

Introduction

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

COMPSCI 453 **Computer Networks**

Professor Jim Kurose

College of Information and Computer Sciences

University of Massachusetts



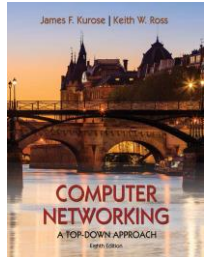
Class textbook:

Computer Networking: A Top-Down Approach (8th ed.)

J.F. Kurose, K.W. Ross

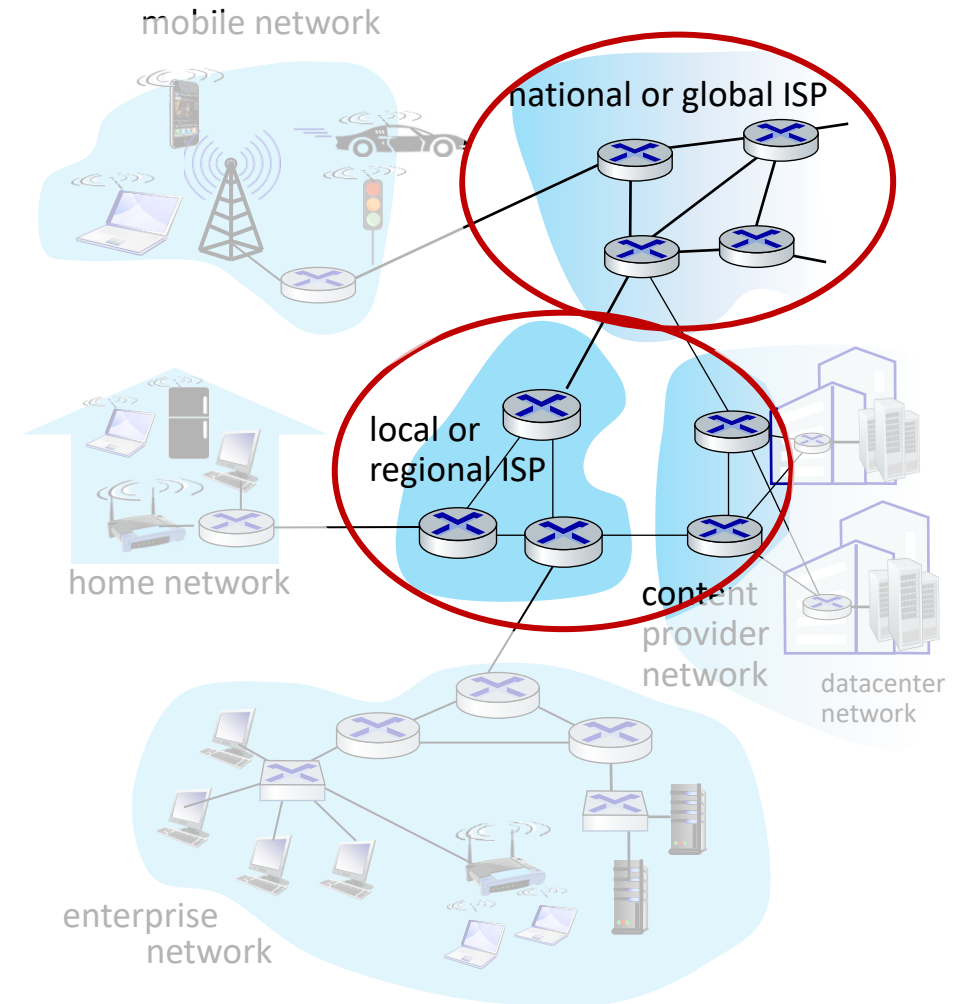
Pearson, 2020

http://gaia.cs.umass.edu/kurose_ross



The network core

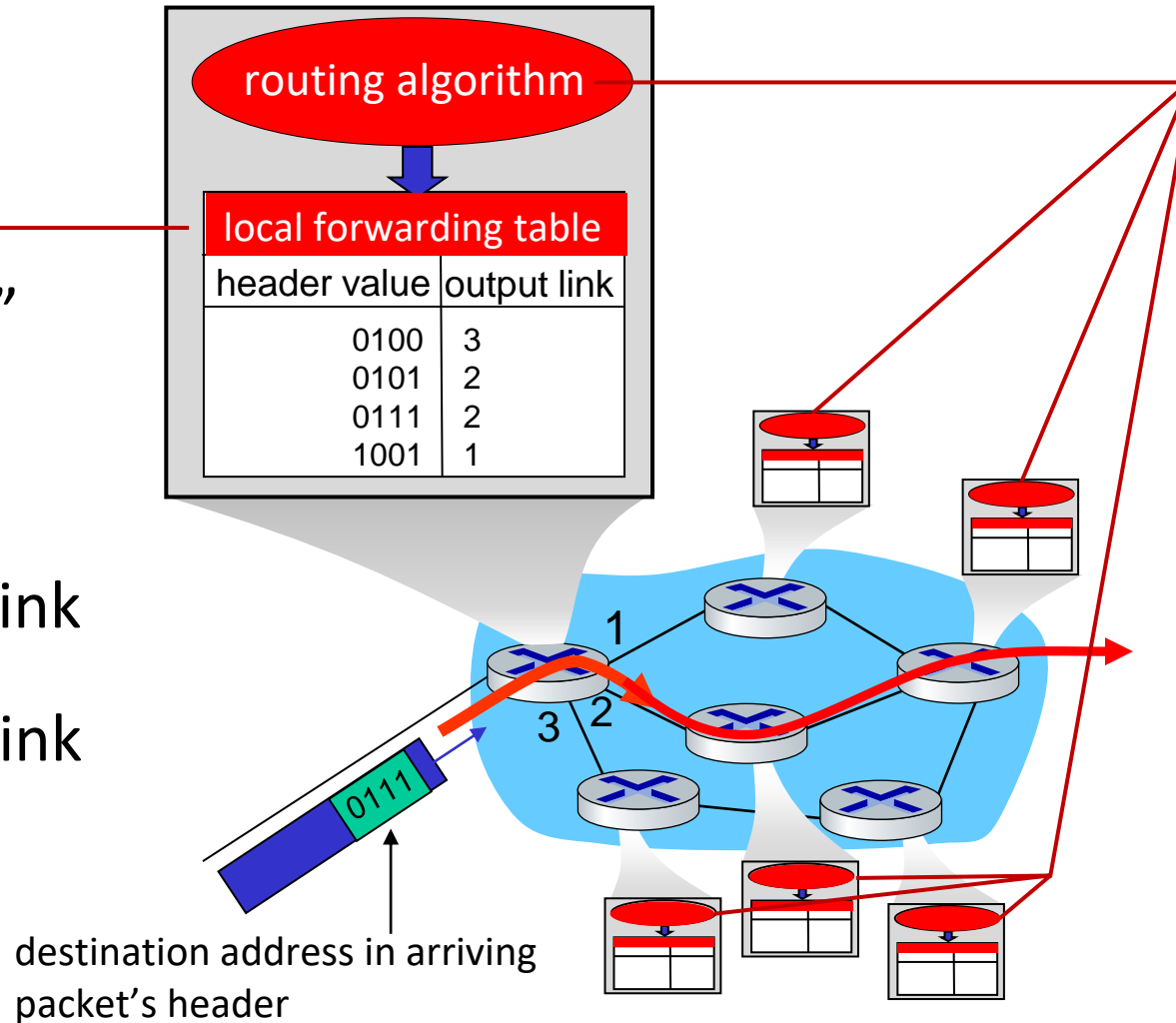
- mesh of interconnected routers
- **packet-switching**: hosts break application-layer messages into *packets*
 - network **forwards** packets from one router to the next, across links on path from **source to destination**



Two key network-core functions

Forwarding:

- aka “switching”
- *local* action: move arriving packets from router’s input link to appropriate router output link



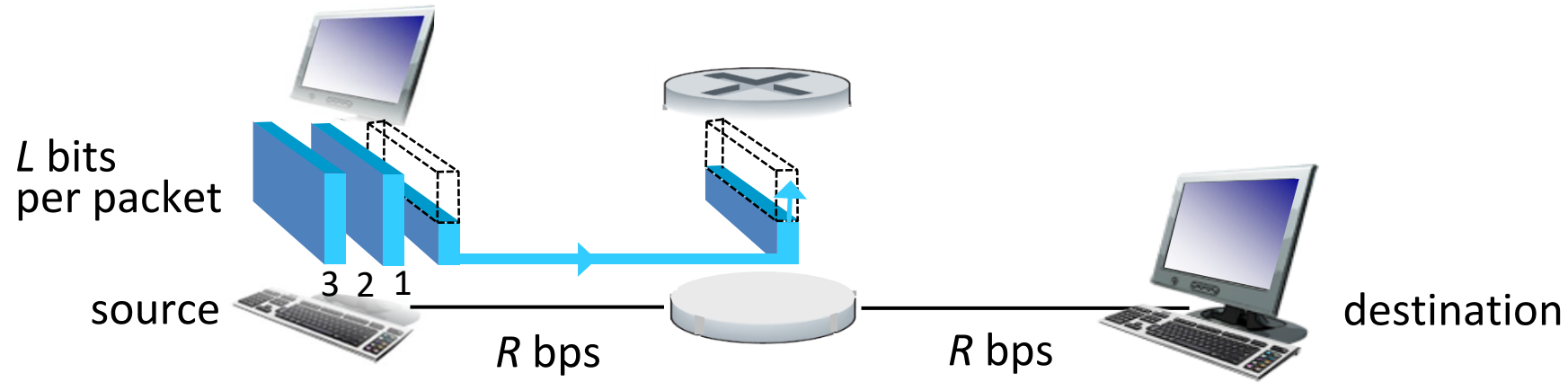
Routing:

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





Packet-switching: store-and-forward

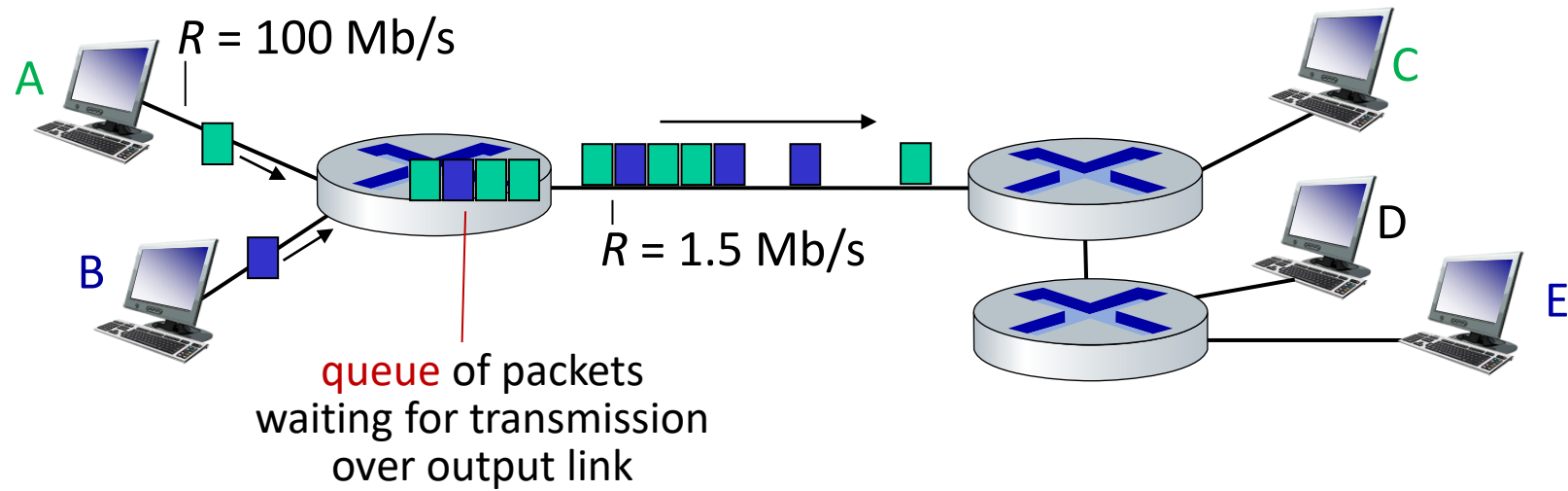


- **packet transmission delay:** takes L/R seconds to transmit (push out) L -bit packet into link at R bps
- **store and forward:** entire packet must arrive at router before it can be transmitted on next link

One-hop numerical example:

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

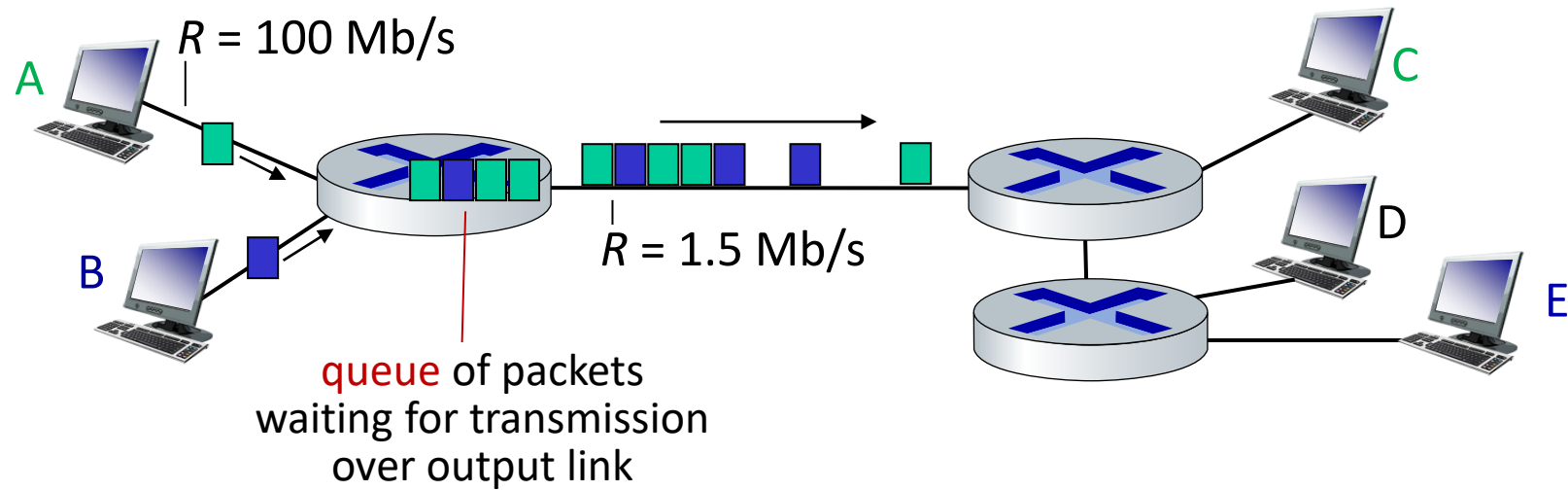
Packet-switching: queueing



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



Packet-switching: queueing



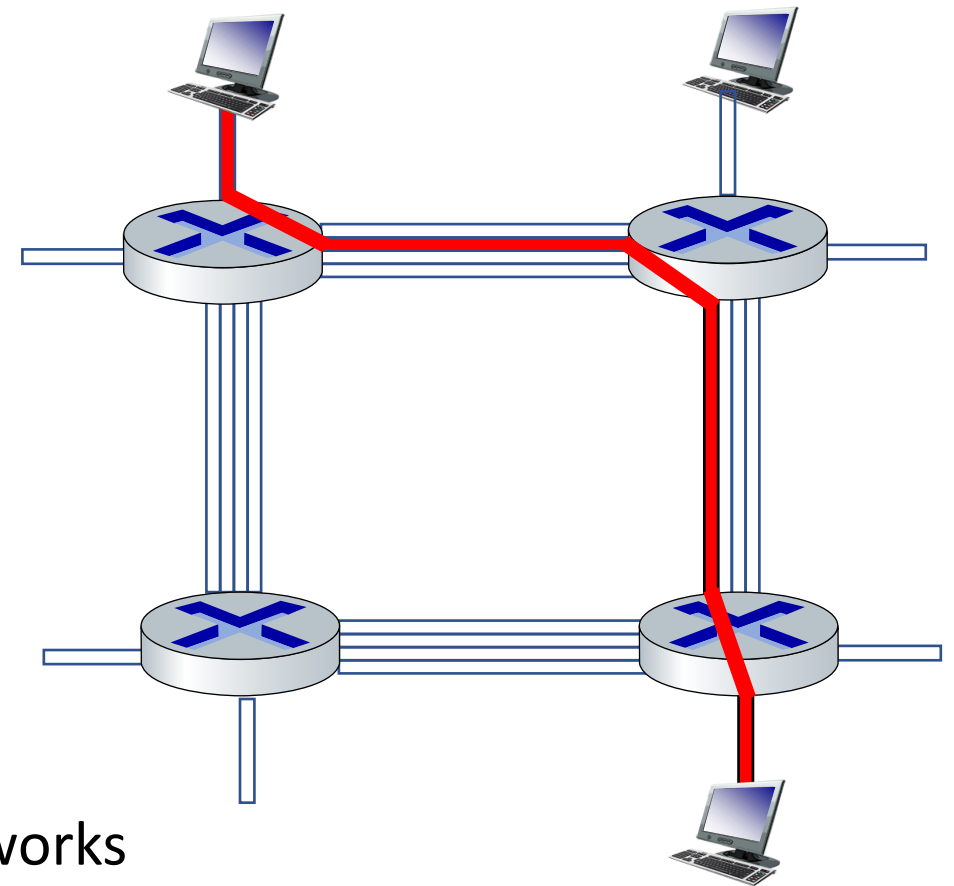
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- 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

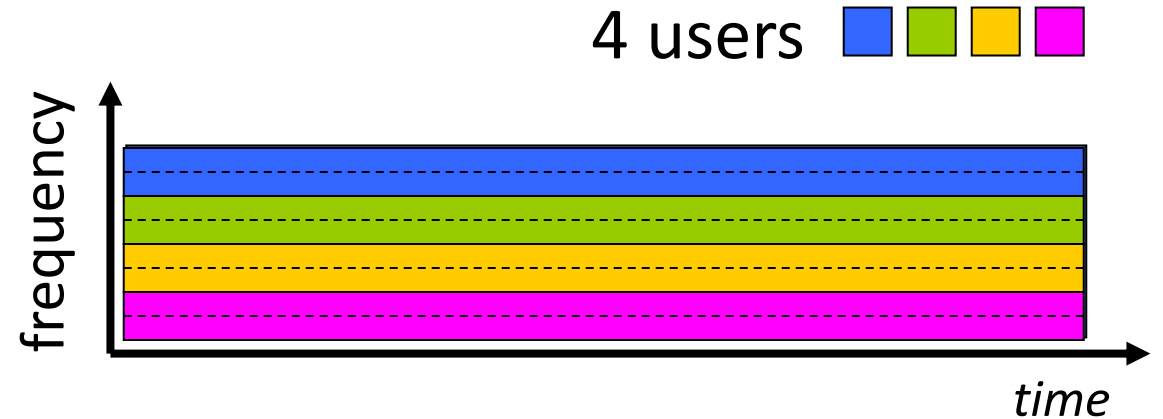
- in diagram, each link has four circuits.
 - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
 - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
- commonly used in traditional telephone networks



Circuit switching: FDM and TDM

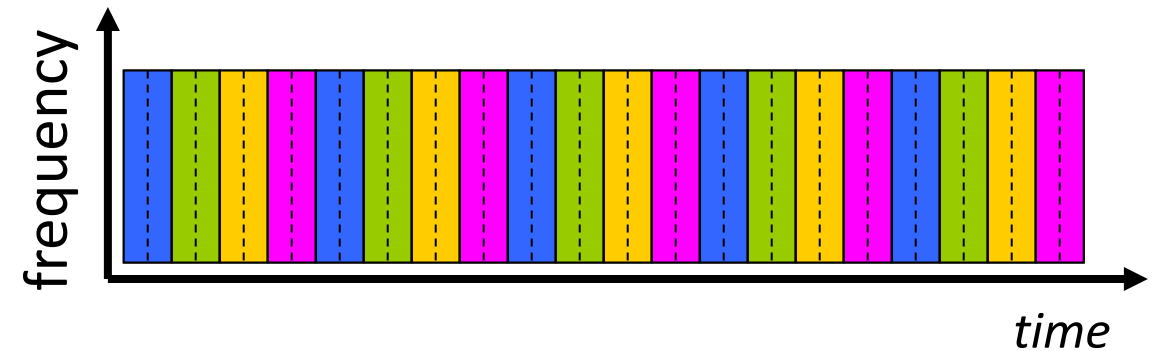
Frequency Division Multiplexing (FDM)

- 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)

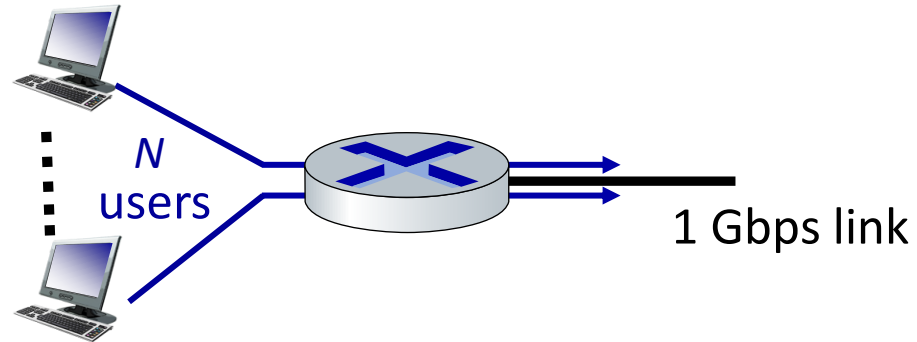
- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)



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?

A: HW problem (for those with course in probability only)

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

Packet switching versus circuit switching

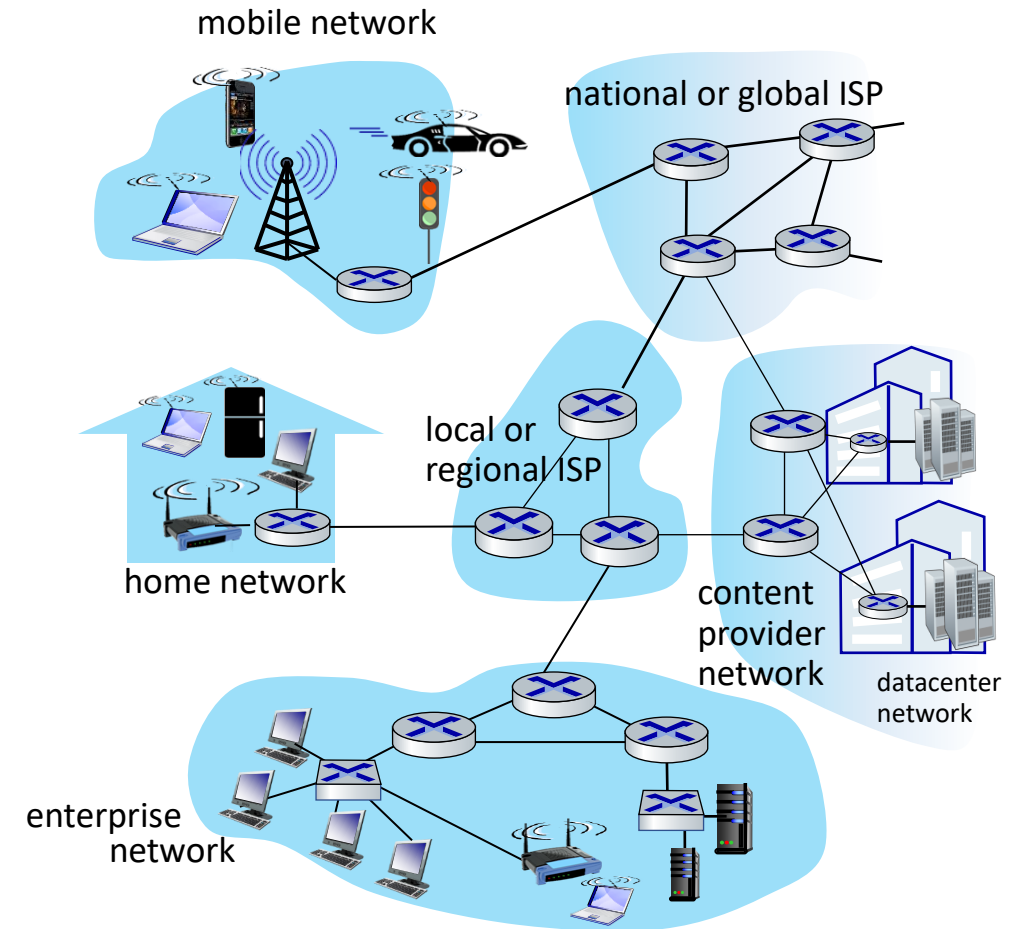
Is packet switching a “slam dunk winner”?

- 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 with packet-switching?**
 - “It’s complicated.” We’ll study 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”

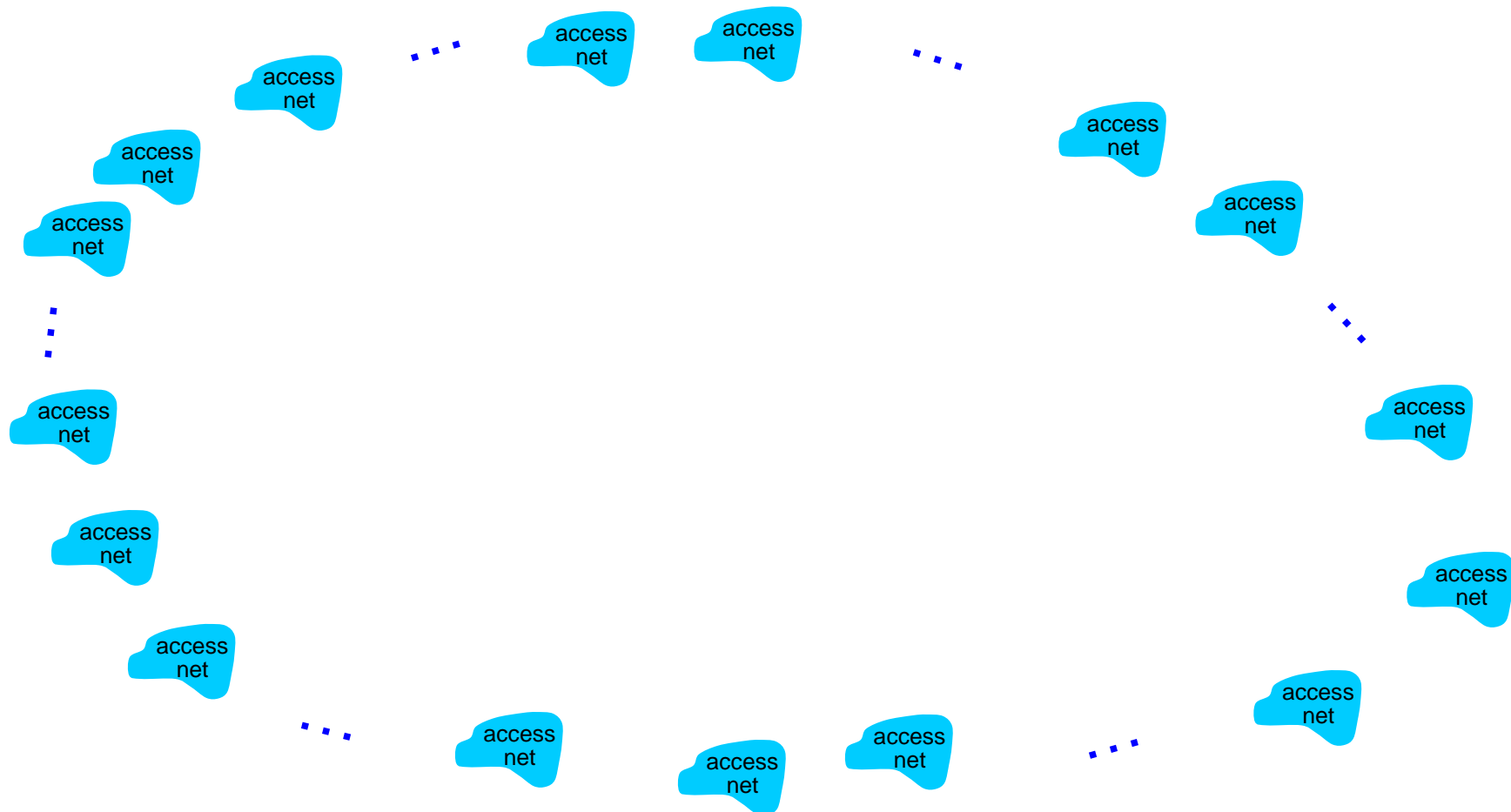
- hosts connect to Internet via **access** Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
 - so that *any* two hosts (*anywhere!*) can send packets to each other
- resulting network of networks is very complex
 - evolution driven by **economics**, **national policies**



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

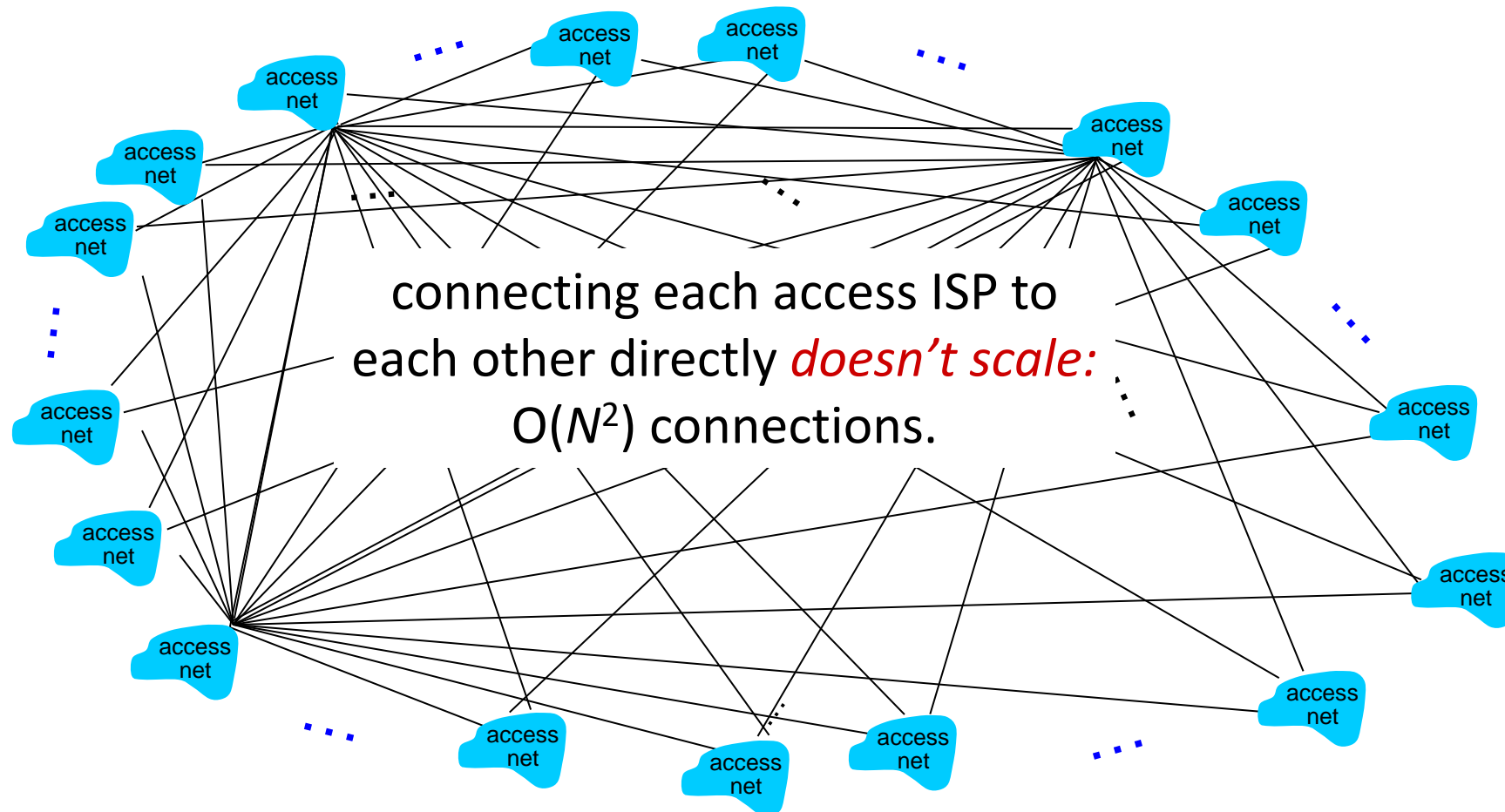
Internet structure: a “network of networks”

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



Internet structure: a “network of networks”

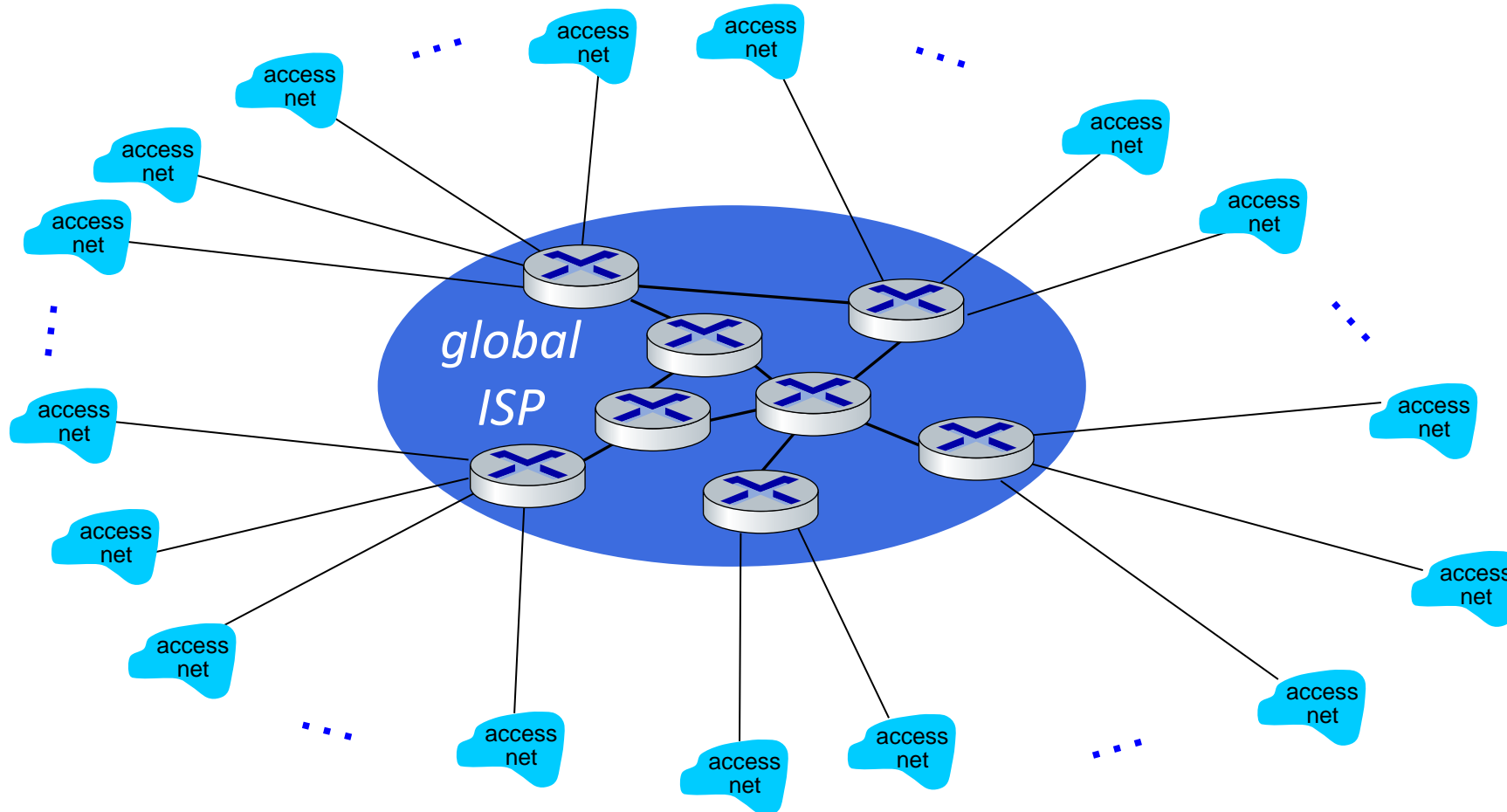
Question: given *millions* of access ISPs, how to connect them together?



Internet structure: a “network of networks”

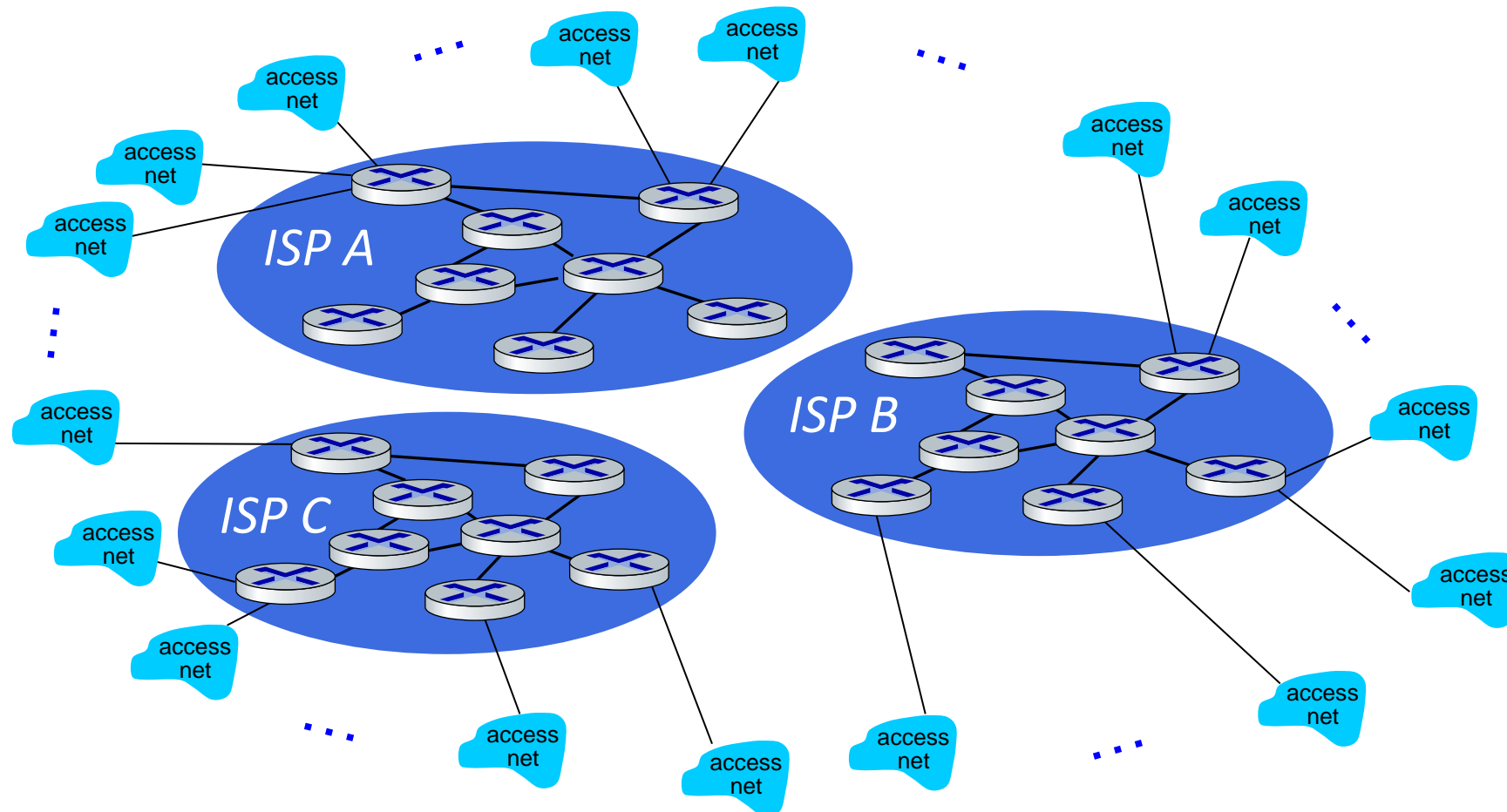
Option: connect each access ISP to one global transit ISP?

Customer and provider ISPs have economic agreement.



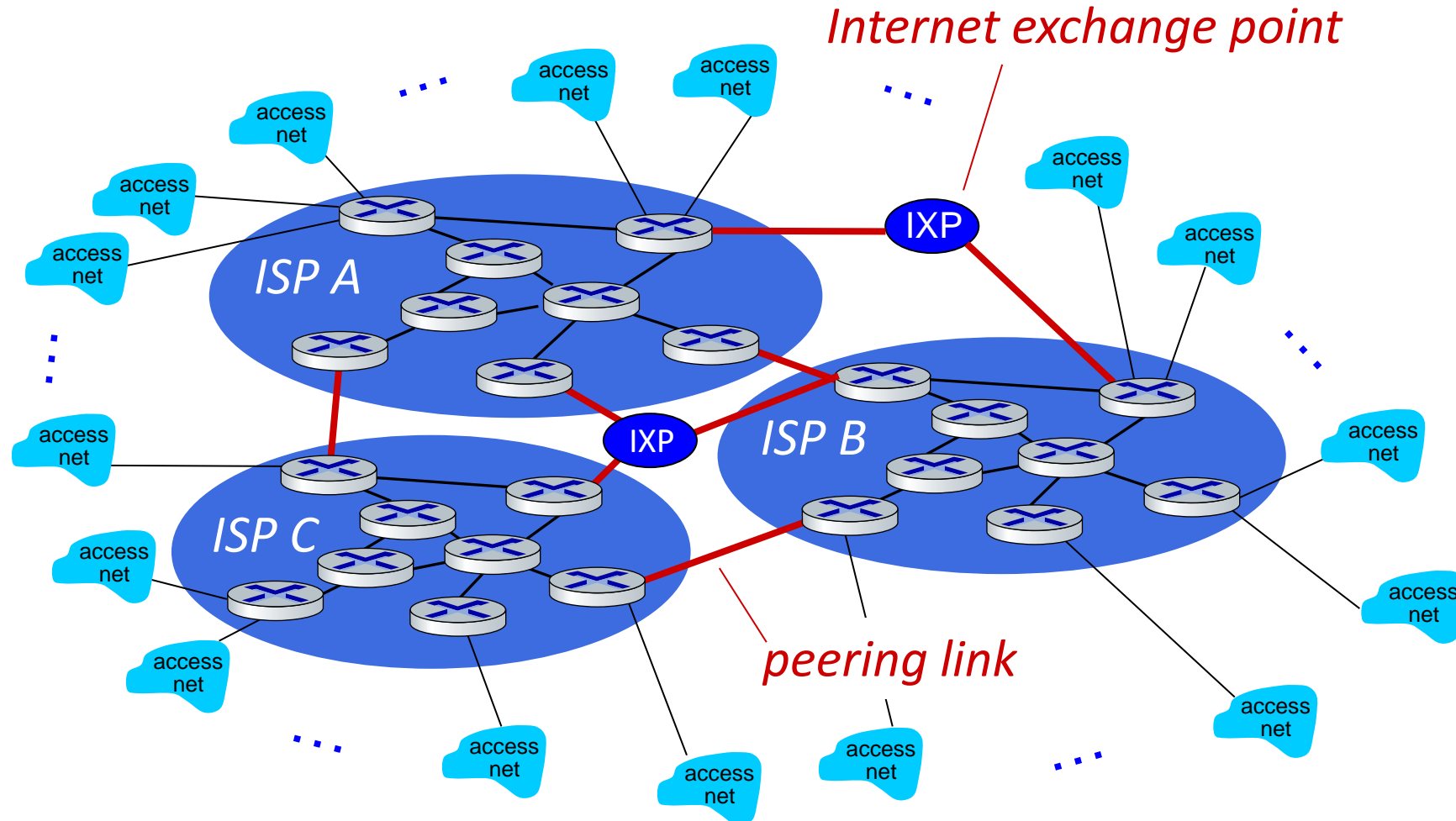
Internet structure: a “network of networks”

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



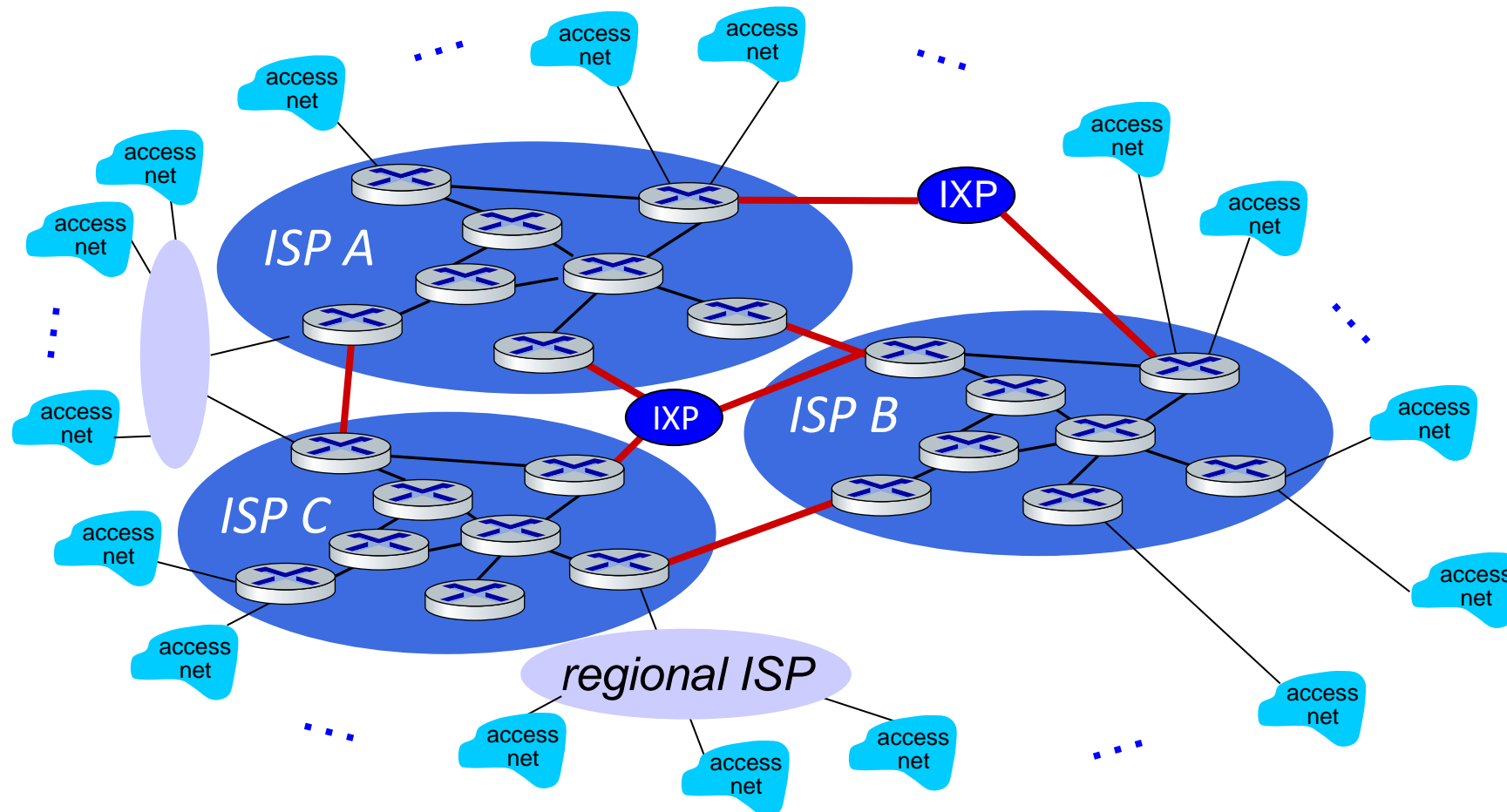
Internet structure: a “network of networks”

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



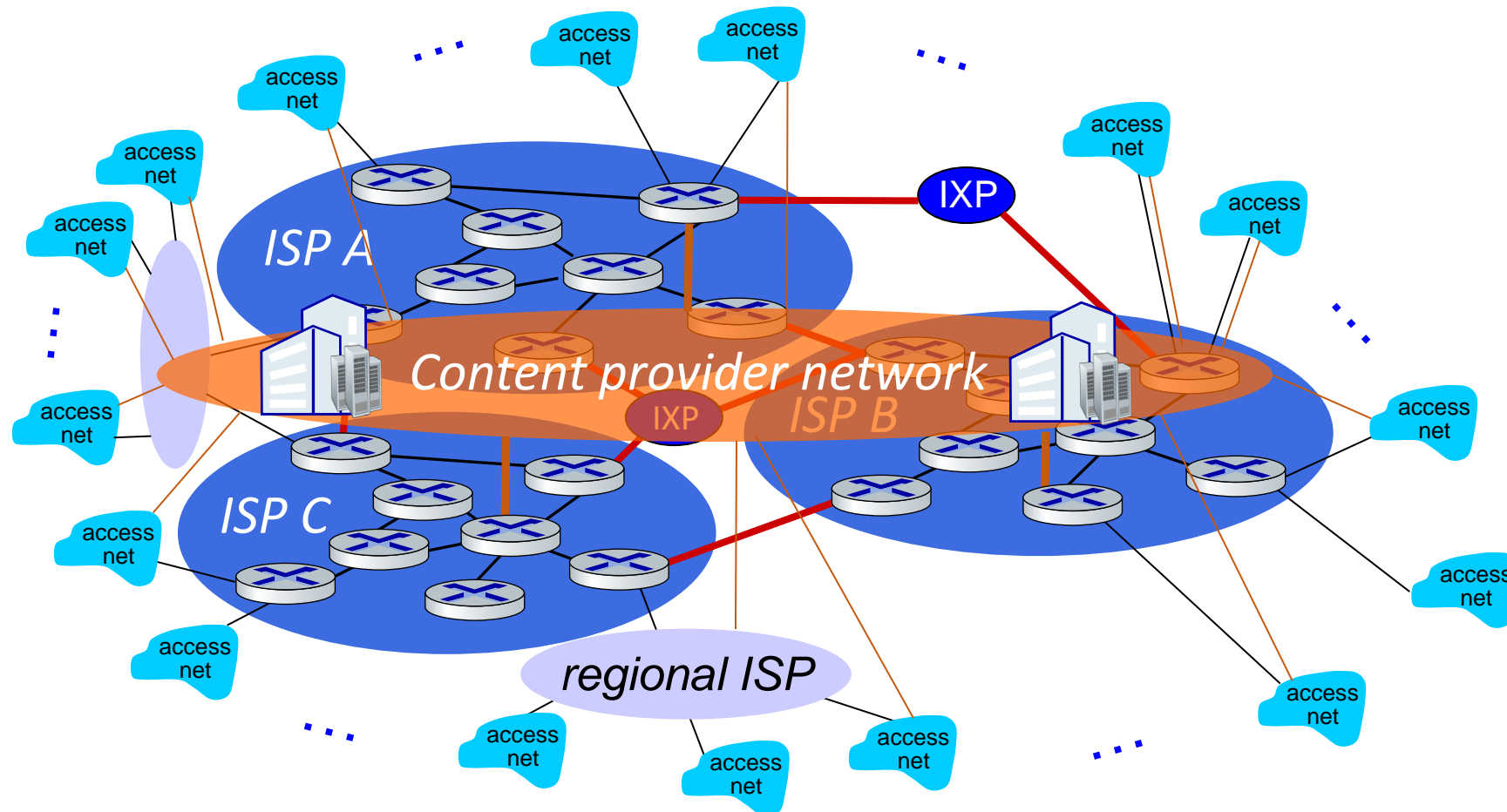
Internet structure: a “network of networks”

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

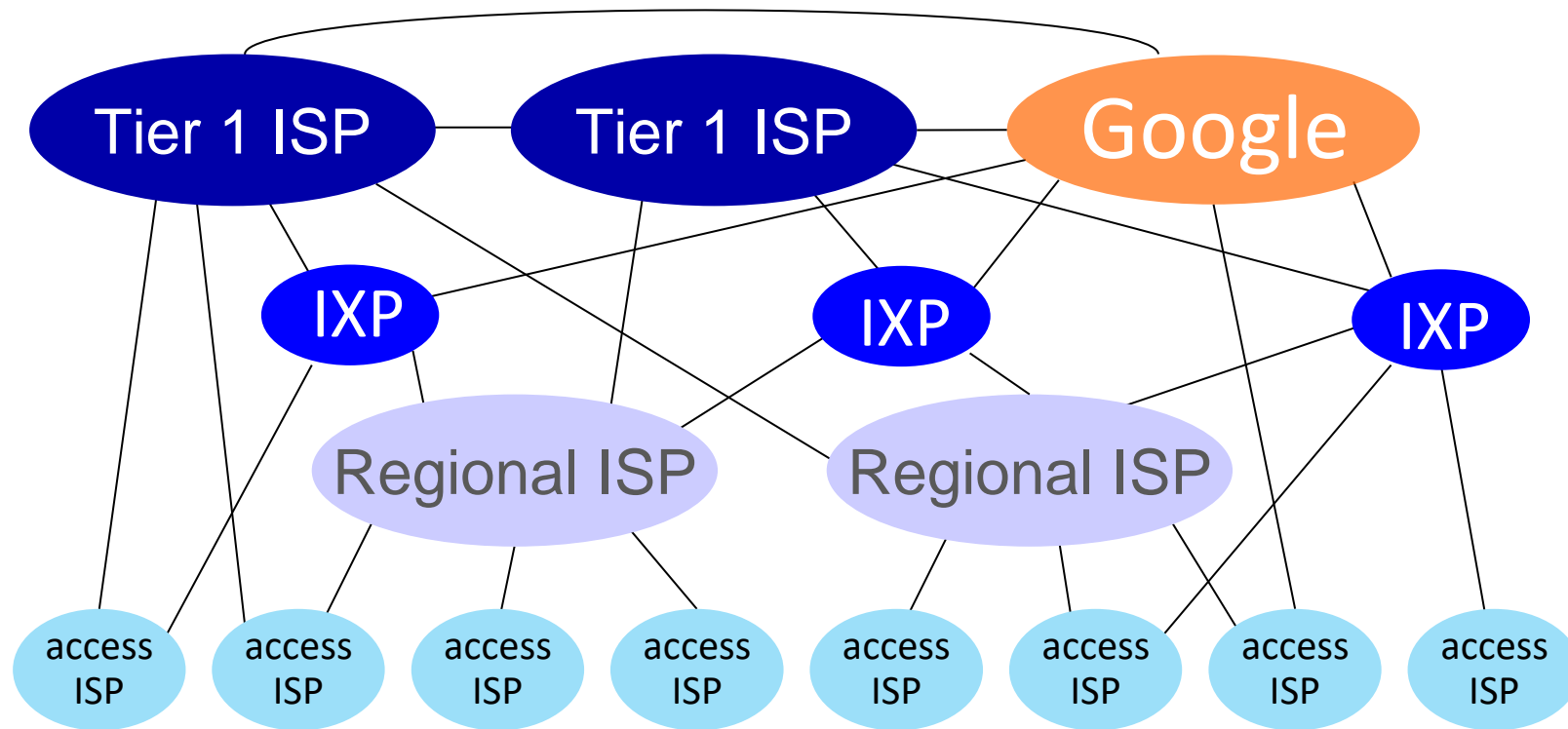


Internet structure: a “network of networks”

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



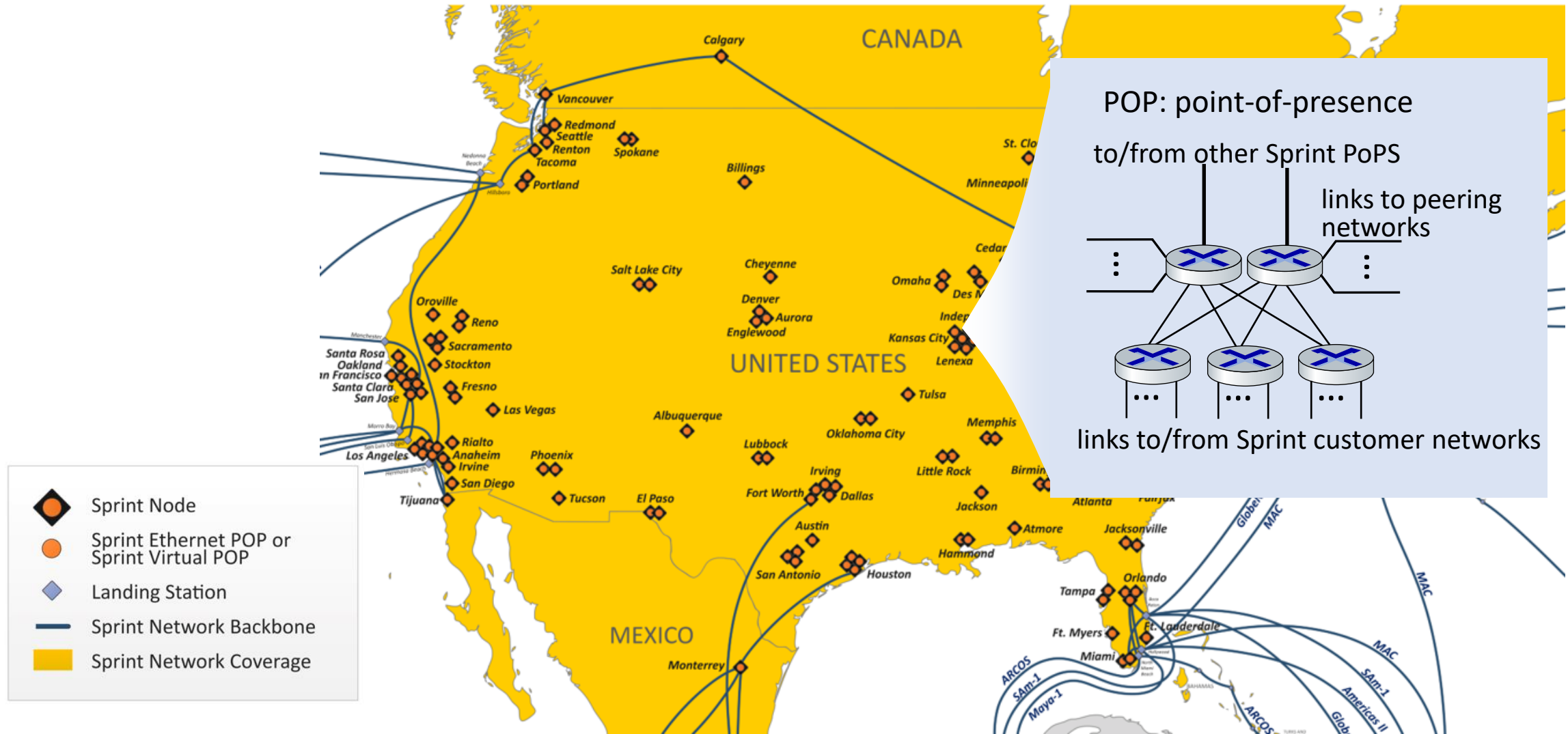
Internet structure: a “network of networks”



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

Tier-1 ISP Network map: Sprint (2019)



Introduction

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

COMPSCI 453 **Computer Networks**

Professor Jim Kurose

College of Information and Computer Sciences

University of Massachusetts



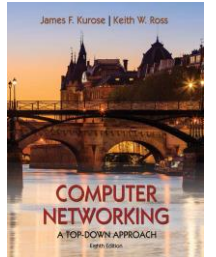
Class textbook:

Computer Networking: A Top-Down Approach (8th ed.)

J.F. Kurose, K.W. Ross

Pearson, 2020

http://gaia.cs.umass.edu/kurose_ross



© Video: 2020, J.F. Kurose, All Rights Reserved

© Powerpoint: 1996-2020, J.F. Kurose, K.W. Ross, All Rights Reserved