Basics of Computer Networks & Internet

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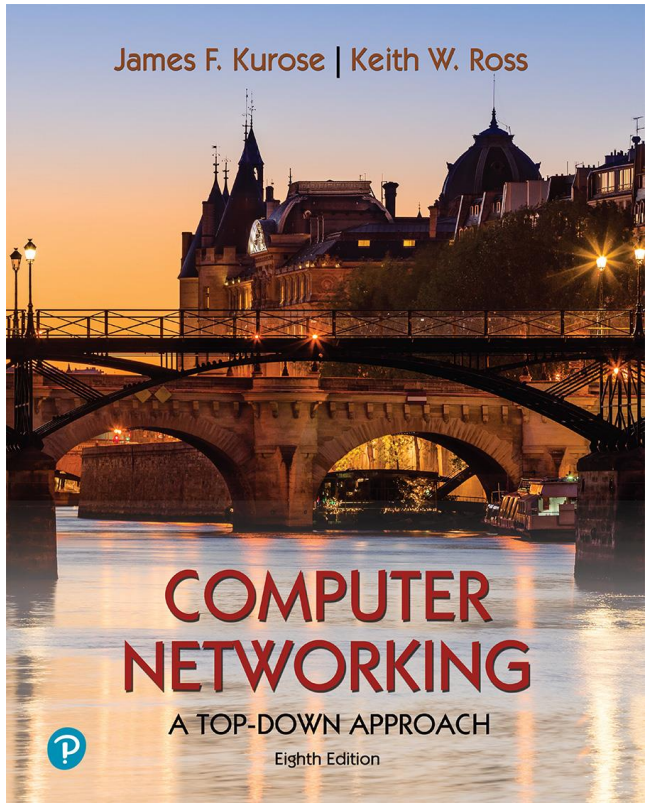


Computer Networking: A Top-Down Approach
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Outline

- What is a computer network?
- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Network Performance: loss, delay, throughput, etc
- Protocol layers, architecture, service models

Computer Networks

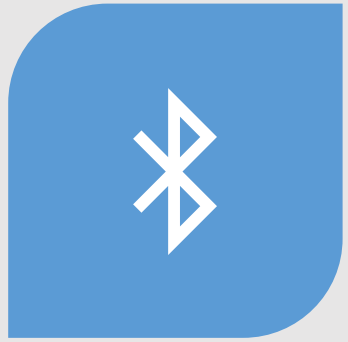
- What is a computer network?
- Other types of networks?
- How is a computer network different from other types of networks?

Computer Network Types

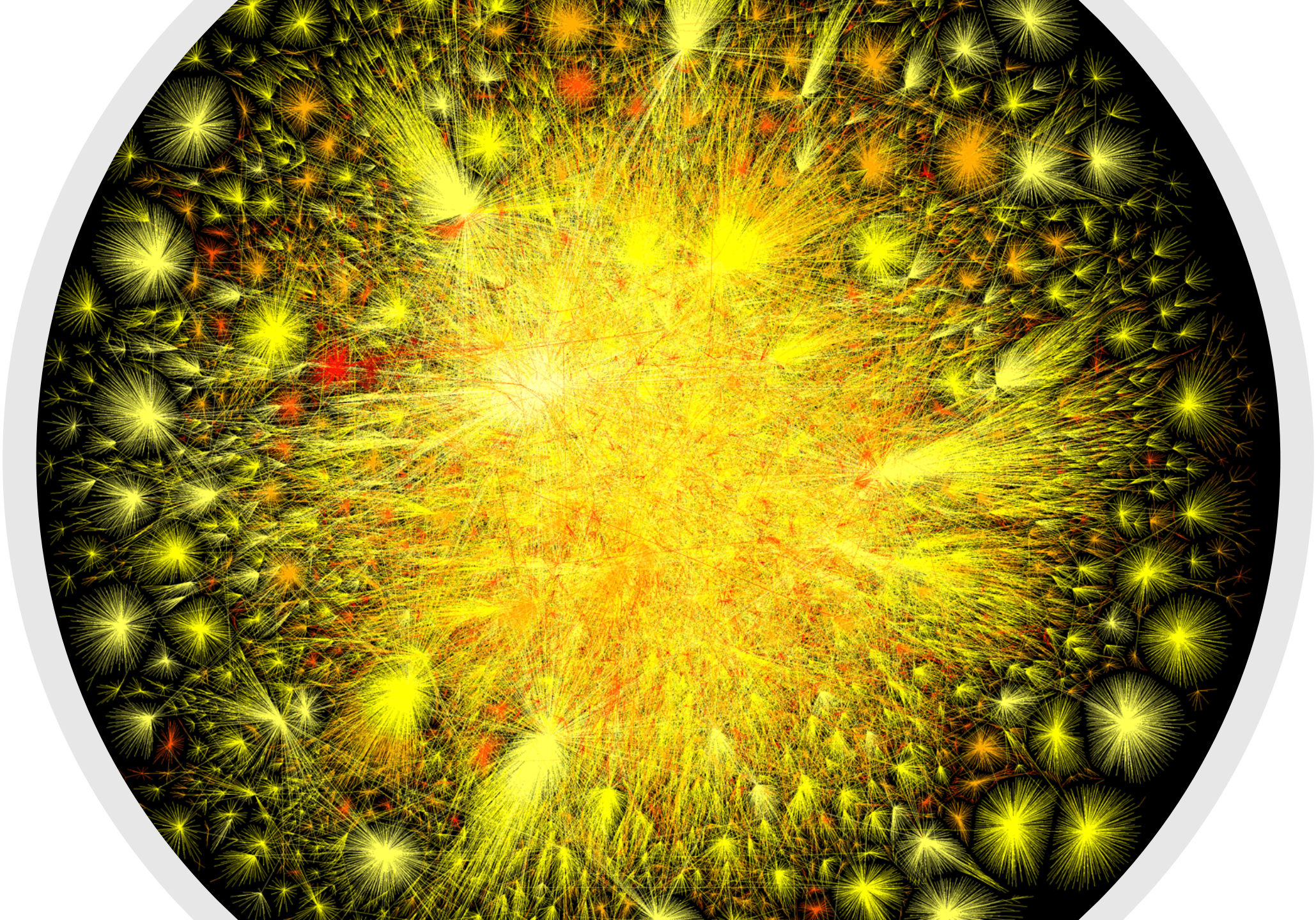
LOCAL AREA NETWORK: ETHERNET

WIRELESS LAN (WLAN): WI-FI

WIDE AREA NETWORK (WAN): 4G/5G, INTERNET



PERSONAL AREA NETWORK (PAN): BLUETOOTH



THE INTERNET☺

The Internet: a "nuts and bolts" view

Billions of connected computing *devices*:

- *hosts = end systems*
- running *network apps* at Internet's "edge"

Packet switches: forward packets (chunks of data)

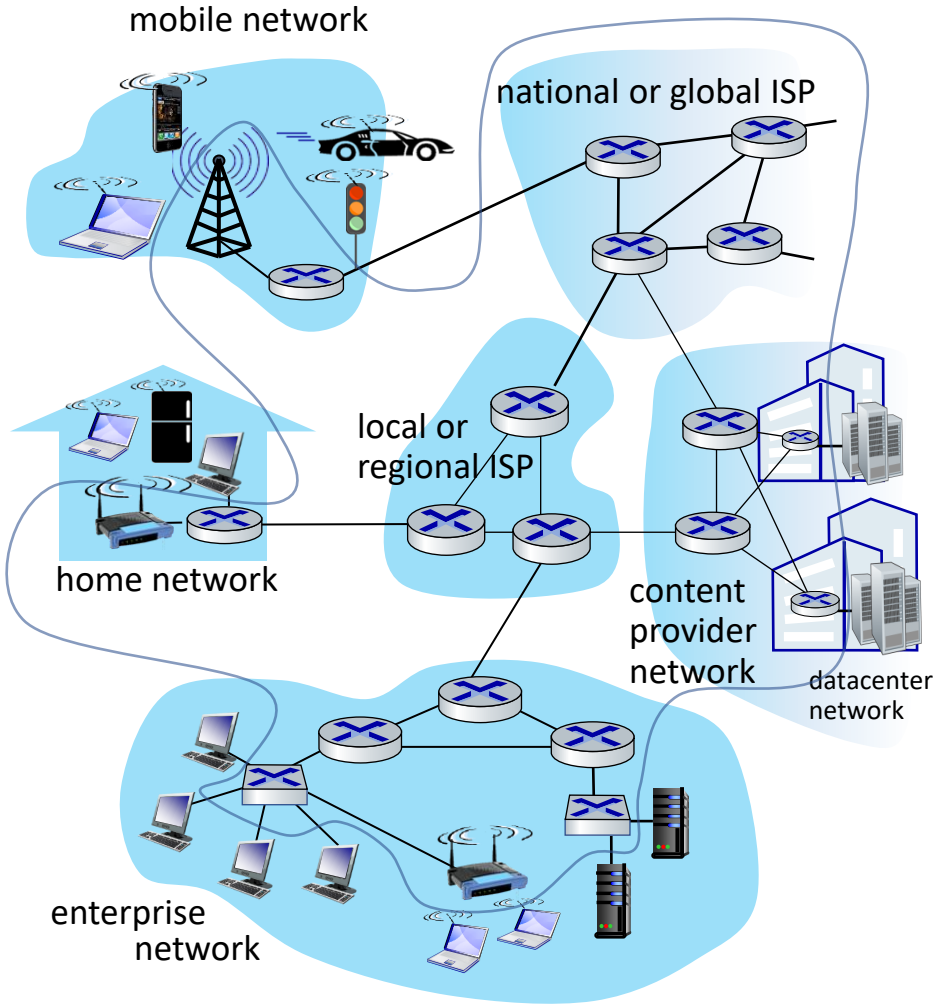
- *routers, switches*

Communication links

- fiber, copper, radio, satellite
- transmission rate: *bandwidth*

Networks

- collection of devices, routers, links: managed by an organization



“Fun” Internet-connected devices

Amazon Echo

Internet refrigerator

IP picture frame

Pacemaker & Monitor

Tweet-a-watt: monitor energy use

bikes

cars

Security Camera

Slingbox: remote control cable TV

Web-enabled toaster + weather forecaster

AR devices

Fitbit

scooters

Internet phones

Gaming devices

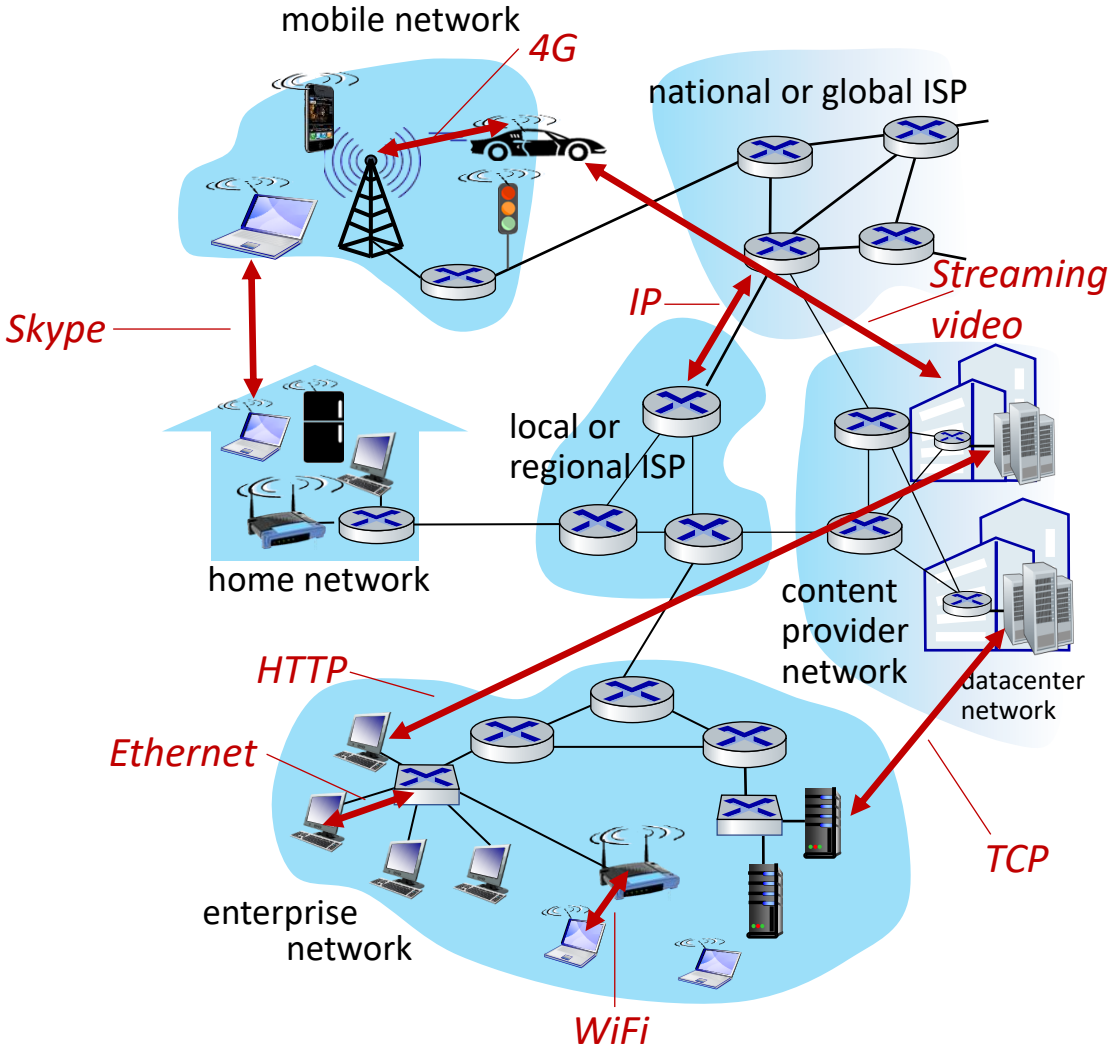
sensorized, bed mattress

diapers

Others?

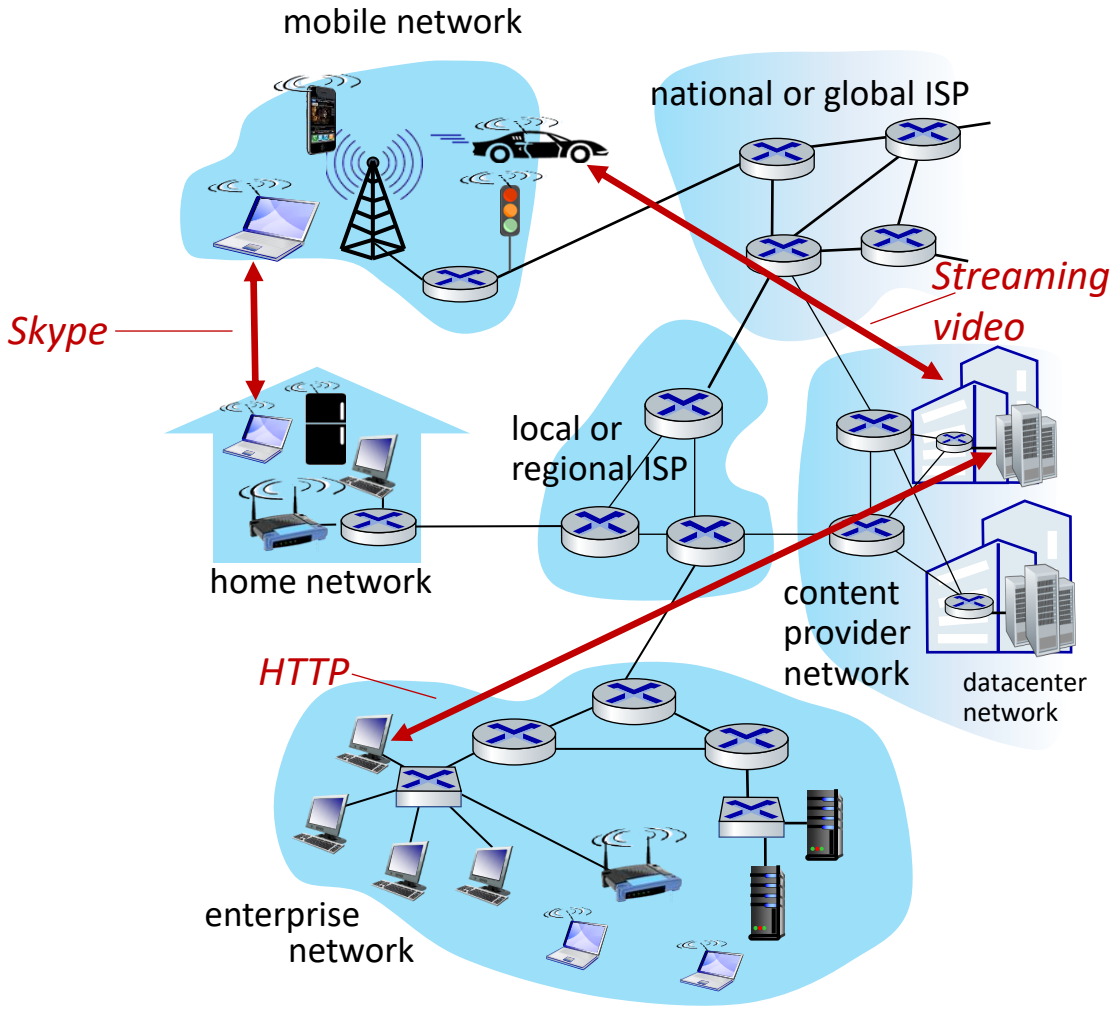
The Internet: a "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
- *protocols* are *everywhere*
  - control sending, receiving of messages
  - e.g., HTTP (Web), Streaming video, Skype, TCP, IP, WiFi, 4/5G, Ethernet
- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force



The Internet: a "services" view

- *Infrastructure* that provides services to applications:
  - Web, streaming video, multimedia teleconferencing, email, games, e-commerce, social media, inter-connected appliances, …
- provides *programming interface* to distributed applications:
  - "hooks" allowing sending/receiving apps to "connect" to, use Internet transport service
  - provides service options, analogous to postal service



What's a protocol?

Human protocols:

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

Rules for:

… specific messages sent

… specific actions taken when message received, or other events

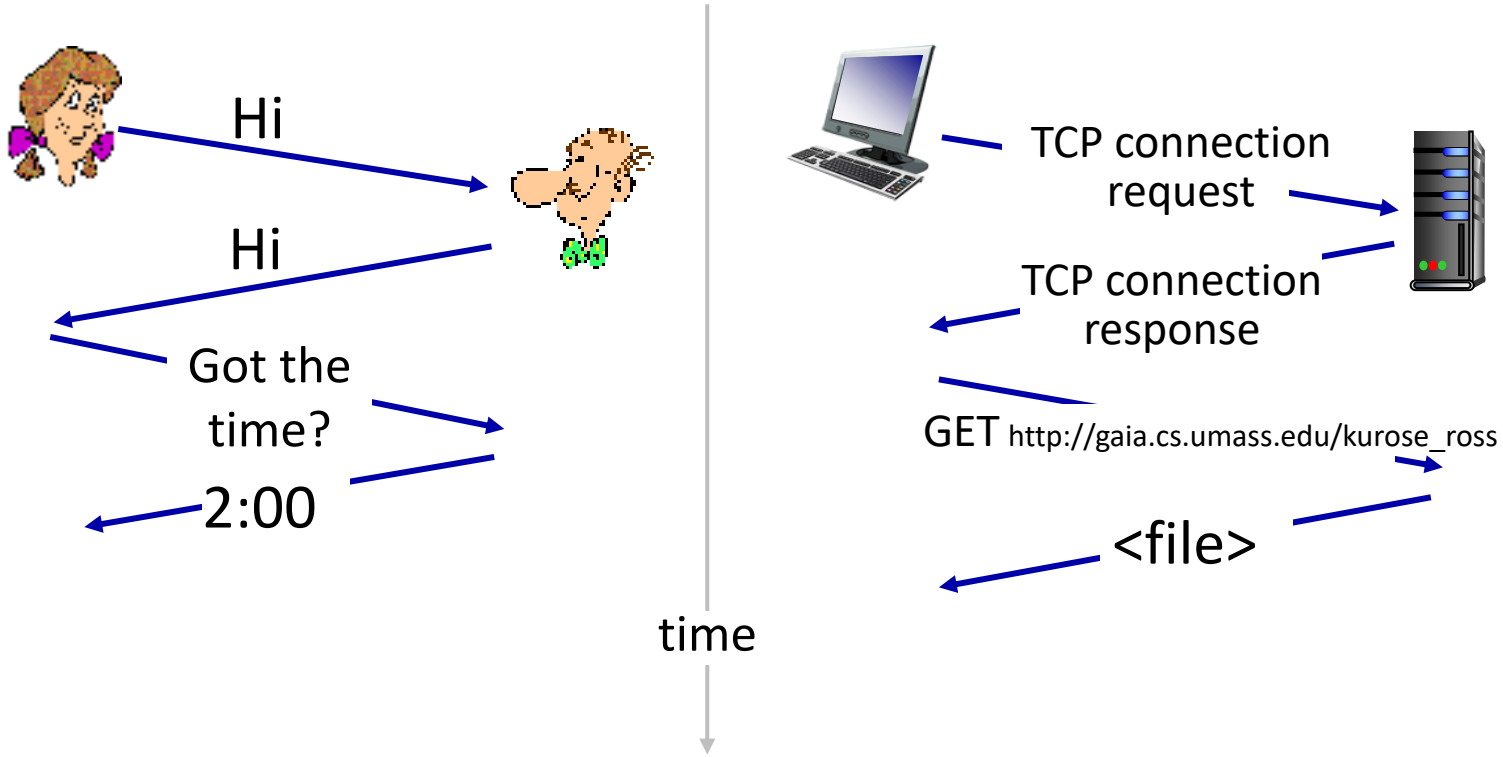
Network protocols:

- computers (devices) rather than humans
- all communication activity in Internet governed by protocols

Protocols define the 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:



Q: other human protocols?

Network Communication Protocols

- TCP (transmission control protocol)
- UDP (user data protocol)
- IP (internet protocol)
- HTTP (hypertext transfer protocol)
- SMTP (simple mail transfer protocol)
- FTP (file transfer protocol)
- 802.3 (Ethernet) Protocol
- 802.11 (Wi-Fi) Protocol

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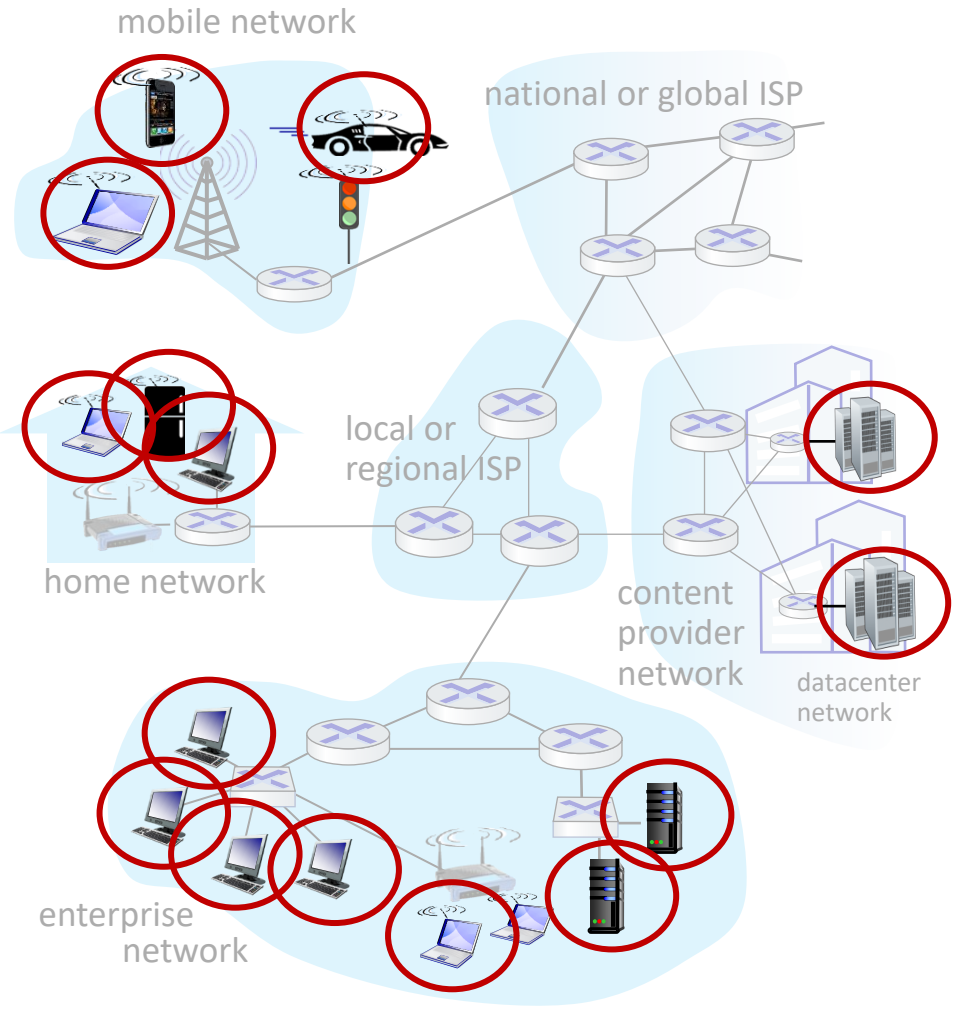
A closer look at Internet structure

Network edge:

- hosts: clients and servers
- servers often in data centers



A closer look at Internet structure

Network edge:

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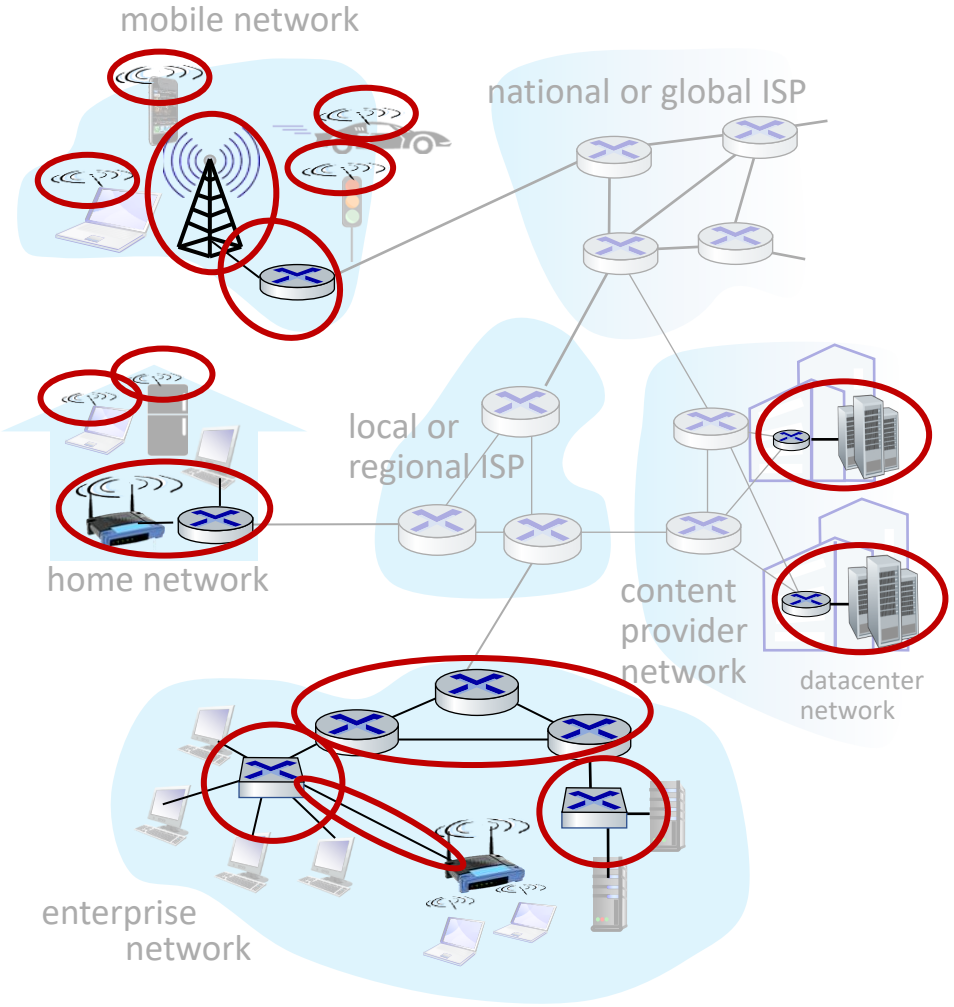
Access networks, physical media:

- wired, wireless communication links



A closer look at Internet structure

Network edge:

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Access networks, physical media:

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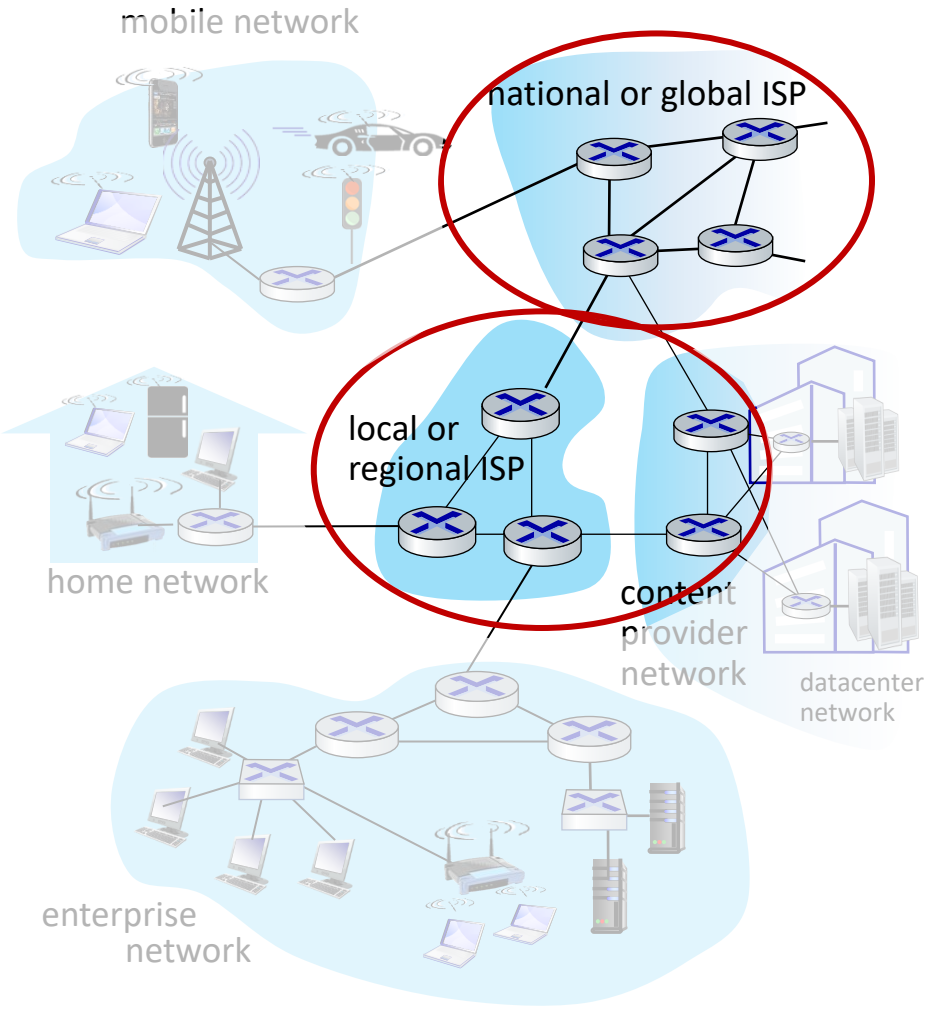
Network core:

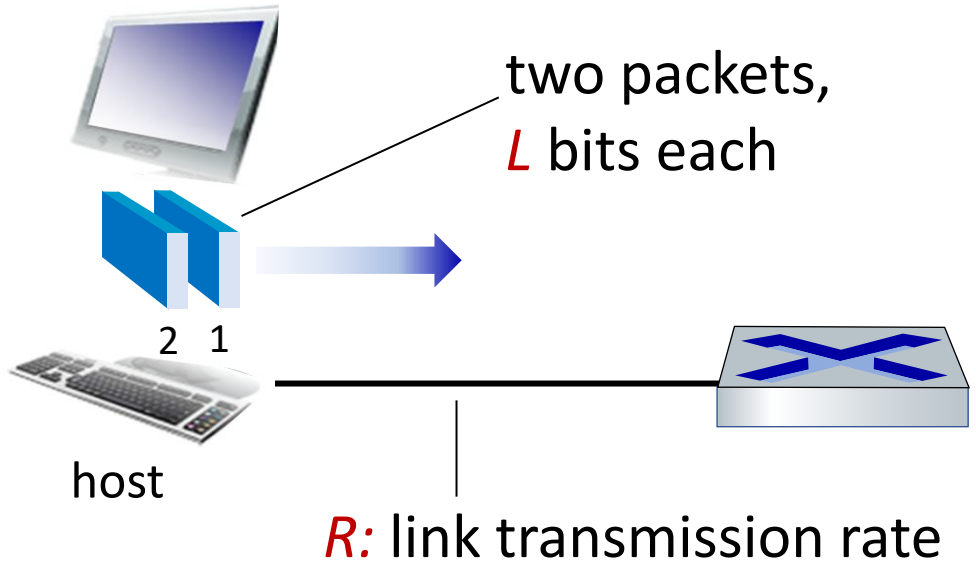
- interconnected routers
- network of networks



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*



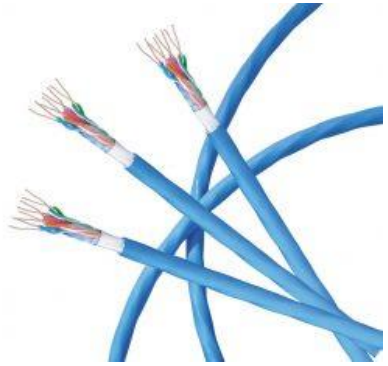
$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Links: physical media

- bits: propagate between transmitter/receiver pairs using electromagnetic waves or light pulses
- physical link/media: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio channels

Twisted pair (TP)

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



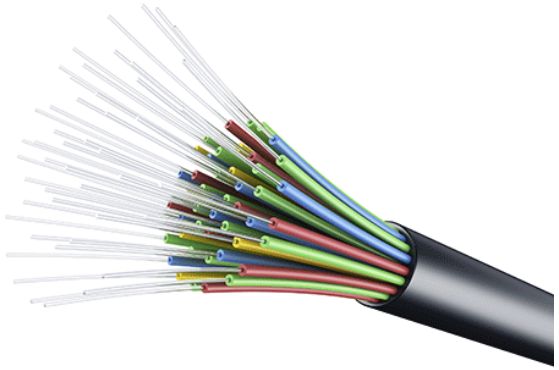
Links: physical media

Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100's Mbps per channel

Fiber optic cable:

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



Links: physical media

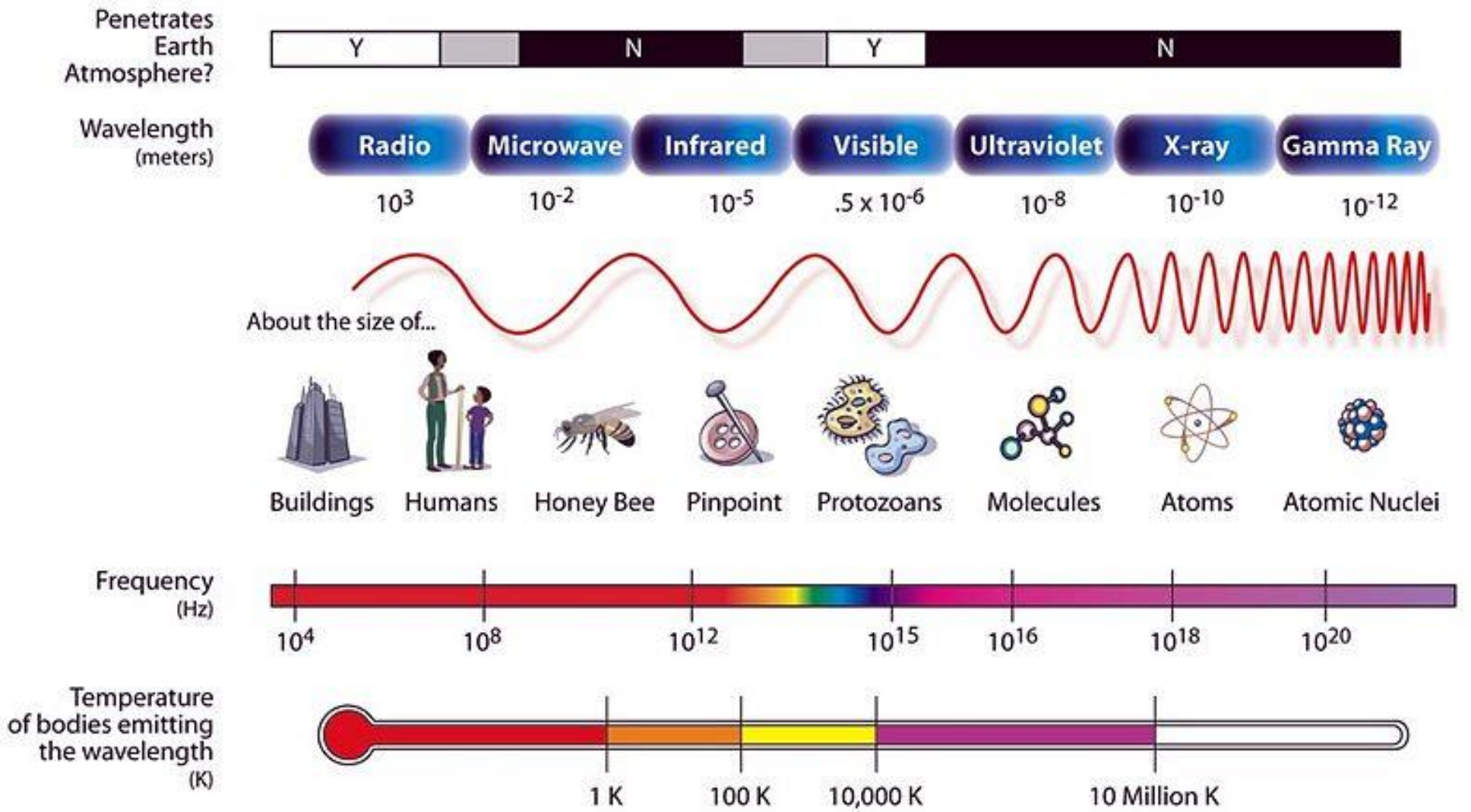
Wireless radio

- signal carried in various "bands" in electromagnetic spectrum
- no physical "wire"
- broadcast, "half-duplex" (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - Interference/noise

Radio link types:

- Wireless LAN (WiFi)
  - 10-100's Mbps; 10's of meters
- wide-area (e.g., 4G/5G cellular)
  - 10's Mbps (4G) over ~10 Km
- Bluetooth: cable replacement
  - short distances, limited rates
- terrestrial microwave
  - point-to-point; 45 Mbps channels
- satellite
  - up to < 100 Mbps (Starlink) downlink
  - 270 msec end-end delay (geostationary)

THE ELECTROMAGNETIC SPECTRUM



Source:NASA

Radio waves

- One type of EM waves
- 30 Hz to 300 GHz
- 1-30 GHz also called as Microwaves
- 30-300 GHz also called as Millimeter waves
  - Unused, abundant, main candidate spectrum for 5G operations

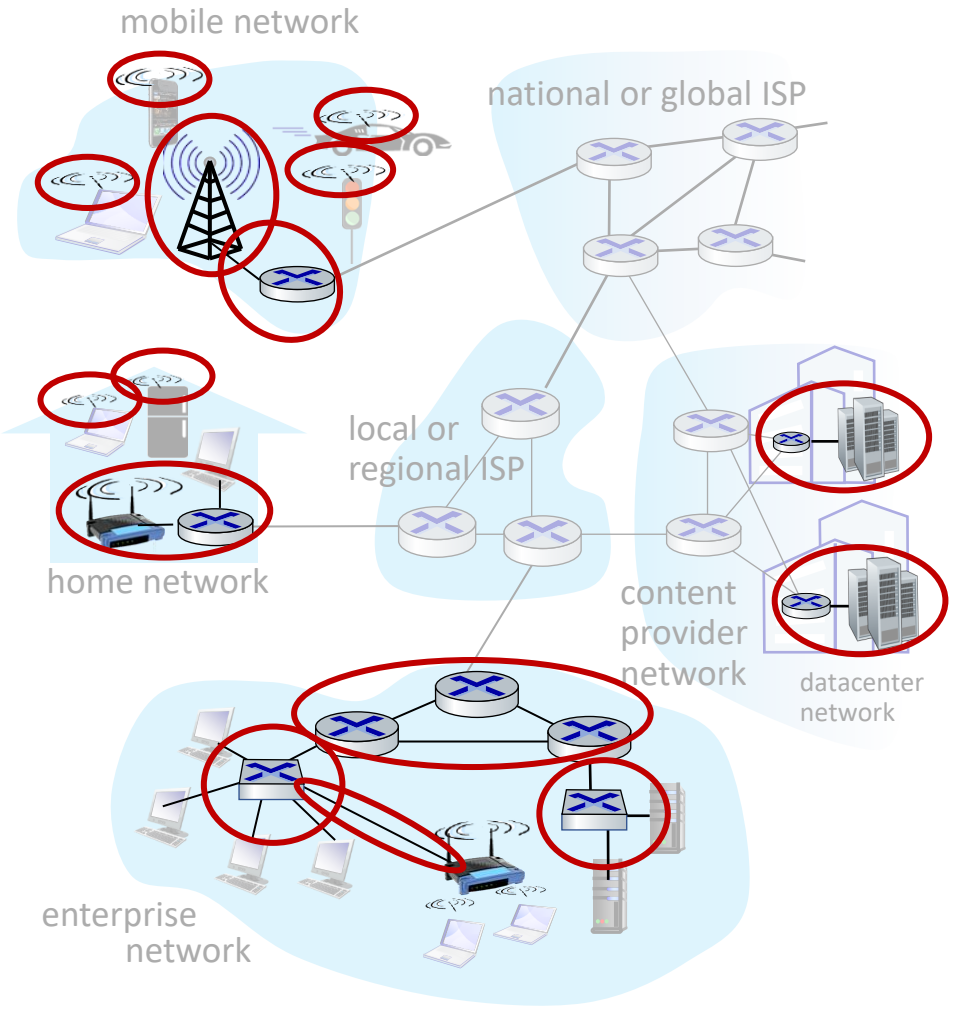
Band	Frequency range	Wavelength range
Extremely Low Frequency (ELF)	<3 kHz	>100 km
Very Low Frequency (VLF)	3 to 30 kHz	10 to 100 km
Low Frequency (LF)	30 to 300 kHz	1 m to 10 km
Medium Frequency (MF)	300 kHz to 3 MHz	100 m to 1 km
High Frequency (HF)	3 to 30 MHz	10 to 100 m
Very High Frequency (VHF)	30 to 300 MHz	1 to 10 m
Ultra High Frequency (UHF)	300 MHz to 3 GHz	10 cm to 1 m
Super High Frequency (SHF)	3 to 30 GHz	1 to 10 cm
Extremely High Frequency (EHF)	30 to 300 GHz	1 mm to 1 cm

http://www.astrosurf.com/luxorion/qsl-propa.htm

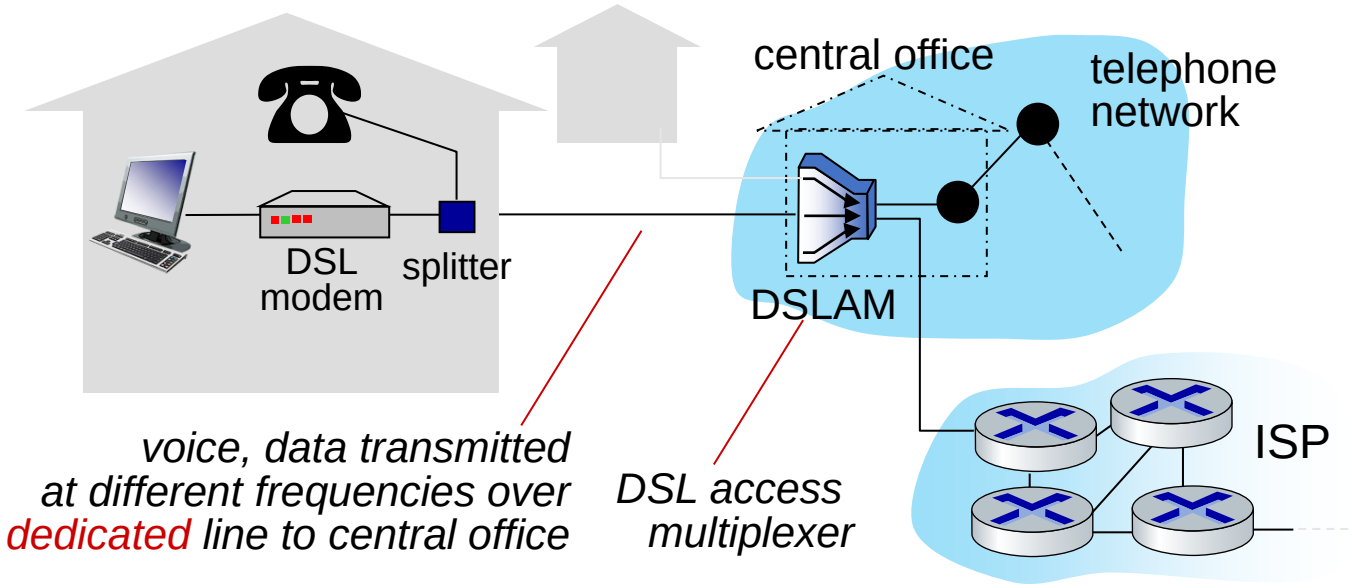
Access networks and physical media

Q: How to connect end systems to edge router?

- residential access networks
- enterprise access networks (school, company)
- wireless access networks (WiFi, 4G/5G)

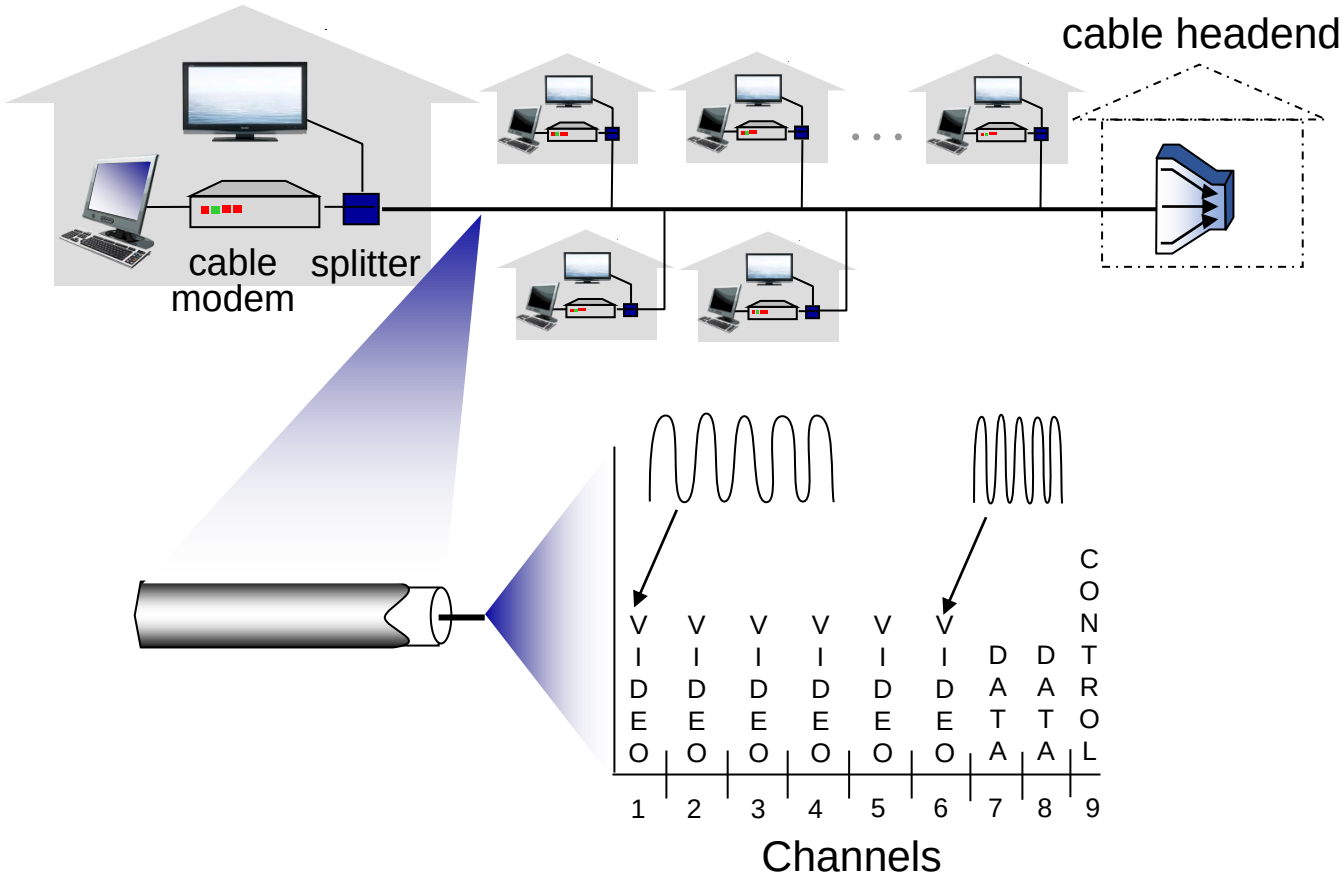


Access networks: digital subscriber line (DSL)



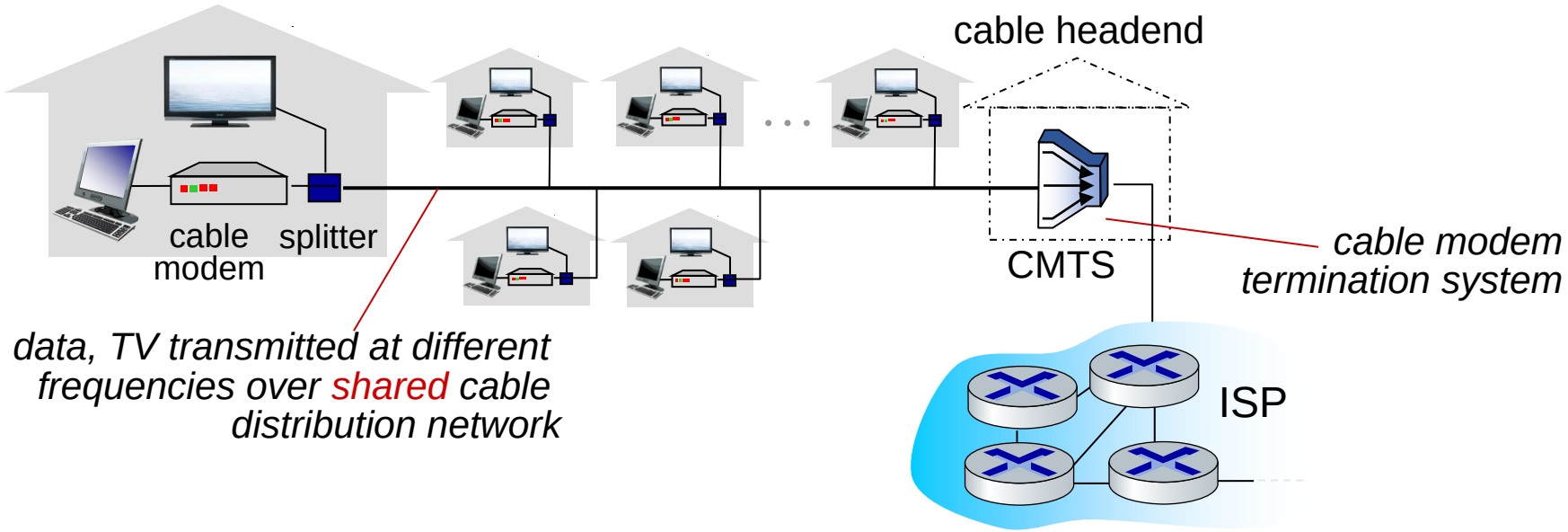
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

Access networks: cable-based access



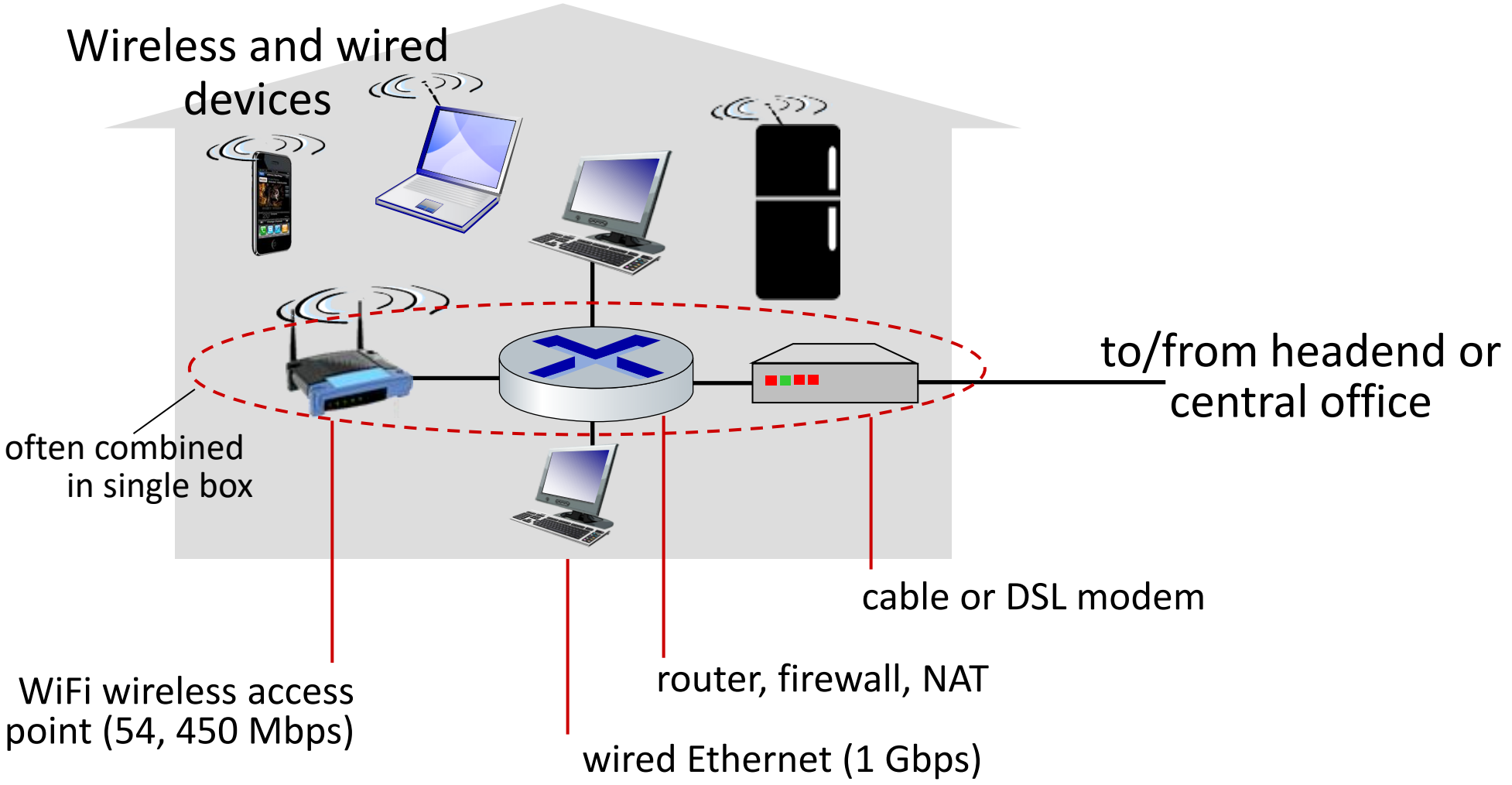
frequency division multiplexing (FDM): different TV channels & data transmitted in different frequency bands on the shared coaxial cable

Access networks: cable-based access

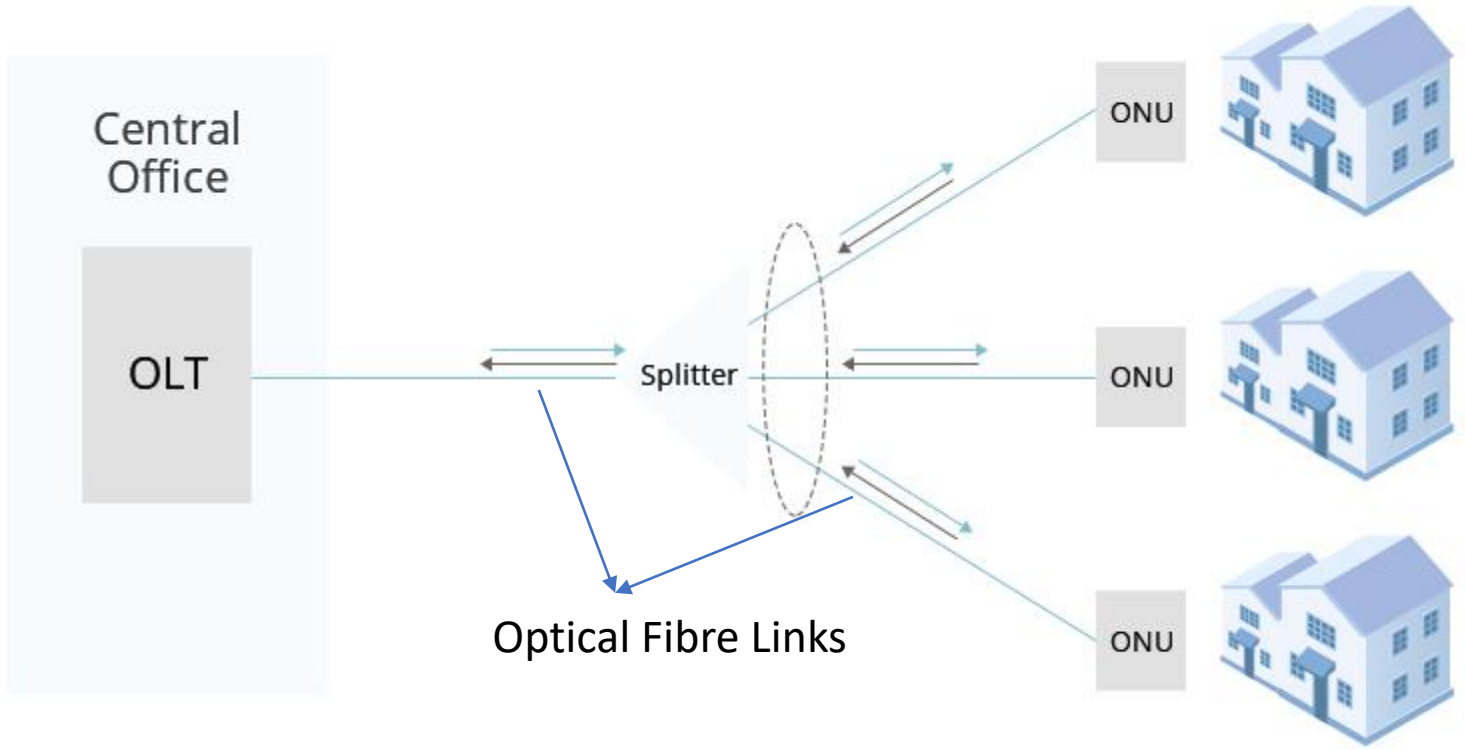


- HFC: hybrid fiber coax
  - asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend

Access networks in homes: Wi-Fi/Ethernet



Access networks in homes: FTTH

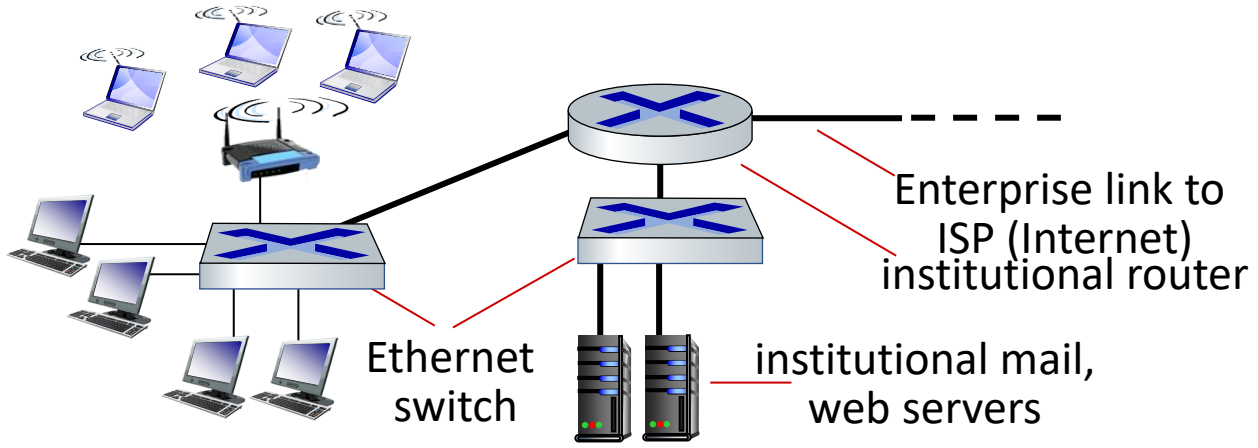


FTTH: Fibre To The Home
OLT: Optical Line Terminal
ONU (ONT): Optical Network Unit/Terminal


Jio
Fiber
Wireless-G
Ethernet
Power
DMZ
WLAN
1
2
3
4
Internet
Wireless-G
Broadband Router


WPS
RESET

Access networks in enterprises



- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
  - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
  - WiFi: wireless access points at 11, 54, 450 Mbps

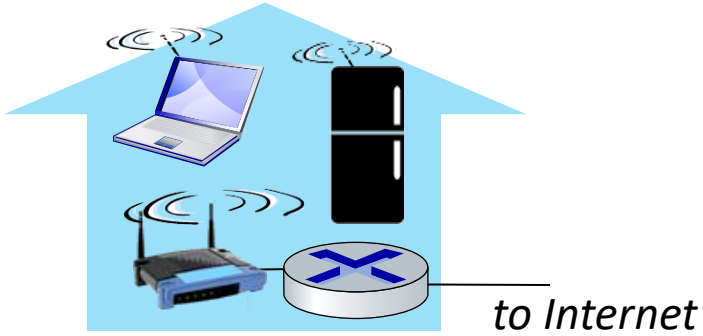
Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka “access point”

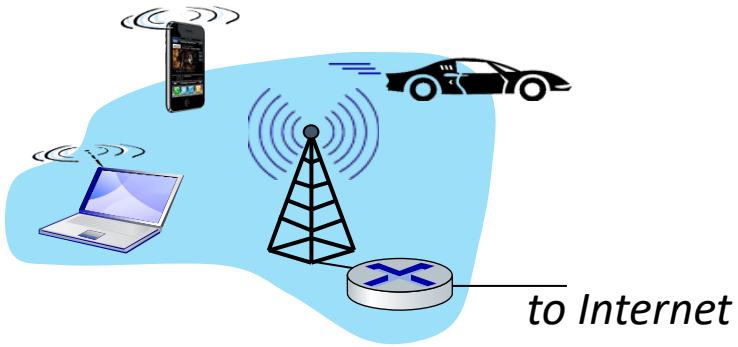
Wireless local area networks (WLANs)

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



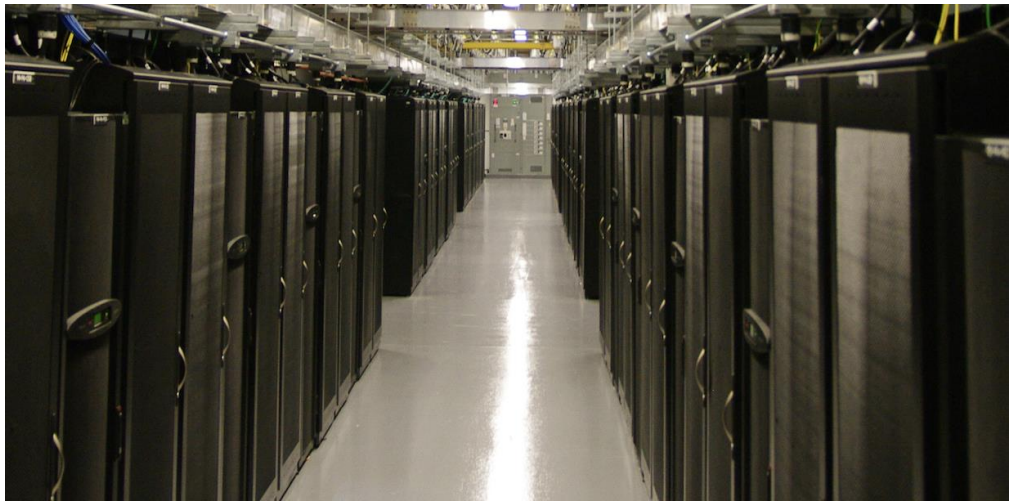
Wide-area cellular access networks

- provided by mobile, cellular network operator (10’s km)
- 10’s Mbps
- 4G/5G cellular networks

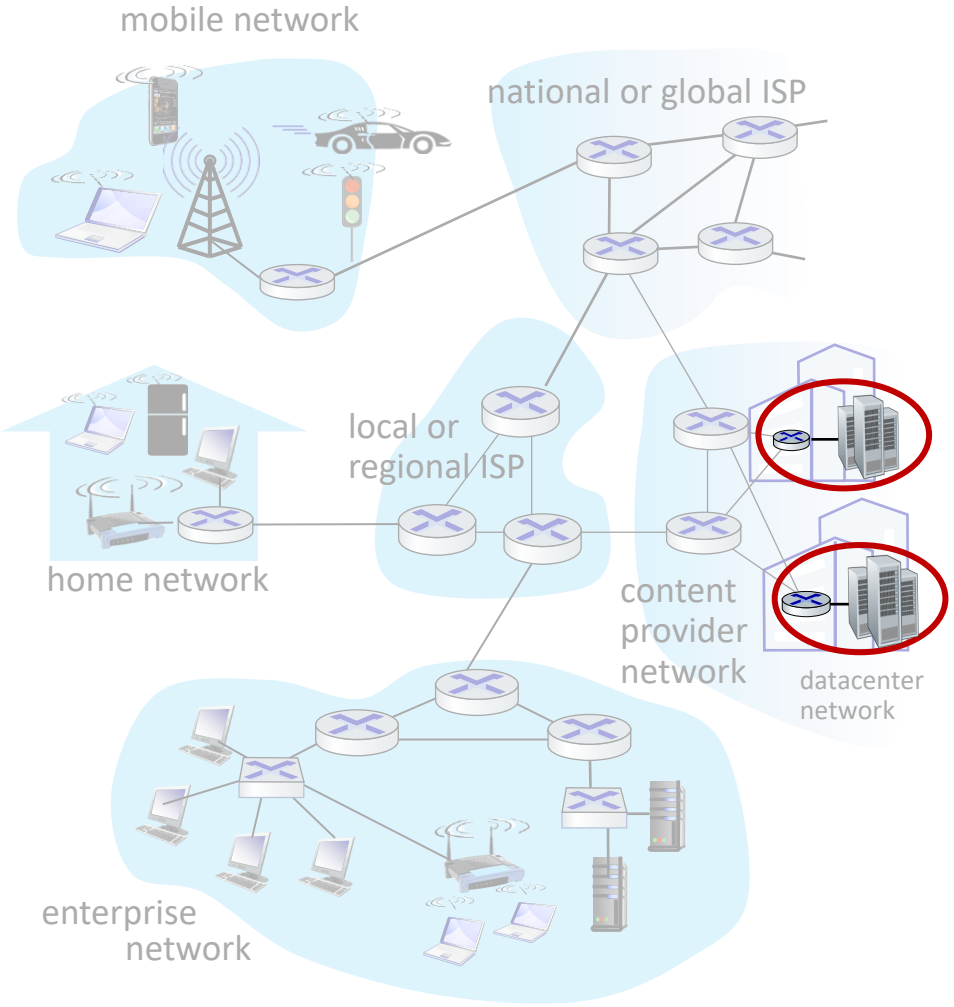


Access networks in data centers

- high-bandwidth links (10s to 100s Gbps) connect hundreds to thousands of servers together, and to Internet



Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)



Next Lecture: Outline

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- Network Performance: loss, delay, throughput, etc
- Protocol layers, service models

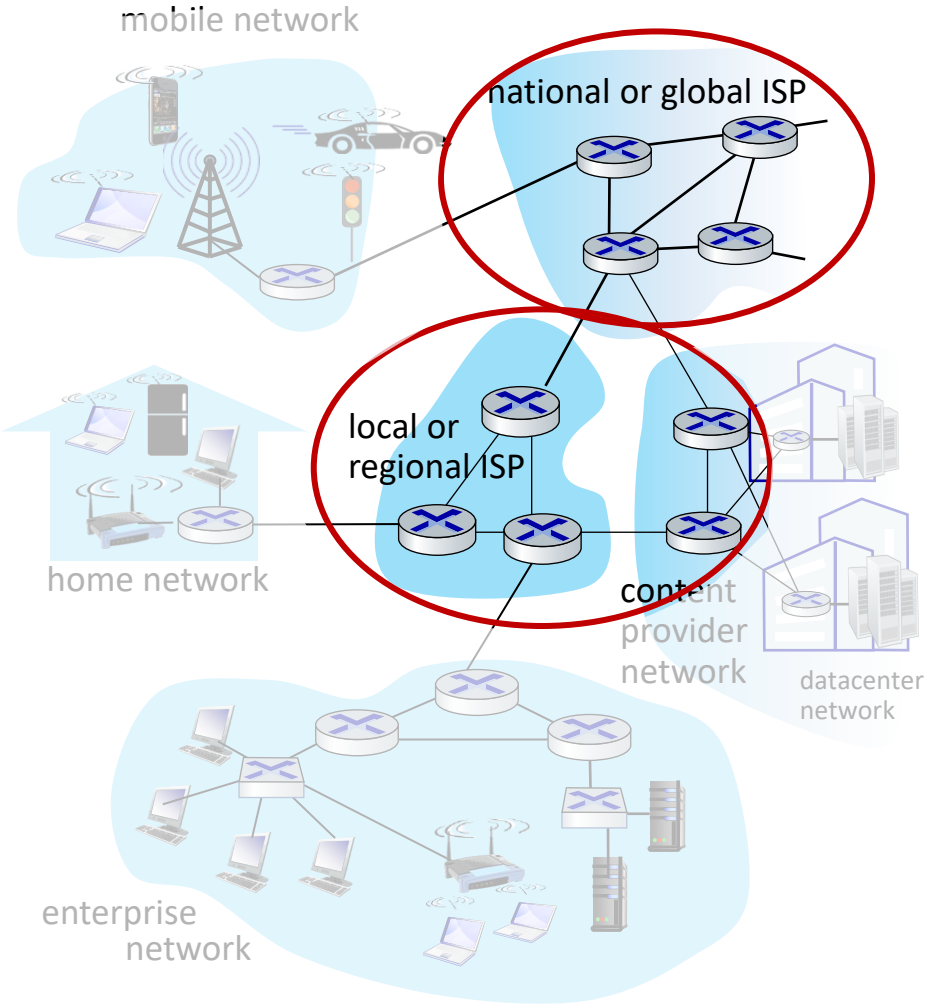
Readings

- Chapter 1.1 & 1.2 of Computer Networking: A Top-Down Approach **by James F. Kurose and Keith W. Ross**, 8th Edition, 2020, Addison Wesley (Pearson Education)
  - https://gaia.cs.umass.edu/kurose_ross/videos/1/

- https://cse.iith.ac.in/academics/plagiarism-policy.html

The network core

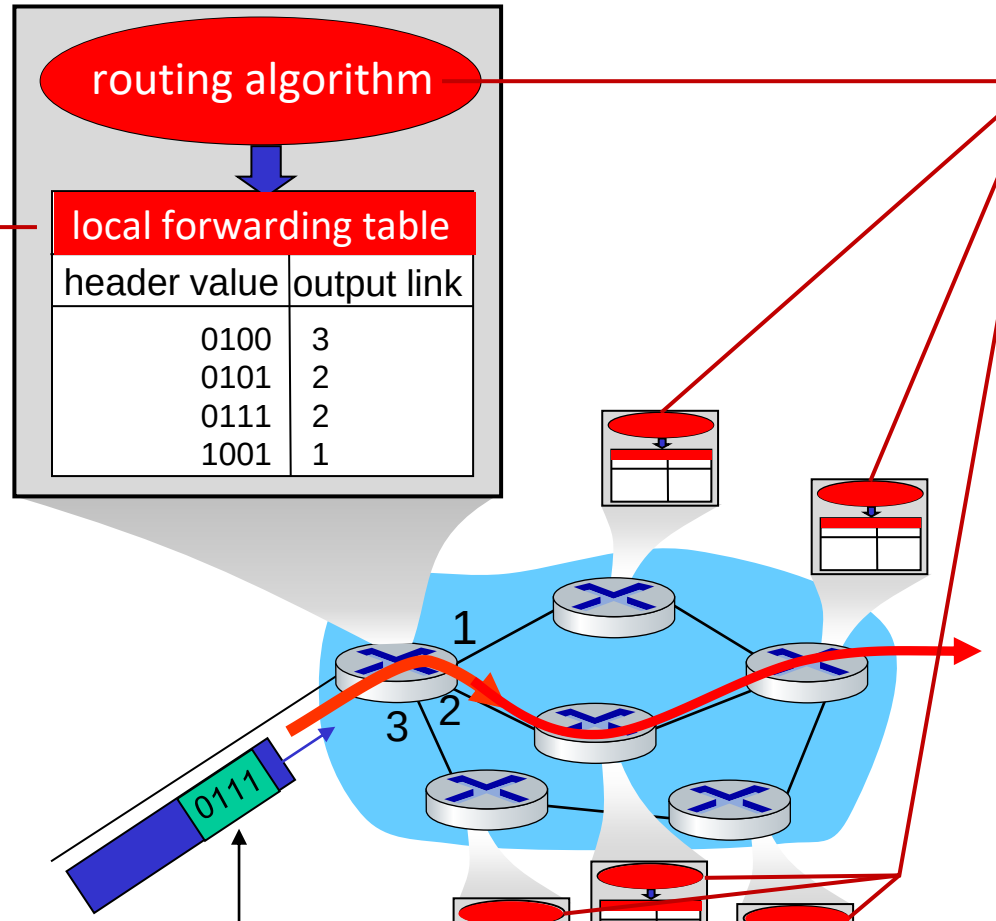
- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
  - network forwards packets from one router to the next, across links on path from source to destination



Two key network-core functions

Forwarding:

- aka "switching"
- *local* action: move arriving packets from router's input link to appropriate router output link



Routing:

- *global* action: determine source-destination paths taken by packets
- routing algorithms


routing
45 h
3,053 miles
48 h
3,309 miles
Victoria
Seattle
WASHINGTON
Portland
OREGON
IDAHO
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
WYOMING
MINNESOTA
Minneapolis
WISCONSIN
MICHIGAN
Toronto
Quebec City
Montreal
Ottawa
MAINE
VERMONT
NEW HAMPSHIRE
Detroit
Chicago
IOWA
Northampton
CT
RI
PENNSYLVANIA
New York
Philadelphia
NJ
MARYLAND
DE
NEVADA
UTAH
COLORADO
United States
Kansas City
ILLINOIS
INDIANA
Indianapolis
OHIO
WEST VIRGINIA
VIRGINIA
KENTUCKY
Sacramento
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Nashville
NORTH CAROLINA
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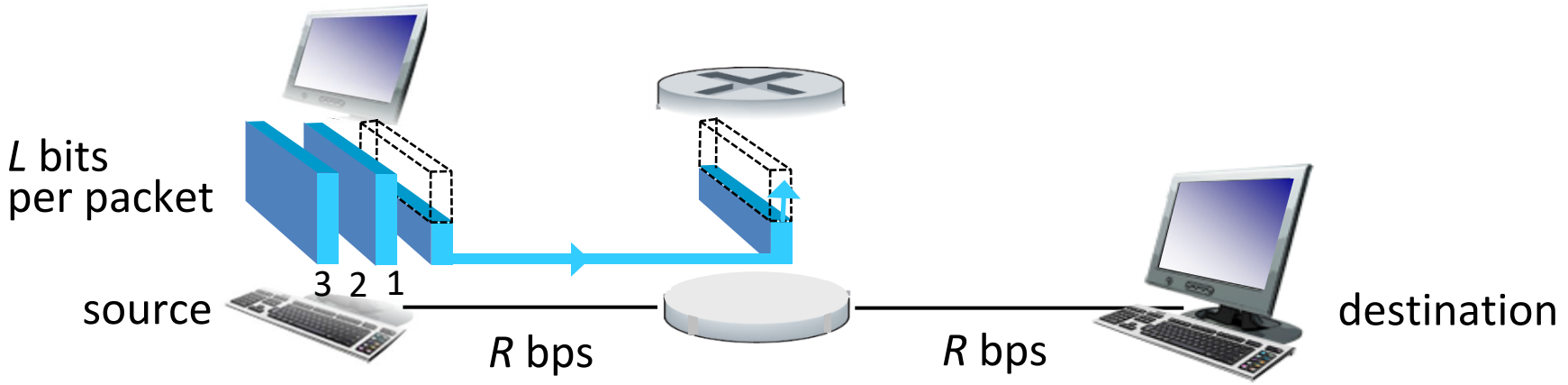
Los Angeles
ARIZONA
NEW MEXICO
Atlanta
SOUTH CAROLINA
MISSISSIPPI
ALABAMA
GEORGIA
San Diego
Phoenix
Dallas
Tucson
El Paso
TEXAS
BAJA CALIFORNIA
SONORA
CHIHUAHUA
Austin
Houston
LOUISIANA
New Orleans
Jacksonville
San Antonio
COAHUILA
Orlando
Tampa
FLORIDA


forwarding
forwarding
45 h
3,053 miles
48 h
3,309 miles
United States
Victoria
Seattle
Portland
WASHINGTON
NORTH DAKOTA
MINNESOTA
SOUTH DAKOTA
Minneapolis
WISCONSIN
MICHIGAN
Toronto
Quebec City
Montreal
Ottawa
MAINE
VERMONT
NEW HAMPSHIRE
Northampton
WYOMING
IOWA
Chicago
Detroit
ILLINOIS
INDIANA
OHIO
Kansas City
Indianapolis
COLORADO
KANSAS
MISSOURI
KENTUCKY
San Francisco
San Jose
CALIFORNIA
Las Vegas
Nashville
TENNESSEE
OKLAHOMA
ARKANSAS
Los Angeles
ARIZONA
NEW MEXICO
Atlanta
MISSISSIPPI
ALABAMA
San Diego
Phoenix
Dallas
Tucson
El Paso
TEXAS
BAJA CALIFORNIA
SONORA
Austin
Houston
LOUISIANA
New Orleans
CHIHUAHUA
San Antonio
COAHUILA
Tampa
FLORIDA
Cleveland
DOWNTOWN
CENTRAL
OHIO CITY

Packet-switching: store-and-forward



- packet transmission delay: L/R seconds
- *store and forward:* *entire* packet must arrive at router before it can be transmitted on next link
- *propagation delay*: Distance/Speed of light

Total one-hop delay?

Total two-hop delay?

One-hop numerical example:

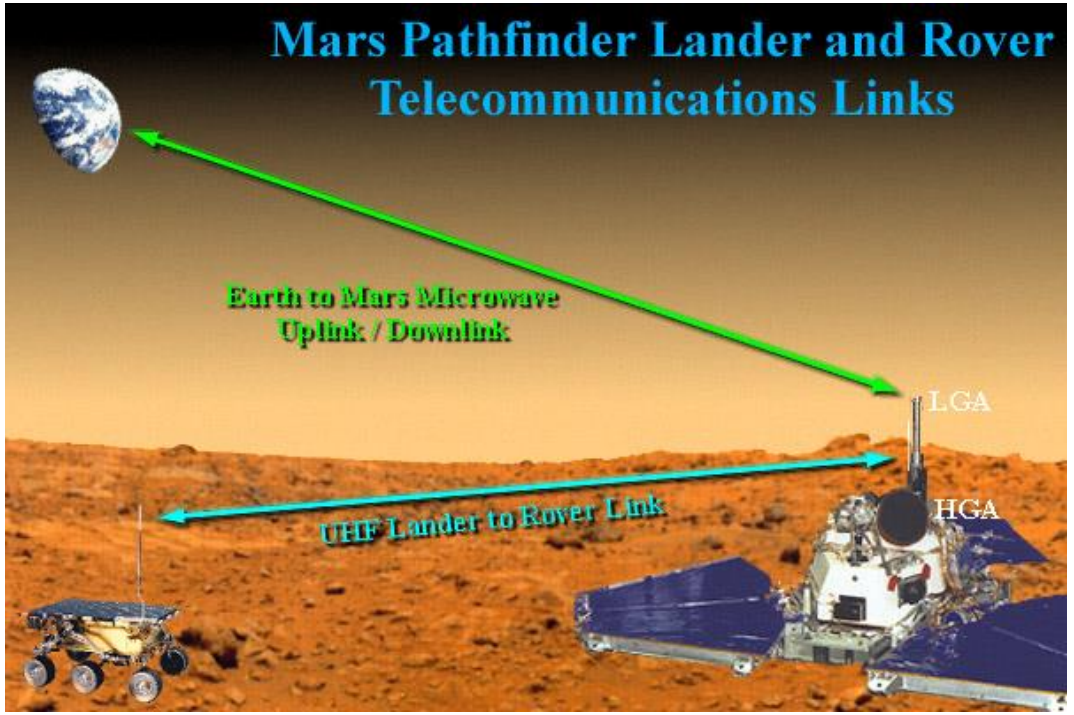
- L = 10 Kbits, D = 300 m
- R = 100 Mbps, S=$3*10^8$ m/s
- one-hop transmission delay = 100 micro-sec
- One-hop propagation delay = 1 micro-sec

Homework (Q1): delay comparison in packet-switching

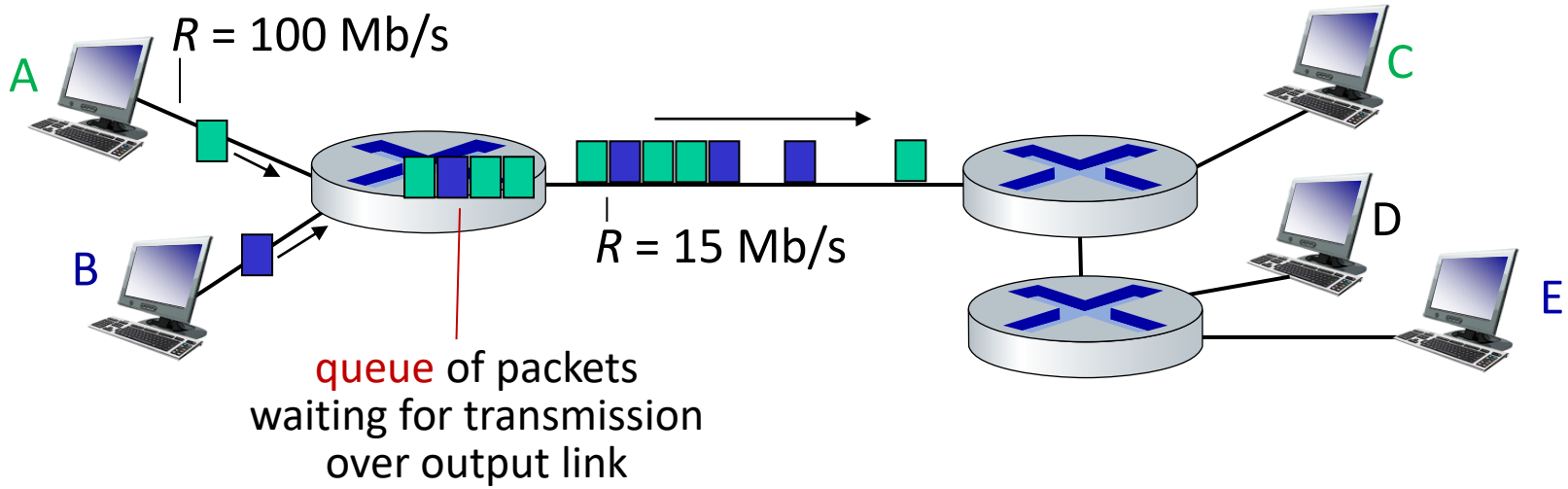
- Packet Size: L bits
- Transmission Rate of links: R bps
- Link length: D meters
- Speed of light: S meters/second
- Total delay incurred in transmitting P packets back-to-back from the source to the destination over N links in case of
  - Store-and-forward switching?
  - Pass-through switching?

Homework (Q2)

- Suppose two hosts, Earth ground station and NASA's Mars Pathfinder, are separated by **250 Million KM** and are connected by a direct point-to-point microwave link of capacity, **R = 1 Mbps**. Suppose the propagation speed of light over the link is **2.5 * 10^8 m/s**. Consider sending a packet of **1MB** from Pathfinder to Earth.
  - How long does it take to receive the packet on Earth's ground station?



Packet-switching: queueing

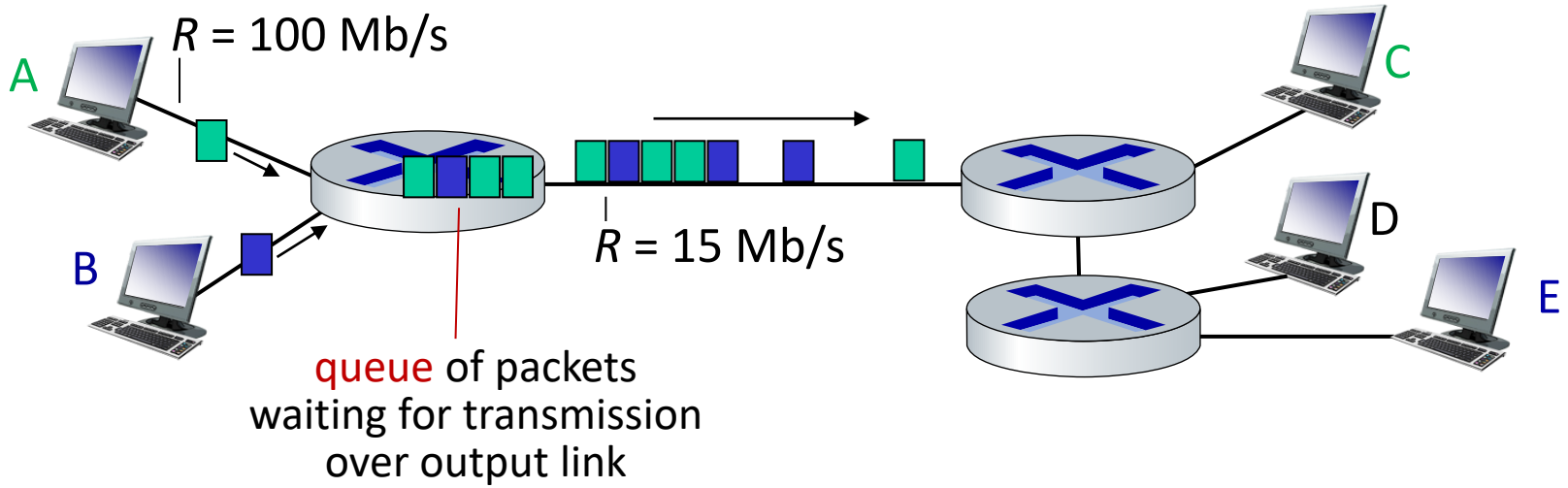


Queueing occurs when work arrives faster than it can be serviced:

Homework

- Task-1: Go through Chapter 1.3 of Computer Networking: A Top-Down Approach **by James F. Kurose and Keith W. Ross**, 8th Edition, 2020, Addison Wesley (Pearson Education)
  - https://gaia.cs.umass.edu/kurose_ross/videos/1/
- Task-2: Do the interactive exercises on circuit-switching at https://gaia.cs.umass.edu/kurose_ross/interactive/circuit_switching.php
- Task-3: Solve Homework problems(Q1 & Q2) in slides 41-42 and post your solutions in Google classroom
- Task-4: Solve Chapter-1 of Kurose and Ross textbook's exercise problems P4, P6 and P7 and post your solutions in Google classroom

Packet-switching: queueing



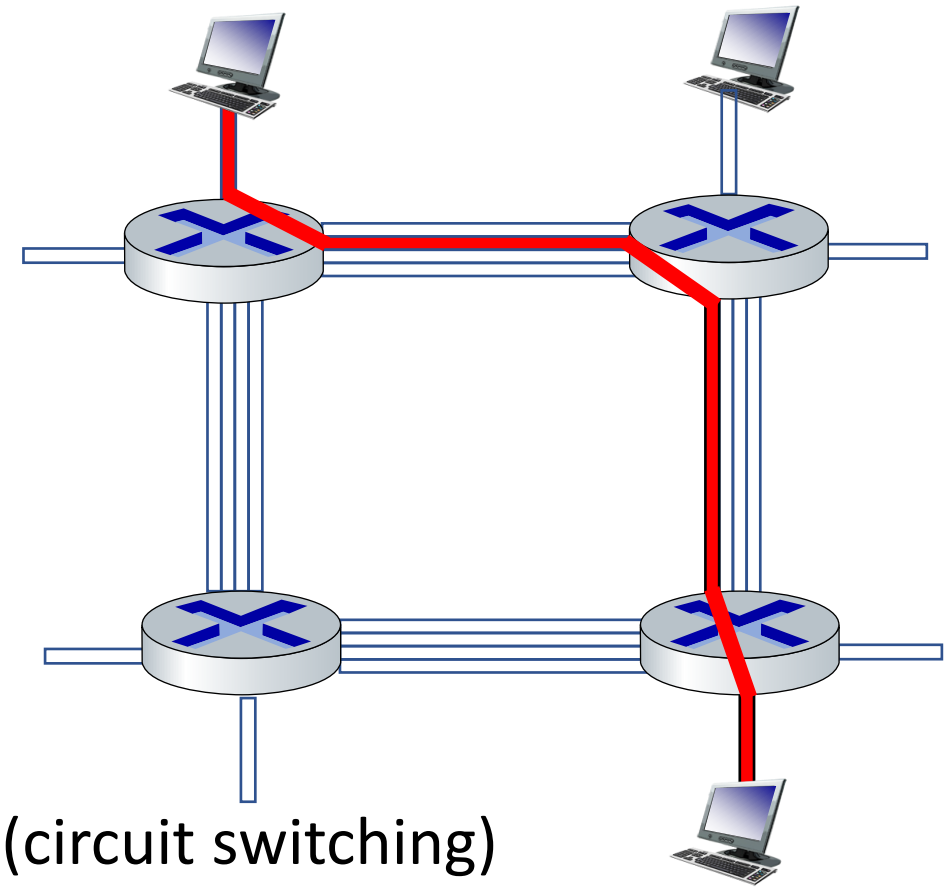
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

Alternative to packet switching: circuit switching

end-to-end resources allocated to, reserved for "call" b/w source & dst

- 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



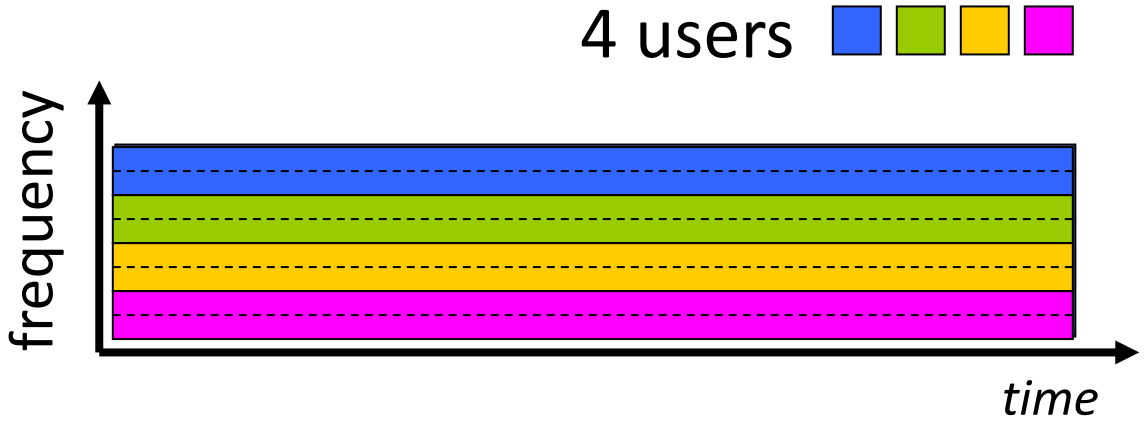
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet switching)?

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive

Circuit switching: FDM and TDM

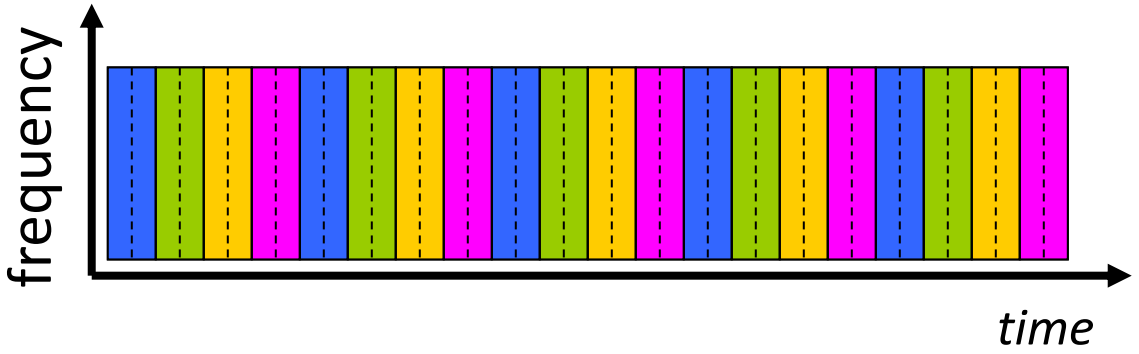
Frequency Division Multiplexing (FDM)

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band



Time Division Multiplexing (TDM)

- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)



Radio waves

- One type of EM waves
- 30 Hz to 300 GHz
- 1-30 GHz also called as Microwaves
- 30-300 GHz also called as Millimeter waves
  - Unused, abundant, main candidate spectrum for 5G operations

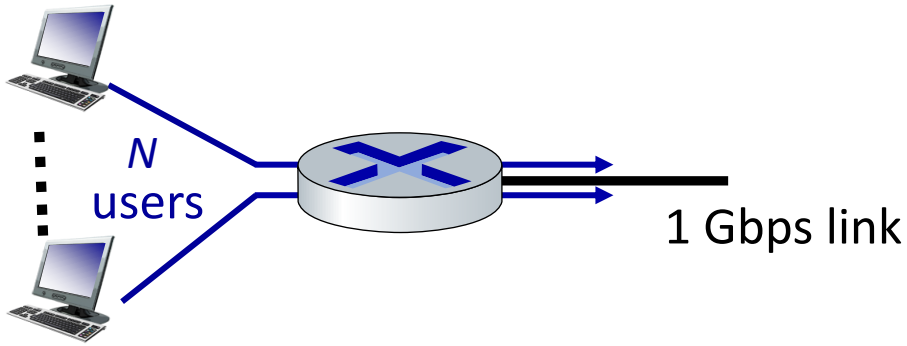
Band	Frequency range	Wavelength range
Extremely Low Frequency (ELF)	<3 kHz	>100 km
Very Low Frequency (VLF)	3 to 30 kHz	10 to 100 km
Low Frequency (LF)	30 to 300 kHz	1 m to 10 km
Medium Frequency (MF)	300 kHz to 3 MHz	100 m to 1 km
High Frequency (HF)	3 to 30 MHz	10 to 100 m
Very High Frequency (VHF)	30 to 300 MHz	1 to 10 m
Ultra High Frequency (UHF)	300 MHz to 3 GHz	10 cm to 1 m
Super High Frequency (SHF)	3 to 30 GHz	1 to 10 cm
Extremely High Frequency (EHF)	30 to 300 GHz	1 mm to 1 cm

http://www.astrosurf.com/luxorion/qsl-propa.htm

Packet switching versus circuit switching

example:

- 1 Gb/s link
- each user:
  - 100 Mb/s when "active"
  - active 10% of time



Q: how many users can use this network under circuit-switching and packet switching?

- *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?

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive
- Online calculator: https://shiny.rit.albany.edu/stat/binomial/

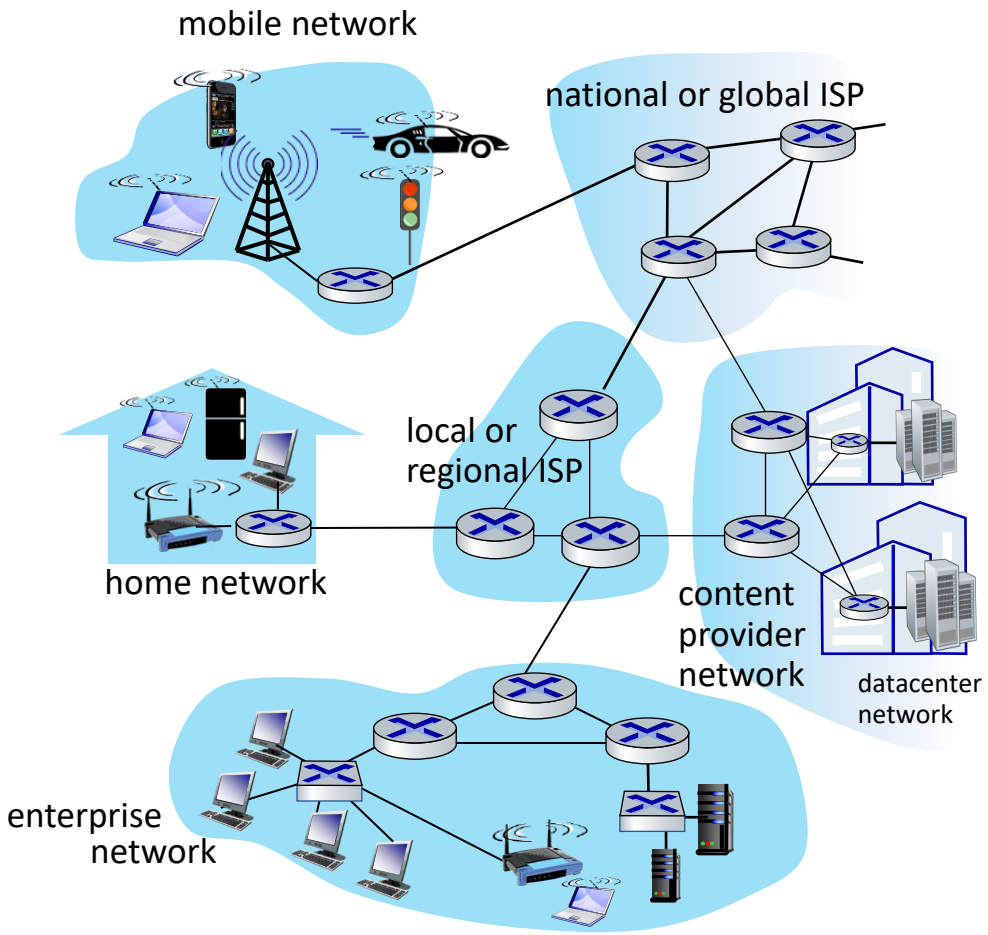
Packet switching versus circuit switching

Is packet switching a “slam dunk winner”?

- great for “bursty” data (which is the case on the Internet) – sometimes has data to send, but at other times not
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss due to buffer overflow
  - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior with packet-switching?
  - “It’s complicated.”
  - We’ll study various techniques that try to make packet switching as “circuit-like” as possible.

Internet structure: a "network of networks"

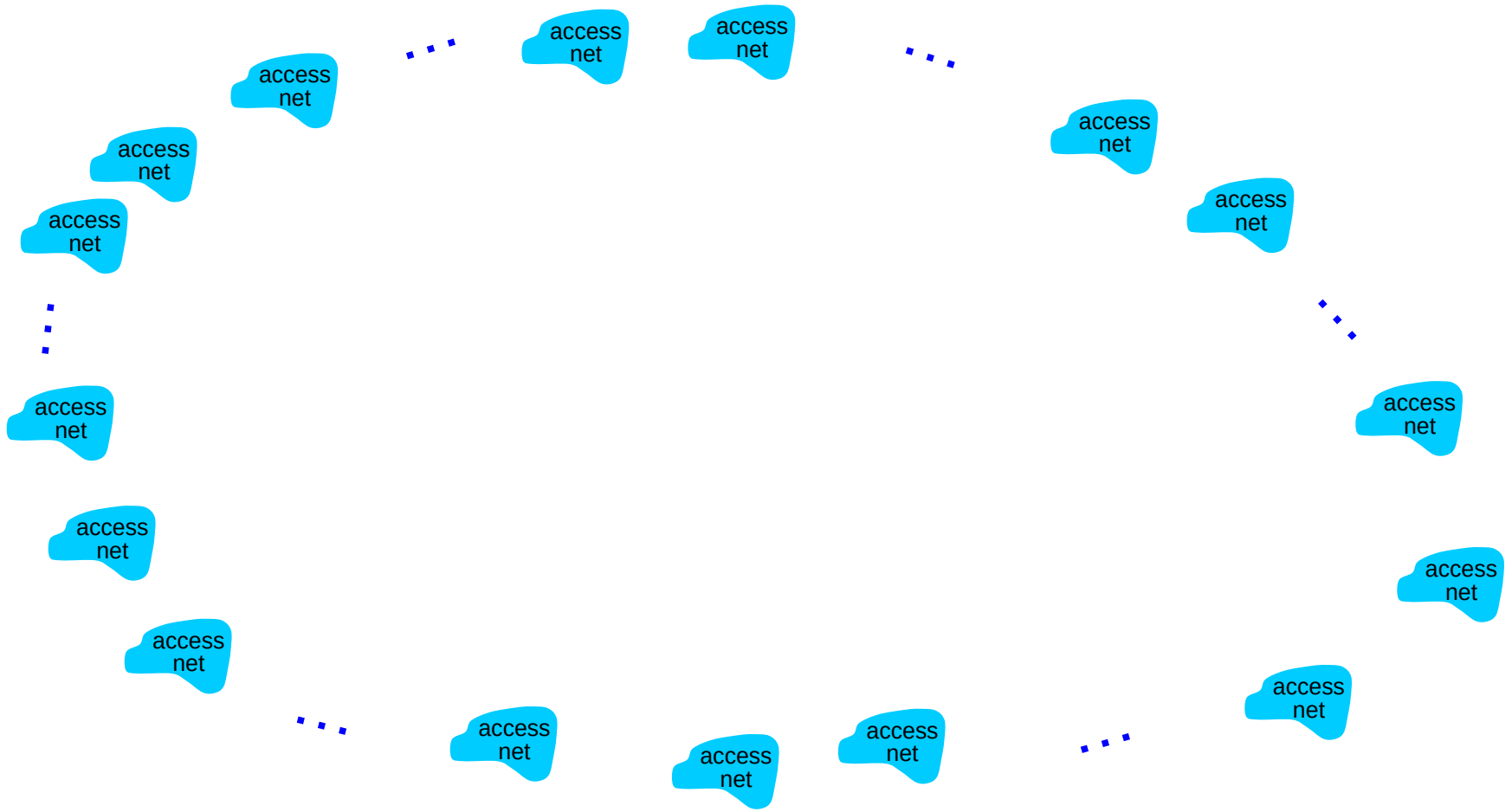
- hosts connect to Internet via access Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts *(anywhere!)* can send packets to each other
- resulting network of networks is very complex
  - evolution driven by economics & national policies



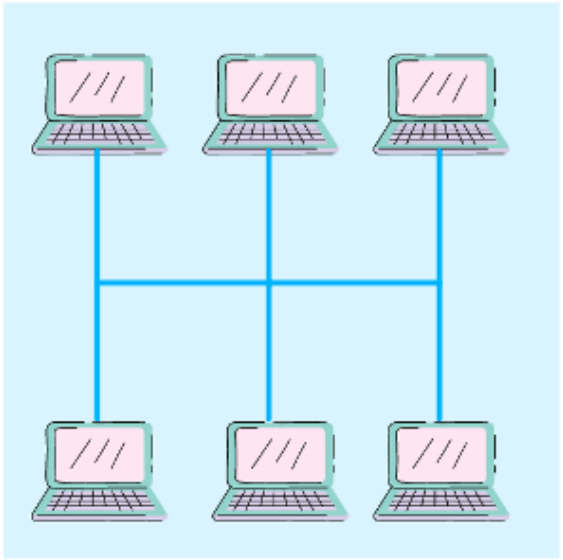
Let's take a stepwise approach to describe current Internet structure

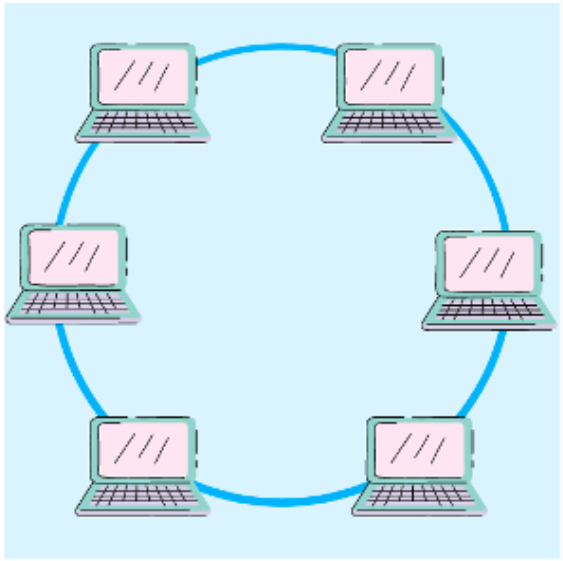
Internet structure: a "network of networks"

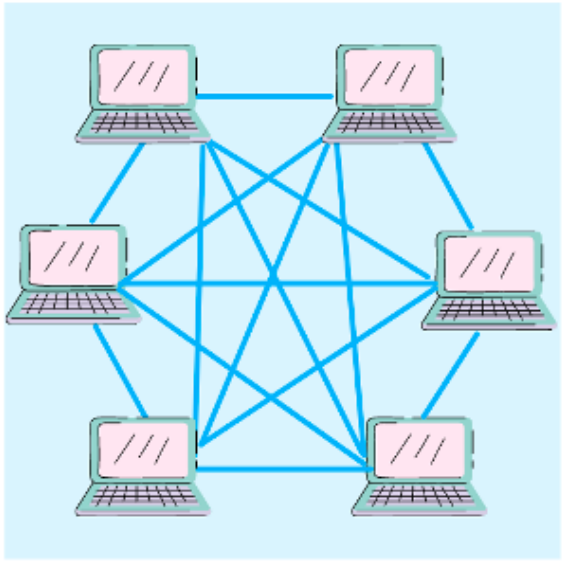
Question: given *millions* of access ISPs, how to connect them together?

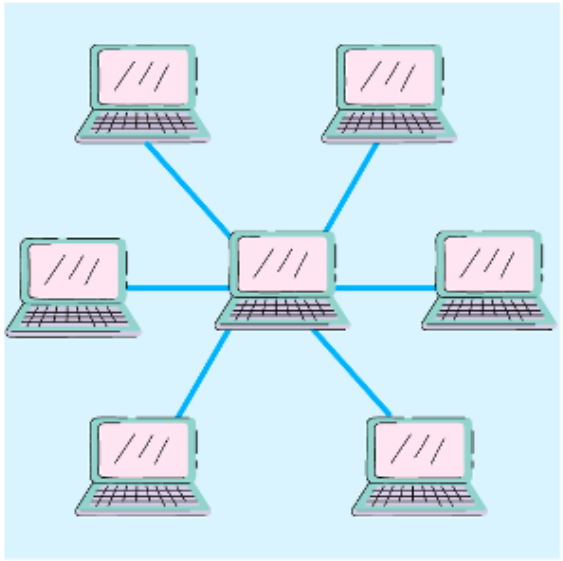


Network Structure: Different Topologies



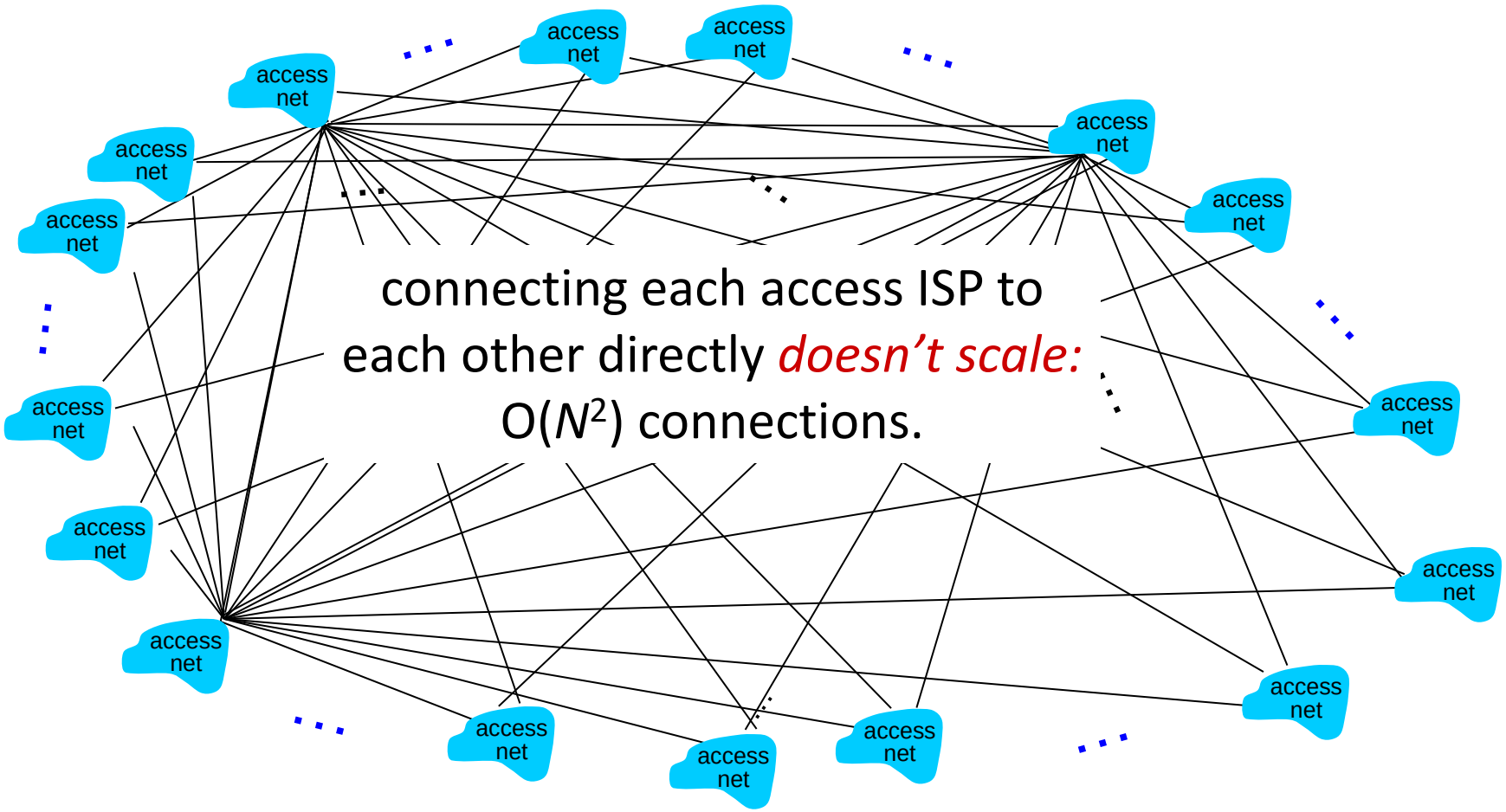






Internet structure: a "network of networks"

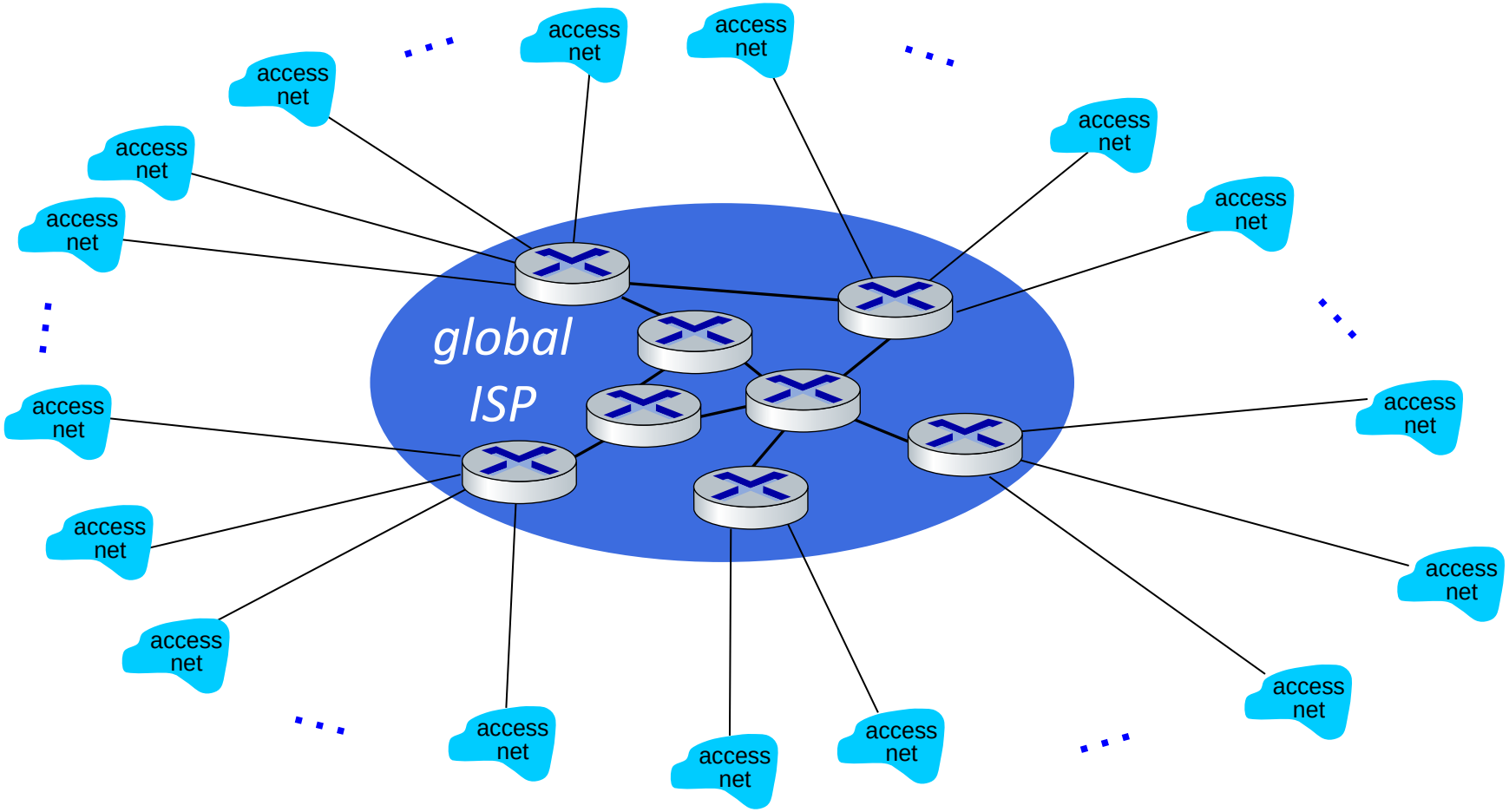
Question: given *millions* of access ISPs, how to connect them together?



Internet structure: a "network of networks"

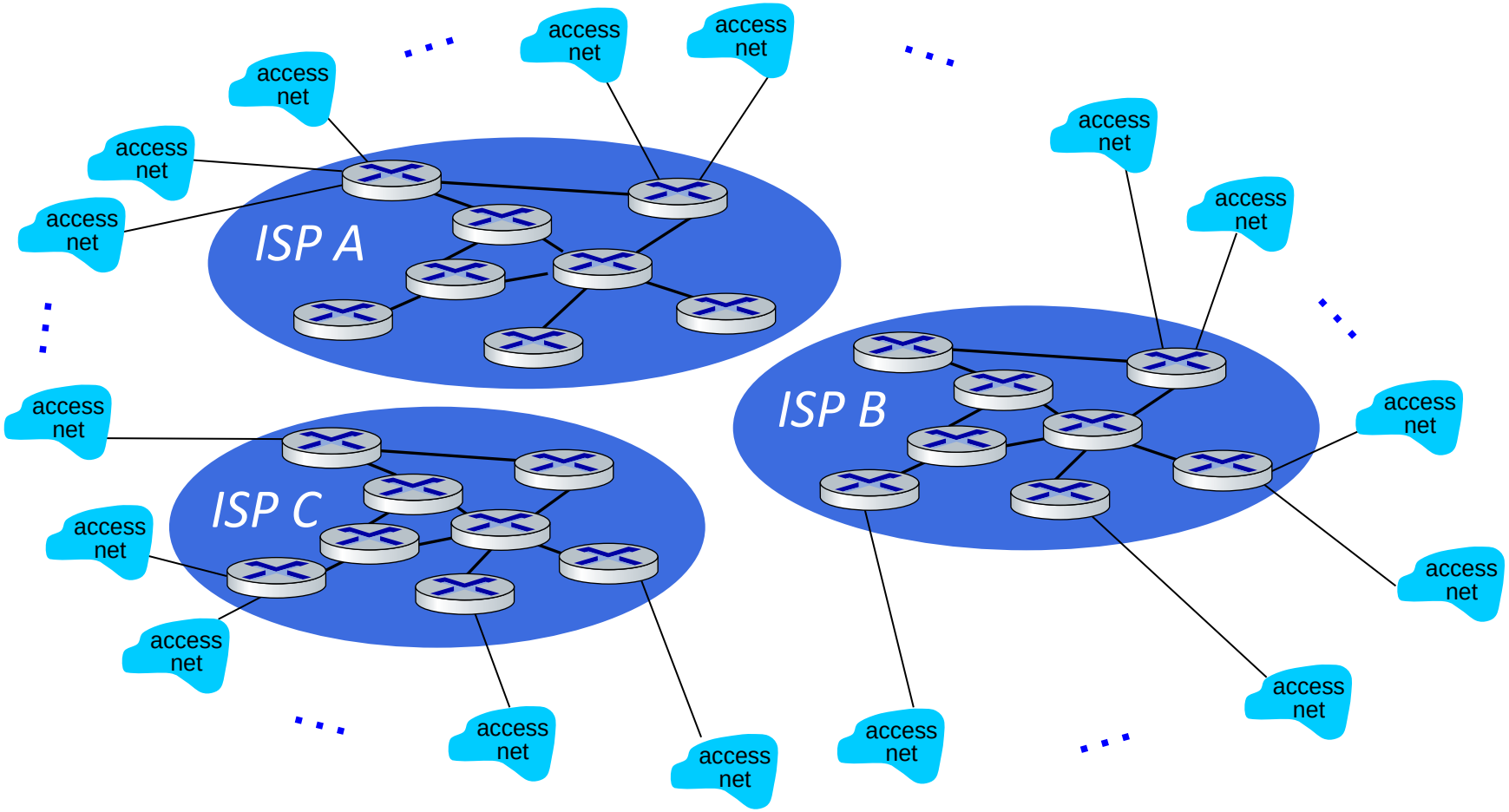
Option: connect each access ISP to one global transit ISP?

Customer and provider ISPs have economic agreement.



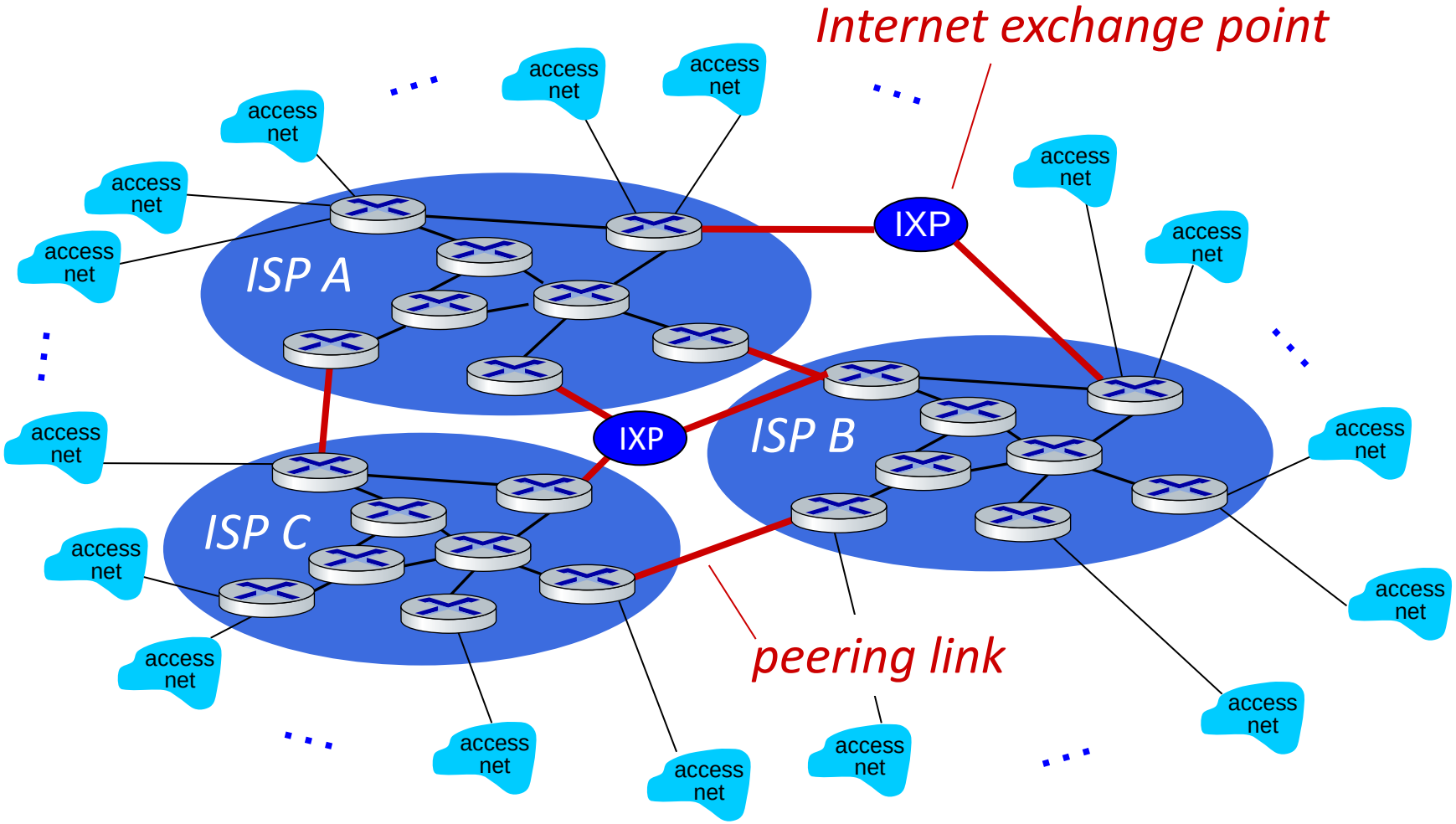
Internet structure: a "network of networks"

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



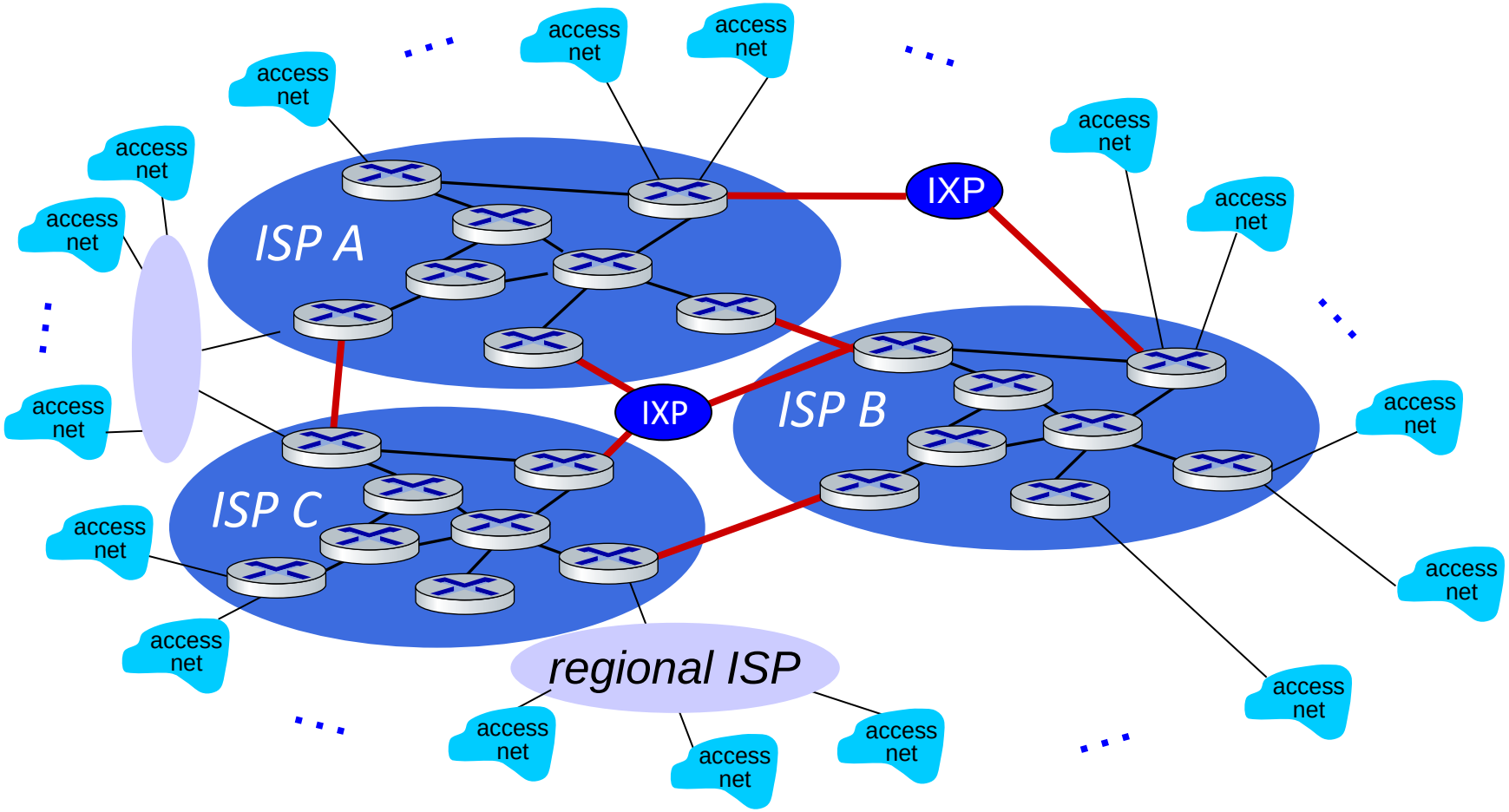
Internet structure: a "network of networks"

But if one global ISP is viable business, there will be competitors …. who will want to be connected



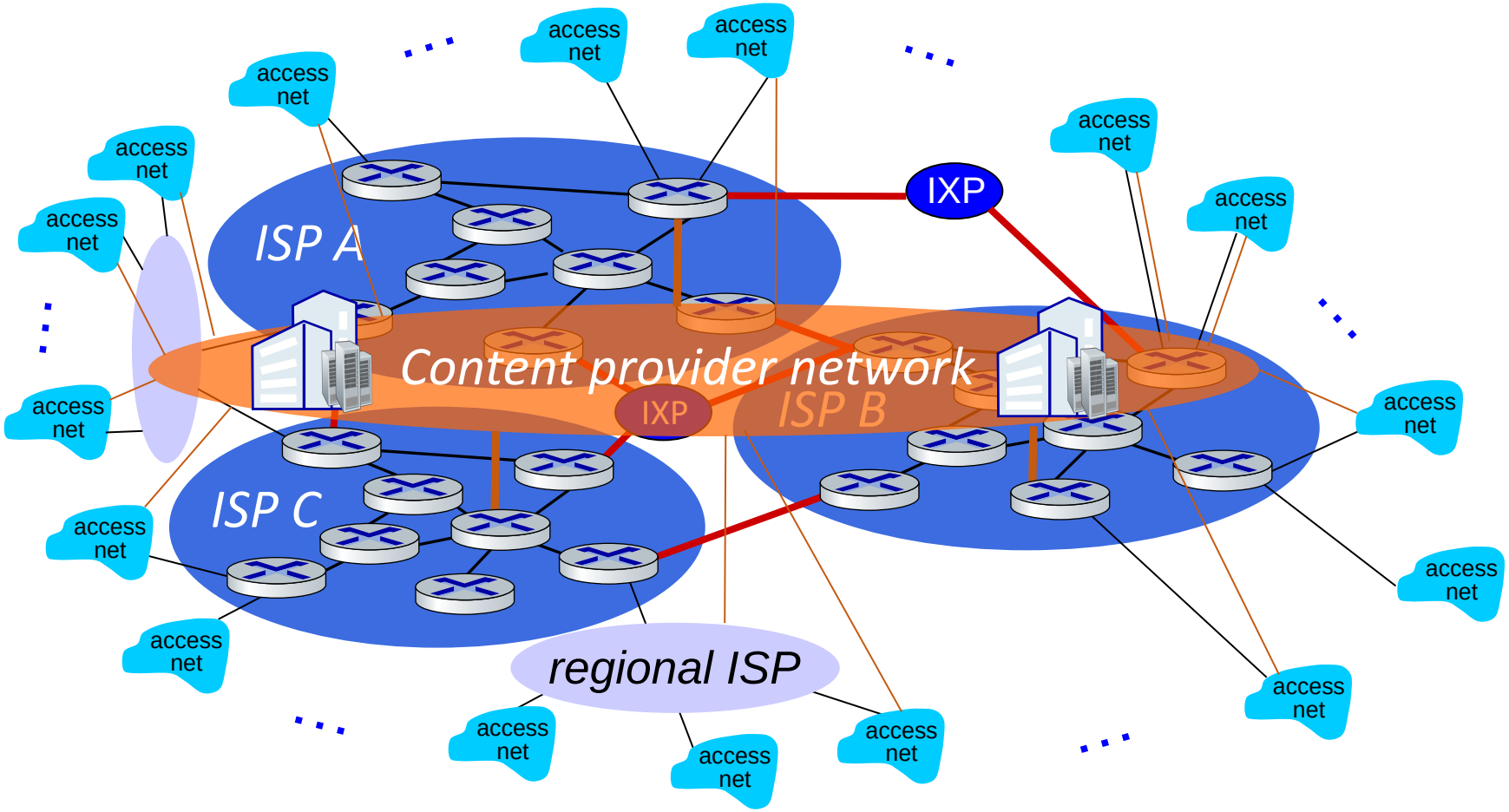
Internet structure: a "network of networks"

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

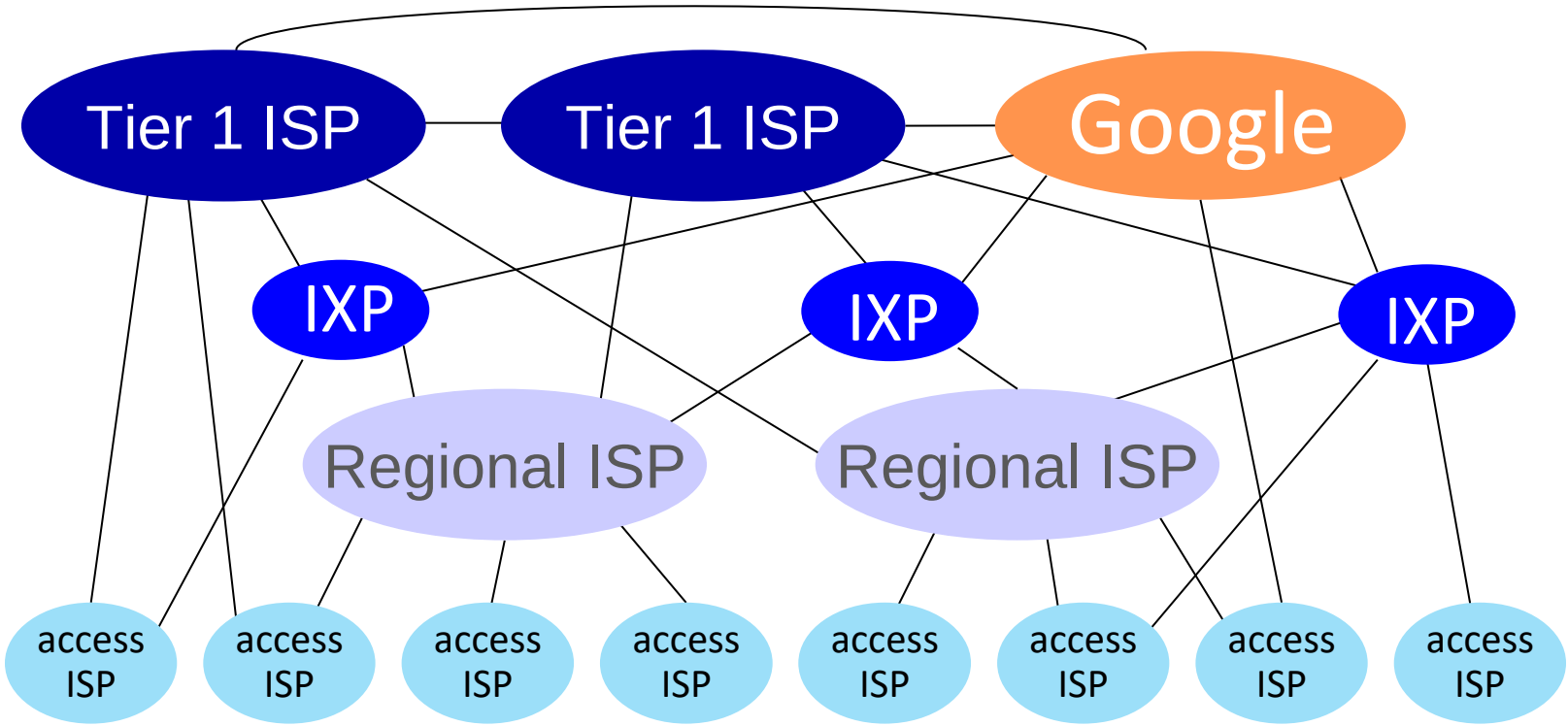


Internet structure: a "network of networks"

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



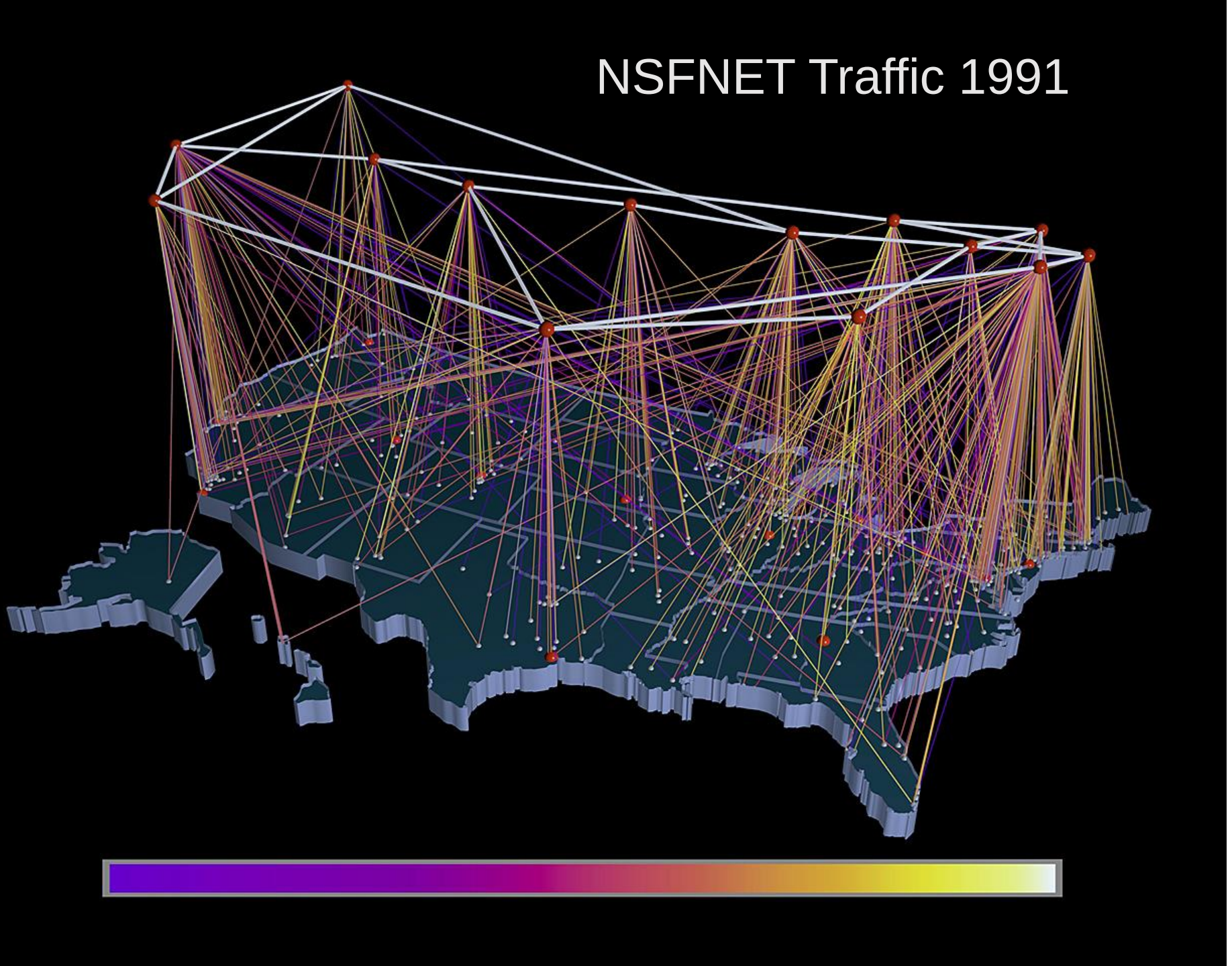
Internet structure: a "network of networks"



At "center": small # of well-connected large networks

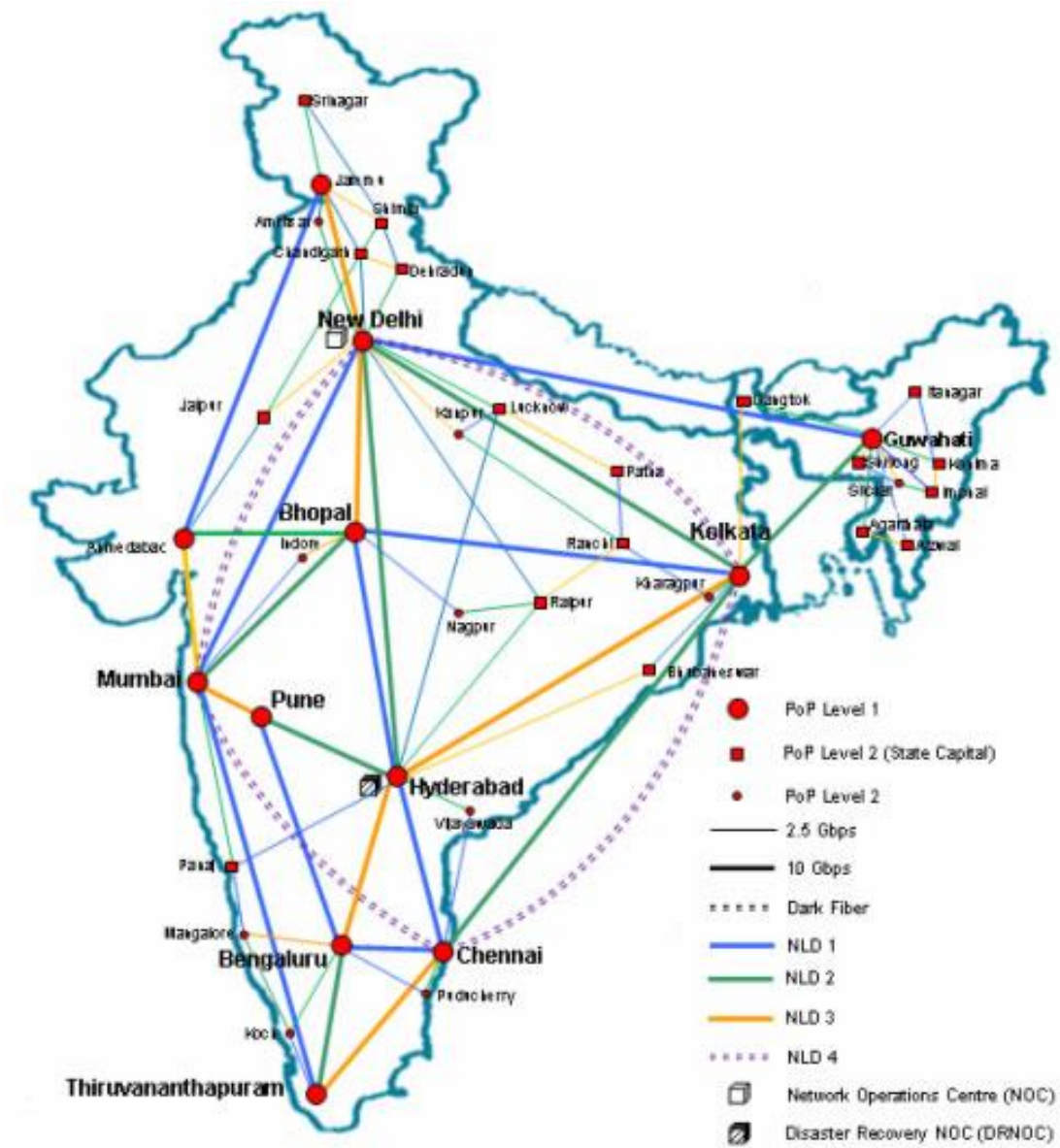
- "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
- content provider networks (e.g., Google, Facebook): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

NSFNET Traffic 1991



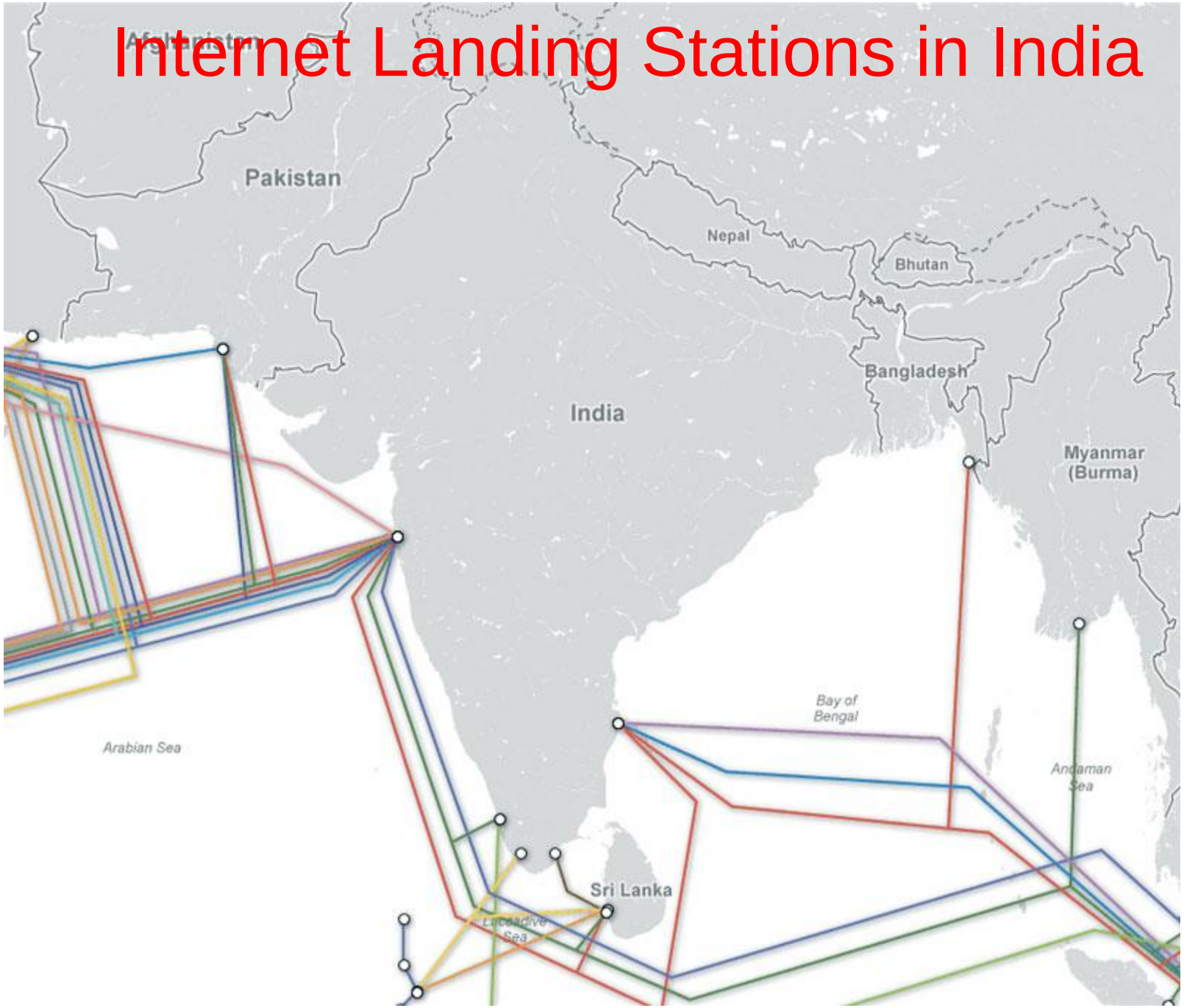
https://avl.ncsa.illinois.edu/project-archive/visualizing-the-early-internet

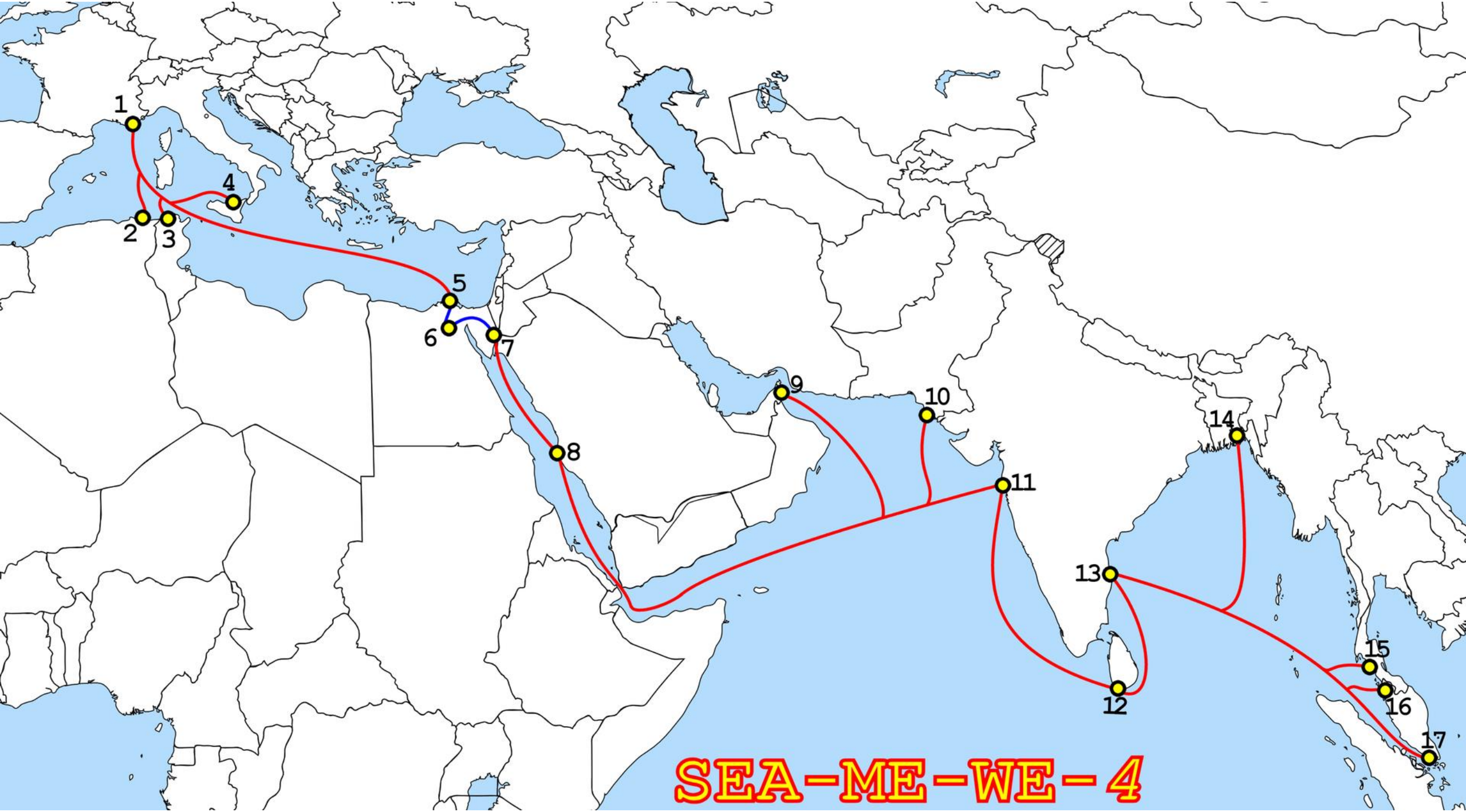
National Knowledge Network



https://nkn.gov.in/en/design-and-architecture-lt-en/detailed-design-lt-en

Internet Landing Stations in India

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SEA-ME-WE-4

Readings

- Go through Chapter 1.3 of Computer Networking: A Top-Down Approach **by James F. Kurose and Keith W. Ross**, 8th Edition, 2020, Addison Wesley (Pearson Education)
  - https://gaia.cs.umass.edu/kurose_ross/videos/1/
- https://www.cloudflare.com/learning/cdn/glossary/internet-exchange-point-ixp/
- https://www.indiatimes.com/technology/news/submarine-cable-network-india-internet-link-world-537327.html
- https://en.wikipedia.org/wiki/Cable_landing_point
- https://www.submarinenetworks.com/stations/asia/india

Homework

- Task-1: Do the interactive exercises on circuit-switching vs pkt-switching

https://gaia.cs.umass.edu/kurose_ross/interactive/ps_versus_cs.php

- Task-2: Solve Chapter-1 of Kurose and Ross textbook's exercise problems P8 and P9 and post your solutions in Google classroom
  - https://shiny.rit.albany.edu/stat/binomial/
  - https://www.danielsoper.com/statcalc/calculator.aspx?id=71