CS3640

Overview (2): Network Edge & Core

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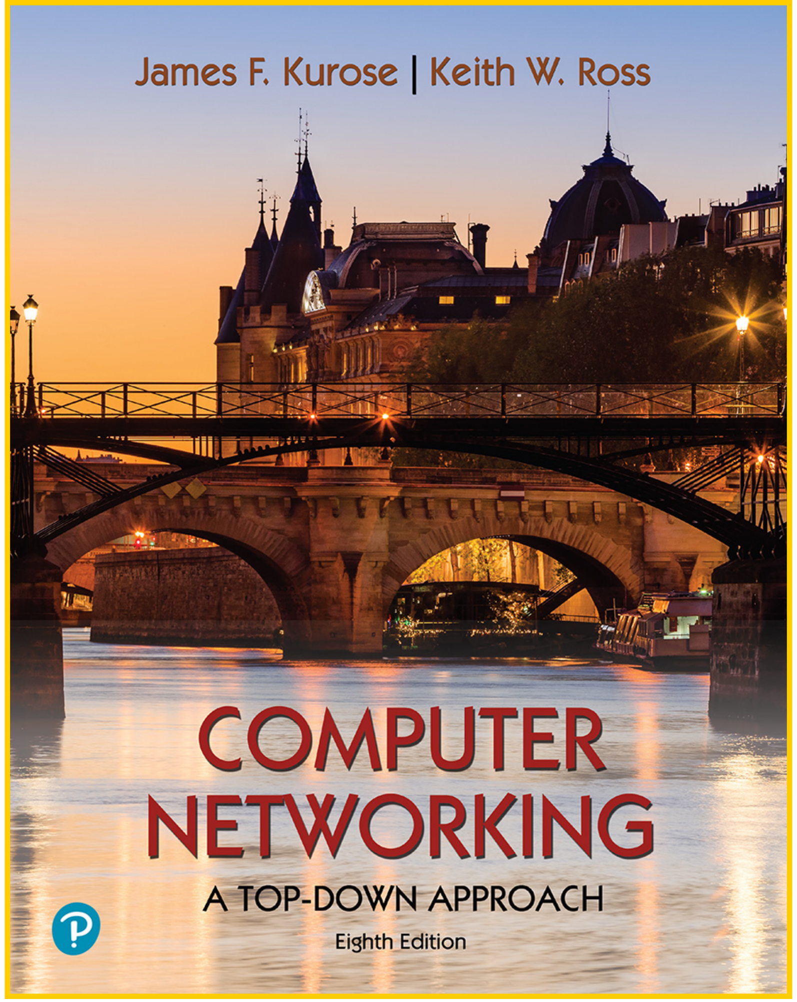
Lecture goals

In-depth look into the structure and functioning of the Internet

- *Network Edge*
- *Network Core*
- *Packet Switching*

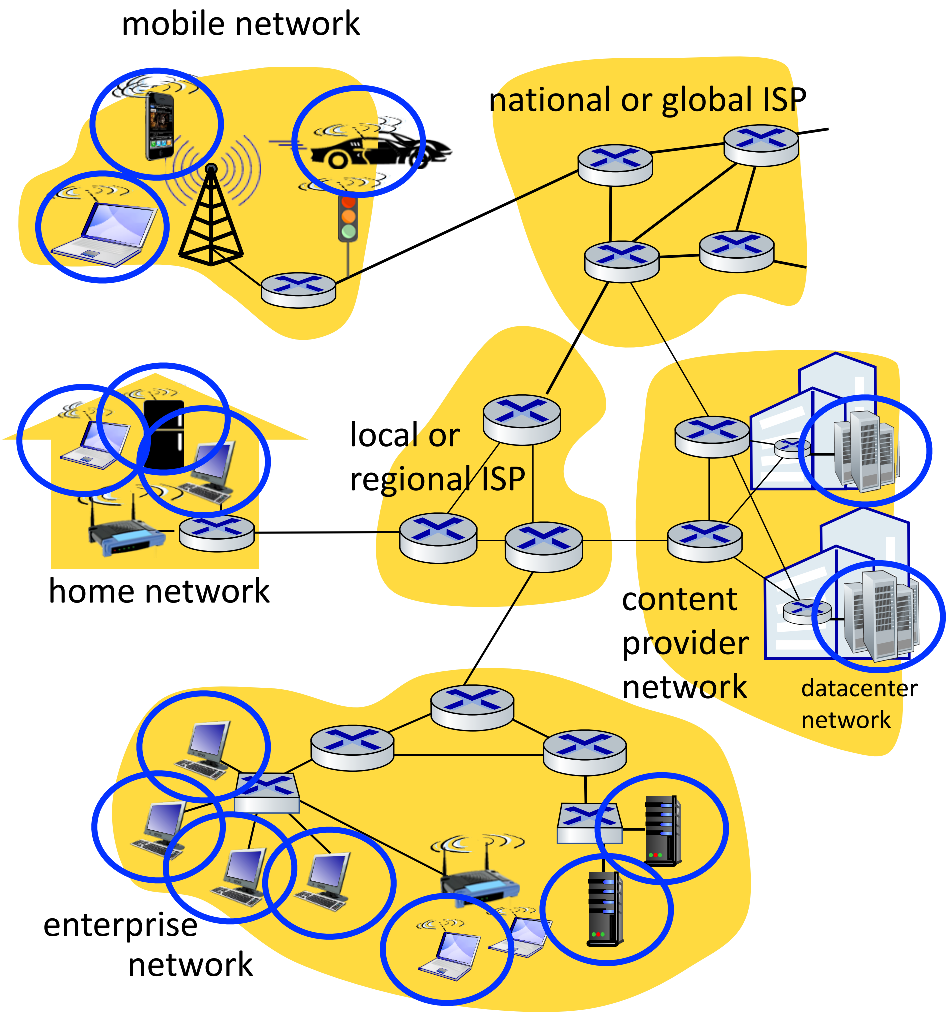


Chapter 1.2 - 1.3

A closer look at Internet structure

Network edge

- hosts: clients and servers
- servers often in data centers



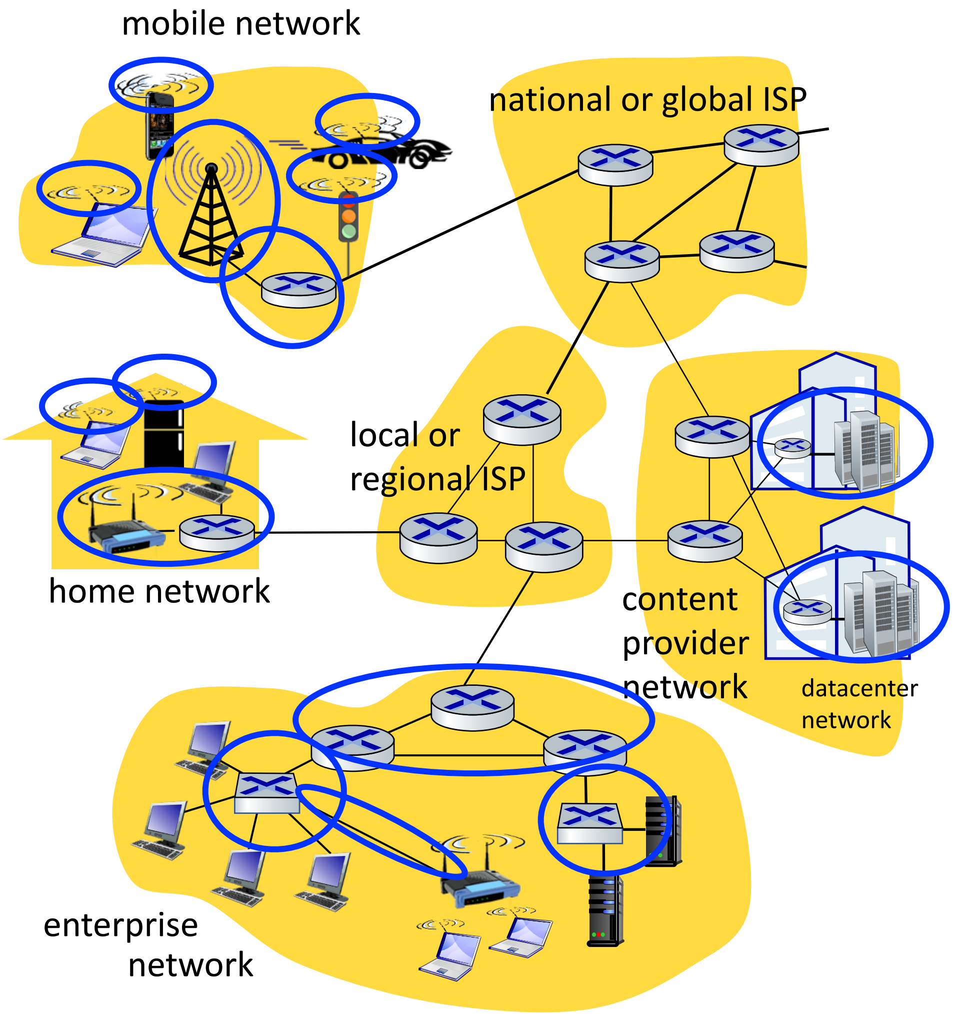
A closer look at Internet structure

Network edge

- hosts: clients and servers
- servers located in data centers

Access networks, physical media

- wired, wireless communication links



A closer look at Internet structure

Network edge

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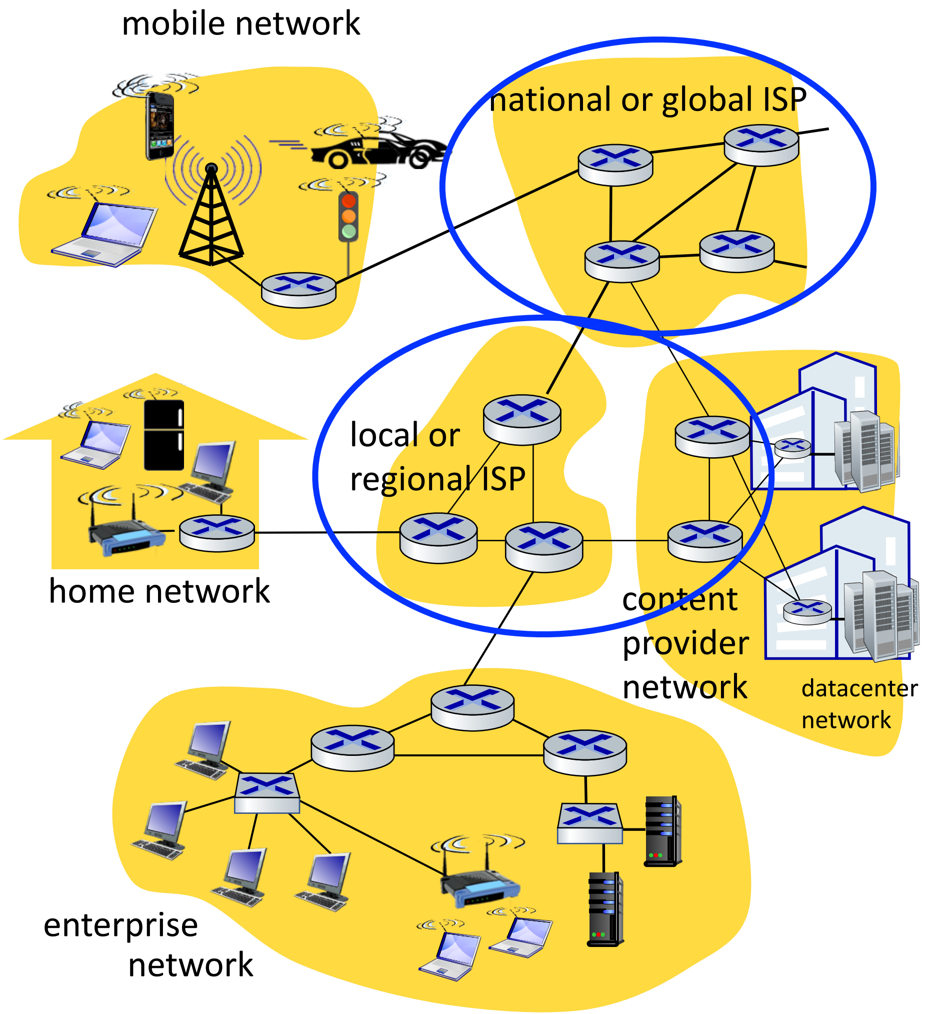
Network core

- interconnected routers
- network of networks



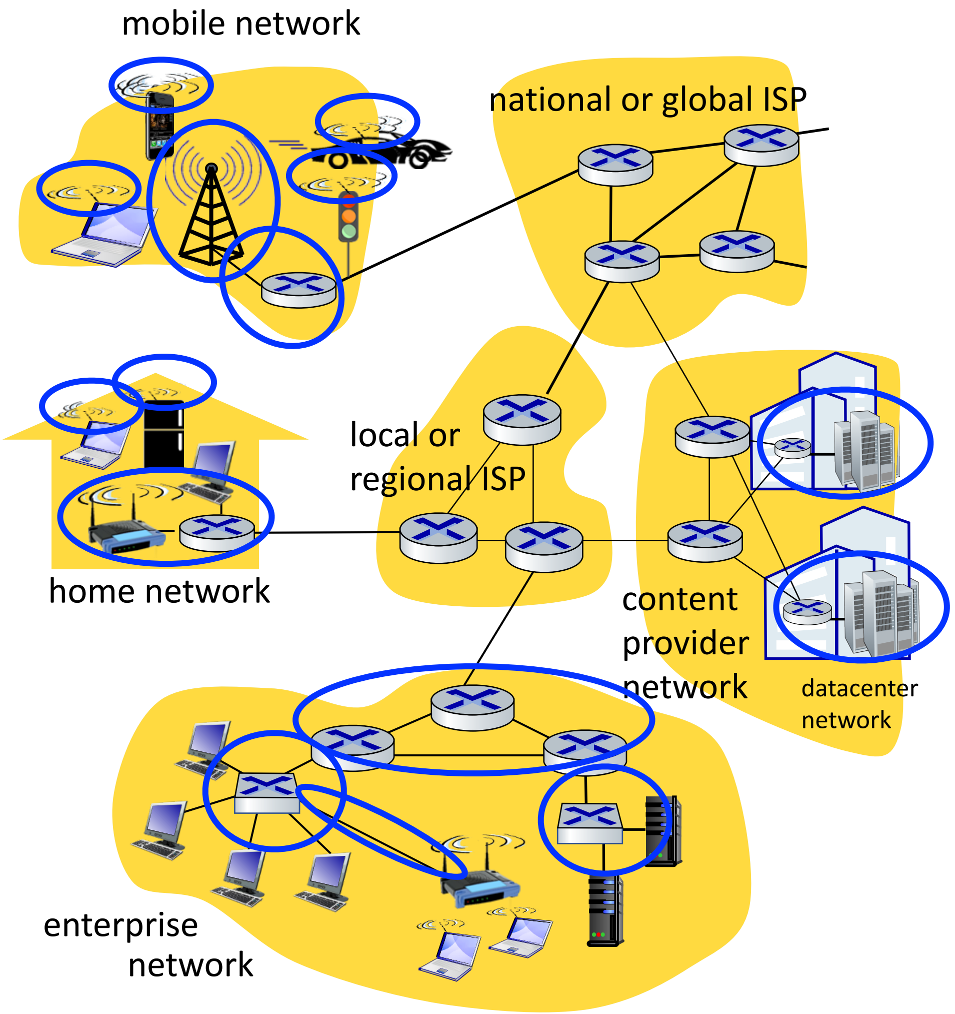
Access networks

Q: How are edge devices connected to the network core?

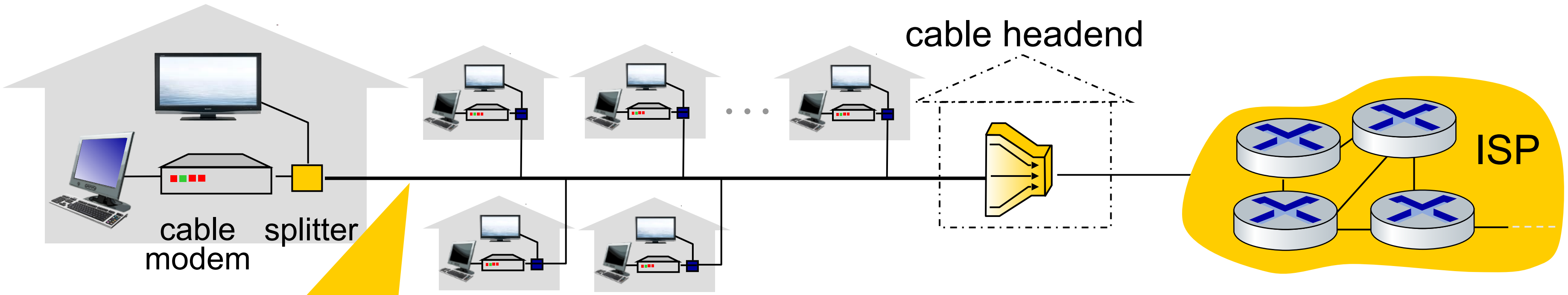
- ***cable*** *based access*
- ***telephone line*** *based access*
- ***wireless*** *or* ***cellular*** *access*

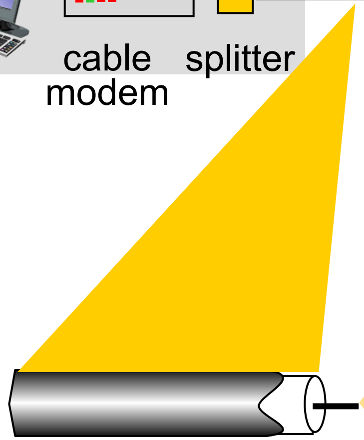
Access network characteristics

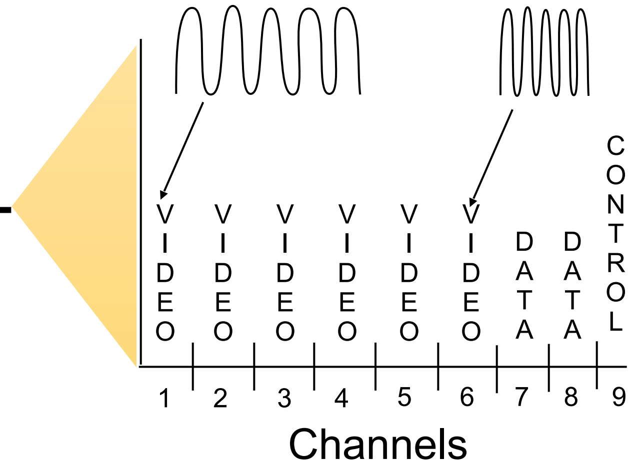
- *Transmission rate of access networks*
- *Dedicated or shared access among hosts*



Access technology: cable-based







Coaxial cable

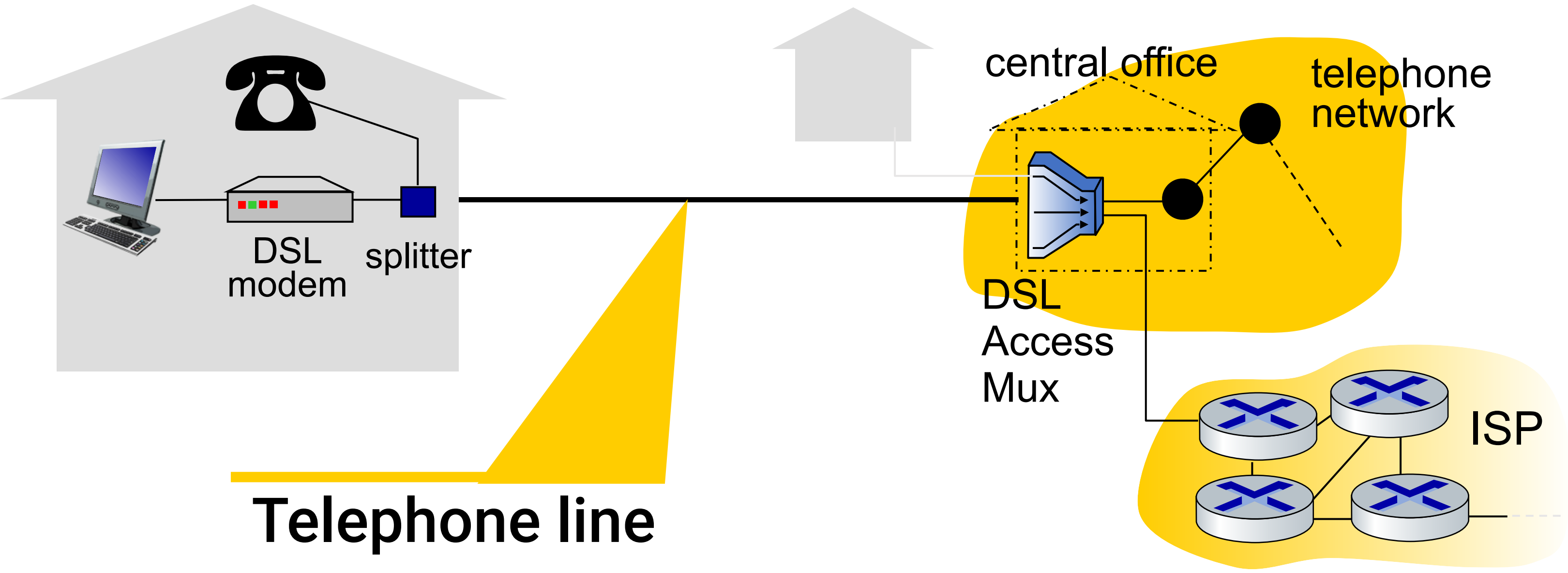
asymmetric transmission rates
40 Mbps -1.2 Gbps downstream
and 30-100 Mbps upstream

Frequency Division Multiplexing (FDM)

different channels transmitted in different frequency bands

shared access

Access technology: digital subscriber line (DSL)



Telephone line

Transmission rates could be symmetric or asymmetric

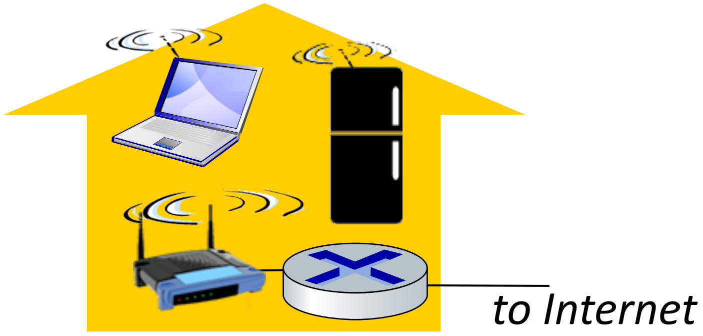
Typical range: 1 - 52 Mbps

dedicated access

Access technology: wireless

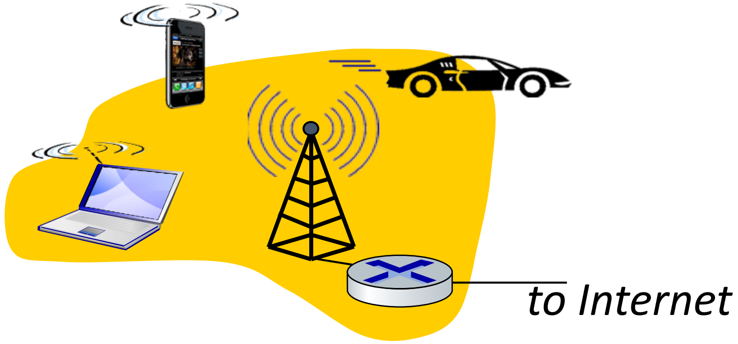
Wireless local area networks (WLANs)

- *802.11b/g/n (WiFi)*
- *Within or around building (~100 ft)*
- *11 - 450 Mbps transmission rate*



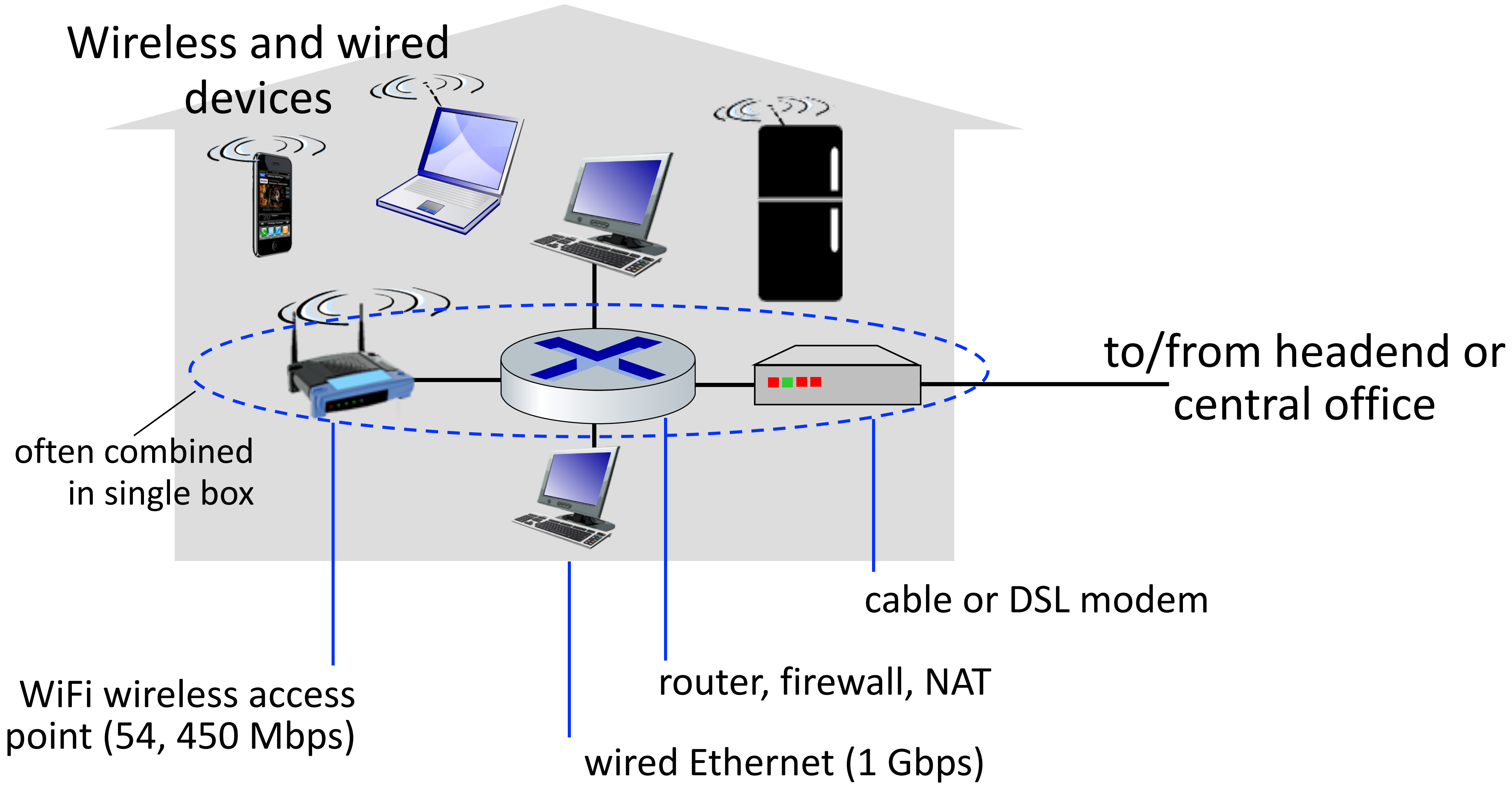
Wide-area cellular networks

- *Provided by cellular operators*
- *3G and 4G cellular networks*
- *Range of 10’s miles*
- *10’s Mbps transmission rate*

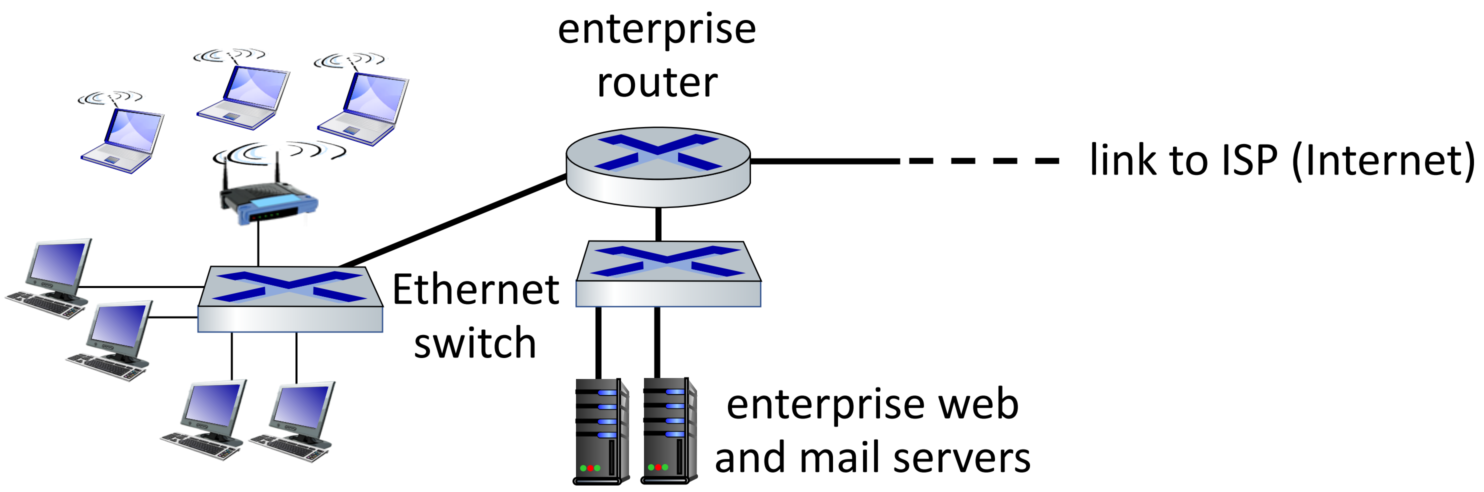


shared access

Access networks: residential



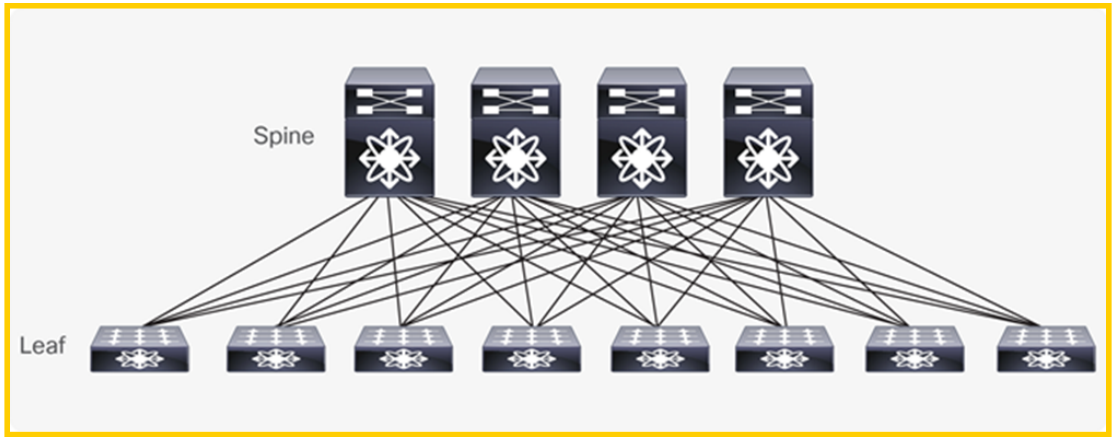
Access networks: enterprise



- *Companies, universities, government agencies etc.,*
- *Mix of wired (e.g., Ethernet) and wireless (e.g., WiFi) technologies*
- *Connected with a hierarchy of switches and routers*

Access networks: data center networks

- Hundreds to thousands of servers connected to each other and to Internet
- High-bandwidth wired links (1 to 100s Gbps)
- Switches and routers organized in intricate **topologies** to maximize bandwidth and minimize latency
  - ➡ ***Spine - leaf topology***
  - ➡ ***Three layer topology***



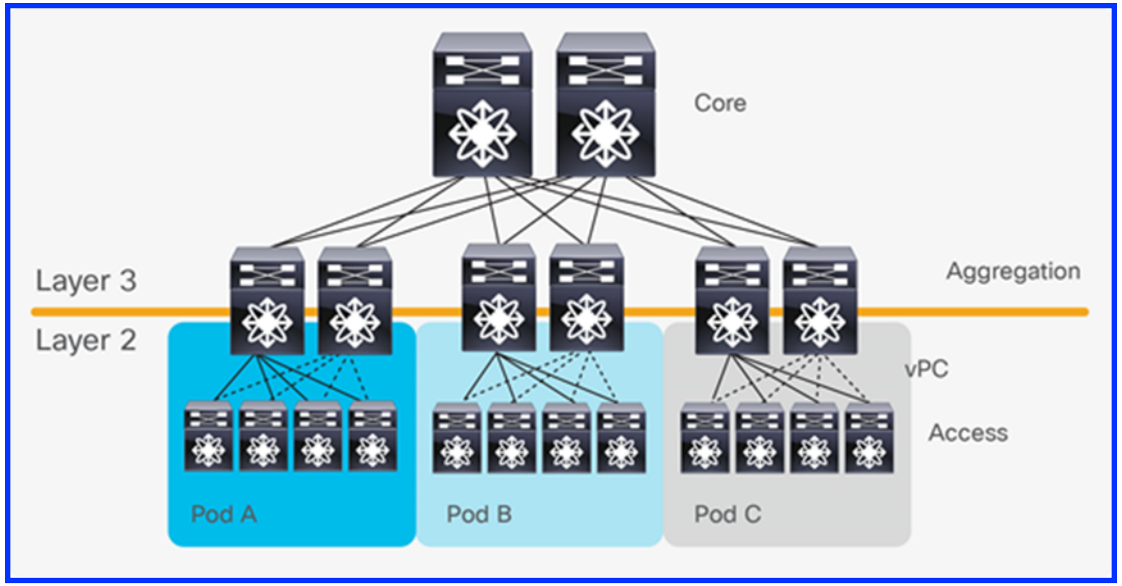
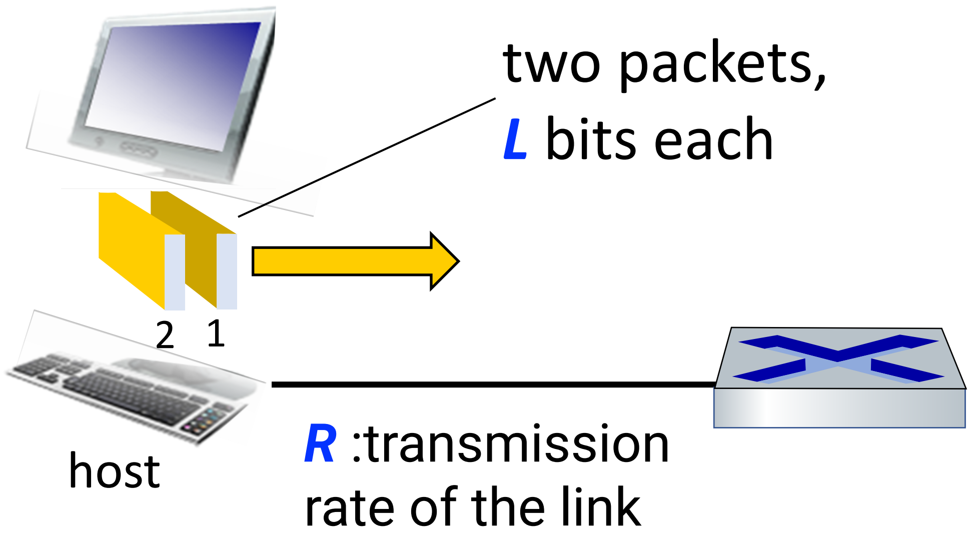


Photo courtesy: Cisco Systems

Host perspective: sending packets of data

Packet sending function

- takes application message
- breaks into smaller chunks, known as **packets**, of ***length L*** bits
- transmits packet into access network at ***transmission rate R*** (aka bandwidth)

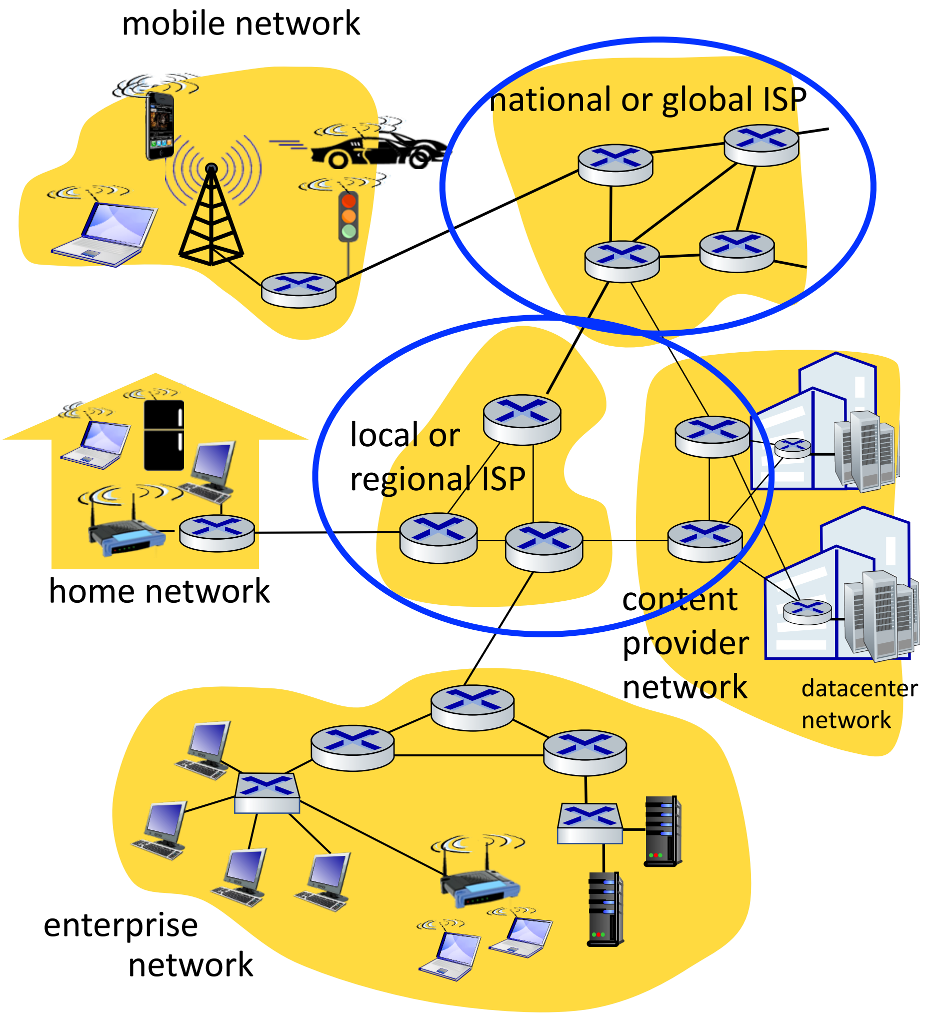


packet transmission delay = time needed to transmit L-bit packet into link = $\dfrac{L \text{ (bits)}}{R \text{ (bits/sec)}}$

Network core and switching

The network core

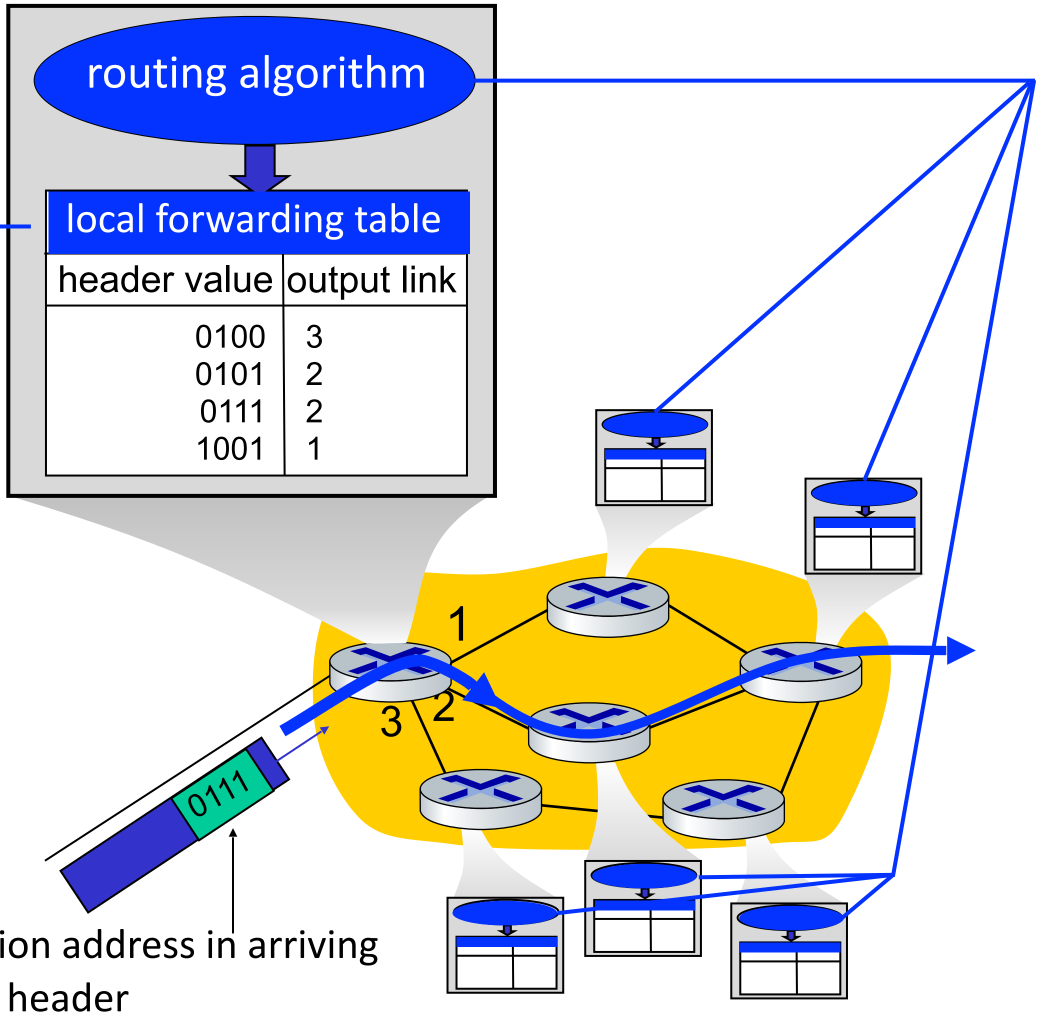
- it is a mesh of interconnected routers
- it performs packet-switching
  - *hosts break application-layer messages into packets*
  - *network forwards packets from one router to the next, across links on path from source to destination*



Two key network-core functions

Forwarding

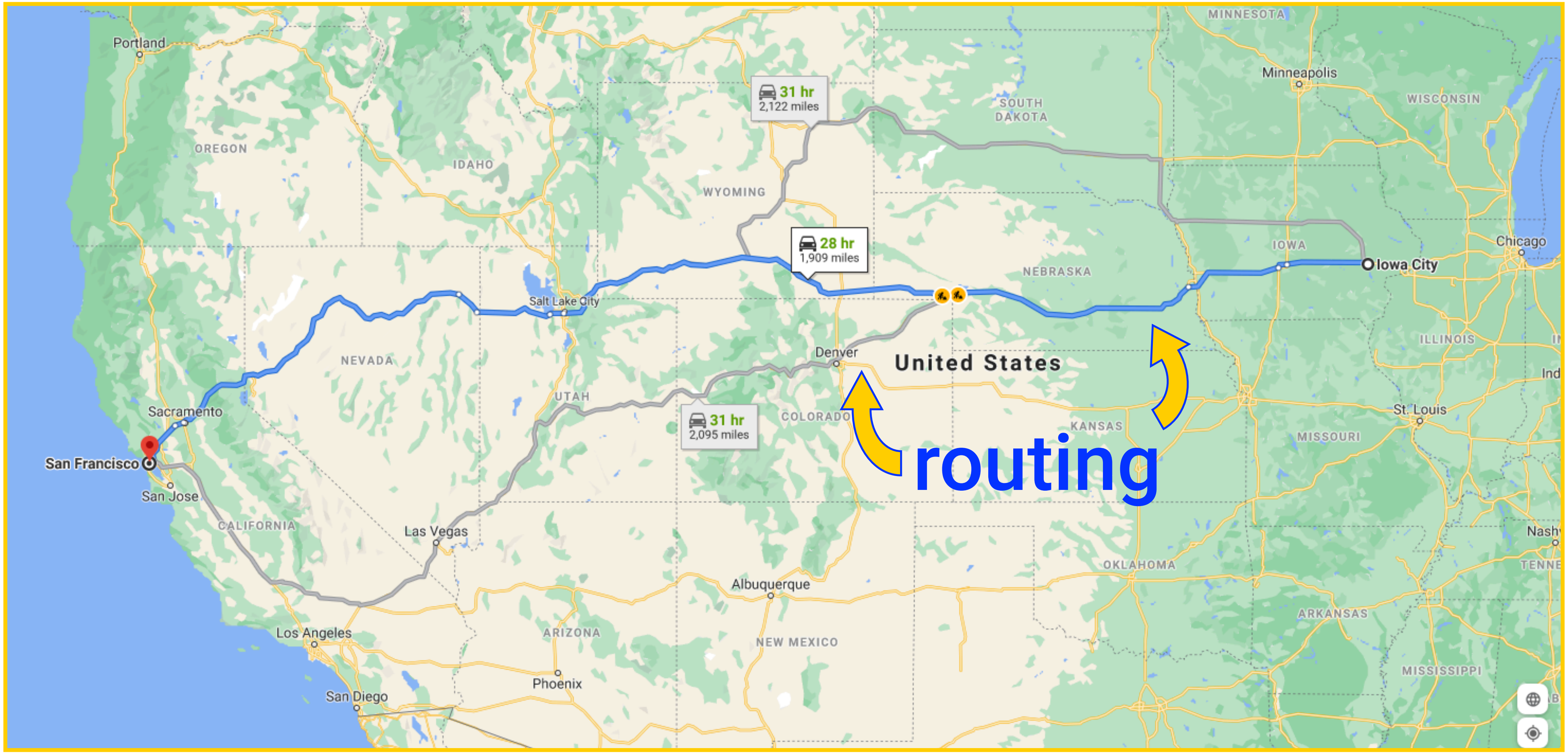
- *aka "switching"*
- ***local action**: move arriving packets from router's input link to appropriate router output link*



Routing

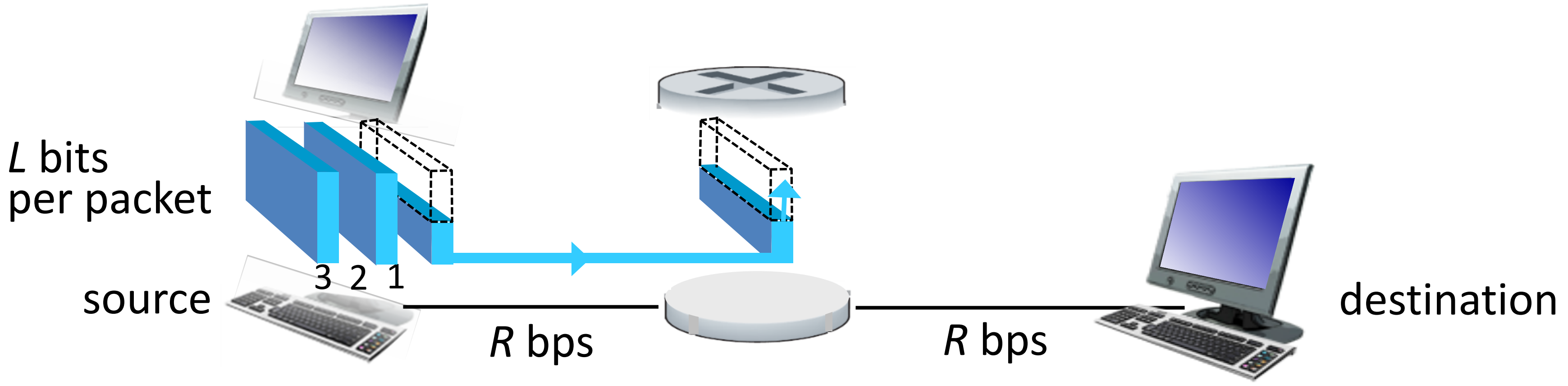
- ***global action**: determine source-destination paths taken by packets*
- *routing algorithms*

Routing vs. forwarding



Routing vs. forwarding

Packet-switching: store-and-forward



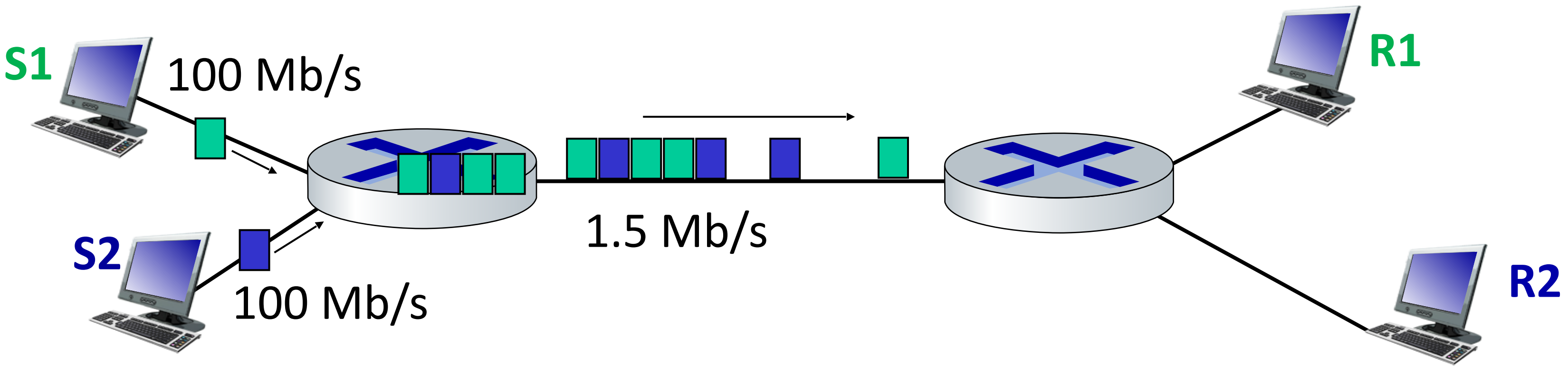
***packet transmission delay**: takes L/R seconds to transmit (push out) L-bit packet into link at R bps*

***store and forward**: entire packet must arrive at router before it can be transmitted on next link*

One-hop example

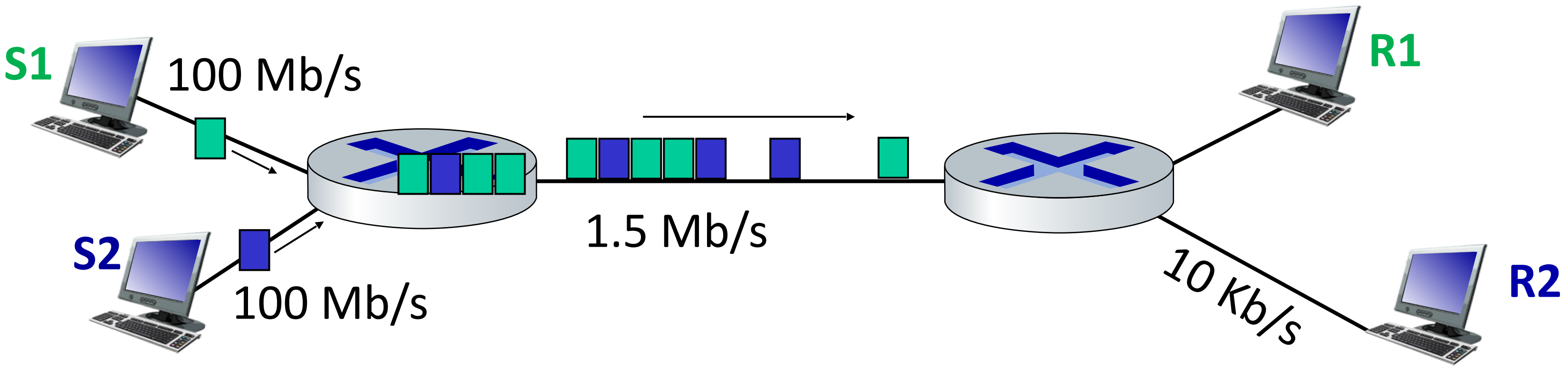
- *L = 10 Kbits*
- *R = 100 Mbps*
- *one-hop transmission delay = 0.1 msec*

Packet-switching: queueing



Queueing occurs when work arrives faster than it can be serviced

Packet-switching: queueing



Packet queuing and loss

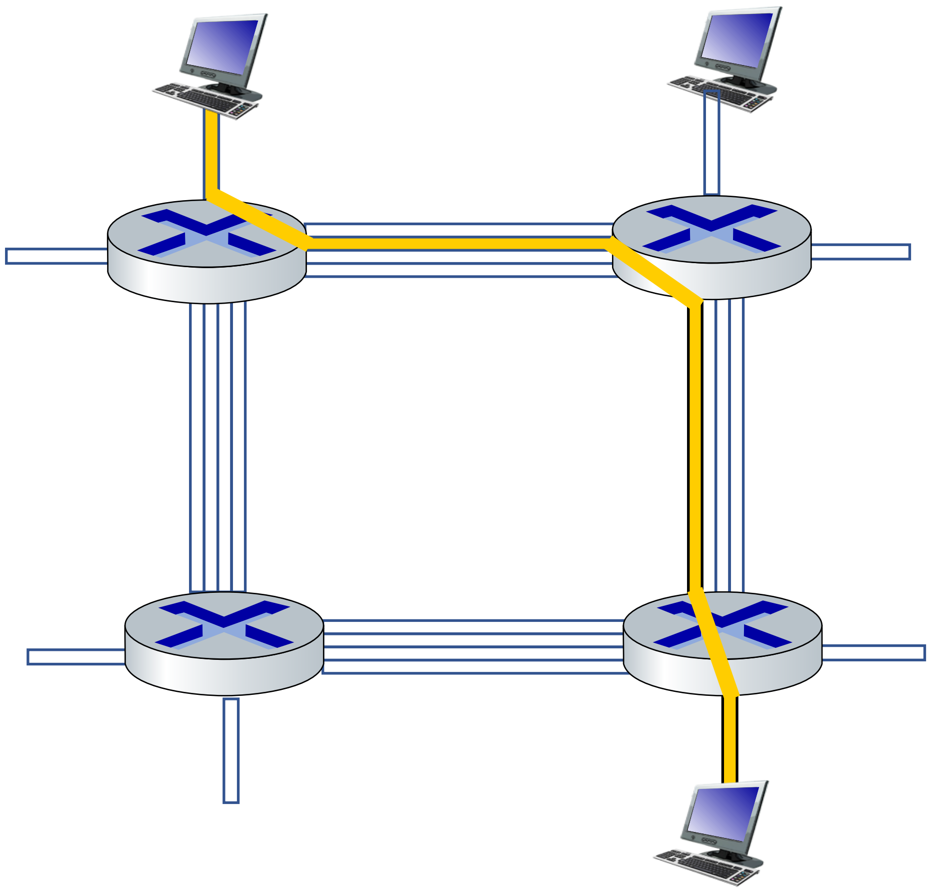
if arrival rate to link exceeds its transmission for some period of time,

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

An alternative: circuit switching

End-end resources are allocated and reserved for the "call" between source and destination

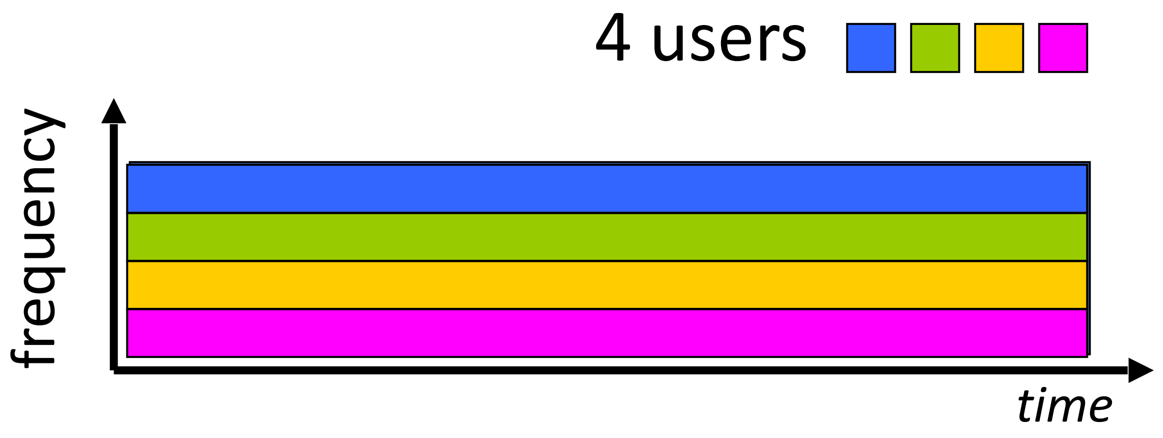
- *each link has four circuits*
- *our call is allocated 2nd circuit in top link and 1st circuit in right link*
- *dedicated resources: no sharing*
- *guaranteed performance*
- *circuit segments remain idle if not used by call*
- *commonly used in traditional telephone networks*



Circuit switching: FDM and TDM

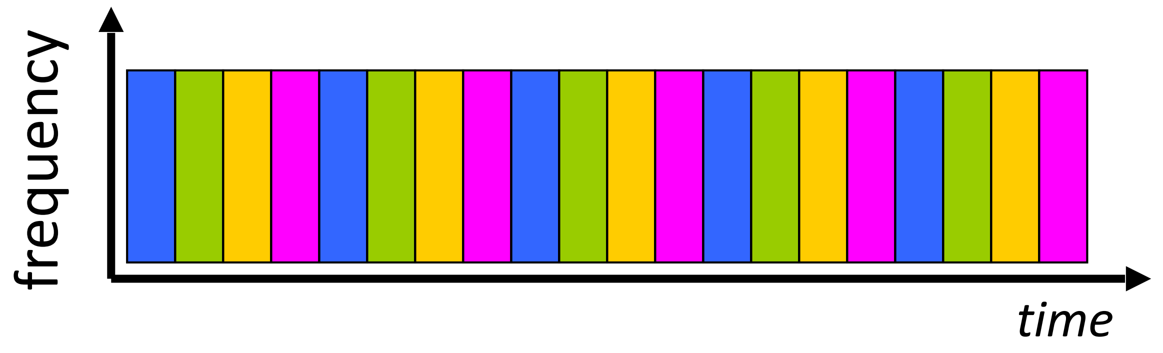
Frequency Division Multiplexing (FDM)

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



Time Division Multiplexing (TDM)

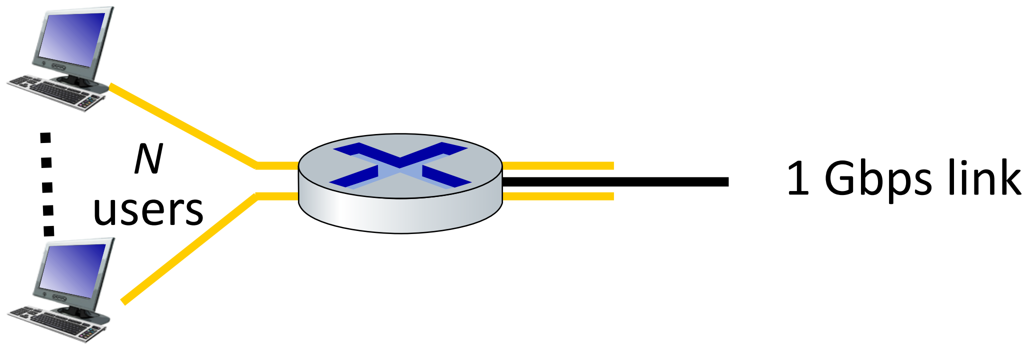
- *time divided into slots*
- *each call allocated periodic slots, can transmit at maximum rate of (wider) frequency band during its time slots*



Packet switching vs. circuit switching

N users, each of them is

- *active 10% of time*
- *use 100 Mb/s when "active"*



How many users can use this network under circuit-switching and packet switching?

10

Circuit switching

>10

Packet switching

With **35** *users*

probability that **>10**

are active at the same time is

< 0.0004

Packet switching vs. circuit switching

Is packet switching a “slam dunk winner”?

- **Great for “bursty” data**
  - *efficient resource sharing via statistical multiplexing*
  - *simpler call setup with no a priori reservations*
- **Congestion could occur**
  - *packets could be delayed or lost due to buffer overflow*
  - *protocols are needed for reliable data transfer, congestion control*

Is there a way to get circuit-like behavior with packet switching?

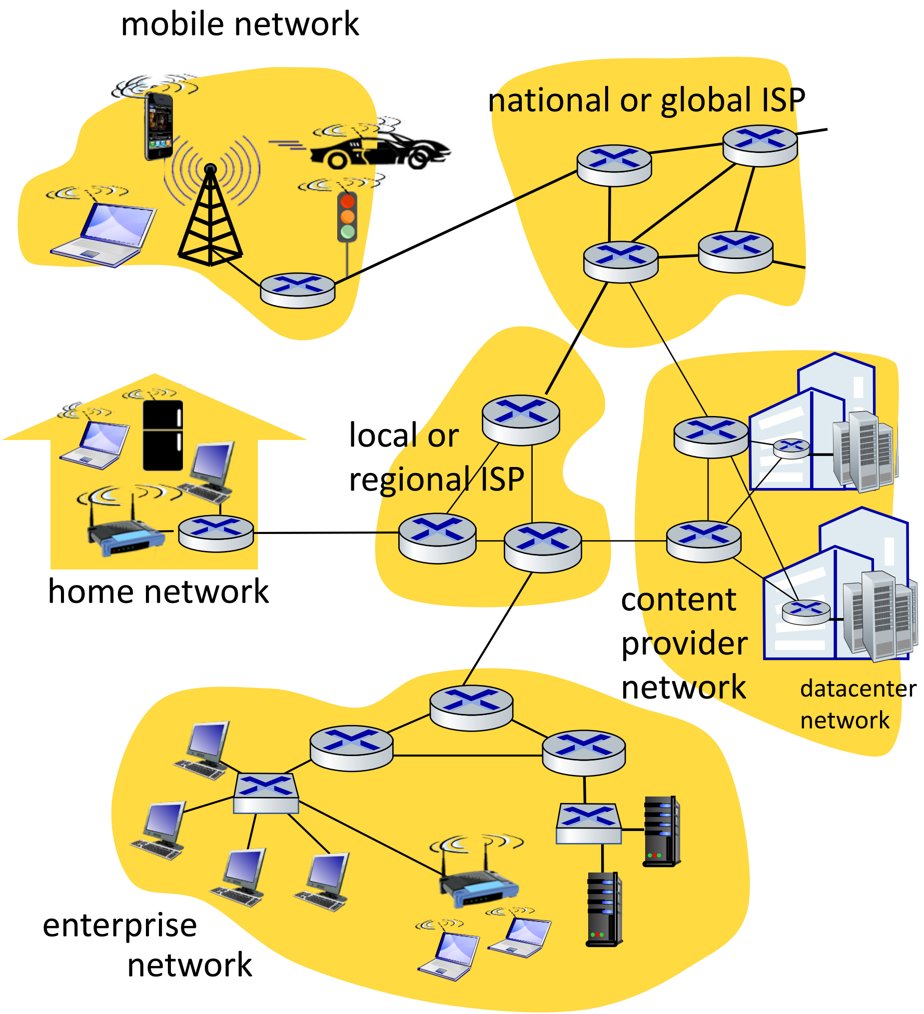
- **Possible but complicated** *(we have three dedicated lectures studying TCP)*

Internet structure: a network of networks

- hosts connect to Internet via access **Internet Service Providers** (ISPs)

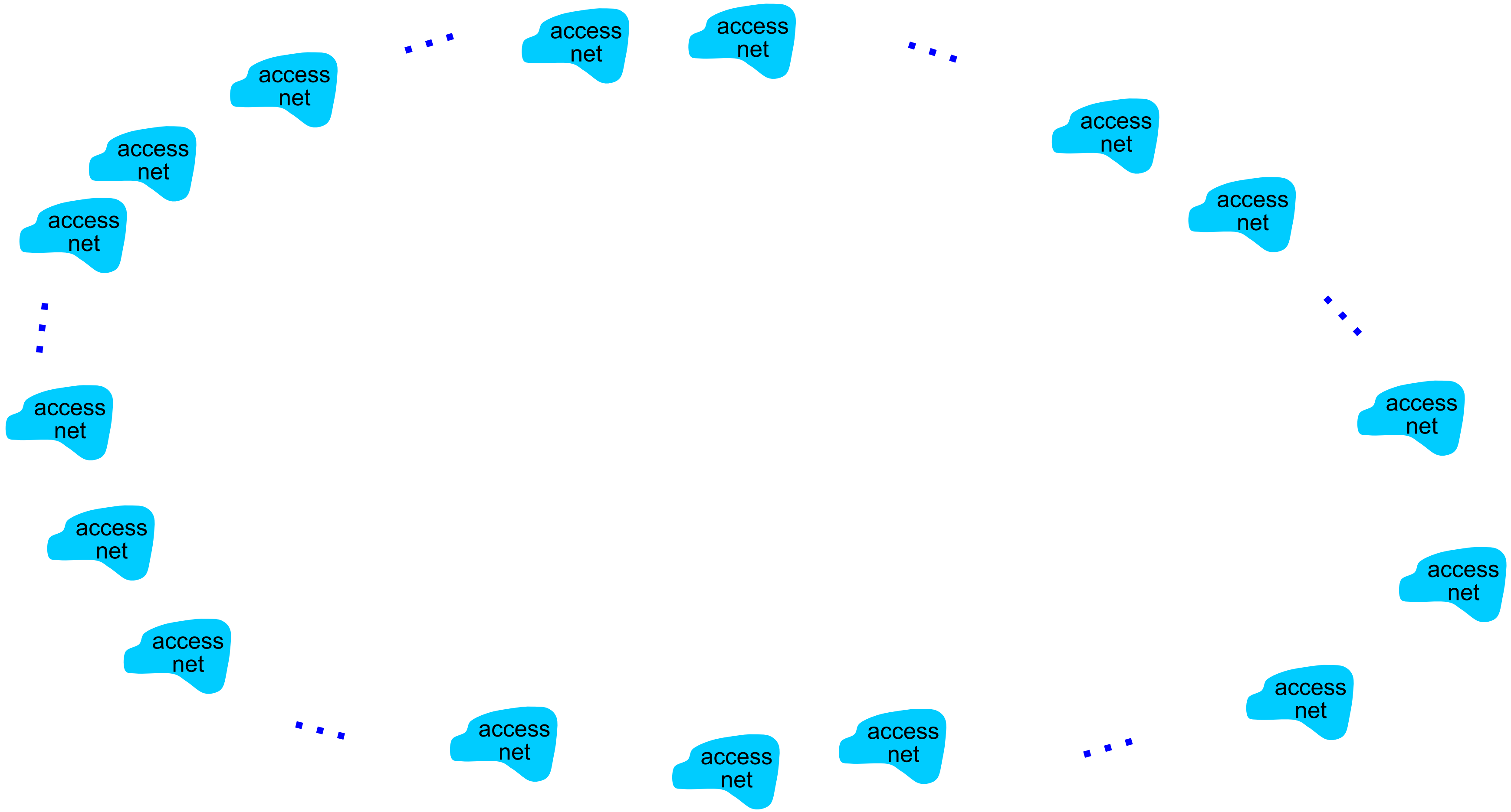
- these access ISPs in turn must be interconnected
  - ➡ *to allow that any pair of hosts (anywhere!) to send packets to each other*

- resulting network of networks is complex
  - ➡ *evolution driven by economics, national policies*



Internet structure: a network of networks

How to connect *millions* of access ISPs together?



Internet structure: a network of networks

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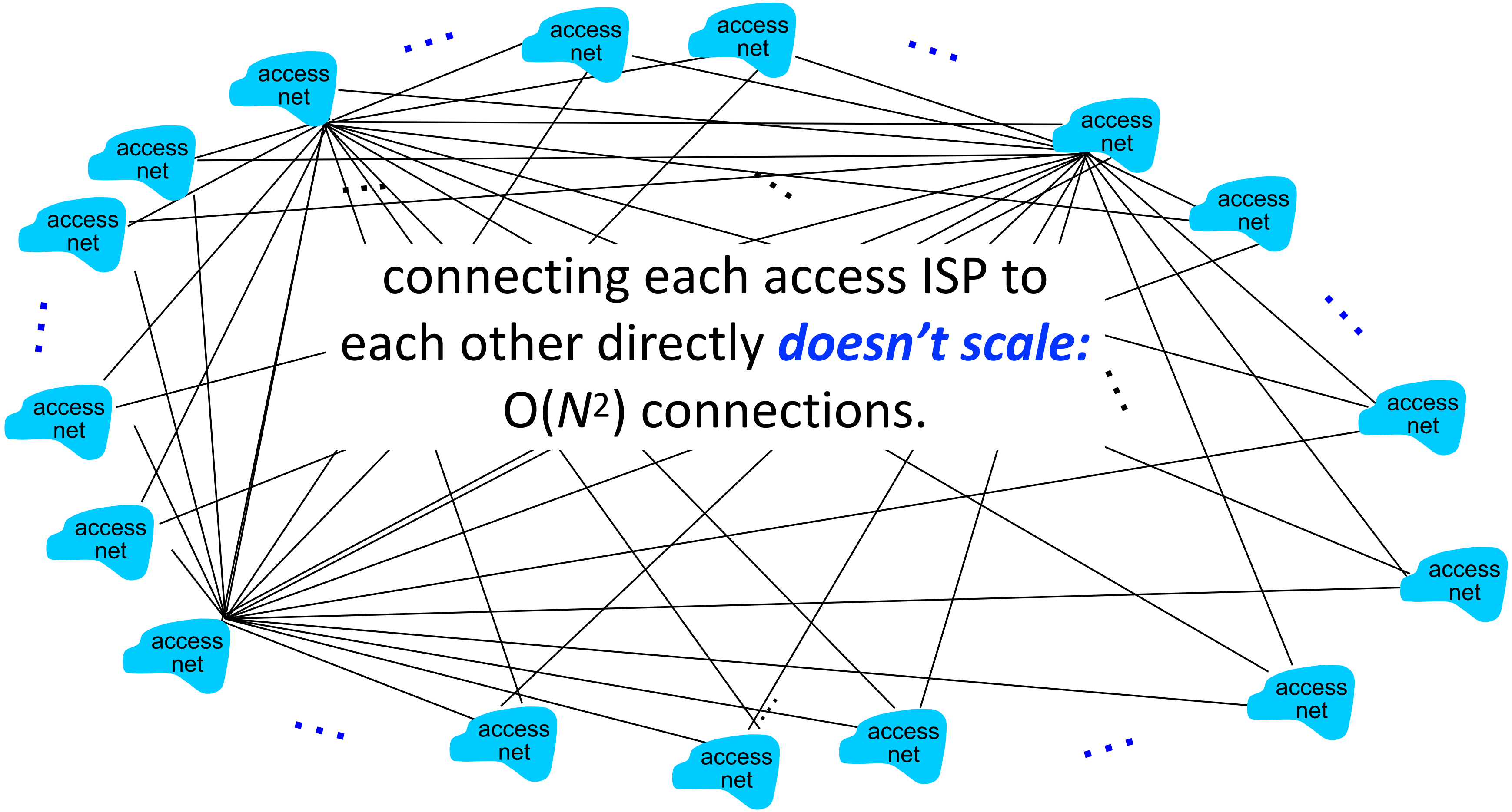
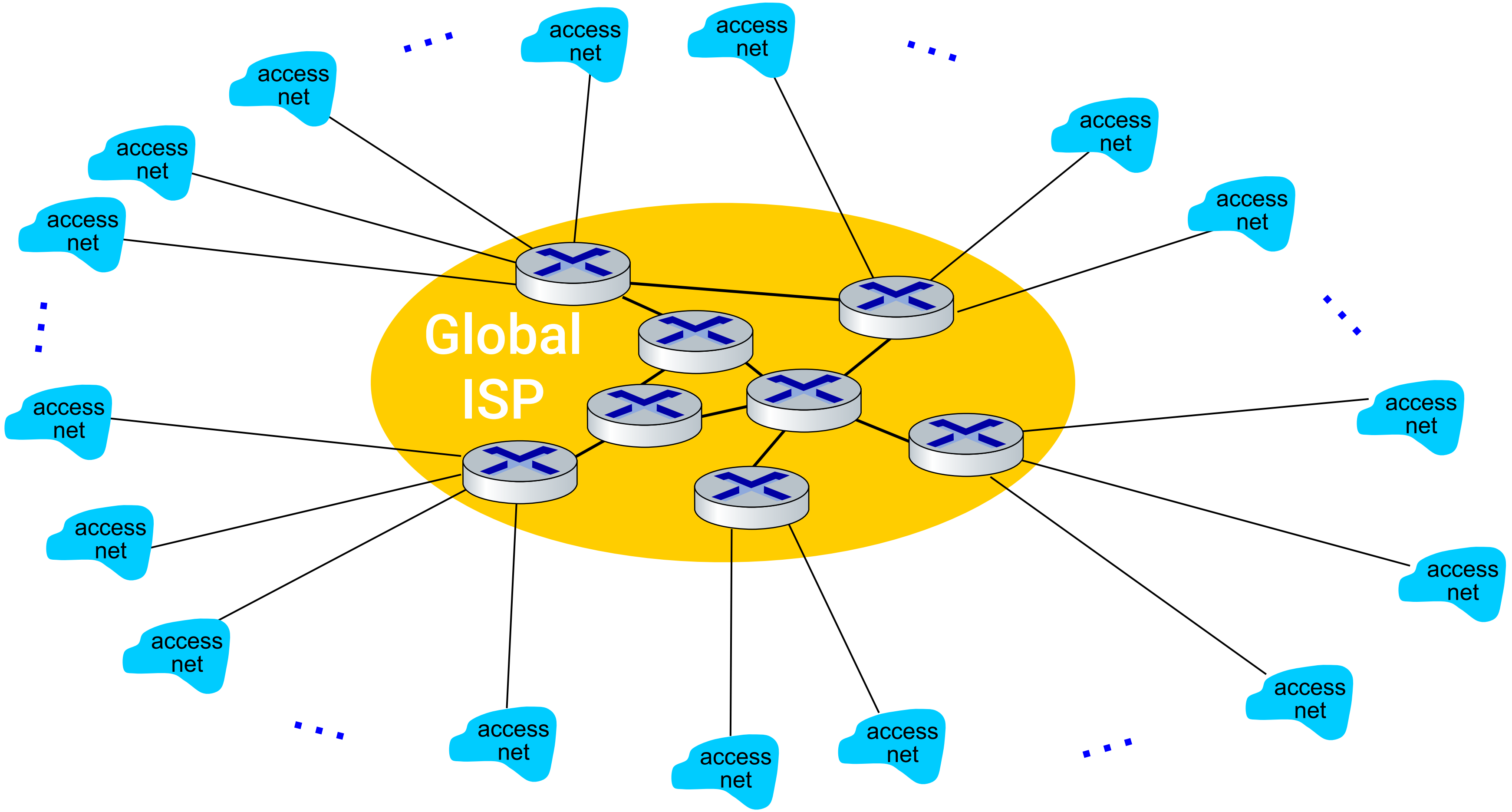


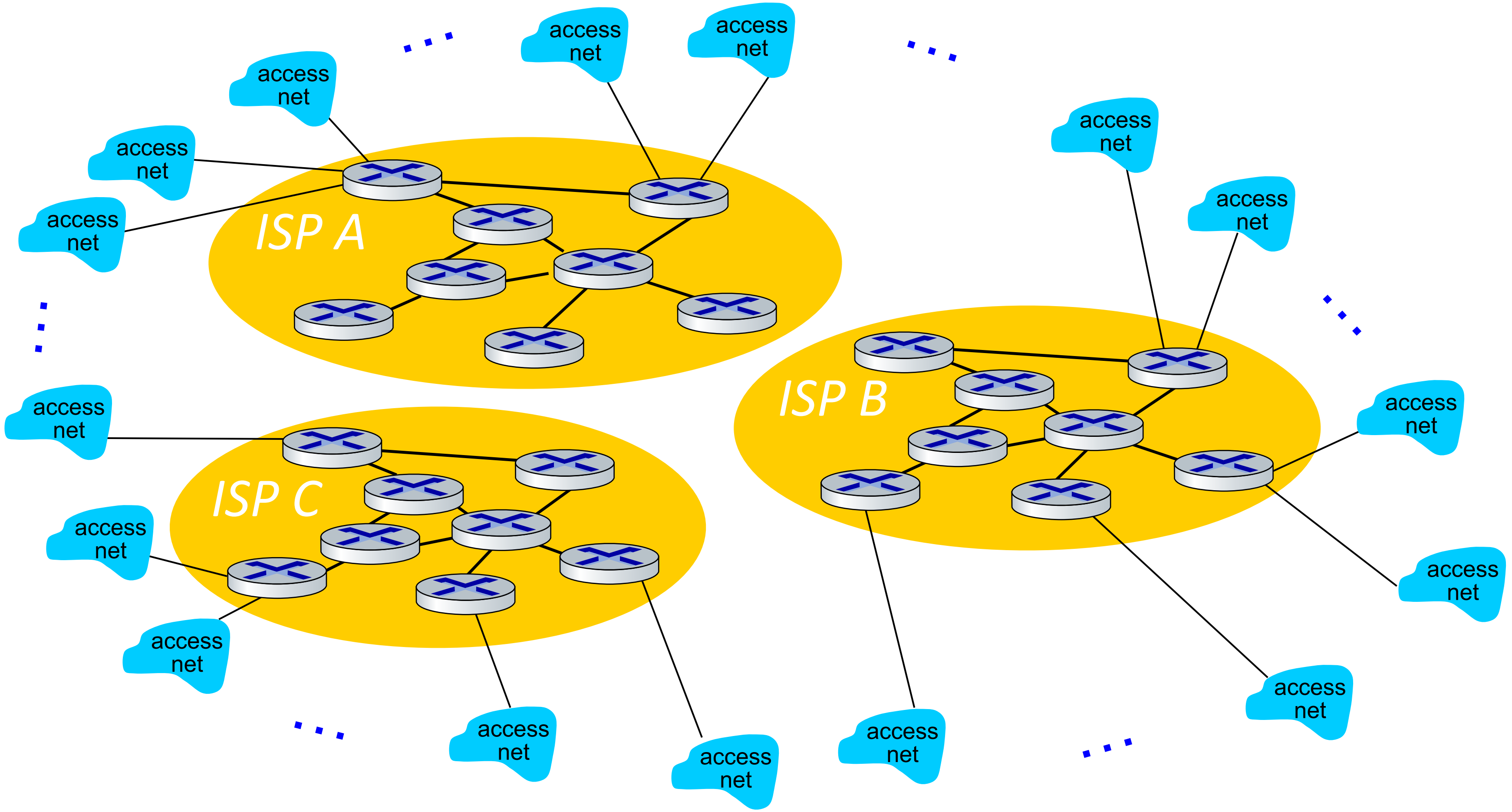
Internet structure: a network of networks

Option: connect each access ISP to one global transit ISP



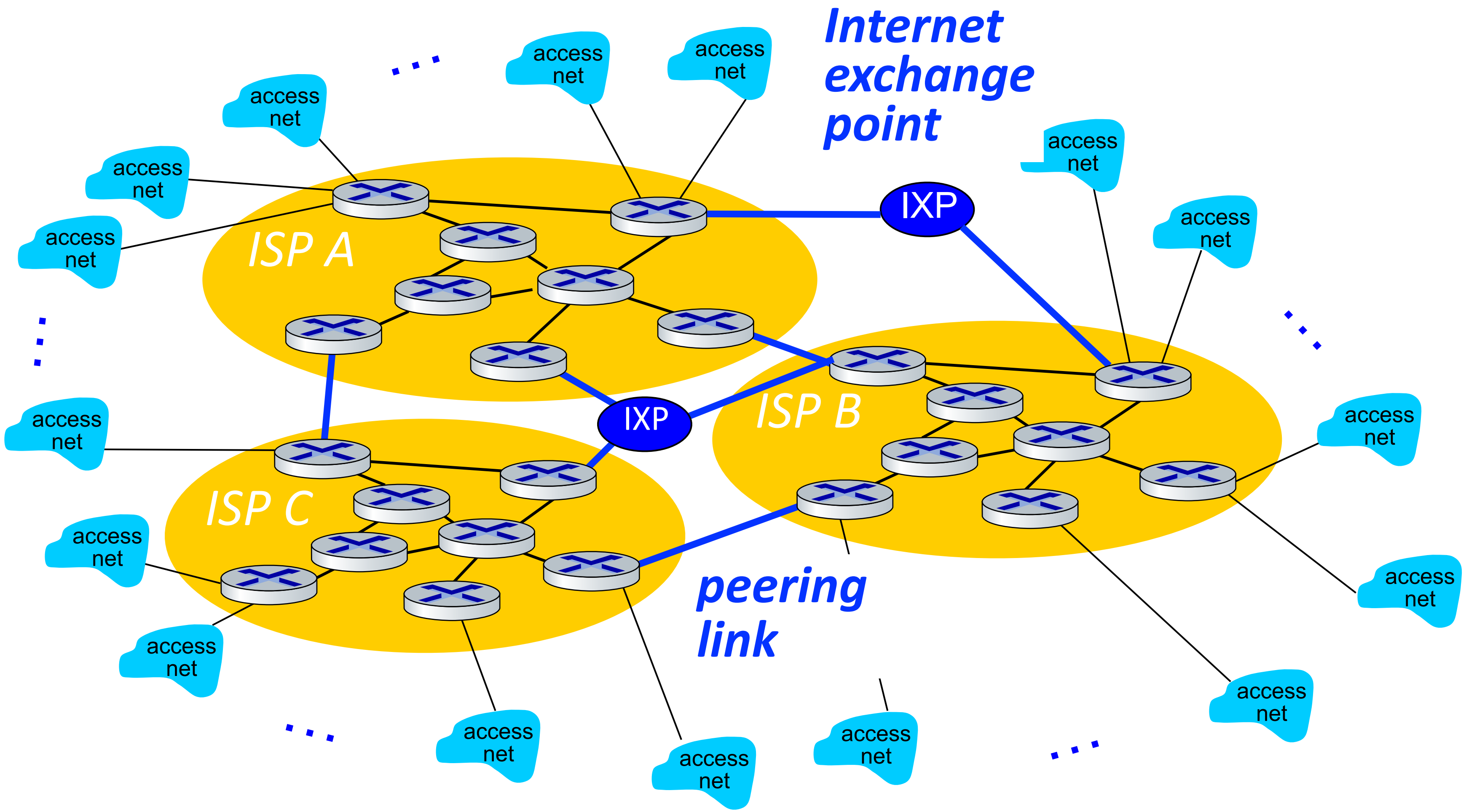
Internet structure: a network of networks

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



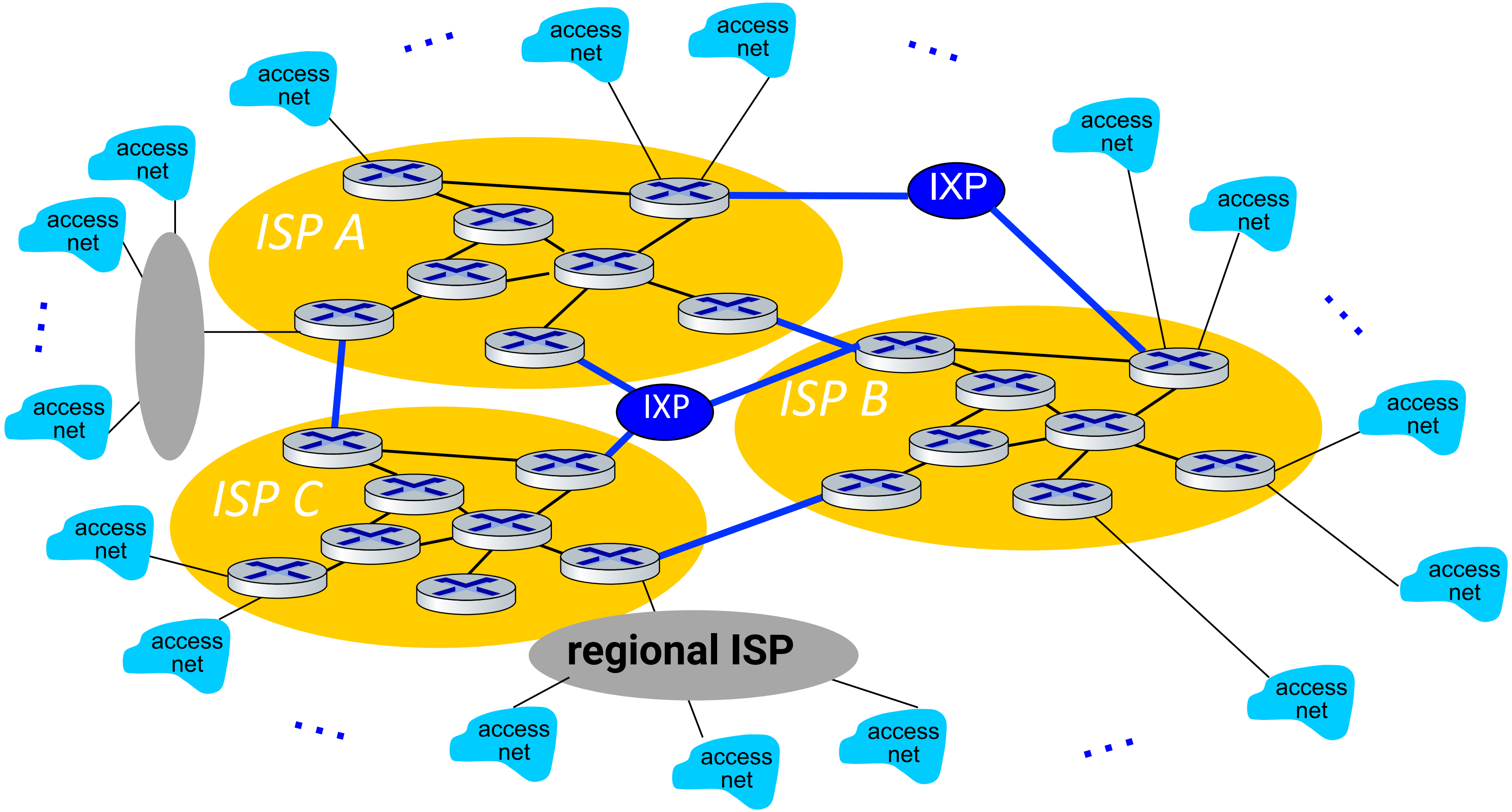
Internet structure: a network of networks

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



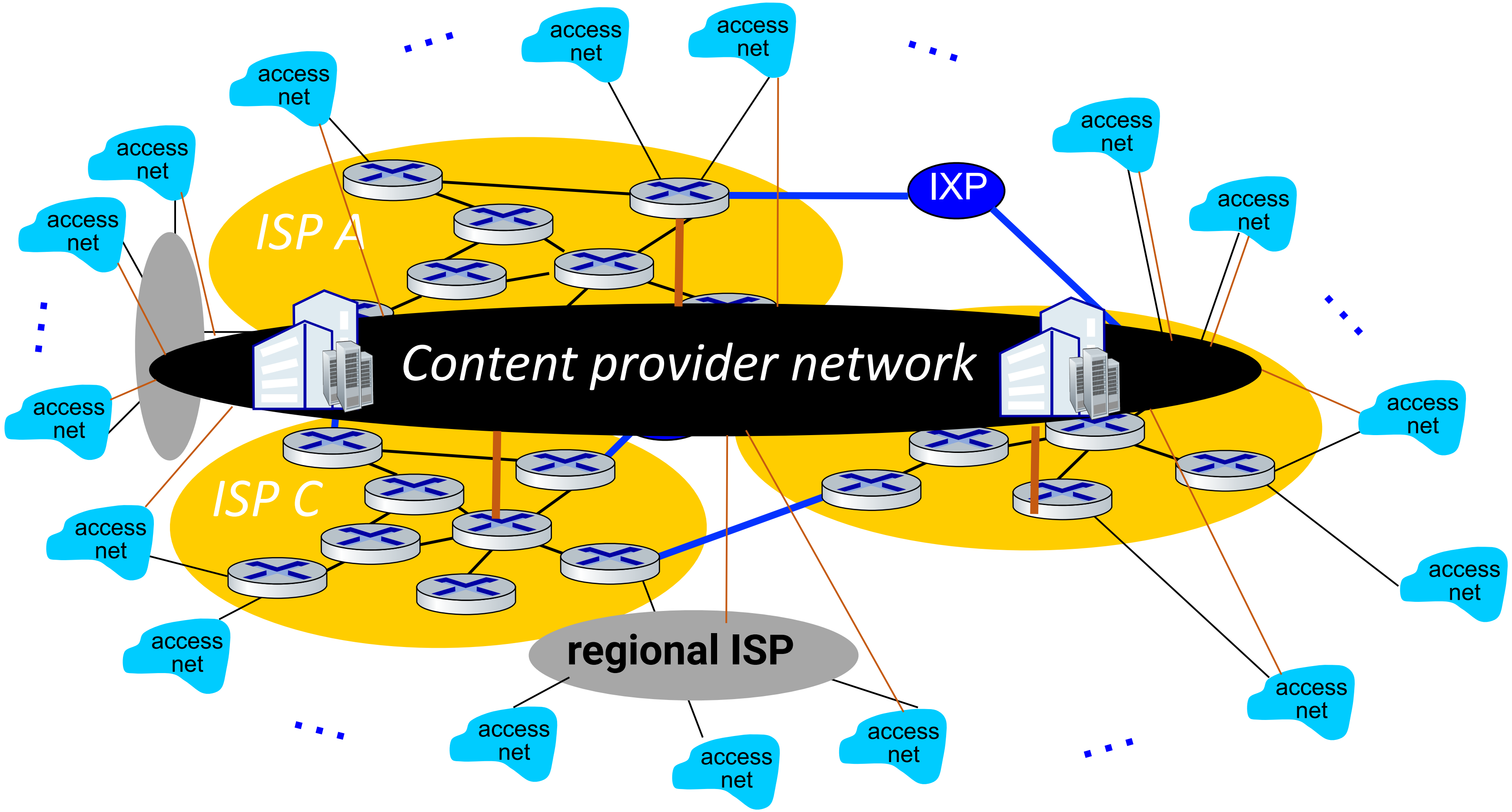
Internet structure: a network of networks

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

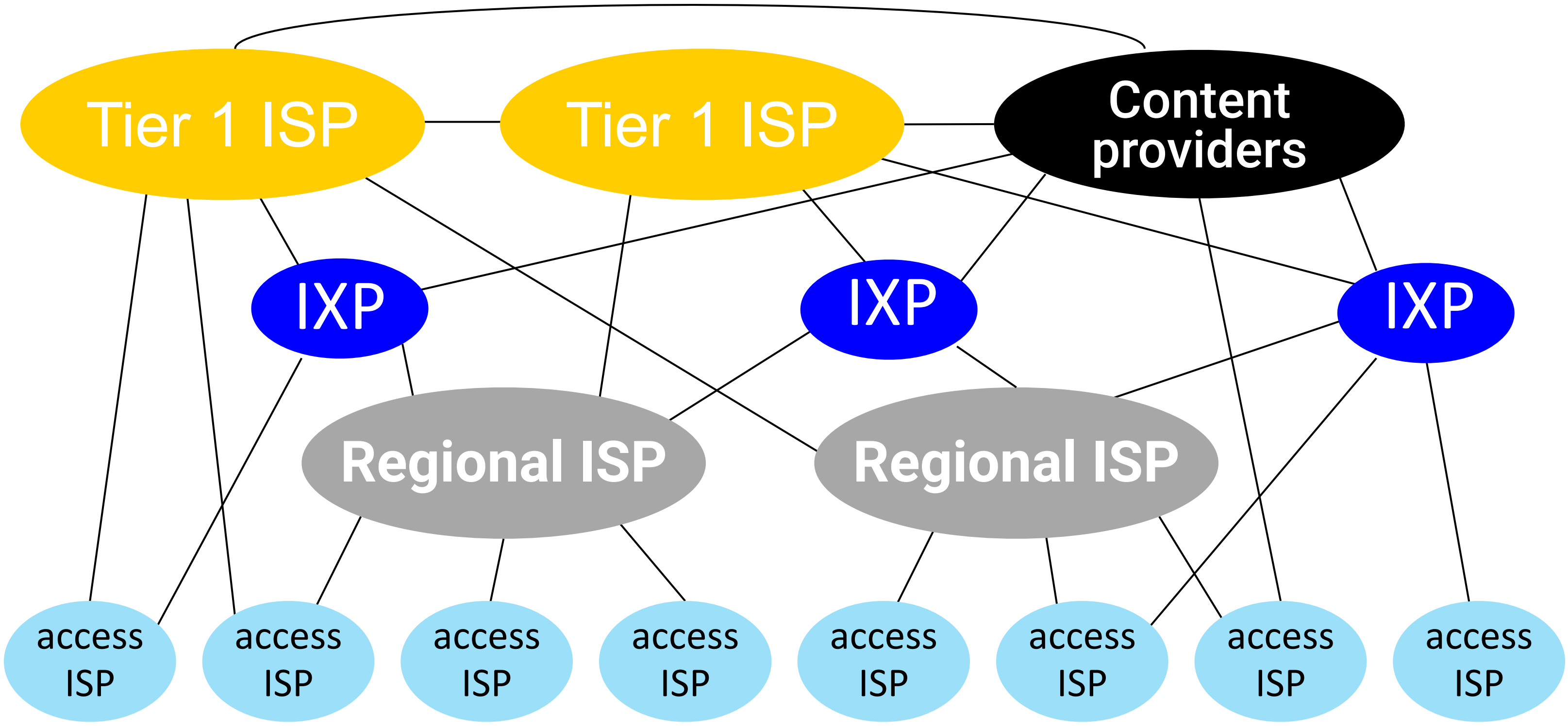


Internet structure: a network of networks

… and content providers (*e.g., Google, Akamai, Amazon*) may run their own network



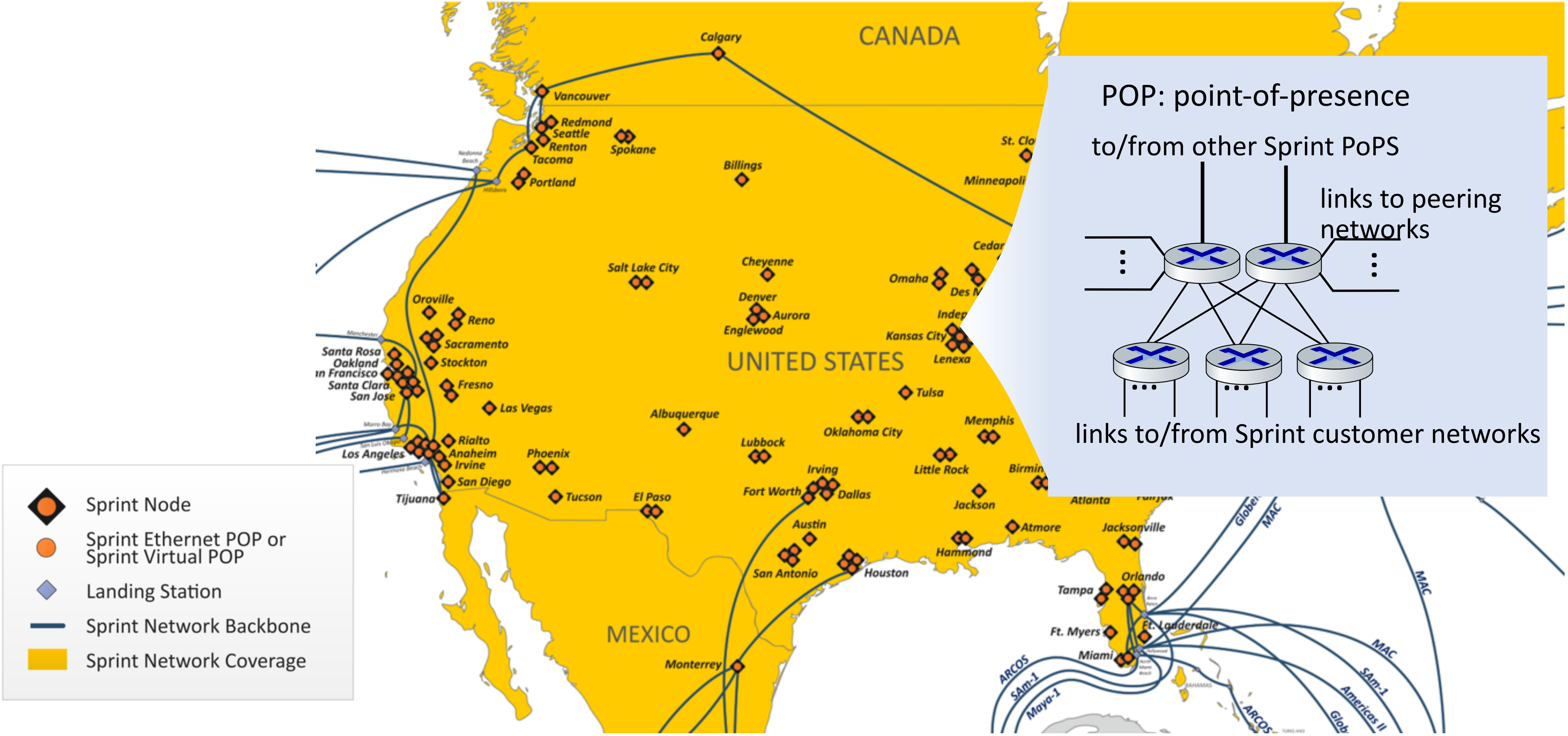
Internet structure: a network of networks



At the center: a small number of well-connected large networks

- *"tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T) for national & international coverage*
- *content provider networks (e.g., Google, Akamai, Amazon): private networks that connect data centers to Internet, often bypassing tier-1 and regional ISPs*

Tier-1 ISP network: Sprint (circa 2019)



Content provider network: Google (circa 2017)

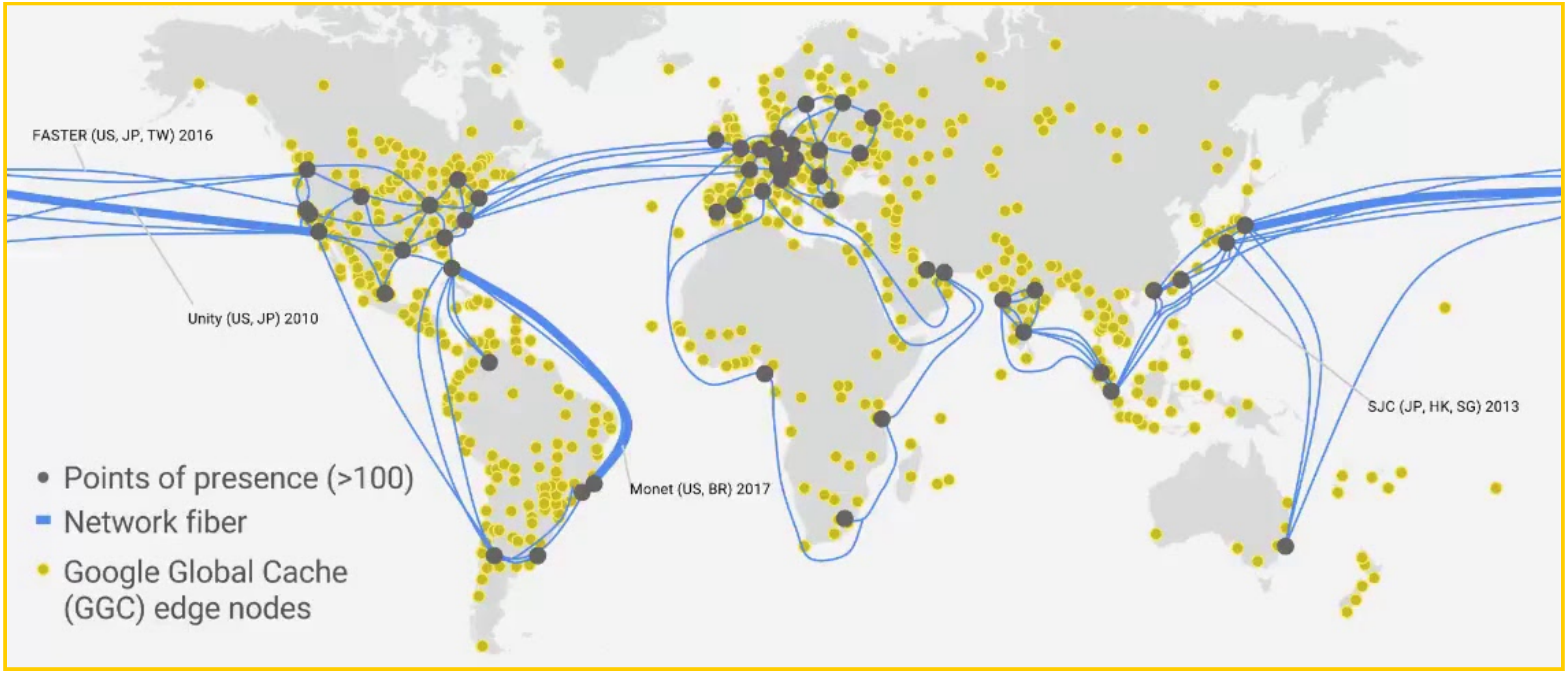
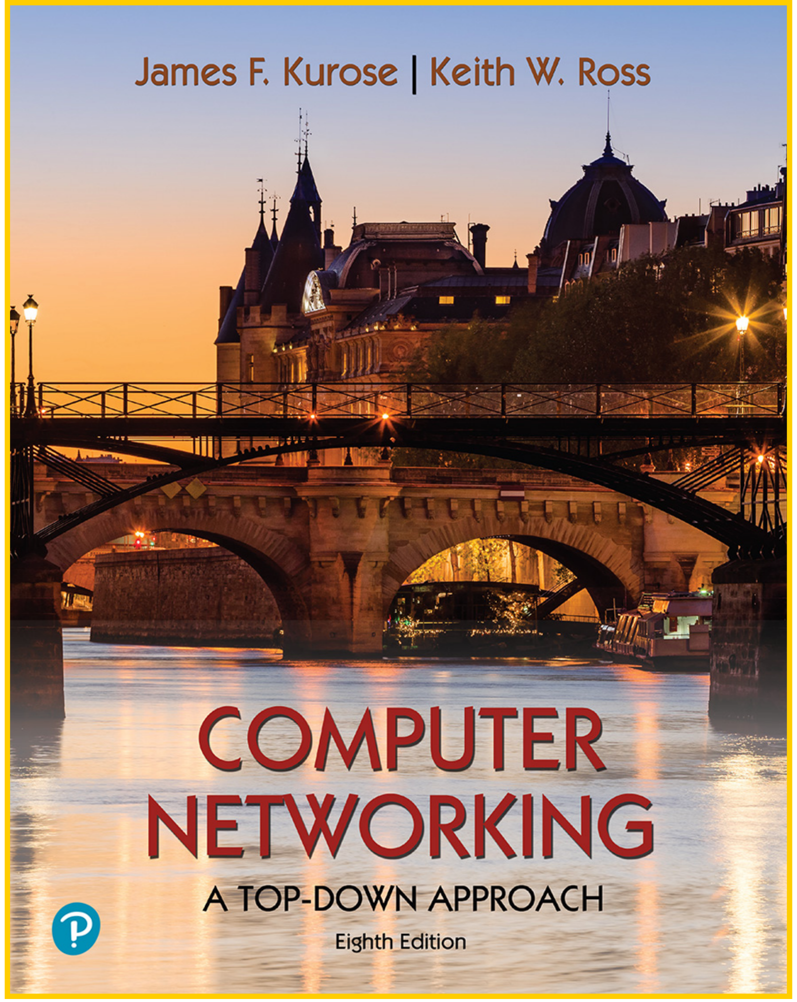


Image courtesy: Google cloud

Next Lecture

Continuing our in-depth exploration into the structure and functioning of the Internet

- *Network performance*
- *Protocol architecture*



Chapter 1.4 - 1.5

Spot Quiz (ICON)