

CSE 3214: Computer Network Protocols and Applications

Suprakash Datta

datta@cse.yorku.ca

Office: LAS 3043

Phone: 416-736-2100 ext 77875

Course page: <http://www.cse.yorku.ca/course/3214>

These slides are adapted from Jim Kurose's slides.

Administrivia

Course webpage:

<http://www.cse.yorku.ca/course/3214>

Lectures: Tue-Thu 10:00-11:30 pm
(Ross N 306)

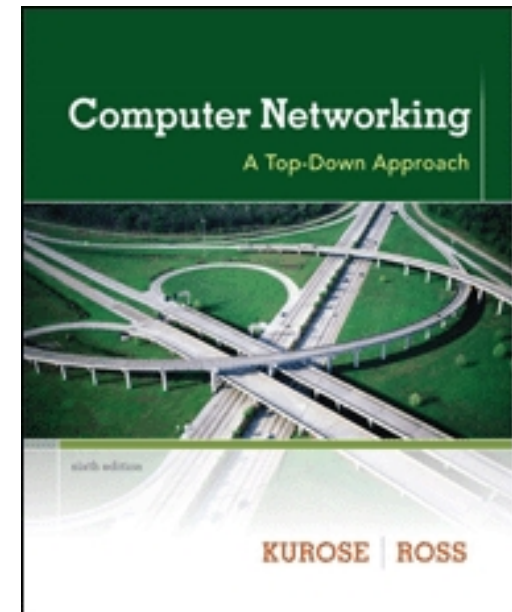
Exams: midterm (30%), final
(40%)

Homework (30%): Assignments.

Slides: should be available the
morning of the class

Office hours: Tuesday 12:30-2:30
pm, Thu 12-1 pm or by
appointment at LAS 3043

Textbook:



*Computer Networking: A Top Down
Approach Featuring the Internet, 6th
edition.*
Jim Kurose, Keith Ross; Pearson.

Administrivia – contd.

- Cheating will not be tolerated. Visit the webpage for more details on policies etc.
- Be careful not to misuse packet sniffing software.
- I would like to have a 2-hour midterm. Your cooperation is greatly appreciated.
- TA: TBA

Course objectives

- Understand the full TCP/IP architecture.
- Become familiar with “advanced topics”
 - P2P systems, multimedia communication (including VoIP), network security, wireless sensor networks.
- Learn about active research areas.

Major differences with 3213

- Top-down approach.
- More algorithmic (less math!)
- More hands-on - TCP/IP programming.

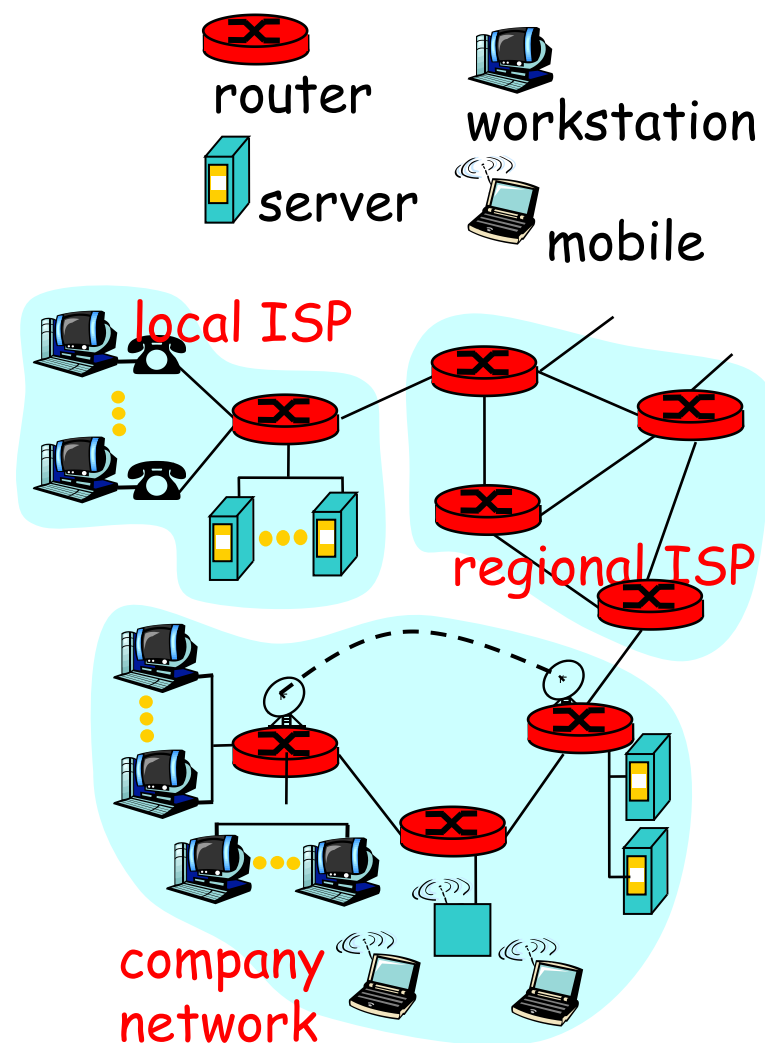
Chapter 1: Introduction

What *is* the Internet?

- Network of networks
- Heterogeneous
- Distributed
- Owned by many different entities
- Allows easy additions and removal from the network

The Internet: “nuts and bolts” view

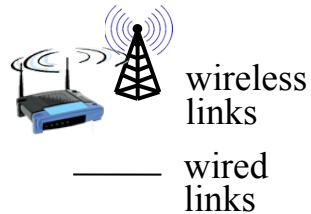
- millions of connected computing devices: *hosts = end systems*
- running *network apps*
- *communication links*
 - fiber, copper, radio, satellite
 - transmission rate = *bandwidth*
- *routers*: forward packets (chunks of data)



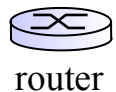
The Internet: “nuts and bolts” view



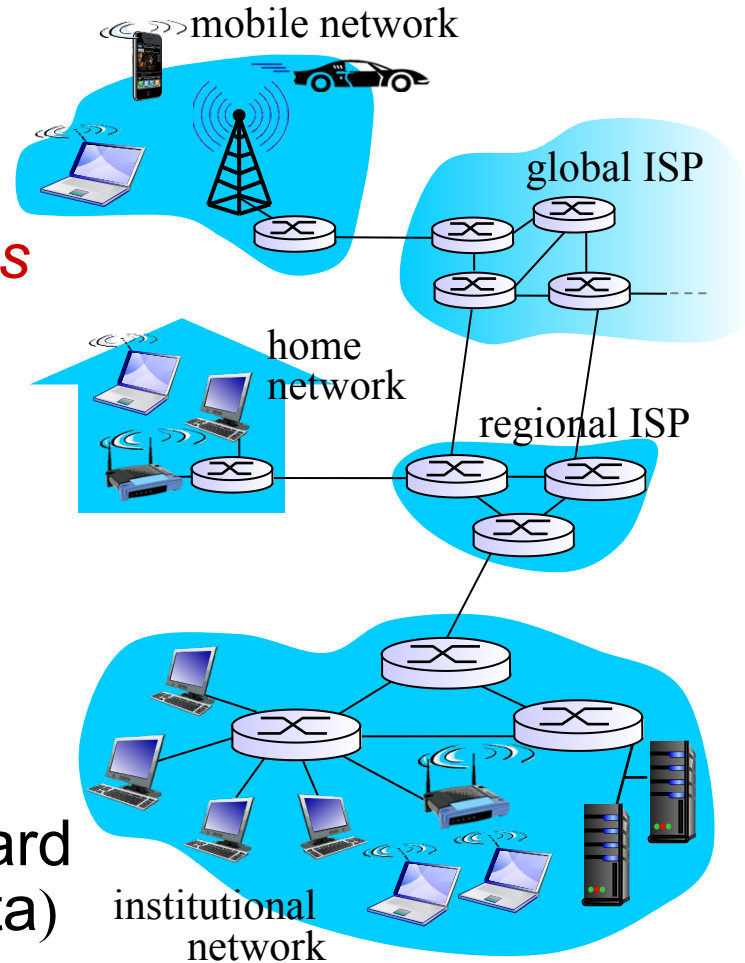
- ❖ millions of connected computing devices:
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- ❖ *communication links*
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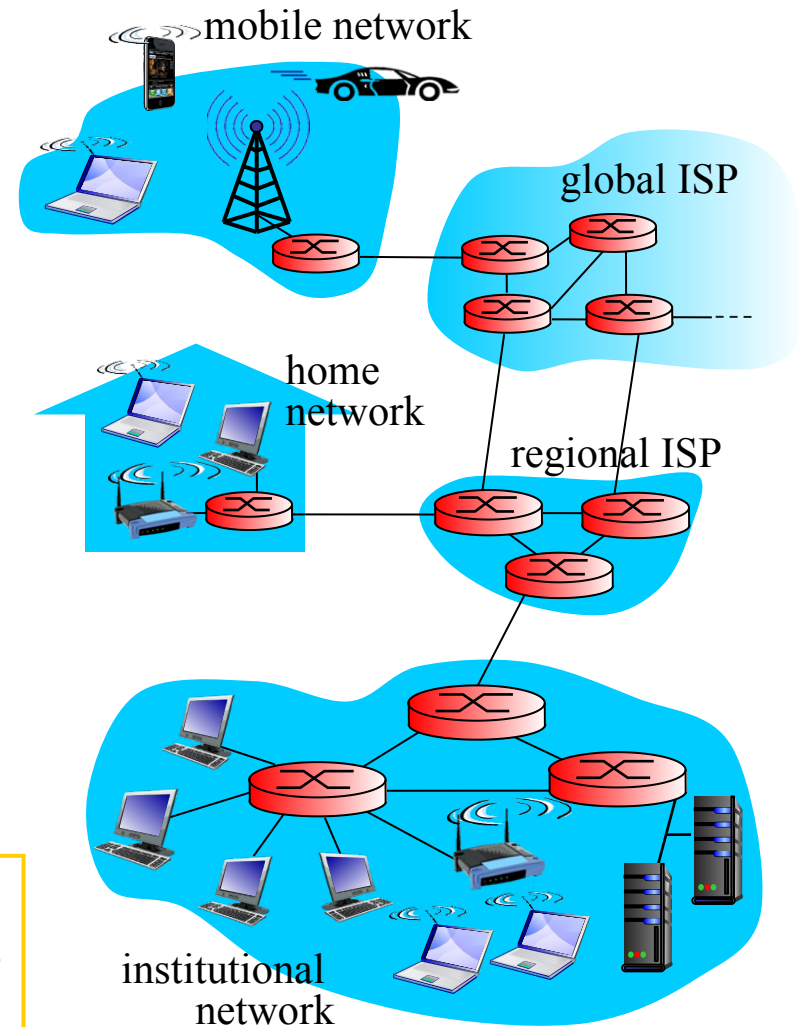
- ❖ *Packet switches*: forward packets (chunks of data)
 - *routers and switches*



The Internet: “nuts and bolts” view

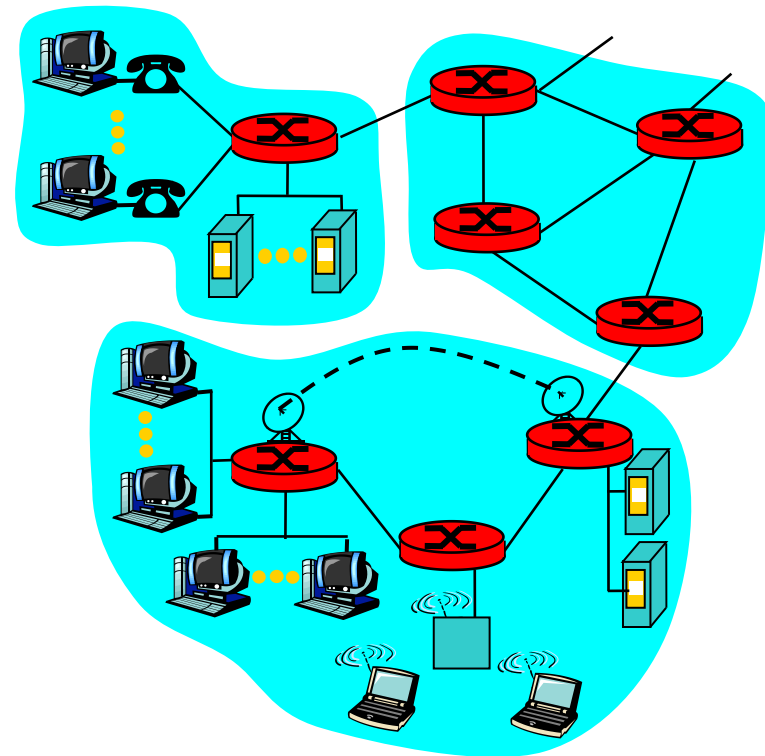
- *protocols* control sending, receiving of msgs
 - e.g., TCP, IP, HTTP, FTP, PPP
- *Internet: “network of networks”*
 - loosely hierarchical
 - public Internet versus private intranet
- Internet standards
 - RFC: Request for comments
 - IETF: Internet Engineering Task Force

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt



The Internet: a service view

- **communication infrastructure** enables distributed applications:
 - Web, email, games, e-commerce, file sharing
- **communication services provided to apps:**
 - Connectionless unreliable
 - Connection-oriented reliable



What's a protocol?

human protocols:

- ❖ “what’s the time?”
- ❖ “I have a question”
- ❖ introductions

... specific msgs sent

... specific actions taken
when msgs received,
or other events

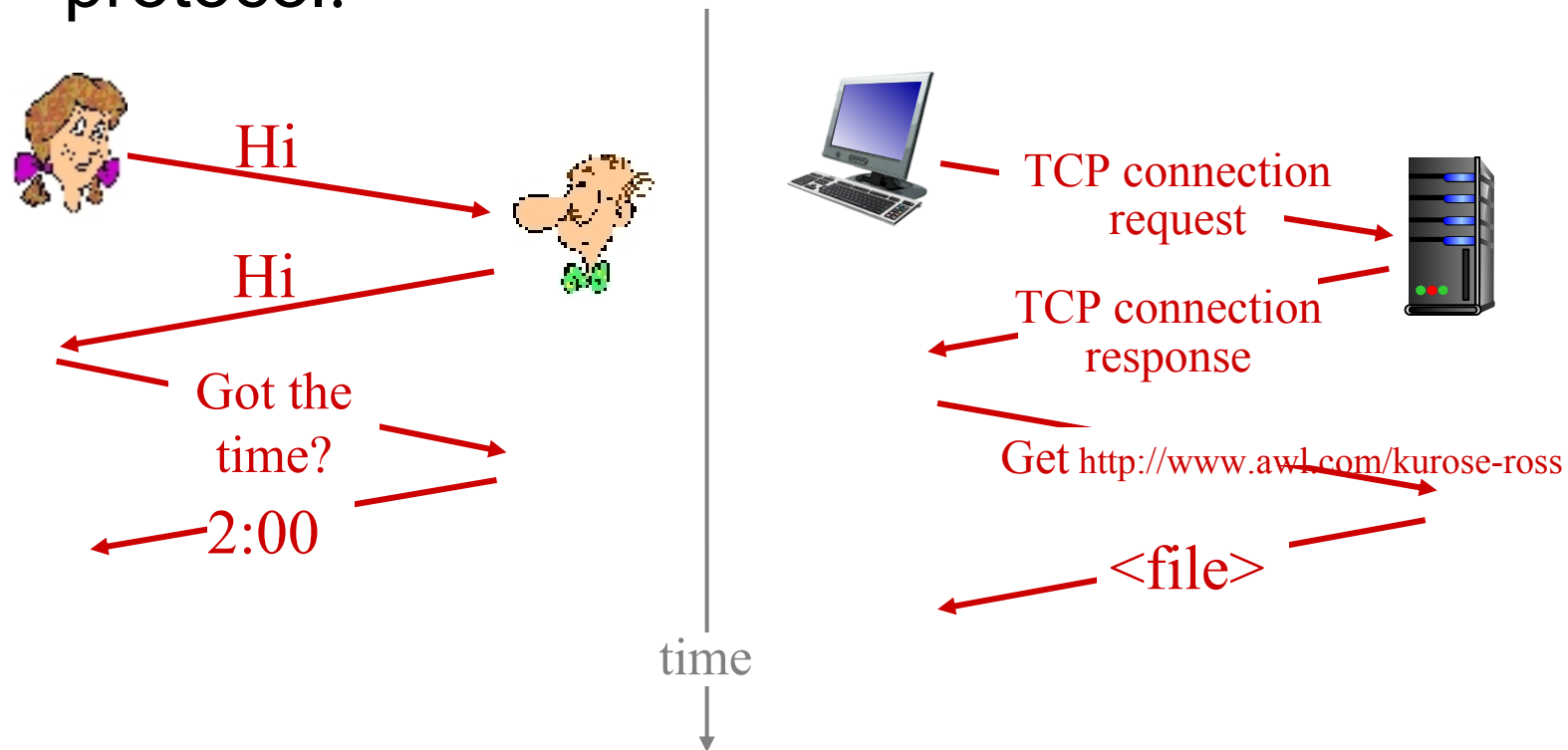
network protocols:

- ❖ machines rather than humans
- ❖ all communication activity in Internet governed by protocols

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

What's a protocol?

a human protocol and a computer network protocol:



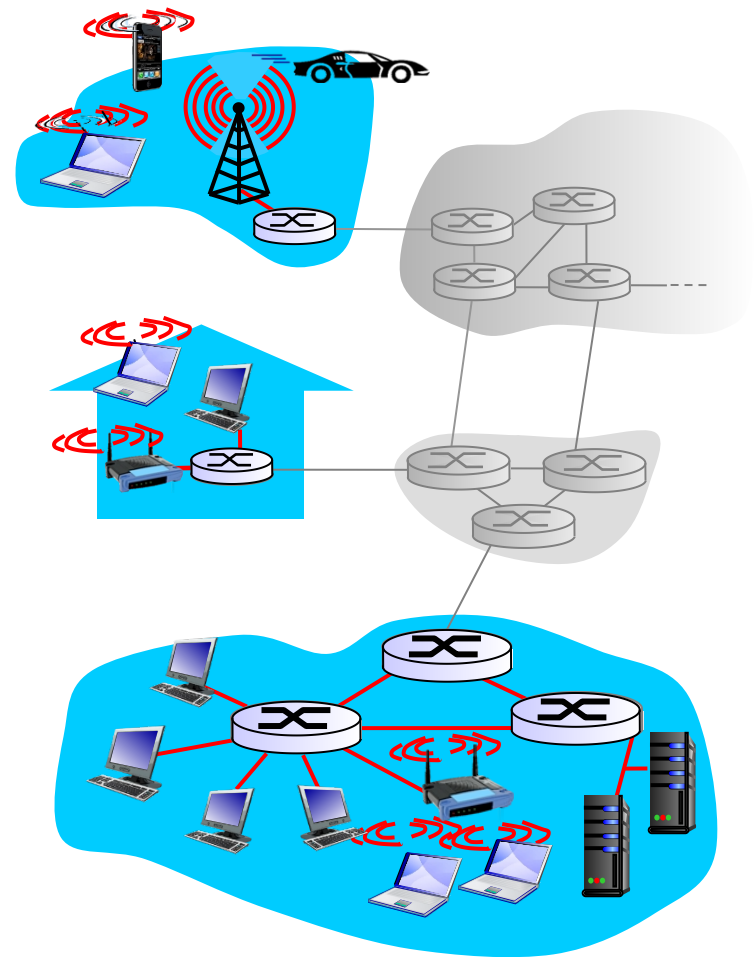
Access networks and physical media

Q: How to connect end systems to edge router?

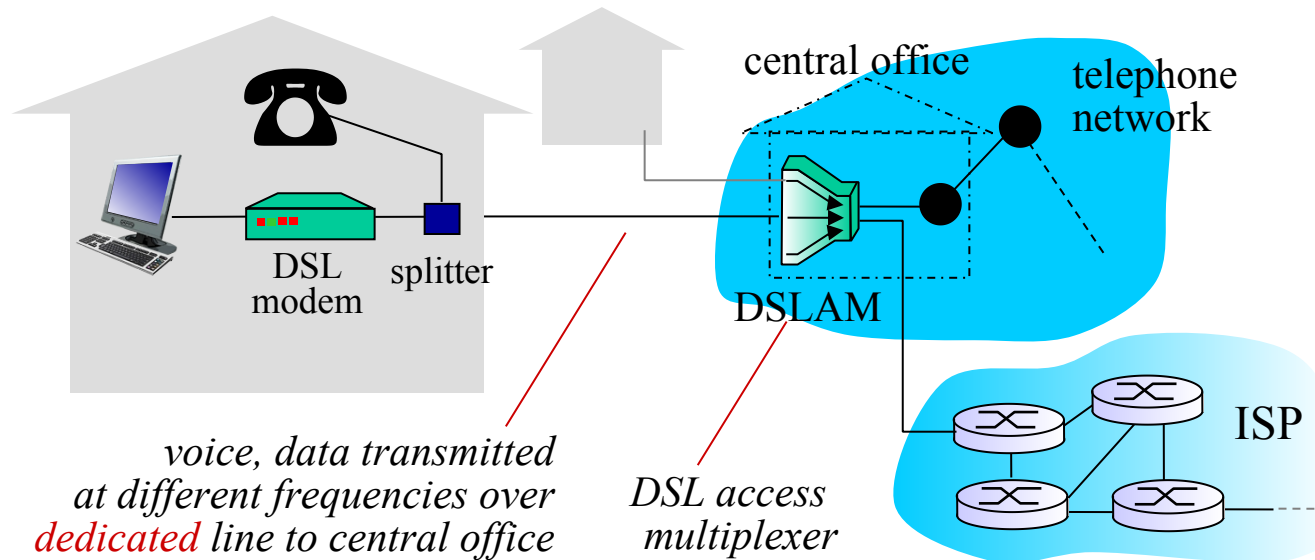
- ❖ residential access nets
- ❖ institutional access networks (school, company)
- ❖ mobile access networks

keep in mind:

- ❖ bandwidth (bits per second) of access network?
- ❖ shared or dedicated?



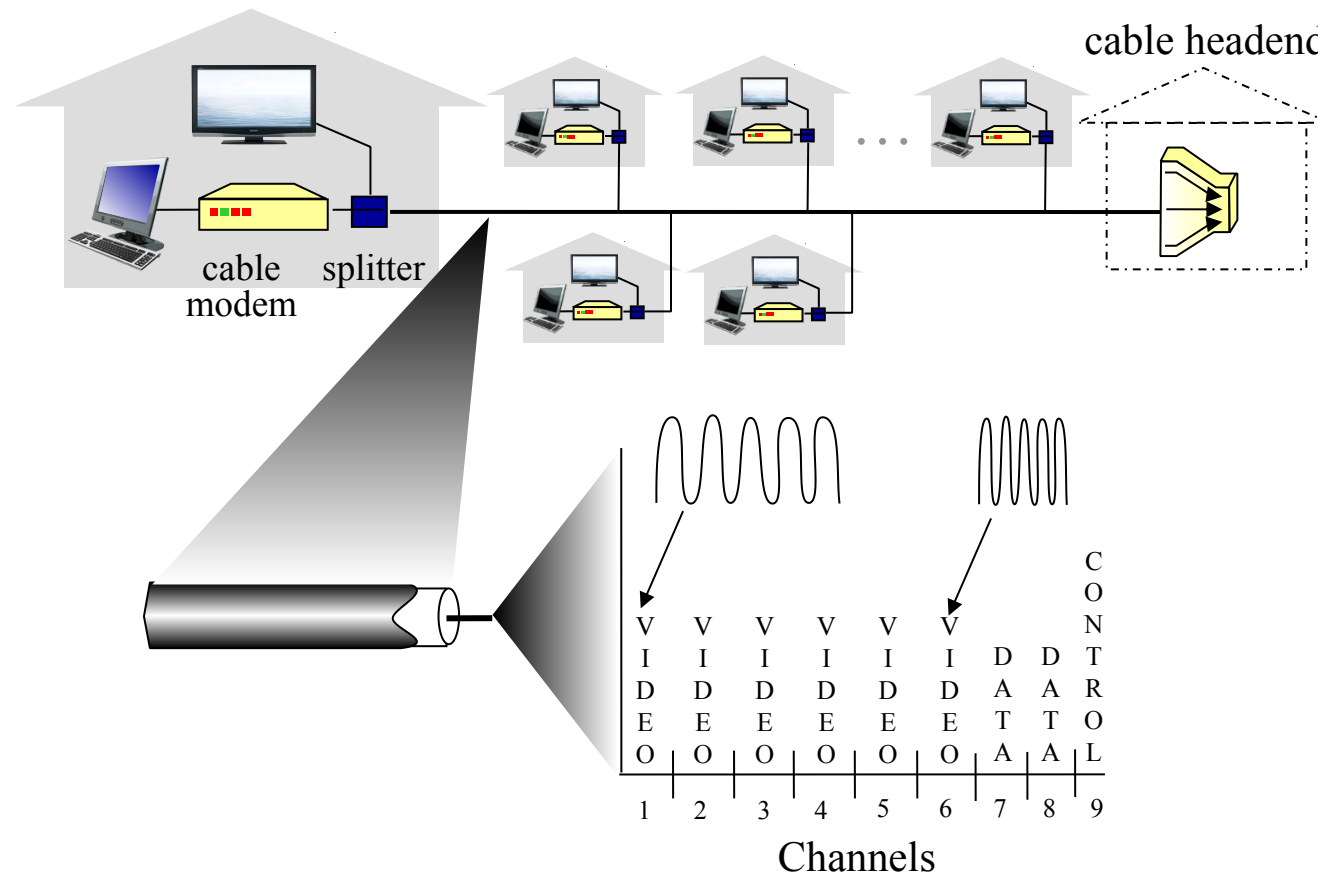
Access net: digital subscriber line (DSL)



use **existing** telephone line to central office DSLAM

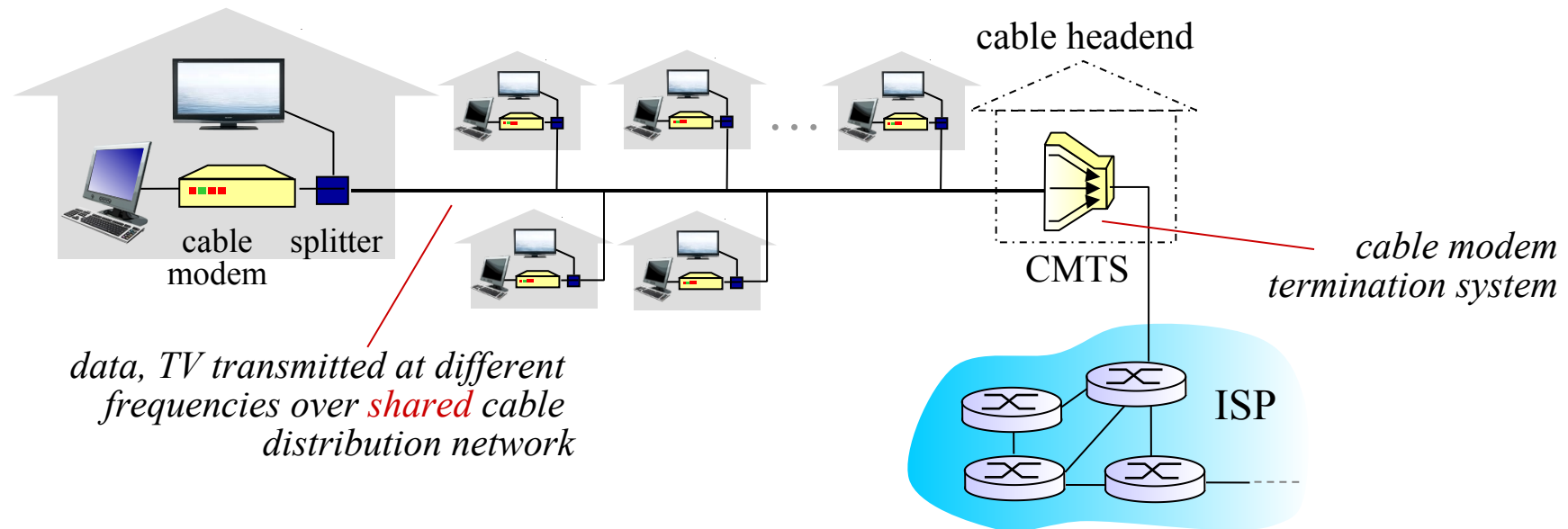
- over DSL phone line goes to Internet
- voice over DSL phone line goes to telephone net
- ❖ < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- ❖ < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access net: cable network



frequency division multiplexing: different channels transmitted in different frequency bands

Access net: cable network



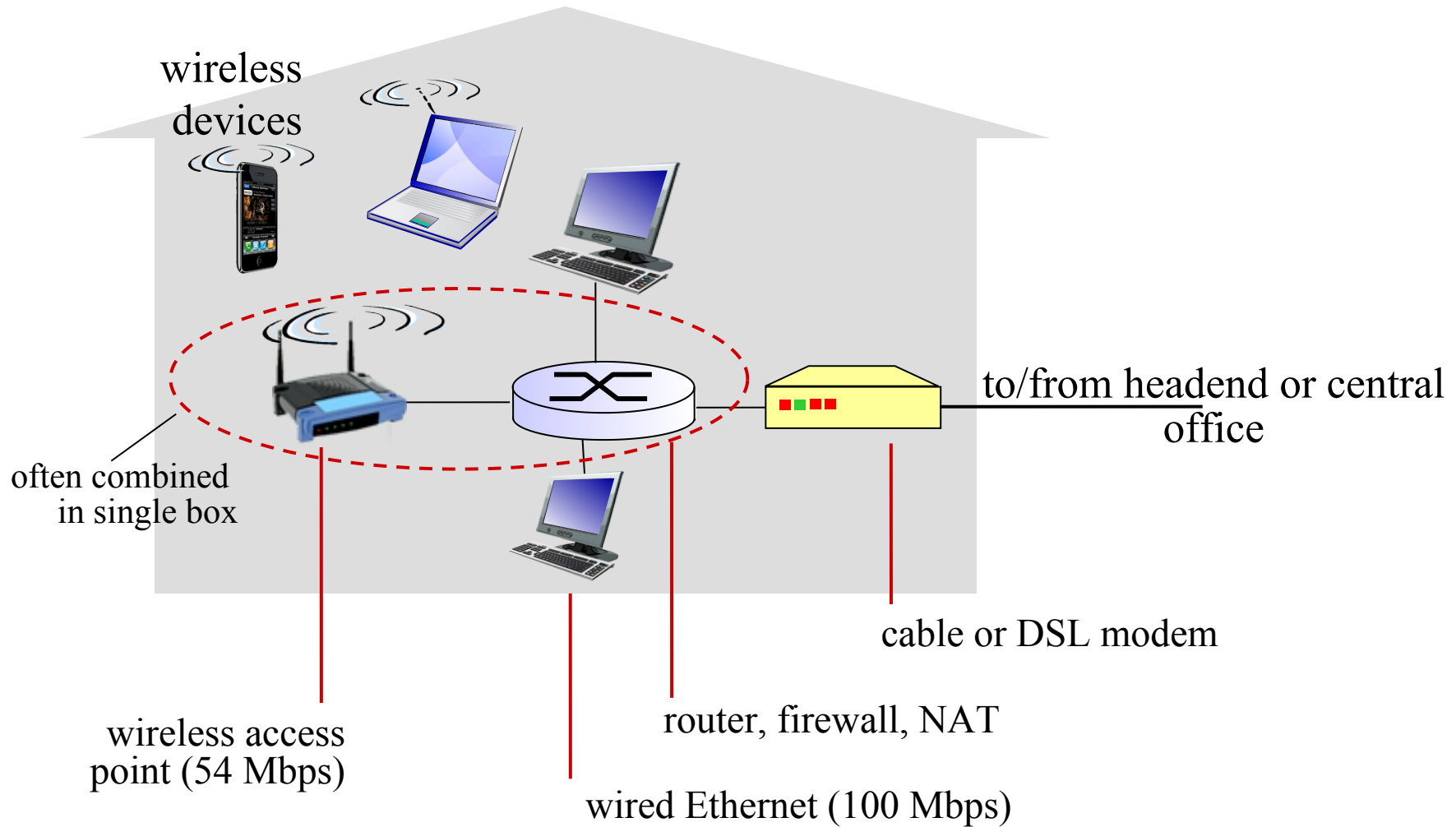
❖ HFC: hybrid fiber coax

- asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate

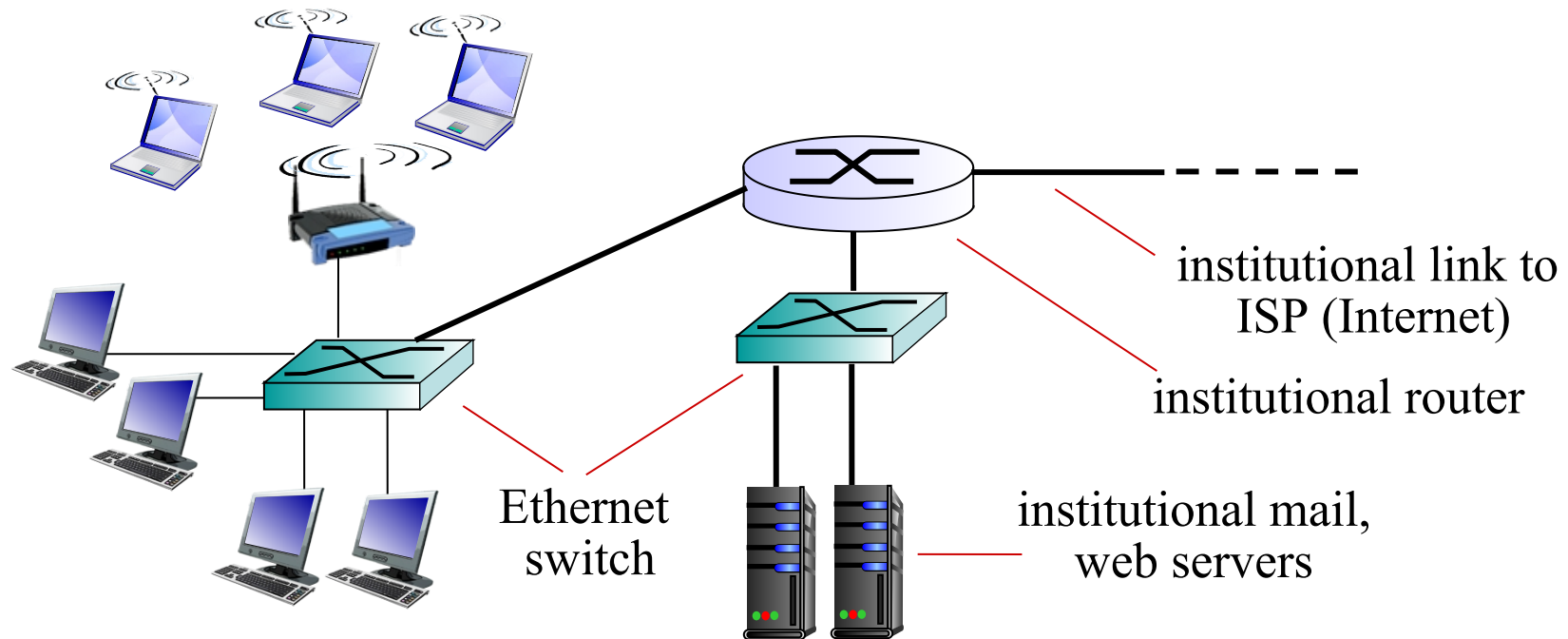
❖ network of cable, fiber attaches homes to ISP router

- homes *share access network* to cable headend
- unlike DSL: DSL has dedicated access to central office

Access net: home network



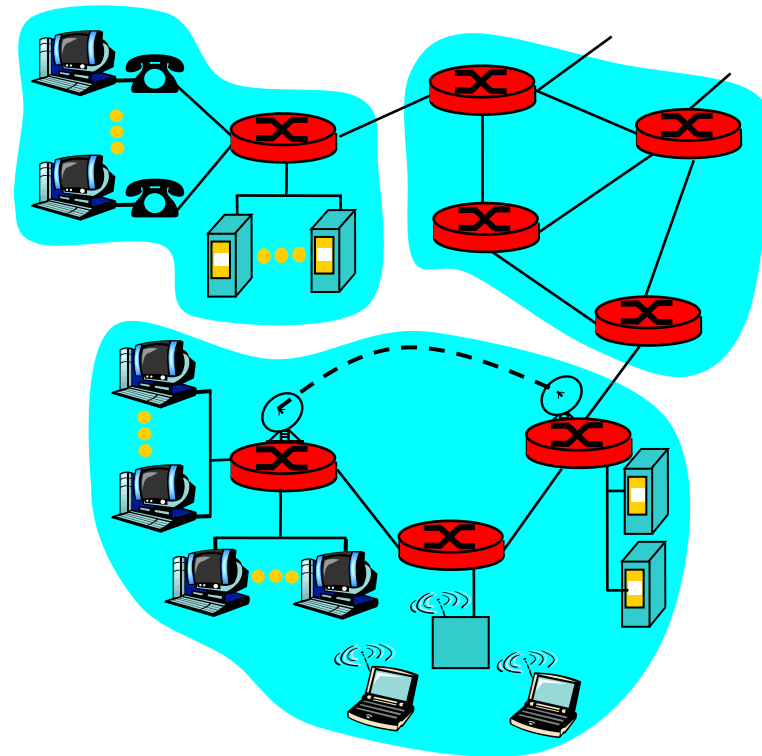
Enterprise access networks (Ethernet)



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

A closer look at network structure

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



Wireless access networks

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

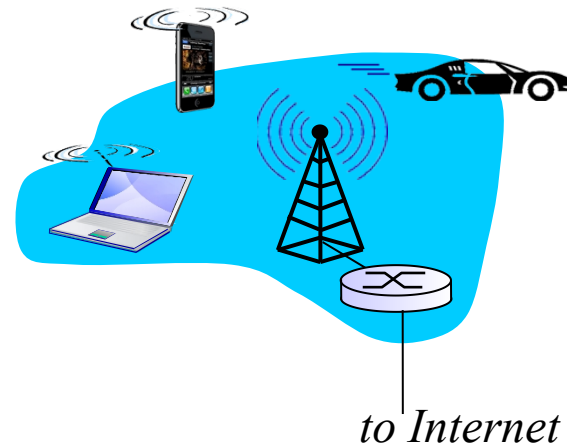
wireless LANs:

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



wide-area wireless access

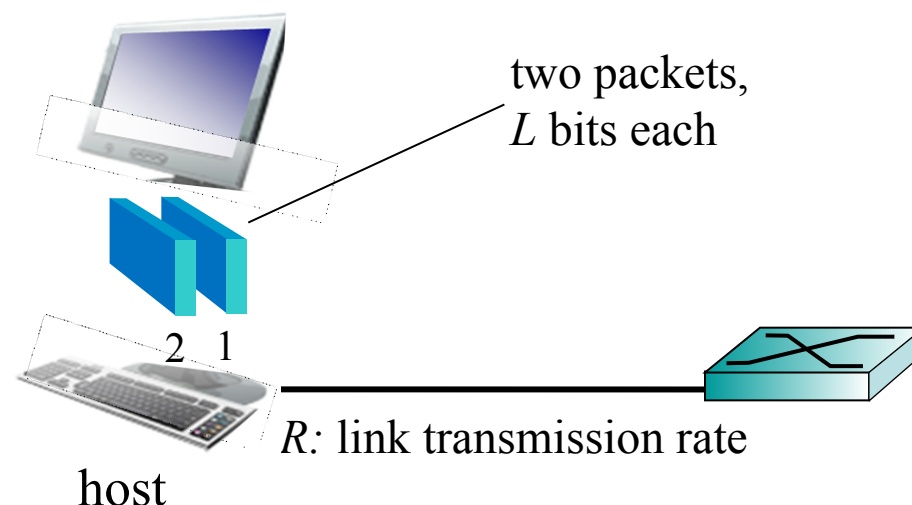
- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE



Host: sends *packets* of data

host sending function:

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



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

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)

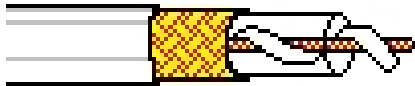
- ❖ two insulated copper wires
 - Category 5: 100 Mbps, 1 Gbps Ethernet
 - Category 6: 10Gbps



Physical media: coax, fiber

coaxial cable:

- ❖ two concentric copper conductors
- ❖ bidirectional
- ❖ broadband:
 - multiple channels on 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

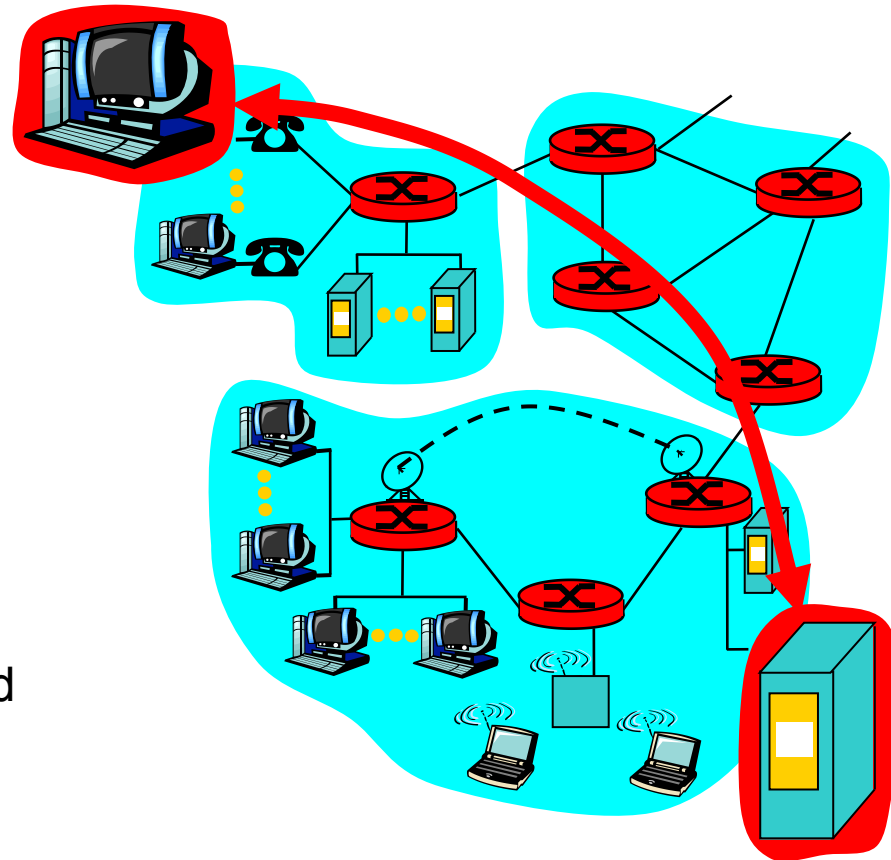
- ❖ signal carried in electromagnetic spectrum
- ❖ no physical “wire”
- ❖ bidirectional
- ❖ propagation environment effects:
 - reflection
 - obstruction by objects
 - interference

radio link types:

- ❖ **terrestrial microwave**
 - e.g. up to 45 Mbps channels
- ❖ **LAN** (e.g., WiFi)
 - 11Mbps, 54 Mbps
- ❖ **wide-area** (e.g., cellular)
 - 3G cellular: ~ few Mbps
- ❖ **satellite**
 - Kbps to 45Mbps channel (or multiple smaller channels)
 - 270 msec end-end delay
 - geosynchronous versus low altitude

The network edge

- **end systems (hosts):**
 - run application programs
 - e.g. Web, email
 - at “edge of network”
- **client/server model**
 - client host requests, receives service from always-on server
 - e.g. Web browser/server; email client/server
- **peer-peer model:**
 - minimal (or no) use of dedicated servers
 - e.g. Gnutella, KaZaA



Network edge: connection-oriented service

Goal: data transfer between end systems

- *handshaking*: setup (prepare for) data transfer ahead of time
 - Hello, hello back human protocol
 - *set up “state”* in two communicating hosts
- TCP - Transmission Control Protocol
 - Internet's connection-oriented service

TCP service [RFC 793]

- *reliable, in-order* byte-stream data transfer
 - loss: acknowledgements and retransmissions
- *flow control*:
 - sender won't overwhelm receiver
- *congestion control*:
 - senders “slow down sending rate” when network congested

Connection-oriented service not the same as that in traditional telephony.

Network edge: connectionless service

Goal: data transfer between end systems

- same as before!
- **UDP** - User Datagram Protocol [RFC 768]:
 - connectionless
 - unreliable data transfer
 - no flow control
 - no congestion control

App's using TCP:

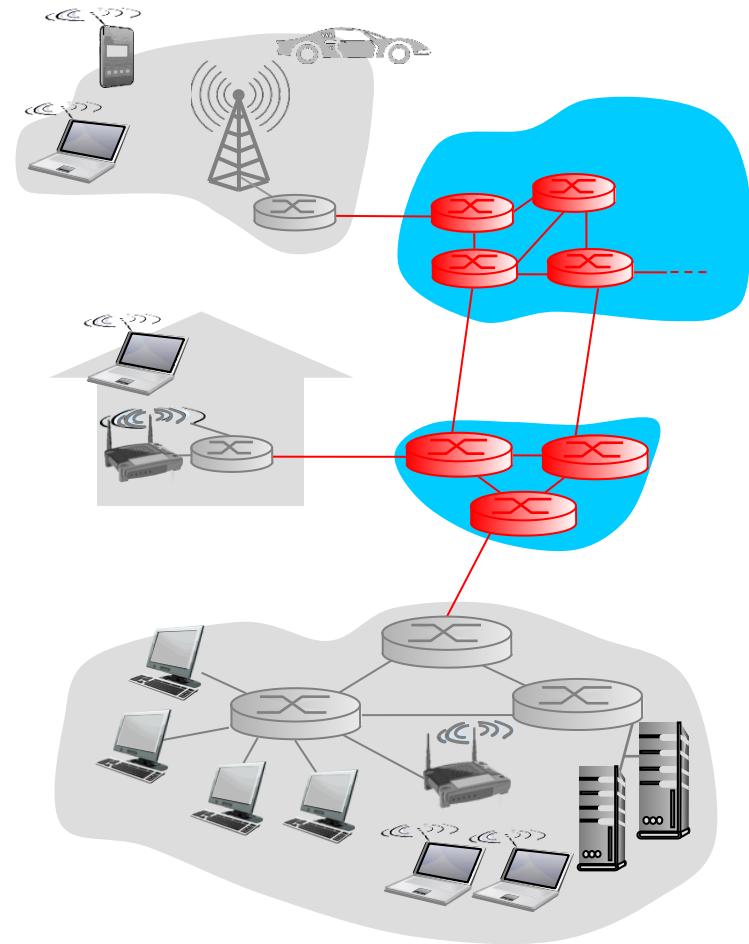
- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

App's using UDP:

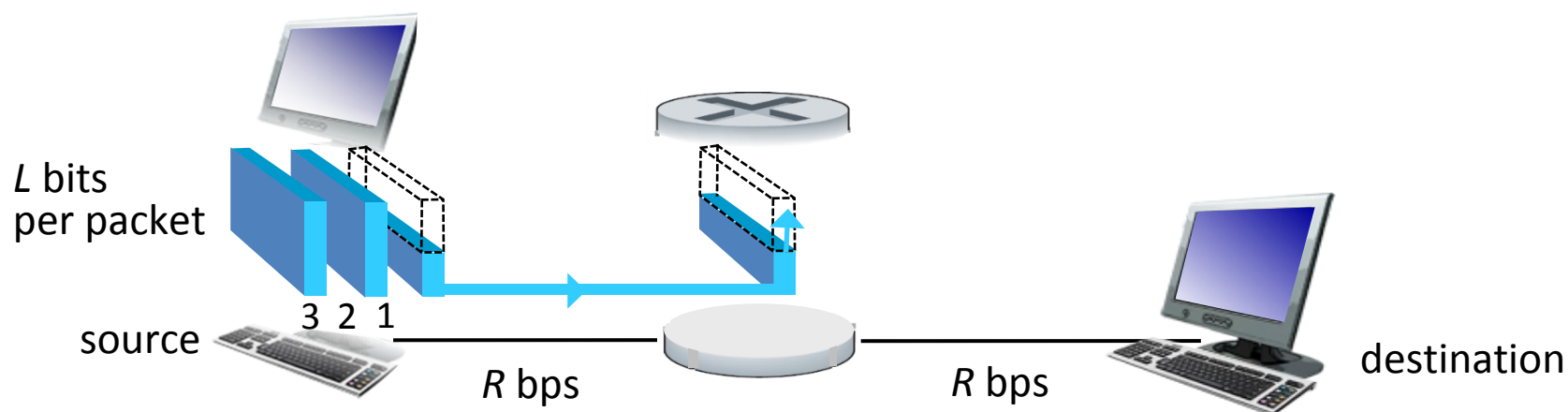
- streaming media, teleconferencing, DNS, Internet telephony

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)

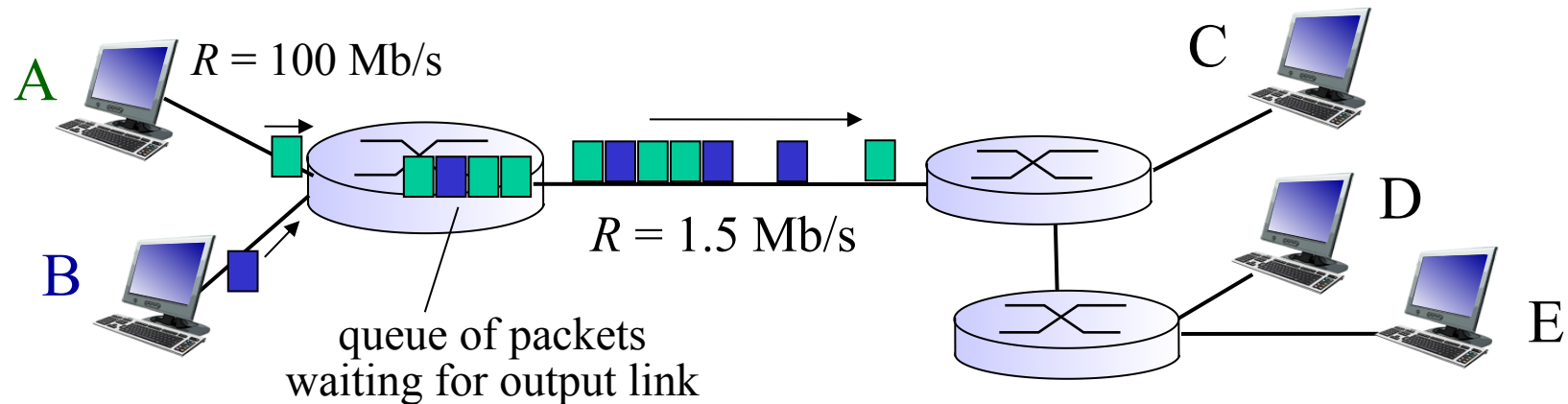
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one-hop numerical example:

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

} more on delay shortly ...

Packet Switching: queueing delay, loss



queueing and loss:

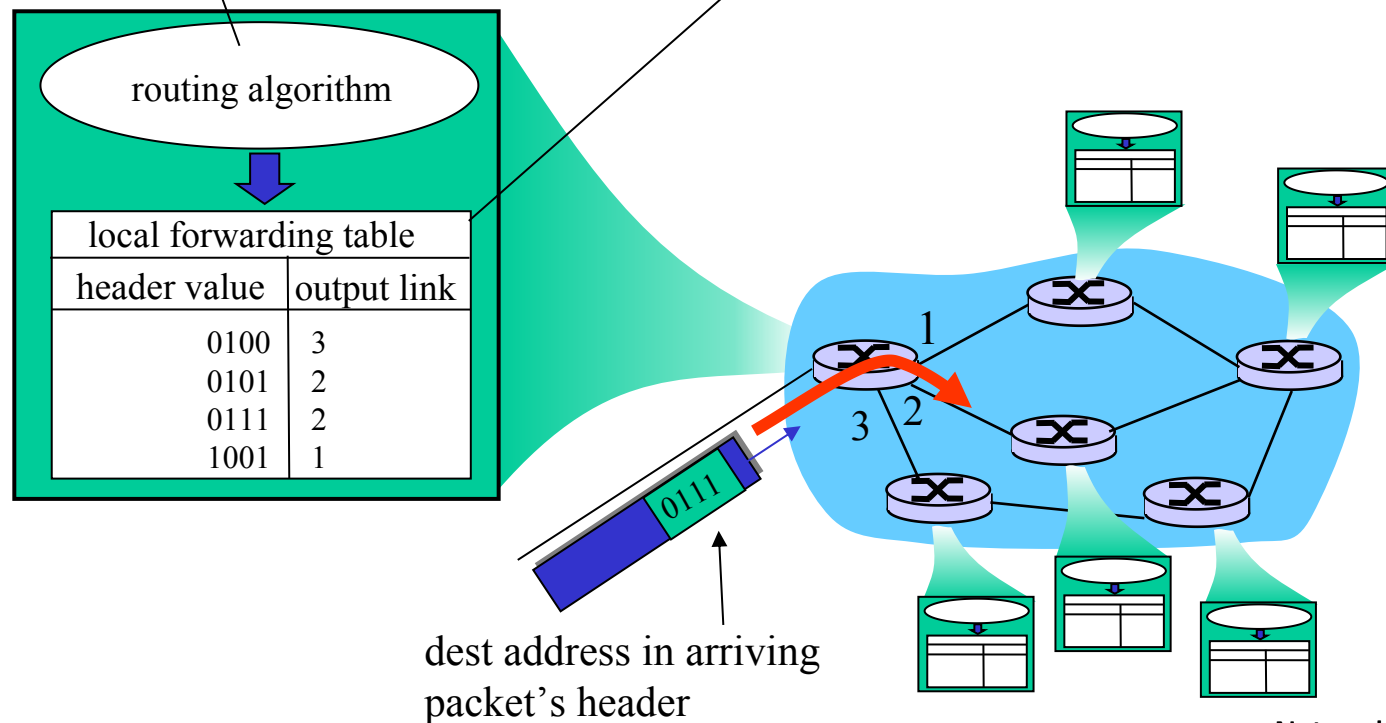
- ❖ If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
 - packets will queue, wait to be transmitted on link
 - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

routing: determines source-destination route taken by packets

- *routing algorithms*

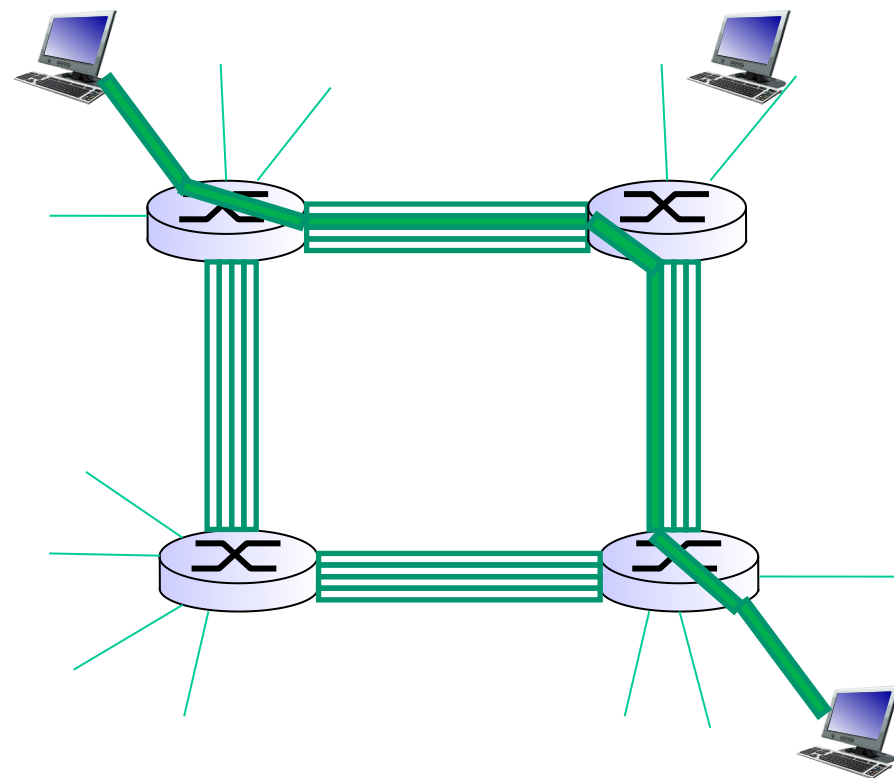
forwarding: move packets from router's input to appropriate router output



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

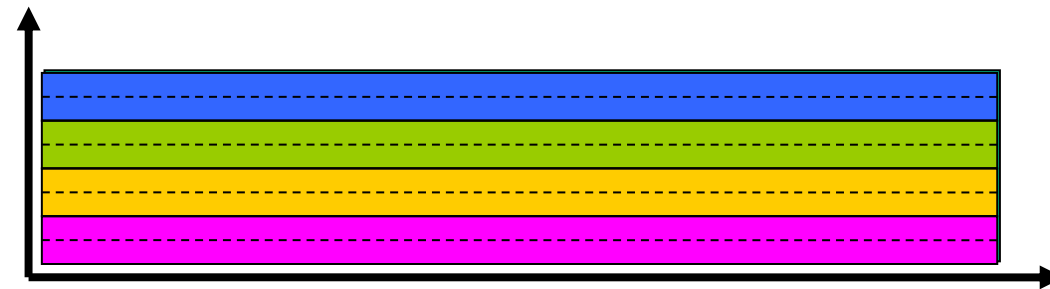
FDM

Example:

4 users



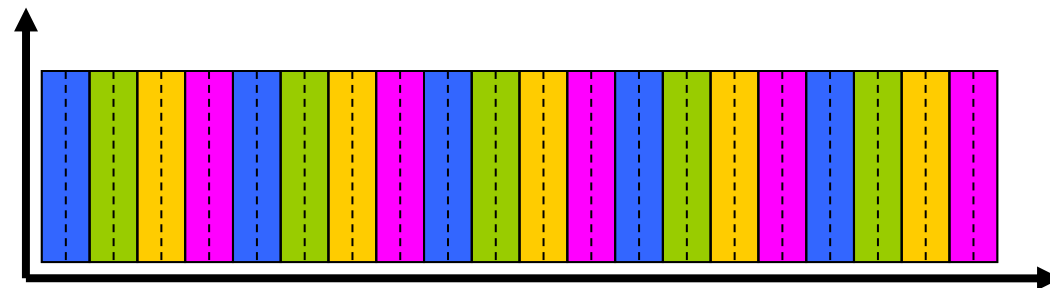
frequency



time

TDM

frequency



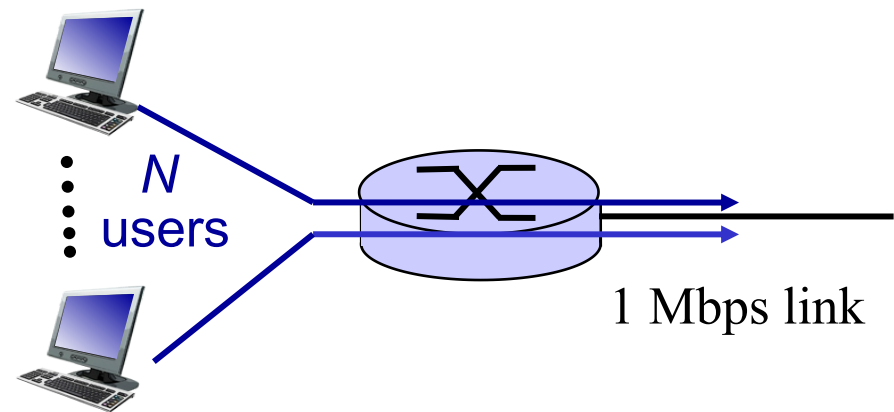
time

Packet switching versus circuit switching

packet switching allows more users to use 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 .0004 *

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

Packet switching vs 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 (chapter 7)

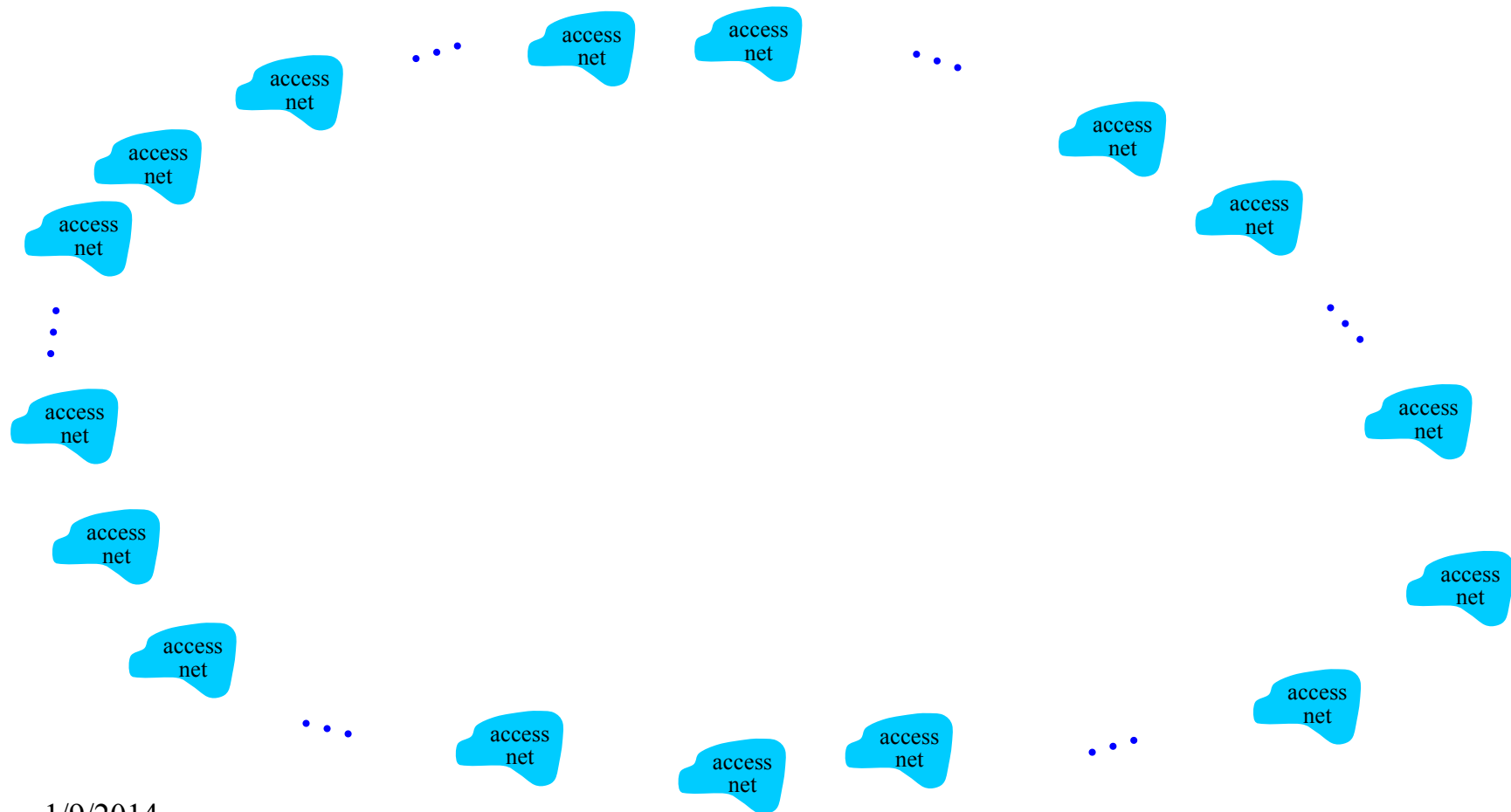
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

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**
- ❖ Let's take a stepwise approach to describe current Internet structure

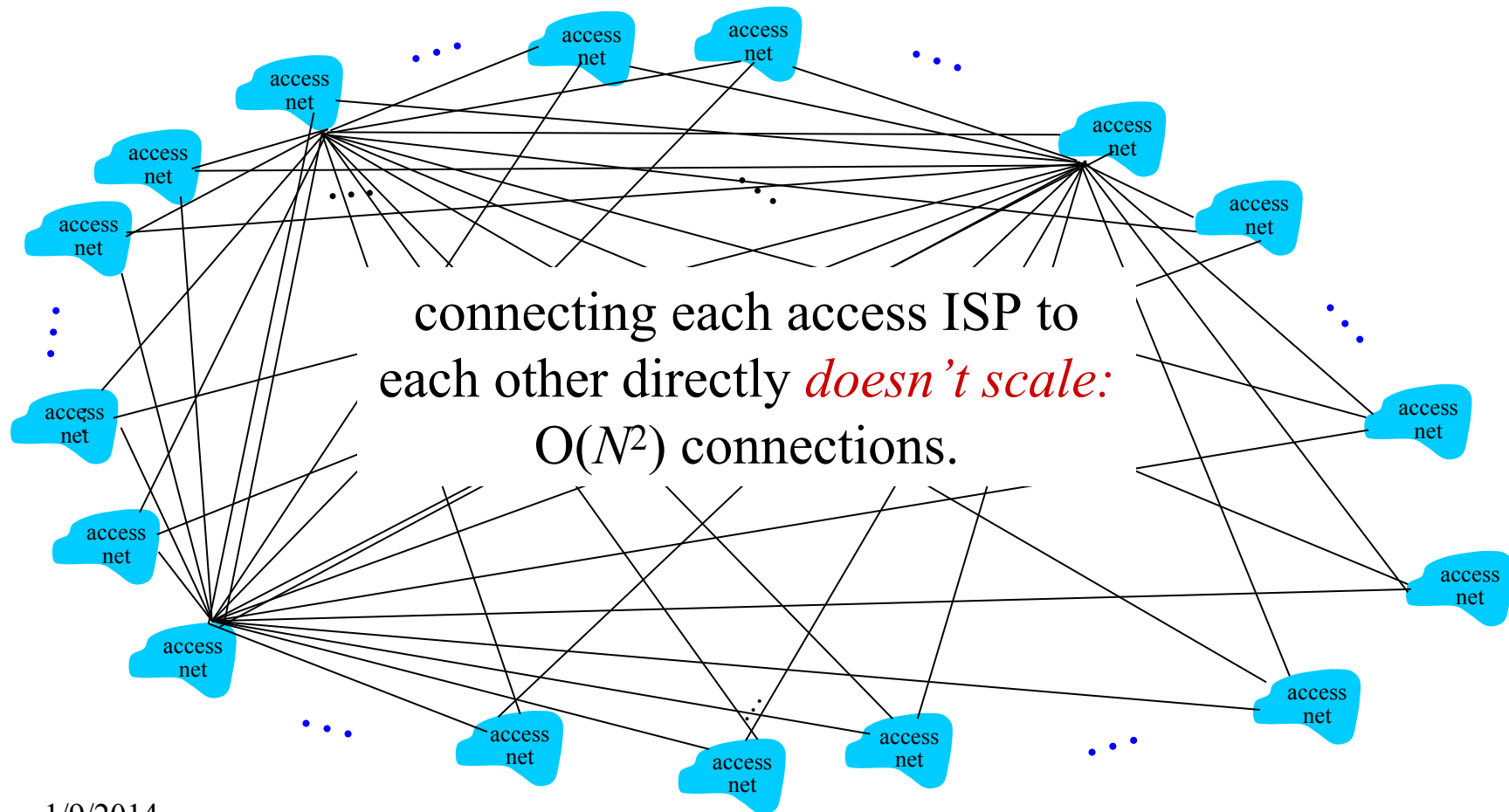
Internet structure: network of networks

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



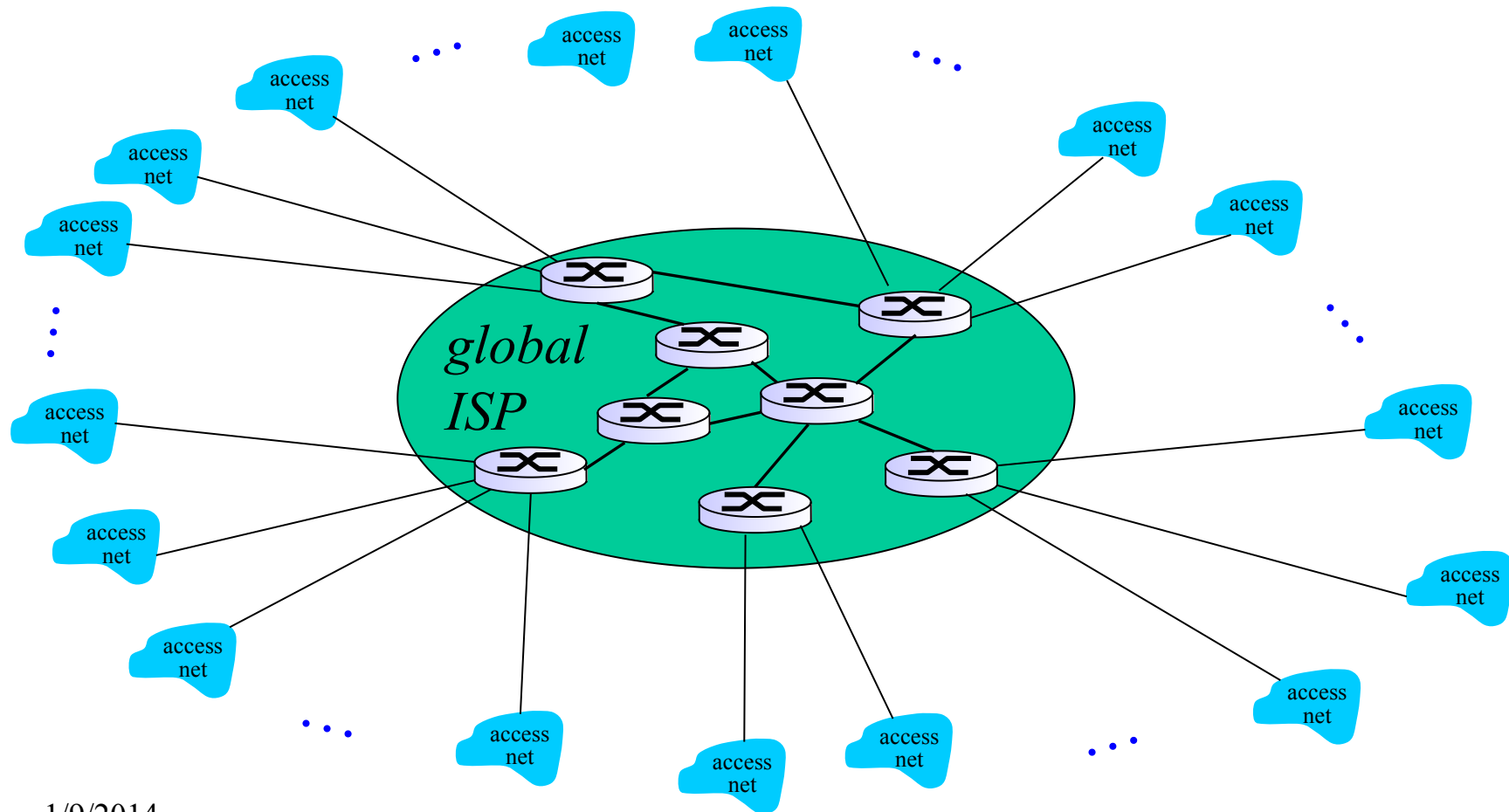
Internet structure: network of networks

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



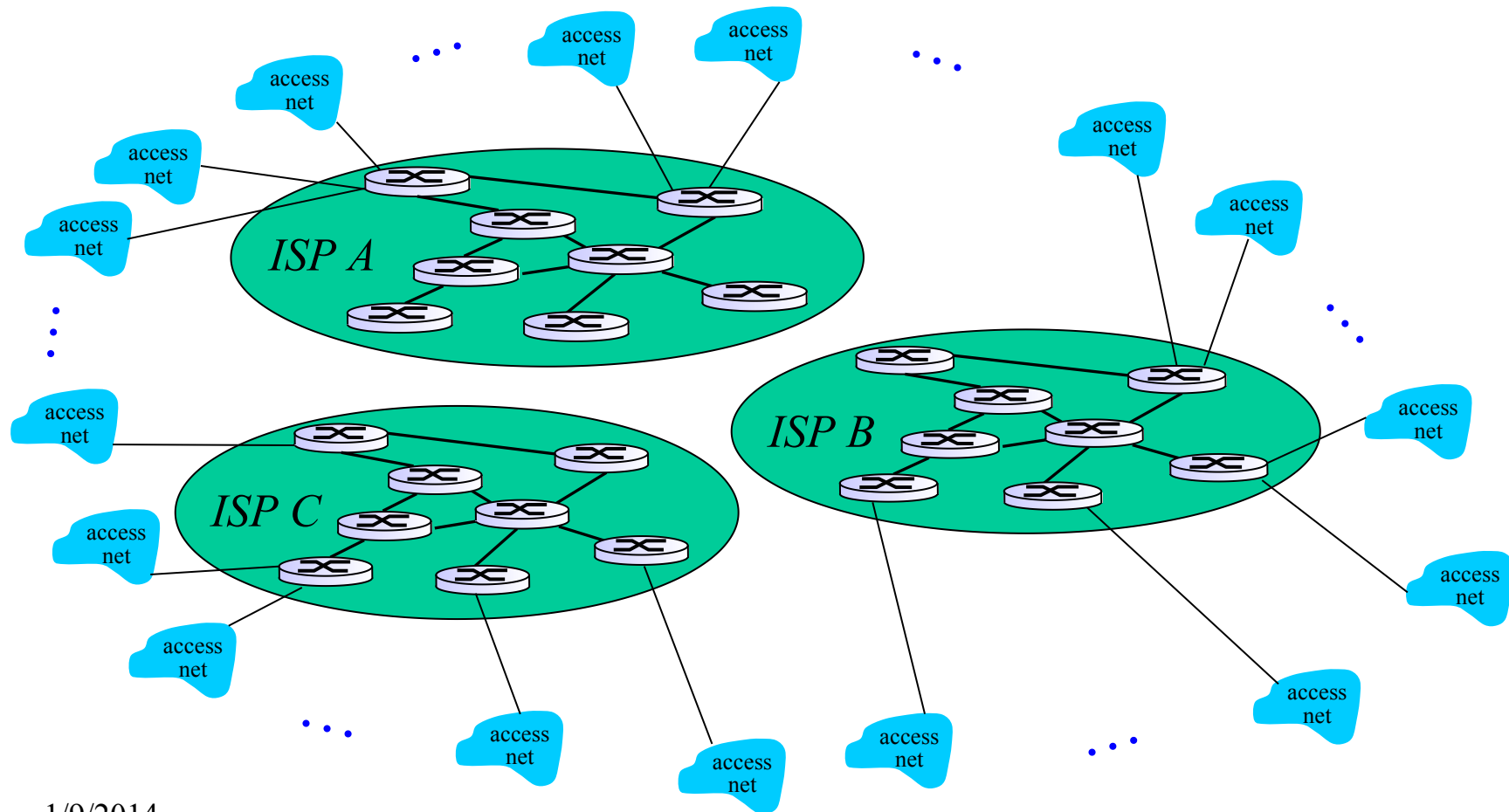
Internet structure: network of networks

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



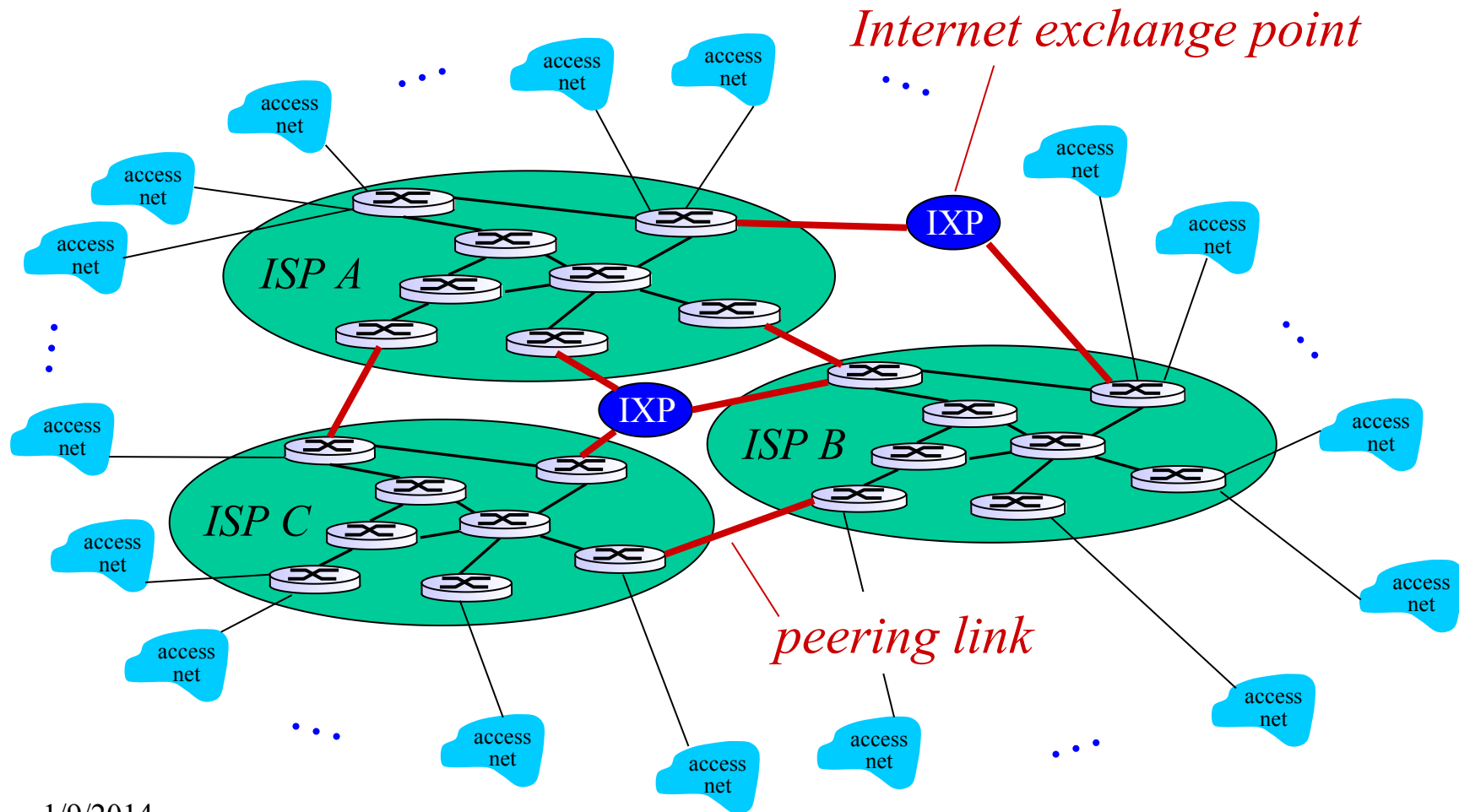
Internet structure: network of networks

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



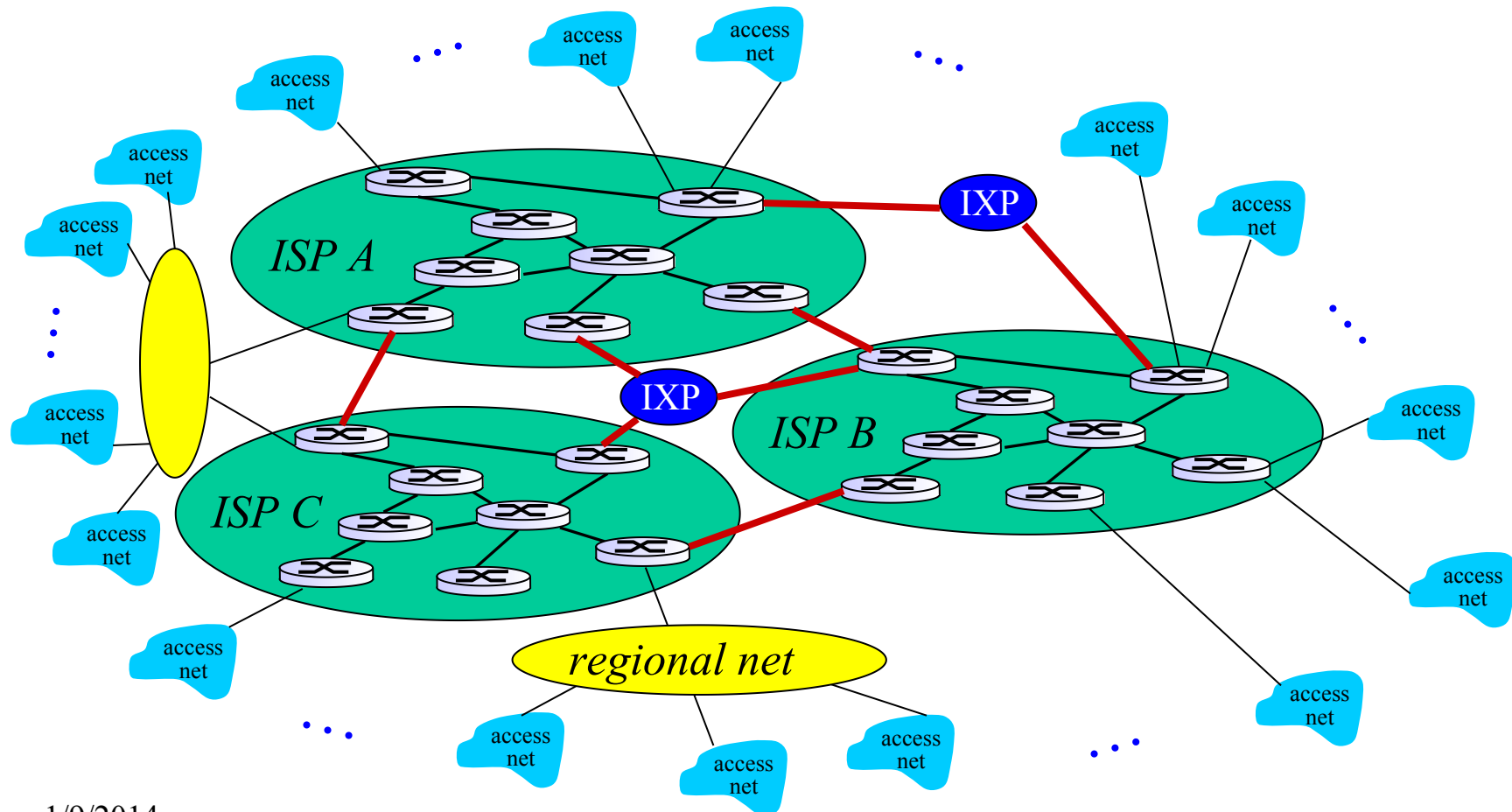
Internet structure: network of networks

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



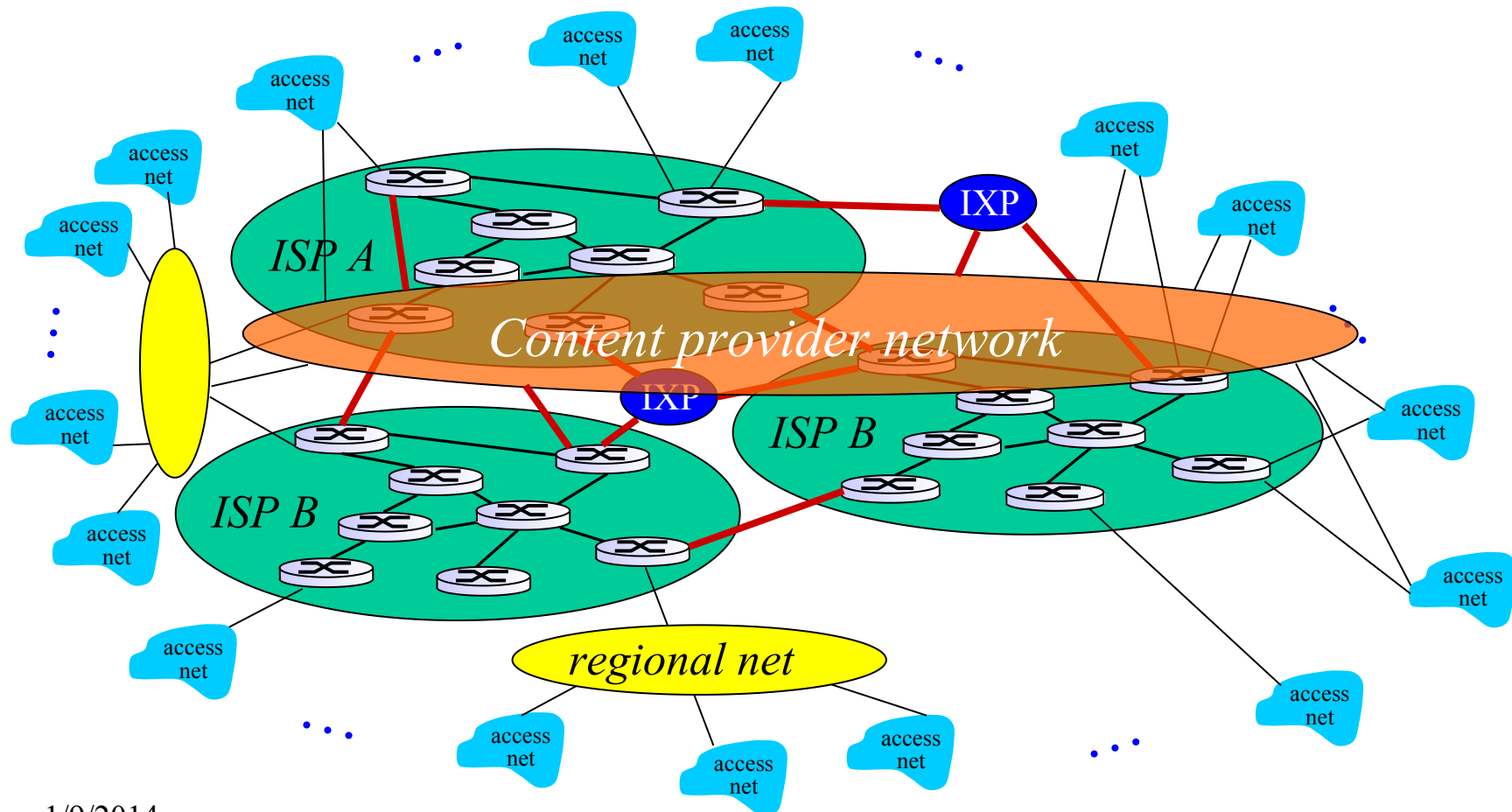
Internet structure: network of networks

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

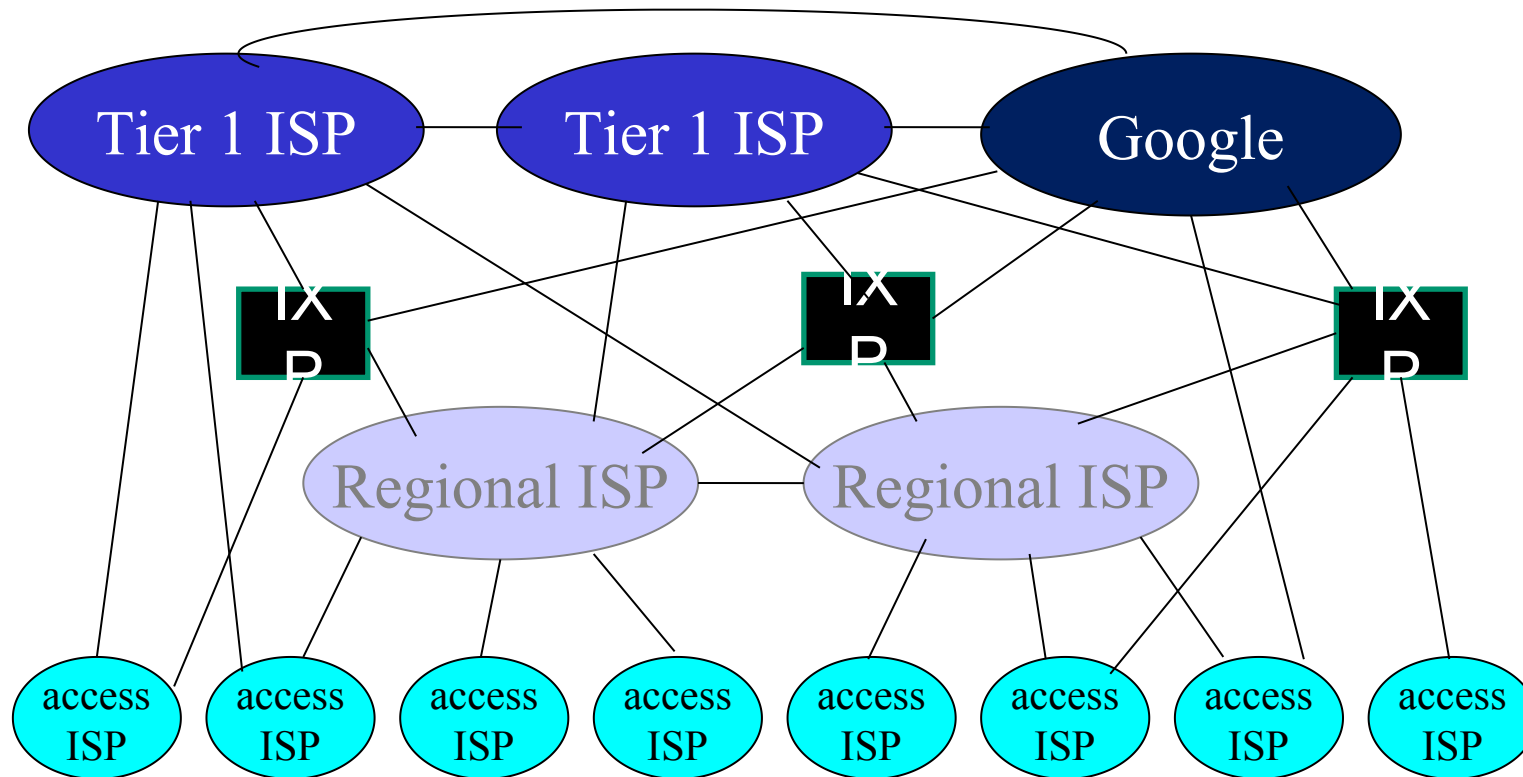


Internet structure: network of networks

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



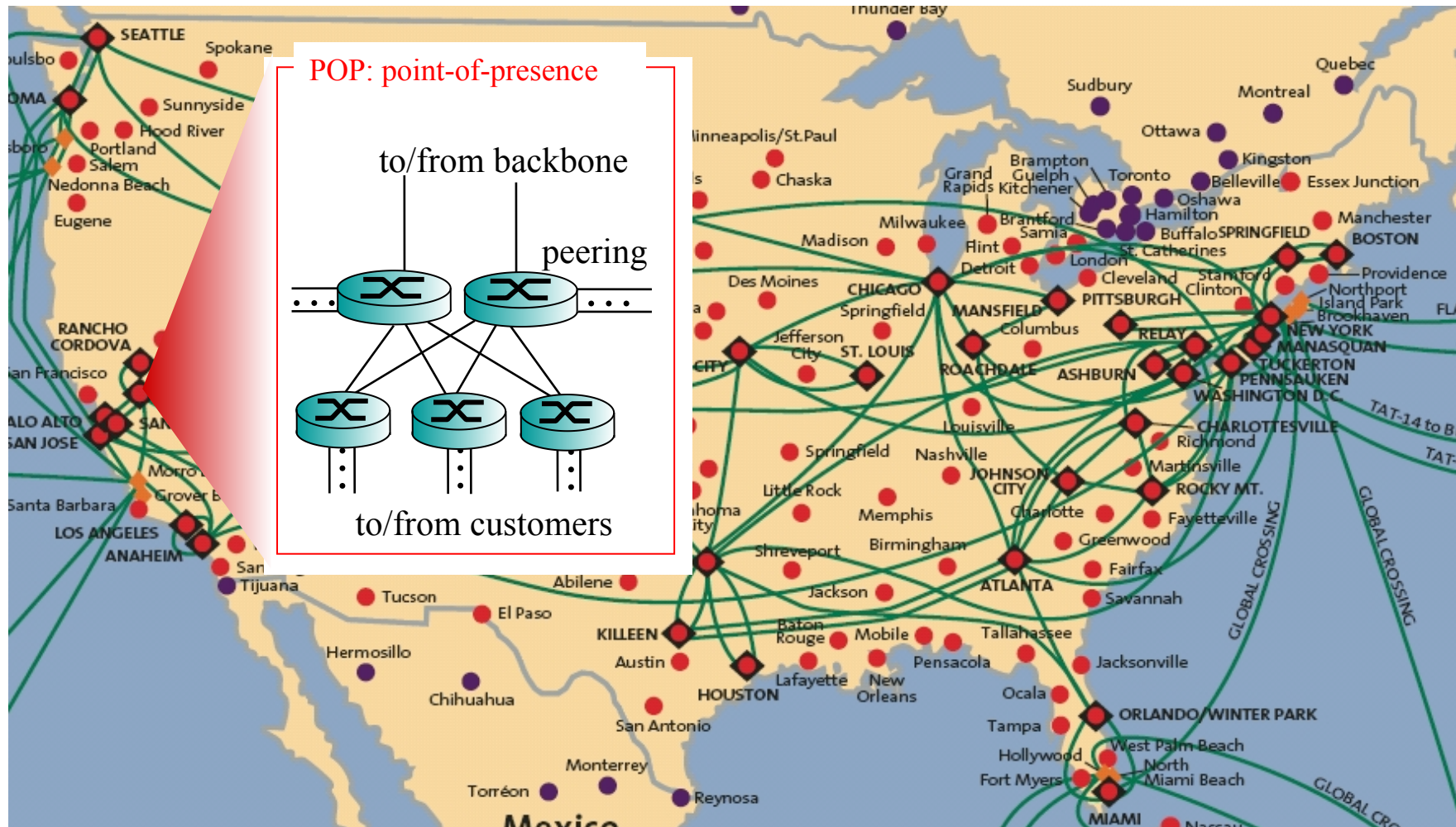
Internet structure: network of networks



- ❖ 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 its data centers to Internet, often bypassing tier-1, regional ISPs

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Tier-1 ISP: e.g., Sprint



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Introduction 1-45

Internet Design Philosophy

- Simple core, complex edge
- Best effort service
- Great support for heterogeneity
- Dynamic by design
- One network for many, many purposes
- Designed primarily for non-real-time text traffic with no QoS requirements other than reliable delivery.

Q: Does this explain why the internet does not work well for many applications?

Protocol “Layers”

Networks are complex!

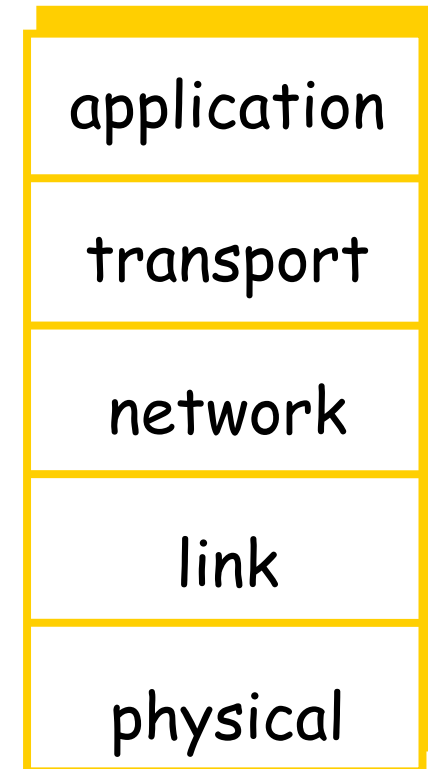
- many “pieces”:
 - hosts
 - routers
 - links of various media
 - applications
 - protocols
 - hardware, software

Pros and cons of layering:

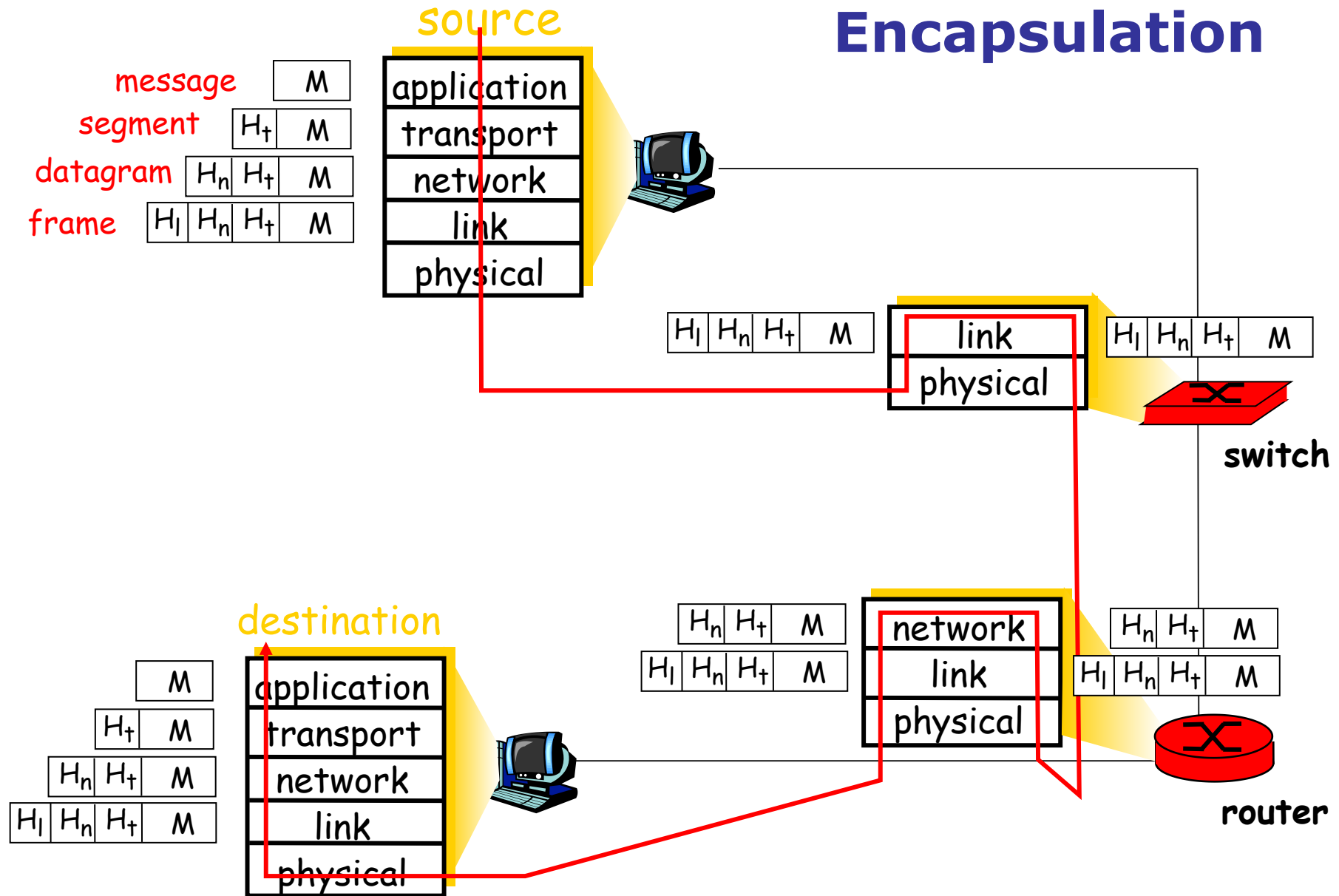
- explicit structure allows identification, relationship of complex system’s pieces
- modularization eases maintenance, updating of system
 - change of implementation of layer’s service transparent to rest of system

Internet protocol “stack”

- **application:** supporting network applications
 - FTP, SMTP, STTP
- **transport:** host-host data transfer
 - TCP, UDP
- **network:** routing of datagrams from source to destination
 - IP, routing protocols
- **link:** data transfer between neighboring network elements
 - PPP, Ethernet
- **physical:** bits “on the wire”



Encapsulation



Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
 - ARPAnet demonstrated publicly
 - NCP (Network Control Protocol) first host-host protocol
 - first e-mail program
 - ARPAnet has 15 nodes

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1973: Metcalfe's PhD thesis proposes Ethernet
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late 70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

Internet History

1990, 2000's: commercialization, the Web, new apps

- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
 - hypertext [Bush 1945, Nelson 1960's]
 - HTML, HTTP: Berners-Lee
 - 1994: Mosaic, later Netscape
 - late 1990's: commercialization of the Web

Late 1990's - 2000's:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Next: Delay and loss in networks

- Reading: Ch 1, 2.