CS 3800: Computer Networks

Lecture 1: Introduction

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Today’s Learning Goals

- Key terminology in Computer Networks
- A broad understanding
  - Details later in course
- Approach:
  - Use the Internet as the example to understand scale

Today's Topics

- What *is* the Internet?
- network edge
  - end systems, access networks, links
- network core
  - packet switching, circuit switching, network structure

What is a Computer Network?

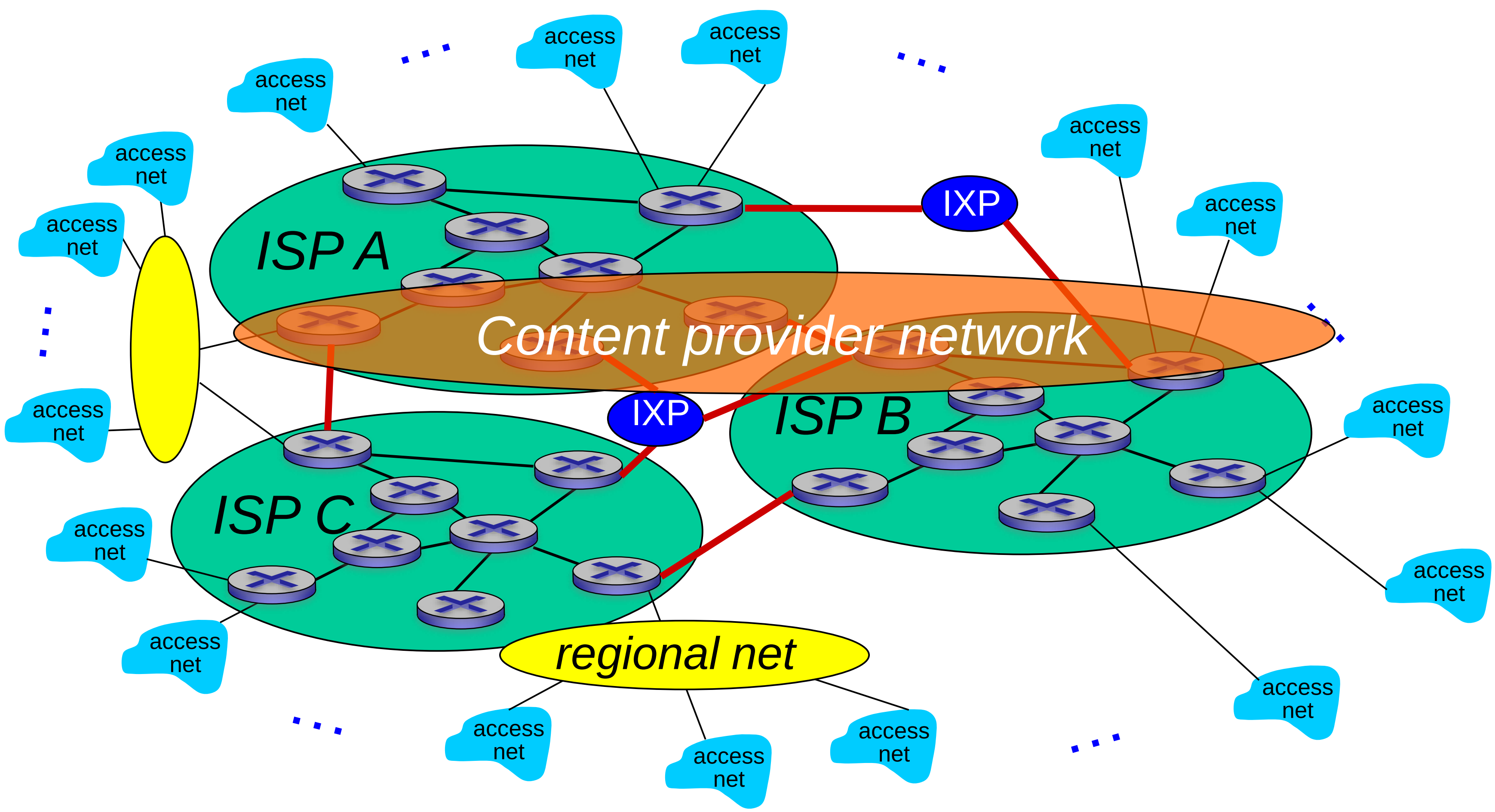
What is a Computer Network?

- Computer Network is a connection of a set of computers for the purpose of sharing data and resourcnces
- What Data?
- What resources?

The Internet

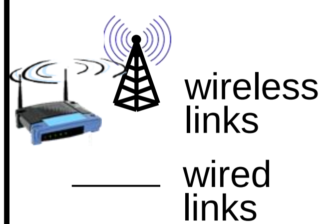
- The most famous network of all
- What is it?

Internet structure: network of networks

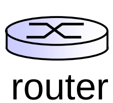


The Internet: "nuts and bolts" view

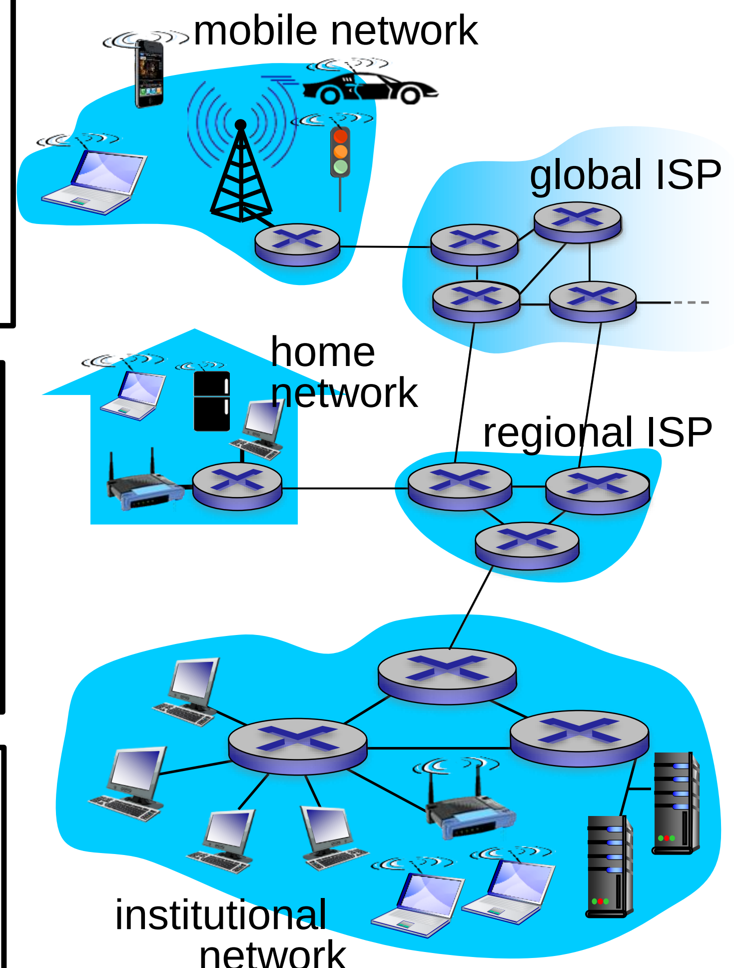
- billions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*



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



- *switches:* forward packets (chunks of data)
  - *routers* and *switches*



Internet vs WWW

- Are they the same?

Internet vs internet

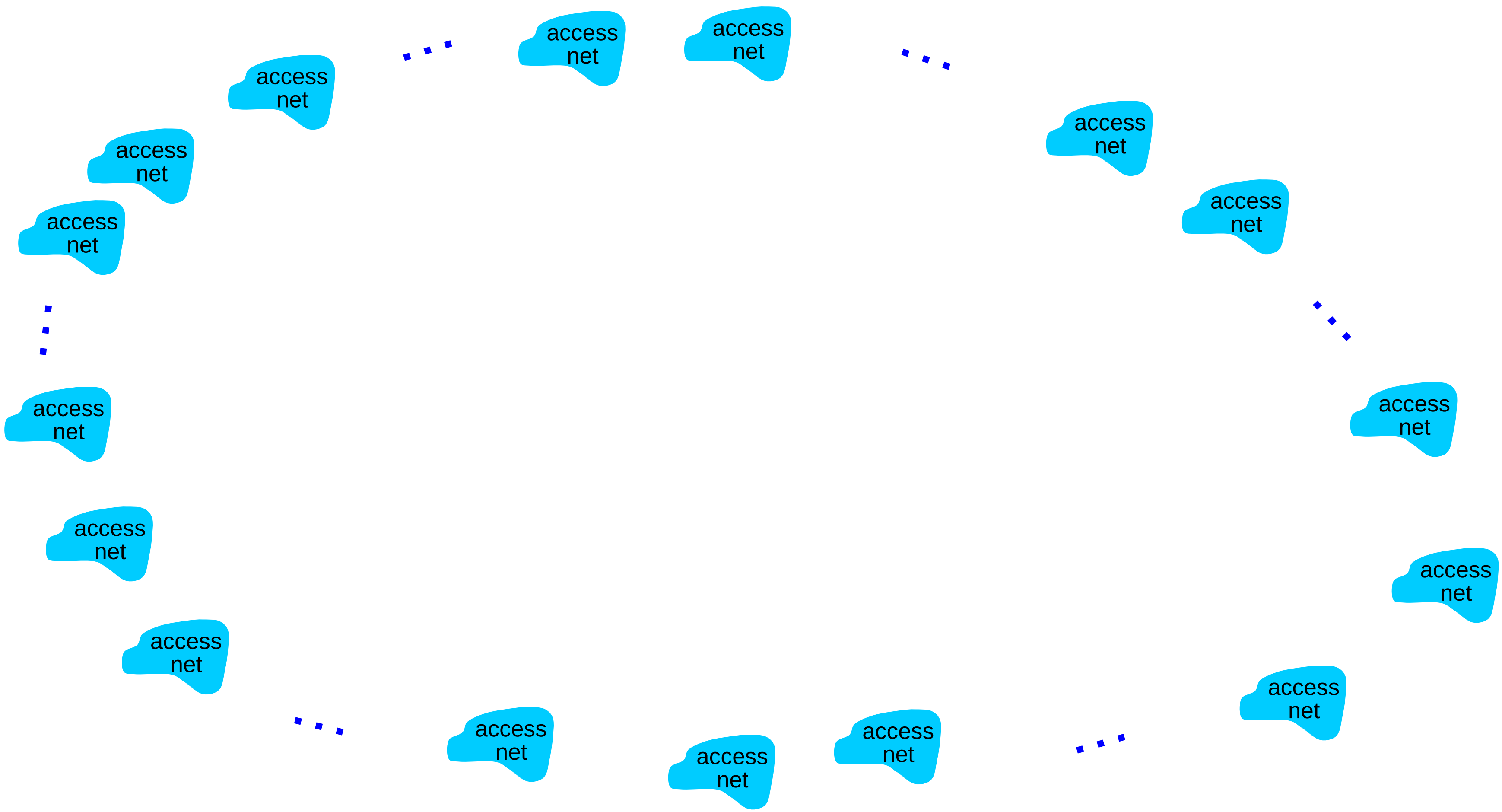
- What is the difference?

Internet vs Intranet

- What is the difference?

Internet structure: network of networks

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



Connecting Hosts

- How do we connect these communicating hosts?
- Connect each node to every other node

Connecting Hosts cont.

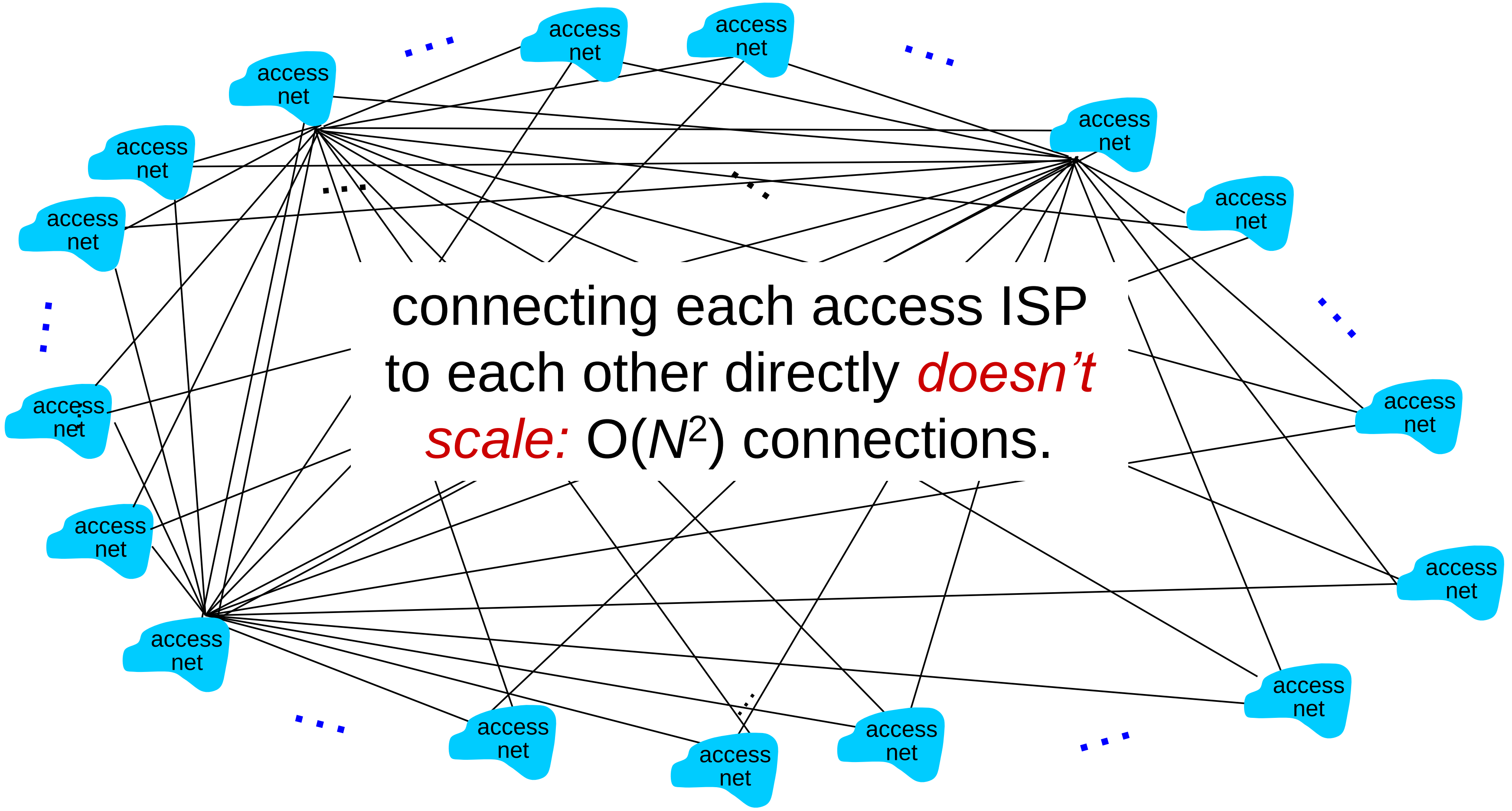
- Idea 1: Connect each pair of nodes
  - How many edges?
- Advantages: ?
- Disadvantages: ?

Connecting Hosts cont.

- Idea 1: Connect each pair of nodes
- Graph theory
  - Hosts are *edges*, connections are *vertices*
- **Complete Graph**, $k_n = \binom{n}{2}$
  - $K_2 = 1$
  - $K_4 = 6$
  - $K_7 = 21$
- Advantages: ?
- Disadvantages: ?

Internet structure: network of networks

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



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

Connecting Hosts cont.

- Other ideas?

Connecting Hosts cont.

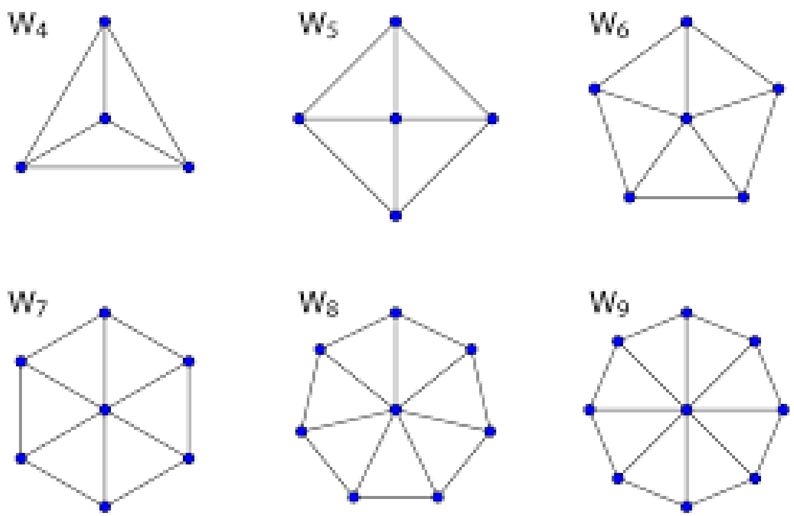
- Path Graph
  - How many connections are required?
  - How many hops to destination?

Connecting Hosts cont.

- **Cycle Graph**
  - A single cycle through all nodes
  - How many connections are required?
  - How many hops to destination?
  - In networking, this is referred to as a ring network.

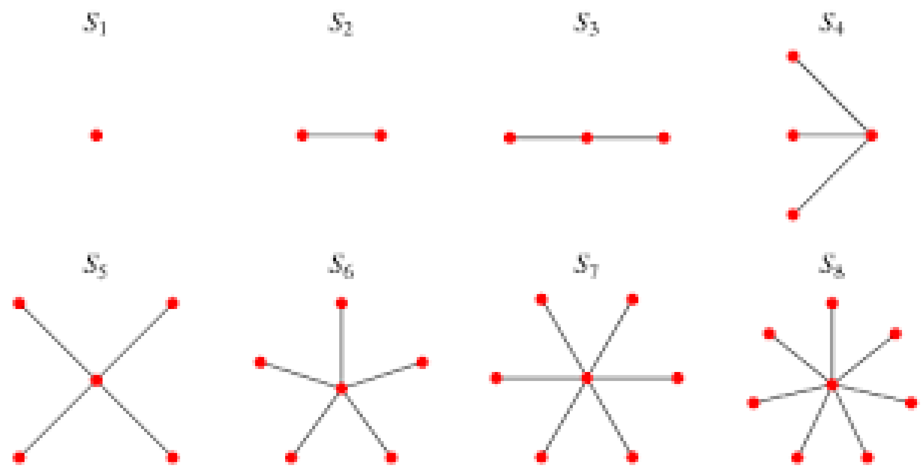
Connecting Hosts cont.

- **Wheel Graph**
  - How many connections are required?
  - How many hops to destination?



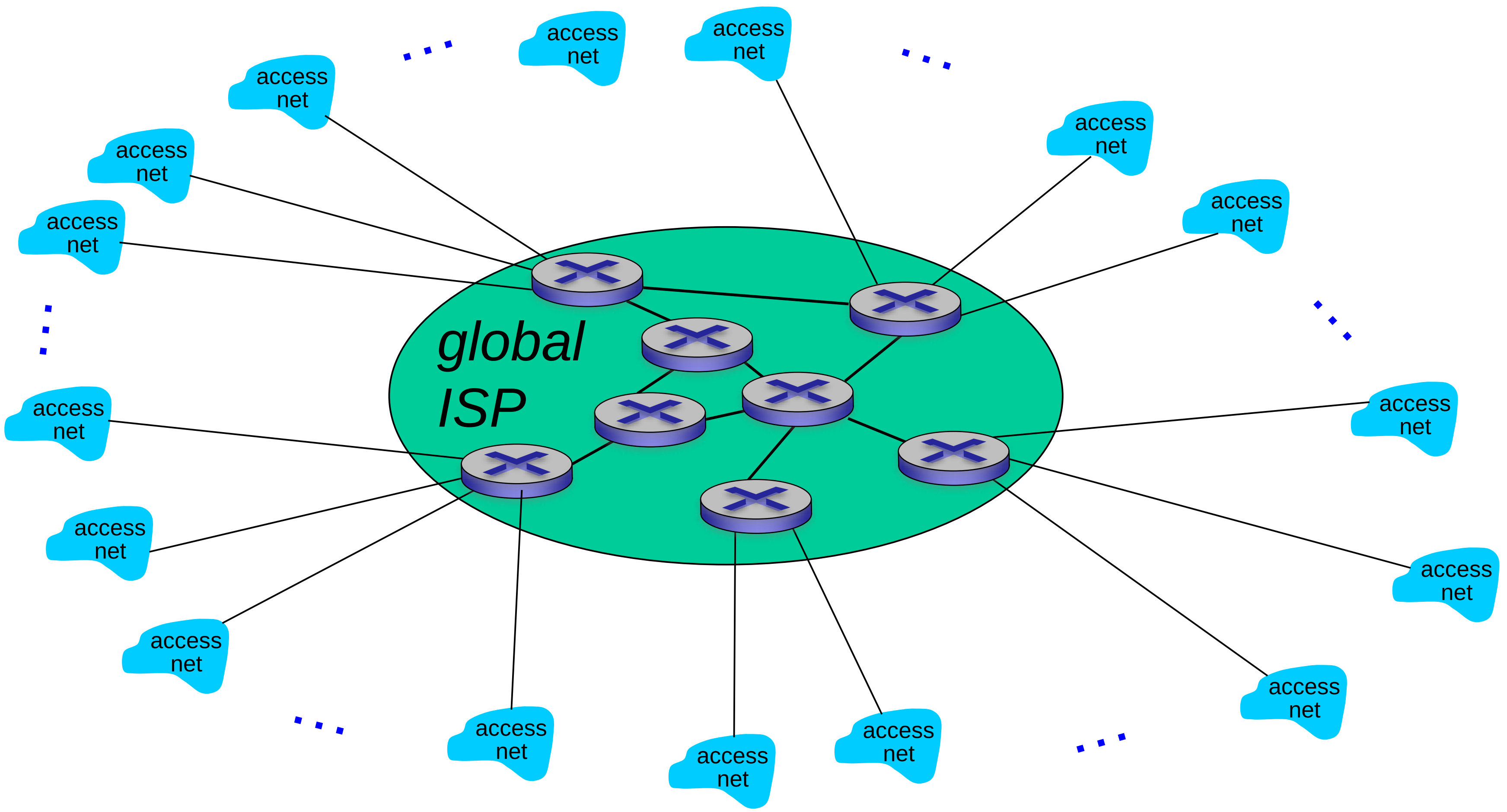
Connecting Hosts cont.

- Star Graph
  - How many connections are required?
  - How many hops to destination?



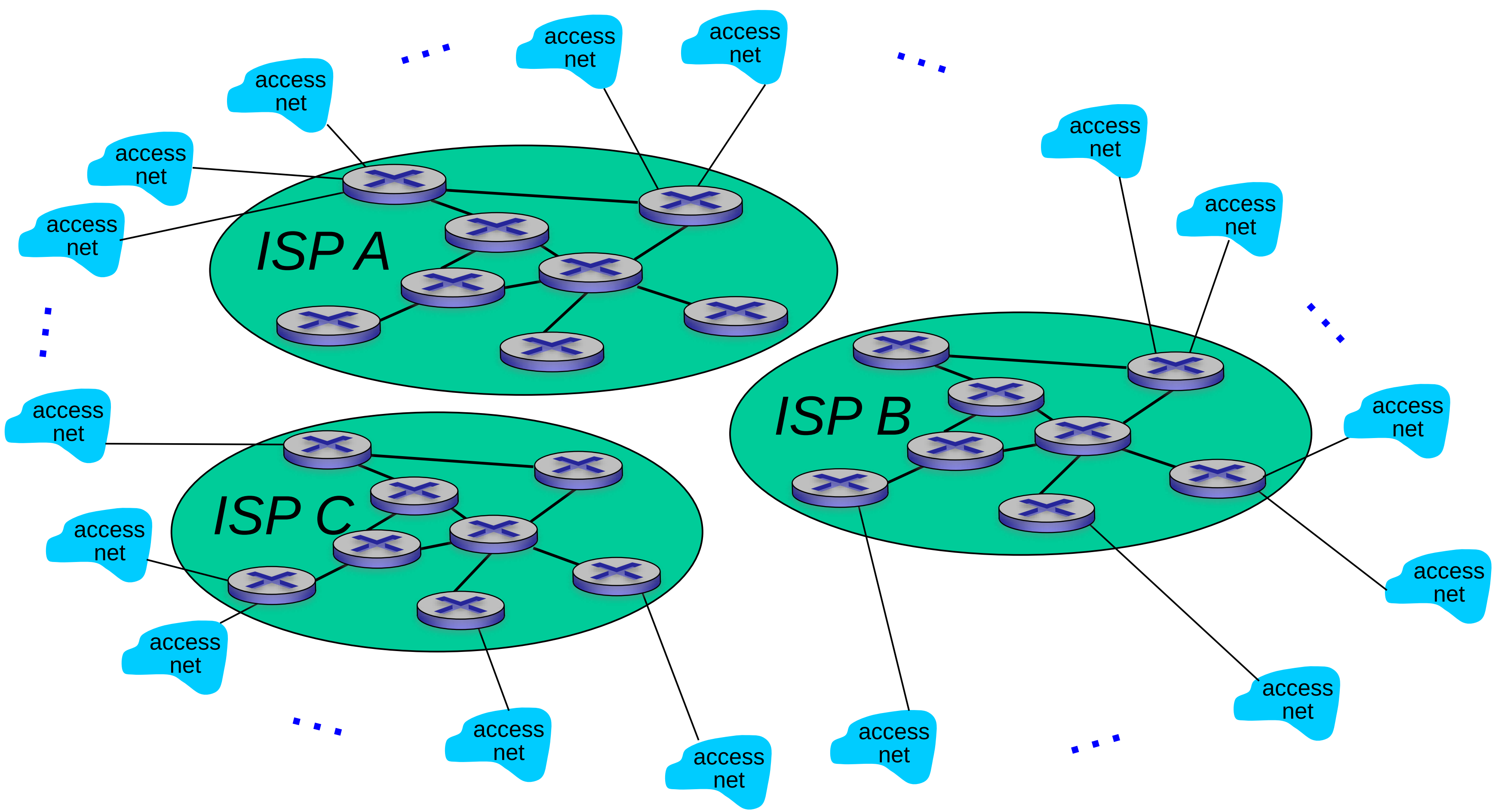
Internet structure: network of networks

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



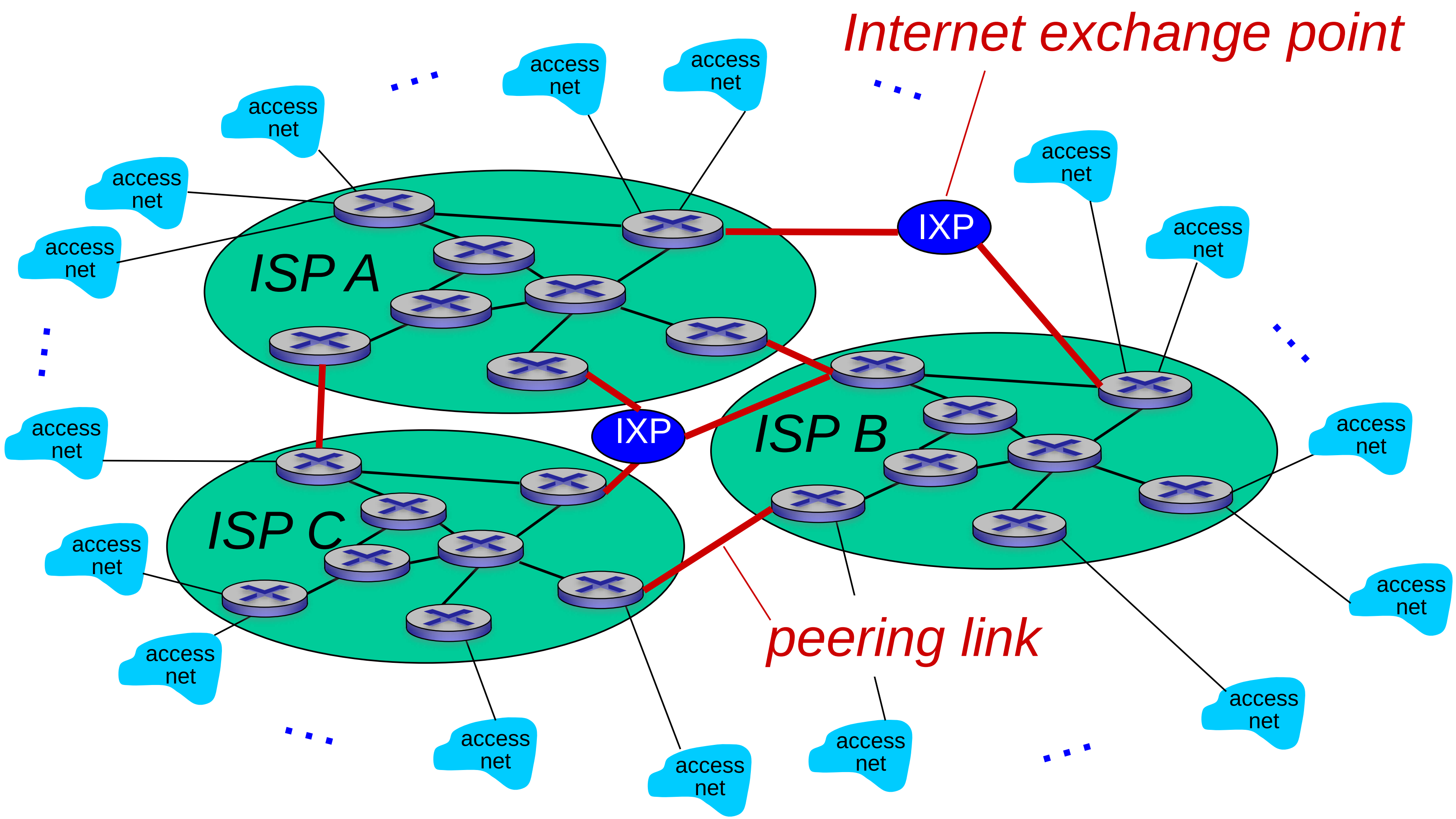
Internet structure: network of networks

But there are multiple global ISPs….



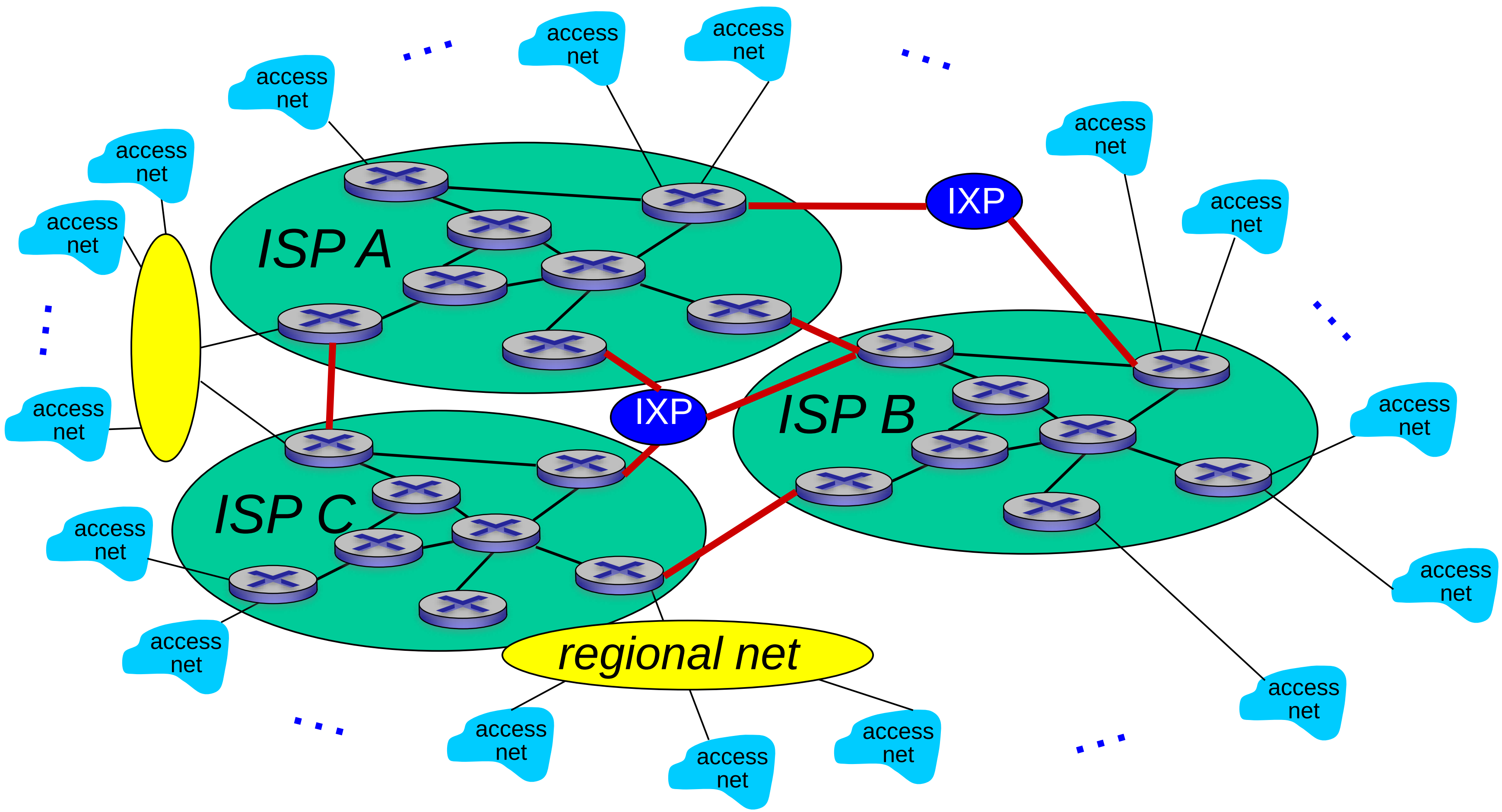
Internet structure: network of networks

But there are multiple global ISPs........ which must be interconnected



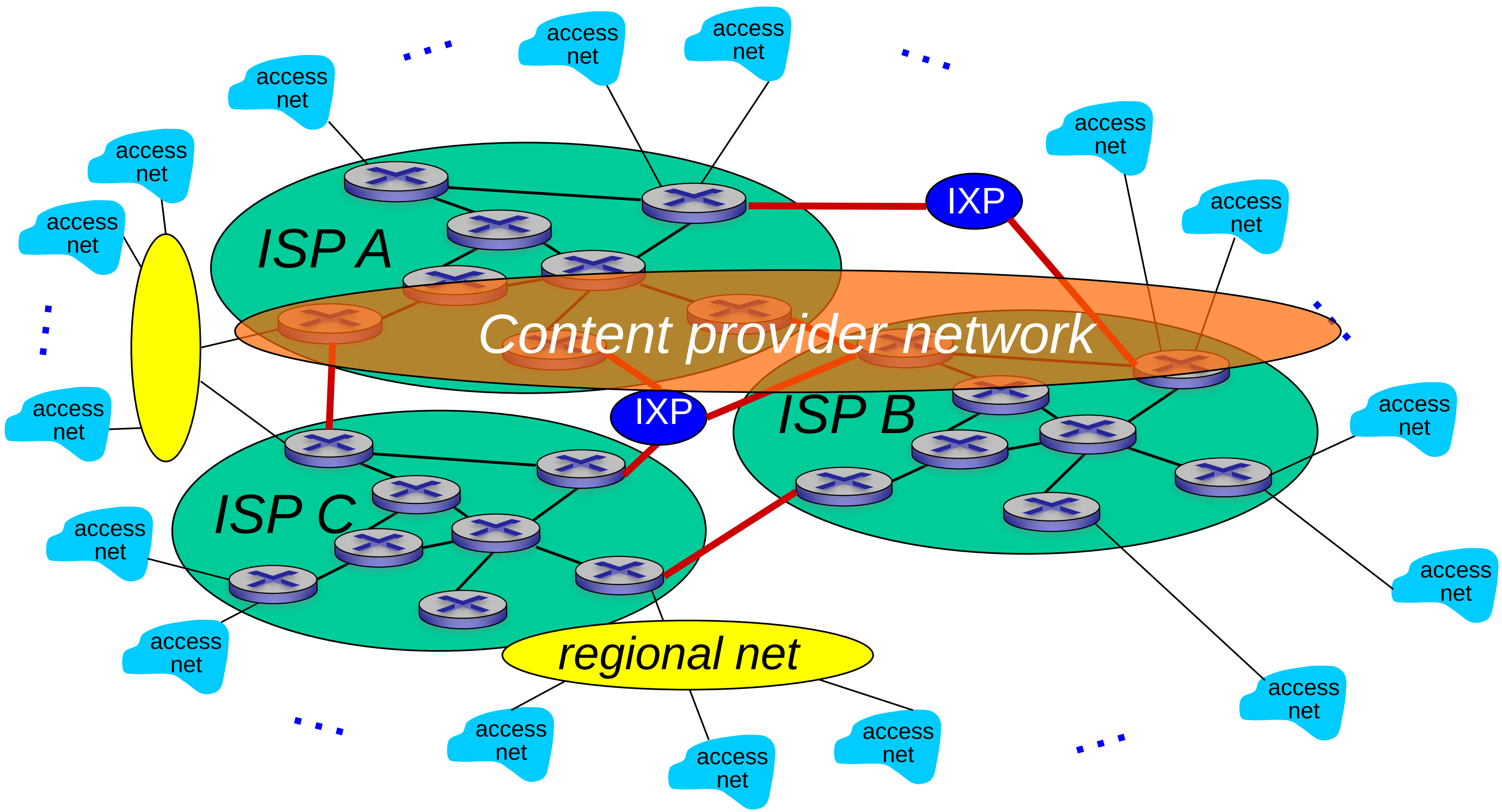
Internet structure: network of networks

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

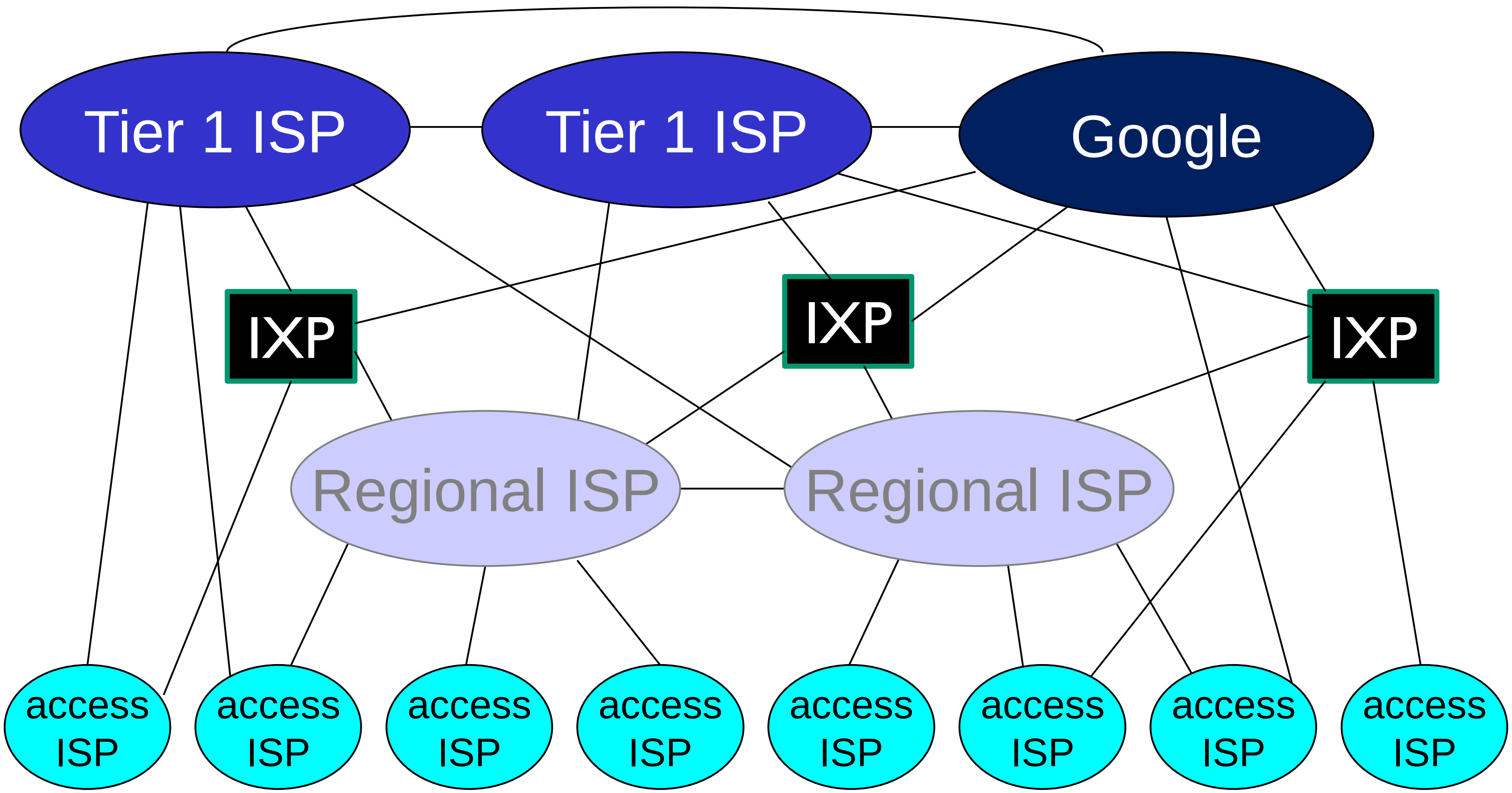


Internet structure: network of networks

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



Internet structure: network of networks

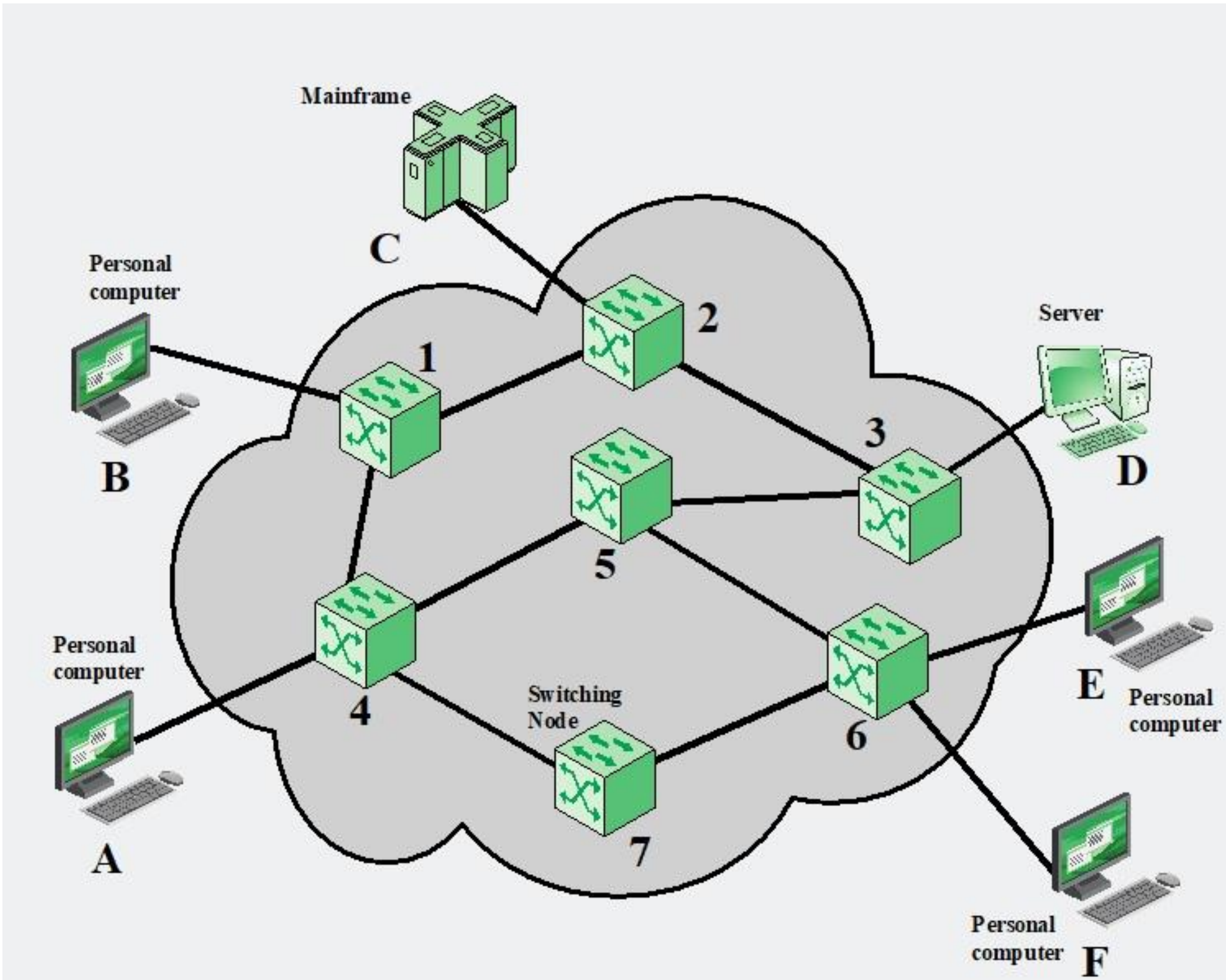


- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Switched Communications Networks

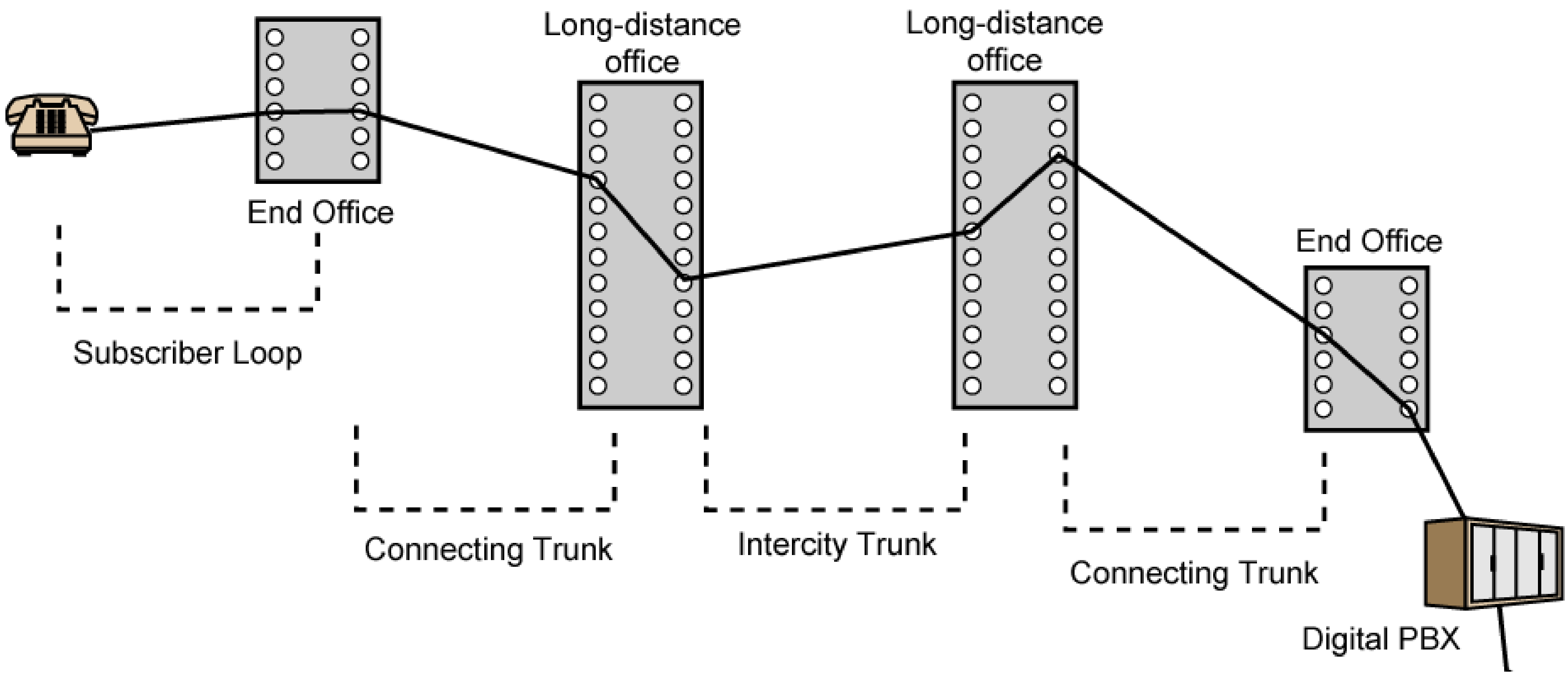
- Long distance transmission between hosts is typically done over a network of **switching nodes**.
- Switching nodes do not concern with content of data. Their purpose is to provide a switching facility that will move the data from node to node until they reach their destination (the destination host).
- A collection of nodes and connections forms a communications network.
- In a switched communications network, data entering the network from a station are **routed** to the destination by being switched from node to node.

Switching Network



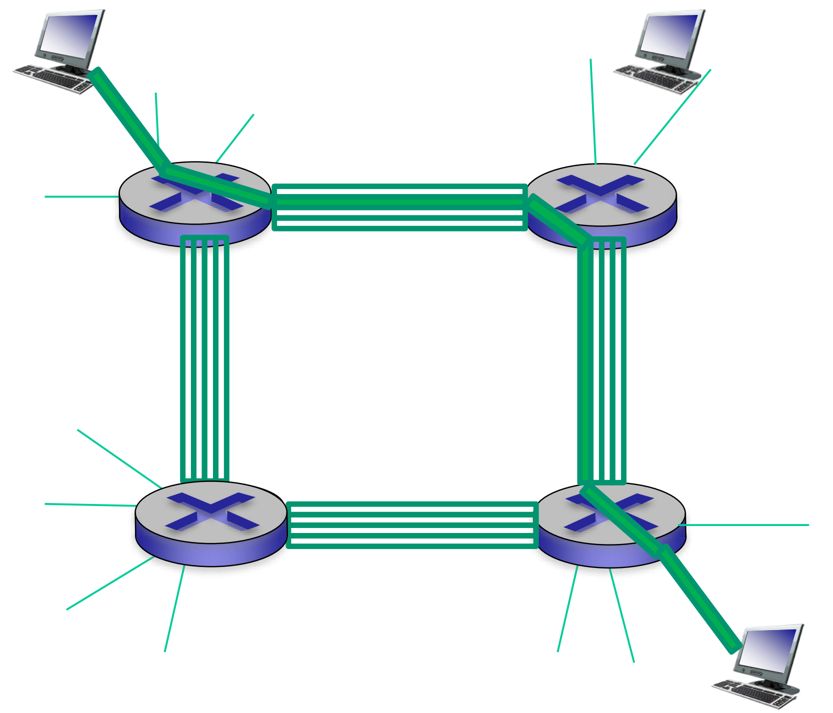
A – F: Hosts 1 – 7 : Switching nodes

Circuit Switched Telephone Network



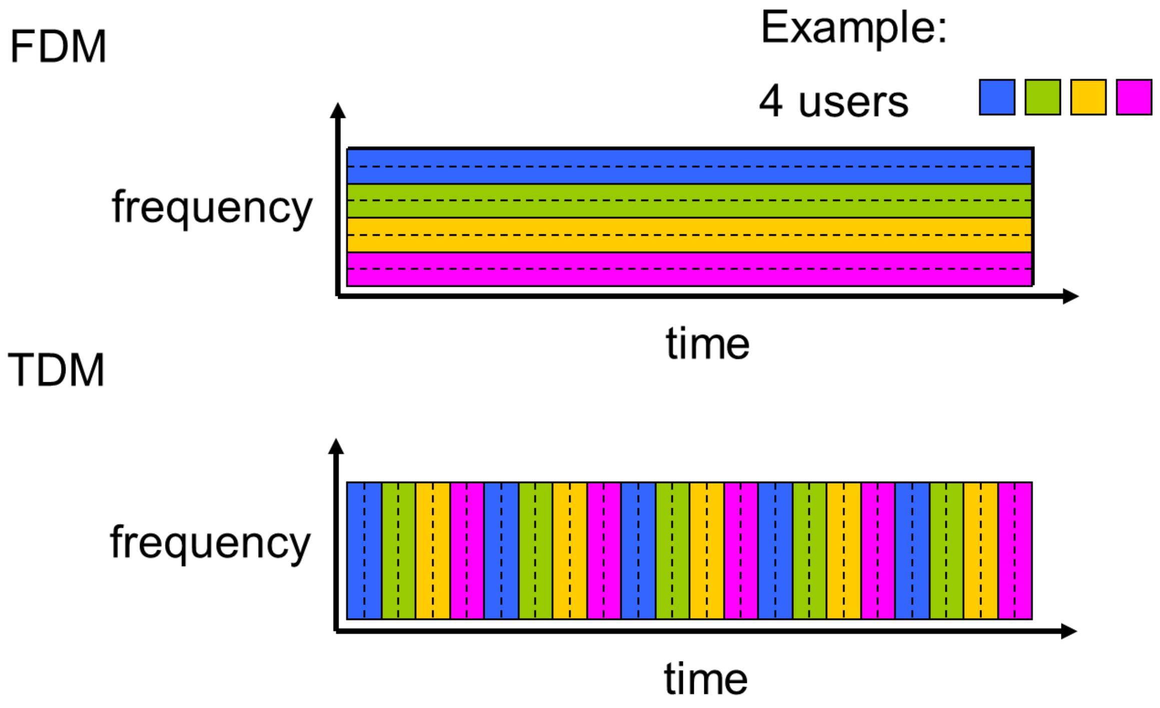
Circuit Switching

- The "old way"
- End-to-end resources are reserved for duration of "call"
- Dedicated communication path between two stations
- Three phases
  - Establish connection
  - Transfer
  - Disconnect
- Commonly used in traditional telephone networks



FDM versus TDM

- Network resources (e.g., bandwidth) is divided into pieces
  - These pieces are allocated to calls
  - Resource is *idle* if owning call is not using resource
- Dividing communication link bandwidth into pieces
  - Time Division Multiplexing (**TDM**)
  - Frequency Division Multiplexing (**FDM**)



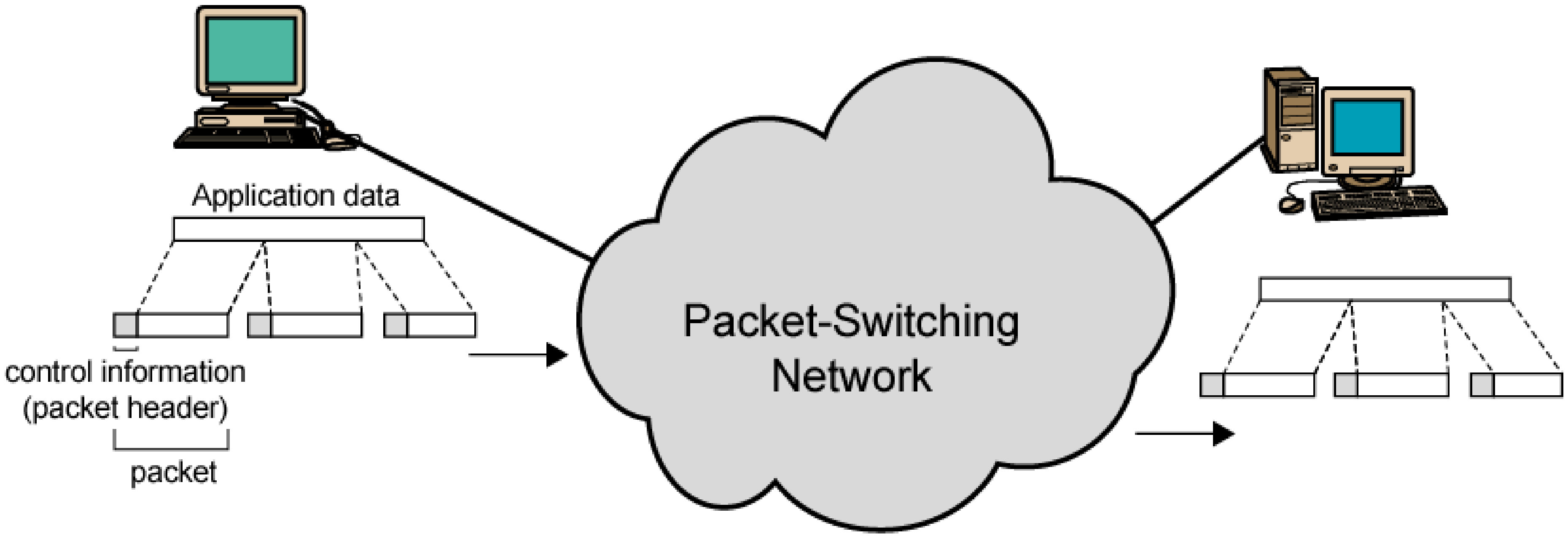
Circuit Switching - Applications

- Advantages:
  - Resources are dedicated for a single “call”
    - no sharing
    - circuit segment idle if not used by call
    - call setup is required
  - *Performance can be guaranteed*
- Disadvantages:
  - Inefficient
    - Channel capacity dedicated for duration of connection
    - If no data, capacity wasted
  - Set up (connection) takes time
  - Once connected, transfer is transparent
  - Developed for voice traffic (phone)

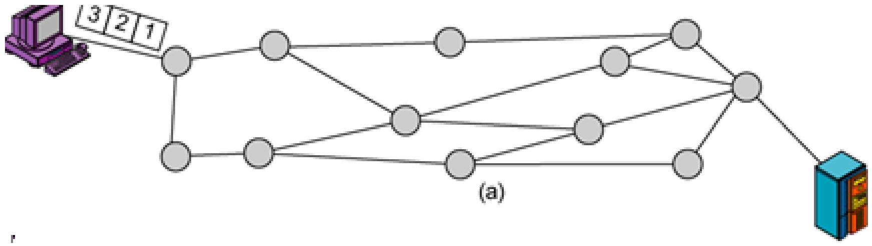
Packet Switching

- Data transmitted in small packets
  - Longer messages split into series of packets
  - Each packet contains a portion of user data plus some control info
- Control info
  - Routing (addressing) info
- Packets are received, stored briefly (buffered) and past on to the next node
  - Store and forward

Packet Switching

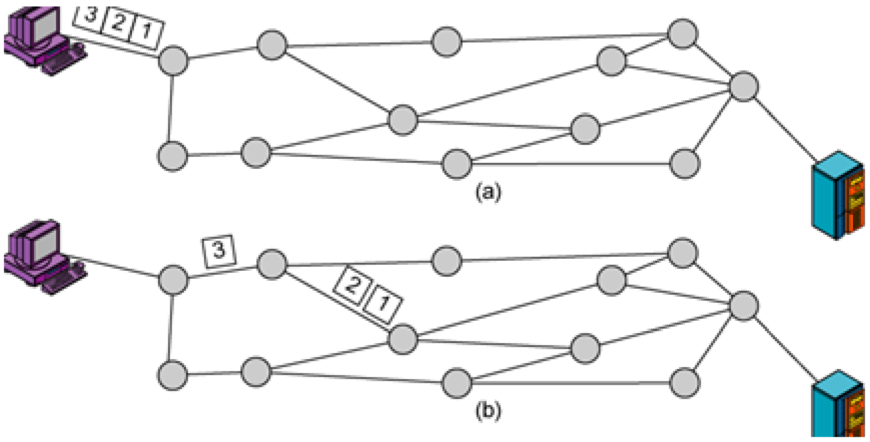


Packet Switching

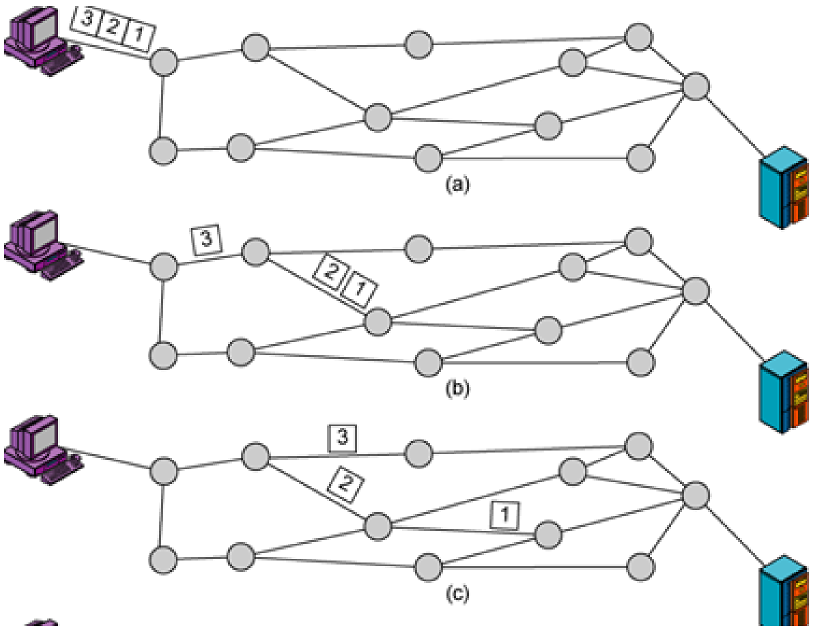


(a)

Packet Switching



Packet Switching



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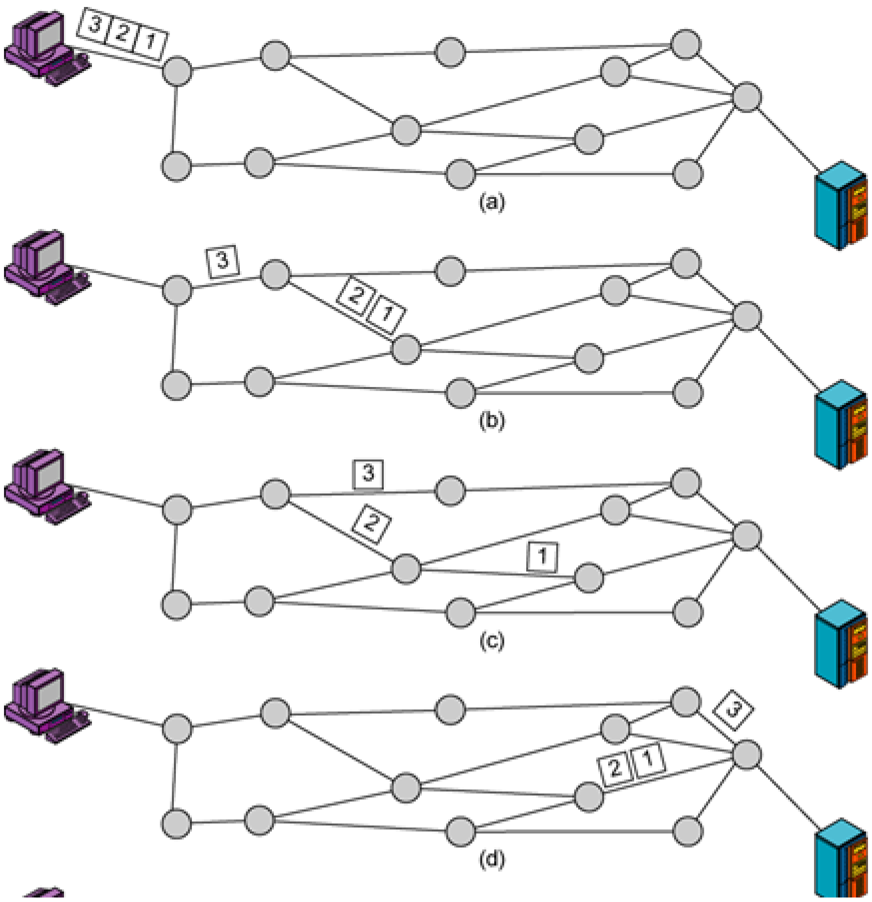

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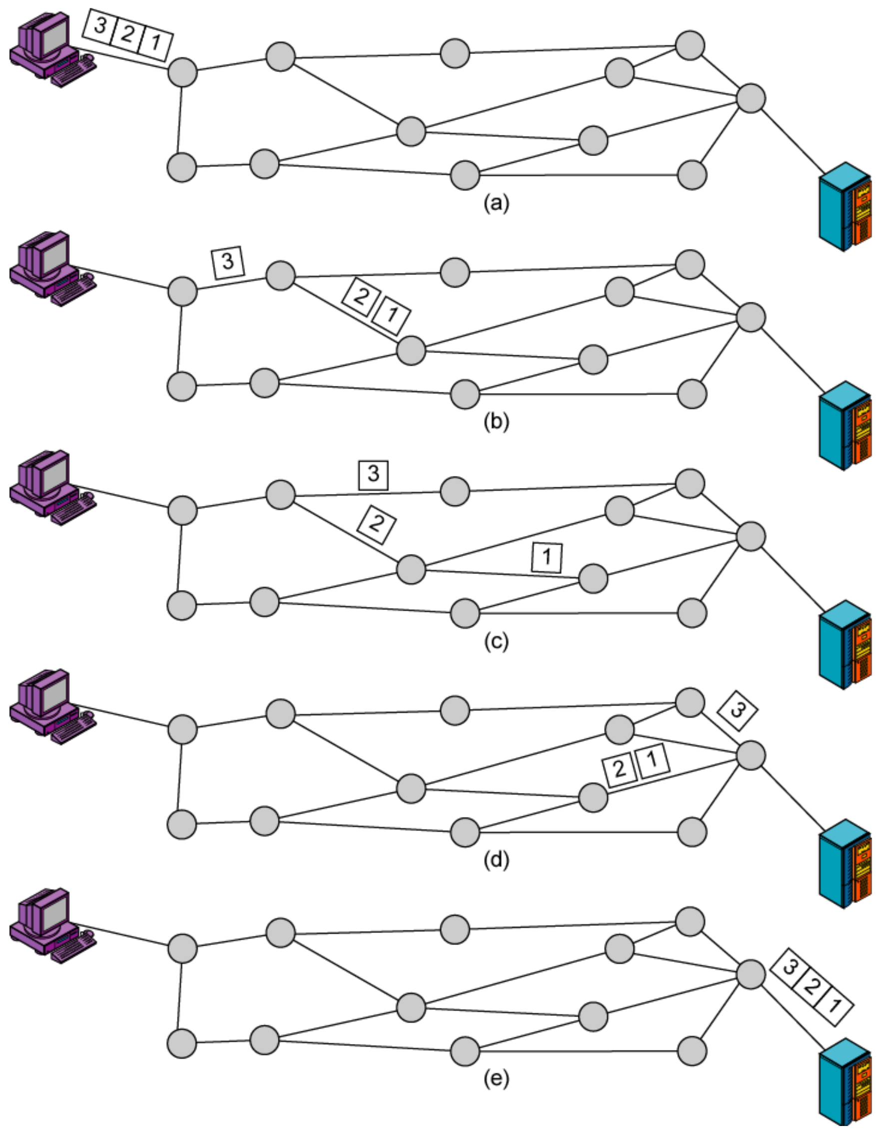
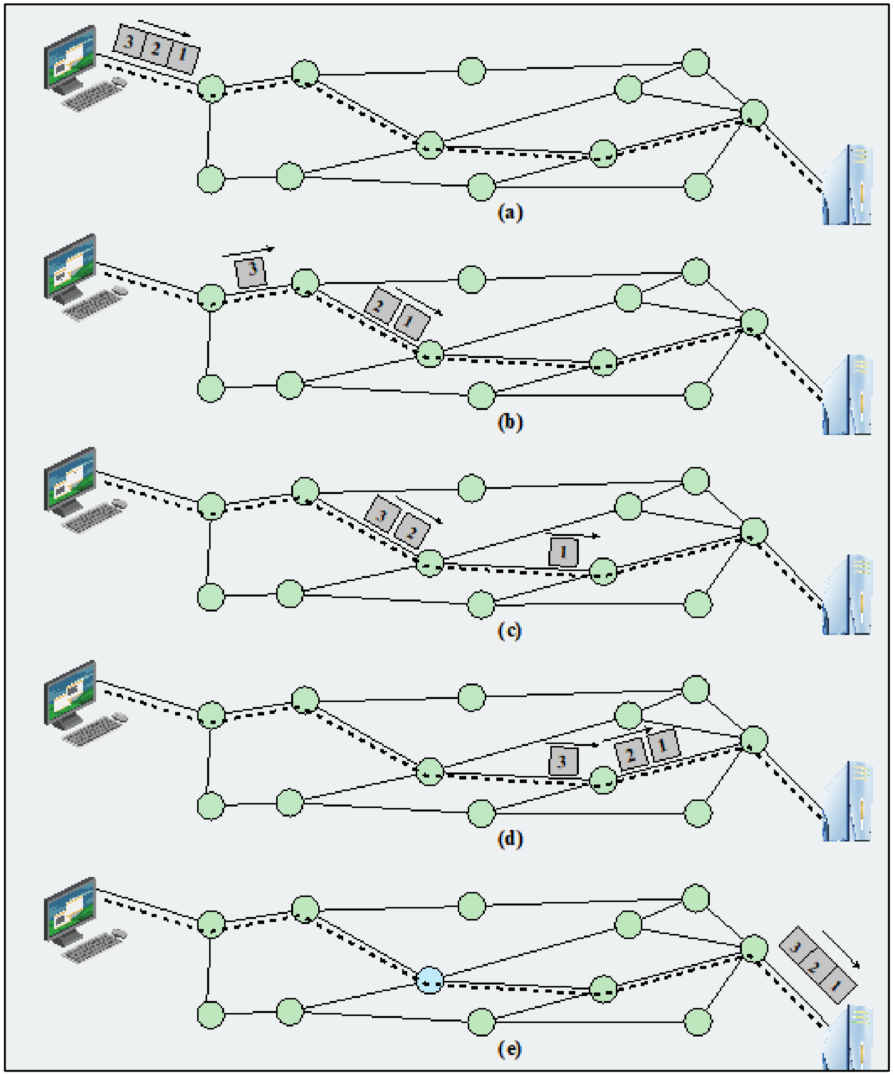
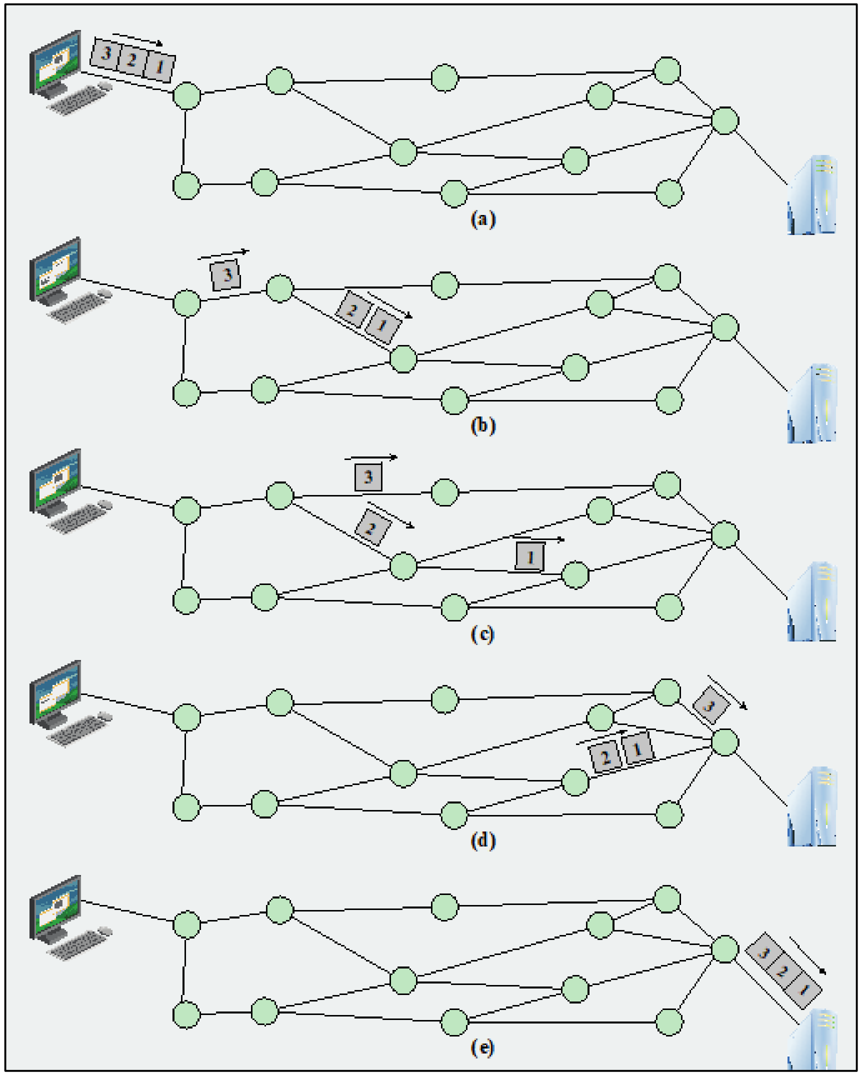


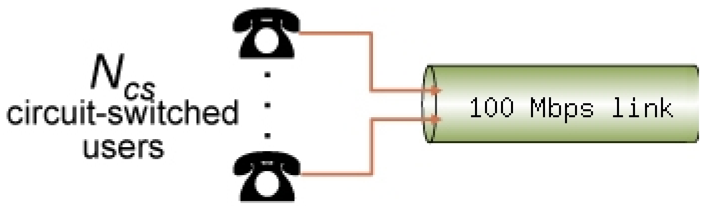




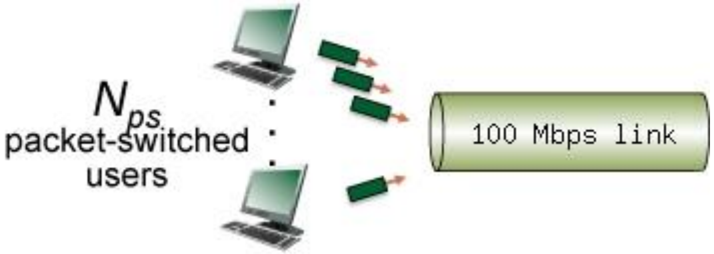
Circuit Switching

Packet Switching

Quantitative Comparison of Packet Switching and Circuit Switching



a) Circuit Switching



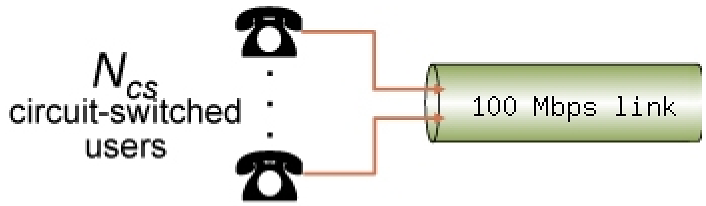
b) Packet Switching

Consider the two scenarios:

a) A circuit-switching scenario in which a set of users N_{cs}, each requiring a bandwidth of 10 Mbps, must share a link of capacity 100 Mbps.

b) A packet-switching scenario in which a set of users N_{ps} , sharing a 100 Mbps link, where each user again requires 10 Mbps when transmitting, but only needs to transmit 30 percent of the time.

Quantitative Comparison of Packet Switching and Circuit Switching



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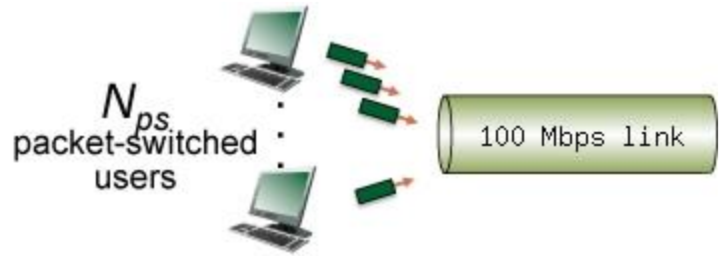

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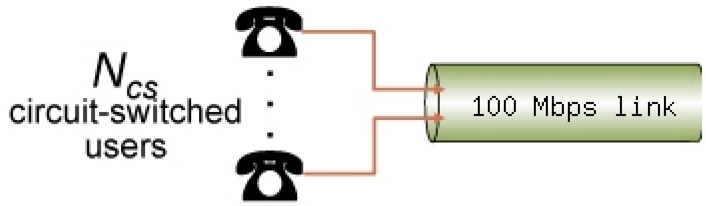
Q: When circuit switching is used, what is the maximum number of circuit-switched users that can be supported?

Quantitative Comparison of Packet Switching and Circuit Switching



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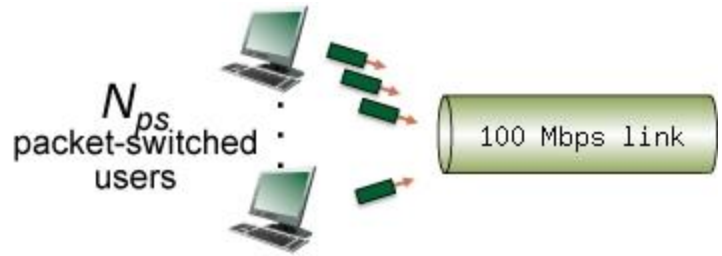

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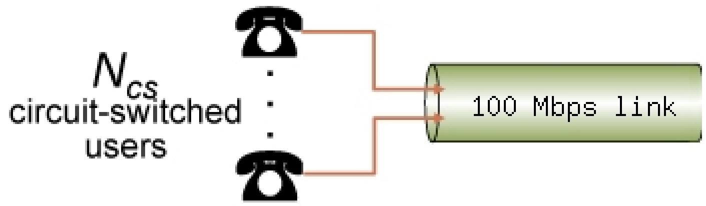
Q: Suppose there are 19 packet-switching users (i.e., $|N_{ps}| = 19$). Can this many users be supported under circuit-switching?

Quantitative Comparison of Packet Switching and Circuit Switching



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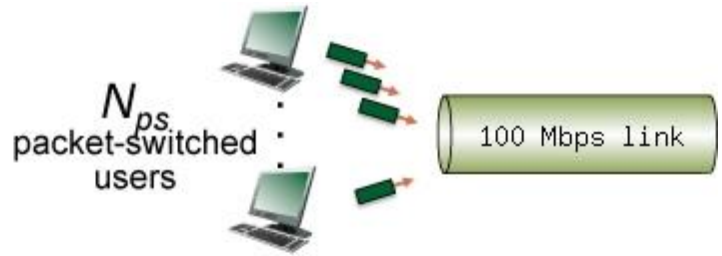

b) Packet Switching

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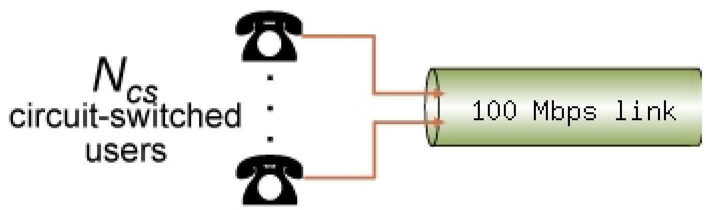
b) A packet-switching scenario with N_{ps} users sharing a 100 Mbps link, where each user again requires 10 Mbps when transmitting, but only needs to transmit 30 percent of the time.

Q: What is the probability that a given (*specific*) user is transmitting, and the remaining users are not transmitting? Assume $N_{ps} = 19$

Quantitative Comparison of Packet Switching and Circuit Switching



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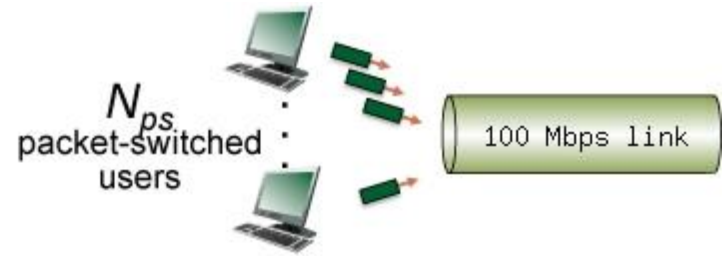

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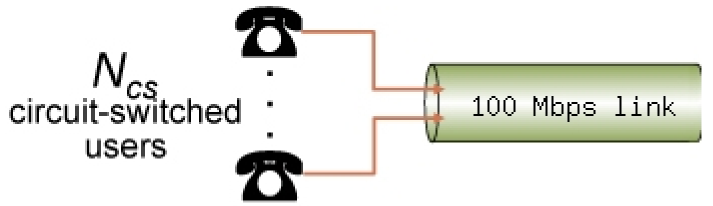
Q: What is the probability that one user (*any* one among the 19 users) is transmitting, and the remaining users are not transmitting? When one user is transmitting, what fraction of the link capacity will be used by this user?

Quantitative Comparison of Packet Switching and Circuit Switching



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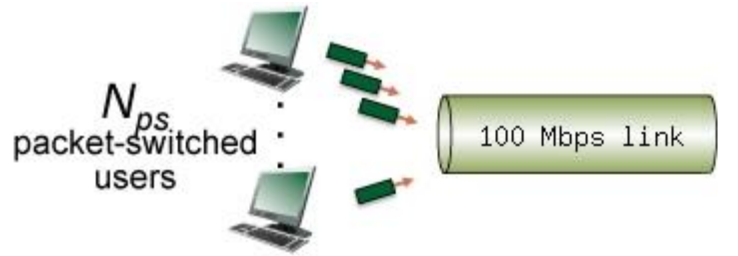

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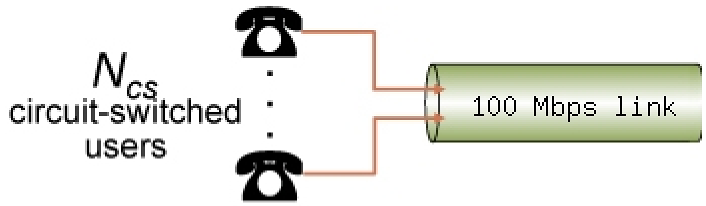
Q: What is the probability that any 10 users (of the total 19 users) are transmitting and the remaining users are not transmitting?

Quantitative Comparison of Packet Switching and Circuit Switching



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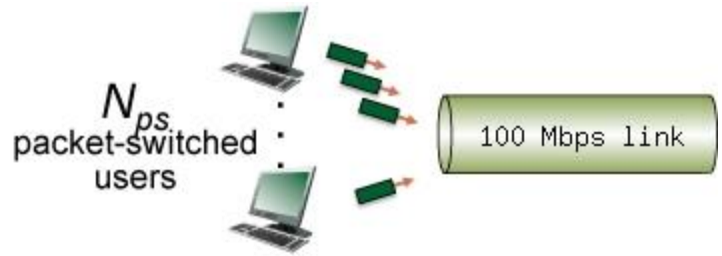

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Q: What is the probability that *more* than 10 users are transmitting? Comment on what this implies about the number of users supportable under circuit switching and packet switching.

Packet Switching

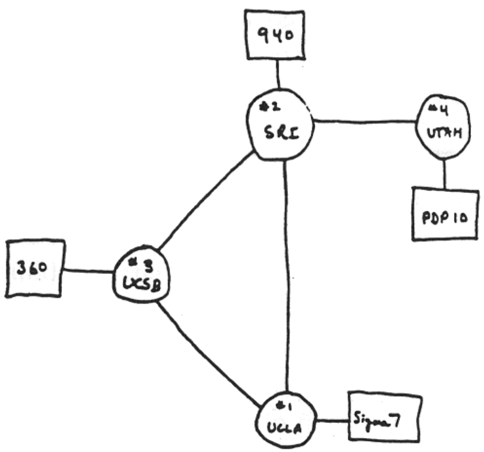
- Advantages:
  - Line efficiency
    - Single node to node link can be shared by many packets over time
    - Packets queued and transmitted as fast as possible
  - Data rate conversion
    - Each station connects to the local node at its own speed
    - Nodes buffer data if required to equalize rates
  - Priorities can be used (quality of service)
- Disadvantages:
  - Congestion and packet delay – can lead to deterioration of service
  - Sophisticated protocols required for packet delivery and routing

Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching
- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

- 1972:
  - ARPAnet public demonstration
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes



THE ARPA NETWORK

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

Internet History

1980-1990: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: smtp e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: ftp protocol defined
- 1988: TCP congestion control
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet History

1990, 2000's: commercialization, the Web, new apps

- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

Late 1990's – 2000's:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

Disruptor: 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

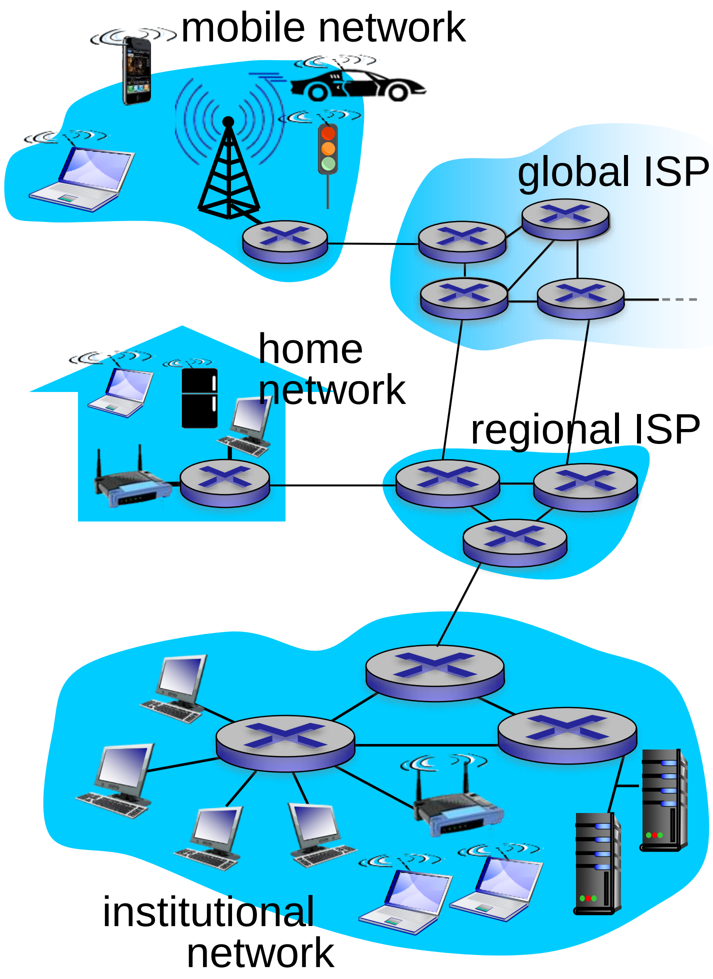
sensorized, bed mattress

Network Pioneers

- Leonard Kleinrock – MIT PhD, Prof. At UCLA
  - First paper on packet switching theory in 1961
- Lawrence Roberts – MIT PhD, ARPA employee
  - Awarded contract to build experimental ARPANET in 1965
- Robert Kahn & Vinton Cerf
  - ARPA employees
  - Helped design protocols for ARPANET (TCP/IP)

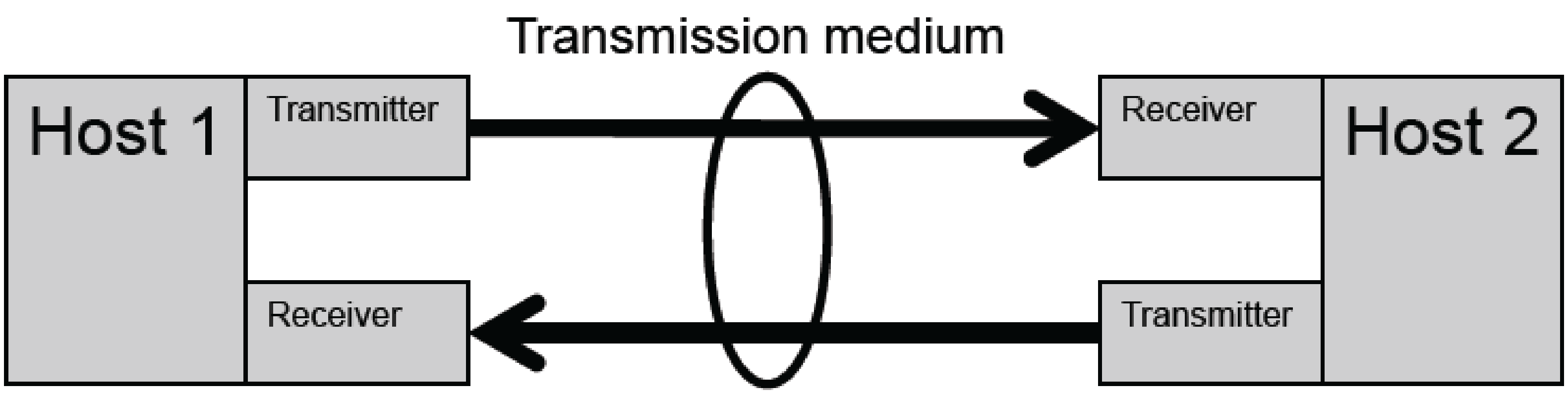
The Internet: "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
- 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



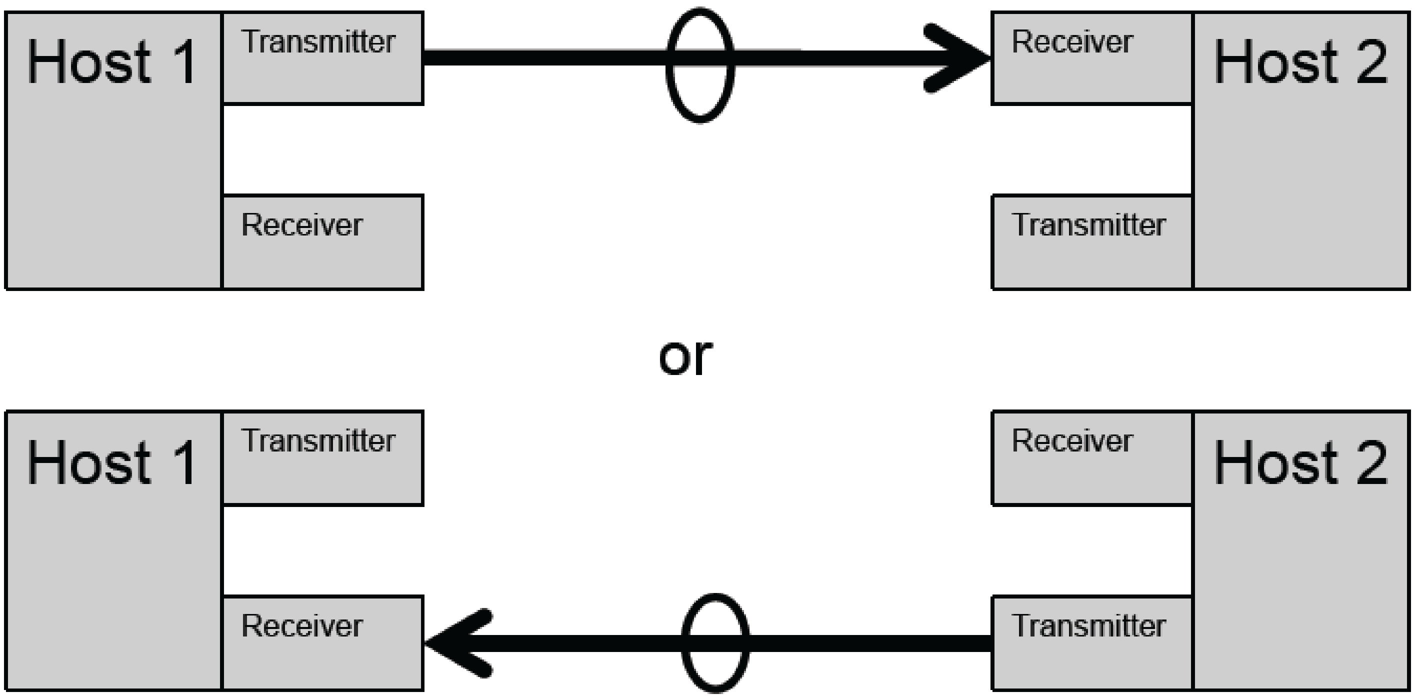
Links

- **Bit** – atomic unit of information
  - 1 or 0
- **Bandwidth** – rate of information communication
  - measured in bits/second
- **Physical link, transmission channel/medium**
  - medium for transmitting bits



Full Duplex

Links cont.



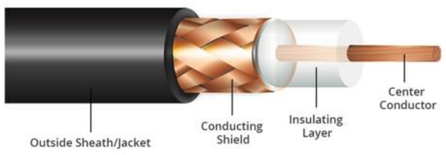
Half Duplex

Transmission Media

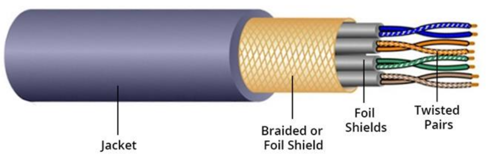
- **Transmission medium** or physical medium
  - A medium in which electromagnetic waves or light waves propagate
  - **Guided** – transmission signals propagate through a solid medium
  - **Unguided** – transmission signals propagate through free space

Guided Transmission Media

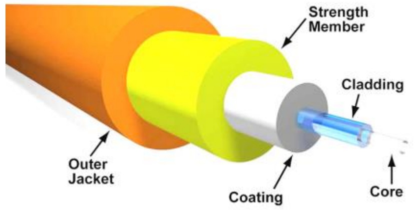
- *coaxial cable:*
  - bidirectional
  - multiple channels on cable



- *twisted pair (TP)*
  - two insulated copper wires
    - Category 5: 100 Mbps, 1 Gbps Ethernet
    - Category 6: 10Gbps



- *fiber optic cable:*
  - glass fiber carrying light pulses, each pulse a bit
  - high-speed operation (e.g., 10's-100's GBPS)



Unguided Transmission Media: Radio

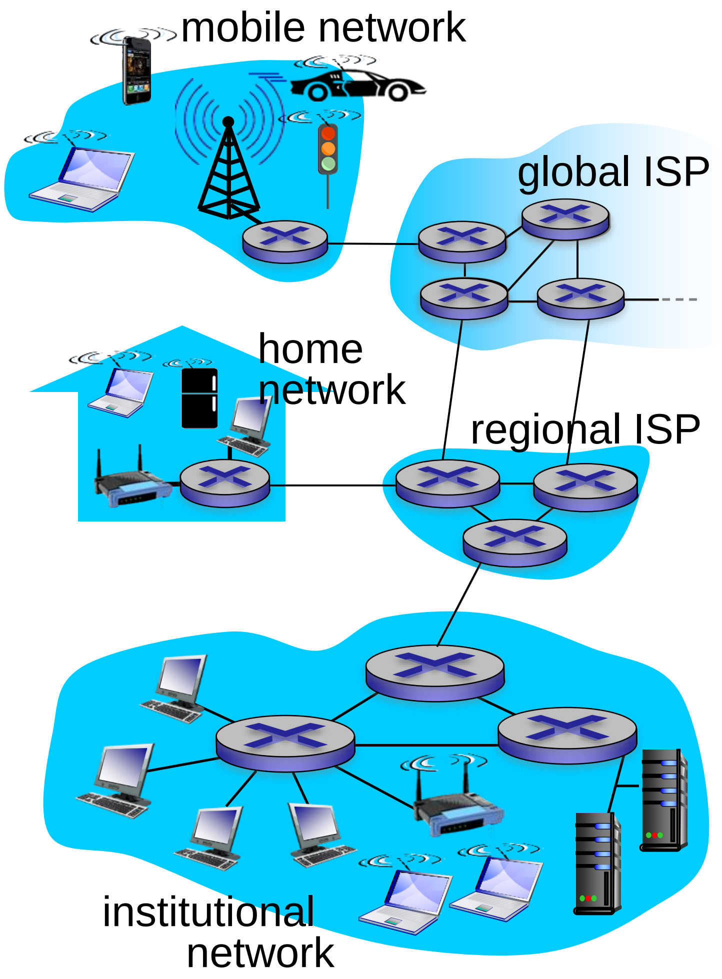
- signal carried in electromagnetic spectrum
- no physical “wire”
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

radio link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- WiFi
  - ~100 Mbps
- Cellular networks
  - 4G: ~ 10 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay

The Internet: "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
- *protocols* control sending, receiving of messages
  - e.g., TCP, IP, HTTP, 802.11



Format of Network Communications: Protocols

human protocols:

- "what's the time?"
- "I have a question"
- introductions

… specific messages sent

… specific actions taken when messages received, or other events

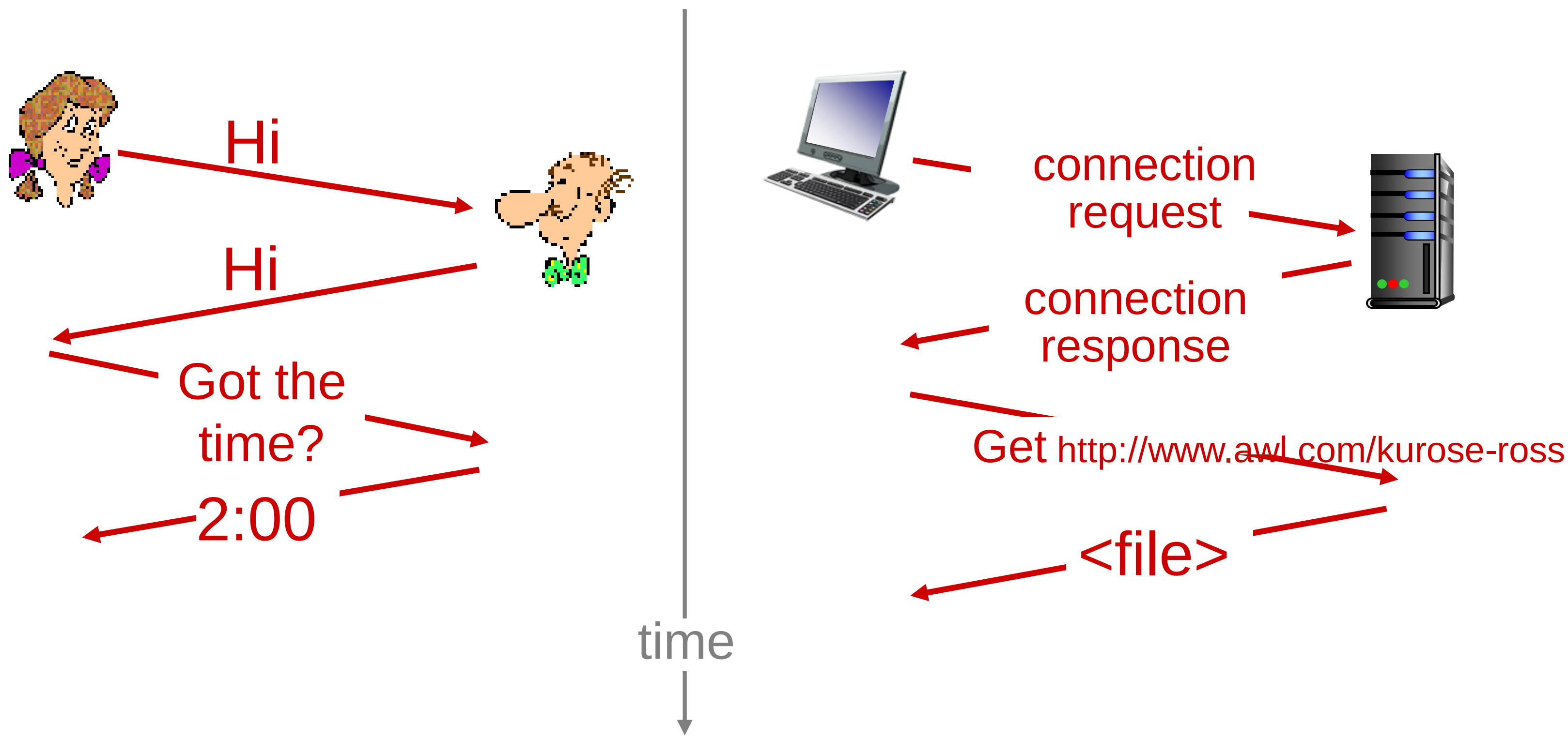
network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

Format of Network Communications: Protocols

a human protocol and a computer network protocol:



Format of Network Communications: Protocols

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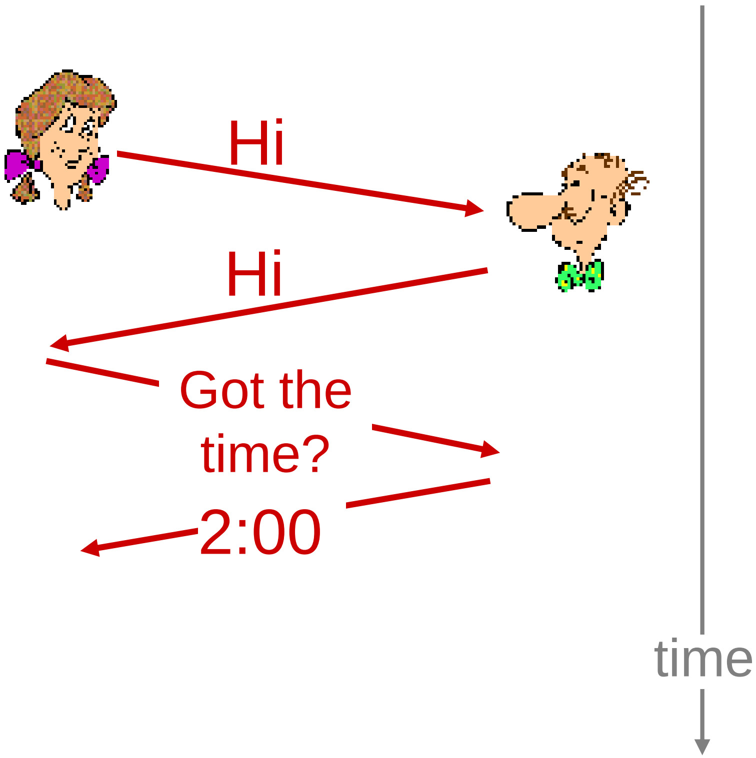
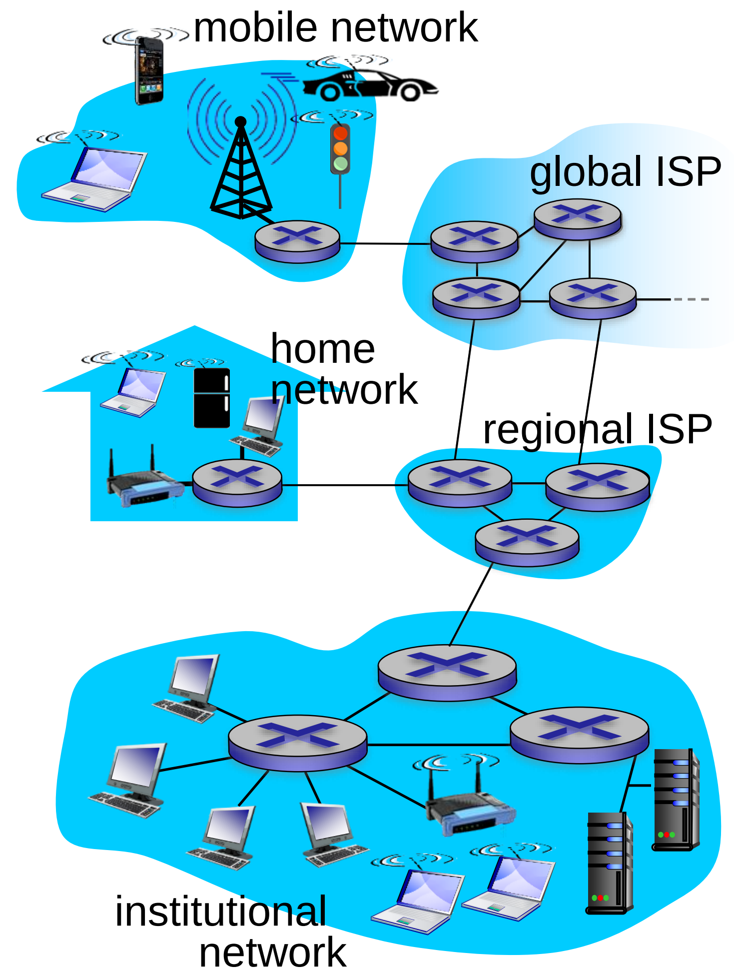


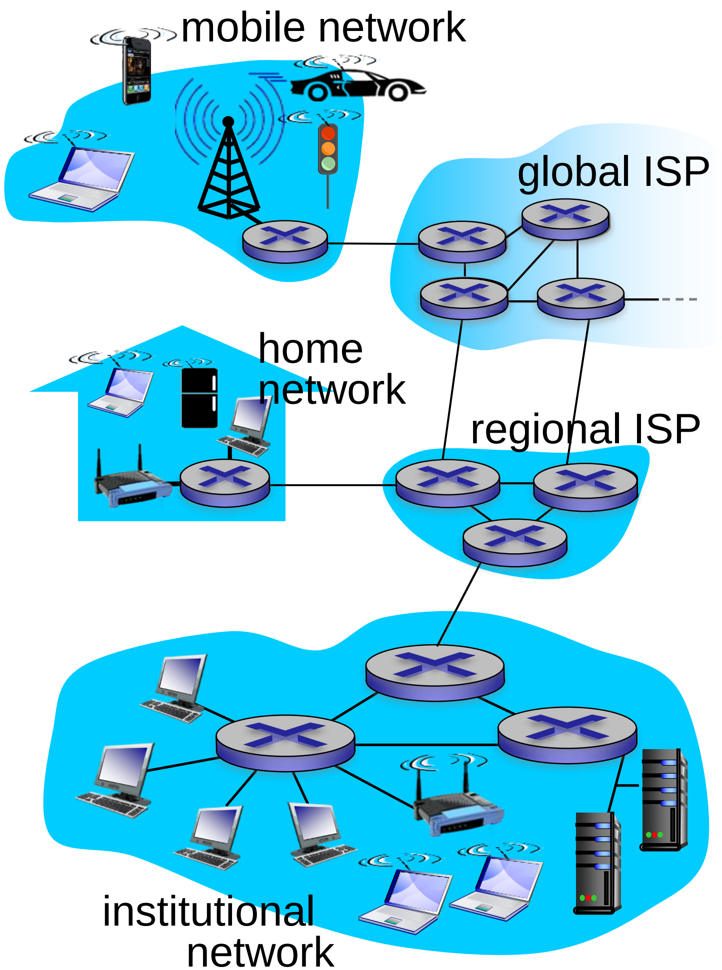
Recall "nuts and bolts" view

- *Internet:* "network of networks"
  - Interconnected ISPs
- *protocols* control sending, receiving of messages
  - e.g., TCP, IP, HTTP, 802.11
- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force



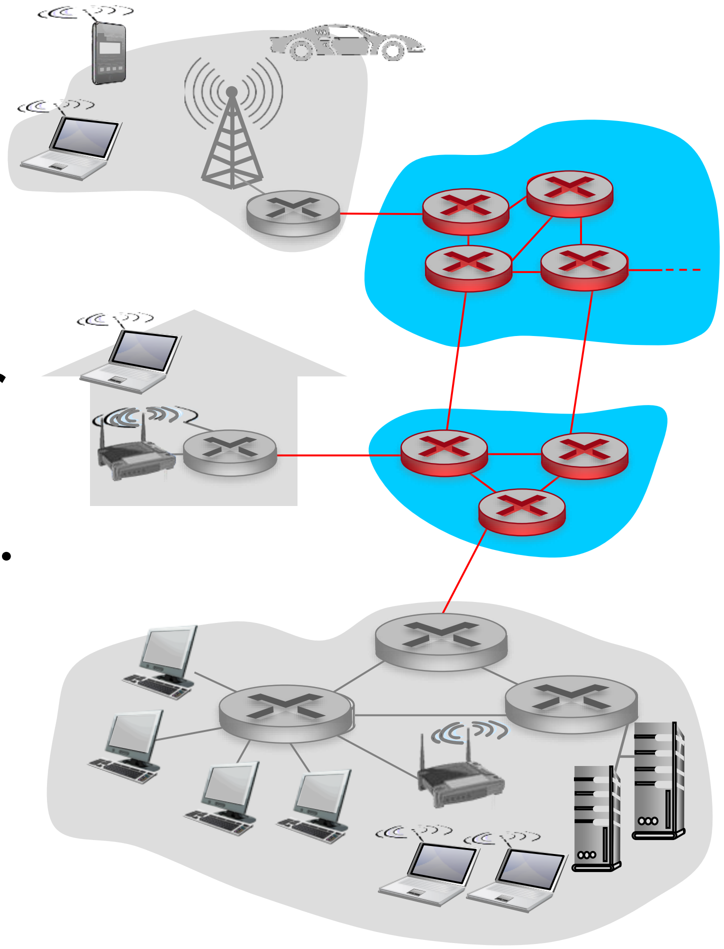
Internet Structure

- *Network edge:*
  - Private networks
  - hosts: clients and servers
  - servers often in data centers
- *Access networks:*
  - wired, wireless communication links
  - Link between Network Edge and Network Core between private and public networks
- *Network core:*
  - Public network
  - interconnected routers



Network core

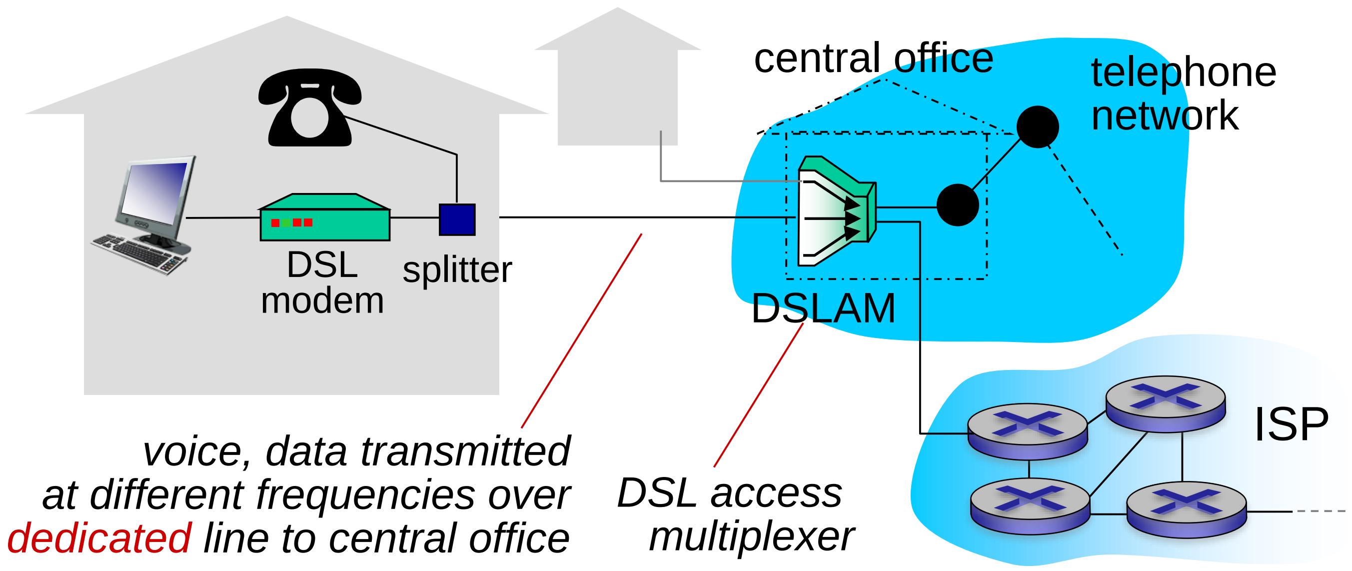
- The network core are the networks built by service providers for **public** consumption
- Primarily connected with fiber optic cables offering high bandwidth up to several TBPS.
- Various individual service provider networks interconnected constitute the network core



Network Edge

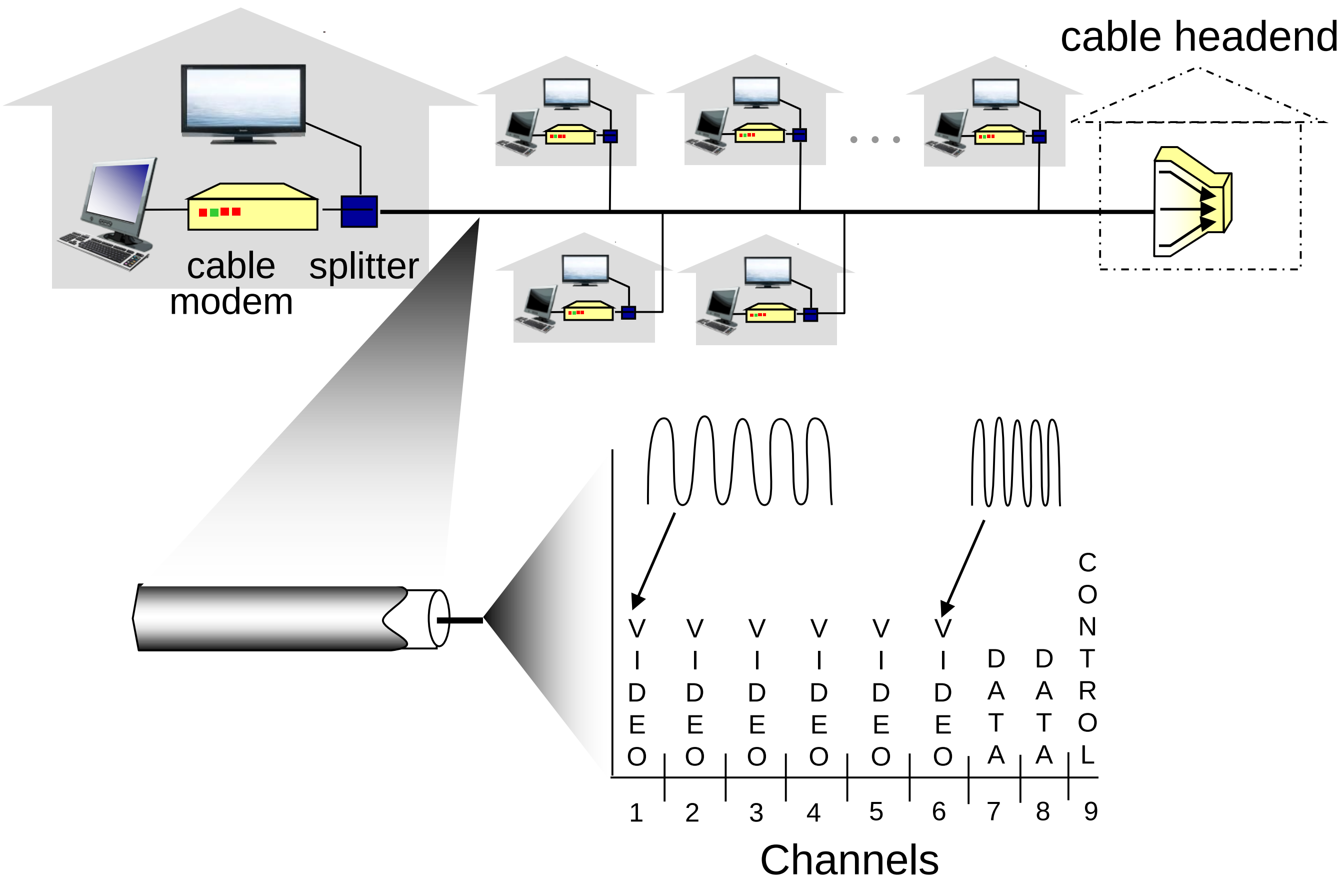
- The network edge are the networks in homes, businesses or institutions built for **private** consumption
- Primarily connected with copper cables carrying high frequency signals
  - up to 1Gbps bandwidth
- Wireless for mobility
- Large institutions may have a fiber optic cabled backbone network

Access network: Digital Subscriber Line (DSL)



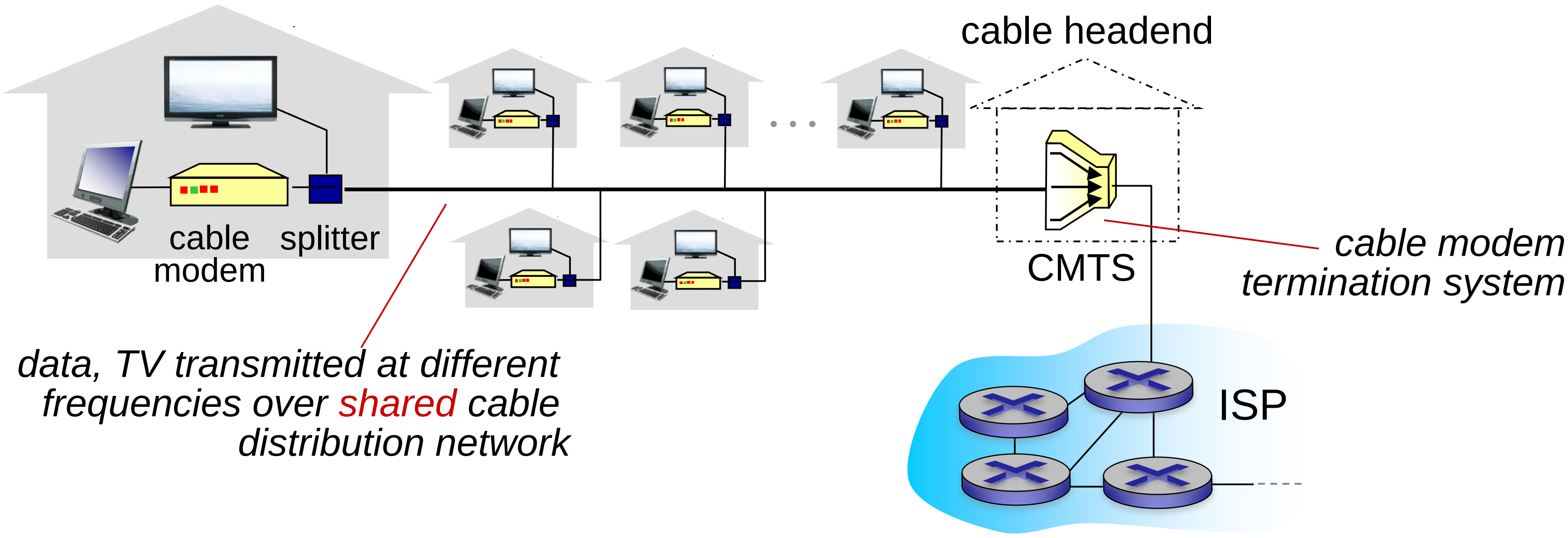
- Use *existing* telephone line
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

Access network: cable network



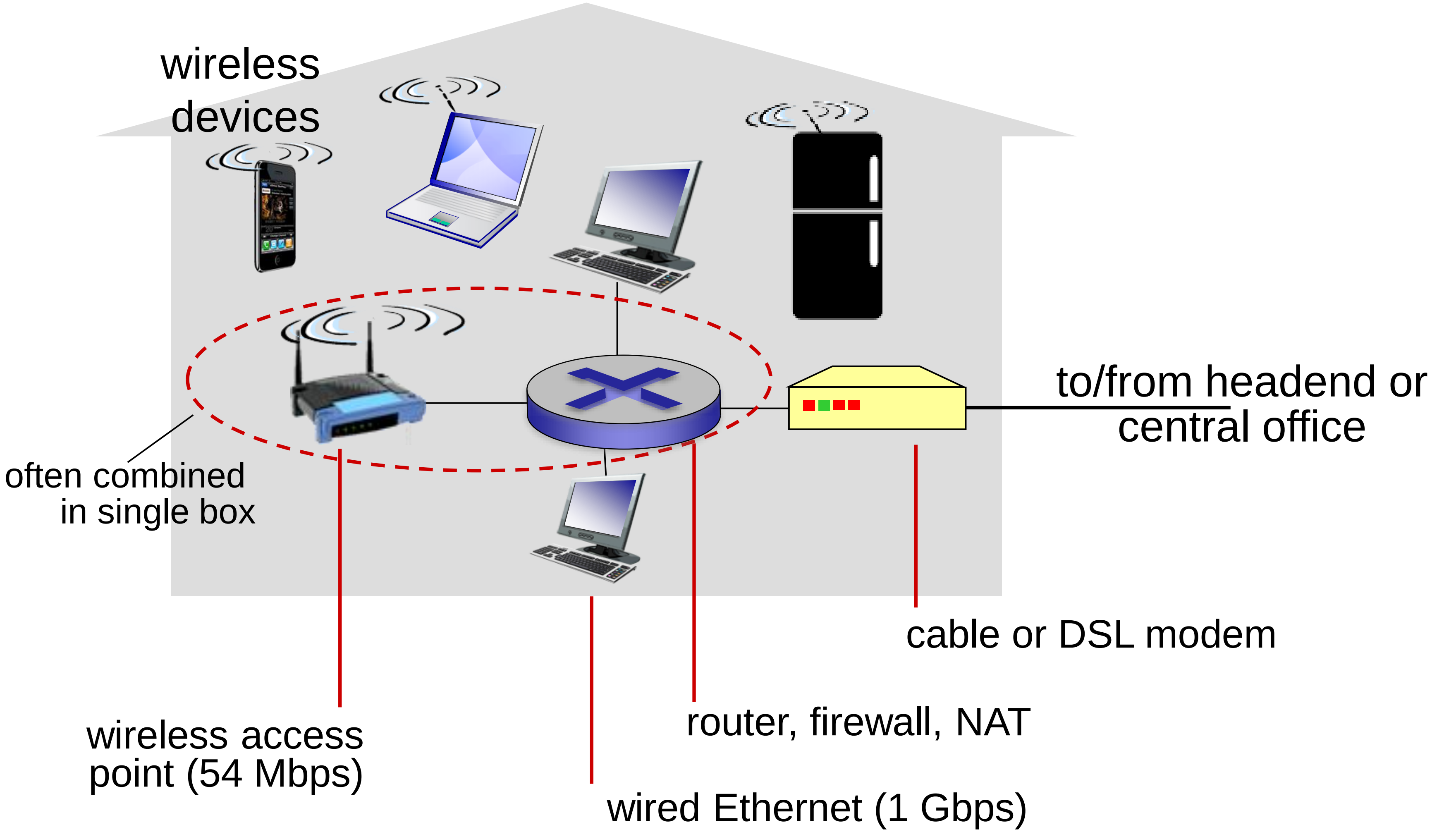
frequency division multiplexing: different channels transmitted in different frequency bands

Access network: cable network

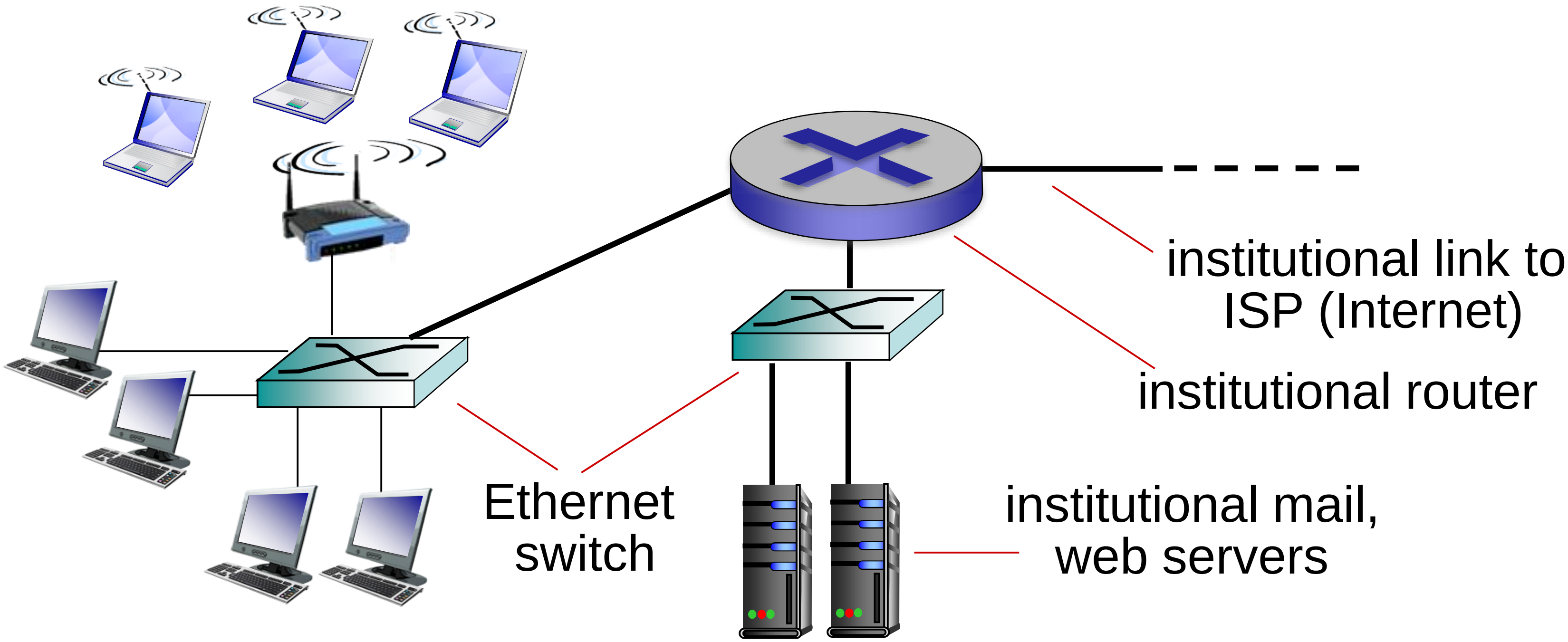


- network of cable attaches homes to ISP router
  - homes *share access network* to cable headend
  - unlike DSL, which has dedicated access to central office

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

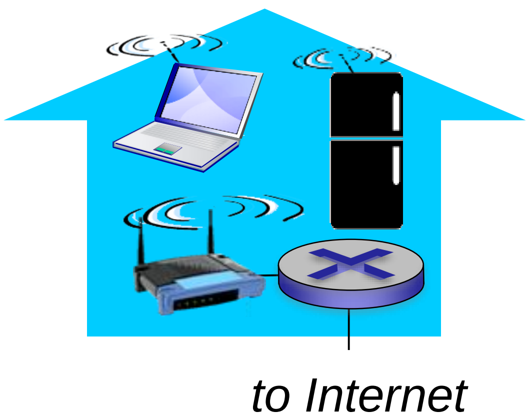
- shared *wireless* access network connects end system to router
  - via base station aka "access point"

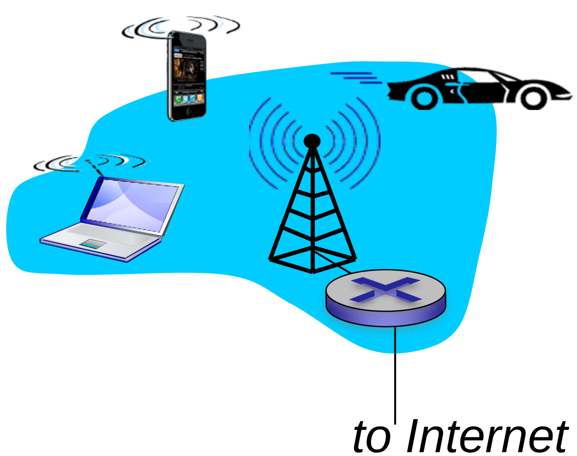
Wireless LANs (WiFi):

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

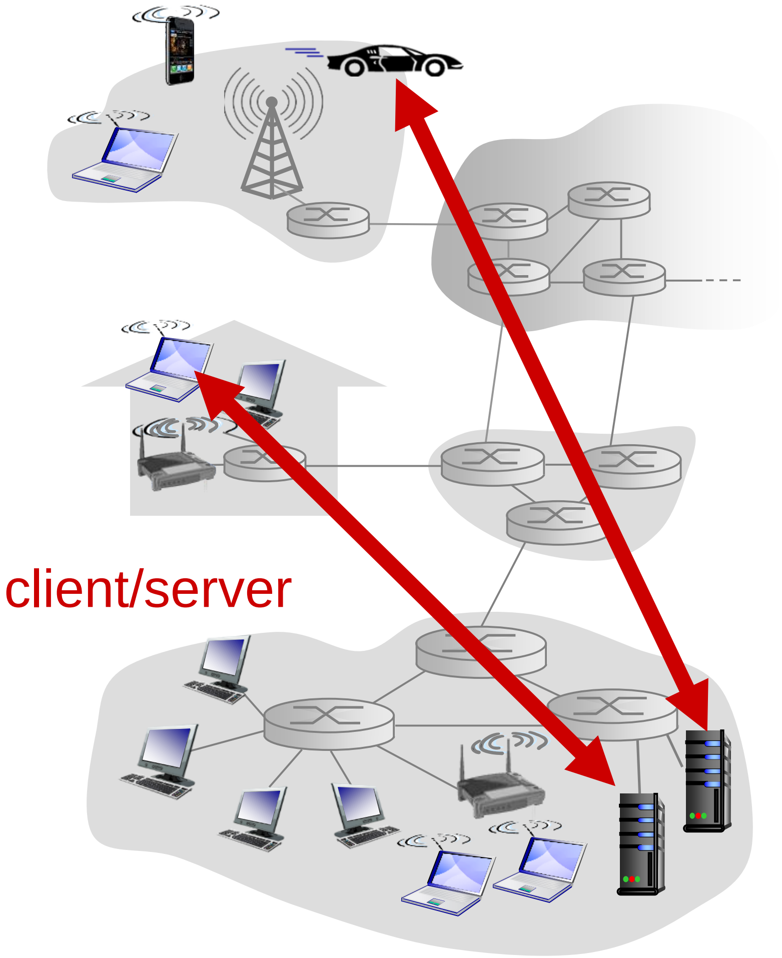
wide-area wireless access (cellular)

- provided by telcom/wireless operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE





Internet Services: Client-server architecture



server:

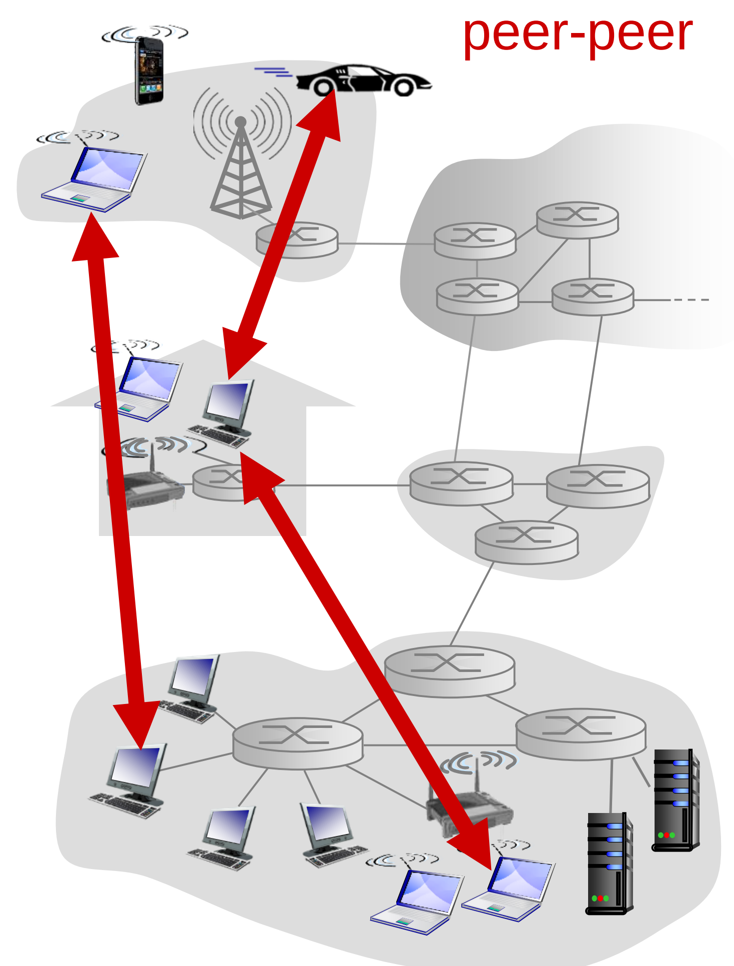
- always-on host
- data centers for scaling

clients:

- communicate with server
- may be intermittently connected
- do not communicate directly with each other

Internet Services: P2P architecture

- *no* always-on server
- arbitrary end systems directly communicate
- peers request service from other peers, provide service in return to other peers
  - *self scalability* – new peers bring new service capacity, as well as new service demands
- peers are intermittently connected and change IP addresses
  - complex management
- Examples ?



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- peers are intermittently connected and change IP addresses
  - complex management
- Examples: BitTorrent, Bitcoin