Introduction

CSC/ECE 570 Computer Networks

Fall 2024

Agenda

1. History
2. Internet Structure
3. Packet vs. circuit switching
4. Internet Structure Continued

History

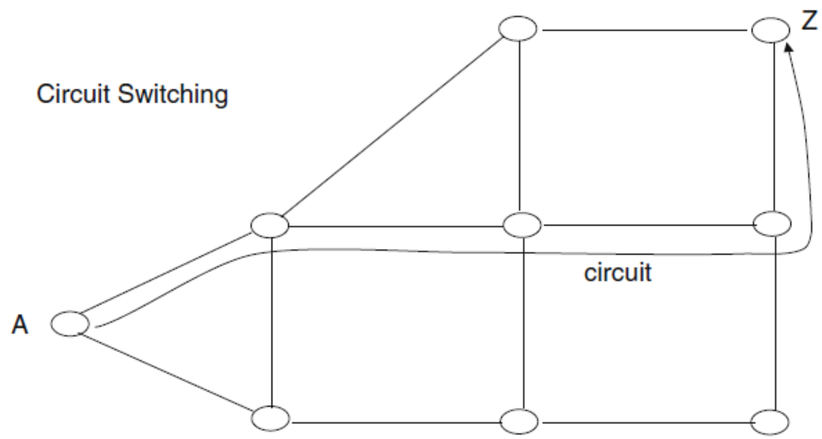
- Cerf and Kahn are considered the Internet founding fathers
  - Vinton Cerf -> Born in 1943, DARPA program manager, funded and chairman of ICANN, president of ACM
  - Bob Kahn -> Born in 1938, Ph.D. from City University of NY, worked at AT&T, and was a professor at MIT

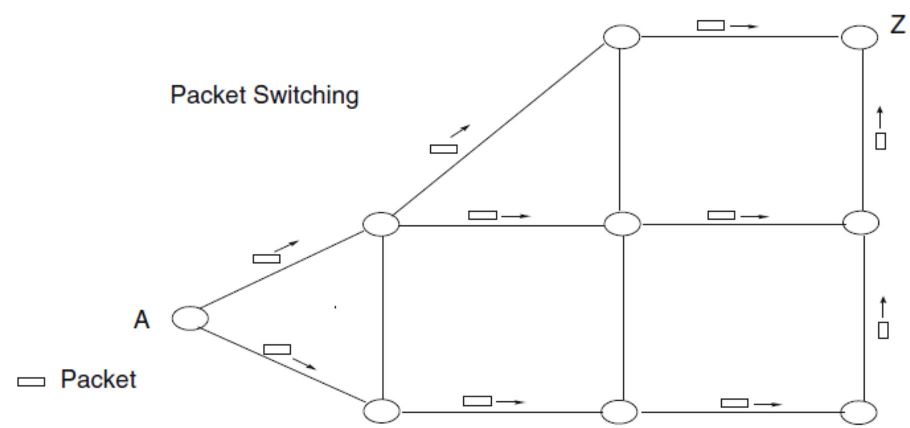
- Established internetworking principles:
  1. *minimalistic, automatic way* - no internal changes required to interconnect networks
  2. *best effort* service model
  3. *stateless routers*

define Internet architecture

Architectures for Networking

- Switched networks
  - Circuit switched vs. Packet switched





1960's: Early Packet-Switching Principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1970: ALOHAnet wireless network in Hawaii

1970's: Internetworking, proprietary nets

- 1972:
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- Late 70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

1980's: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: SMTP e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: FTP protocol defined
- 1988: TCP congestion control
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

1990, 2000's: Commercialization, the Web, new apps

- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web
- late 1990's – 2000's:
  - more killer apps: instant messaging, P2P file sharing
  - network security to forefront
  - est. 50 million hosts, 100 million+ users
  - backbone links running at Gbps

2005 - present

- ~750 million hosts
- Smartphones and tablets
- Aggressive deployment of broadband access
- Increasing ubiquity of high-speed wireless access
- Emergence of online social networks:
  - Facebook: soon one billion users
- Service providers (Google, Microsoft) create their own networks
  - Bypass Internet, providing “instantaneous” access to search, email, etc.
- E-commerce, universities, enterprises running their services in “cloud” (eg, Amazon EC2)

IOSC, IETF and RFCs

- **ISOC:** the Internet Society (founded by Cerf, Kahn and Lyman Chapin), main support body of IETF
- **IETF:** Internet Engineering Task Force, major standardization body of the Internet
- **RFCs (Request For Comments):** formal documentation of Internet standards submitted to/approved by IETF; all open access at https://www.rfc-editor.org/search/rfc_search.php
  - RFC 768 (Aug. 1980): UDP
  - RFC 791 (Sep. 1981): IP
  - RFC 793 (Sep. 1981): TCP
  - RFC 1034/1035 (Nov. 1987): DNS
  - …
  - RFC 8888 (Jan. 2021): RTP Control Protocol Congestion Control

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Network devices

- Endhosts (computers and clients)
- Routers, switches, and hubs to connect endhosts
- Links of different media: wired/wireless

- A network consists of some number of endhosts interconnected through routers/switches/hubs
- The Internet interconnects networks

Types of Networks

- Not all networks are created equal!

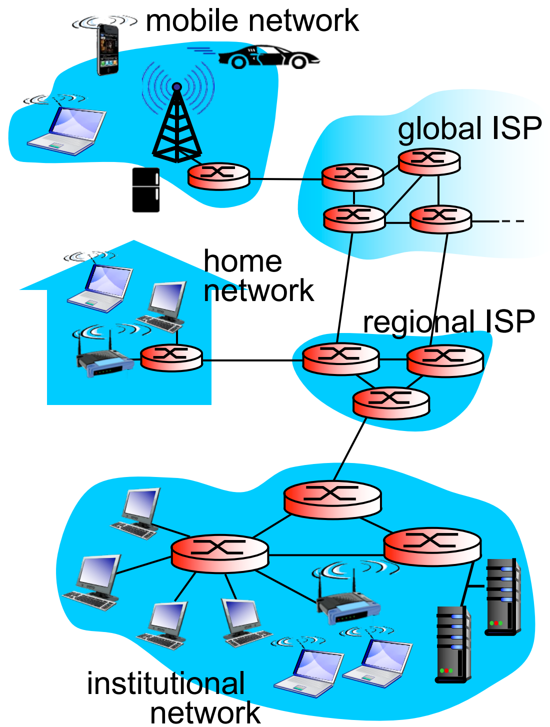
1. Edge Networks: Carry own traffic

   Examples: Customer networks such as home networks and NCSU network

2. Core Networks: Carry transit traffic; i.e. traffic for their customers (in addition to own traffic)

   Examples: ISP networks such as Sprint, AT&T, etc.

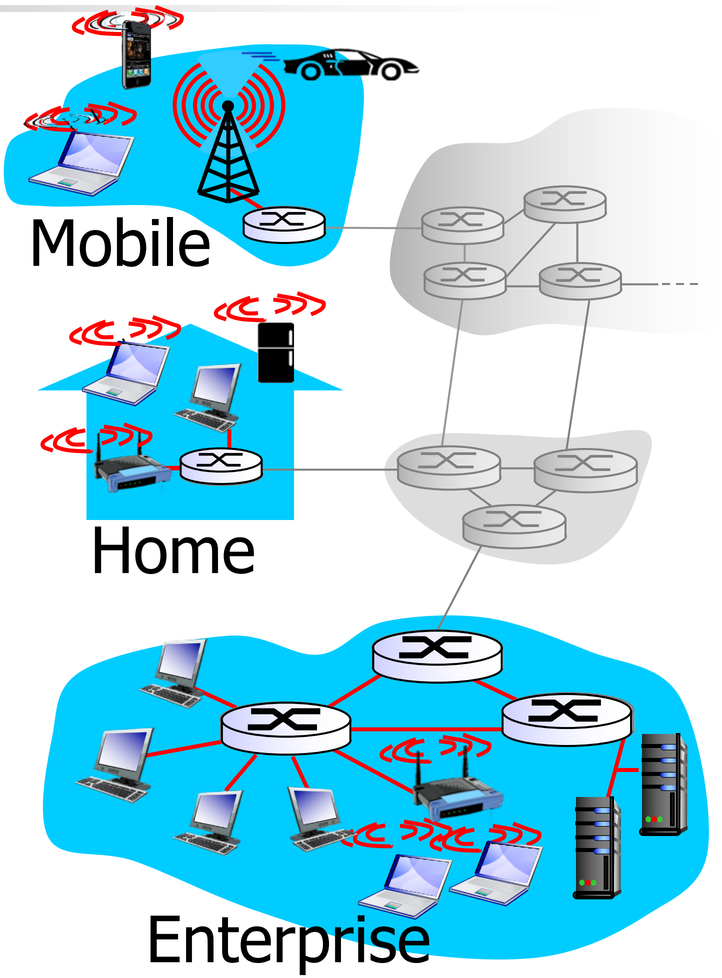
A closer look at network structure:



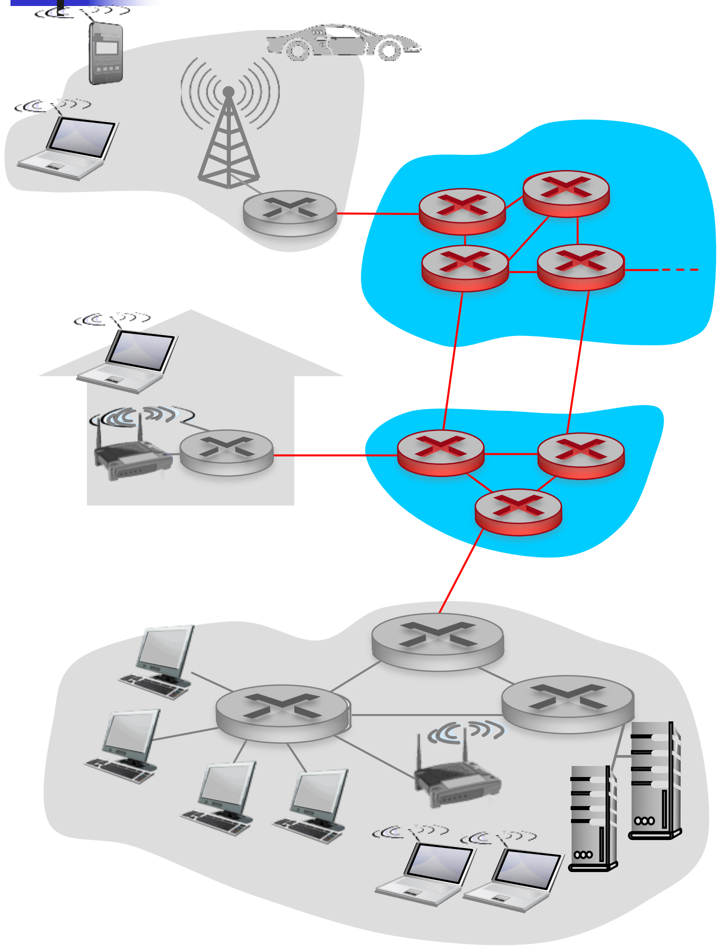
- *network edge:*
  - end systems/hosts, applications
  - clients & servers
- *access networks, physical media:* wired, wireless communication links
- *network core:*
  - interconnected routers
  - network of networks

Edge/Access Networks

- Connecting end-devices to edge routers
  - home access nets
  - enterprise access networks (school, company)
  - mobile access networks
- Heterogeneity, usually centralized
  - Media, hardware/devices, protocols
  - Bandwidth, delay, characteristics, …



Core Networks



- Mesh of interconnected routers
  - Usually by fiber optics
- Decentralized autonomous systems (ASs)
- Peering between ASs of different ISPs

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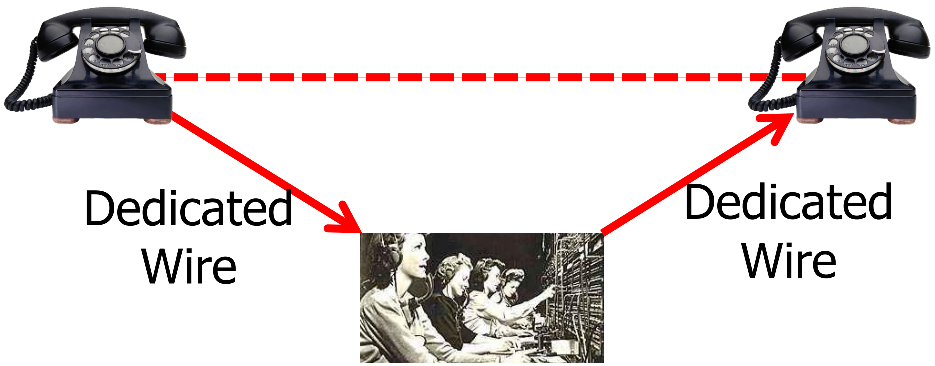
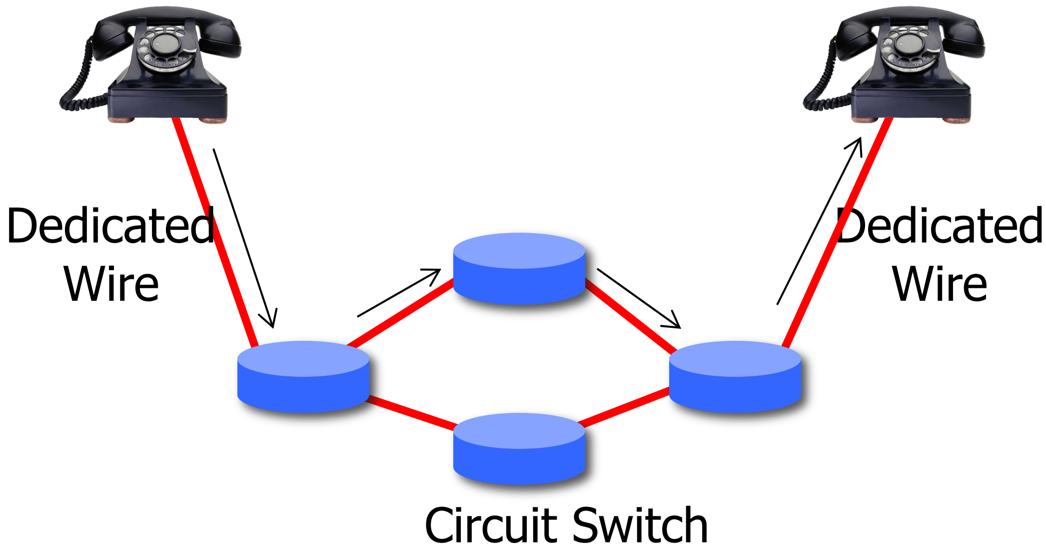
Circuit Switching: Telephone Network



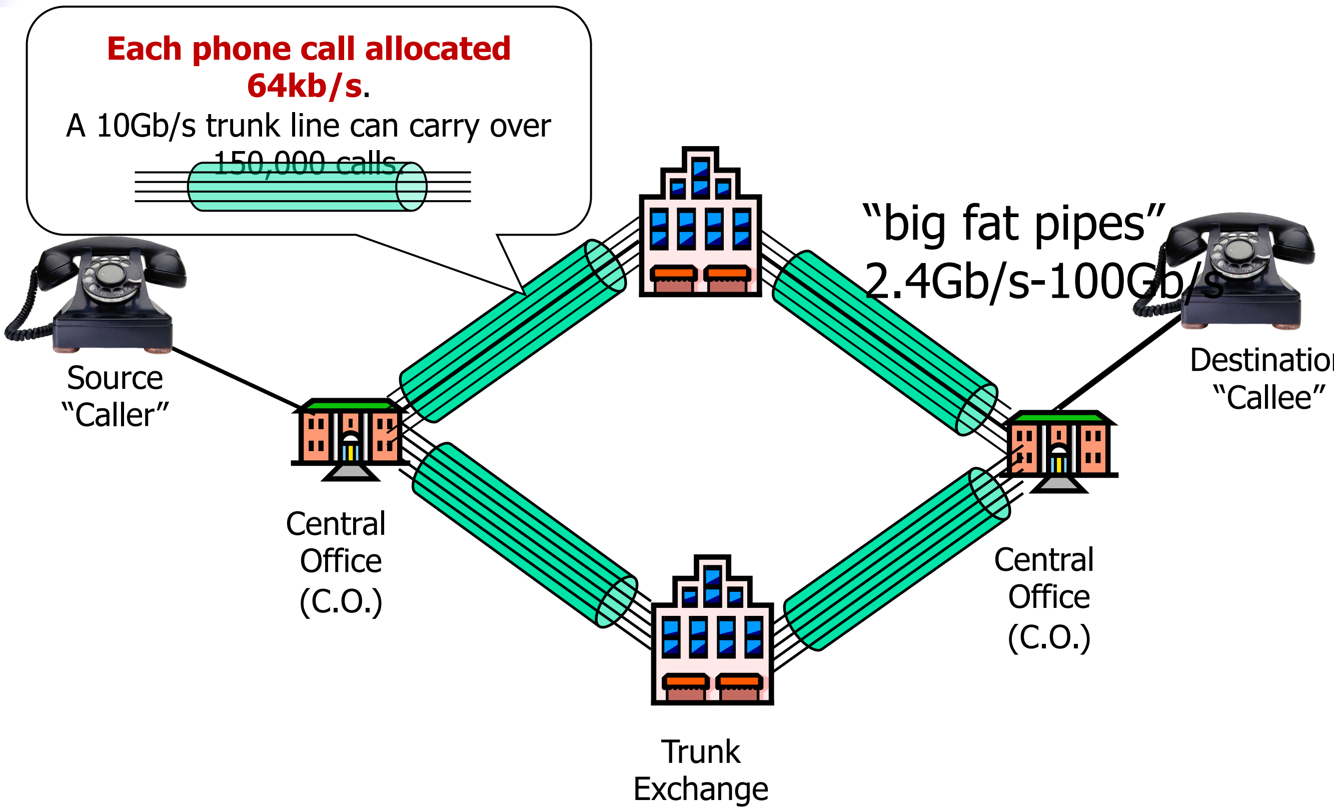
- telephones are connected by a dedicated wire to a local exchange
- Early days, switchboard operators used a big patch-panel to manually connect
- the wire is dedicated to the phone conversation from the start to the end of the phone call.

Circuit Switching: Telephone Network



1. **Dial a number**, which creates a dedicated circuit between the two phones. Each switch maintains state to map the incoming circuit to the correct outgoing circuit.
2. **Talk**: digital phone system, our voice is **sampled and digitized**, and sent over the dedicated circuit, typically **64kb/s for voice**. Our phone conversation has a dedicated circuit
3. **Hang up:** the circuit is removed, and any state is removed at the switches along the path.

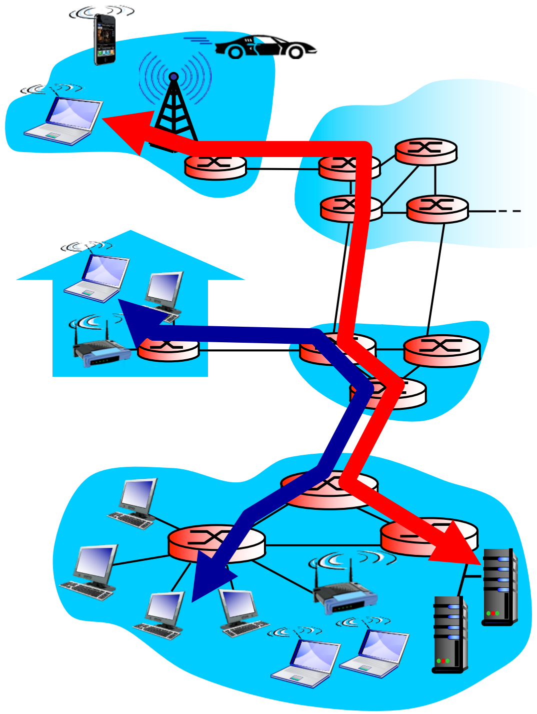
Circuit Switching: Telephone Network



Circuit switching for the Internet's core

end-end resources reserved for, "call" between source, destination:

- dedicated resources: **no** sharing
  - circuit-like (guaranteed) performance
- resource piece idle if not used by owning call *(no sharing)*
- dividing link bandwidth into "pieces"
  - frequency division
  - time division



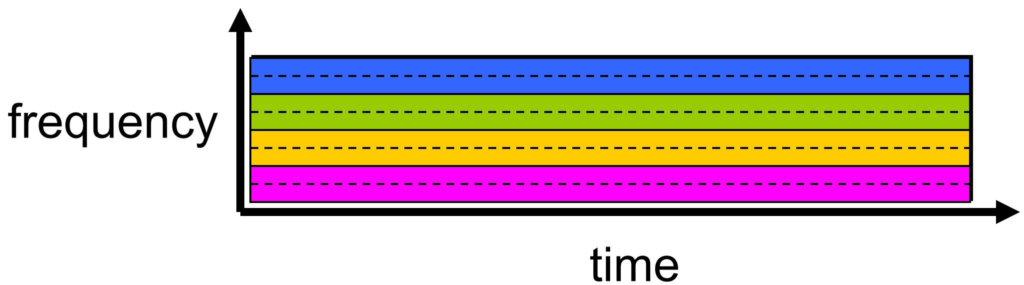
Restaurant Analogy

Circuit switching: FDM versus TDM

Example:

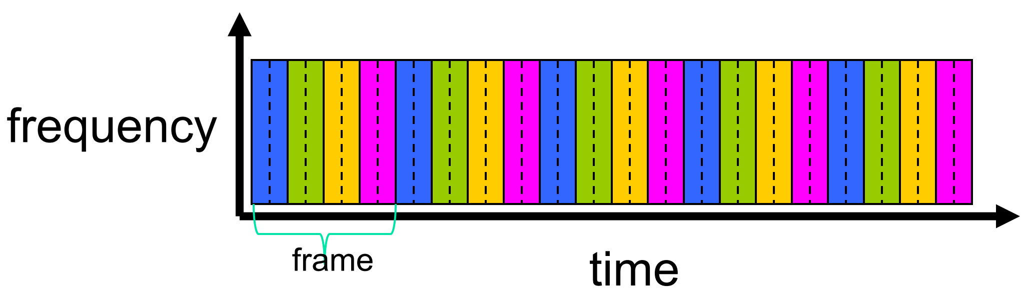
4 users

FDM



FM radio stations use FDM 88MHz to 108 MHz

TDM



time is divided into frames of certain duration

e.g 8000 frames/sec, each slot 8bits -> 64Kbps circuit

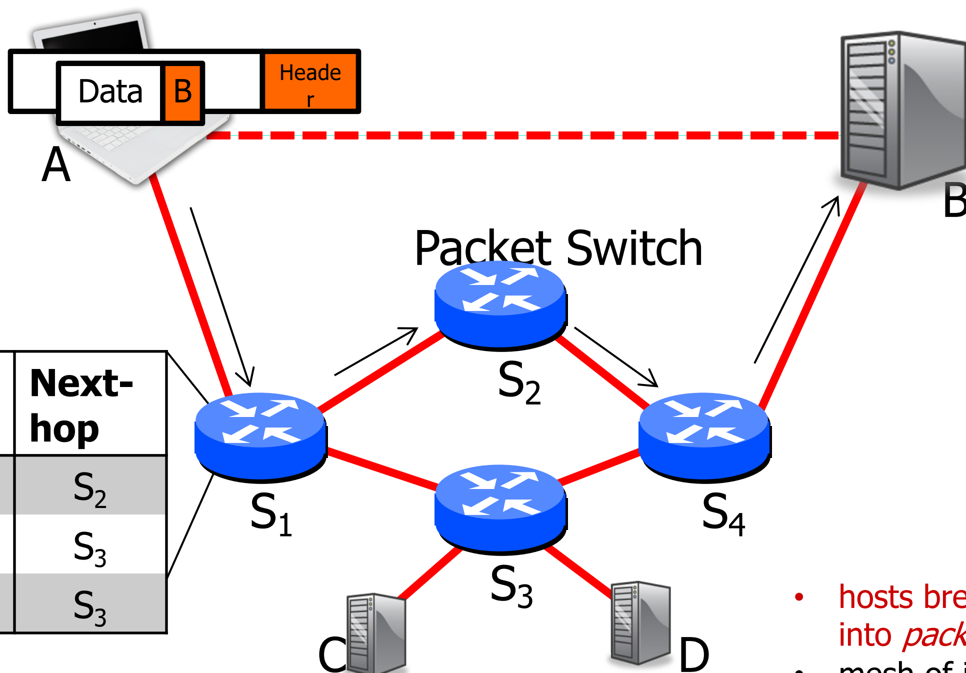
Circuit Switching Issues for the Internet

1. **Inefficient**. Computer communication tends to be very **bursty**. *e.g*. typing over an ssh connection, or viewing a sequence of web pages. If each communication has a dedicated circuit, it will be used very inefficiently.

2. **Diverse Rates**. Computers communicate at many different rates. *e.g.* a web server streaming video at 6Mb/s, or typing at 1 character per second over ssh. A fixed rate circuit will not be much use!

3. **State Management**. Circuit switches maintain per-communication state, which must be managed.

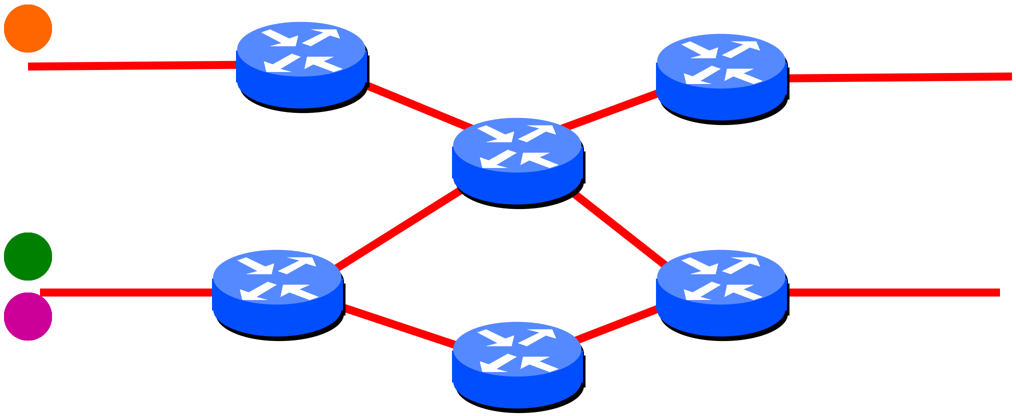
Packet Switching



Address	Next-hop
B	S_2
C	S_3
D	S_3

- hosts break application-layer messages into *packets*
- mesh of interconnected routers
- forward packets from one router to the next, across links on path from source to destination
- The routers maintain **no** per-communication state.

Packet Switching

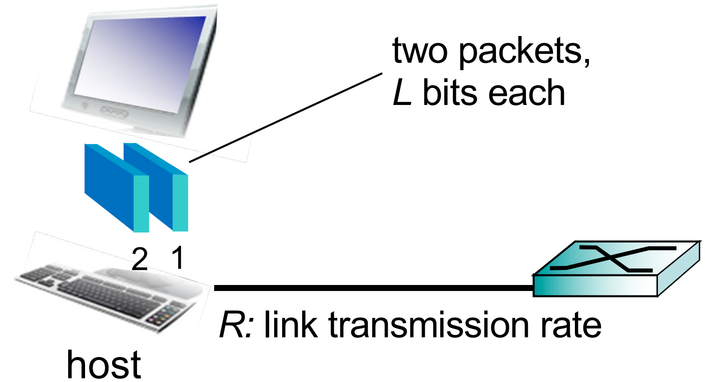


Packet Switch

Host: sends *packets* of data

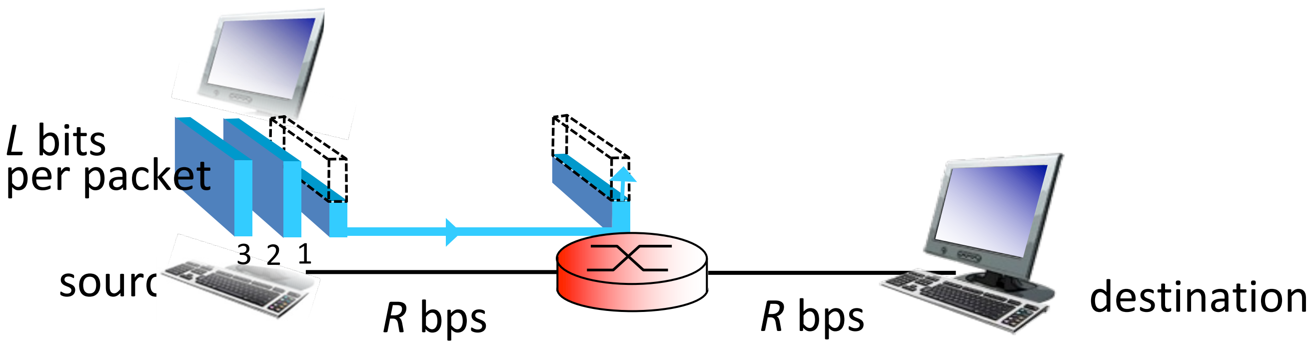
host sending function:

- 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*



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

Packet-switching: store-and-forward

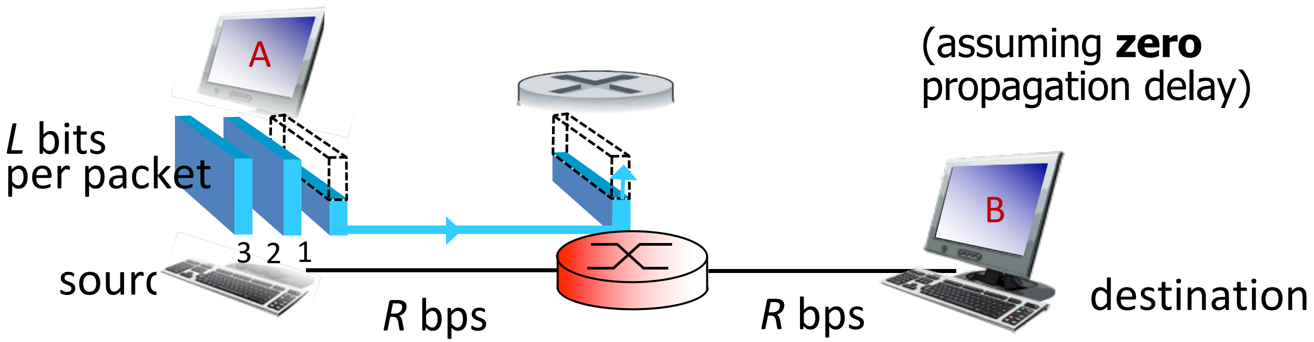


- takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link

(assuming **zero** propagation, and processing delay)

$$delay = \frac{2L}{R}$$

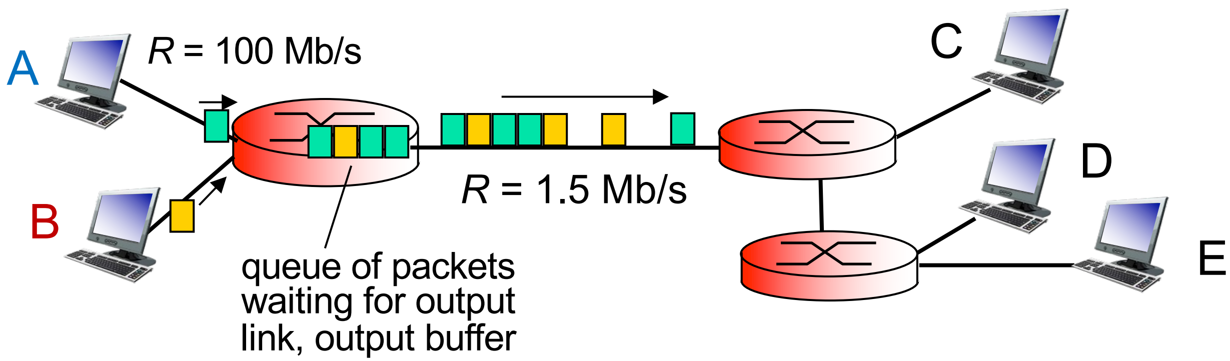
Packet-switching: store-and-forward



(assuming **zero** propagation delay)

Q: What is the time between when the source begins to send the first packet until the destination has received all three packets?

Packet Switching: queueing delay, loss



resource contention:

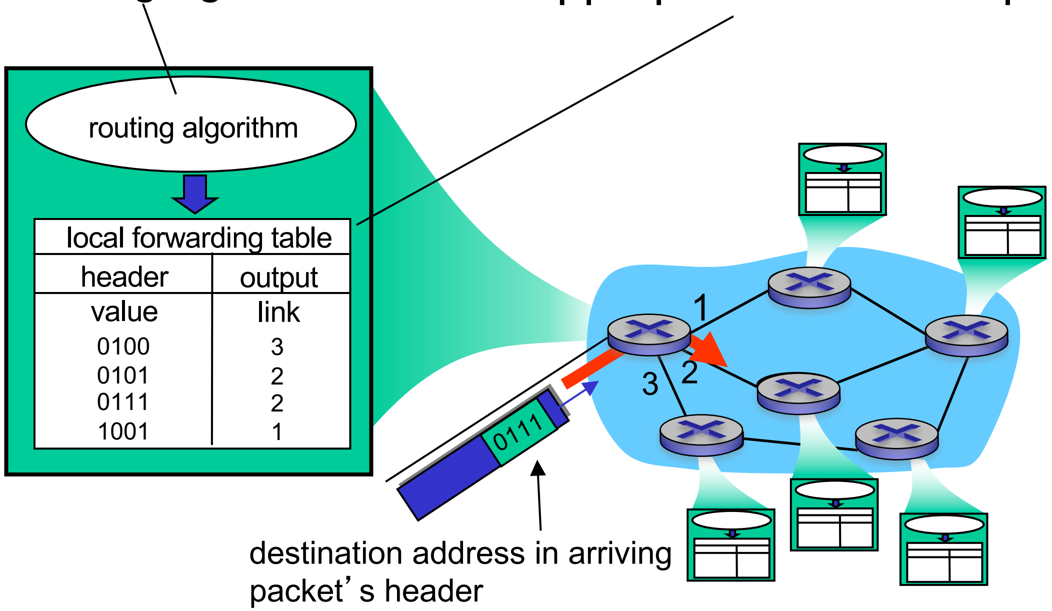
- aggregate resource demand (use of transmission link) can exceed amount available
- *congestion:*
  - packets will queue, wait for an available link use
  - packets can be dropped (lost) if no memory to store them

Forwarding Tables and Routing Protocols

routing: determines source-destination route taken by packets

- *routing algorithms*

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

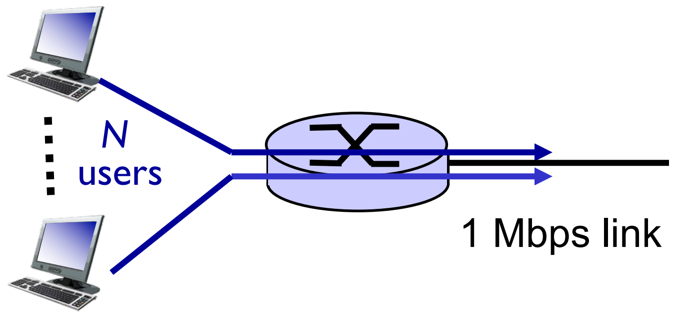


Packet Switching versus Circuit Switching

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 more than 10 users

Packet switching vs. circuit switching

- great for bursty data
  - resource sharing
  - simpler, no call setup
- Resilience to failure of links & routers
- 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 (will be revisited later in this course)

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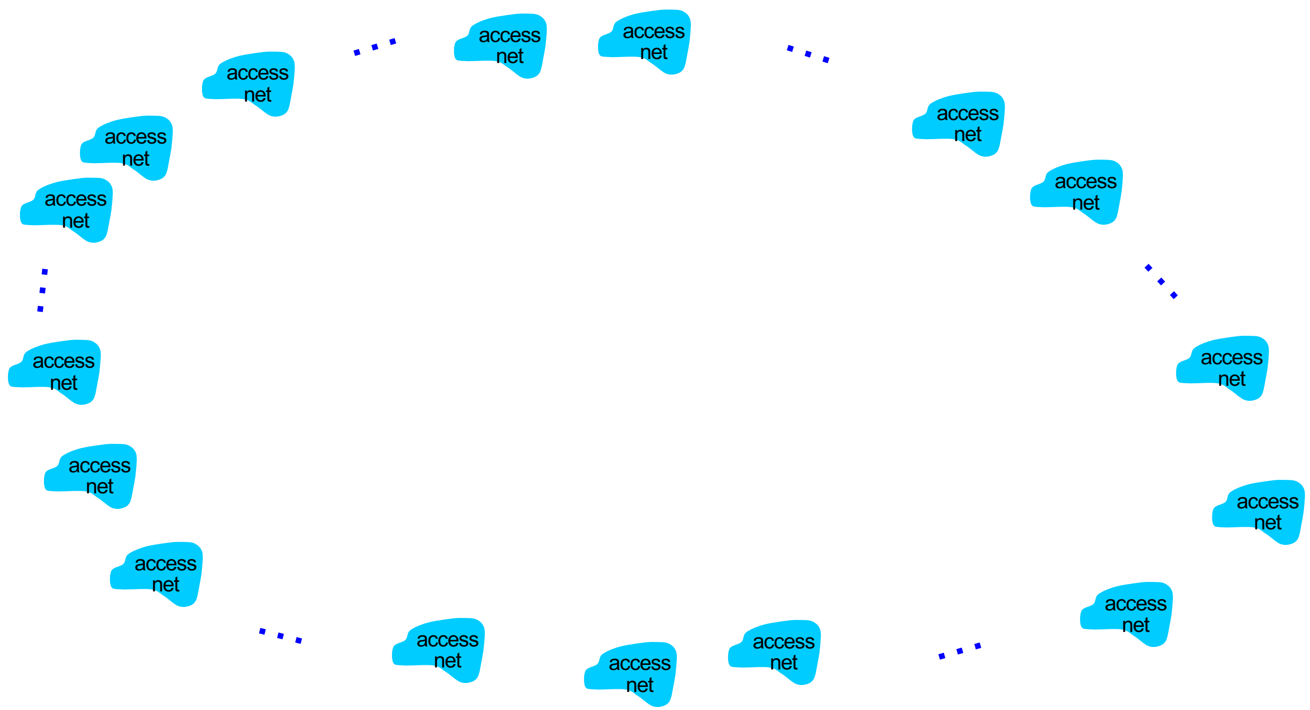
Internet structure: network of networks

- 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

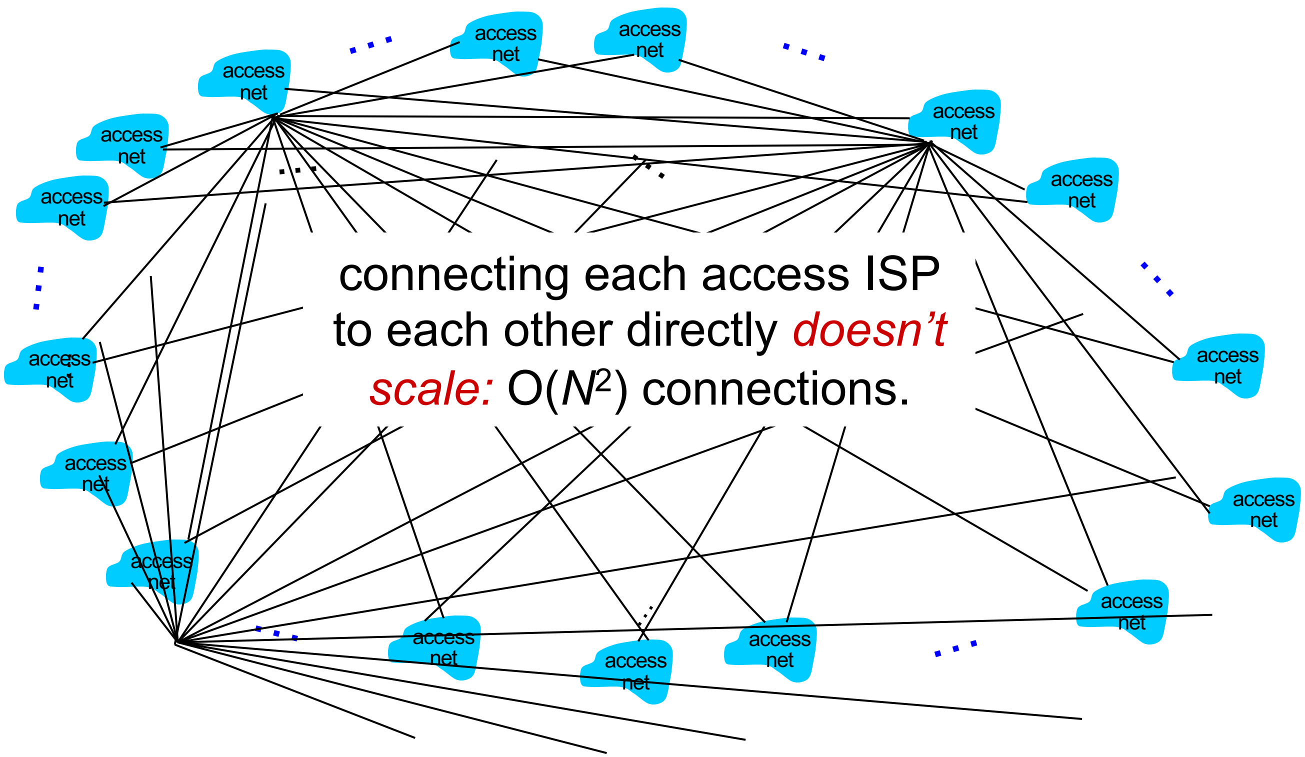
Internet structure: network of networks

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



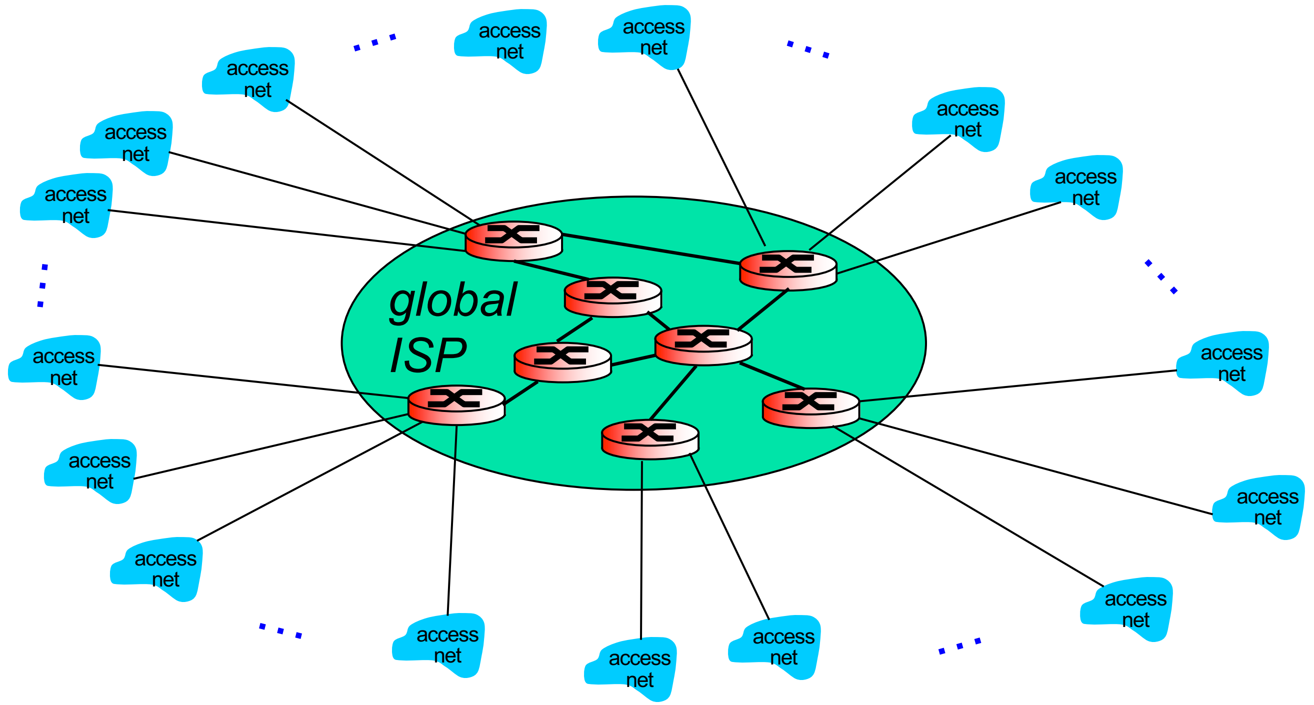
Internet structure: network of networks

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



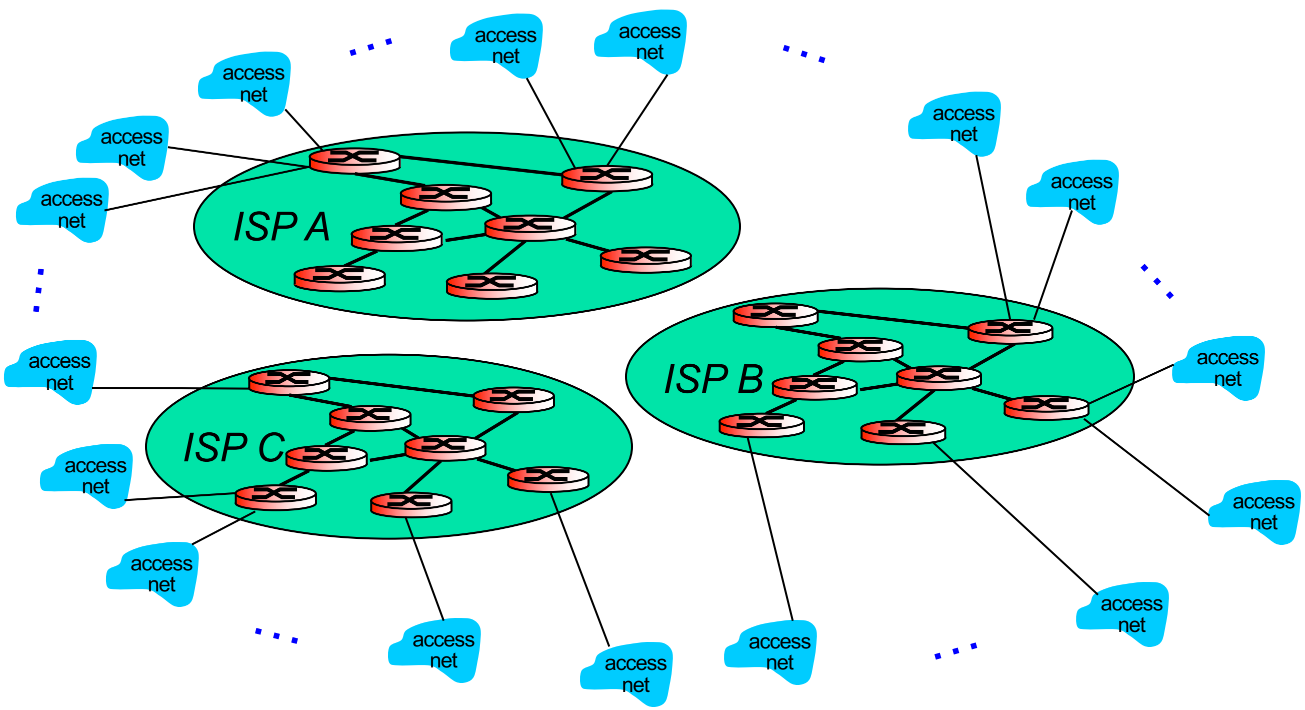
Internet structure: network of networks

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



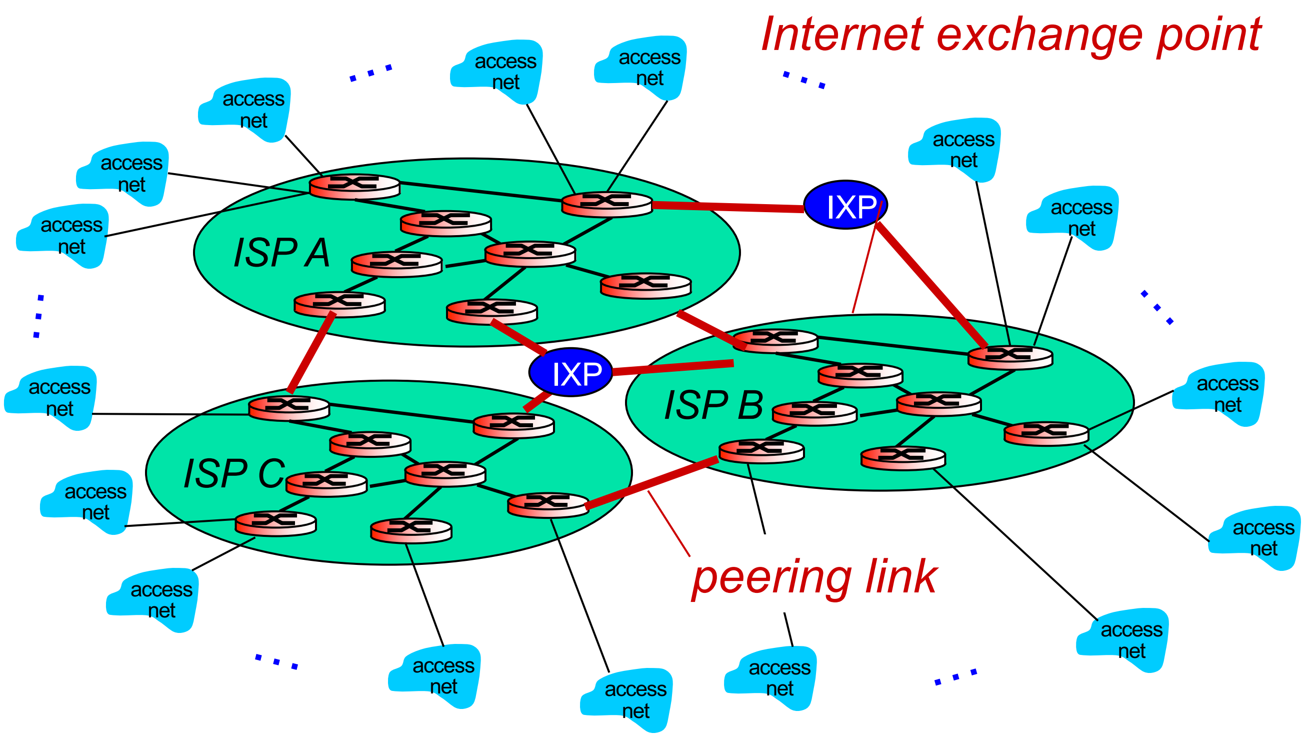
Internet structure: network of networks

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



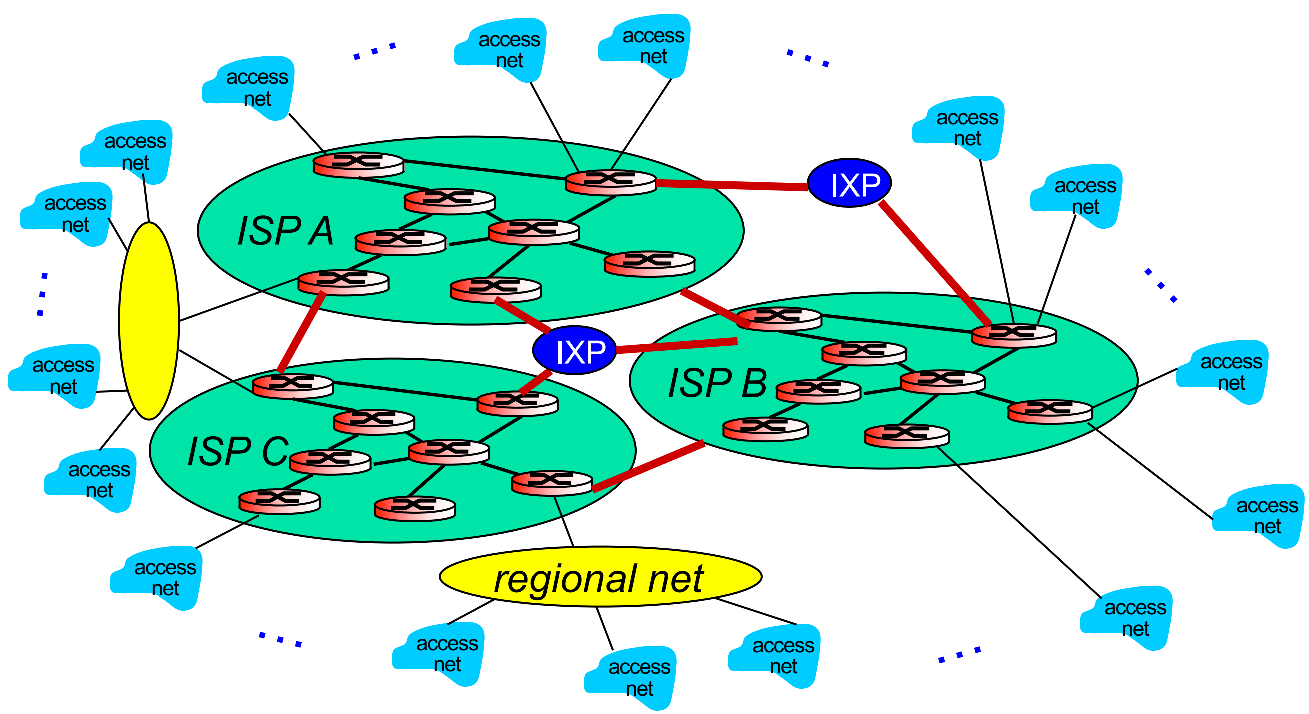
Internet structure: network of networks

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



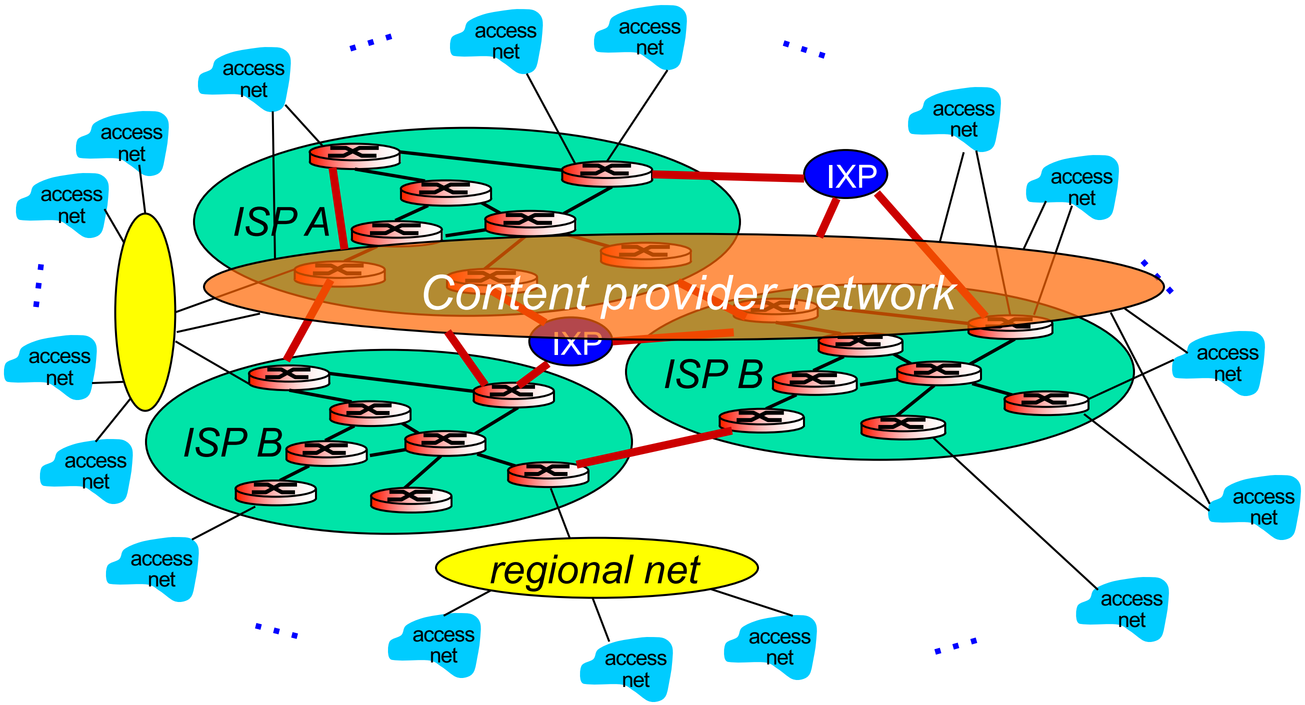
Internet structure: network of networks

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

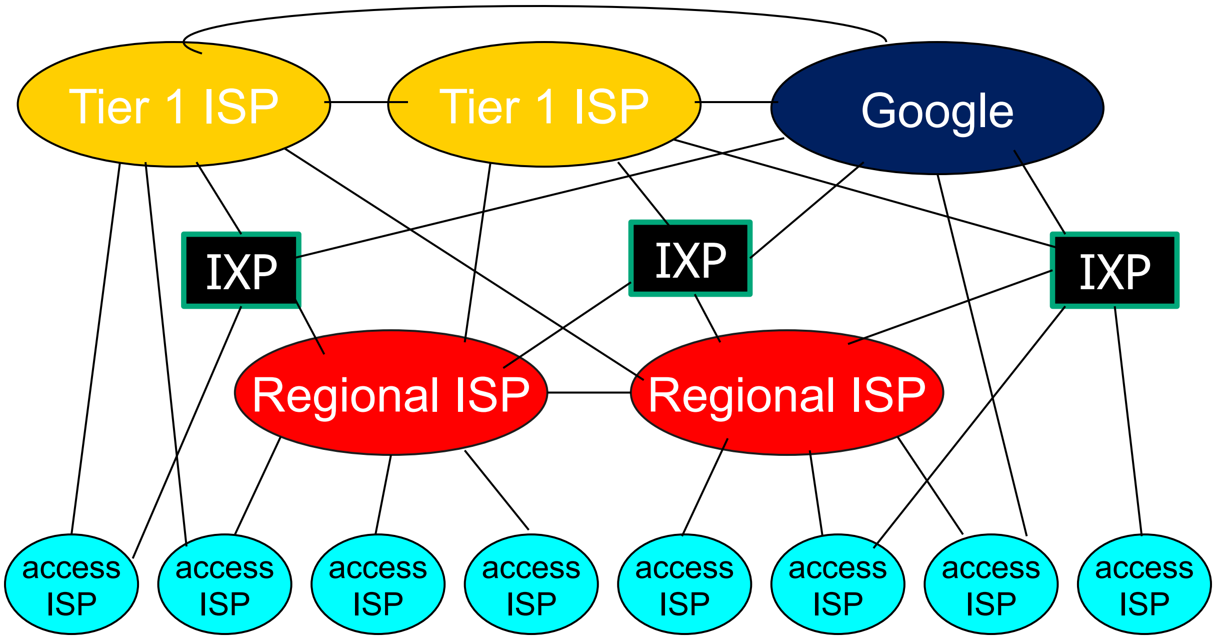


Internet structure: network of networks

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



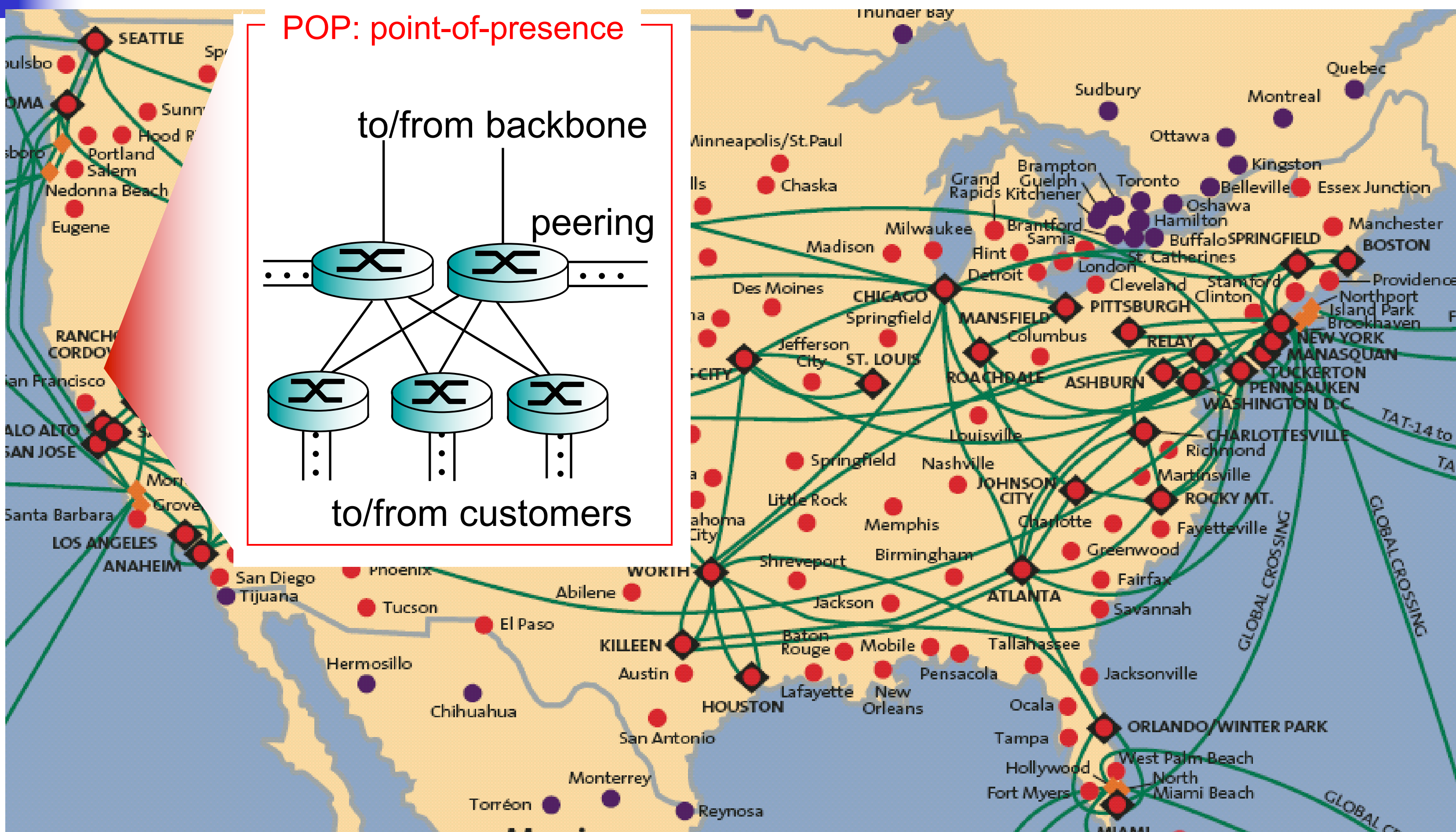
Internet structure: network of networks



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

Sprint Network Structure



Next Lecture

1. The Layers!