بسمه تعالی

School of Computer Engineering

Advanced Computer Networks

Introduction: Basics of Computer Networks

Part 3

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Fall 1401

Chapter 1: roadmap

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

The network core

The origins of computer networking and the Internet

- **The main problem**: Connecting the computers to each other to share resources and communicate.

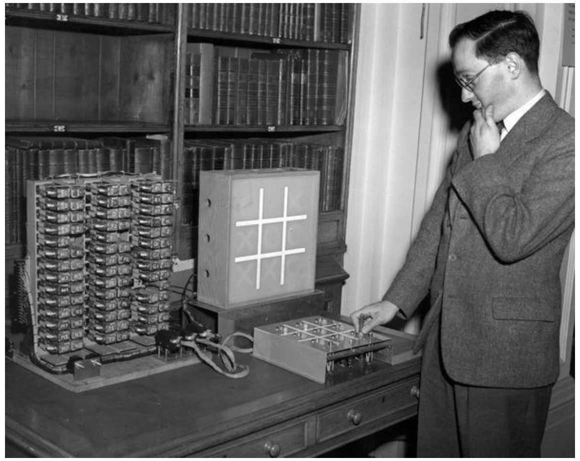
- **A Potential (existing) approach**: Use network such as that of for telephones based on circuit switching.

- The idea however was not accepted by the scientists.
  - **The reason (in short)** : Telephone networks work based on voice that is different from computer networks and it results in waste of resources.
  - **The Solution**: Packet switching.

The network core

The origins of computer networking and the Internet

- Three works independent of each other shaped the basic ideas.
- Davis and Baran implemented such a network, while Kleinrock established the queueing theory behind efficiency of packet switching.



Donald Davies at NPL (UK)
Approach: Bursty Traffic

Paul Baran at RAND (USA)
Approach: Resiliency

Leonard Kleinrock at UCLA (USA)
Approach: Queueing Theory

The network core

The origins of computer networking and the Internet: Donald Davis and NPL

- Davies was an engineer at national physics laboratory (NPL), UK.
- He was a colleague of Alan Turing in this institute since 1947, and was collaborating in designing the first computers.
- In 1965, Davies developed the idea of **packet switching**, dividing computer messages into packets that are routed independently across a network, possibly via differing routes, and are reassembled at the destination.
- Davies used the word "*packets*" after consulting with a linguist because it was capable of being translated into languages other than English without compromise.

The network core

The origins of computer networking and the Internet: Donald Davis and NPL

- Davies' key insight came in the realisation that computer network traffic was inherently "bursty" with periods of silence, compared with relatively constant telephone traffic.

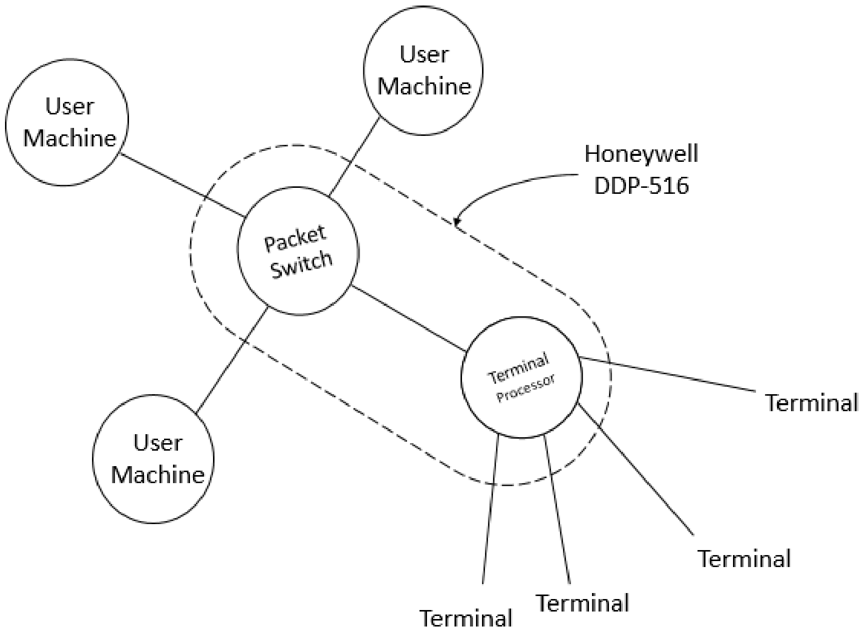
- He designed and proposed a commercial national data network based on packet switching in his 1966 Proposal for the Development of a National Communications Service for On-line Data Processing.

- Davies was the first to describe the concept of an "*Interface computer*", in 1966, today known as a *router*.

- He and his team were one of the first to use the term '*protocol*' in a data-commutation context in 1967.

The network core

The origins of computer networking and the Internet: Donald Davis and NPL



The network core

The origins of computer networking and the Internet: Paul Baran

- Baran graduated with a BSc of electrical engineering from Drexel university in 1949 and then joined the Eckert-Mauchly Computer Company, where he did technical work on UNIVAC models, the first brand of commercial computers in the United States.

- With a MSc from UCLA in 1959, a heavy travel and work schedule forced him to abandon his doctoral work.

- After joining the RAND Corporation in 1959, Baran took on the task of designing a "survivable" communications system that could maintain communication between end points in the face of damage from nuclear weapons during the Cold War.

The network core

The origins of computer networking and the Internet: Paul Baran

- Using the minicomputer technology of the day, Baran and his team developed a simulation suite to test basic connectivity of an array of nodes with varying degrees of linking (a network of *n*-ary degree of connectivity would have *n* links per node)
- The simulation randomly "killed" nodes and subsequently tested the percentage of nodes that remained connected.
- The result of the simulation revealed that networks in which $n \geq 3$ had a significant increase in resilience against even as much as 50% node loss.
- Baran's insight gained from the simulation was that **redundancy was the key**. His first work was published as a RAND report in 1960, with more papers generalizing the techniques in the next two years.

The network core

The origins of computer networking and the Internet: Paul Baran

- After proving survivability, Baran and his team needed to show proof of concept for that design so that it could be built.
- That involved high-level schematics detailing the operation, construction, and cost of all the components required to construct a network that leveraged the new insight of redundant links.
- The result was one of the *first store-and-forward data layer switching protocols*, a routing protocol, and an unproved connection-oriented transport protocol.

The network core

The origins of computer networking and the Internet: Paul Baran

- The design flew in the face of telephony design of the time by placing inexpensive and unreliable nodes at the center of the network and more intelligent terminating 'multiplexer' devices at the endpoints.
- In Baran's words, unlike the telephone company's equipment, his design did not require expensive "gold plated" components to be reliable. The Distributed Network that Baran introduced was intended to route around damage.
- It provided connection to others through many points, not one centralized connection.
- Fundamental to the scheme was the division of the information into "blocks" before they were sent out across the network. That enabled the data to travel faster and communications lines to be used more efficiently.
- Each block was sent separately, traveling different paths and rejoining into a whole when they were received at their destination.

The network core

The origins of computer networking and the Internet: Paul Baran

- The concept of Distributed Networks

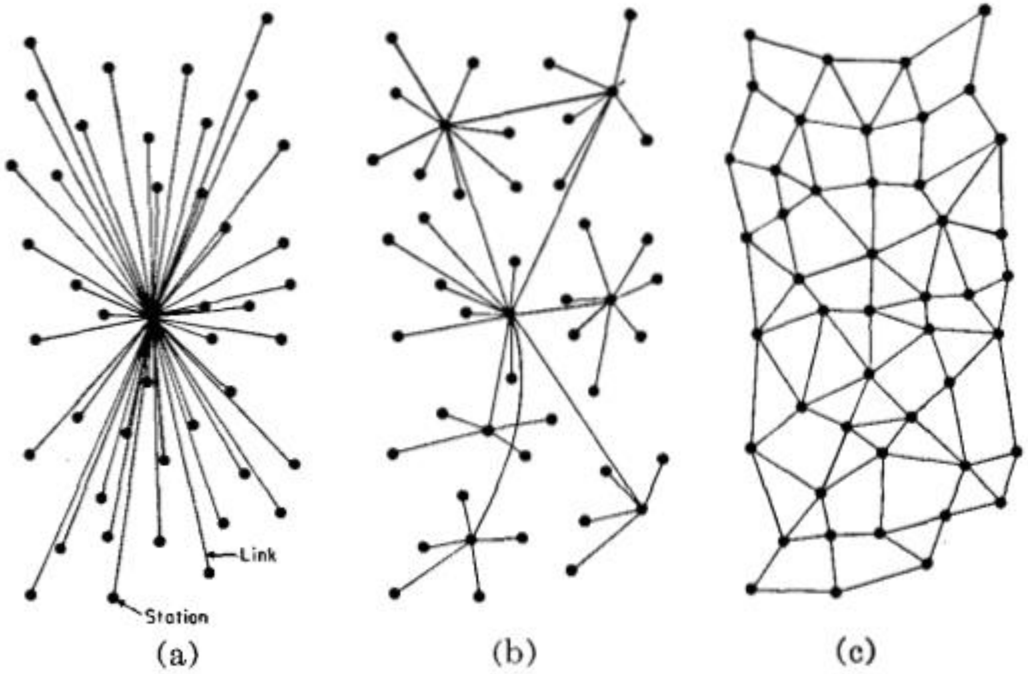


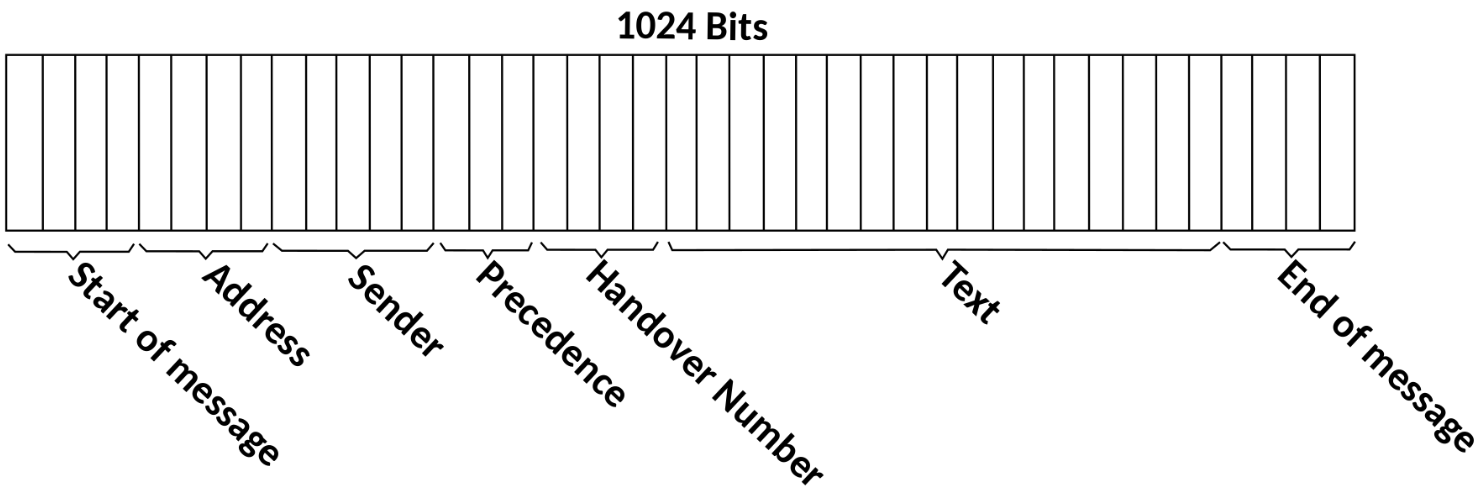
Fig. 1—(a) Centralized. (b) Decentralized. (c) Distributed networks.

Baran, Paul. "On distributed communications networks." *IEEE transactions on Communications Systems* 12, no. 1 (1964): 1-9.

The network core

The origins of computer networking and the Internet: Paul Baran

- The "block message" as suggested by Paul Baran in 1964, this is the very first data packet that was ever proposed.



Baran, Paul. "On distributed communications networks." *IEEE transactions on Communications Systems* 12, no. 1 (1964): 1-9.

The network core

The origins of computer networking and the Internet: Paul Baran

- It was in fact Davies's work on packet switching, not Baran's, that initially caught the attention of the developers of ARPANET at the Symposium on Operating Systems Principles in October 1967.
- In 1969, when the US Advanced Research Projects Agency (ARPA) started developing the idea of an internetworked set of terminals to share computing resources, the reference materials that they considered included Baran and the RAND Corporation's "On Distributed Communications" volumes.
- The resiliency of a packet-switched network that uses link-state routing protocols, which are used on the Internet, stems in some part from the research to develop a network that could survive a nuclear attack.

The network core

The origins of computer networking and the Internet: Leonard Kleinrock

- Leonard Kleinrock in his PhD thesis at MIT worked on queueing theory to show the efficiency of time sharing in store-and-forward nodes.
- Therefore, a part of community believe Kleinrock’s work as the underlaying theory behind packet switching.
- However, it is challenged by some other such as Davies.
- Davies stated why Kleinrock only has considered a single node analysis.
- A large debate shaped on this from 1990 to the death of Davies (2000) on this subject!!

The network core

The origins of computer networking and the Internet: ARPANET

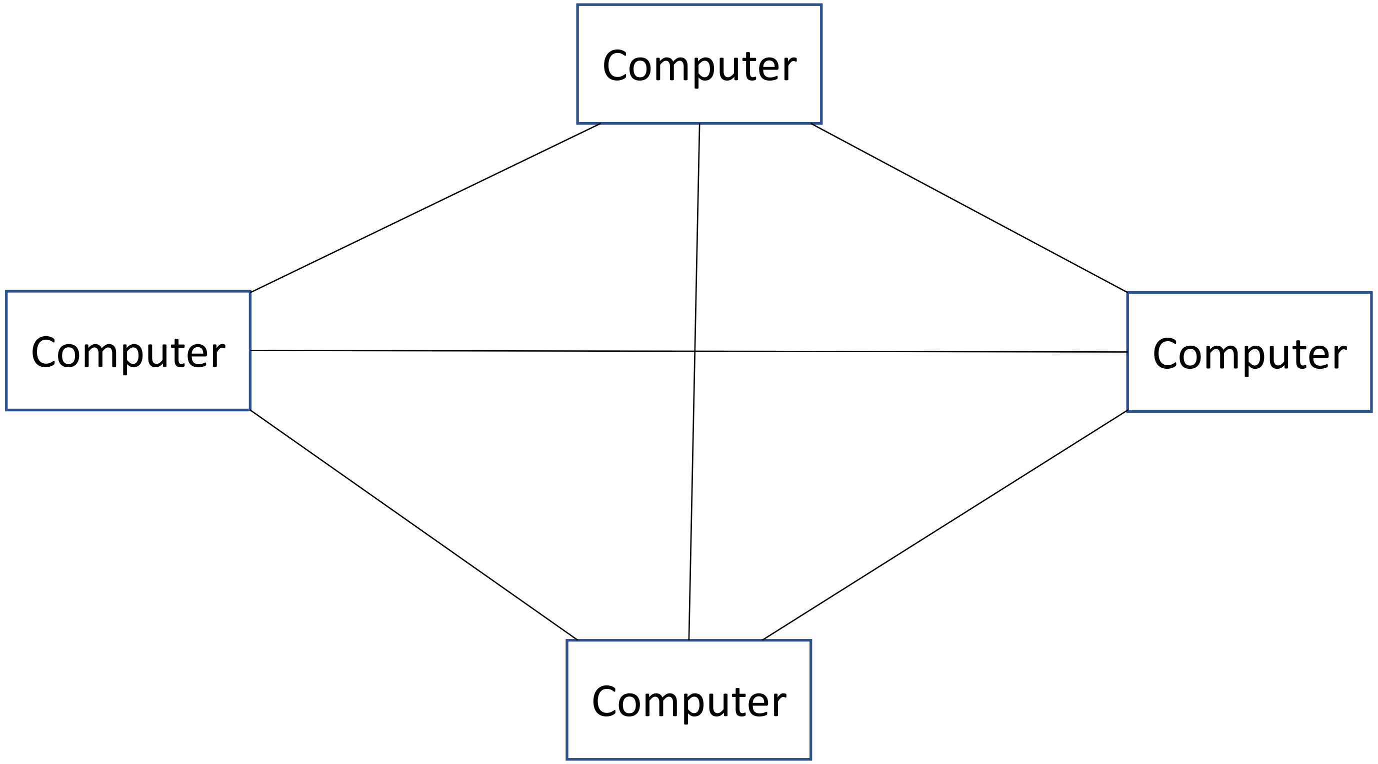
- The primary goal of the ARPA project was to permit persons and programs at one research center to access data and use interactively programs that exist and run in other computers of the network.
- Study of the technology and tariffs of available communications facilities showed that use of conventional *line switching* facilities would be economically and technically inefficient.
- The traditional method of routing information through the common-carrier switched network establishes a dedicated path for each conversation.
- With that technology, the time required for this task is on the order of seconds.

Heart, Frank E., Robert E. Kahn, Severo M. Ornstein, William R. Crowther, and David C. Walden. "The interface message processor for the ARPA computer network." In *Proceedings of the May 5-7, 1970, spring joint computer conference*, pp. 551-567. 1970.

The network core

The origins of computer networking and the Internet: ARPANET

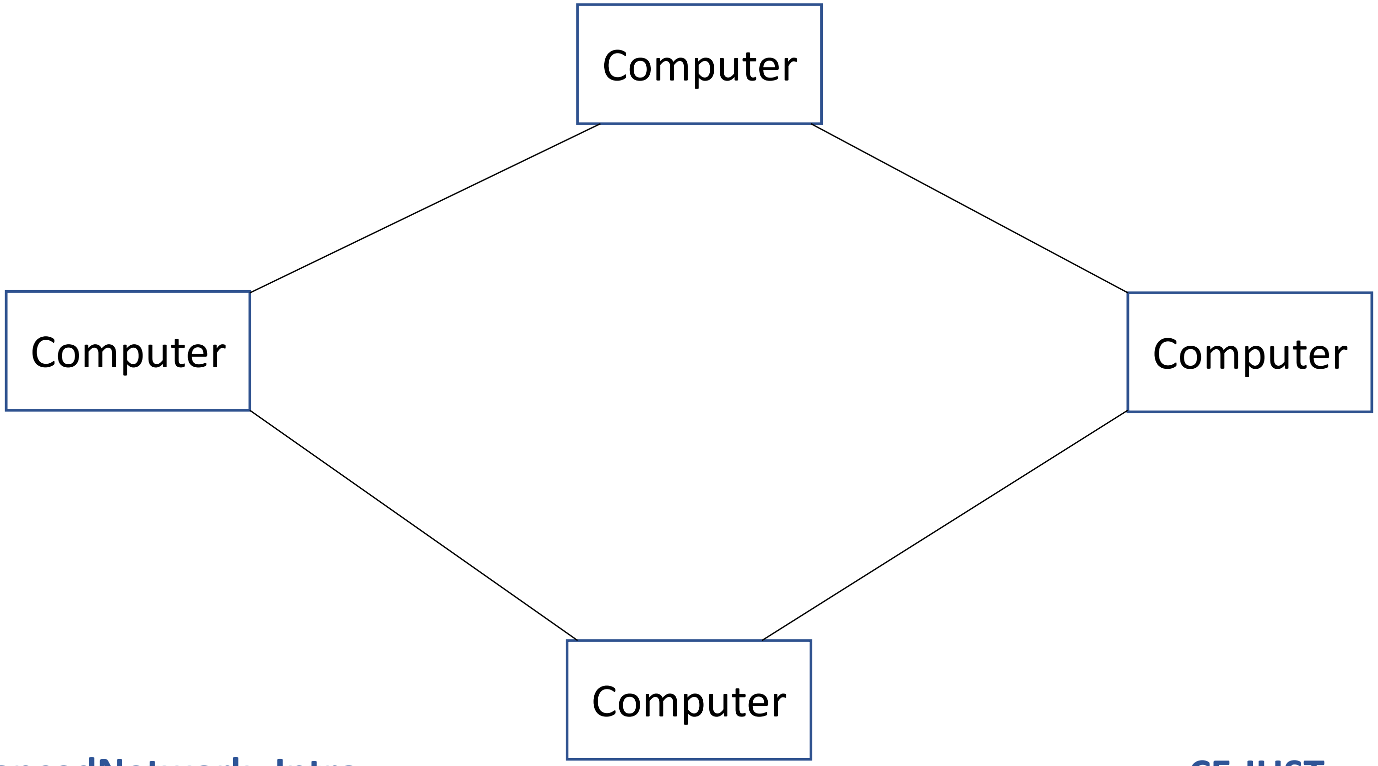
- A fully connected network



The network core

The origins of computer networking and the Internet: ARPANET

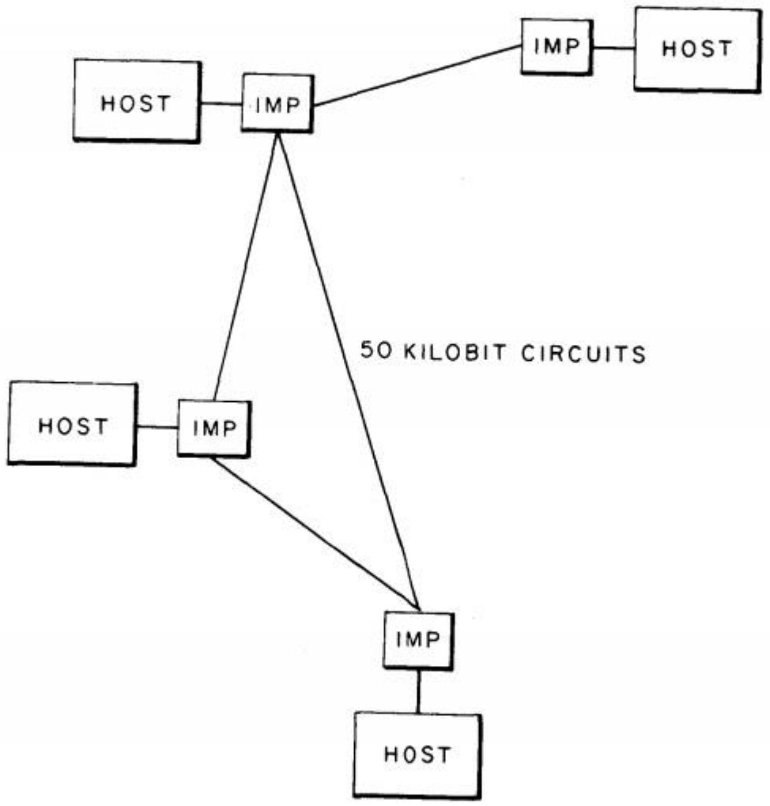
- Store and Forward Concept:
  - **Challenges**: Computer centers must deal with problems of routing, buffering, synchronization, error control, reliability, and other related issues.
  - **Solution**: To insulate the network from the problems of the computer centers, ARPA decided to place **identical small processors** at each network node, to interconnect these small processors with leased common-carrier circuits to form a subnet, and to connect each research computer center into the net via the local small processor.

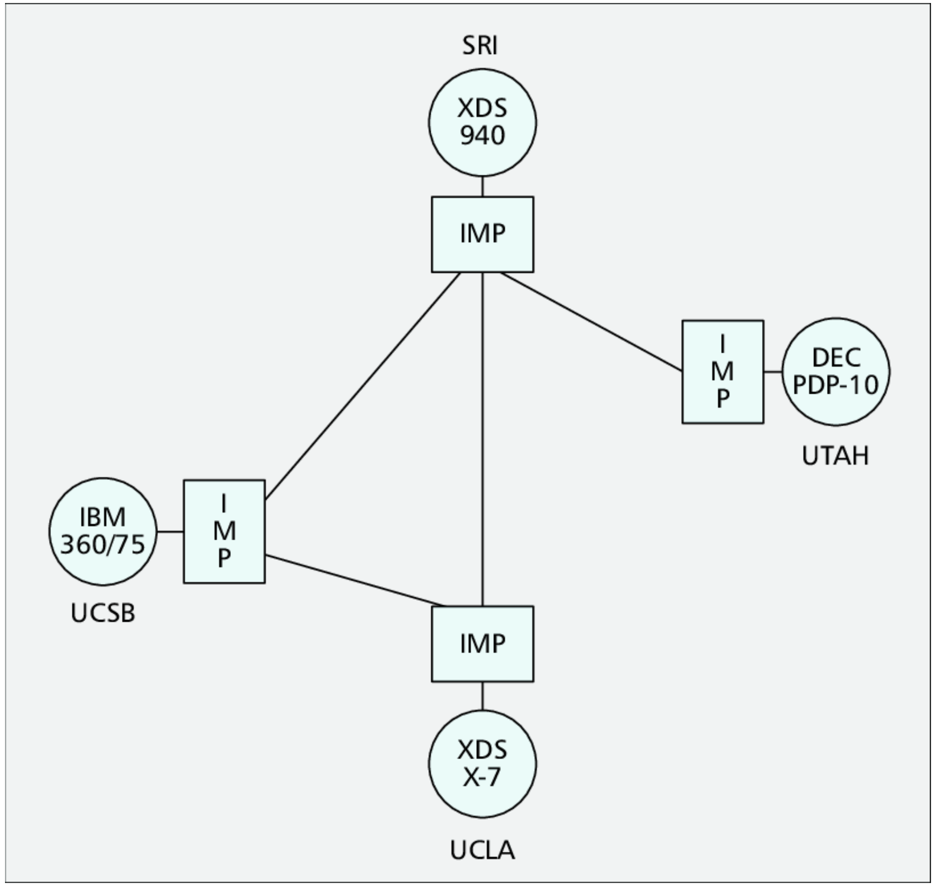


The network core

The origins of computer networking and the Internet: ARPANET

- Store and Forward Concept with IMPs





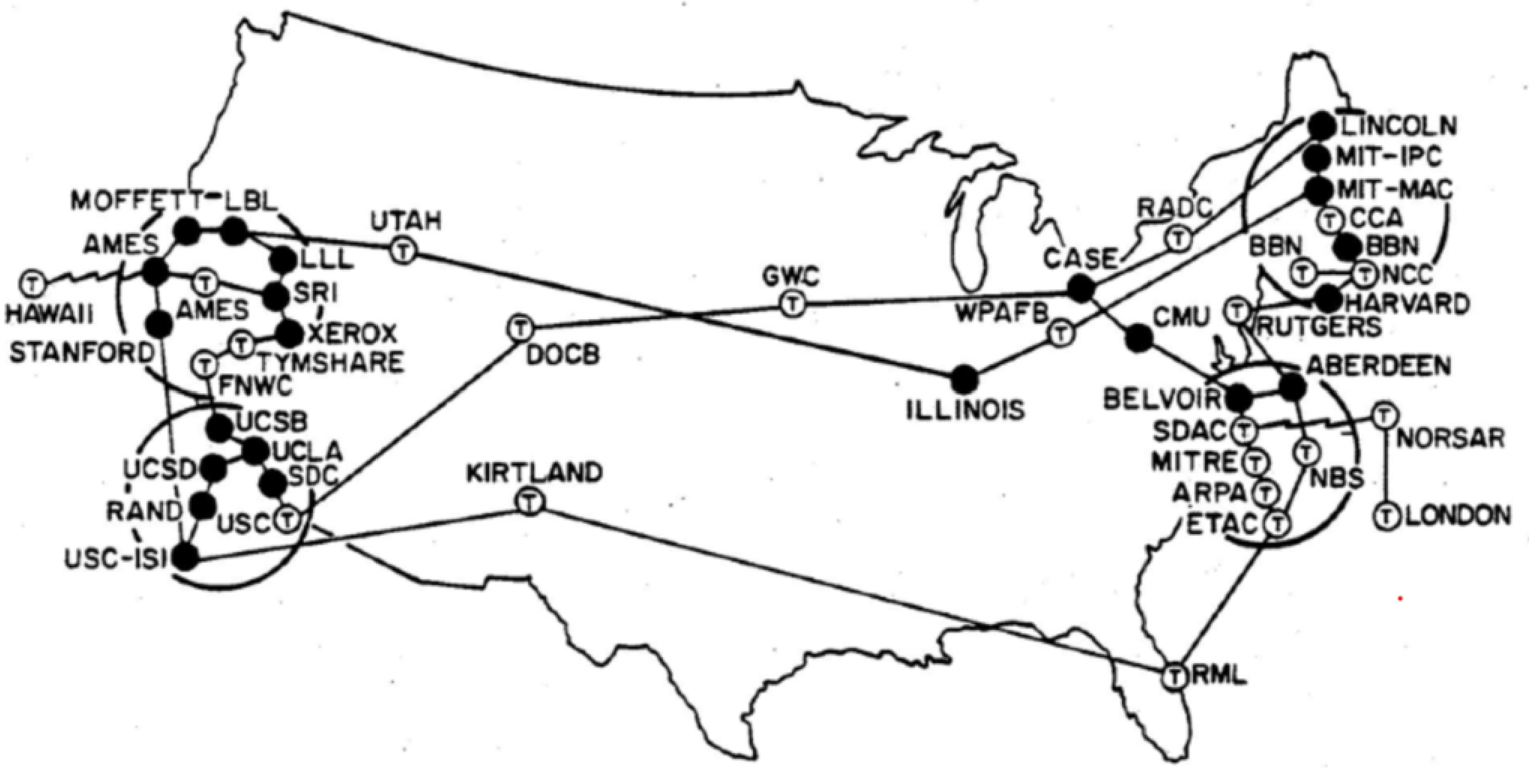
The network core

- Interface Message Processor (IMP)

The network core

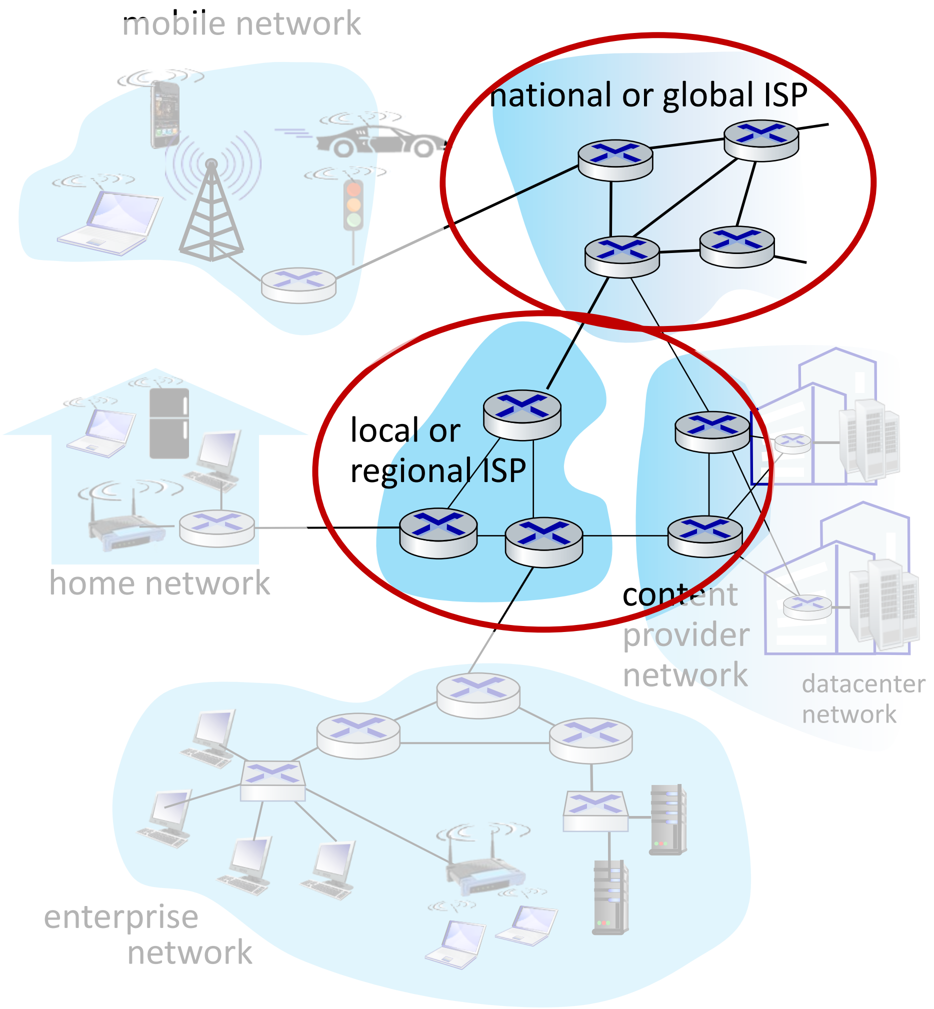
The origins of computer networking and the Internet: ARPANET

- The evolution: ARPANET access points in the 1970s



The network core

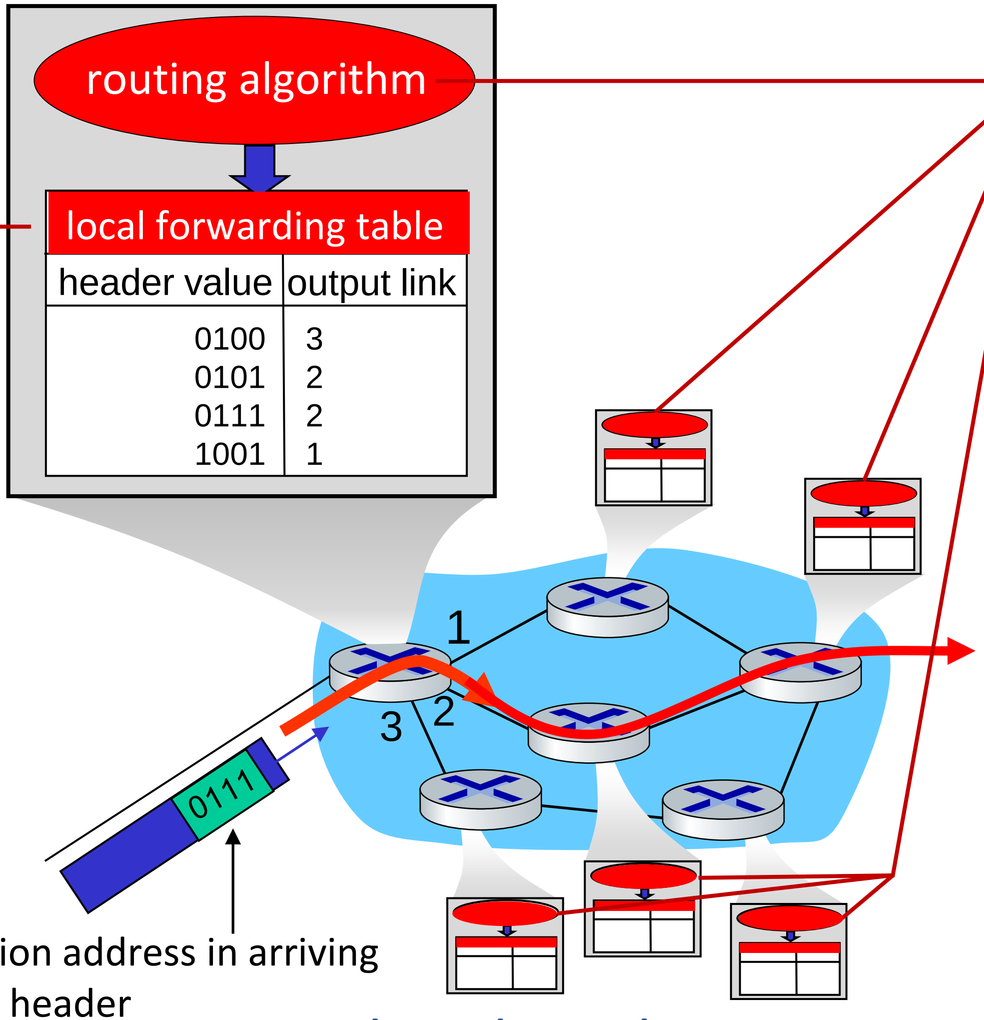
- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
  - network forwards packets from one router to the next, across links on path from source to destination



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


45 h
3,053 miles
48 h
3,309 miles
San Jose
Northampton
United States
routing


forwarding
forwarding
45 h
3,053 miles
48 h
3,309 miles
United States
Victoria
Seattle
WASHINGTON
Portland
San Francisco
San Jose
CALIFORNIA
Las Vegas
Los Angeles
San Diego
Phoenix
Tucson
El Paso
ARIZONA
NEW MEXICO
COLORADO
KANSAS
WYOMING
NORTH DAKOTA
SOUTH DAKOTA
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Kansas City
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ARKANSAS
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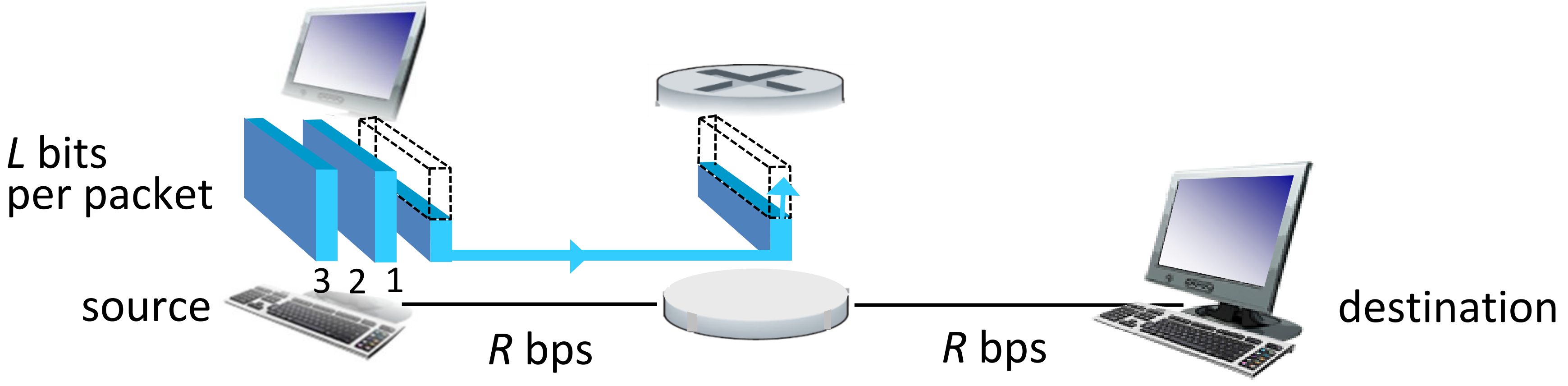
ALABAMA
Atlanta
Dallas
TEXAS
Austin
Houston
San Antonio
LOUISIANA
New Orleans
Tampa
FLORIDA
BAJA CALIFORNIA
SONORA
CHIHUAHUA
COAHUILA
Sacramento
Arden-Arcade
Cleveland
DOWNTOWN
OHIO CITY
CENTRAL

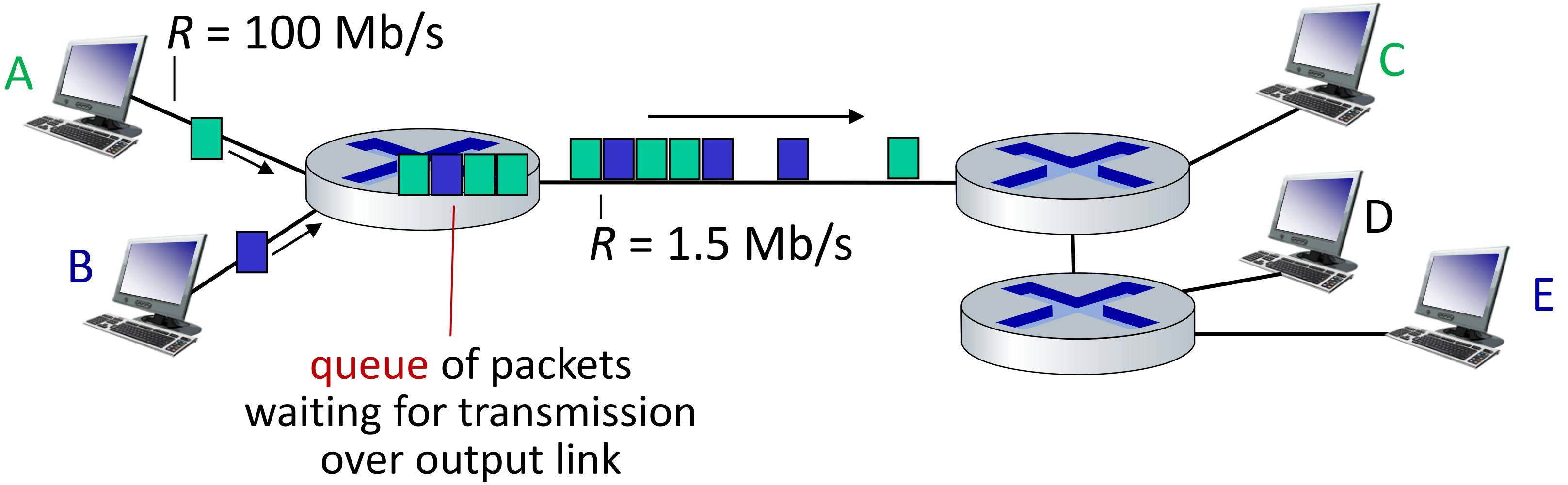
Packet-switching: store-and-forward



- packet 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

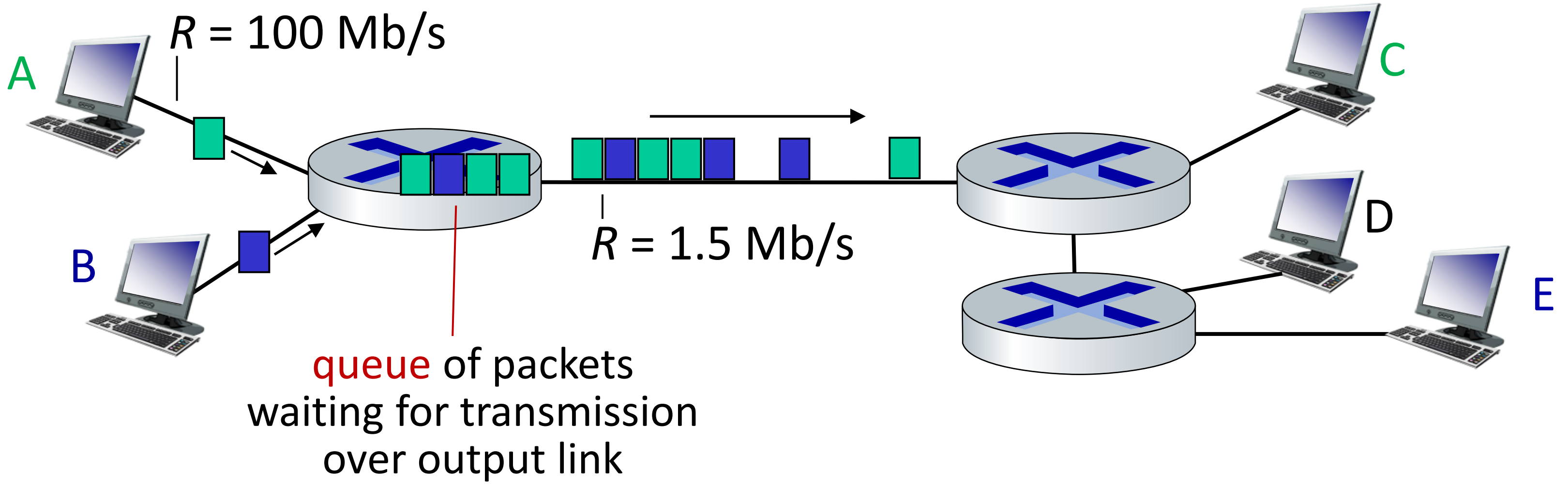
One-hop numerical example:
- L = 10 Kbits
- R = 100 Mbps
- one-hop transmission delay = 0.1 msec

Packet-switching: queueing



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

Packet-switching: queueing



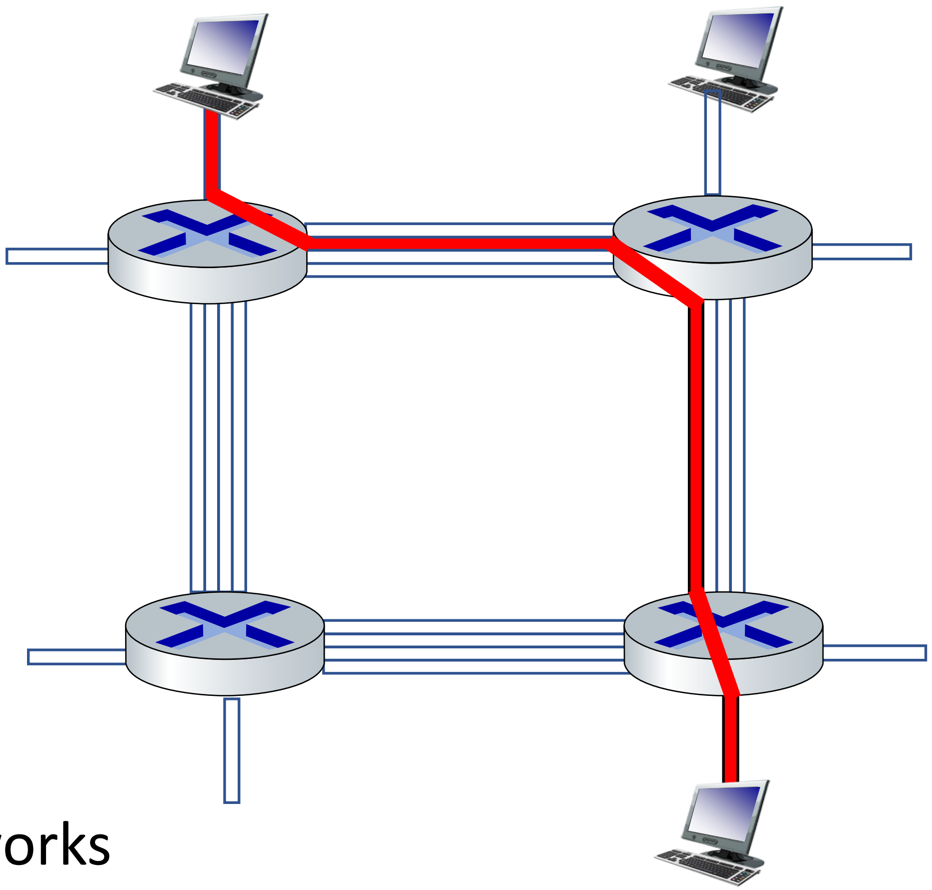
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- 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-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

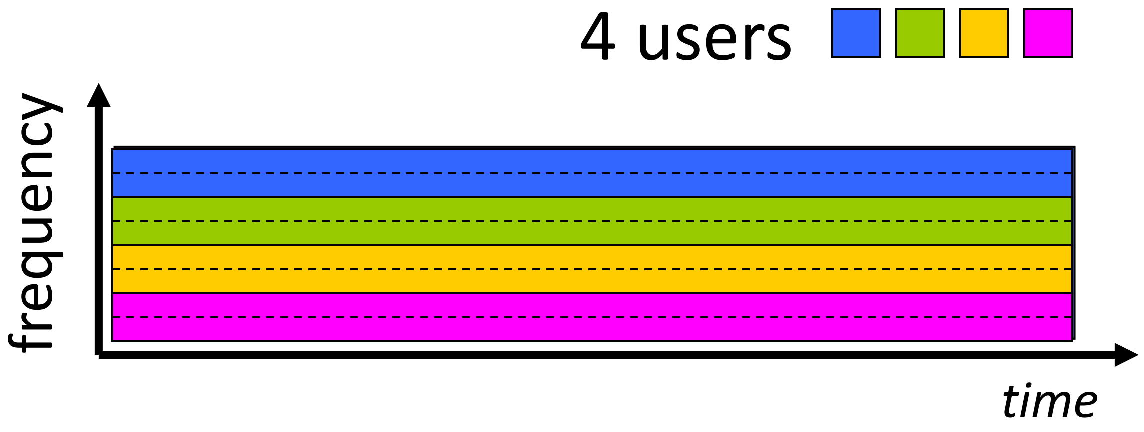


* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive

Circuit switching: FDM and TDM

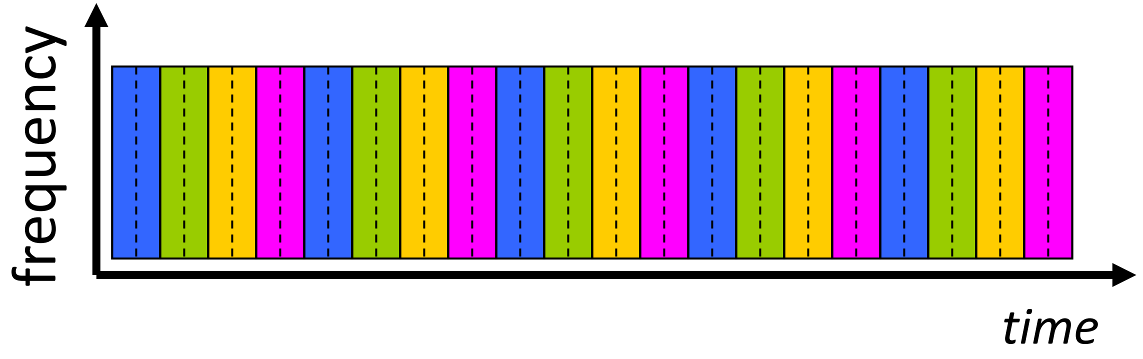
Frequency Division Multiplexing (FDM)

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



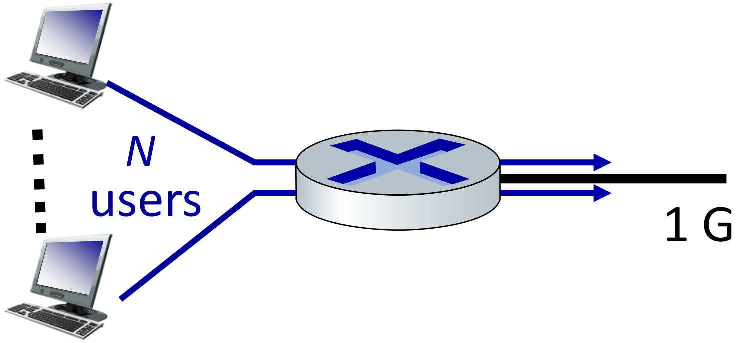
Time Division Multiplexing (TDM)

- 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)



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?

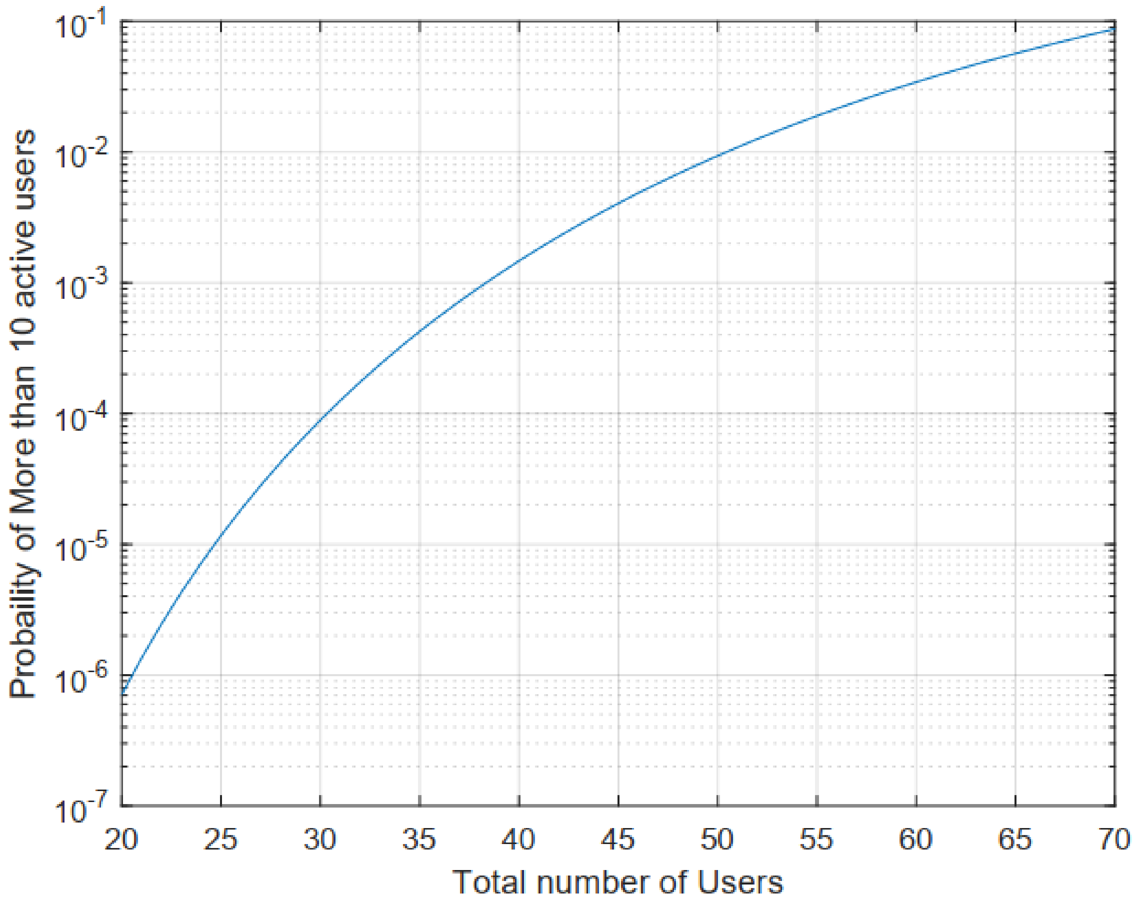
- *circuit-switching:* 10 users
- *packet switching:* with 35 users, probability > 10 active at same time is less than .0004 *

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

Packet switching versus circuit switching

- *Answer:* Probability of number of active users follows a binomial distribution



Packet switching versus circuit switching

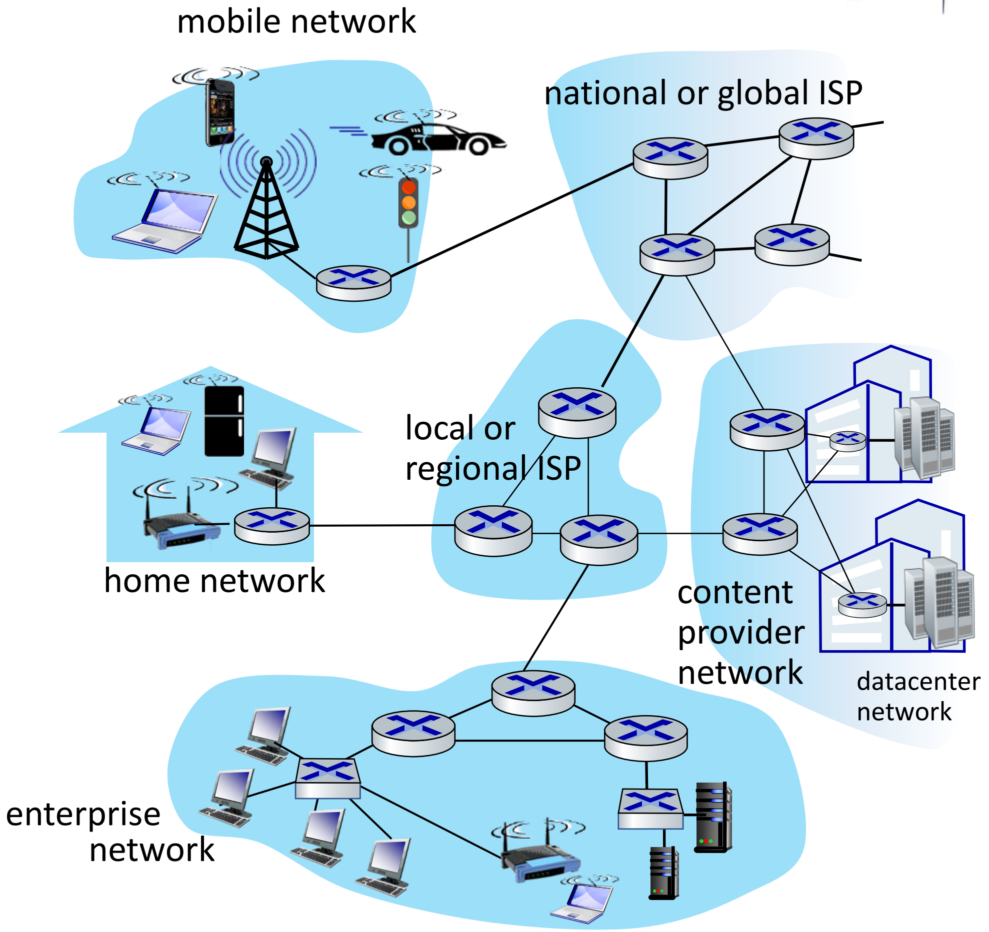
Is packet switching a "slam dunk winner"?

- 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 with packet-switching?
  - "It's complicated." There are various techniques that try to make packet switching as "circuit-like" as possible.

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

Internet structure: a "network of networks"

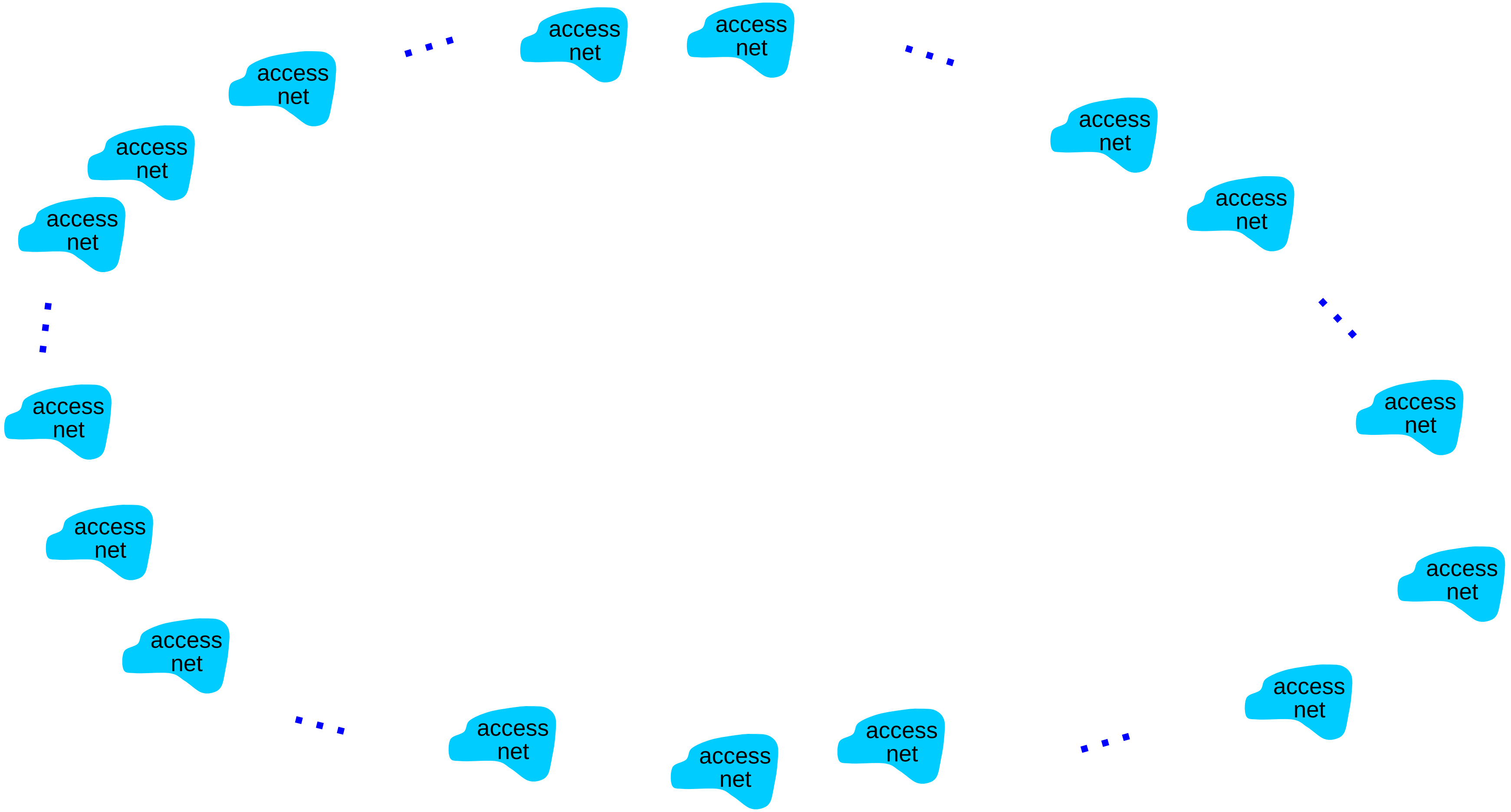
- hosts connect to Internet via access Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts *(anywhere!)* can send packets to each other
- resulting network of networks is very complex
  - evolution driven by economics, national policies



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

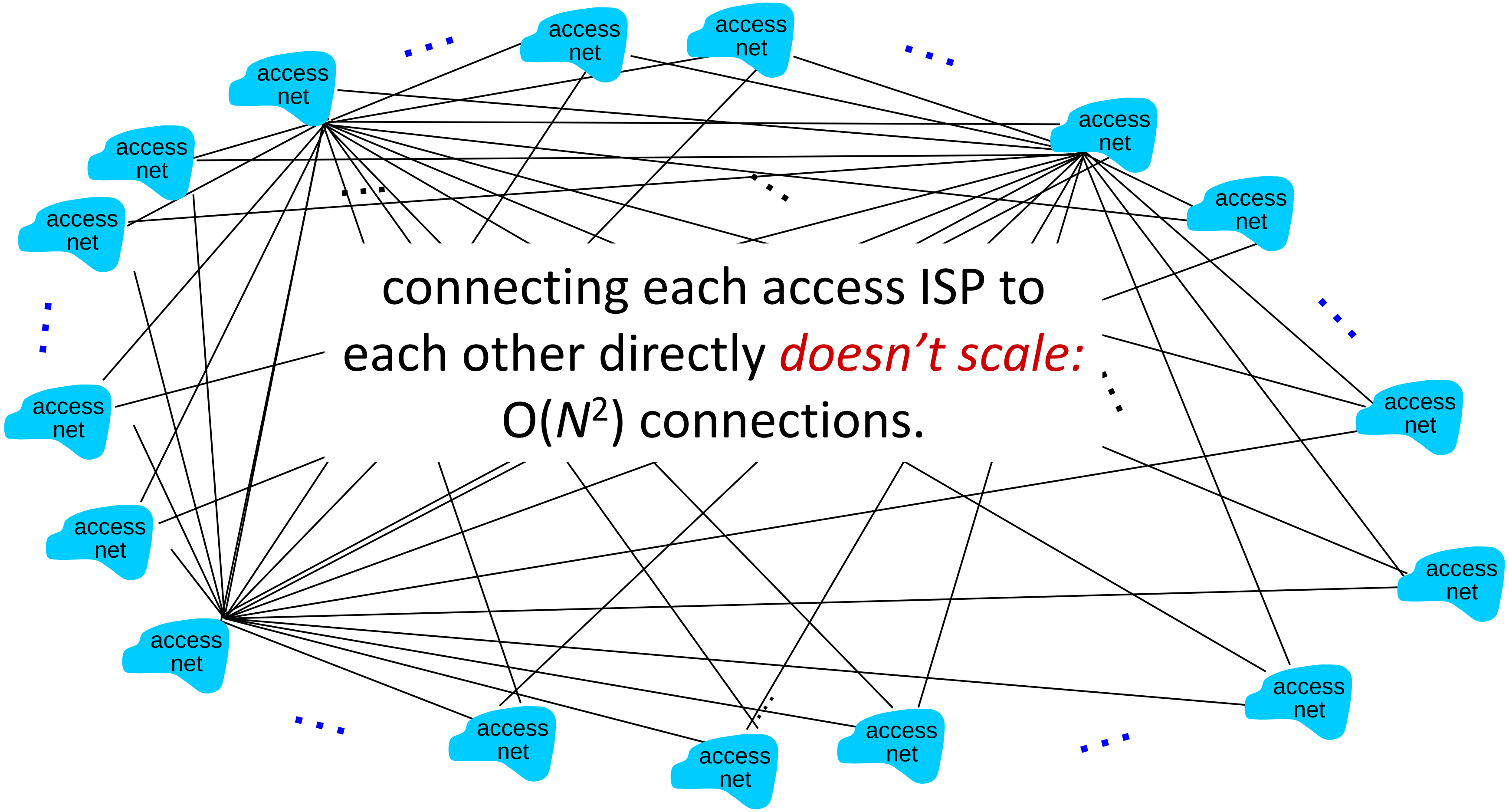
Internet structure: a “network of networks”

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



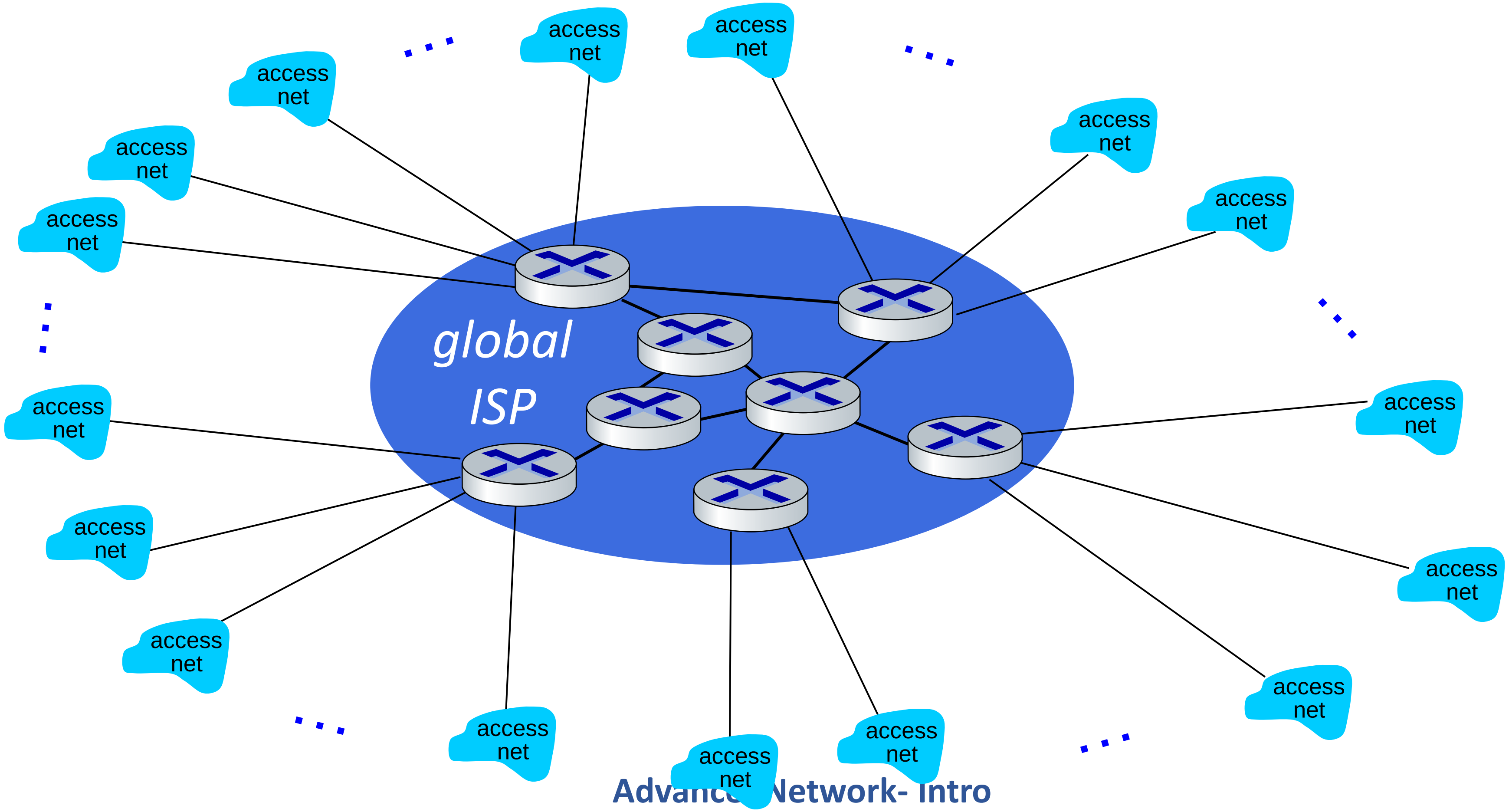
Internet structure: a “network of networks”

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



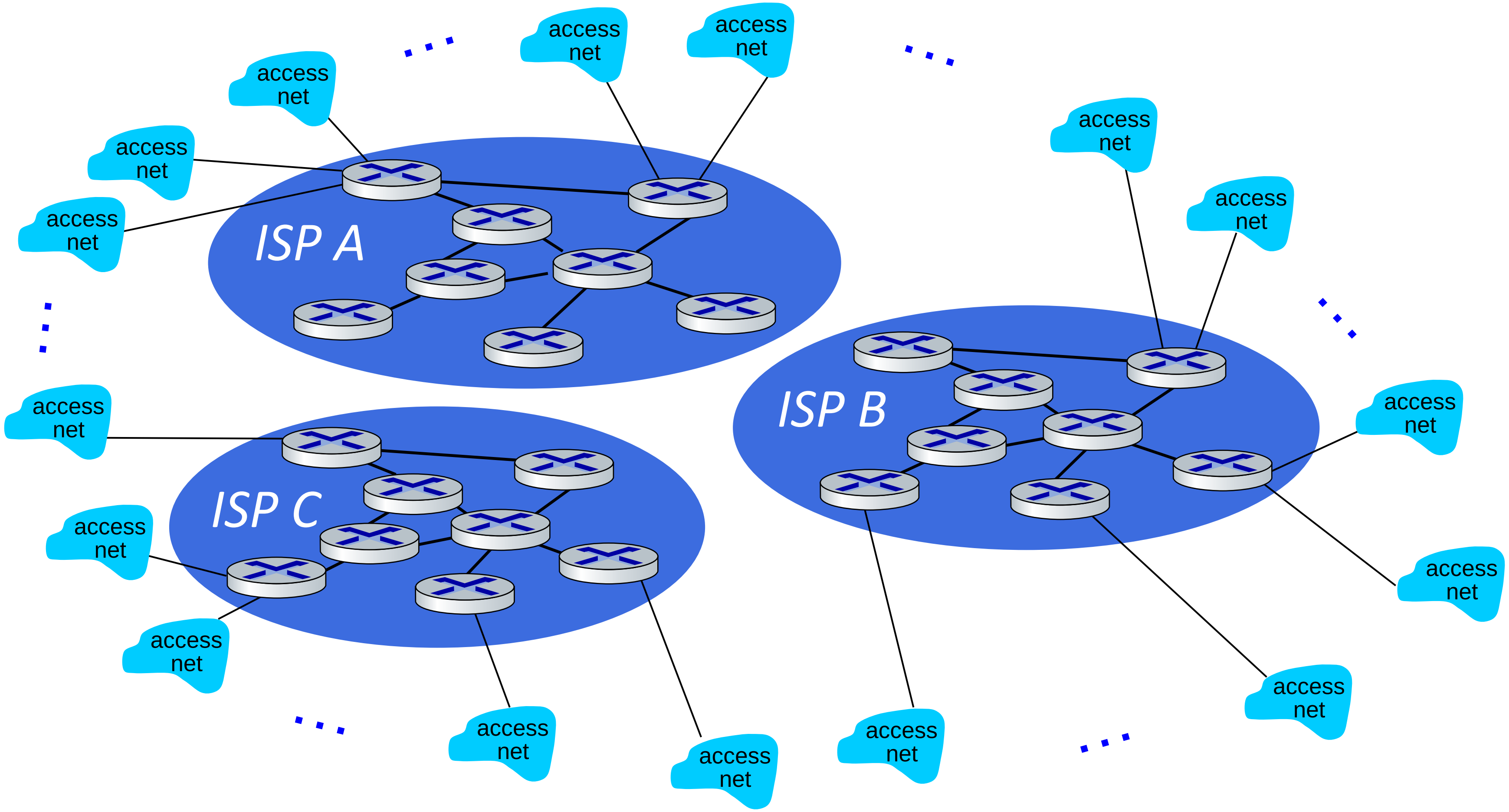
Internet structure: a "network of networks"

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



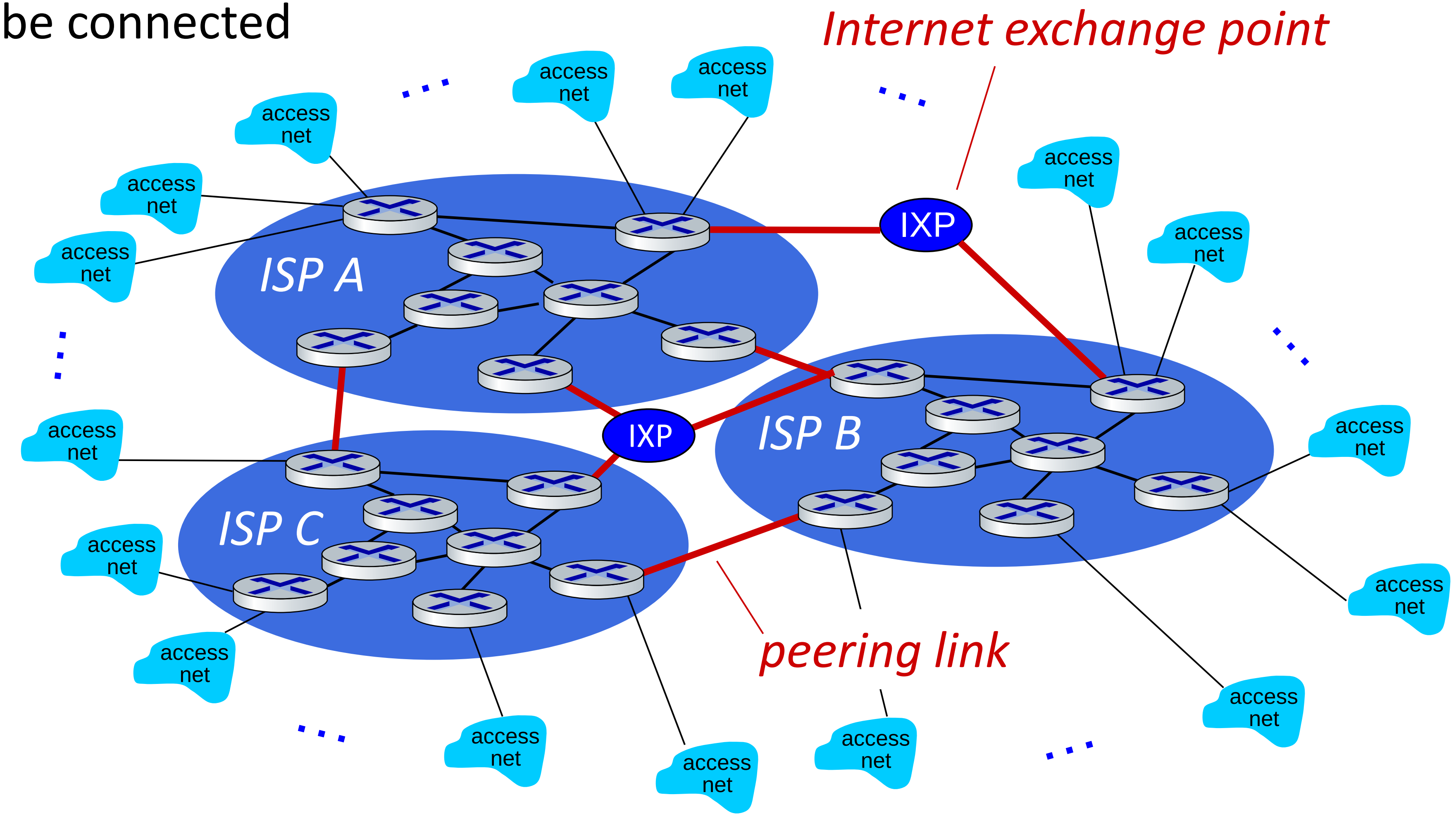
Internet structure: a "network of networks"

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



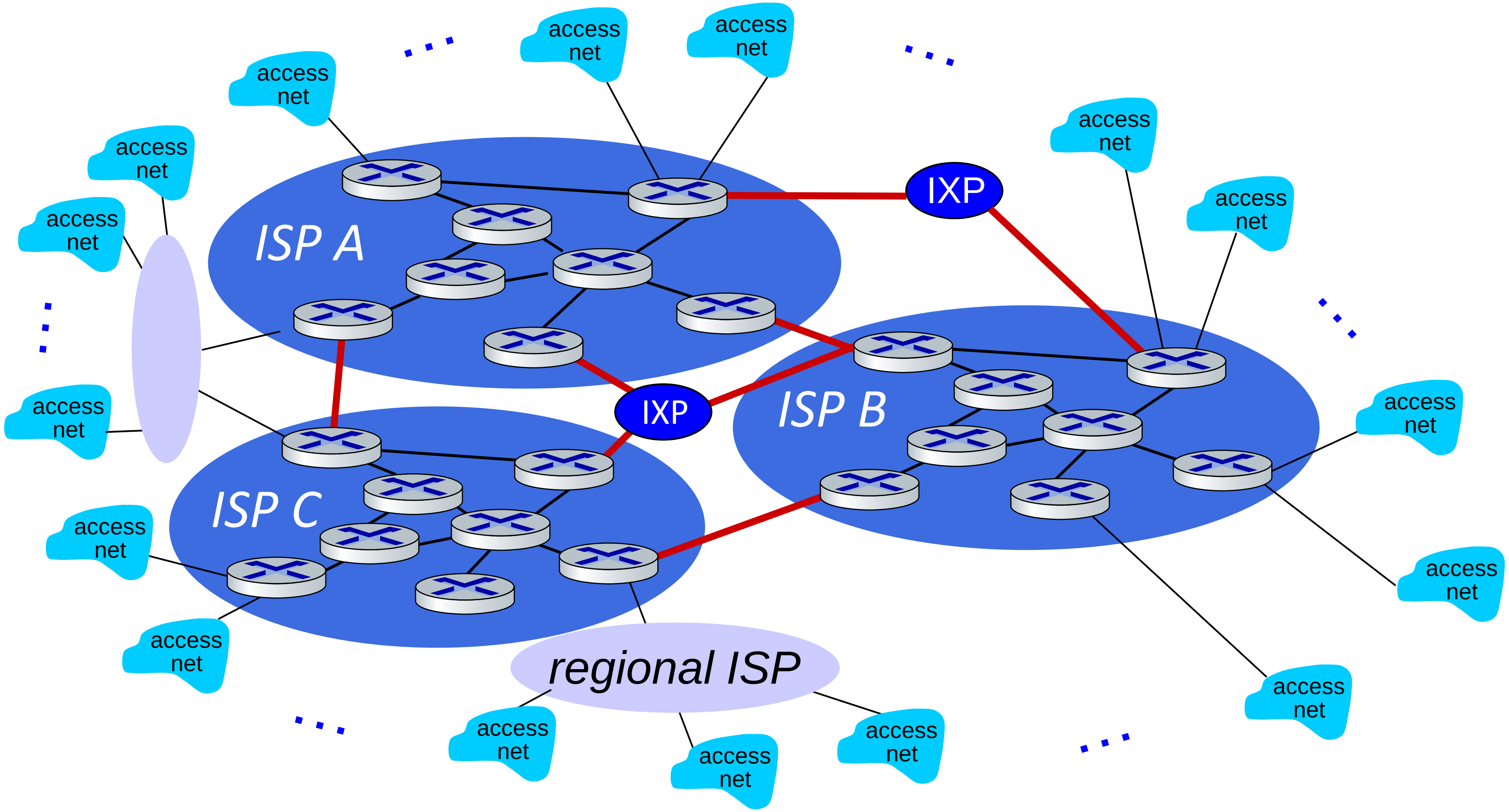
Internet structure: a "network of networks"

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



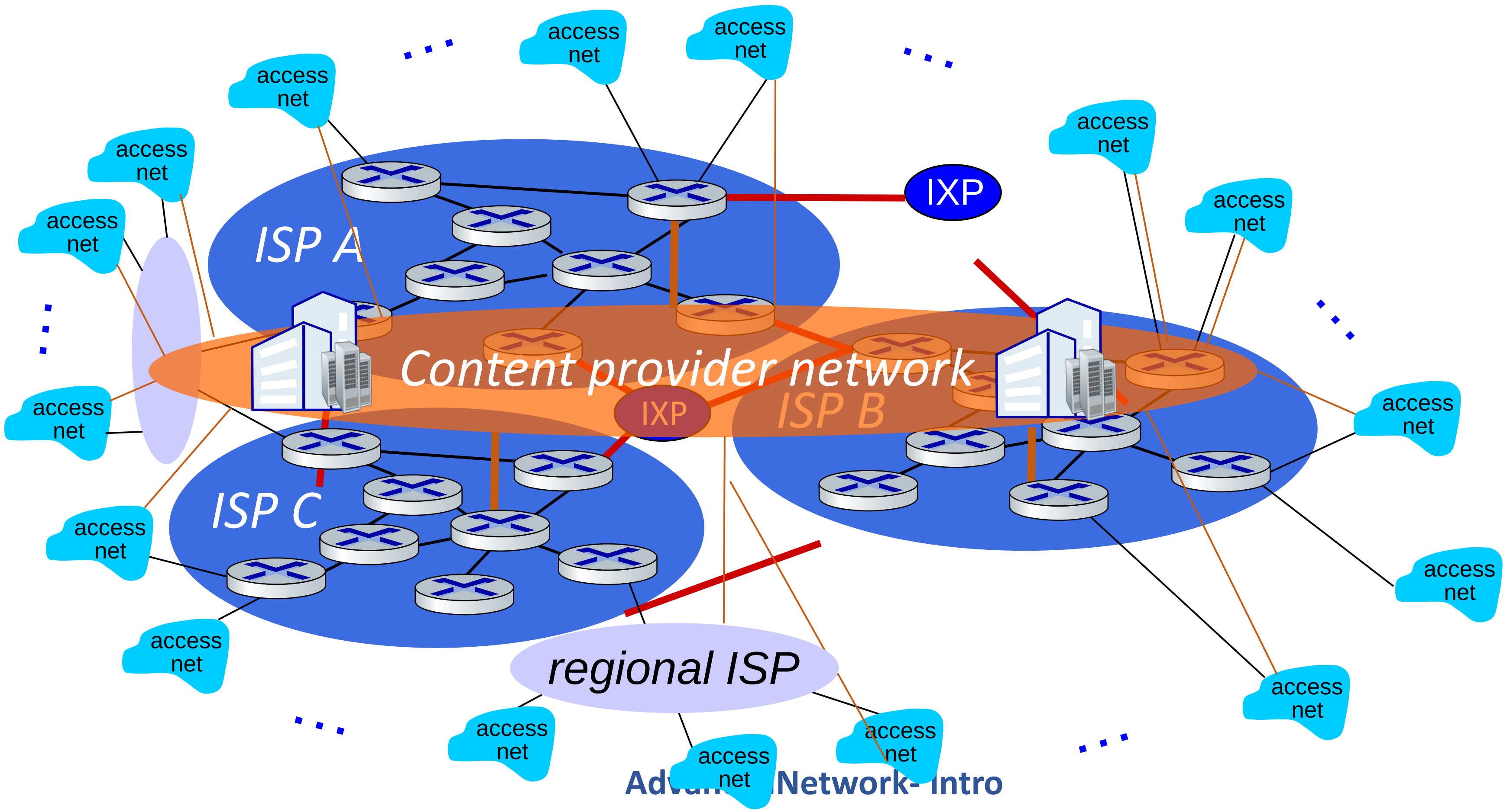
Internet structure: a "network of networks"

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

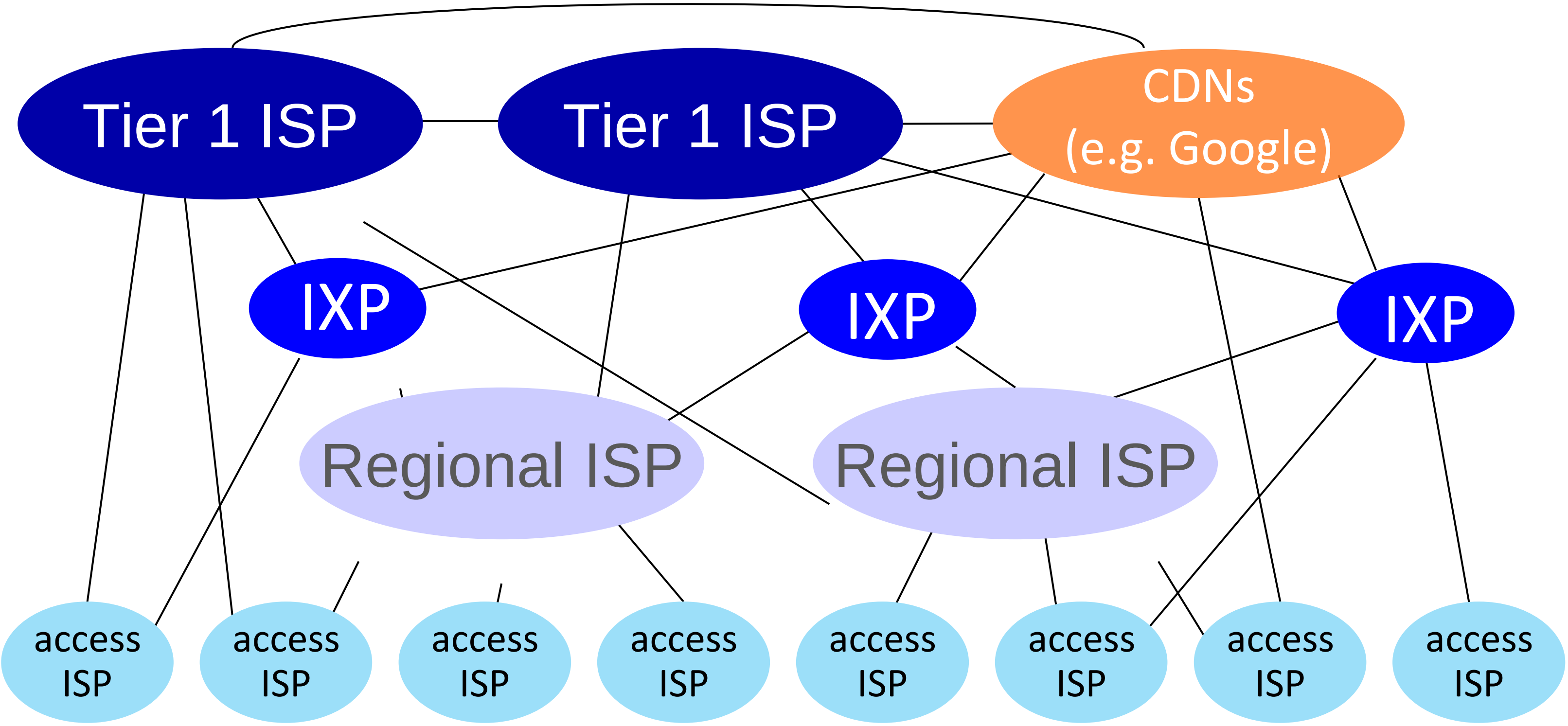


Internet structure: a "network of networks"

... 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”

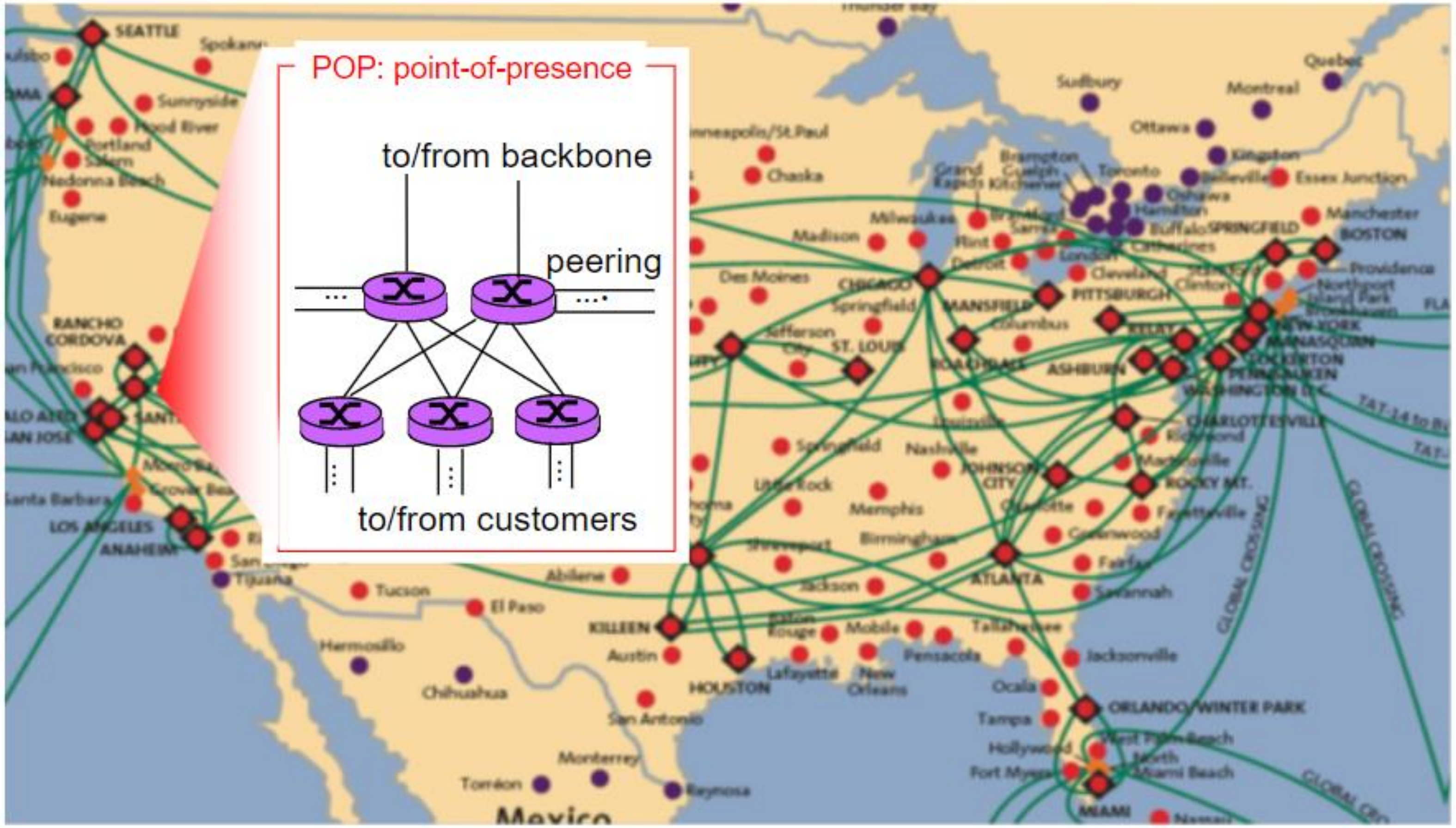


At “center”: small # of well-connected large networks

- “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

Internet structure: a “network of networks”

Tier-1 ISP, Example: Sprint



Internet structure: a "network of networks"

Example: CDN (Amazon)