Computer Networks
CS3001
(Section BDS-7A)
Lecture 03

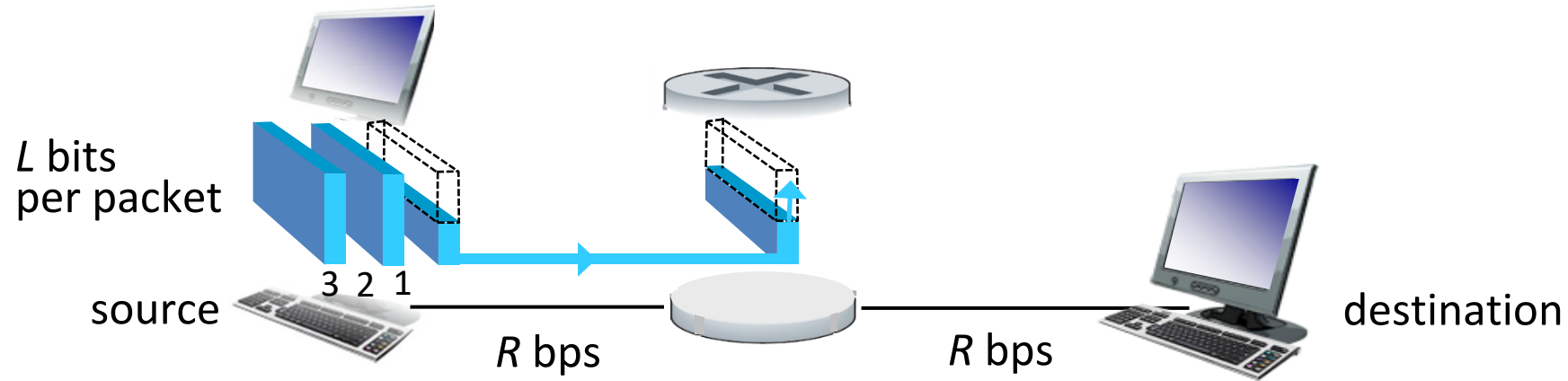Instructor: Dr. Syed Mohammad Irteza

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routing

forwarding

forwarding

forwarding

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
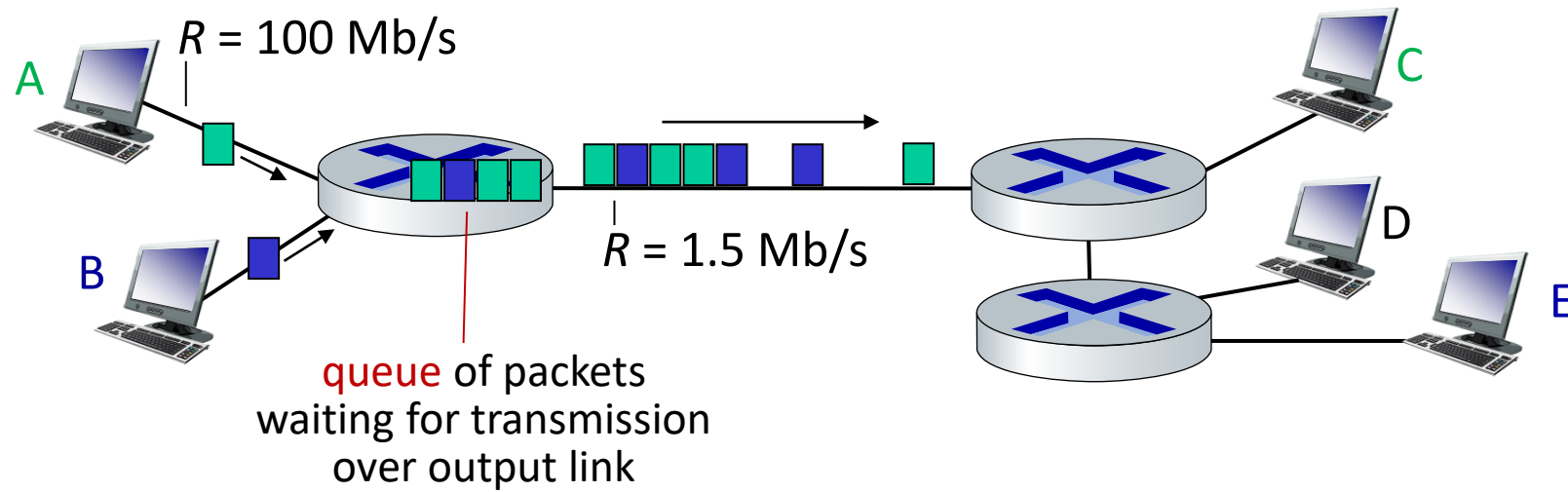- R = 100 Mbps
- one-hop transmission delay = 0.1 msec

Packet-switching: queueing

R = 100 Mb/s

R = 1.5 Mb/s

A

B

C

D

E

queue of packets
waiting for transmission
over output link
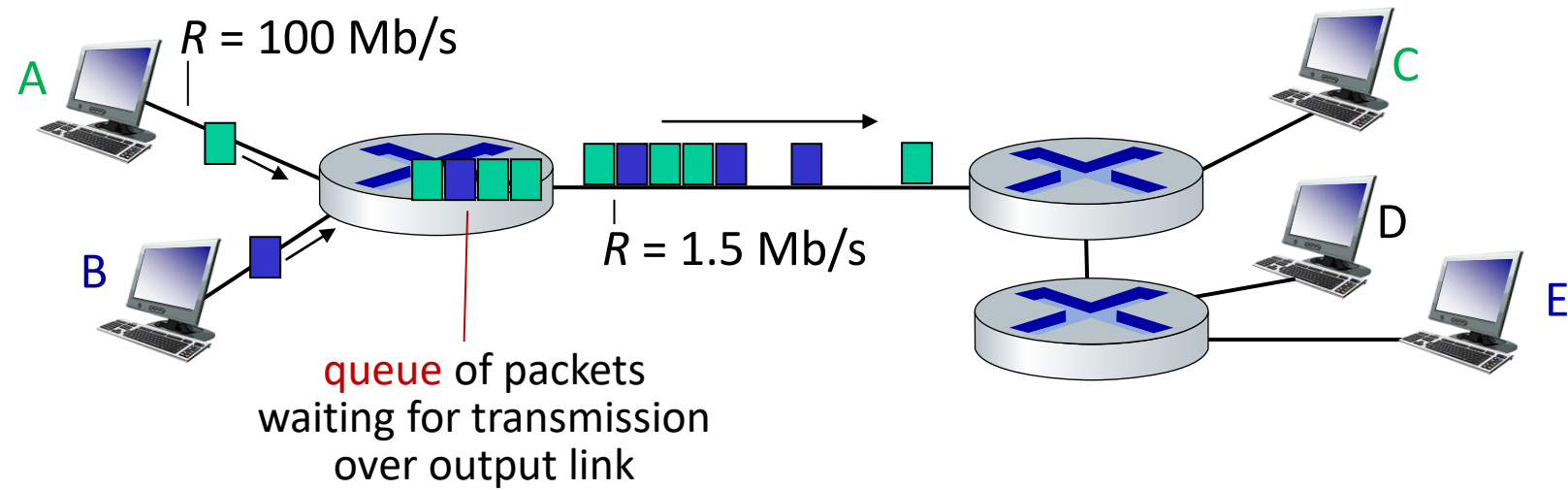
Queueing occurs when work arrives faster than it can be serviced:

Packet-switching: queueing

queue of packets
waiting for transmission
over output link

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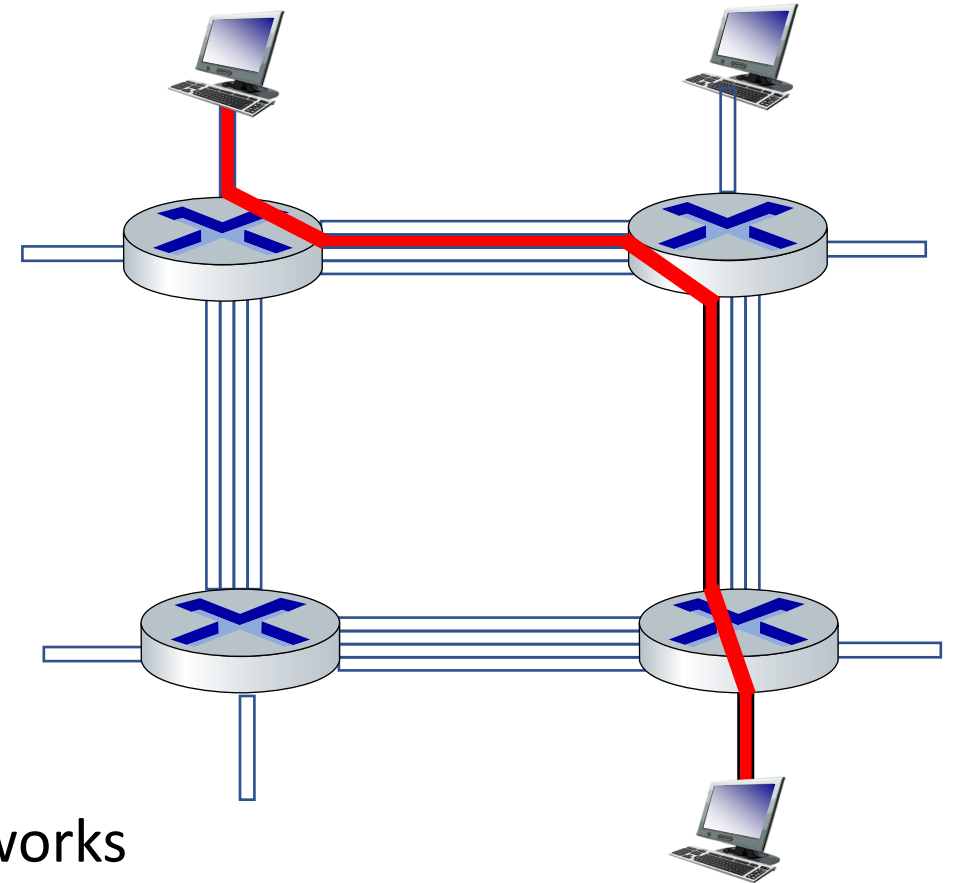
* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive

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

4 users
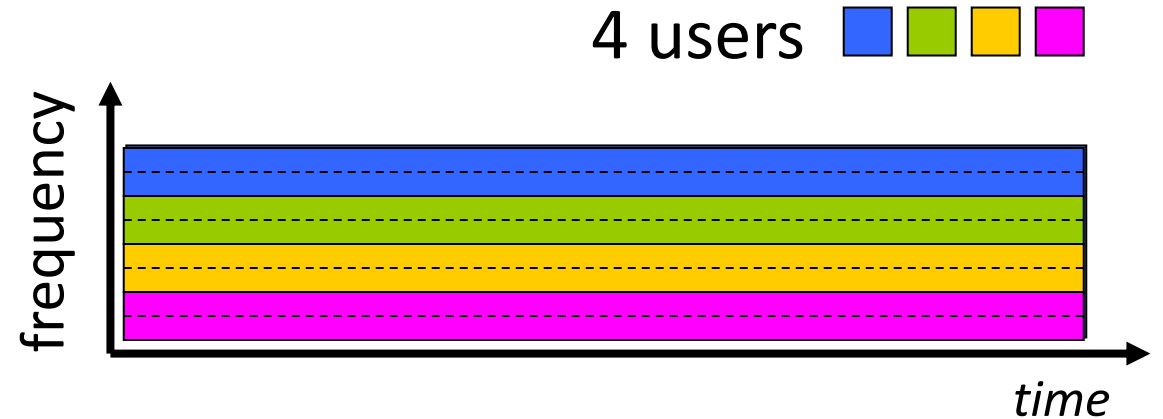
Time Division Multiplexing (TDM)

  - 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)
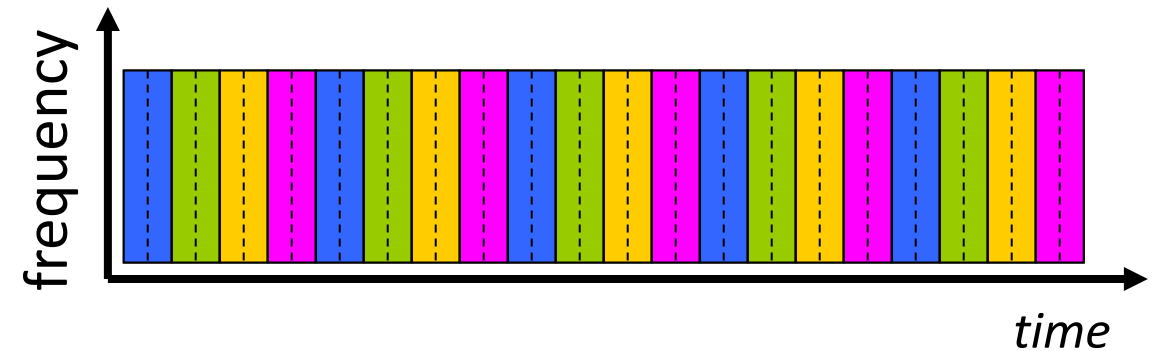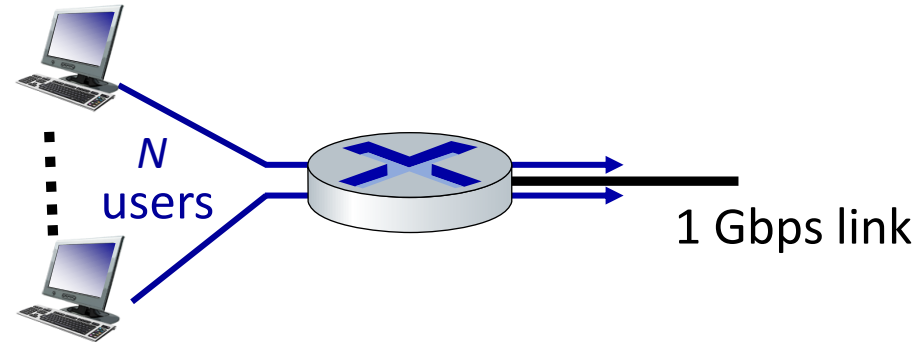
Packet switching versus circuit switching

example:
- 1 Gb/s link
- each user:
  - 100 Mb/s when "active"
  - active 10% of time

N users

1 Gbps link

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)?
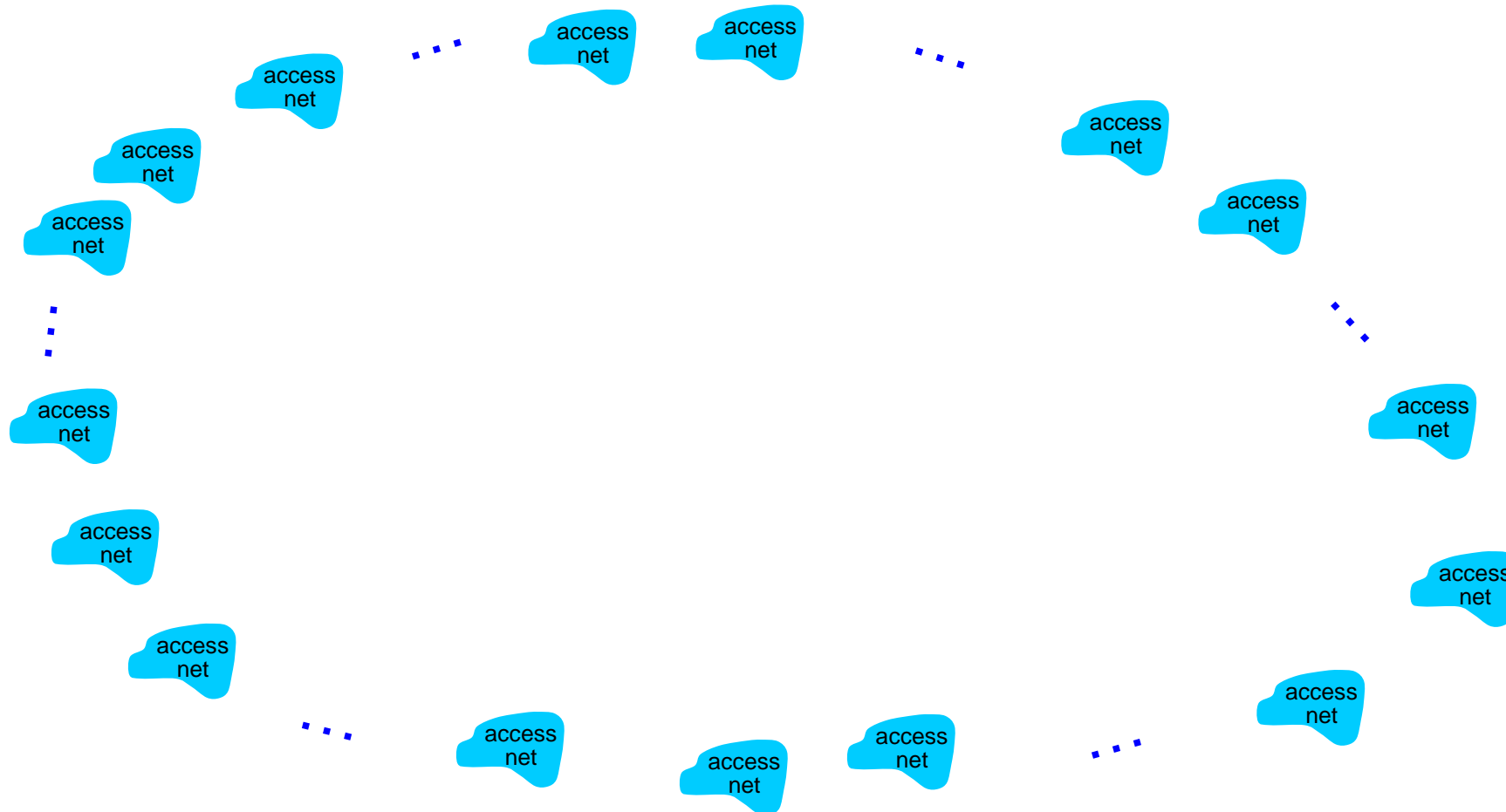
Internet structure: a "network of networks"

- 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
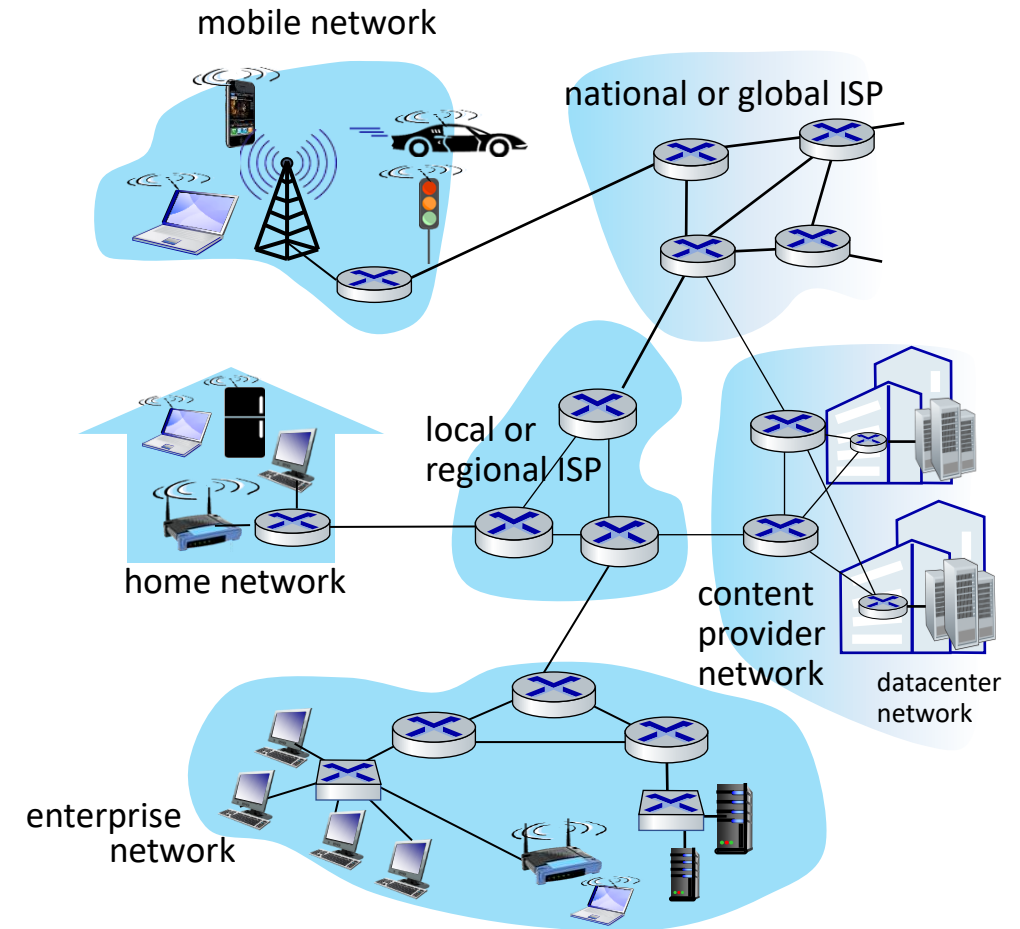
Let's take a stepwise approach to describe current Internet structure
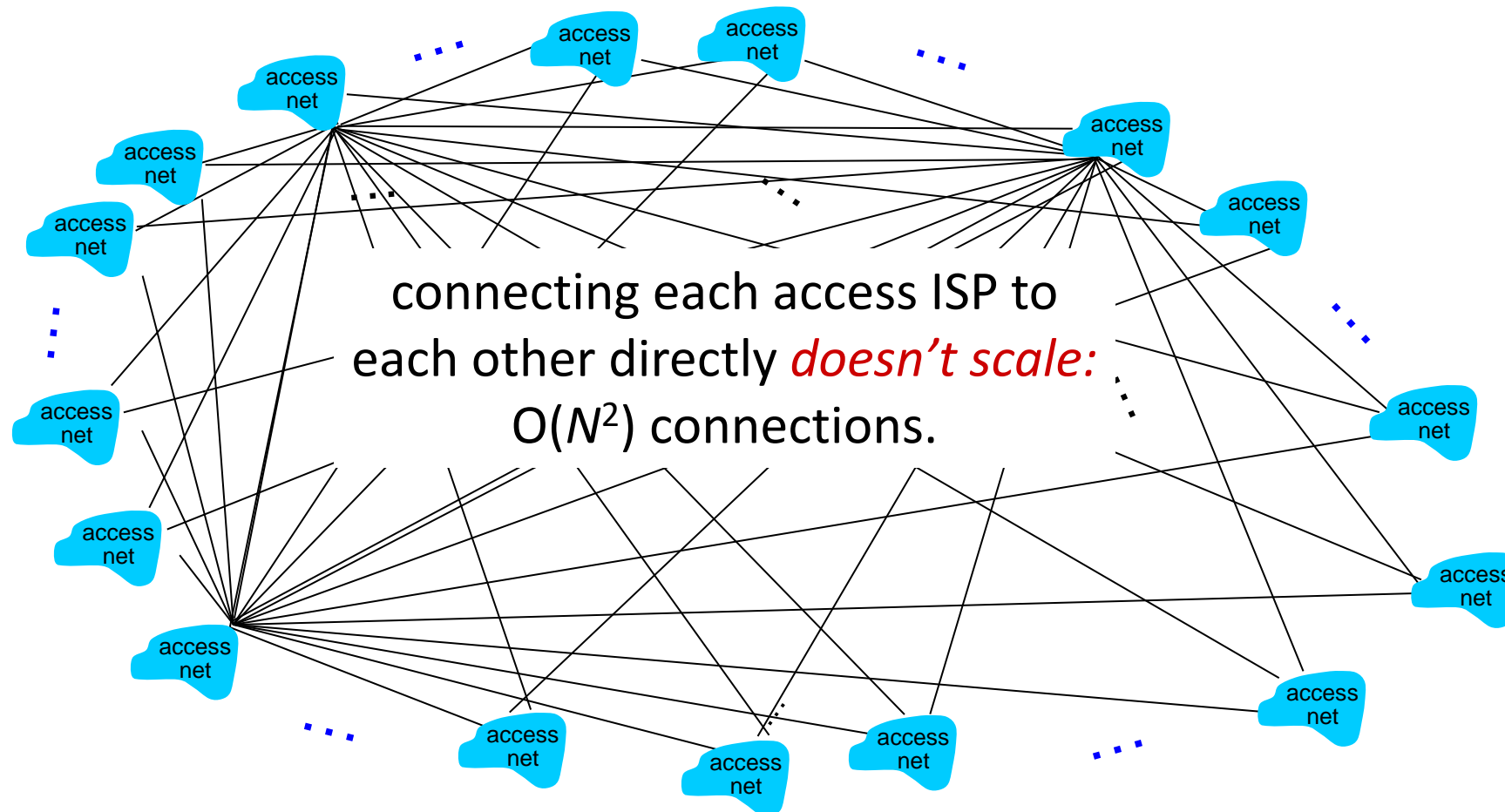
Internet structure: a "network of networks"

Question: given *millions* of access ISPs, how to connect them together?
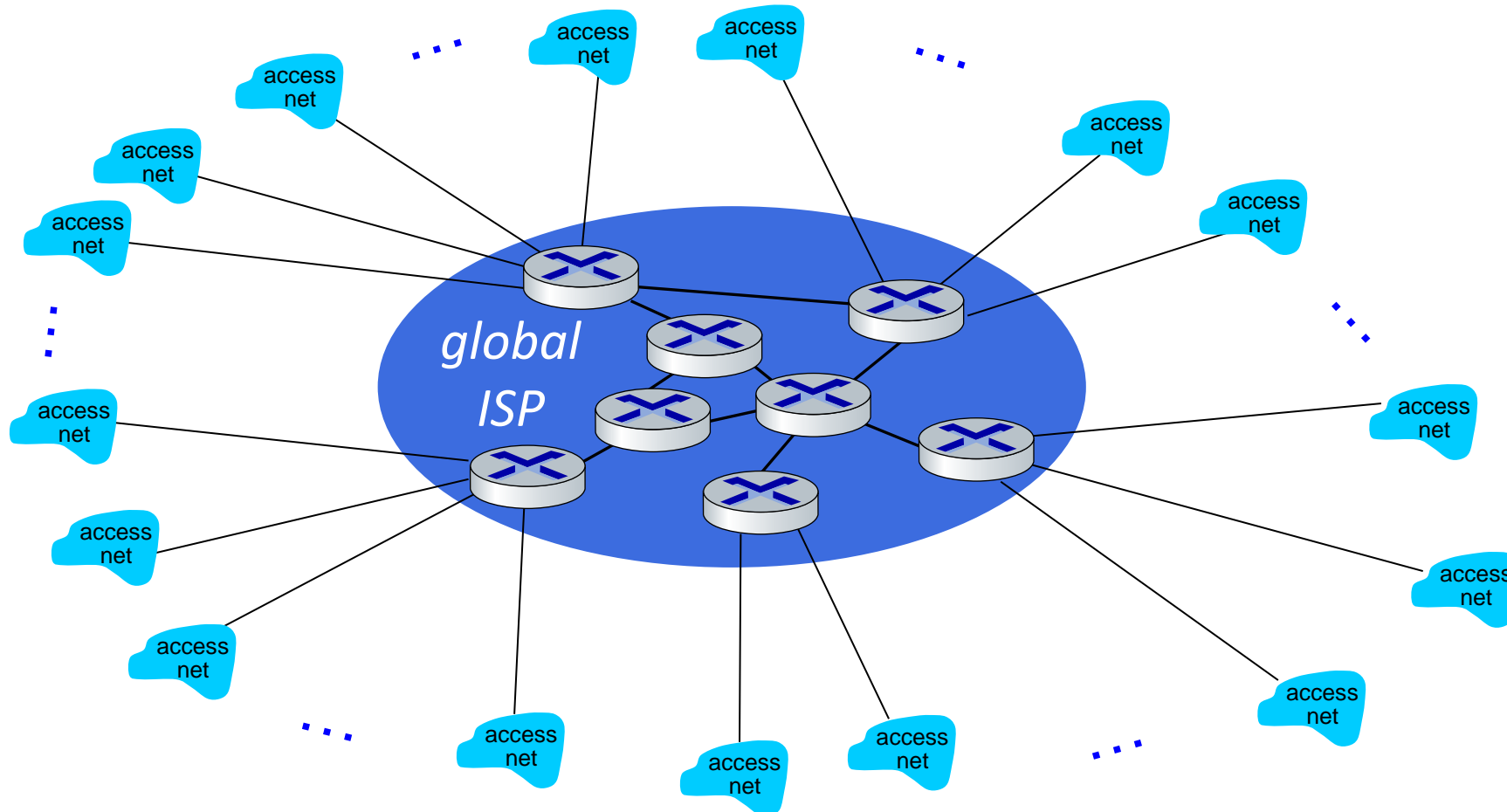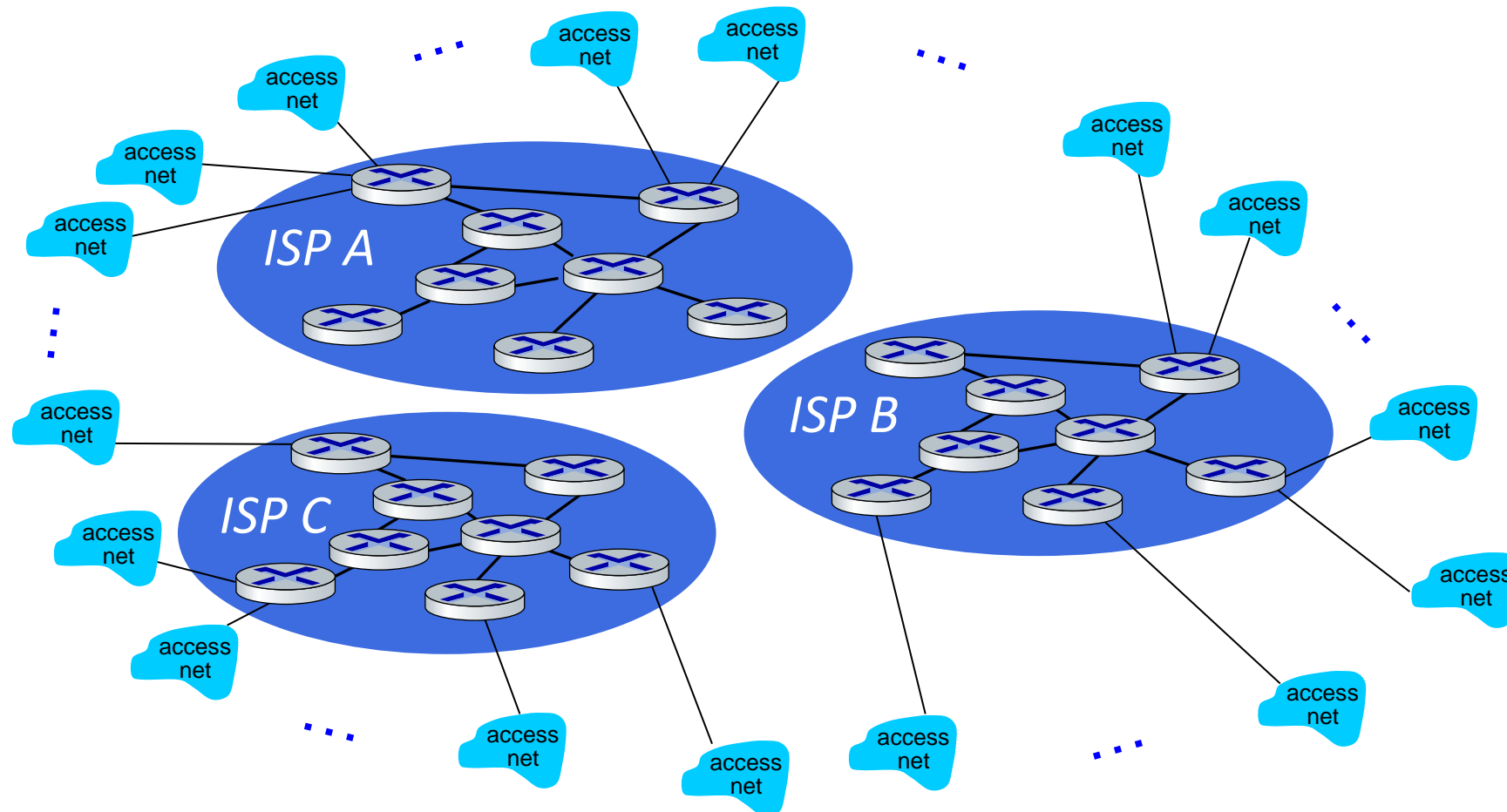
Internet structure: a "network of networks"

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

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?
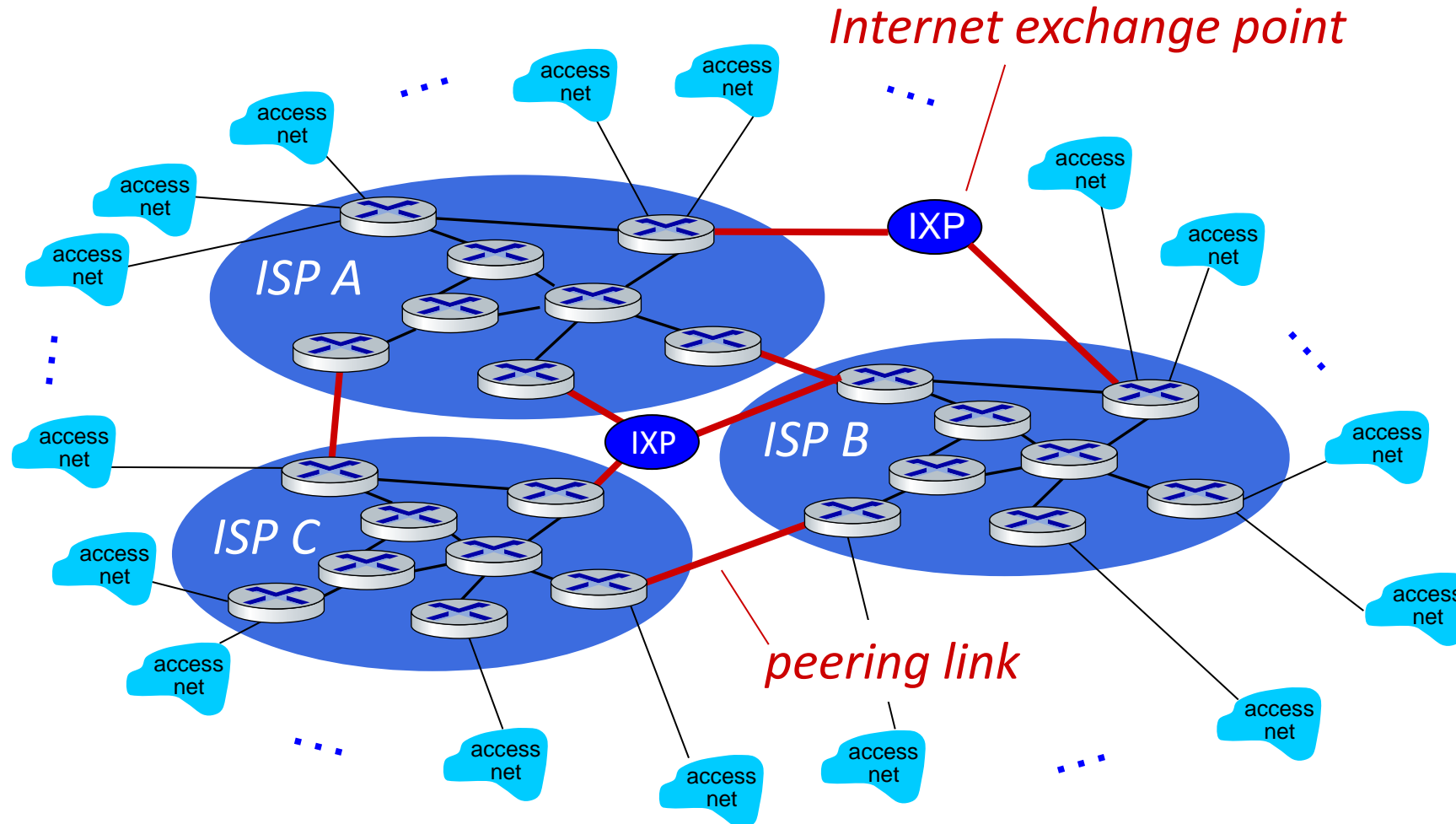*Customer* and *provider* ISPs have economic agreement.

Internet structure: a "network of networks"

But if one global ISP is viable business, there will be competitors ….
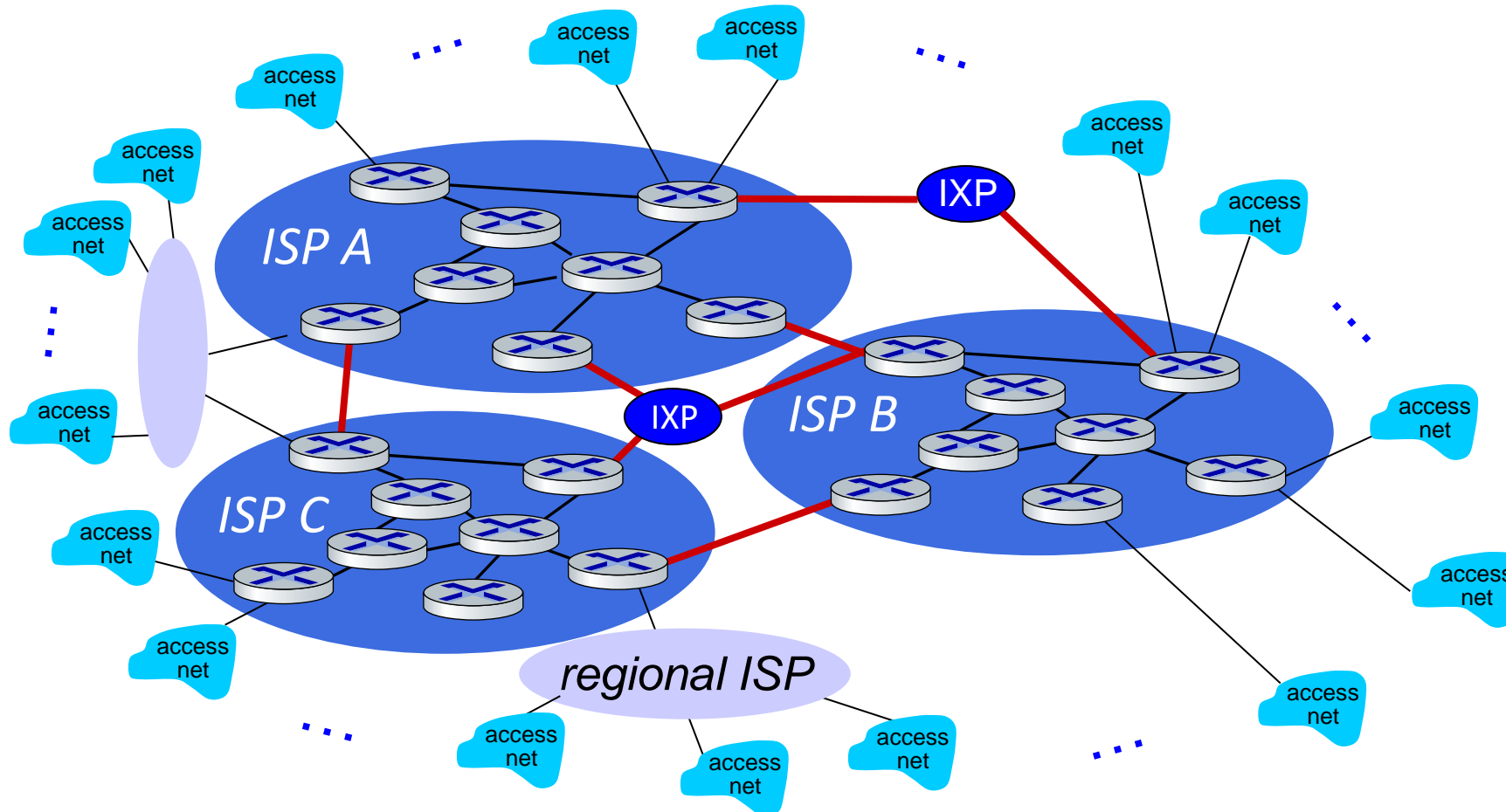
Internet structure: a "network of networks"

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

Internet exchange point

peering link

Internet structure: a "network of networks"

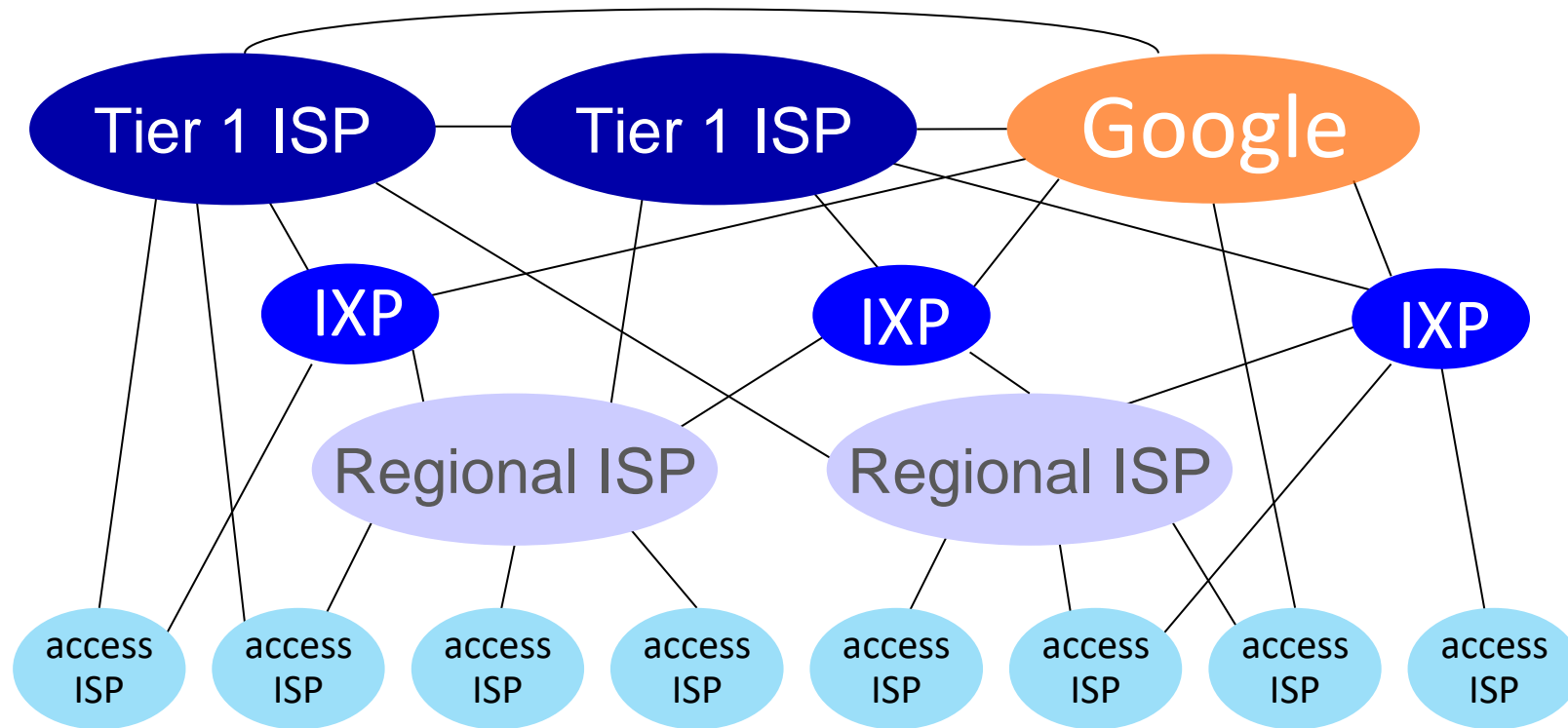## ... and regional networks may arise to connect access nets to ISPs

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
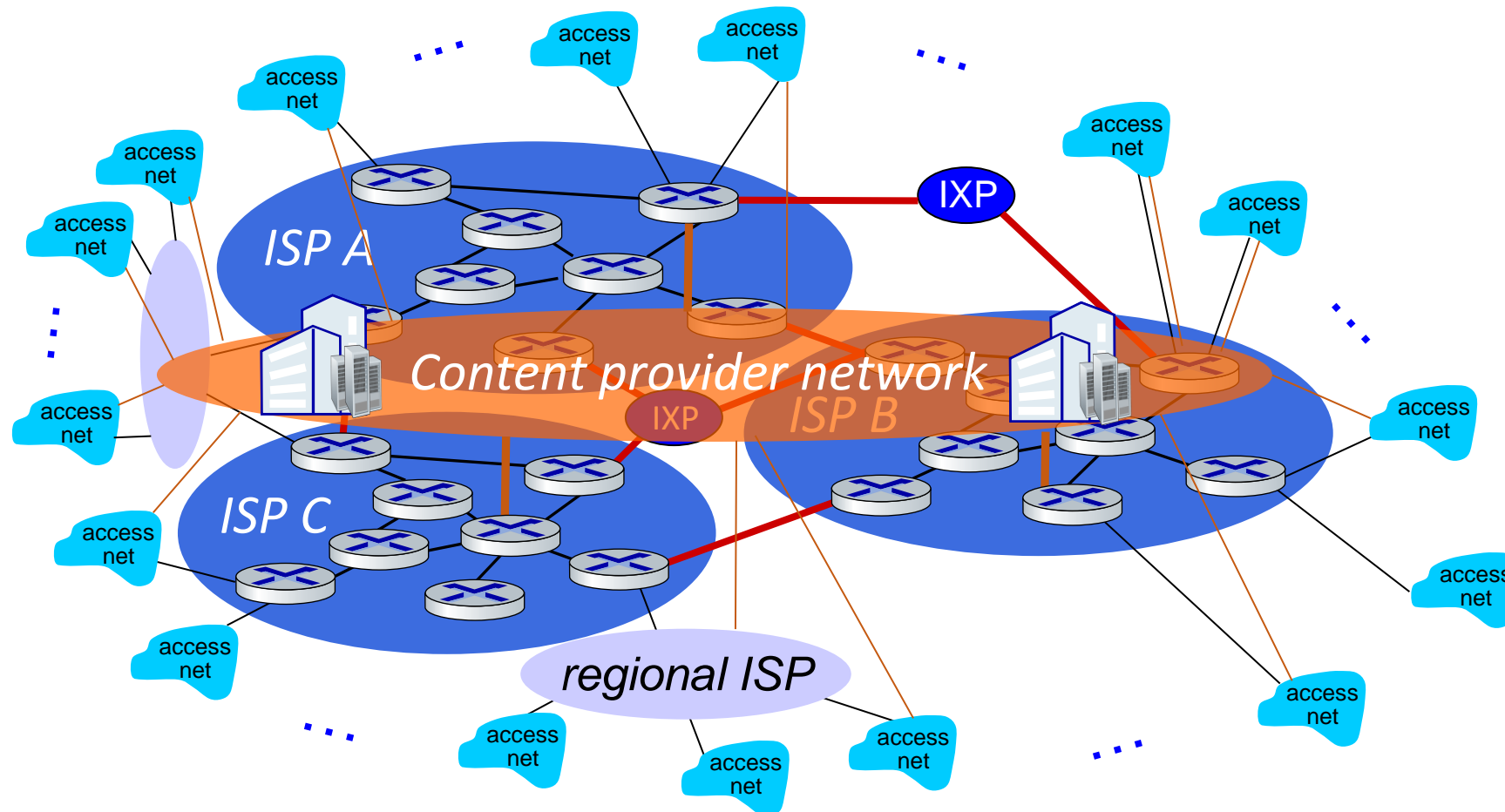
Internet structure: a "network of networks"

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

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