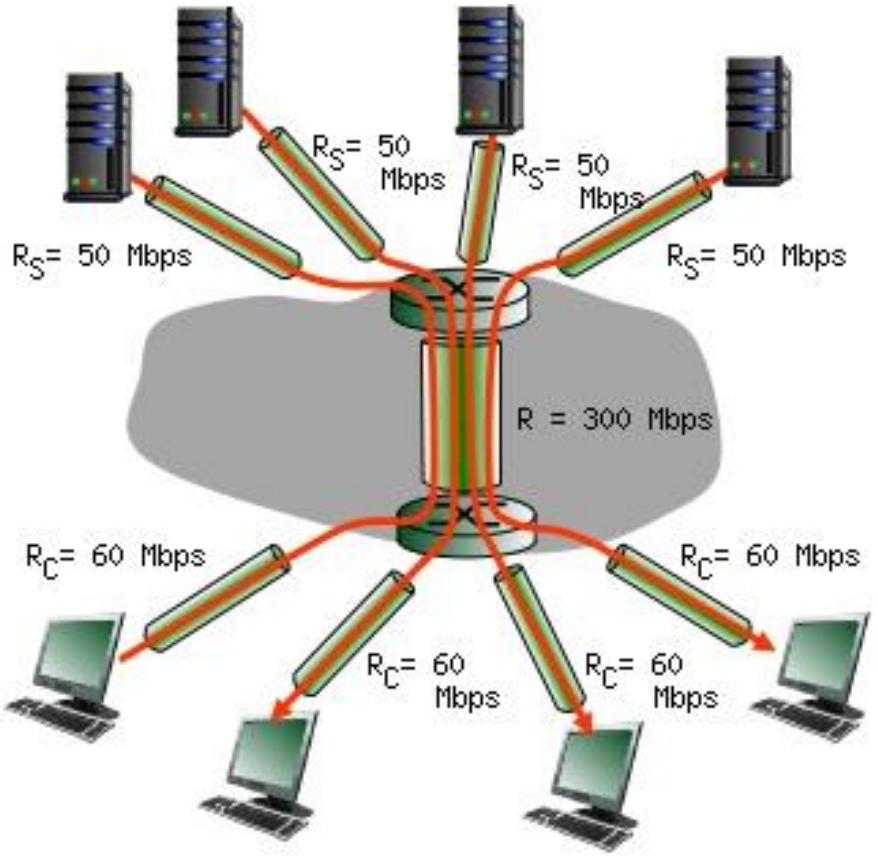
Example

- maximum achievable end-end throughput (in Mbps) = ?
- bottleneck link for each session = ?
- Utilization of each link
  - ? for Rs
  - ? for R
  - ? for Rc



Example

- maximum achievable end-end throughput (in Mbps) = 50 Mbps
- bottleneck link for each session = 50 Mbps
- Utilization of each link
  - 50/50 * 100% = 100% for Rs
  - 50/75 * 100% = 66.67% for R
  - 50/60 * 100% = 83.33% for Rc



Summary

Today:

- Sending packets
- Bandwidth (bps)
- Latency (delay)
- Bandwidth – Delay (Volume) (bits)
- Throughput (bits/ time unit)

Camino discussion:

- Reflection
- Exit ticket

Next time:

- read 1.5, 1.6, and 1.7 of K&R
- follow on Canvas! material and announcements

Any questions?