CS 372 Lecture #4

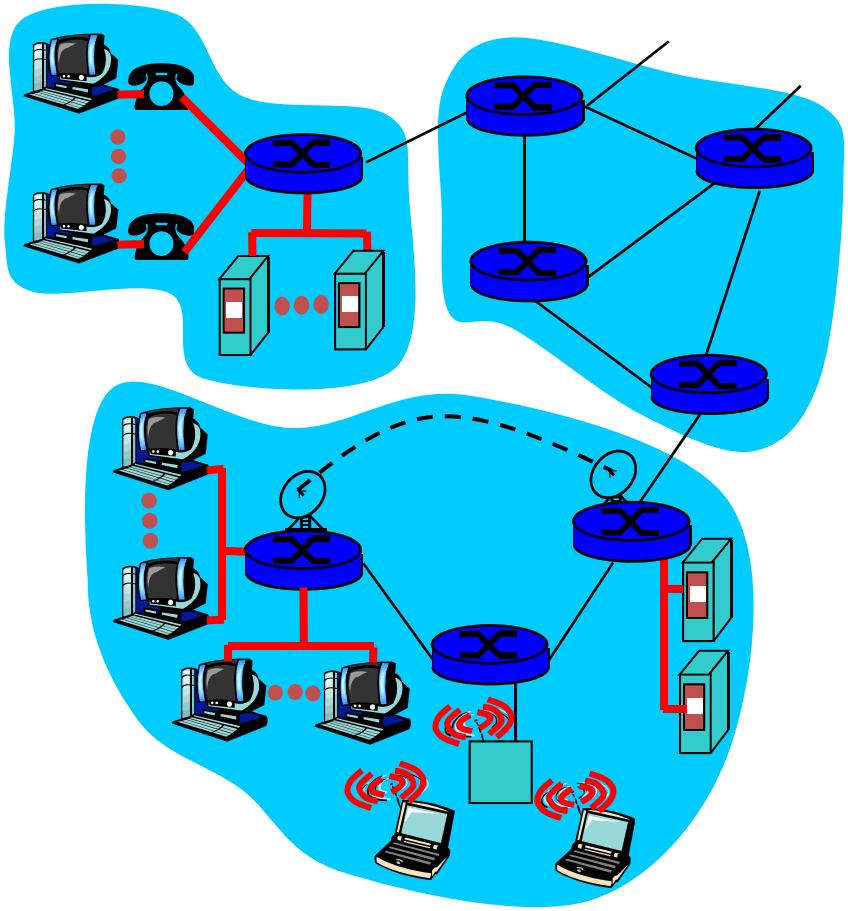
Overview of Networking:

- access networks
- internet structure
- network performance
  - throughput
  - nodal delay

Note: Many of the lecture slides are based on presentations that accompany *Computer Networking: A Top Down Approach,* 6th edition, by Jim Kurose & Keith Ross, Addison-Wesley, 2013.

Access networks

Access Networks are managed by Internet Service Providers (ISP)



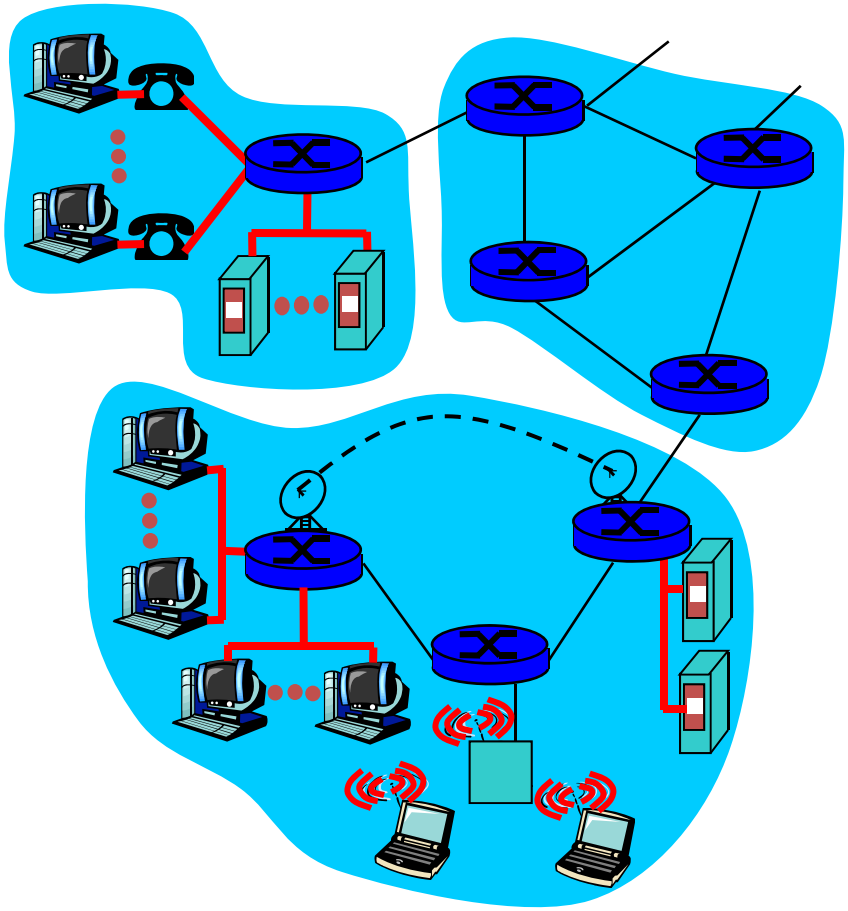
- Connection to ISP edge routers via
  - Telephone lines
  - Cable
    - copper coaxial
    - fiber
  - Wireless
    - stationary
    - mobile

More later on transmission media

Access networks

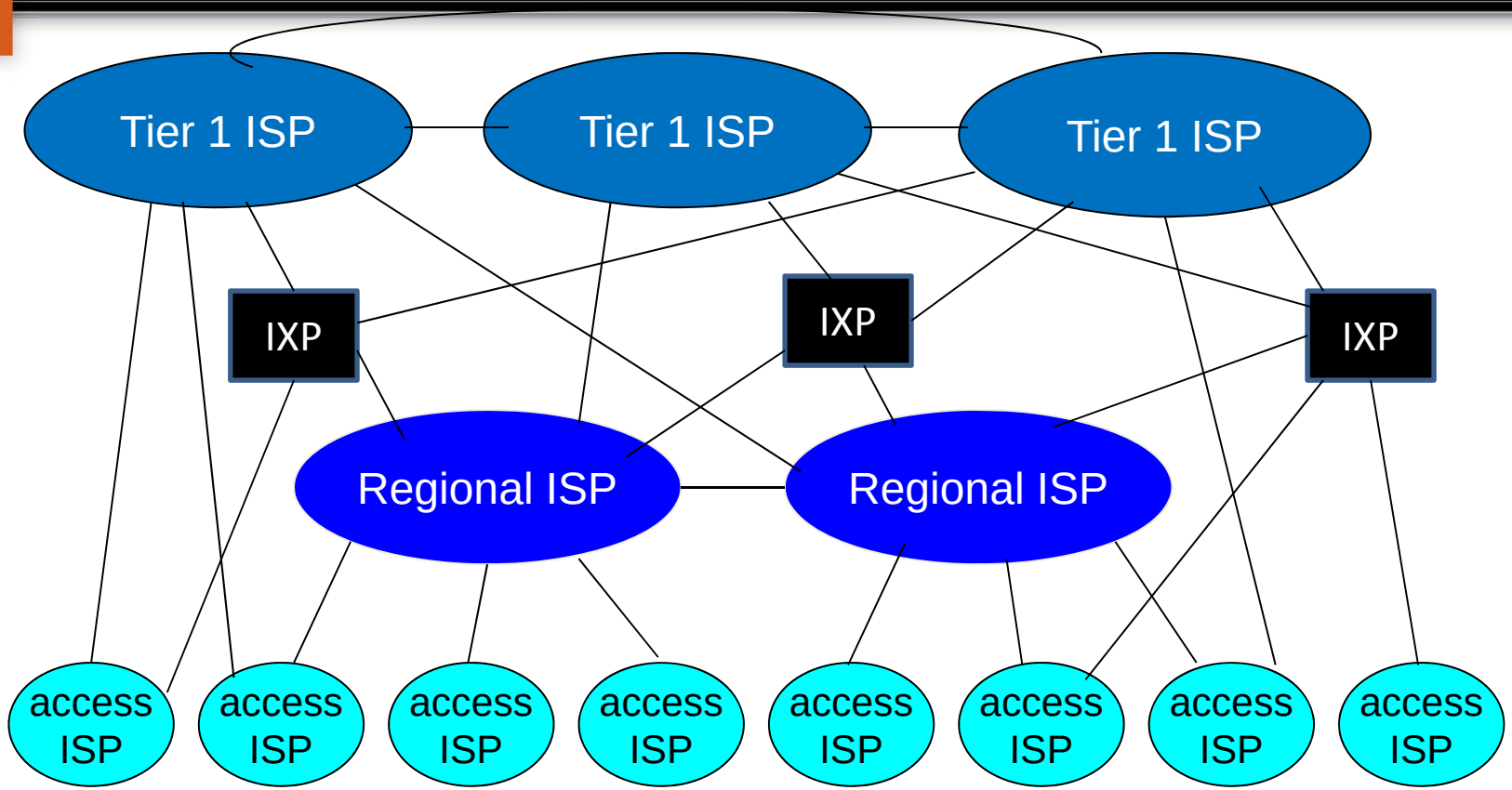
Modems *connect end systems to edge routers via access network media*

- Legacy
  - Dial-up
  - DSL (digital subscriber line)
- Cable
  - residential access nets
  - institutional access networks (school, company)
- Wireless
  - WiFi, WiMax



More later on routers and modems

Internet structure: network of networks



Hierarchical Structure of the Internet core.

- Tier 1 includes commercial ISPs (AT&T, Sprint, etc.) and content provider ISPs (Google, etc.)
- Tier 1 ISPs connect to each other, regional ISPs, and access networks via Internet Exchange Points (IXPs), or sometimes bypass the IXPs to connect more directly.

Network performance metrics

Throughput :

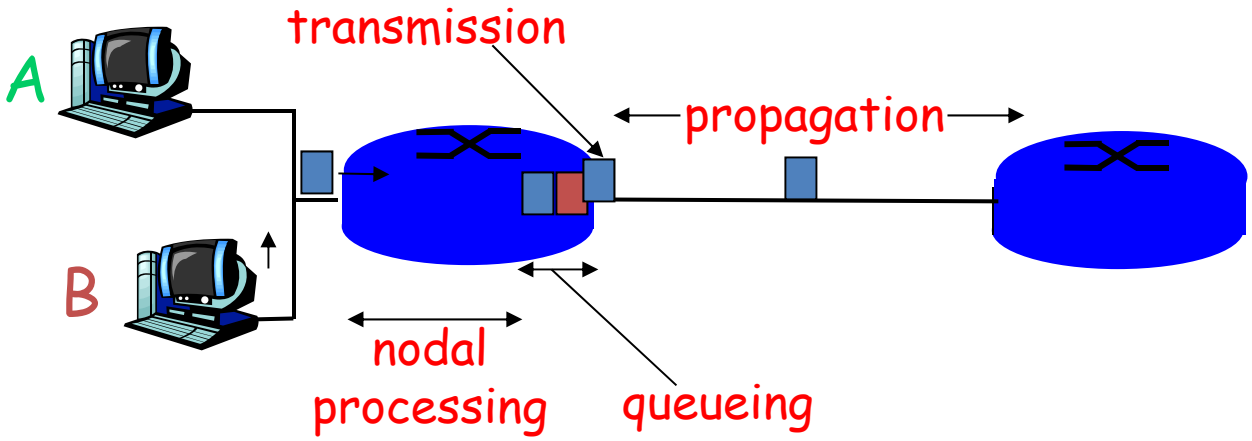
- Rate (bits/sec) at which bits are actually being transferred between sender/receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time

End-to-end delay (nodal delay) :

- Total time from initiating “send” (from source) to completed “receive” (at destination)

Four sources of packet delay

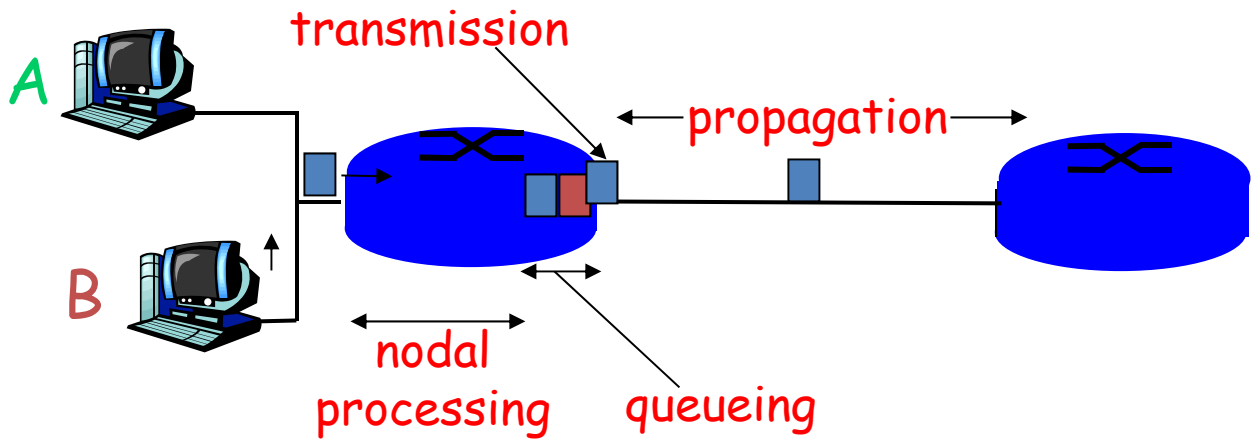
- 1. nodal processing:
  - check bit errors
  - determine output link
- 2. queueing delay
  - time waiting at output link for transmission
  - depends on congestion level of router



Four sources of packet delay

- 3. Transmission delay:
  - **R**=link bandwidth (speed in bits per second, i.e. "bps")
  - **L**=packet length (in bits)
  - transmission delay = **L/R**
- 4. Propagation delay:
  - **d** = length of physical link (in meters)
  - **s** = propagation speed in medium (~2.5 x 10^8 m/sec)
  - propagation delay = **d/s**

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

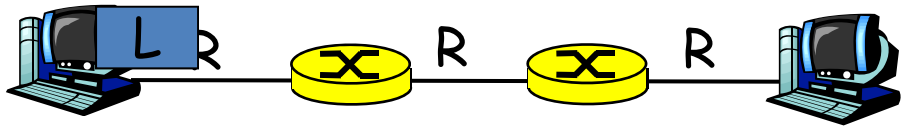


Nodal delay

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

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

The network core: Packet-switching: store-and-forward



- It takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- Entire packet must arrive at router before it can be transmitted on next link: *store and forward*
- delay = 3 x L/R (assuming zero propagation delay)

Example:

- L = 12000 bits
- R = 1.5 Mbps
- The packet is transmitted 3 times, so delay =

  3 x (12000/1500000)

  = 0.024 sec

Measuring delay with *traceroute*

- Sends 3 packets to each router in path to destination.
- Each router replies, and sender calculates total round-trip delay.

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

```
> traceroute www.eurecom.fr
```

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

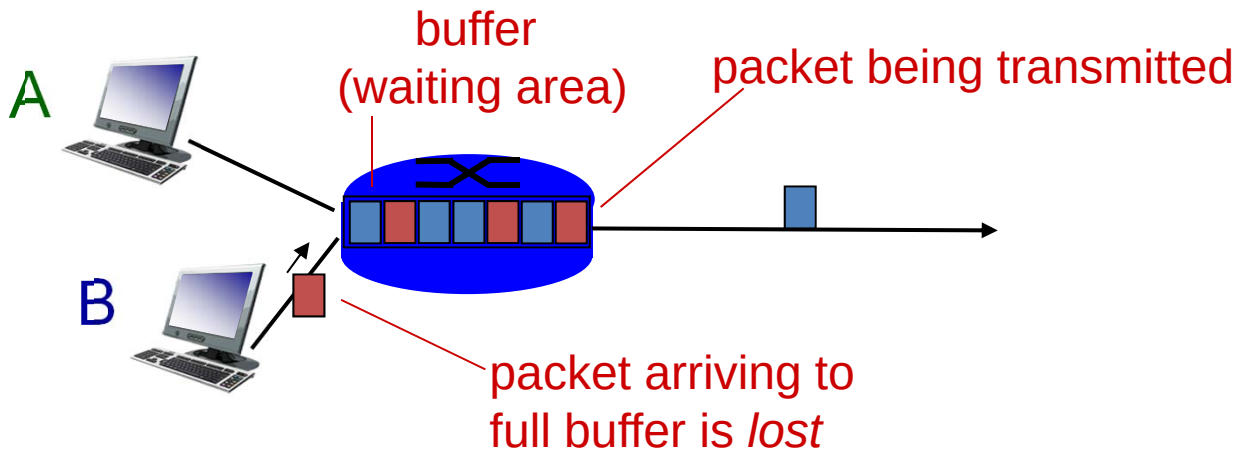
```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 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 (buffer) has finite capacity
- If packet arrives at a full queue, it is dropped (lost)
- Lost packet may possibly be retransmitted by the previous node, by the source, or not at all



See the Java applet animations on the textbook website.

Summary Lecture #4

- Access networks
- Structure of the Internet
- Definitions:
  - Throughput
  - Nodal delay
    - processing, queuing, transmission, propagation
  - Store-and-forward

See the Java applet animations on the textbook website.