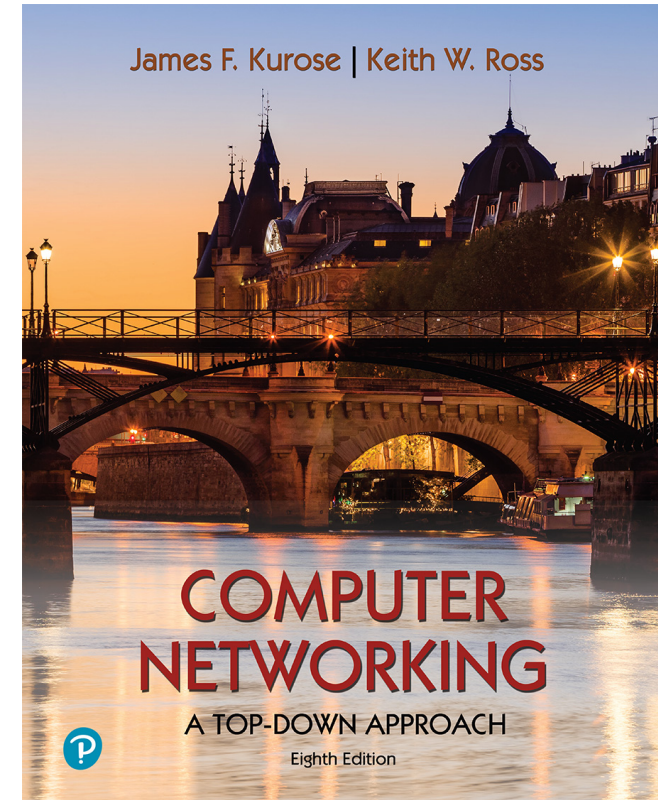


# Chapter 1

## Introduction



### *Computer Networking: A Top-Down Approach*

8<sup>th</sup> edition

Jim Kurose, Keith Ross  
Pearson, 2020

Acknowledgement: Based on the textbook's website:  
[https://gaia.cs.umass.edu/kurose\\_ross/index.php](https://gaia.cs.umass.edu/kurose_ross/index.php)

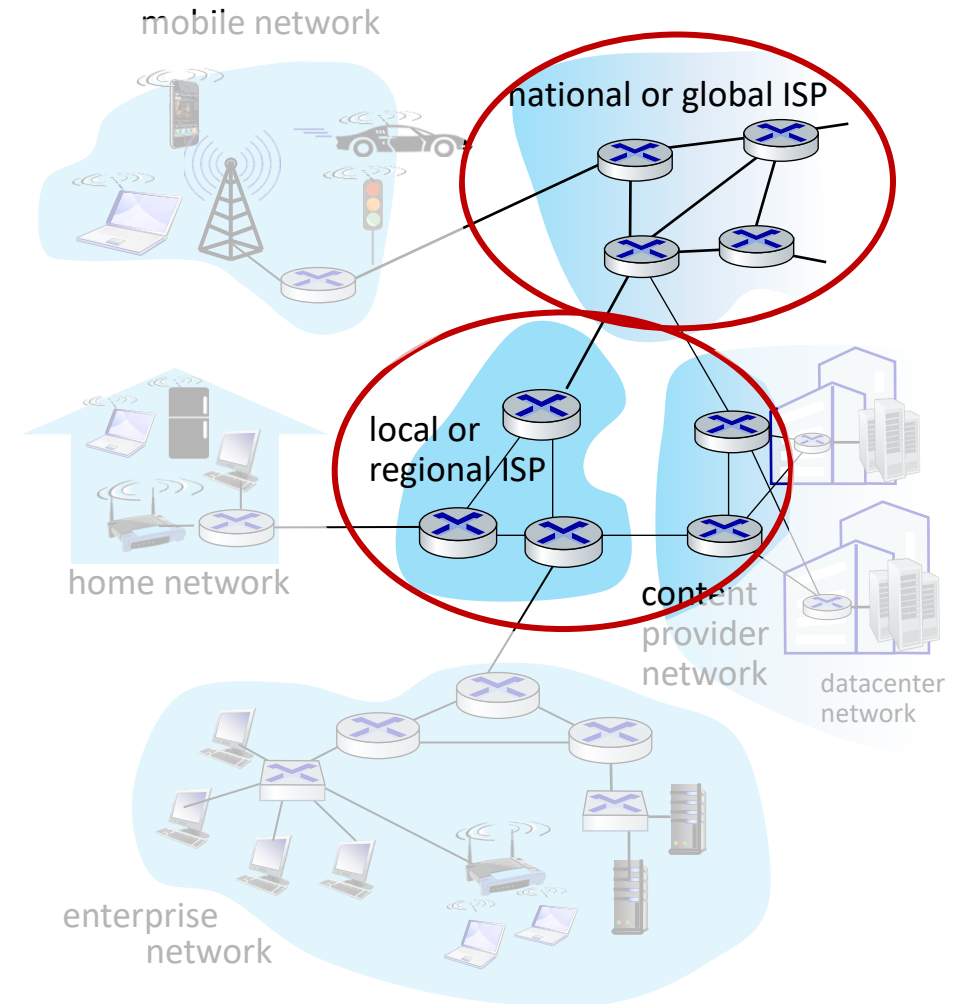
# Chapter 1: roadmap

- 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

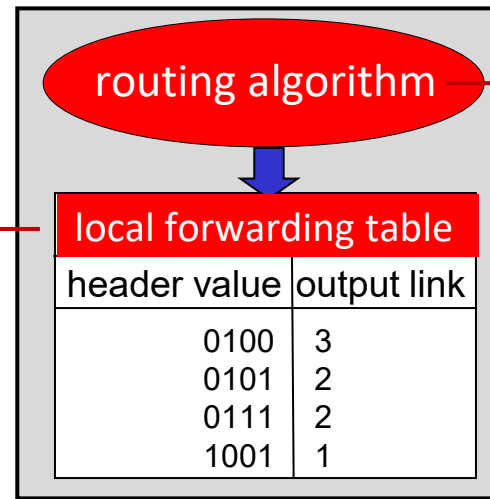
- mesh of interconnected routers
- **packet-switching**: hosts break application-layer messages into *packets*
  - network **forwards** packets from one router to the next, across links on path from **source to destination**



# Two key network-core functions

## Forwarding:

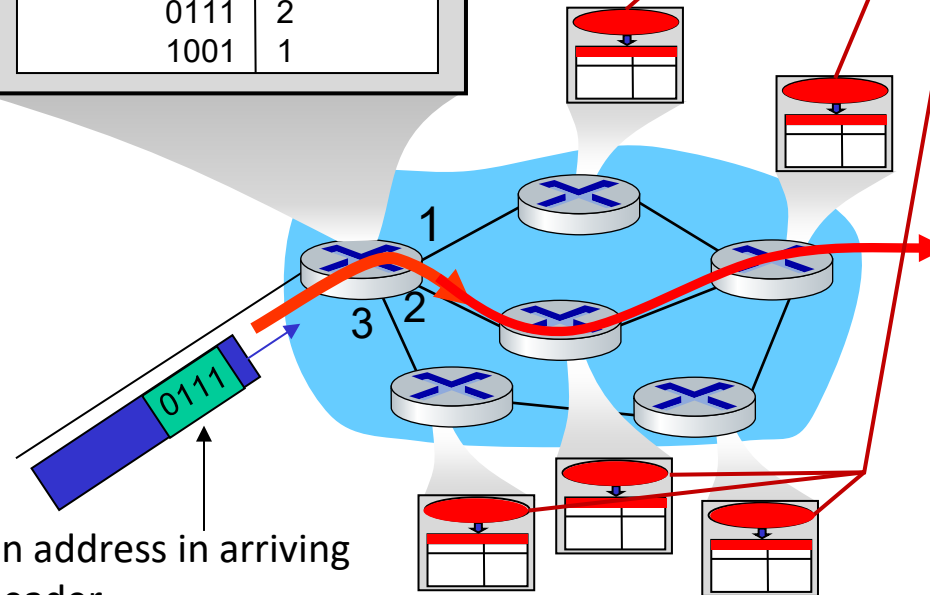
- aka “switching”
- *local* action: move arriving packets from router’s input link to appropriate router output link



destination address in arriving packet's header

## Routing:

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



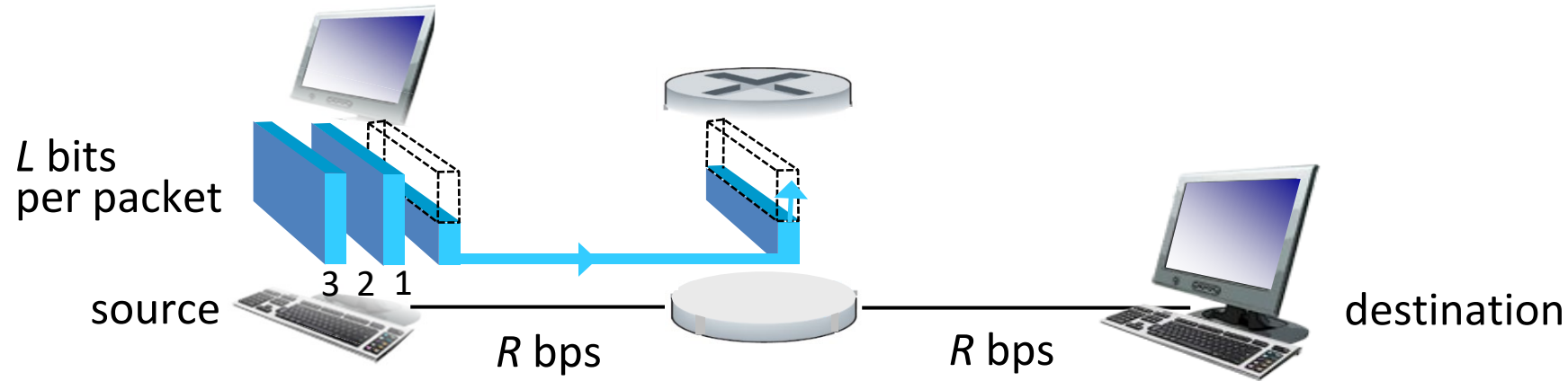








# Packet-switching: store-and-forward

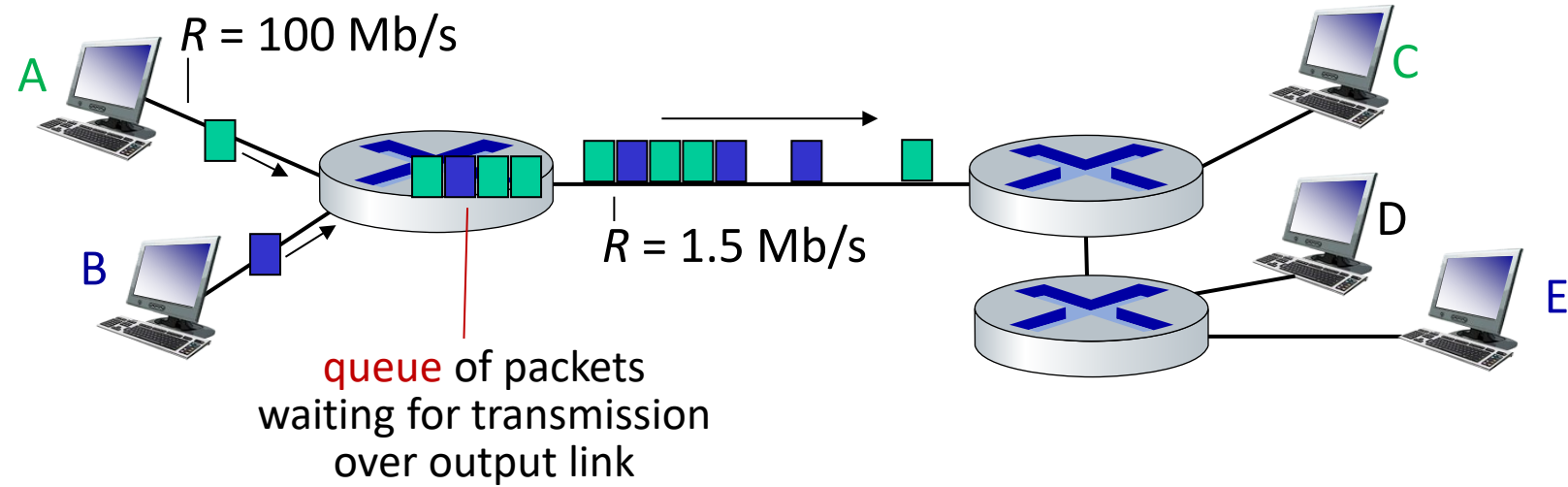


- **packet transmission delay:** takes  $L/R$  seconds to transmit (push out)  $L$ -bit packet into link at  $R$  bps
- **store and forward:** entire packet must arrive at router before it can be transmitted on next link

## *One-hop numerical example:*

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

# Packet-switching: queueing

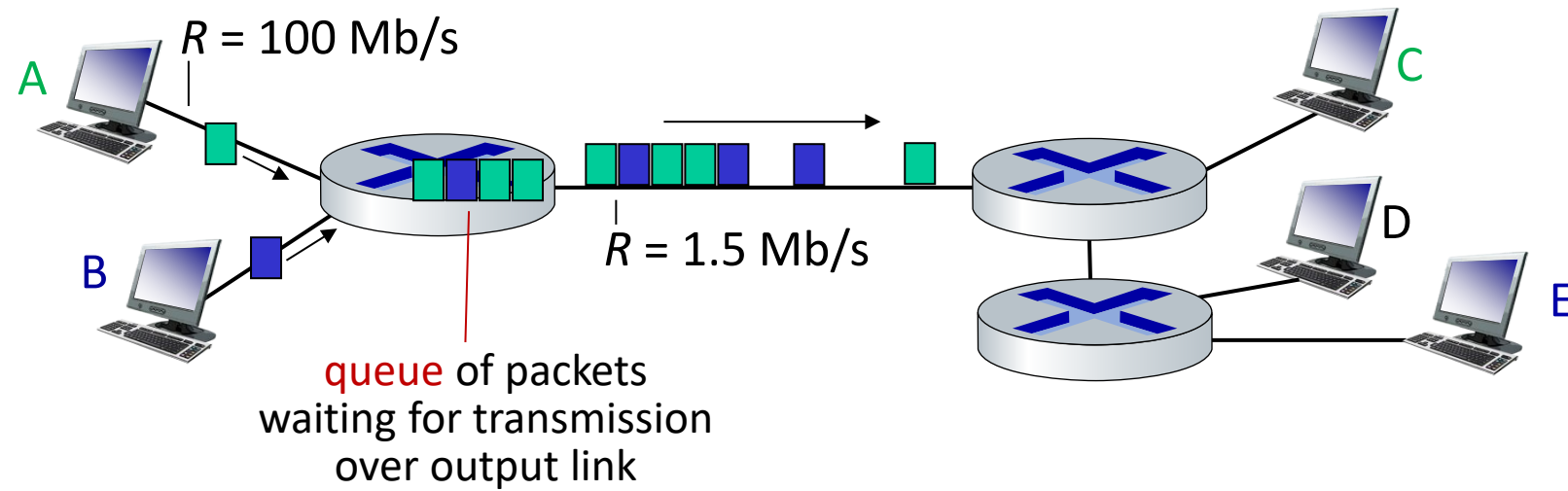


**Queueing** occurs when work arrives faster than it can be serviced:





# Packet-switching: queueing



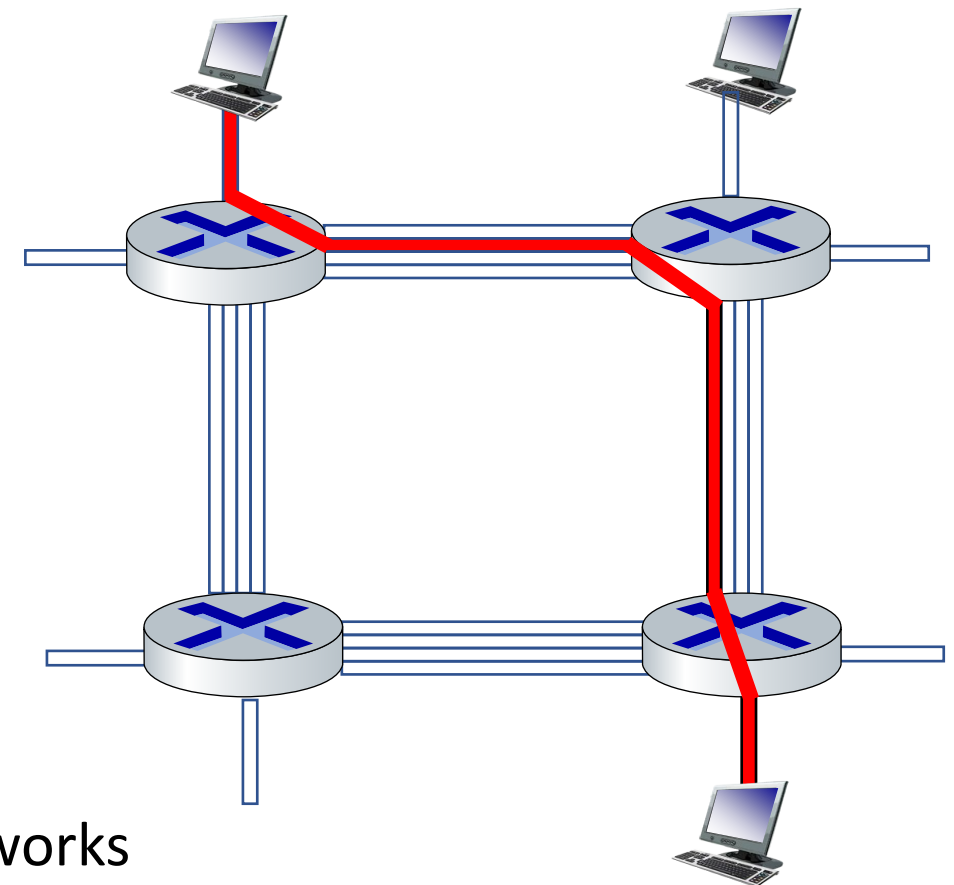
***Packet queueing and loss:*** if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- 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 2<sup>nd</sup> circuit in top link and 1<sup>st</sup> 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

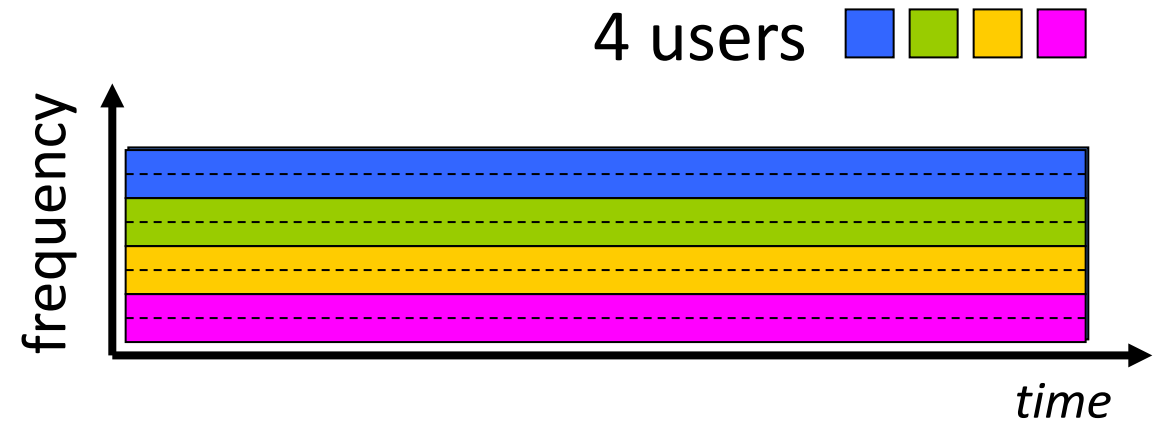


\* Check out the online interactive exercises for more examples: [http://gaia.cs.umass.edu/kurose\\_ross/interactive](http://gaia.cs.umass.edu/kurose_ross/interactive)

# Circuit switching: FDM and TDM

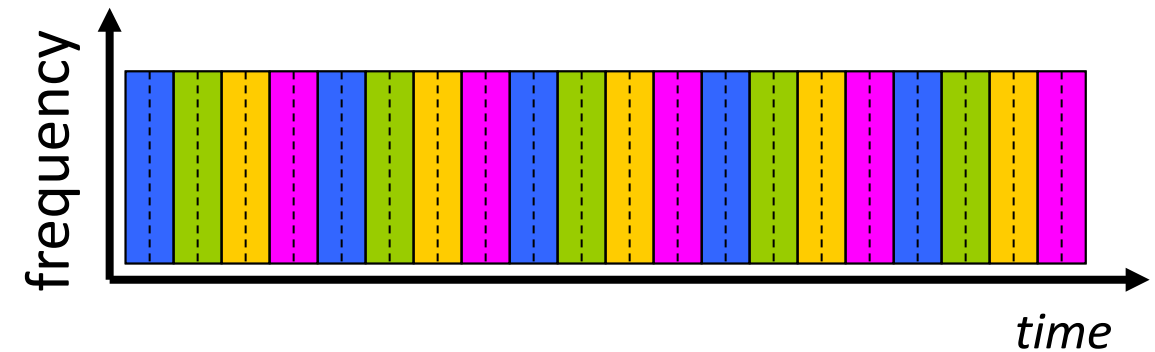
## Frequency Division Multiplexing (FDM)

- 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)

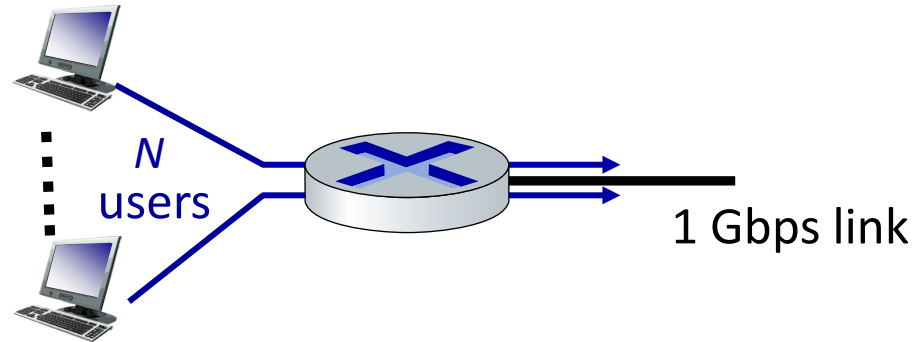




# Packet switching versus circuit switching

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](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 10 or fewer active users at the same time, then subtract that from 1 to get the probability of having 11 or more users active at the same time.
- First, we calculate  $P(X \leq 10)$  using the cumulative binomial probability function:
  - $P(X \leq 10) = \sum_{k=0}^{10} C(35,k) * 0.1^k * 0.9^{(35-k)}$
  - 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”?

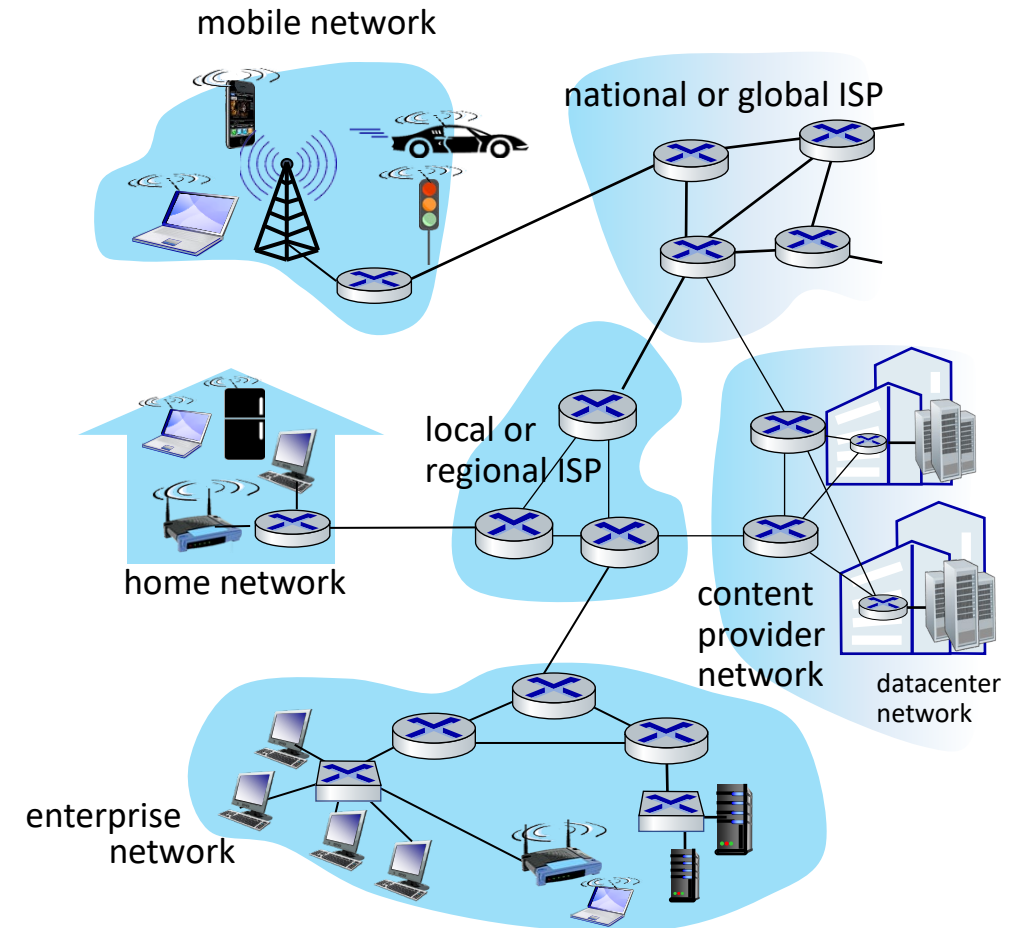
- great for “bursty” data – sometimes has data to send, but at other times not
  - resource sharing
  - simpler, no call setup
- **excessive congestion possible:** packet delay and loss due to buffer overflow
  - protocols needed for reliable data transfer, congestion control
- **Q: How to provide circuit-like 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”

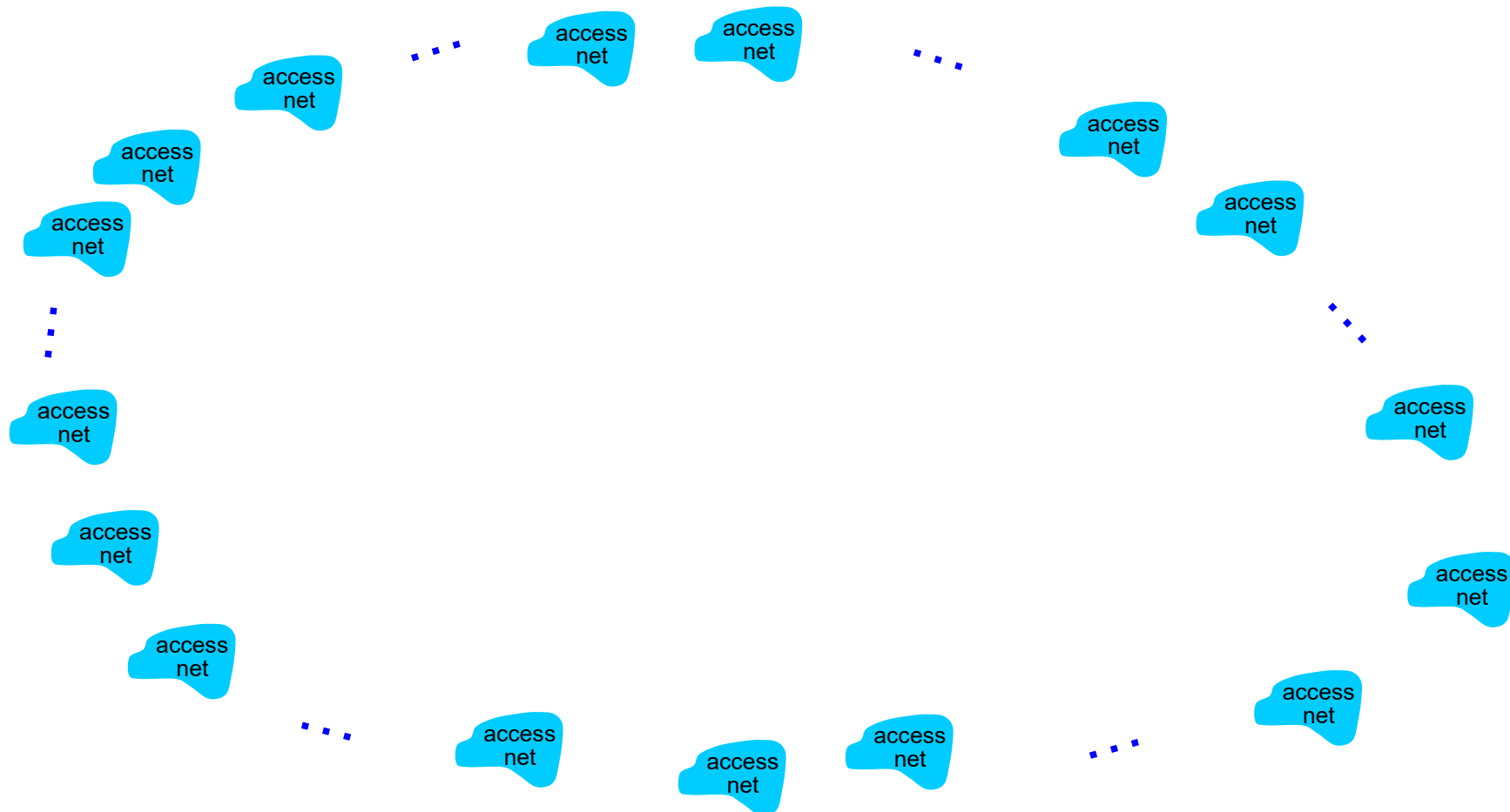
- hosts connect to Internet via **access** Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts (*anywhere!*) can send packets to each other
- resulting network of networks is very complex
  - evolution driven by **economics**, **national policies**



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

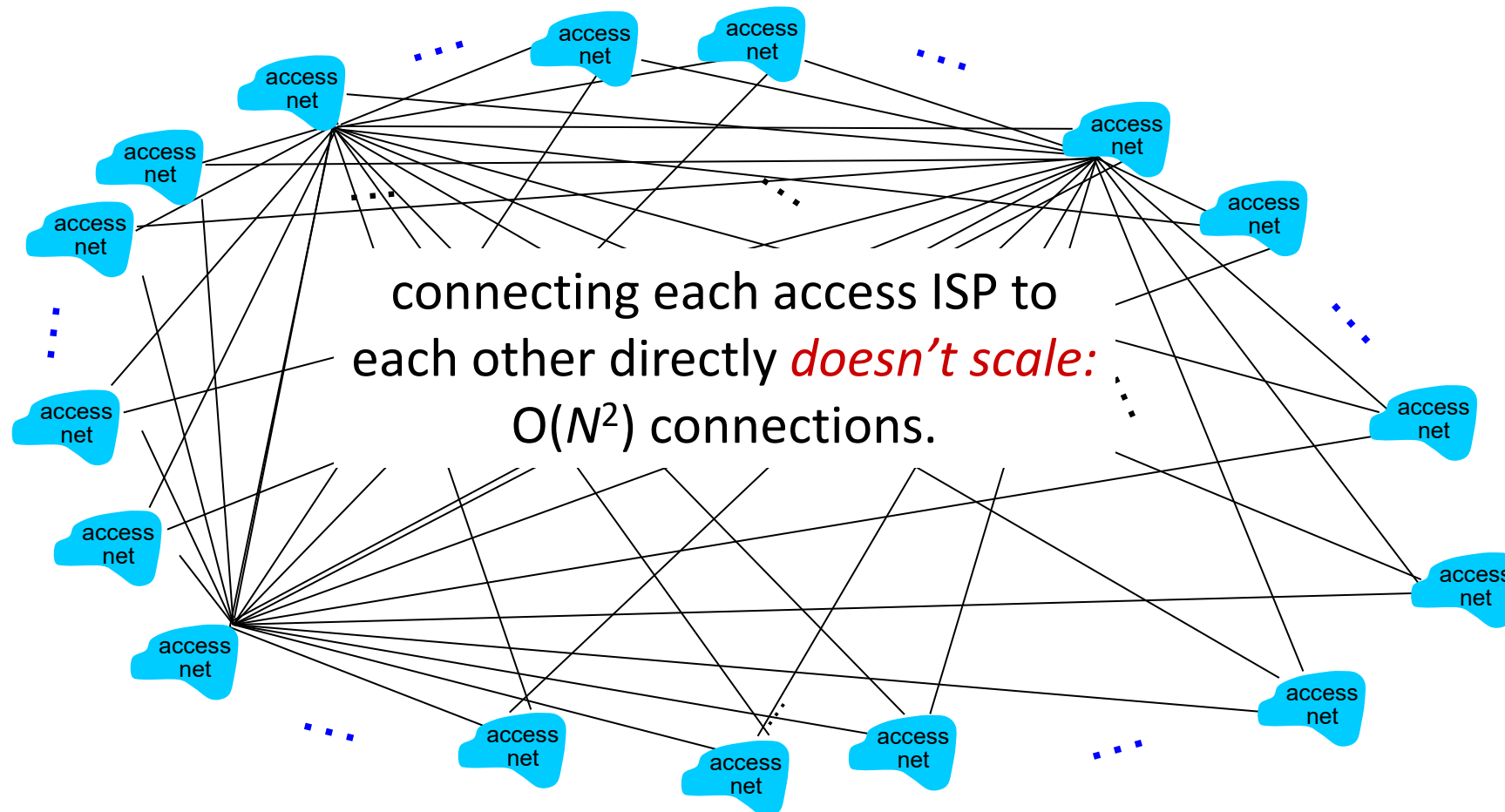
# Internet structure: a “network of networks”

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



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

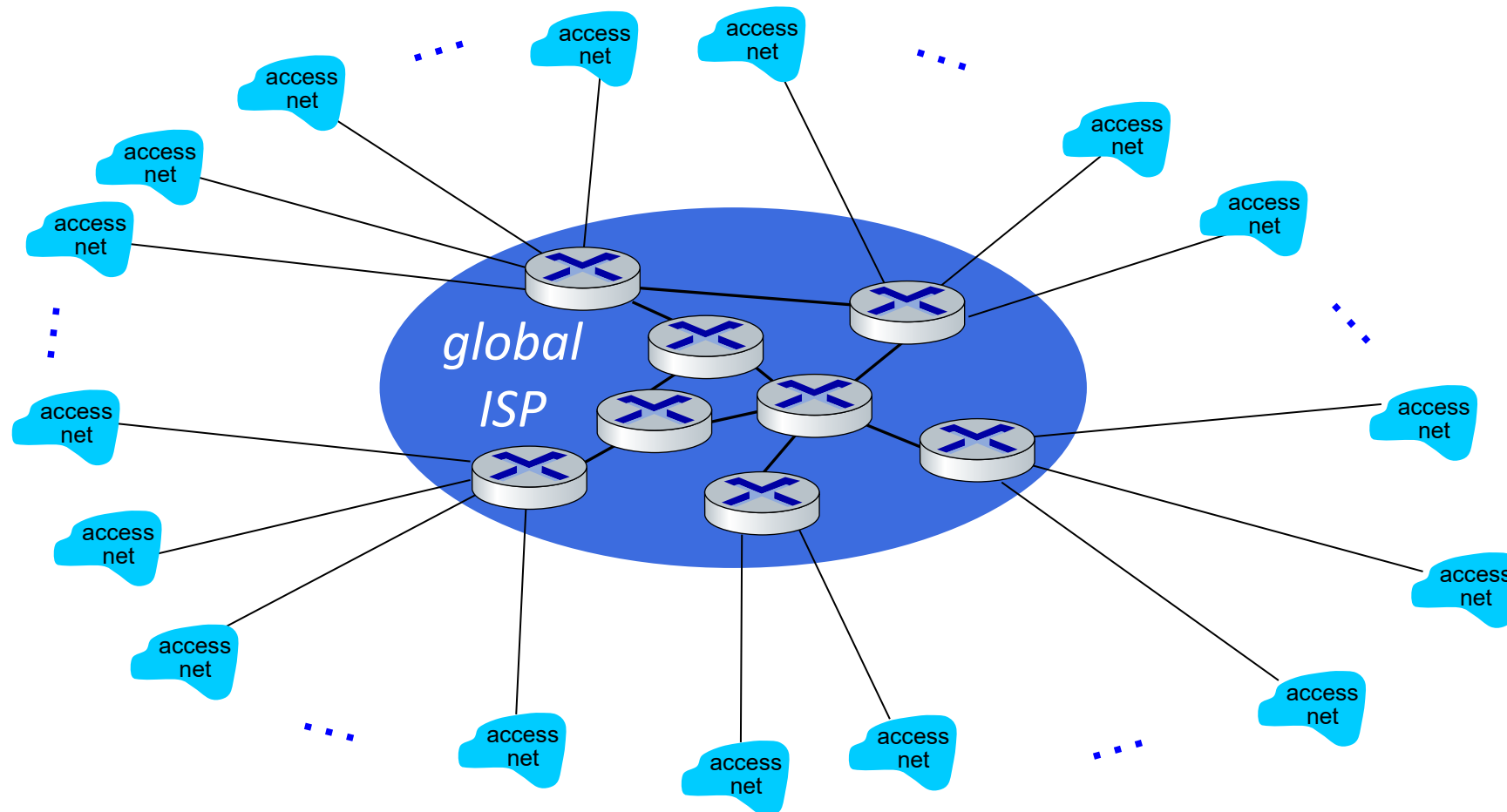




# Internet structure: a “network of networks”

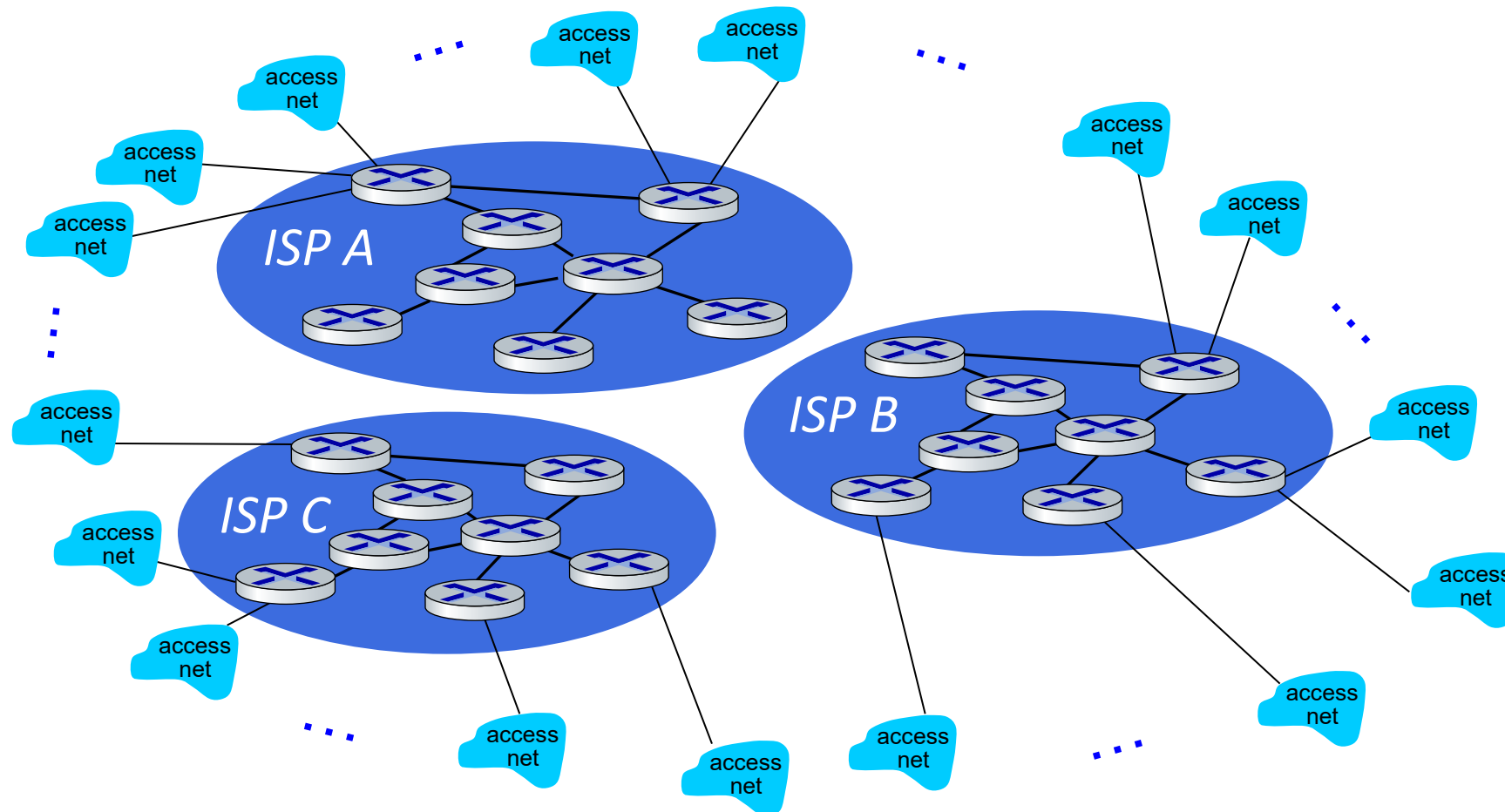
*Option: connect each access ISP to one global transit ISP?*

*Customer and provider ISPs have economic agreement.*



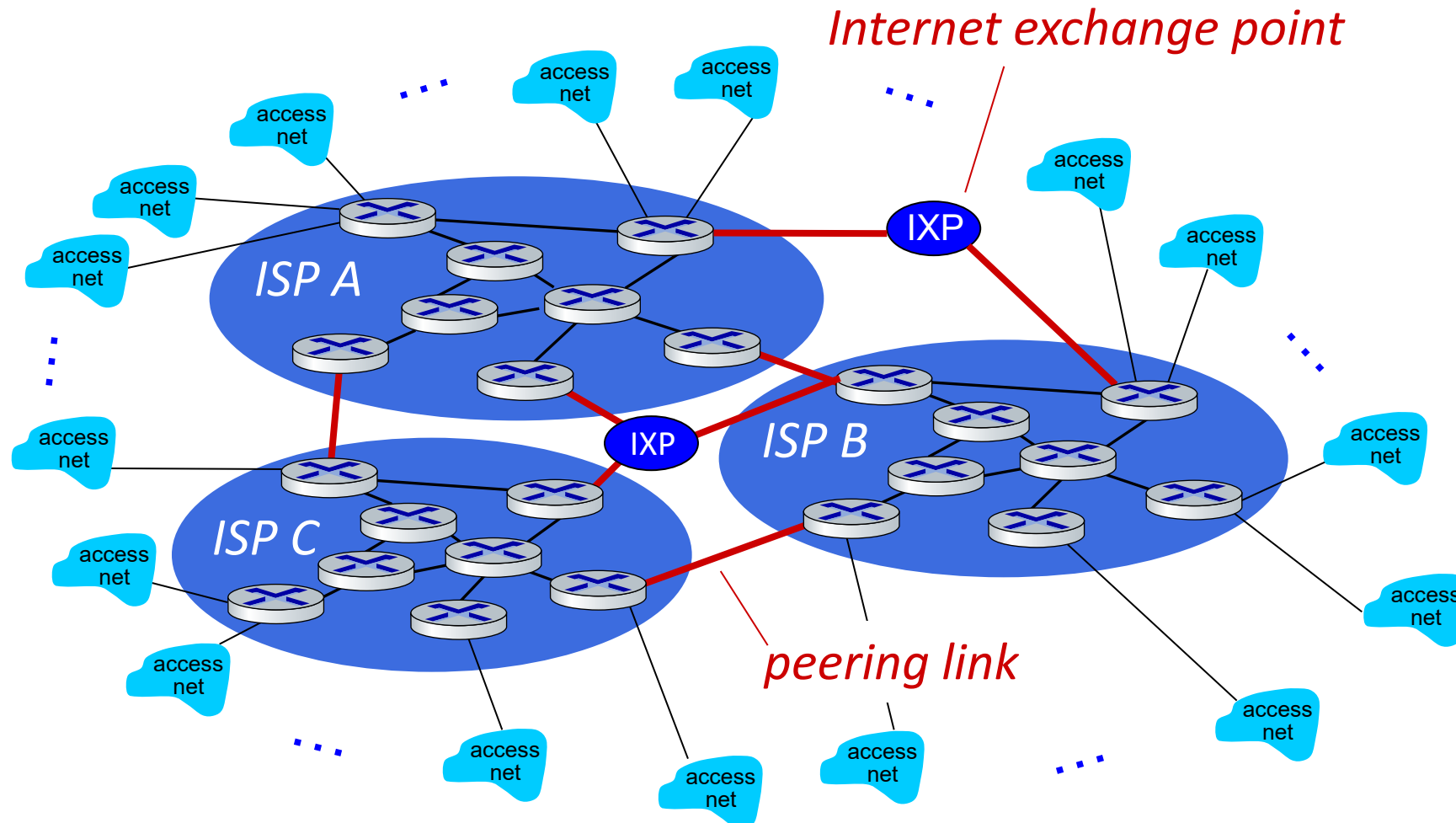
# Internet structure: a “network of networks”

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



# Internet structure: a “network of networks”

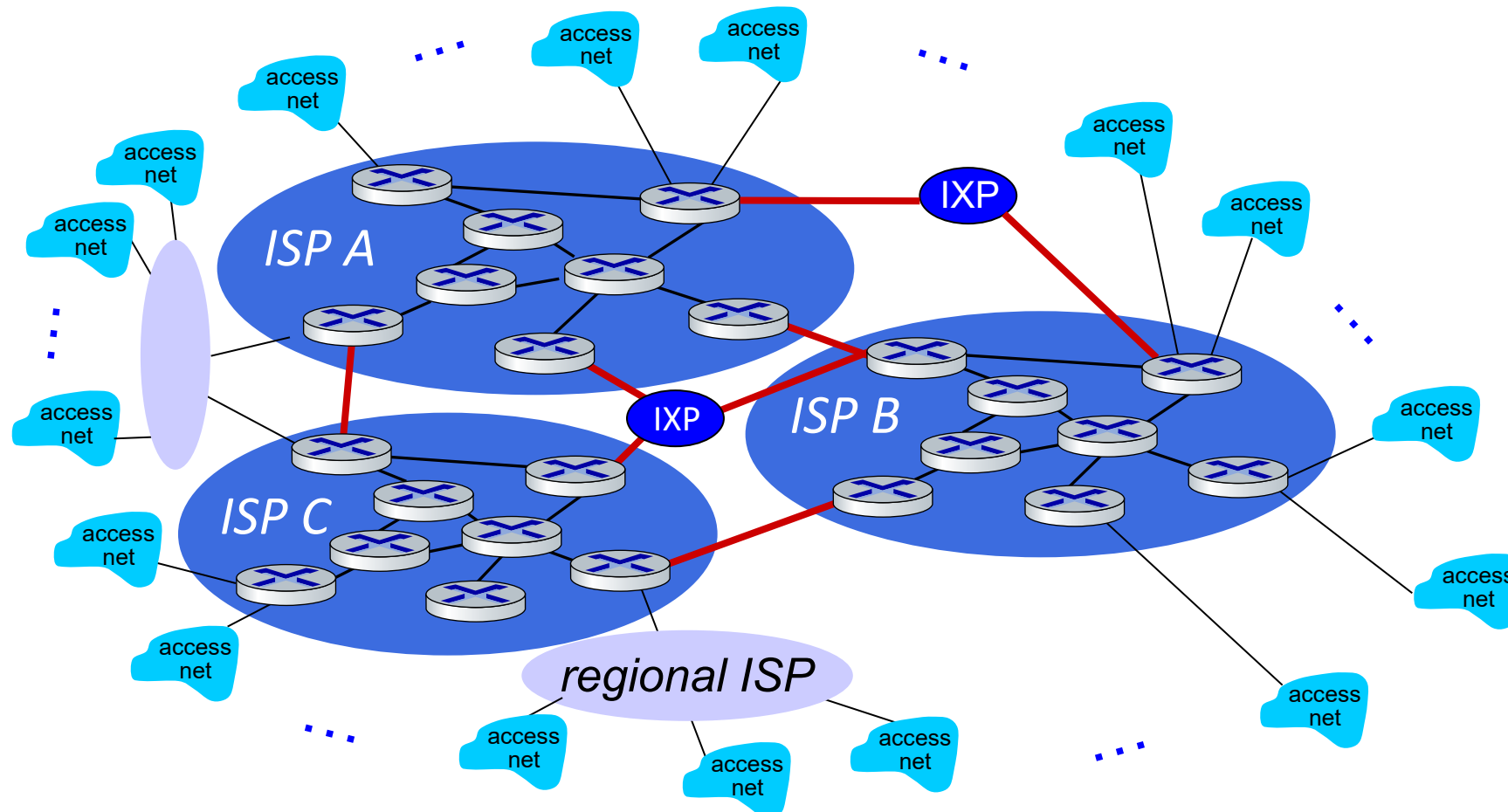
But if one global ISP is viable business, there will be competitors .... who will want to be connected





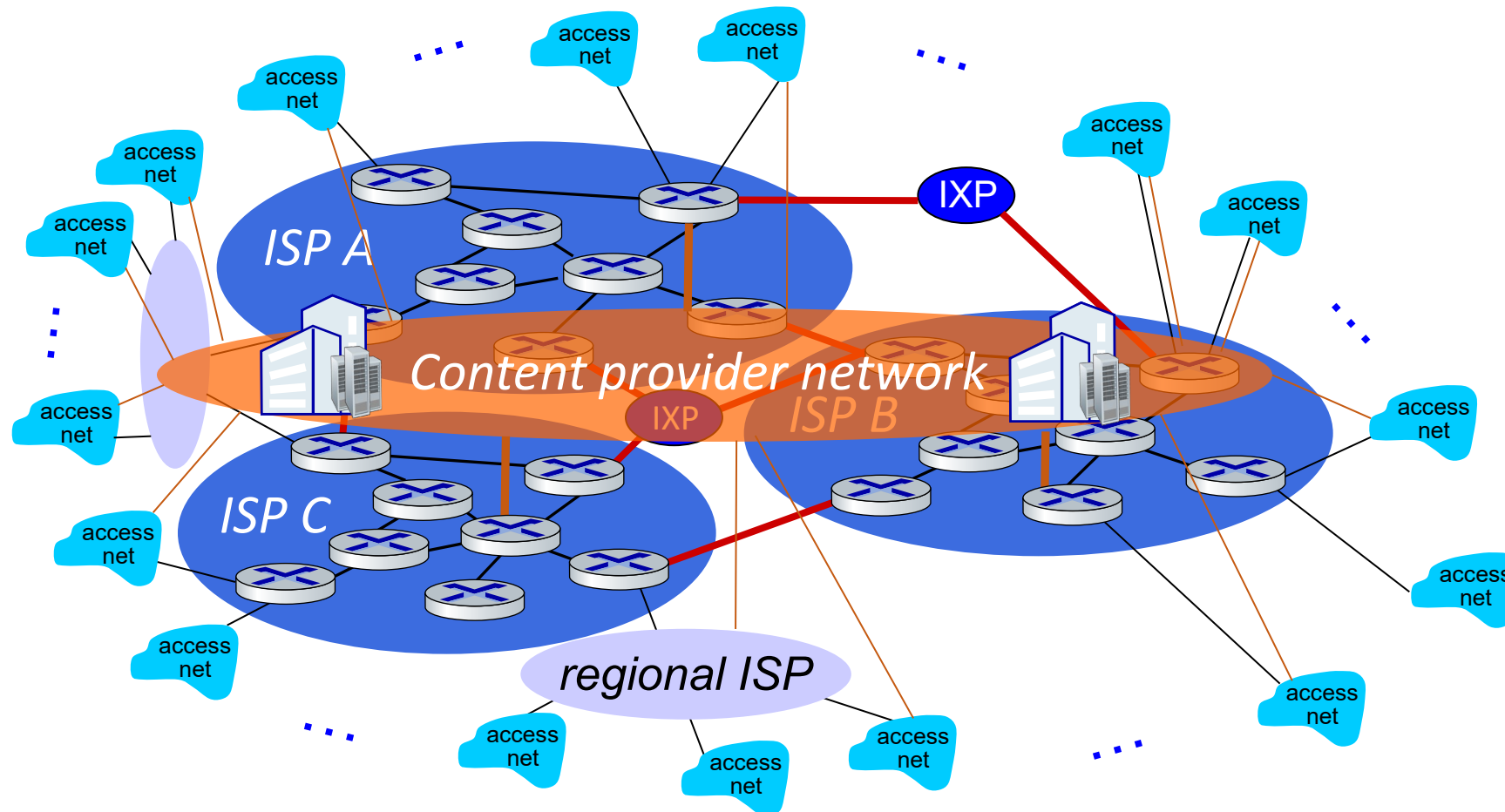
# Internet structure: a “network of networks”

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

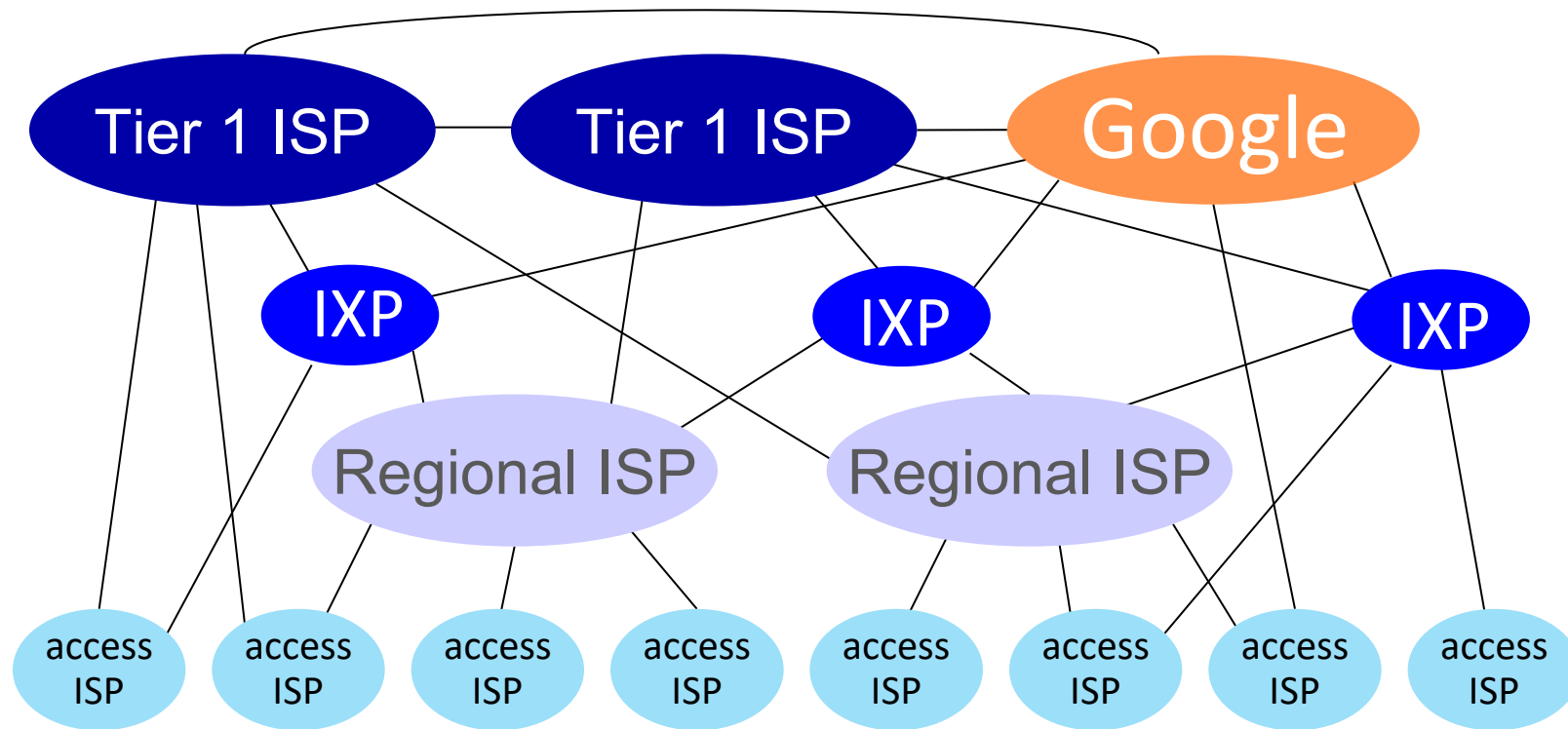


# Internet structure: a “network of networks”

... 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