Circuit and Packet Switching

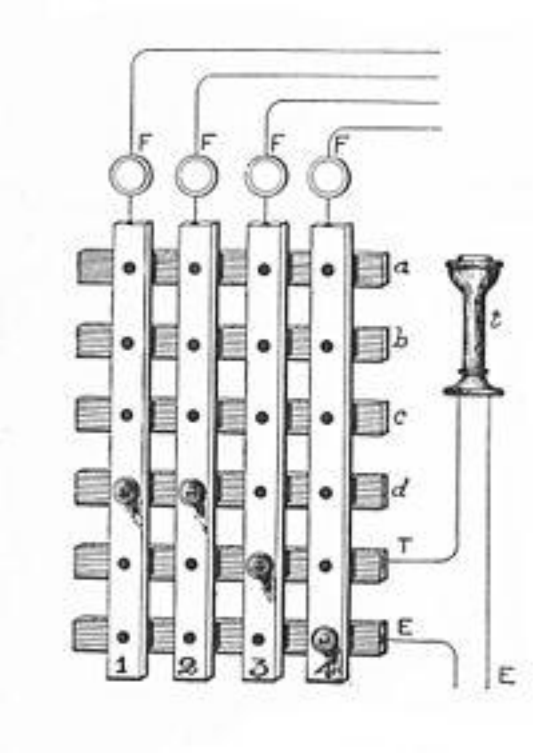
References

- https://www.youtube.com/watch?v=ulKhM0edtDI
- Kurose, Ross – Computer Networking: A Top-Down Approach

Circuit Switching – the Beginning

- The concept of how telephone switching works – creates a dedicated communication links between two communication nodes (telephones)

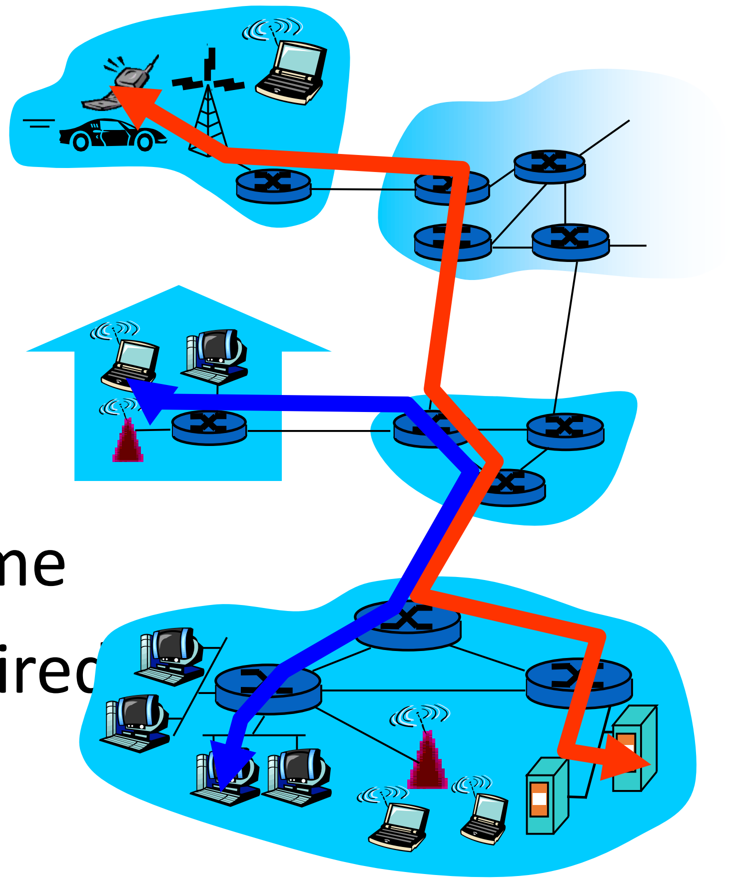
- In January 1878, the first telephone switch went into operation in New Haven Connecticut.



Circuit Switching

End-end resources reserved for "call"

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup (connection setup – effort and time for dedicating links for transmission) is required



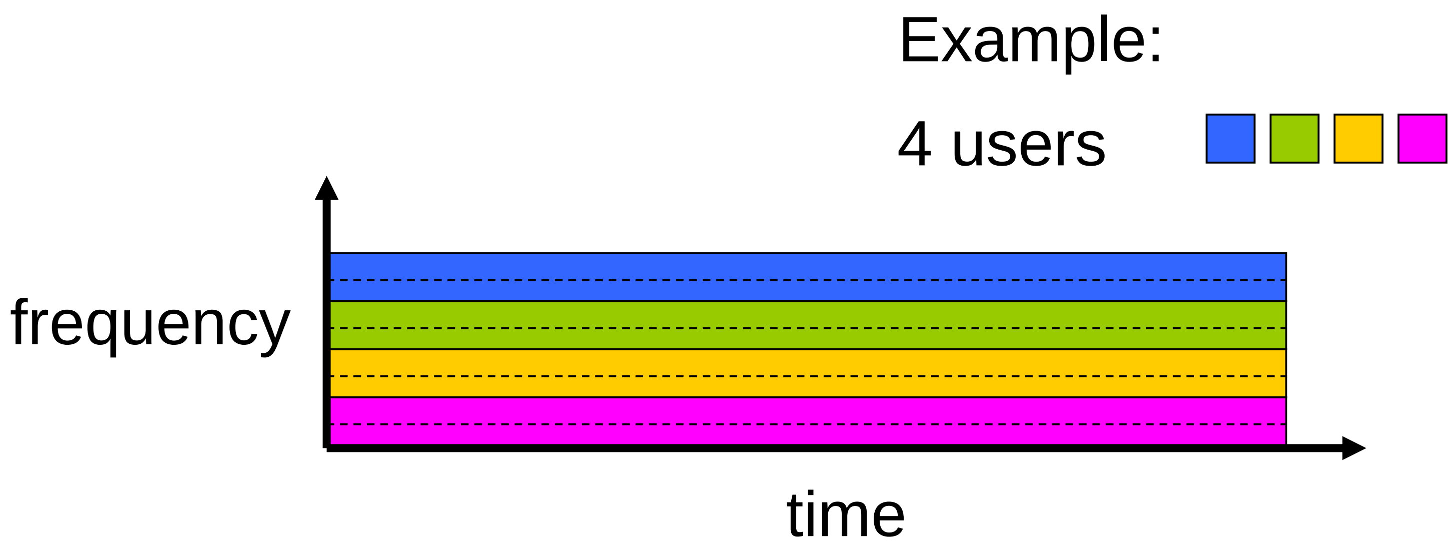
Circuit Switching

network resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- resource piece *idle* if not used by owning call *(no sharing)*

- dividing link bandwidth into "pieces"
  - frequency division
  - time division

- **Frequency-division Multiplexing (FDM)**
  - the frequency spectrum of a link is divided up among the connections established across the link.
  - the link dedicates a frequency band to each connection for the duration of the connection.



- **Frequency-division Multiplexing (FDM)**
  - Example: FM radio stations share the frequency spectrum between 88 MHz and 108 MHz, with each station being allocated a specific frequency band.

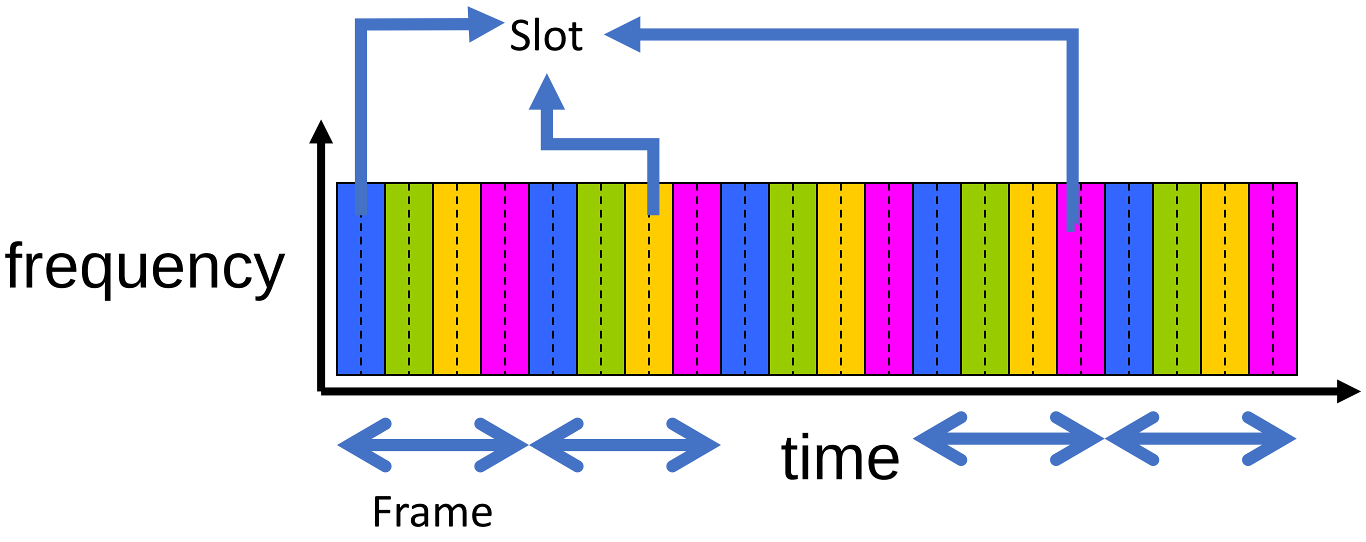
- **Time Division Multiplexing (TDM)**
    - time is divided into frames of fixed duration, and each frame is divided into a fixed number of time slots.
    - the network dedicates one time slot in every frame to this connection. These slots are dedicated for the sole use of that connection, with one time slot available for use (in every frame) to transmit the connection’s data.

Circuit Switching: TDM

Example:

4 users

TDM



Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

Example:

4 users

- Link capacity: 1.536 Mbps
- Link has 24 slots/sec

- Per slot capacity =
  - = 1.536/24 = 0.064 Mbps

- In one frame, one user gets 1 slot

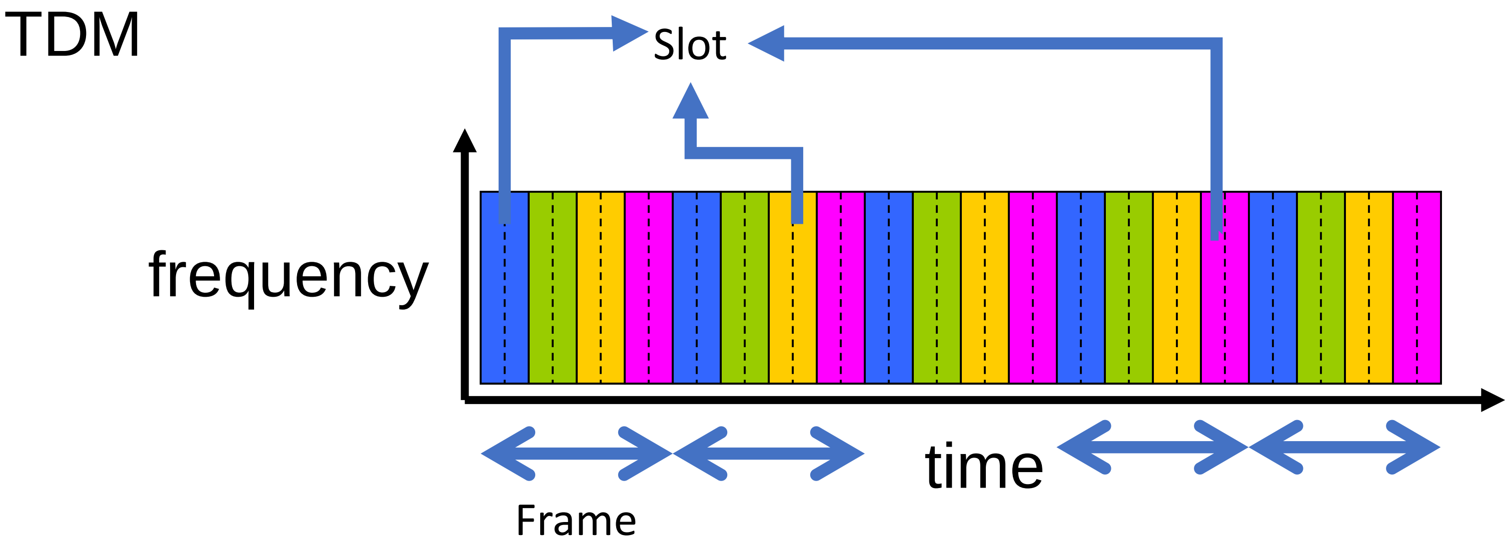
And in 1 slot = 0.064Mbits can be transmitted.

The file length = 640000 bits,

Thus time required = File length/Slot capacity

= 640000/0.064Mbps = 10 seconds

- Total time = Circuit setup time + Transmission time = 10 seconds + 500 msec = 10.5 sec.



Network Core: Packet Switching

each end-end data stream divided into *packets*

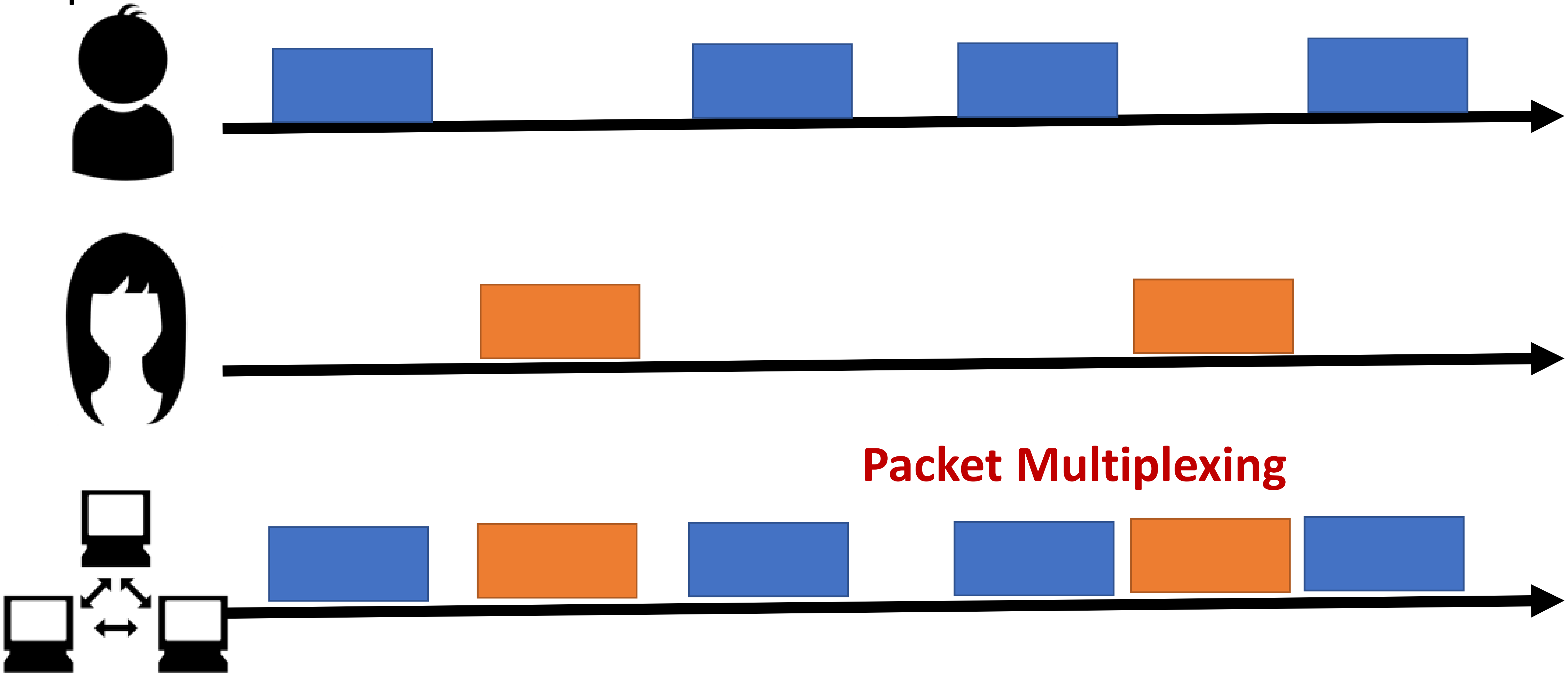
- user A, B packets *share* network resources
- each packet uses full link bandwidth
- resources used *as needed*

~~Bandwidth division into "pieces"~~
~~Dedicated allocation~~
~~Resource reservation~~

- **store and forward**: packets move one hop at a time
  - Node receives complete packet before forwarding

Packet Switching

- Decide data boundary from the communication of one user – data packets

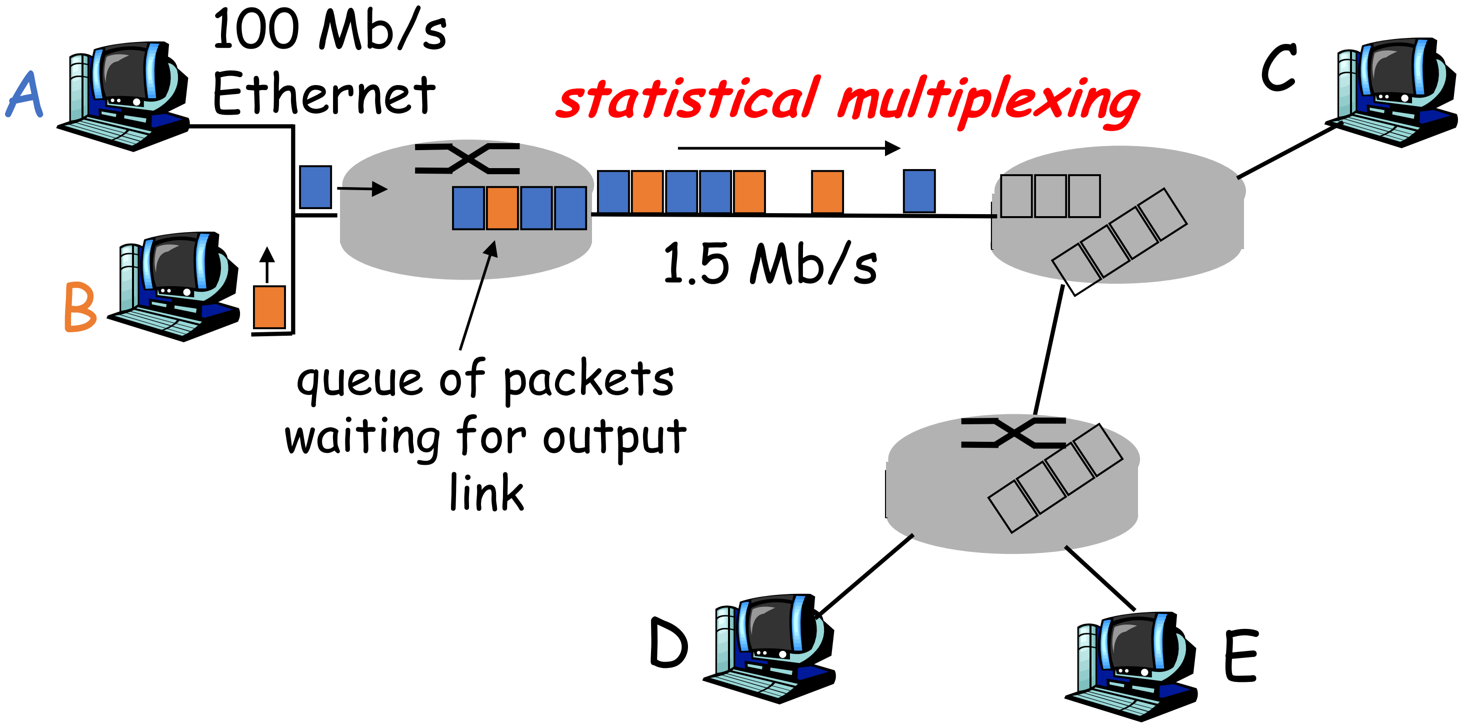


Packet Switching: Statistical Multiplexing

- **Statistics**: the science that deals with the collection, classification, analysis, and interpretation of numerical facts or data.

- **Statistical multiplexing** refers to merging data packets from multiple sources and transmitting over a common channel.

Packet Switching: Statistical Multiplexing



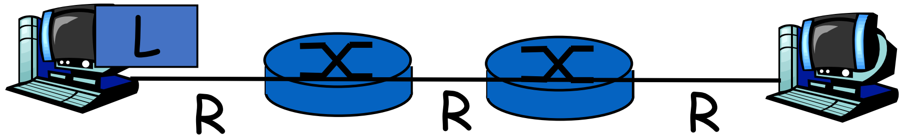
Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand ***statistical multiplexing***.

TDM: each host gets same slot in revolving TDM frame.

Network Core: Packet Switching

- **store and forward**: packets move one hop at a time
  - Node receives complete packet before forwarding

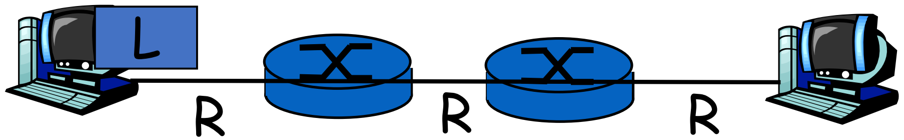
Packet-switching: store-and-forward



- Source has 3 packets, each having length L bits
- Transmission rate over a link is R bits per second (R bits/sec or R bps)

- Calculate the delay from transmitting all the 3 packets from one end system to another ?

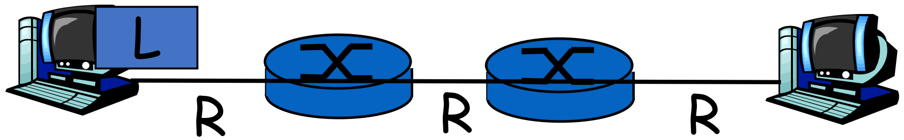
Packet-switching: store-and-forward



- Transmission Time (Time to transmit a packet over a link) = L/R seconds

- It takes L/R seconds to transmit (push out) packet of L bits on to link at R bps – At L/R seconds, the packet reaches the first router

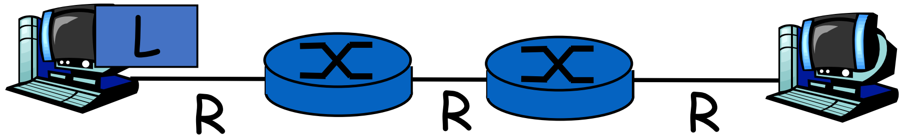
Packet-switching: store-and-forward



- The packet will take L/R (from first router to second) and additional L/R (from second router to end system) to reach the system at the other end.

- Thus, it takes 3L/R seconds to reach the system at other end

Packet-switching: store-and-forward



- End –to-end delay for 1 packet= 3L/R (assuming zero propagation delay)

- For the 3 packets at source to reach destination, end-to-end delay = 3*(3L/R) = 9L/R

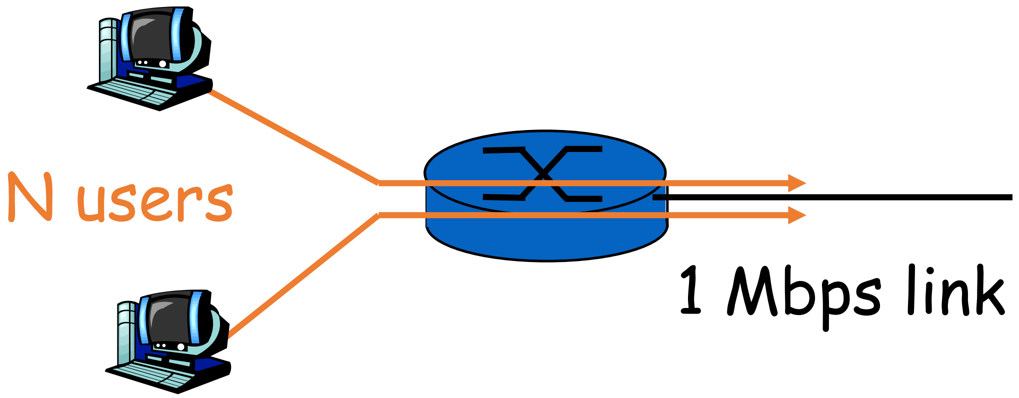
<u>Example:</u>

- L = 7.5 Mbits
- R = 1.5 Mbps
- transmission delay = 15 sec

Packet switching versus circuit switching

Packet switching allows more users to use network!

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time
- *circuit-switching:*
  - 10 users
- *packet switching:*
  - with 35 users, probability > 10 active at same time is less than .0004



Q: how did we get value 0.0004?

Packet switching allows more users to use network!

- For circuit switching
  - Number of users = Link Capacity/ Required Capacity (data rate) for each user

    = 1Mbps / 100 Kbps = 10 users

- For Packet Switching
  - The same link can be shared by users at any given time
  - And, not all users are active always. (10% of duration – active, otherwise - passive)
  - So, we need to find the number of users such that the probability of having 10 users active at any given time is zero (or close to zero)

  - It turns out, that when number of users is 35, the probability of 10 users being active simultaneously is close to 0

Packet switching versus circuit switching

Is packet switching a "winner?"

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion: packet delay and loss
- protocols needed for reliable data transfer, congestion control

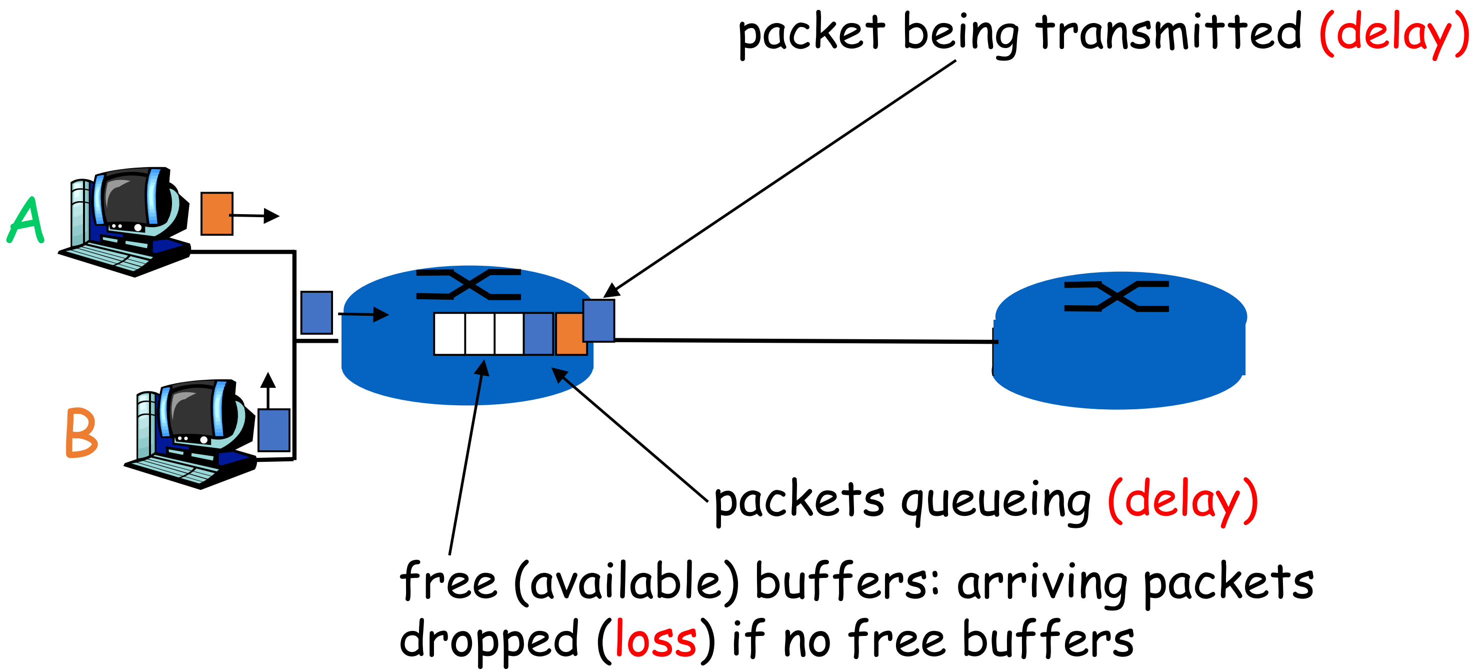
- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - Virtual circuit switching is a packet switching technology that emulates circuit switching, in the sense that the connection is established before any packets are transferred, and packets are delivered in order.

Delay, loss and throughput in packet-switched networks

How do loss and delay occur?

packets *queue* in router buffers

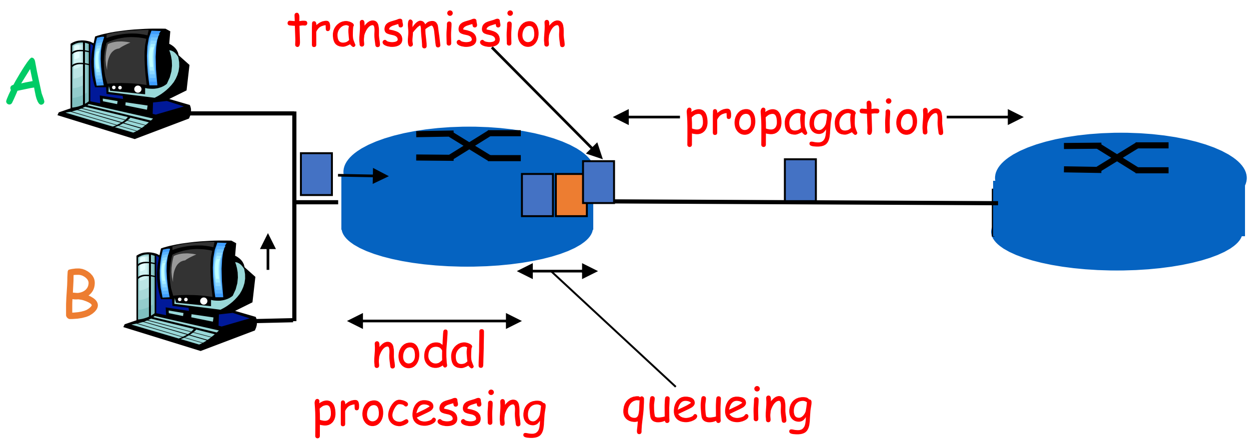
- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn



Four sources of packet delay

- 1. nodal processing:
  - check bit errors
  - determine output link

- 2. queueing
  - time waiting at output link for transmission
  - depends on congestion level of router



Delay in packet-switched networks

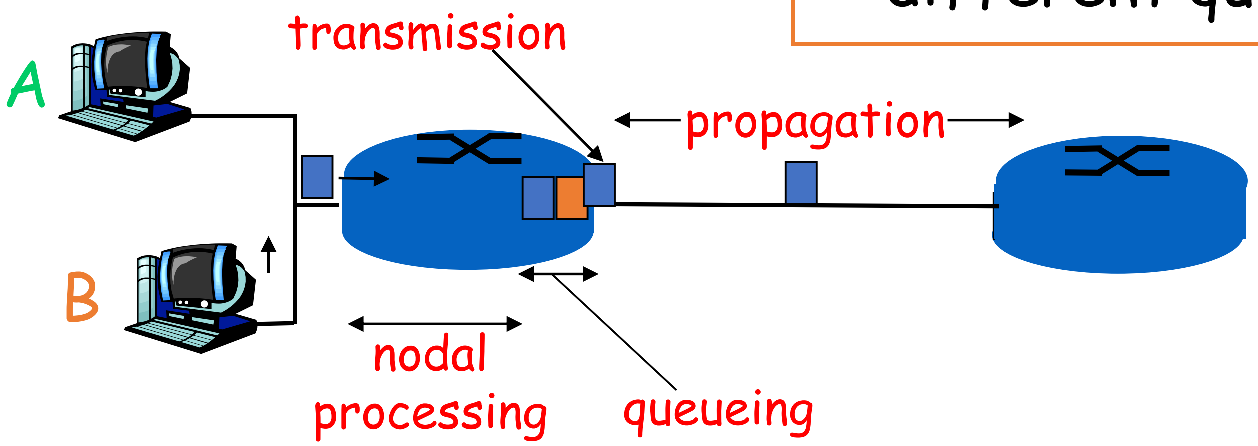
3. Transmission delay:

- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

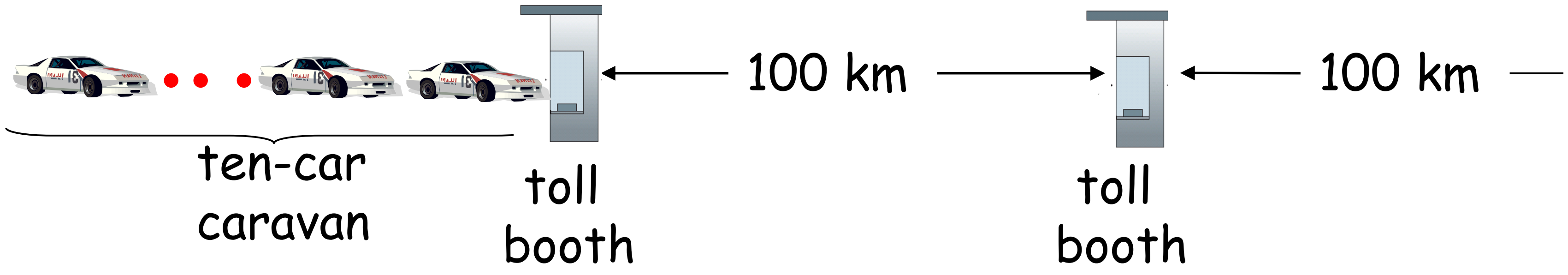
4. Propagation delay:

- d = length of physical link
- s = propagation speed in medium (~3x10^8 m/sec)
- propagation delay = d/s

Note: s and R are *very* different quantities!

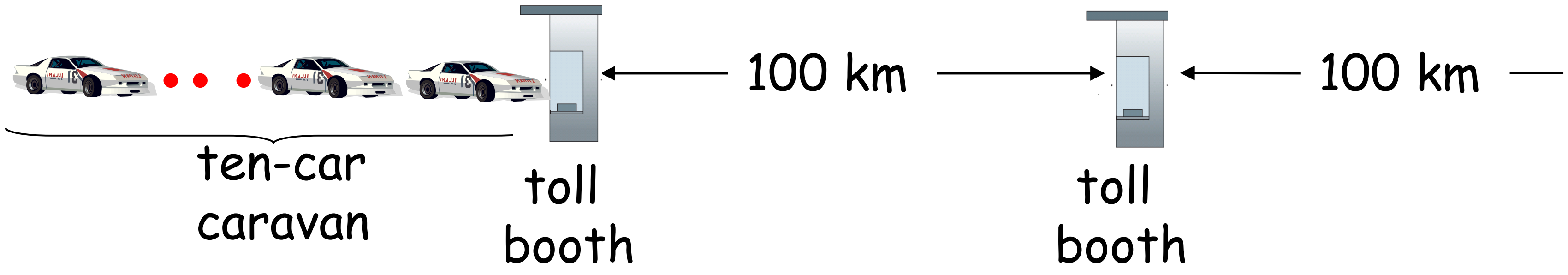


Caravan analogy



- cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (transmission time)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?
- Time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- A: 62 minutes

Caravan analogy (more)



- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?

- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!

Nodal delay

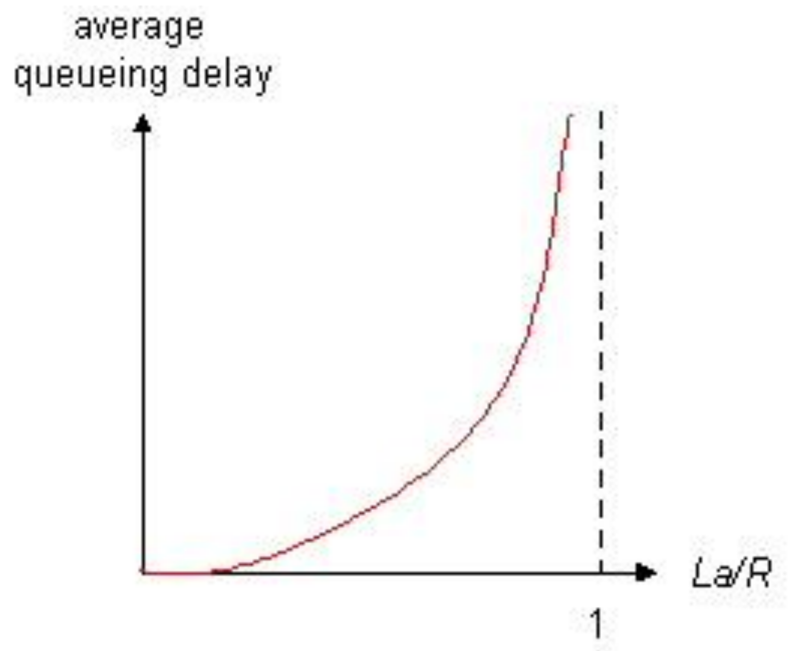
$$\boxed{d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}}$$

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

Queueing delay (revisited)

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate(packets per second)

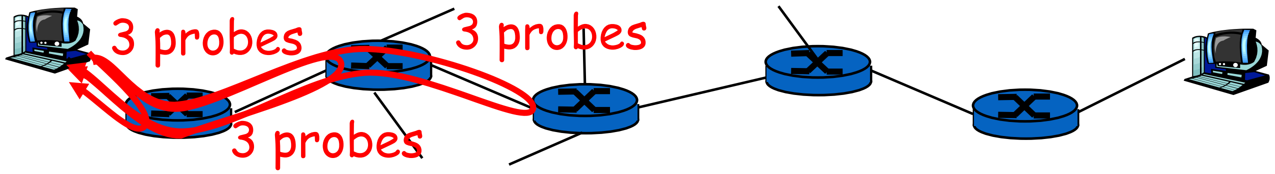
traffic intensity = La/R



- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

“Real” Internet delays and routes

- What do “real” Internet delay & loss look like?
- **`Traceroute`** program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.



“Real” Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measurements from
gaia.cs.umass.edu to cs-gw.cs.umass.edu

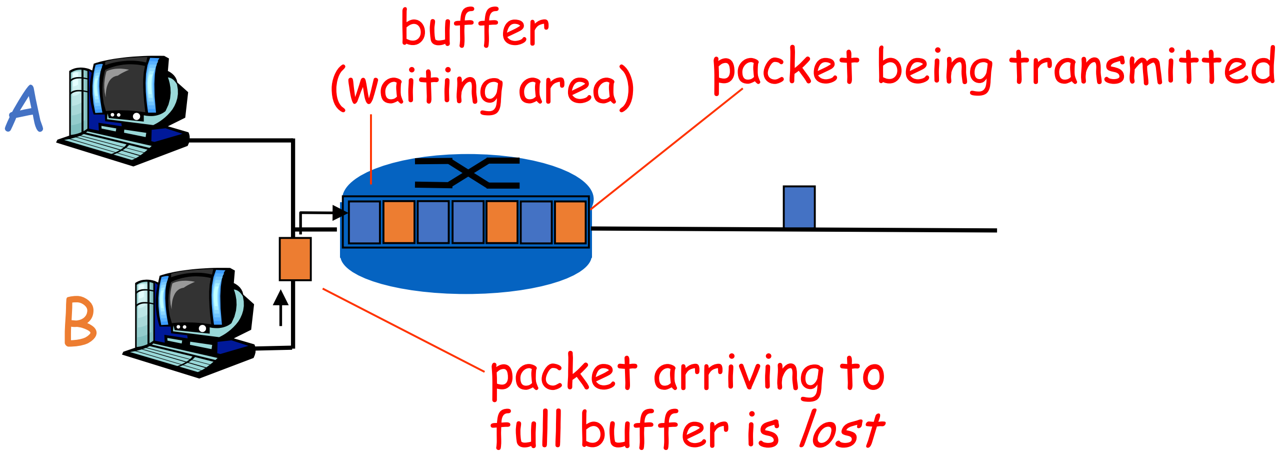
```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link

* means no response (probe lost, router not replying)

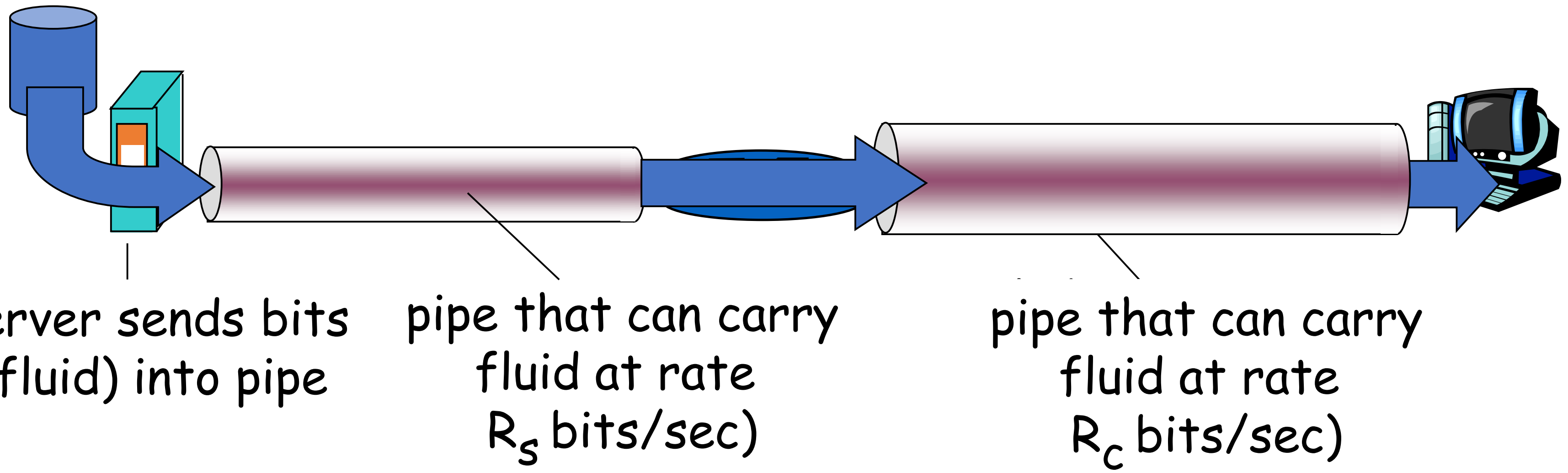
Packet loss

- 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



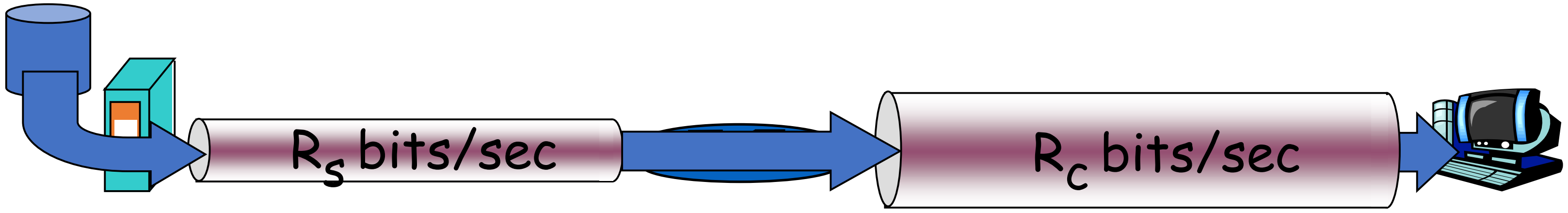
Throughput

- *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



Throughput (more)

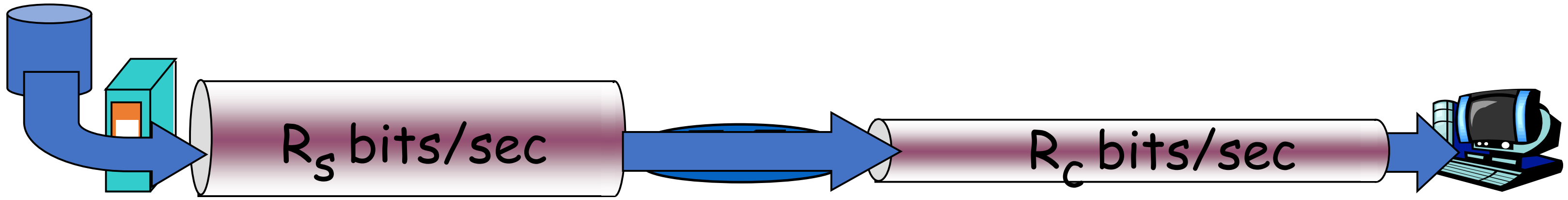
- $R_s < R_c$ What is average end-end throughput?



- Throughput at the client side will be R_s

Throughput (more)

- $R_s > R_c$ What is average end-end throughput?



- Throughput at the client side will be R_c

Throughput (more)

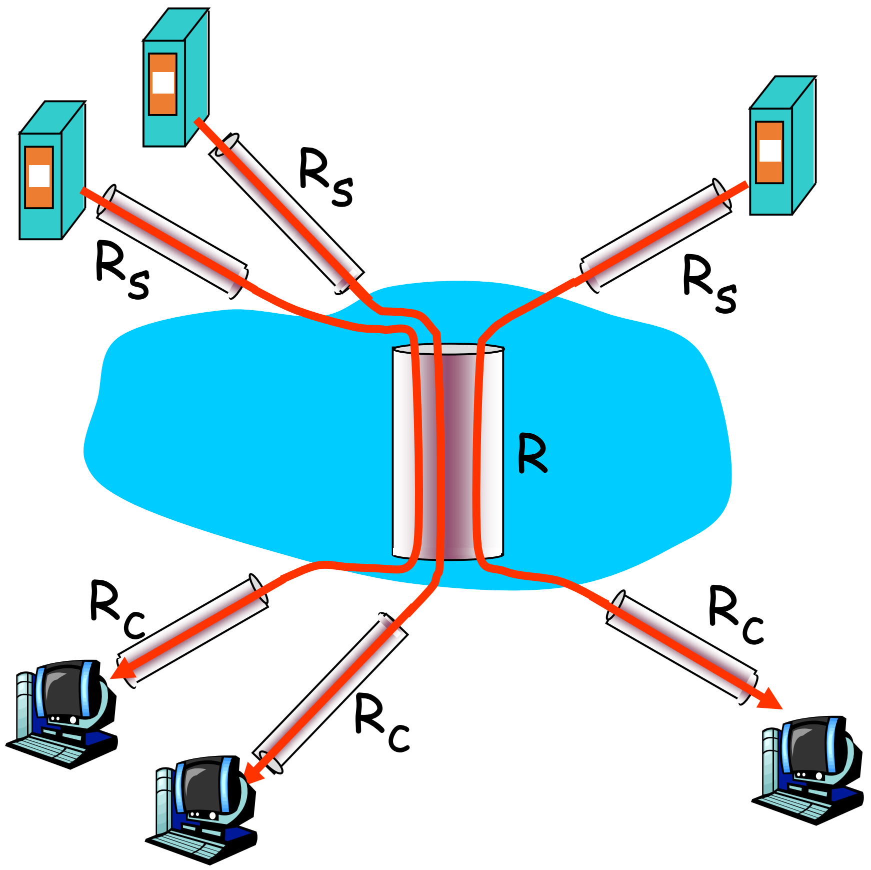
bottleneck link

link on end-end path that constrains end-end throughput

Throughput for a simple two-link (two-hop) network will be min (R_s, R_c

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

Virtual Circuit Switching

- A virtual-circuit network is a combination of a circuit-switched network and a datagram network.

- https://www.coursera.org/lecture/packet-switching-networks-algorithms/packet-switching-virtual-circuits-mskWr

- https://www.youtube.com/watch?v=856eO4vvXas

Virtual Circuit Switching

- It has characteristics of both – Circuit switched and Packet Switched:
  - As in a circuit-switched network, there are **setup and teardown phases** in addition to the data transfer phase.
  - Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
  - As in a circuit-switched network, **all packets follow the same path established during the connection**.
  - As in a datagram network, **data are packetized and each packet carries an address in the header**. However, the address in the header has local jurisdiction not end-to-end jurisdiction. The reader may ask how the intermediate switches know where to send the packet if there is no final destination address carried by a packet.

Comparison between VC and Packet/Datagram Switching

Issue	Datagram network	Virtual-circuit network
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Routers do not hold state information about connections	Each VC requires router table space per connection
Routing	Each packet is routed independently	Route chosen when VC is set up; all packets follow it
Effect of router failures	None, except for packets lost during the crash	All VCs that passed through the failed router are terminated
Quality of service	Difficult	Easy if enough resources can be allocated in advance for each VC
Congestion control	Difficult	Easy if enough resources can be allocated in advance for each VC

Virtual Circuit Switching

- A virtual-circuit network is normally implemented in the data link layer, while a circuit-Switched network is implemented in the physical layer and a datagram network in the network layer.