# Redes de Comunicação
# 2024/2025

# T01
# Computer Networks and the Internet

Jorge Granjal
University of Coimbra

UNIVERSIDADE D COIMBRA

# T01
# Computer Networks and the Internet

*Our Goals:*

- Provide an introduction to the dynamic field of computer networking
- Explore the fundamental aspects to understand today's and tomorrow's networks
- Set the context for the rest of the subjects explored during the course

# T01: Computer Networks and the Internet

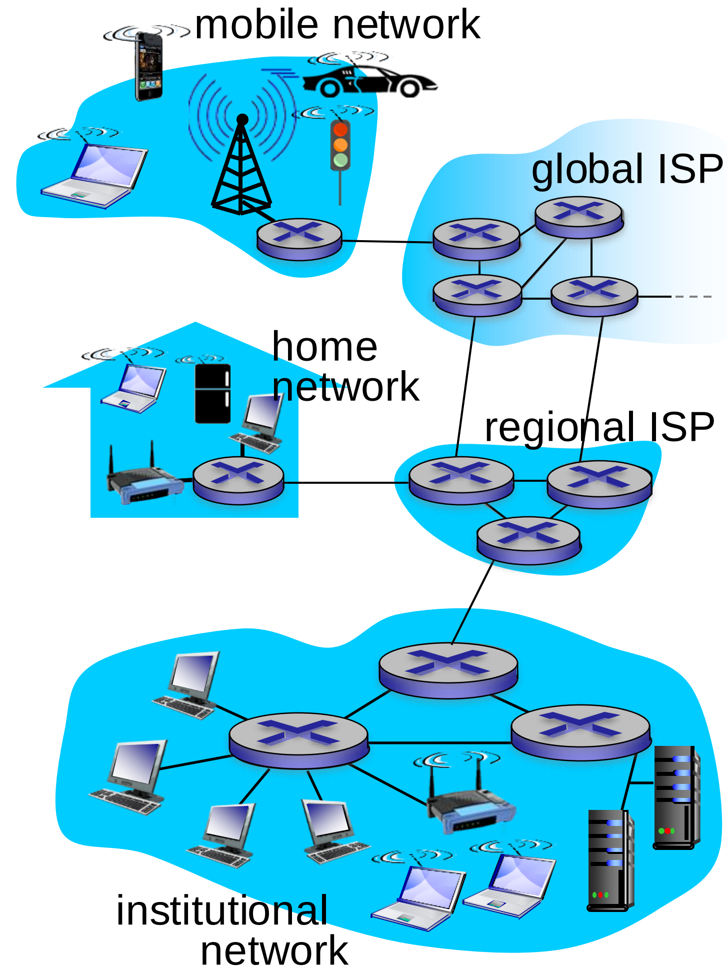
*Overview:*

- what's the Internet?
- what's a protocol?
- network edge; hosts, access net, physical media
- network core: packet/circuit switching, Internet structure
- protocol layers, service models
- history

# T01: roadmap

# What's the Internet?


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



# “Fun” Internet-connected devices

IP picture frame
http://www.ceiva.com/

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

Internet
refrigerator

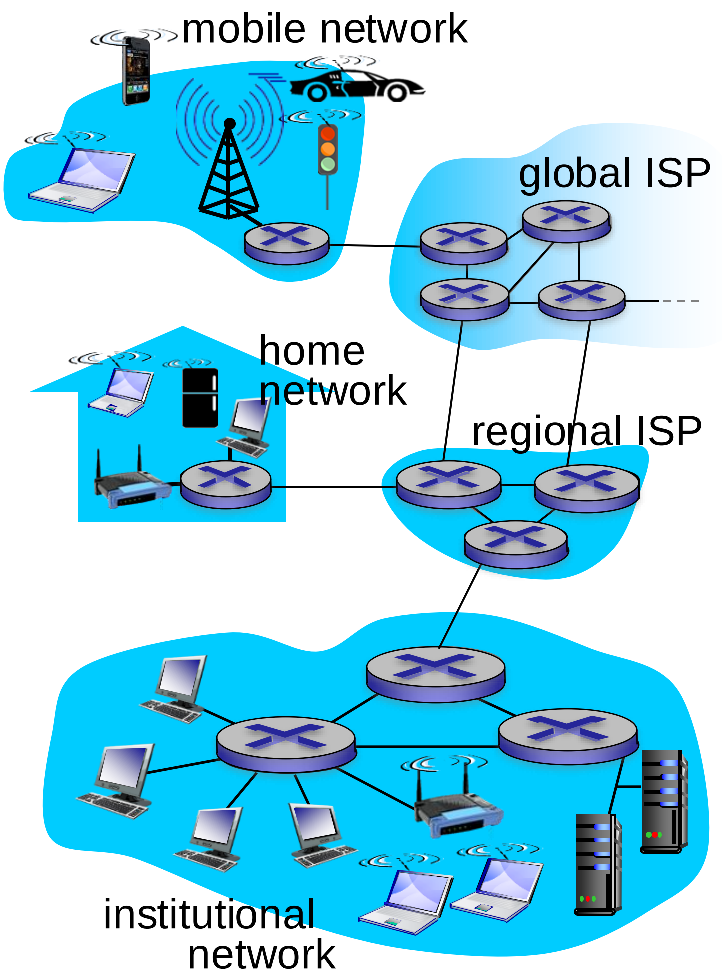
Slingbox: watch,
control cable TV remotely

sensorized,
bed
mattress

Internet phones

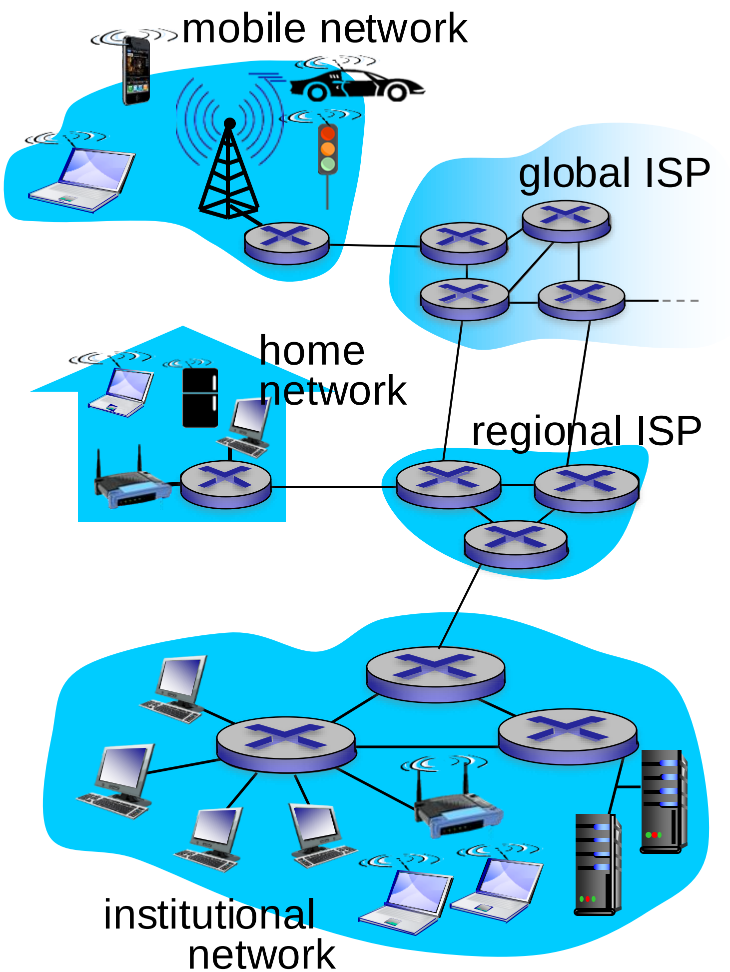
# What's the Internet?

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



# What's the Internet: a "service view"

- *infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social nets, …
- *provides programming interface to apps*
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - provides service options, analogous to postal service



# What's a protocol?

*human protocols:*

- "what's the time?"
- "I have a question"
- introductions

… specific messages sent

… specific actions taken when messages received, or other events

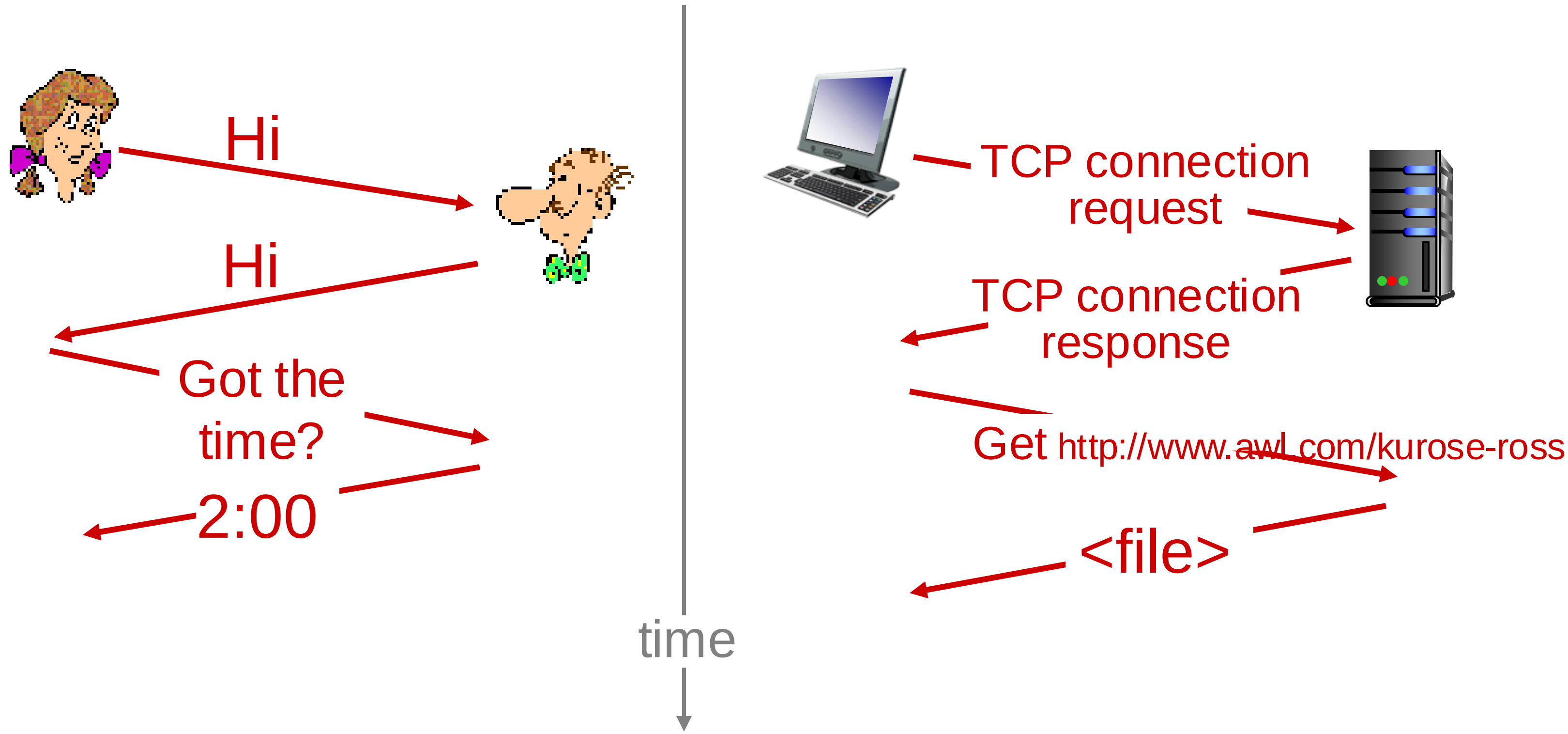
*network protocols:*

- machines rather than humans
- 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*

# What's a protocol?

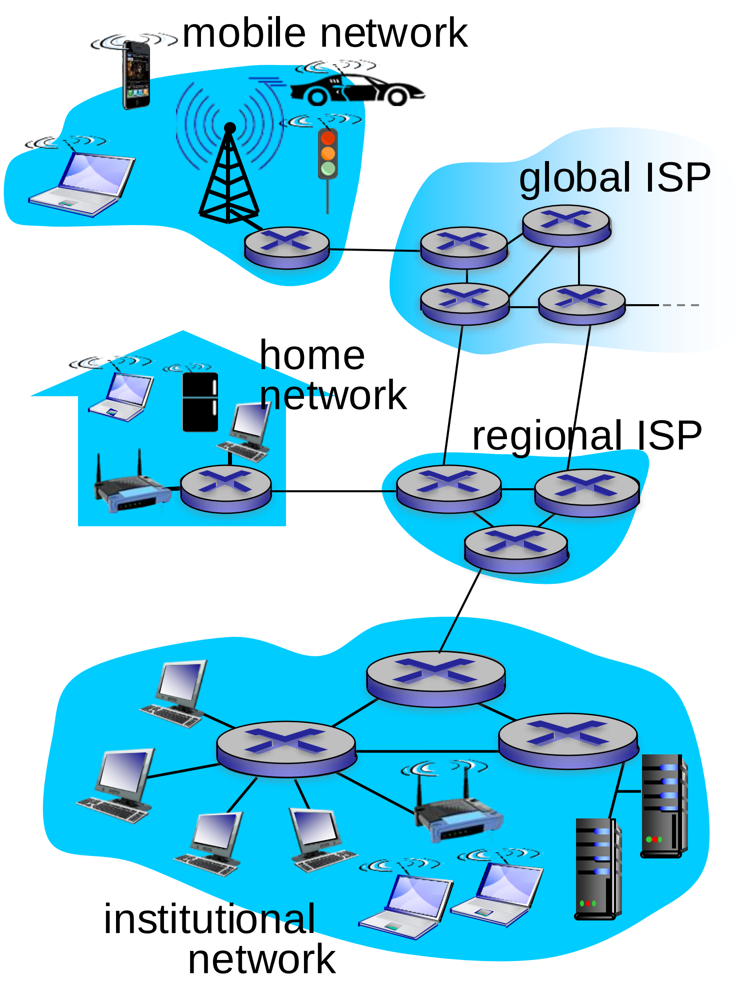
a human protocol and a computer network protocol:



# T01: roadmap

# A closer look at network structure:

- *network 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



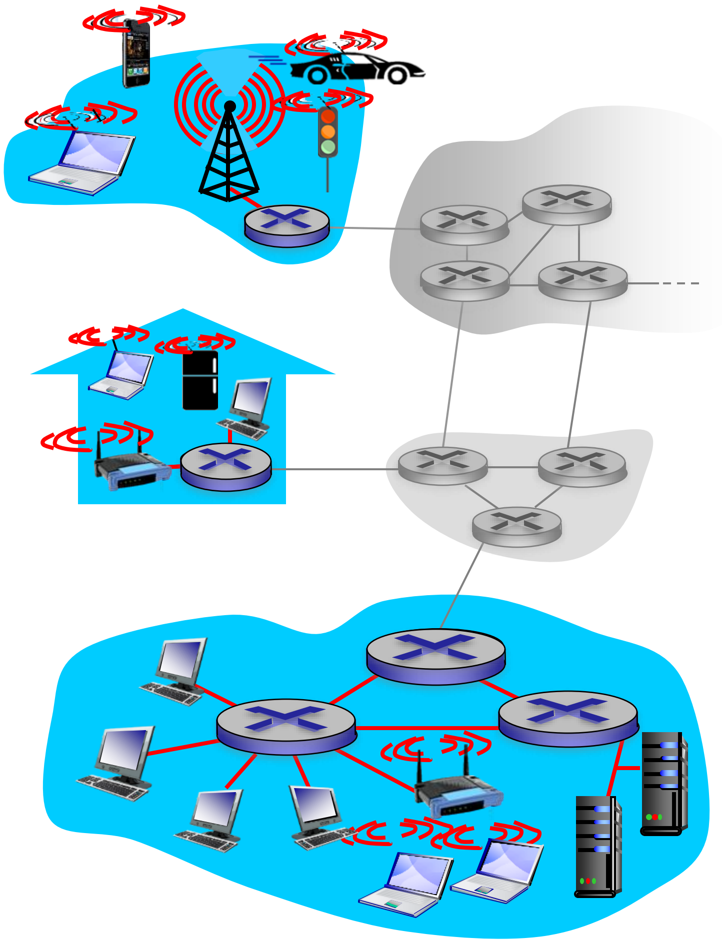
# Access networks and physical media

*Q: How to connect end systems to edge router?*

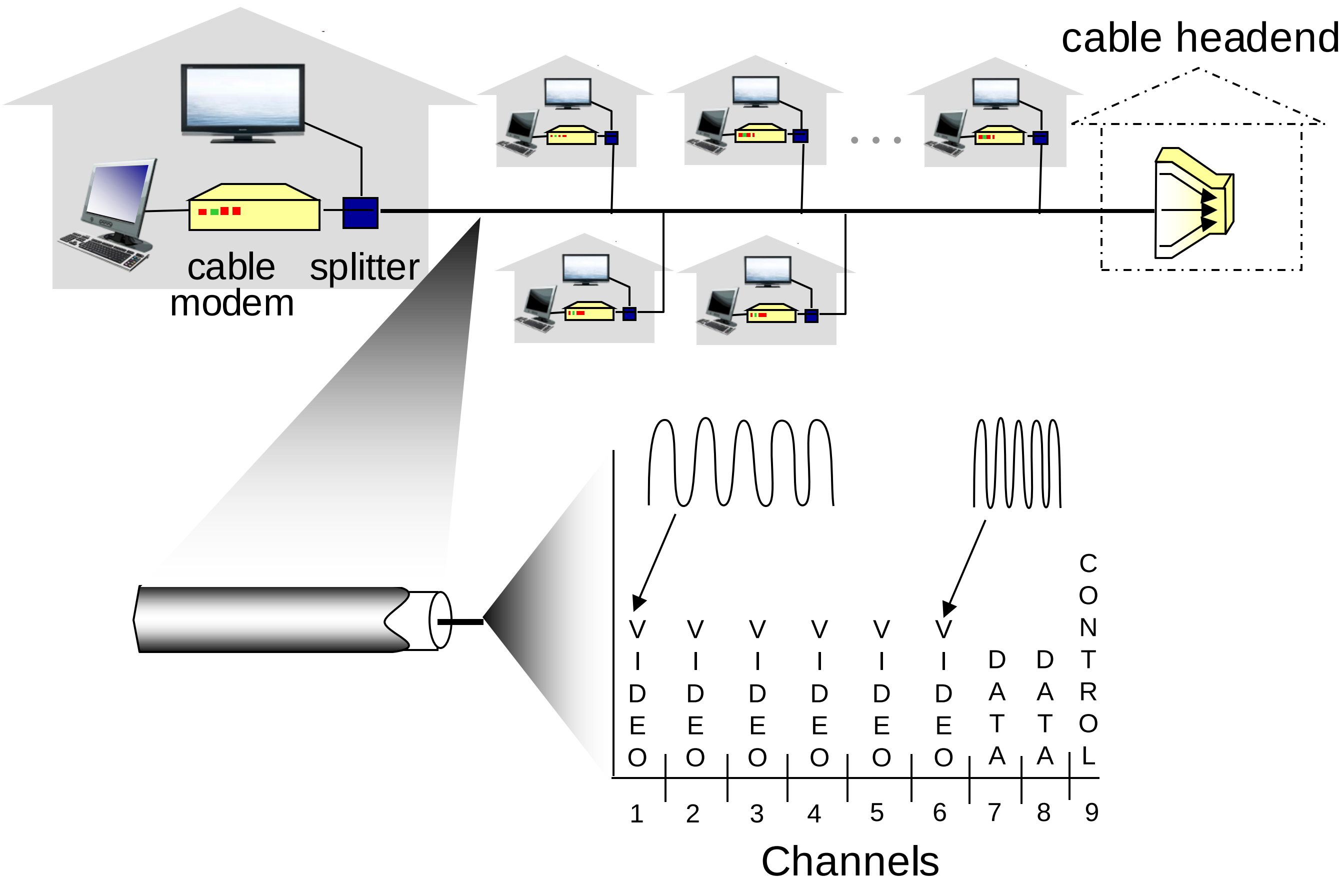
- residential access nets
- institutional access networks (school, company)
- mobile access networks

*keep in mind:*

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

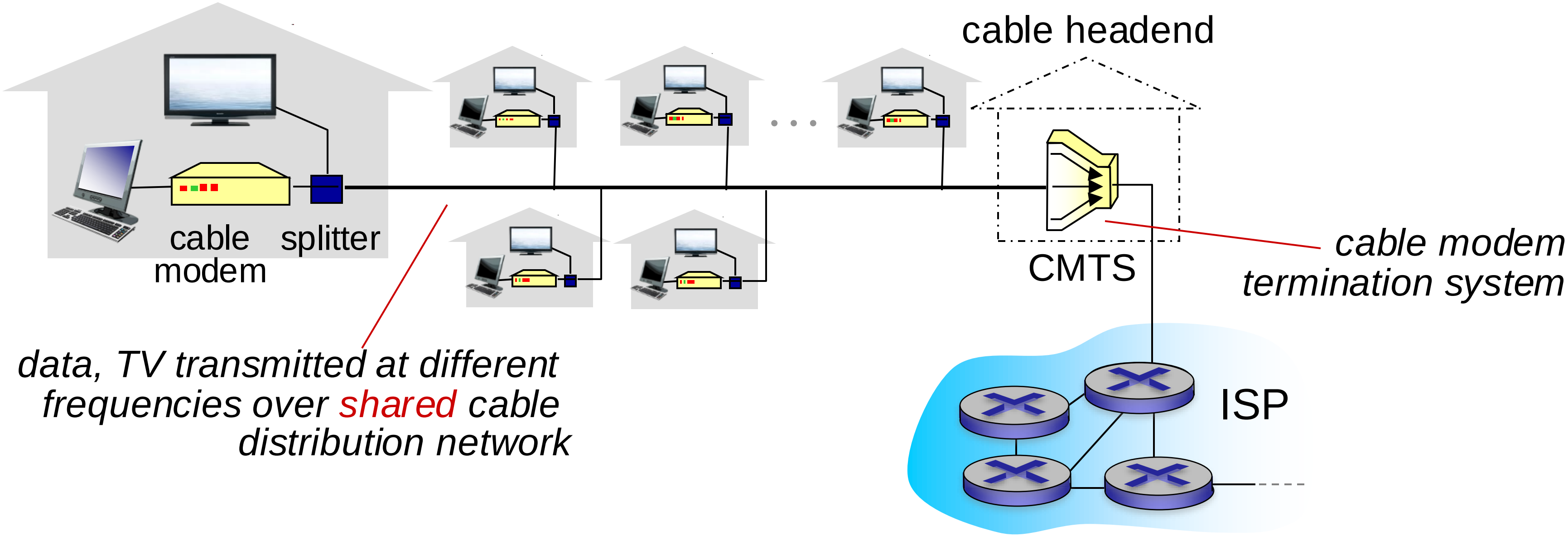


# Access network: cable network



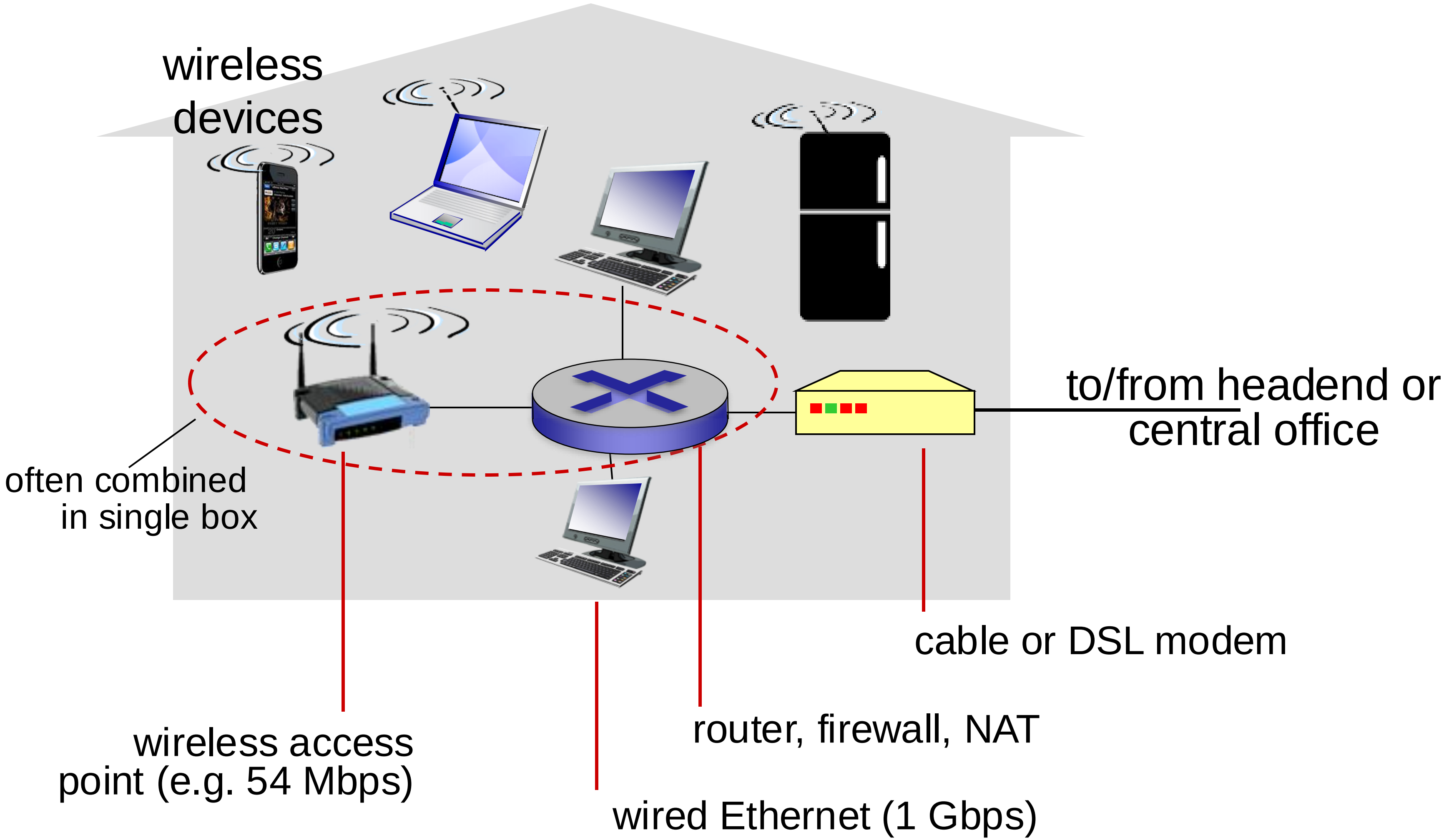

*frequency division multiplexing:* different channels transmitted in different frequency bands

# Access network: cable network

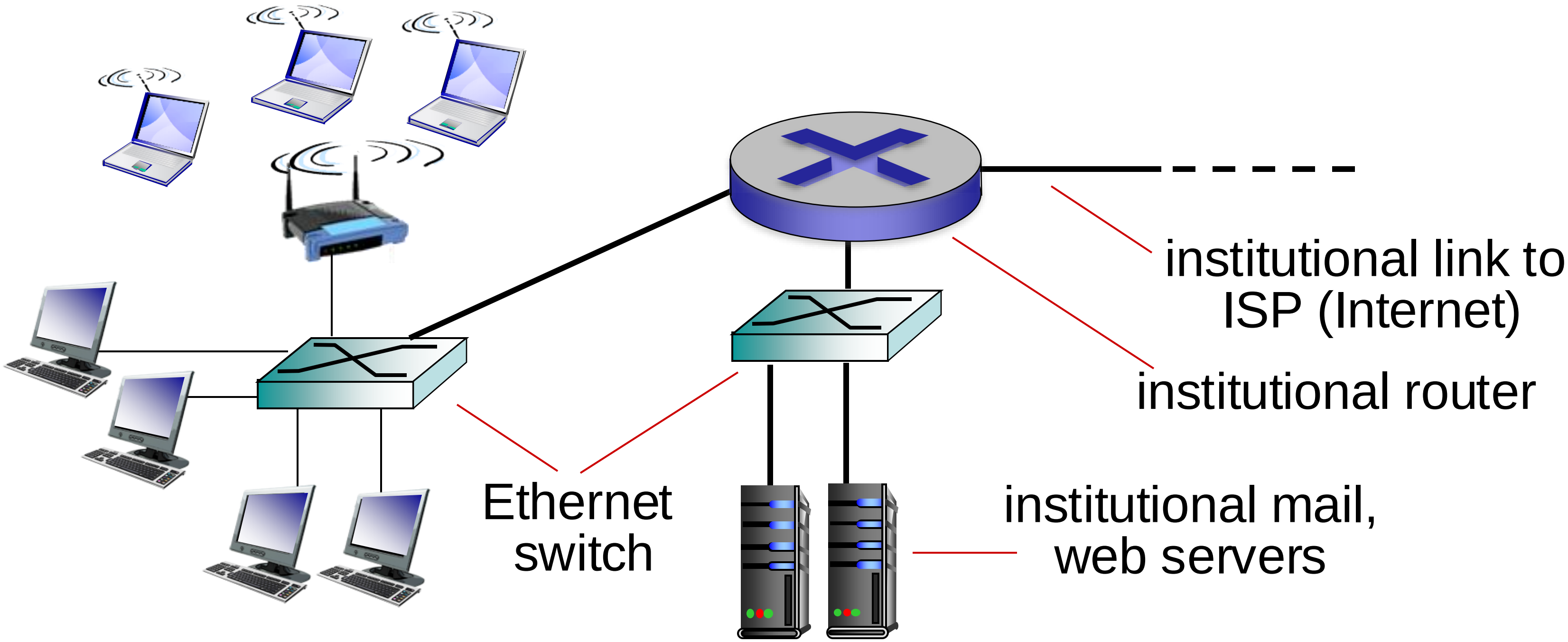



- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend

# Access network: home network



# Enterprise access networks (Ethernet)



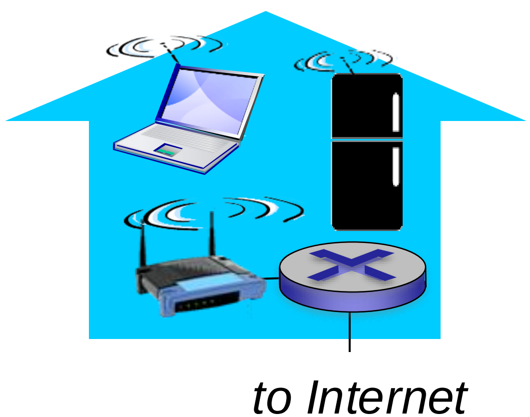

- typically used in companies, universities, etc.
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

# Wireless access networks

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

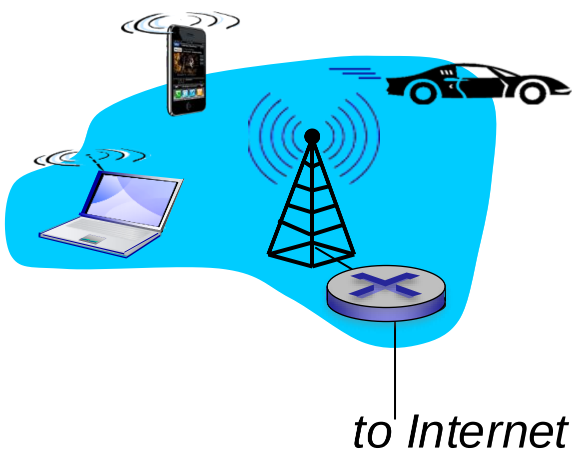
*wireless LANs:*

- within building (100 ft.)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate




wide-area wireless access

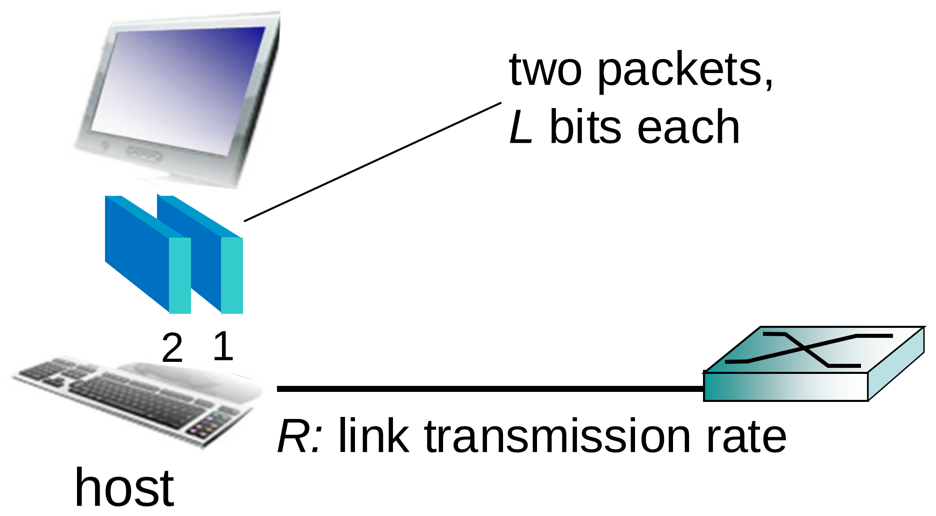
- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE, (5G!)



# 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*



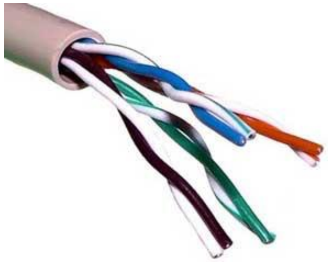

$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

# 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



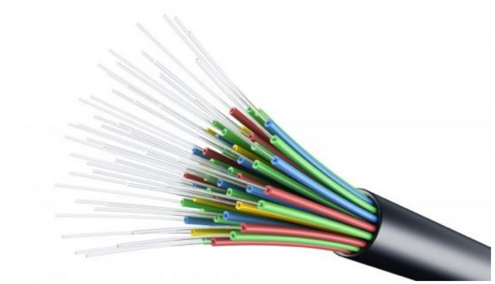
# Physical media: coax, fiber

*coaxial cable:*

- two concentric copper conductors
- Up to 500m
- bidirectional
- broadband:
  - multiple channels on cable
  - HFC (Hybrid fibe-coaxial)

*fiber optic cable:*

- glass fiber carrying light pulses, each pulse a bit
- Up to 40 km (single mode)
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gbps 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

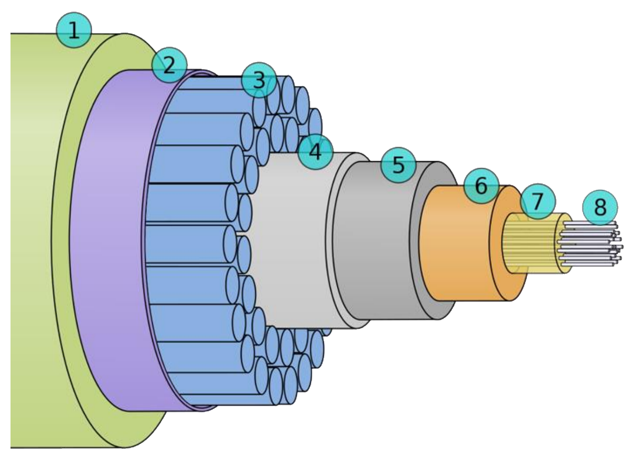
*radio link types:*

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 54 Mbps (and more)
- wide-area (e.g., cellular)
  - 4G cellular: ~ 10 Mbps
  - 5G cellular: up to 20 Gbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay

# Submarine communications

- The first submarine communications cable became operational in1858, and carried telegraphy traffic
- Modern cables use optical fiber technology to carry digital data, which includes telephone, Internet and private data traffic
- Currently 99% of the data traffic that is crossing oceans is carried by undersea cables
- Although very expensive, submarine cables transport terabits per second, while satellites typically offer only 1,000 megabits per second and display higher latency

A cross section of the shore-end of a modern submarine communications cable.
1 – Polyethylene
2 – Mylar tape
3 – Stranded steel wires
4 – Aluminium water barrier
5 – Polycarbonate
6 – Copper or aluminium tube
7 – Petroleum jelly
8 – Optical fibers



# T01: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

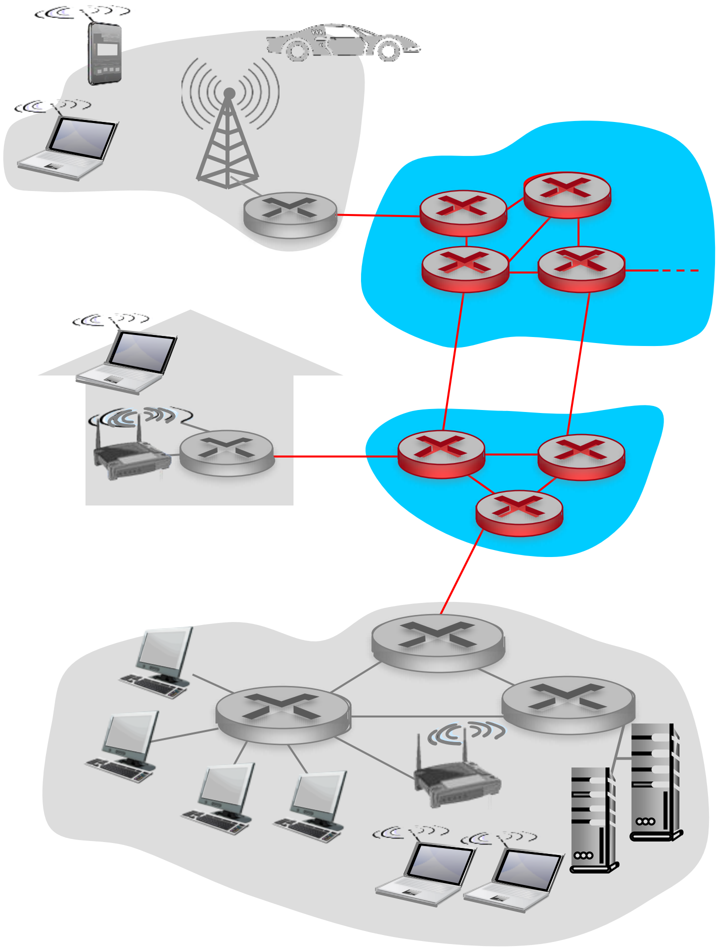
- packet switching, circuit switching, network structure

1.4 protocol layers, service models

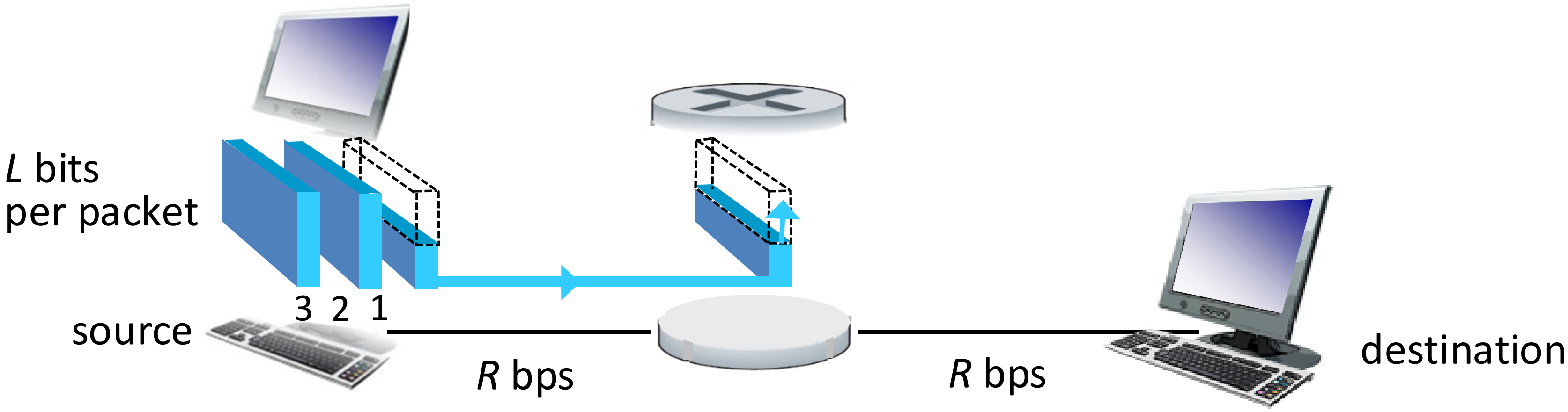
1.5 history

# 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



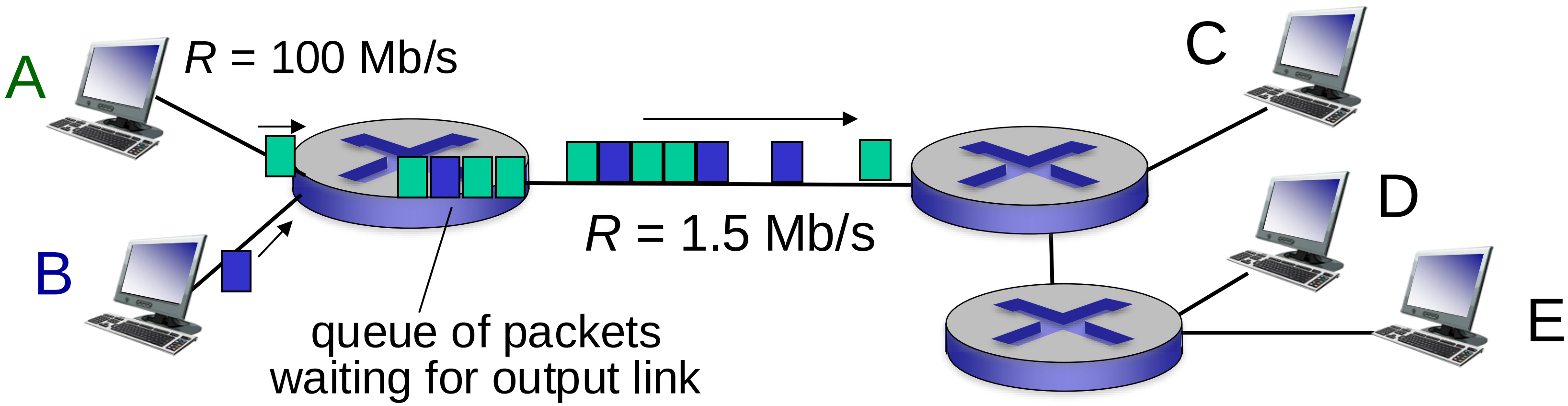

- takes $L/R$ seconds to transmit (push out) $L$-bit packet into link at $R$ bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = $2L/R$ (<u>assuming zero propagation delay</u>)

more on delay shortly …

*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:

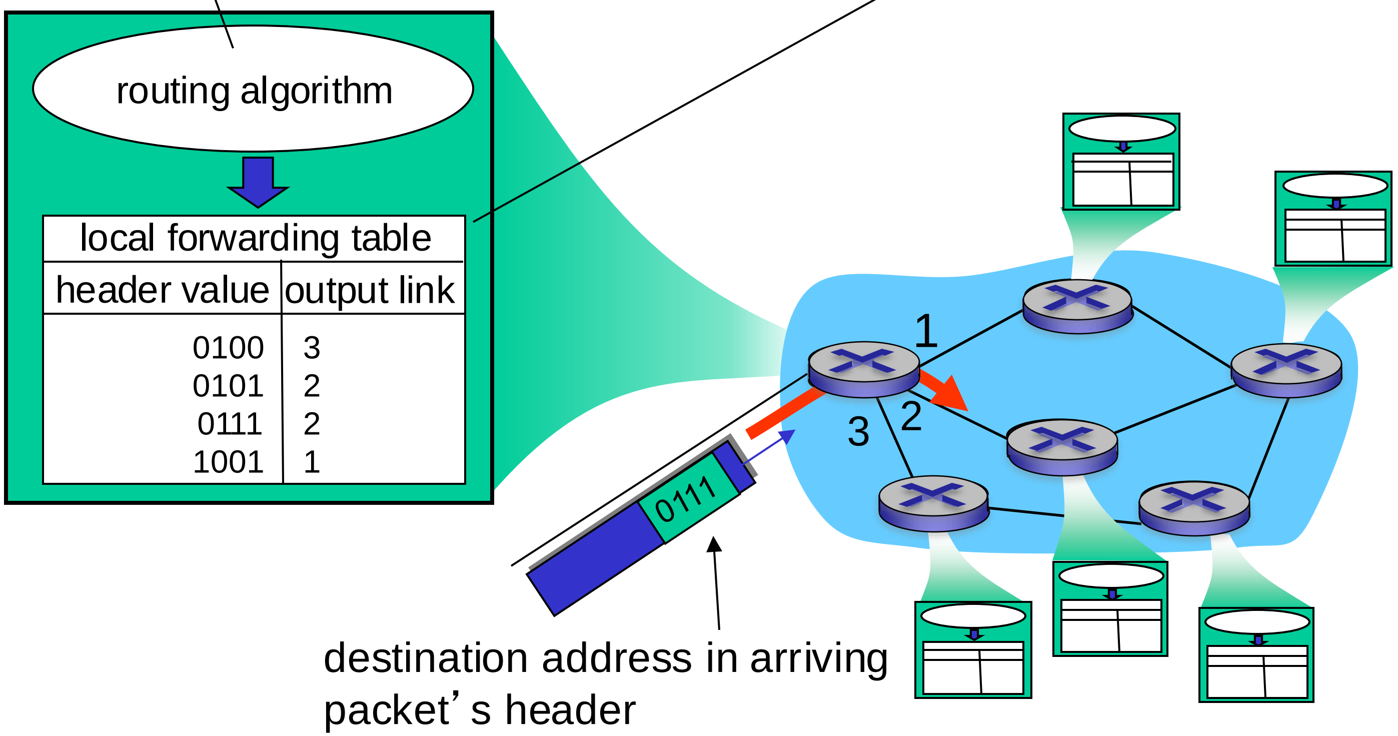
- if arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up
  - Bandwidth shared on demand: statistical multiplexing.

# Two key network-core functions

*routing:* determines source-destination route taken by packets

- *routing algorithms*

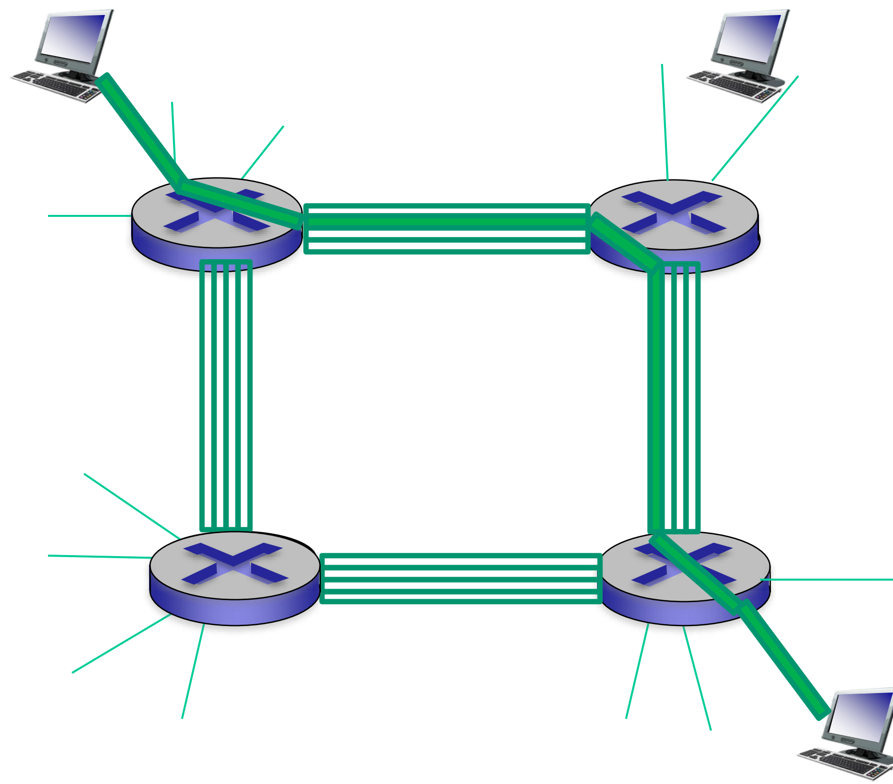
*forwarding:* move packets from router's input to appropriate router output



# Alternative core: circuit switching

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

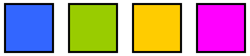
- in diagram, each link has four circuits.
  - call gets $2^{nd}$ circuit in top link and $1^{st}$ circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- commonly used in traditional telephone networks



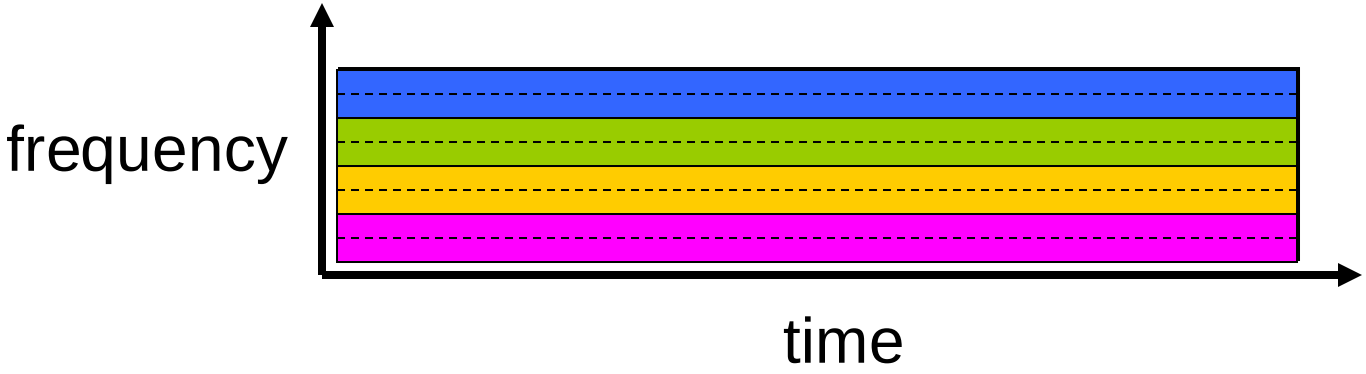
# Circuit switching: FDM versus TDM

Example:

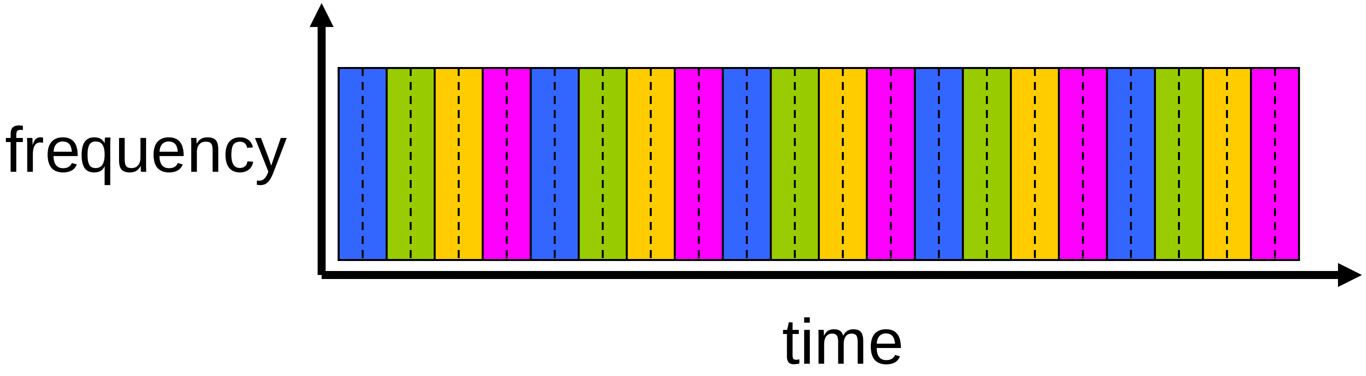
4 users



FDM




TDM

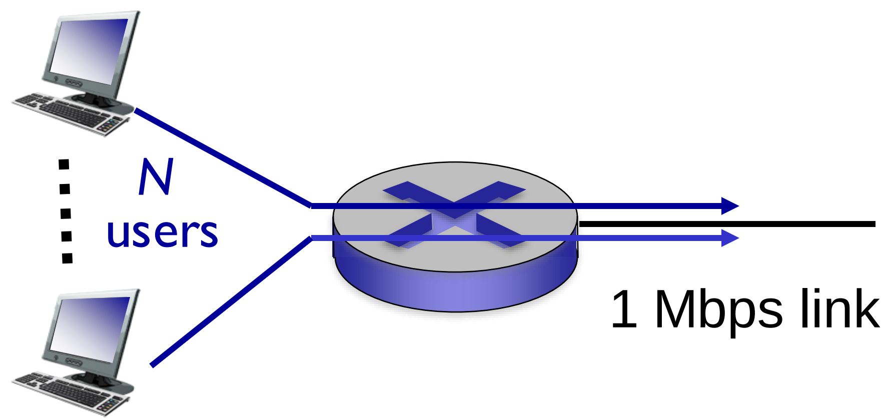


# Packet switching vs. circuit switching

*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 around .0004
  - with 10 or fewer active users data packets flow through the link without delay

*Q:* how did we get value 0.0004?

*A:* using a binomial distribution

$$P(X \geq 11) = \sum_{n=11}^{35} \binom{35}{n} \cdot 0.1^n \cdot (1-0.1)^{35-n}.$$

Check computation in WolframAlpha

# Packet switching vs. circuit switching

## is packet switching superior?

- Packet switching is easier and more affordable than circuit switching
- Packet switching is great for "bursty" data
  - resource sharing
  - simpler, no call setup (simpler infrastructure)
- excessive congestion possible: packet delay and loss
  - end-to-end delays are unpredictable (due primarily to queuing delays)
  - 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 (later in the course)

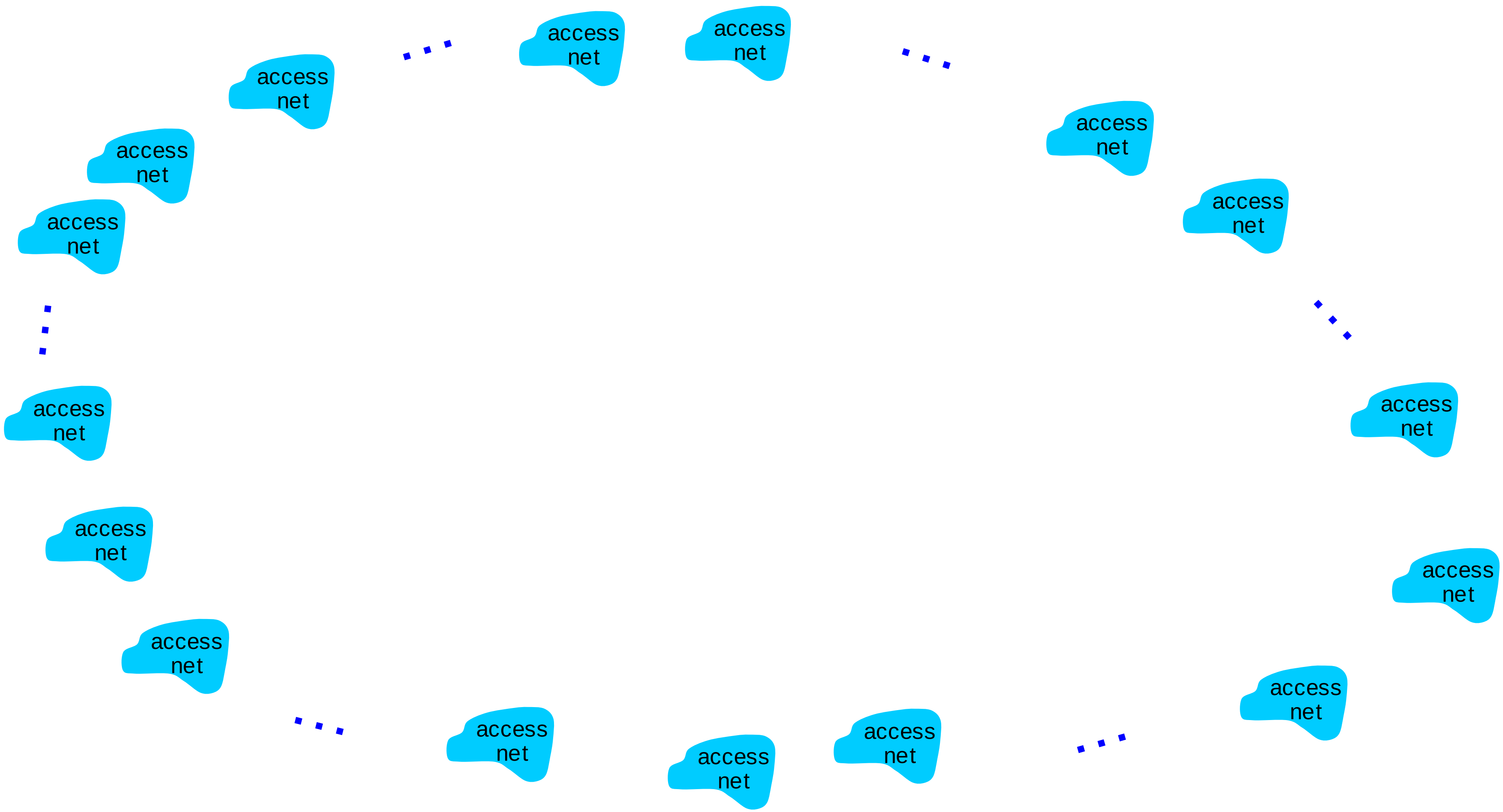
*Q:* a human analogy of a reserved resource (circuit switching) versus on-demand allocation (packet-switching)?

# 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

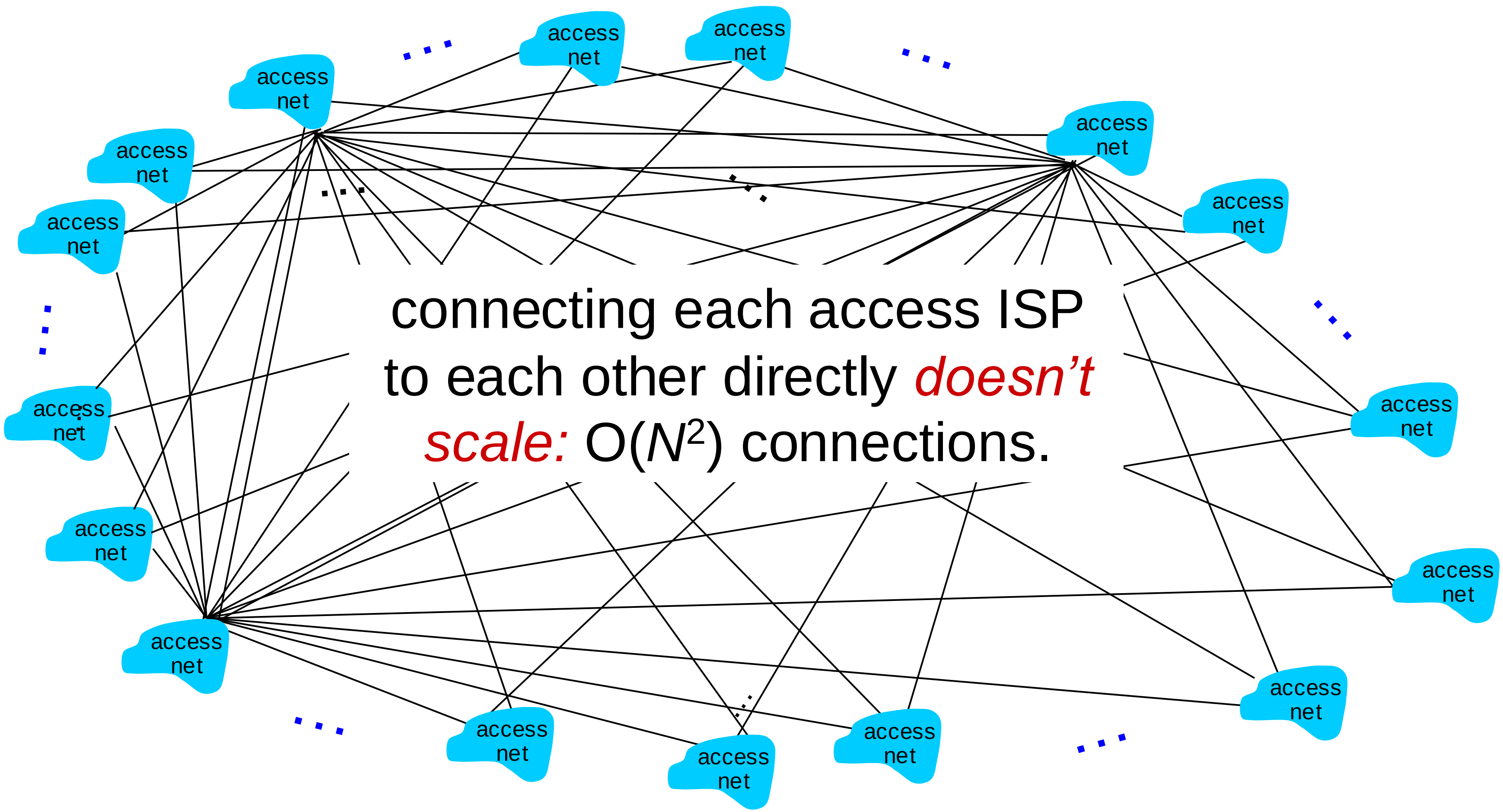
# Internet structure: network of networks

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



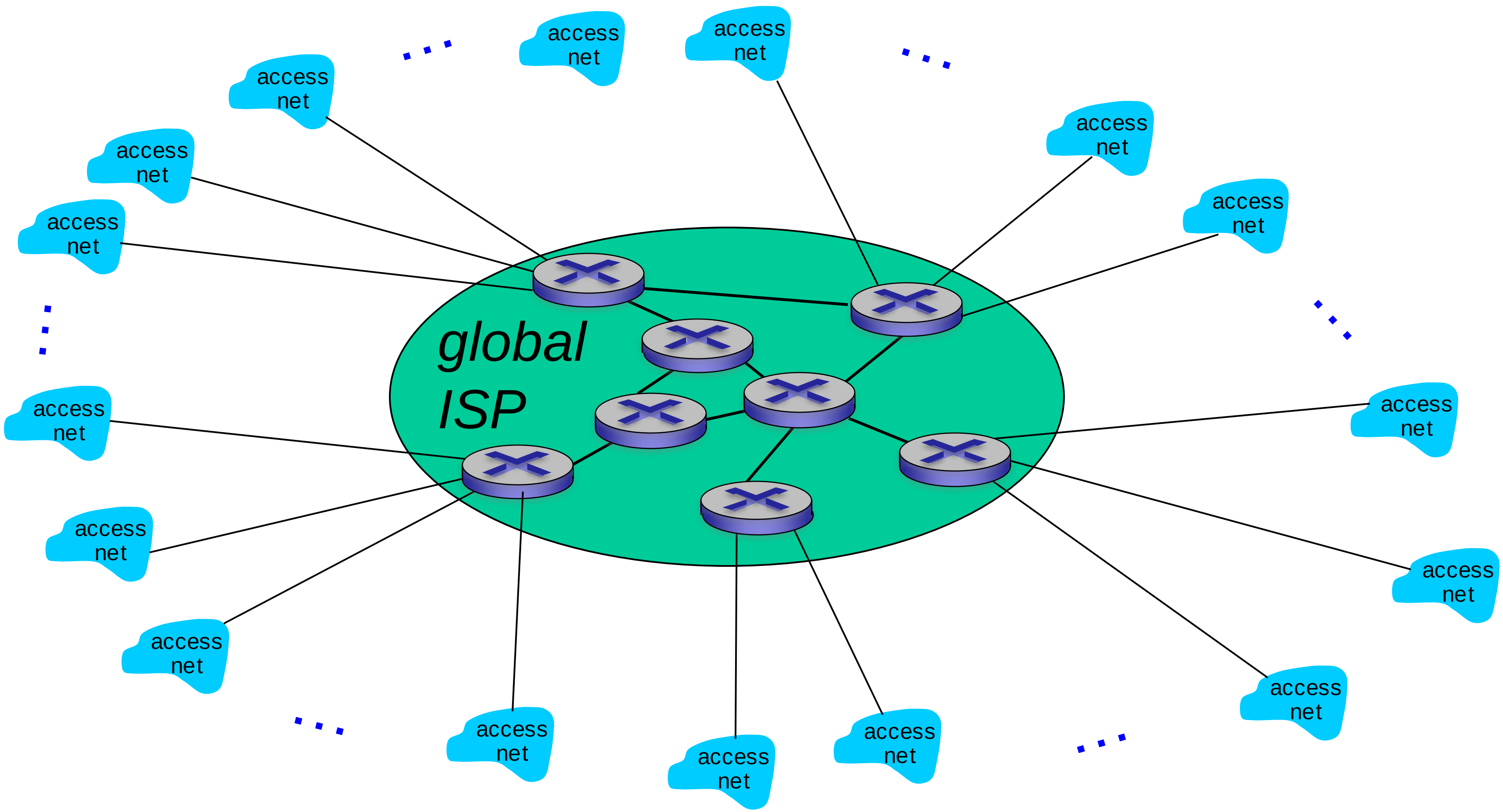
# Internet structure: network of networks

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



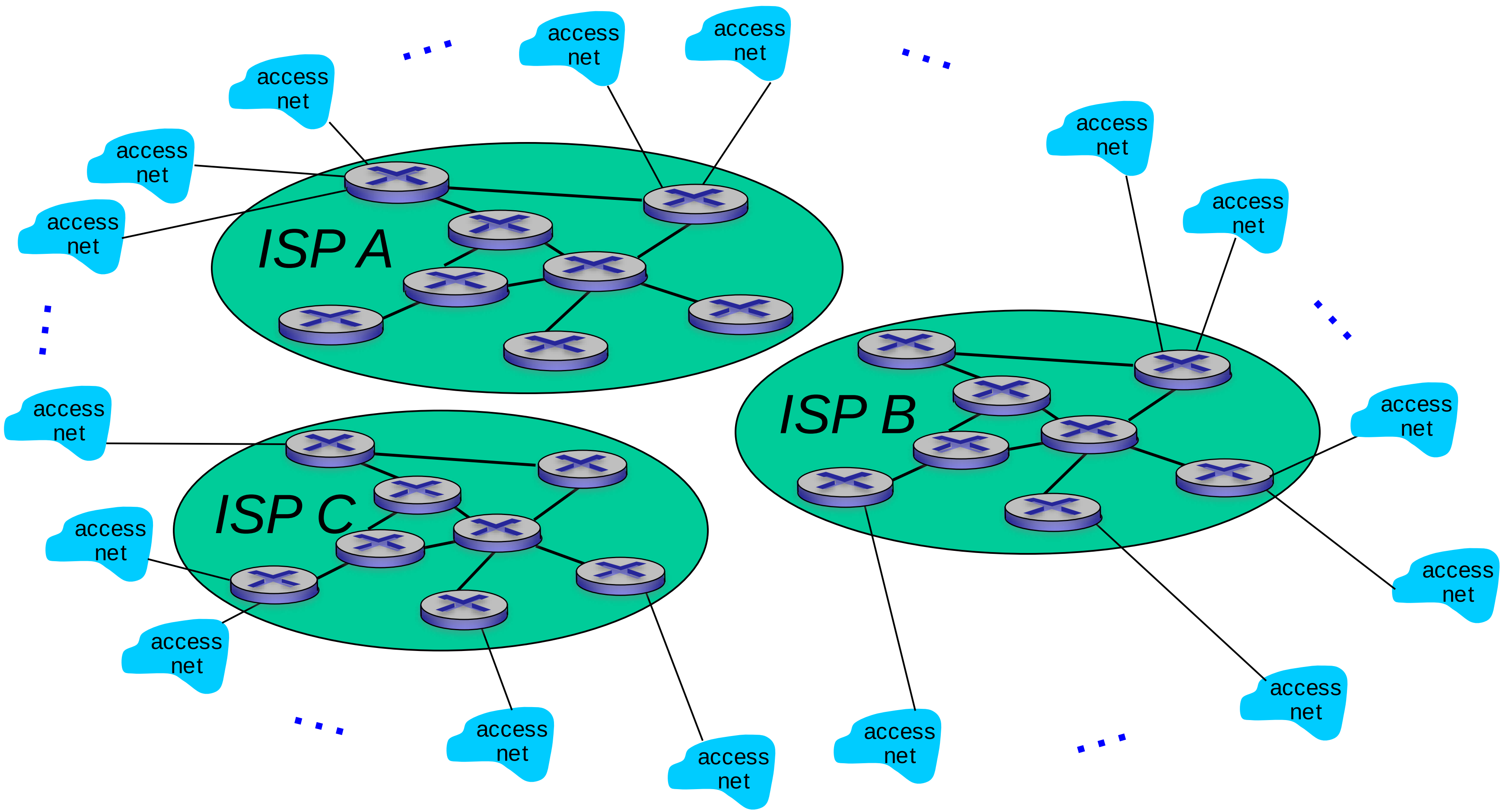
# Internet structure: network of networks

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



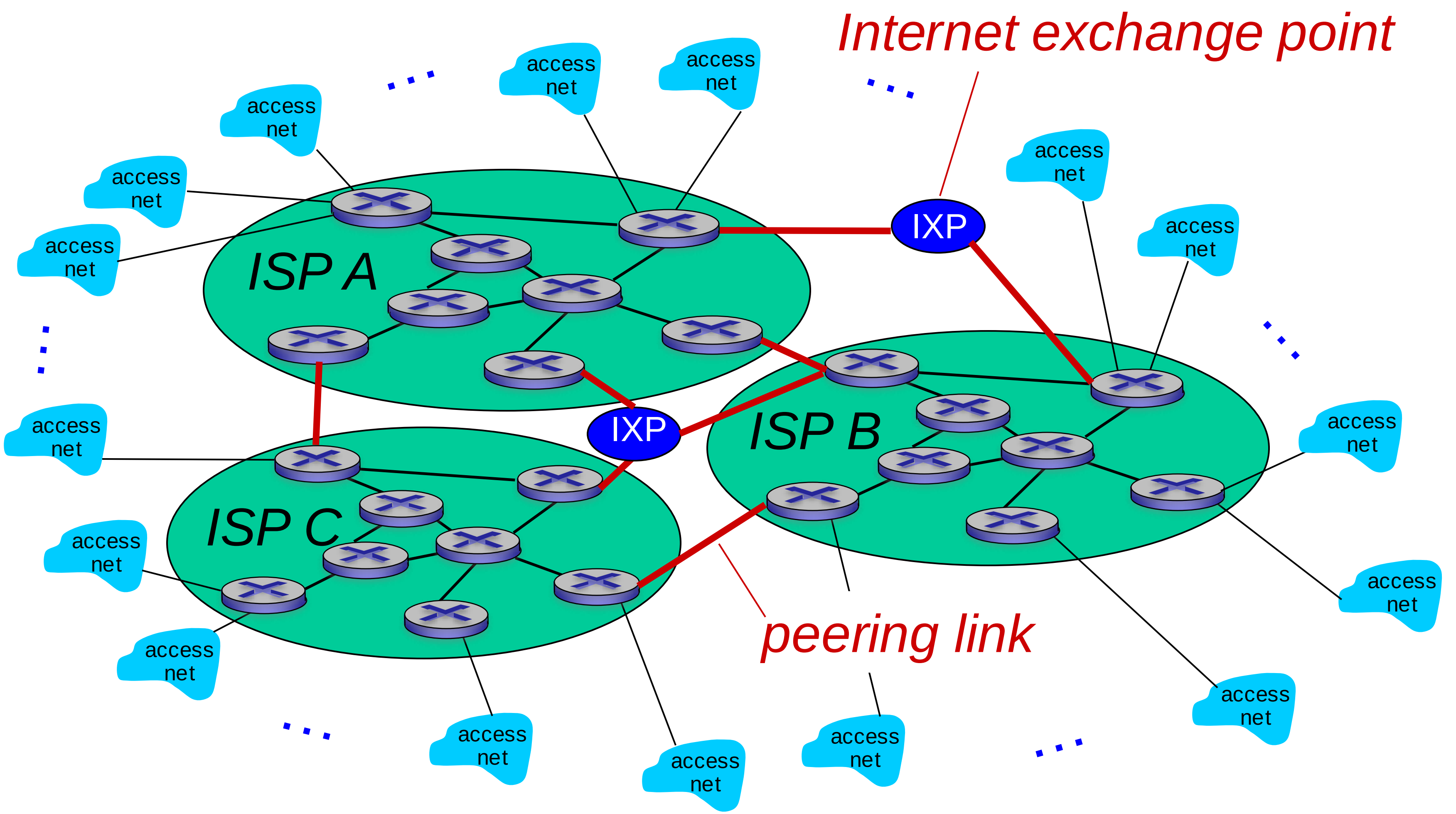
# Internet structure: network of networks

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



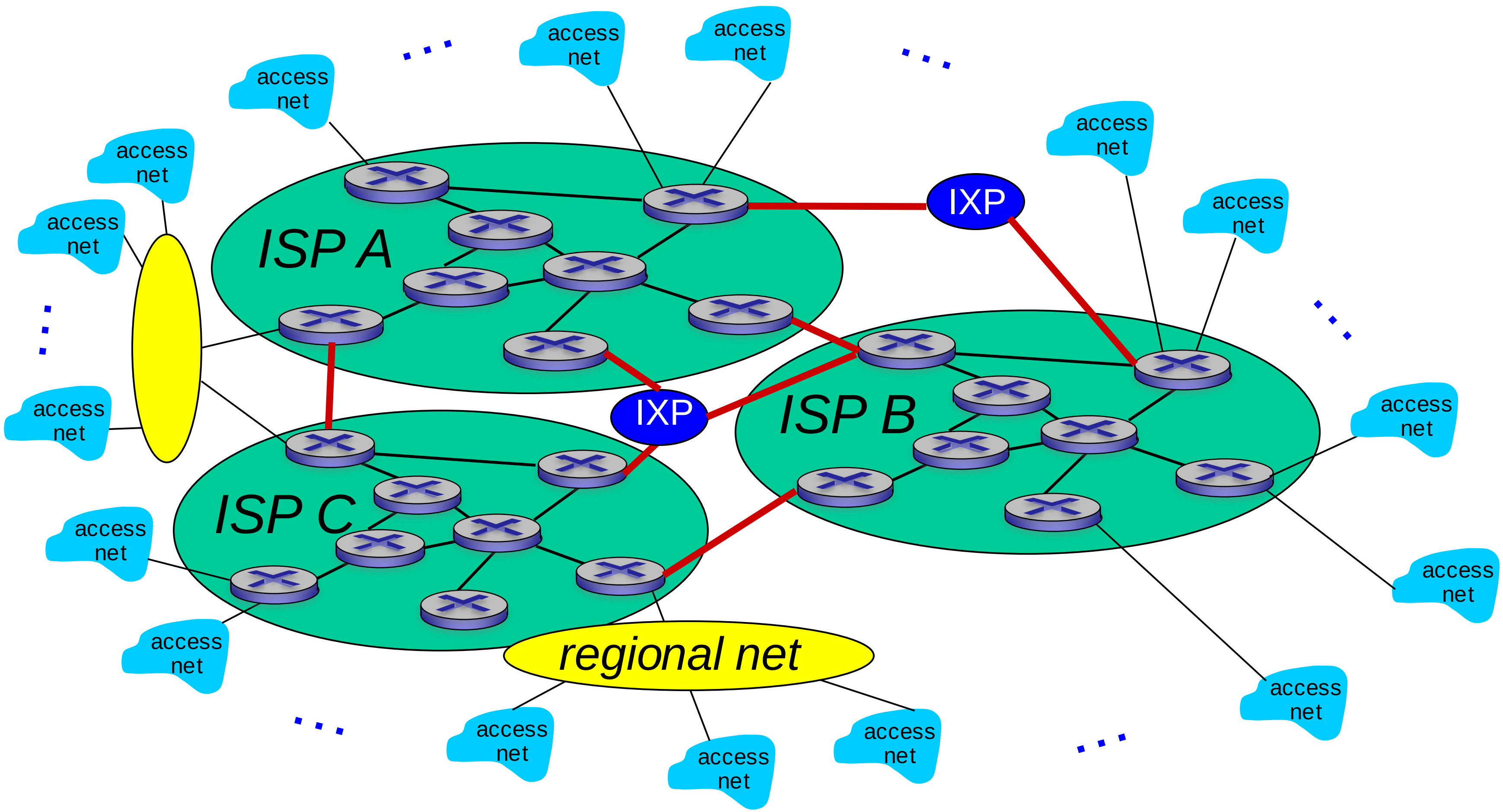
# Internet structure: network of networks

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



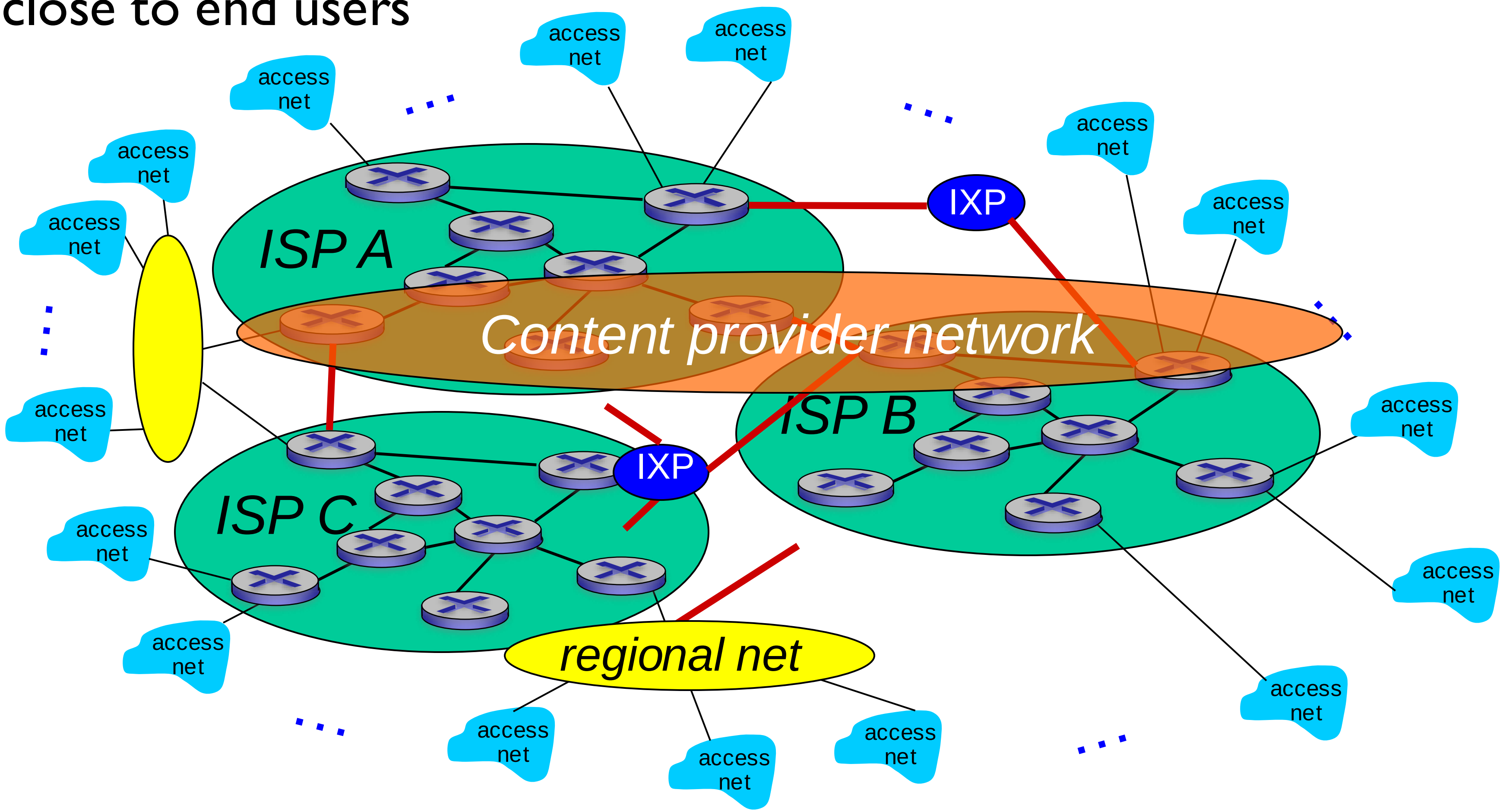
# Internet structure: network of networks

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



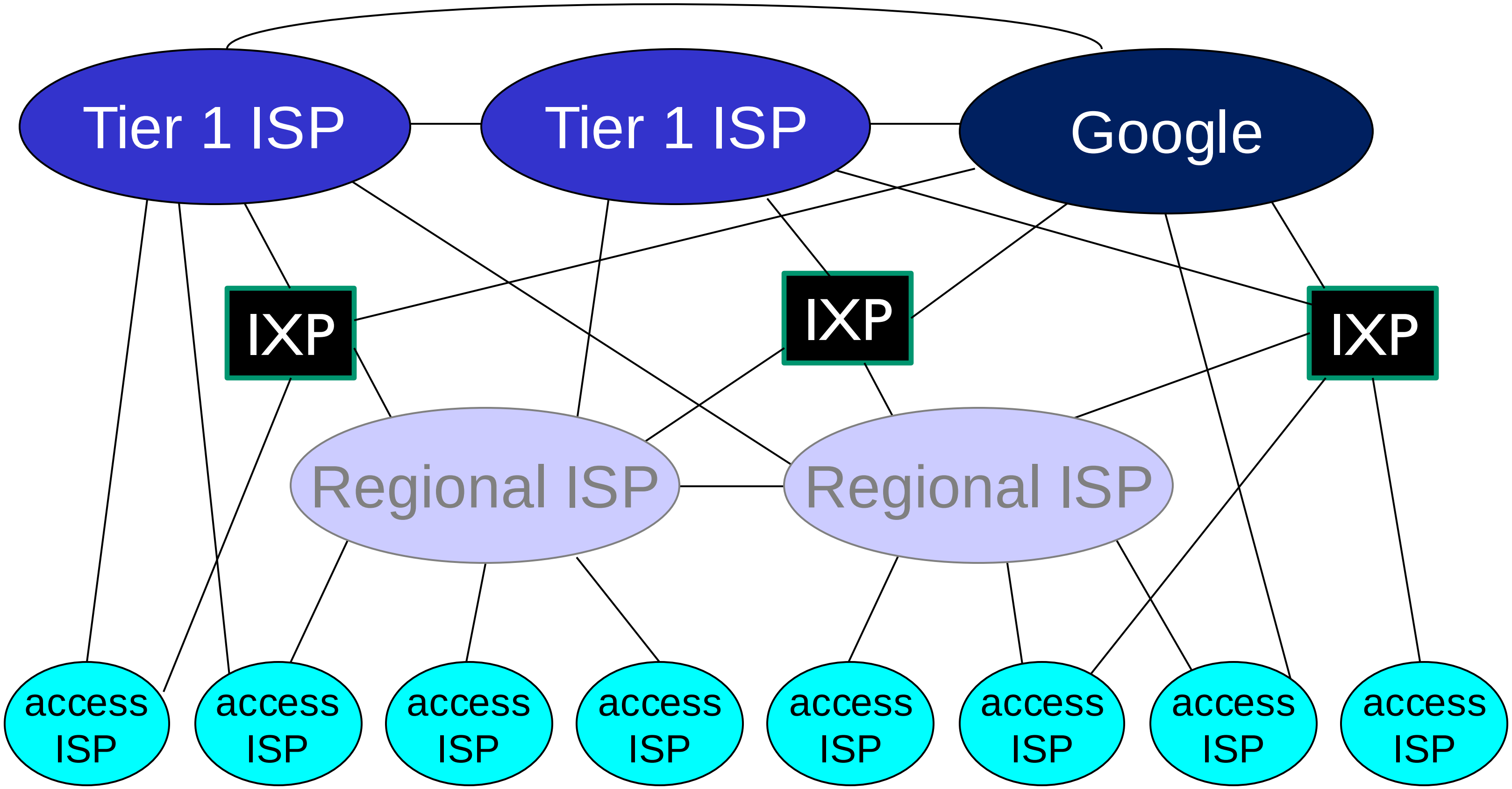
# Internet structure: network of networks

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



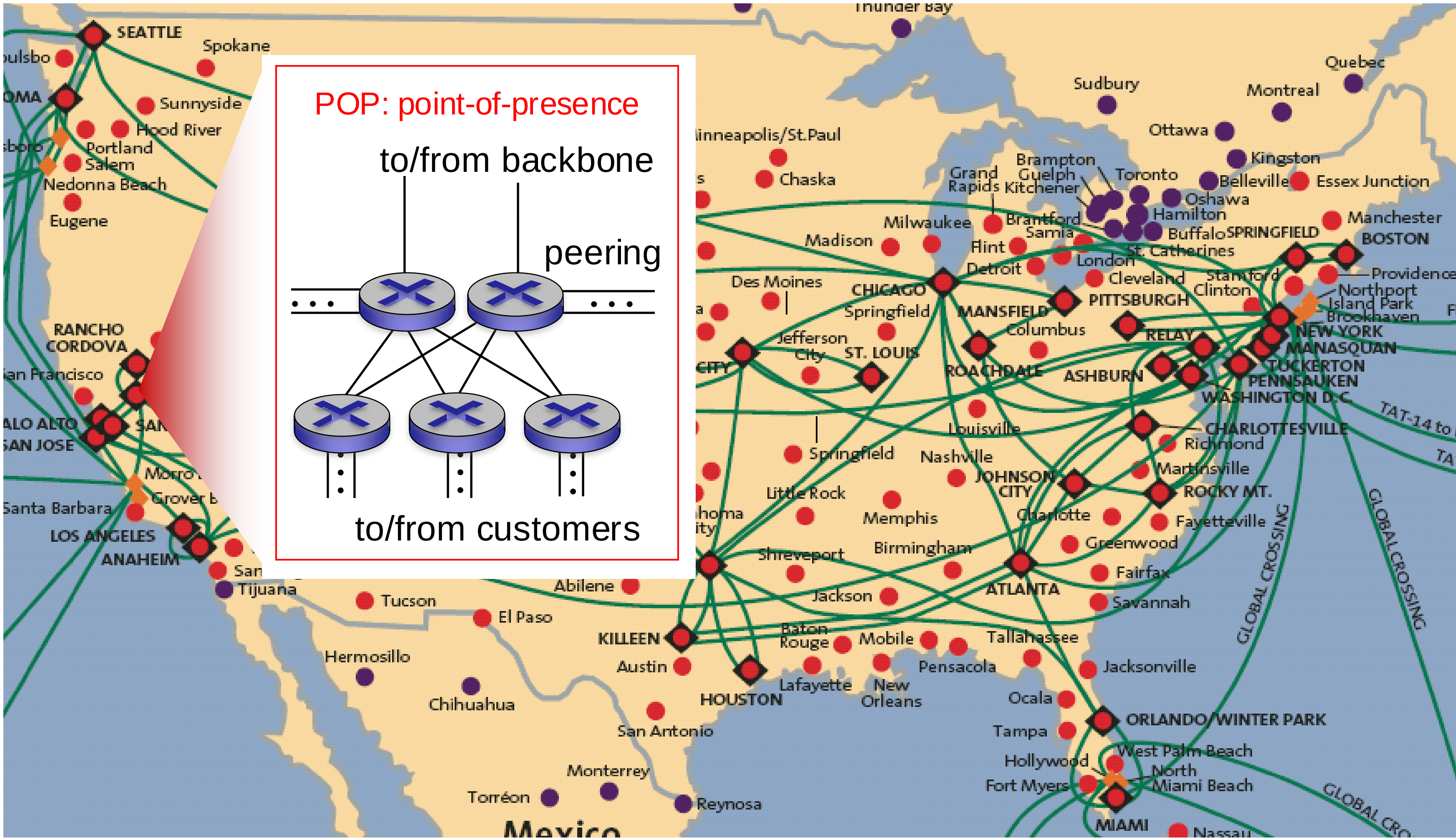

See also: Internet Exchange (IXP) Map

# 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 it data centers to Internet, often bypassing tier-1, regional ISPs

# Tier-1 ISP: e.g., Sprint



# T01: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 protocol layers, service models

1.5 history

# Protocol "layers"

*Networks are complex, with many "pieces":*

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

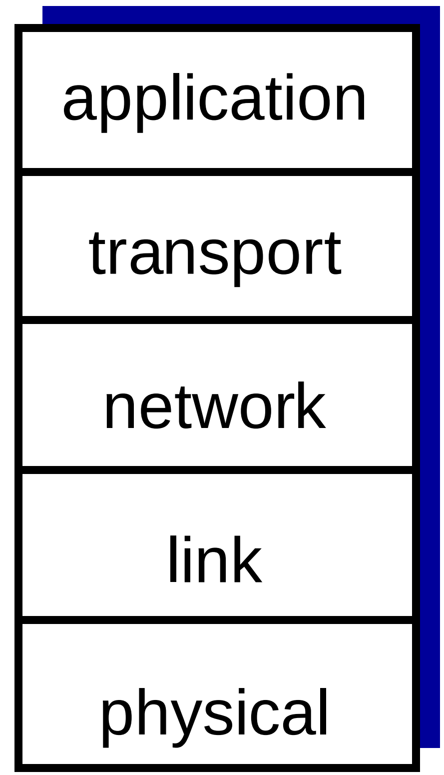
*Question:*

is there any hope of *organizing* structure of network?

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

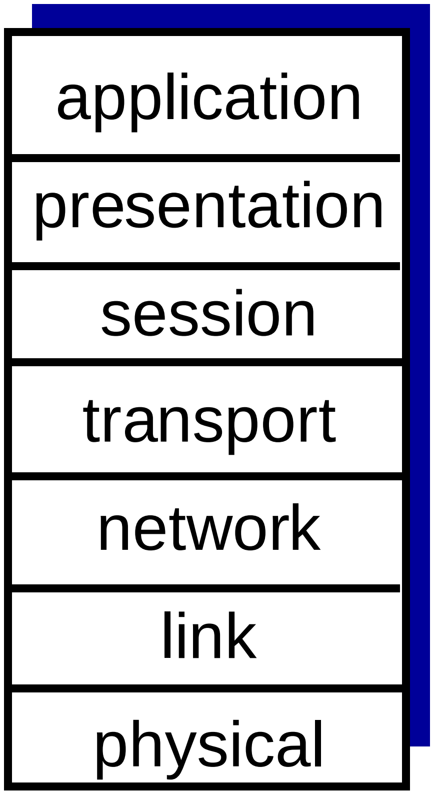
# Internet (TCP/IP) protocol stack

- *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, 802.111 (WiFi), PPP
- *physical:* bits "on the wire"

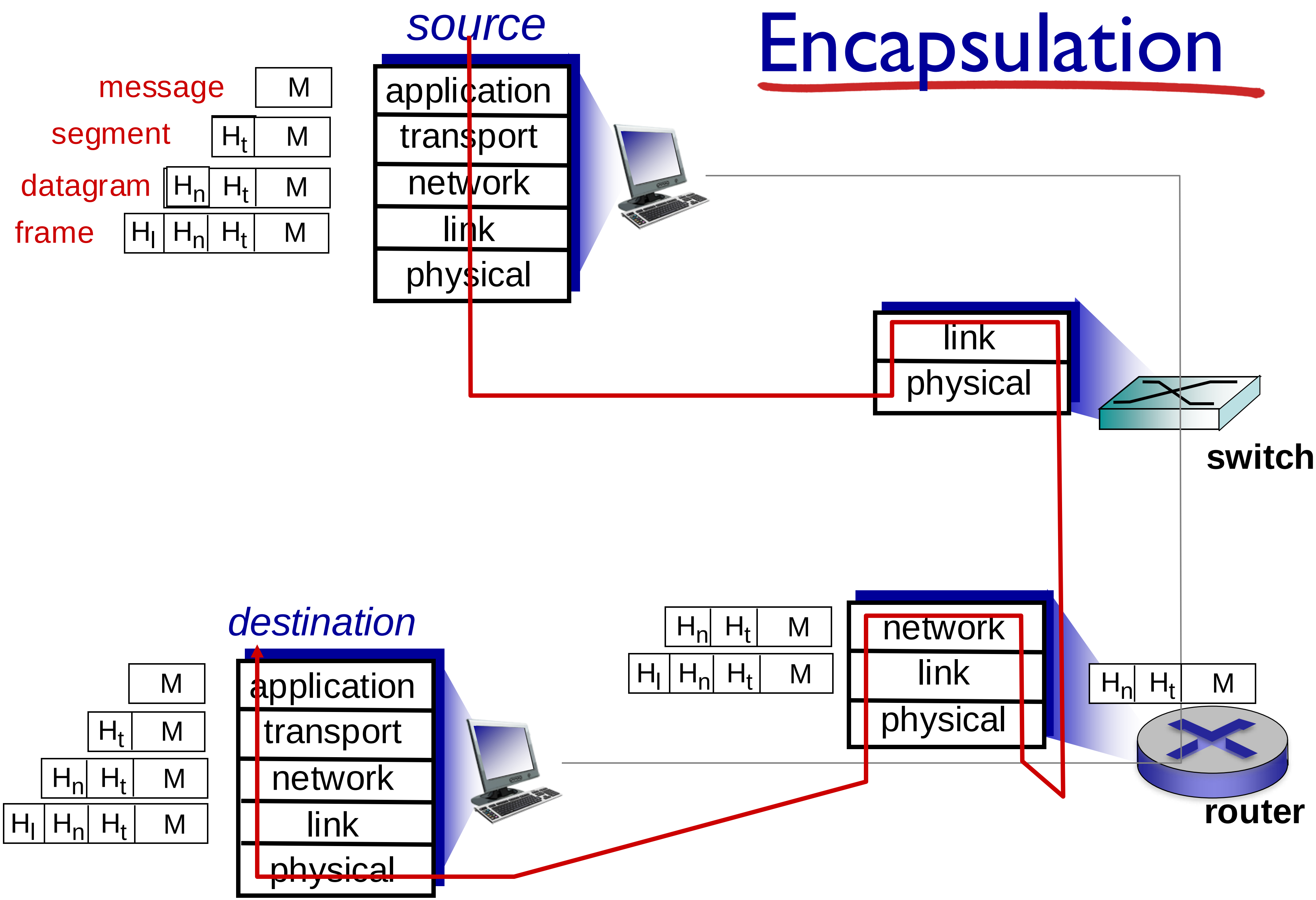


# ISO/OSI reference model

- *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



# Encapsulation



# T01: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

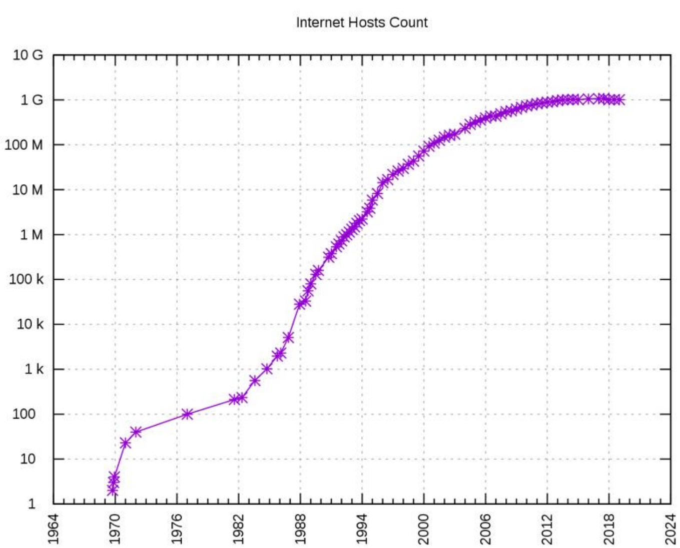
1.4 delay, loss, throughput in networks

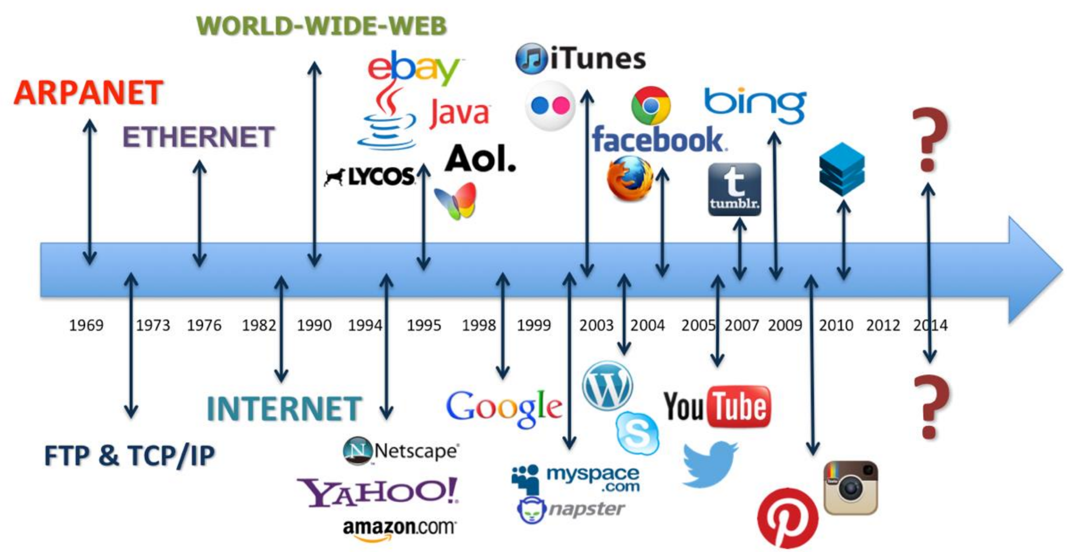
1.5 protocol layers, service models

1.6 history

# Internet history

- 1961-1972: Early packet-switching principles
- 1972-1980: Internetworking, new and proprietary nets
- 1980-1990: new protocols, a proliferation of networks
- 1990, 2000's: commercialization, the Web, new apps
- 2005 to present: ubiquity of high-speed Internet access, social networks and service providers



# T01: Summary

*covered a "ton" of material!*

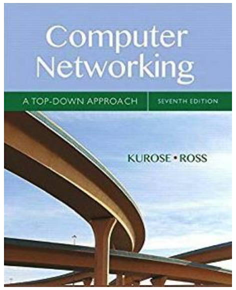
- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- layering, service models
- a little bit of history

*you now have:*

- context, overview, "feel" of networking
- more depth, detail *to follow!*

# T01: Bibliography

J. Kurose and K. Ross, “Computer Networking – a top-down approach”, Pearson. Chapter 1: Computer Networks and the Internet



# Redes de Comunicação 2024/2025

# T01 Computer Networks and the Internet Extra material

Jorge Granjal
University of Coimbra

UNIVERSIDADE D COIMBRA

# T01: Data Centers

- Most servers reside in large data centers
- Estimated total of 2.5 million servers

[Google Data Center Locations]

[Google Data Center 360 Tour]

# T01: Submarine Cables

- Most data traffic crossing oceans is transmitted via submarine cables
- Over 420 submarine cables, with a total of over 1.1 million km

[Submarine Cable Map]

[Inside the installation of new undersea transatlantic cable]