Computer Networks
@CS.NYCU

Lecture 1: Introduction

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Slides modified from
"Computer Networking: A Top-Down Approach" 7th Edition

Outline

- What's the Internet?
- What's a protocol?
- Network edge
  - hosts, access network, physical links
- Network core
  - packet/circuit switching, Internet structure
- Performance
  - loss, delay, throughput
- Protocol layers, service models
- Network security

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What is the Internet?

Two types of description:

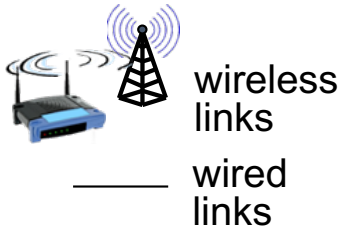
- **Nuts and bolts of the Internet**
  - i.e., hardware and software components
  - from the structure perspective

- **An infrastructure that provides services to applications**
  - Distributed applications: end systems exchange data with each other
    - including email, Web, games, P2P, VoIP, streaming, social networking, messaging, etc
  - from the functionality perspective

“Nuts and Bolts” View (HW)

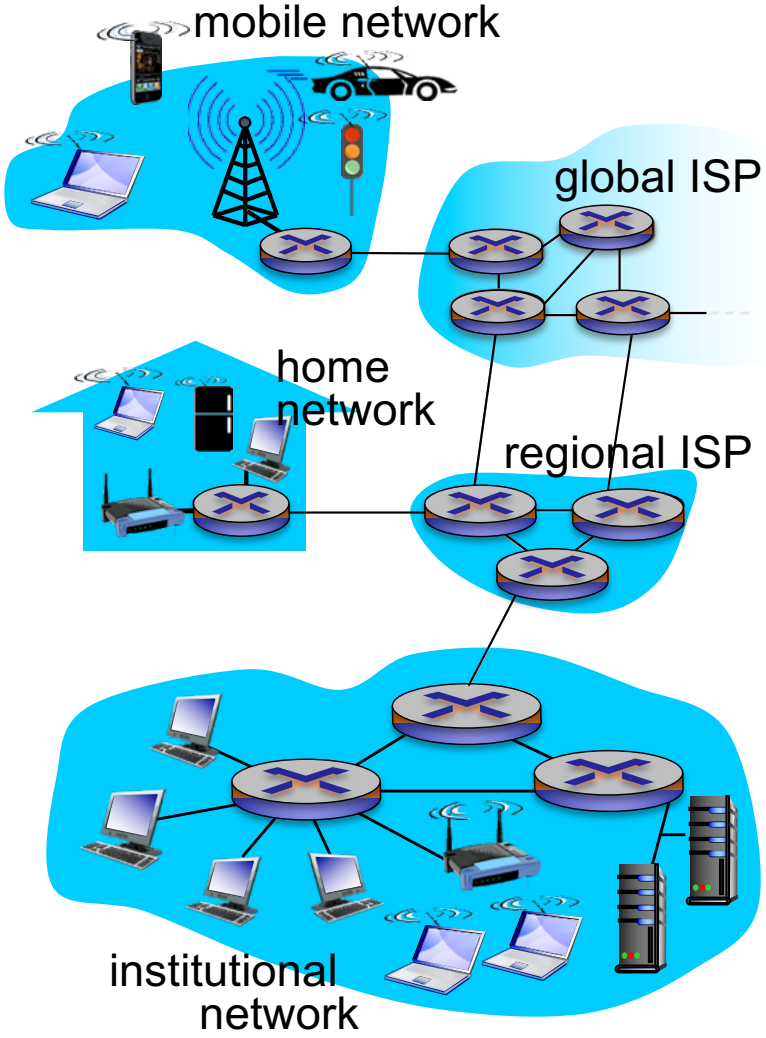
- billions of connected computing devices (things)

- **hosts = end systems**
  - running network apps



- **communication links**
  - fiber, copper, radio, satellite
  - transmission rate: **bandwidth**

- **packet switches:** forward packets
  - **routers** and **switches**



Internet of "Things"

IP picture frame
http://www.ceiva.com/

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

Internet
refrigerator

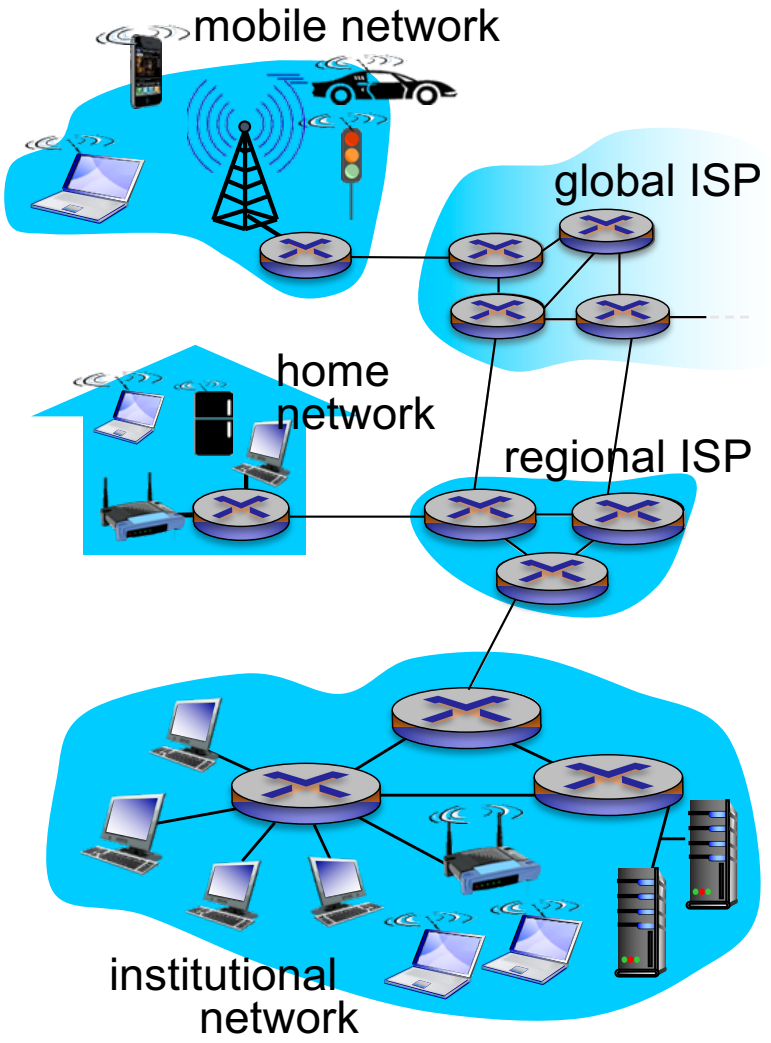
Slingbox: watch,
control cable TV remotely

sensorized,
bed
mattress

Internet phones

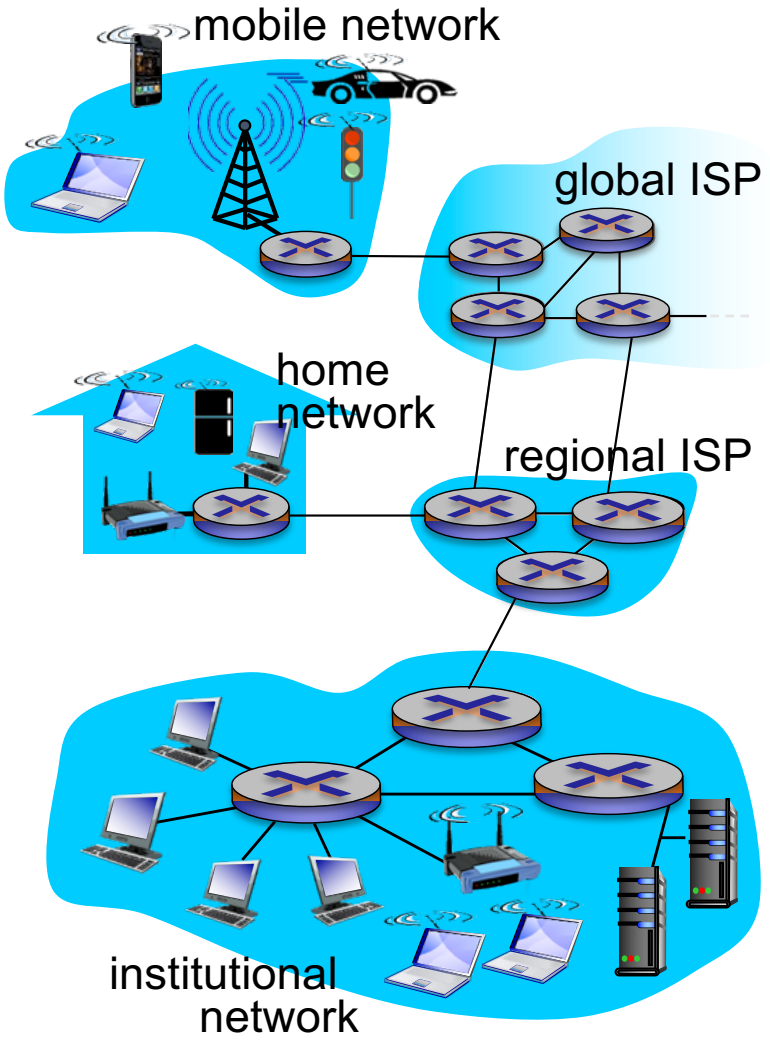
“Nuts and Bolts” View (SW)

- **Internet: “network of networks”**
  - Interconnected ISPs (Internet Service Providers)
- **Protocols**
  - Set of rules
  - Control sending, receiving of messages
  - e.g., TCP, IP, HTTP, Skype, 802.11
- **Internet standards**
  - Documents that specify guidelines to be followed
  - RFC (Request for comments), IETF (Internet Engineering Task Force), etc.



"Service" View

- **Infrastructure that provides services to applications:**
  - Web, VoIP, email, games, e-commerce, social nets, …
- **Provide socket interface to apps**
  - A program running on end systems
  - *Distributed application*: run in hosts
  - Delivering data between applications



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- Protocol layers, service models
- History

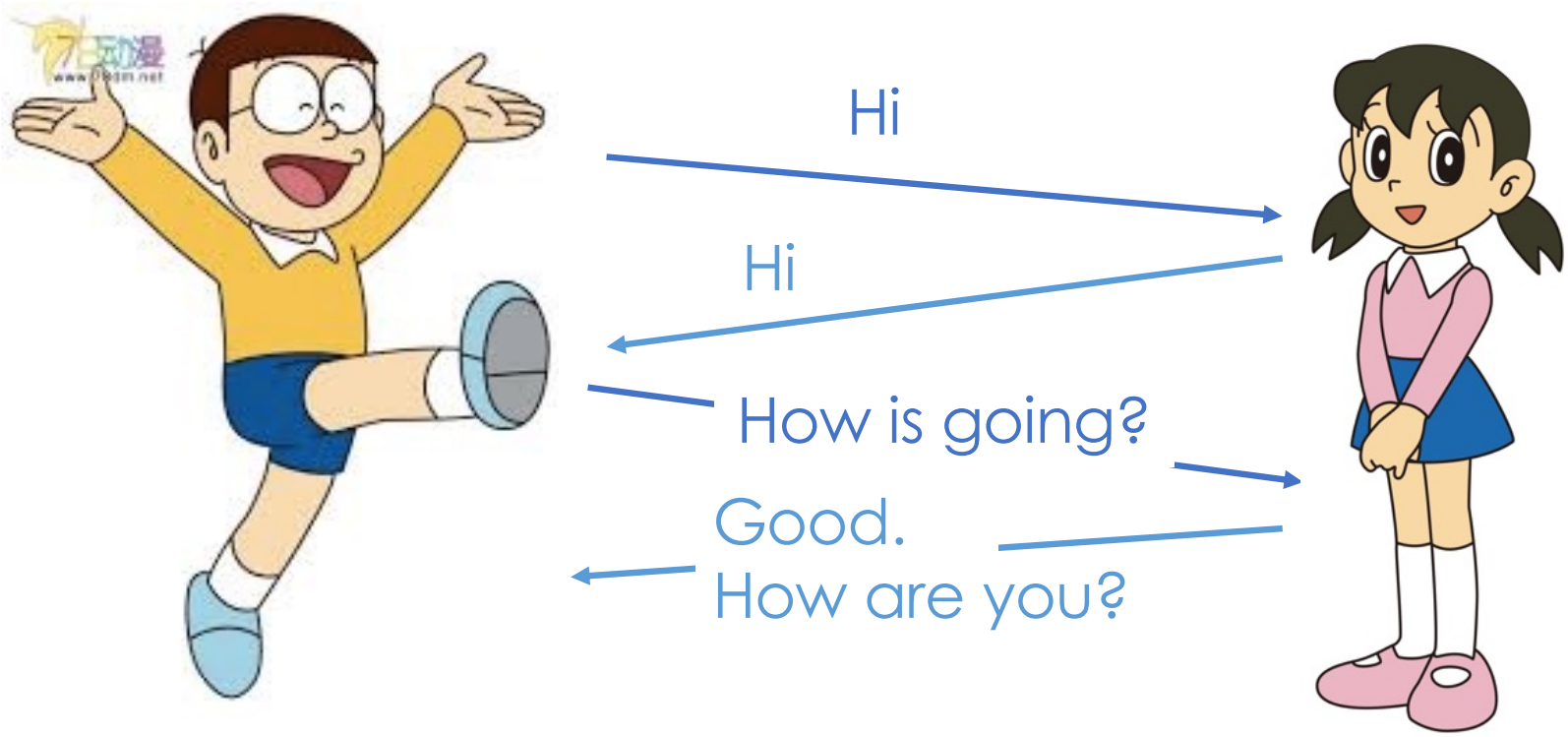
What is a Protocol?

Protocols define

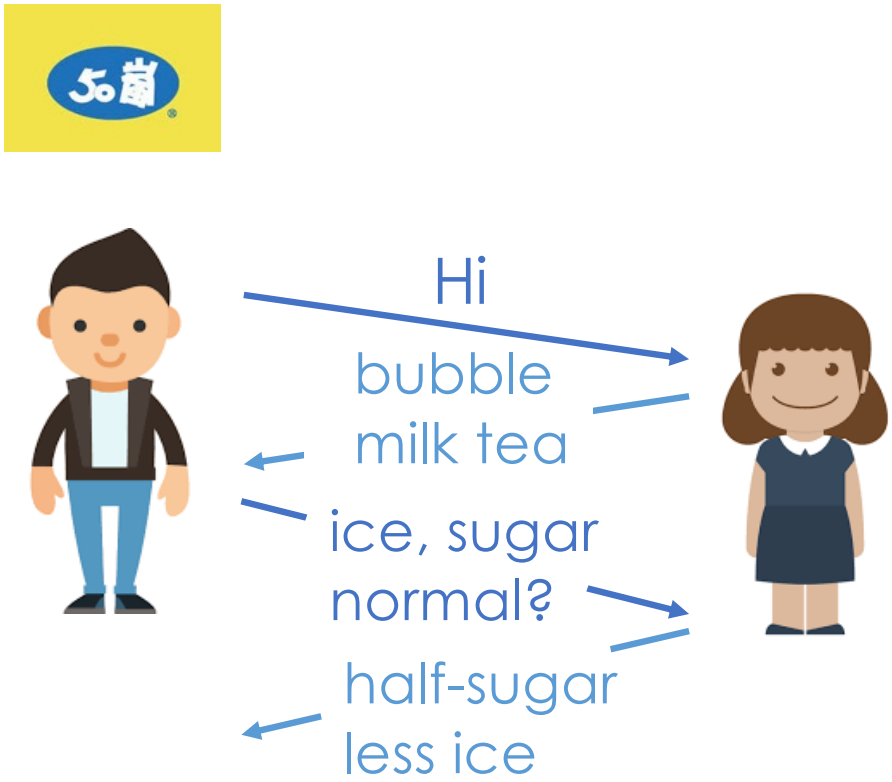
1. **format**, **order** of **messages sent and received** among network entities, and
2. **actions taken** on message transmission, receipt

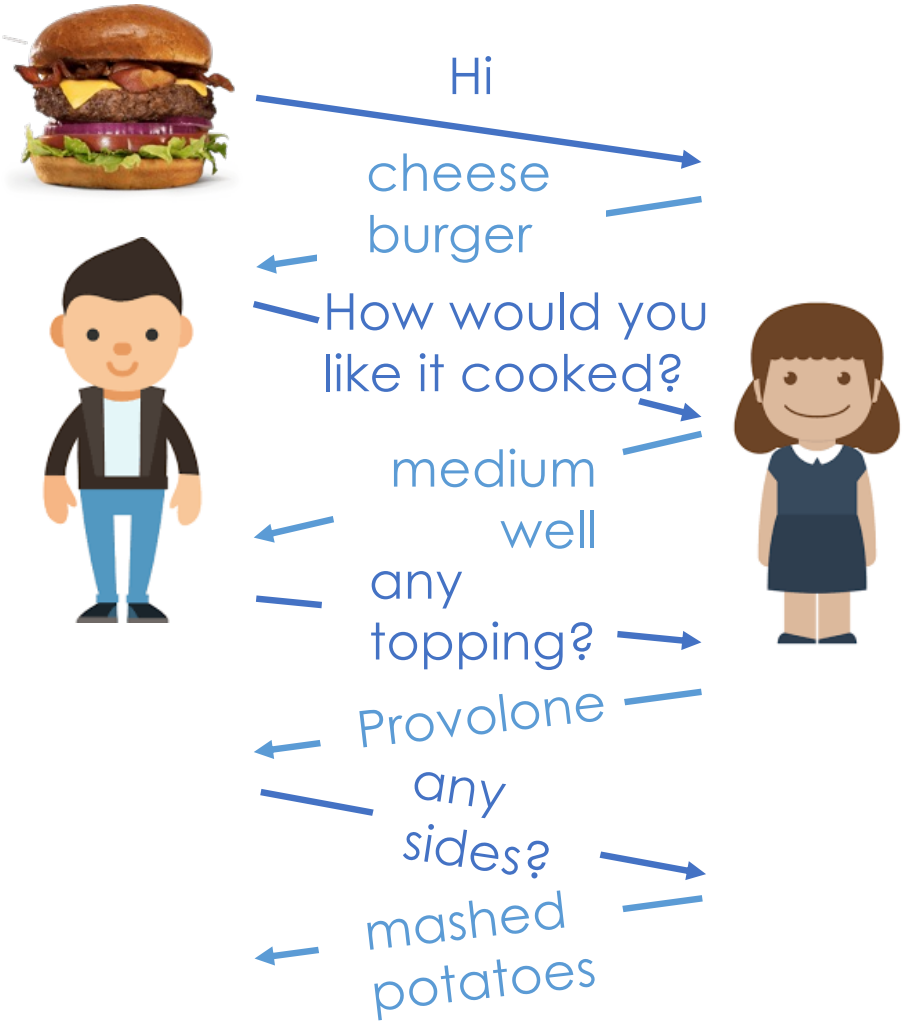
	Action taker	Message
Human protocols	human	Speech, gestures
Network protocols	Machines (end devices, switches, routers, etc.)	packets

Human Protocols

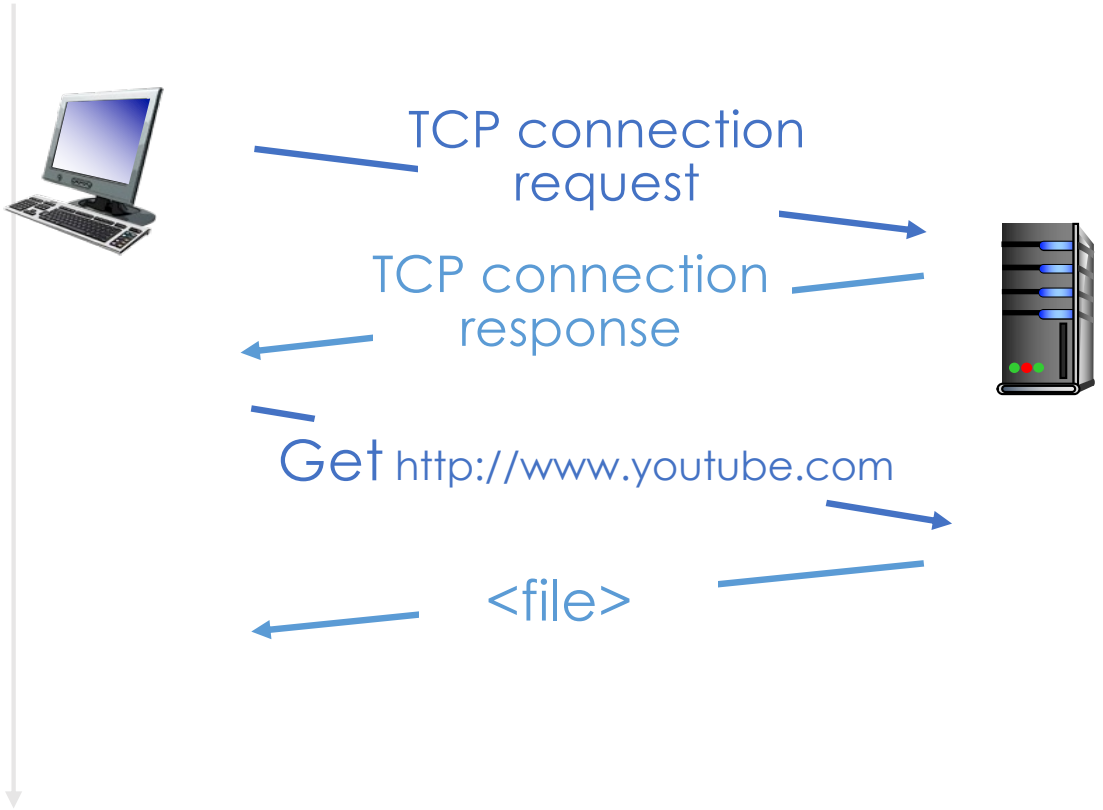


Human Protocols





Network Protocols



- A sequence of packets with a specific format known by all the end devices
- Can involve two or more end devices

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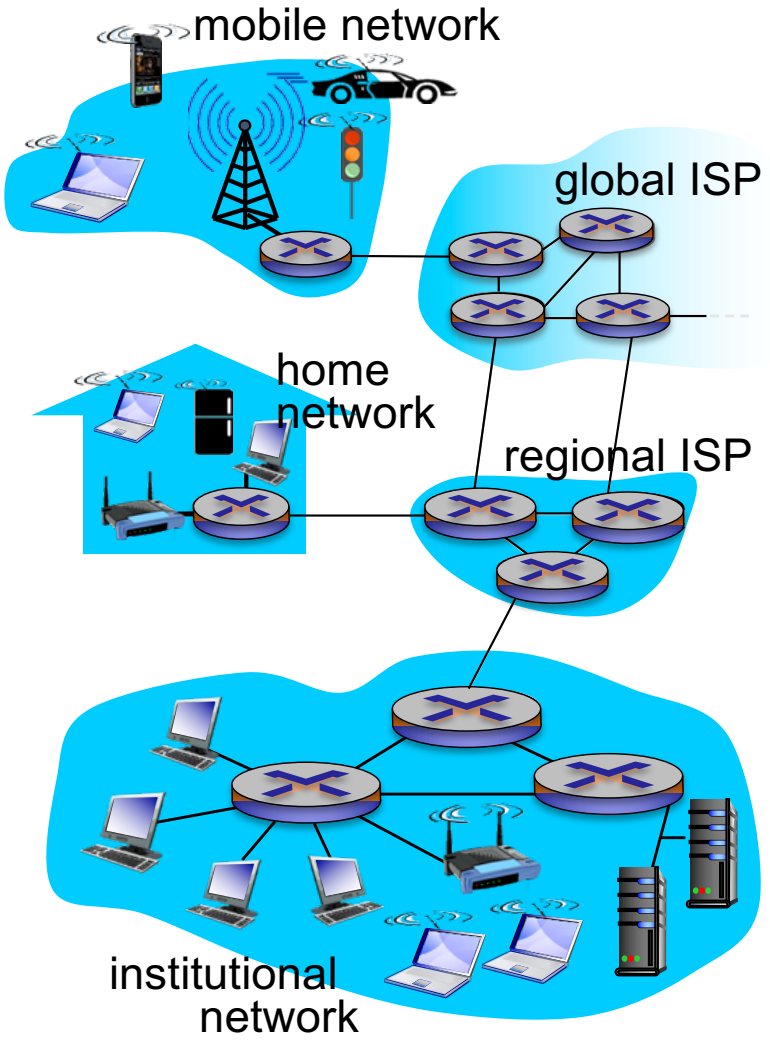
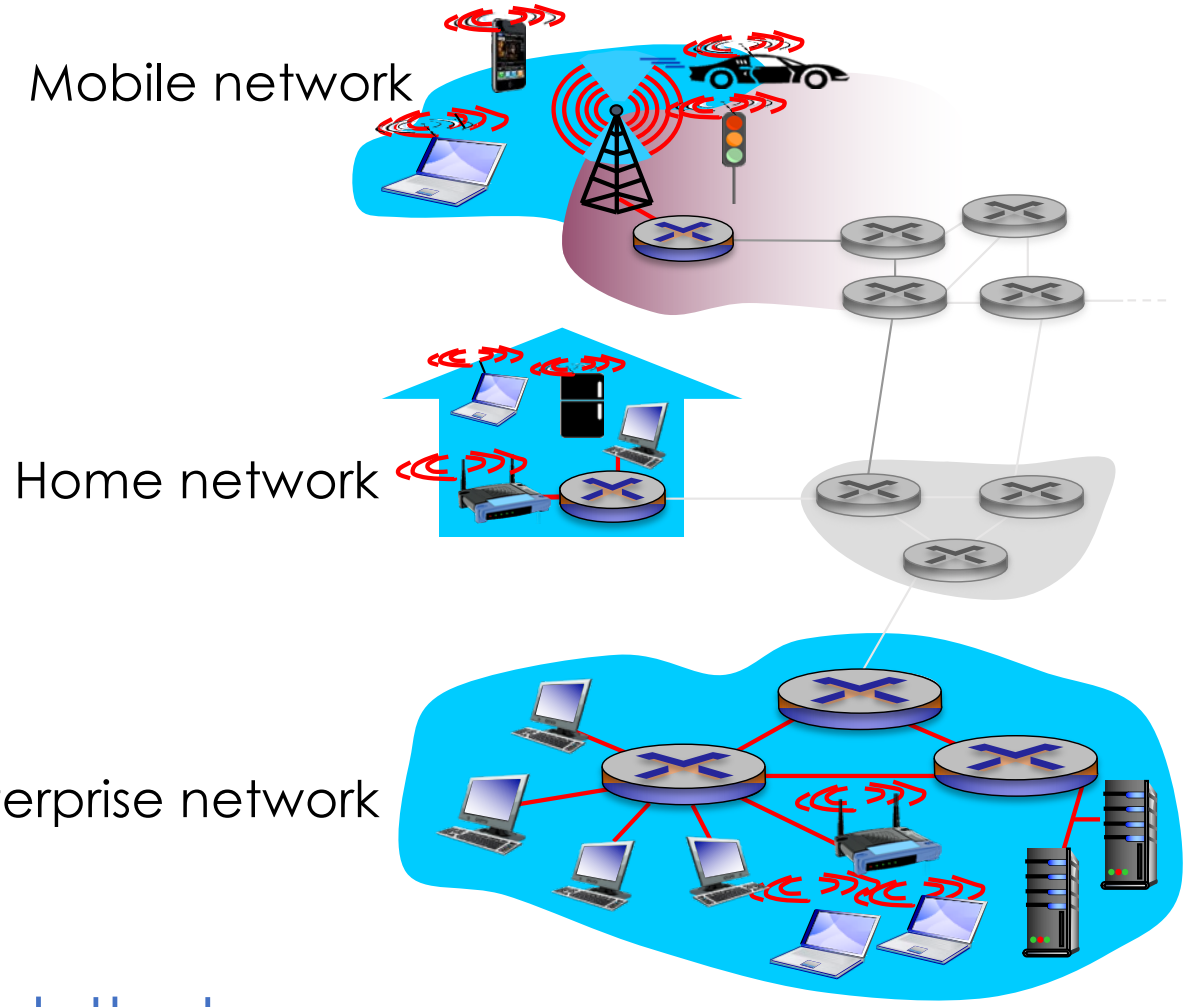
Network Structure

- **Network edge:**
  - Hosts: clients and servers
  - Servers often in data centers
- **Access networks, physical media:**
  - Connect hosts to first routers (edge routers)
- **Network core:**
  - Interconnected routers
  - Network of networks



Access Networks

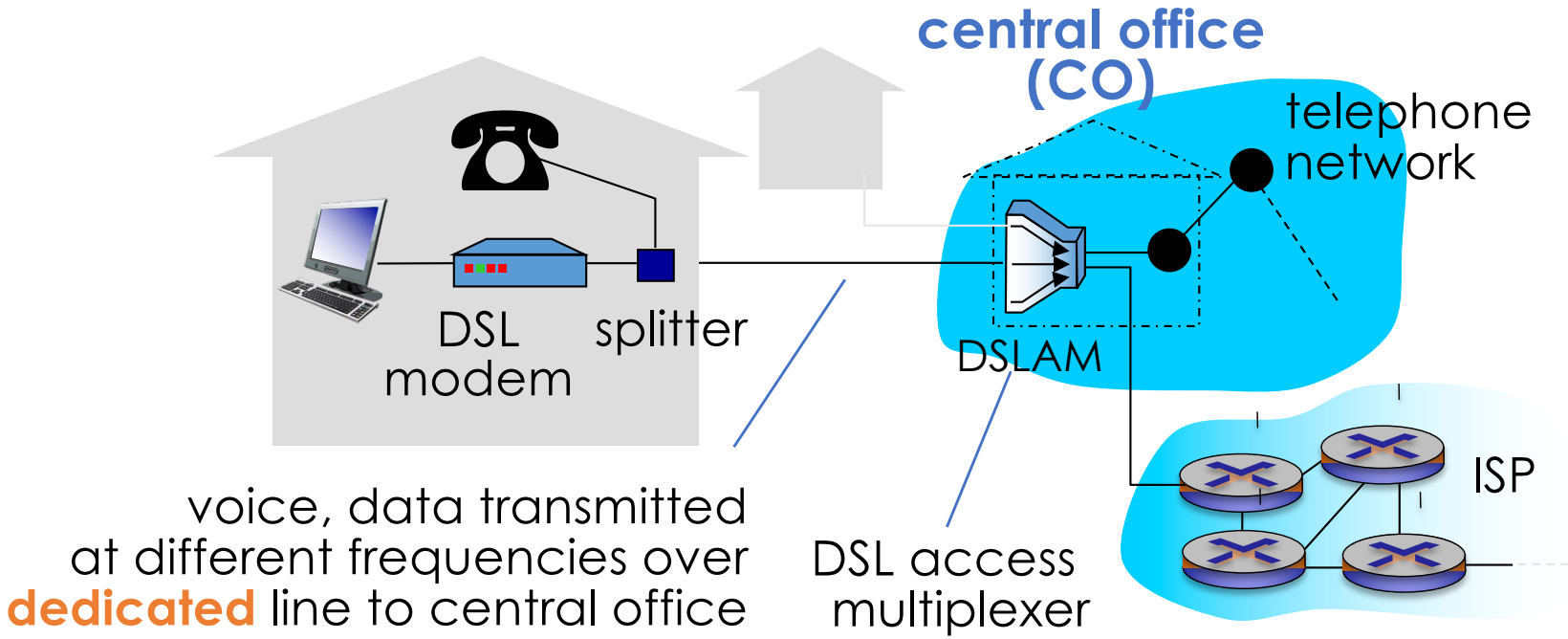


The network that
physically connects an end system to the first router

Types of Home Access Networks

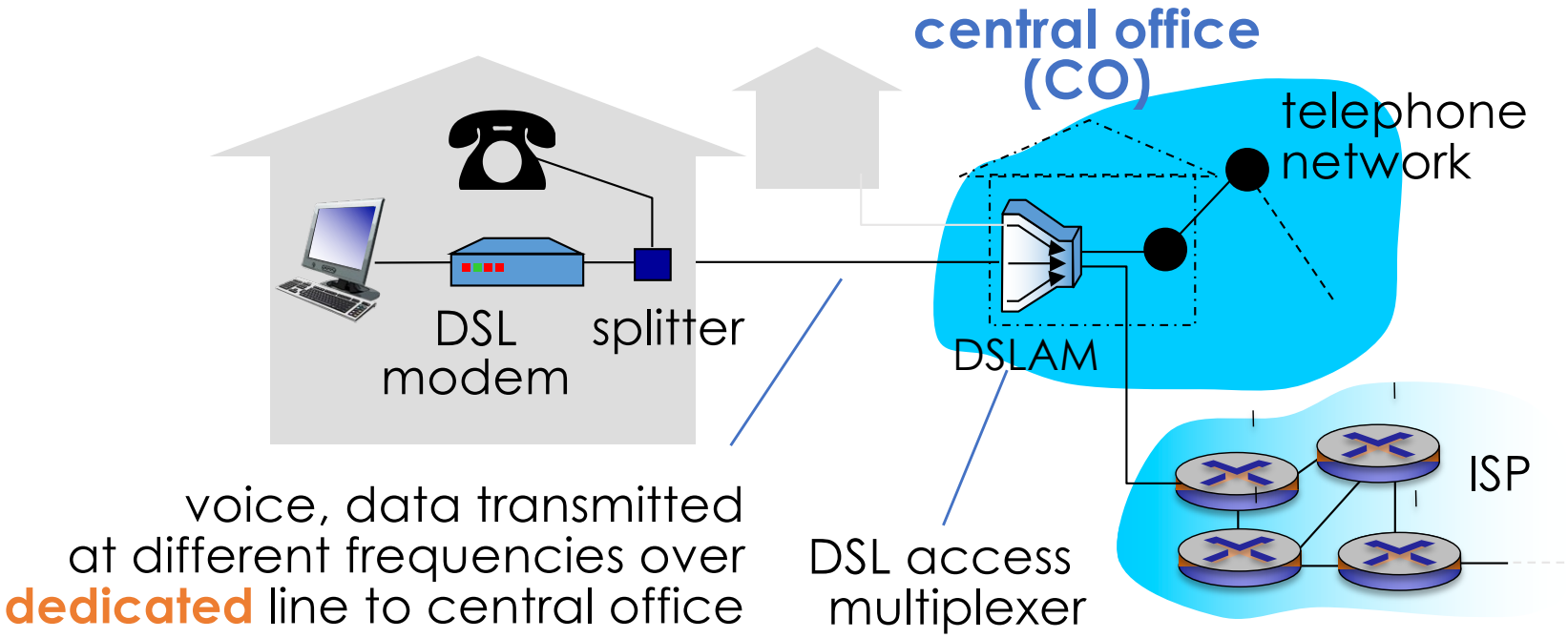
- **DSL**: Digital Subscriber Line
- **Cable** Internet Access
- **FTTH**: Fiber To The Home
- **Satellite** Access

Access Net: DSL



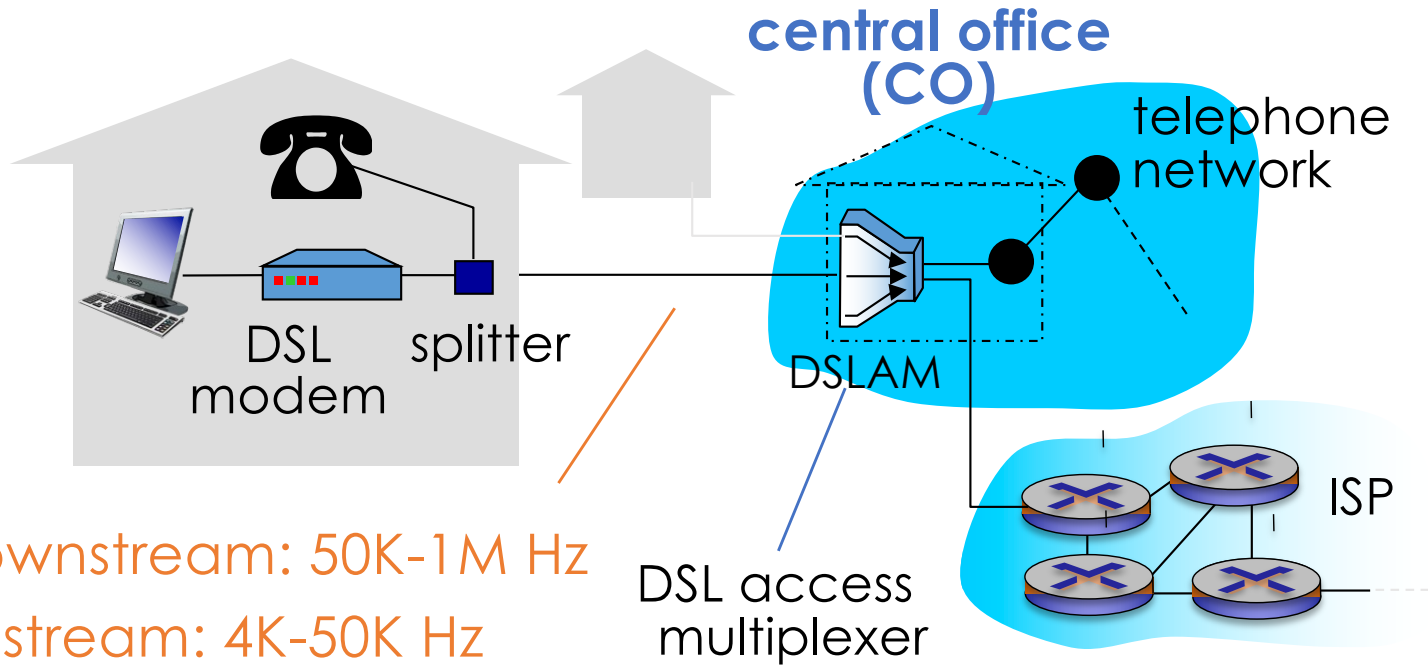
- Use existing telephone line to central office DSLAM (**D**igital **S**ubscriber **L**ine Access Multiplexer)
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net

Access Net: DSL



- < 2.5 Mbps for upstream → **Asymmetric!**
- < 24 Mbps for downstream → **'A'DSL**
- Maximum rate is limited by the distance between the home and the CO (Typically within 5-10 miles)

Access Net: DSL

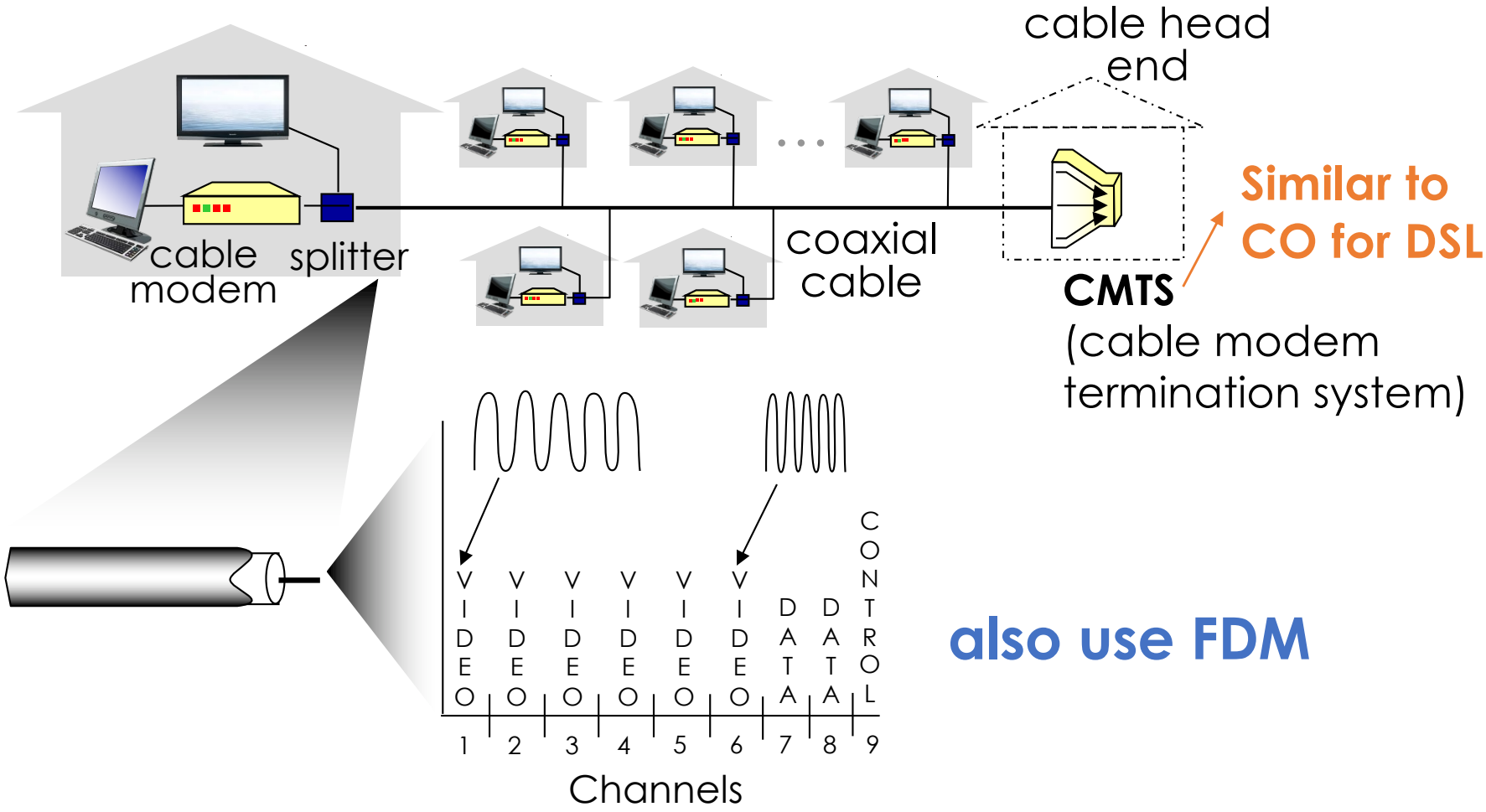


- Downstream: 50K-1M Hz
- Upstream: 4K-50K Hz
- Telephone: 0-4K Hz

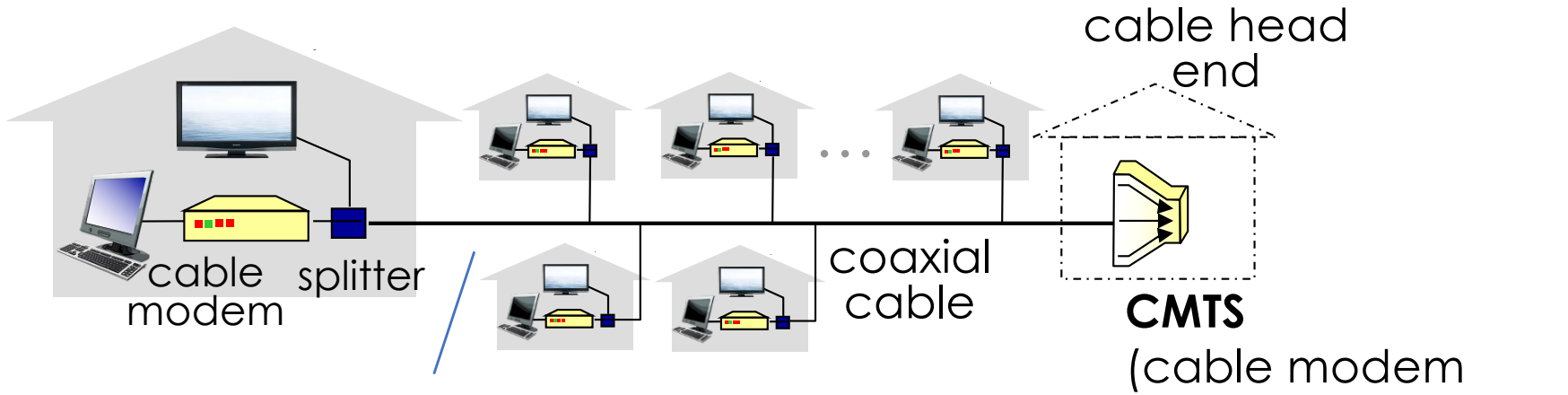
- **Frequency Division Multiplexing (FDM)**
  - Data and telephone call transmitted in different frequency bands, but share the same DSL link

Access Net: Cable Network

- Reuse TV cable

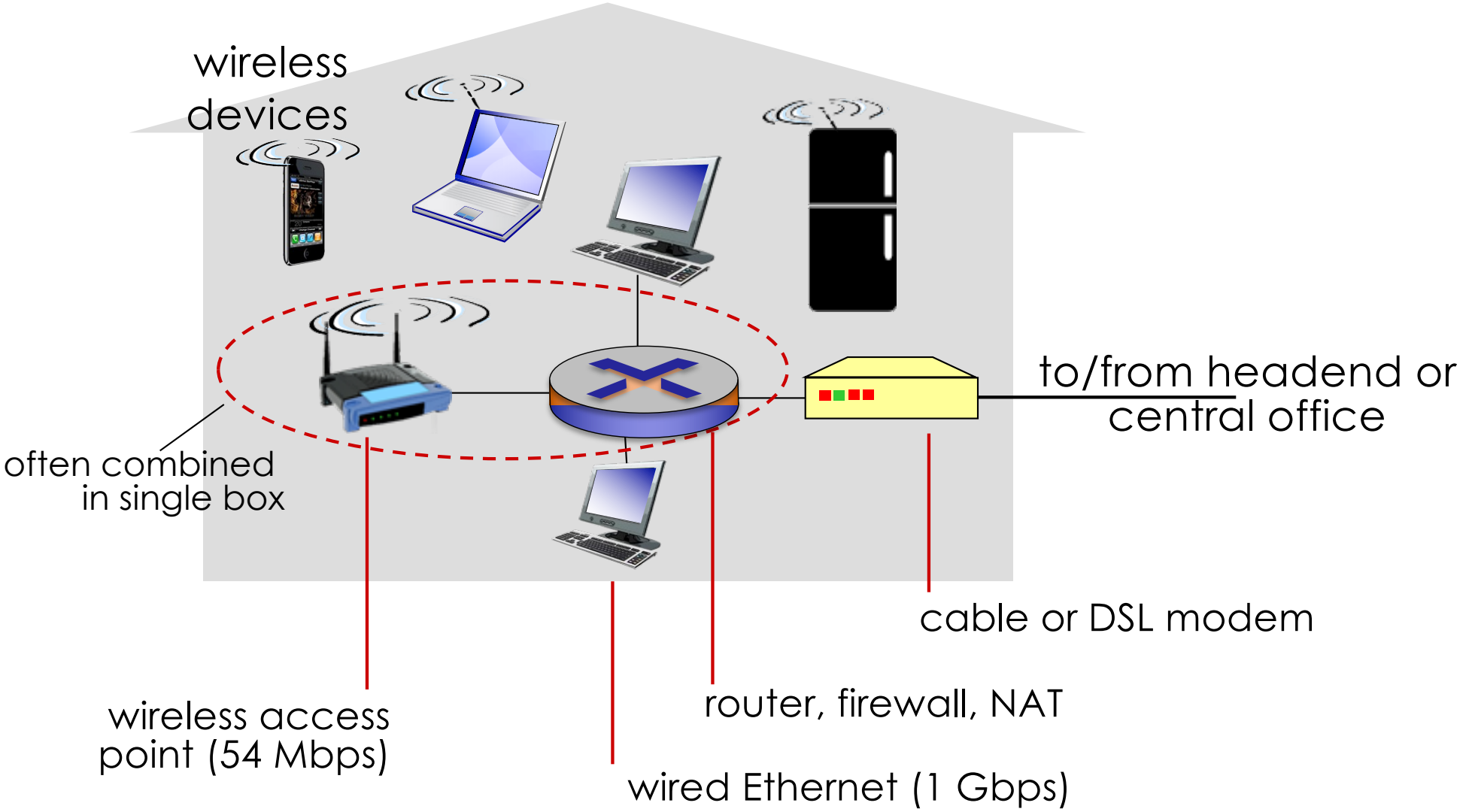


Access Net: Cable Network

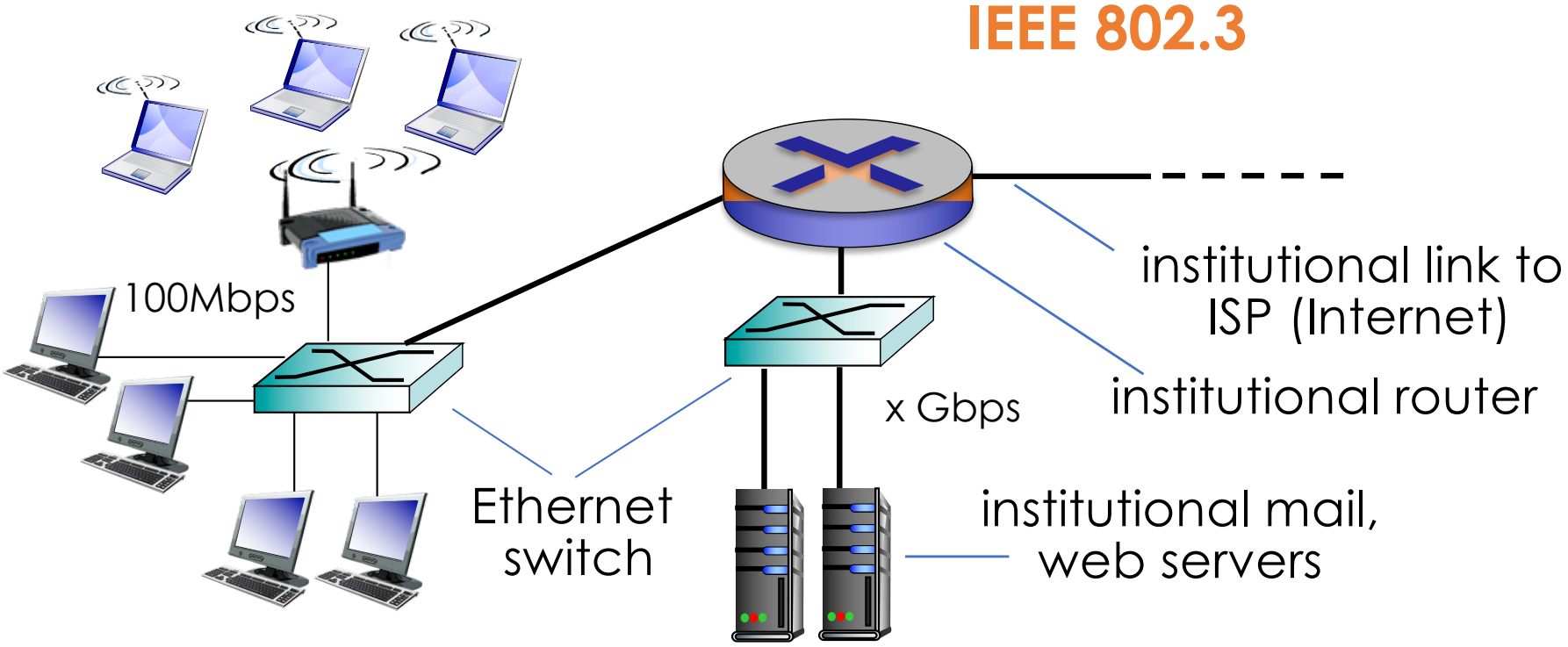


- HFC: hybrid fiber coax
  - asymmetric: up to 30Mbps for downstream, 2 Mbps for upstream
- Network of cable, fiber attaches homes to ISP router
  - homes share access network to cable headend → **fairness?**
  - unlike DSL, which has dedicated access to central office → **access control?**

Access Network: Home Network



Enterprise Access Networks (Ethernet)



- Typically used in companies, universities, etc.
  - 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
  - Today, end systems typically connect into Ethernet switch

Wireless Access Networks

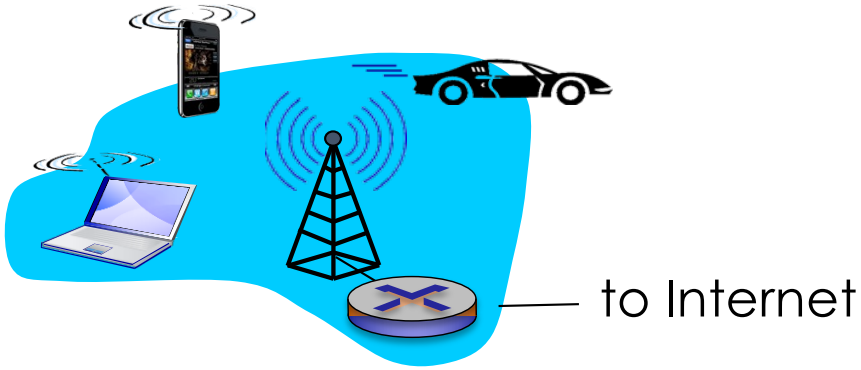
- Shared wireless access network connects end systems to routers
  - via base station (BS) aka "access point" (AP)

wireless LANs (WLANs)

- within building (100 ft.)
- 802.11b/g/n/ac/ad (WiFi): 11, 54, 450, 7000 Mbps transmission rate

wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE (Long-Term Evolution)



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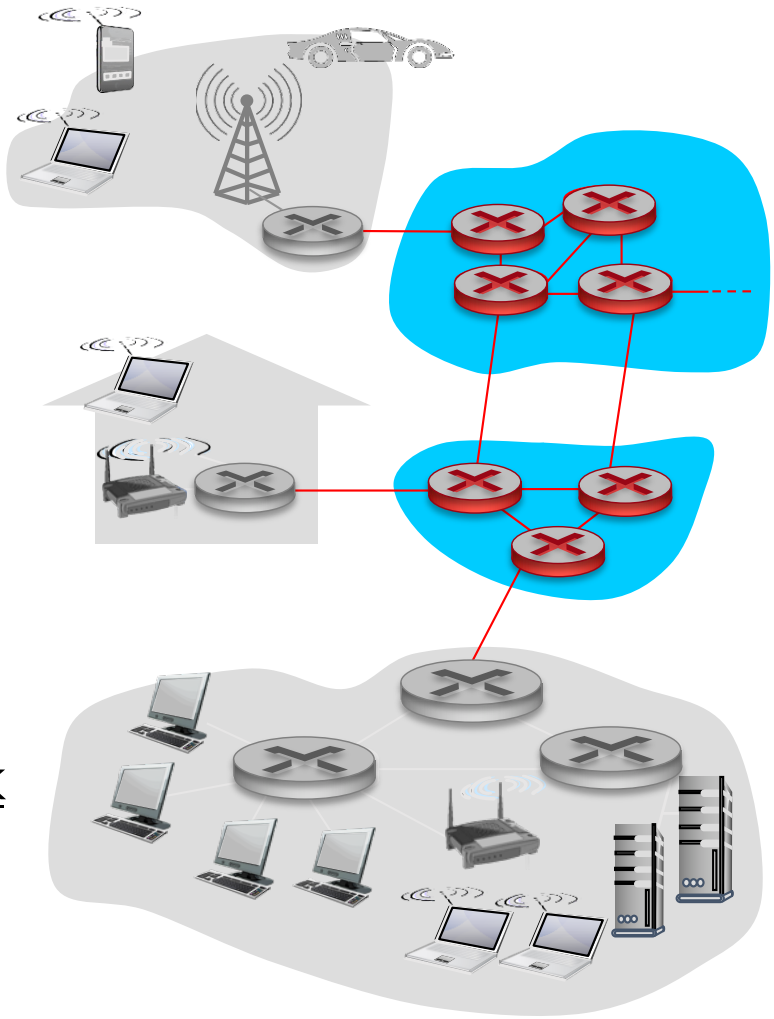
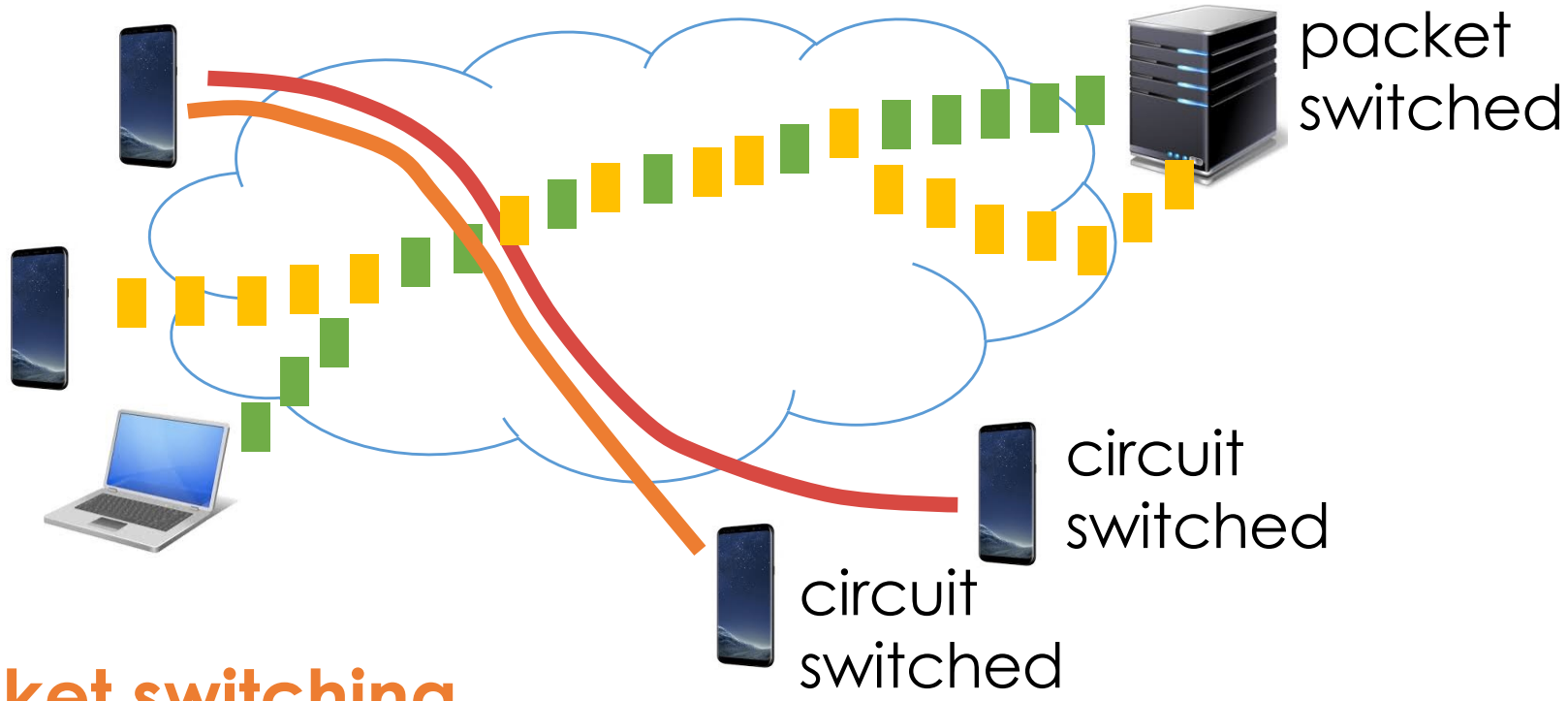
Network Core

- Mesh of interconnected routers
- **Packet-switching**: hosts break application-layer messages into packets
  - Forward packets from one router to the next, across links on path from source to destination
  - Each packet transmitted at full link capacity



Two Switching Models

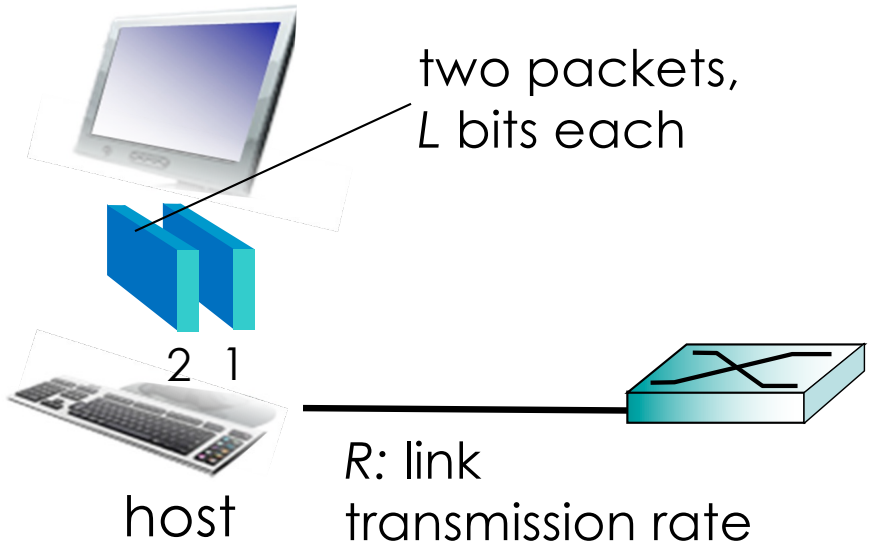


- **Packet switching**
  - Store and forward
  - Resources are not reserved for any source-destination pairs
- **Circuit switching**
  - Resources needed along a path are reserved for a duration

Host: Sends Packets of Data

How to send data?

1. takes application message
2. breaks into smaller chunks (aka packets) of length L bits
3. transmits packet into access network at transmission rate R
   - link transmission rate, i.e., *link capacity* or *link bandwidth*



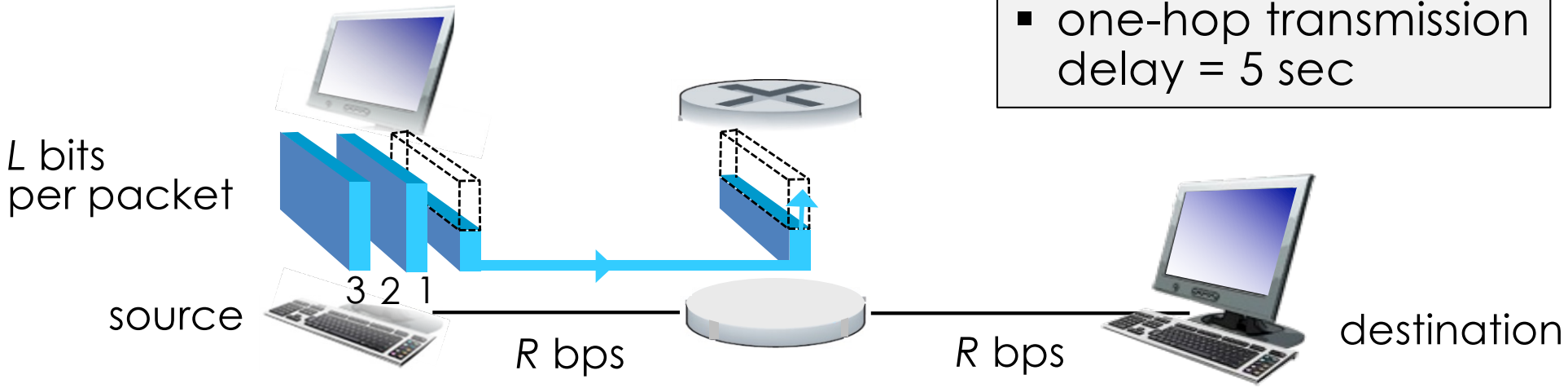
$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

Packet Switching

- Take **L/R** seconds to transmit (push out) **L**-bit packet into link at **R** bps
- Store-and-forward transmission
  - Entire packet must arrive at router before it can be transmitted on next link
- N-hop end-end delay = **N*L/R**
  - assuming zero propagation delay

one-hop example:

- *L* = 7.5 Mbits
- *R* = 1.5 Mbps
- one-hop transmission delay = 5 sec



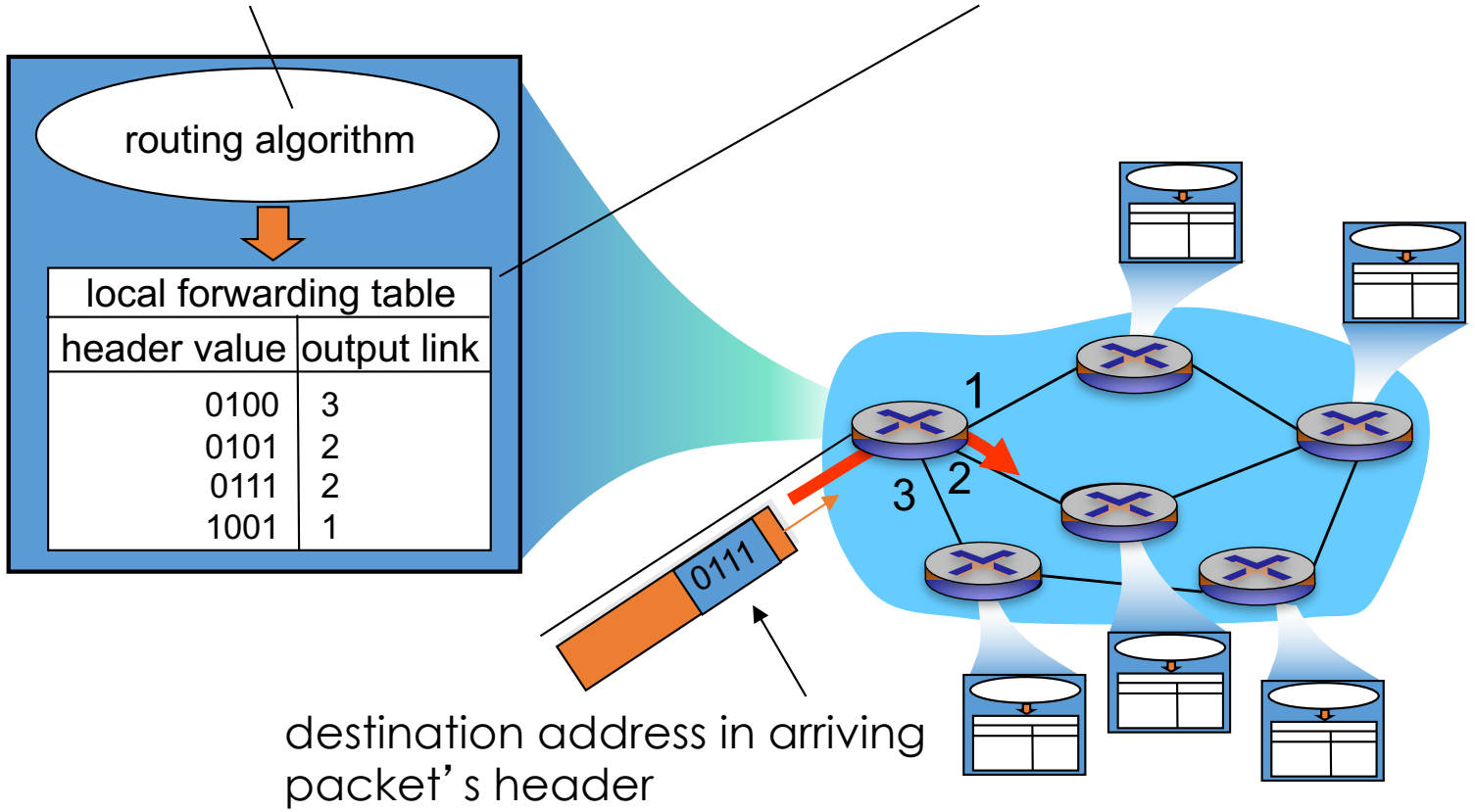
Q: How much time is required to send three packets?

Two Key Network-Core Functions

routing: determines source-destination route taken by packets

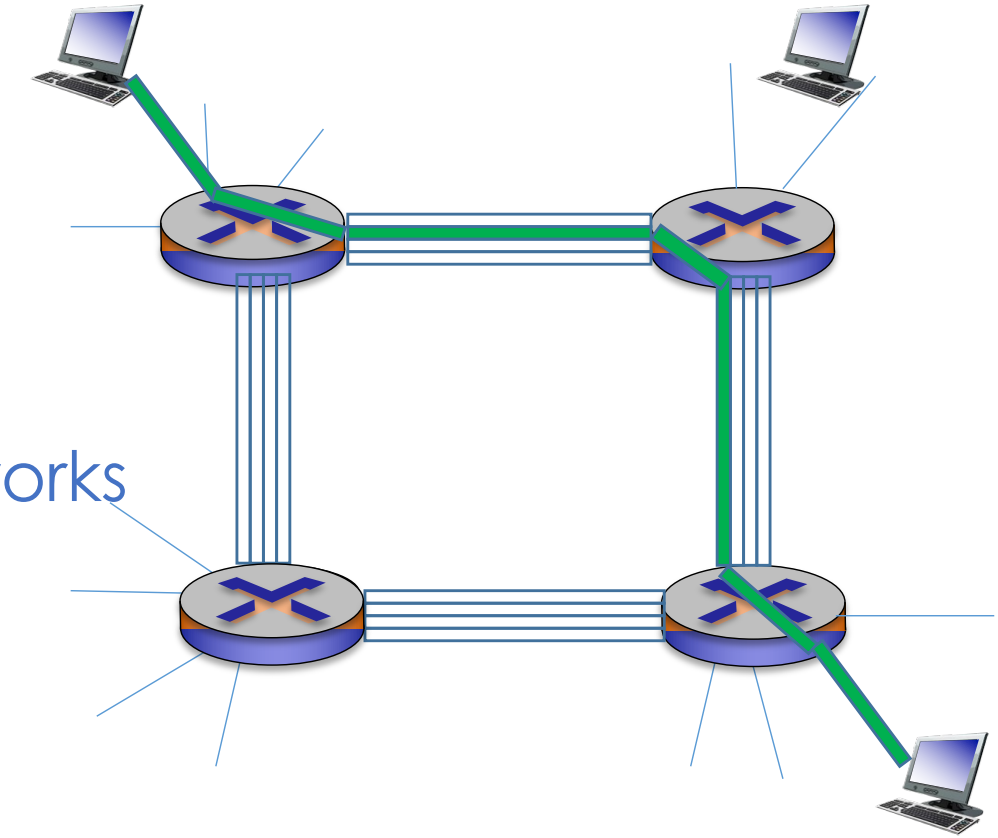
- *routing algorithms*

forwarding: move packets from router's input to appropriate router output



Circuit Switching

- End-end resources allocated to, **reserved** for "call" between source & destination
- In diagram, each link has four circuits
- Dedicated resources
  - **no sharing**
  - **guaranteed performance**
- Commonly used in traditional telephone networks
- Circuit segment idle if not used by call

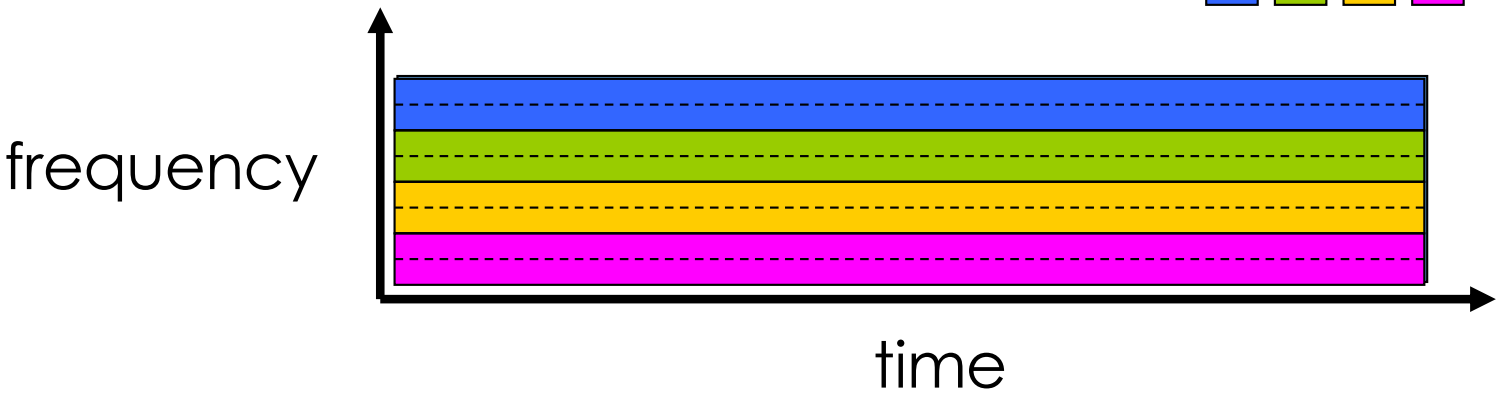


Circuit Switching: FDM vs. TDM

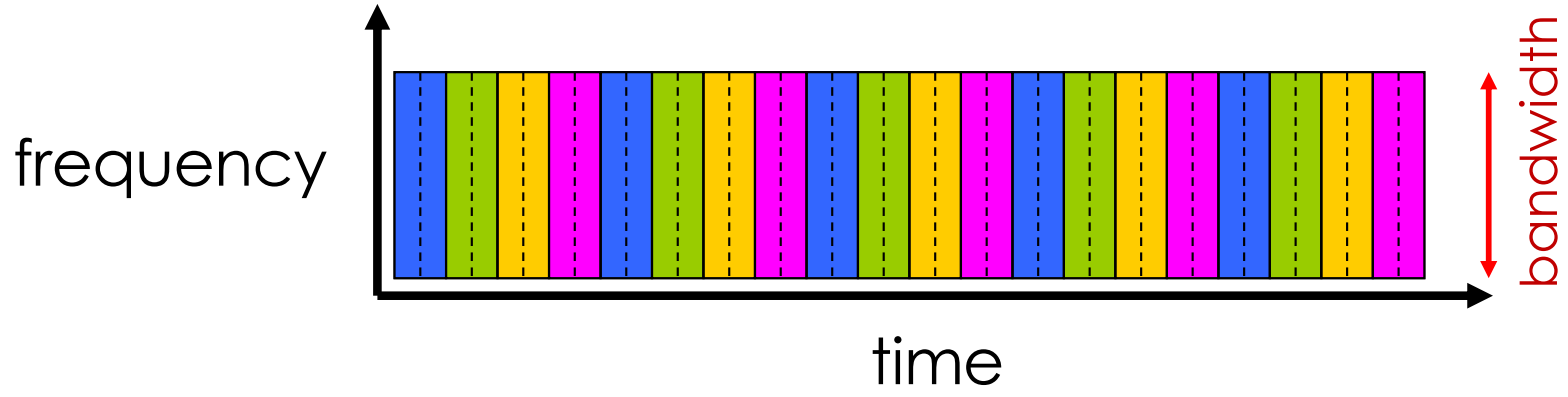
- **Multiplexing**: allocate resources to multiple users

FDM (Frequency division multiplexing)

Example: 4 users



TDM (Time division multiplexing)



Pros and Cons of Packet Switching

☺ Better sharing

☺ Simpler

☺ More efficient

☺ Better utilization

☺ Support more users

☹ Loss and delay

☹ Might suffer from congestion

☹ No performance guarantee

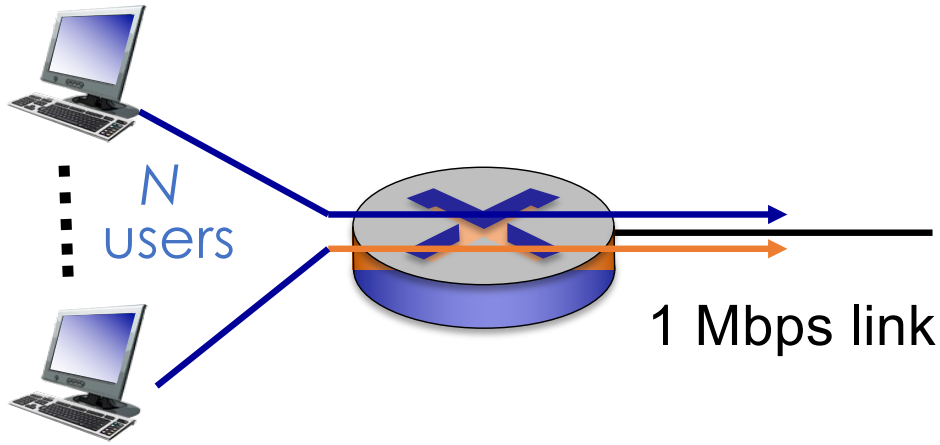
☹ Less suitable for real-time applications

Example of Sharing

packet switching allows more users to use network!

Example:

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

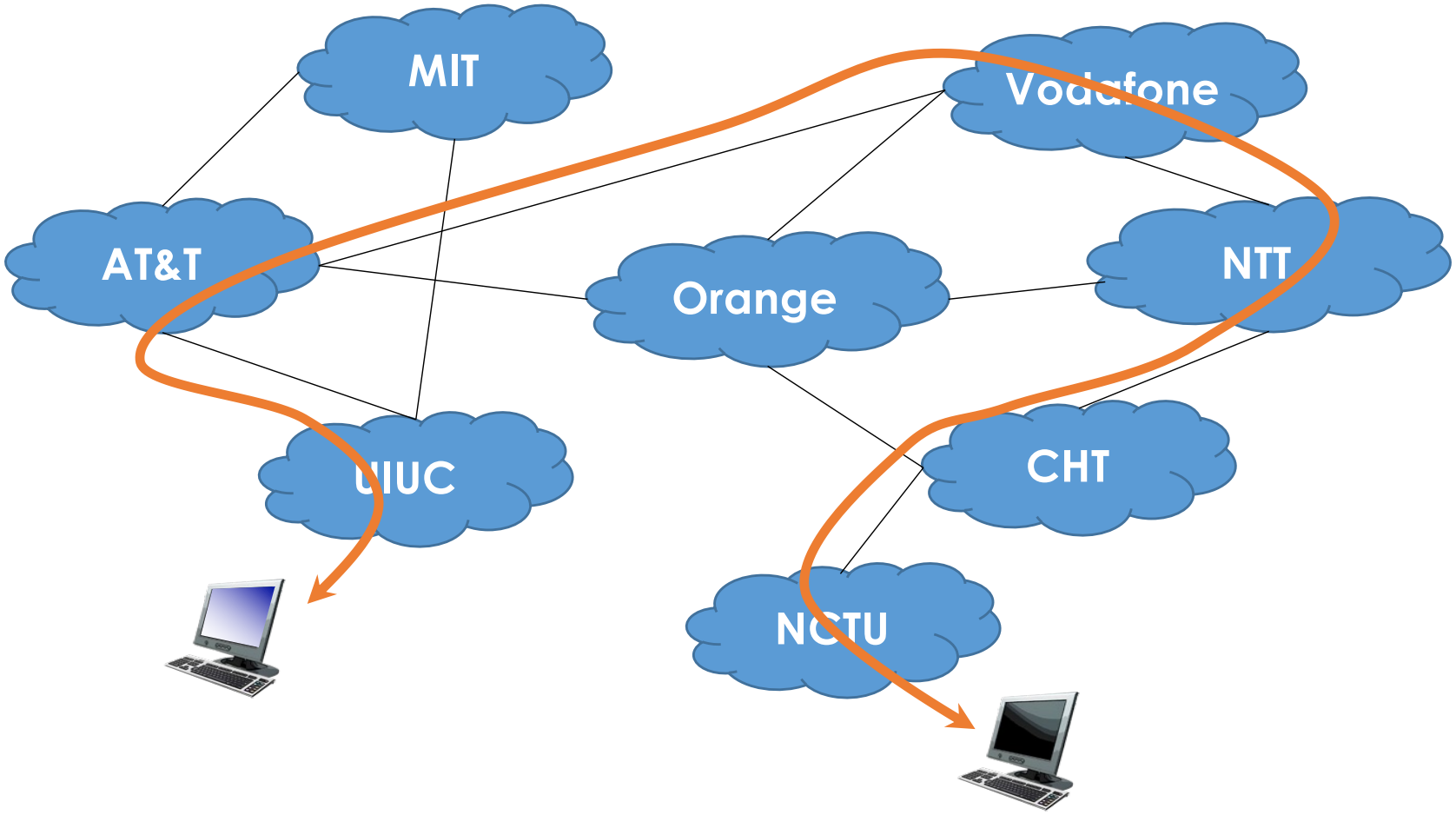


- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability >10 active simultaneously is less than .0004

Q: How do we get 0.0004?

Network of Networks

ISP (Internet Service Providers)



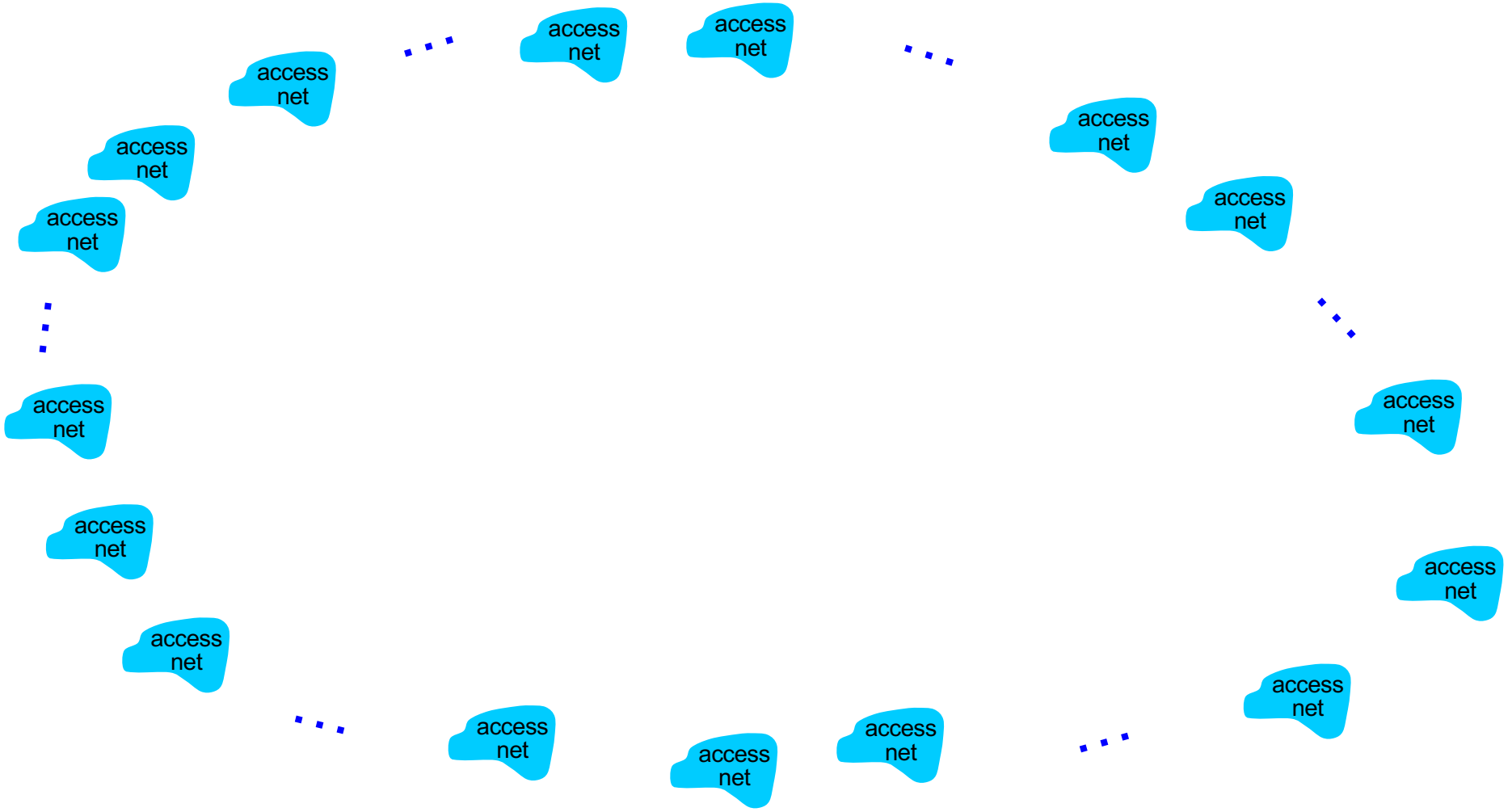
Network of Networks

- End systems connect to Internet via access ISPs (Internet Service Providers)
  - residential, company and university ISPs
- Access ISPs in turn must be interconnected
  - so that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - evolution was driven by economics and national policies (rather than performance consideration)

Structure: Ring

Q: Inefficient? Why?

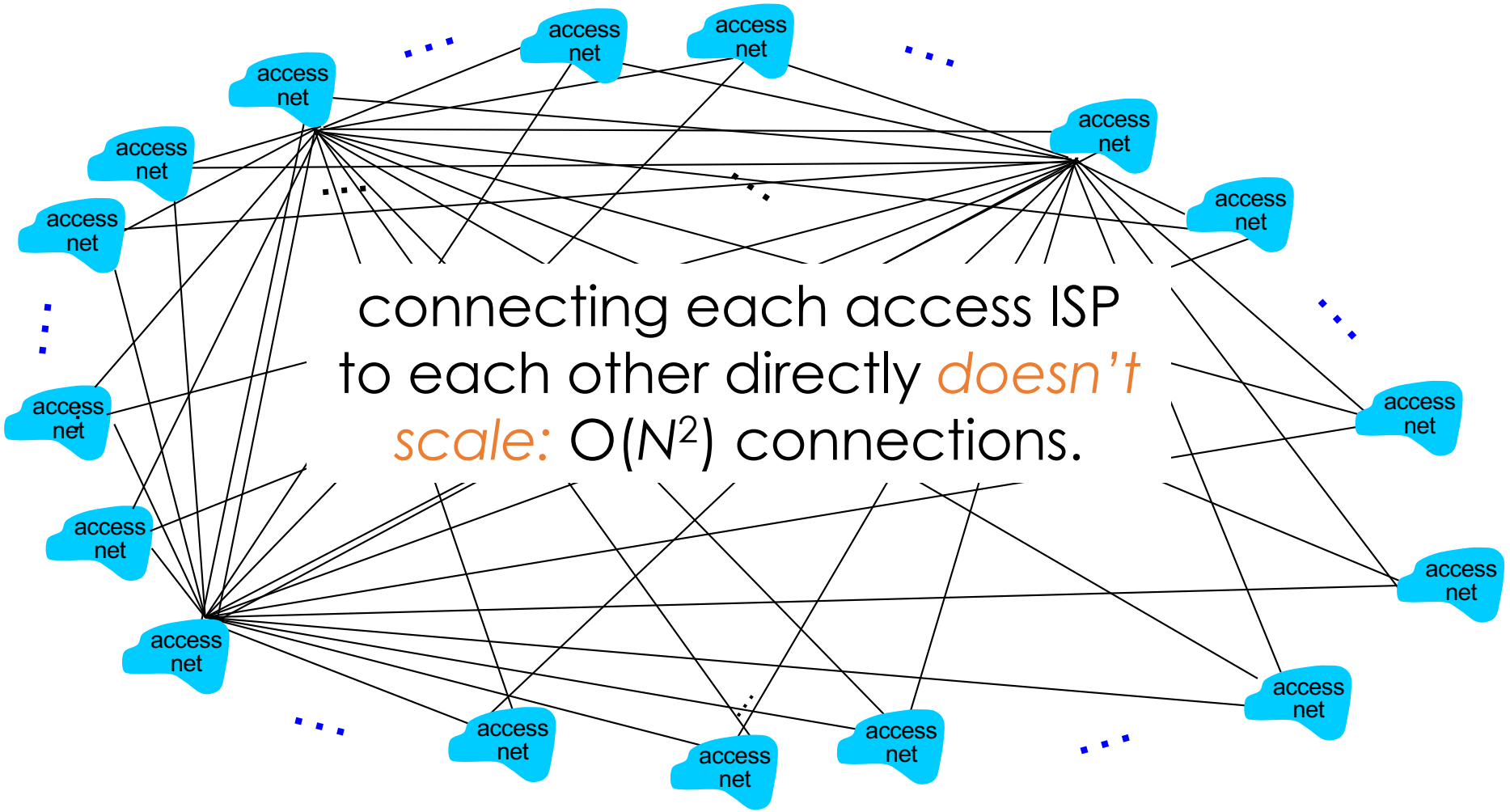
Question: given *millions* of access ISPs, how to connect them together?



Structure: Mesh

Q: scalability?

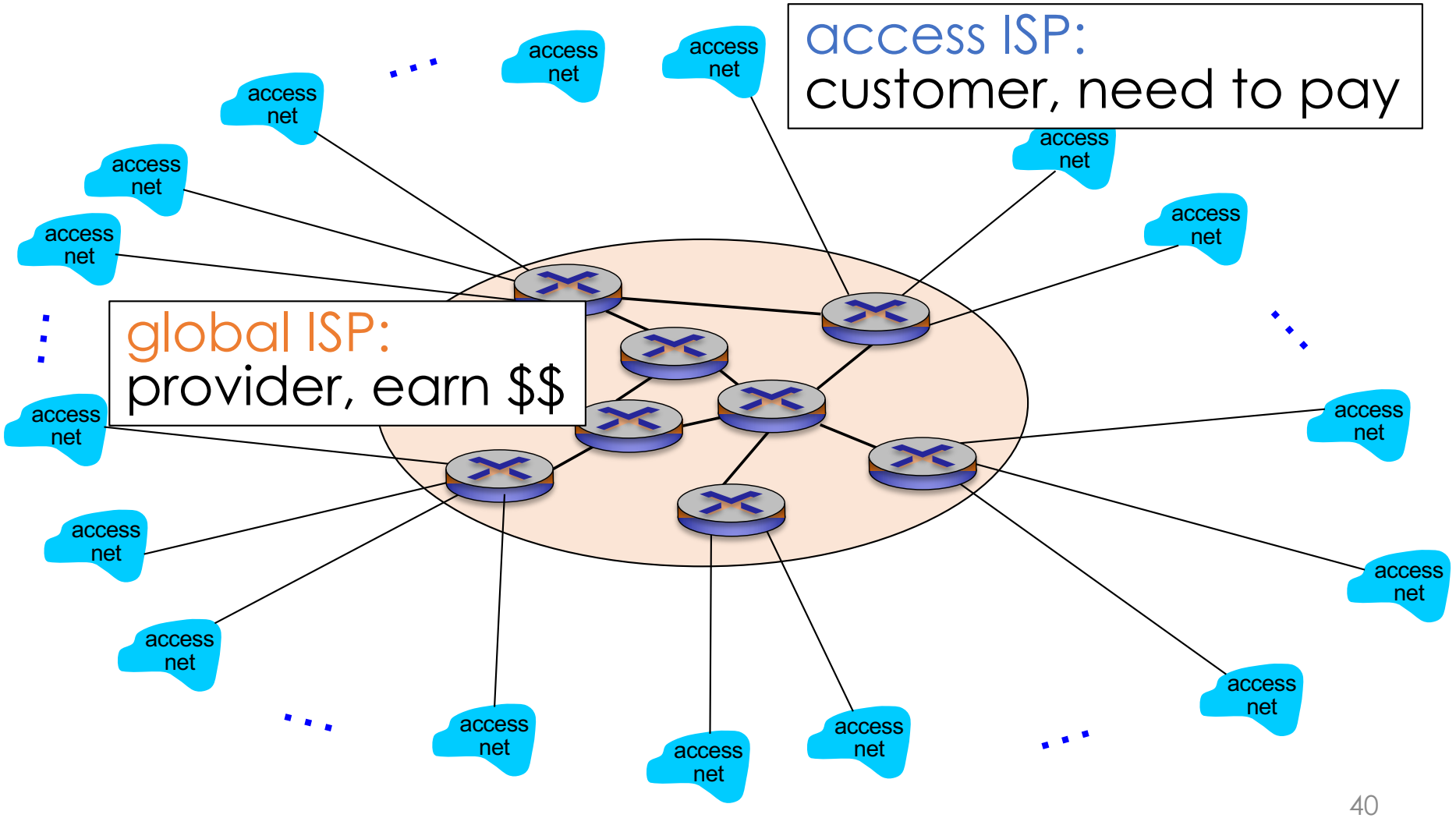
Option: connect each access ISP to every other access ISP?



Structure: 2-Tier Hierarchy

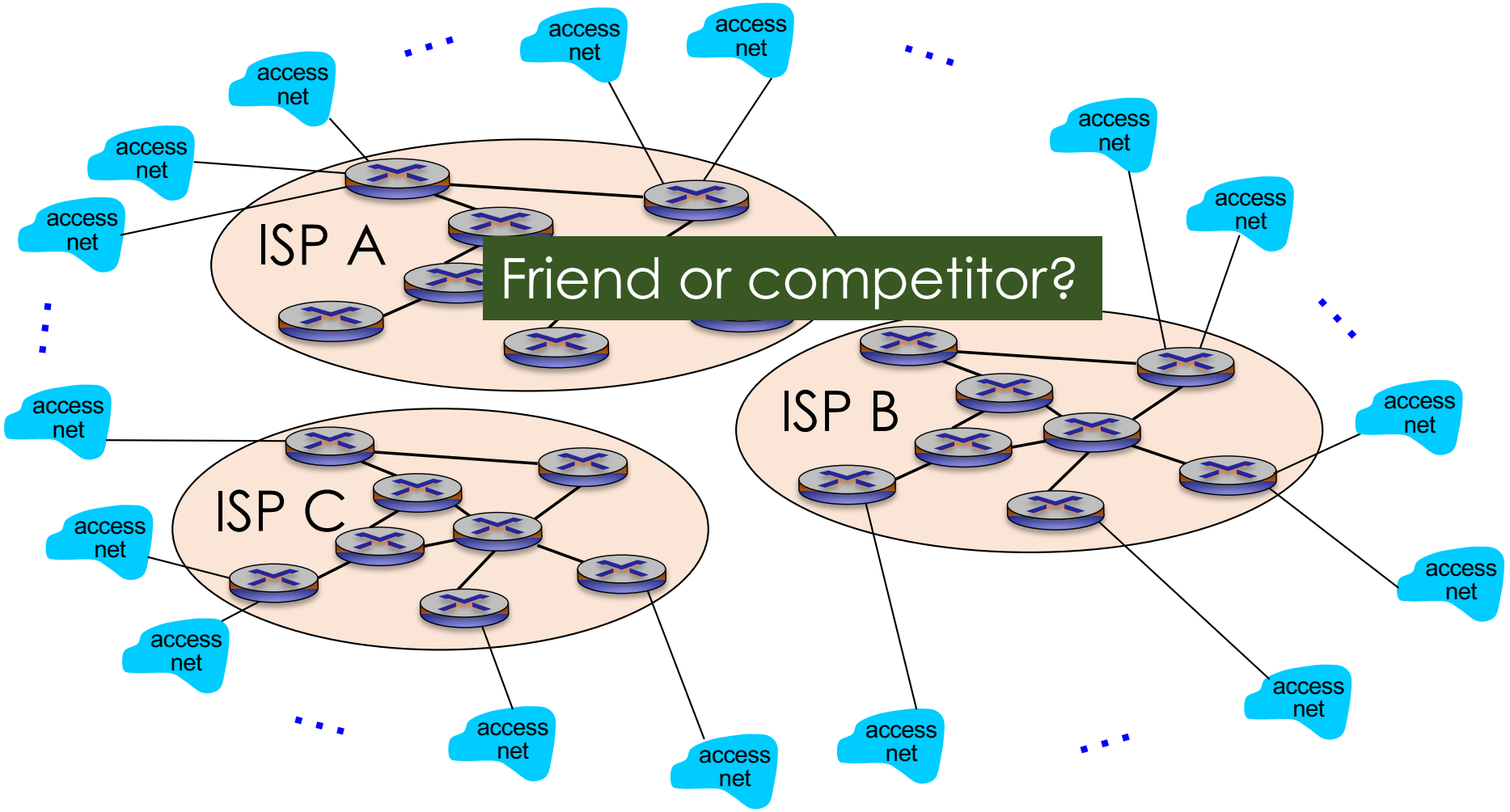
Q: Incentive?

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



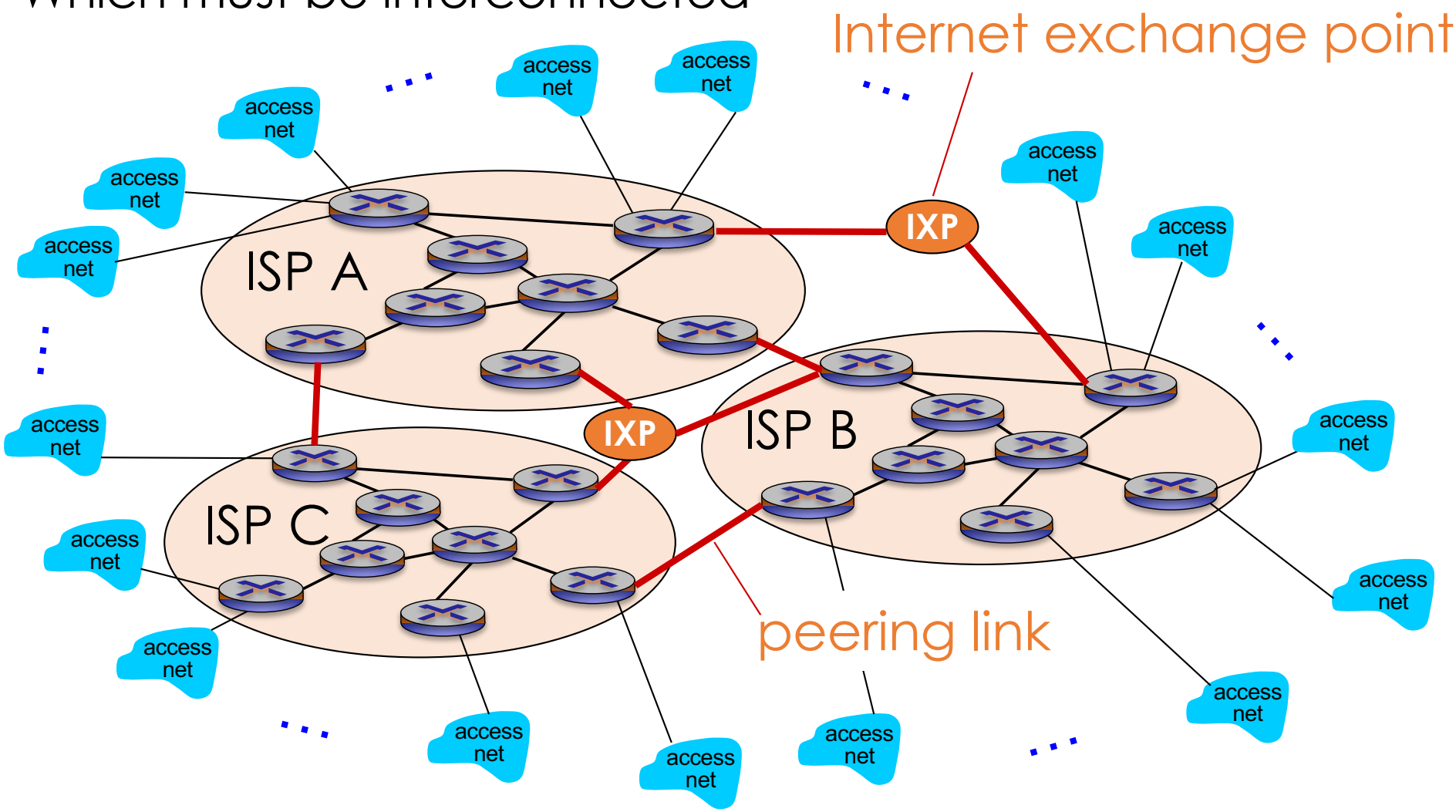
Structure: 2-Tier Hierarchy

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



Structure: 2-Tier Hierarchy

But if one global ISP is viable business, there will be competitors
→ Which must be interconnected



Structure: 2-Tier Hierarchy

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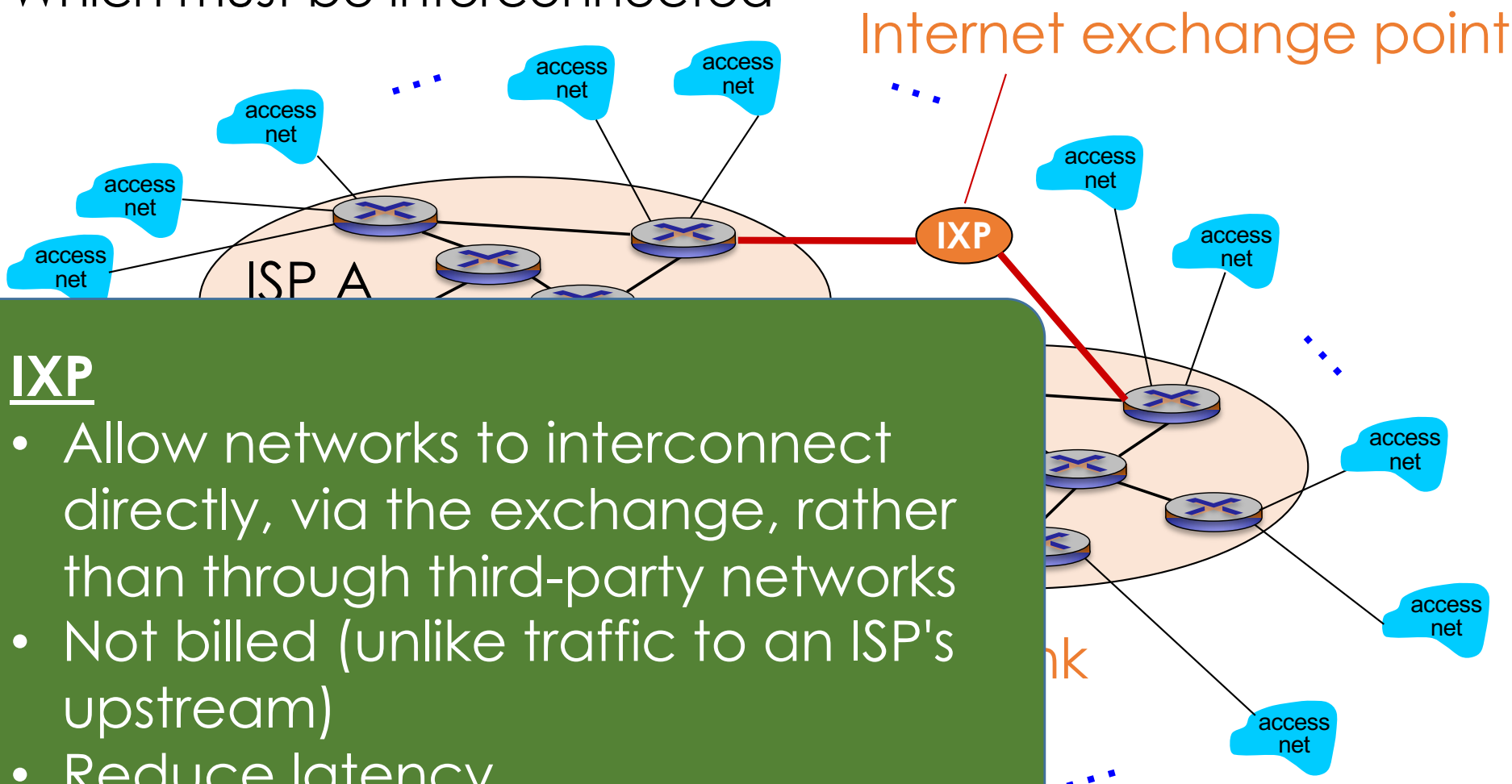


IXP

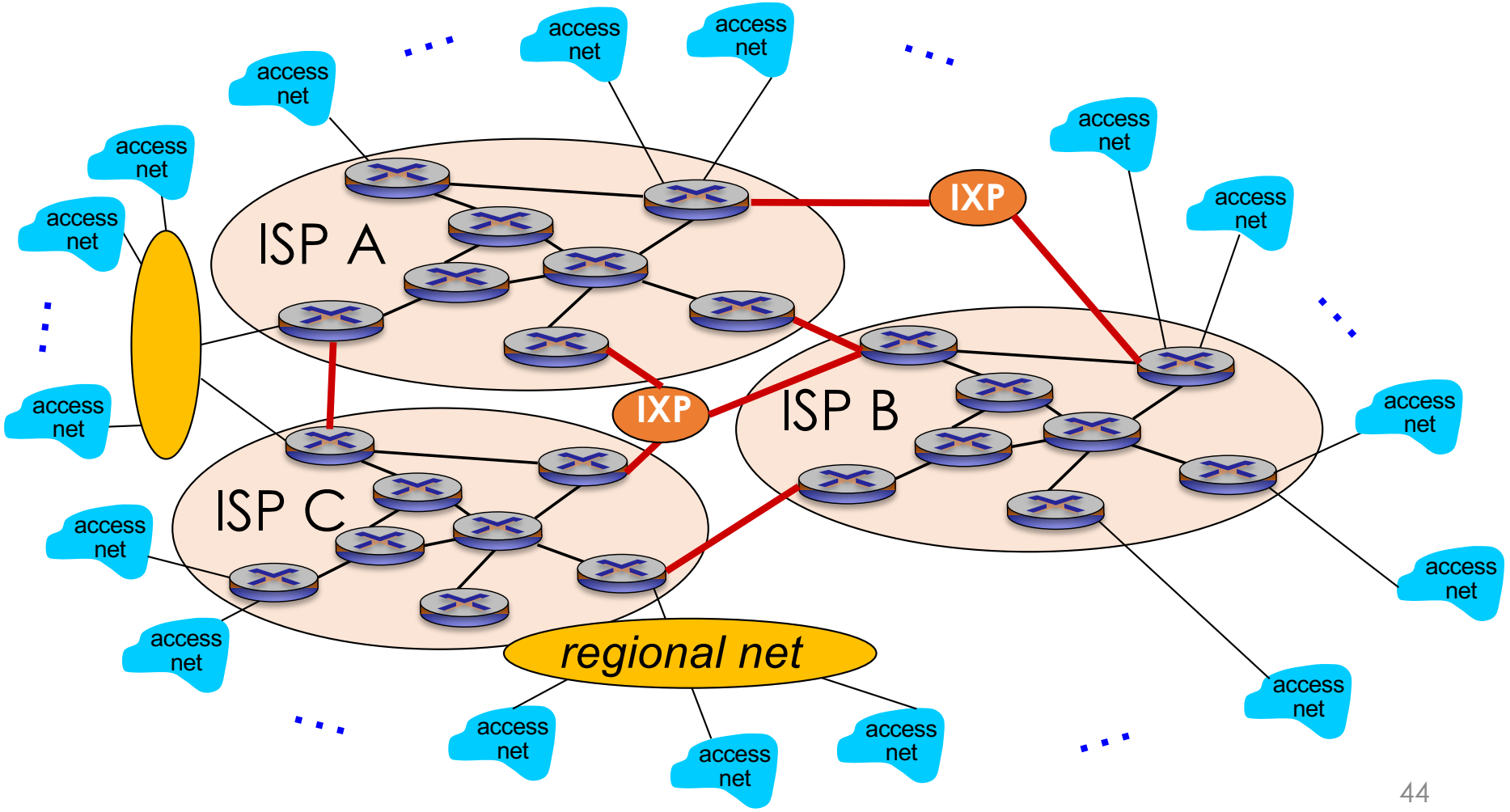
- Allow networks to interconnect directly, via the exchange, rather than through third-party networks
- Not billed (unlike traffic to an ISP's upstream)
- Reduce latency

Structure: Multi-Tier Hierarchy

Regional networks may arise to connect access nets to ISPs

→ Each access ISP pays the connected regional ISPs

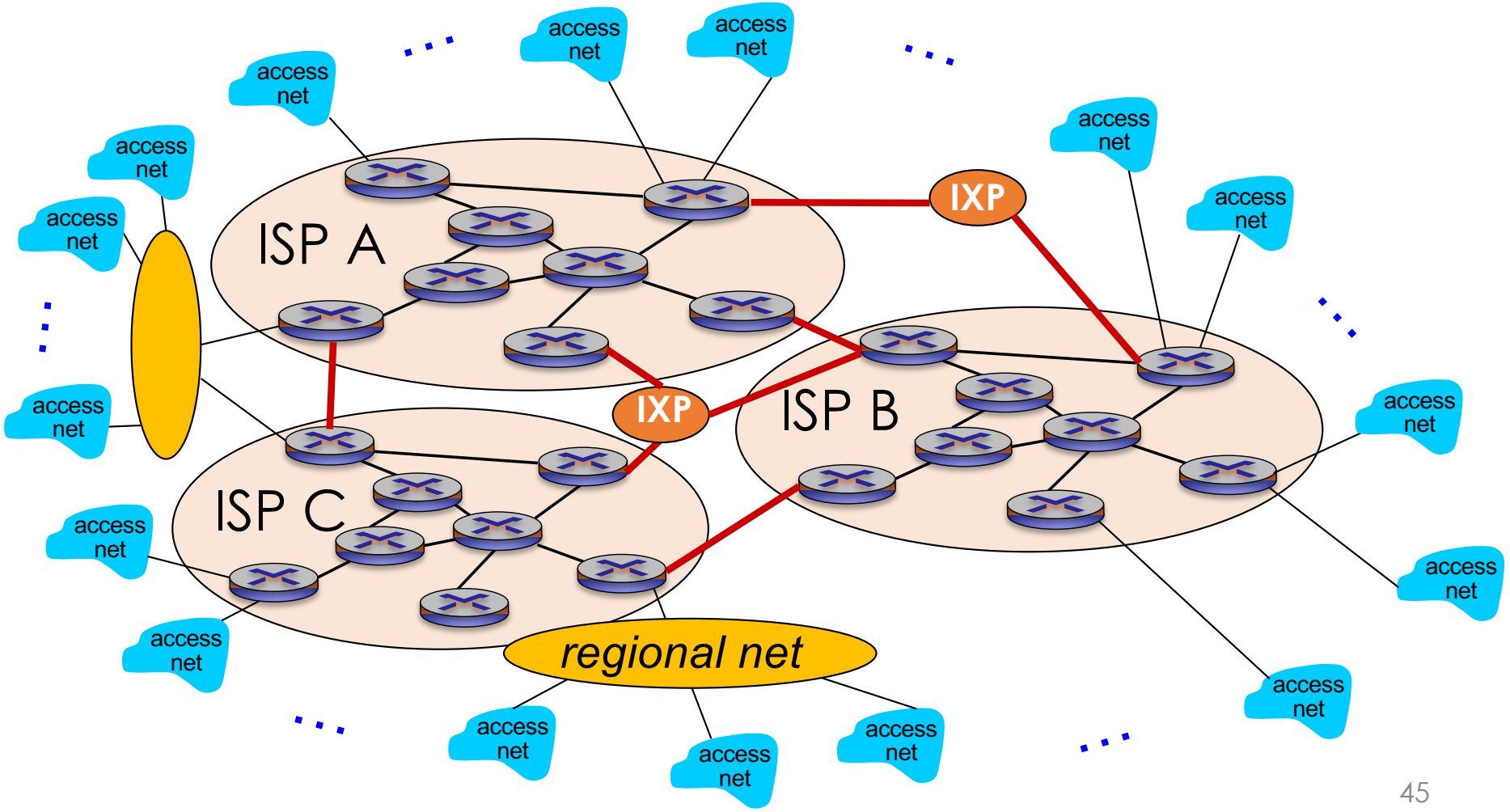
→ Each regional ISP pays tier-1 ISPs



Structure: Multi-Tier Hierarchy

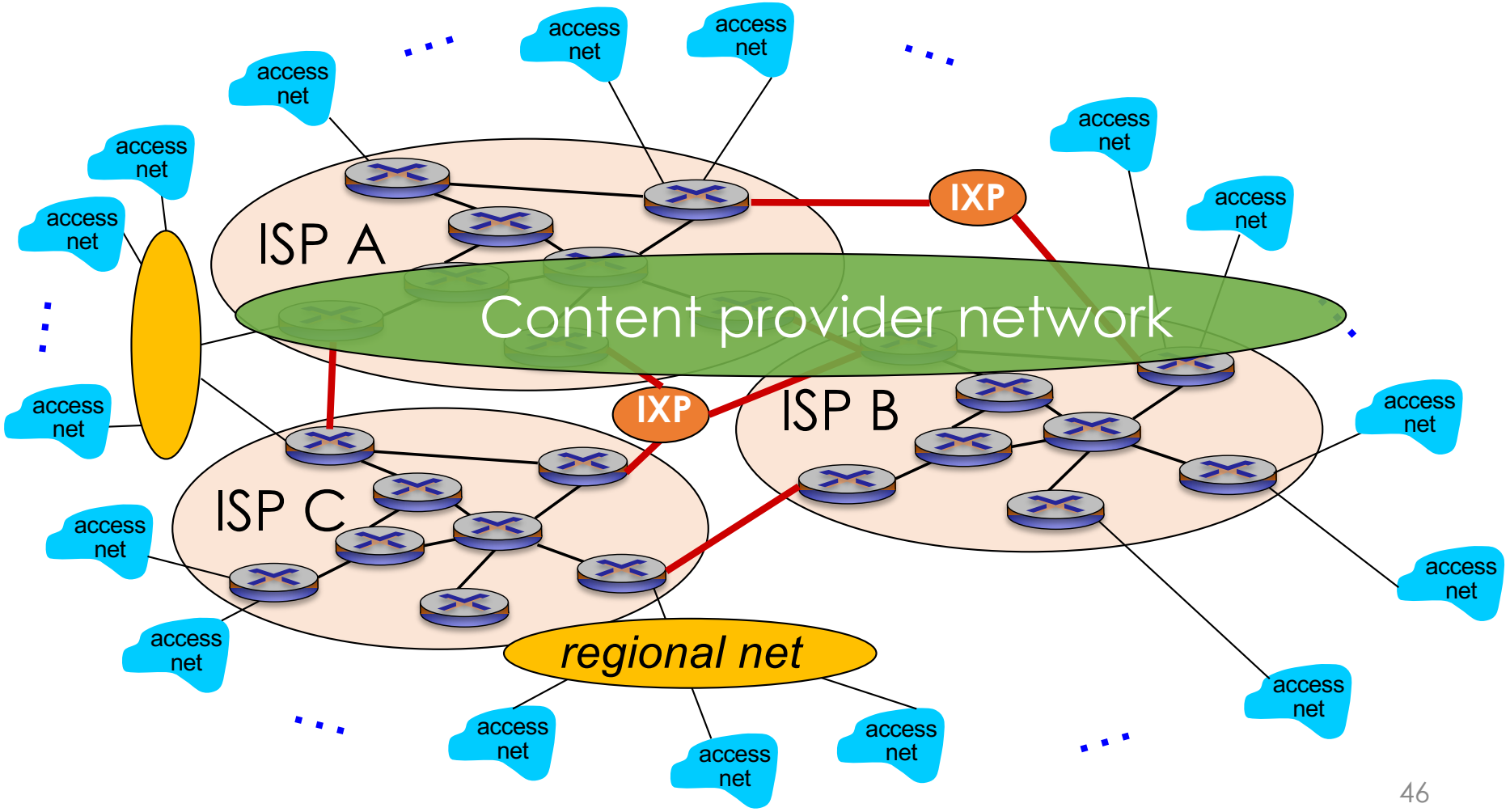
Multi-home:

An ISP may connect to several provider ISPs to ensure reliability



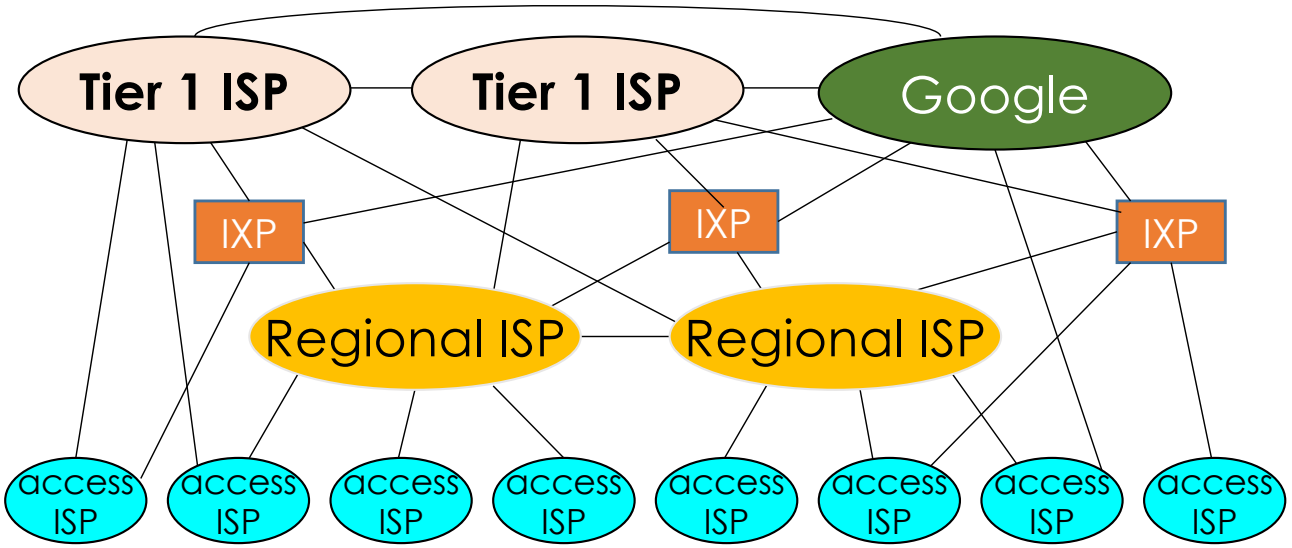
Structure: Content Provider Network

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



Structure: Content Provider Network

- At center: small number of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs



Tier-1 ISP: e.g., Sprint