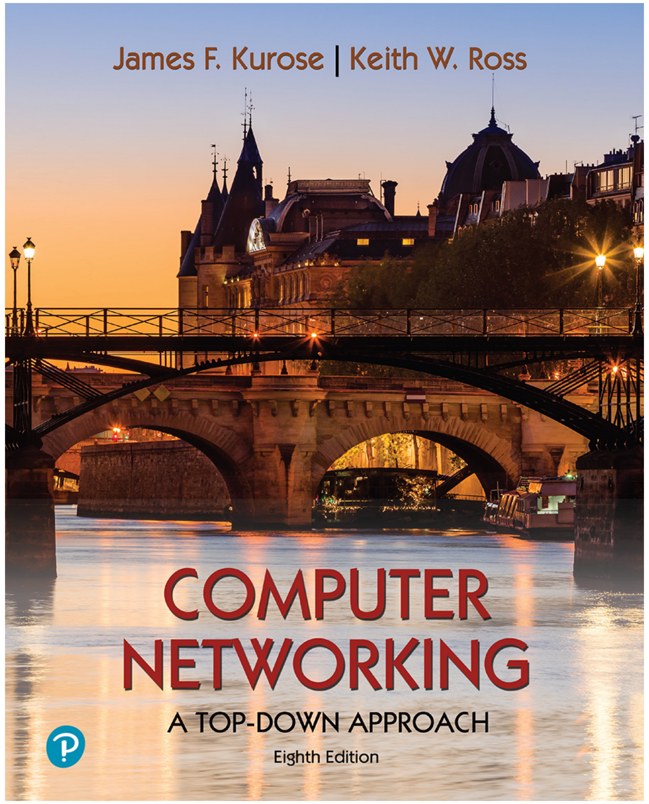
Chapter 1
Introduction



Computer Networking: A Top-Down Approach
8^{th} edition
Jim Kurose, Keith Ross
Pearson, 2020

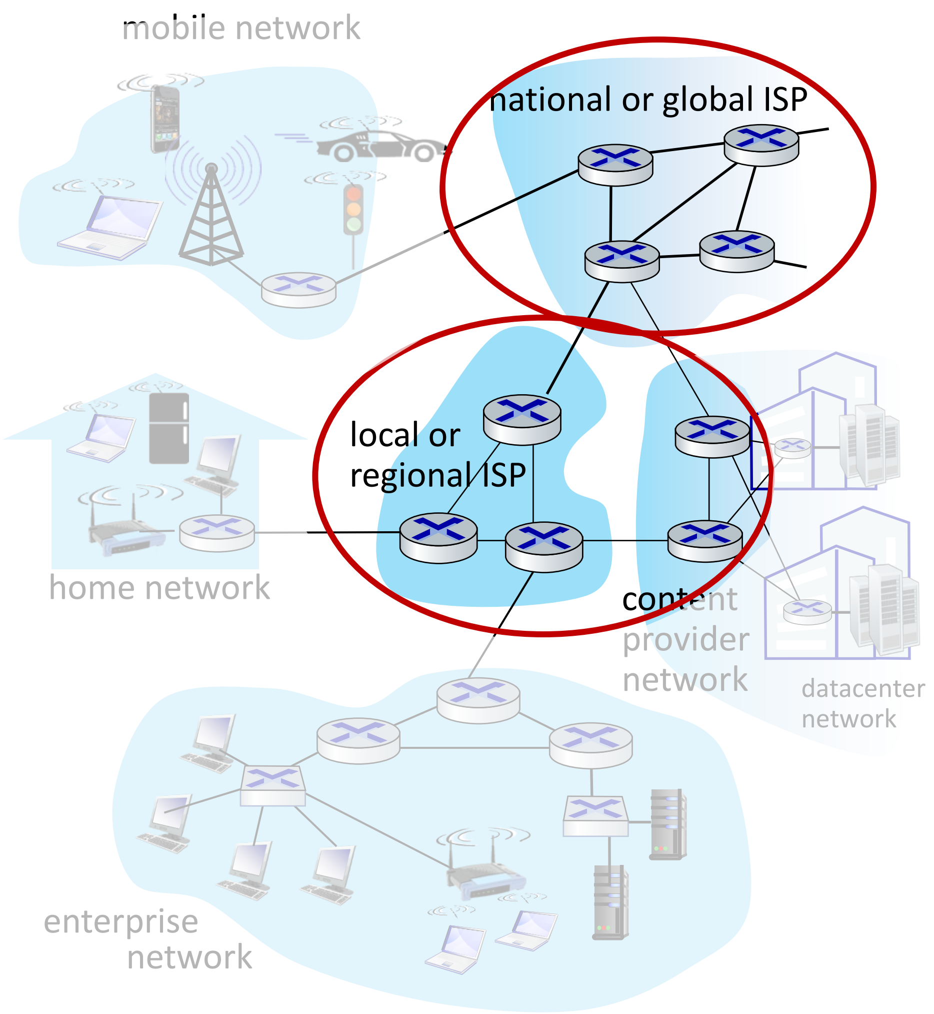
Acknowledgement: Based on the textbook's website:
https://gaia.cs.umass.edu/kurose_ross/index.php

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

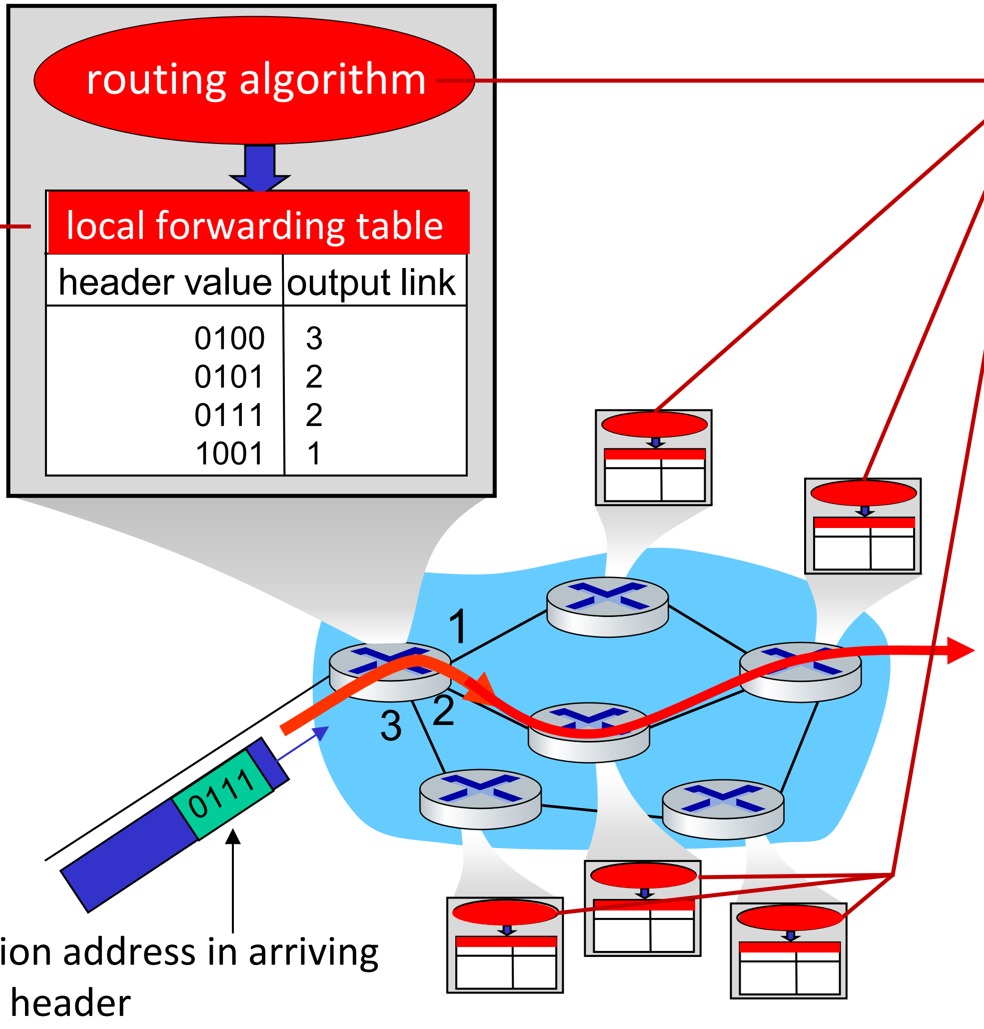
The network core

- 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


routing
45 h
3,053 miles
48 h
3,309 miles
San Jose
Northampton
United States
Victoria
Seattle
WASHINGTON
Portland
OREGON
IDAHO
MONTANA
WYOMING
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
Minneapolis
WISCONSIN
IOWA
MICHIGAN
Chicago
Detroit
Toronto
Ottawa
Montreal
Quebec City
MAINE
VERMONT
NEW HAMPSHIRE
CT
RI
New York
PENNSYLVANIA
Philadelphia
NJ
MARYLAND
DE
OHIO
INDIANA
Indianapolis
ILLINOIS
Kansas City
MISSOURI
NEVADA
UTAH
COLORADO
Sacramento
San Francisco
CALIFORNIA
Las Vegas
Los Angeles
San Diego
ARIZONA
Phoenix
Tucson
NEW MEXICO
El Paso
OKLAHOMA
ARKANSAS
TEXAS
Dallas
Austin
Houston
San Antonio
LOUISIANA
New Orleans
MISSISSIPPI
ALABAMA
GEORGIA
Atlanta
TENNESSEE
Nashville
KENTUCKY
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
Charlotte
SOUTH CAROLINA
Jacksonville
Orlando
Tampa
FLORIDA
BAJA CALIFORNIA
SONORA
CHIHUAHUA
COAHUILA


forwarding
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Tucson
El Paso
Dallas
Austin
Houston
San Antonio
New Orleans
Kansas City
Minneapolis
Chicago
Detroit
Indianapolis
Nashville
Atlanta
Toronto
Ottawa
Montreal
Quebec City
Tampa
WASHINGTON
CALIFORNIA
ARIZONA
NEW MEXICO
TEXAS
COLORADO
KANSAS
OKLAHOMA
WYOMING
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
WISCONSIN
IOWA
MISSOURI
ARKANSAS
ILLINOIS
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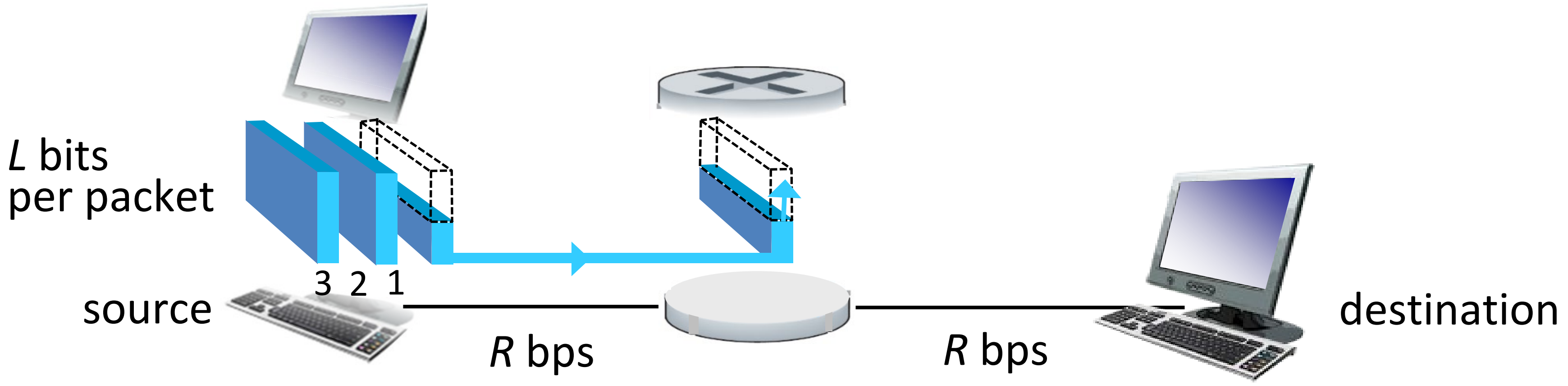
CHIHUAHUA
COAHUILA

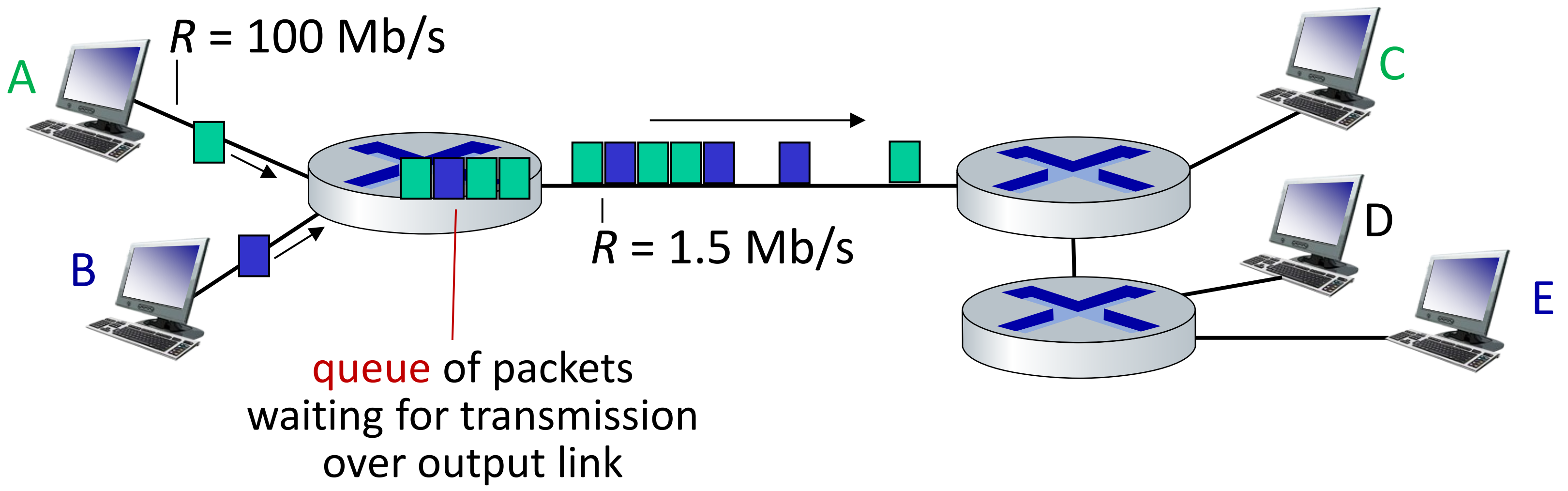
Packet-switching: store-and-forward



- 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

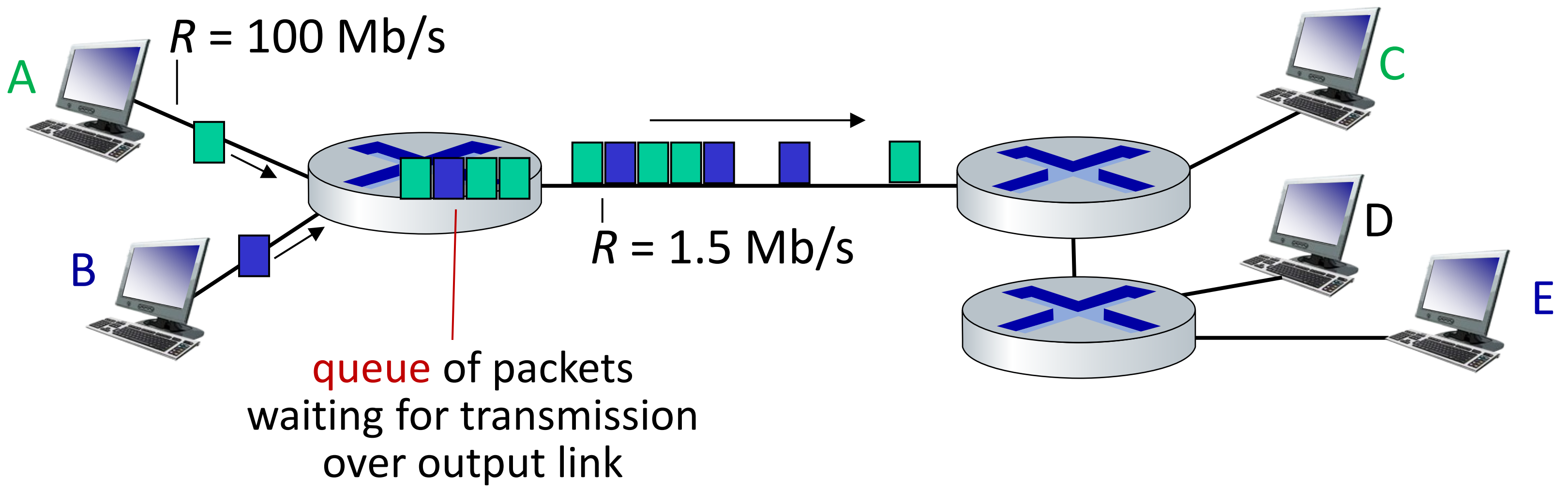
One-hop numerical example:
- *L* = 10 Kbits
- *R* = 100 Mbps
- one-hop transmission delay = 0.1 msec

Packet-switching: queueing



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

Packet-switching: queueing



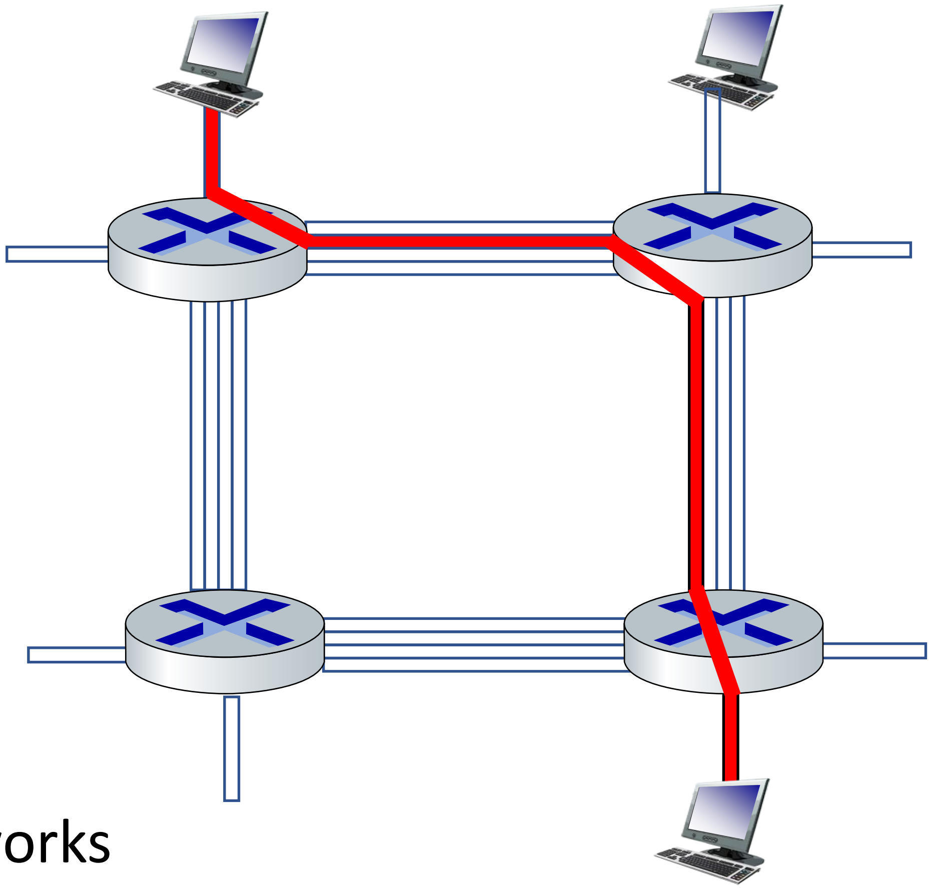
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- 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

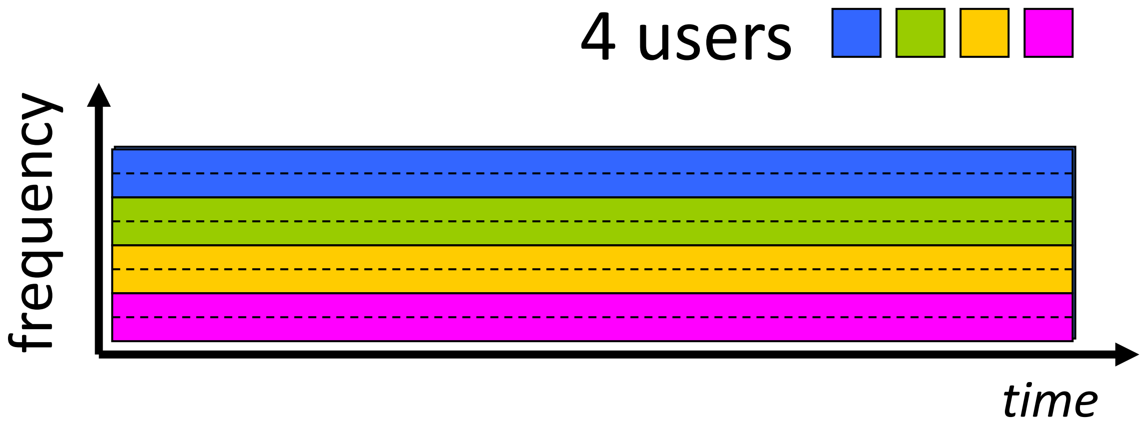


* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive

Circuit switching: FDM and TDM

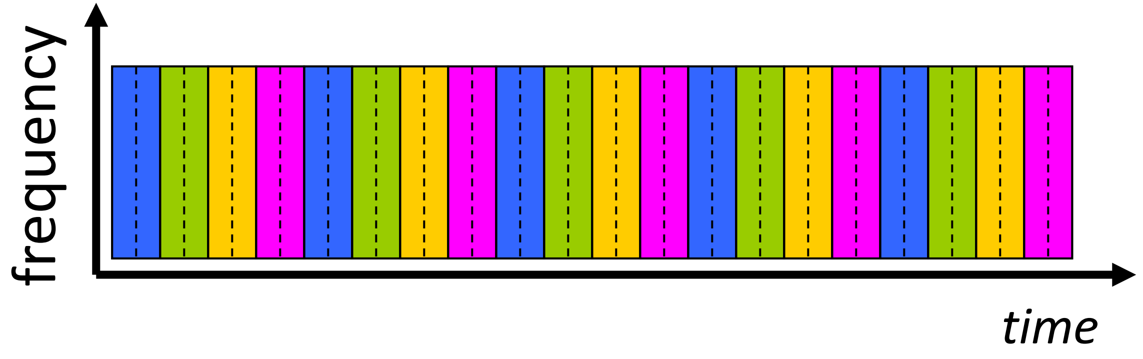
Frequency Division Multiplexing (FDM)

- 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)

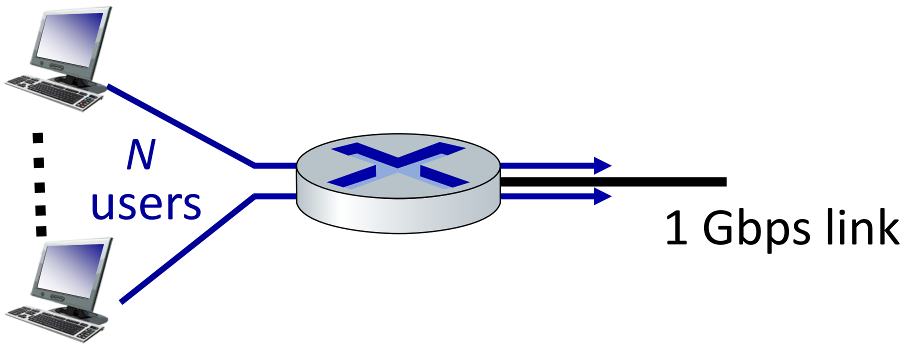
- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)



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?

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

Proof: with 35 users, probability > 10 active at same time is less than .0004

- Problem Setup:
  - Number of users: 35
  - Probability of each user being active: 10% = 0.1
  - We want to find P(X > 10), where X is the number of active users
- Calculation:
  - We need to calculate the probability of having 11 or more users active at the same time, then subtract that from 1 to get the probability of having 10 or fewer active users.
  - First, we calculate P(X ≤ 10) using the cumulative binomial probability function:
    - $P(X \leq 10) = \sum(k=0 \text{ to } 10)\ C(35,k) * 0.1^{k} * 0.9^{(35-k)}$
    - Where C(35,k) is the binomial coefficient "35 choose k".
    - Each term is probability of k users being active and (35-k) users being idle
  - Then, we can find P(X > 10) by subtracting from 1:
    - $P(X > 10) = 1 - P(X \leq 10) \approx 0.0003846$

Packet switching versus circuit switching

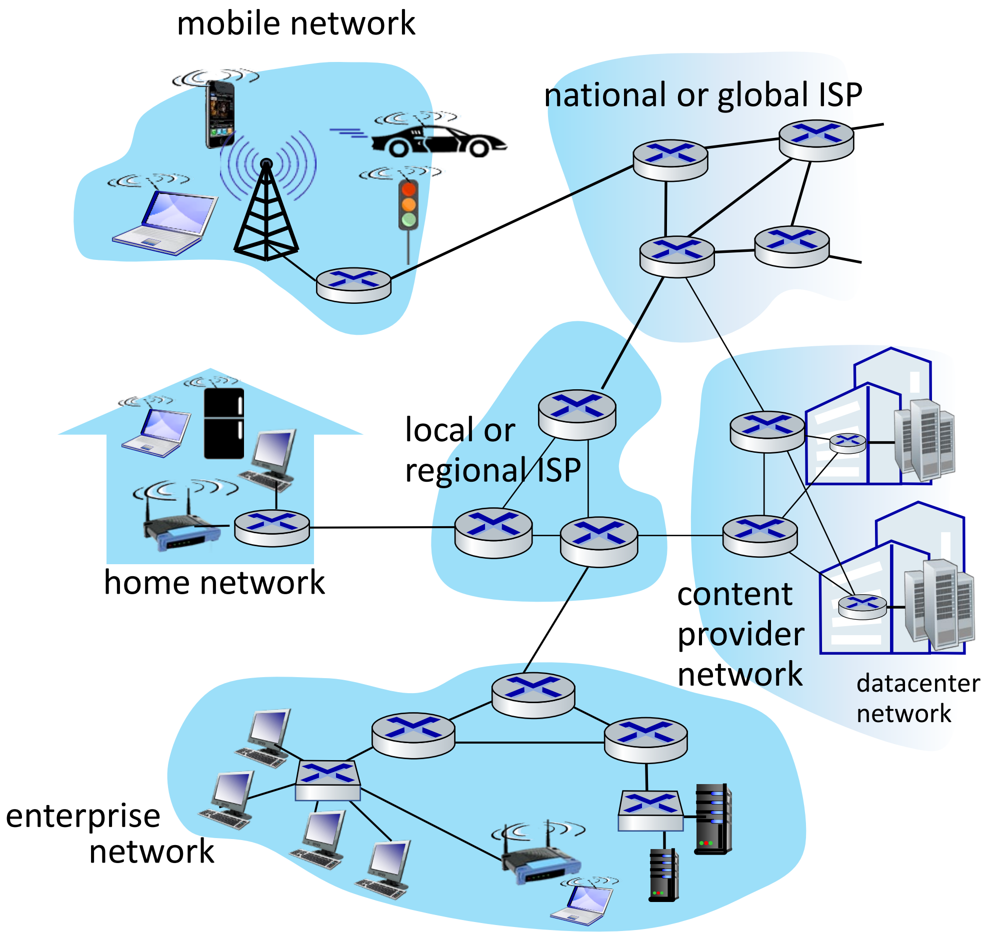
Is packet switching a "slam dunk winner"?

- 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"

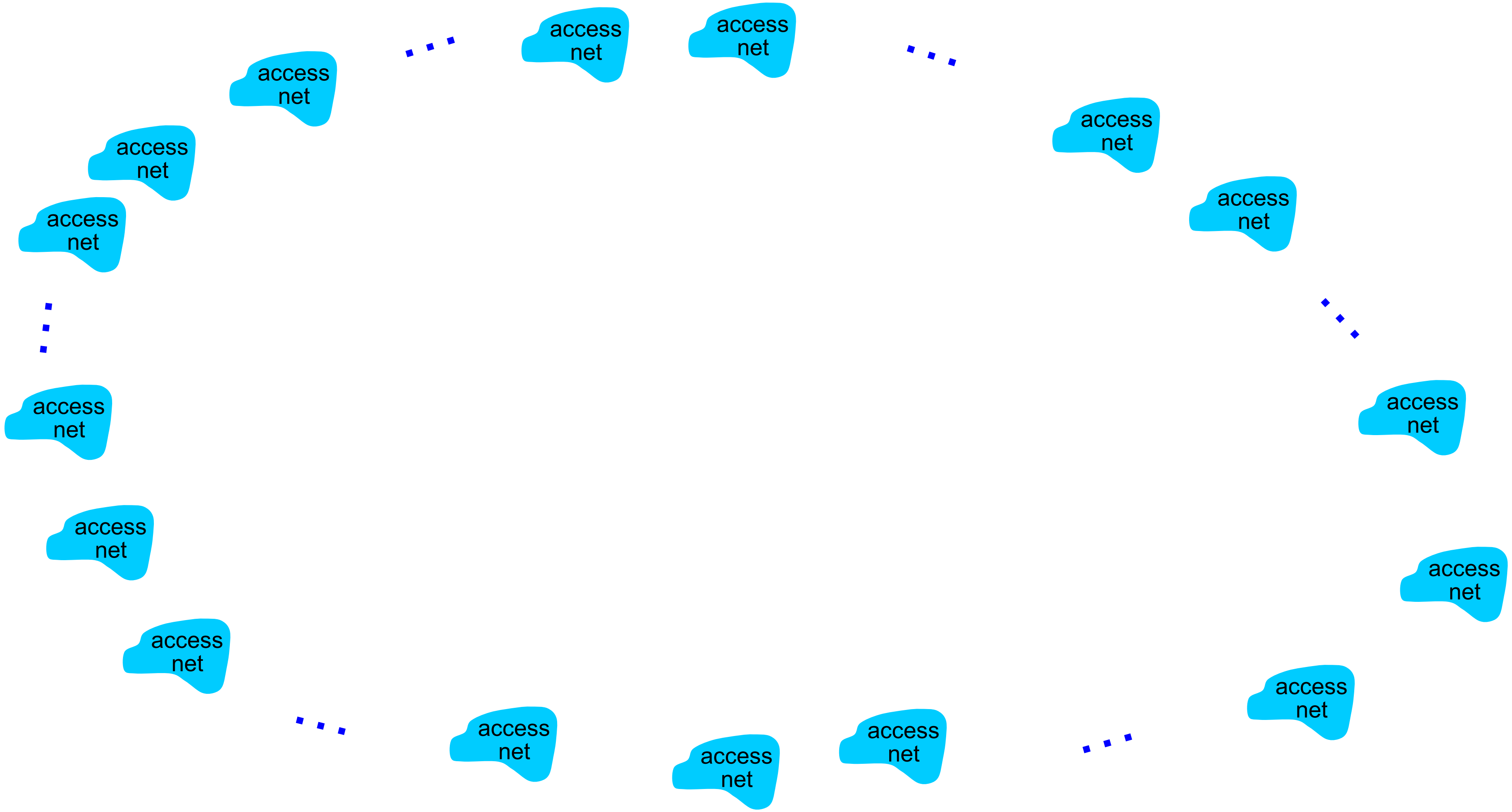
- hosts connect to Internet via access Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts *(anywhere!)* can send packets to each other
- resulting network of networks is very complex
  - evolution driven by economics, national policies



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

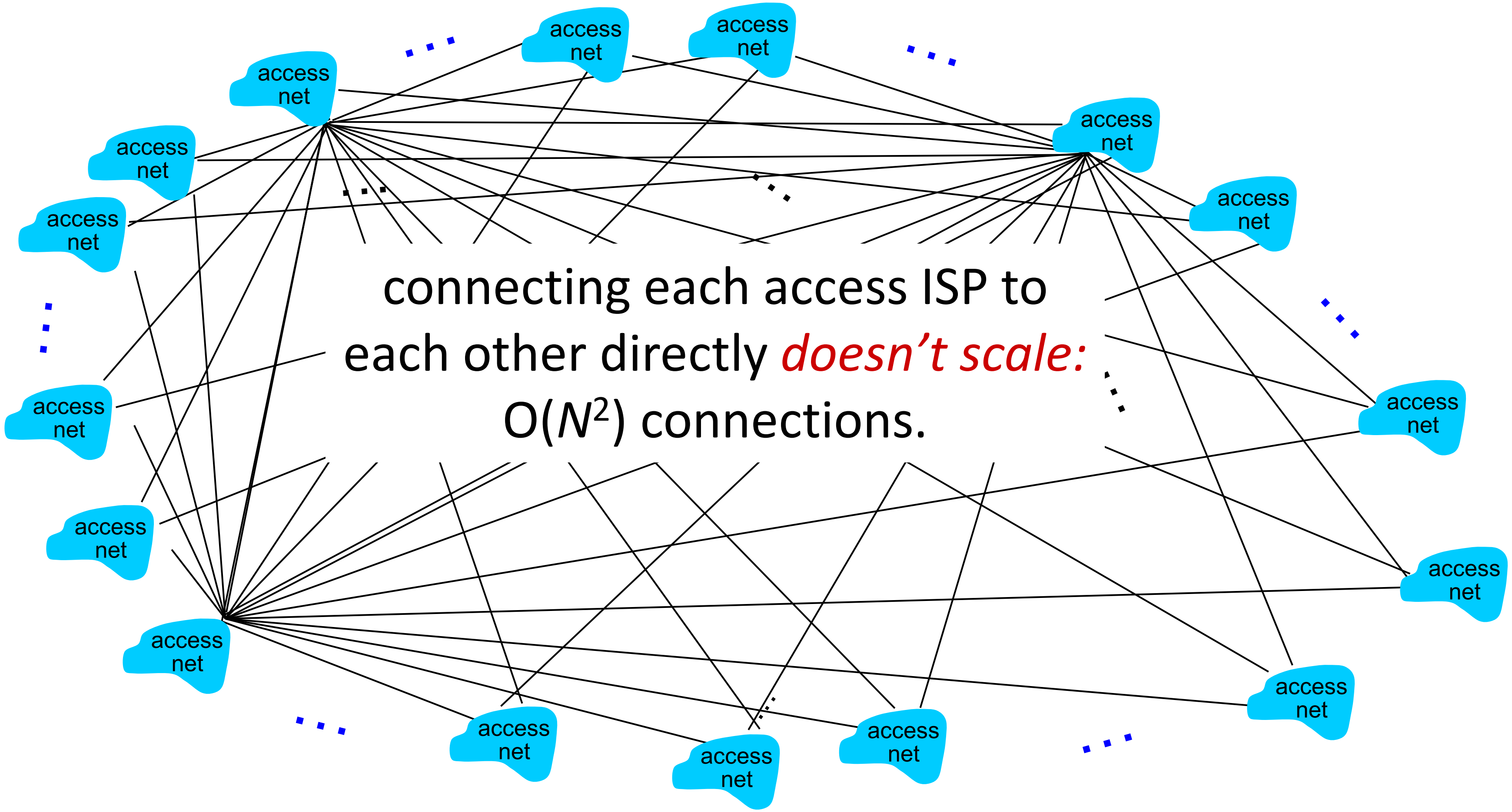
Internet structure: a "network of networks"

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



Internet structure: a “network of networks”

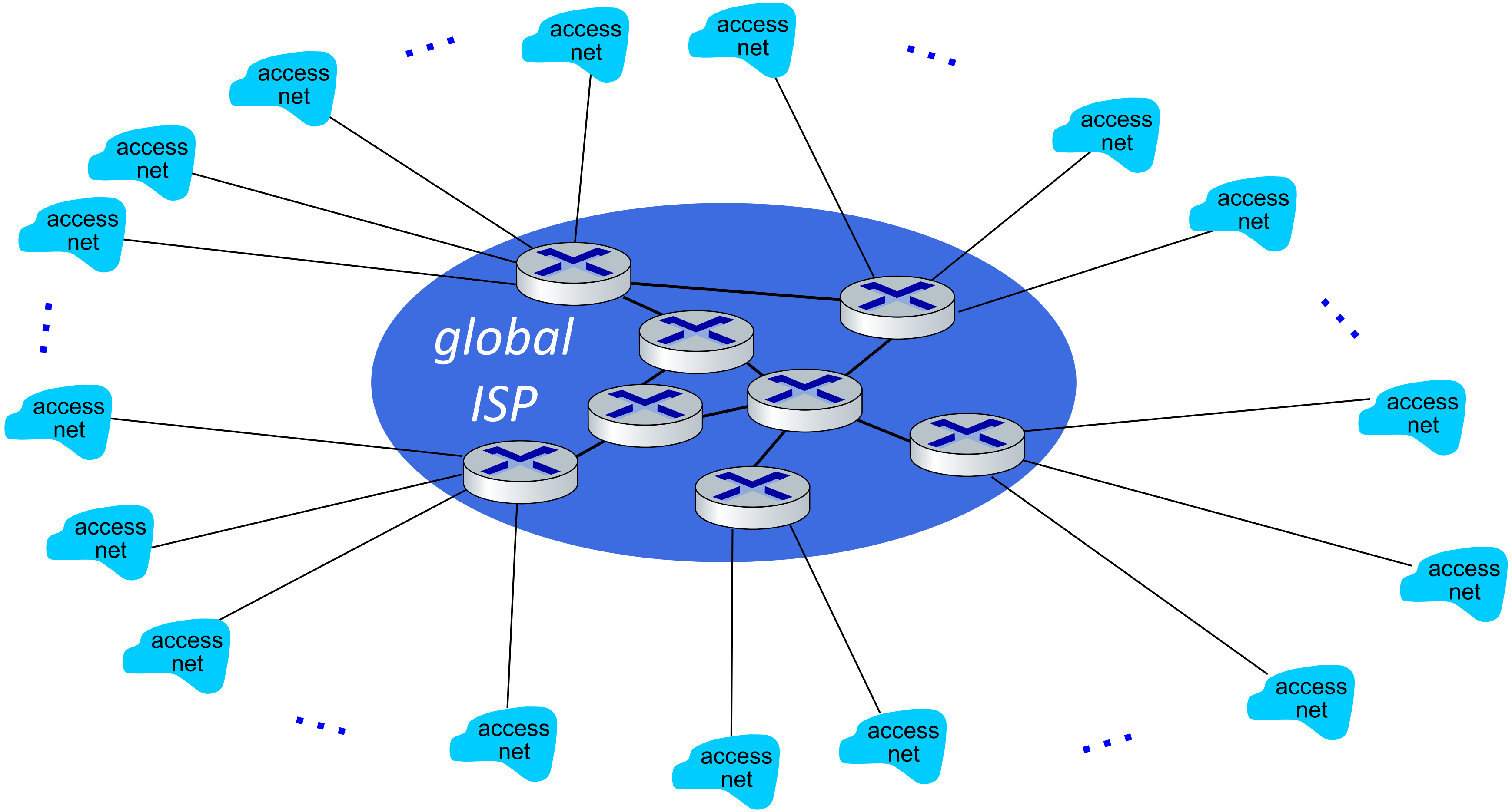
Question: given *millions* of access ISPs, how to connect them together?



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

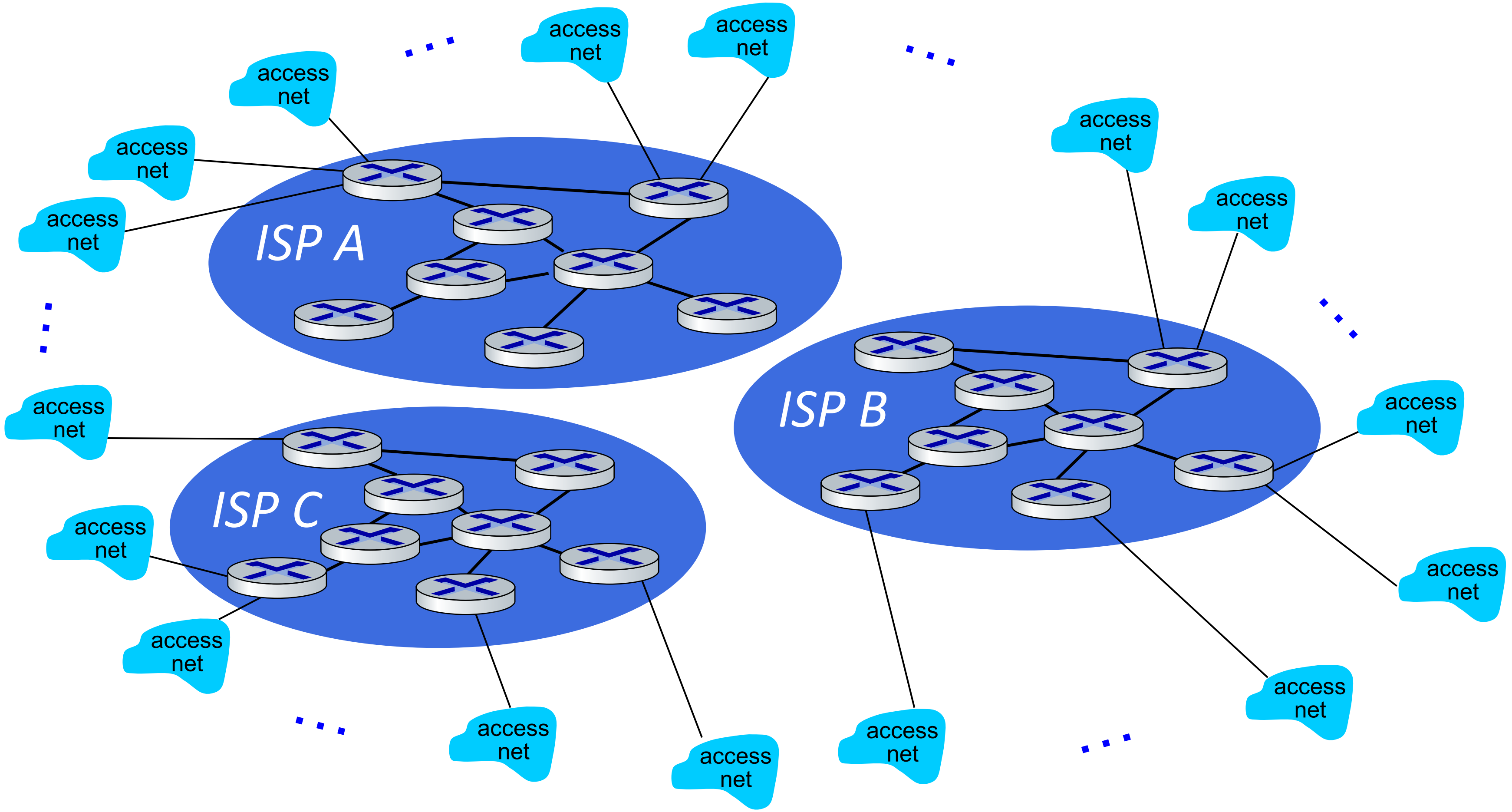
Internet structure: a "network of networks"

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



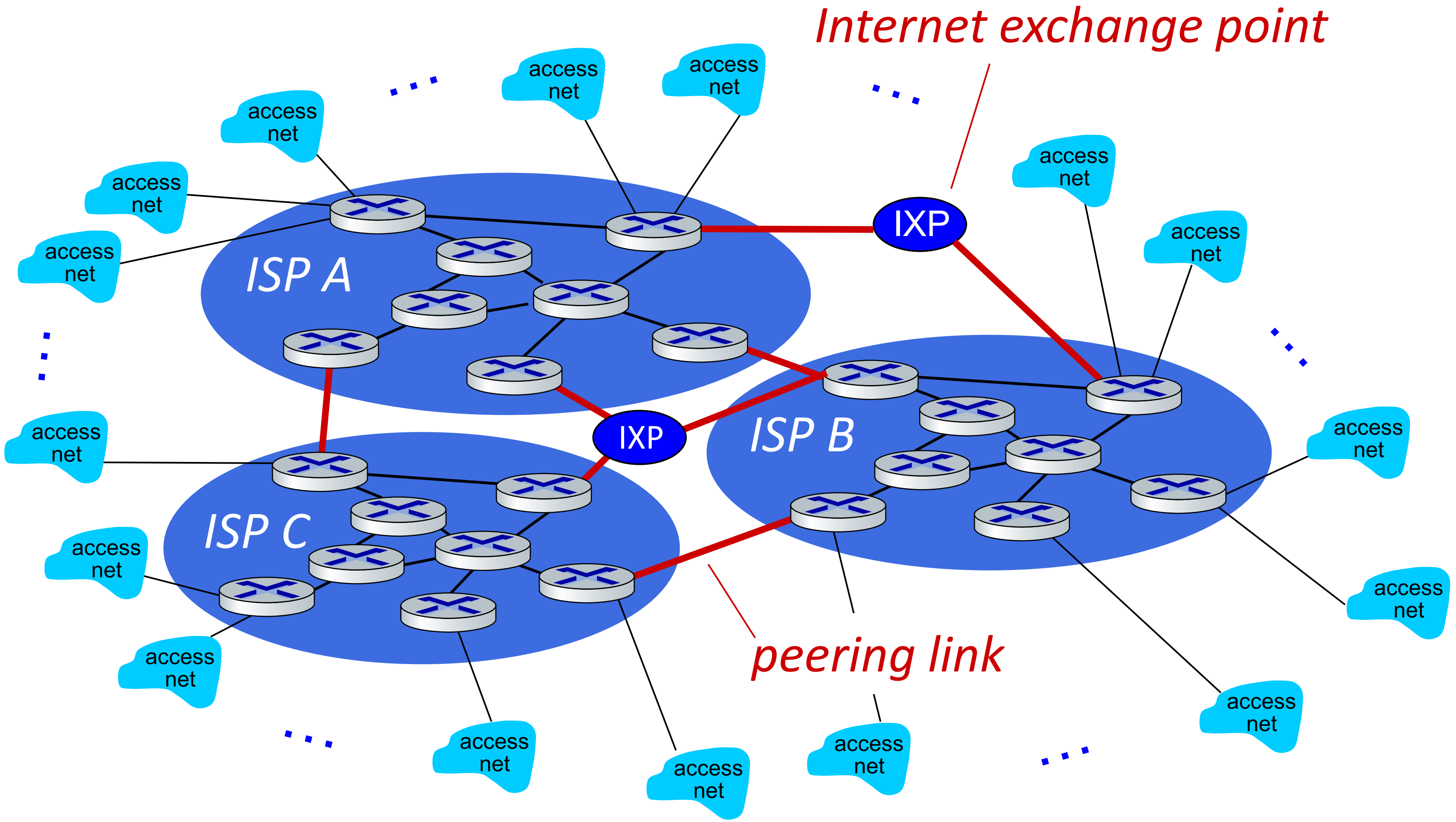
Internet structure: a "network of networks"

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



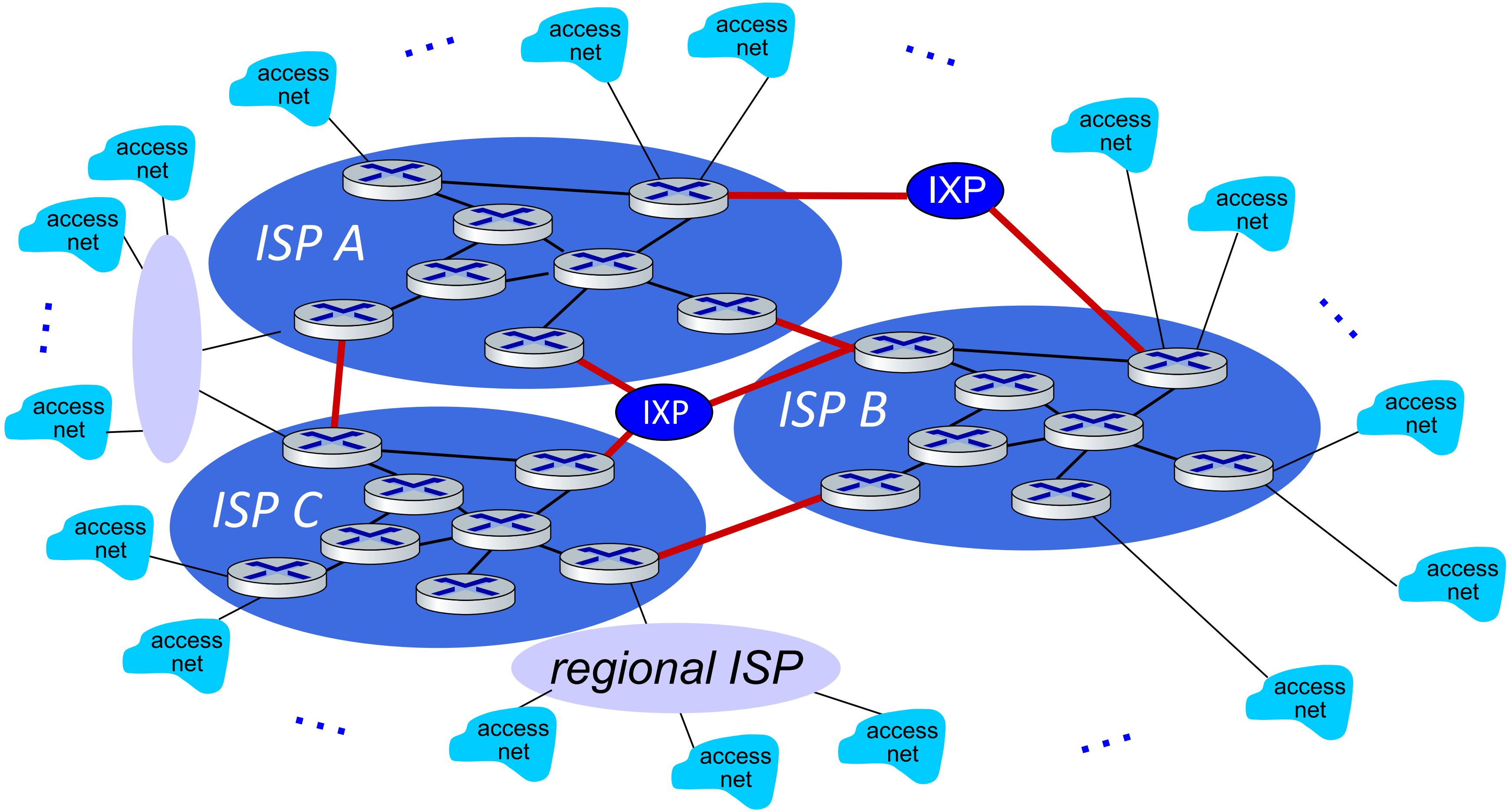
Internet structure: a “network of networks”

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



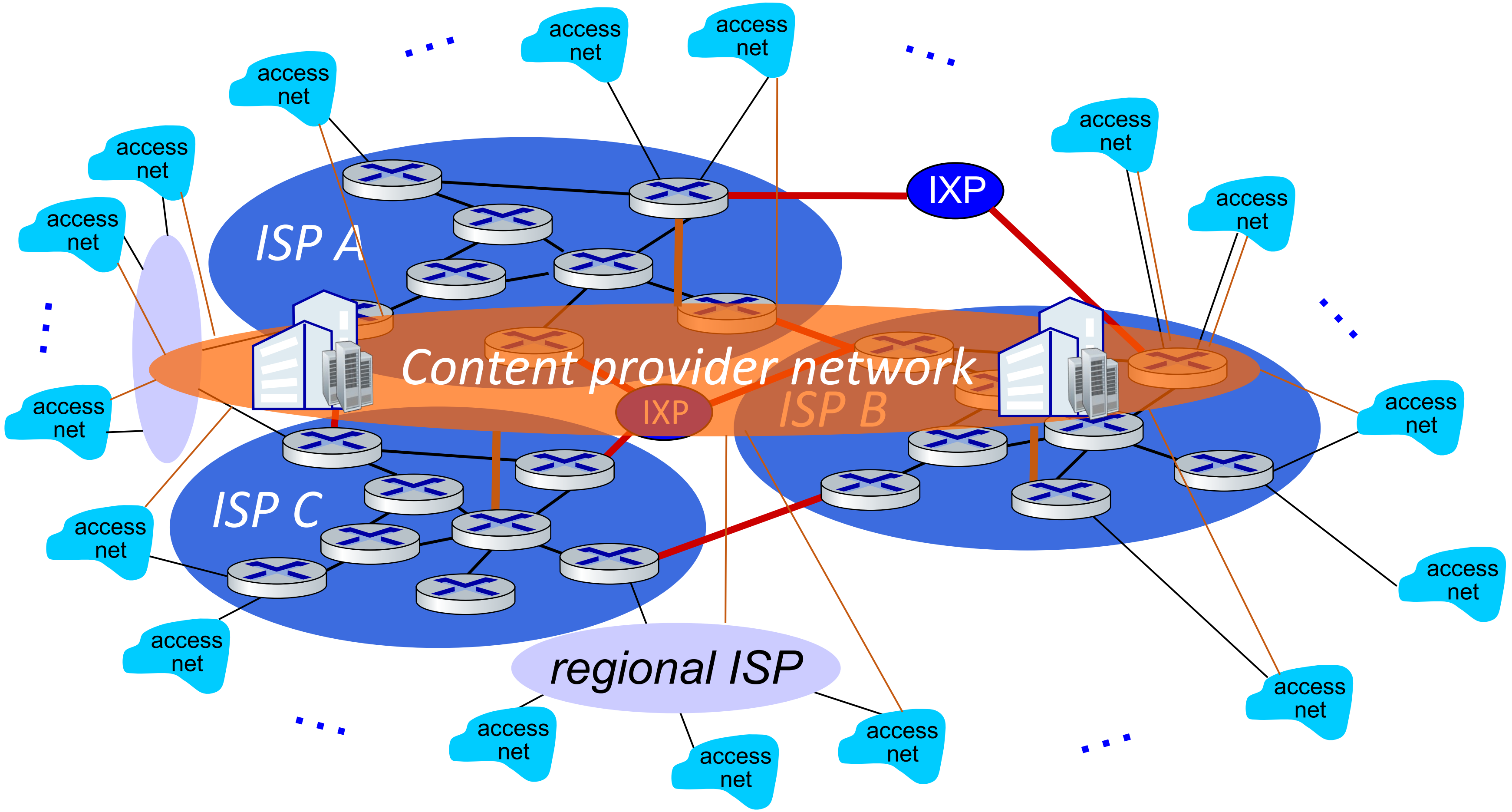
Internet structure: a "network of networks"

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

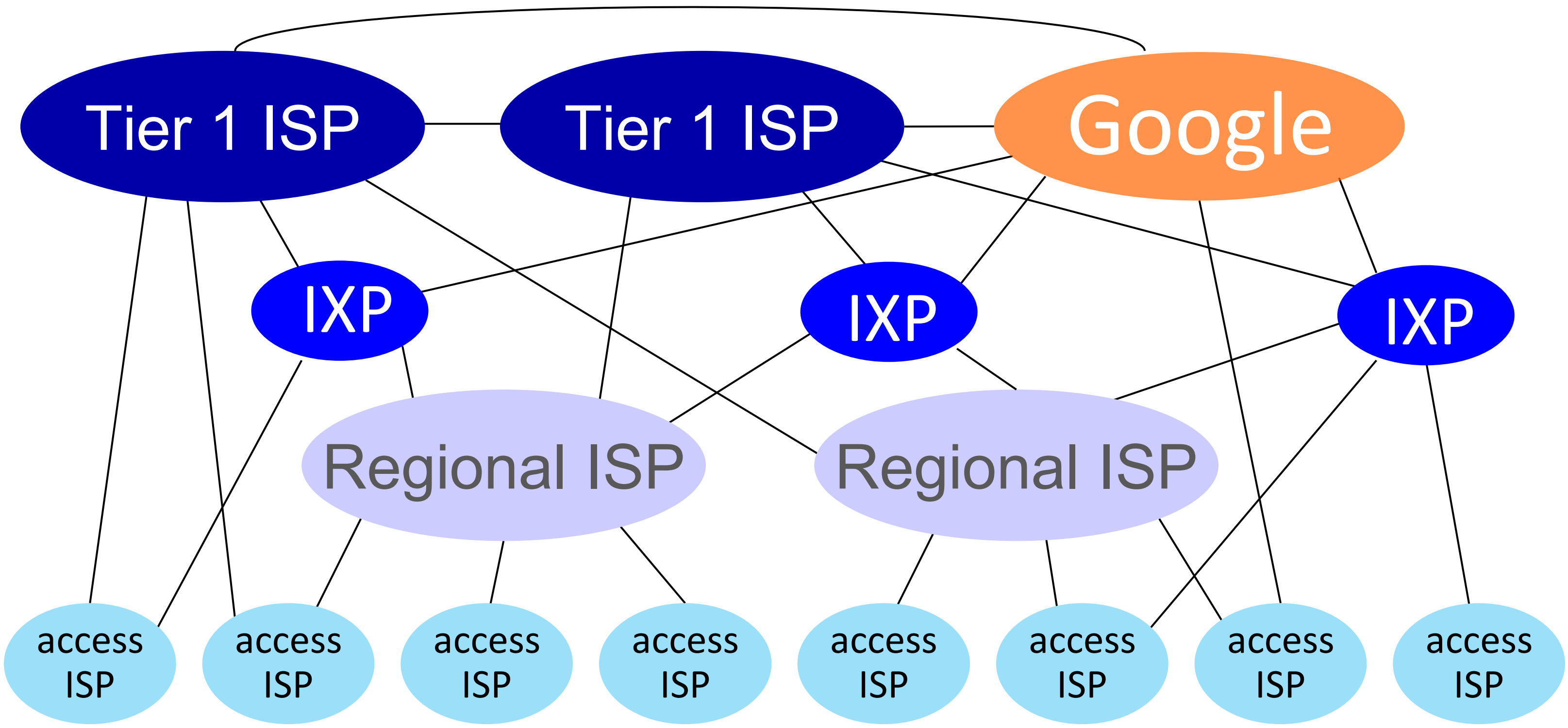


Internet structure: a "network of networks"

… 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