

Computer Networks

CS 341, CS 342

September-November 2020

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Prof. Sukumar Nandi

CS 341- Computer Networks

Welcome to CS 341 (Theory) and CS 342 (Lab) !

- Course components:
- Lectures
- Class Notes
- Assignments
- Quizes
- End sem

Quiz : 6 in total (6 x 10% weightage)

End sem: Theory + Viva (20 % + 20 % weightage)

Quiz: Approximately after every 6 lectures. Dates will be declared well ahead of time.

References:

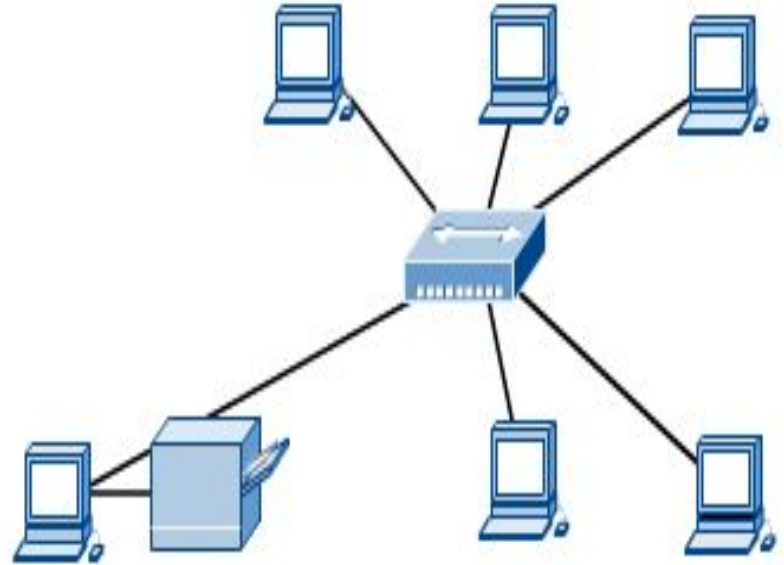
- **Computer Networking- A Top-Down Approach, Jim Kurose and Keith W. Ross**
- Computer Networks, by Andrew S Tanenbaum and David J Wetherall, 5th Ed and above, Prentice Hall.

Syllabus (Tentative , to be handled by Moumita Patra):

- Classification of Communication Networks. Standard models of communication: OSI and TCP/IP. Importance of layering and service models.
- Application layer services and protocols. Study of SMTP, HTTP, FTP, and DNS.
- Transport layer services, principles and protocols: study of TCP and UDP. Principles of reliability: sliding window protocols, selective repeat and go-back-N. Principles of congestion control: TCP case study. Details of TCP working.
- Network layer services, algorithms and protocols. Study of routing algorithms. Study of Internet router architecture. IP addressing principles: assignment and aggregation. Study of DHCP.

Computer Networks

- Computer networks connects two autonomous devices (PCs/mobile phones, etc.)
- The devices can be geographically located anywhere.



The Internet

- Millions of connected devices



PC



server



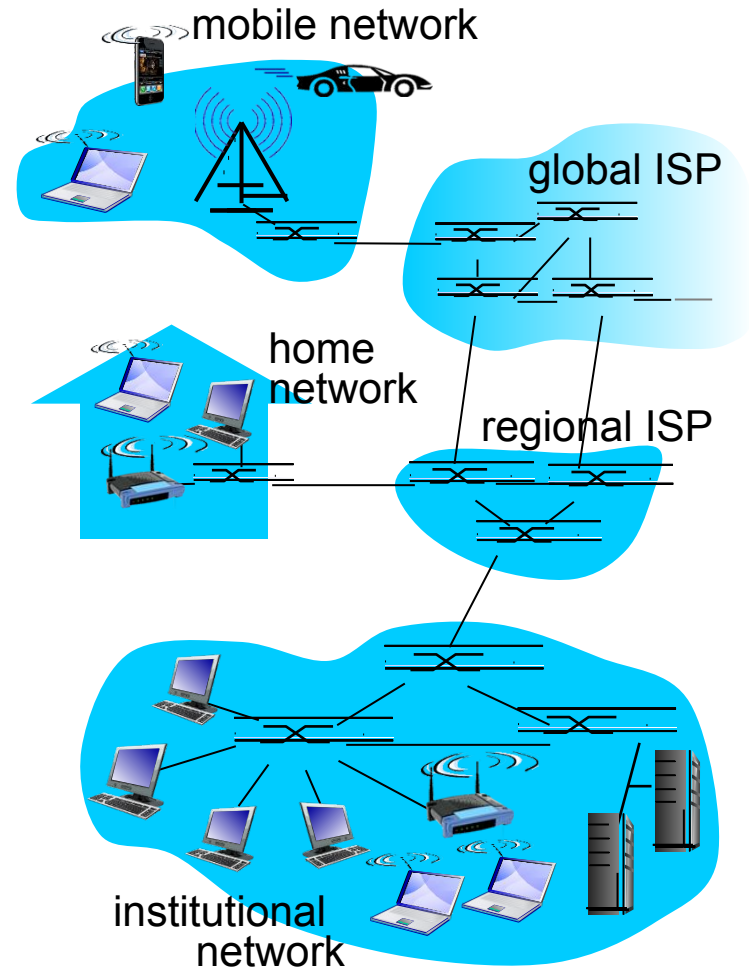
Wireless laptop



smartphone

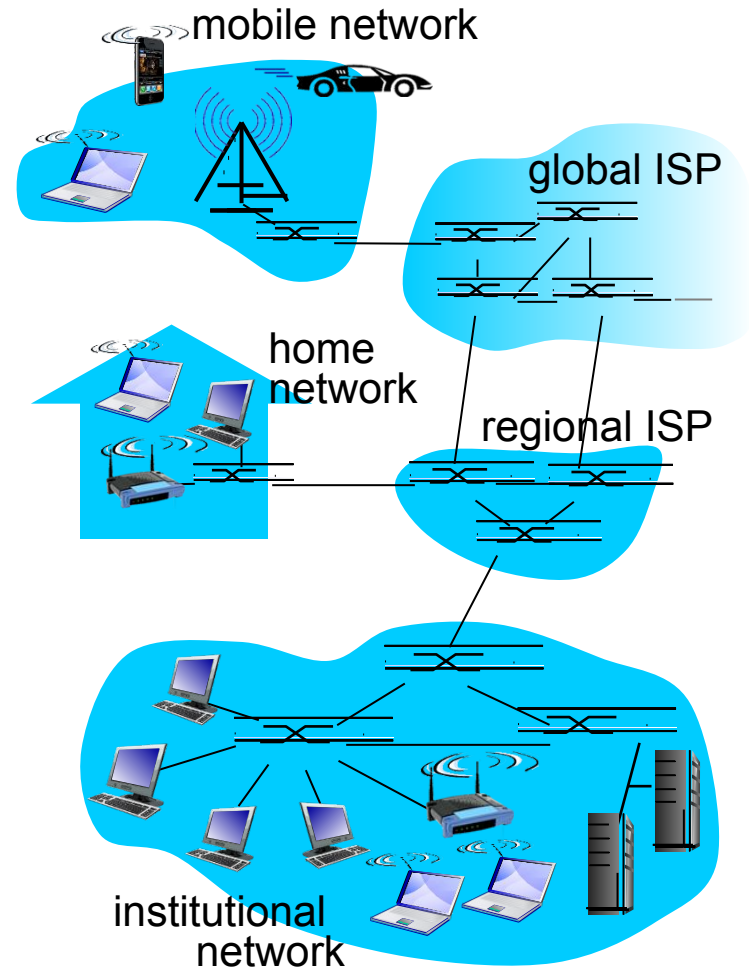
Hosts = end systems

Running network applications

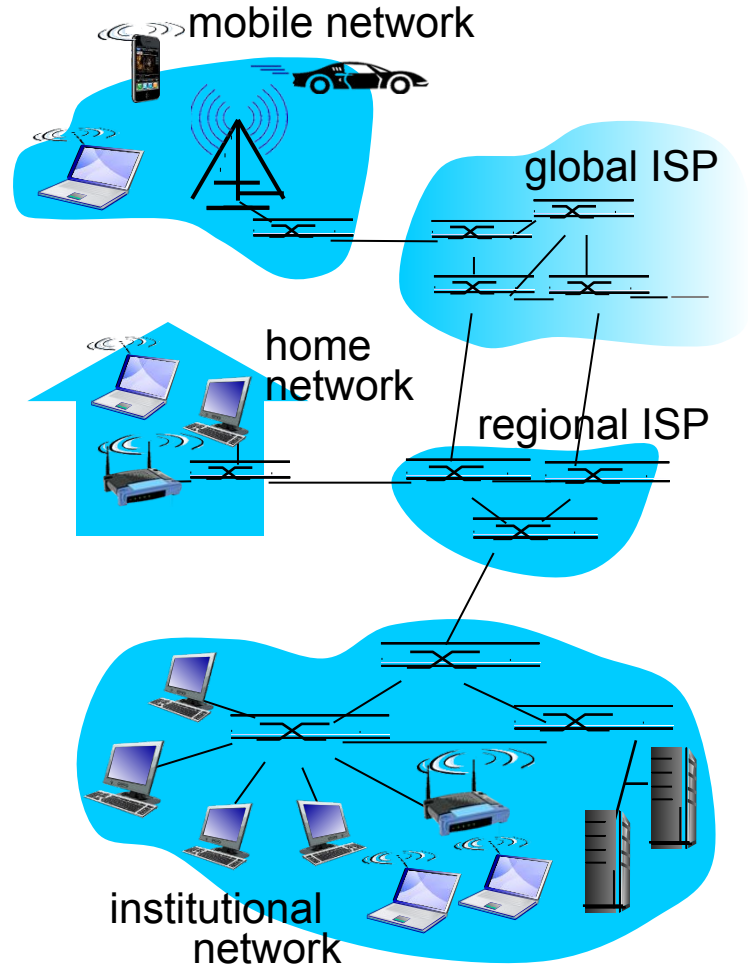


Communication Links

- Wired links
 - Wireless links
 - fiber, copper, radio, satellite
 - transmission rate: different links can transmit data at different rates
-
- Routers and Switches
 - Forward chunks of data (packets)



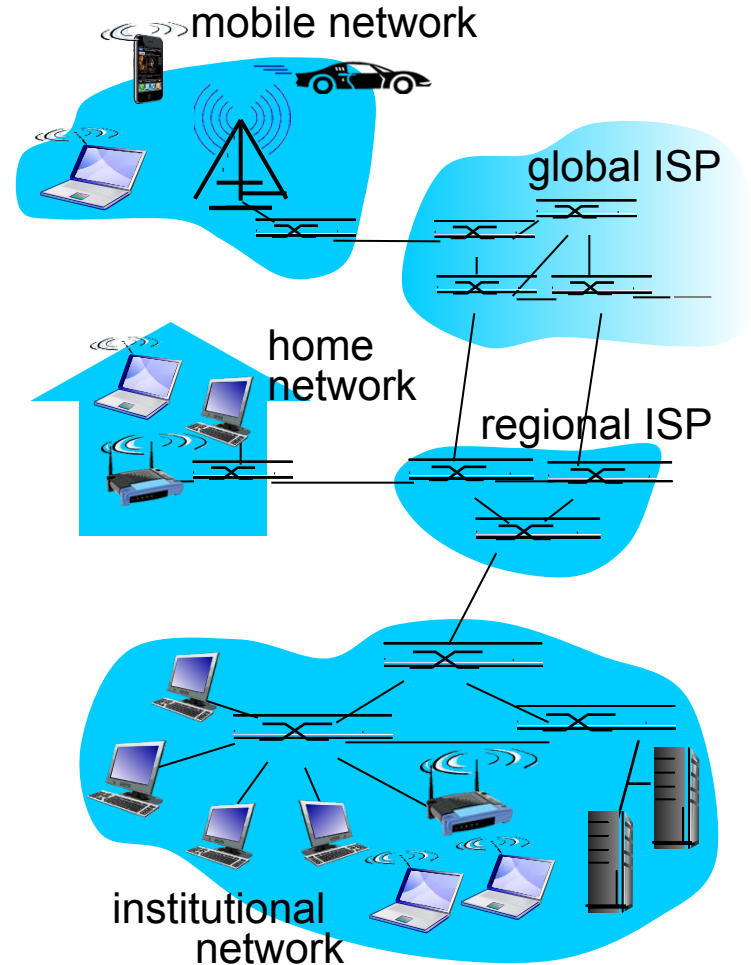
- ❖ **Internet:** “network of networks”
 - Interconnected ISPs
- ❖ **protocols** control sending and receiving of data
 - e.g., TCP, IP, HTTP, Skype, 802.11
- ❖ **Internet standards**
 - RFC: Request for comments
 - IETF: Internet Engineering Task Force
 - Internet standards are developed by the IETF.
 - The IETF standards documents are called RFCs.



A “service view” of the Internet

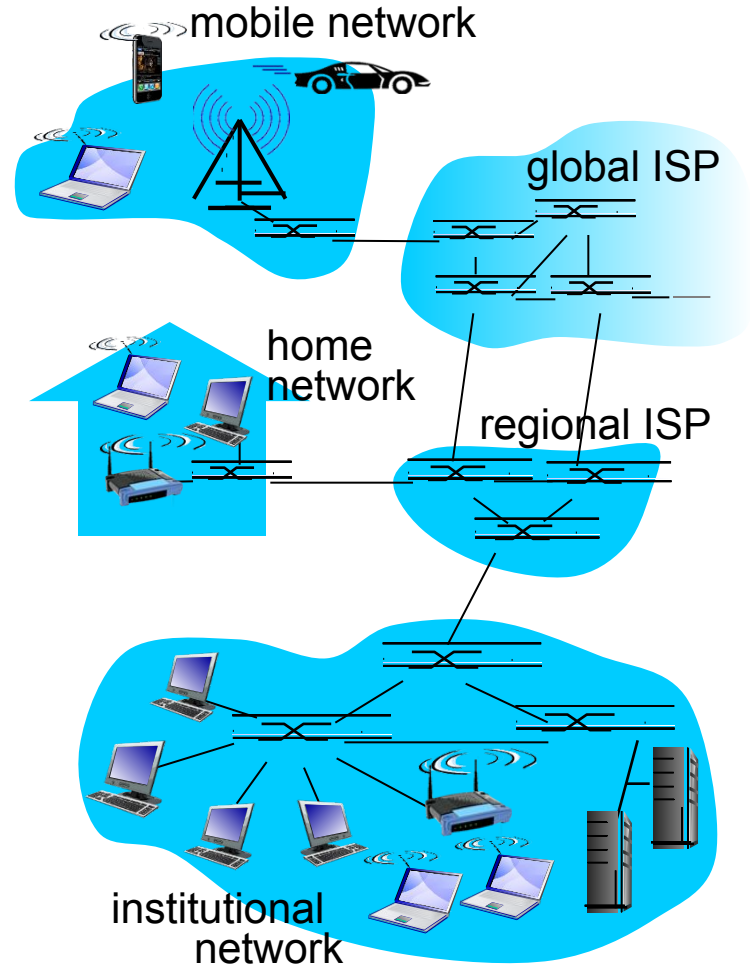
❖ *Infrastructure that provides services to applications:*

- E.g- Web, VoIP, email, games, e-commerce, social networking, etc.
- Applications are said to be distributed
- Applications involve multiple end systems that exchange data with each other.

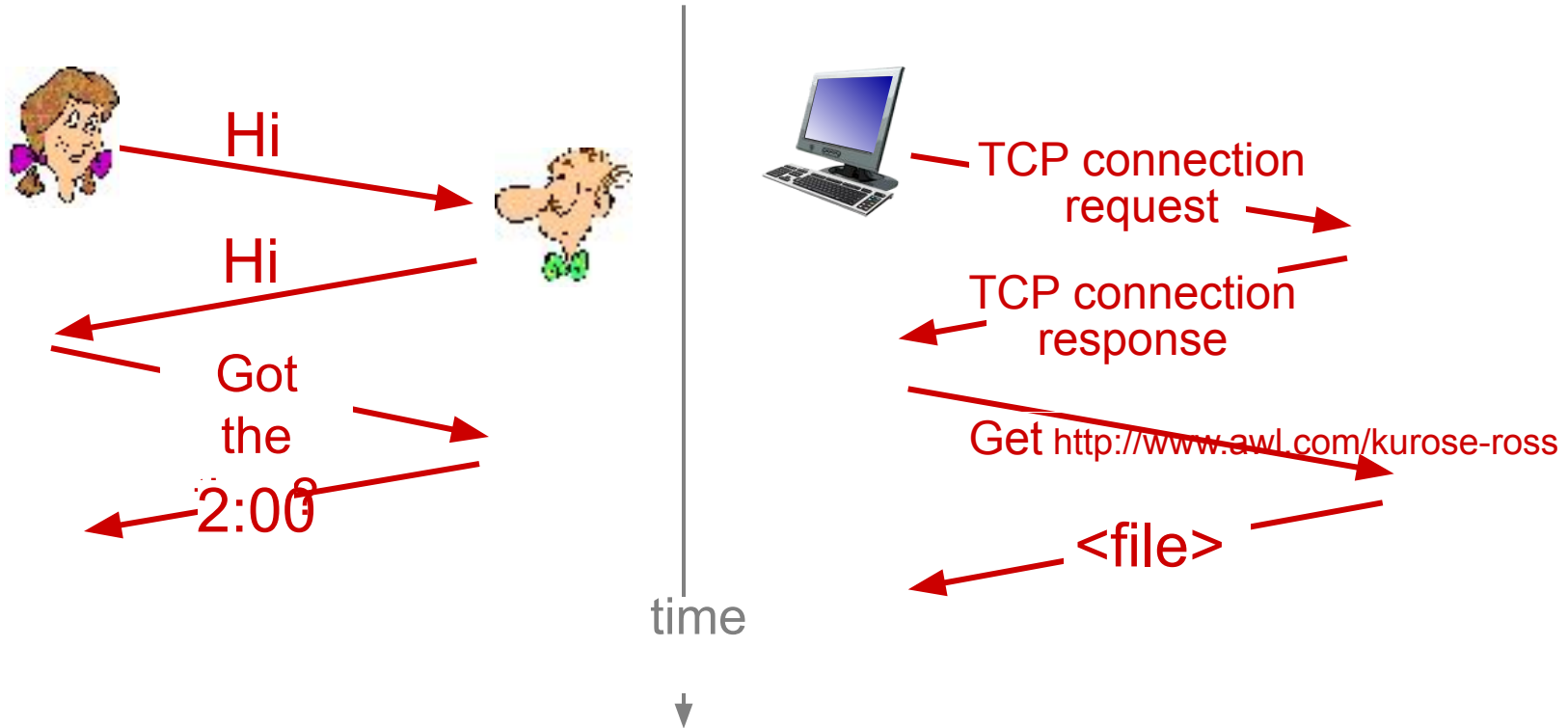


- Internet applications run on end systems- not in the network core.

- ❖ *provides programming interface to applications*
 - allows sending and receiving application programs to “connect” to Internet



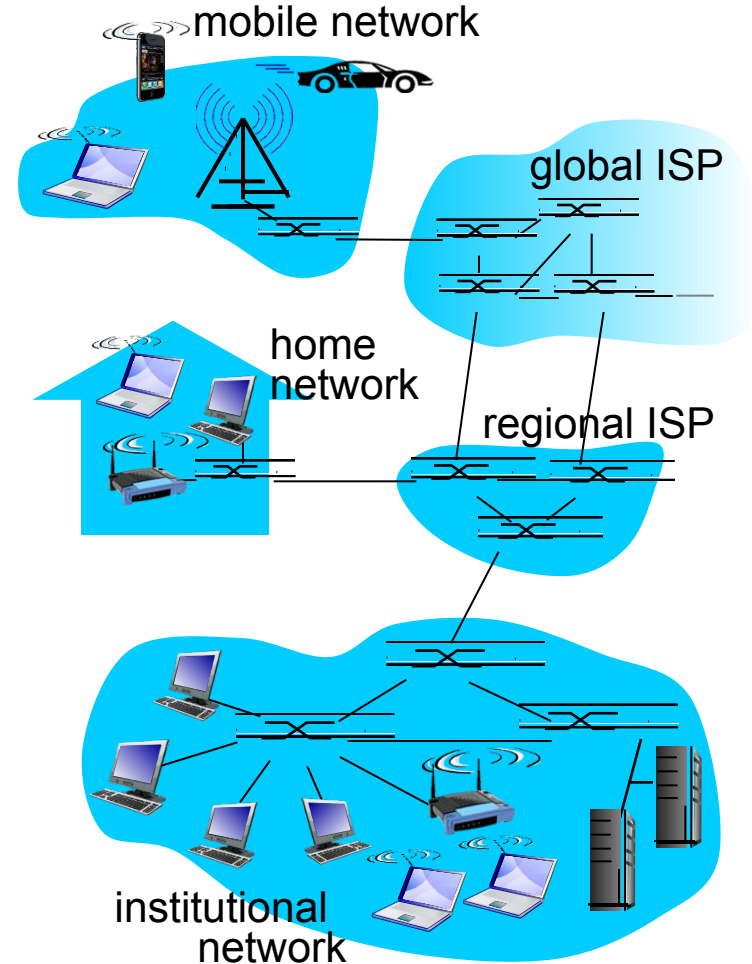
Protocols



A protocol defines the format and order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or receipt of a message or other event.

Network Structure

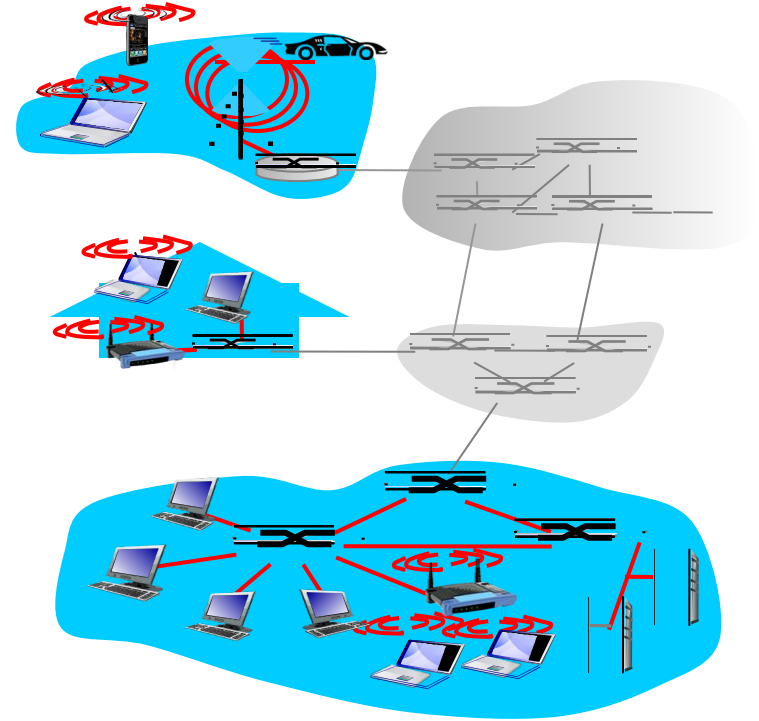
- *network edge:*
 - hosts: clients and servers
- *access networks, physical media:*
- wired, wireless communication links
- *network core:*
 - interconnected routers
 - network of networks



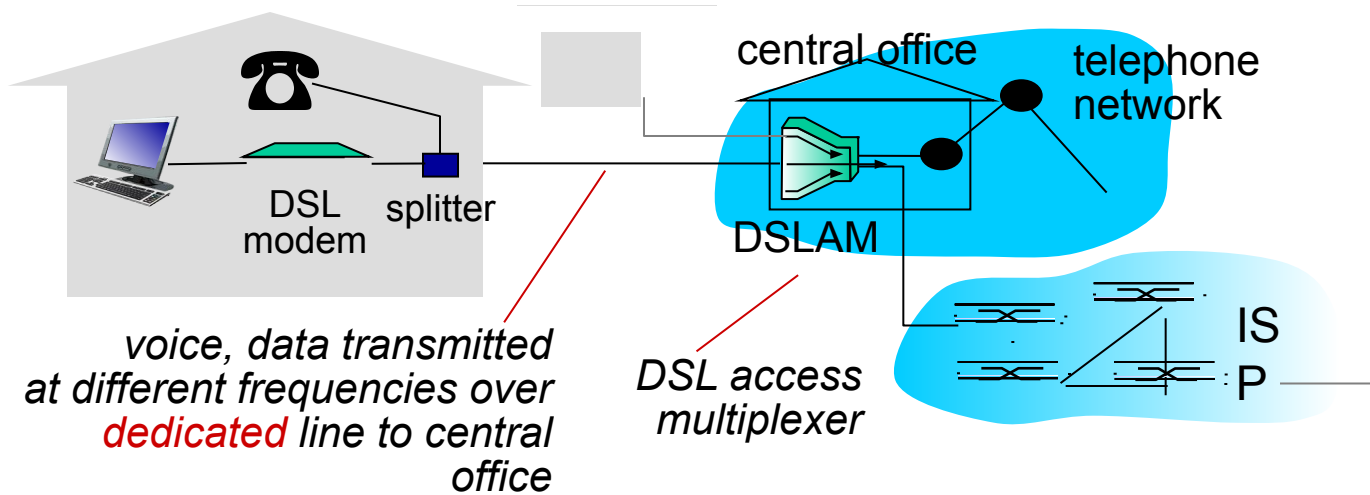
Access networks and physical media

Q: How to connect end systems to edge router?

- ❖ residential access networks
- ❖ institutional access networks (school, company)
- ❖ mobile access networks

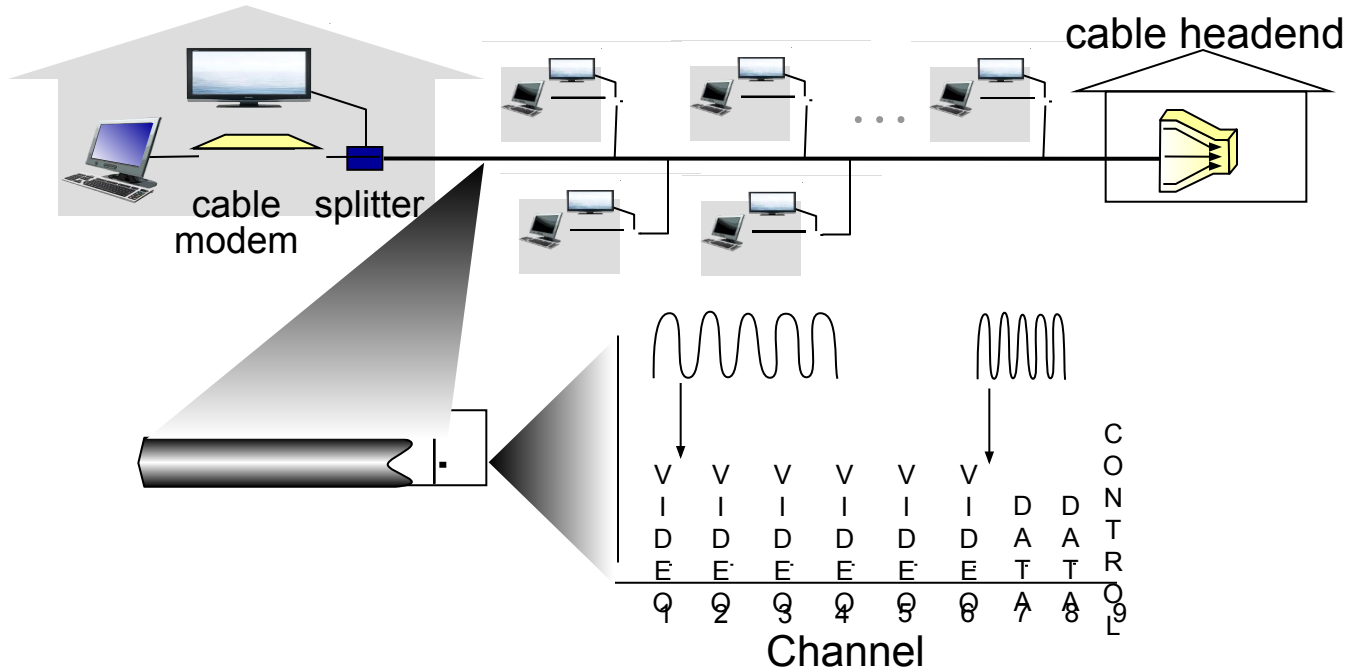


Access net: Digital Subscriber Line (DSL)



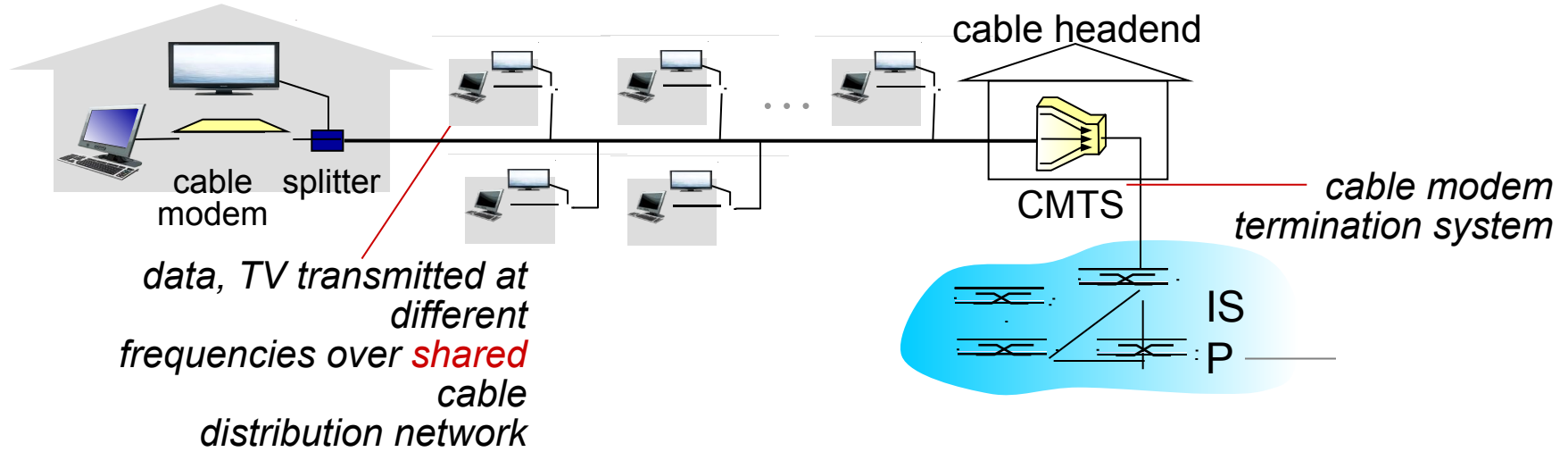
- ❖ use *existing* telephone line to central office DSLAM
 - data over DSL phone line goes to Internet
 - voice over DSL phone line goes to telephone net
- ❖ < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- ❖ < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access net: cable network



frequency division multiplexing: ^sdifferent channels transmitted in different frequency bands

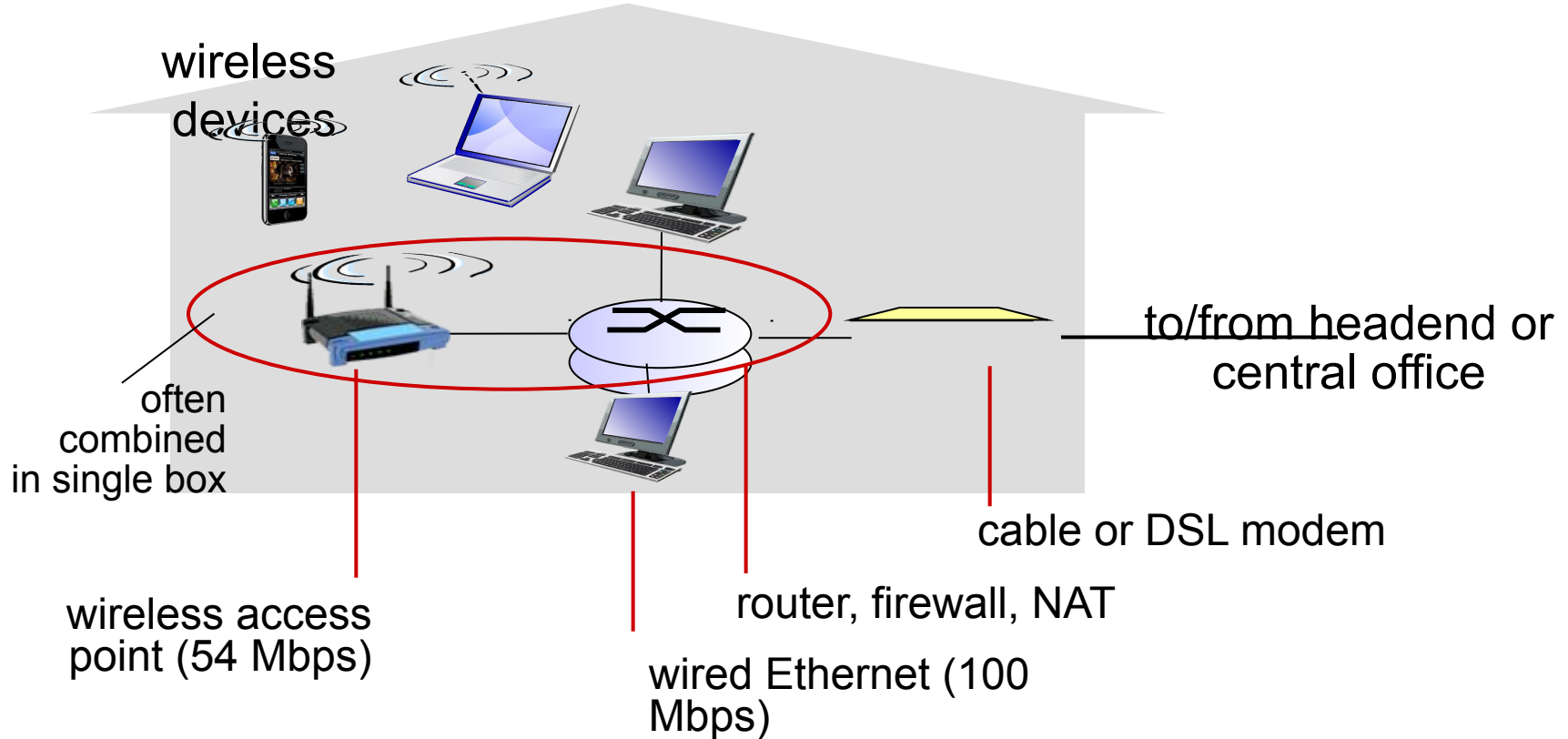
Access net: cable network



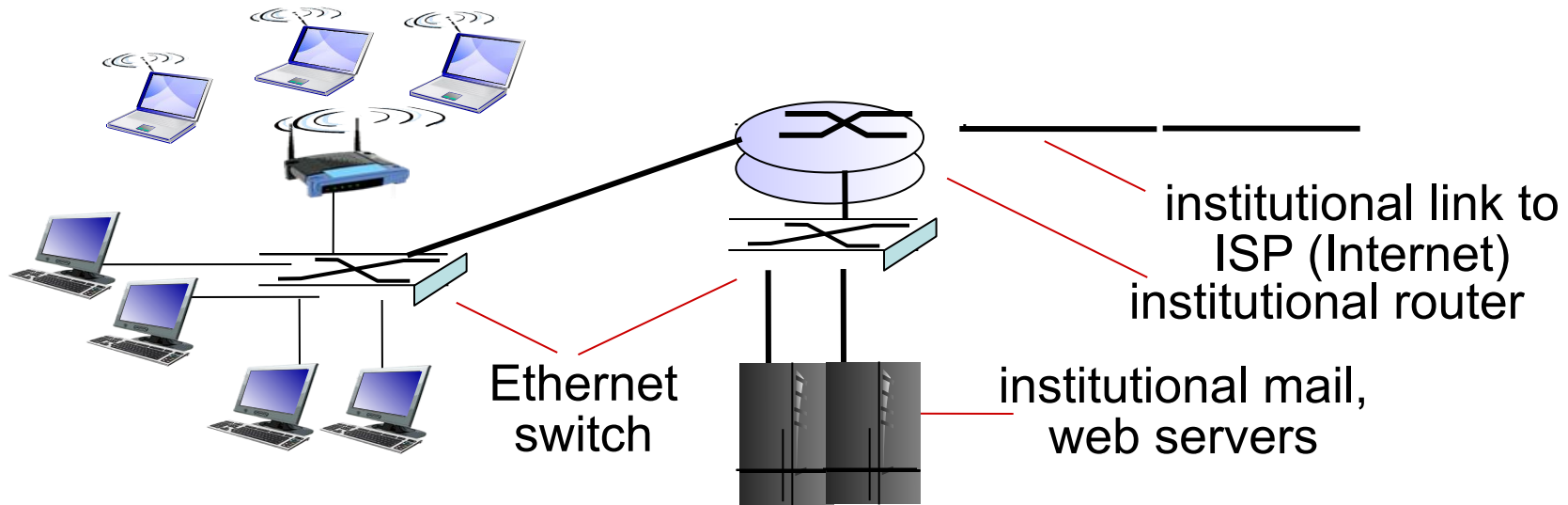
❖ HFC: hybrid fiber coax

- asymmetric: upto 30 Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- ❖ **network** of cable, fiber attaches homes to ISP router
 - homes **share access network** to cable head end
 - unlike DSL, which has dedicated access to central office

Access net: home network



Enterprise access networks (Ethernet)



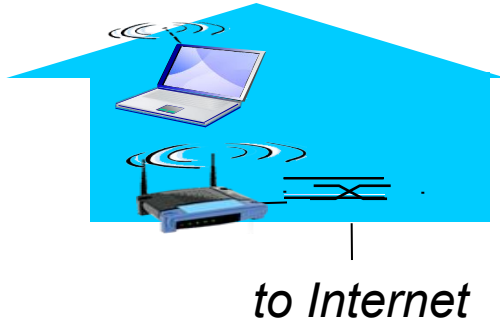
- ❖ typically used in companies, universities, etc
- ❖ 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- ❖ today, end systems typically connect into Ethernet switch

Wireless access networks

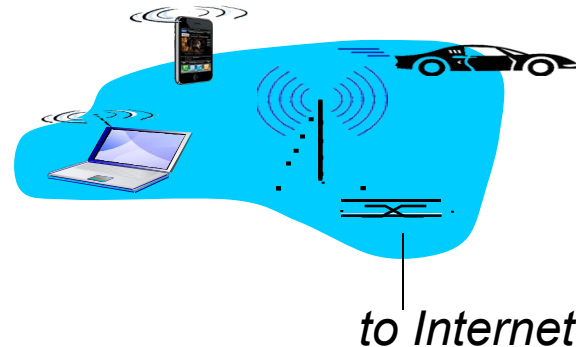
- ❖ shared *wireless* access network connects end system to router
 - via base station aka “access point” **wide-area wireless access**

wireless LANs:

- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate



- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE



Physical Media

- ❖ **bit:** propagates between transmitter/receiver pairs
- ❖ **physical link:** what lies between transmitter & receiver
- ❖ **guided media:**
 - signals propagate in solid media: copper, fiber, coax
- ❖ **unguided media:**
 - signals propagate freely, e.g., radio

twisted pair (TP)

- ❖ two insulated copper wires
 - Category 5: 100 Mbps, 1 Gbps Ethernet
 - Category 6: 10Gbps



Physical Media: coax and fiber

coaxial cable:

- ❖ two concentric copper conductors
- ❖ bidirectional
- ❖ broadband:
 - multiple channels on cable
 - HFC(High Fiber Coax)-
Both fiber and coaxial cable



fiber optic cable:

- ❖ glass fiber carrying light pulses, each pulse a bit
- ❖ high-speed operation:
 - high-speed point-to-point transmission (e.g., 10's-100's Gpbs transmission rate)
- ❖ low error rate:
 - repeaters spaced far apart
 - immune to electromagnetic noise

Physical media: Radio

radio link types:

- ❖ signal carried in electromagnetic spectrum
- ❖ no physical “wire”
- ❖ bidirectional
- ❖ propagation environment effects:
 - reflection
 - obstruction by objects
 - interference
- ❖ **terrestrial microwave**
 - e.g. up to 45 Mbps channels
- ❖ **LAN** (e.g., WiFi)
 - 11 Mbps, 54 Mbps
- ❖ **wide-area** (e.g., cellular)
 - 3G cellular: ~ few Mbps
- ❖ **satellite**
 - Upto 45Mbps channel (or multiple smaller channels)
 - 270 msec end-end delay
 - geosynchronous versus low altitude

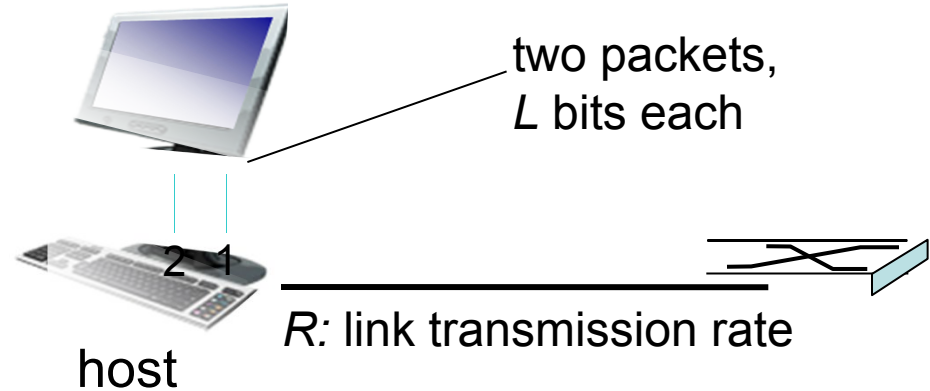
Network core

- **packet switching, circuit switching,
network structure**

Host: sends *packets* of data

host sending function:

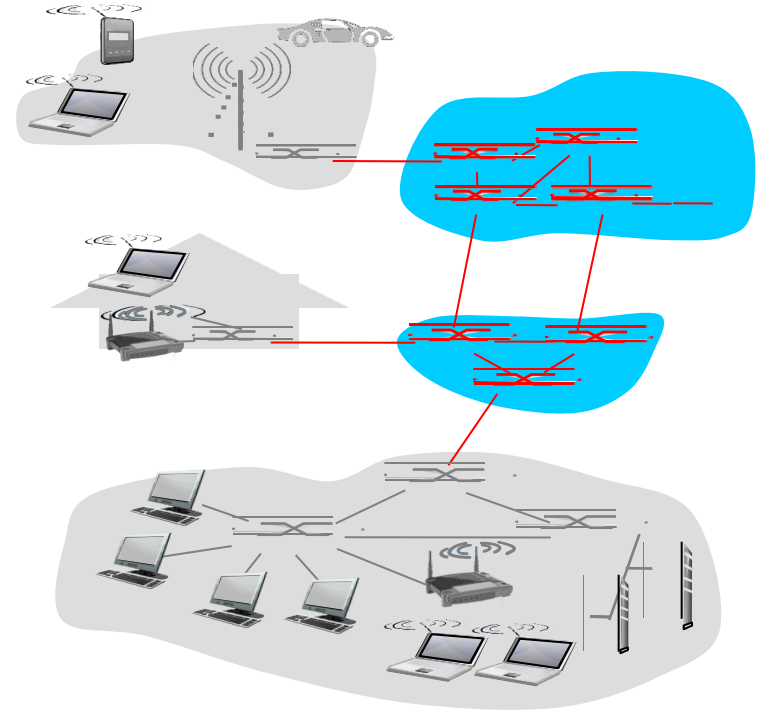
- ❖ takes application message
- ❖ breaks into smaller chunks, known as *packets*, of length L bits
- ❖ transmits packet into access network at *transmission rate* R
 - link transmission rate, aka link *capacity*, aka link *bandwidth*



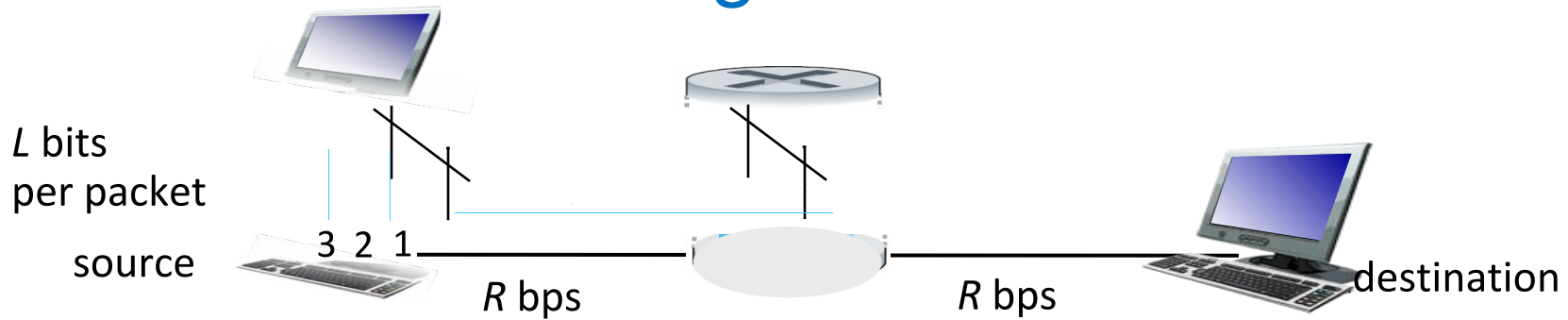
$$\begin{array}{ccccc} \text{packet} & & \text{time needed to} & & L \text{ (bits)} \\ \text{transmission} & = & \text{transmit } L\text{-bit} & = & \\ \text{delay} & & \text{packet into link} & & \hline & & & & R \text{ (bits/sec)} \end{array}$$

The Network Core

- ❖ mesh of interconnected routers
- ❖ packet-switching: hosts break application-layer messages into *packets*
 - forward packets from one router to the next, across links on path from source to destination
 - each packet transmitted at full link capacity



Packet Switching: Store-and-forward

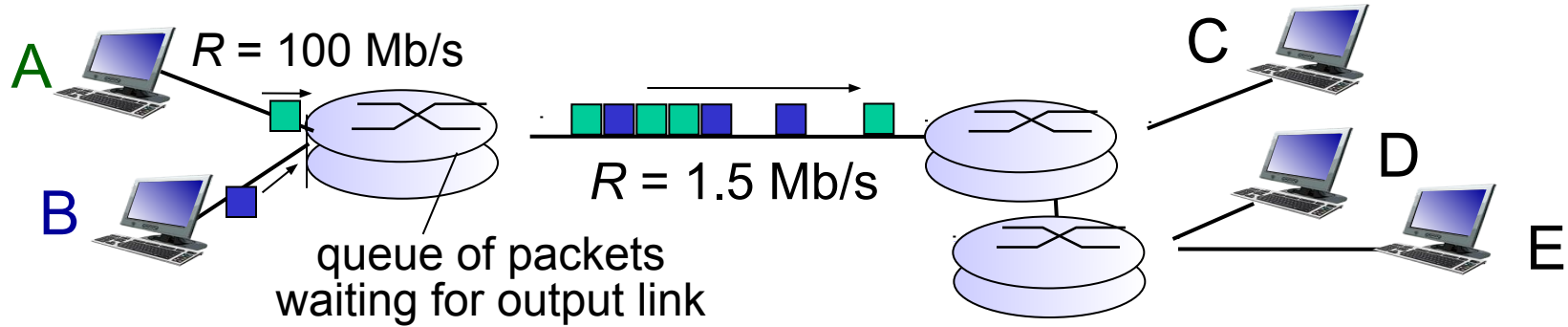


- ❖ takes L/R seconds to transmit (push out) L -bit packet into link at R bps
- ❖ **store and forward**: entire packet must arrive at router before it can be transmitted on next link
- ❖ end-end delay = $2L/R$ (assuming zero propagation delay)

one-hop numerical example:

- $L = 7.5$ Mbits
- $R = 1.5$ Mbps
- one-hop transmission delay = 5 sec

Packet Switching: queueing delay, loss



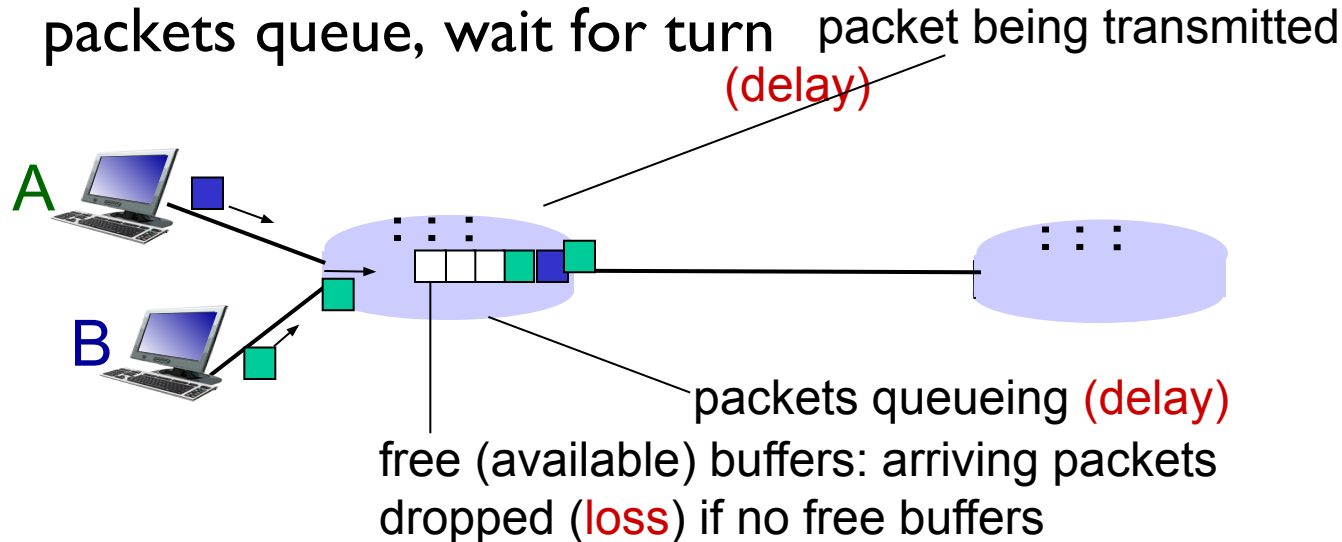
queuing and loss:

- ❖ 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

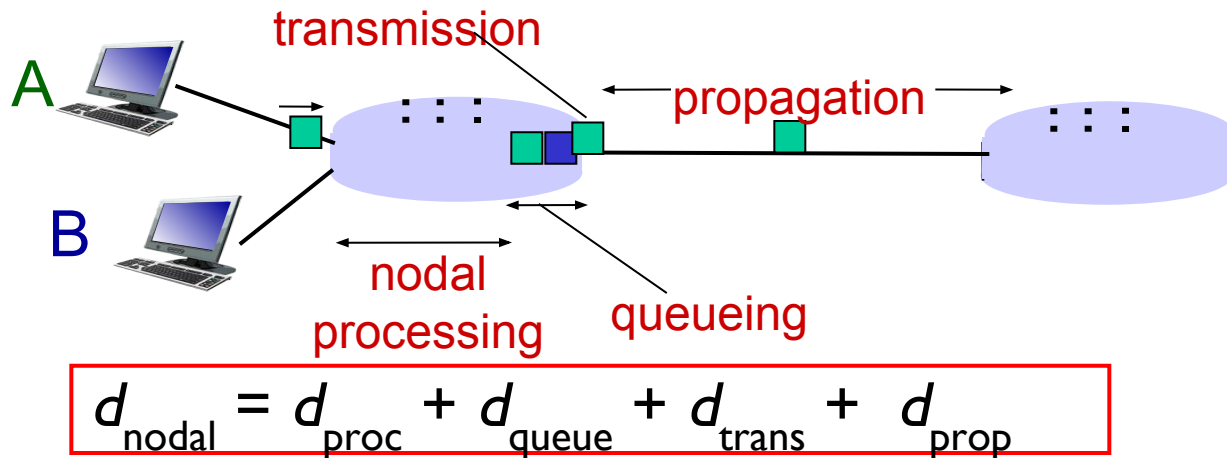
How do loss and delay occur?

packets *queue* in router buffers

- ❖ packet arrival rate to link (temporarily) exceeds output link capacity
- ❖ packets queue, wait for turn



Sources of packet delay



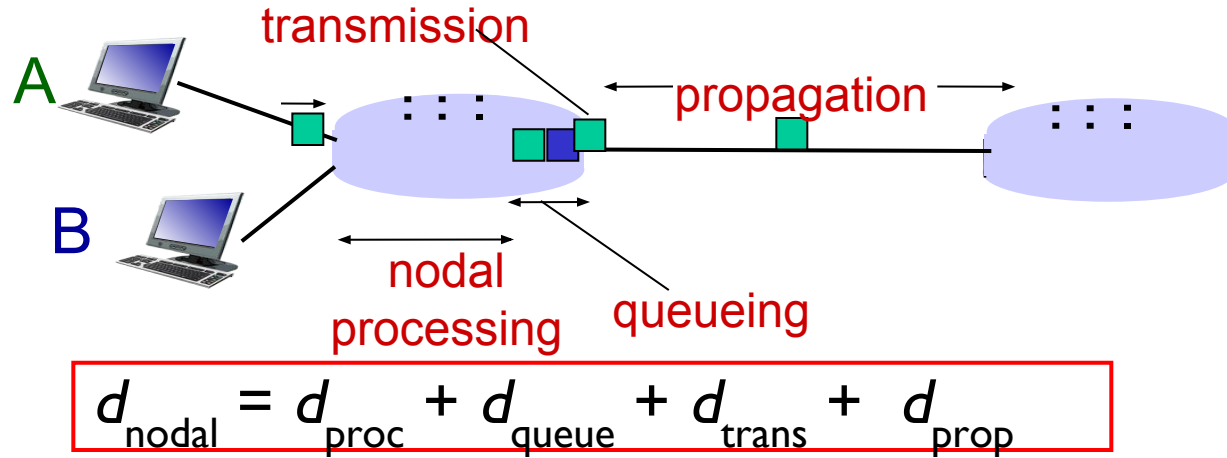
d_{proc} : nodal processing

- 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

Sources of packet delay



d_{trans} : transmission delay:

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

d_{prop} : propagation delay:

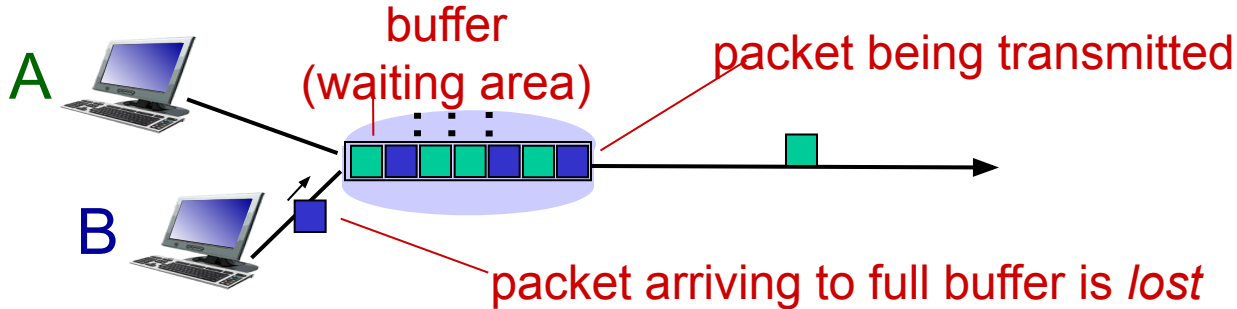
- d : length of physical link
- s : propagation speed in medium ($\sim 2 \times 10^8$ m/sec)
- $d_{\text{prop}} = d/s$

d_{trans} and d_{prop}
very different

* Check out the Java applet for an interactive animation on trans vs. prop delay

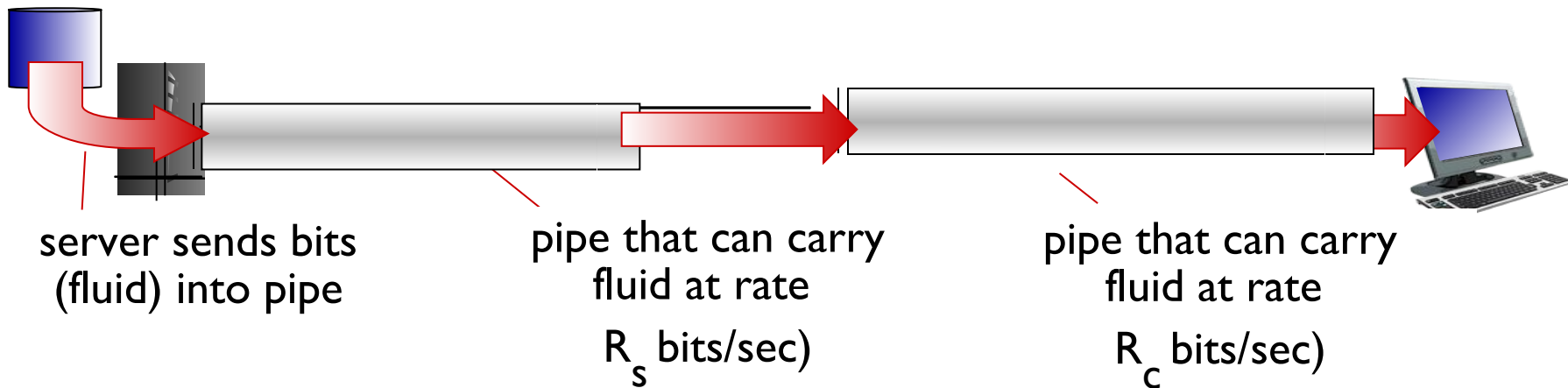
Packet loss

- ❖ 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

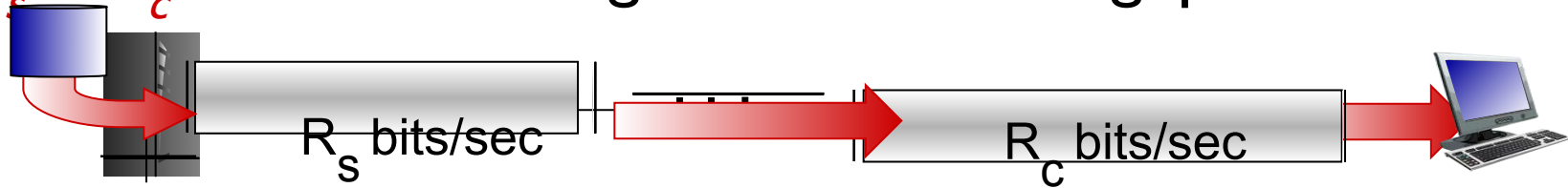


Throughput

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



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



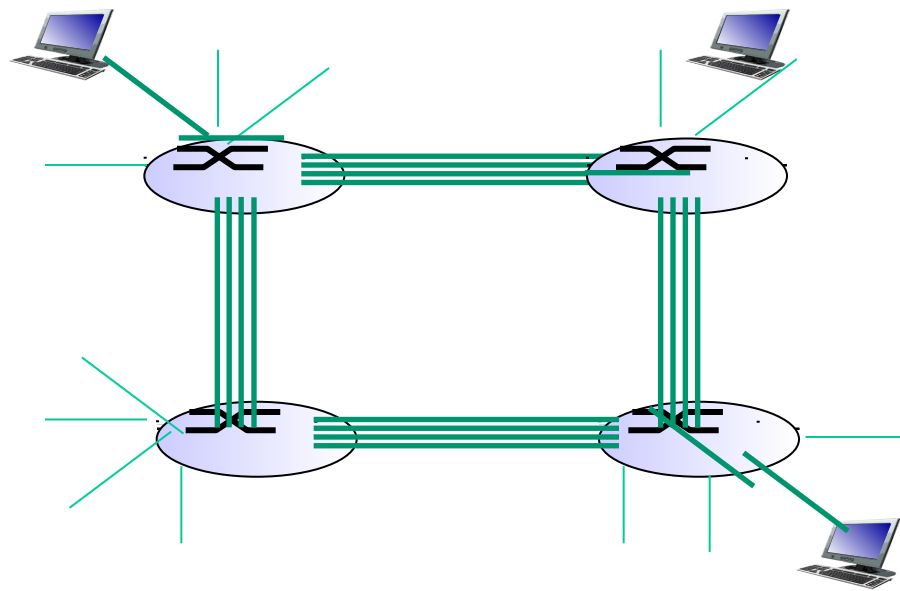
bottleneck link

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

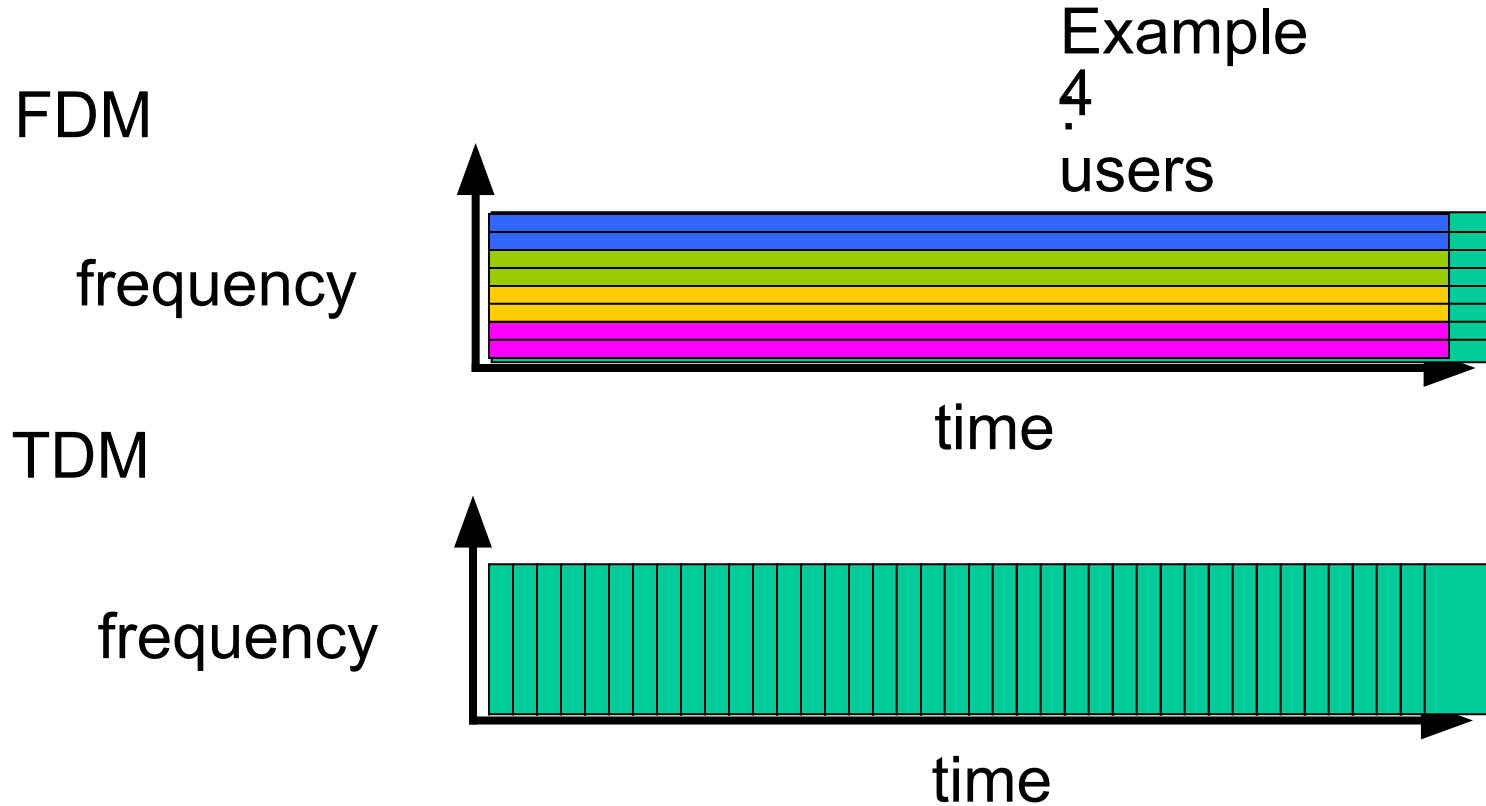
Alternative core: circuit switching

end-end resources allocated to,
reserved for “call” between
source & dest:

- ❖ In diagram, 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*)
- ❖ Commonly used in traditional telephone networks



Circuit switching: FDM versus TDM



Packet Switching

- ❖ Resources are not reserved.
- ❖ A session's message use the resources on demand.
- ❖ Message may have to wait for access to a communication link.

Advantages over circuit-switching

- ❖ Better sharing of bandwidth
- ❖ Simple
- ❖ Efficient
- ❖ Less costly

Packet switching versus circuit switching

is packet switching a “slam dunk winner?”

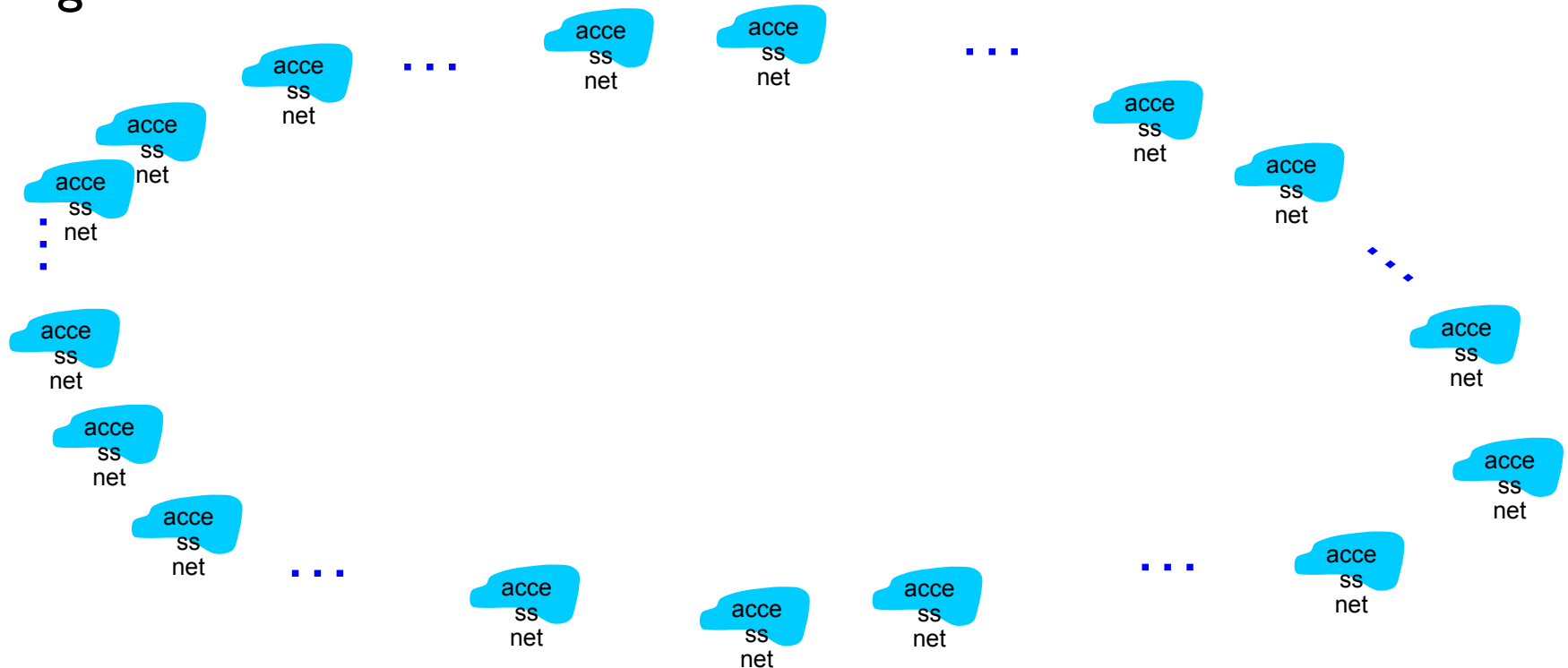
- ❖ great for bursty data
 - resource sharing
 - simpler, no call setup
- ❖ **excessive congestion possible:** packet delay and loss
 - protocols needed for reliable data transfer, congestion control
- ❖ **Q: How to provide circuit-like behavior?**
 - bandwidth guarantees needed for audio/video apps
 - still an unsolved problem

Internet structure: network of networks

- ❖ End systems connect to Internet via **access ISPs** (Internet Service Providers)
 - ❖ Residential, company and university ISPs
- ❖ 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**

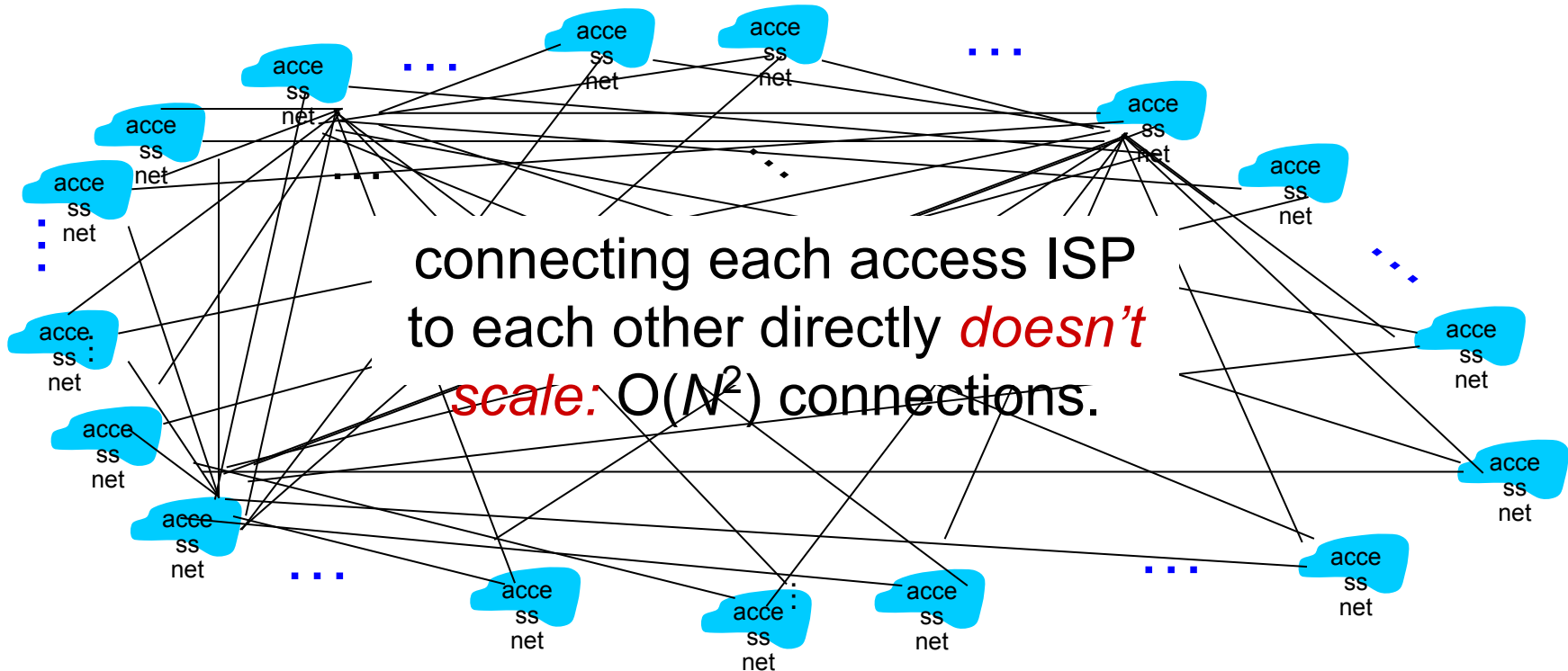
Internet structure: network of networks

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



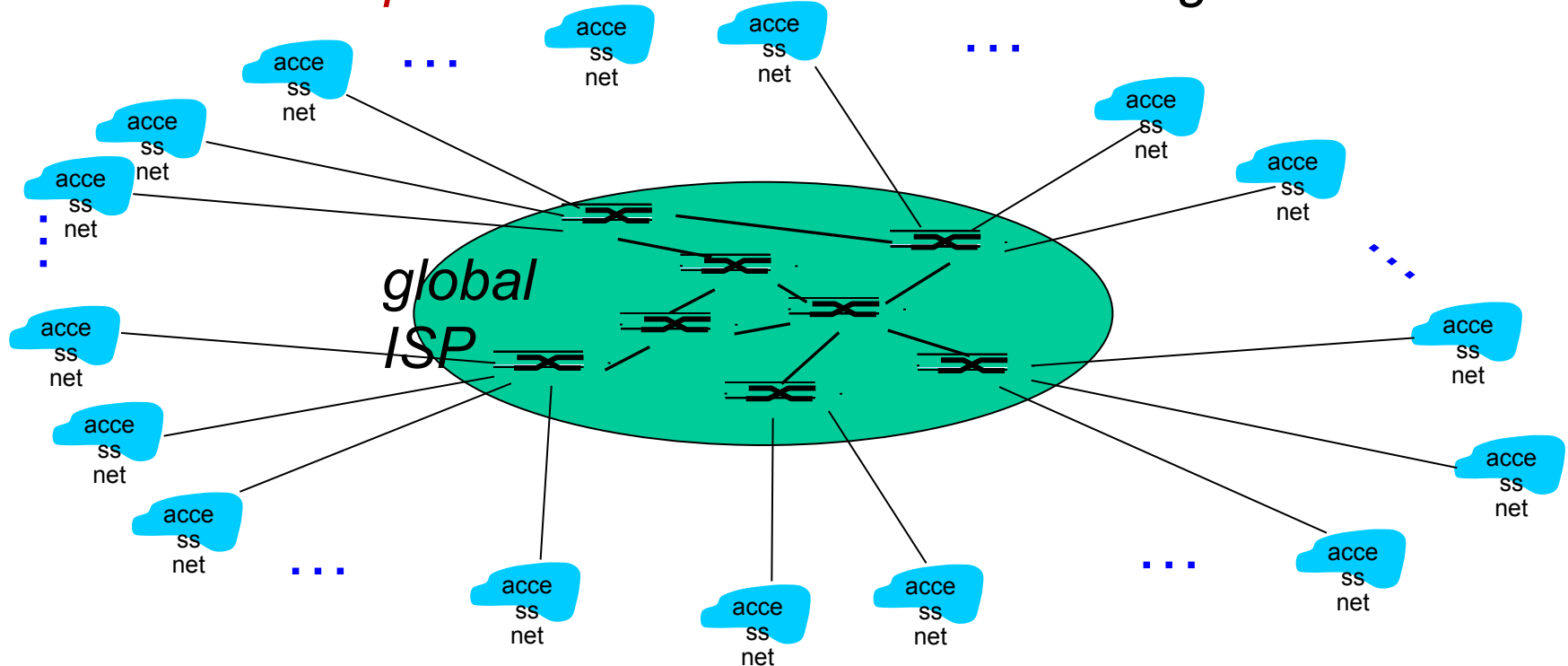
Internet structure: network of networks

Option: connect each access ISP to every other access ISP?



Internet structure: network of networks

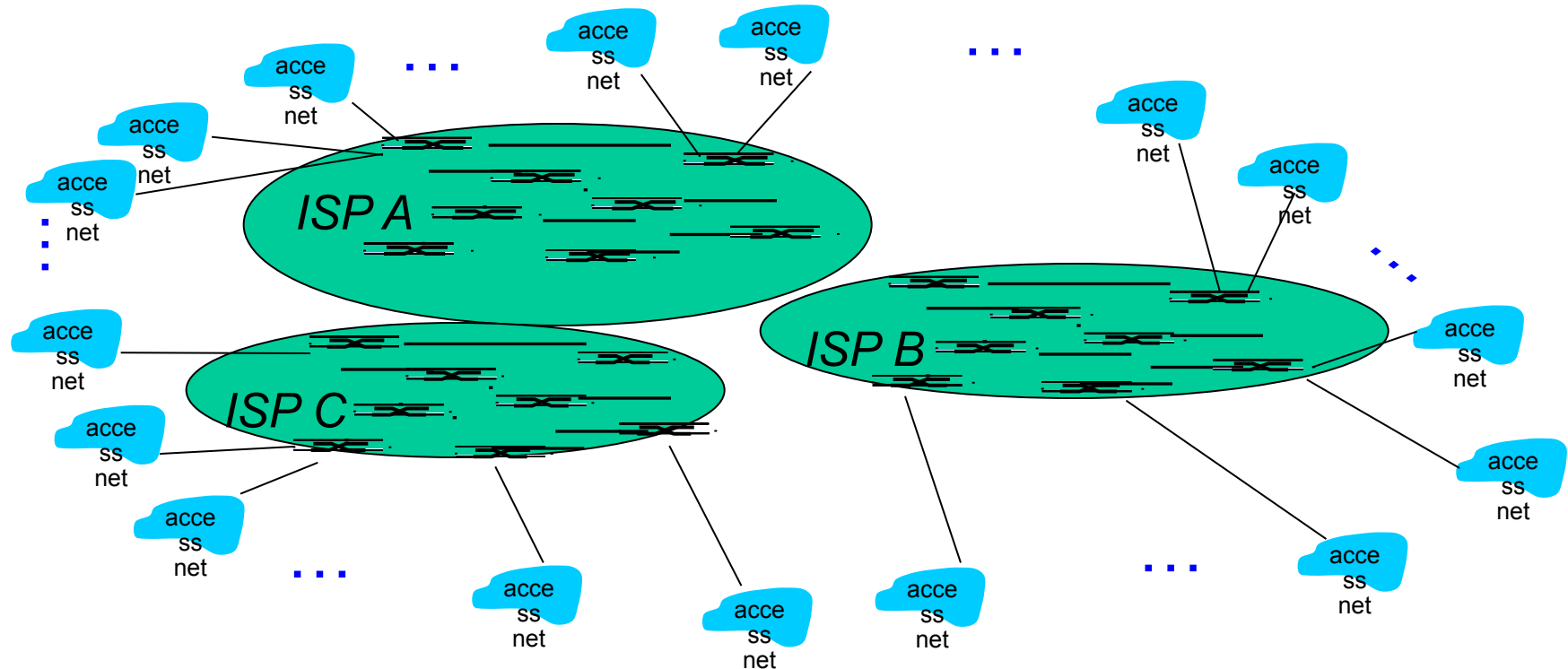
Option: connect each access ISP to a global transit ISP?
Customer and provider ISPs have economic agreement.



Internet structure: network of networks

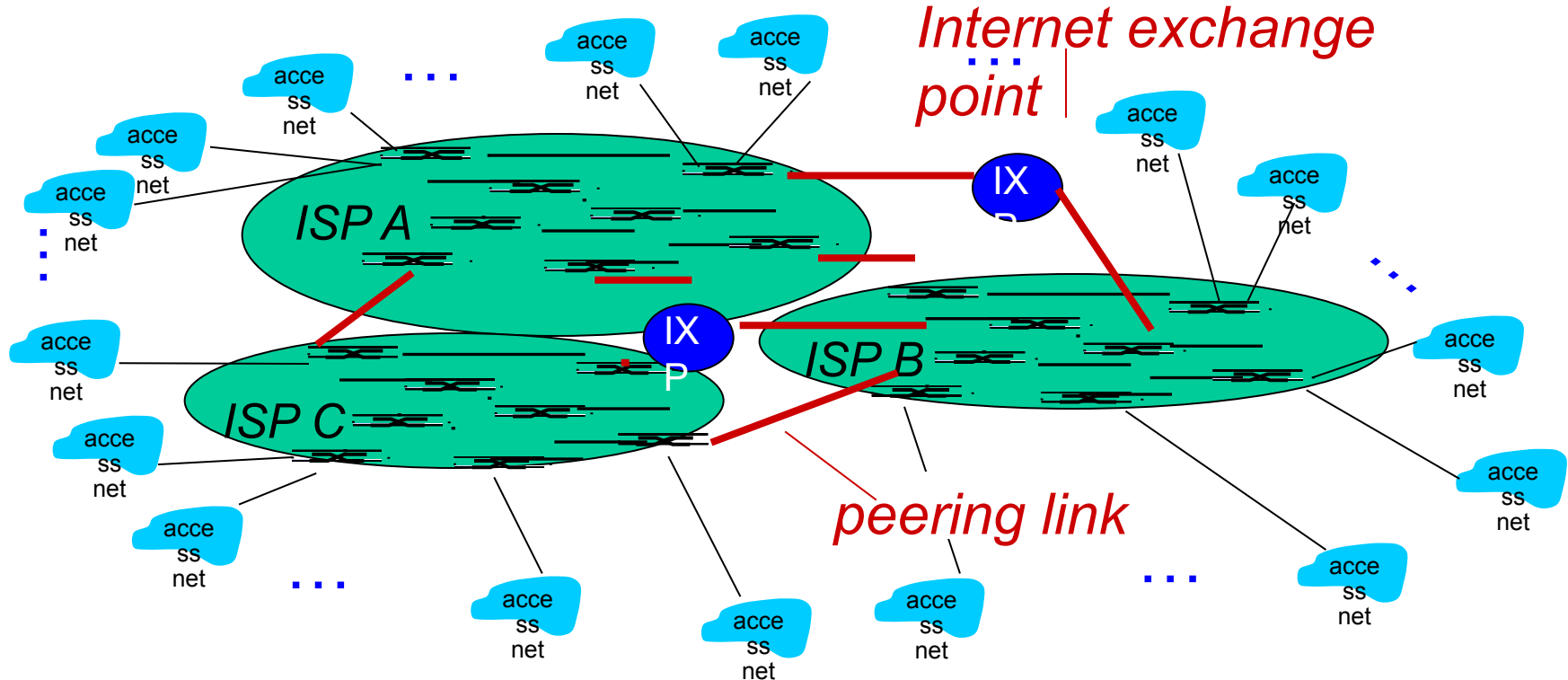
But if one global ISP is viable business, there will be competitors

....



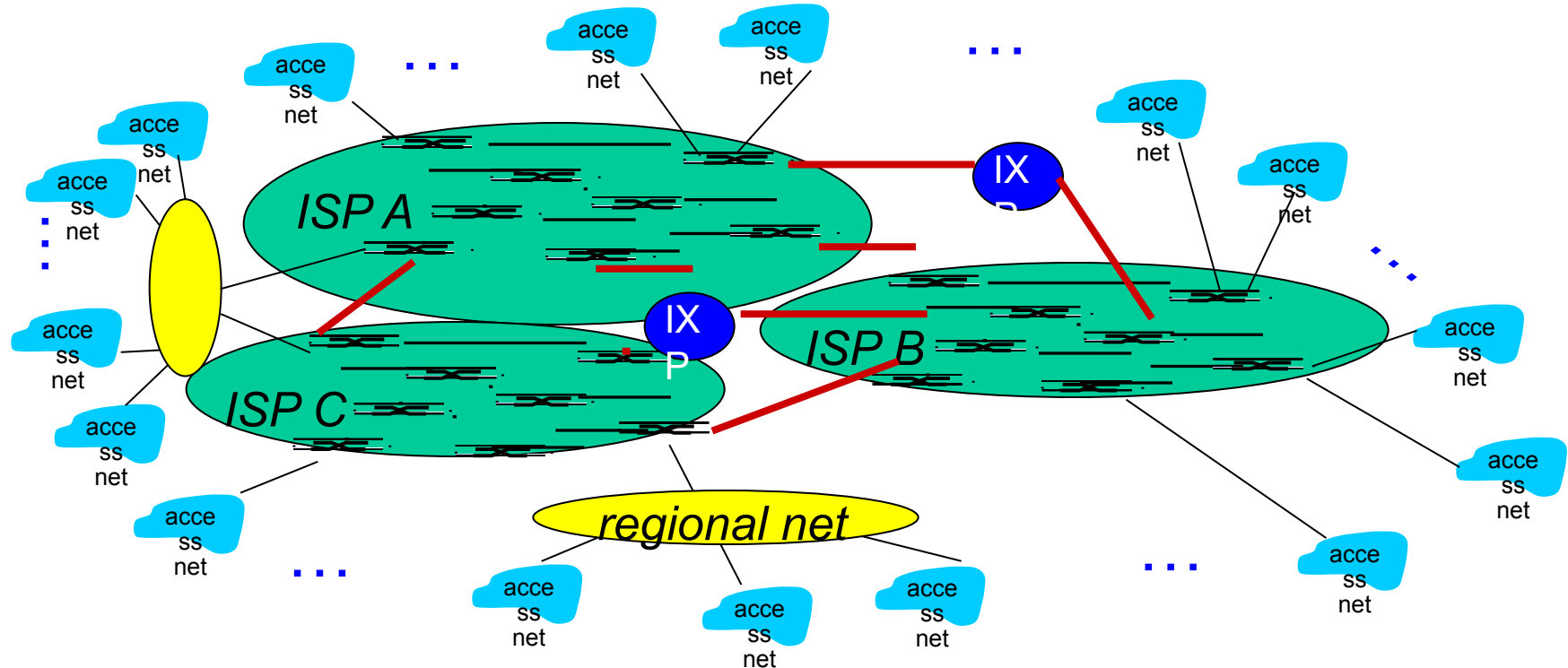
Internet structure: network of networks

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



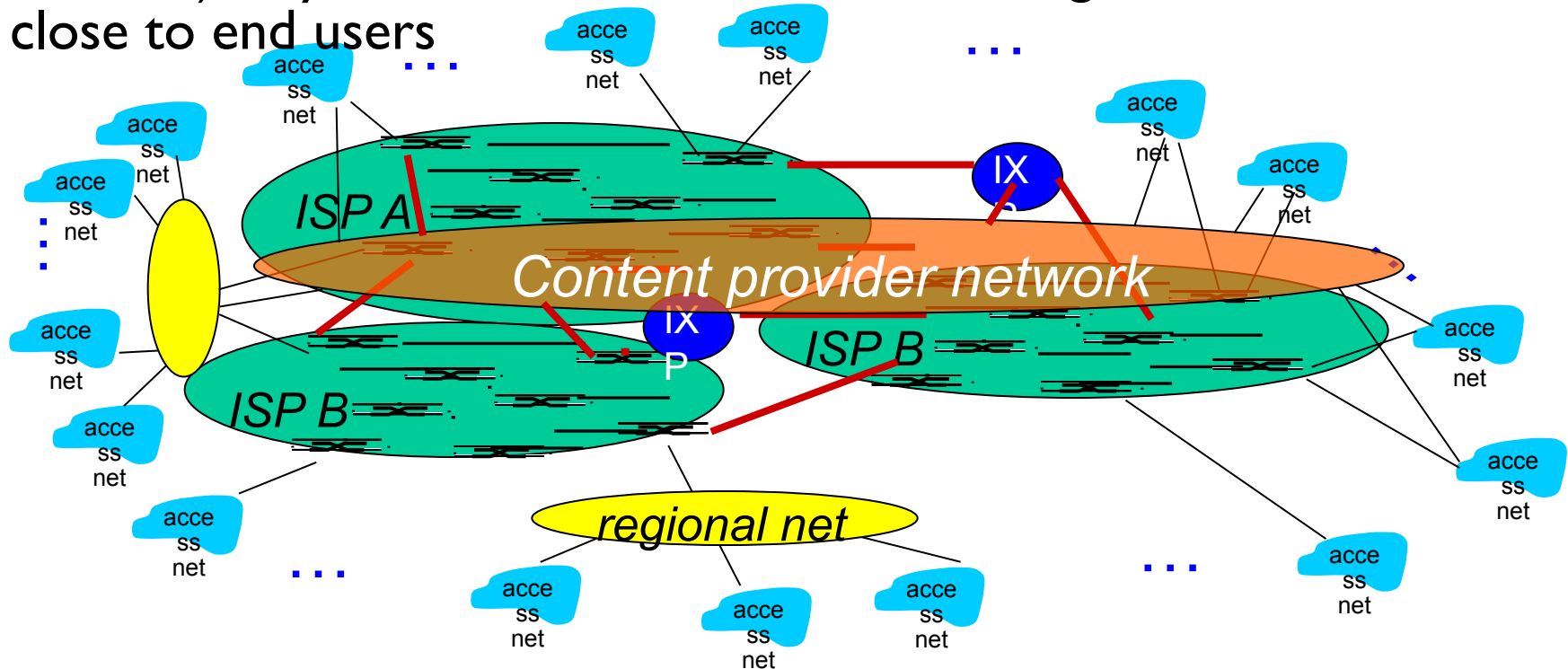
Internet structure: network of networks

... and regional networks may arise to connect access nets to ISPs



Internet structure: network of networks

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



Protocol “layers”

*Networks are complex,
with many “pieces”:*

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

is there any hope of
organizing structure of
network?

.... or at least our discussion
of networks?

- **Layering** – Structured discussion of system components.
- A layer is a structured component which tells us what are the protocols that a packet has to follow in order to get transmitted over a medium.

Why layering?

- To understand how a message is transmitted from source to destination.
- A lot of steps are involved.
- A lot of different protocols.
- In order to have better understanding, layering can be used.
- Maintained by ISO.

Advantages:

- Provides a structured way to discuss system components.
- Provides modularity.

Drawbacks:

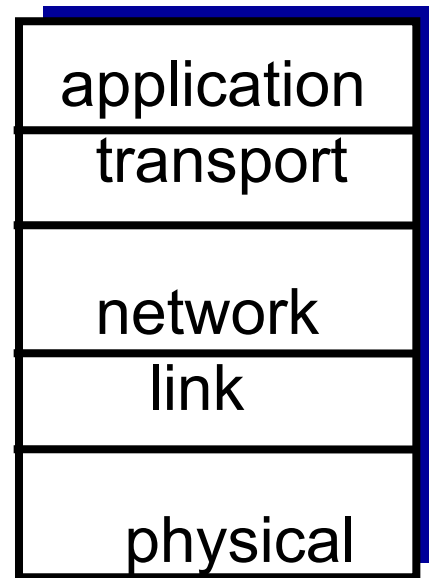
- One layer may duplicate lower layer functionality.
- One layer may need information from other layer, which violates the goal of separation of layers.

□ **Internet Protocol (IP) stack**

□ **OSI reference model**

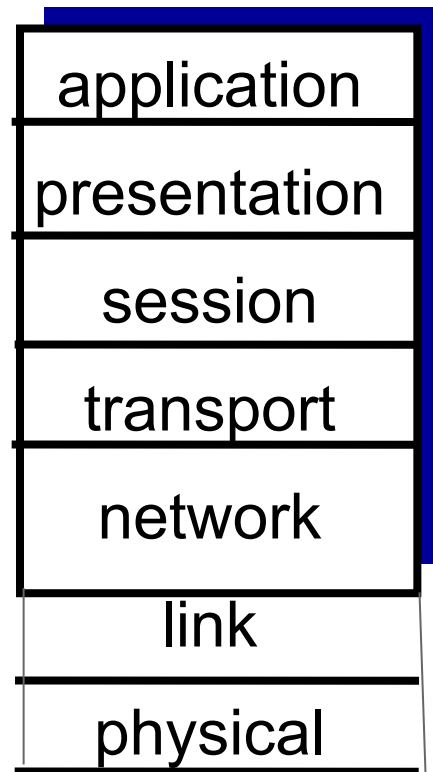
Internet protocol stack

- ❖ *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)
- ❖ *physical*: bits “on the wire”



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
 - needed?



Encapsulation

