Chapter 1:Computer Networks and the Internet

Chapter 1: road map

1.1 What is the Internet?

1.2 The Network Edge

1.3 The Network Core

1.4 Delay, Loss, and Throught in Packet-Swicthed Networks

1.5 Protocol Layer and Their Services Models

1.6 Networks Under Works

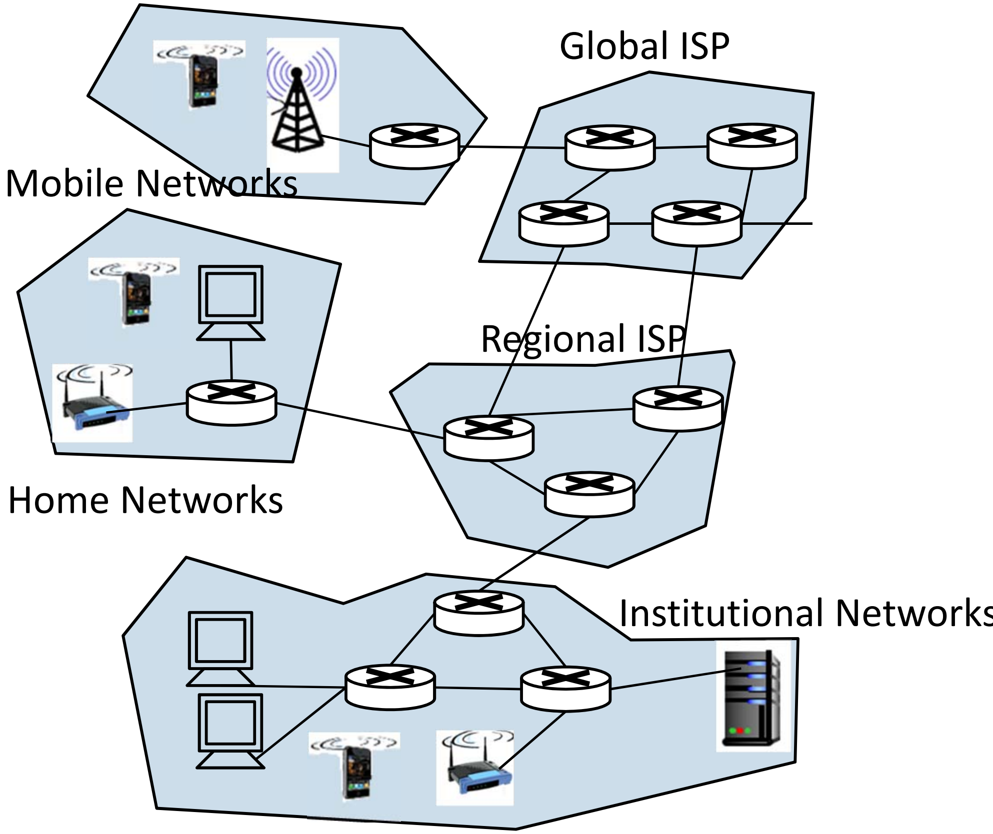
1.7 History of Computer Networking and the Internet

1.8 Summary

1.1 What Is the Internet

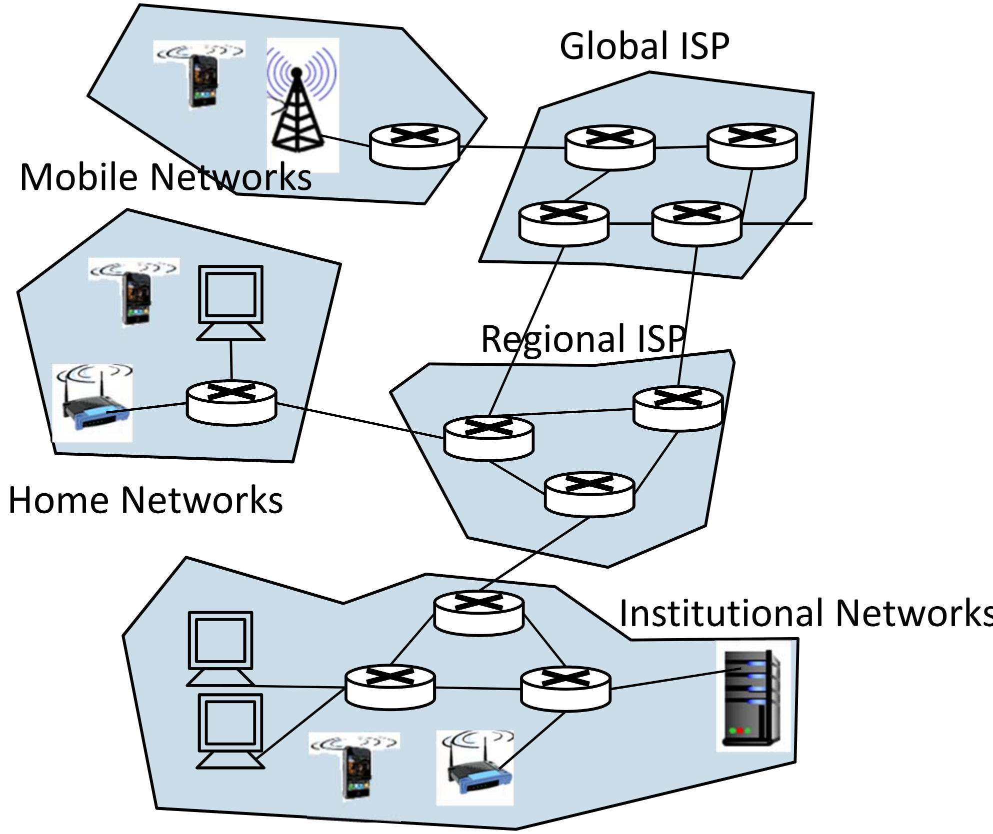
1.1.1 A Nuts-and-Bolts Description

- Millions of connected computing devices:
  - ***hosts = end systems***
  - ***Running networks apps***
- ***communication links:***
  - **fiber, copper, radio, satellite**
  - **transmission rate: *bandwidth***
- ***Packets switches:*** forward packets(chunk of data)
  - ***routers and switches***



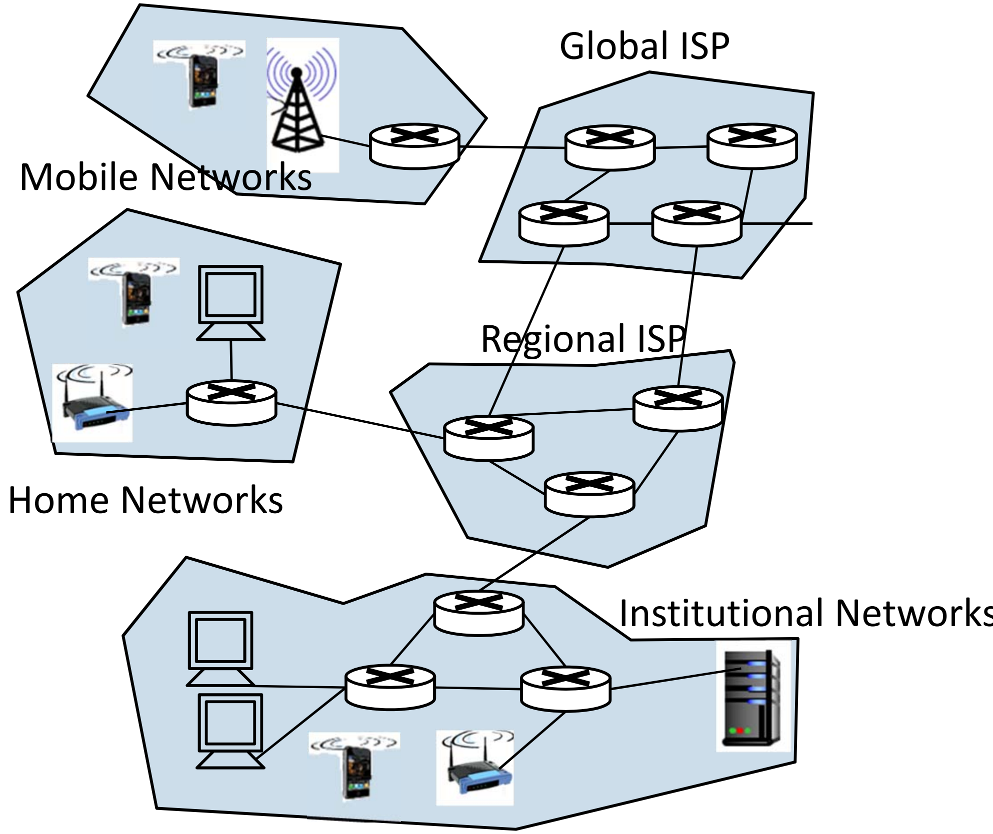
1.1.1 A Nuts-and-Bolts Description

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

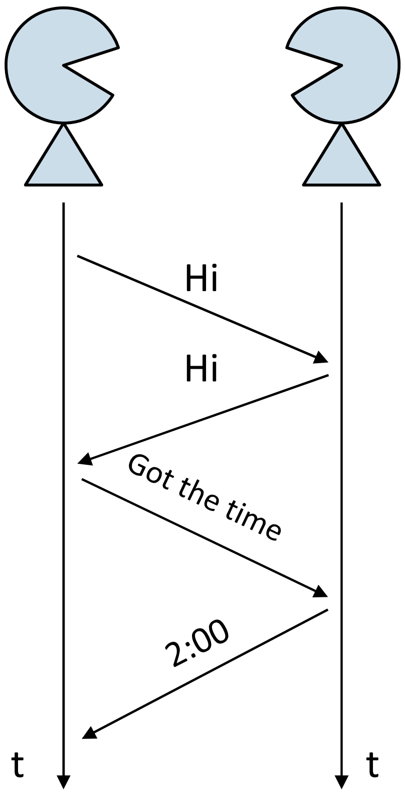


1.1.2 A Services Description

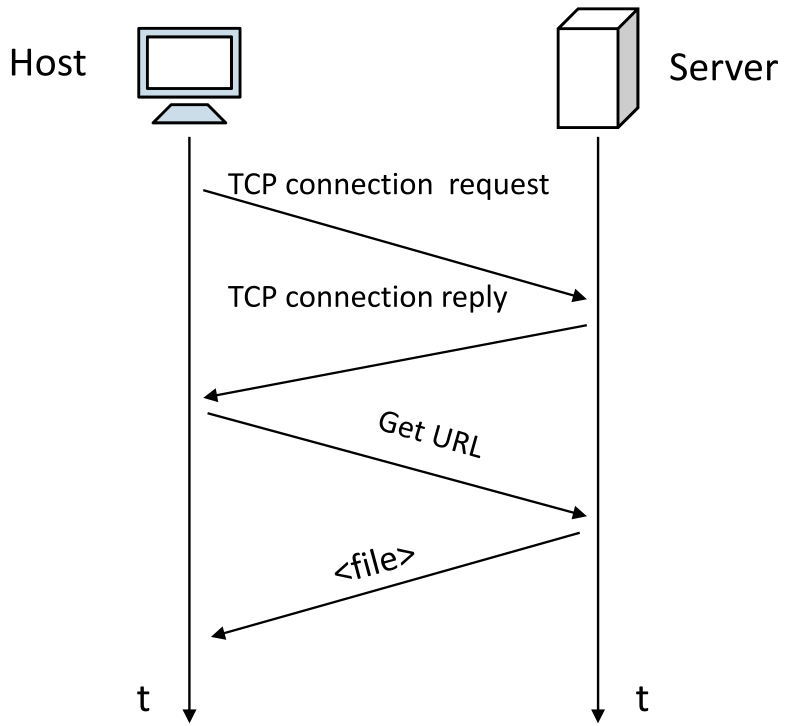
- ***"An Infrastructure that provides services to applications" :***
  - *Distributed applications*
  - E-mail, Web, SNS (Social Network Services), Online games…
- ***Provides programming interface to apps***
  - Hooks that allow sending and receiving app programs to "connect" to Internet
  - Provides services options, analogous to postal services
  - Socket interfaces: Ch. 2



1.1.3 What Is a Protocol?



Human Protocol



networks Protocol

Networks Protocols:

- *All communication activity in Internet governed by Protocols*

Protocols define format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

1.2 The Networks Edge

1.2.1 Access Networks

Network Structure:

➢ ***Networks edge:***

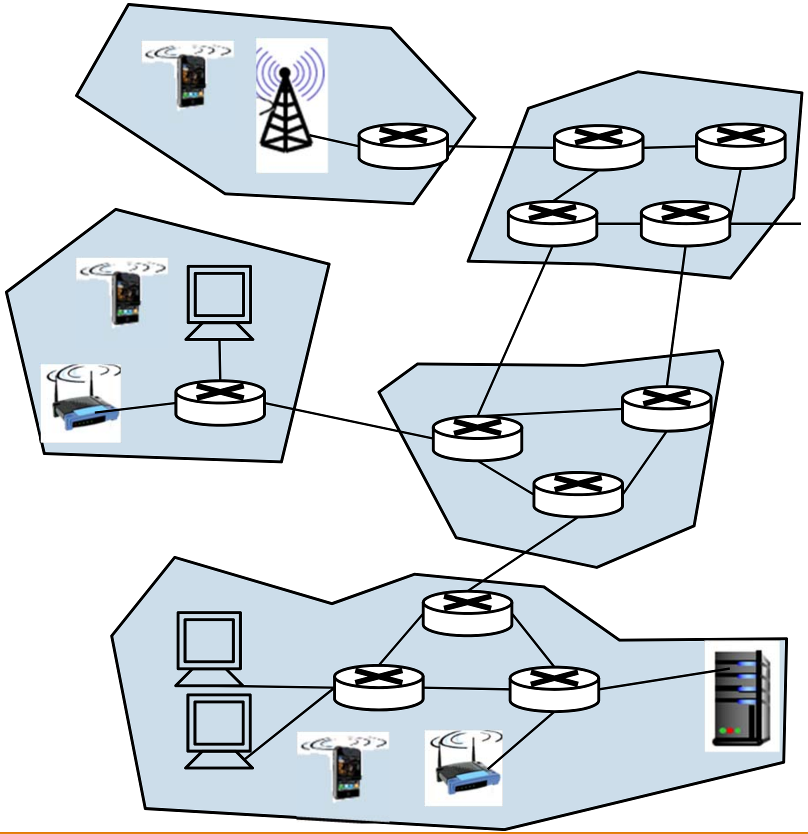
- Hosts : clients and servers
- Servers often in data centers

➢ ***Access networks, Physical media:***

- wired, wireless communication links

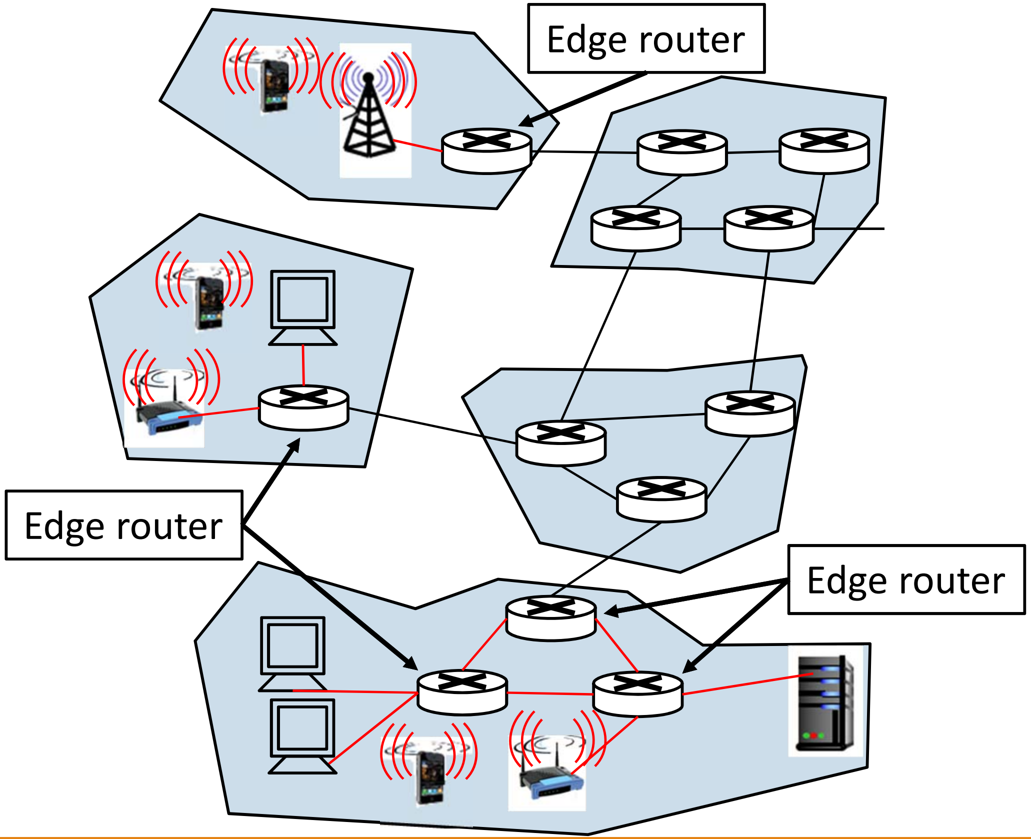
➢ ***Network Core:***

- Interconnected routers
- network of networks

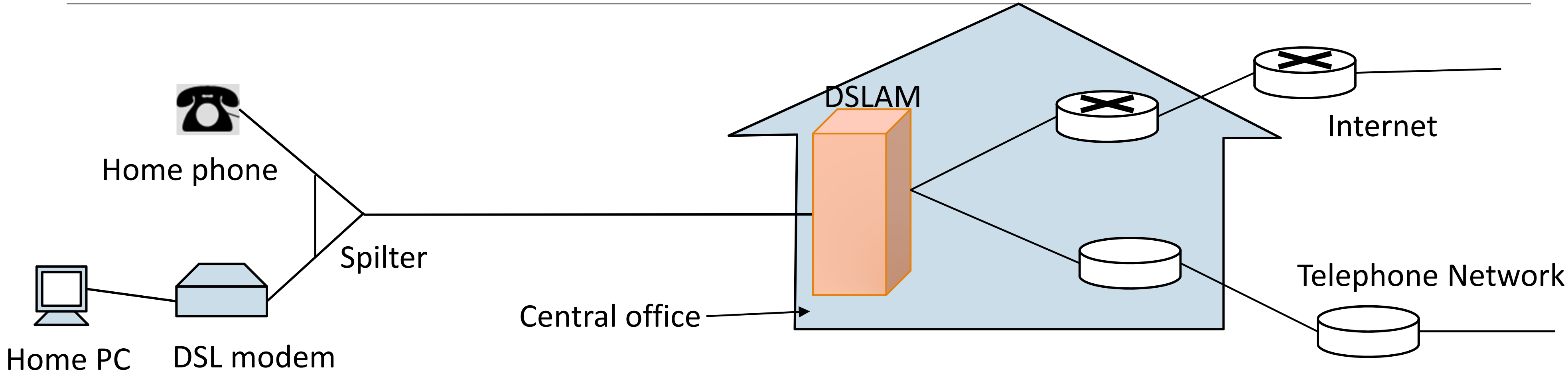


1.2.1 Access Networks

➢ ***How to connect "end systems" to "edge router"?***
- ***Residential access?***
- ***Institutional access networks(school, company)?***
- ***Mobile access networks?***

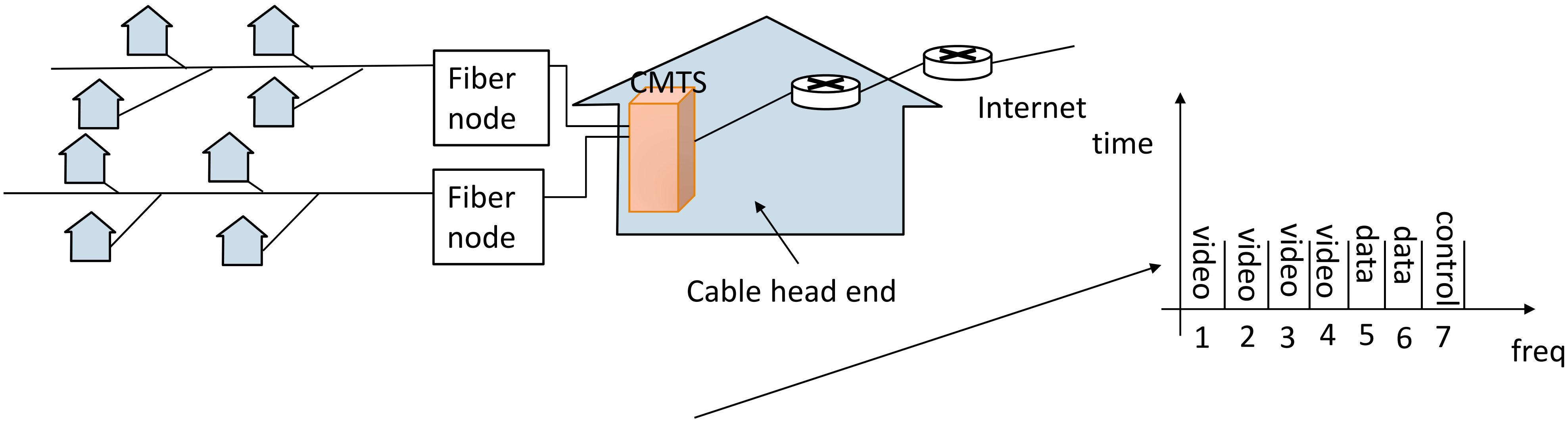


Access Networks-digital subscriber line(DSL)



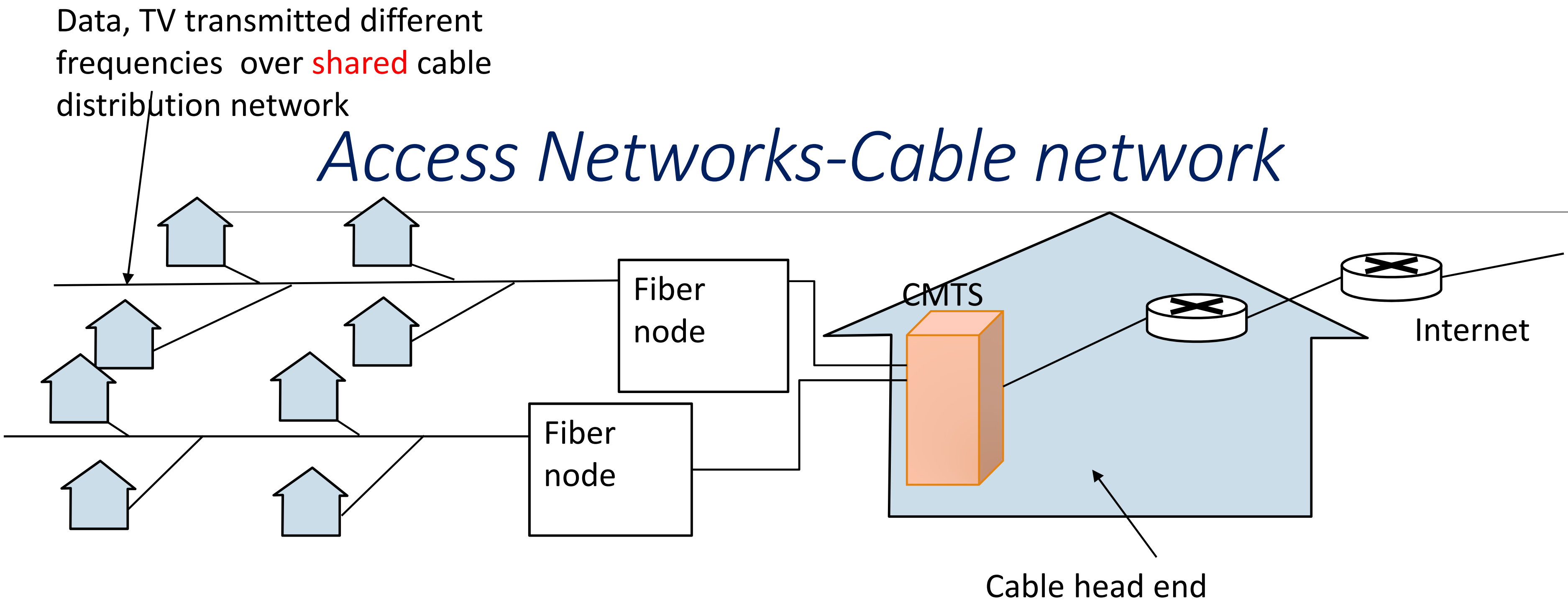
- ***Use existing telephone line to central office DSLAM (*** Digital Subscriber Line Access Multiplexer ***)***
  - *Data over DSL phone line goes to Internet*
  - *Voice over DSL Phone line goes to telephone net*
- ***< 2.5 Mbps upstream transmission rate(Typically < 1Mbps)***
- ***< 24 Mbps downstream transmission rate(Typically < 10Mbps)***

Access Networks-Cable network



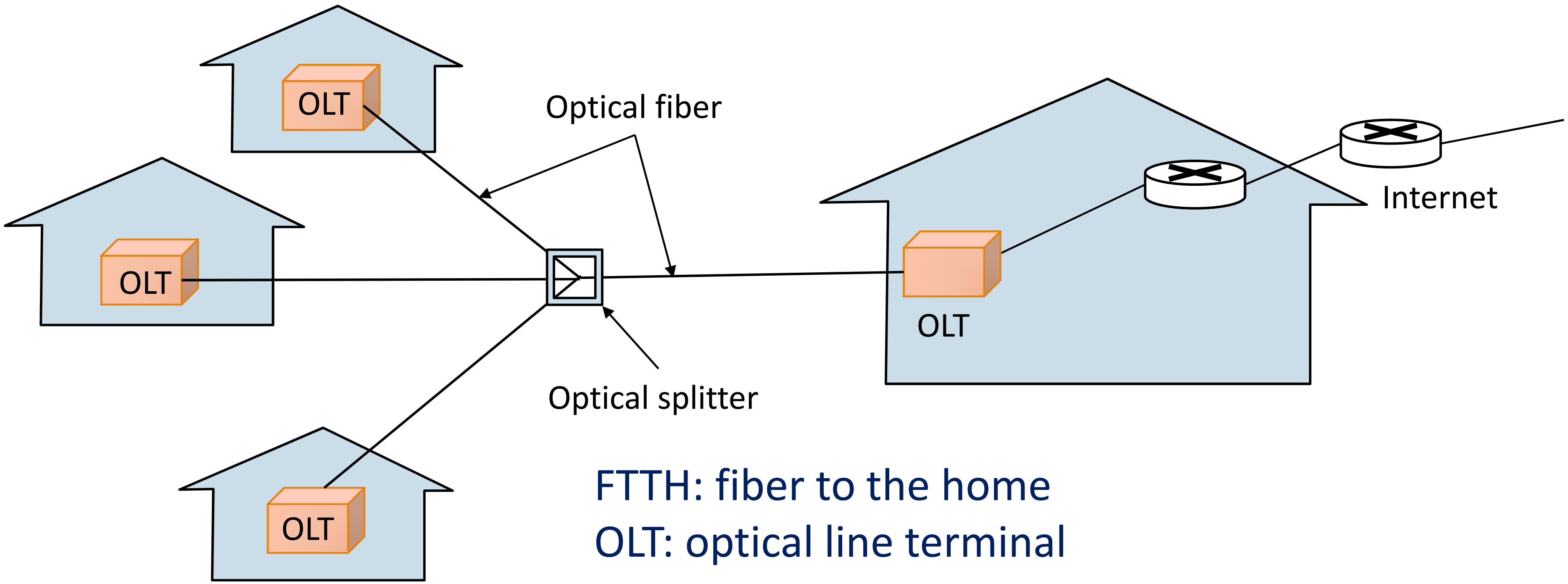
- ***Frequency division multiplexing(FDM): different channels transmitted in different frequency bands***

Access Networks-Cable network



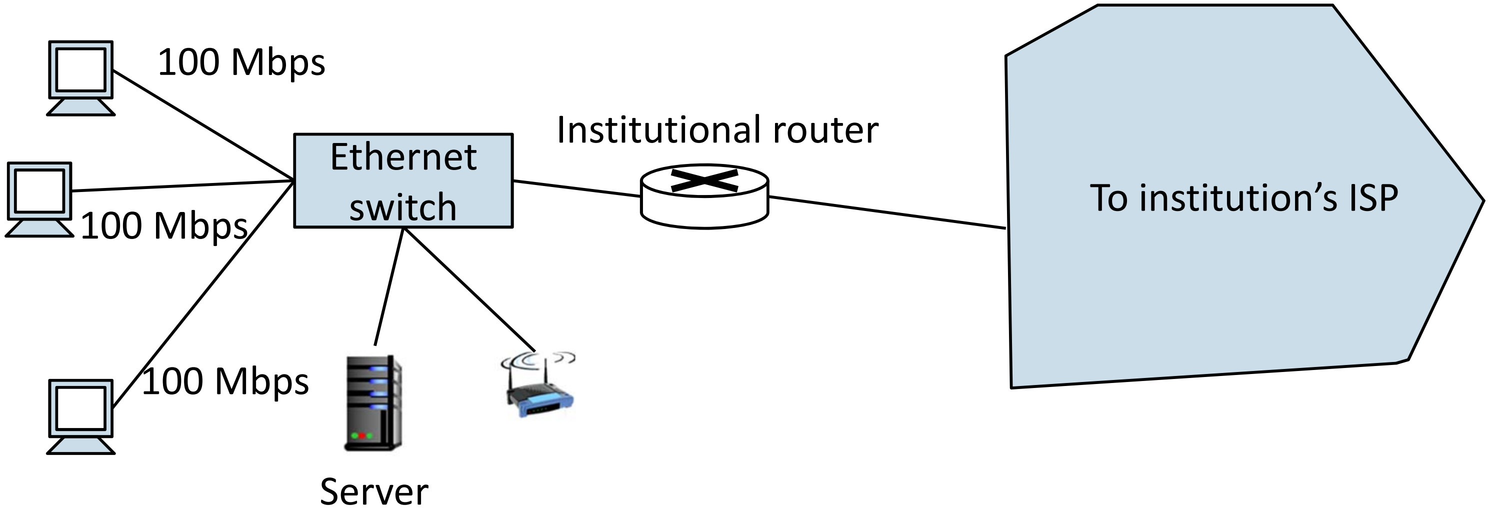
- ***HFC: Hybrid fiber coax***
  - ***Asymmetric: up to 30 Mbps downstream transmission rate, 2 Mbps upstream transmission rate***
- ***Network of cable, fiber attaches homes to ISP routers***
  - ***Homes share access network to cable headend***
  - ***Unlike DSL, which has dedicated access to central office***

Access Networks-Cable network (FTTH)



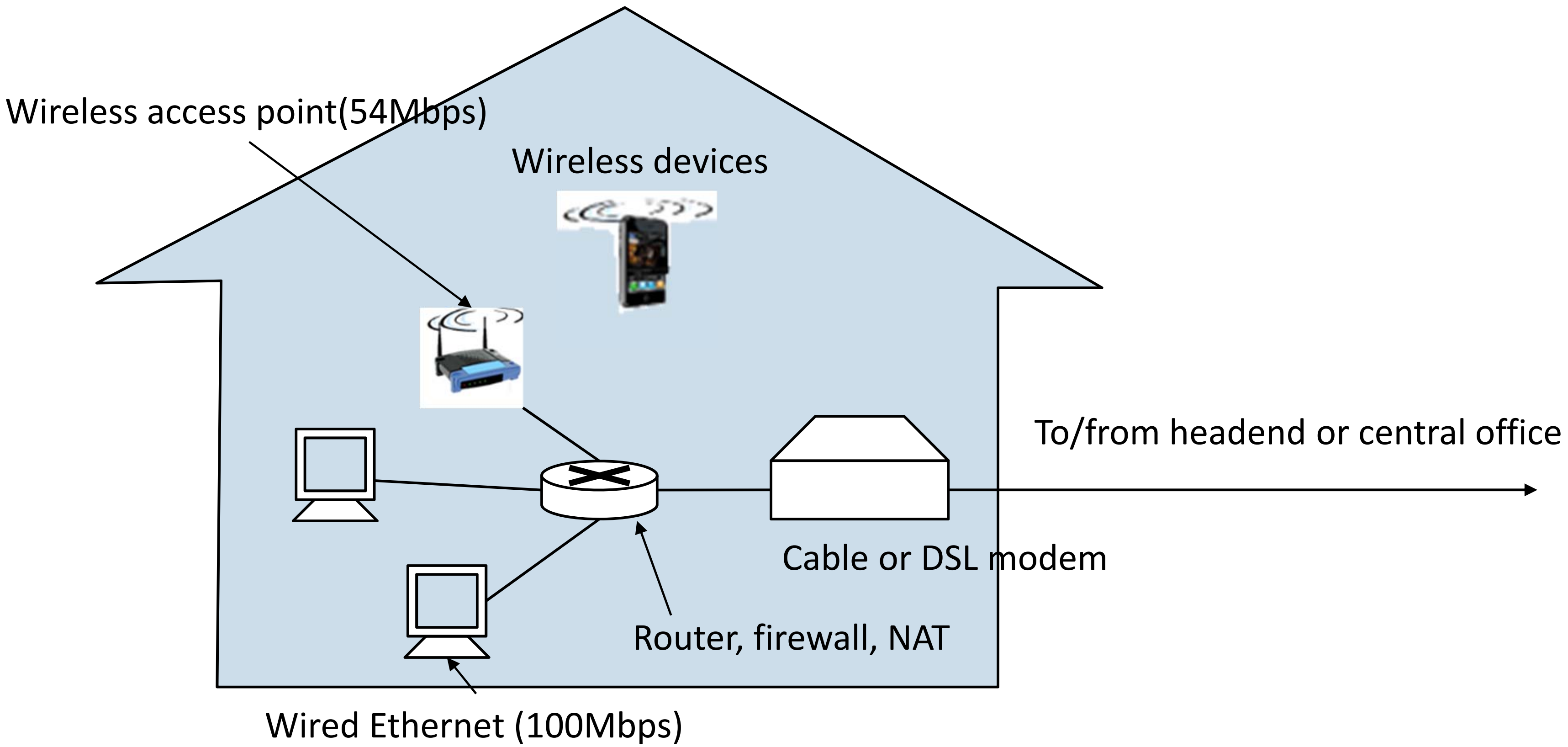
FTTH: fiber to the home
OLT: optical line terminal

Access Networks: Enterprise(Ethernet)



- Typically used in companies, universities, etc.
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- Today, end systems typically connect into Ethernet switch

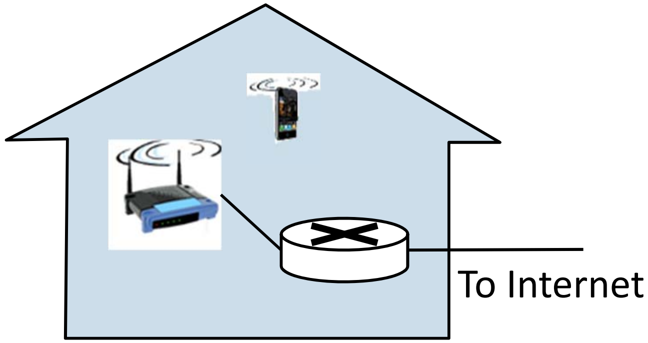
Access Networks: Home network



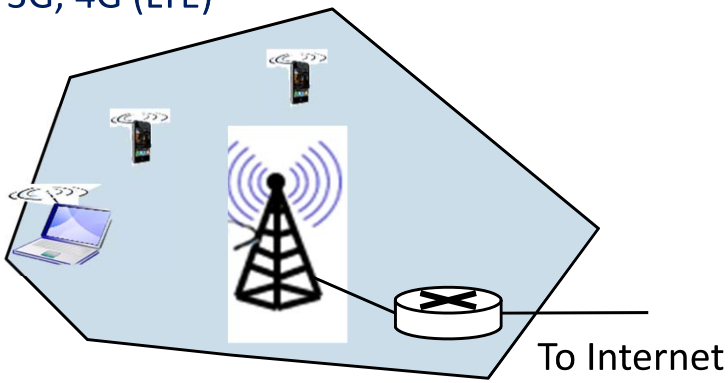
Access Networks: Wireless Access Networks

- *Shared wireless access network connects end system to router*
  - *via base station aka "access point" or "AP"*

- ***wireless LANs:***
  - Within building (100 feet)
  - 802.11b/g (Wi-Fi): 11, 54 Mbps transmission rate



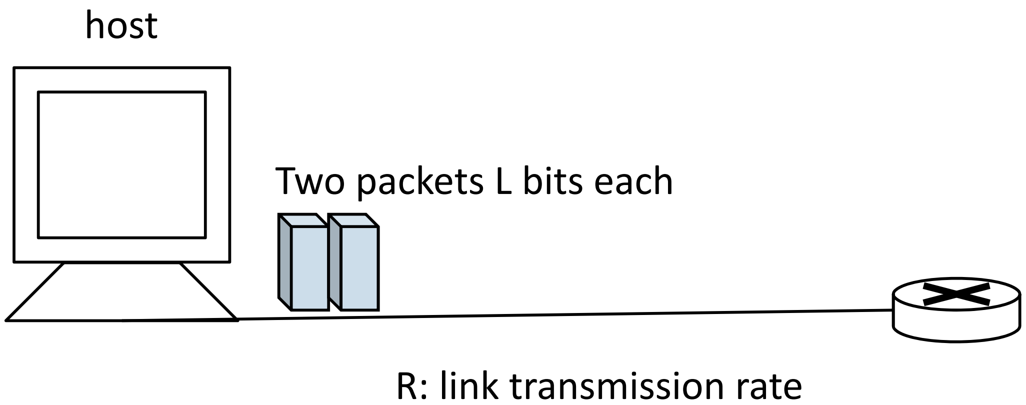
- ***wide-area wireless access:***
  - Provided by telco (cellular) operator, 10's km
  - Between 1 and 10Mbps
  - 3G, 4G (LTE)



Host: sends packets of data

Host sending function:

- Takes application message
- Breaks into smaller chunks, known as packets, of length L bits
- Transmits packets into access network at transmission rate R
  - *Link transmission rate, aka link capacity, link bandwidth*



Packet transmission delay (sec) = time needed to transmit L-bits packet into link = $\frac{L\text{(bit)}}{R\text{ (bit/sec)}}$

1.2.2 Physical Media

- *bit*: propagates between transmitter/receiver pairs
- *physical link*: what lies between transmitter and receiver
- *guided media*:
  - Signals propagate in solid media: copper, fiber, coax
- *unguided media*:
  - Signals propagate freely: radio

Twisted pair (TP):

- ***Two insulated copper wires***
  - ***Category 5 (Cat 5): 100Mbps, 1Gbps Ethernet***
  - ***Category 6 (Cat 6): 10Gbps***

1.2.2 Physical Media-coax, fiber

coaxial cable:

- ***two concentric copper conductors***
- ***bidirectional***
- ***broadband:***
  - ***Multiple channels on cable***
  - ***HFC***

fiber optic cable:

- ***glass fiber carrying light pulses, each pulse a bit***
- ***high speed operation***
- ***Low error rate:***
  - ***Repeaters spaced far apart***
  - ***Immune to electromagnetic noise***

1.2.2 Physical Media-radio

- ***signal carried in electromagnetic spectrum***
- ***No physical "wire"***
- ***bidirectional***
- ***propagation environment effects:***
  - ***Reflection***
  - ***Obstruction by objects***
  - ***interference***

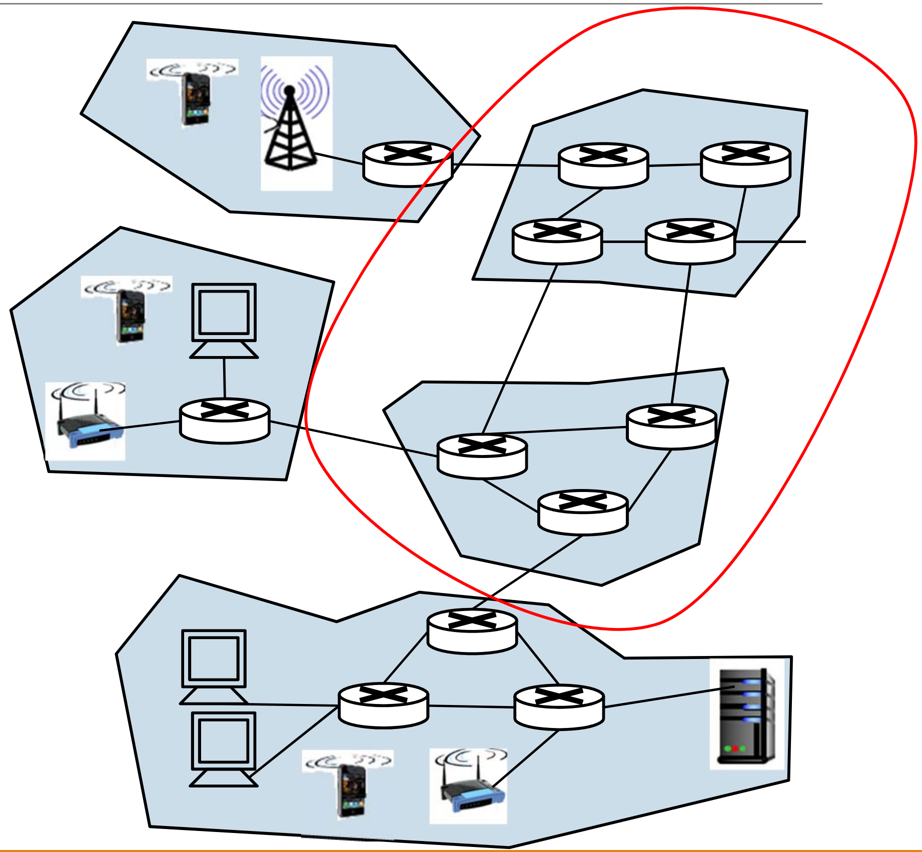
Radio link type:

- ***Terrestrial microwave***
  - ***E.g. up to 45Mbps channels***
- ***LAN (E.g. Wi-Fi)***
  - ***11Mbps, 54Mbps***
- ***Wide-area (E.g. cellular)***
  - ***3G cellular: ~few Mbps***
- ***Satellite***
  - ***Kbps to 45Mbps channel (or multiple smaller channels)***
  - ***270 msec end-end delay***
  - ***Geosynchronous vs. low altitude***

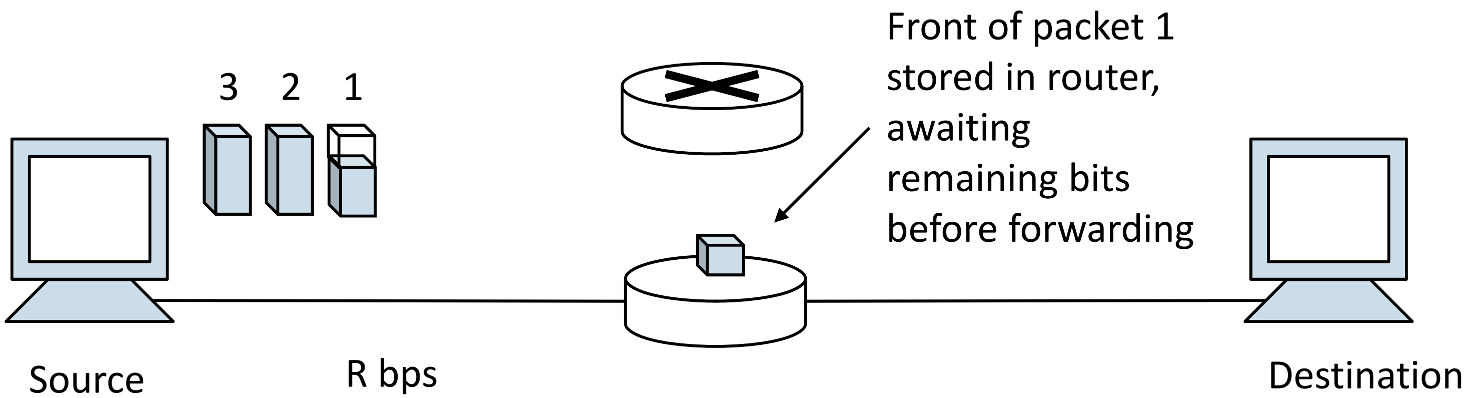
1.3 The Networks Core

1.3.1 Packet Switching

- Meshes of interconnected routers
- ***Packet-switching: hosts breaks application-layer messages in packets***
  - *Forward packets from one router to the next, across links on path from source to destination*
  - *Each packet transmitted at full link capacity*



1.3.1 *Packet Switching: store-and-forward*

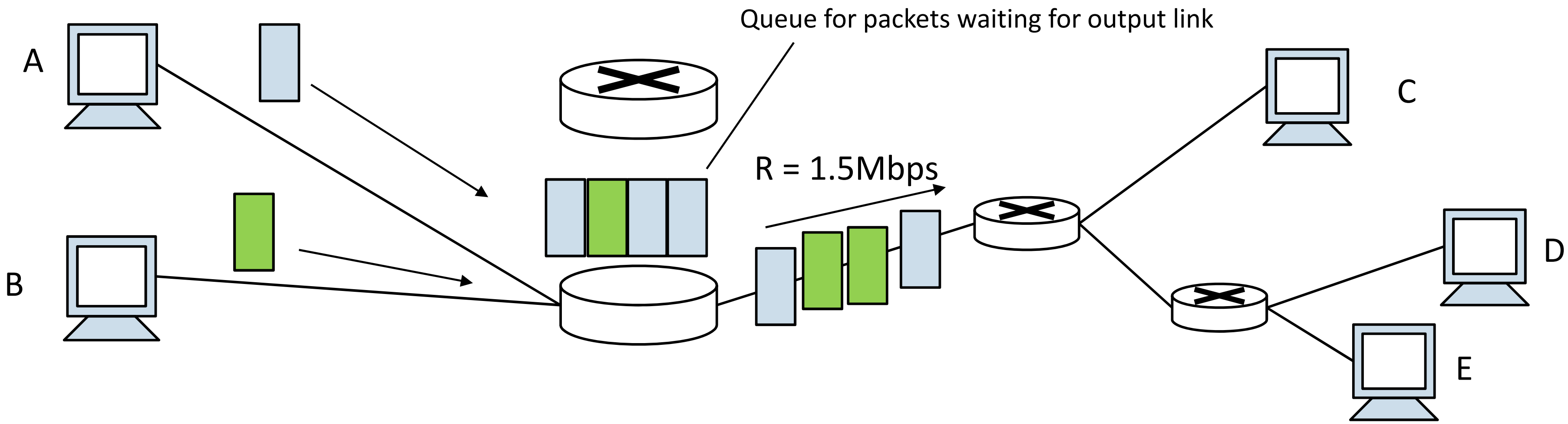


- *Takes* $\mathrm{L/R}$ *seconds to transmit L-bits packets into links at R bps*
- *store-and-forward:* entire packets must arrive at router before it can be transmitted on next link
- *end-end delay* = $\mathrm{NL/R}$ *N links*

One-hop numerical example:

- $\boldsymbol{L} = 7.5$ Mbits
- $\mathrm{R} = 1.5$ Mbps
- ***One-hop transmission delay = 5 sec***

1.3.1 Packet Switching:
Queue and loss



Queue and loss:

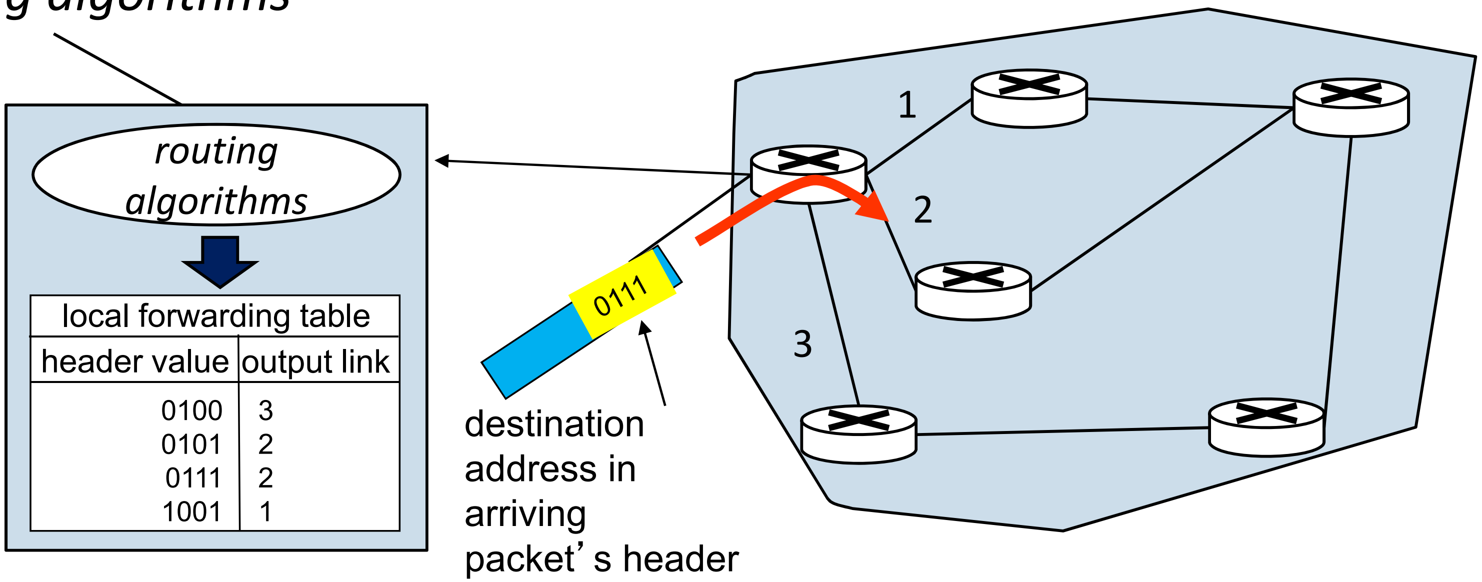
➢ ***if arrival rate (in bits) to link exceeds transmission rate of link for a period of time:***
- ***Packets will queue, wait to be transmitted on link***
- ***Packets can be dropped (lost) if memory (buffer) fills up***

Two key network-core functions

routing: determines source-destination route taken by packets

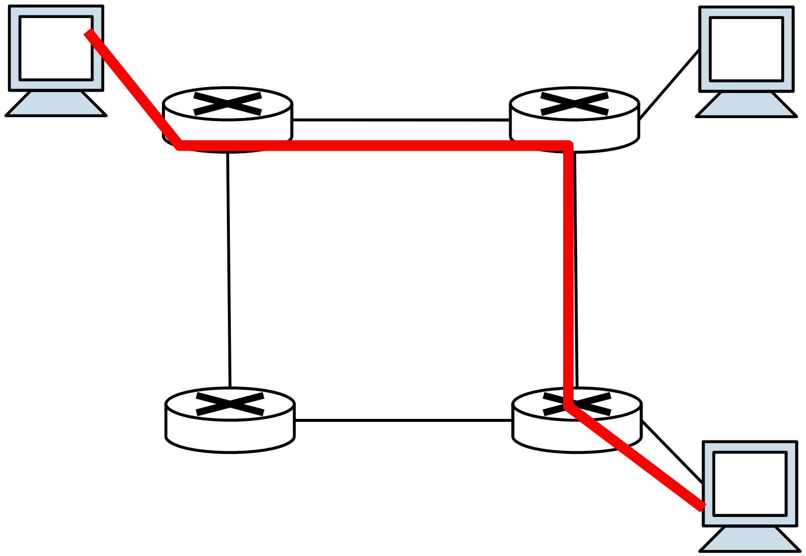
- *routing algorithms*

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



1.3.2 Circuit Switching

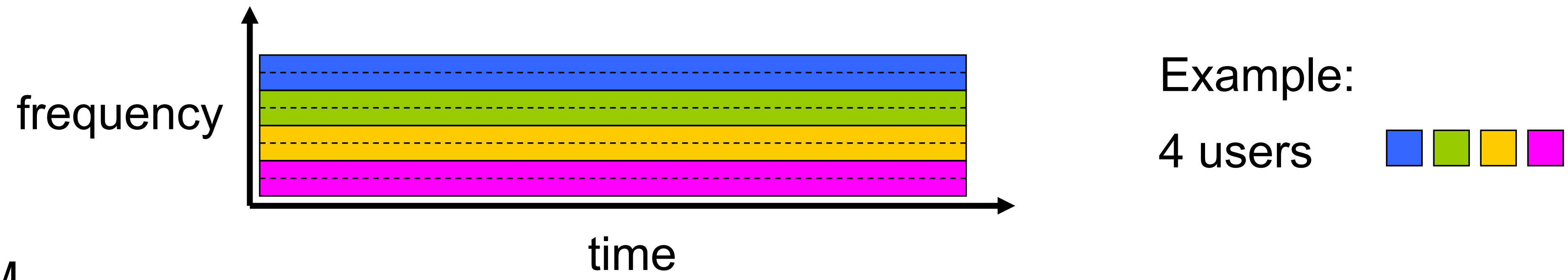
end-end resources allocated to, reserved for "call" between source and destination:



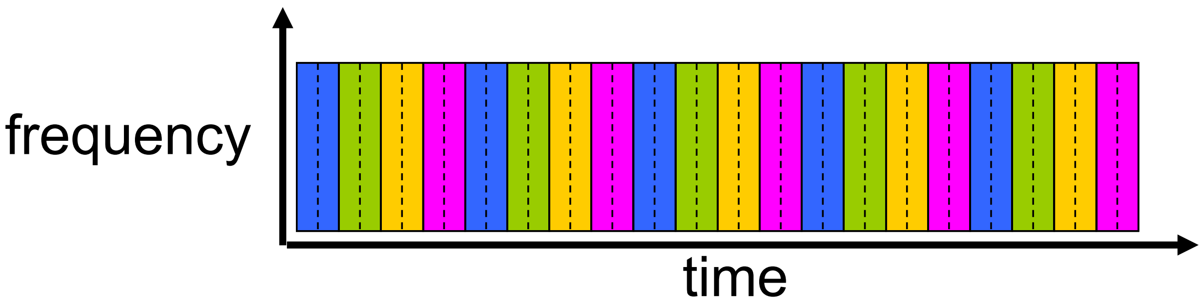
- *Dedicated resources: no sharing*
    - *Circuit-like (guaranteed) performance*
- *Circuit segment idle if not used by call (**no sharing**)*

1.3.2 Circuit Switching: *FDM vs. TDM*

FDM



TDM



1.3.2 Circuit Switching:
Packet switching vs. Circuit Switching

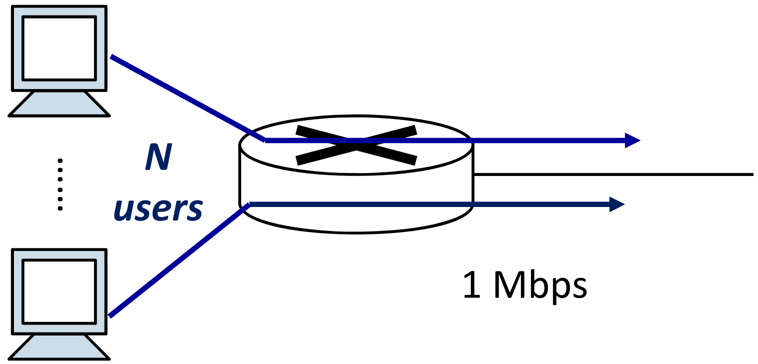
Packet switching: allow more users to network!

example:

- 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 0.0004 *



1.3.2 Circuit Switching:
Packet switching vs. Circuit Switching

Packet switching:

- **Great for bursty data**
    - Resource sharing
    - Simpler, no call setup
- **Excessive congestion possible**: packet delay and loss
    - Protocols needed for reliable data transfer, congestion control

Circuit switching:

- **Dedicated resource**
    - **Needed call for using resource**
    - **Guaranteed transmission rate**
- **Can only have limited users use simultaneously**

1.3.3 A Network of Networks

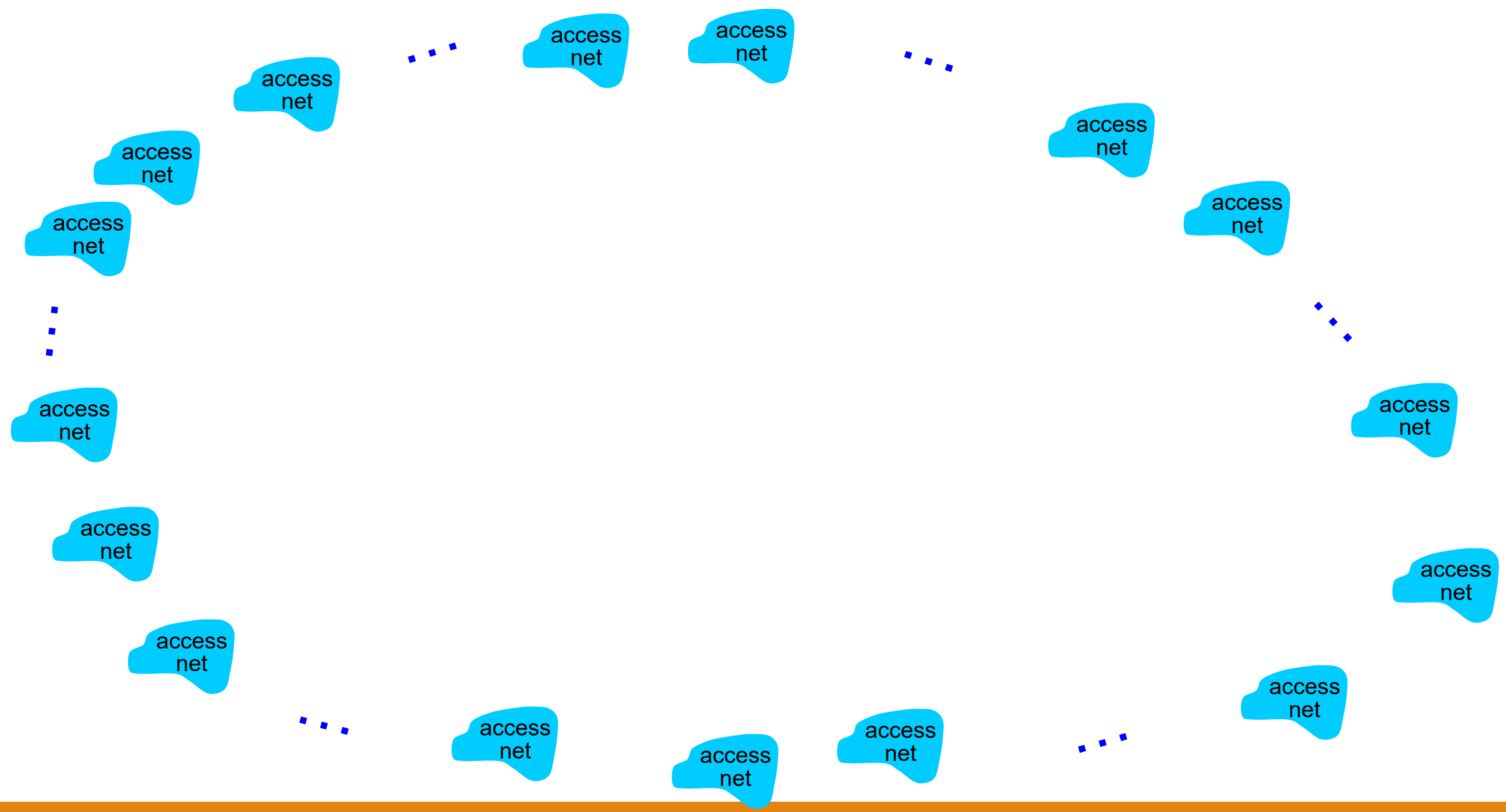
- End systems connect to Internet via access ISPs
    - Residential, enterprise....etc.

- Access ISPs in turn must be interconnected
    - So that any two hosts can send packets to each other

- Resulting network of networks is very complex
    - Evolution was driven by economics and national policies

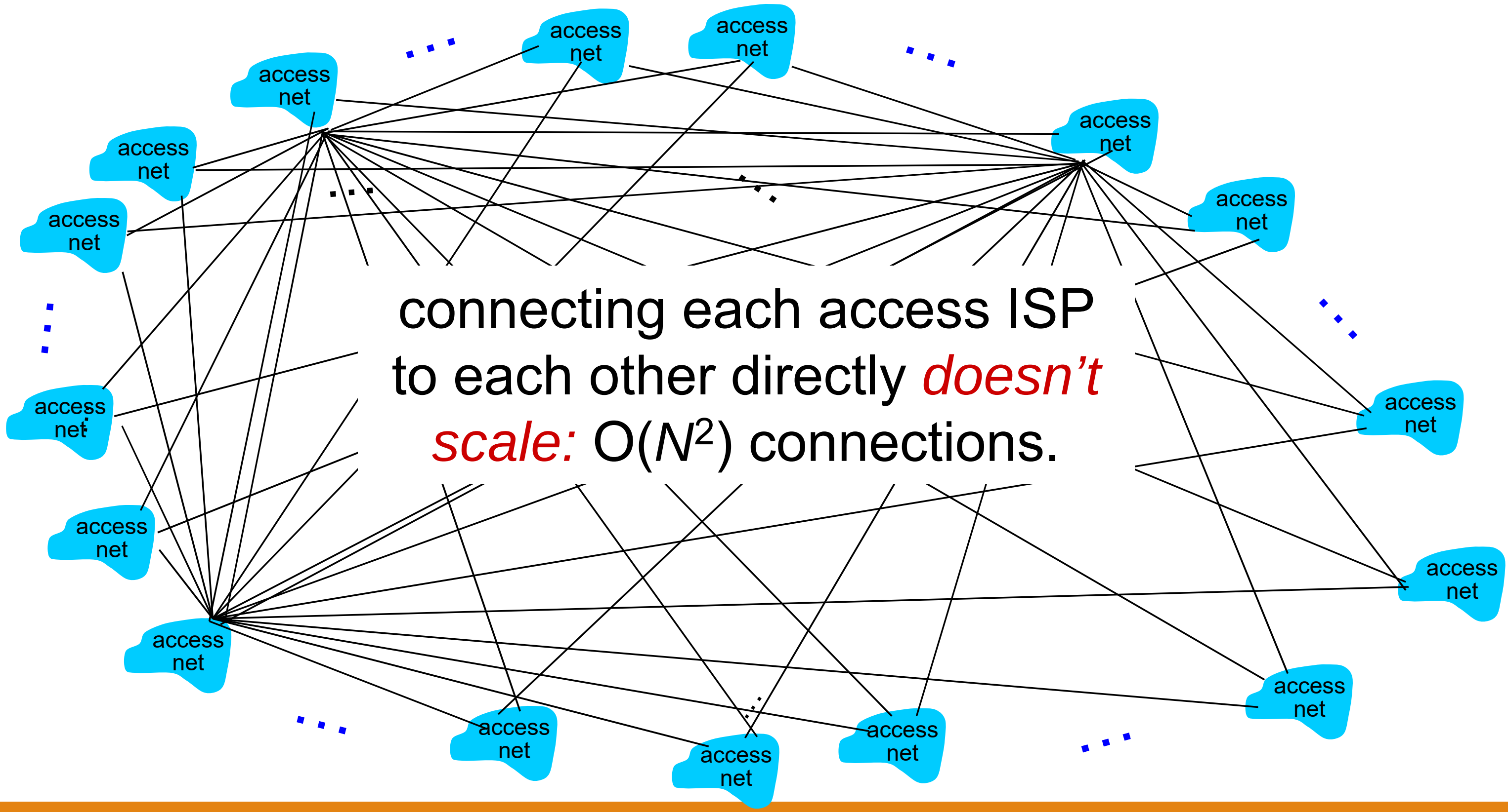
1.3.3 A Network of Networks

Questions:
given millions of access ISPs, how to connect them together?



1.3.3 A Network of Networks

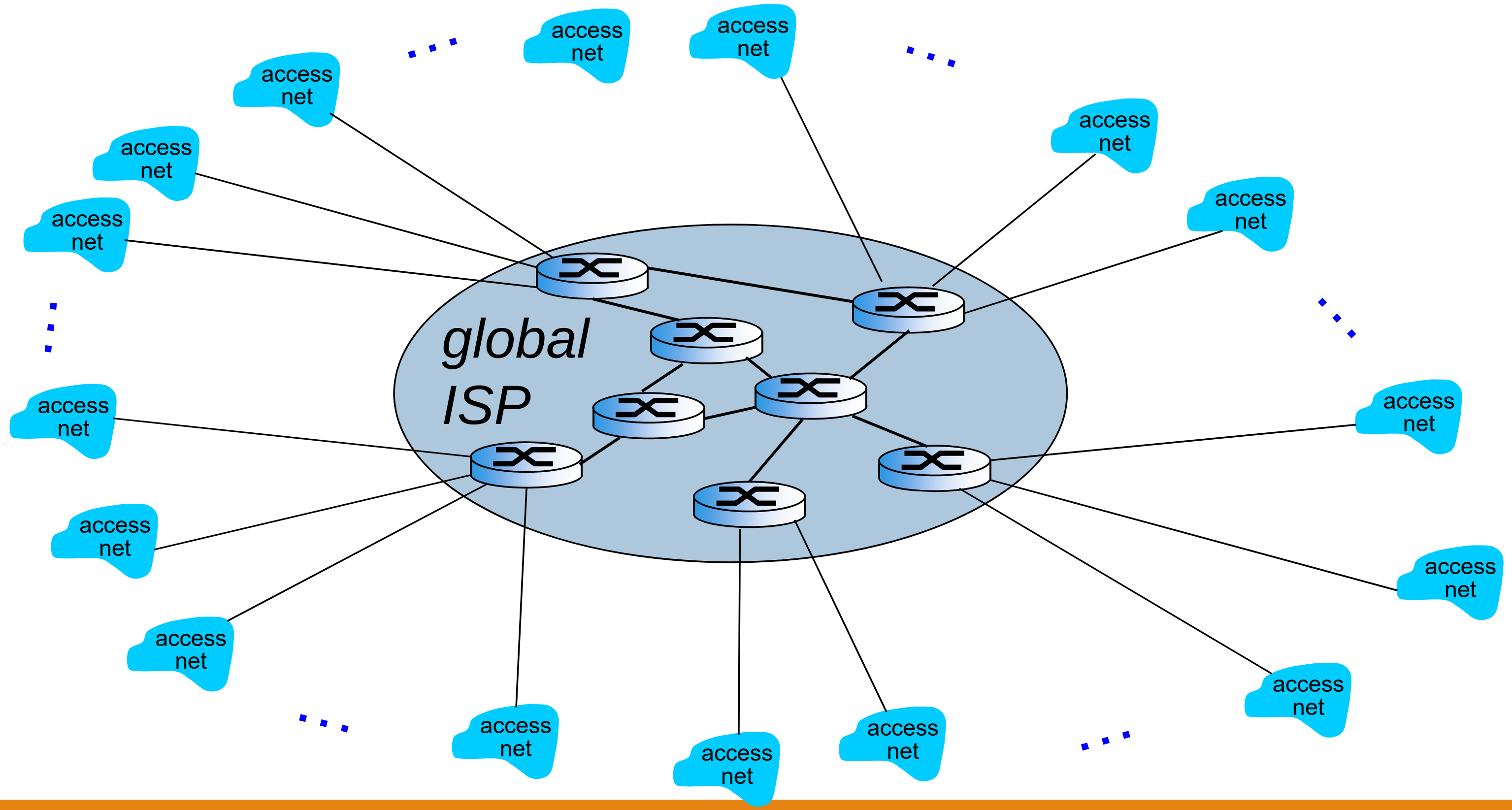
Option 1:
Connect each access ISP to every other access ISPs?



1.3.3 A Network of Networks

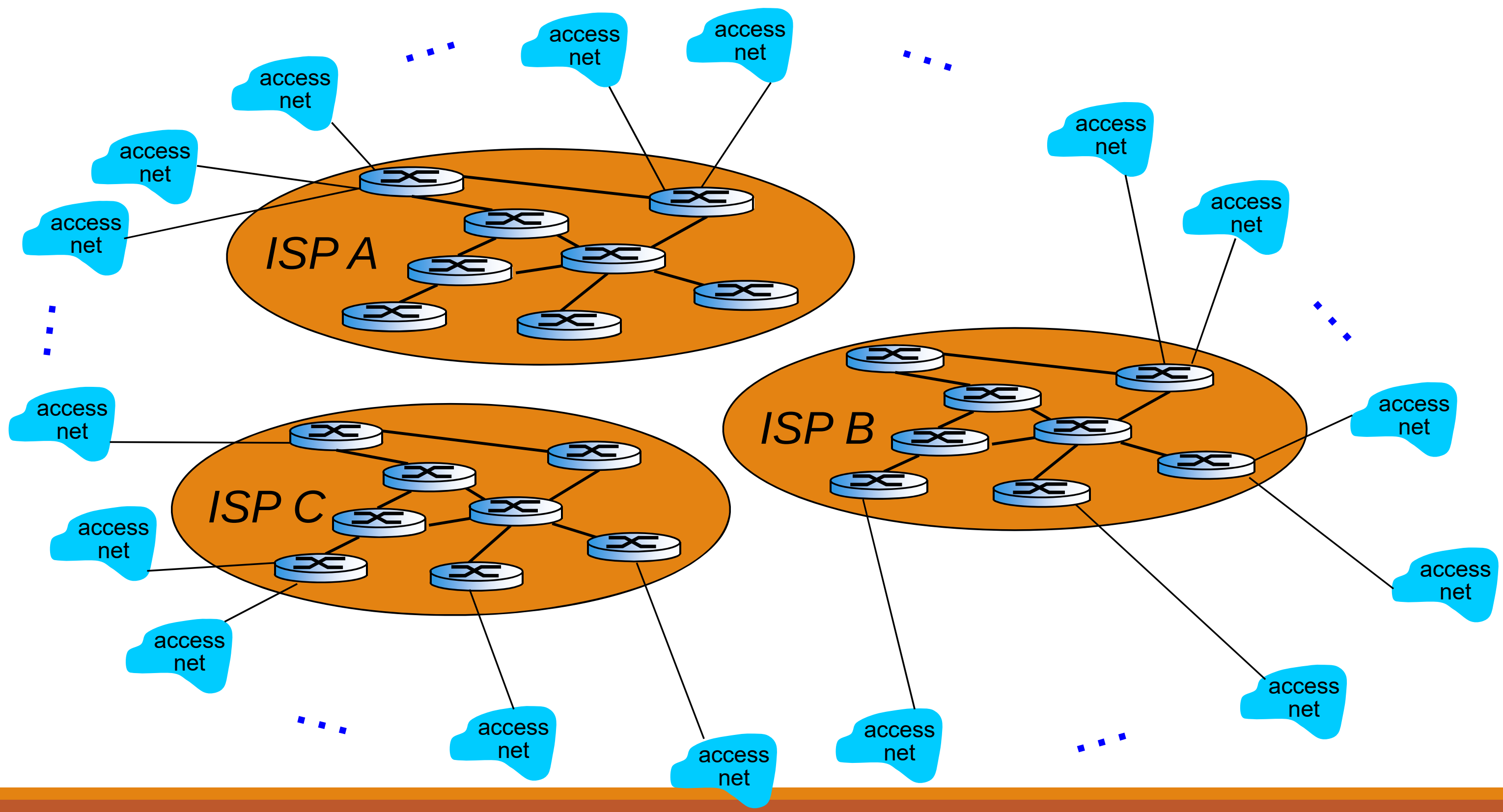
Option 2:
Connect each access ISP to a global transit ISP?

Customer and Provider ISPs have economic agreement.



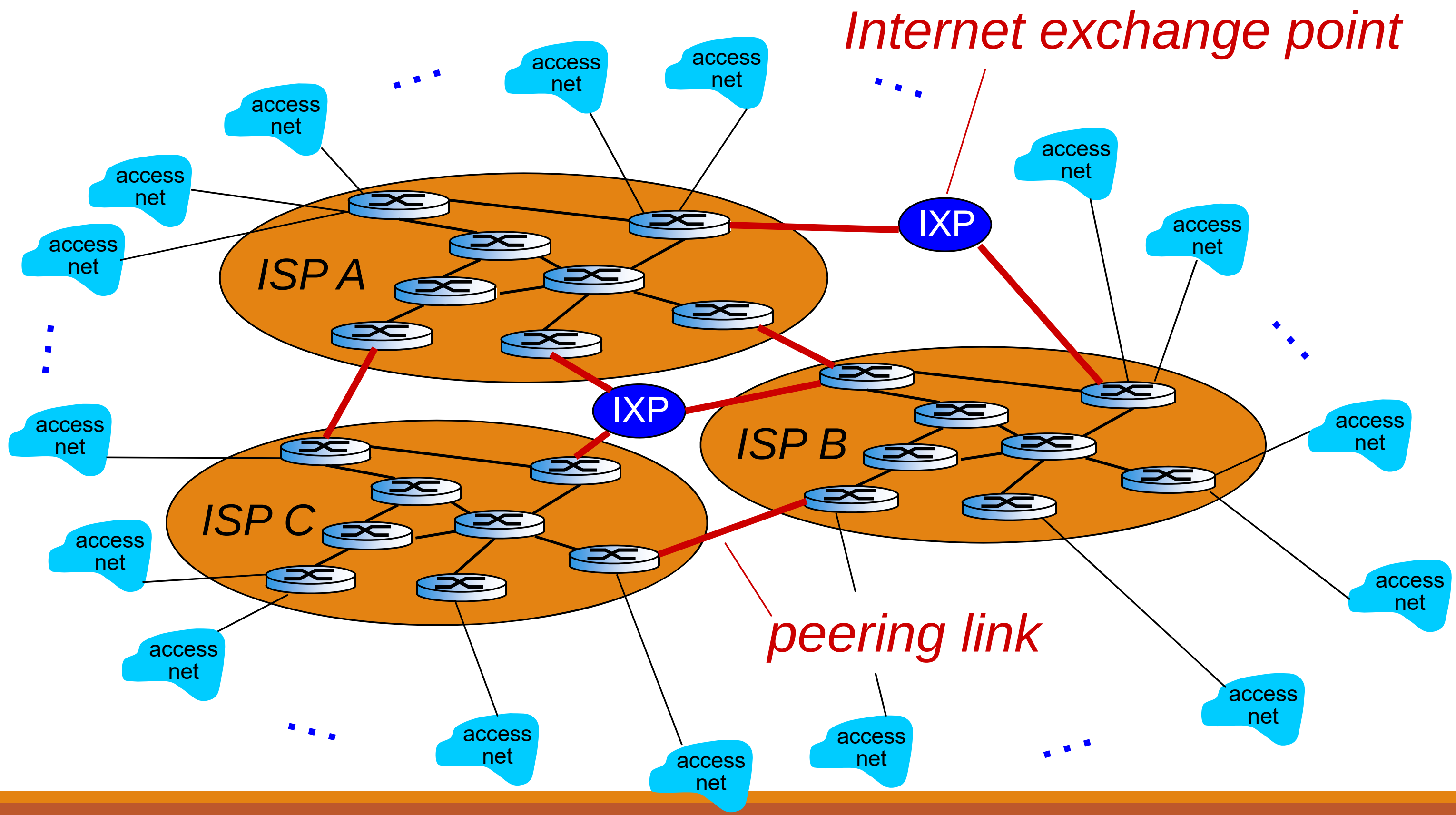
1.3.3 A Network of Networks

But if one global ISP is viable business, there will be competitors….



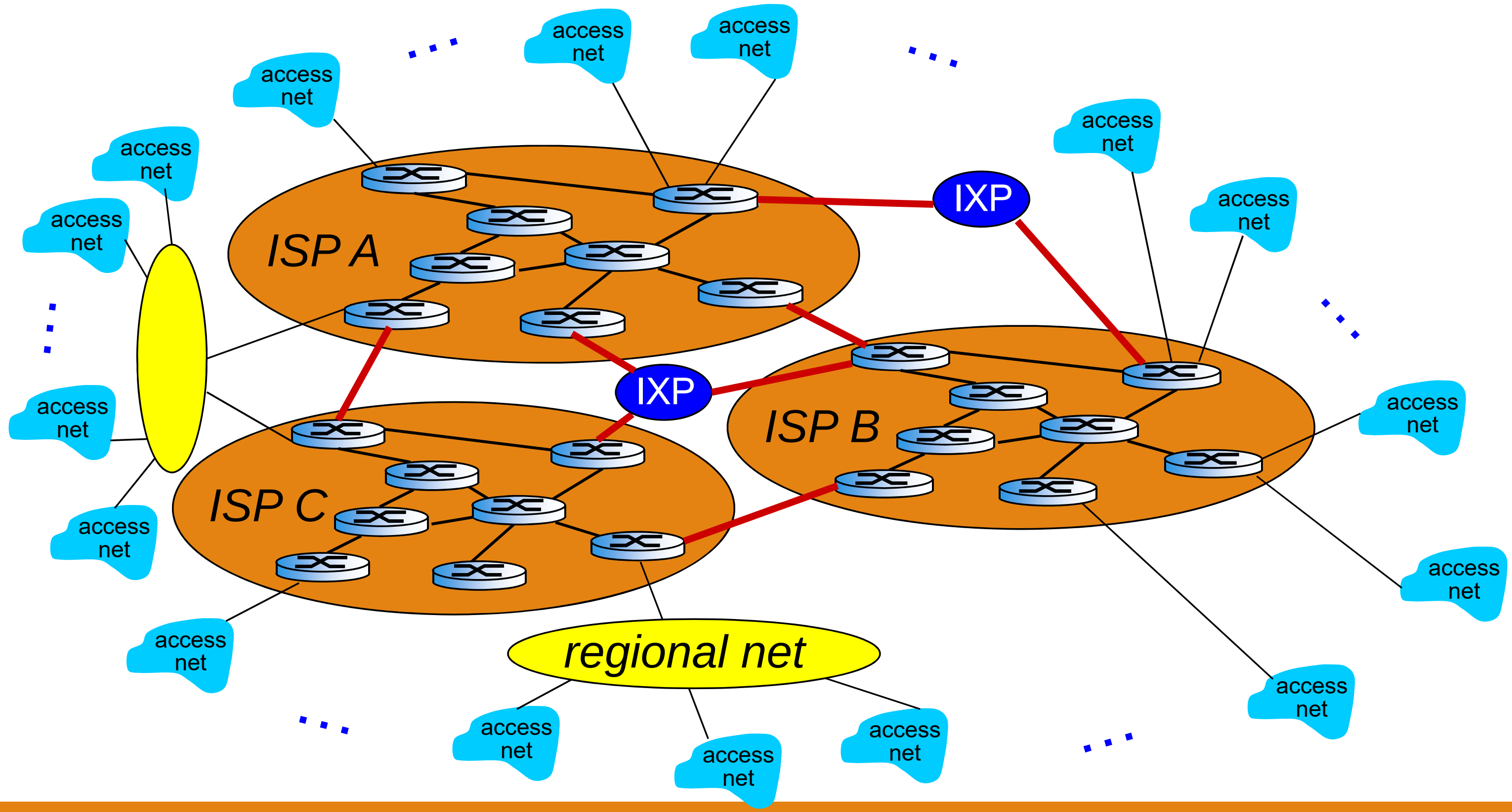
1.3.3 A Network of Networks

But if one global ISP is viable business, there will be competitors….which must be interconnected



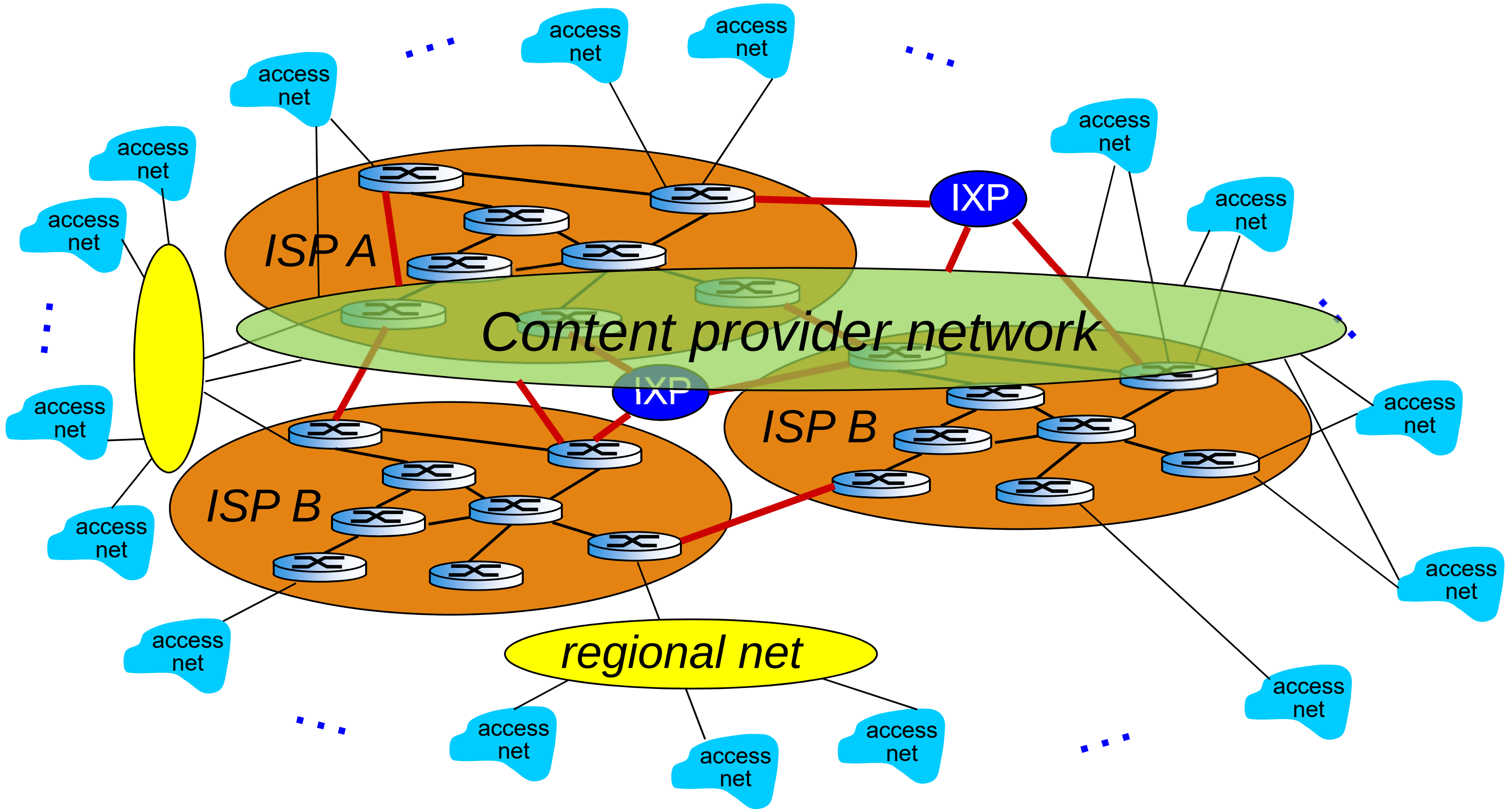
1.3.3 A Network of Networks

Regional networks may arise to connect access nets to ISPs

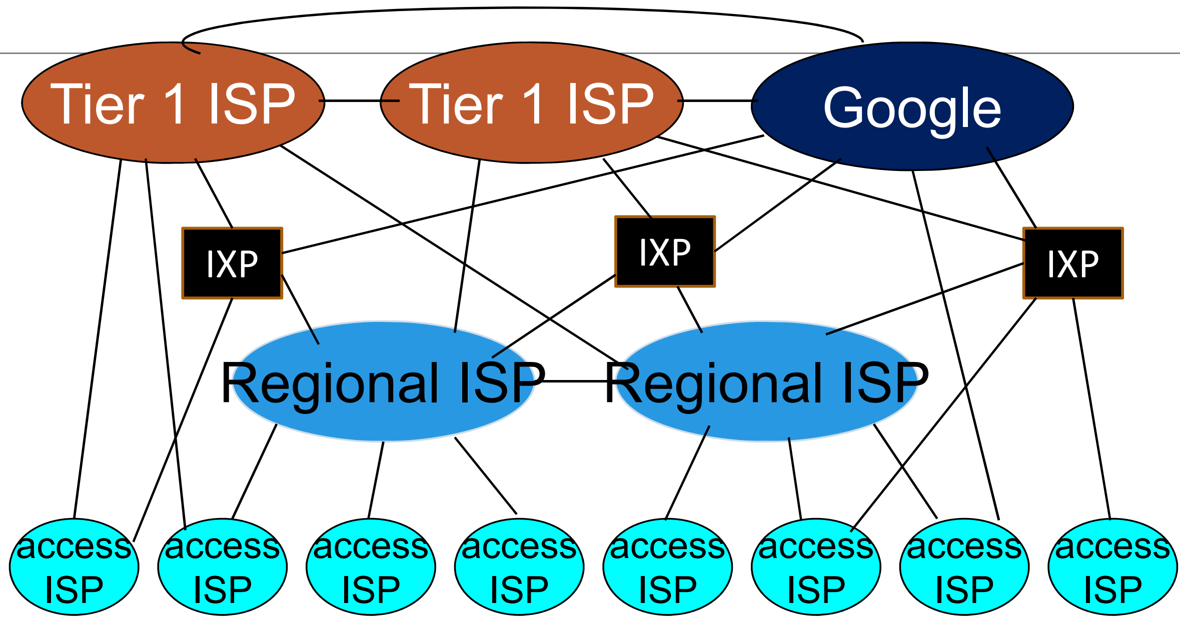


1.3.3 A Network of Networks

Content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users



1.3.3 A Network of Networks



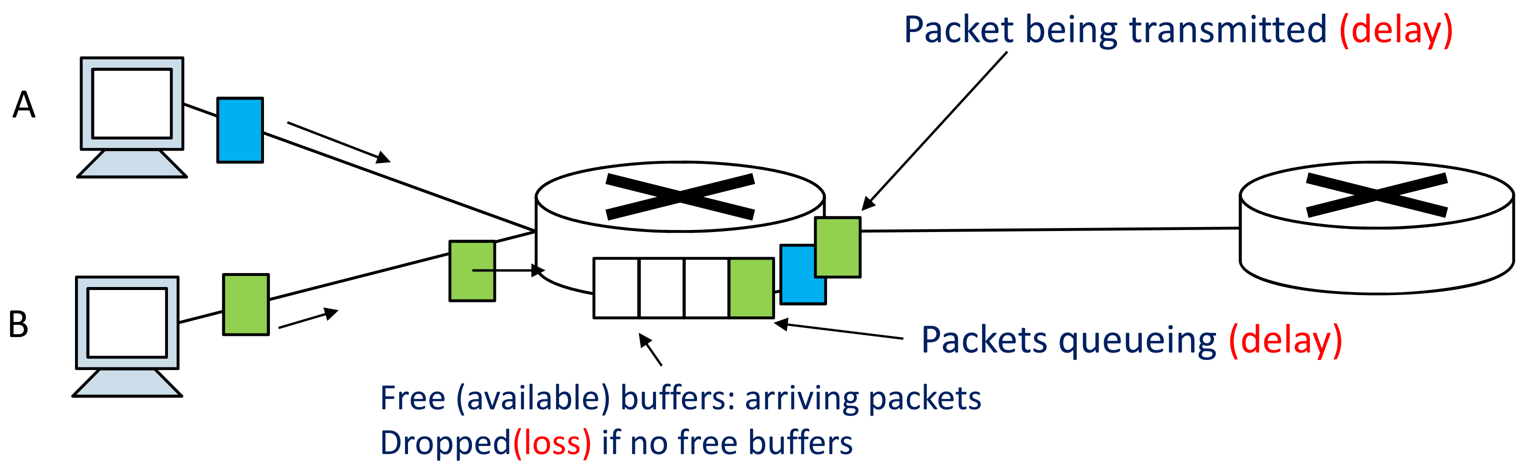
- at center: small # of well-connected large networks
  - **"tier-1" commercial ISPs** (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - **content provider network** (e.g., Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

1.4 Delay, Loss, and Throughput in Packet-Switched Networks
1.4.1 Overview of Delay in Packet-Switched Networks

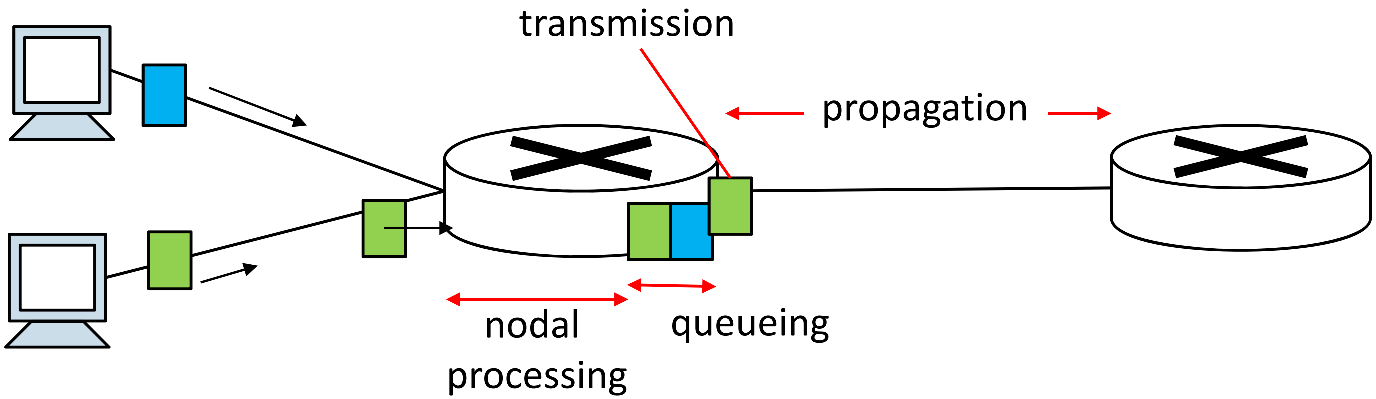
Q:How do loss and delay occur?

Packets queue in router buffers

- ➢ Packet arrival rate to link(temporarily) exceeds output capacity
- ➢ Packet queue wait for turn



1.4.1 *Overview of Delay in Packet-Switched Networks:*
Four types of delay

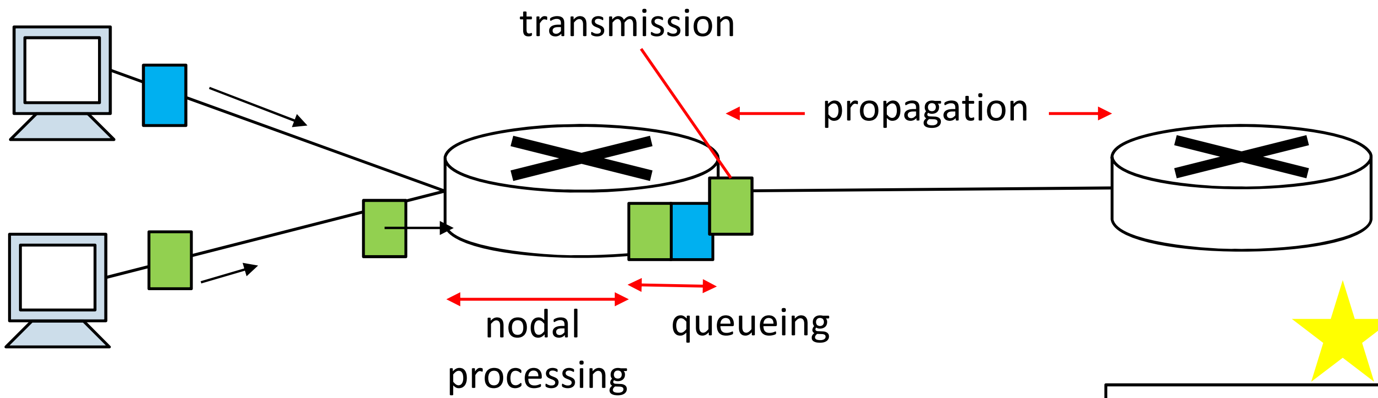


$$\boxed{d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}}$$

d_{nodal}: nodal processing
- *Check bit error*
- *Determine output link*
- *typically < msec*

d_{queue}: queueing delay
- *Time waiting at output link for transmission*
- *Depends on congestion level of router*

1.4.1 Overview of Delay in Packet-Switched Networks: Four types of delay



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

d_{trans} and d_{prop} are very different

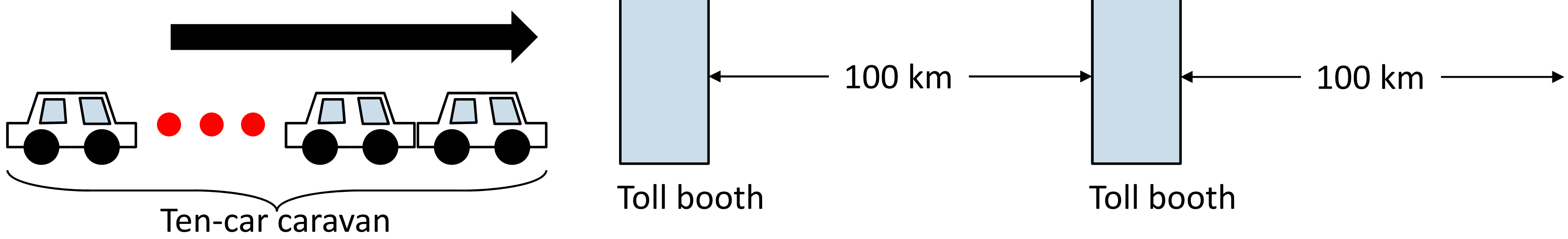
d_{trans}: transmission delay

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

d_{prop}: propagation delay

- *d : length of physical link*
- *s : propagation speed in medium* ($\sim 2 \times 10^8\ m/sec$)
- $d_{prop} = d/s$

1.4.1 Overview of Delay in Packet-Switched Networks: Caravan analogy

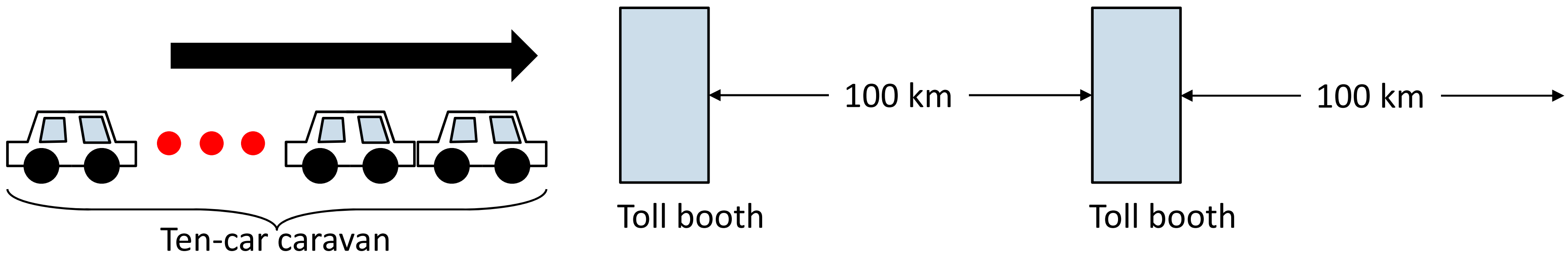


- Cars "propagate" at 100 km/hr
- Toll booth takes 12 sec to service car(bit transmission time)
- Car ~bits; caravan ~packet

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 booth: 100 km / (100 km/hr) = 1hr
- *A:62 minutes*

1.4.1 Overview of Delay in Packet-Switched Networks: *Caravan analogy*



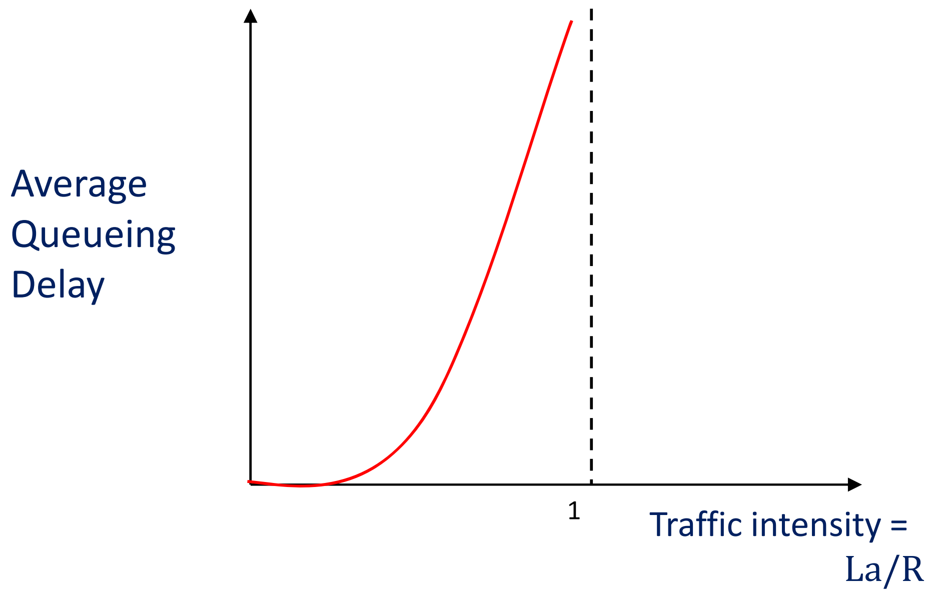
- *Suppose cars now "propagate" at 100km/hr*
- *And suppose toll booth now takes one minute to service a car*

- *Q:Will cars arrive to 2nd booth before all cars serviced at first booth?*
  - *A:Yes after 7min, 1st car arrives at 2nd booth; three cars still at 1st booth*

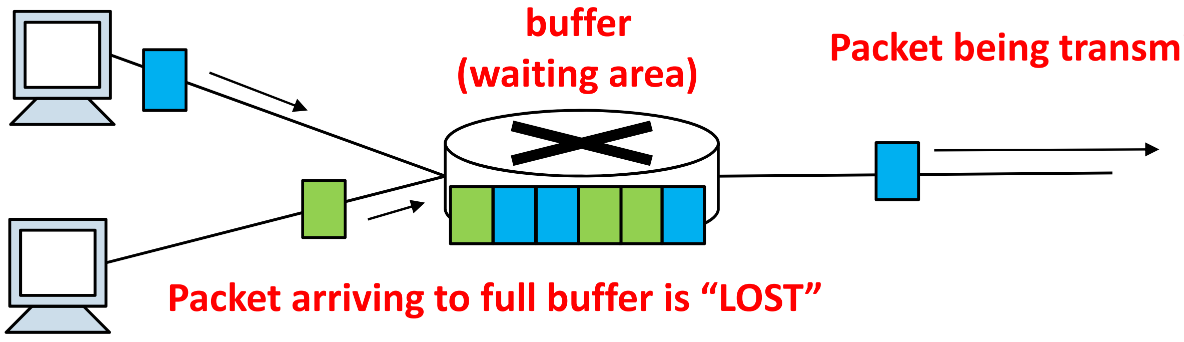
1.4.2 Queueing Delay and Packet Loss: Traffic Intensity

- *L : packet length (bits)*
- *R : link bandwidth(bps)*
- *a : average packet arrival rate*

- $La/R \sim 0$: avg. queueing delay small
- $La/R \approx 1$: avg. queueing delay large
- $La/R > 1$*:* more "work" arriving than can be serviced, avg. queueing delay infinite

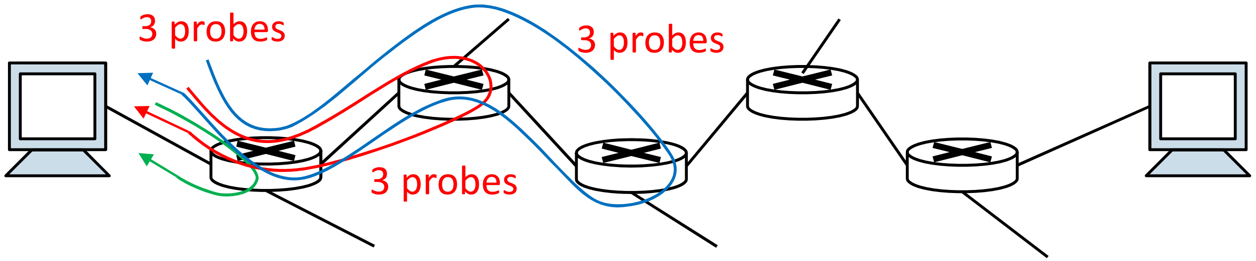


1.4.2 Queueing Delay and Packet Loss: Packet Loss



- *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*

1.4.3 End-to-End Delay
traceroute



$$d_{end-end} = N(d_{proc} + d_{trans} + d_{prop})$$ **N:the number of router**

➢ ***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.***

1.4.3 End-to-End Delay
traceroute(con.)

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

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

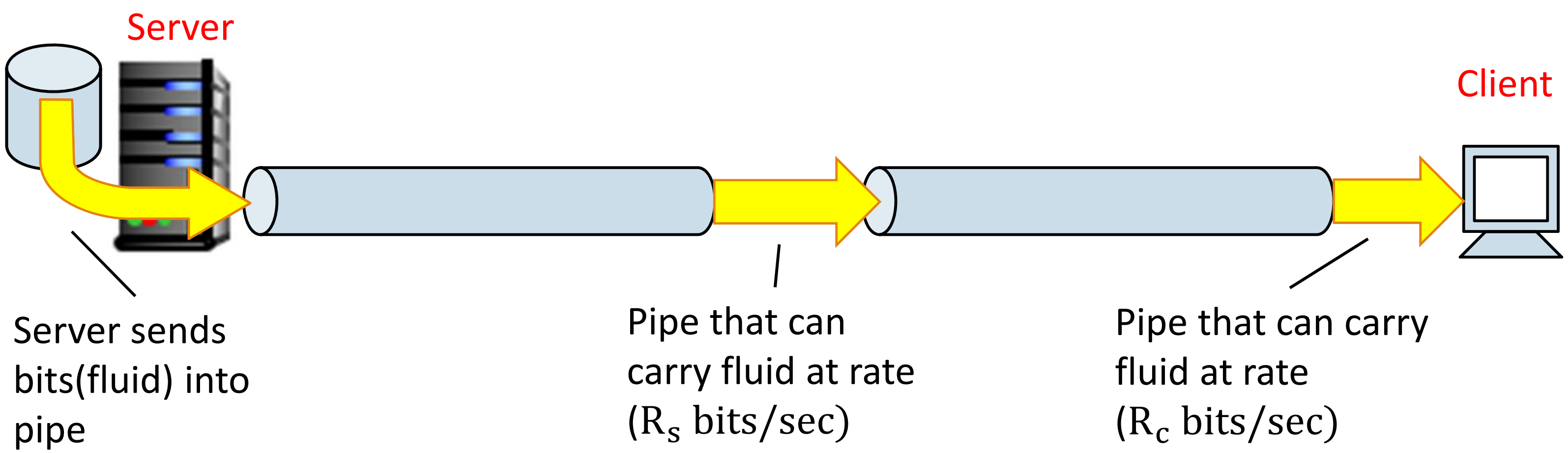
1 cs-gw (128.119.240.254) 1 ms 1 ms 2 ms
2 border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145) 1 ms 1 ms 2 ms
3 cht-vbns.gw.umass.edu (128.119.3.130) 6 ms 5 ms 5 ms
4 jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms
5 jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms
6 abilene-vbns.abilene.ucaid.edu (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)

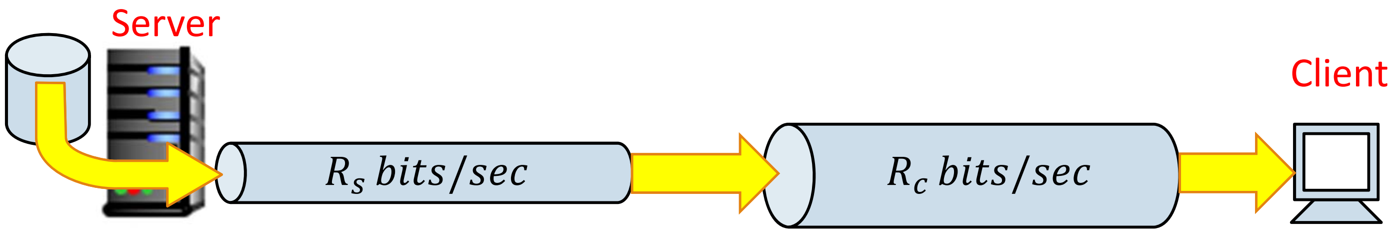
1.4.4 Throughput in Computer Networks

- **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*

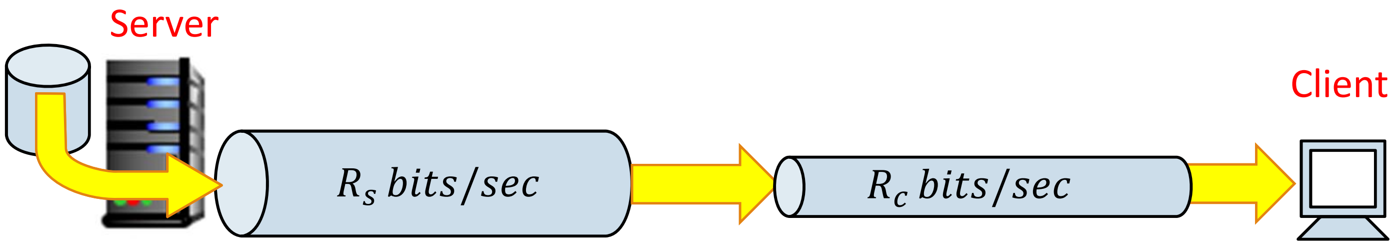


1.4.4 Throughput in Computer Networks

- Q: $R_s < R_c$ *What is average end-end throughput?*

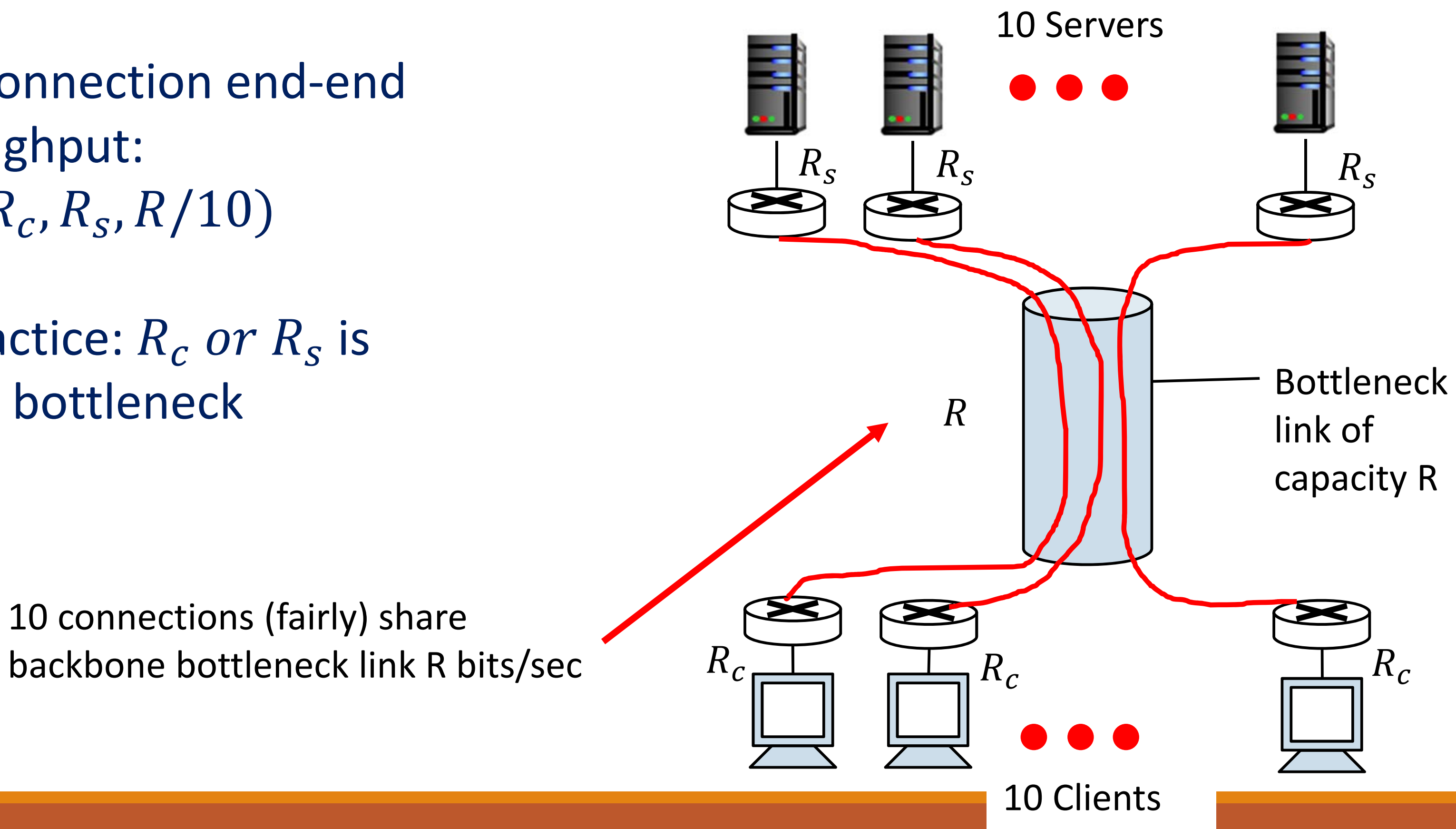


- Q: $R_s > R_c$ *What is average end-end throughput?*



1.4.4 Throughput in Computer Networks: bottleneck link

- Per-connection end-end throughput: $\min(R_c, R_s, R/10)$
- In practice: R_c *or* R_s is often bottleneck



1.5 protocol Layers and Their Services Models
1.5.1 Layered Architecture

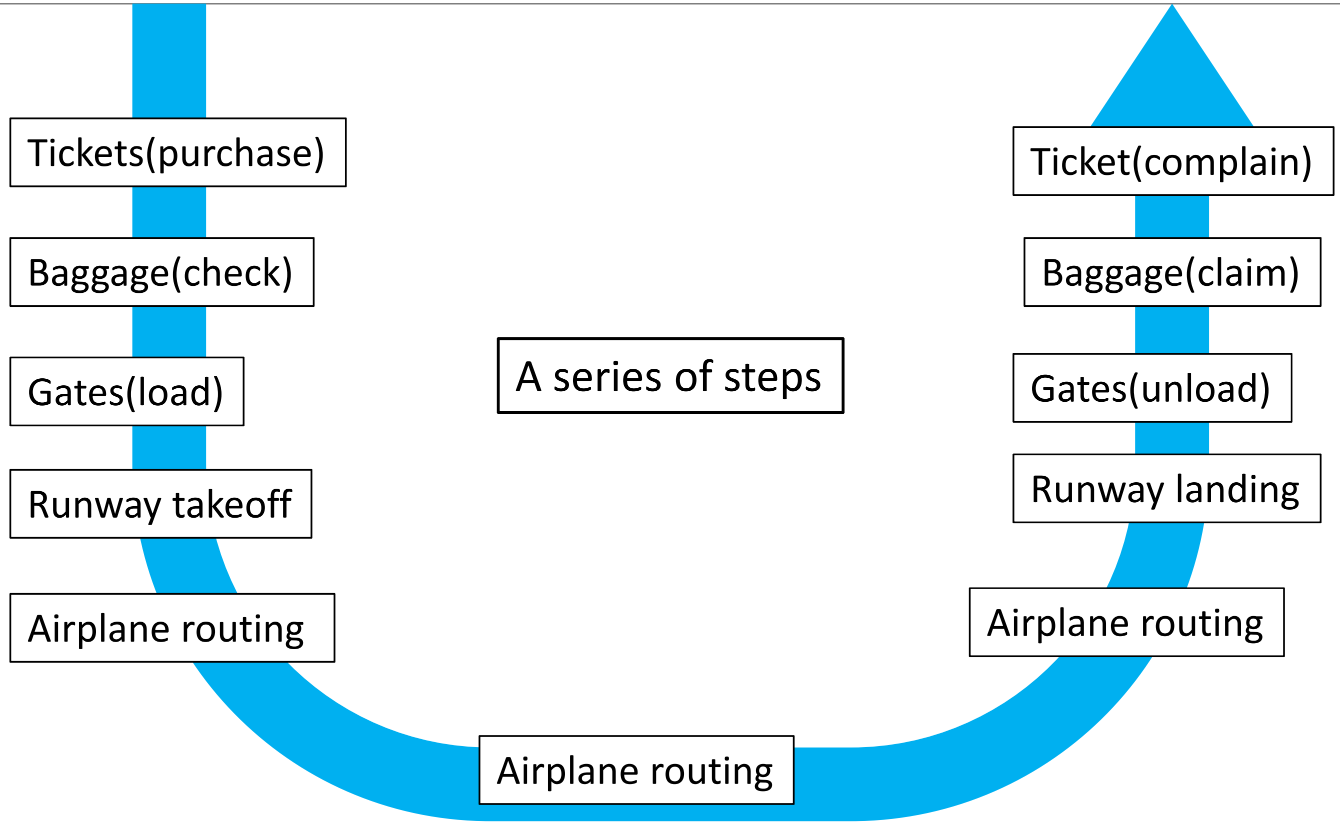
Protocol "layers"
Networks are complex,
with many "pieces":

- *Hosts*
- *Routers*
- *Link of various media*
- *Applications*
- *Protocols*
- *Hardware, software*

Q: Is there any hope of "organizing" structure of networks?

… or at least our discussion of networks?

1.5 protocol Layers and Their Services Models
1.5.1 Layered Architecture



1.5 protocol Layers and Their Services Models
1.5.1 Layered Architecture

Tickets(purchase)			Ticket(complain)	**Ticket**
Baggage(check)			Baggage(claim)	**Baggage**
Gates(load)			Gates(unload)	**Gate**
Runway takeoff			Runway landing	**Takeoff /Landing**
Airplane routing	Airplane routing	Airplane routing	Airplane routing	**Airplane routing**
Departure airport	**Intermediate air-traffic control centers**		**Arrival airport**	

Layers : each layer implement a service

- *Via its own internal-layer actions*
- *Relying on services provided by later below*

1.5.1 *Layered Architecture:* *Internet protocol stack*

- ***application*** : supporting network applications
  - FTP, SMTP, HTTP
- ***transport*** : process-process data transfer
  - TCP, UDP
- ***network*** : routing of datagrams from source to destination
  - IP, routing protocols
- ***link*** : data transfer between neighboring network elements
  - Ethernet, 802.11(WiFi), PPP
- ***physical*** : bit “on the wire”

Application	message
Transport	segment
Network	datagram
Link	frame
Physical	bit on the wire

1.5.1 Layered Architecture: *ISO/OSI reference model*

- ***presentation***: allow applications to interpret meaning of data,
  - E.g. encryption, compression, machine-specific conventions
- ***session***: synchronization, checkpointing, recovery of data exchange
- Internet stack "missing " these layers
  - These services, *if needed*, must be implemented in ***application layer***

Application
Presentation
Session
Transport
Network
Link
Physical

1.5.2 Encapsulation