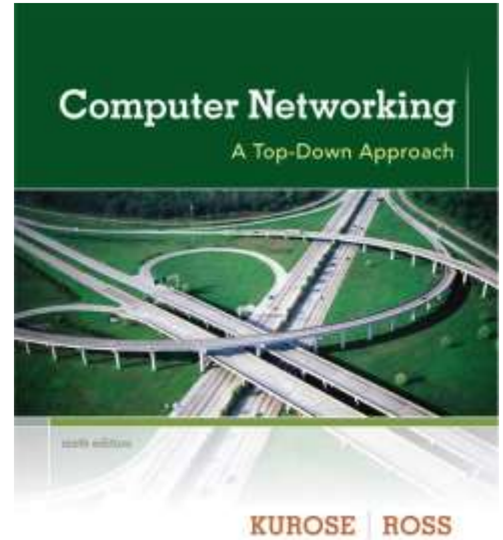
Chapter 1
Introduction



Lecture 2

Computer Networking: A Top Down Approach
6th edition
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Addison-Wesley
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Chapter 1: 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

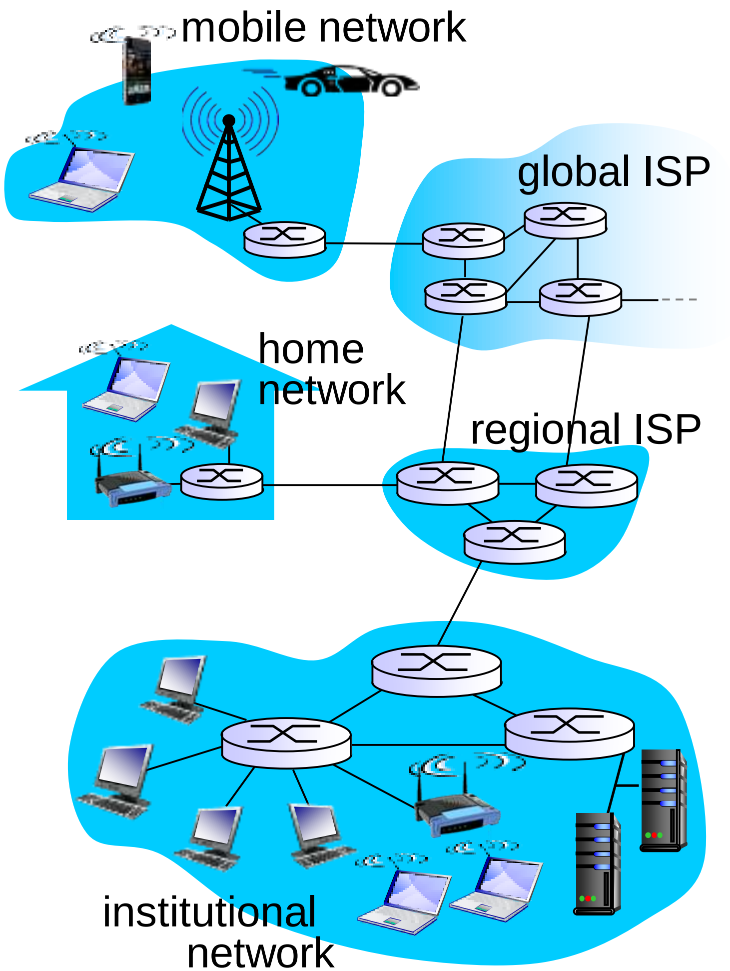
1.5 protocol layers, service models

1.6 networks under attack: security

1.7 history

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



end systems:

❖End systems are also referred to as *hosts because they host (that is, run) application* programs such as a Web browser program, a Web server program, an e-mail client program, ...

❖ Hosts are sometimes further divided into two categories: **clients and servers.**

❖clients tend to be *(desktop and mobile PCs,smartphones, and so on,)*

❖servers tend to be*(more powerful machines that store and distribute Web pages, stream video, and so on).*

❖ servers often in data centers

For example, Google has 30–50 data centers, with many having more than one hundred thousand servers.

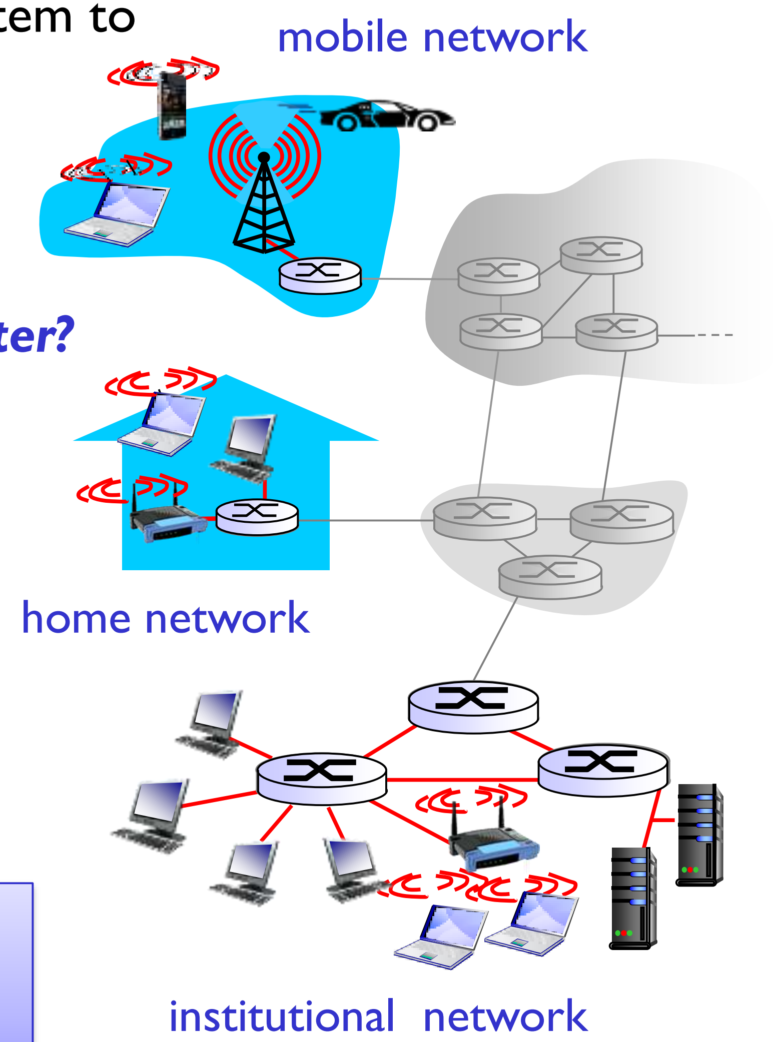
access networks

❖the network that physically connects an end system to the first router (also known as the "edge router")

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

- home access network
- institutional access networks (school, company)
- mobile access networks

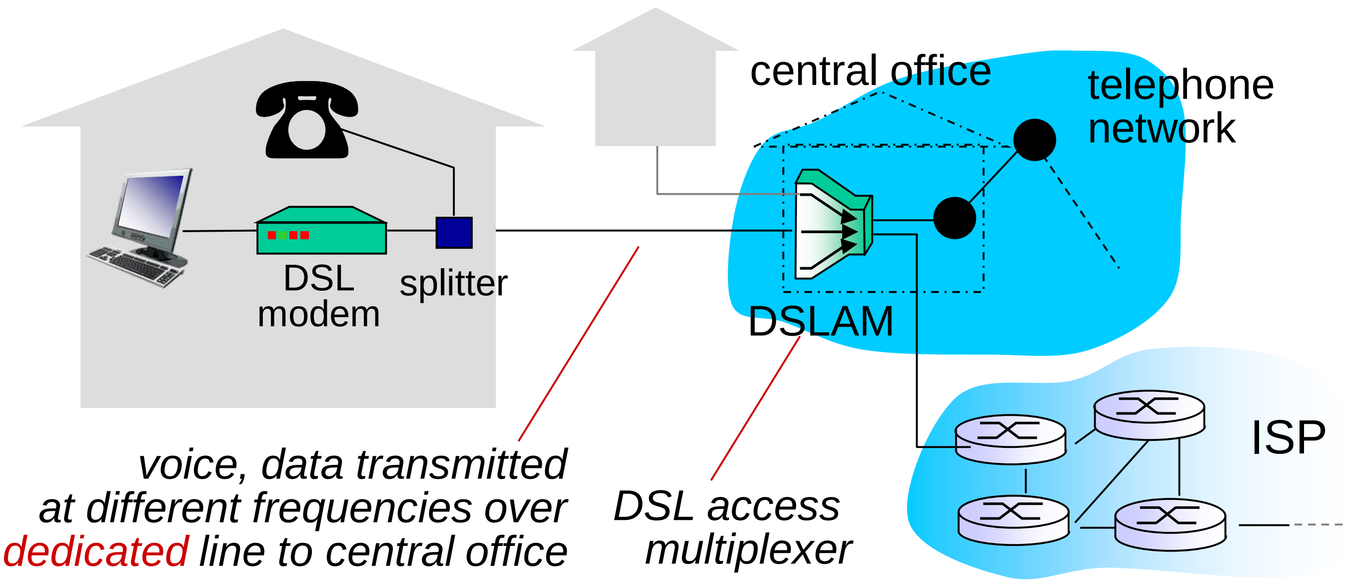
keep in mind:
bandwidth (bits per second) of access network shared or dedicated?



Home access nets (DSL, Cable, and Satellite)

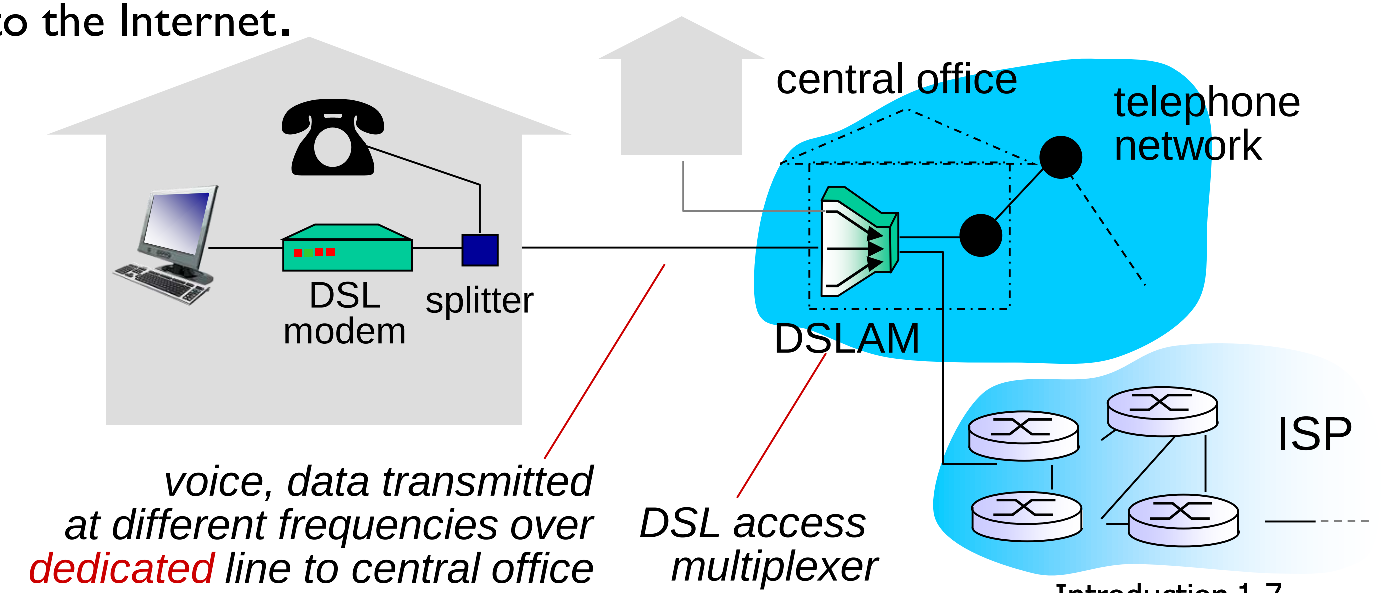
Digital subscriber line (DSL)

- residence typically obtains DSL Internet access from the same local telephone company (telco).
- each customer's DSL modem uses the existing telephone line to exchange data with a digital subscriber line access multiplexer (DSLAM).
- (DSLAM) located in the telco's local central office (CO).
- The home's DSL modem takes digital data and translates it to high frequency tones for transmission over telephone wires to the CO;

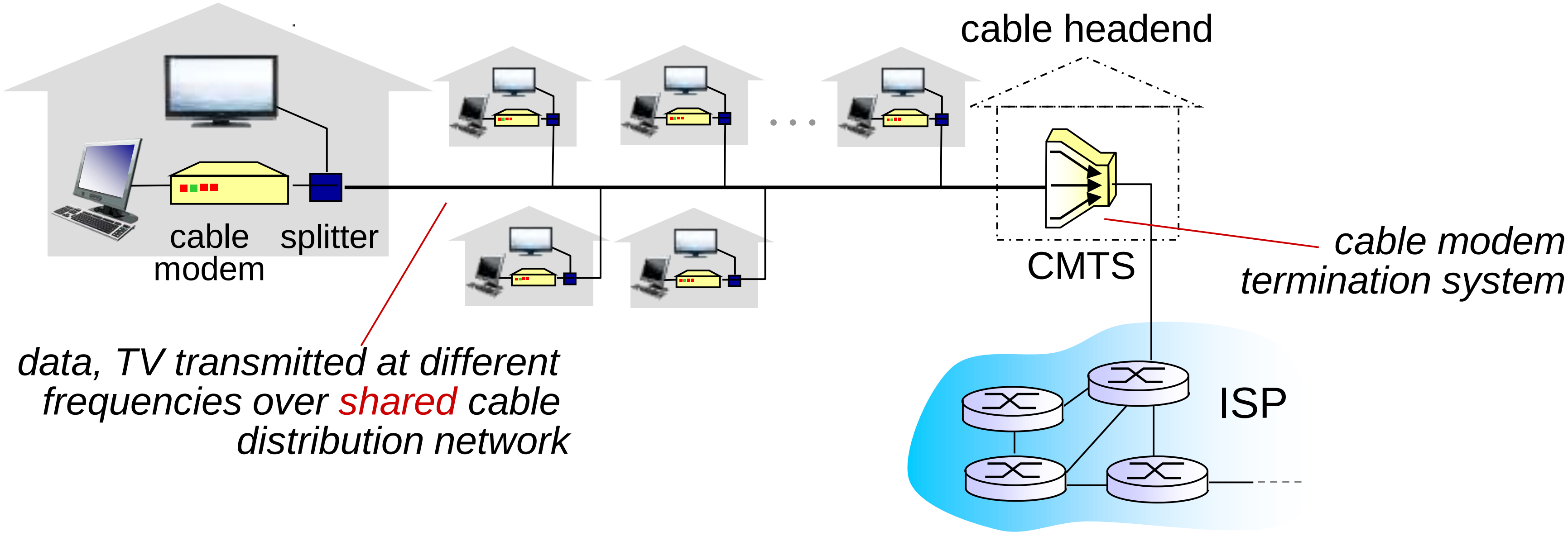


- the analog signals from many such houses are translated back into digital format at the DSLAM.
- a telephone call and an Internet connection can share the DSL link at the same time.
    - data over DSL phone line goes to Internet
    - voice over DSL phone line goes to telephone net
    - < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
    - < 24 Mbps downstream transmission rate (typically < 10 Mbps)

- On the customer side, a splitter separates the data and telephone signals arriving to the home and forwards the data signal to the DSL modem.
- On the telco side, in the CO, the DSLAM separates the data and phone signals and sends the data into the Internet.



Access net: cable network



- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable head end
  - unlike DSL, which has dedicated access to central office

Access net: cable network

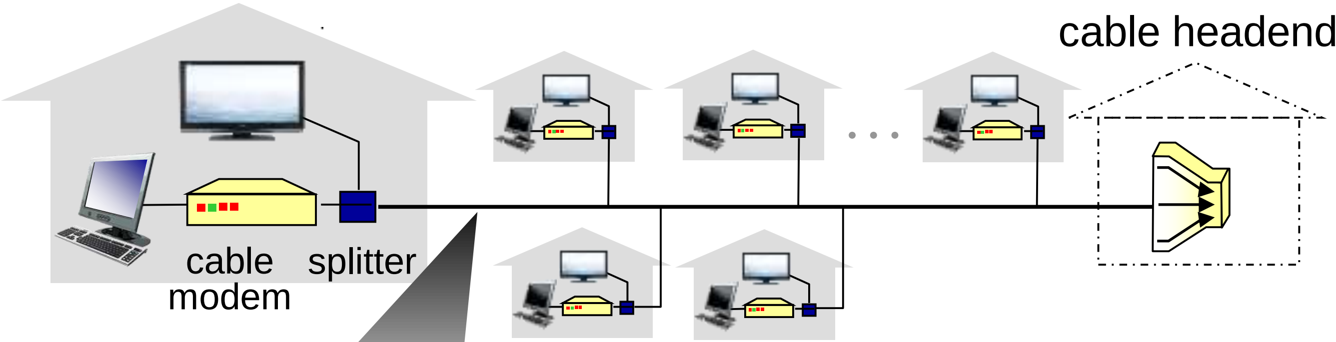
- Cable internet access requires special modems, called cable modems
- the cable modem is typically an external device and connects to the home PC.

- At the cable head end, the cable modem termination system (CMTS) turning the analog signal sent from the cable modems in many downstream homes back into digital format.

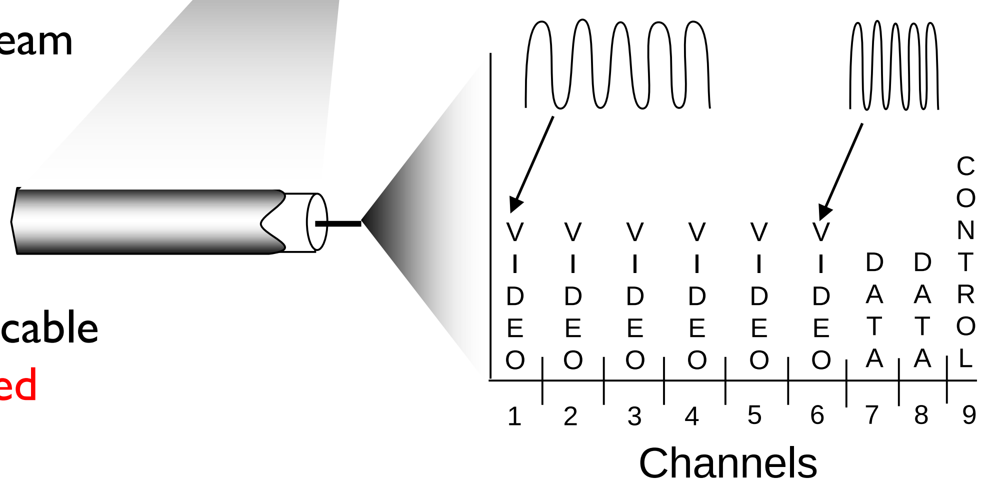
- Cable modems divide the HFC (hybrid fiber coax) network into two channels, a downstream and an upstream channel

every packet sent by the head end travels downstream on every link to every home and every packet sent by a home travels on the upstream channel to the head end.

Access net: cable network



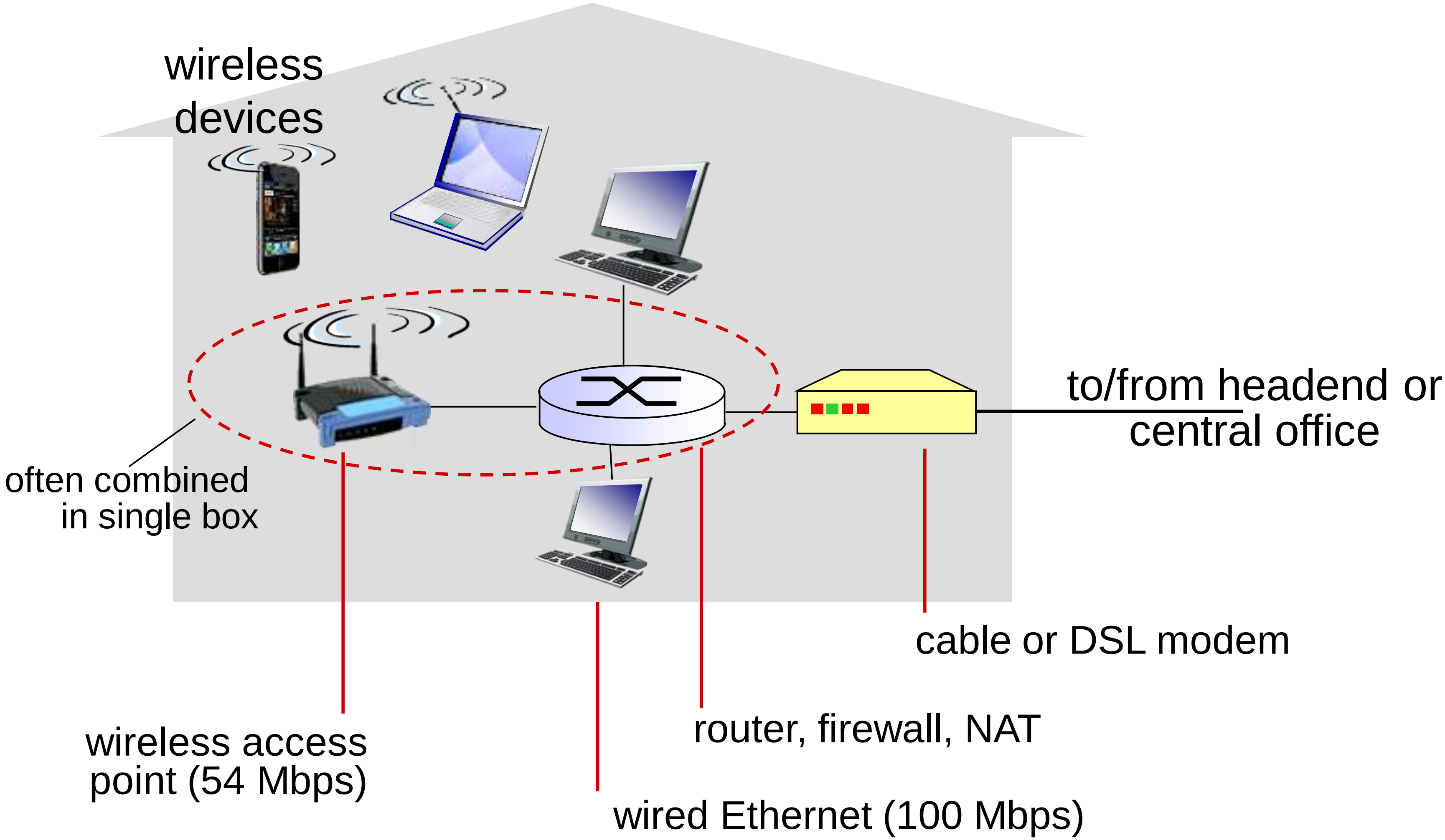
- asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate.



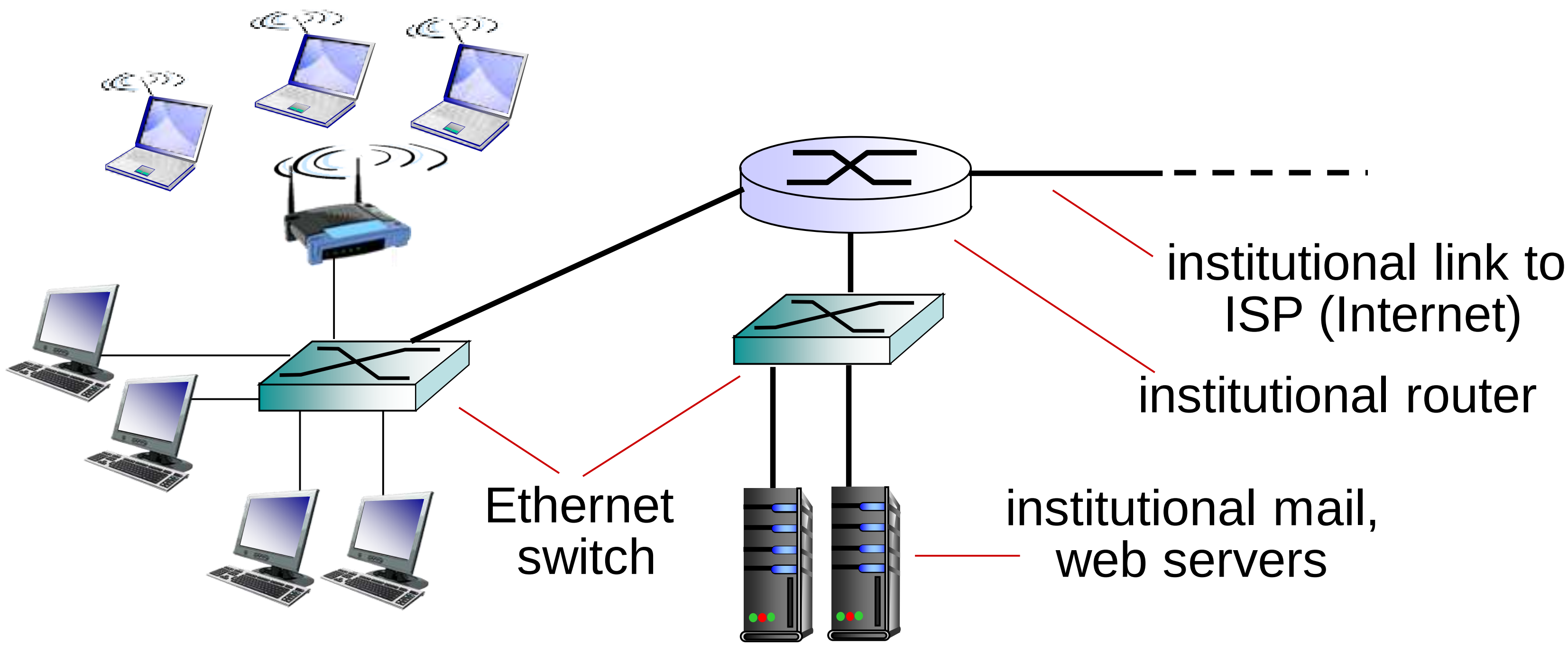
- One important characteristic of cable Internet access is that it is a shared broadcast medium.

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

Access net: home network



Enterprise access networks (Ethernet)



- typically used in companies, universities, etc
- The Ethernet switch or network is used to connect an end system to the edge router.
- The Ethernet switch or network , is then in turn connected into the larger Internet.
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates

Wireless access networks

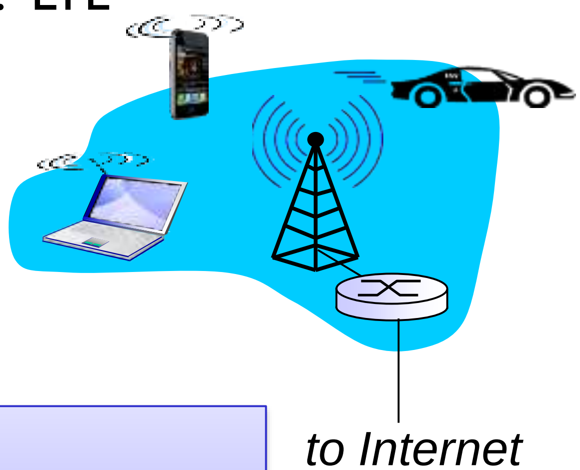
- shared *wireless* access network connects end system to router
  - via base station aka "access point"

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

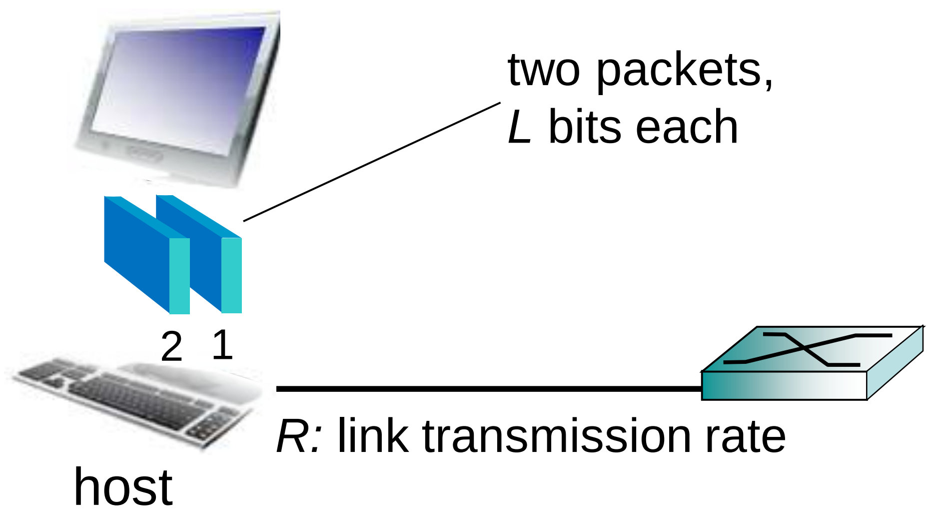


- ➢third-generation (3G) wireless, at speeds in excess of 1 Mbps.
- ➢higher-speed wide-area access technologies—a fourth-generation (4G)
- ➢ LTE (for "Long-Term Evolution", and can potentially achieve rates in excess of 10 Mbps.

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*



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

Transmission media

- For each transmitter-receiver pair, the bit is sent by propagating electromagnetic waves or optical pulses across a **physical medium.**

- Physical media fall into two categories: **guided media and unguided media**

With guided media, the waves are guided along a solid medium, such as a fiber-optic cable, a twisted-pair copper wire, or a coaxial cable

With unguided media, the waves propagate in the atmosphere and in outer space, such as in a wireless LAN or a digital satellite channel.

guided media

twisted pair (TP)

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

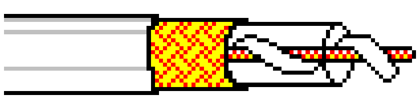
- The data rates that can be achieved depend on the thickness of the wire and the distance between transmitter and receiver.

- The least expensive
- The wires are twisted together to reduce the electrical interference .

guided media

coaxial cable:

- two concentric copper conductors
- Bidirectional
- Coaxial cable is quite common in cable television systems.
- broadband:
  - Coaxial cable can be used as a guided **shared medium**



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:
  - immune to electromagnetic noise

unguided media ' Radio Channels'

- signal carried in electromagnetic spectrum
- no physical "wire"
- can penetrate walls,
- carry a signal for long distances.

propagation environment effects:

- reflection (multipath fading (due to signal reflection off of interfering objects)
- obstruction by objects(which decrease the signal strength as the signal travels over a distance and around/through obstructing objects),
- Interference: (due to other transmissions and electromagnetic signals).

radio link types:

- microwave
  - up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
- Satellite
  - satellite links, which can operate at speeds of hundreds of Mbps,.
  - The huge distance from ground station through satellite back to ground station introduces a substantial signal propagation delay of 280 milliseconds.

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- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

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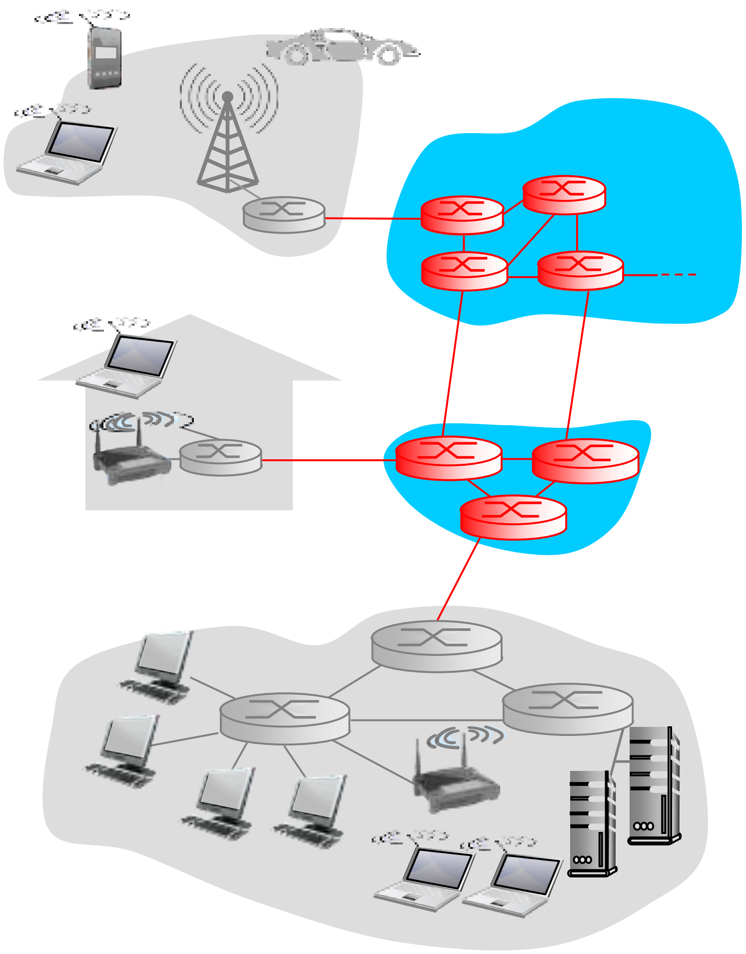
The network core

- the mesh of packet switches and links that interconnects the Internet's end systems.

- There are two fundamental approaches to moving data through a network of links and switches : **(packet switching and circuit switching .)**

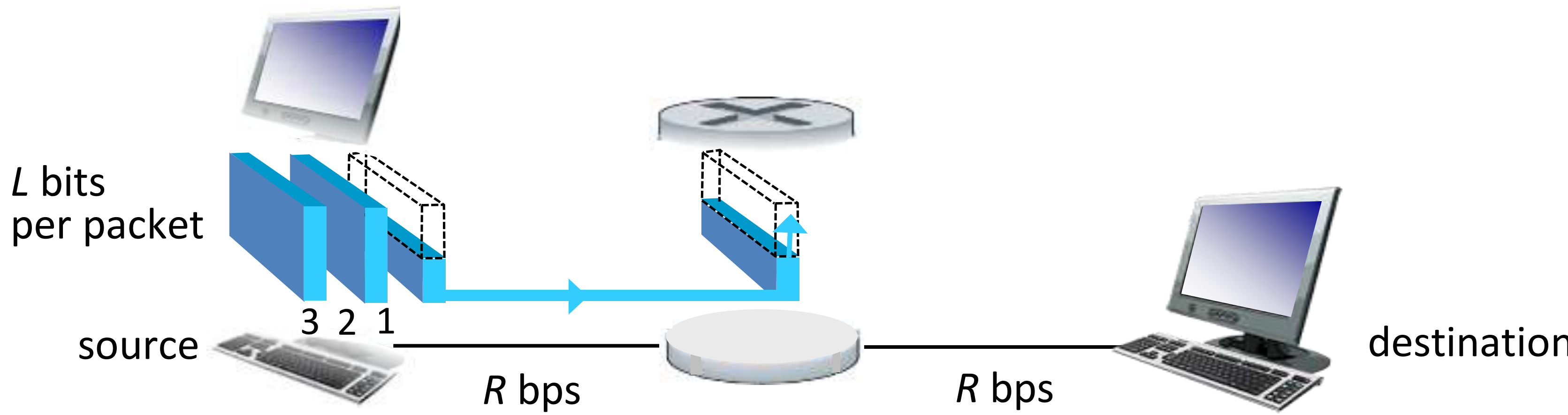
- **packet-switching:**
- To send a message from a source end system to a destination end system, the source breaks long messages into smaller chunks of data known as **packets.**

- 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

store and forward: entire packet must arrive at router before it can be transmitted on next link.

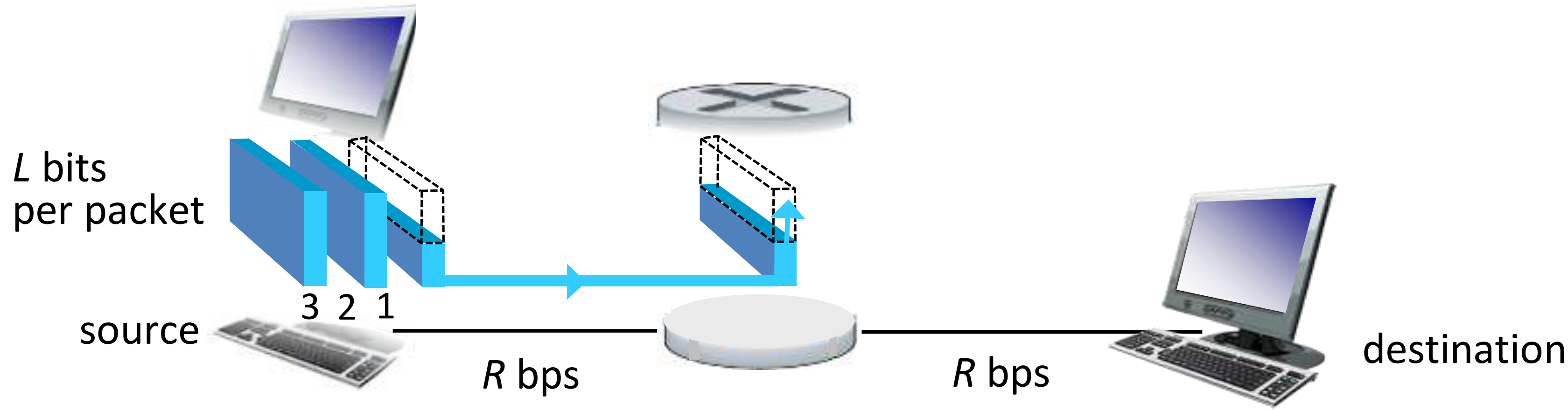


Ex:

- the router has the rather simple task of transferring a packet from one (input) link to the only other attached link.

- the source has three packets, each consisting of *L bits, to send to the destination*.
  the source has transmitted some of packet 1, and the front of packet 1 has already arrived at the router.
- the router employs store-and-forwarding, at this instant of time, the router cannot transmit the bits it has received, it "store" the packet's bits.
- Only after the router has received *all of the packet's bits*. can it begin to transmit "forward" the packet onto the outbound link.

Packet-switching: store-and-forward



- takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps*(at the router)*
- end-end delay = 2*L*/*R*

one-hop numerical example:

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

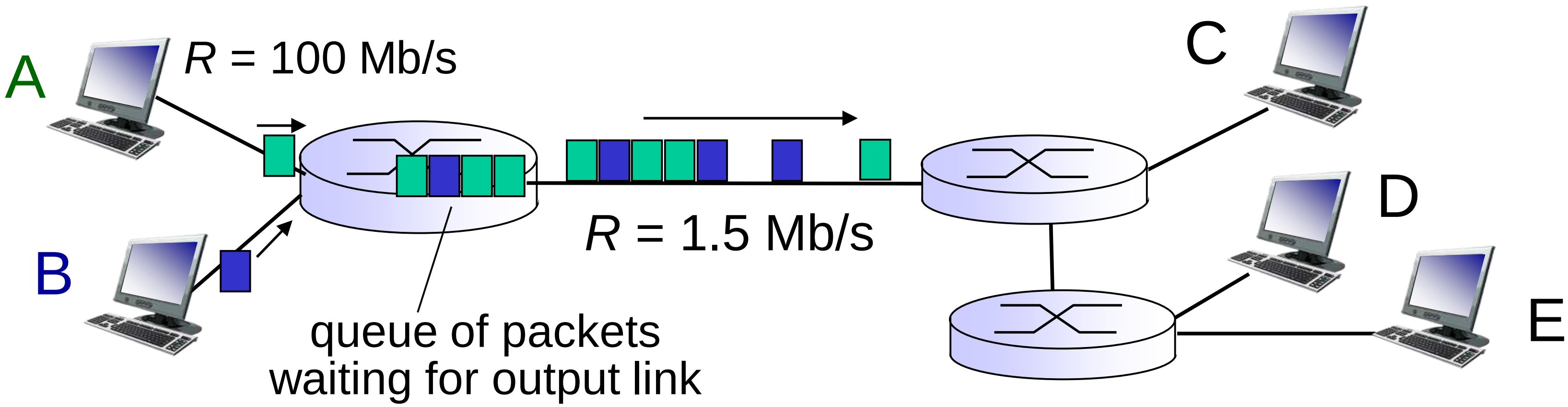
Keep In mind

end-end delay = N *L*/*R*

N links

there are *N-1 routers* between source and destination)

Packet Switching: queueing delay, loss



- The packet switch has an **output buffer (also called an output queue),** which stores packets that the router is about to send into that link.

- If an arriving packet needs to be transmitted onto a link but finds the link busy with the transmission of another packet, the arriving packet must wait in the output buffer.

Packet Switching: queueing delay, loss

- in addition to the store-and-forward delays, packets suffer output buffer **queuing delays.**

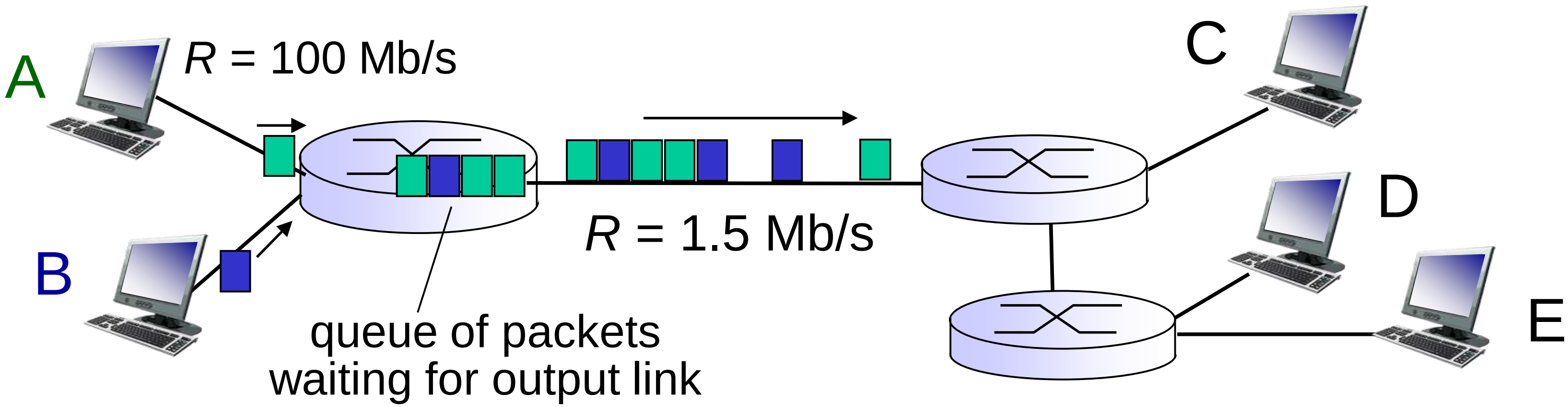
- an arriving packet may find that the buffer is completely full with other packets waiting for transmission. In this case, **packet loss** will occur

queuing delays are variable and depend on the level of congestion in the network.

- In this **ex**, all packets have the same width and hence the same length

- Suppose Hosts A and B are sending packets to Host E.

- Hosts A and B first send their packets along 100 Mbps Ethernet links to the first router.
- The router then directs these packets to the 1.5 Mbps link.



- congestion will occur at the router as packets queue in the link's output buffer before being transmitted onto the link.

queuing and loss:

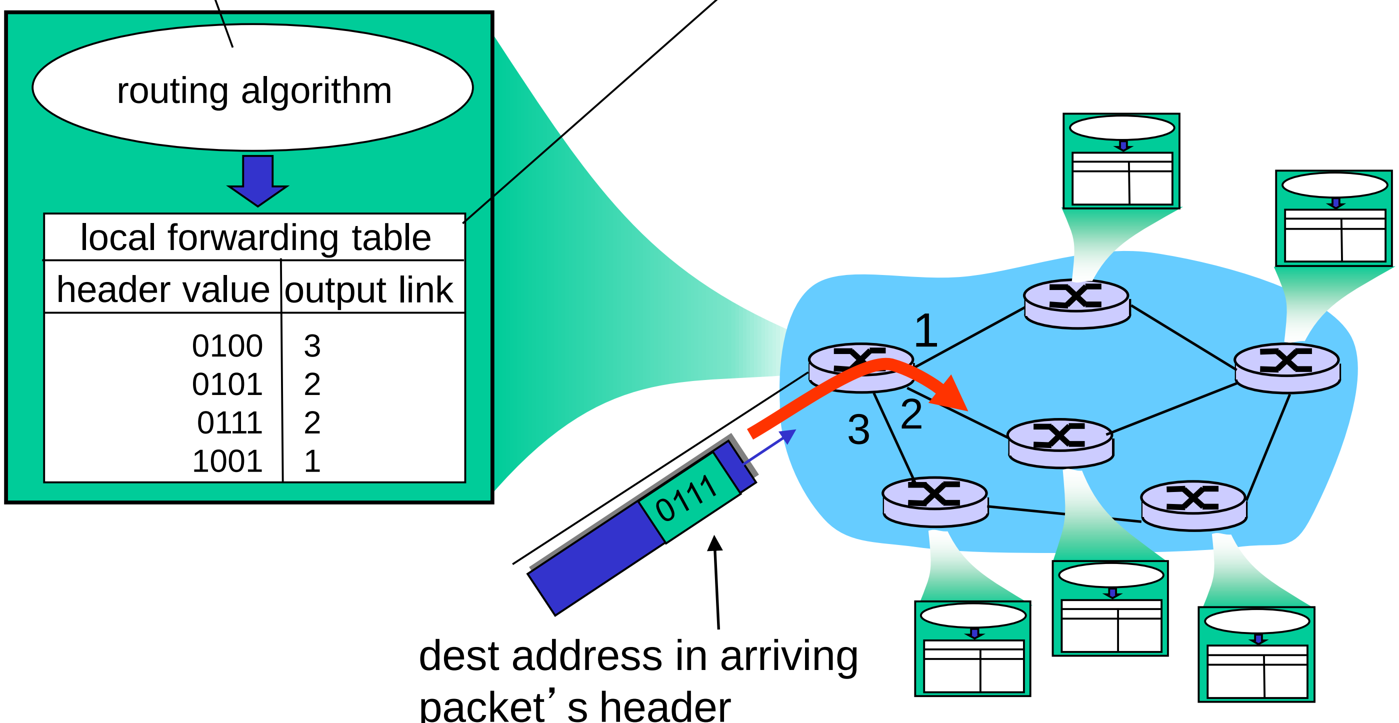
- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

Two key network-core functions

routing: determines source-destination route taken by packets

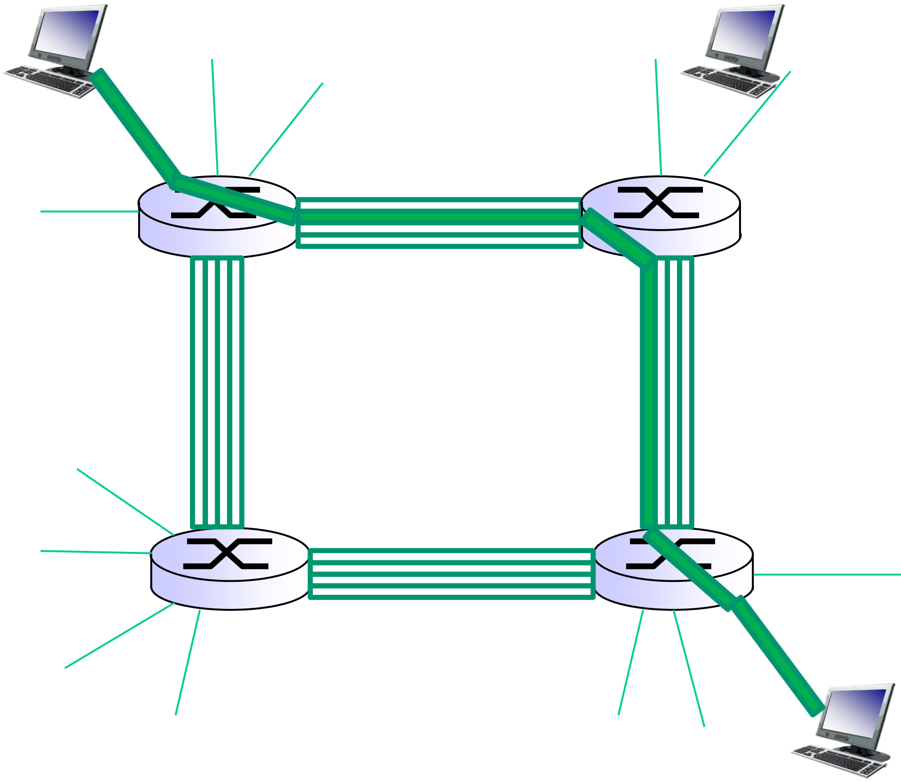
- *routing algorithms*

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:

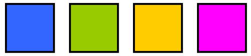


- In diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- Commonly used in traditional telephone networks

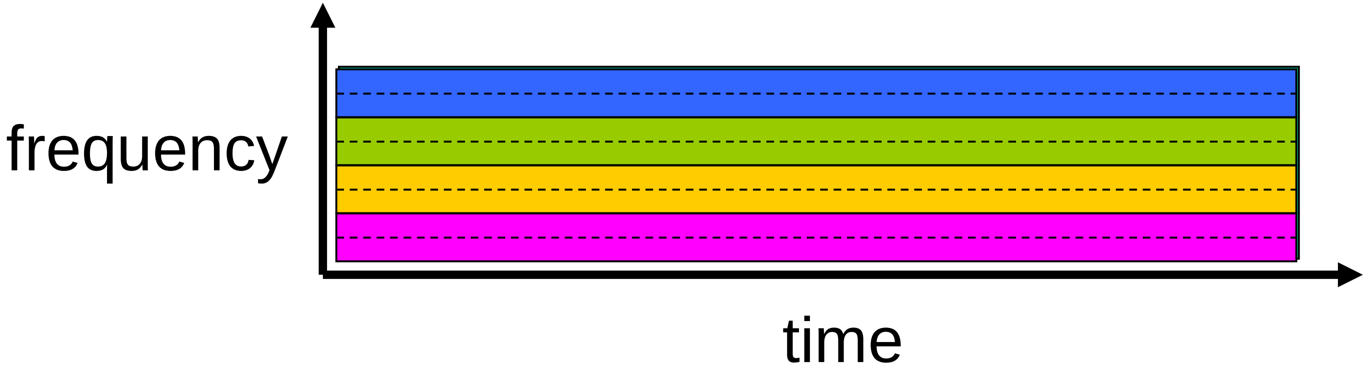
Circuit switching: FDM versus TDM

Example:

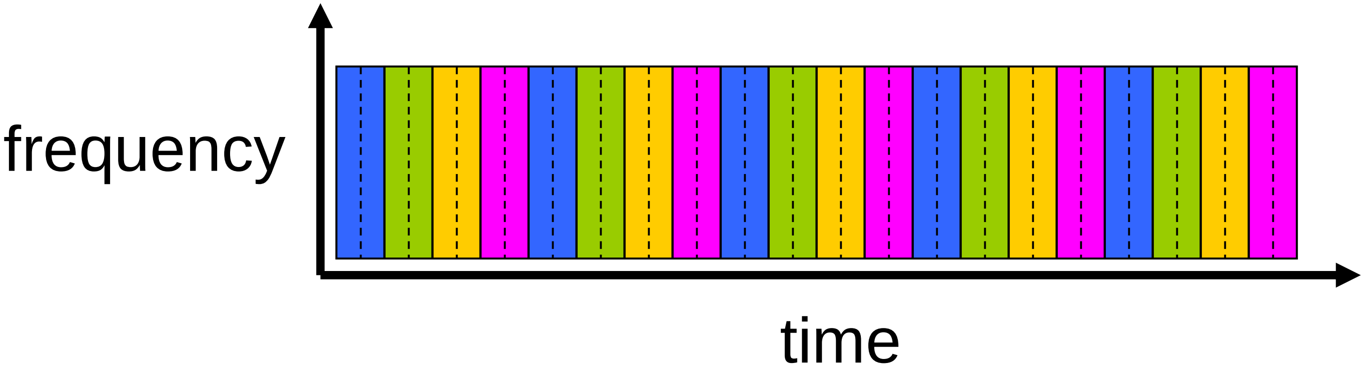
4 users



FDM



TDM

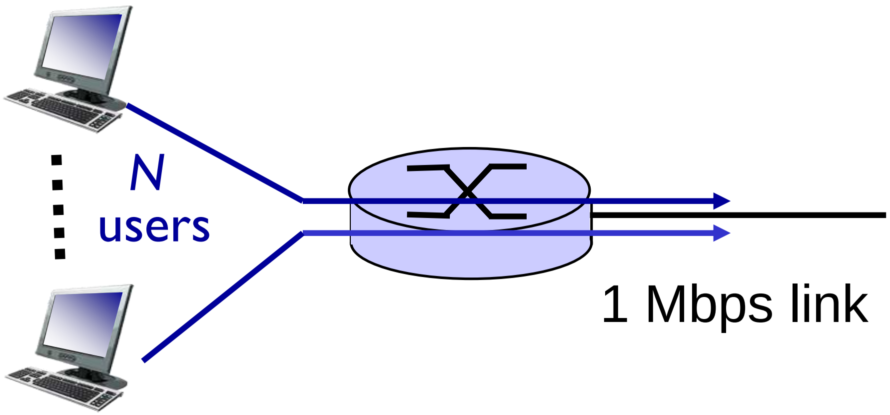


Packet switching versus circuit switching

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 *

* Check out the online interactive exercises for more examples

Packet switching versus circuit switching

is packet switching a "slam dunk winner?"

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 7)

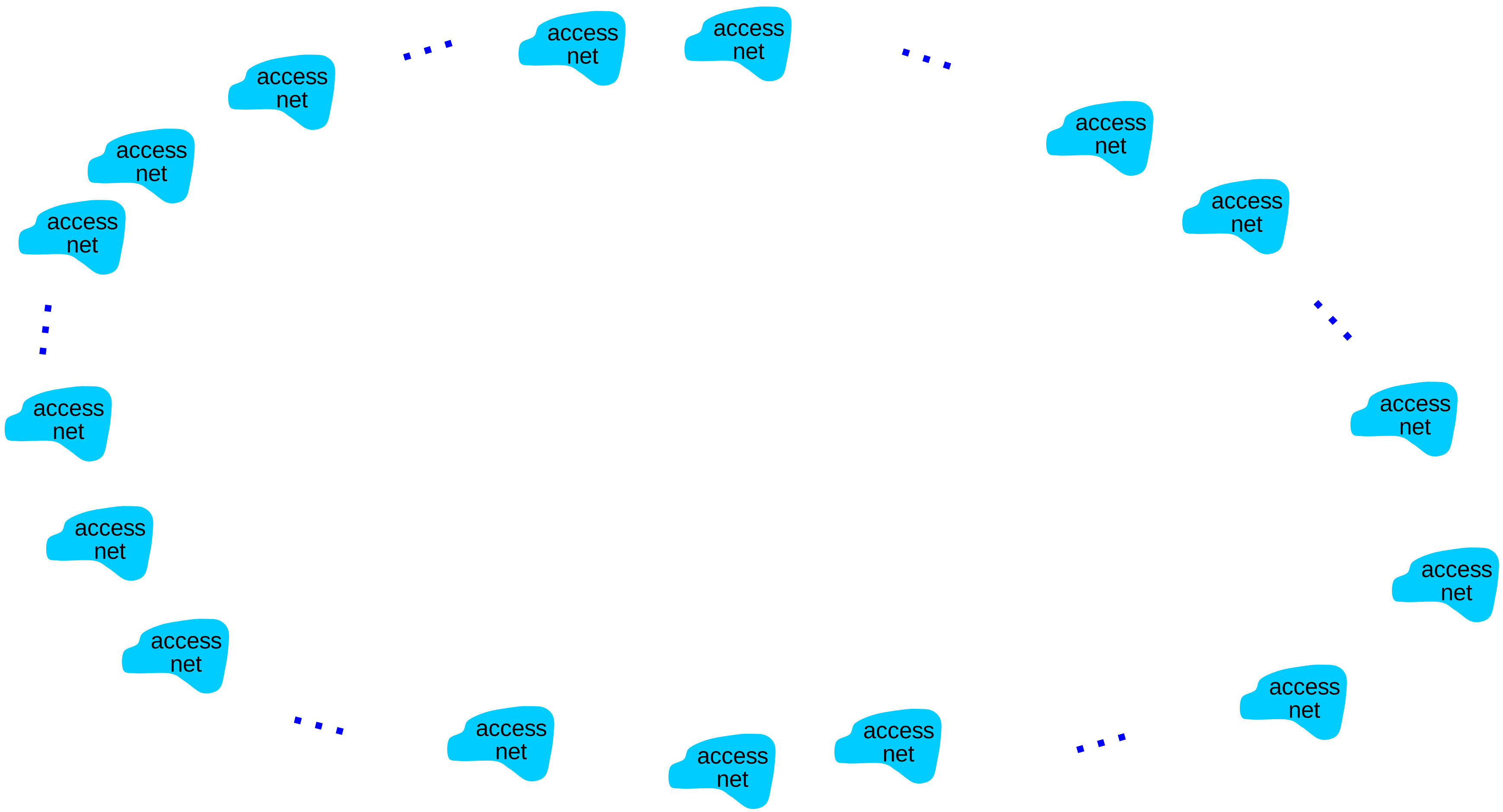
Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

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

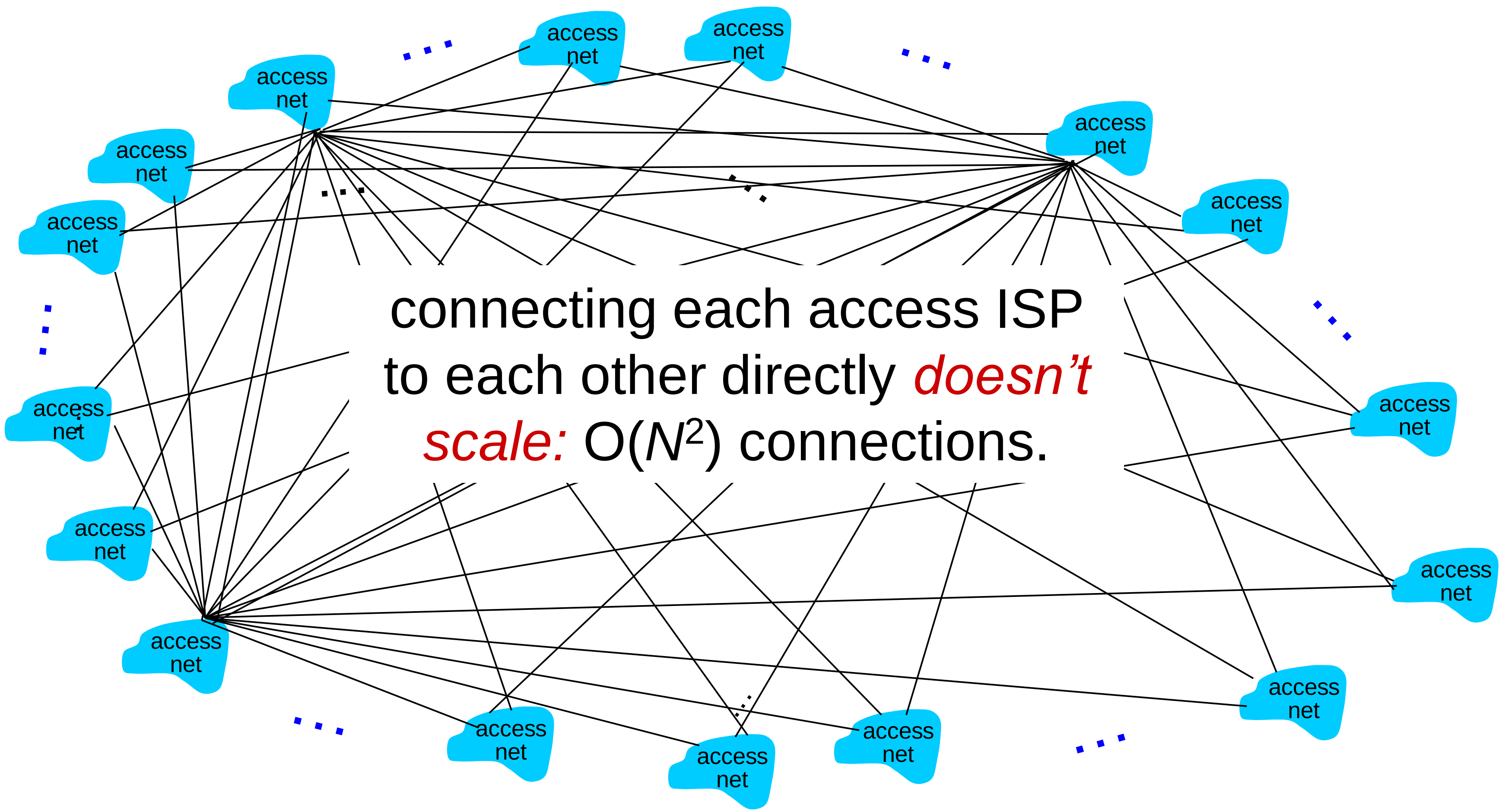
Internet structure: network of networks

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



Internet structure: network of networks

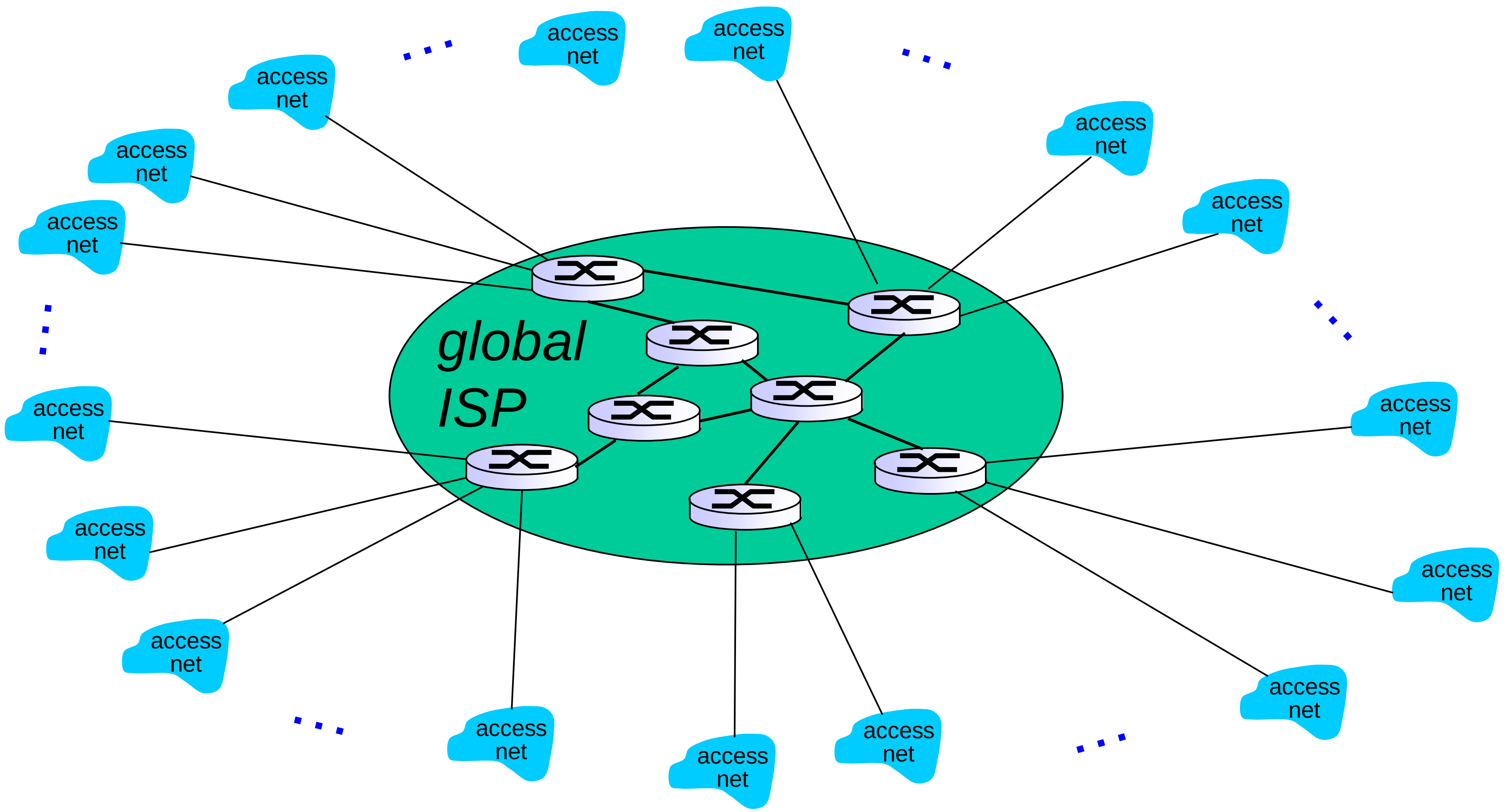
Option: connect each access ISP to every other access ISP?



connecting each access ISP to each other directly *doesn't scale:* O(N^2) connections.

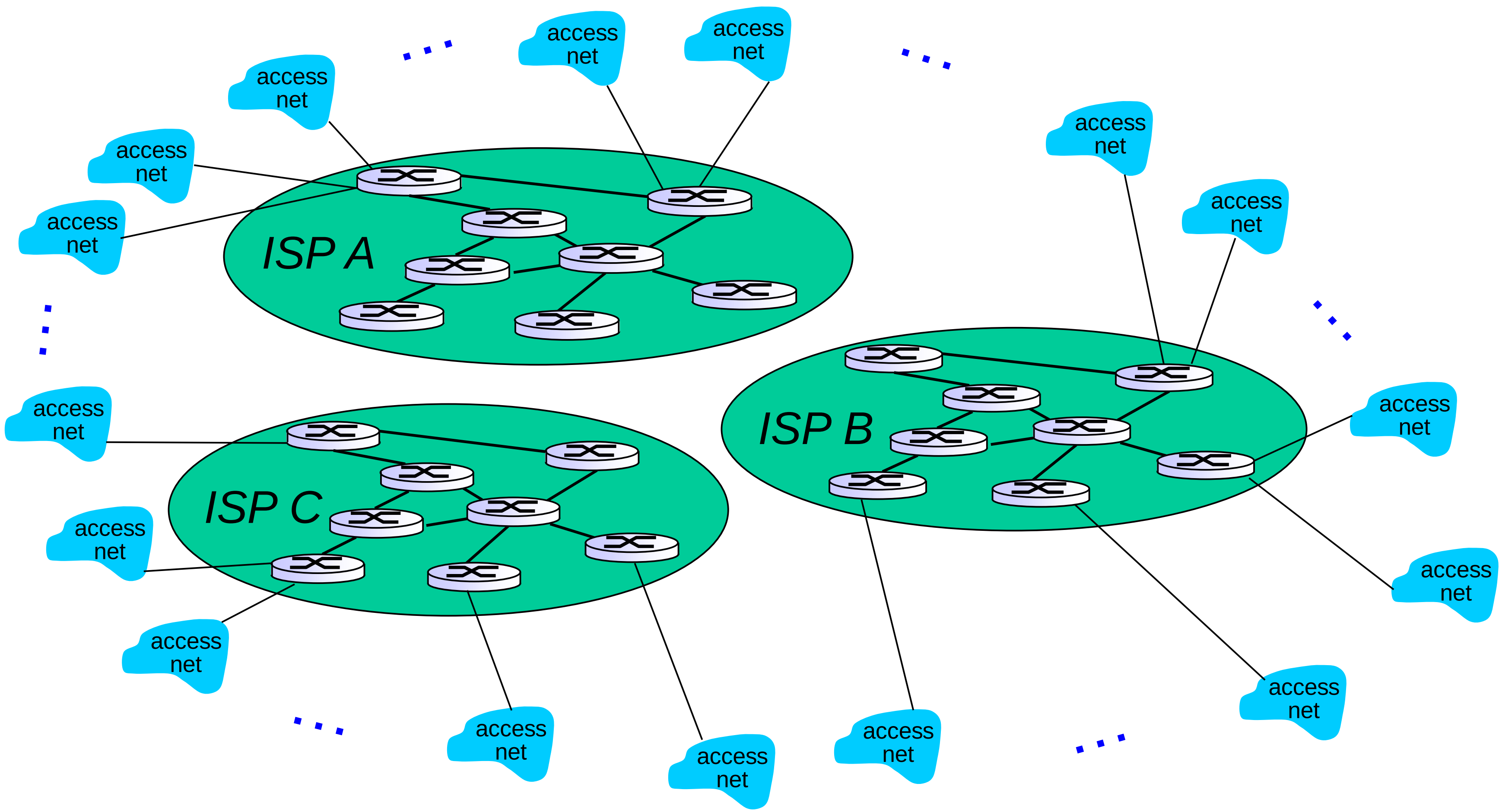
Internet structure: network of networks

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



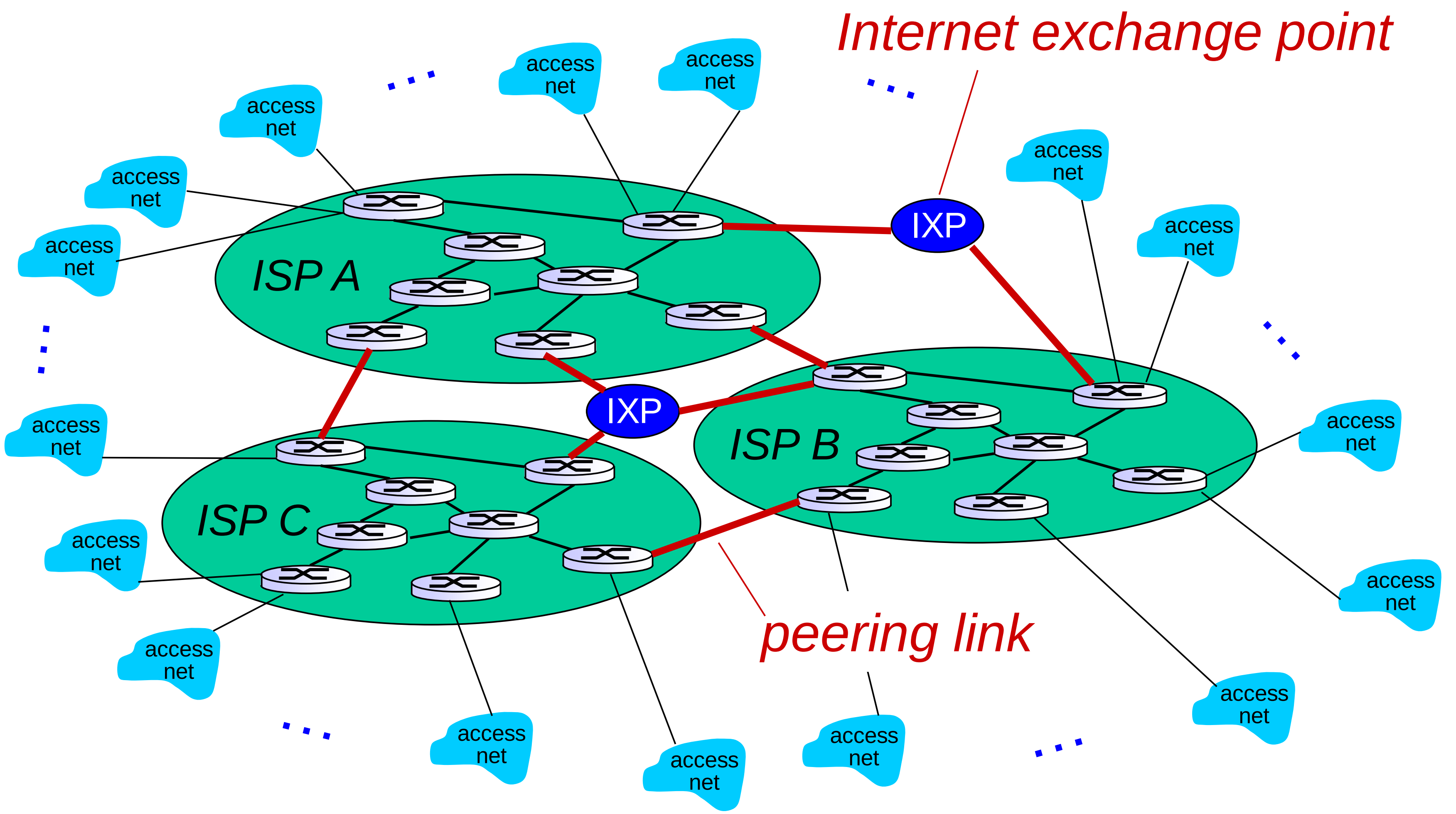
Internet structure: network of networks

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



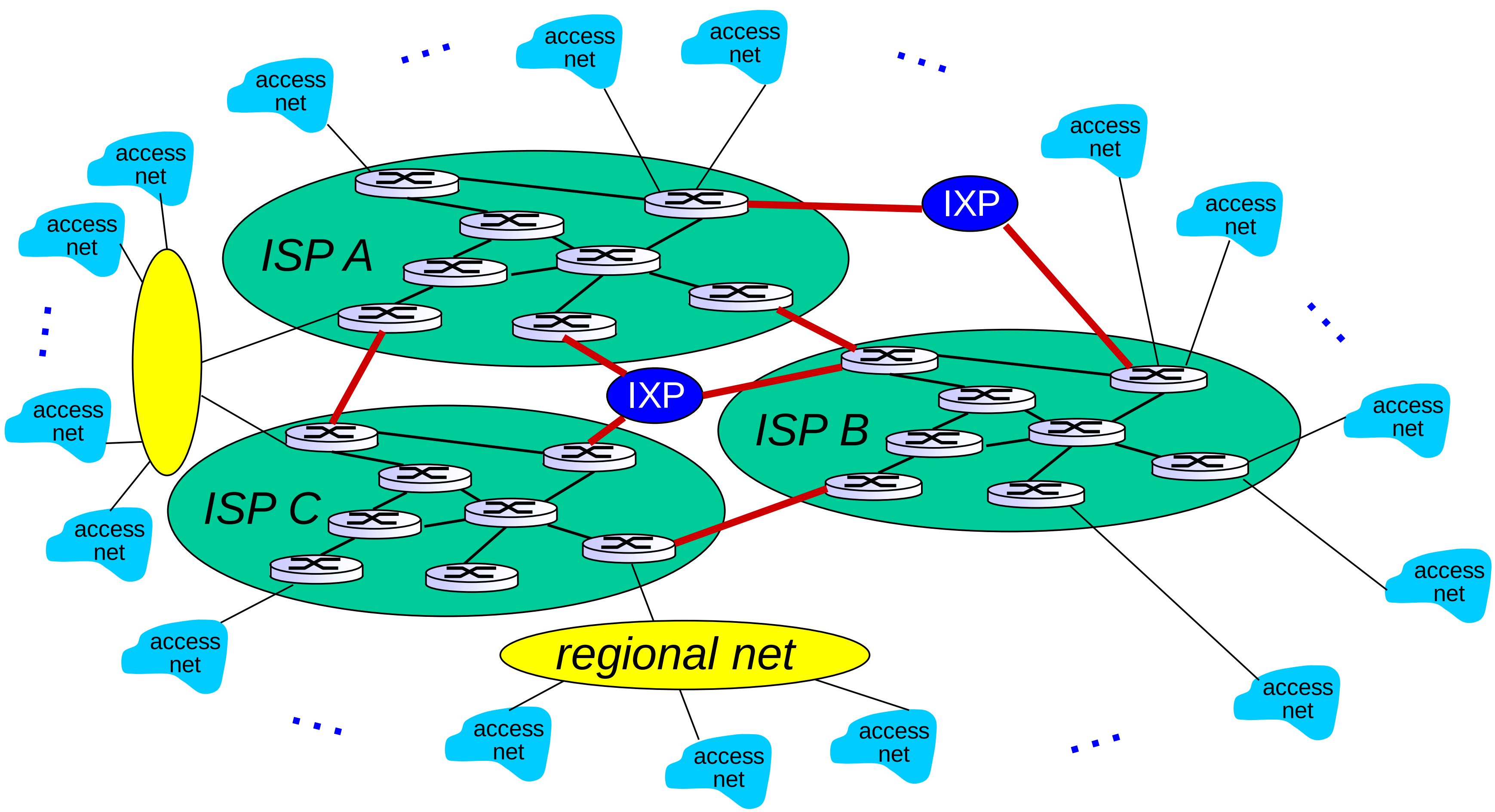
Internet structure: network of networks

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



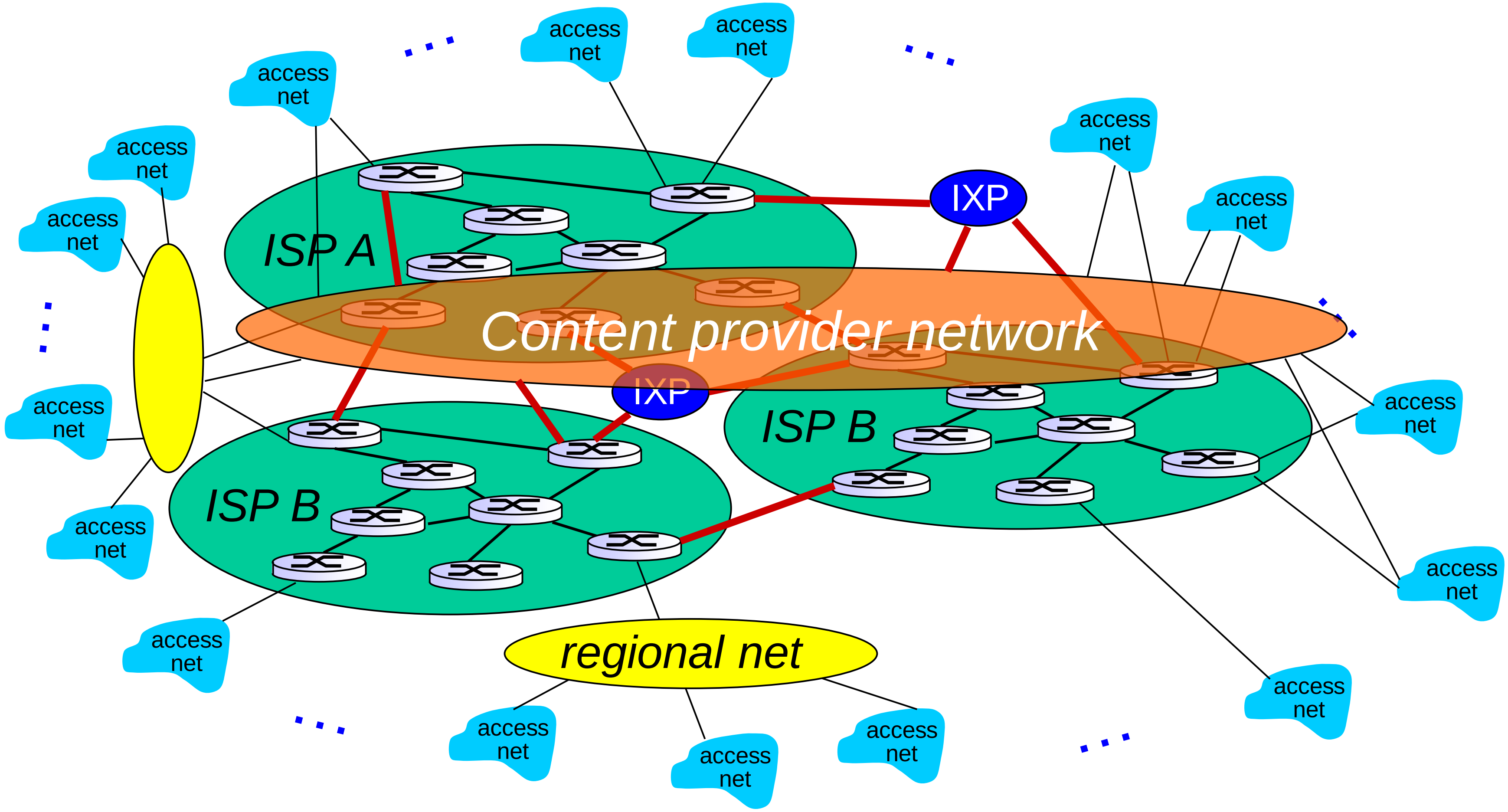
Internet structure: network of networks

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

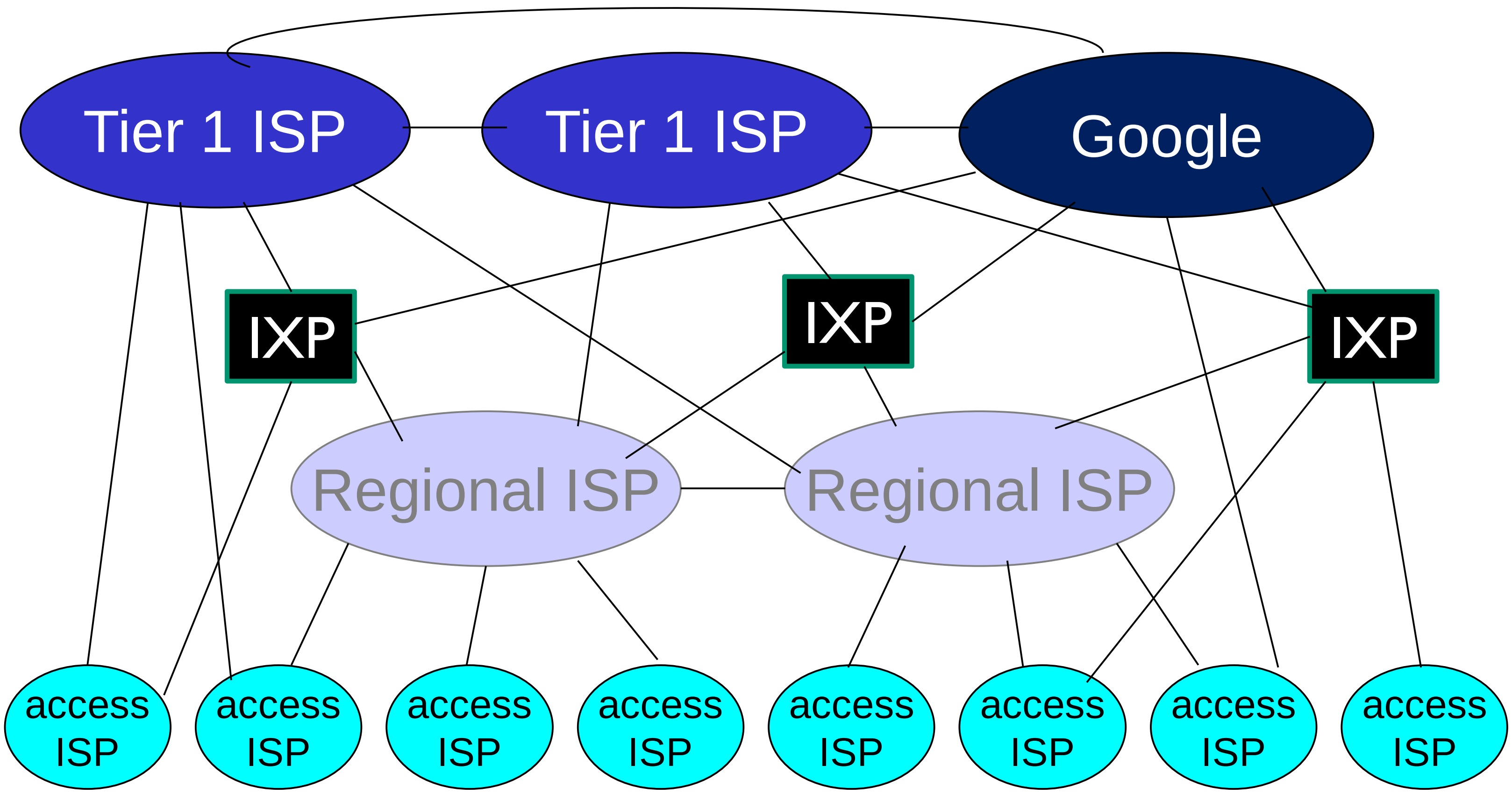


Internet structure: network of networks

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

Tier-1 ISP: e.g., Sprint