



Networks (2IRR20)

Introduction: Network structure (01a)

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This slide set

Goal:

- Get “feel,” “big picture,” introduction to terminology
 - more depth, detail *later* in course
- Approach:
 - use Internet as example

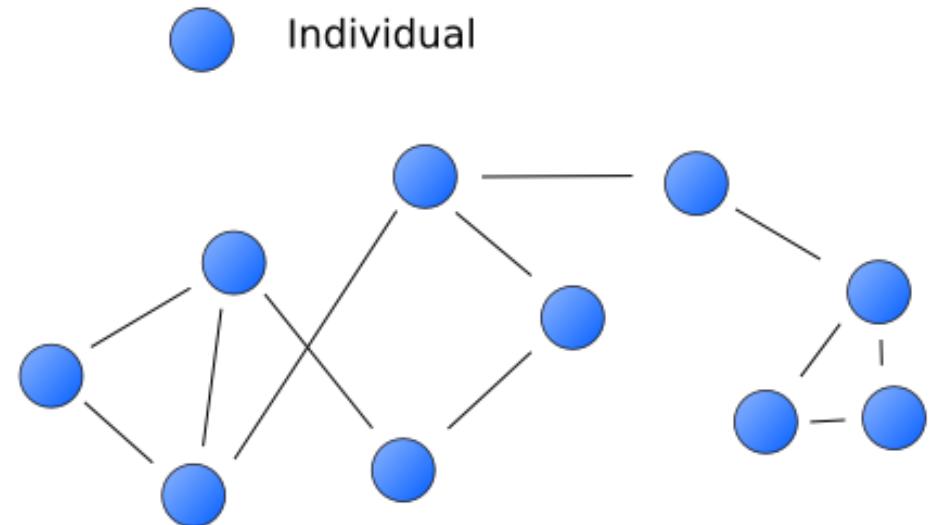
Overview:

- What *is* a network, what is the Internet?
- A closer look at Internet structure
 - Network edge: hosts, access network, physical media
 - Network core: packet/circuit switching

Networks, the Internet

What is a network?

- An interconnected configuration of system components
 - designed to communicate and share
- A connected system of things or people
 - e.g., a network of gossip or spies



What is a computer network?

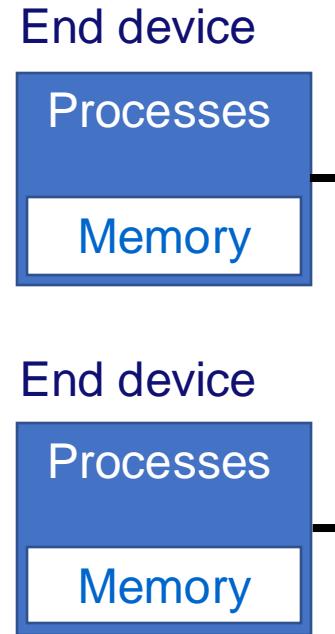
Physically (nuts and bolts view):

An “infrastructure” interconnecting “end-devices”

- End-devices
 - PC's, game consoles, smart TV's, smart phones...
 - Network Interface Cards (NIC) and OS are included
- Infrastructure
 - Communication links (e.g. fiber cable, radio)
 - Packet switches (e.g. routers, link layer switches)

Logically (service view):

A facility providing information exchange between processes that are **not** sharing memory.



What is *the* Internet?

Physically (nuts and bolts view)
?

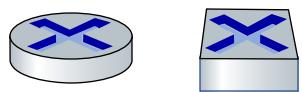
Logically (service view)
?

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



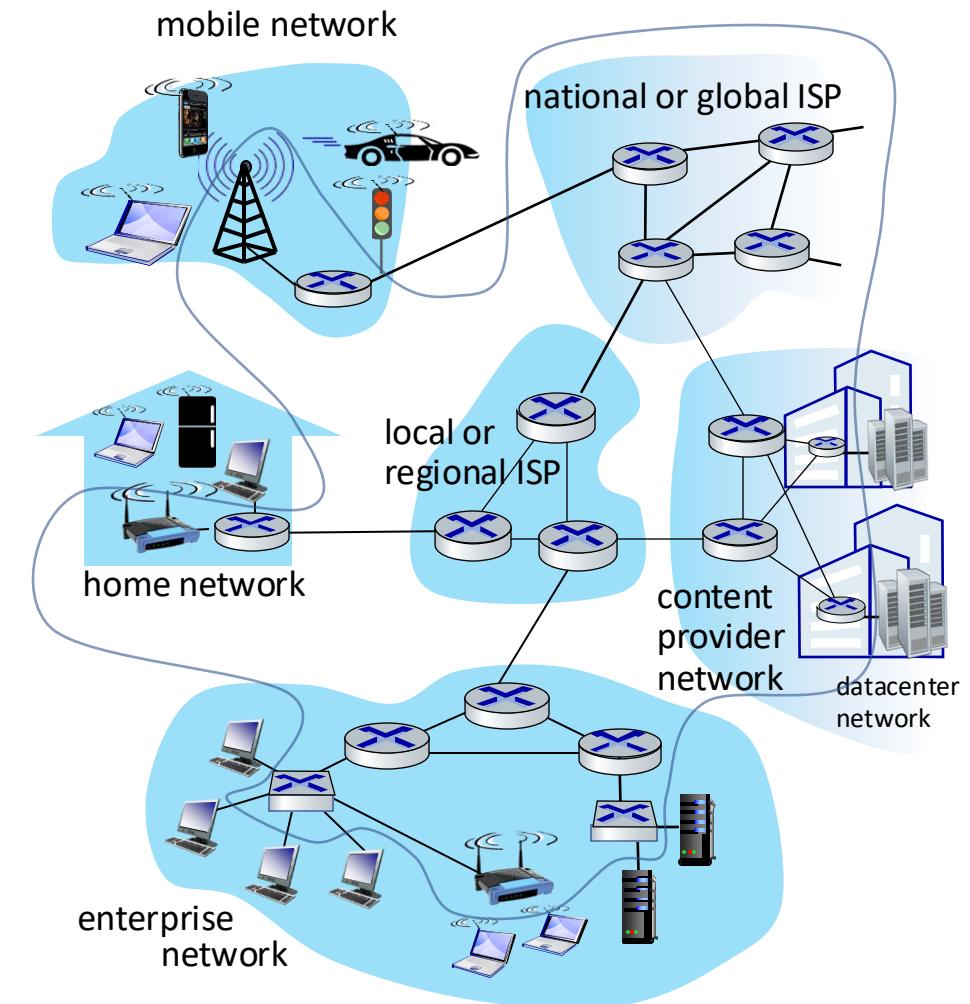
Communication links

- fiber, copper, radio, satellite



Networks

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



“Fun” Internet-connected devices



Amazon Echo



Internet refrigerator



Security Camera



IP picture frame



Slingbox: remote control cable TV



Internet phones



Pacemaker & Monitor



Fitbit



sensorized,
bed
mattress



Tweet-a-watt:
monitor energy use

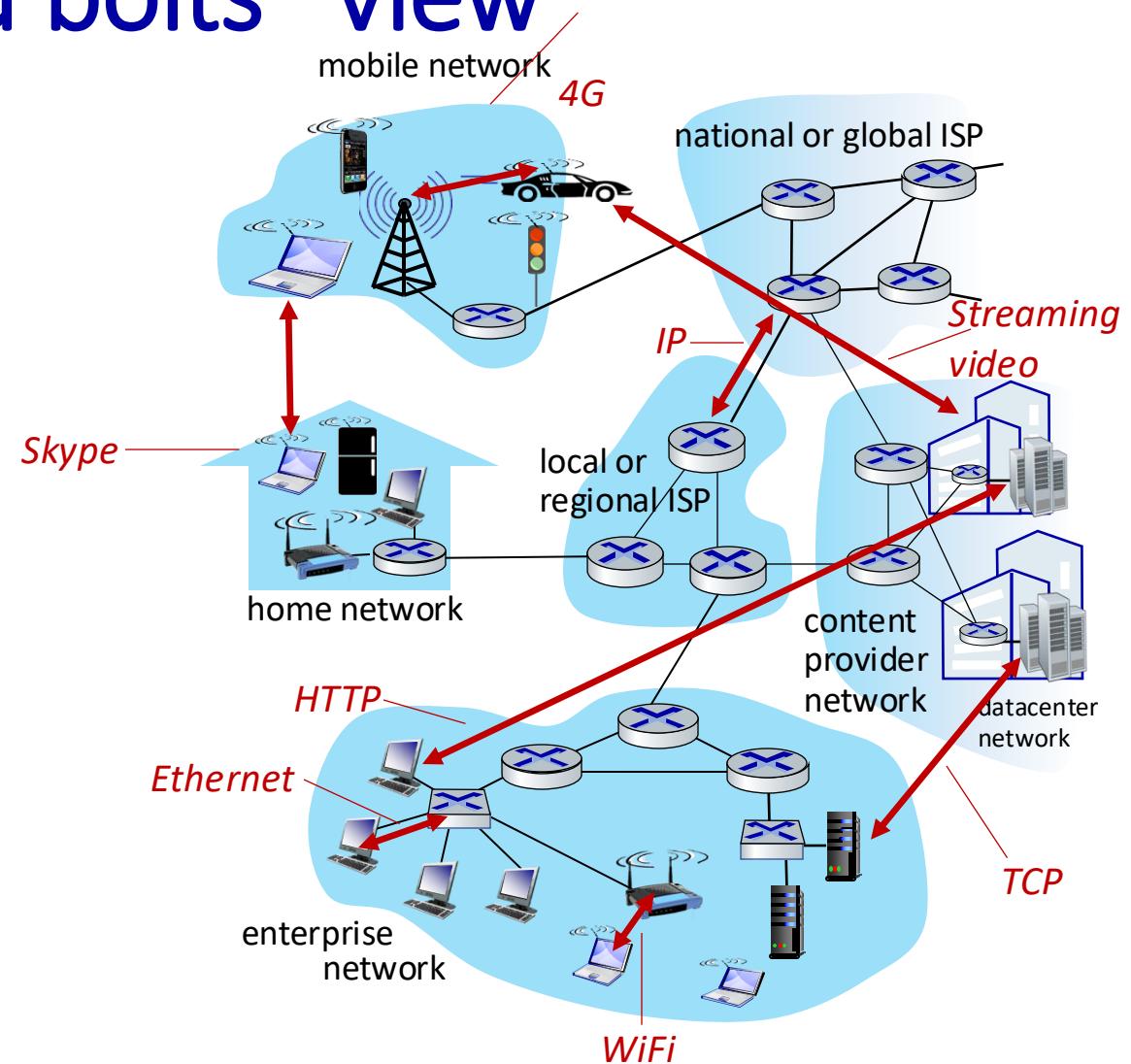


AR devices

Others?

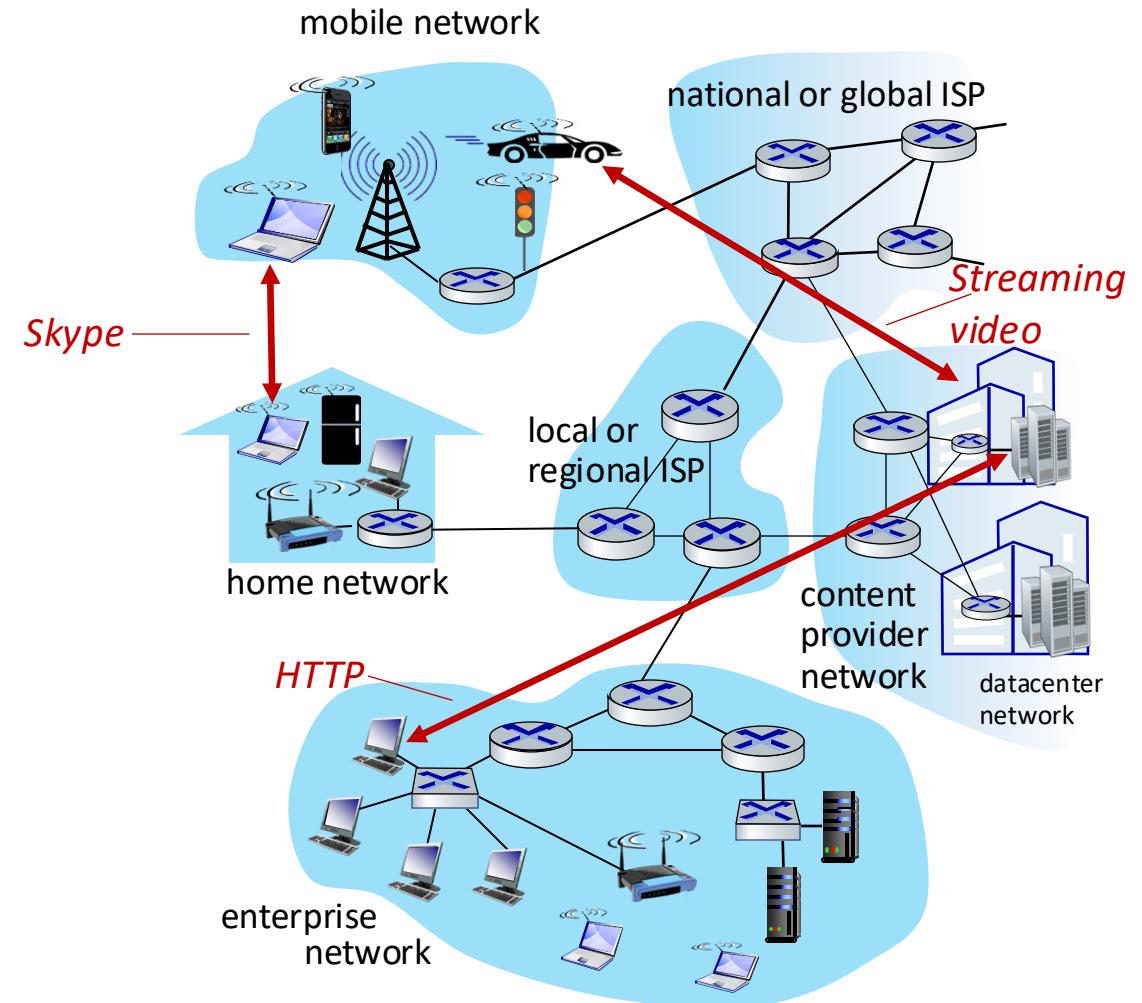
The Internet: a “nuts and bolts” view

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



The Internet: a “service” view

- *Infrastructure* that provides services to applications:
 - Web, streaming video, multimedia teleconferencing, email, games, e-commerce, social media, interconnected 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



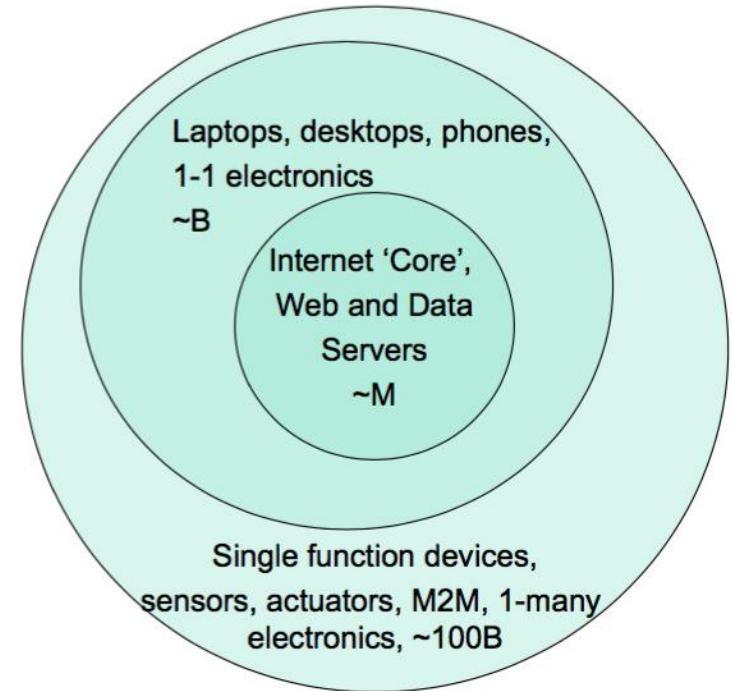
What is *the* Internet of Things?

IoT physically:

- An extension of the Internet to billions of resource-poor devices.
 - billions of 'Things': constrained devices with limited memory, processing power, energy and accessibility ...

IoT logically:

- A network that extends the reach of distributed applications to the physical world (including humans, animals, plants, terrain etc).
 - e.g. vehicular networks, intelligent lighting, patient monitoring, smart cities, smart manufacturing, agriculture...

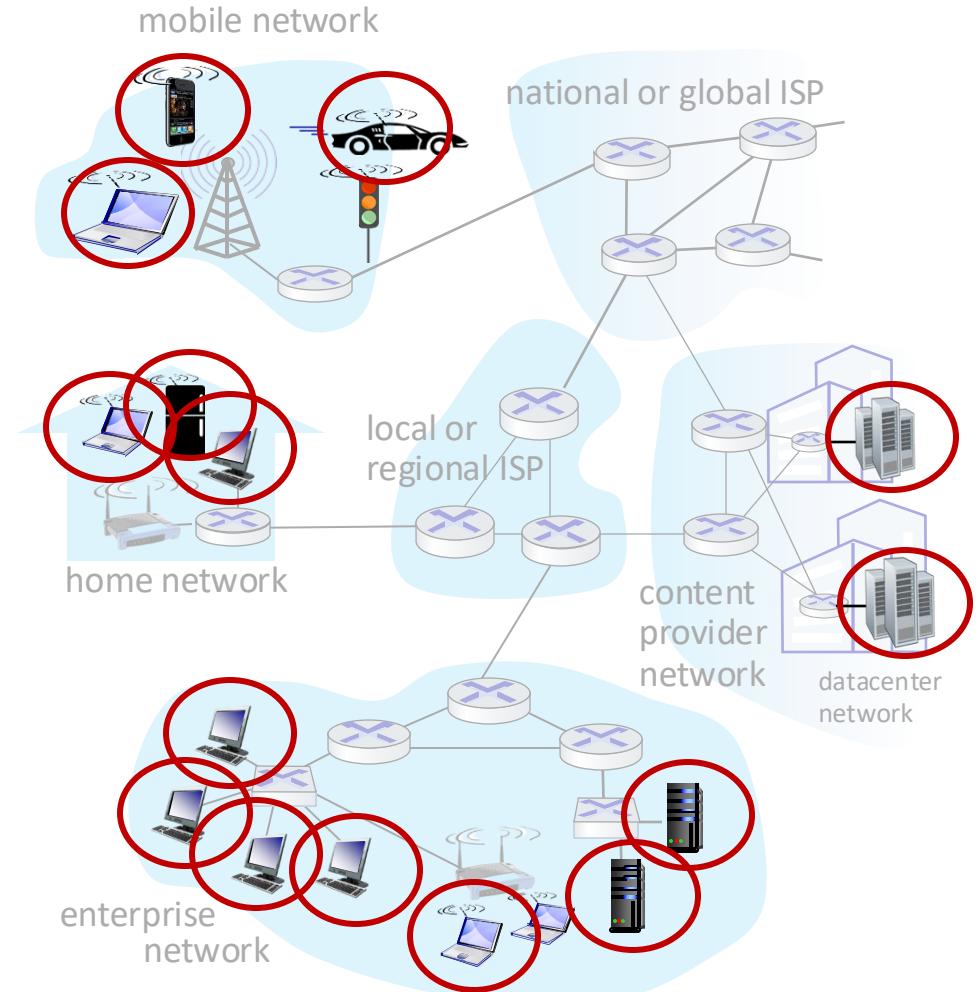


A closer look at Internet structure

A closer look at Internet structure

Network edge:

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



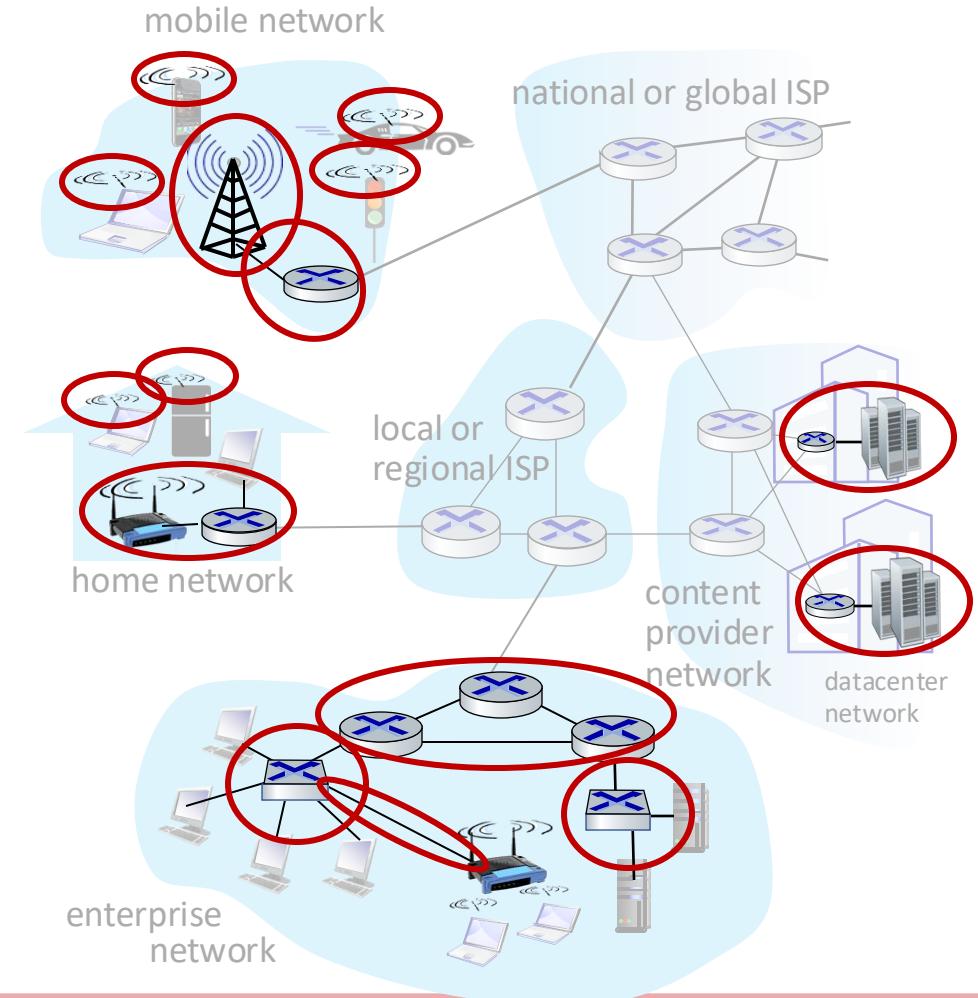
A closer look at Internet structure

Network edge:

- hosts: clients and servers
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Access networks, physical media:

- wired, wireless communication links



A closer look at Internet structure

Network edge:

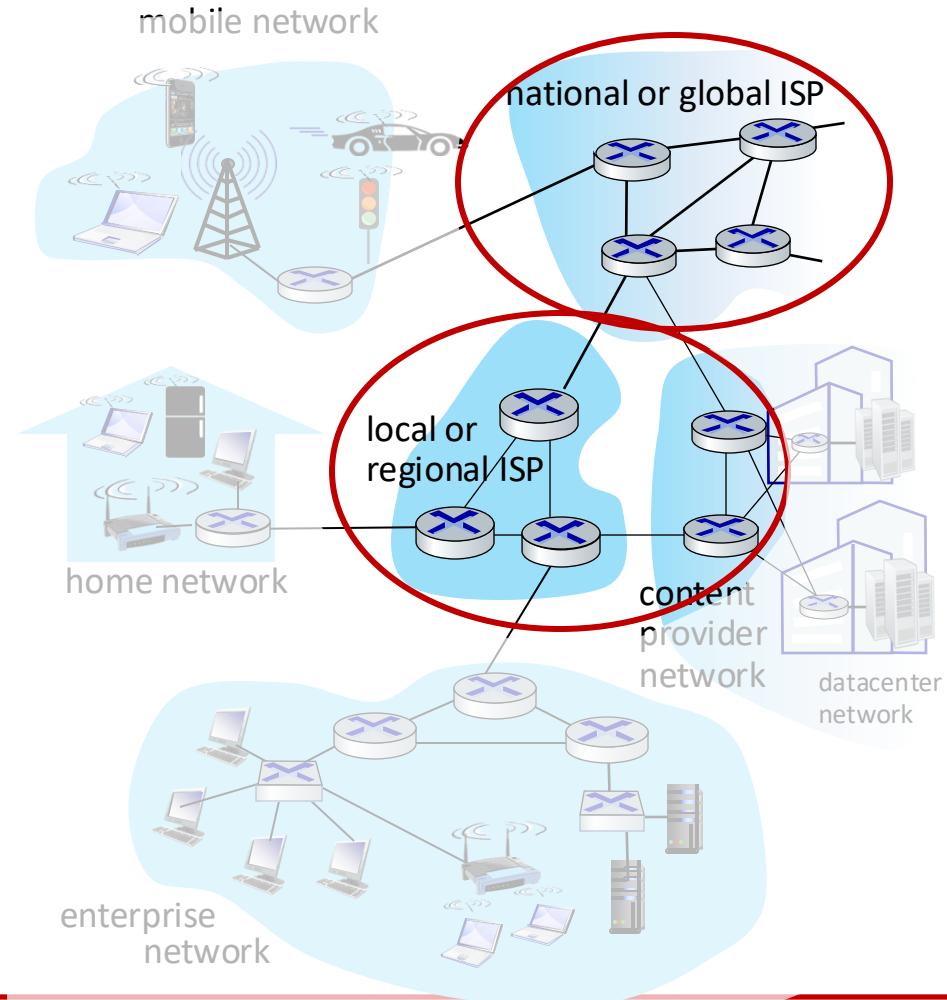
- hosts: clients and servers
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Access networks, physical media:

- wired, wireless communication links

Network core:

- interconnected routers
- network of networks



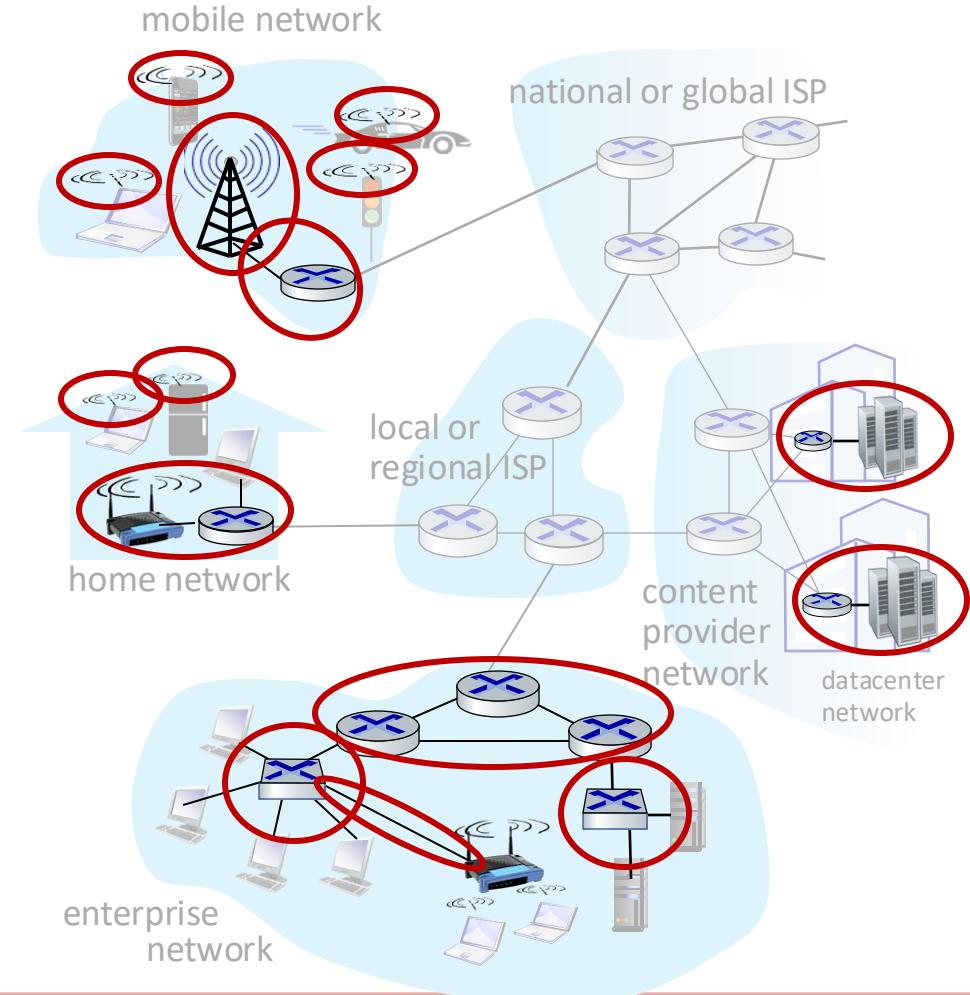
Access networks and physical media

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

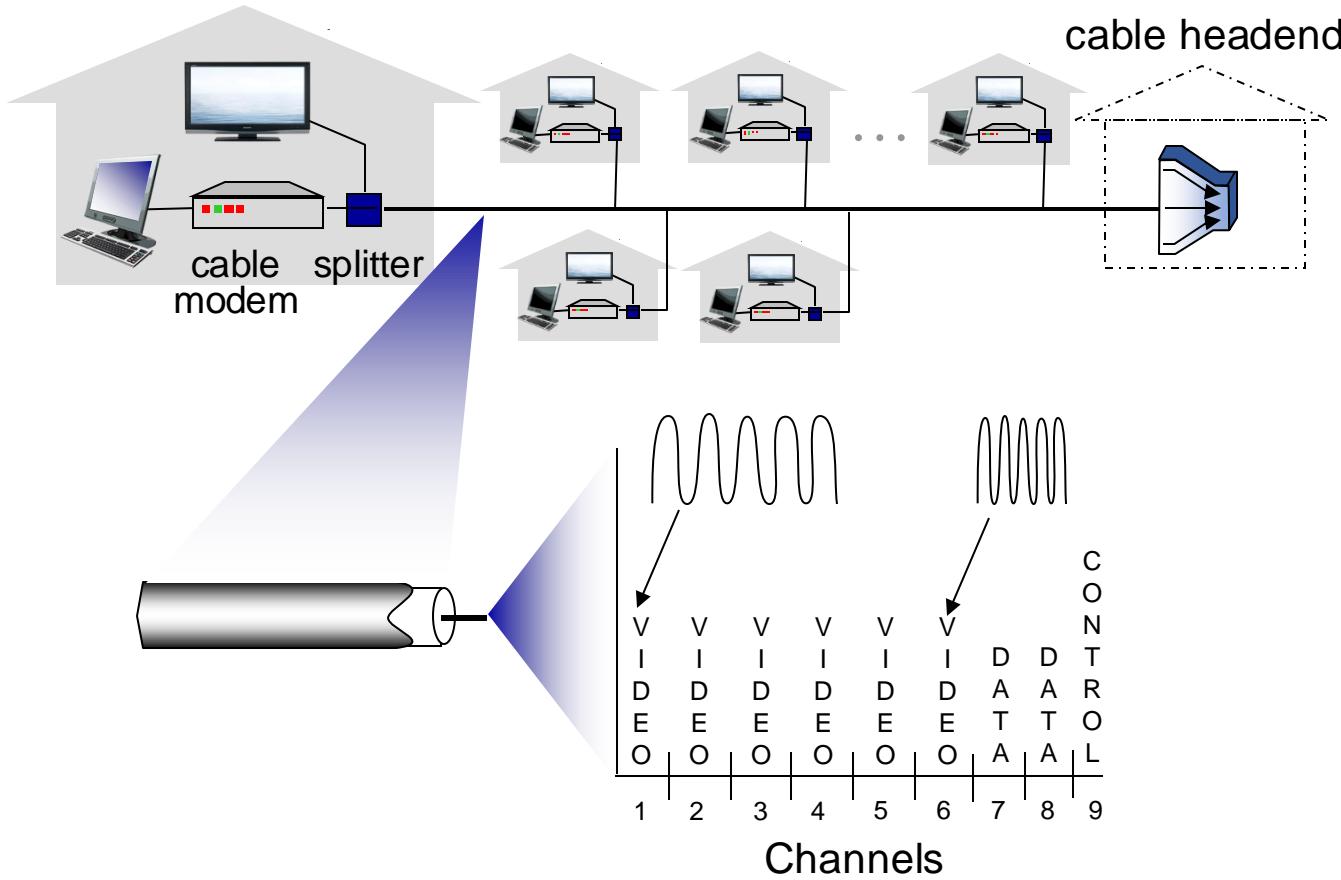
- residential access nets
- institutional access networks (school, company)
- mobile access networks (WiFi, 4G/5G)

What to look for:

- transmission rate (bits per second) of access network?
- shared or dedicated access among users?

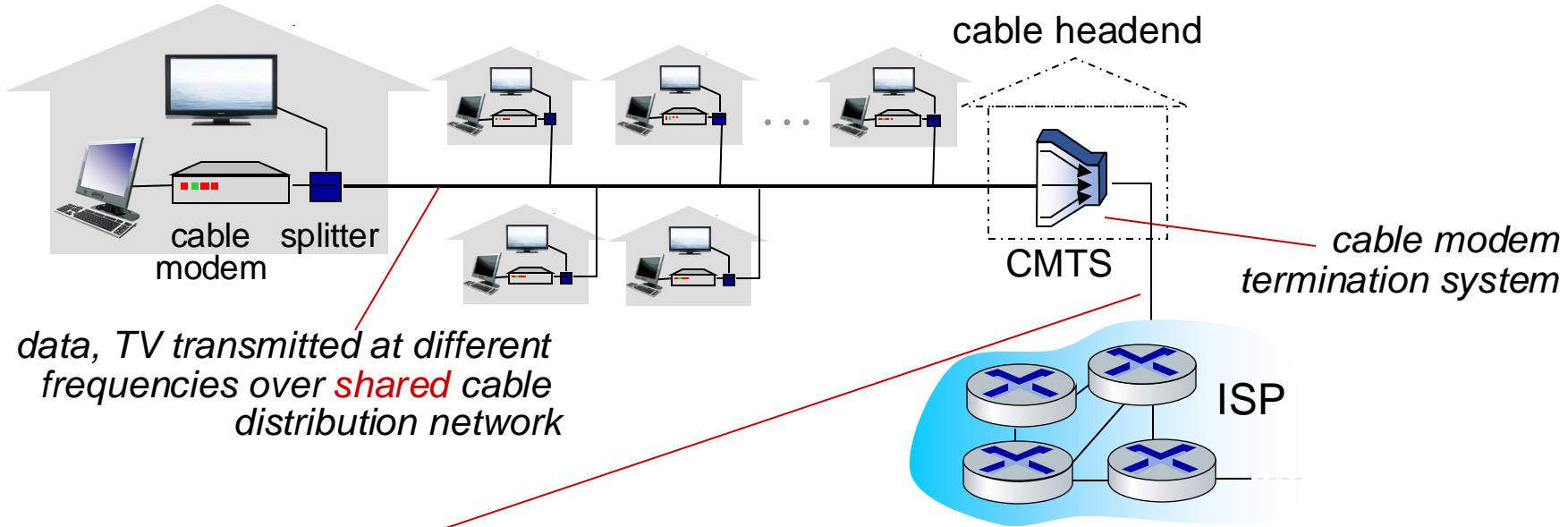


Access networks: cable-based access



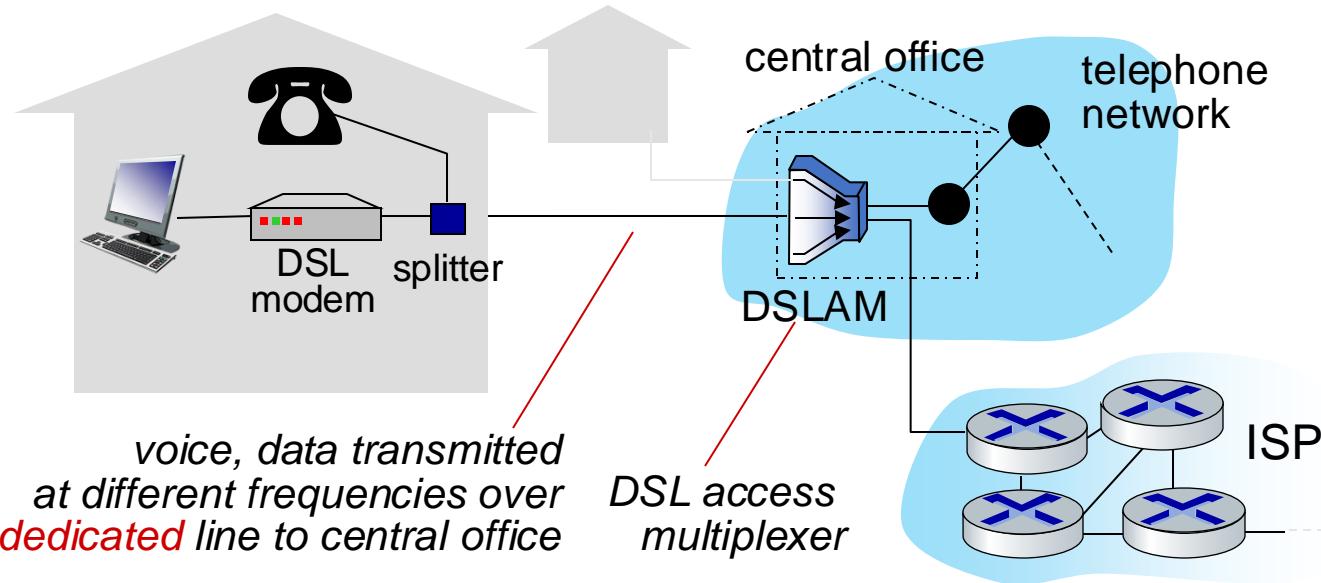
frequency division multiplexing (FDM): different channels transmitted in different frequency bands

Access networks: cable-based access



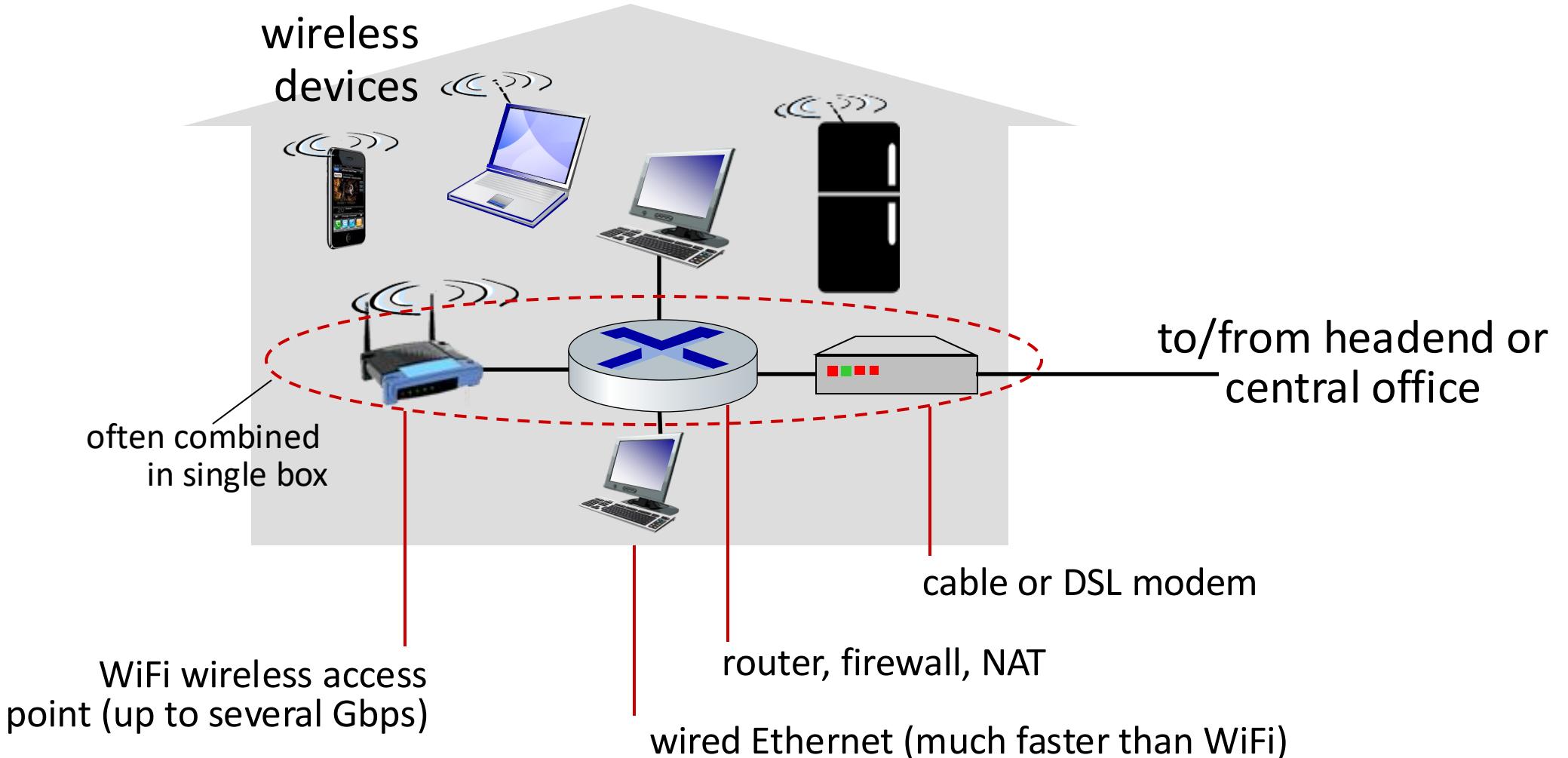
- HFC: hybrid fiber coax
 - asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
 - homes **share access network** to cable headend

Access networks: 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
- up to 1 Gbps on aggregate (downstream + upstream), asymmetric

Access networks: home networks



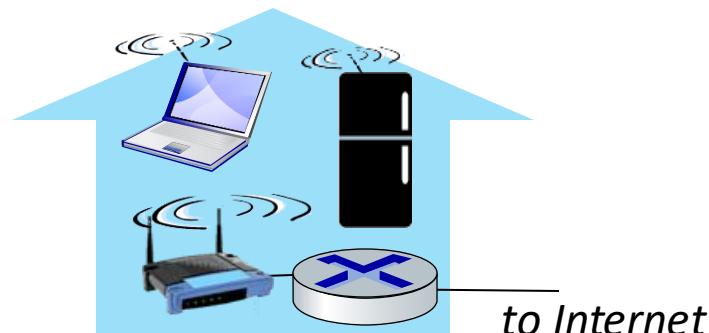
Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka “access point”

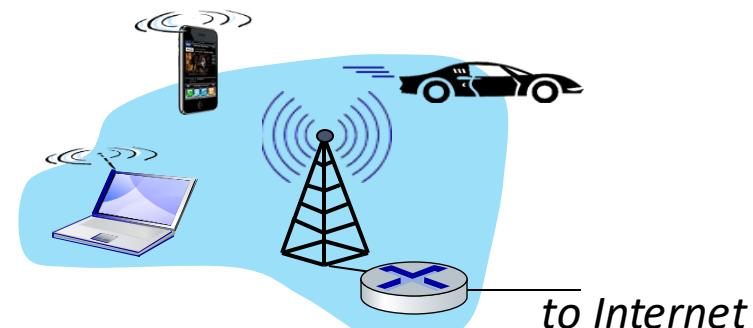
Wireless local area networks (WLANs)

- typically within or around building
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps
 - later versions even faster

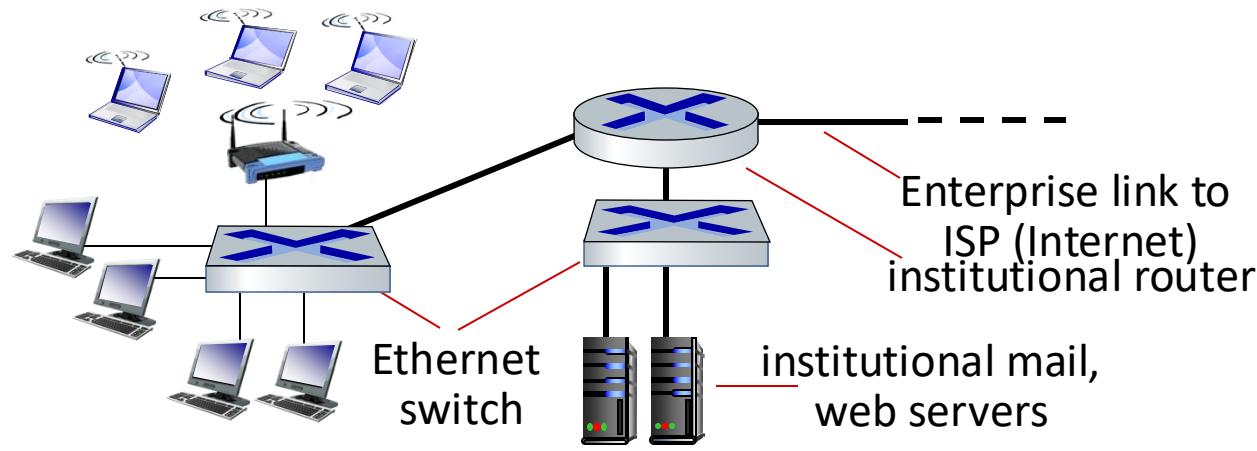


Wide-area cellular access networks

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



Access networks: enterprise networks

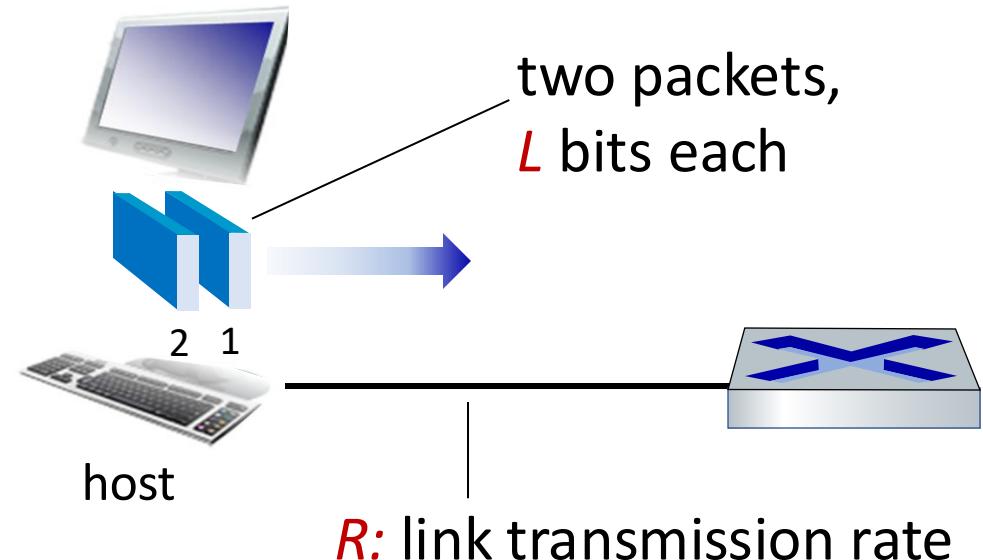


- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
 - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps (and more)
 - WiFi: wireless access points at 11, 54, 450 Mbps (and more)

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*



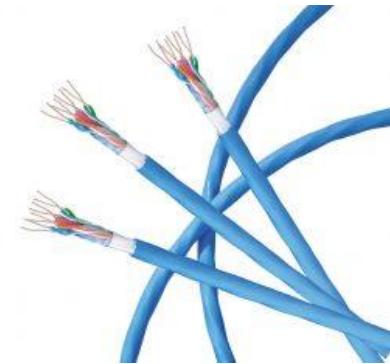
$$\text{packet transmission delay} = \frac{\text{time needed to transmit } L\text{-bit packet into link}}{R \text{ (bits/sec)}} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Links: 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 Ethernet



Links: physical media

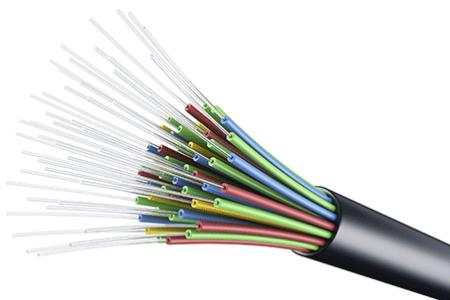
Coaxial cable:

- 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

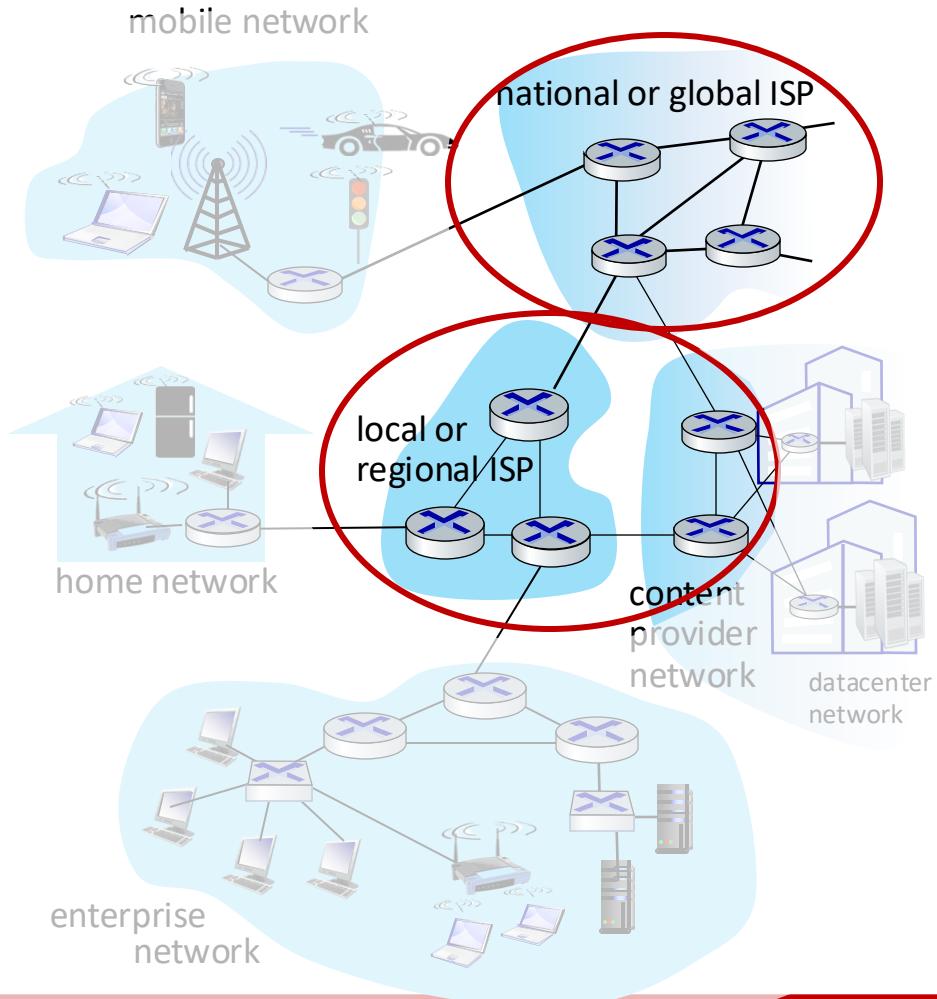
- signal carried in electromagnetic spectrum
- environment effects:
 - reflection
 - obstruction by objects
 - interference

Radio link types:

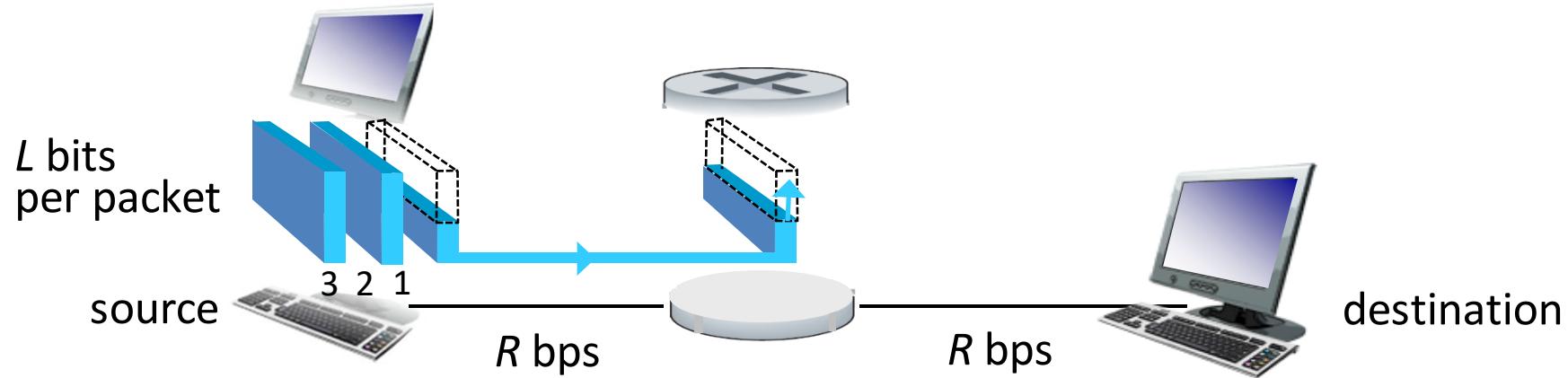
- terrestrial microwave
 - up to 45 Mbps channels
- Wireless LAN (WiFi)
 - Up to 100's Mbps
- wide-area (e.g., cellular)
 - 4G cellular: ~ 10's Mbps
- satellite
 - up to 45 Mbps per channel
 - 270 msec end-end delay
 - geosynchronous versus low-earth-orbit

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

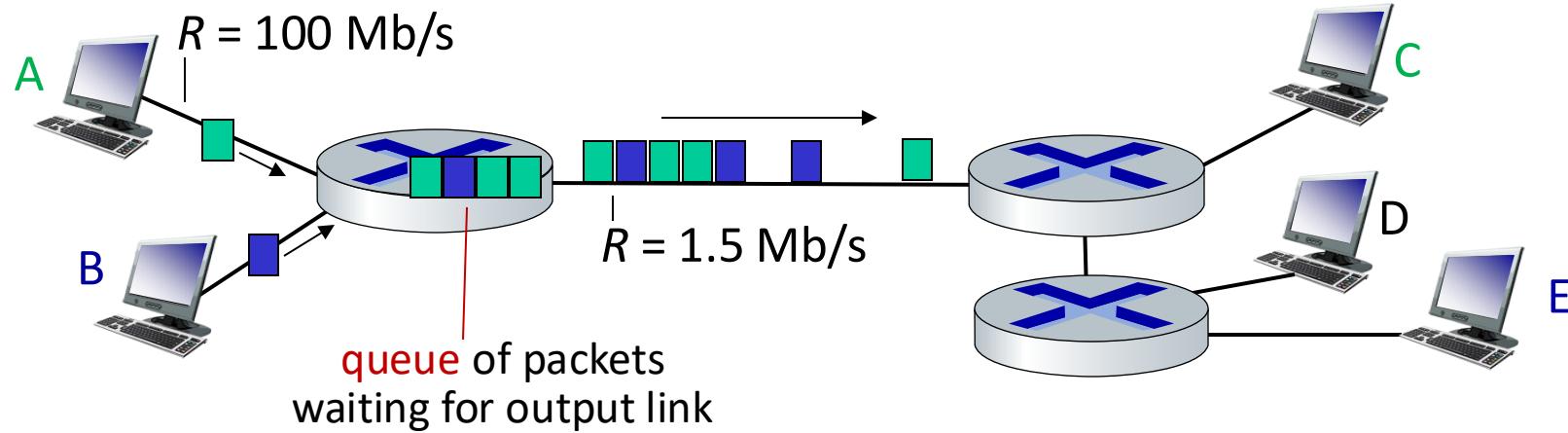


- **Transmission delay:** takes L/R seconds to transmit (push out) L -bit packet into link at R bps
- **Store and forward:** entire packet must arrive at router before it can be transmitted on next link
- **End-end delay:** $2L/R$ (above), assuming zero propagation delay (more on delay shortly)

One-hop numerical example:

- $L = 10$ Kbits
- $R = 100$ Mbps
- one-hop transmission delay = 0.1 msec

Packet-switching: queueing delay, loss



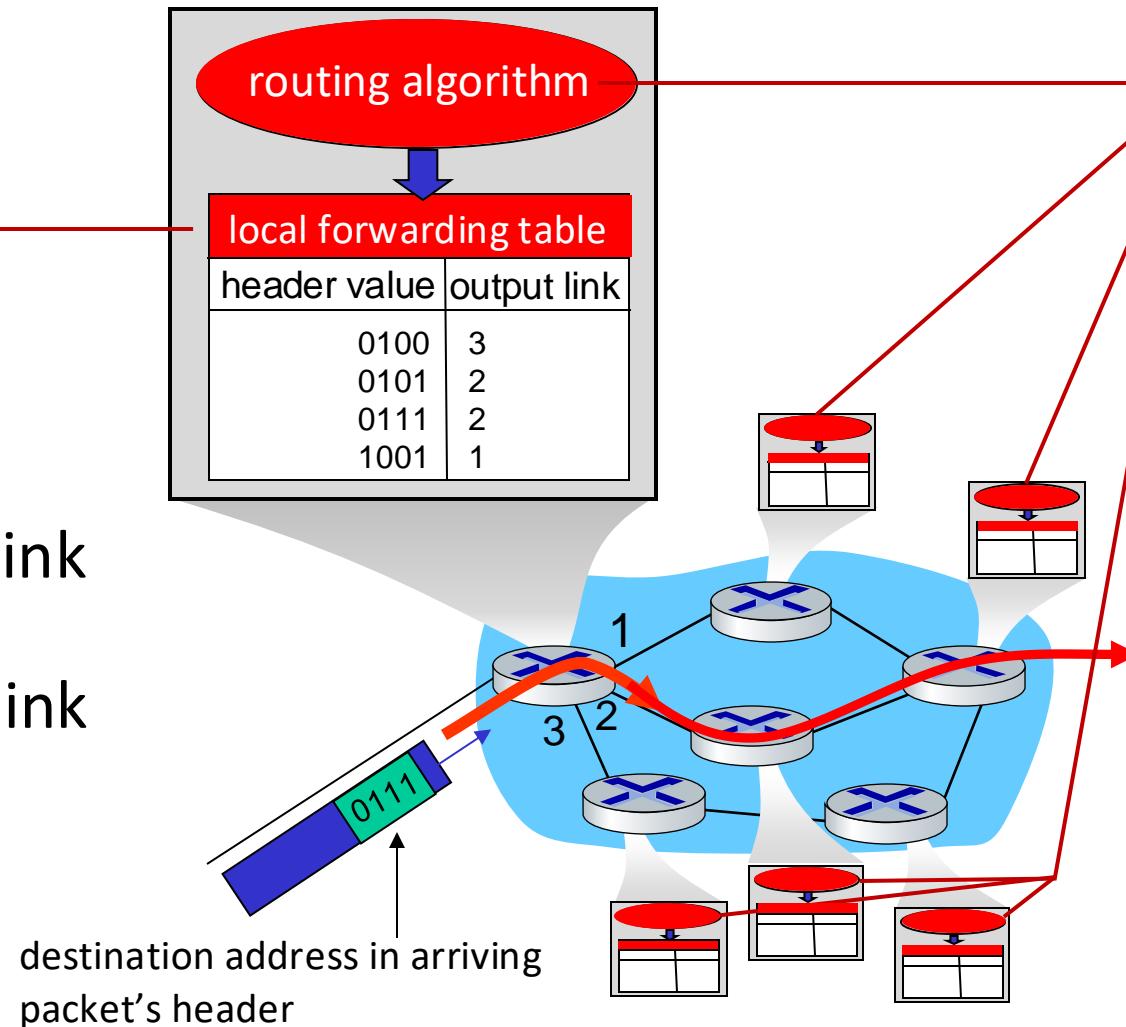
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for a period of time:

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

Two key network-core functions

Forwarding:

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



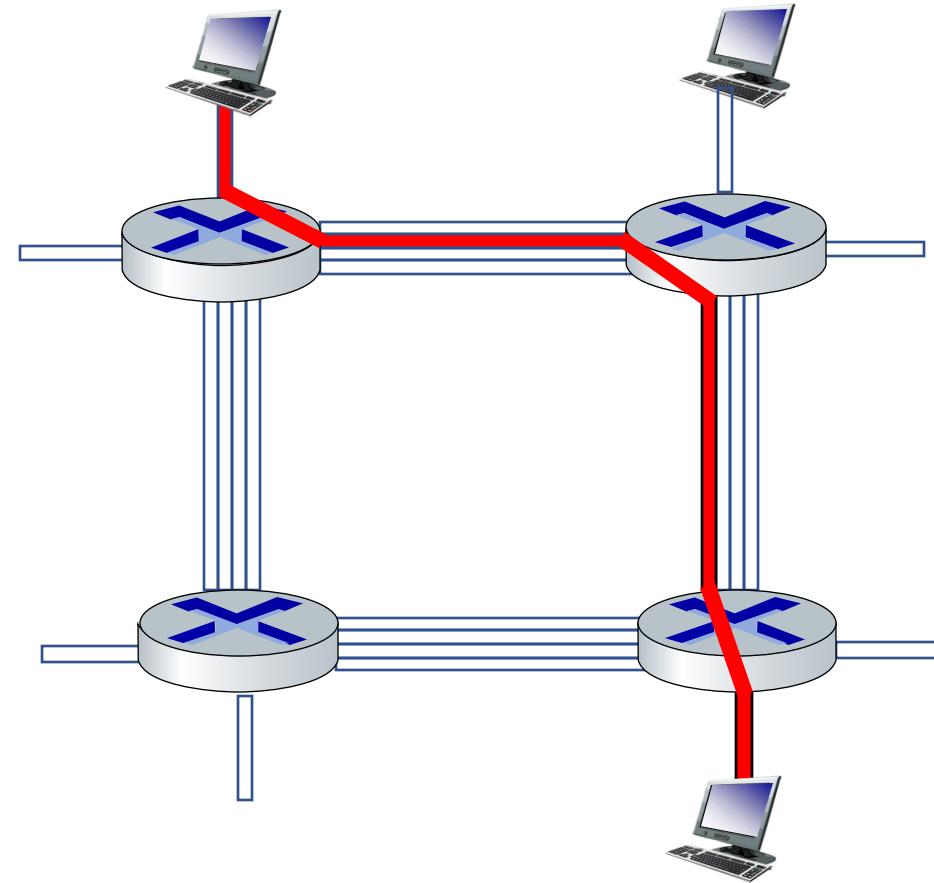
Routing:

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

Alternative to packet switching: circuit switching

end-end resources allocated to,
reserved for “call” between source and
destination

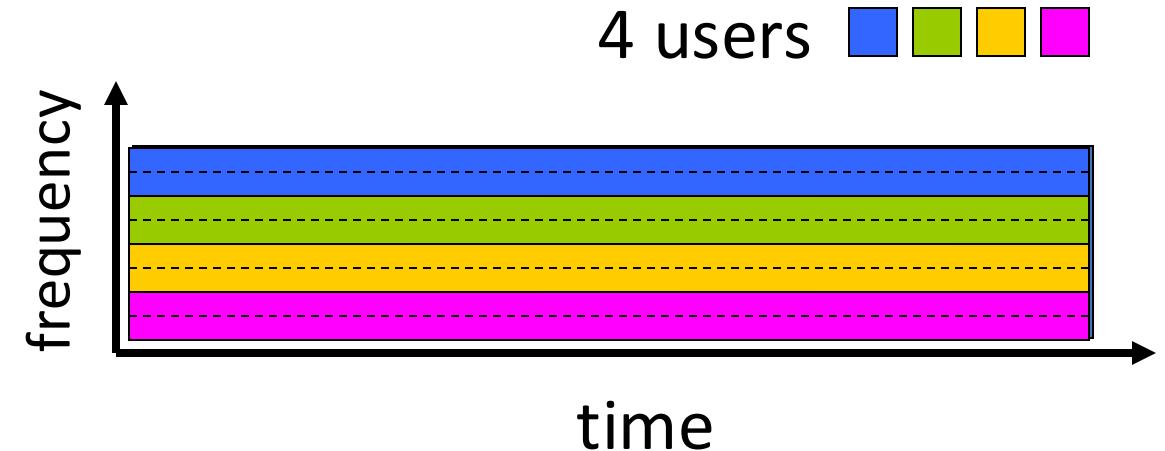
- in diagram, each link has four circuits.
 - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
 - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
- commonly used in traditional telephone networks



Circuit switching: FDM and TDM

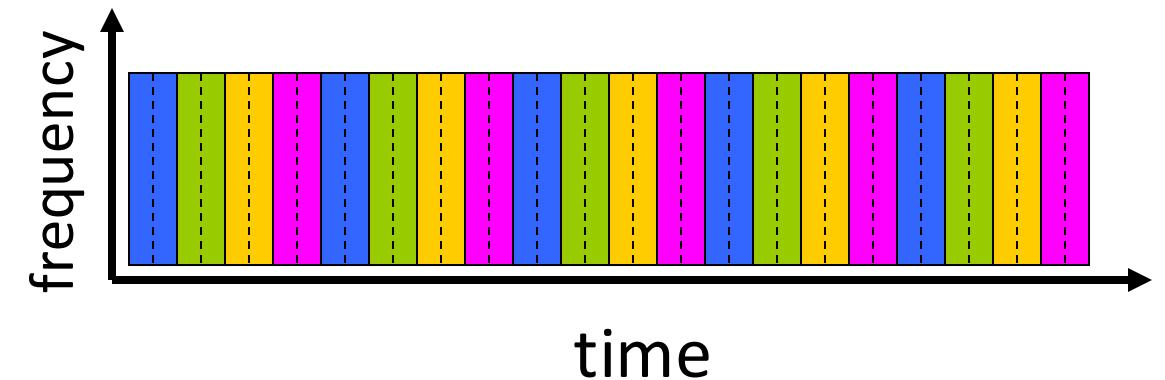
Frequency Division Multiplexing (FDM)

- 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, but only during its time slot(s)

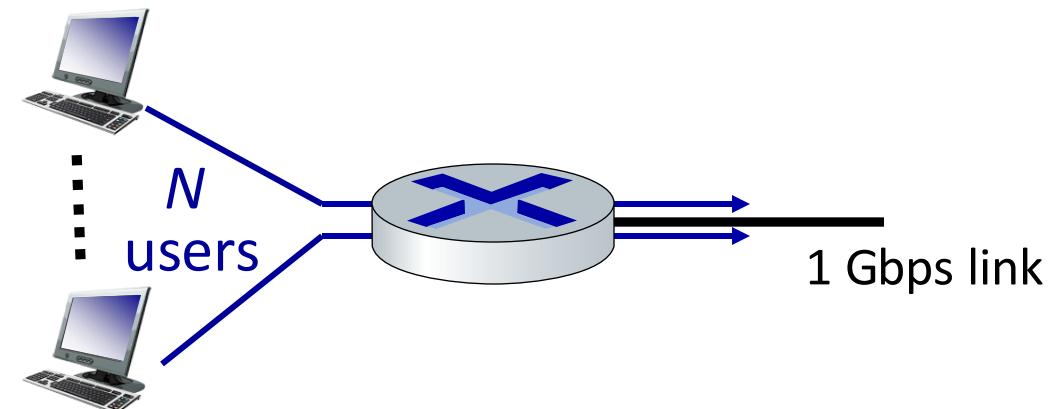


Packet switching versus circuit switching

packet switching allows more users to use network!

Example:

- 1 Gb/s link
- each user:
 - 100 Mb/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 ?

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

Packet switching versus circuit switching

Is packet switching a “slam dunk winner”?

- great for “bursty” data – 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?**
 - bandwidth guarantees traditionally used for audio/video applications

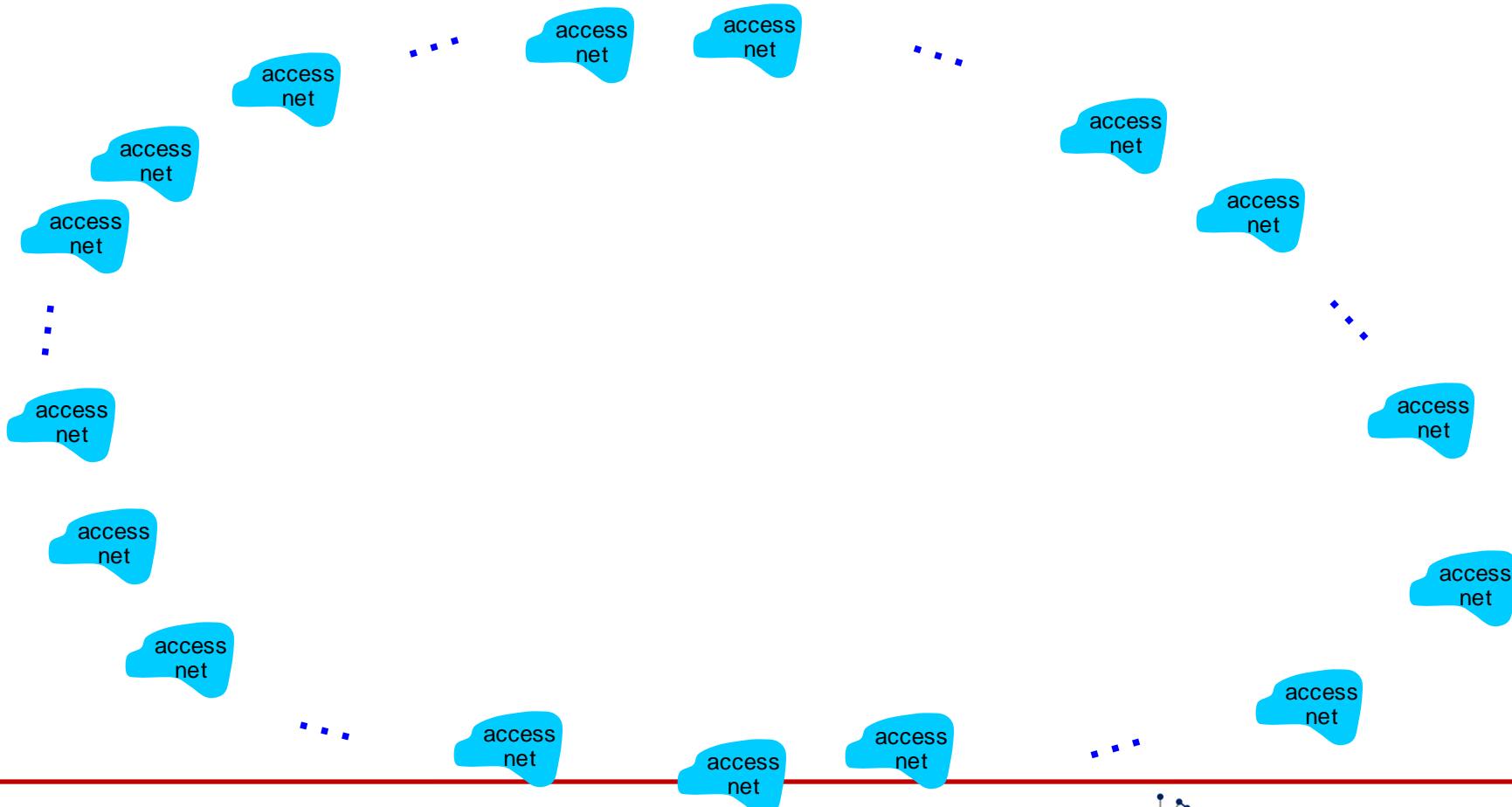
Q: human analogies of reserved resources (circuit switching)
versus on-demand allocation (packet switching)?

Internet structure: a “network of networks”

- Hosts connect to Internet via **access** Internet Service Providers (ISPs)
 - residential, enterprise (company, university, commercial) 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

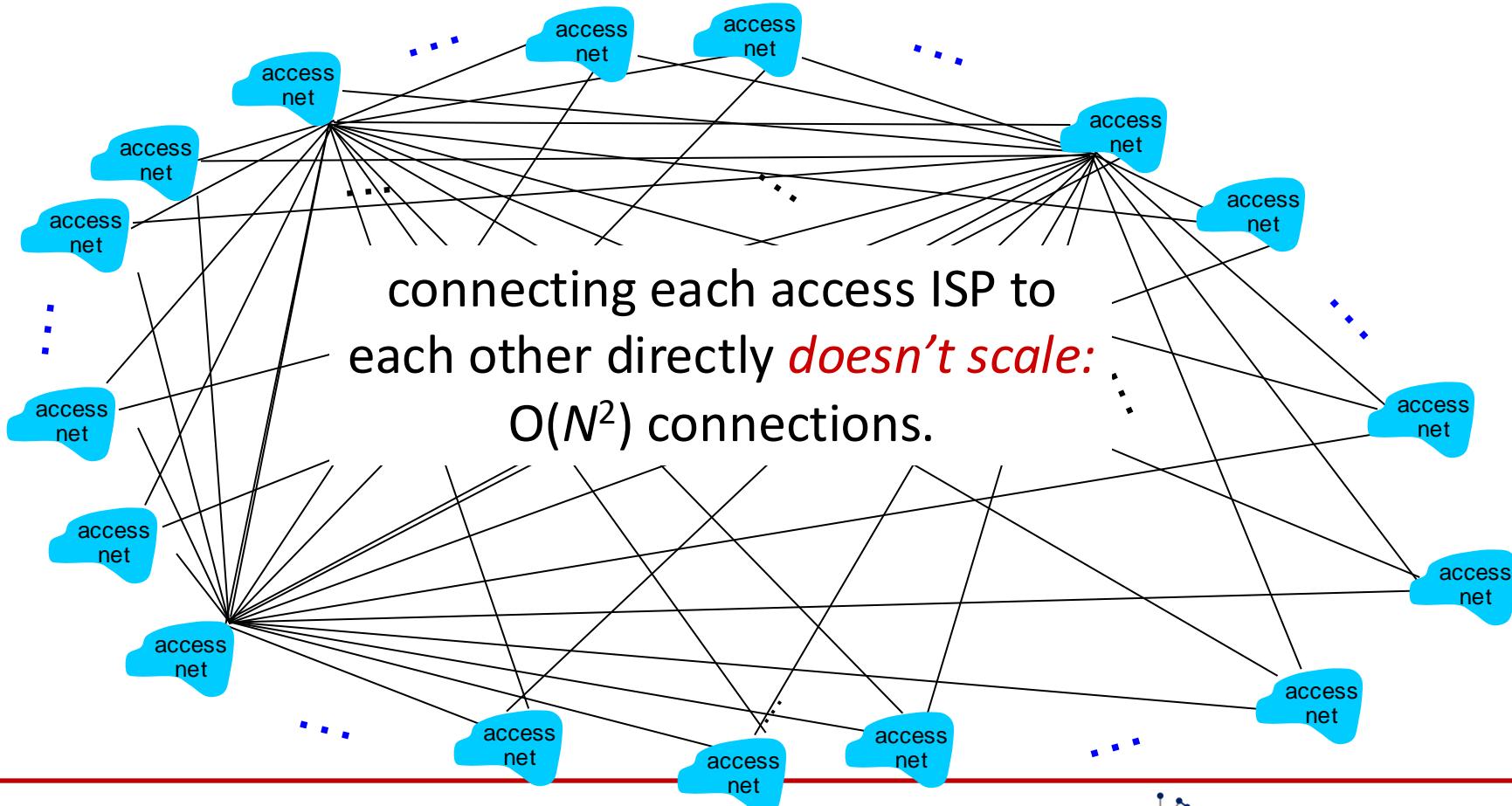
Internet structure: a “network of networks”

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



Internet structure: a “network of networks”

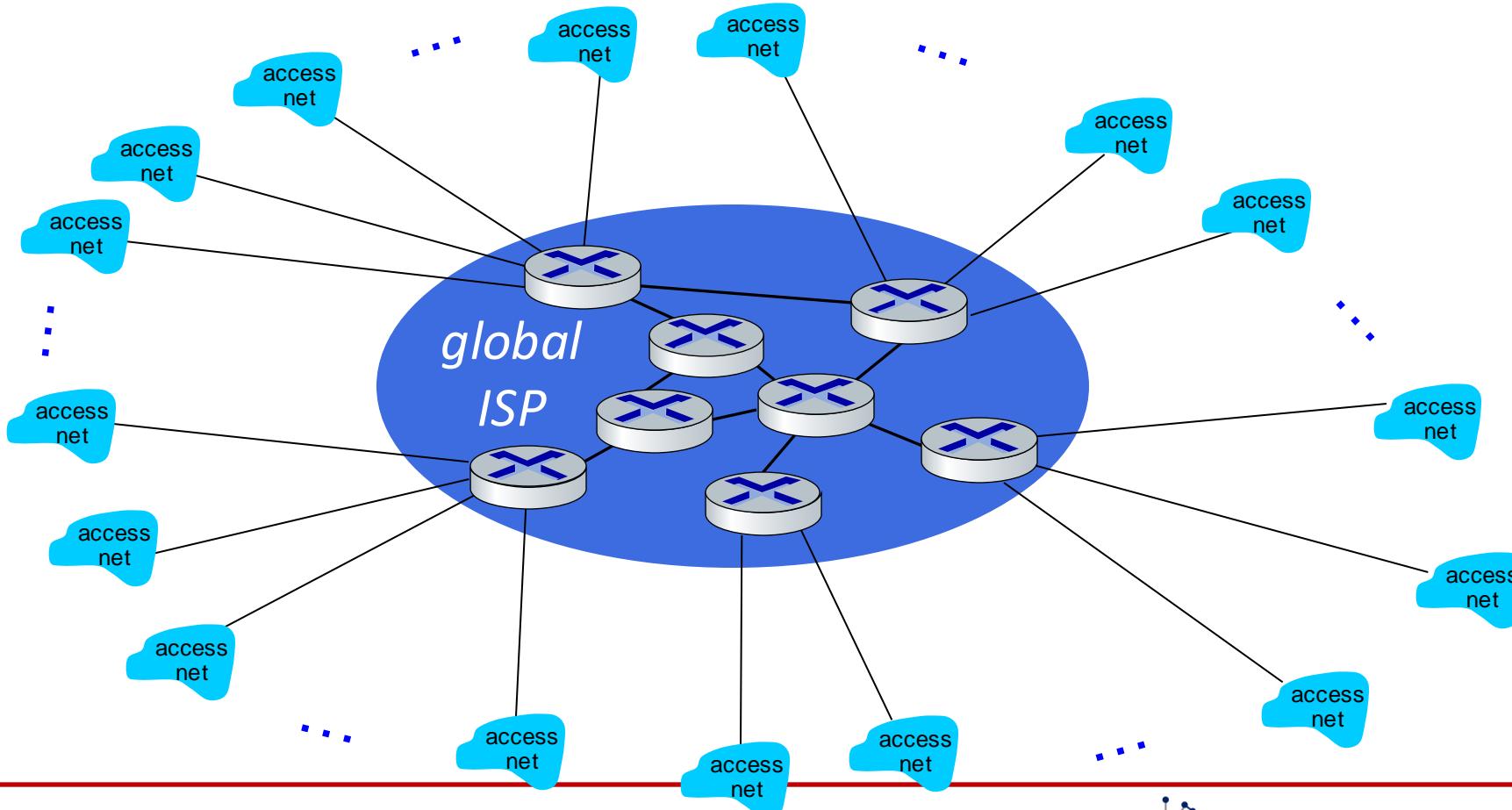
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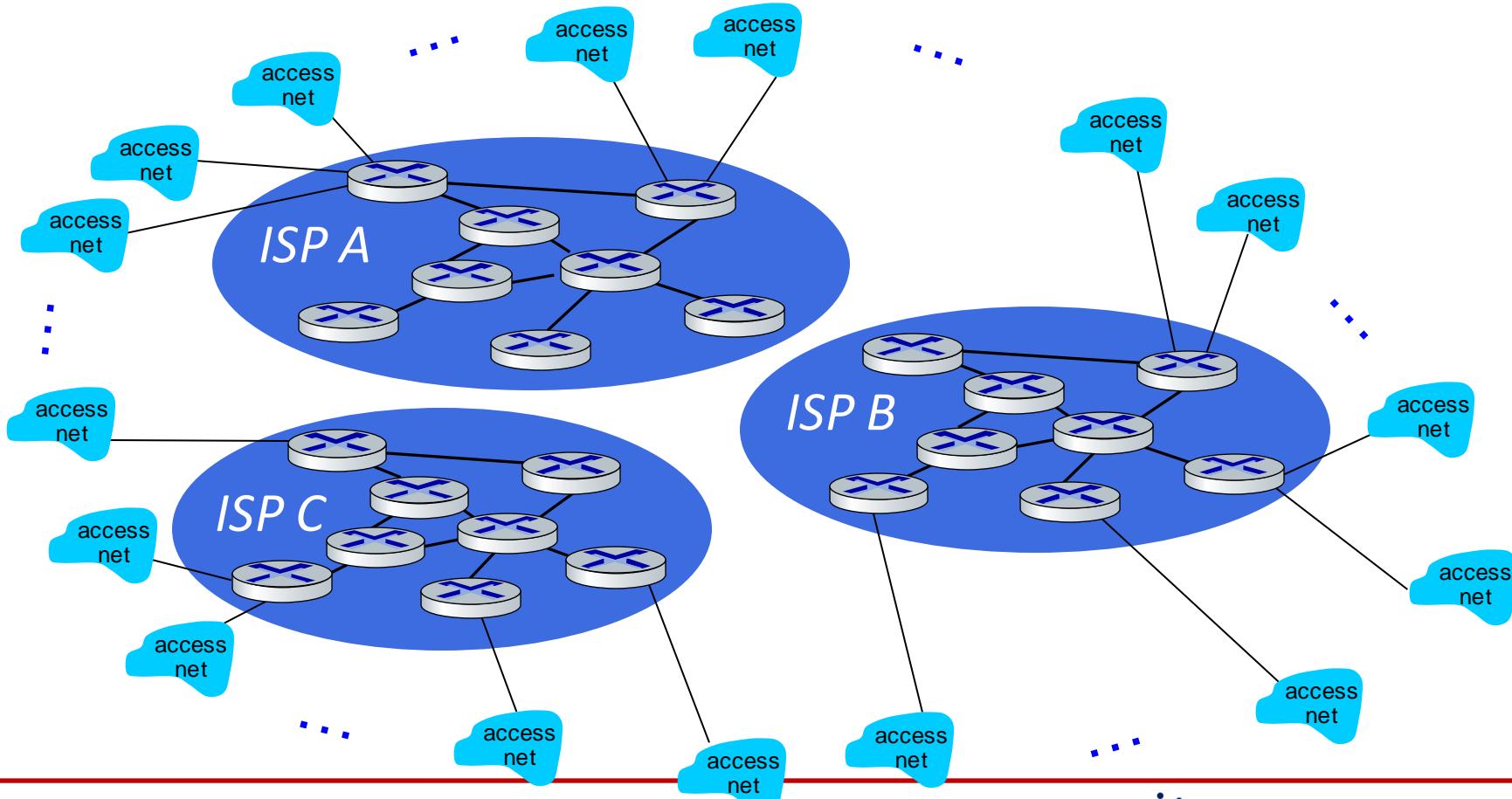
Option: connect each access ISP to one global transit ISP?

Customer and provider ISPs have economic agreement.



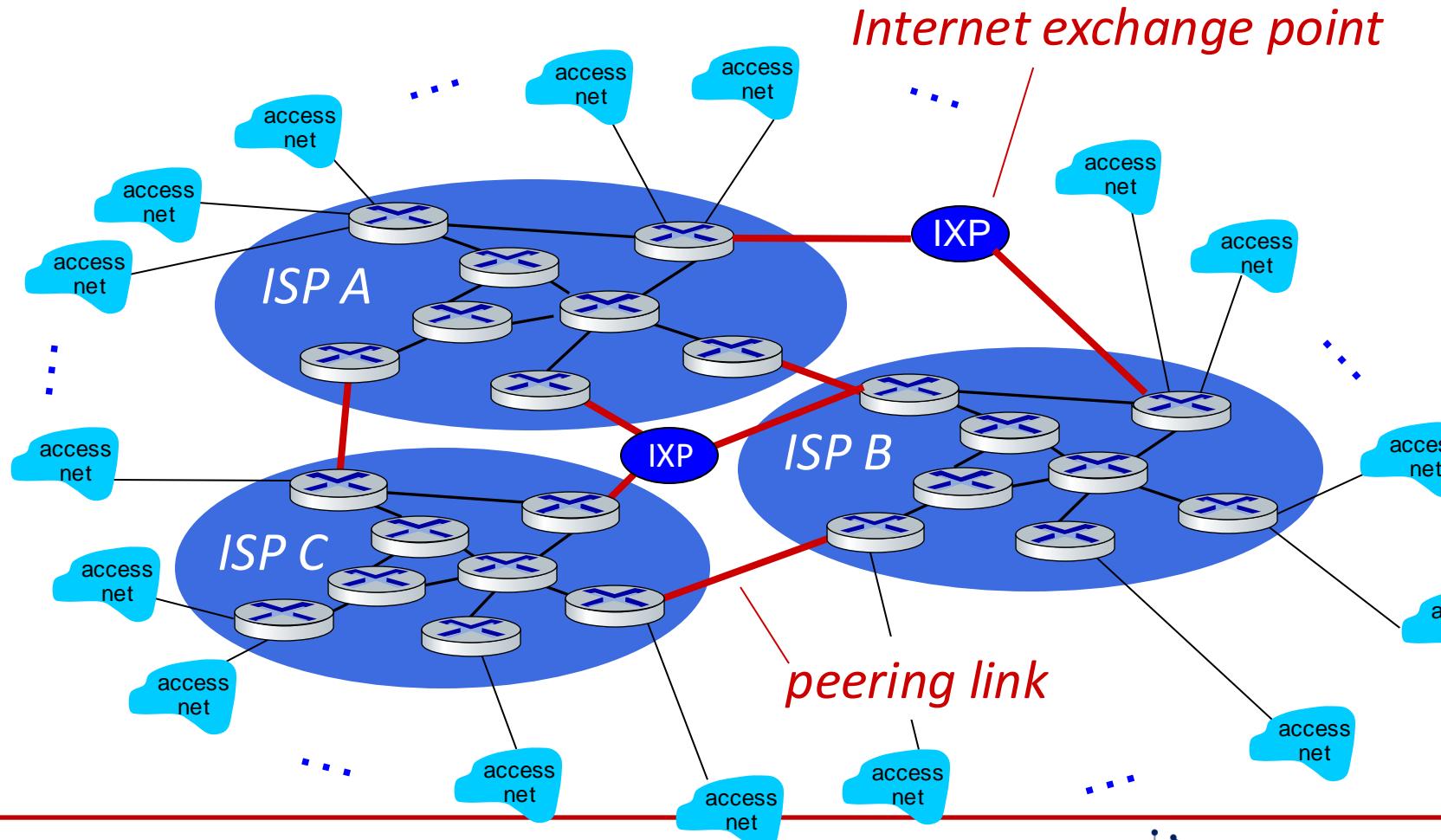
Internet structure: a “network of networks”

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



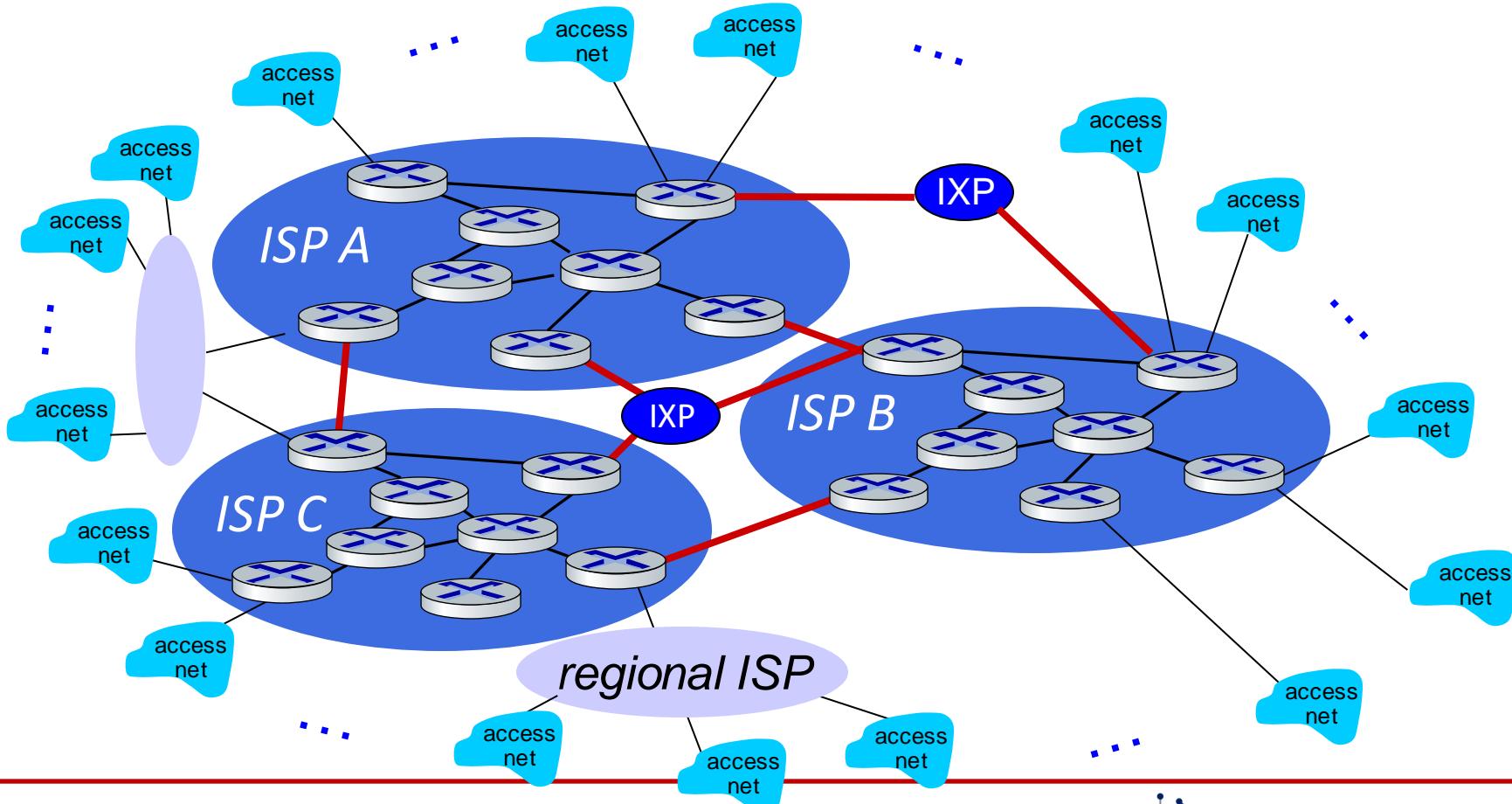
Internet structure: a “network of networks”

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



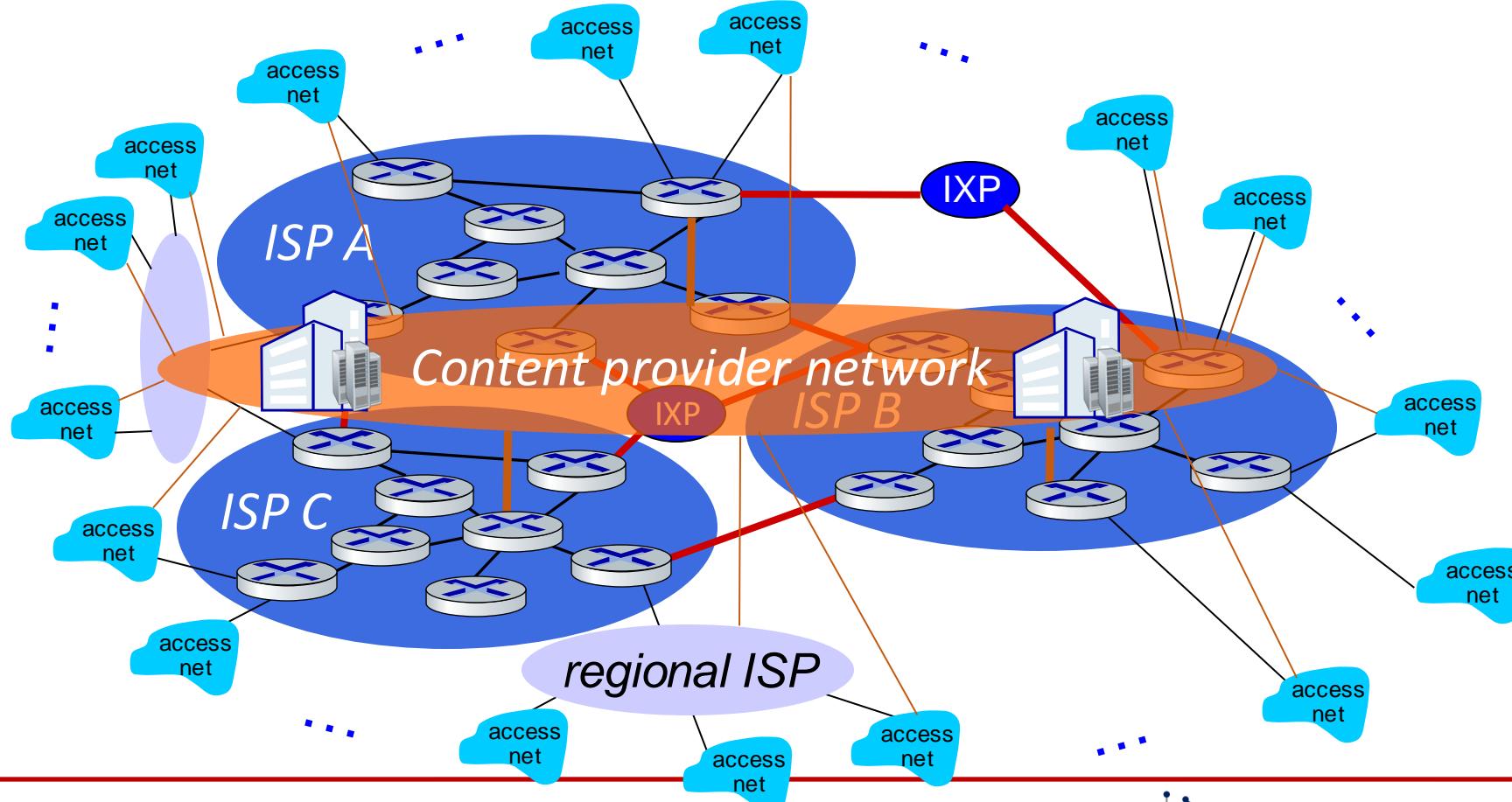
Internet structure: a “network of networks”

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

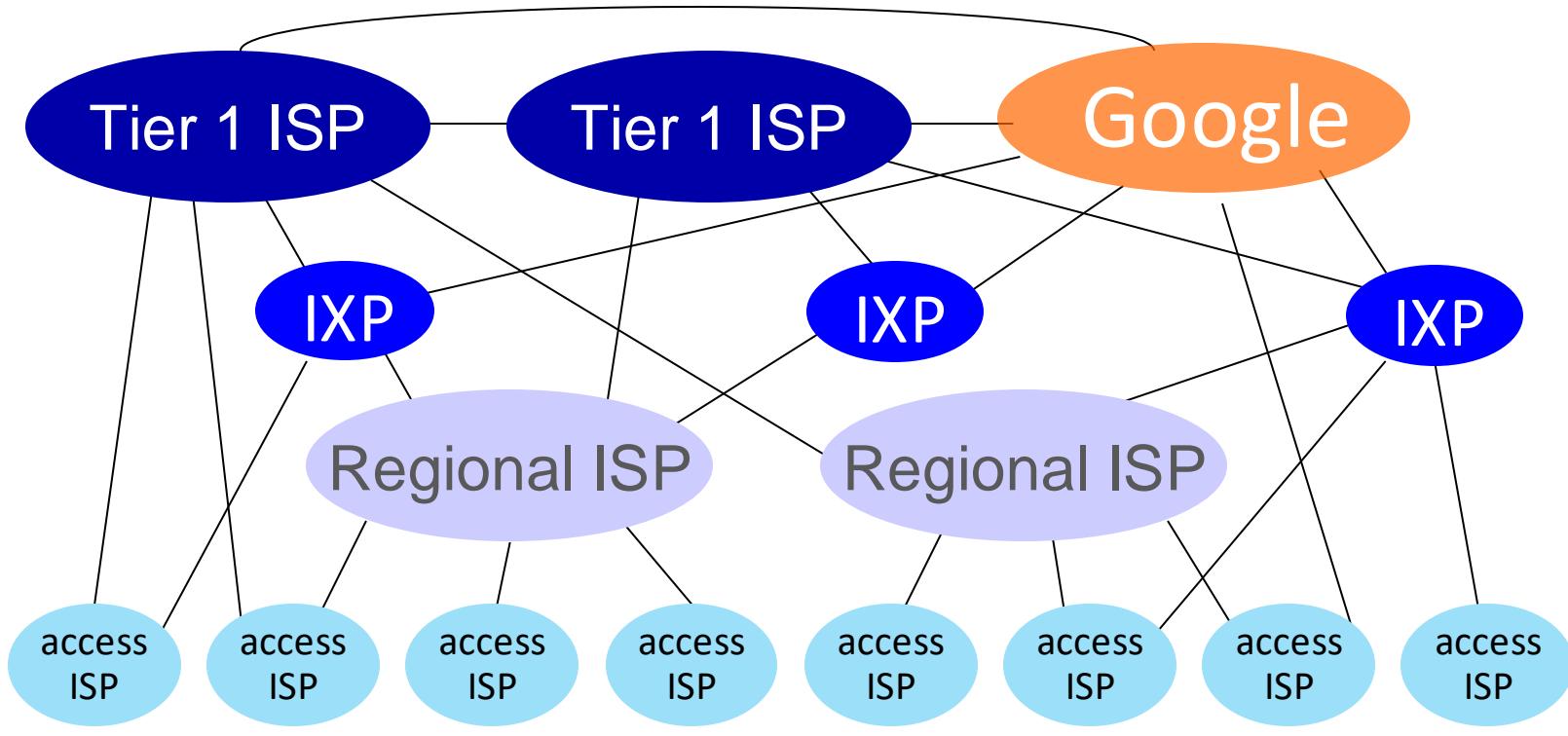


Internet structure: a “network of networks”

... 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

Tier-1 ISP Network map: Sprint (2019)

