

# 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:

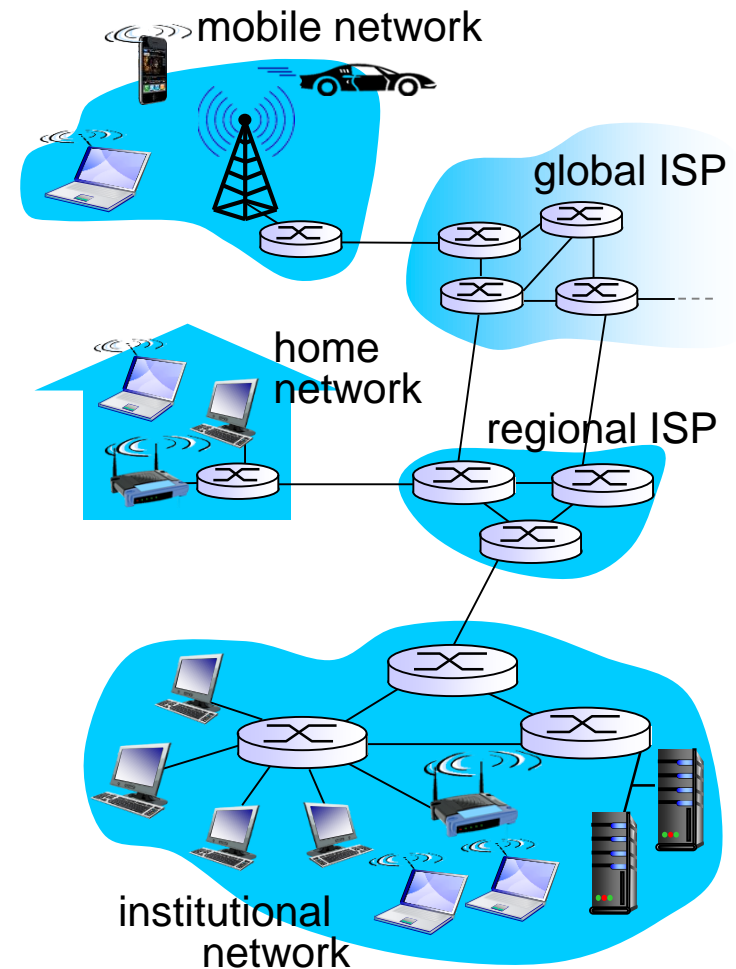
## ❖ *network edge:*

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

## ❖ *access networks, physical media:* wired, wireless communication links

## ❖ *network core:*

- interconnected routers
- network of networks



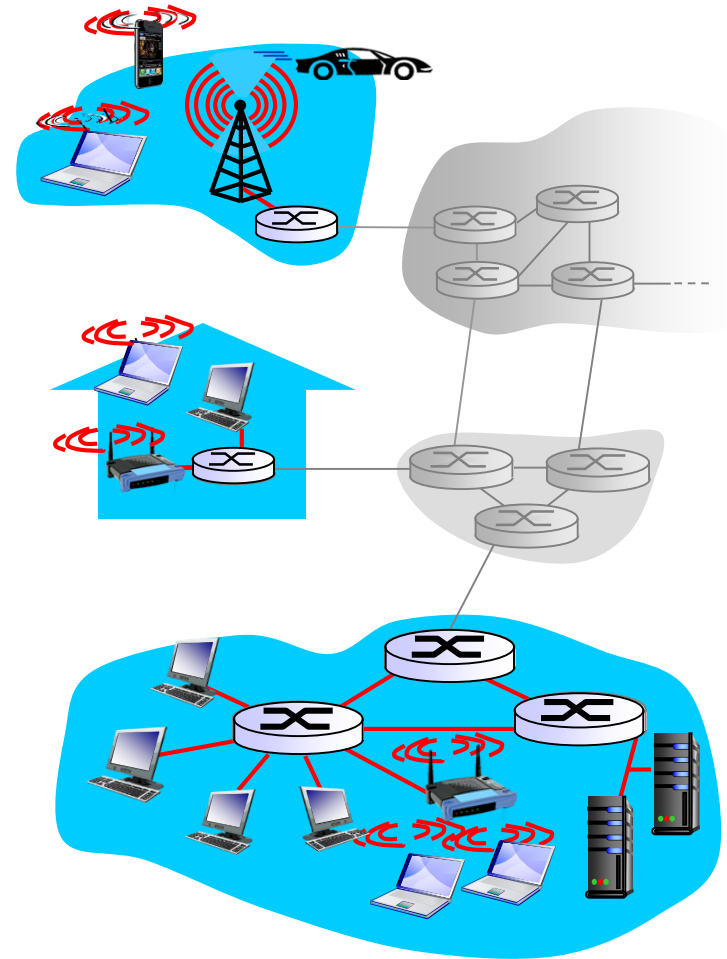
# Access networks and physical media

*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?

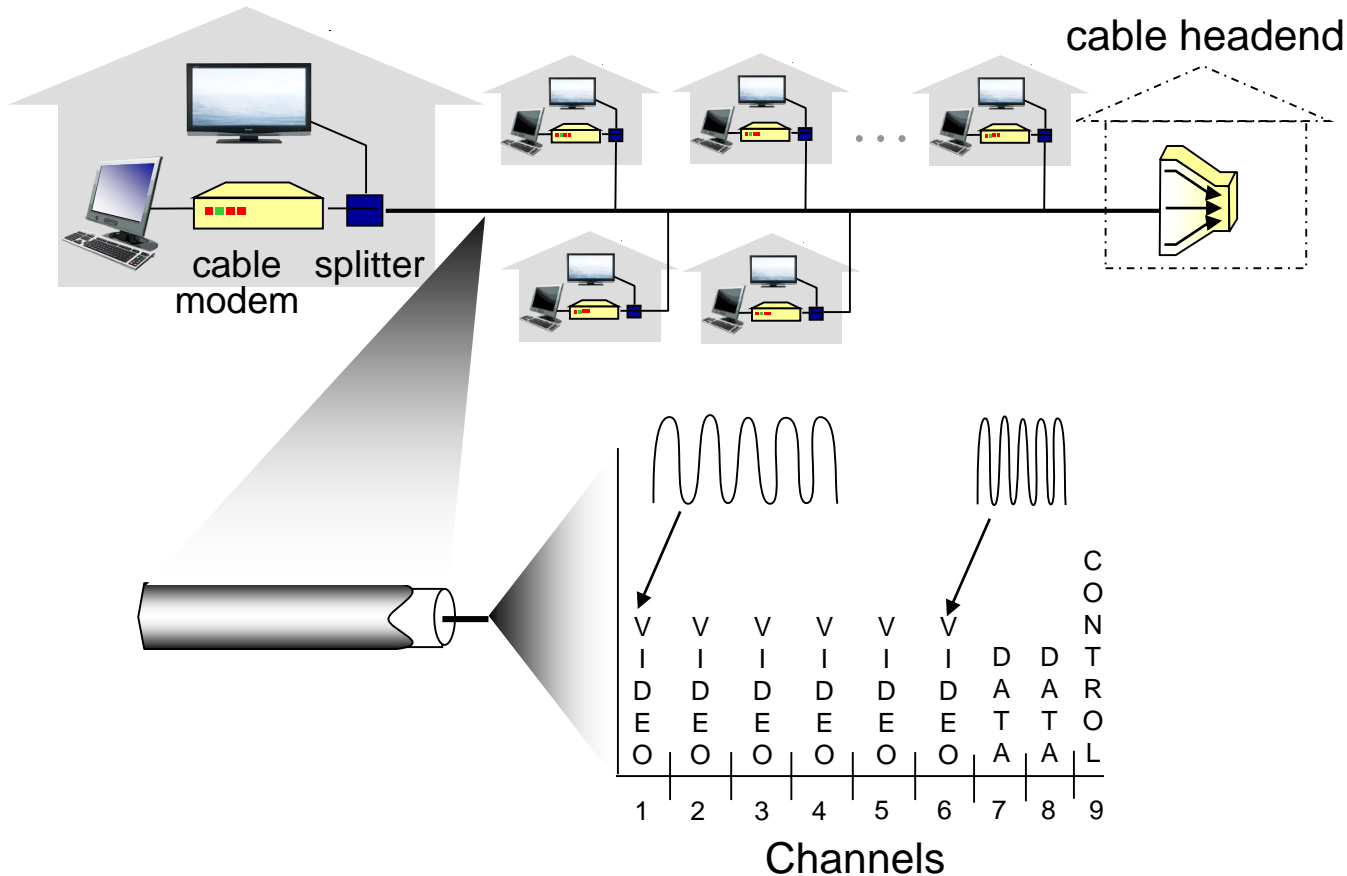


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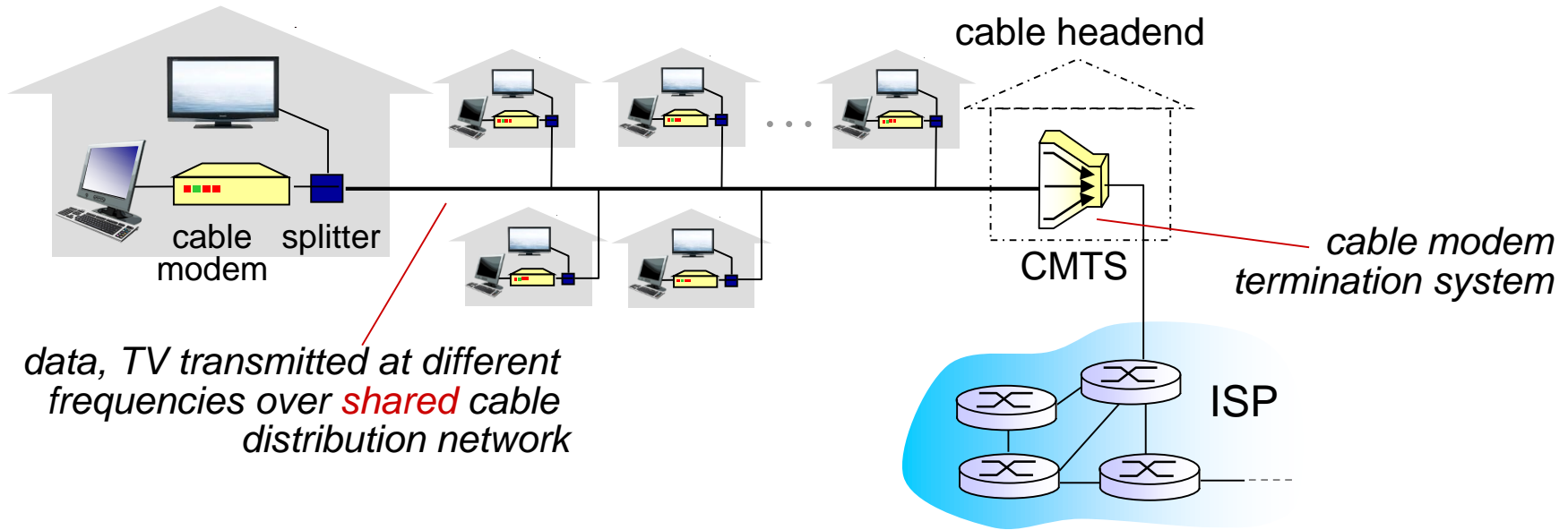
- ❖ use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- ❖ < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- ❖ < 24 Mbps downstream transmission rate (typically < 10 Mbps)

# Access net: cable network



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

# Access net: cable network



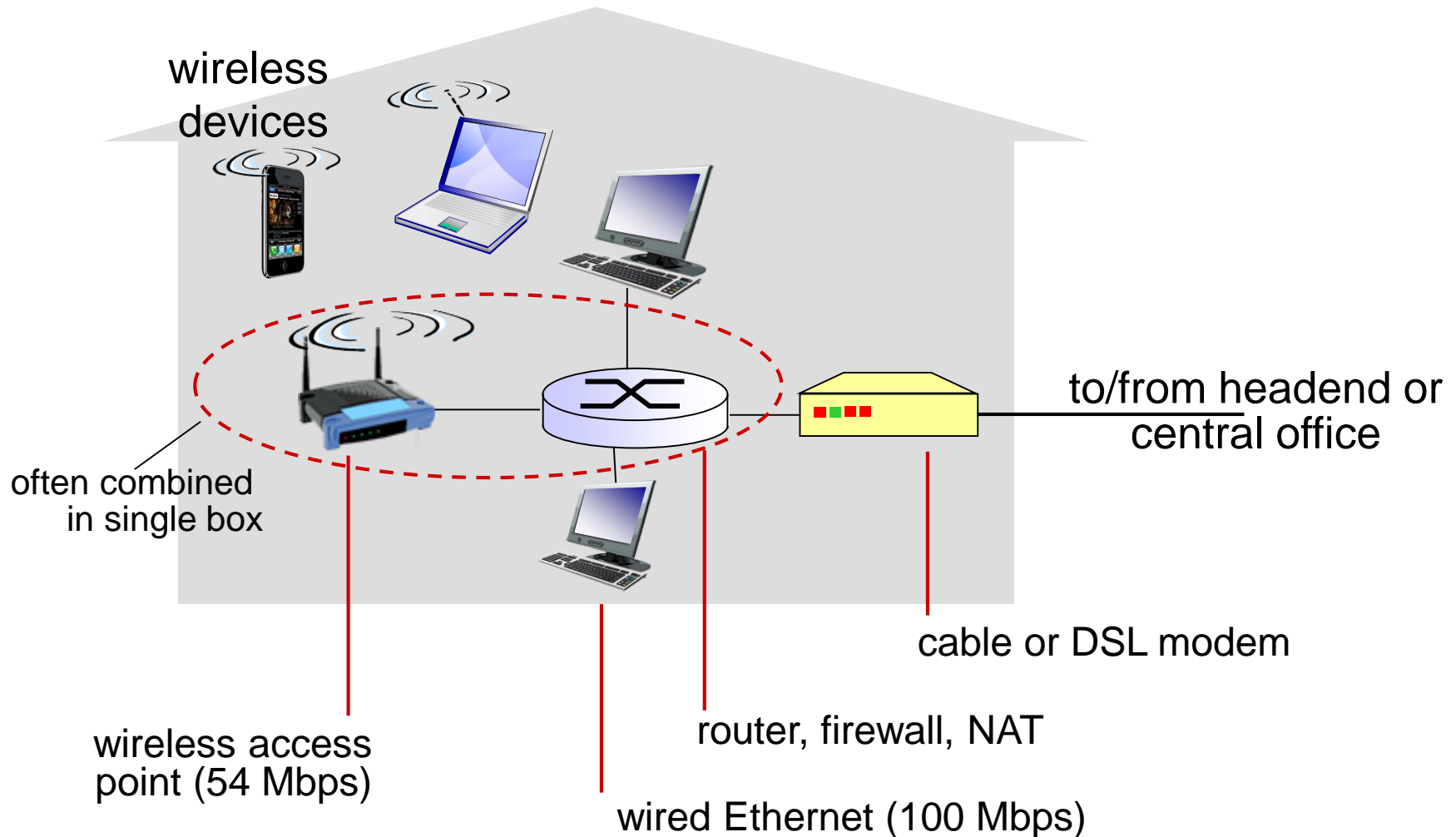
## ❖ HFC: hybrid fiber coax

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

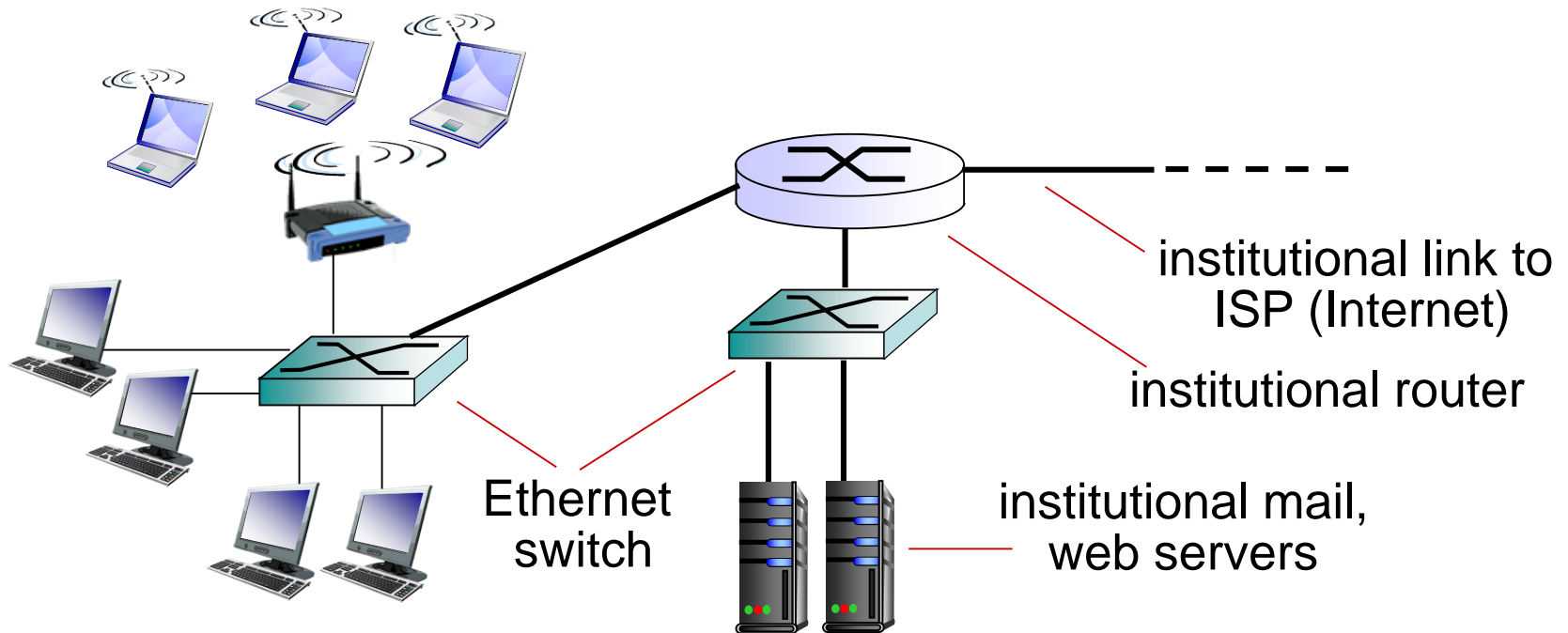
## ❖ network of cable, fiber attaches homes to ISP router

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

# Access net: home network



# Enterprise access networks (Ethernet)



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

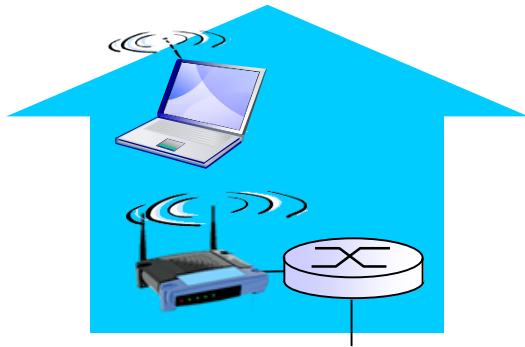


# Wireless access networks

- ❖ 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



*to Internet*

## *wide-area wireless access*

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

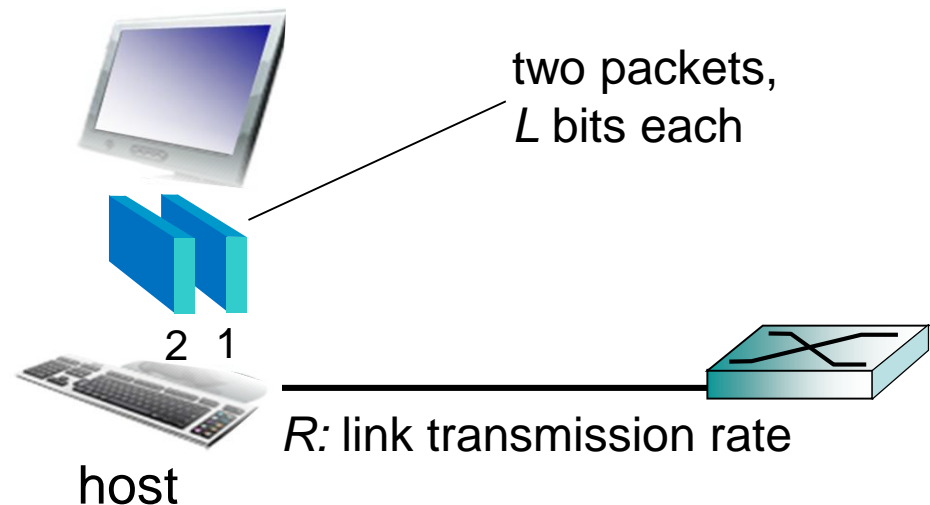


*to Internet*

# Host: sends *packets* of data

host sending function:

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



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

# Physical media

- ❖ **bit:** propagates between transmitter/receiver pairs
- ❖ **physical link:** what lies between transmitter & receiver
- ❖ **guided media:**
  - signals propagate in solid media: copper, fiber, coax
- ❖ **unguided media:**
  - signals propagate freely, e.g., radio

## *twisted pair (TP)*

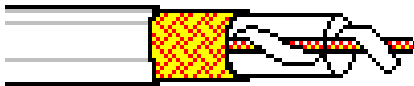
- ❖ two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10Gbps



# Physical media: coax, fiber

## *coaxial cable:*

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



## *fiber optic cable:*

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



# Physical media: radio

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

## *radio link types:*

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

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- packet switching, circuit switching, network structure

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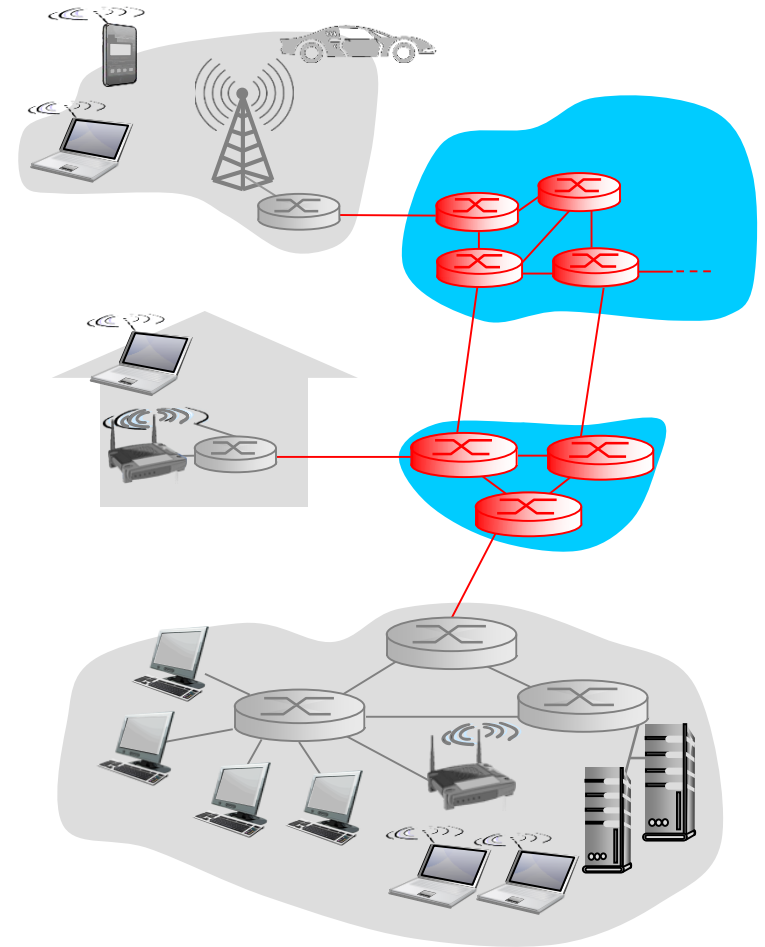
1.5 protocol layers, service models

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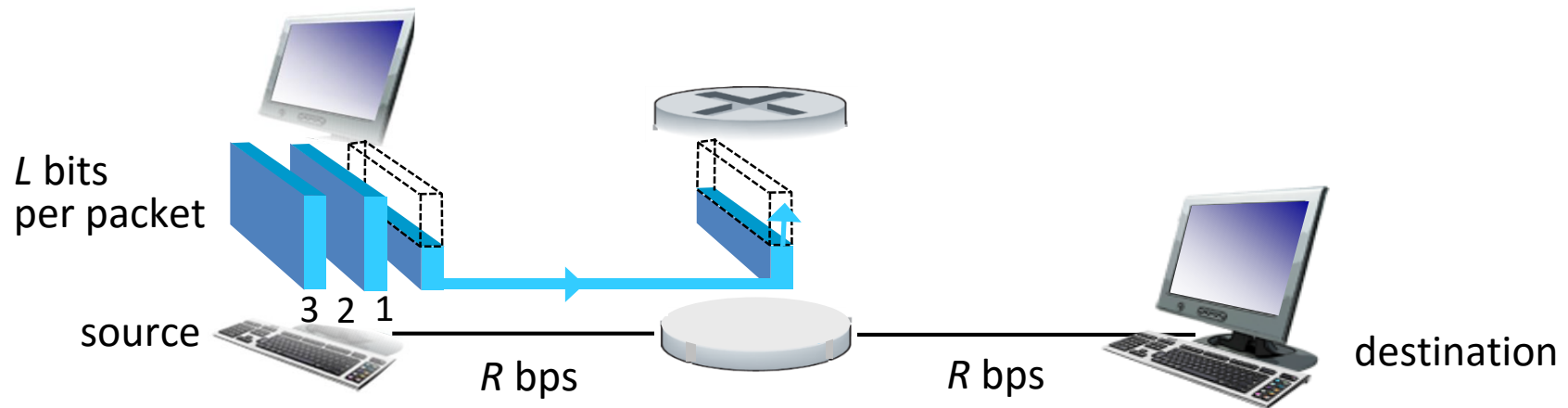
1.7 history

# 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 =  $2L/R$  (assuming zero propagation delay)

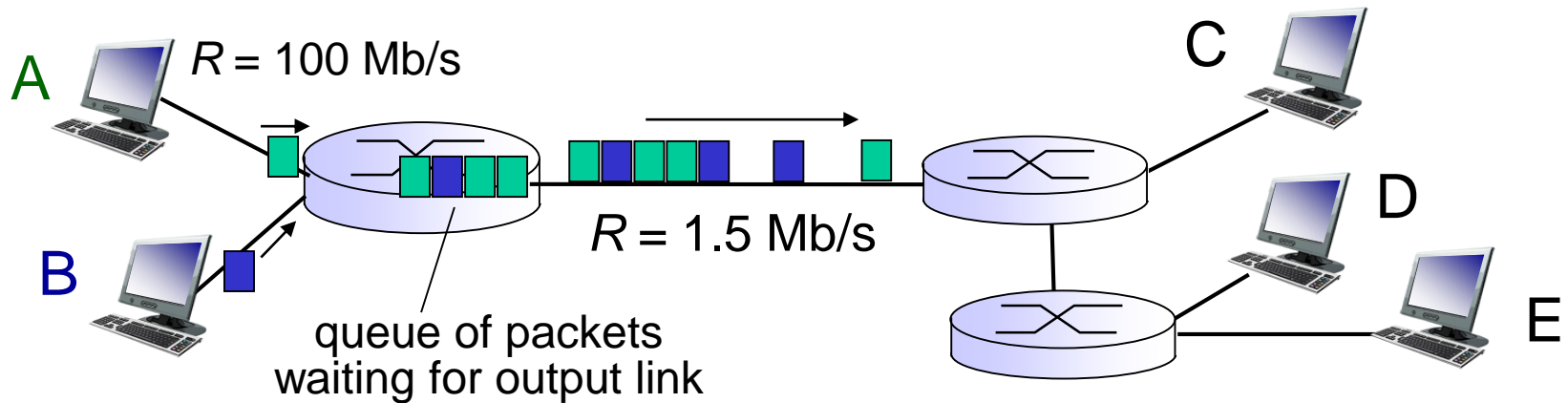
*one-hop numerical example:*

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

} more on delay shortly ...



# Packet Switching: queueing delay, loss



## queuing and loss:

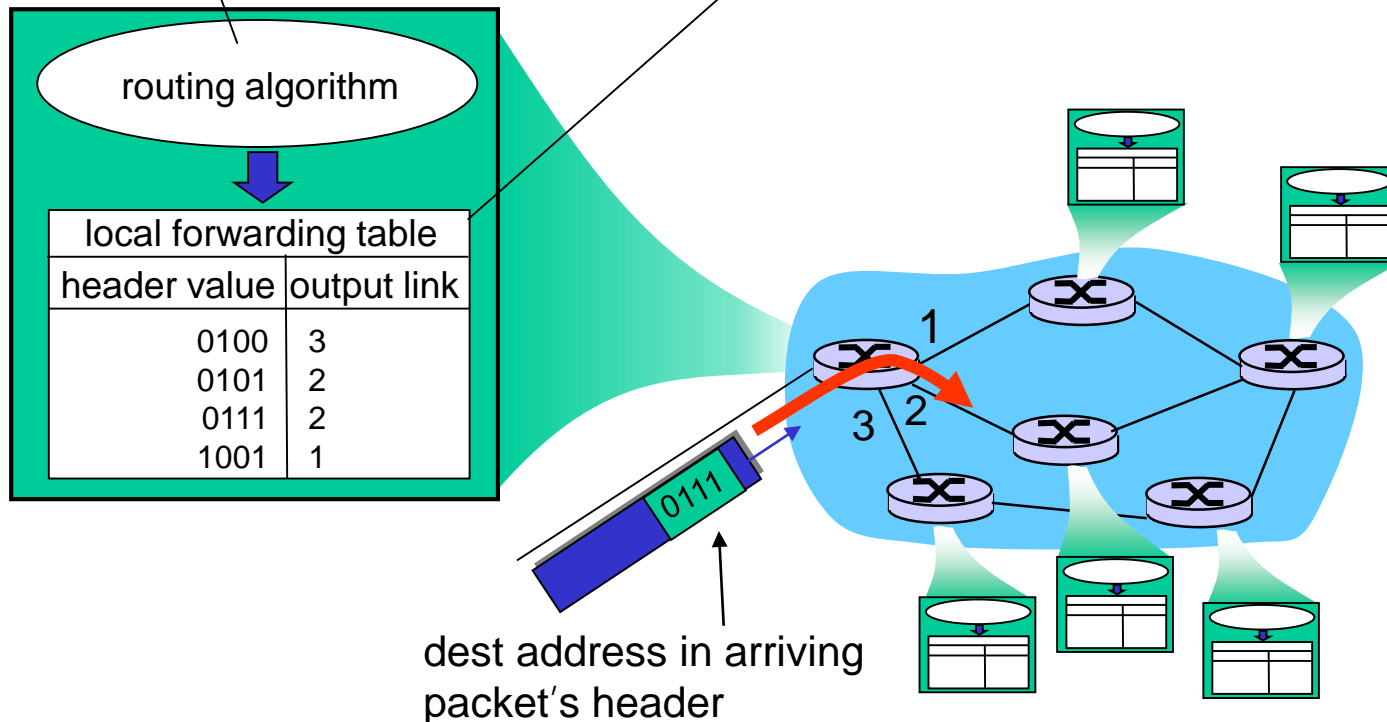
- ❖ If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

# Two key network-core functions

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

- *routing algorithms*

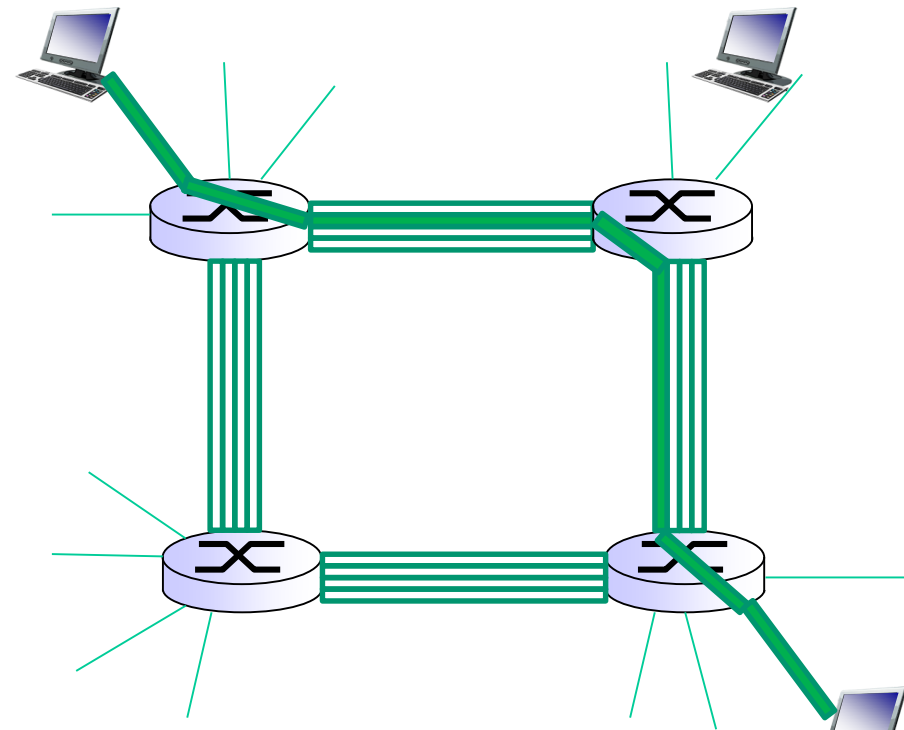
**forwarding:** move packets from router's input to appropriate router output



# Alternative core: circuit switching

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

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

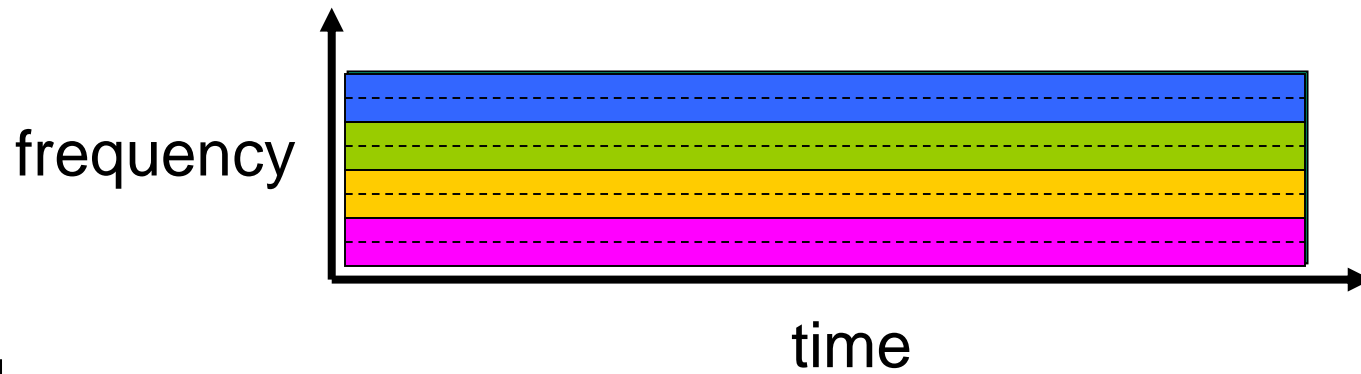


# Circuit switching: FDM versus TDM

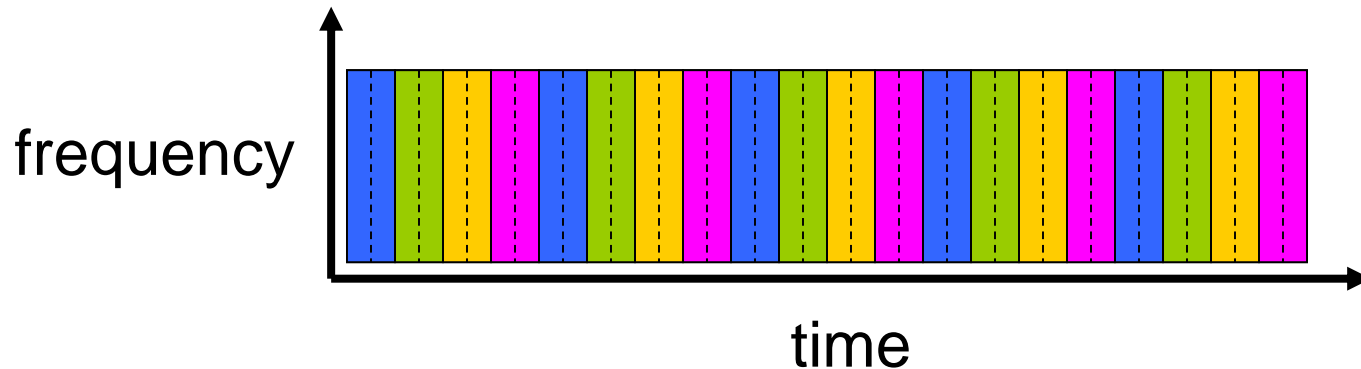
FDM

Example:

4 users



TDM

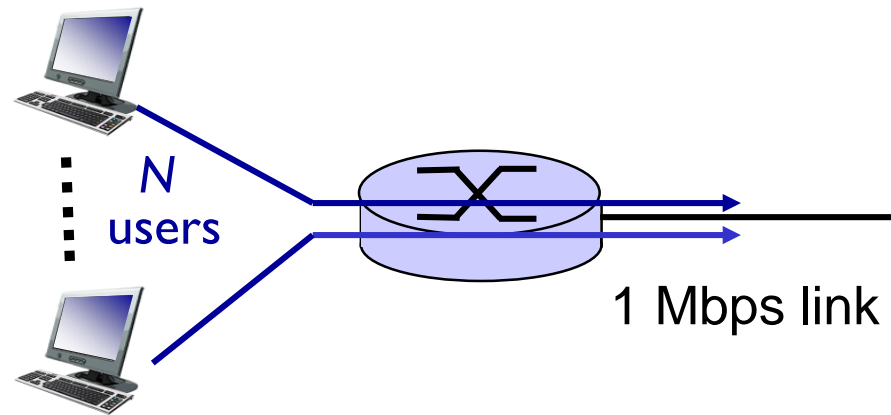


# Packet switching versus circuit switching

*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 \*

Q: how did we get value 0.0004?

Q: what happens if  $> 35$  users ?

# 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)

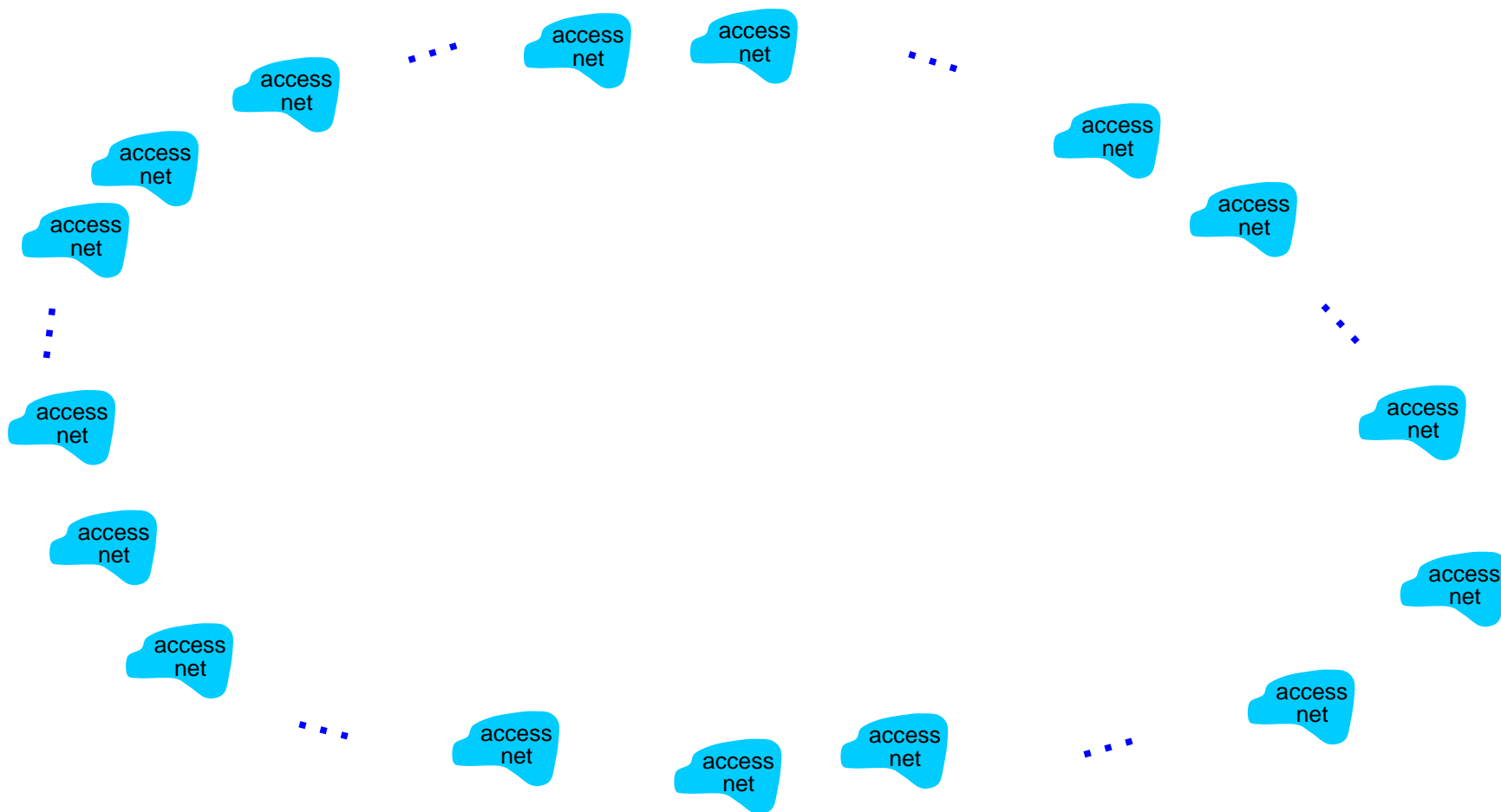
**Q:** human analogies of reserved resources (circuit switching) versus on-demand allocation (packet-switching)?

# 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

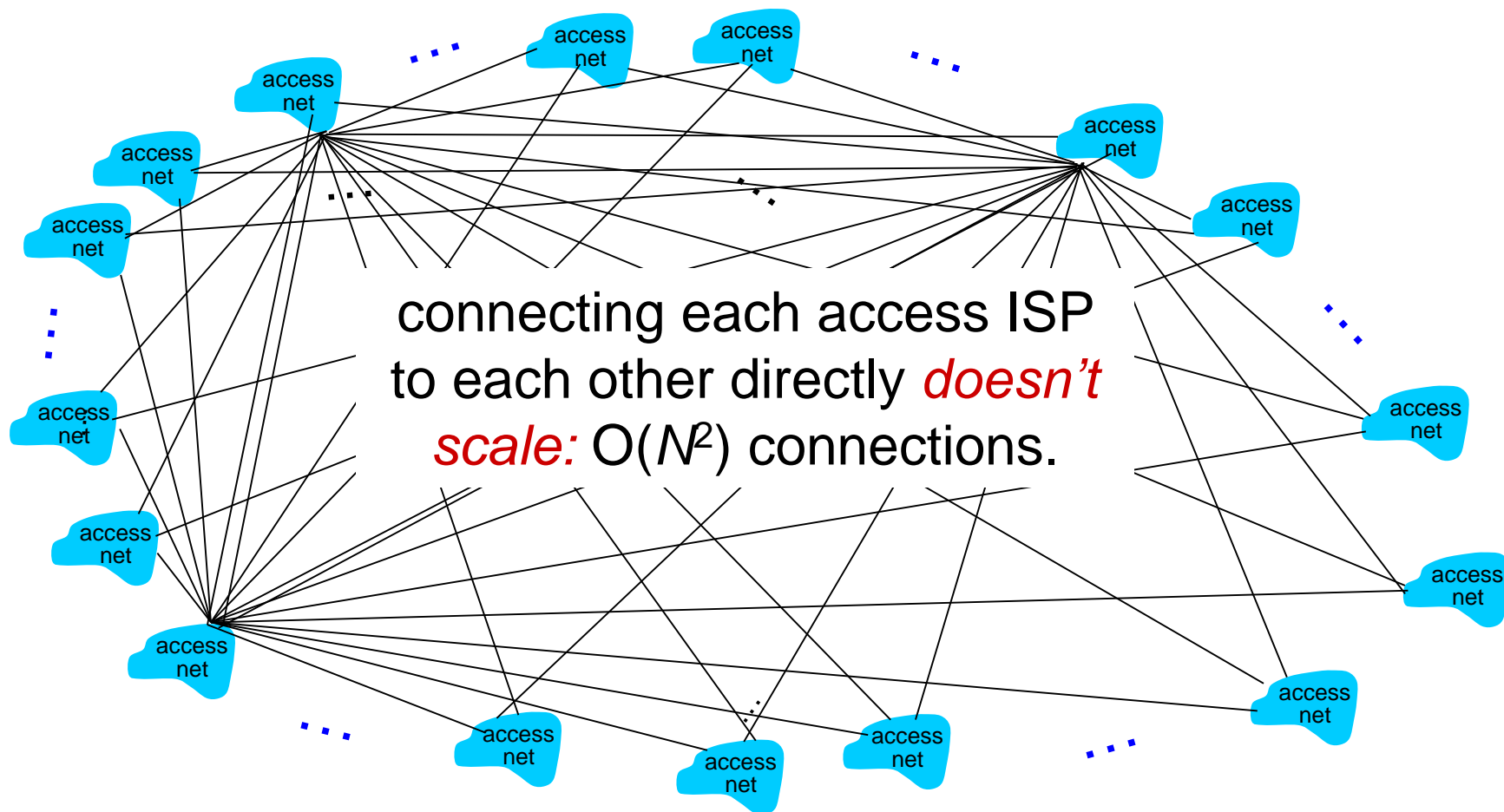
**Question:** given *millions* of access ISPs, how to connect them together?





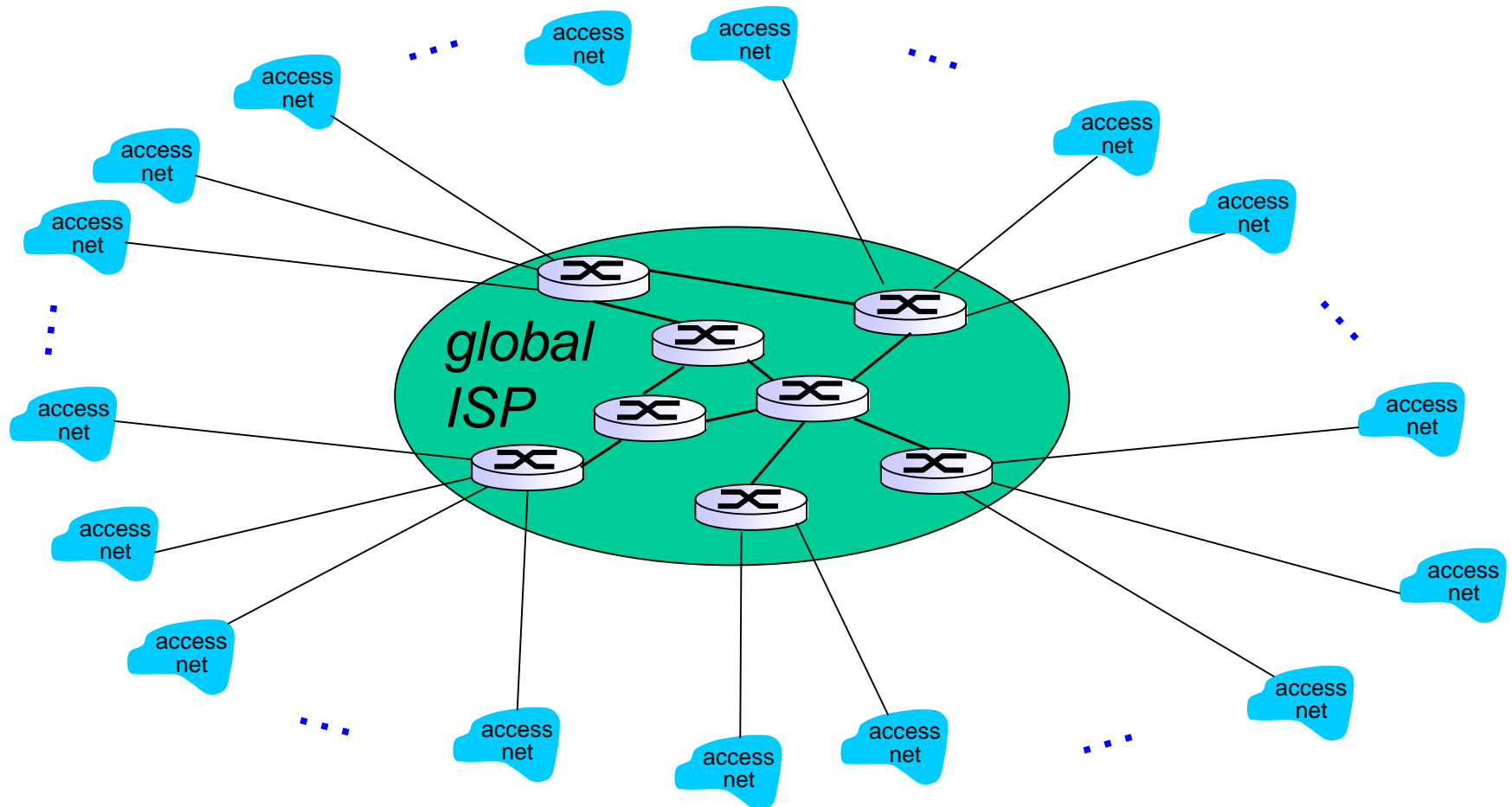
# Internet structure: network of networks

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



# Internet structure: network of networks

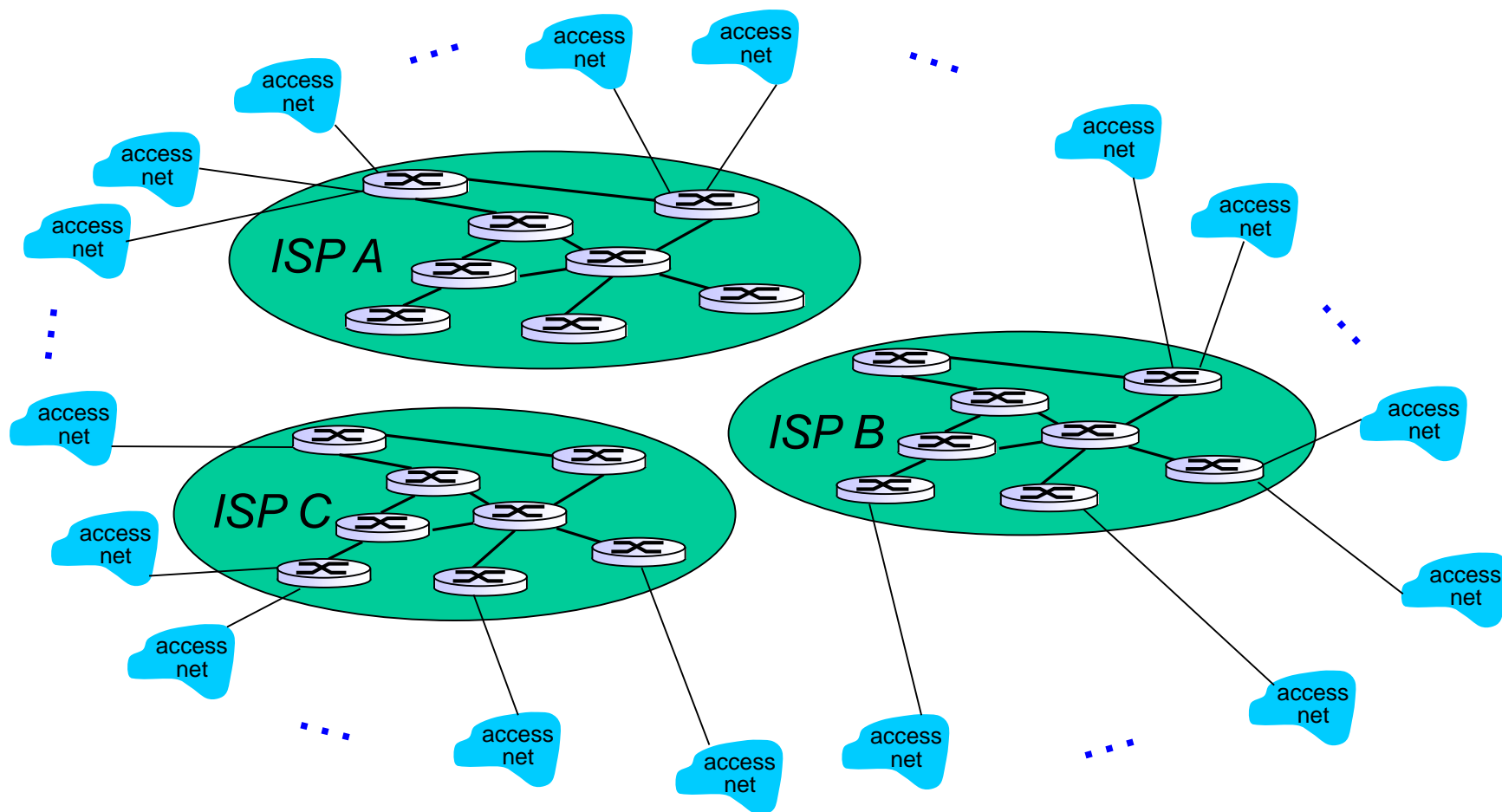
*Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.*



# Internet structure: network of networks

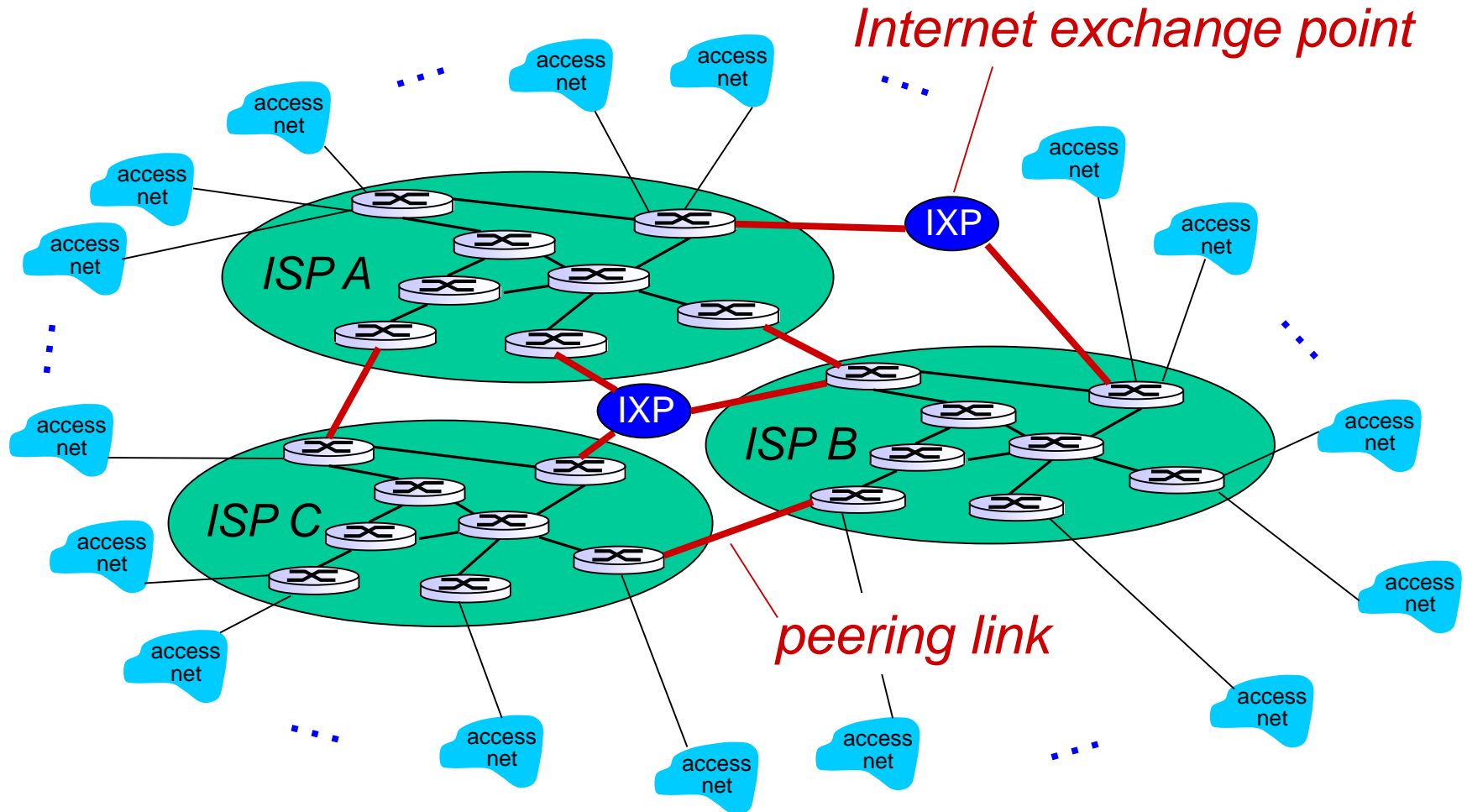
But if one global ISP is viable business, there will be competitors

....



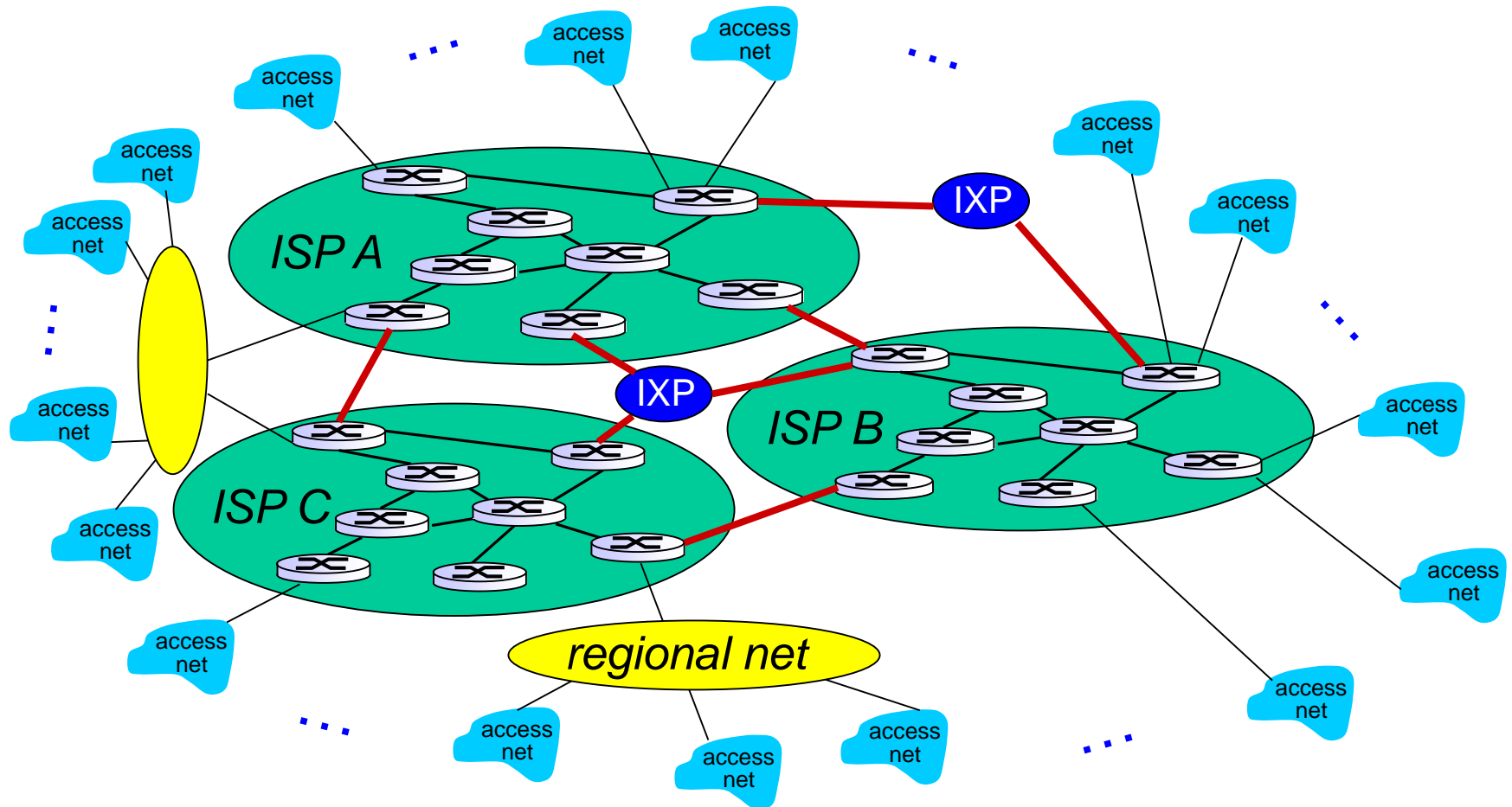
# Internet structure: network of networks

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



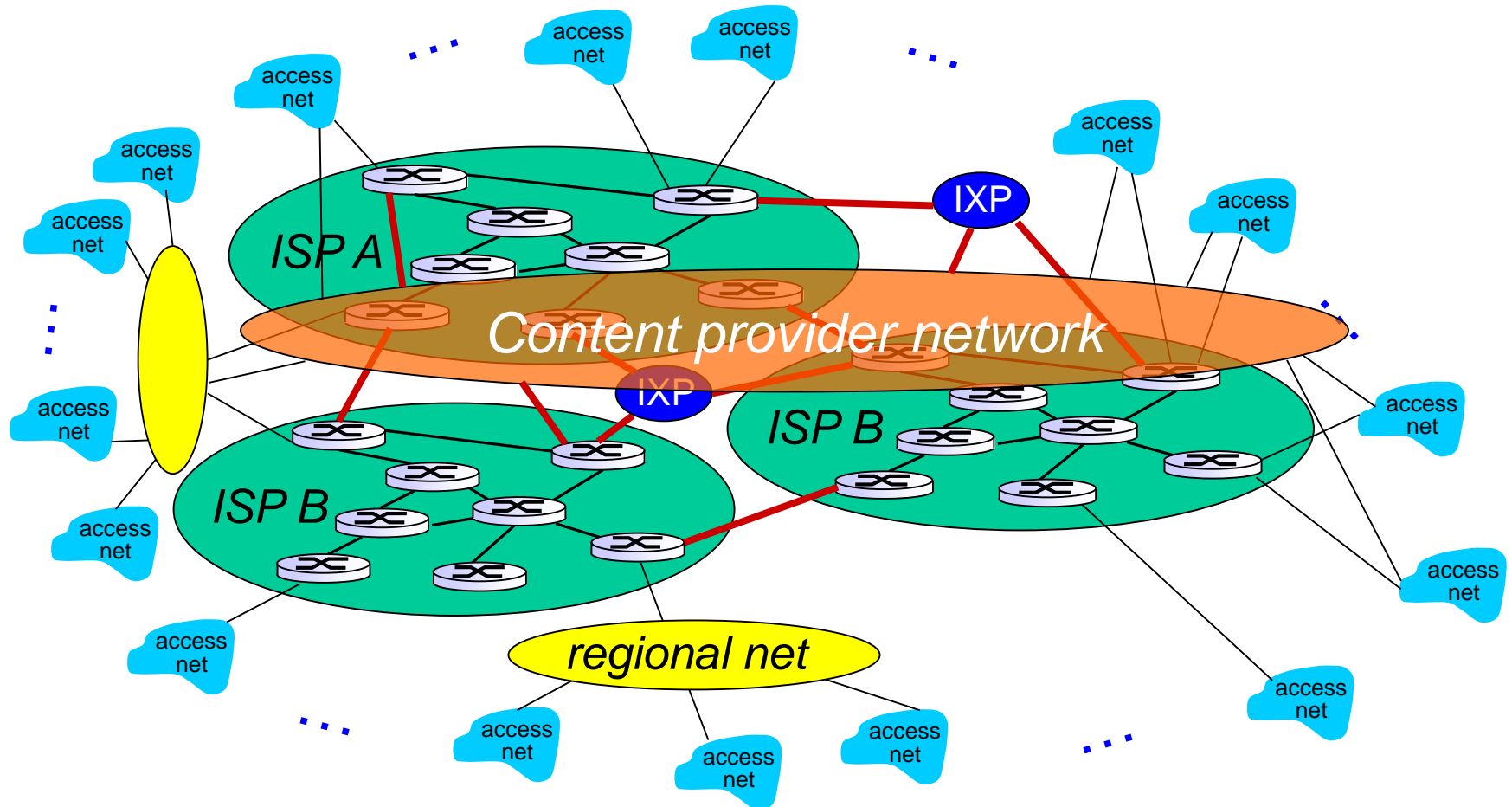
# Internet structure: network of networks

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

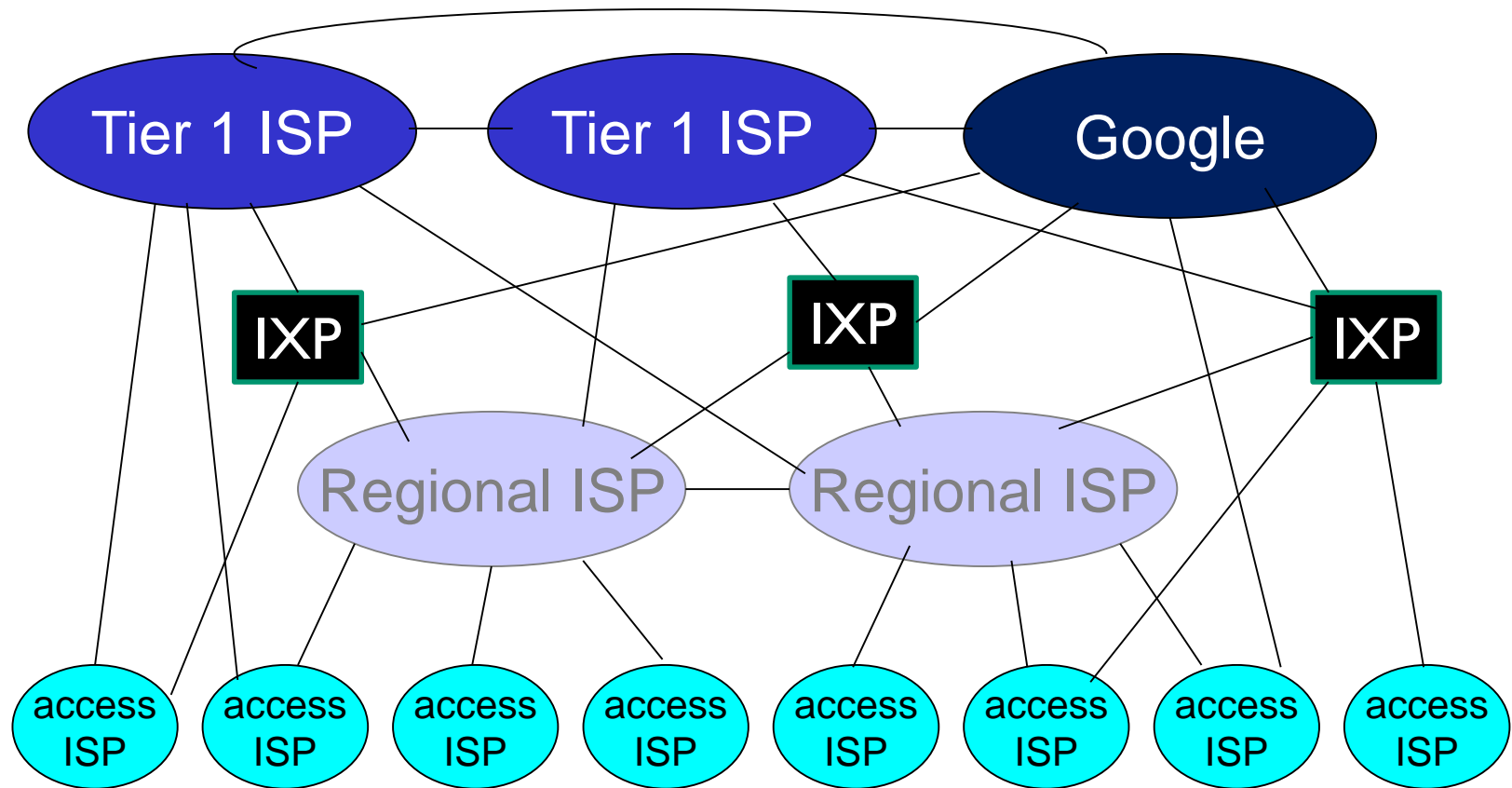


# Internet structure: network of networks

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

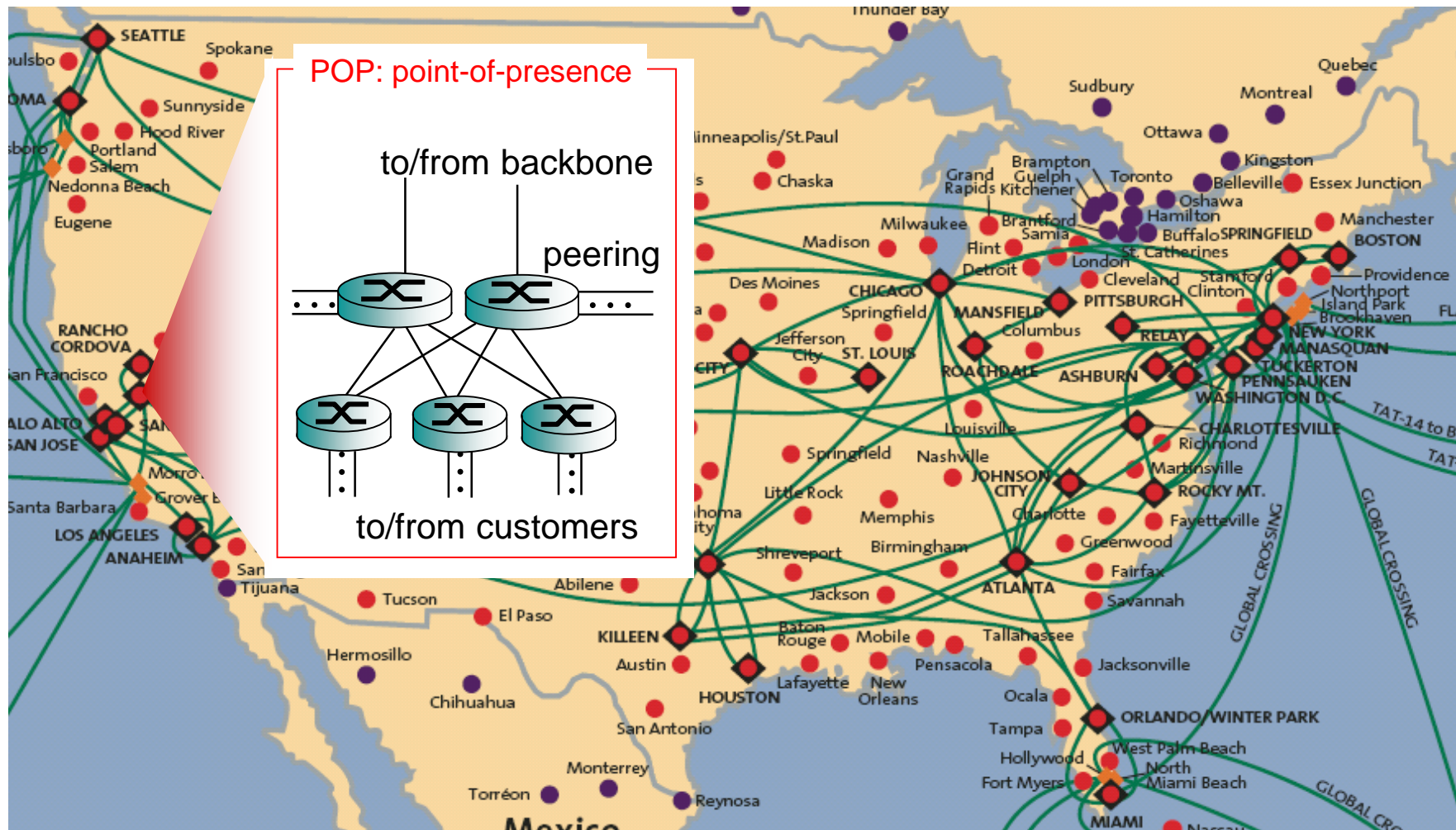


# Internet structure: network of networks



- ❖ at center: small # of well-connected large networks
  - **"tier-1" commercial ISPs** (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - **content provider network** (e.g., Google): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

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





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