University of Southern California

Viterbi School of Engineering

EE450
Computer Networks

Introduction

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Spring 2013

EE450 Goals

Network

- A **network** is a set of devices connected by communication links
- A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network
- What is a computer network?
  - A computer network is a collection of computers and devices connected to each other

What is Internet?

- Internet is the network of network; a computer network that interconnects hundreds of millions of computing devices throughout the world

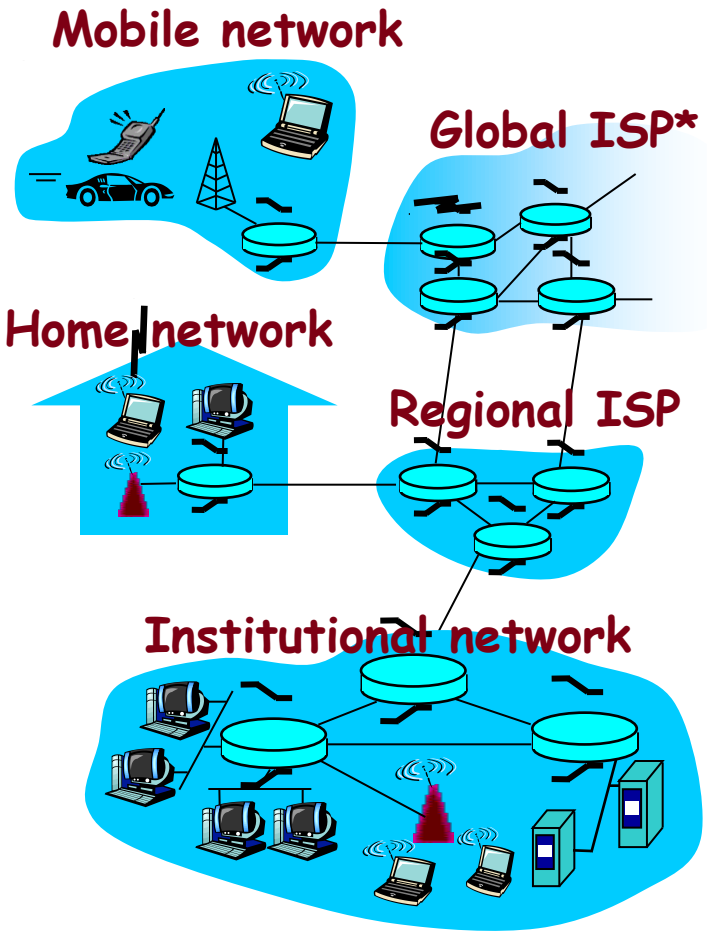
- Increasingly, nontraditional Internet end systems such as laptops, cell phones, automobiles, TVs, home electrical and security systems, gaming consoles, and environmental sensing devices are being connected to the internet, making the term "computer network" out-of-date

- The goal of a computer network is to provide the end systems (users) with some services

Computer Network Components

- Nodes and edges

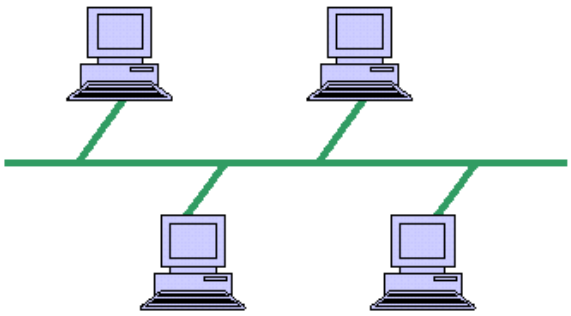
- The nodes are interconnected using transmission facilities
  - Coaxial cable, twisted-pair copper wire, fiber optics, microwave channels, radio channels and satellite channels are examples of transmission facilities



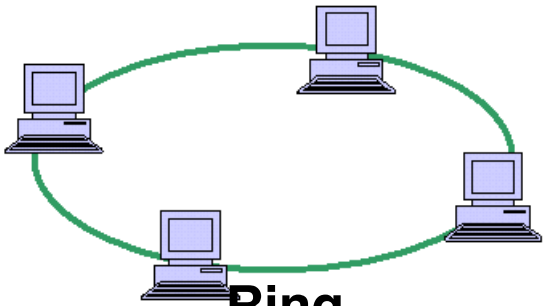
* ISP (Internet Service Provider)

Network Topology

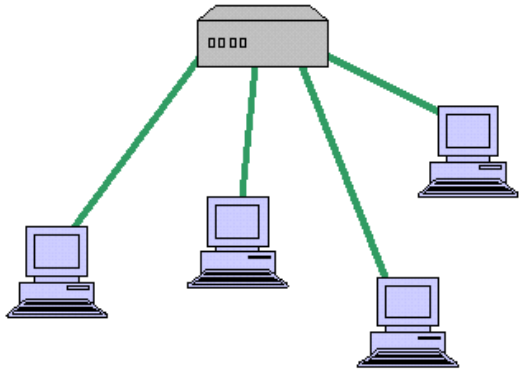
- Network topologies are categorized into bus, ring, star, line, tree, [partially connected] mesh and fully-connected [mesh]
- Note: Topology is not about how the devices operate



Bus

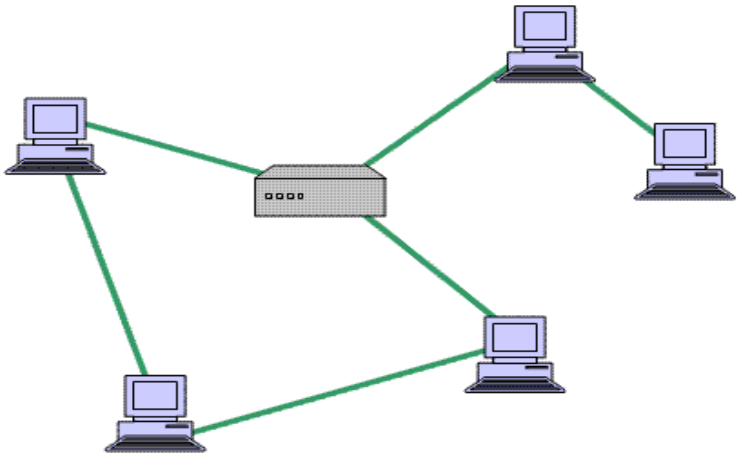


Ring

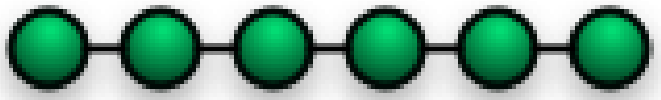


Star

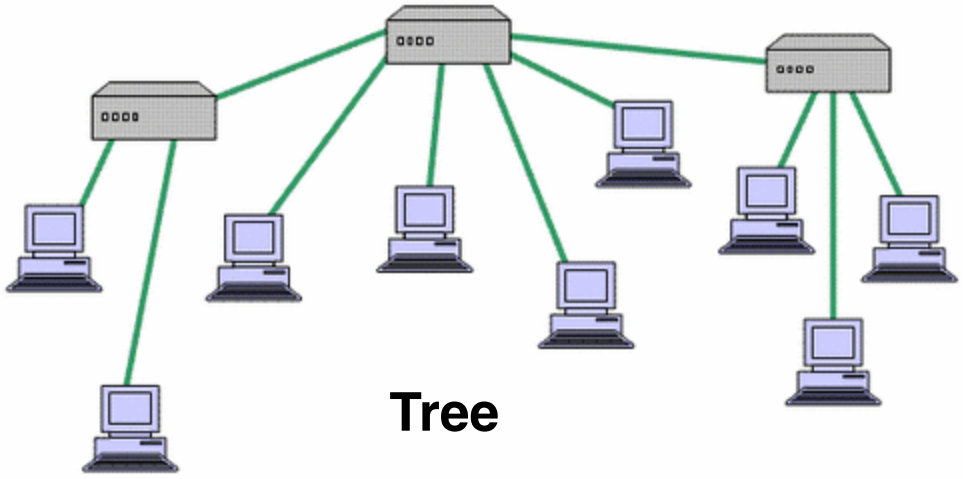
Network Topology (Cont.)



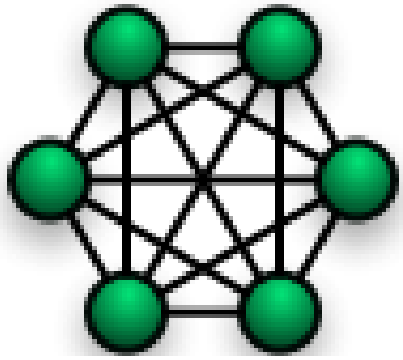
[Partially Connected] Mesh



Line



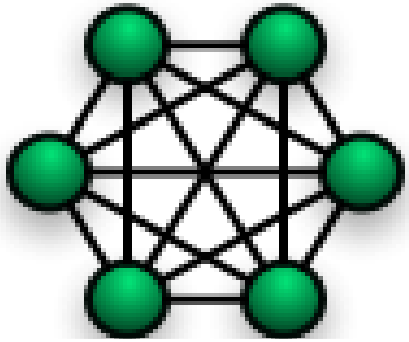
Tree



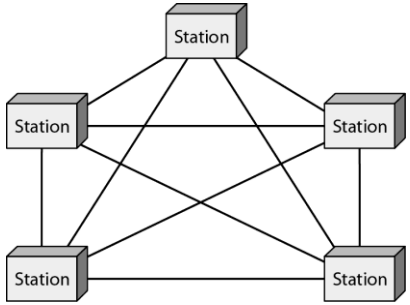
Fully Connected [Mesh]

Network Topology (Cont.)

- For the following 6 nodes in a fully-connected topology (point-to-point connection) the number of connections is 15
- How often each of those connections are used? Fully-connected may be very inefficient if many of them are rarely used
- Fully connected topology may still be practical only for small networks such as the home networks



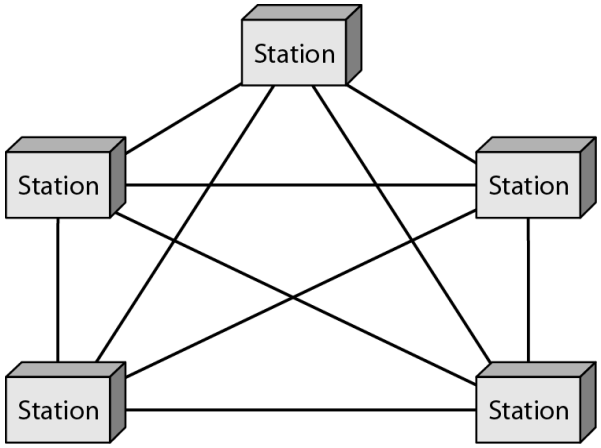
Fully Connected (6 nodes)



Fully Connected (5 nodes)

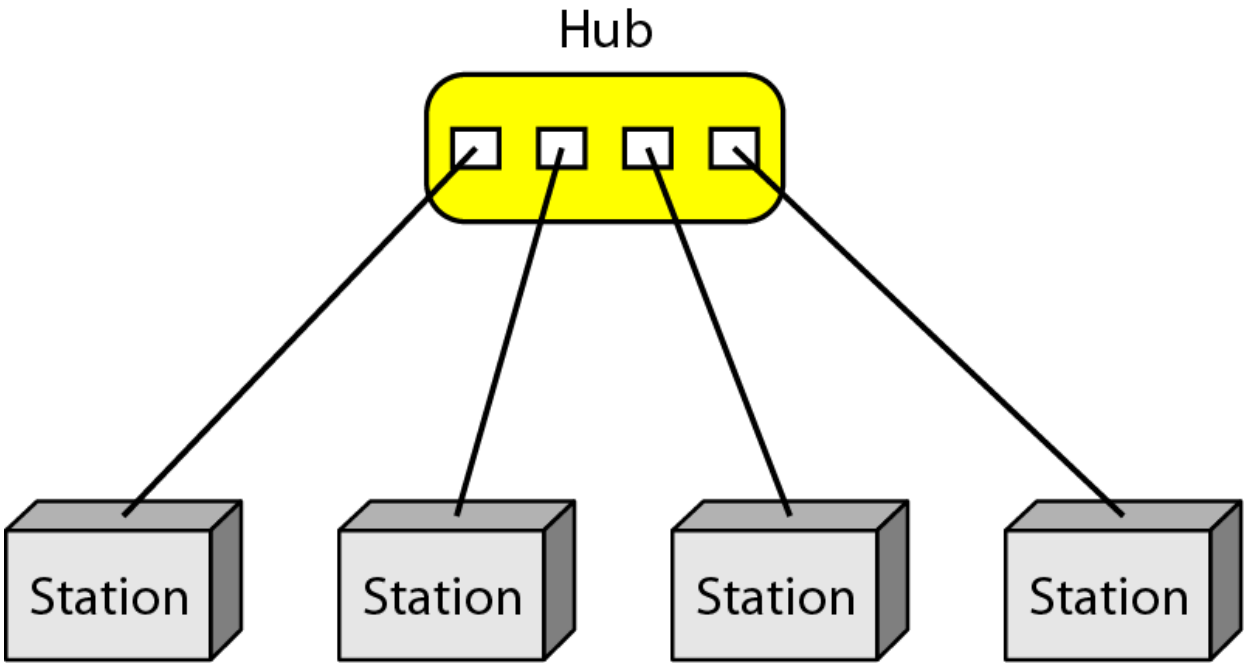
Network Topology (Cont.)

- Note that there are 100s of millions of end systems that could be too far apart and connecting them fully will not be feasible
- Also note that the nodes (computers) are becoming less costly, but the trend for the physical transmission facilities such as cables is upward

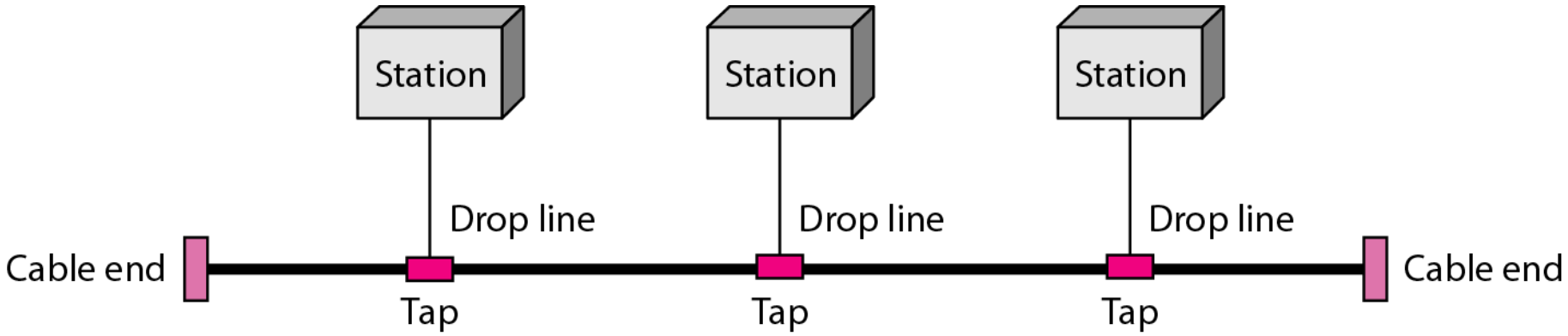


Fully Connected (5 nodes)

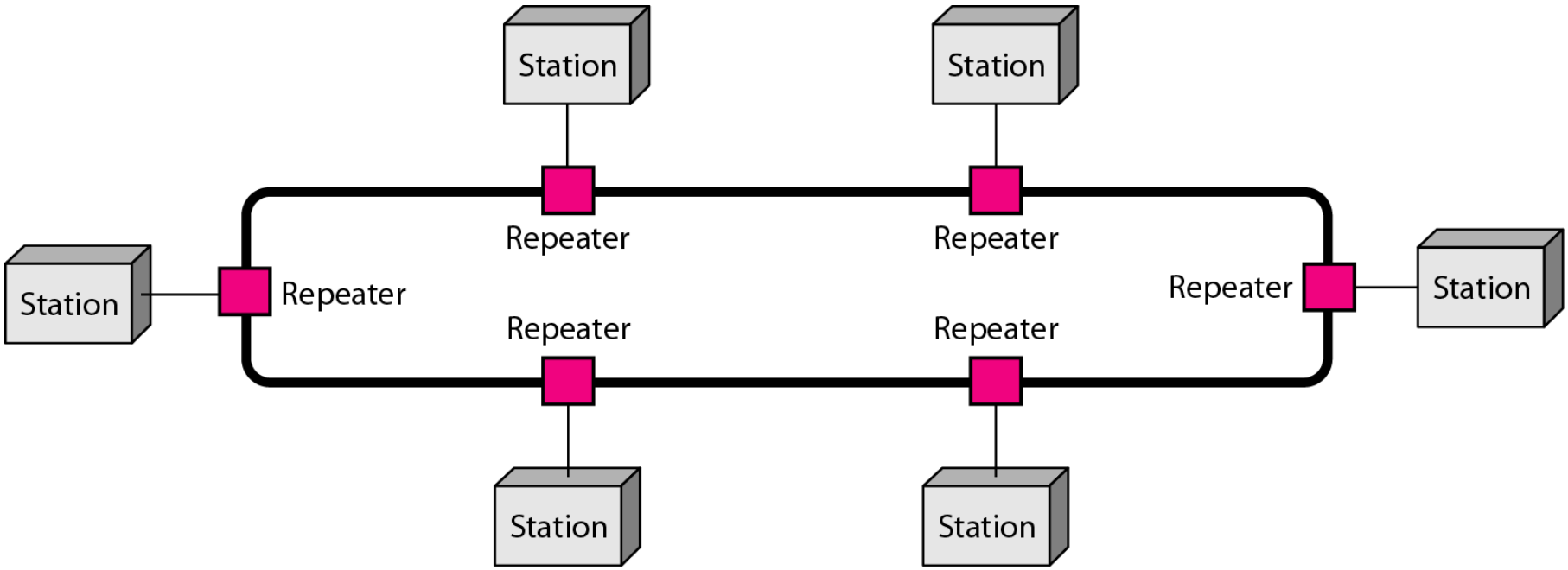
A Star Topology Connecting 4 stations



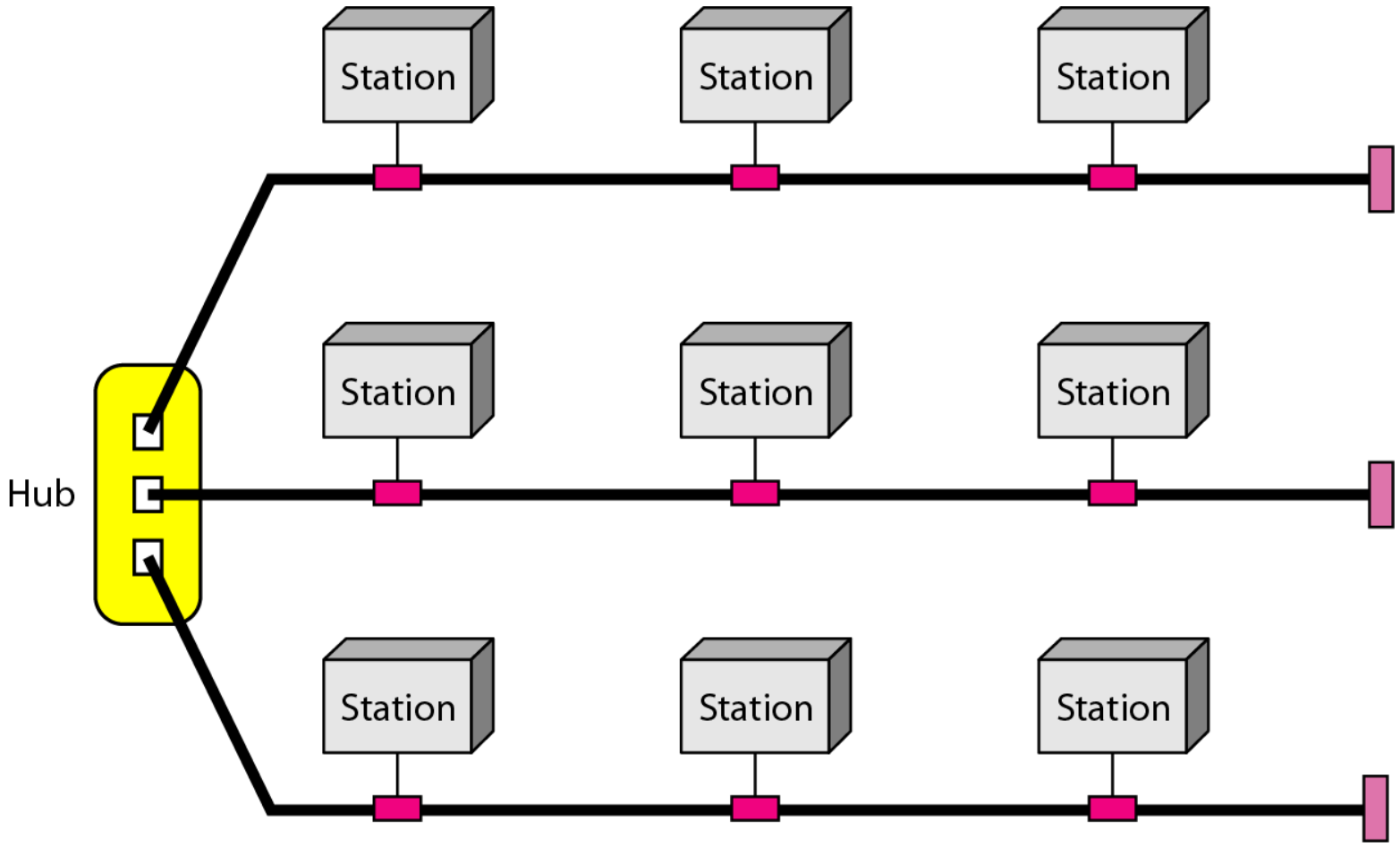
A Bus Topology Connecting 3 Stations



A Ring Topology Connecting 6 Stations

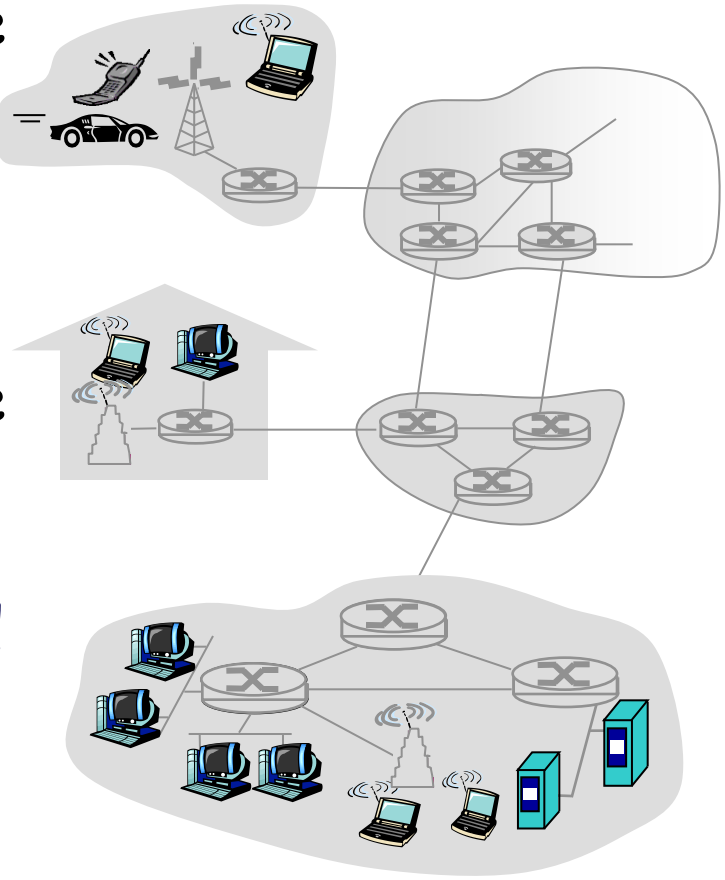


A Hybrid Topology



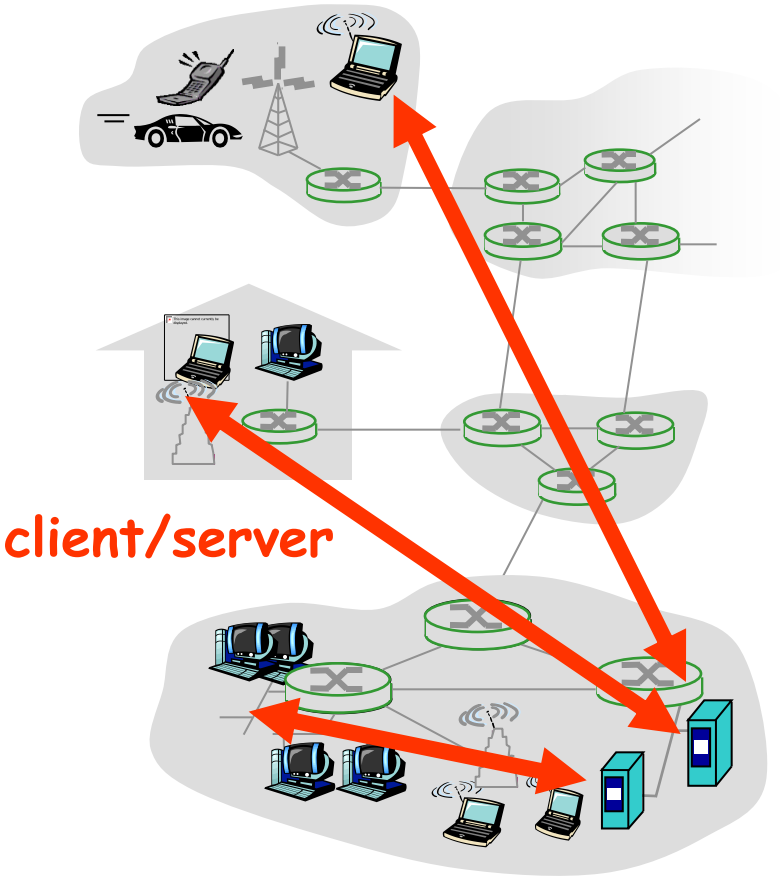
Network Computer

- A network computer can either provide service or request service
- Clients and servers
- A server provides service to multiple clients
- Note that clients and servers are pieces of **software**; the machines that these softwares are running in, are referred to as clients and servers, respectively



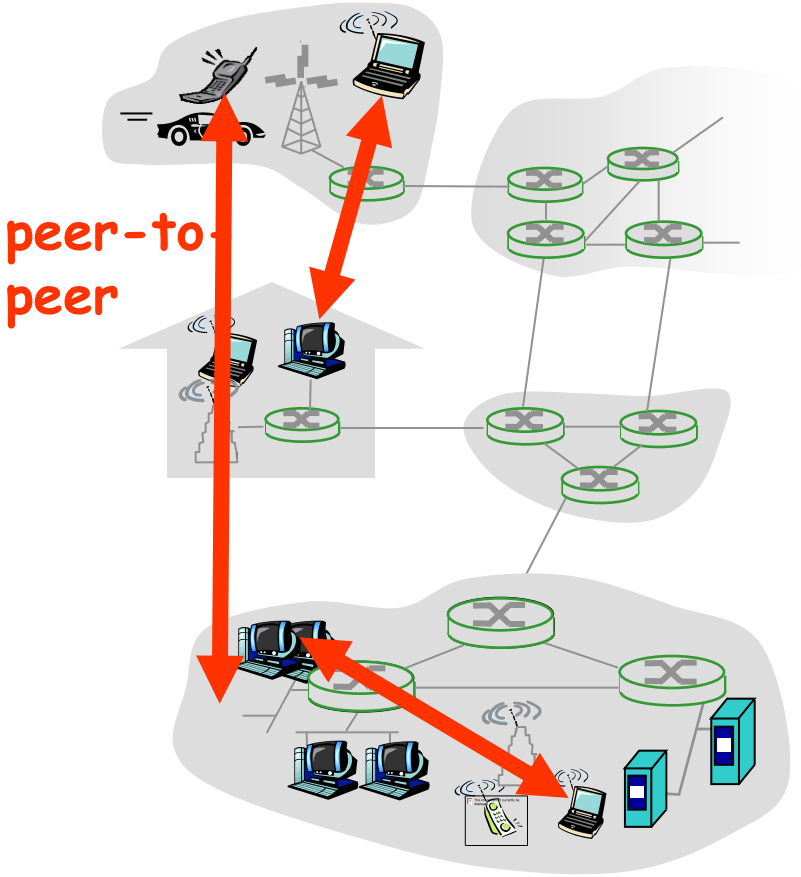
Client/Server Model

- Client host requests, and receives service from server
- Example - WWW: Web browser/server. Client is a web browser, and the destination is a web server which responds to client's inquiry, say summer.html by sending the html file to client
- Example – Email client/server



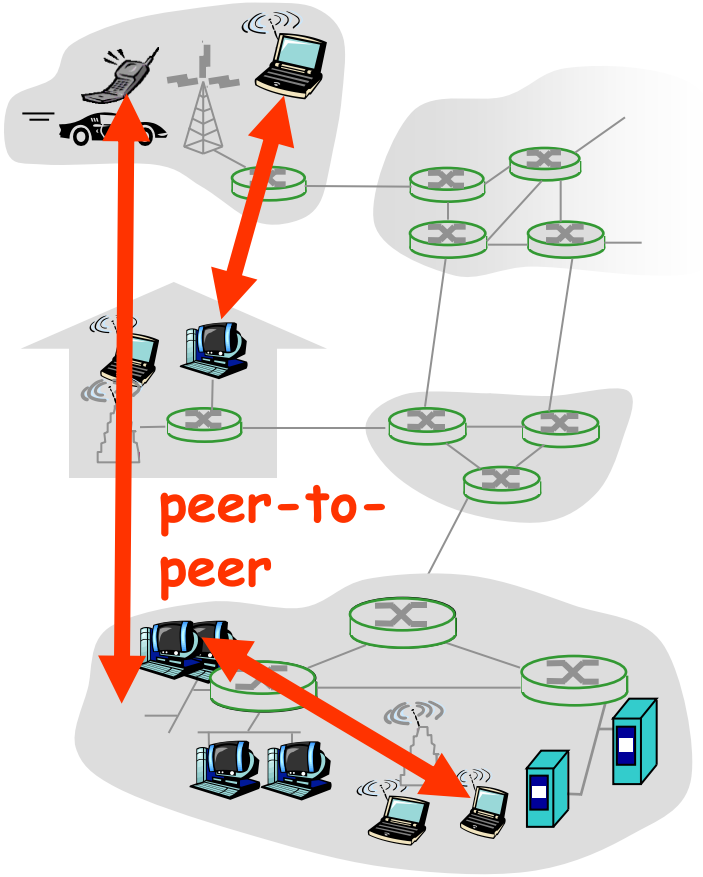
Peer-to-Peer Model

- In a Peer-to-Peer network all computers are equal and they all provide and request services
- Another words, servers are peer-to-peer and they can act as a client
- e.g. Skype, Kazaa, BitTorrent, Napster, Gnutella



Peer-to-Peer Model (Cont.)

- A dedicated server (a peer directory) is still required, just to let hosts know where their peers are, that you can communicate with them Peer-to-Peer style
- Note: a dedicated server such as the one in a client/server model, is more powerful than a peer server because all it should do is about providing service



Server

- **Web Servers:** Run WWW (World Wide Web) and FTP (File Transfer Protocol) servers for access via the Internet
- **File Servers:** Manage access to shared files. The idea is to have one copy of a file on the server machine instead a separate copy on each single machine. The clients can download the file from the file server and use it
- **Application servers:** They are similar to file servers with some processing
- **Printer Servers:** manage user access to print resources (Note: dedicated printers are not efficient)

Server

- **DNS Servers:** AKA DNS (Directory Name Servers) Servers locate information about networks such as domains. The idea used here is very similar to that of telephone directory or a yellow page in the sense that a DNS server maps a host name to an address (i.e., the host's IP address [IP stands for Internet Protocol])
- **Mail servers**: Manage electronic messages between users
- **Communication Servers**: AKA Remote Access Servers (RAS) manage data flow and electronic messages from one network to another

Network Software

- **NOS** (Network Operating System) includes special functions for connecting hosts into a network and managing the shared resources and services, security, authentications, passwords, etc.

- NOS vs OS
  - OS manages the local resources, such as CPUs, I/Os and memories, therefore your computer needs an OS even if it's not connected to the network

- UNIX, Microsoft NT/ Windows 2000, Linux, OS/2, Novell Netware are some examples of NOS

Network Software (Cont.)

- Network hosts communicate through the use of a client software (which is referred to as shell, redirector, or requestor, depending on the NOS)
- The purpose of client software is that if you are operating on a network computer, i.e., a computer connected to network, this piece of software decides whether your request is for a shared resource or a local resource, if it is for a local resource, your request will be redirected to the OS, if the request is for a shared resource, your request will be directed to a piece of software called a Network Protocol that enables data transmission across the network

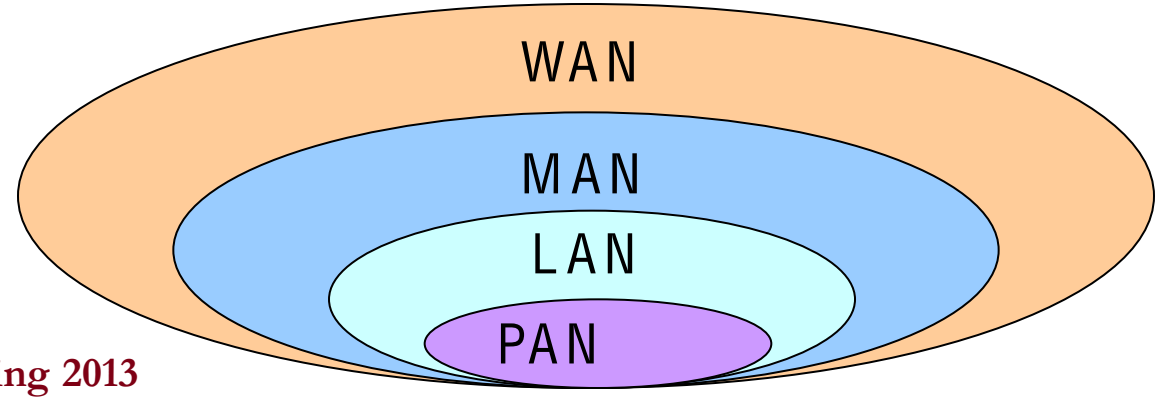
Network Hardware

- Network top view or architecture: SW vs HW

- End systems which are accessing network resources must have a pathway to those resources
- A NIC (Network Interface Card) or adaptor card is an expansion card used to connect hosts to the network
- NIC design is based on the network type, for example the wireless NIC has different design to that of an Ethernet NIC
- Network cards communicate by sending signals through the transmission facilities (also referred to as medium) such as twisted pair copper, coax cable, fiber and radio

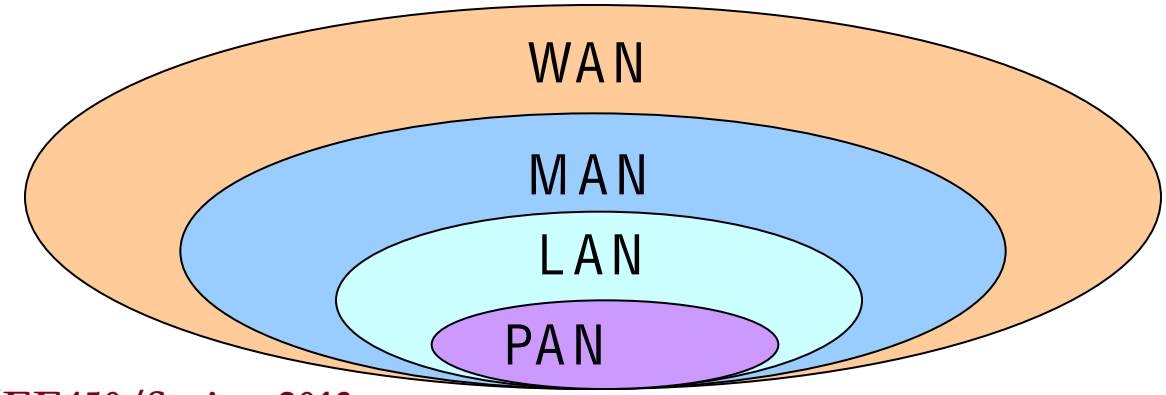
Network Classifications Based on Coverage

- **PAN** (Personal Area Network) is a computer network used for communication among computer devices (including telephones and personal digital assistants) close to one person. The devices may or may not belong to the person in question
- Personal area networks may be wired with computer buses such as USB (Universal Serial Bus) and FireWire. A **Wireless Personal Area Network** can also be made possible with network topologies such as IrDA (Infrared Data Association), Bluetooth, UWB (Ultra-WideBand), Z-Wave and ZigBee

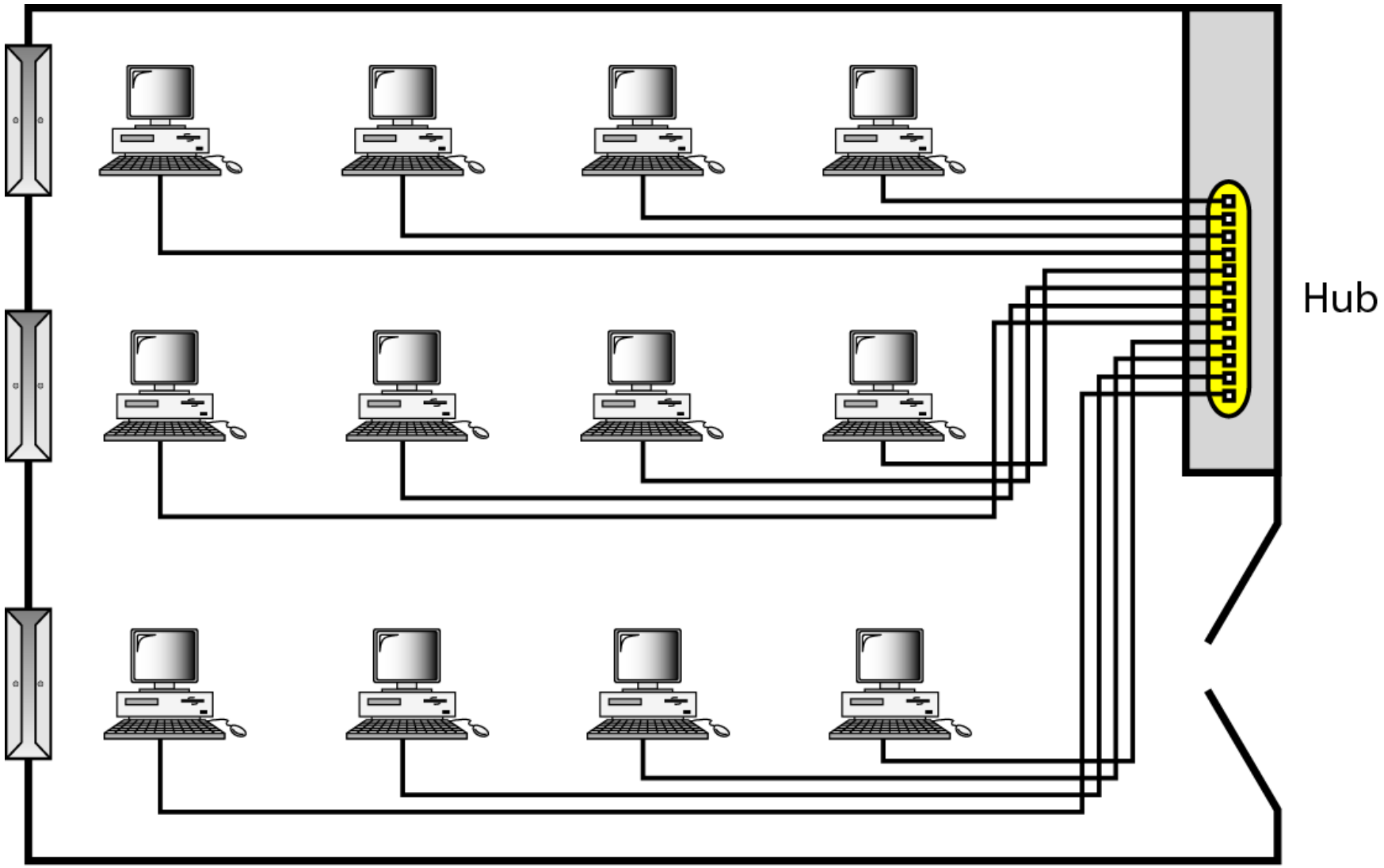


Network Classifications – LAN

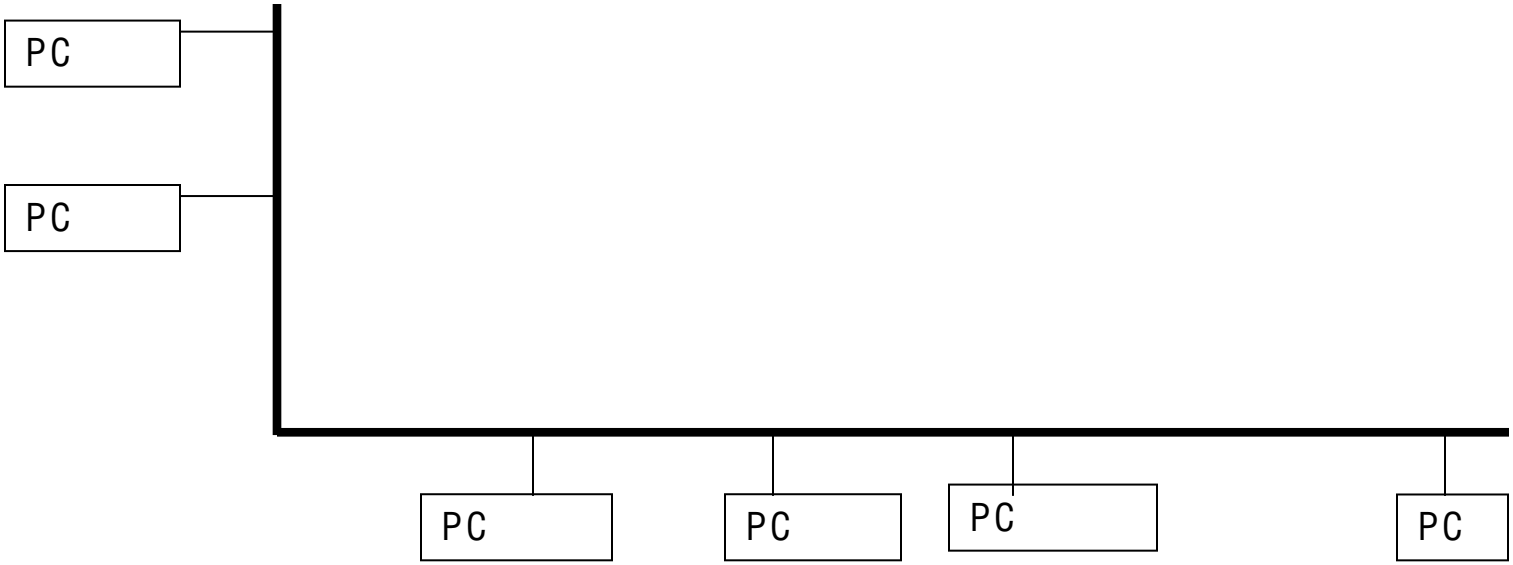
- **LAN** (Local Area Networks) is a computer network covering a limited geographic area, e.g., a building or campus (designed to allow resources to be shared)
  - LAN can be used as an isolated network to connect computers/resources in an organization, however LANs are typically also linked to a Wide Area Network (WAN) or the Internet. LANs are distinguished by their size, topology and transmission media
  - Wireless LANs are the newest evolution in LAN technology



An Isolated LAN Connecting 12 Computers to a Hub in a Closet

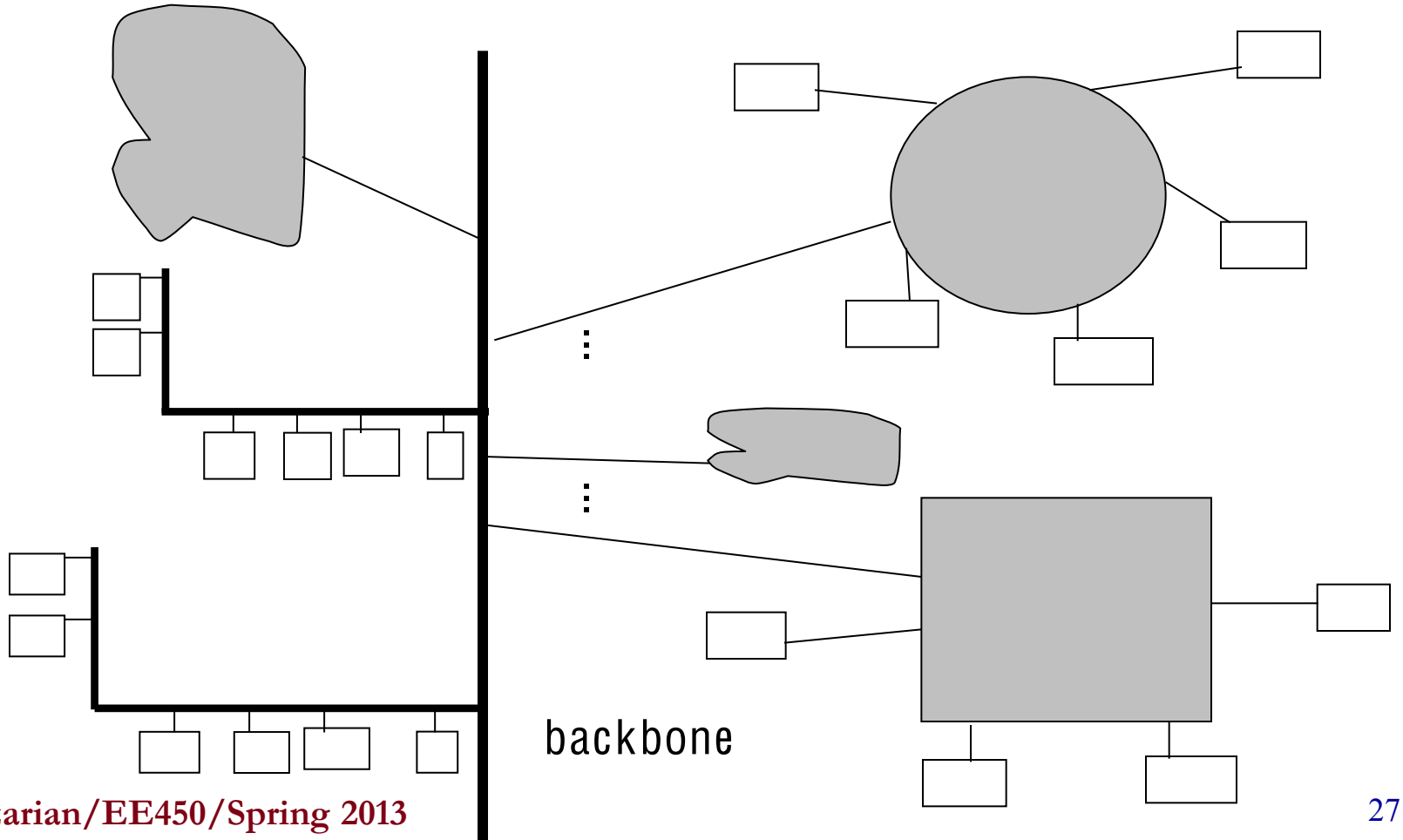


LAN – An Example with 6 Hosts



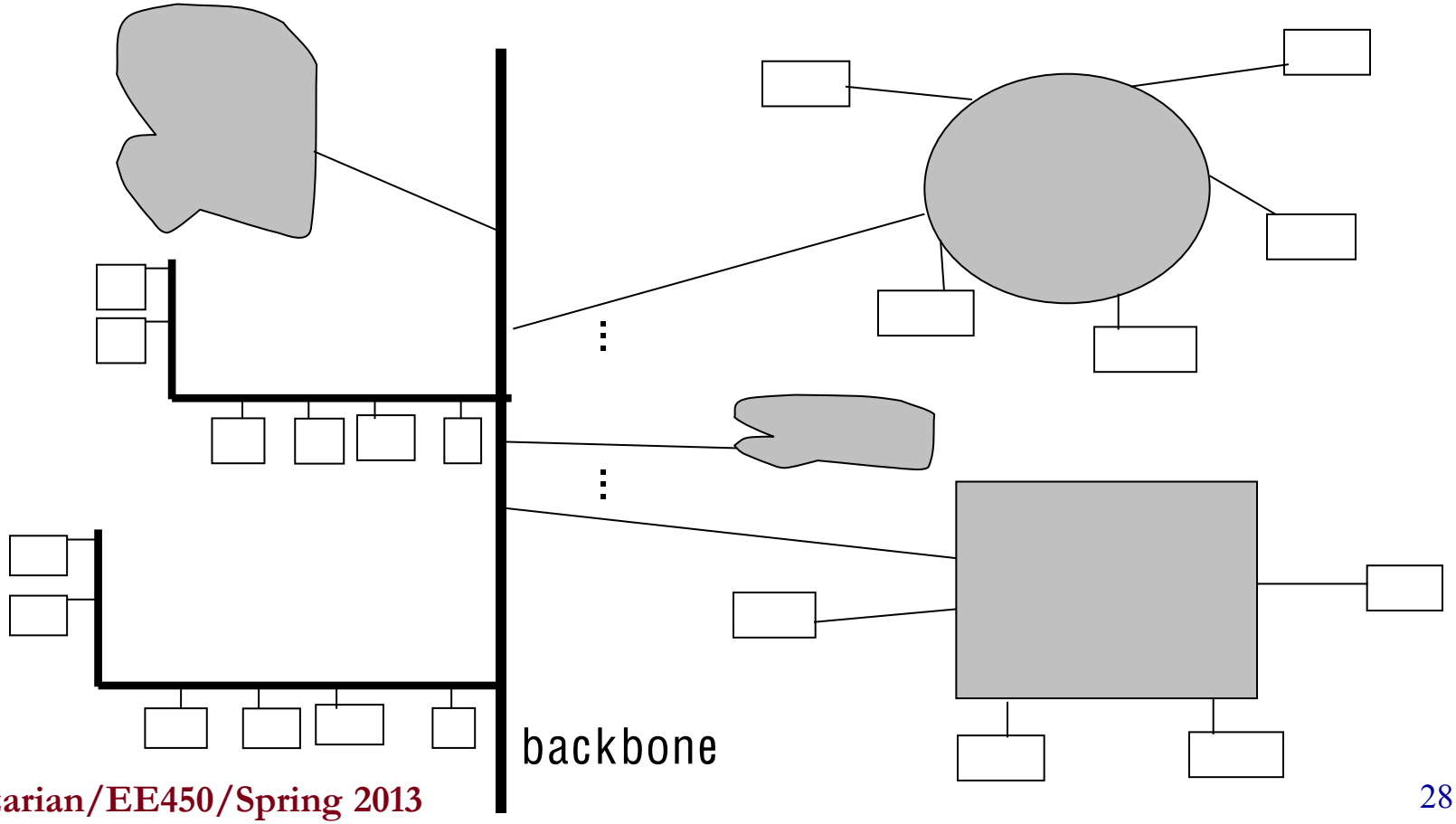
Backbone Networks

- A backbone network allows several LANs to be connected. No station is directly connected to the backbone. The backbone itself is a LAN and uses a LAN
- Each connection to the backbone is itself another LAN



LAN – Internet Backbone (Cont.)

- There are many different architectures for backbone networks such as bus backbone and star backbone
- Different buildings (rooms) each one has its own network with different topologies and all are connected to a high-speed backbone network



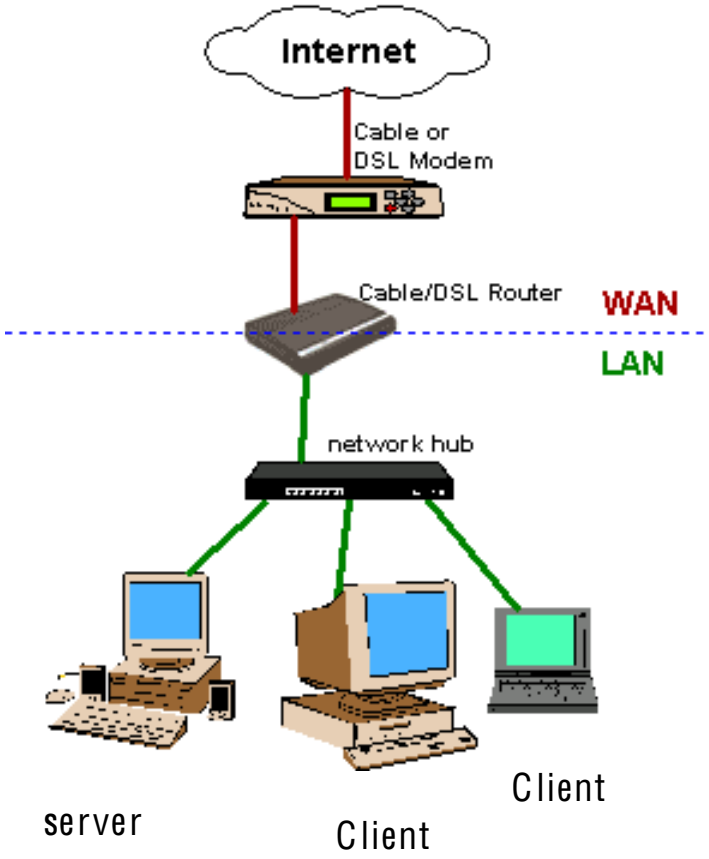
Ethernet

- Ethernet is a family of frame-based computer networking protocols for LANs
- It defines a number of wiring and signaling standards for the Physical Layer of the OSI (Open Systems Interconnection) networking model, through means of network access at the Media Access Control (MAC)/Data Link Layer, and a common addressing format
- Ethernet is standardized as IEEE 802.3
- OSI is an effort to standardize networking that was started in 1977 by the International Organization for Standardization (ISO), along with the ITU-T*

* ITU-T (the Telecommunication Standardization Sector) coordinates standards for telecommunications on behalf of the ITU (International Telecommunication Union)

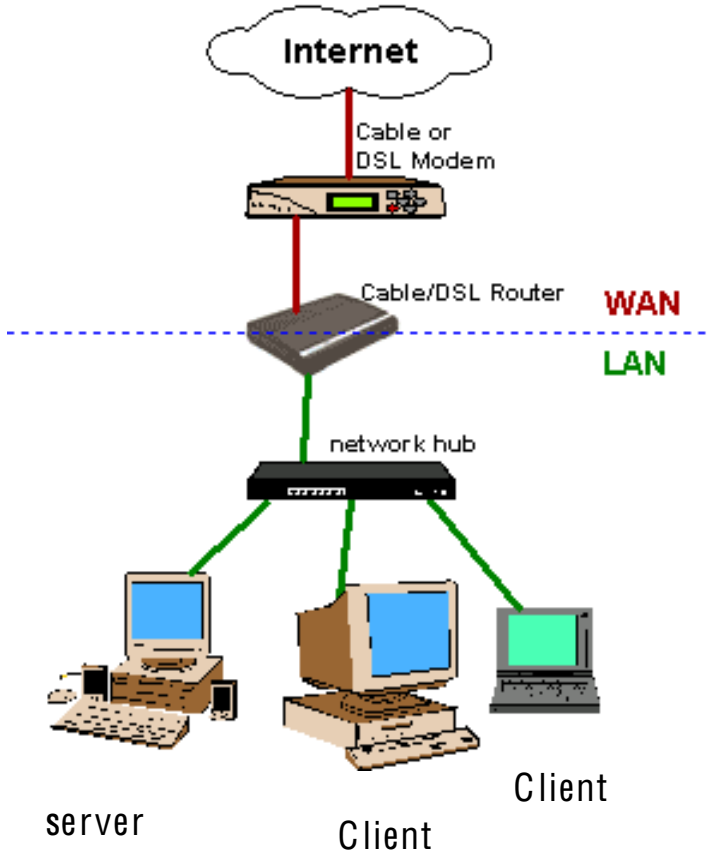
Hub

- A network hub or repeater hub is a device for connecting multiple twisted pair or fiber optic Ethernet devices (end systems: client or server) together and thus making them act as a single network segment



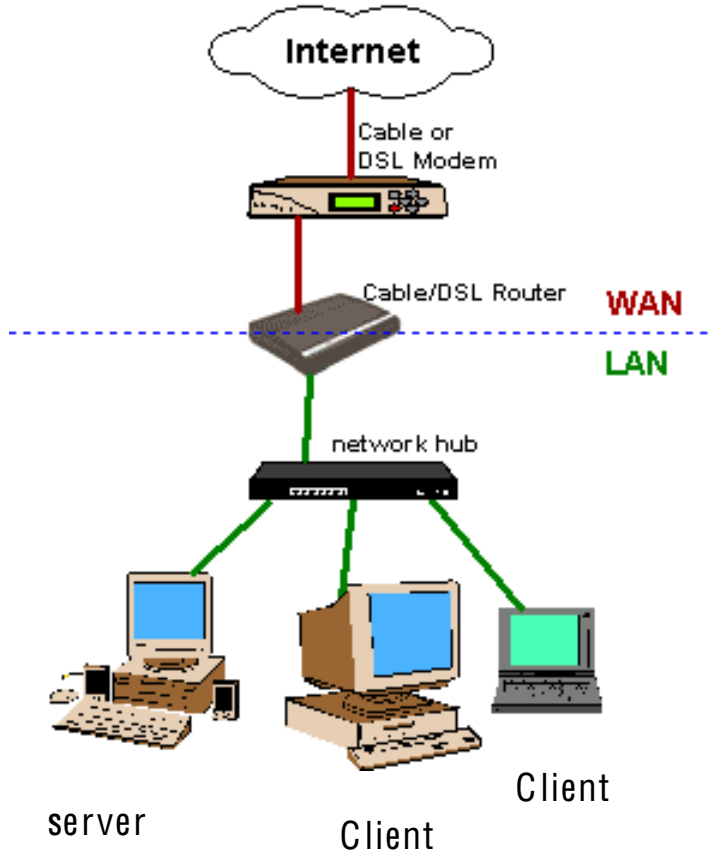
LAN – Hub-based

- Hub is connected to the router and thru that to the rest of Internet
- Hub relays every transmission from sender to all other end systems so this is a **shared** network (a broadcast LAN)
- For example, when a client requests to access a server, every end system's NIC receives that request through the hub, however all NICs but that of the server will ignore it
- Question: what happens if the hub is connected directly to the Internet (not through a router?)



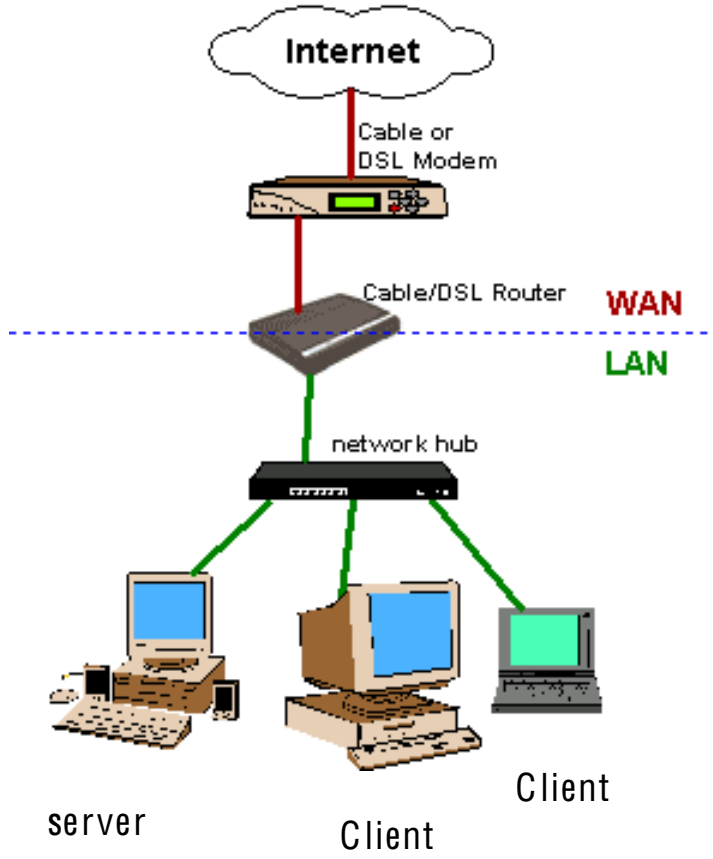
Hub-based LAN – Collision Problem

- Note that whenever a hub receives a bit from one of its nodes it sends a copy of that bit to all other nodes, therefore if a hub receives frames from two different nodes at the same time a **collision** occurs and the nodes that created the frames must retransmit those frames again



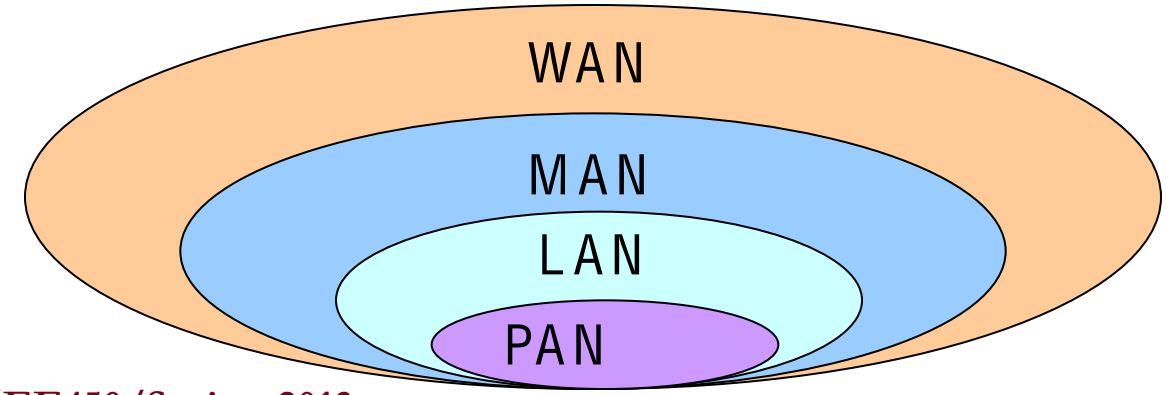
LAN – Switch-based (Cont.)

- In the early 2000s Ethernet standard replaced hub with a switch which is not only collisionless but also a store-and-forward packet switch
- Router vs switch

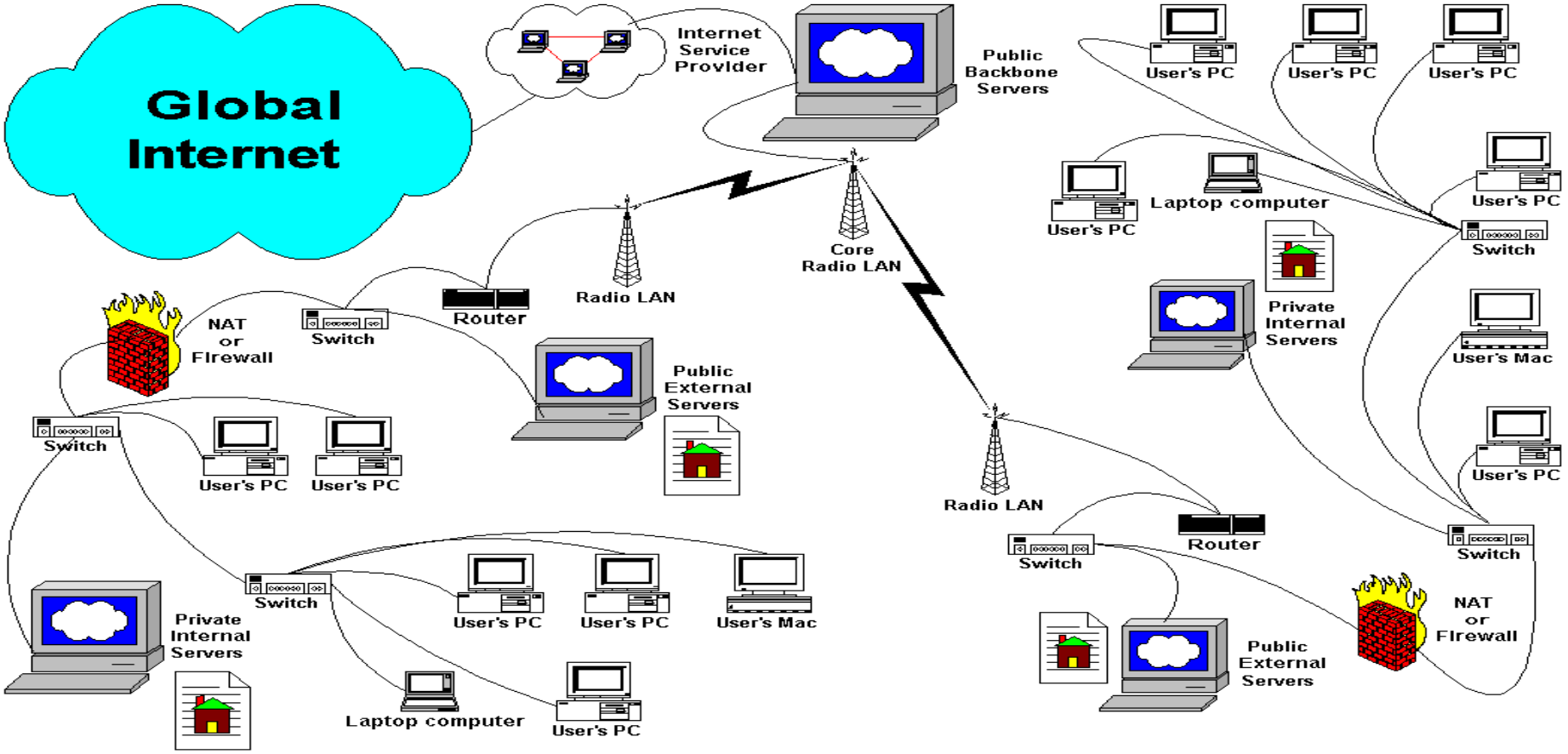


Network Classifications – MAN

- **MAN** (Metropolitan Area Network) is a large computer network usually spanning a city (with a size btn a LAN and a WAN)
  - It typically uses wireless infrastructure or optical fiber connections to link its sites which have their own separate network
  - Examples are cable TV network for high-speed data connection to Internet, and part of the telephone company that can provide high-speed DSL lines to customers

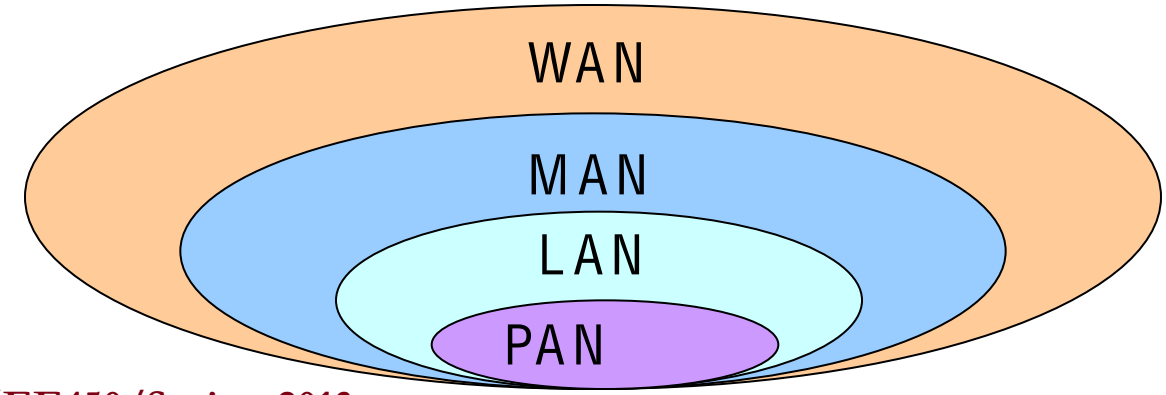


MAN Example


Global Internet
Internet Service Provider
Public Backbone Servers
User's PC
User's PC
User's PC
Laptop computer
User's PC
Switch
User's Mac
User's PC
Core Radio LAN
Radio LAN
Router
NAT or Firewall
Switch
Public External Servers
Private Internal Servers
Switch
User's PC
User's PC
Radio LAN
Router
Switch
Switch
User's PC
User's PC
User's Mac
NAT or Firewall
Private Internal Servers
Public External Servers
Laptop computer
User's PC

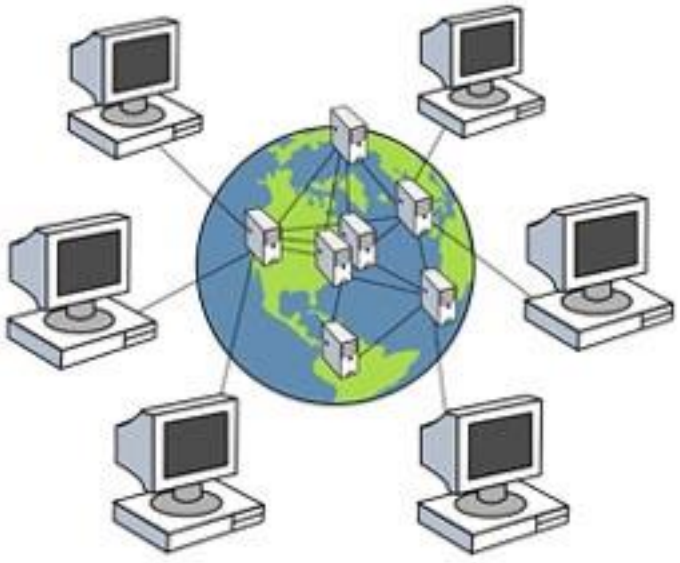
Network Classifications – WAN

- **WAN** (Wide Area Network) covers a broad area (i.e., any network whose communication links cross metropolitan, regional, or national boundaries) in contrast with PANs, LANs or MANs which are usually limited to a room, building, campus or a city
- Example: The one that covers the North America

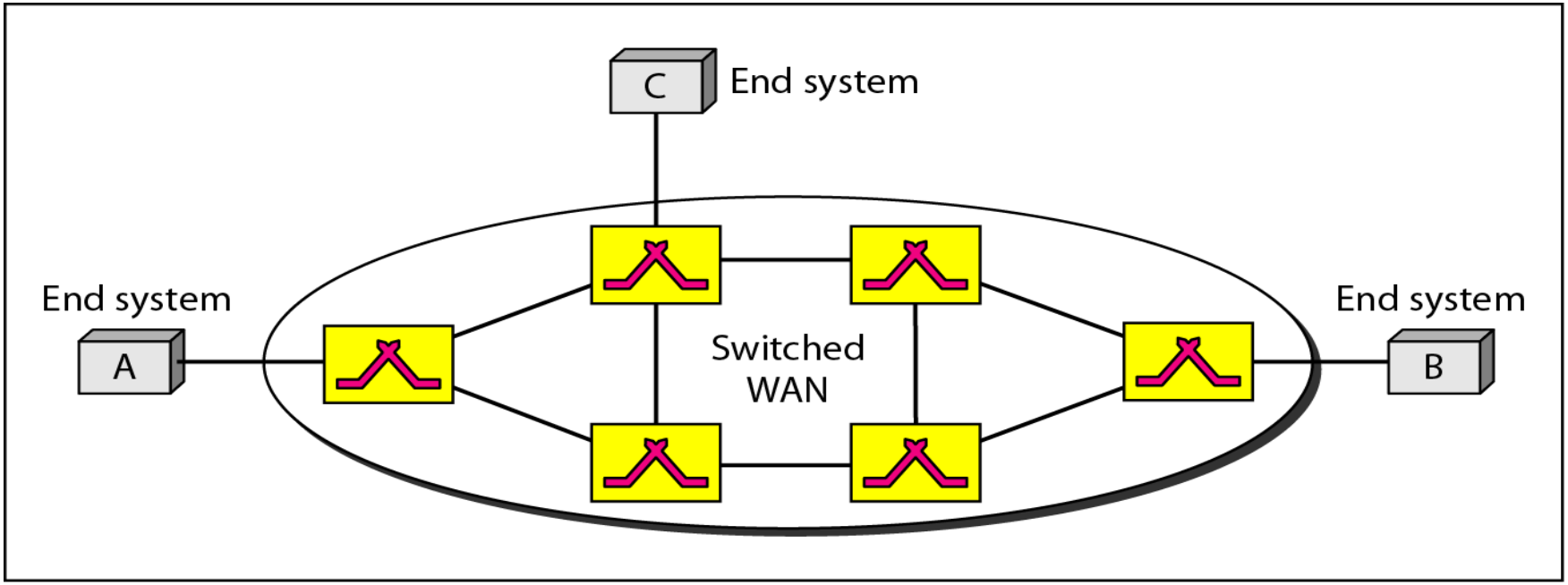


WAN (Cont.)

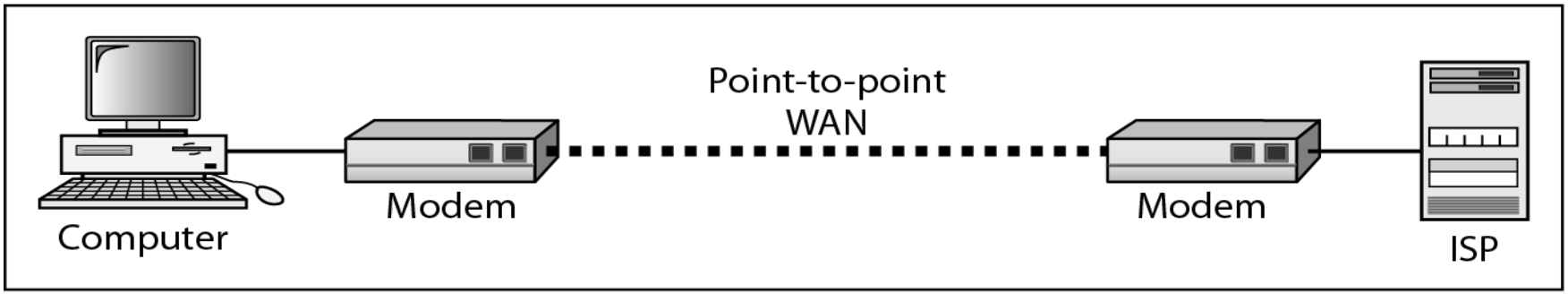
- WAN can be global, such as the whole Internet and PSTN
- Internet is the most well-known and one of the largest examples of a WAN
- Question: which one is the largest WAN? Internet or PSTN



WANs: A Switched WAN and a Point-to-Point WAN



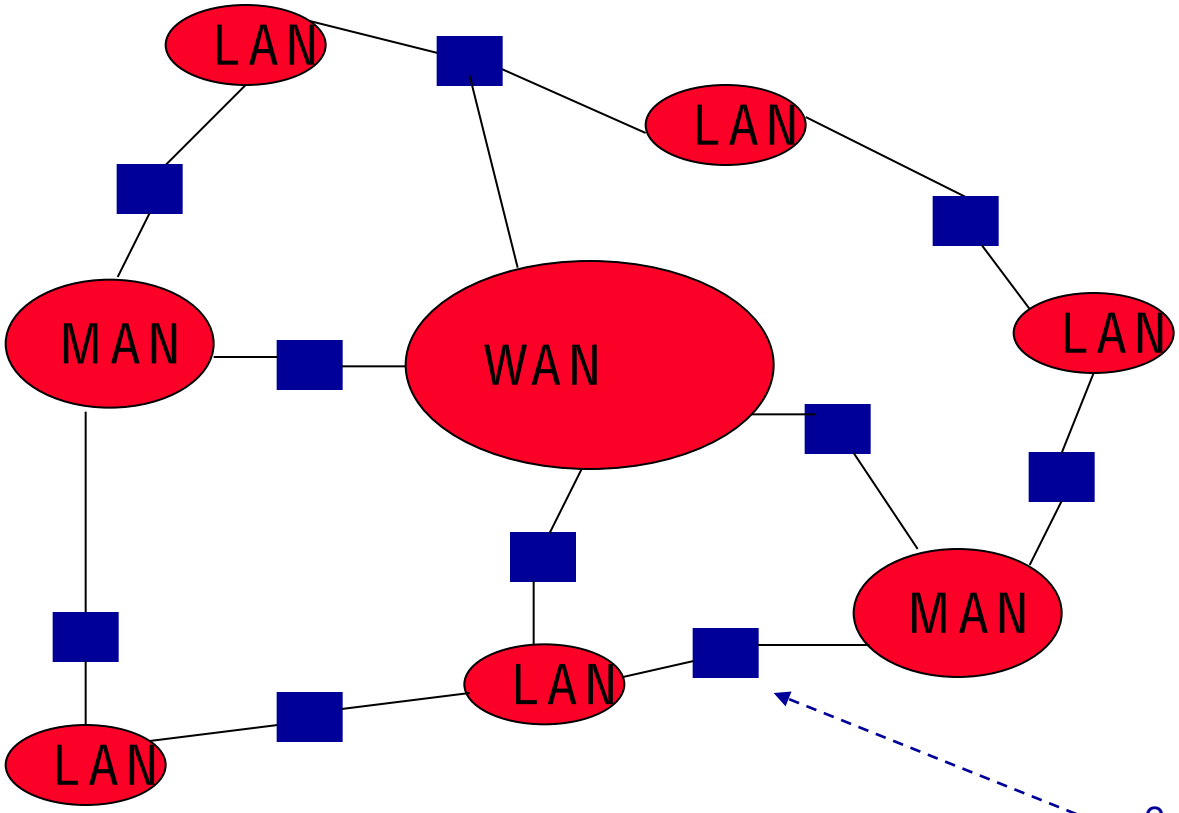
a. Switched WAN



b. Point-to-point WAN

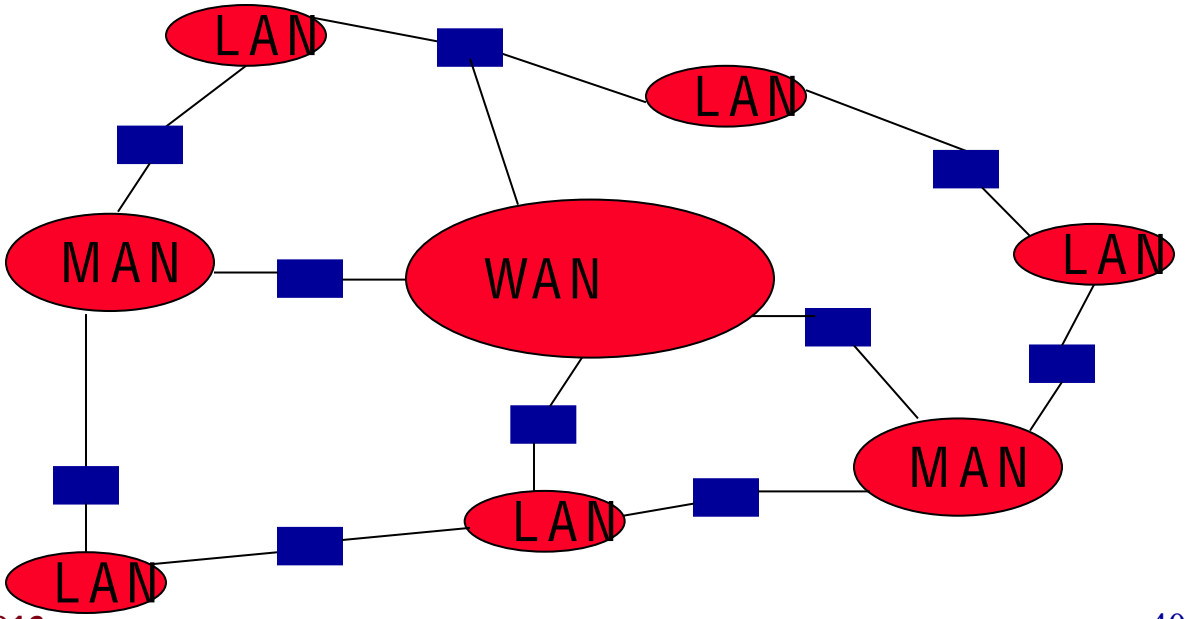
Internetworking

- **Internetworking** involves connecting two or more computer networks using a common routing technology. The result is called an *internetwork* (often shortened to *internet*)



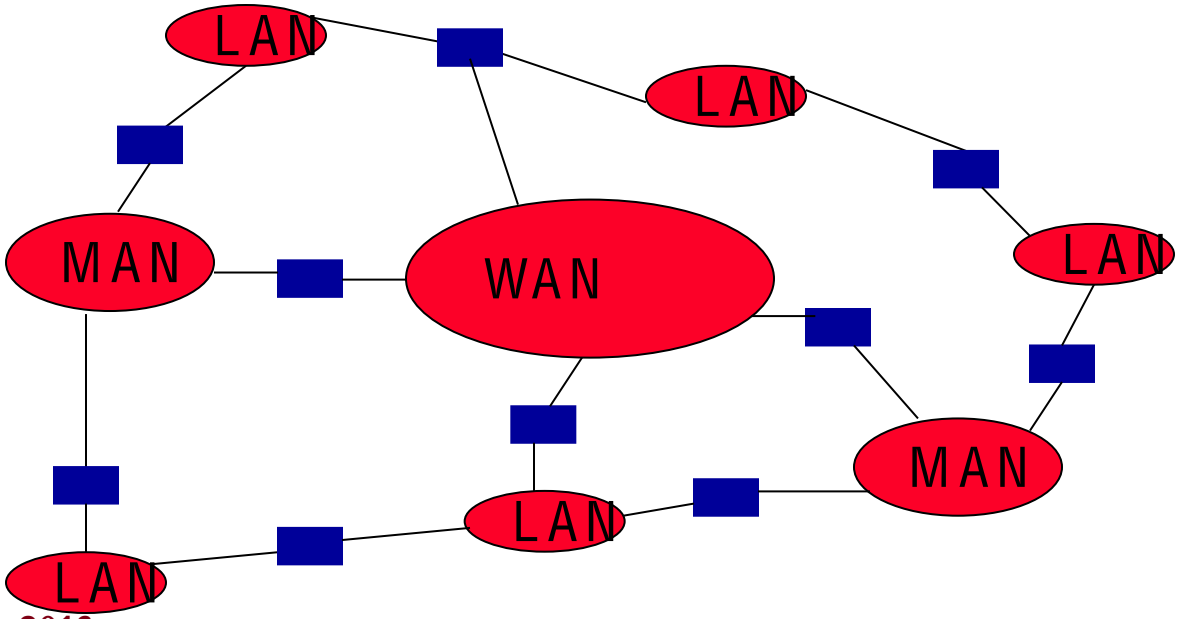
Internetworking (Cont.)

- The gateway has to be at least a router, i.e., a 3rd layer switch that can recognize IP addresses
- How about hubs and switches?

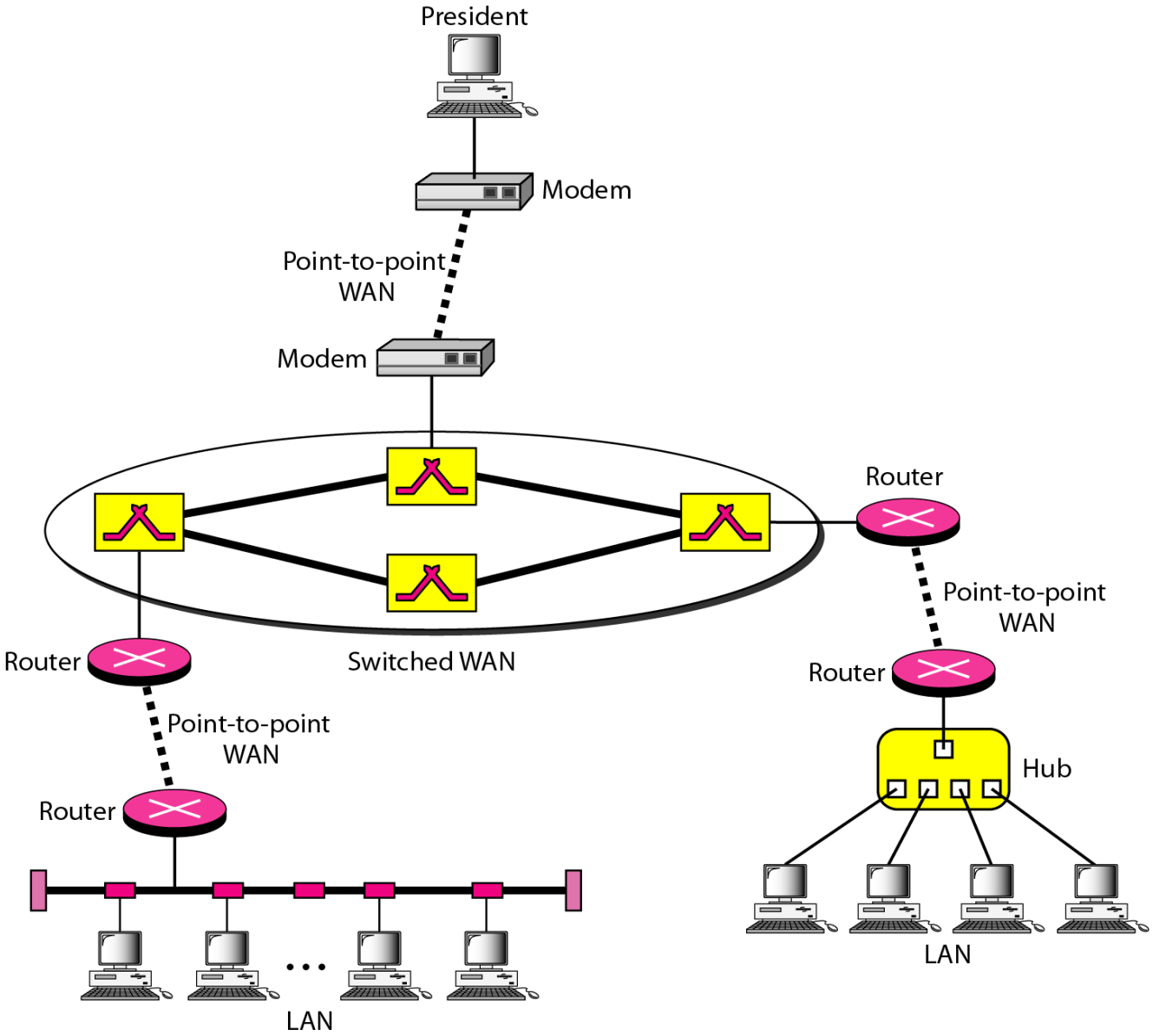


Internetworking (Cont.)

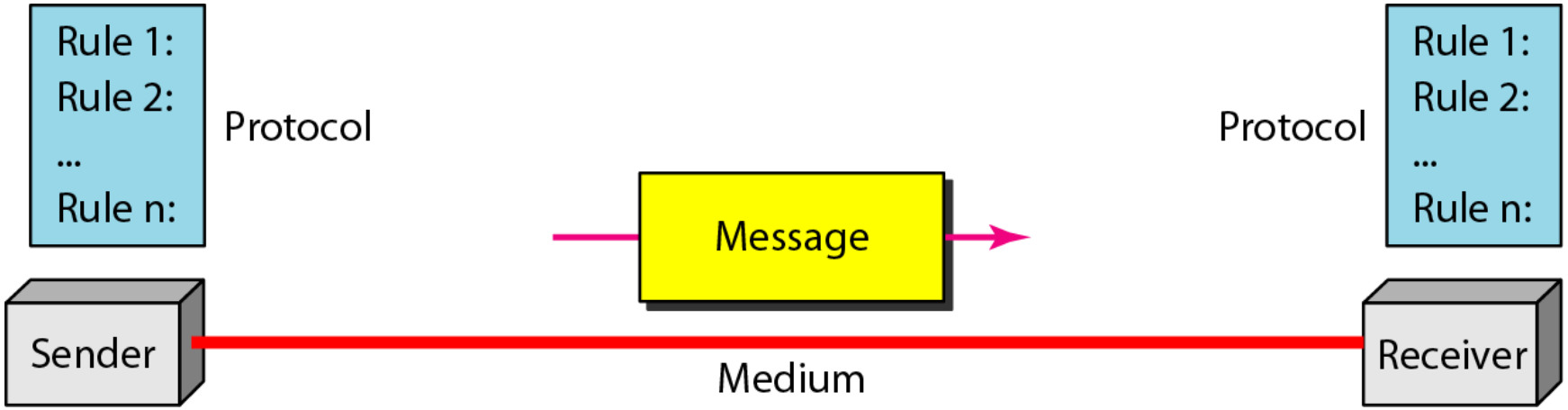
- The most notable example of internetworking is the Internet (note: it's often, but not always, capitalized), a network of networks based on many underlying hardware technologies, but unified by an internetworking protocol standard, the Internet Protocol Suite, i.e., TCP/IP



Example – A Heterogeneous Network Made of 4 WANs and 2 LANs



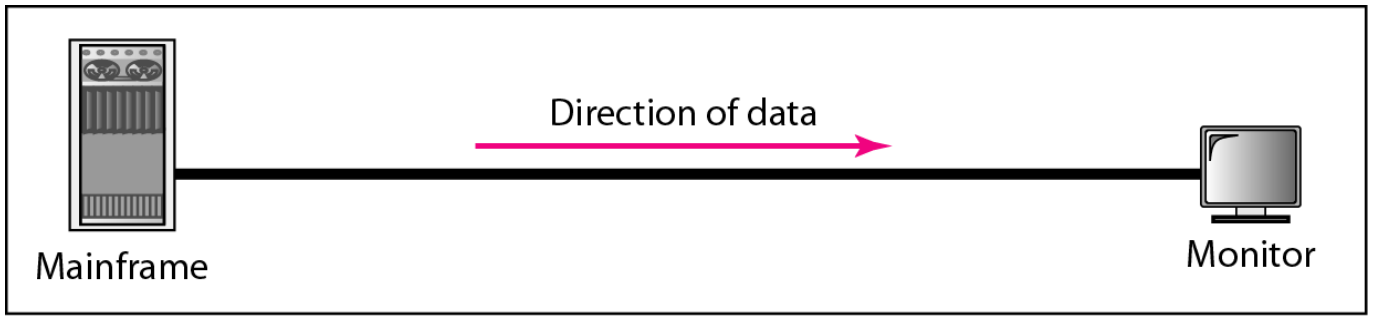
Communication Components



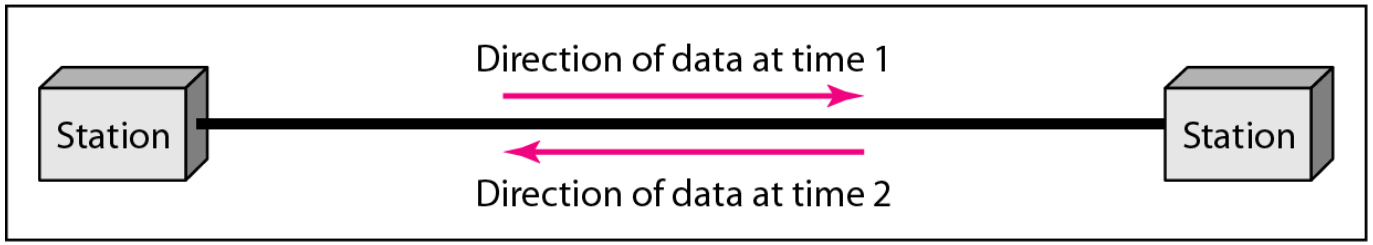
Transmission Types

- Transmission is in one direction one device always transmits (T/X) one always receives (R/X), they cannot switch roles, e.g., in Radio/TV broadcasting
- In half duplex, both sides can transmit, but one at a time, so if one is T/X, the other R/X is, vice versa. One pushes the button to talk, and releases to receive, e.g., the ones in police cars or cabs
- In full duplex, both sides transmit at the same time
- Which one works for Telephony?

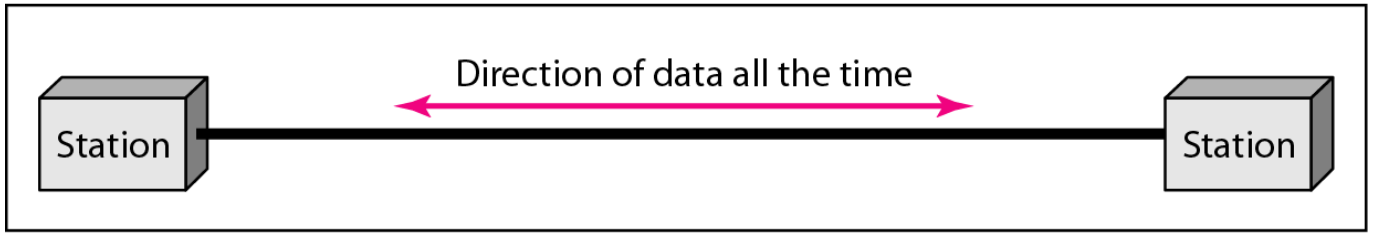
Transmission Types – Data Flow Example



a. Simplex



b. Half-duplex

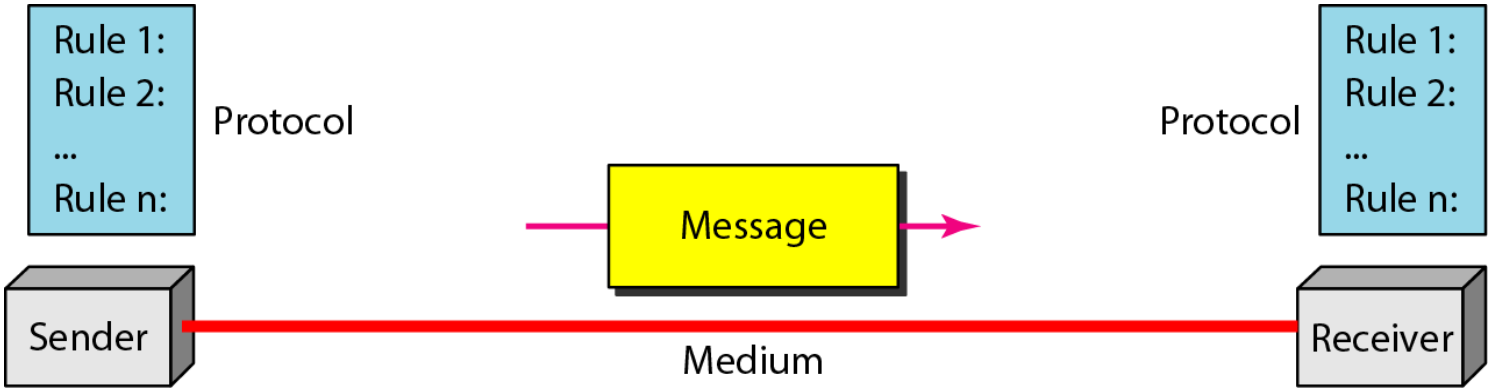


c. Full-duplex

Communication

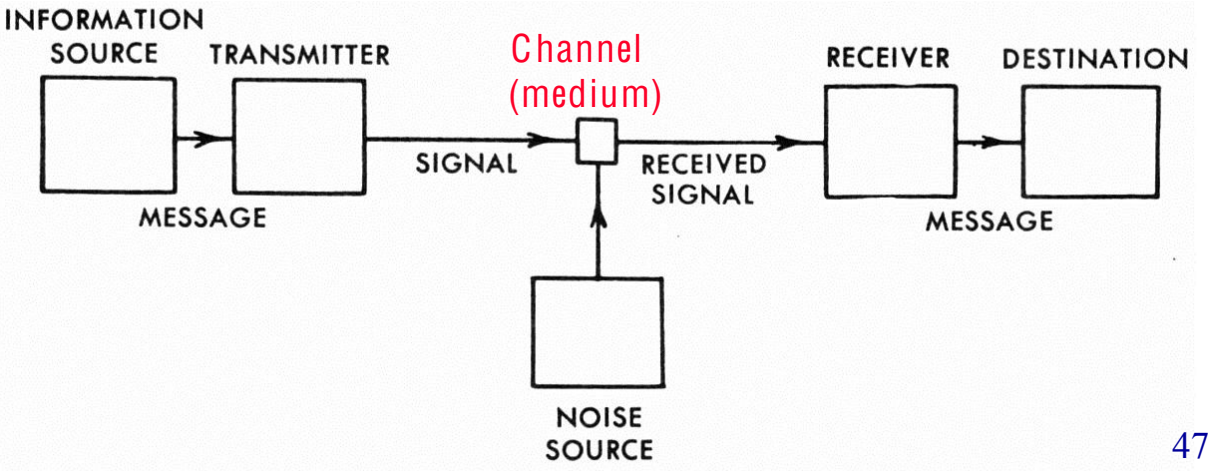
- **Communication** is sharing of information
- **Remote communication** or **telecommunication** includes telephony, telegraphy, and television and means communication at a distance

- 5 components of communications



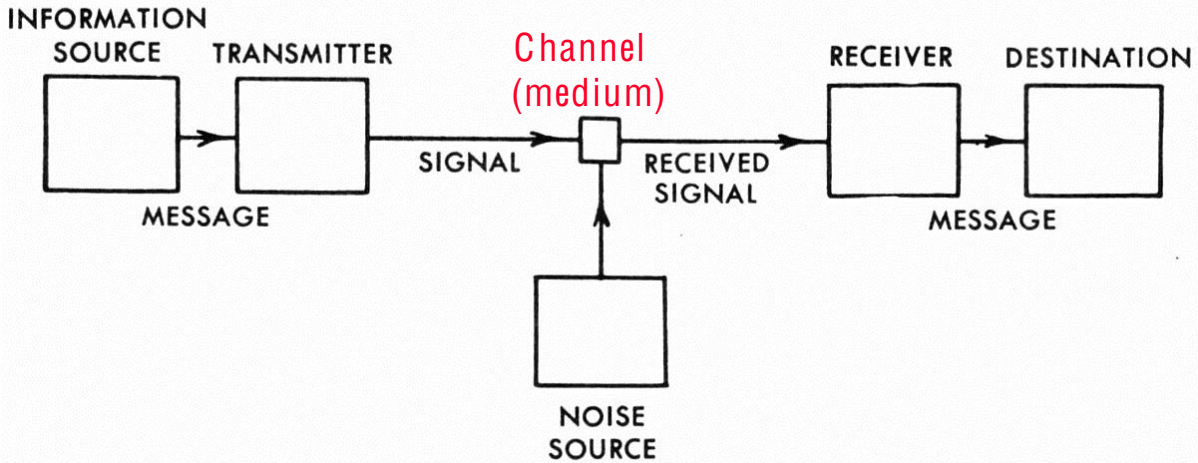
The Shannon-Weaver Simple Communication Model, Year 1949

- The message (data or information) is generated by source in analog or digital and then passed to the transmitter to be transformed to a proper form for the medium. e.g., consider a PC as the source and the telephone line as the channel, so a dialup connection is going to be used to transfer data
- A transmitter is required to convert the data from digital to analog which is suitable for the telephone line. This transmitter is called the **MODEM** (**Modulator and Demodulator**)



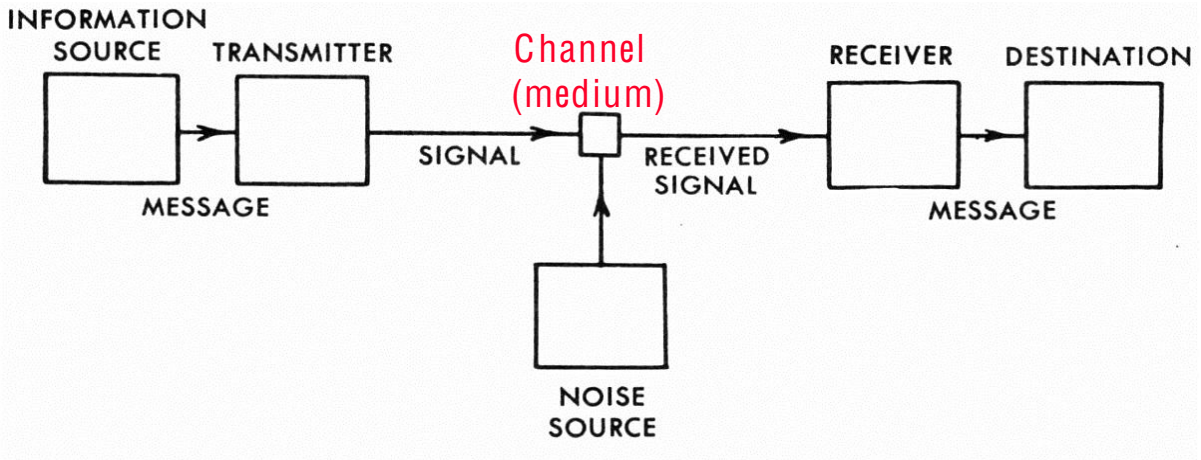
Shannon Communication Model (Cont.)

- Note that analog signal is the proper form for the telephone line, because telephone line was designed to carry voice signal which is analog
- Modem is needed for dialup, DSL, or cable
- The channel or the transmission medium can be copper wire, coaxial cable, optical fiber, wireless radio and satellite or microwave
- Note that this is a simple communication model, and a lot of steps and tasks that need to be performed are not shown



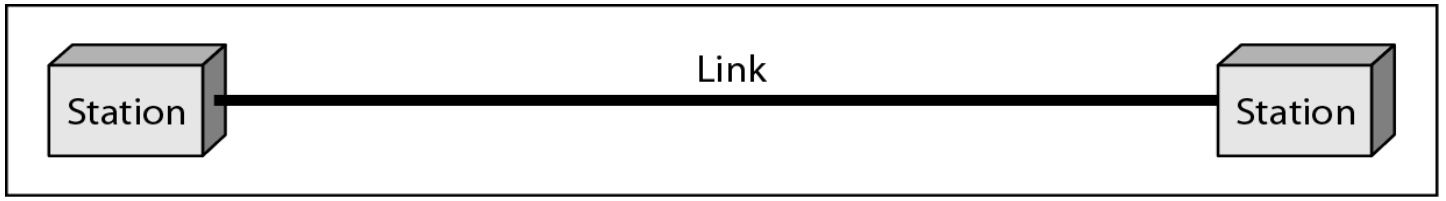
Shannon Communication Model (Cont.)

- When signal travels through the transmission medium it will degrade due to noise (interference.) The level of degradation depends on the medium
- The receiver side, reverses what the transmitter has done on the signal
- Suppose in the transmitter side, a directory is tarred into a file and then zipped; the receiver should then try to unzip and untar the file into the original directory

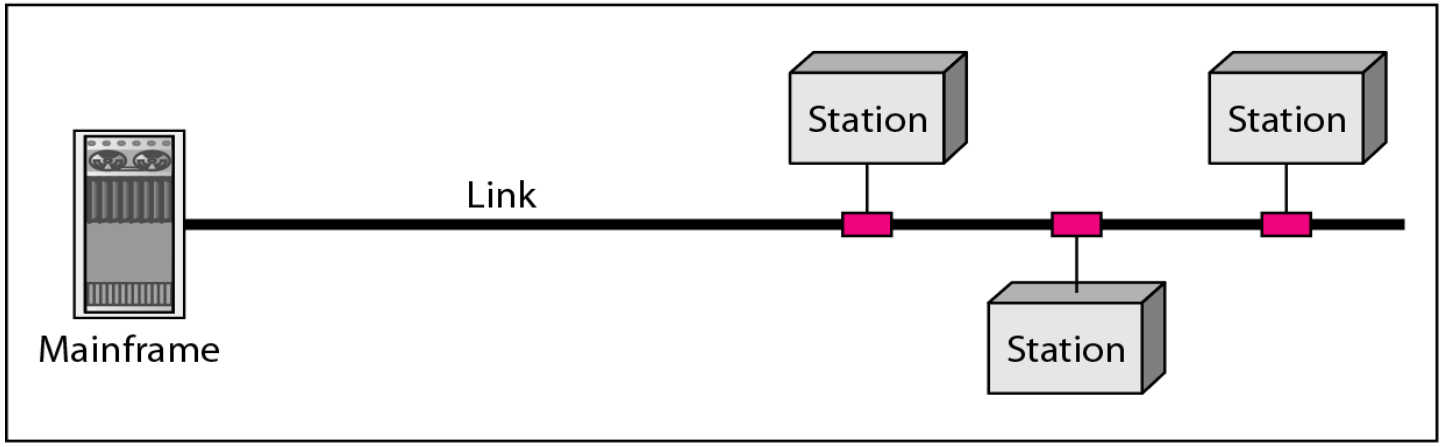


Point-to-Point Link

- PSTN and Internet (in general WANs) are switched networks and use point-to-point links



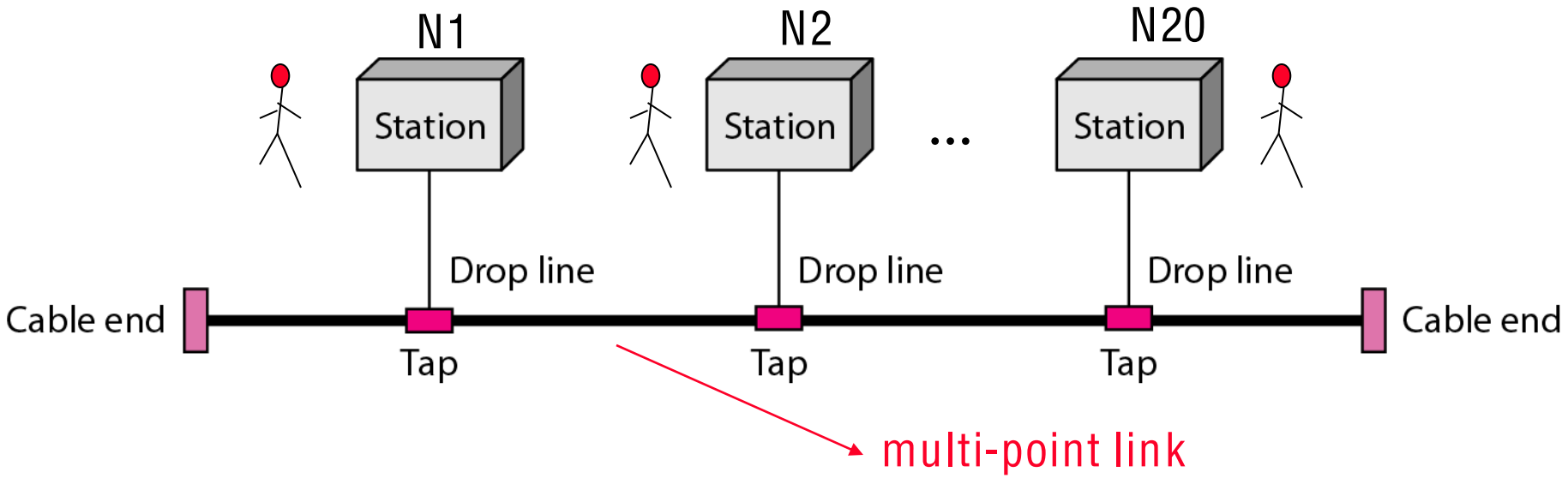
a. Point-to-point



b. Multipoint

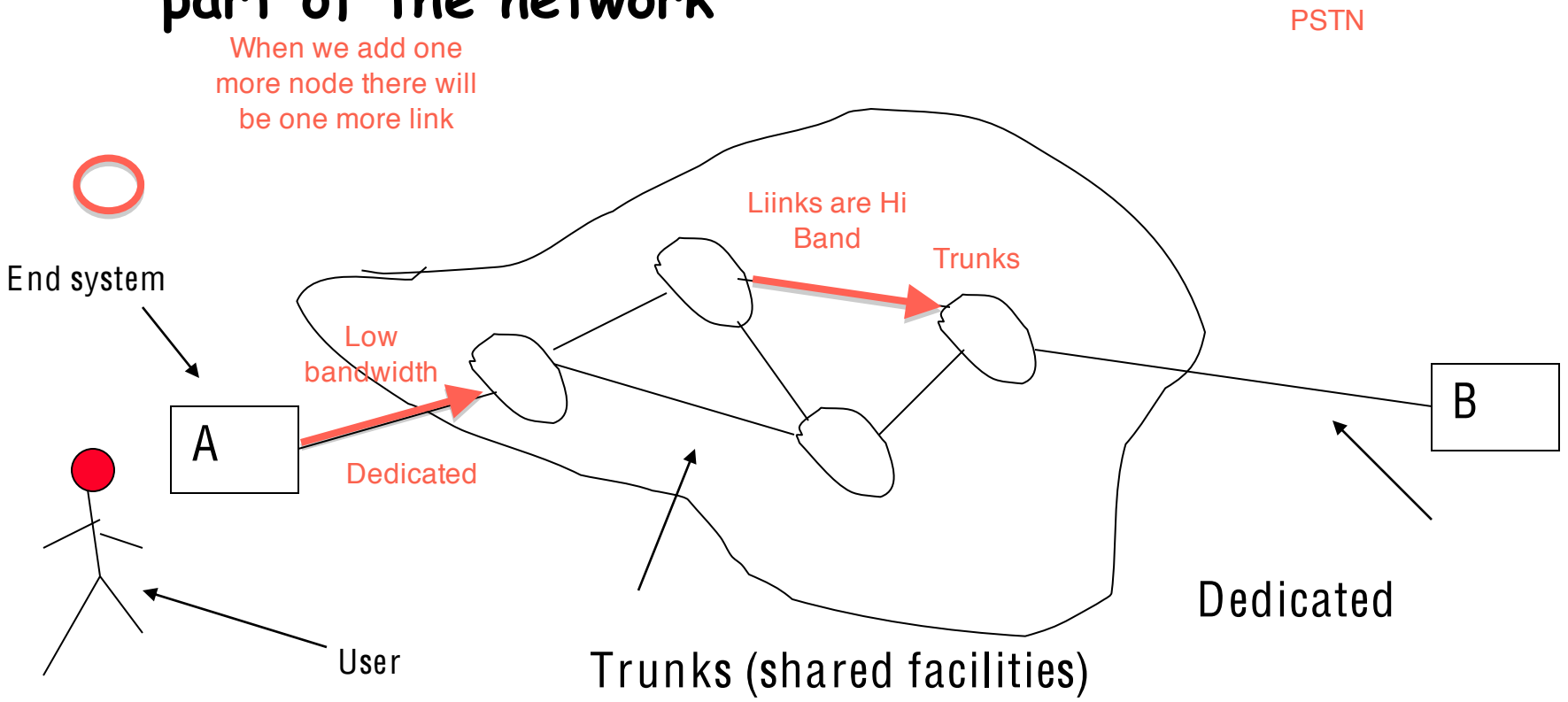
Multi-Point Link

- In a shared network, all the nodes share the same medium, i.e., they use a multi-point link



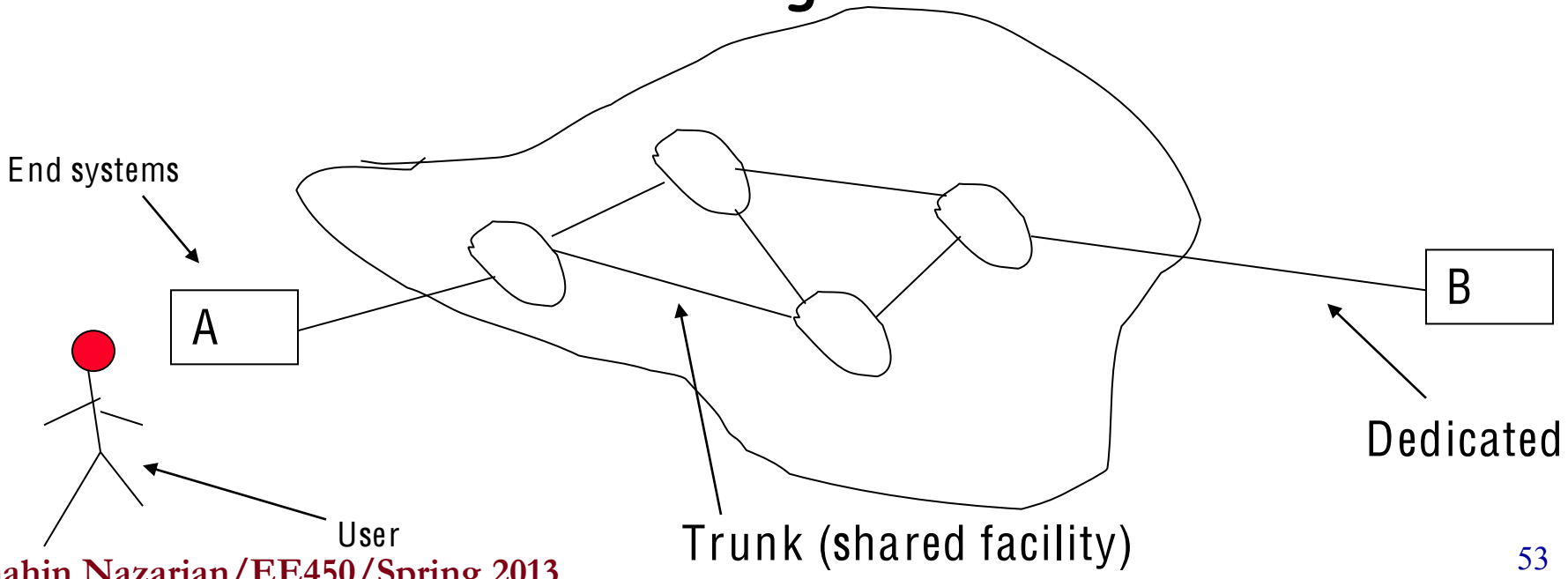
Transmission Facilities – Shared or Dedicated

- Hosts: A and B are called the hosts or end systems. Note that the end system and end user are not the same
- Once you connect the host, the host becomes part of the network



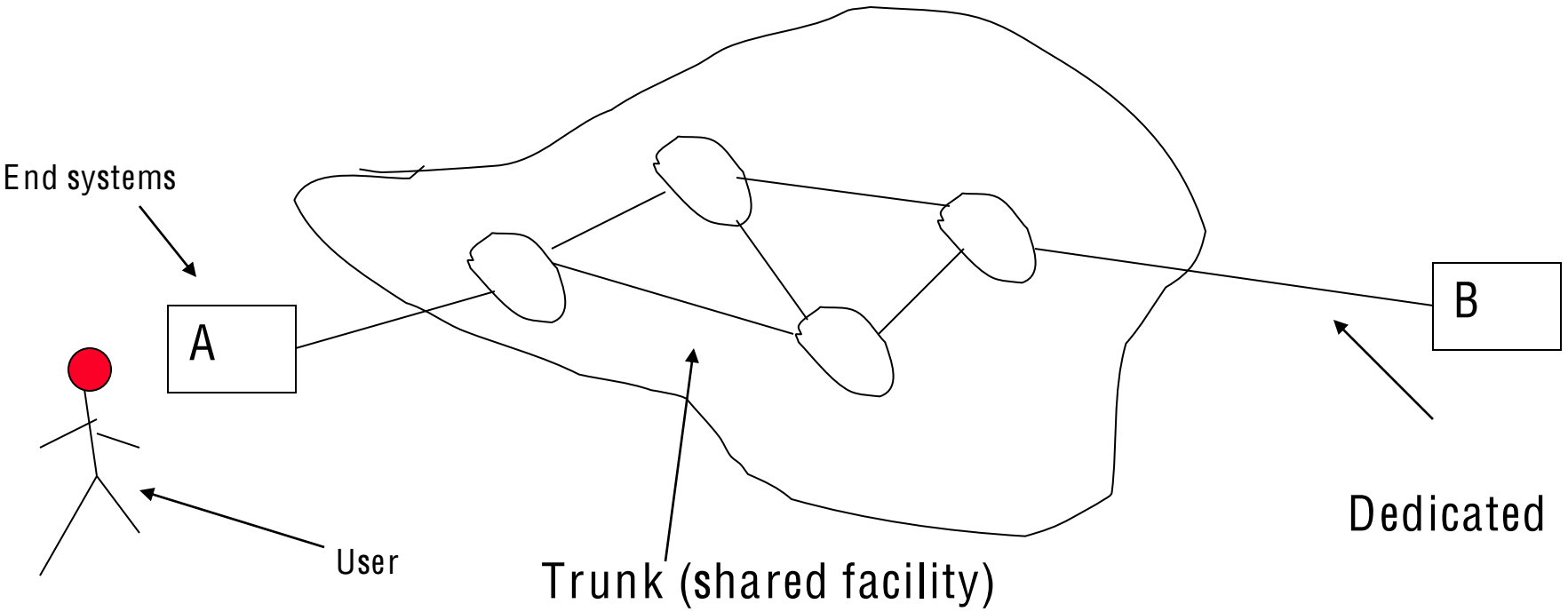
Shared Facilities (Cont.)

- Transmission facilities can be shared or dedicated
- Shared facilities (referred to as trunks) have huge capacity (bandwidth) and so are able to support large volume of data, because they are shared, the traffic comes from all users
- Shared facilities are typically fibers, satellite links, microwave which can have high bandwidths



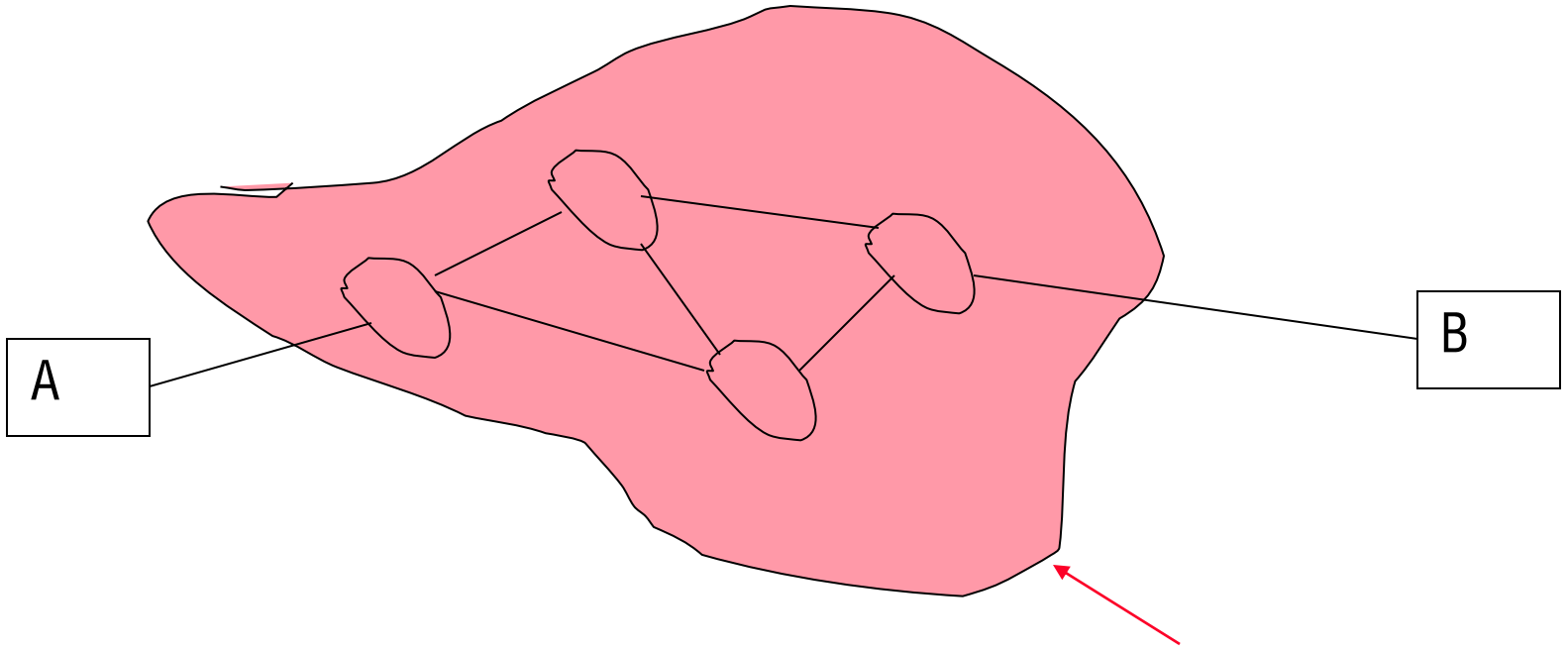
Dedicated Facilities

- **Dedicated** facilities are, however low bandwidth because they are supporting traffic from a single user or a single host



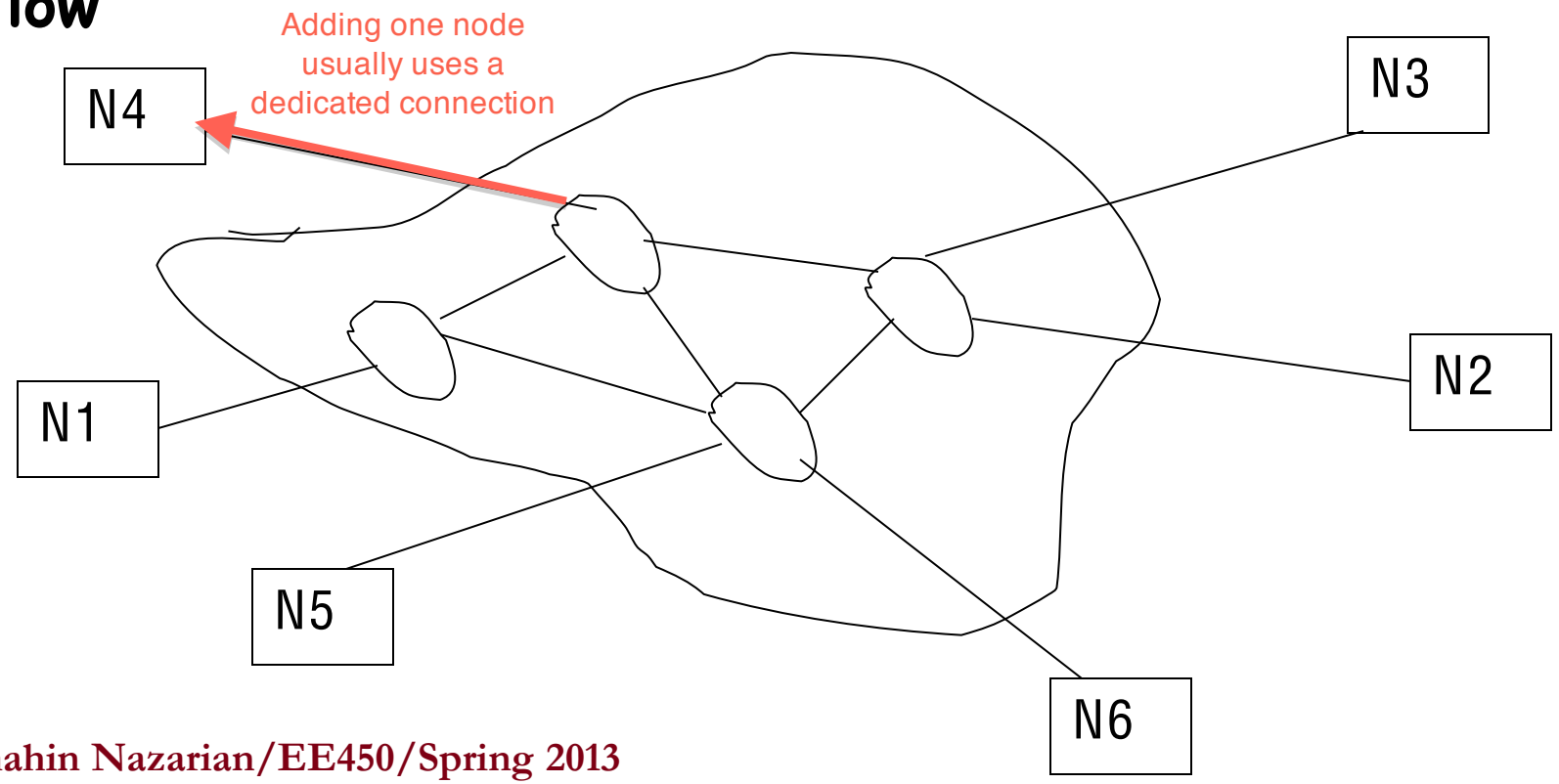
Network Cloud

- Which switches make it possible for a A to B call to go through?



Network Cloud (Cont.)

- Having the network cloud already established and supported by network providers, connecting a host can become possible by adding one port and a shared/dedicated? interconnect, therefore compared to a fully-connected topology, the cost is extremely low



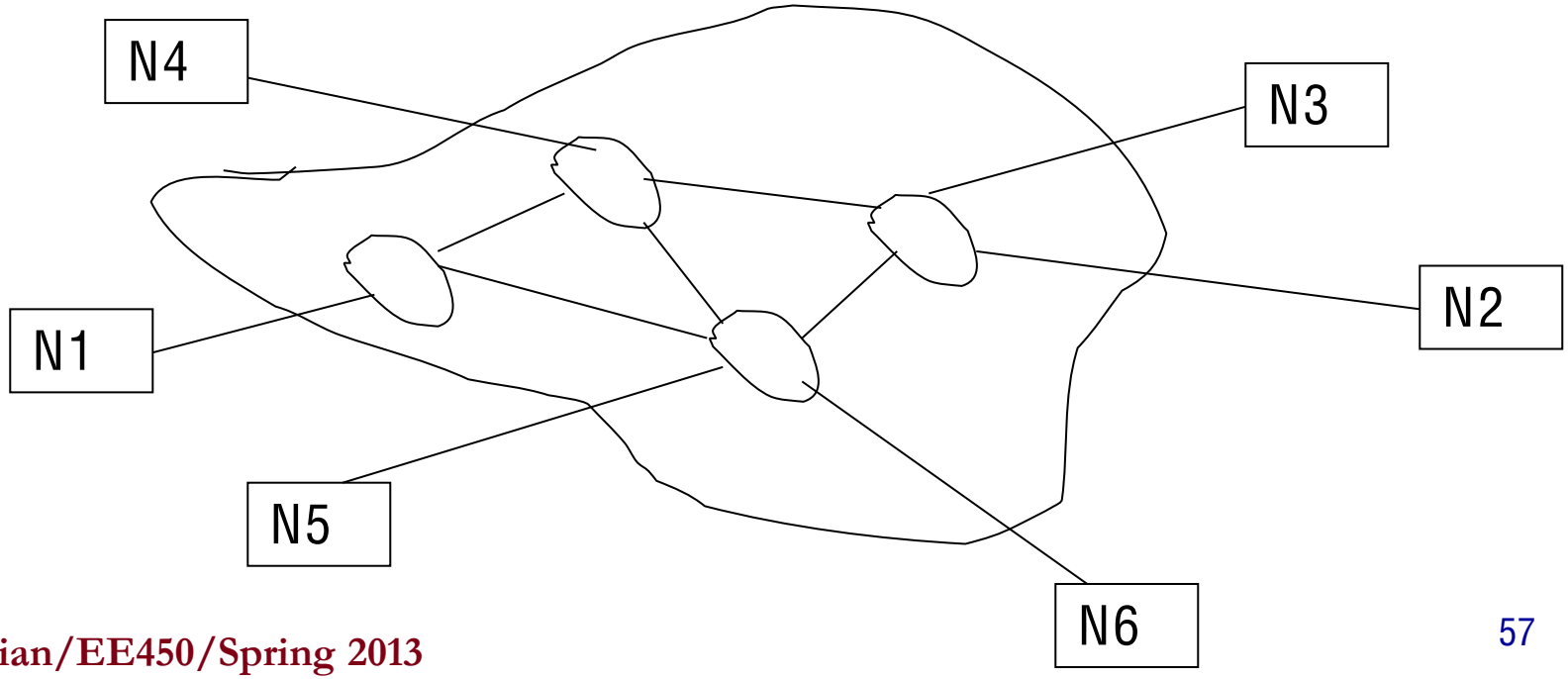
Network Cloud (Cont.)

- Example: the cost for 6 nodes full-connected vs cloud

6 -> 7 F.C.

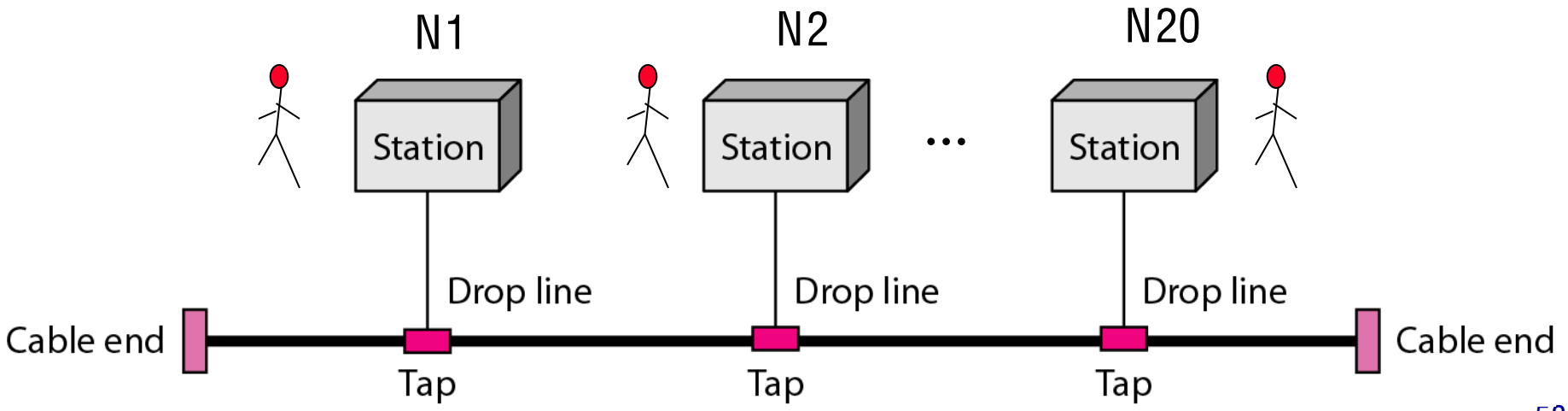
Used for data/ Voice

- Now in terms of cost: the cloud belongs to the network provider, you are not going to encounter the cost for yourself, instead it will be distributed among all users, each only responsible for one line and port!



Network Classifications – Switched or Shared (broadcasted)

- In a shared network, messages are broadcasted as explained in the following:
- Example: N1 wants to message N15 (e.g., using email as an Internet application

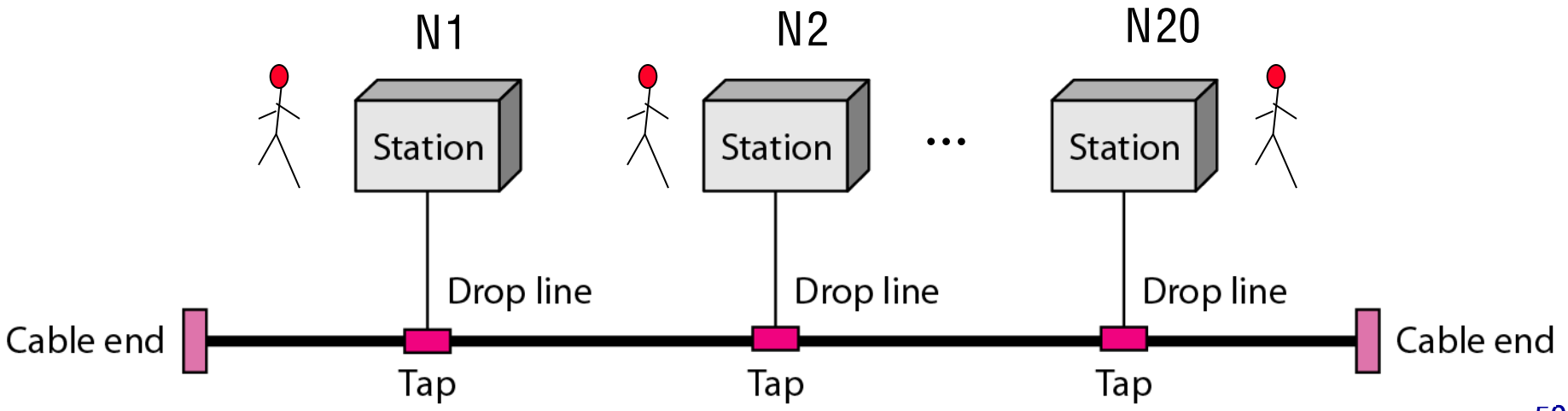


Shared (Broadcast) Network

- **Question: Which NIC would receive the frames?**

Broadcast (everyone)
Unicast (one reciever)
Multicast (sent to a group)

- **The reason is that the link is shared, so the messages (frames) are broadcasted**

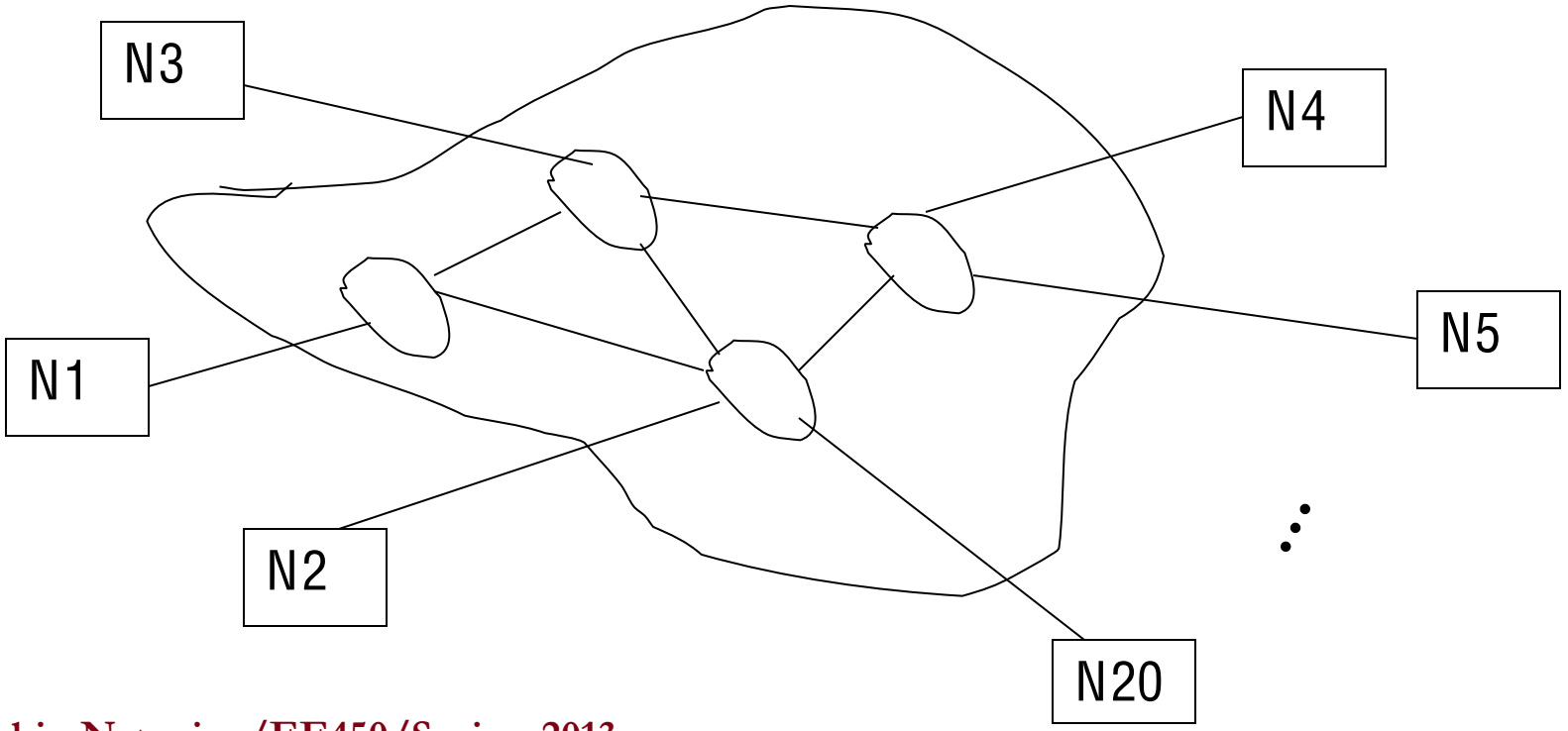


Shared Network – A broadcast message

- Now let's assume N2 wants to broadcast an email (one to all)
- In this case all the NIC cards will recognize that this email is a broadcast message and hence all of them will process the message all the way to the end user and all end users will receive that broadcast email

Switched Network

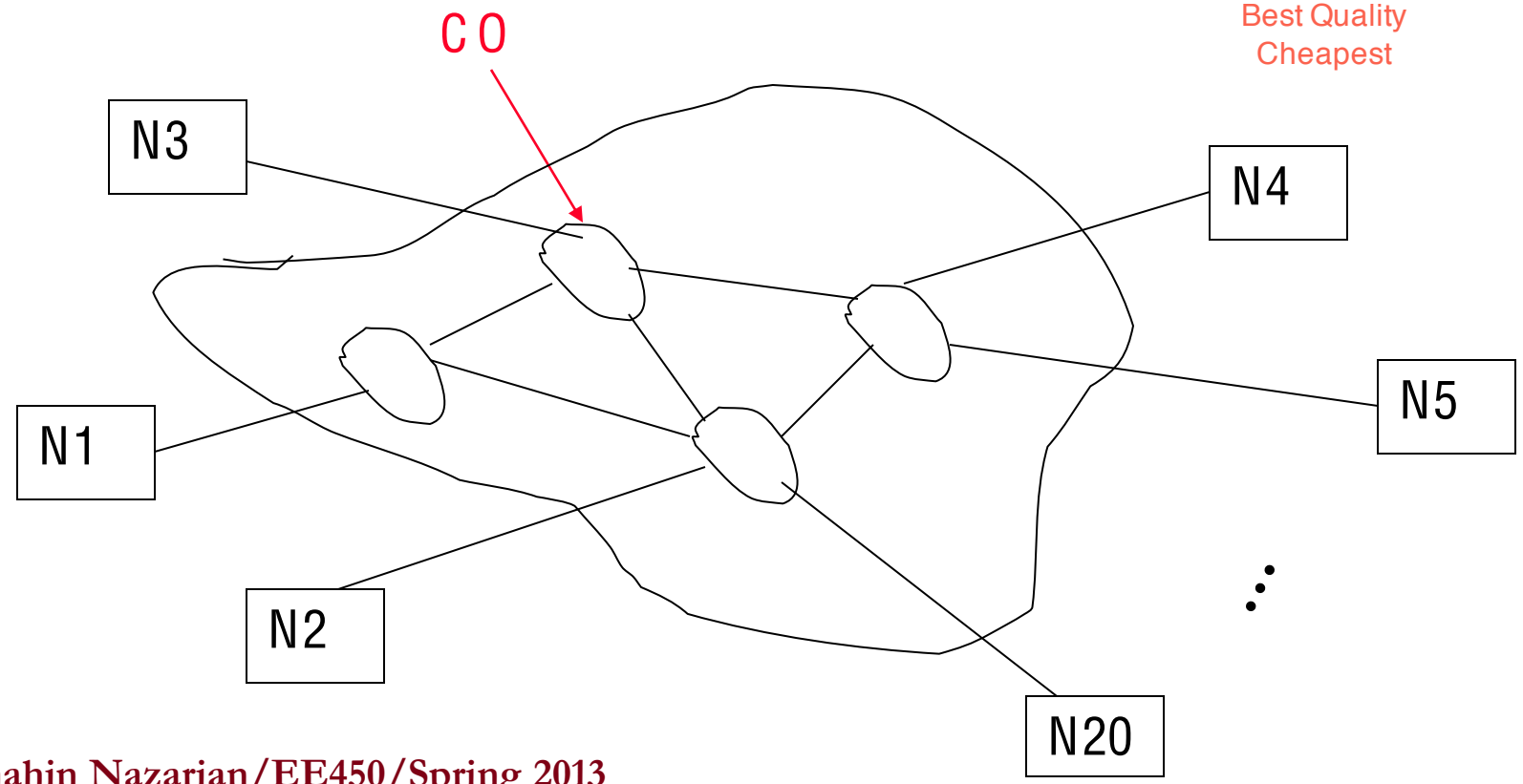
- **Switched network**: when N1 communicates with N5, none of other nodes (NICs) will receive the message because of the fact that the network is of type switched
- Example: **PSTN**



Switched Network (Cont.)

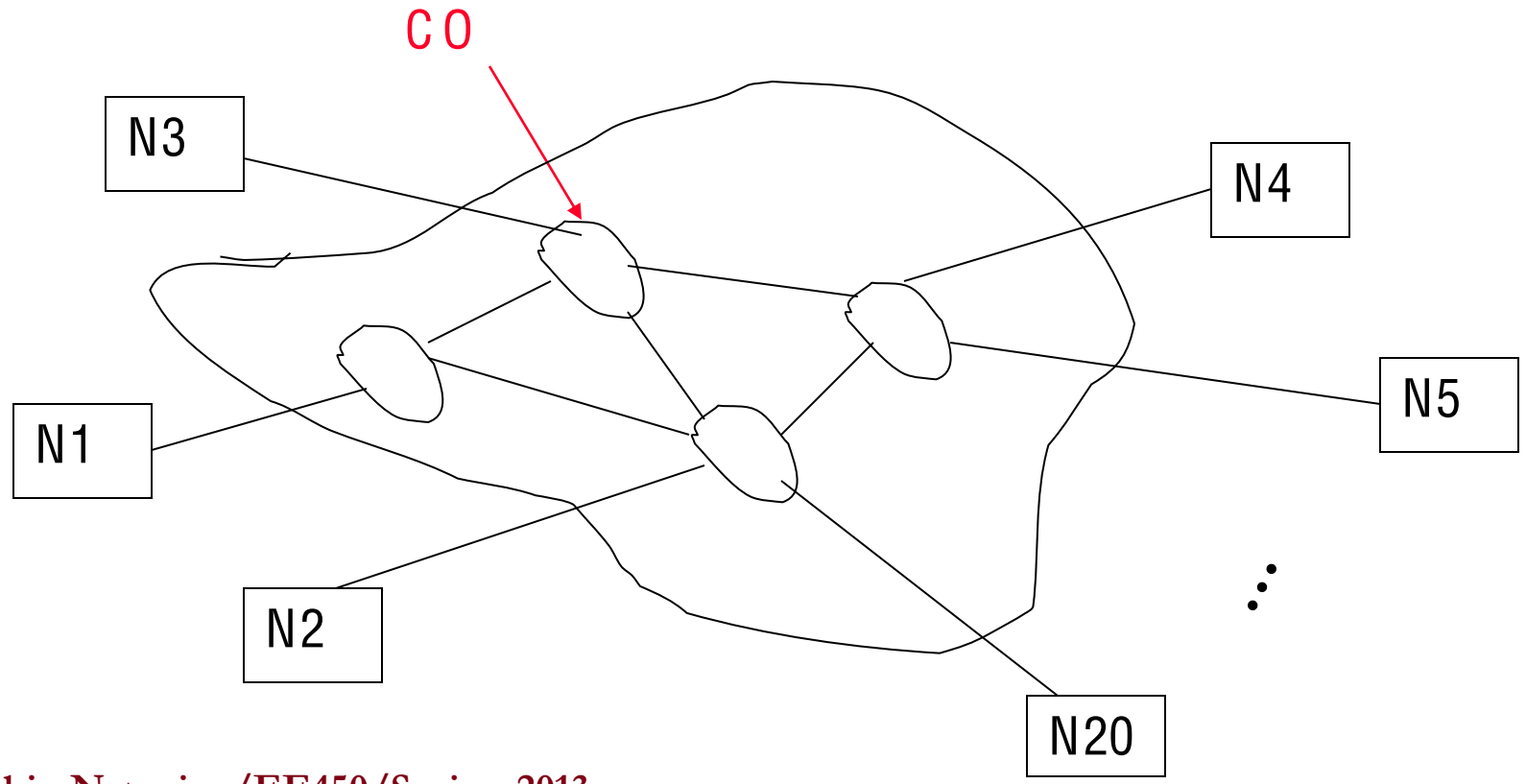
- Nodes may be called differently based on the network
- In PSTN, the nodes are referred to as the **switches**
- Nodes in Internet are referred to as the **routers**

Different kinds of routing
Shortest
Fastest
Best Quality
Cheapest



Switched Network (Cont.)

- Each node in a switched network is connected to a **Central Office** (**CO**). A CO is a switch where a telephone line will terminate in
- N1 wants to message N15 and even if it is not connected to N15, it can demand to have connection

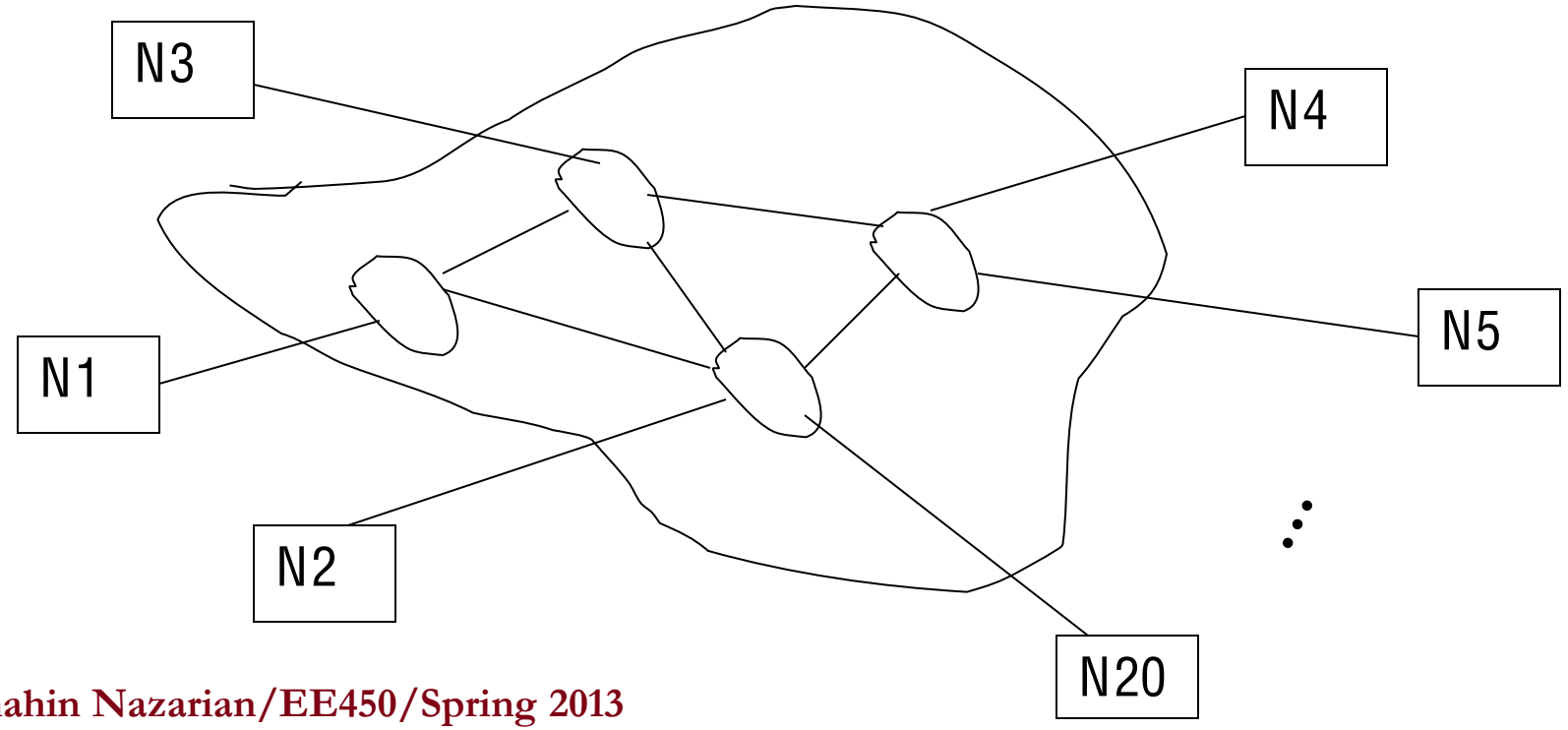


PSTN and Internet for Voice and Data

- PSTN is primarily designed to handle telephone calls and optimized to transfer voice however it can transfer data, but the quality of the communication may not be satisfactory
- Similarly the Internet is primarily designed to handle data communications and optimized to transfer data, however it can transfer voice too

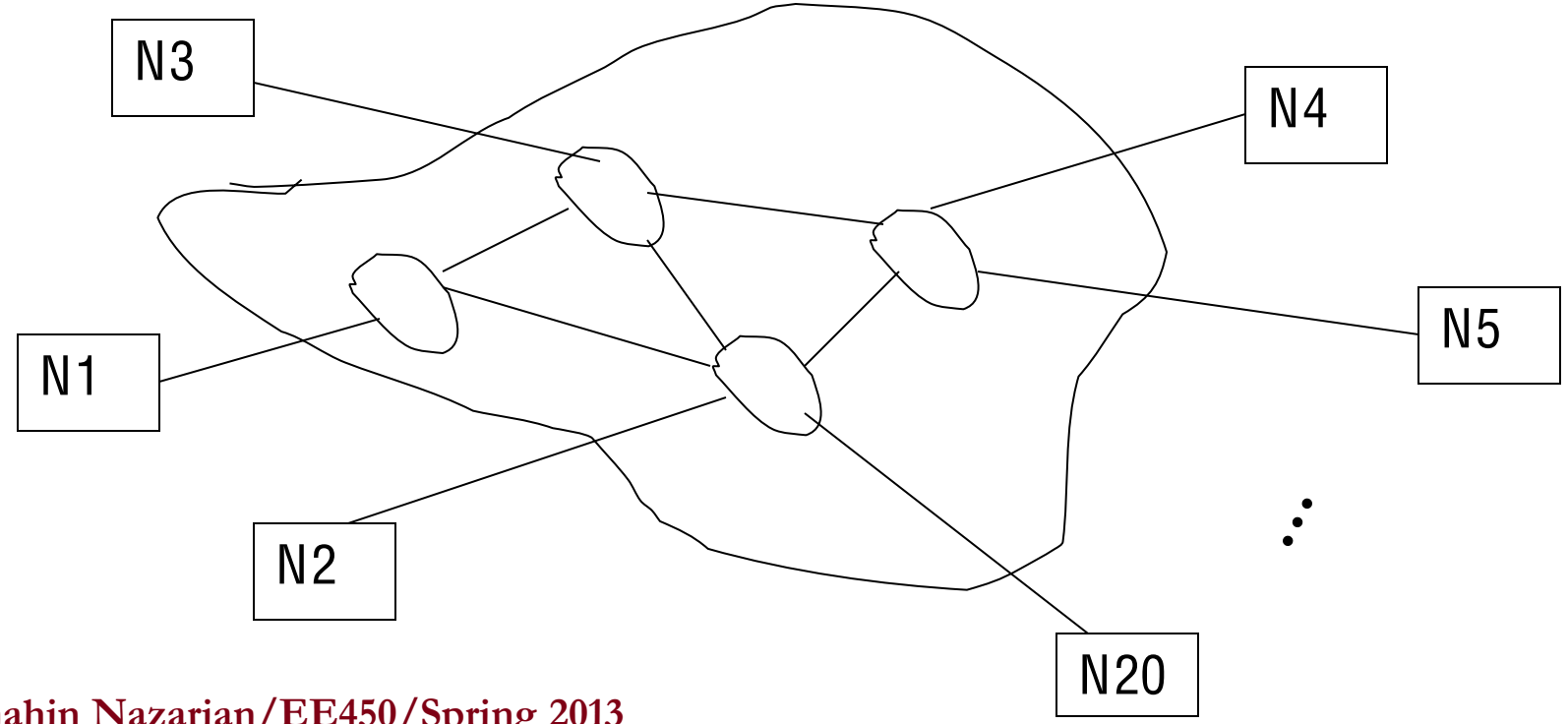
PSTN – Call and Circuit setup

- N1 wants to call N15
- The dial tone indicates that network understood N1 has requested service and that it is ready to accept its destination number (address)



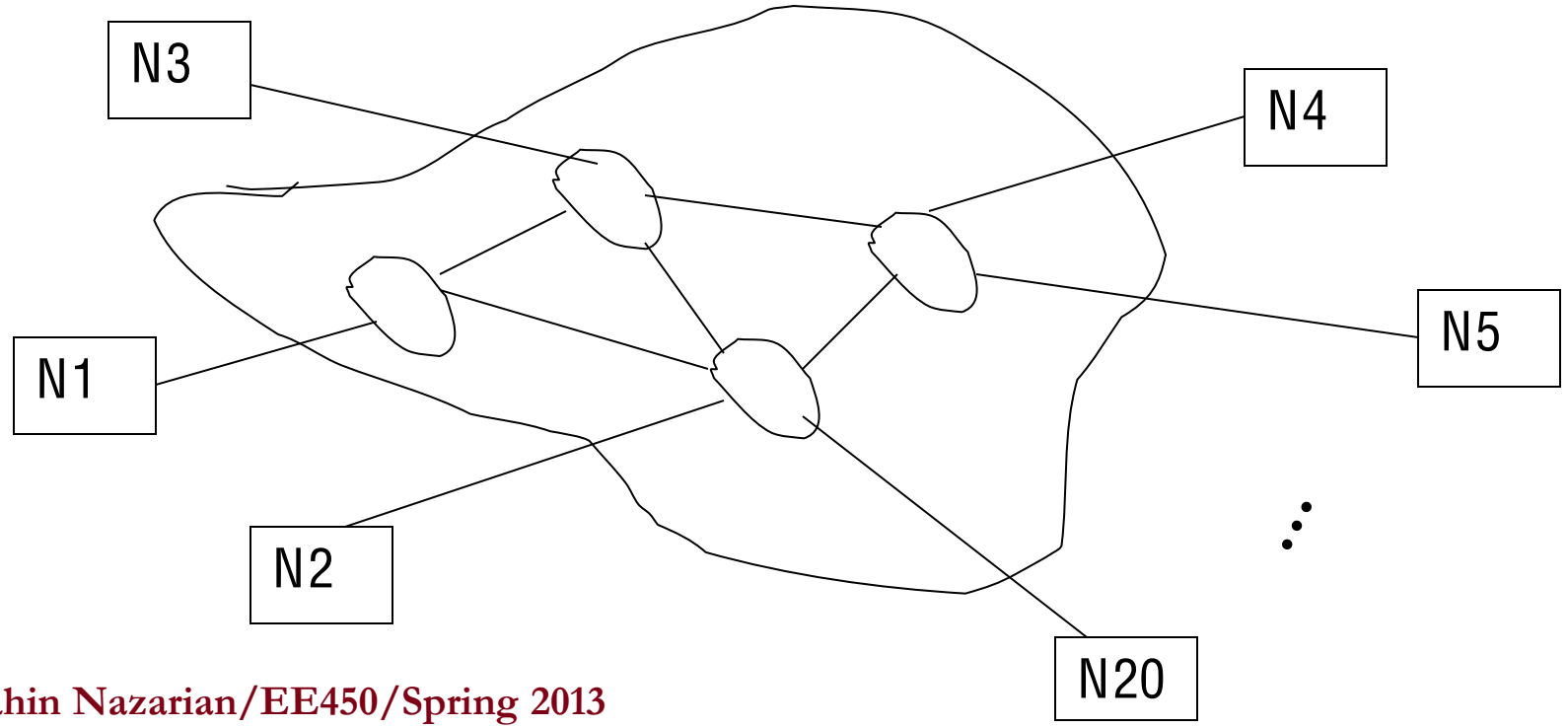
PSTN – Call and Circuit setup (Cont.)

- N1 then dials the number, the CO examines the address or number (the area code, etc.) to decide where the destination is; then the switches will switch the address from one to another and choose a certain route based on that number or address



PSTN – Call and Circuit setup (Cont.)

- Note: N1 does not know the route
- Ringing tone
- Ring back tone



PSTN – Call and Circuit setup (Cont.)

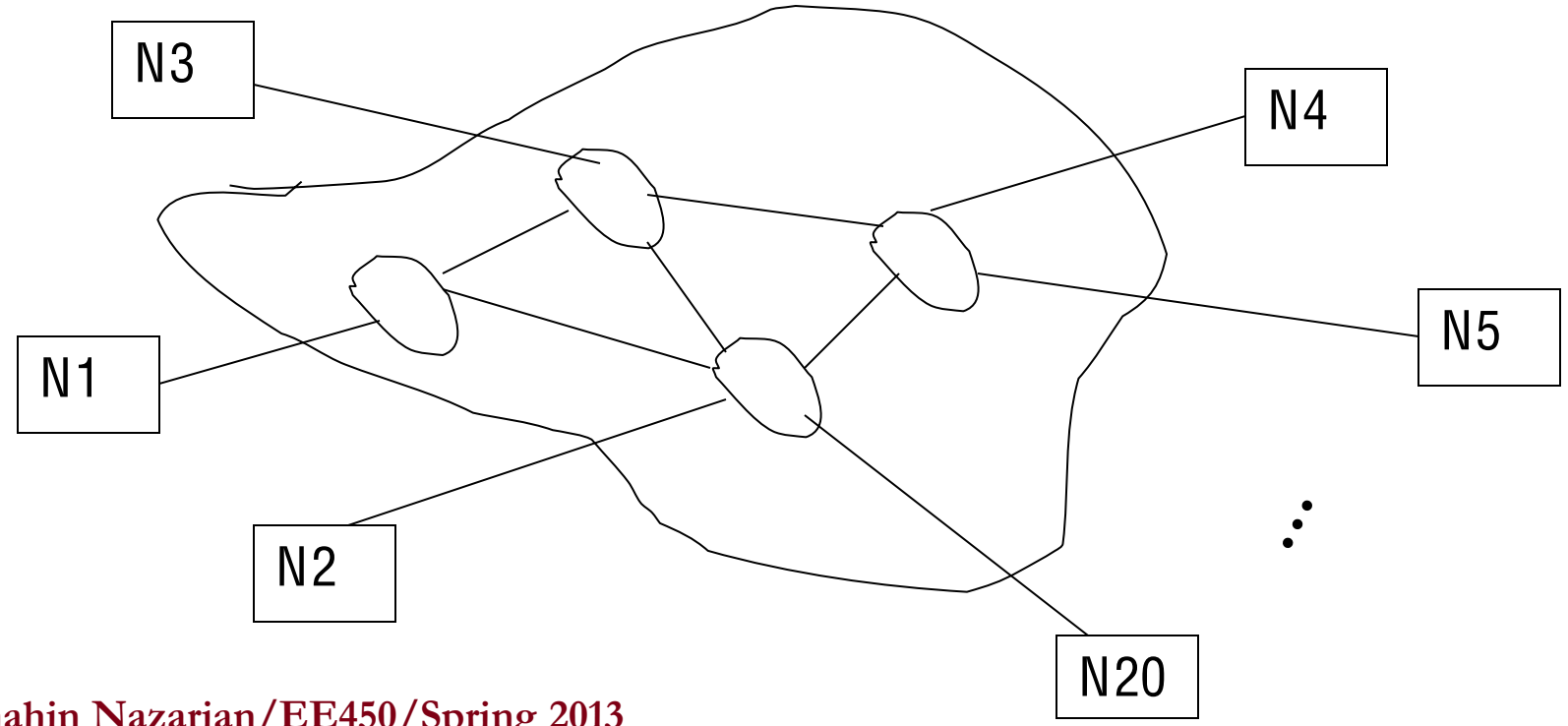
- When N15 picks up the phone, the ringing tone is cut off, ring back will also cut off

F.C. Fully connected

Most things are not dedicated in internet

- Dedicated circuit

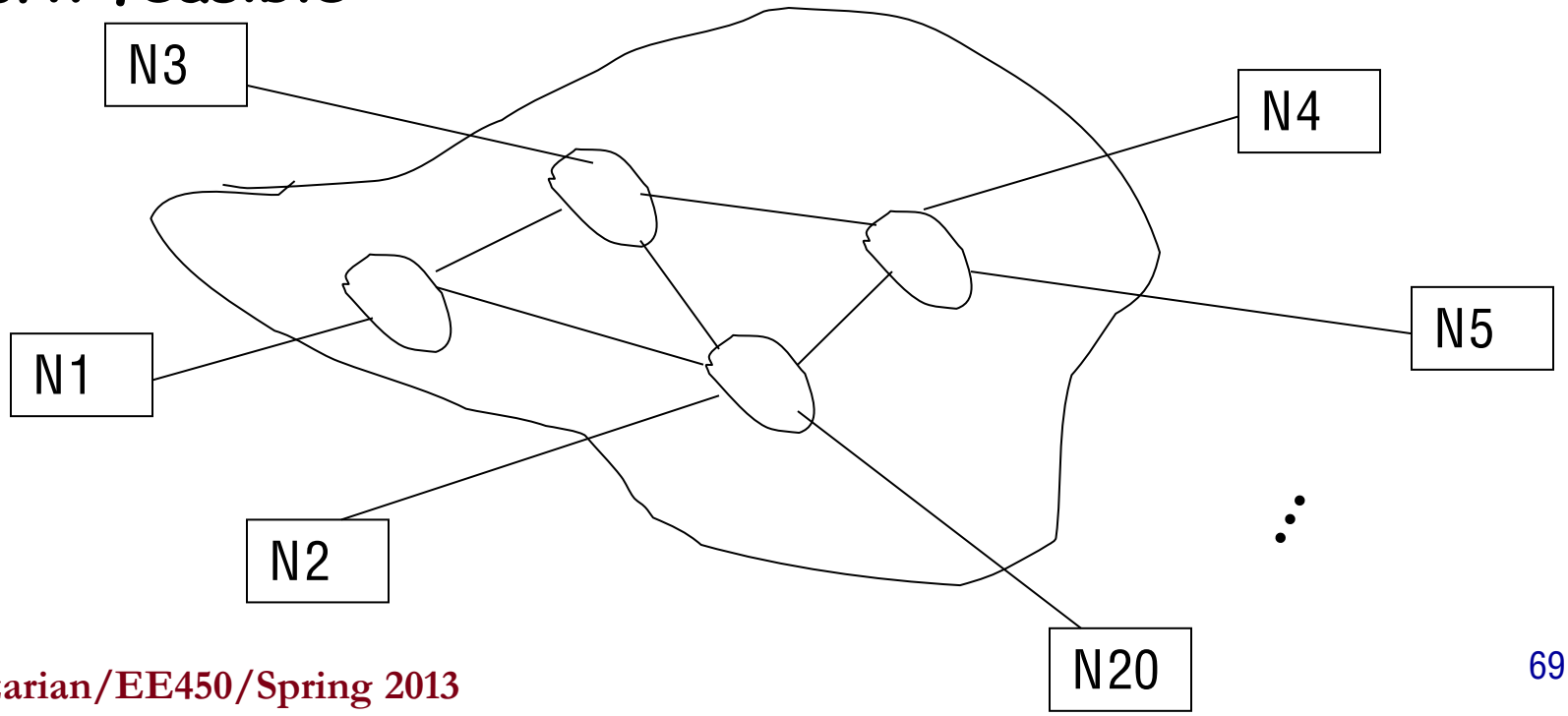
Per damnd for the duration of the call



PSTN – Call and Circuit setup (Cont.)

- Note that if N1 demands connection to N15 the circuit (channel) will be dedicated btn N1 and N15, (as if N1 were connected to N15 in a fully-connected topology)

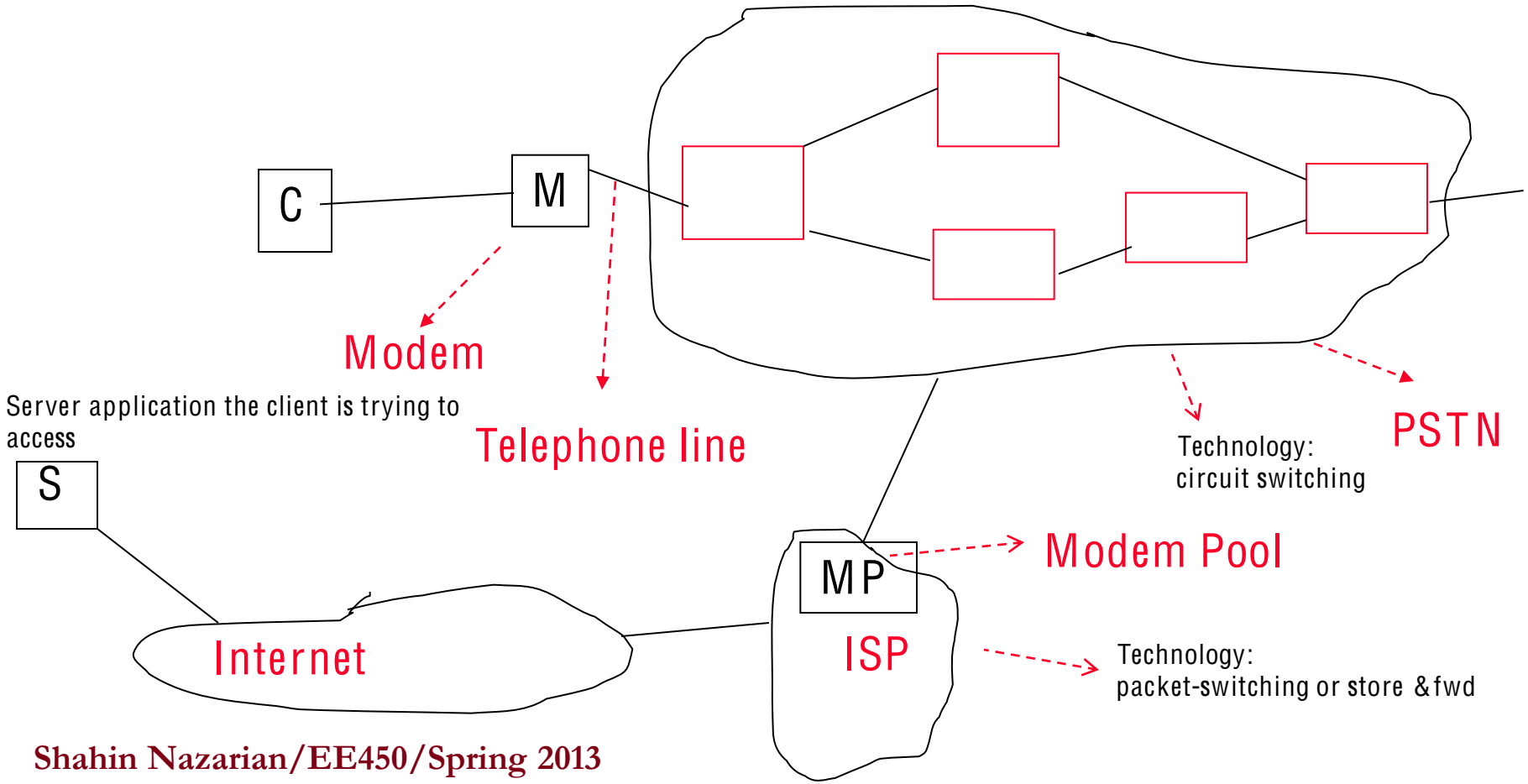
- The idea of per demand dedicated circuits makes the network feasible



PSTN Connection to ISP

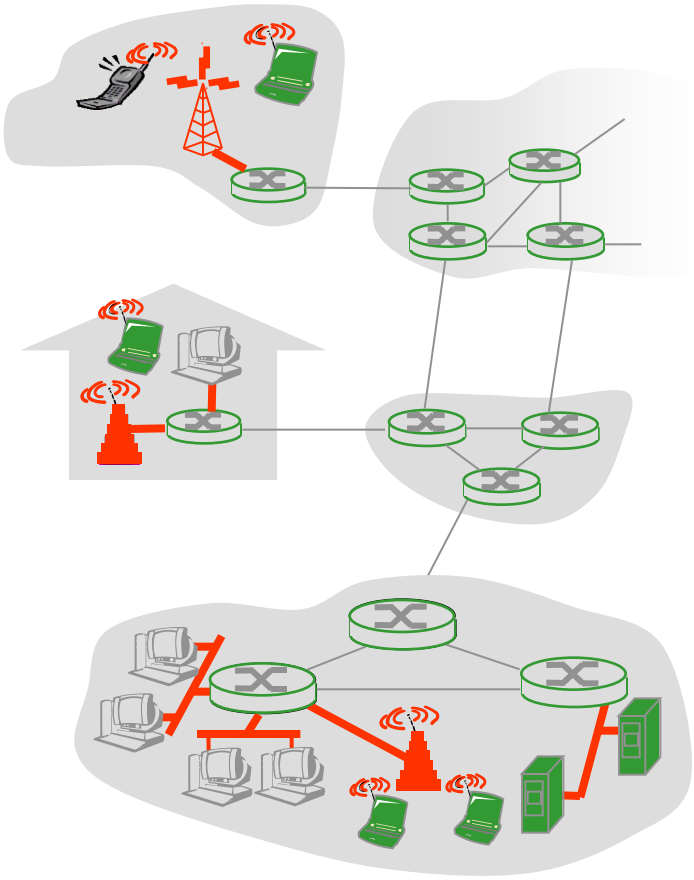
- ISP is connected to PSTN, just like any other telephone
- Shared modem pool

2 KHZ for voice
2 KHZ for data



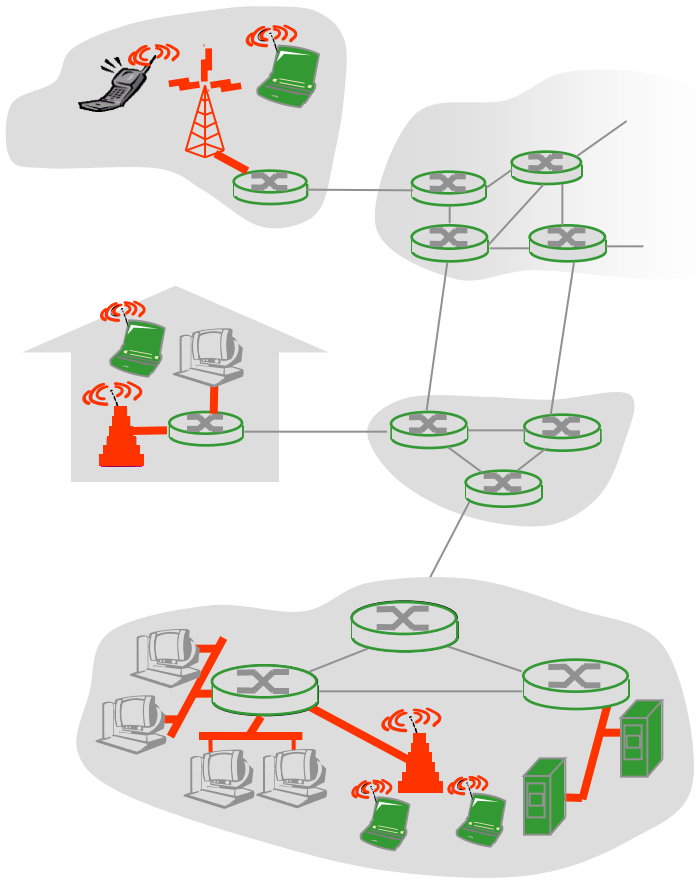
Private Networks

- Contrary to public networks (that are open to every one) are the private networks such as LANs with private IP addresses



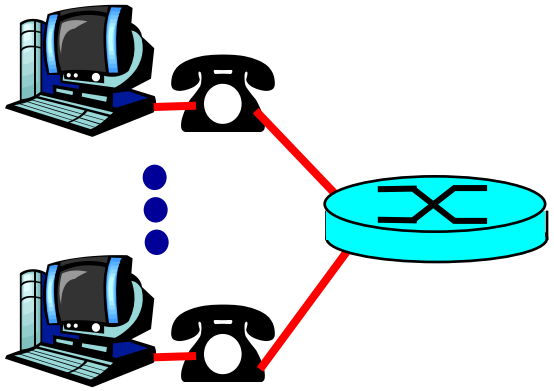
Access Networks

- Consider the applications and the end systems as the edge of the network then access network are the physical links that connect an end system to its edge router
- Access network classes are residential access, company access, and wireless access



Residential Access: Point-to-Point Access

- Dialup via modem
  - Up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: cannot be "always ON"

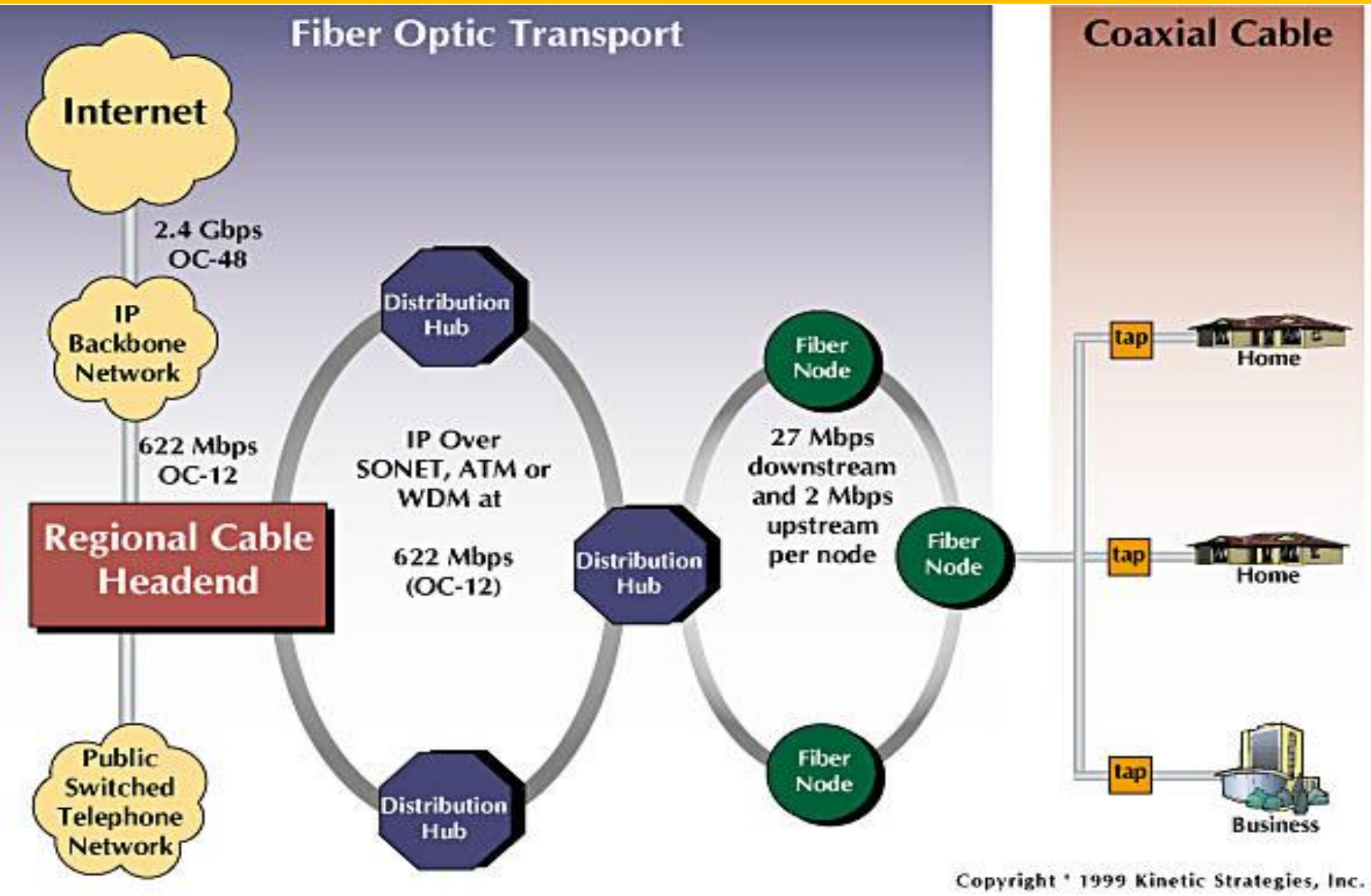


- DSL (Digital Subscriber Line)
  - A new modem technology over existing twisted-pair telephone lines, but by restricting the distances btn the user and ISP modem, DSL can transmit and receive data at much higher rates from ISP router to home than from the home to the ISP router
  - Up to 1 Mbps upstream (typically < 750 kbps)
  - Up to 8 Mbps downstream (typically < 6 Mbps)
  - Dedicated physical line to telephone central office

Residential Access: Cable Modems

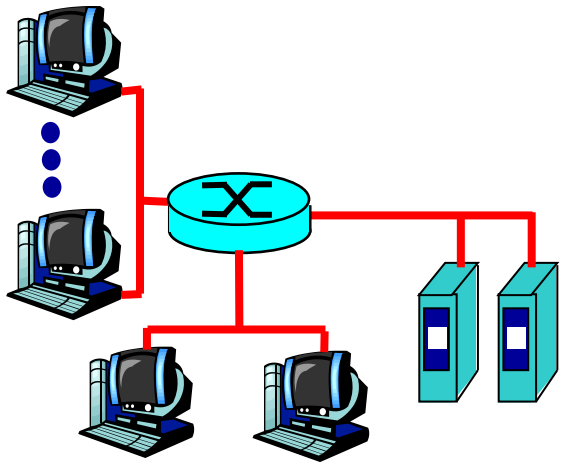
- HFC: Hybrid Fiber Coax
  - Asymmetric: up to 30Mbps downstream, 2 Mbps upstream
  - Network of cable and fiber attaches homes to ISP router
    - Homes share access to router
  - Deployment: available via cable TV companies
  - HFC is a shared broadcast medium
- DSL and HFC require special modems, called **cable modems**
- In DSL, HFC, and satellite access, service is always ON, i.e., the user PC can remain permanently connected to an ISP while simultaneously making and receiving phone calls

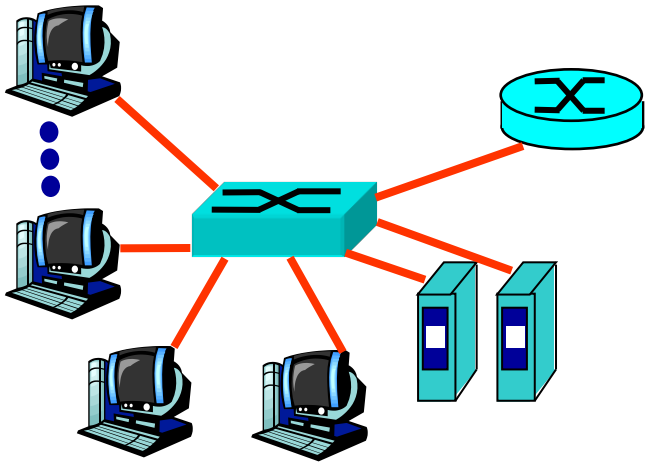
Residential Access: Cable Modems



Company access: Local Area Networks

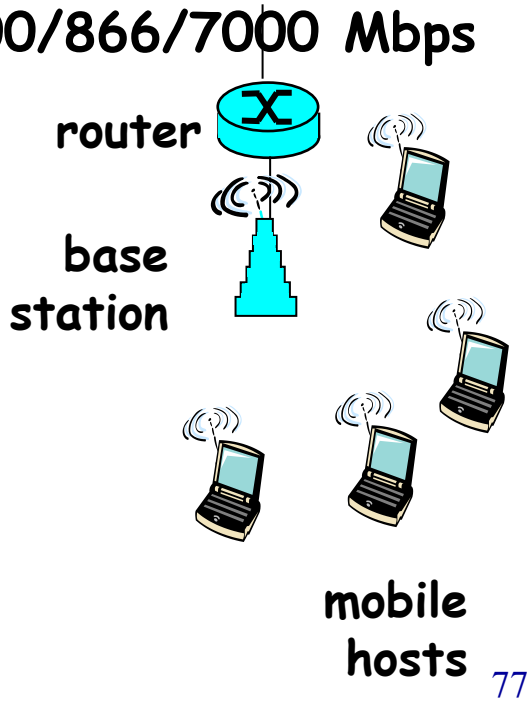
- Company/univ local area network (LAN) connects end system to the edge router
- There are many types of LAN technology, however Ethernet is currently by far the most prevalent access technology
- Ethernet:
  - Uses either twisted-pair copper wire or coaxial cable; like HFC, Ethernet can use shared medium
  - 10Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
  - Modern configuration: end systems connect into *Ethernet switch*





Wireless Access Networks

- It is predicted that wireless (and often mobile) handheld devices such as mobile phones and PDAs will overtake wired computers as the dominant Internet access devices through out the world
- Shared *wireless* access network connects end system to router via base station aka Access Point (AP)
- 1) Wireless LANs: base station within radius of a few tens of meters
  - 802.11b/a,g/n/ac/ad (WiFi): 11/54/54/600/866/7000 Mbps
- 2) Wider-area wireless access
  - Uses the same structure used for cellular with base station thus managed by the telecommunication providers that rely on Third/4th Generation wireless technologies which provide wide-area wireless Internet access at speeds in excess of 1Mbps (4G: 1Gbps for low mobility devices)



Wireless Access Networks

2) Wider-area wireless access (Cont.)

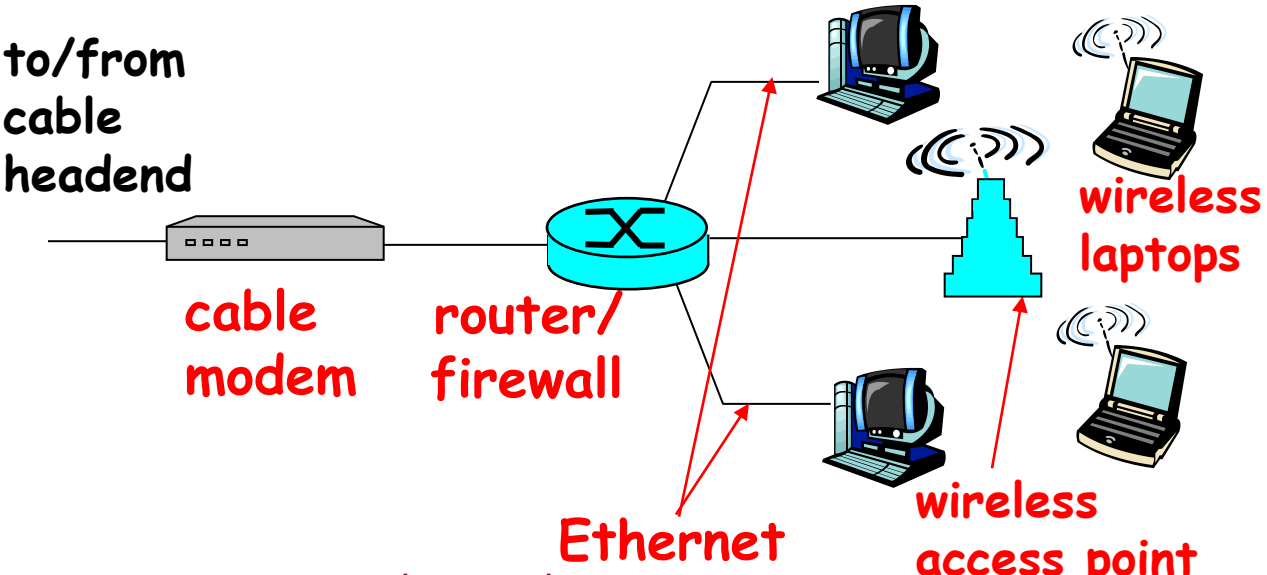
- Two main 3G standards are EVDO (EVolution-Data Optimized-arguably as one of the worst acronyms ever invented!) and HSDPA (High-Speed Downlink Packet Access)

- WiMAX aka IEEE802.16 very similar to 802.11 WiFi operates independently of the cellular network and promises speeds of 5 to 10 Mbps or higher with in distance of 10s of Kms
- Future:
  - Mobile Ad hoc NETwork (MANET) and Sensor Networks
  - MANET also called a mobile mesh network, is a self-configuring network of mobile devices connected by wireless links (communicating with each other) and with no access point

Home Networks (Are Private Networks)

Typical home network components:

- Dialup, DSL or cable modem. The slowest is the dialup
- Router/firewall/NAT* Modem and router can come together in one package
  - Firewall blocks outside penetration into the home network
- Ethernet
- Wireless access point (it is like a base station to mobile systems) can come with the router as one package



* NAT is the process of modifying network address information in datagram packet headers while in transit across a traffic routing device for the purpose of remapping a given address space into another [more details later]

Physical (Transmission) Media

- Mode: Transmission modes include unicast, (i.e., one-to-one,) broadcast (one-to-all) and multicast (one-to-a-selected group)
- Bit: propagates between transmitter/receiver pairs
- Physical link: what lies between transmitter & receiver
  - Guided media:
    - Signals propagate in solid media: copper, fiber, coax
  - Unguided media:
    - Signals propagate freely, e.g., radio

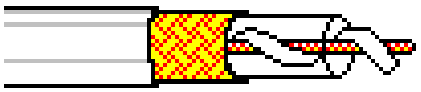
1) Twisted Pair (TP)

- Two insulated copper wires
  - Category 3: traditional phone wires, 10Mbps Ethernet
  - Category 5: 100Mbps Ethernet

Physical Media – Coax

2) Coaxial Cable:

- Two concentric (rather than parallel) copper conductors with special shielding and isolation to have high bit rates
- Bidirectional and it can be used as shared medium
- Baseband (no modulation is involved)
  - Single channel on cable
  - Legacy Ethernet (half-duplex)



- Broadband
  - Multiple channels on cable like Cable TV
  - HFC (hybrid fiber-coax)
  - Cable TV was originally one direction but since Internet it became bidirectional

Physical Media – Fiber

3) Fiber Optic Cable:

- Glass fiber carrying light pulses, each pulse represent a bit
- High-speed operation:
  - High-speed point-to-point transmission (100s of Gbps)
  - WDM (Wavelength Division Multiplexing) Networks
- Low error rate (e.g. 10^{-9} or one bit per billion bits)
- Has a very low signal attenuation (up to 100km) so repeaters are spaced far apart; it's immune to electromagnetic noise, because it uses light which is a lot higher in frequency

Physical Media – Radio

4) Radio

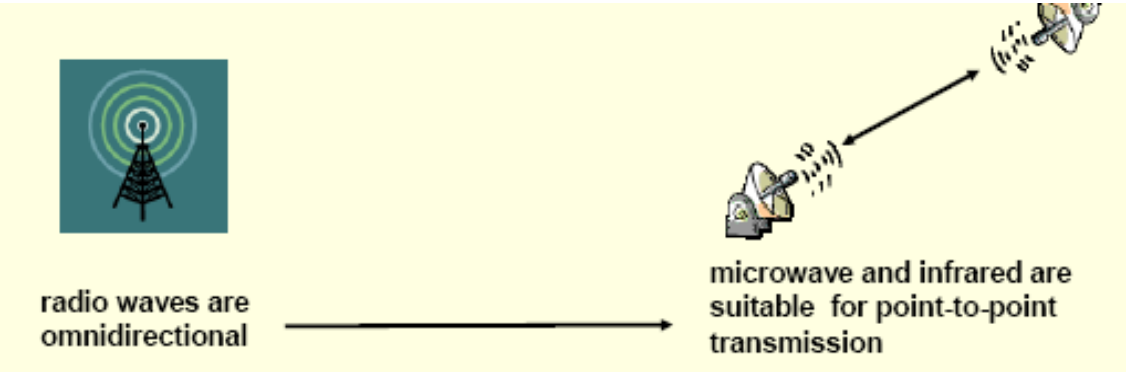
- There is no physical wire; signal is carried in electromagnetic spectrum. Radio is bidirectional
- Propagation environment effects include reflection, obstruction by objects, and Interference
- Radio waves: 100000Km (3Hz) to 30cm (1GHz)
- Microwaves: 30cm (1 GHz) to 1cm (30 GHz)
- Infrared: 1mm (300 GHz) to 750um (400THz)
- Laser: in future
- The smaller the wavelength (higher frequency) the more suitable waves are for point-to-point transmission

Radio Link Types

- Terrestrial microwave e.g. up to 45 Mbps channels
- LAN (e.g., Wifi) 11Mbps, 54 Mbps
- Wide-area (e.g., cellular) 3G cellular: ~ 1 Mbps
- Satellite
  - There is a ground terminal that communicates with satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270msec end-to-end delay
  - Geosynchronous versus low altitude

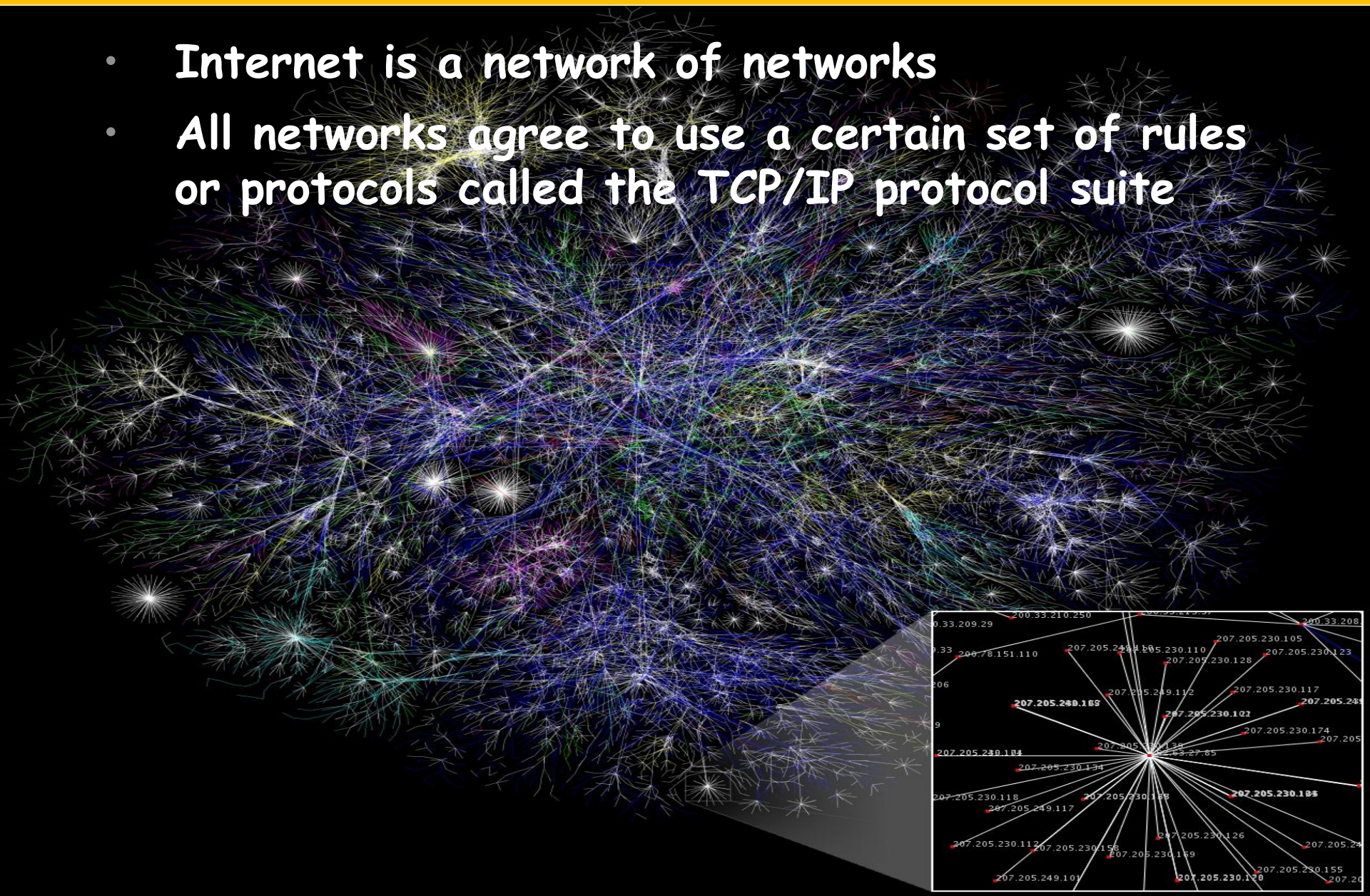
Terrestrial Microwave

- Terrestrial microwave communication employs earth-based transmitters and receivers, in low-GHz frequencies, which limits all communications to **LOS**
- Maximum distance btn towers are 20-30 miles
- You probably have seen terrestrial microwave equipment in the form of telephone relay towers, which are placed every few miles to relay telephone signals cross country



What is Internet? "Nuts & Bolts" View

- Internet is a network of networks
- All networks agree to use a certain set of rules or protocols called the TCP/IP protocol suite



Internet - Nuts & Bolts View (Cont.)


PC


server


wireless laptop


cellular handheld

- Millions of connected computing devices:
  hosts = end systems
  - Run *network apps*

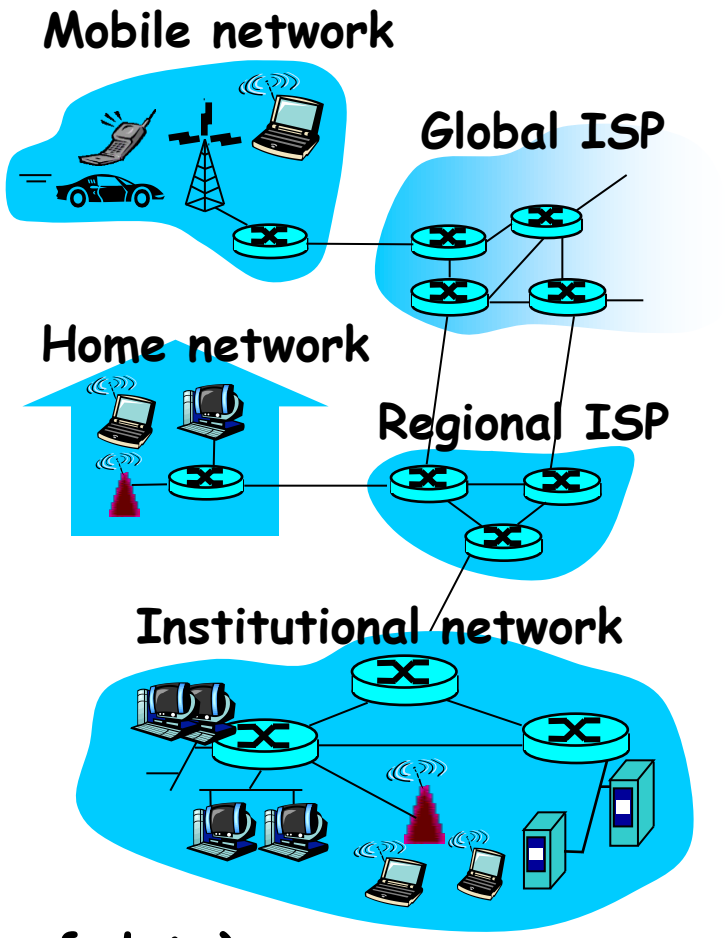

access points

wired links

- *Communication links*
  - Fiber, copper, radio, satellite
  - Transmission rate (*bandwidth*)

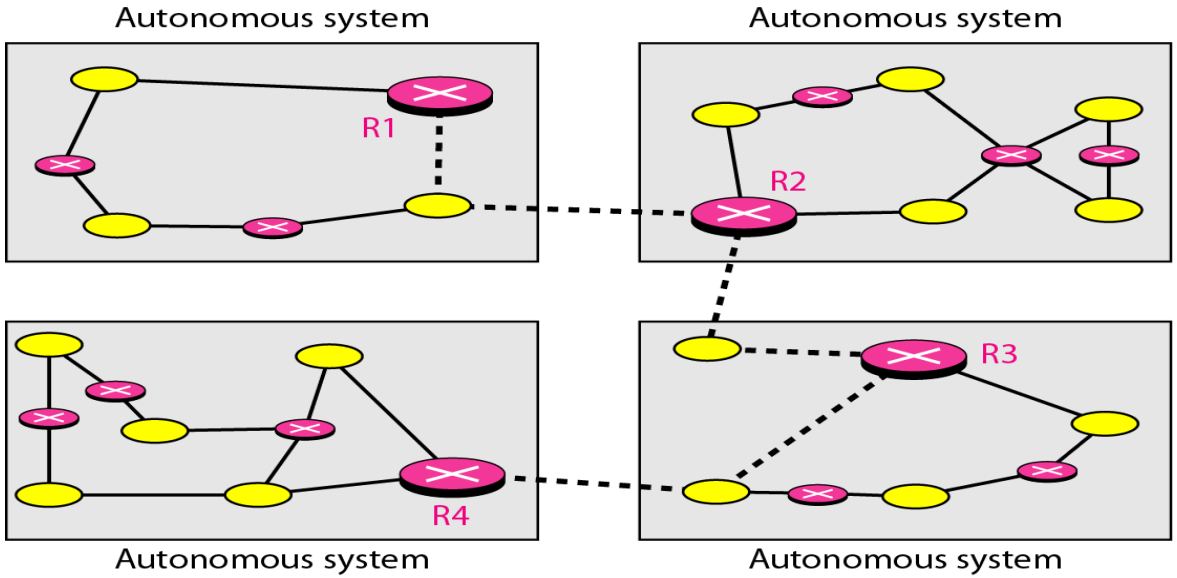

router

- *Routers:*
  - Forward packets (chunks of data) from source to the destination



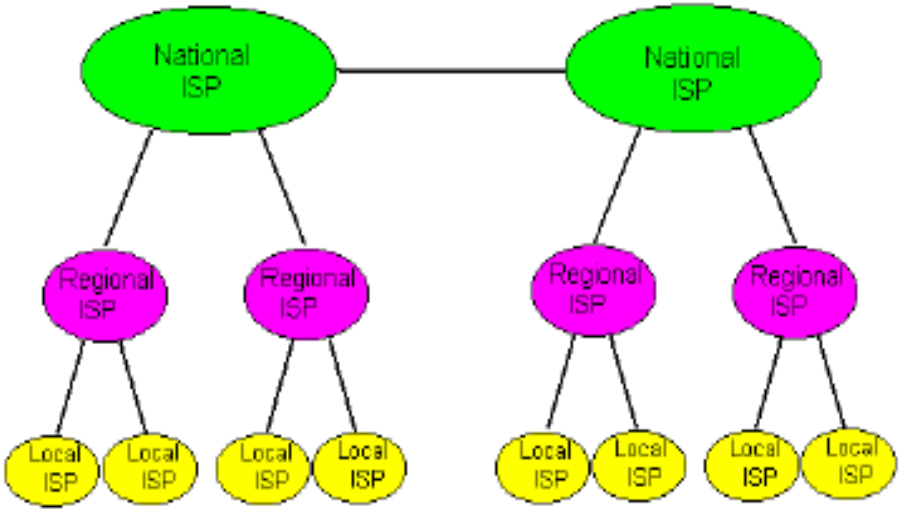
Intra and Interdomain Routing

- A internet can be very large and one routing protocol cannot handle the task of updating routing tables of routers; therefore, an internet is divided into **autonomous systems**. An autonomous system (**AS**) is a group of networks and routers under the authority of a single administration. Routing inside an AS is referred to intradomain routing. Each AS can choose one or more intradomain routing protocols to handle routing inside the AS. However only one interdomain routing protocol handles routing between autonomous systems

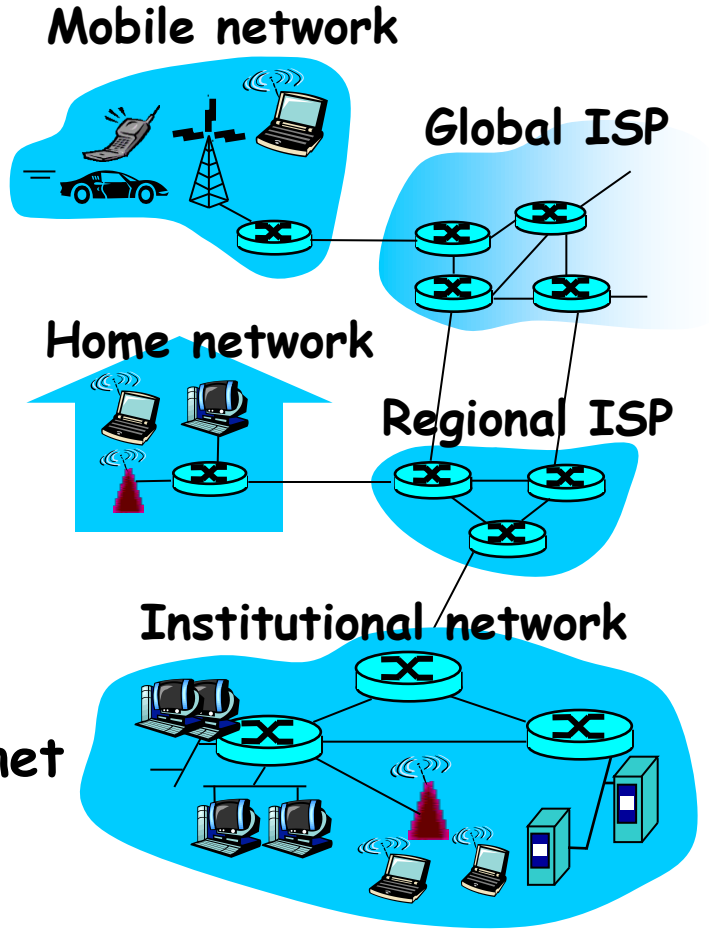


Internet Protocols and Standards

- **Protocols** control sending, receiving of messages
  - TCP, IP, HTTP, Ethernet
- *Internet* ("network of networks")
  - Loosely hierarchical



  - Public Internet versus private intranet
  - **Intranet** is a private network that uses the same set of protocols (TCP/IP) as the Internet



Internet Protocols and Standards (Cont.)

RFC (Request For Comments)

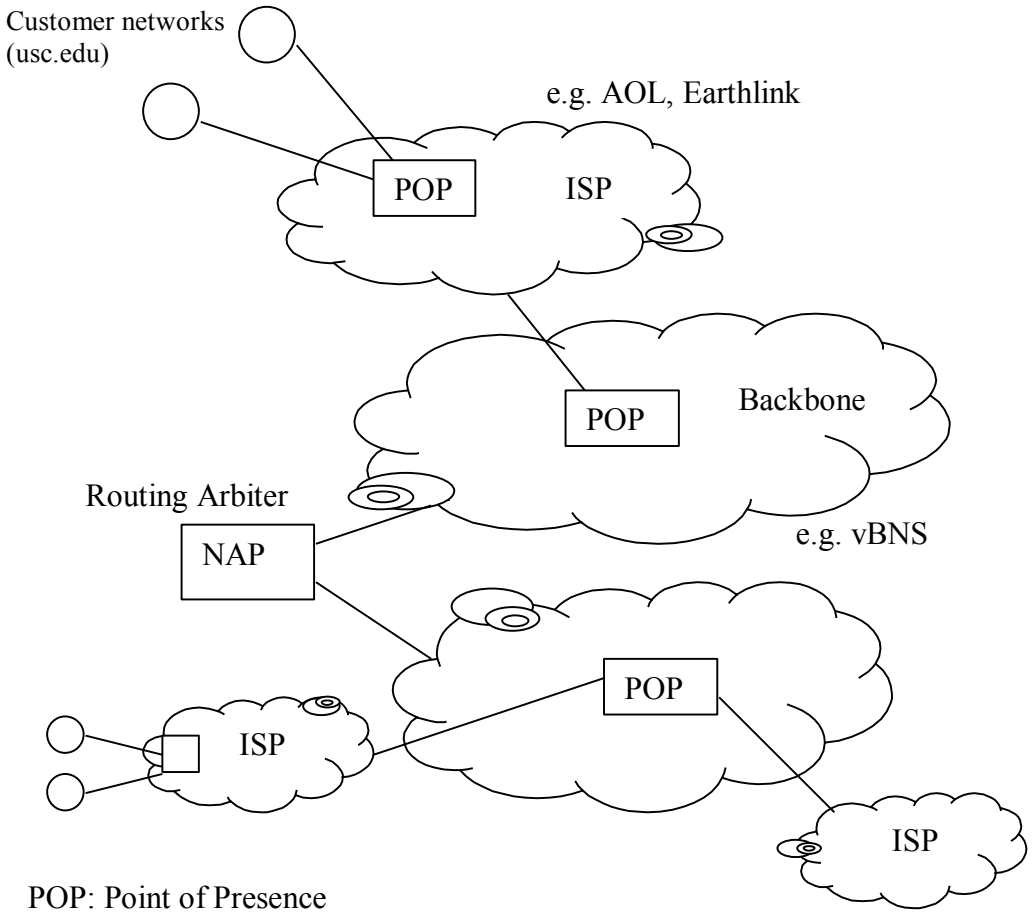
- When new set of protocols are developed they are published and numbered and referred to as "RFC" followed by that specific number, so that others can comment on that RFC
  - E.g., RFC 0780 for MAIL TRANSFER PROTOCOL

IETF (Internet Engineering Task Force)

- IETF is a large open international community of network designers, operators, vendors and researchers (in companies and universities) that deals with developing the protocols and is concerned with the evolution of the Internet architecture and the smooth operation of the Internet
  - The IETF Mission Statement is documented in RFC 3935

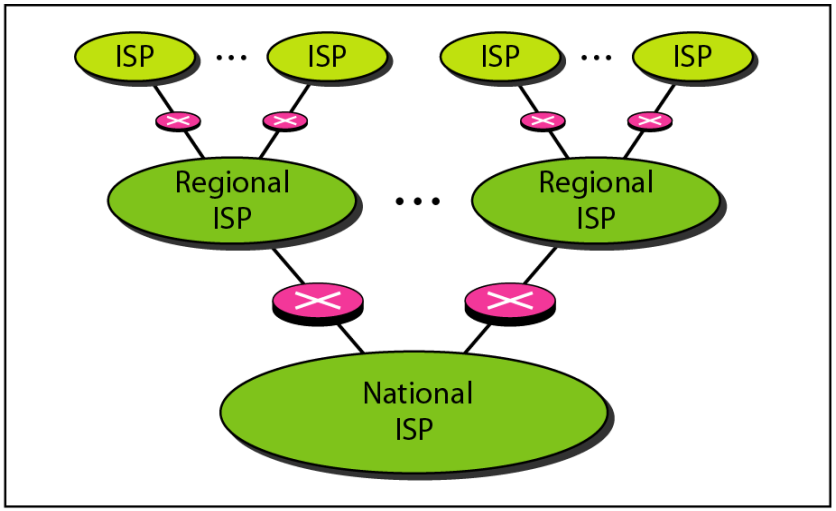
(Loose) Hierarchy of the Internet

- **Internet is hierarchical based on administrative regions/providers**

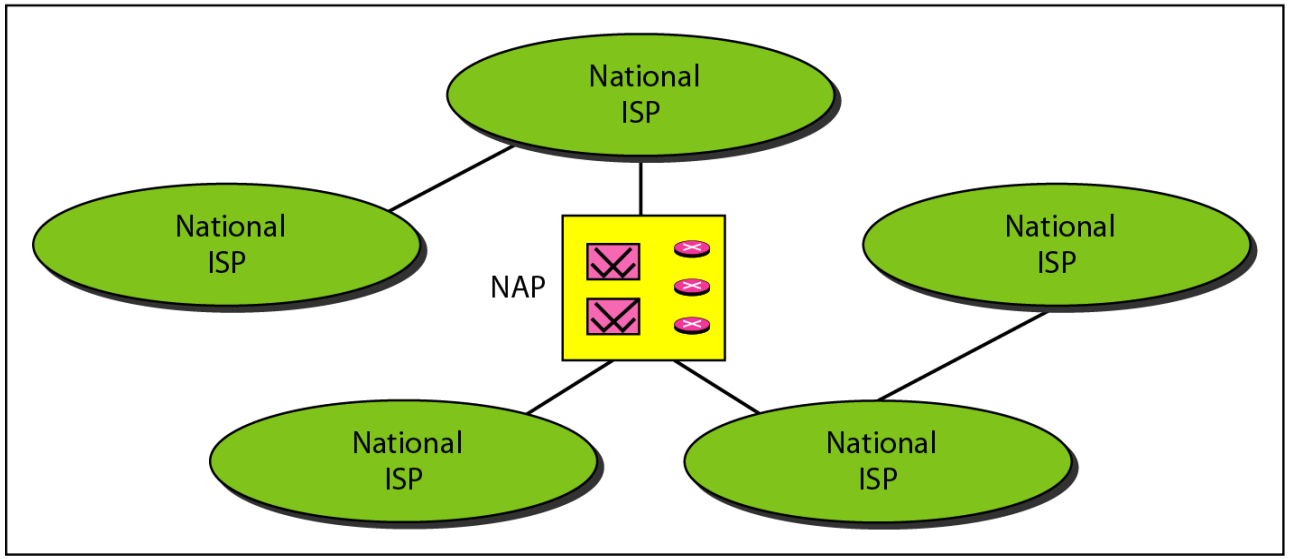


POP: Point of Presence
ISP: Internet Service Provider
NAP: Network Access Point
vBNS: very high speed network service 'Sprint'

Hierarchy of the Internet (Cont.)



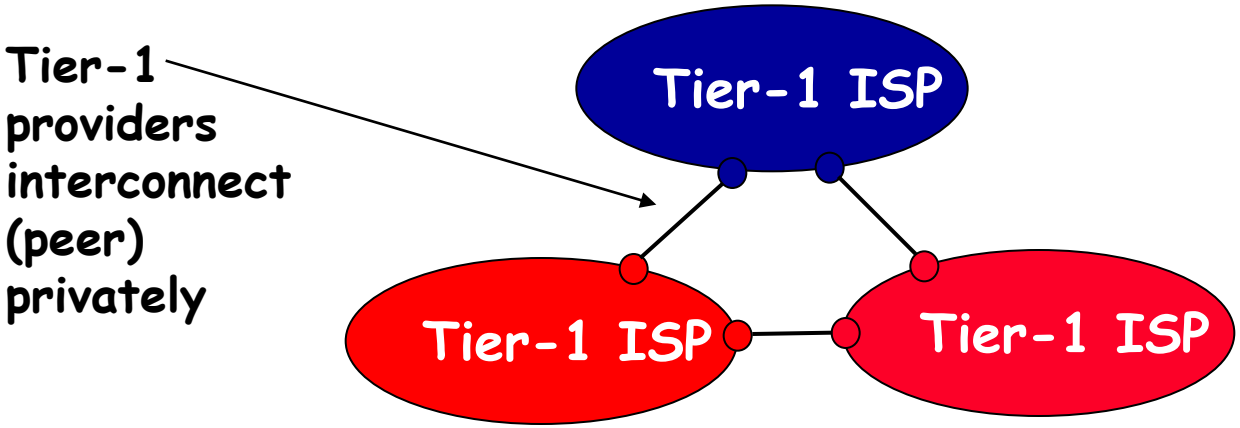
a. Structure of a national ISP



b. Interconnection of national ISPs

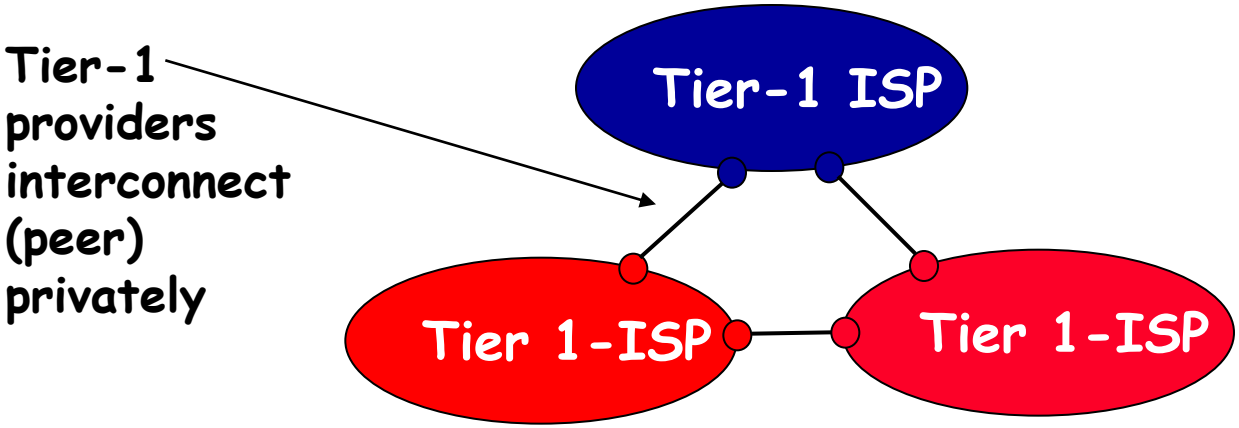
Internet Structure: Tier-1

- Tier-1 ISPs (also referred to as the Backbone Service Providers) are the biggest and provide national/international coverage, e.g. Verizon, Sprint, AT&T, Cable and Wireless
- They treat each other as equals (peers) even if they are competitors; each may cover a wide geographic area, however does not cover everywhere, so they need each others' help

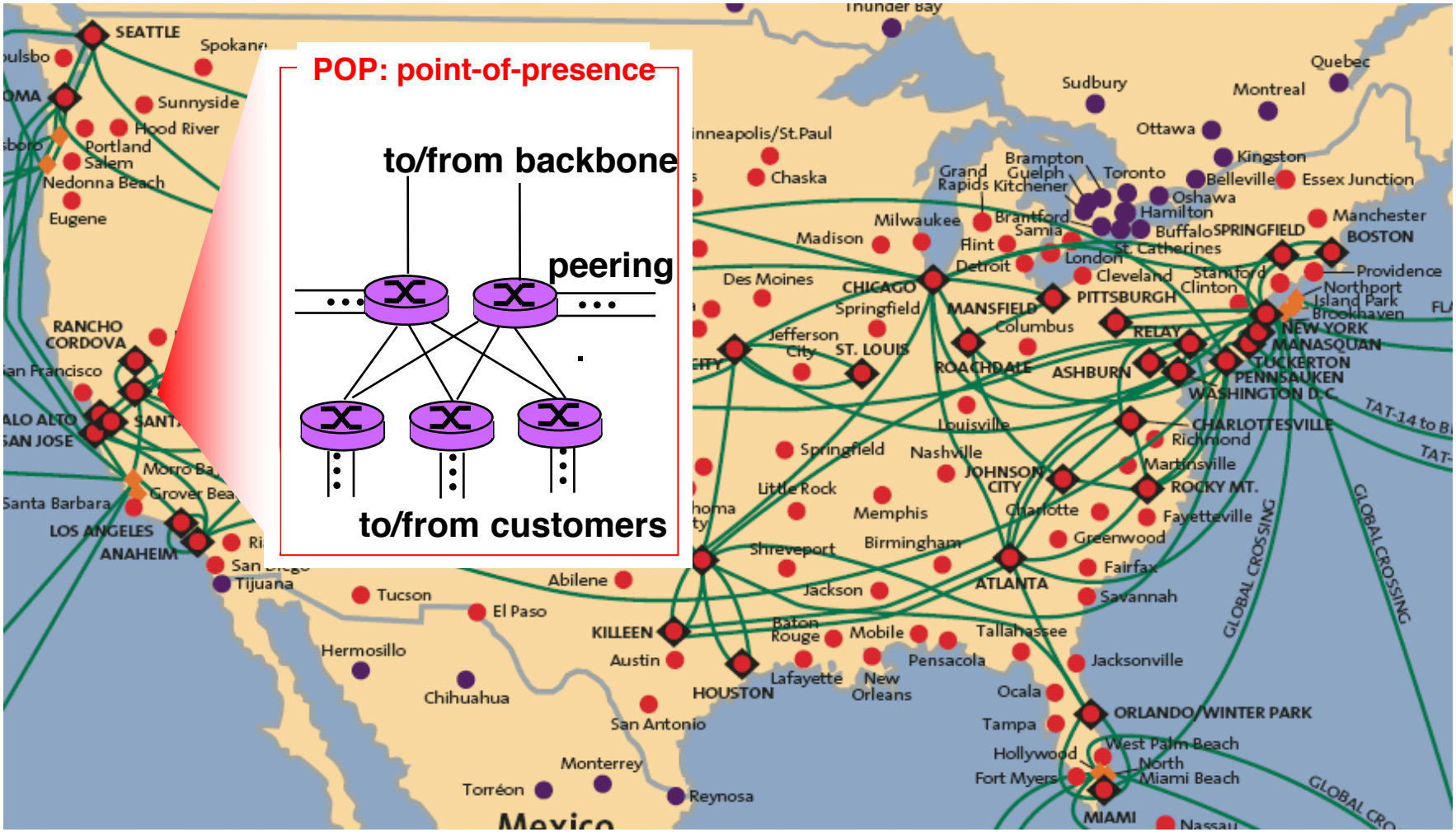


Internet Structure: Tier-1 (Cont.)

- Tier 1 peers treat each other equally by carrying each other's Internet traffic without paying to each other



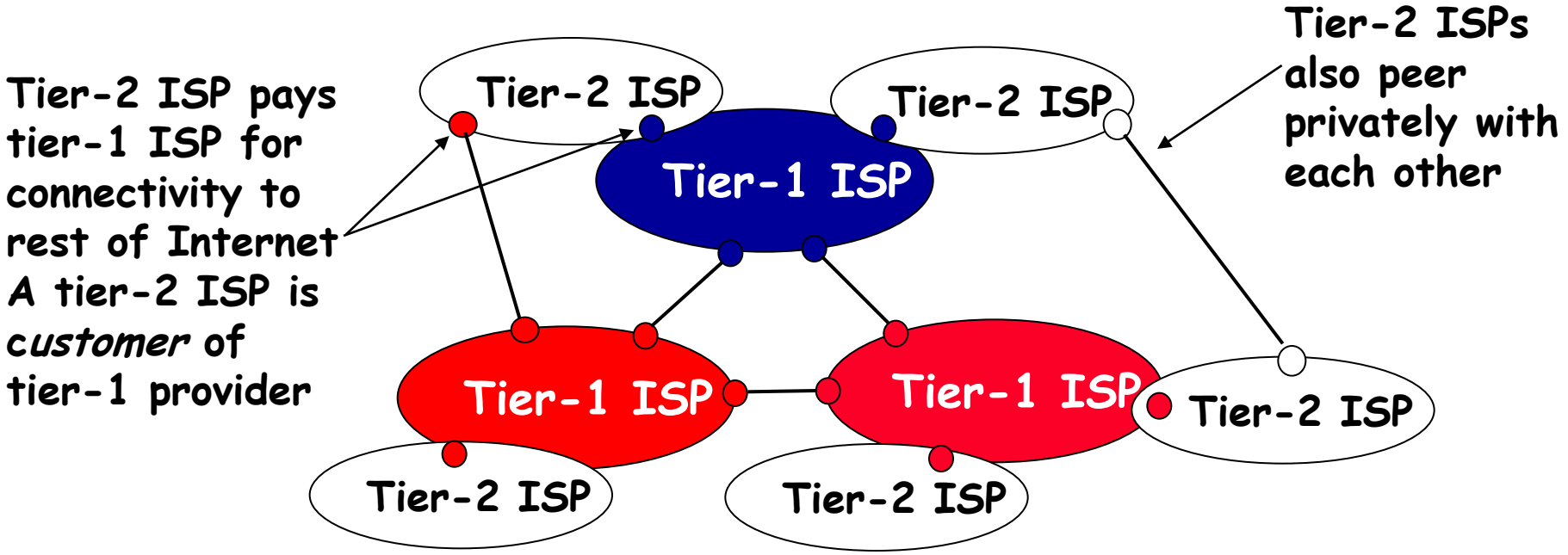
Tier-1 ISP: e.g., Sprint



POP (Point of Presence) is a switching center where traffic is exchanged

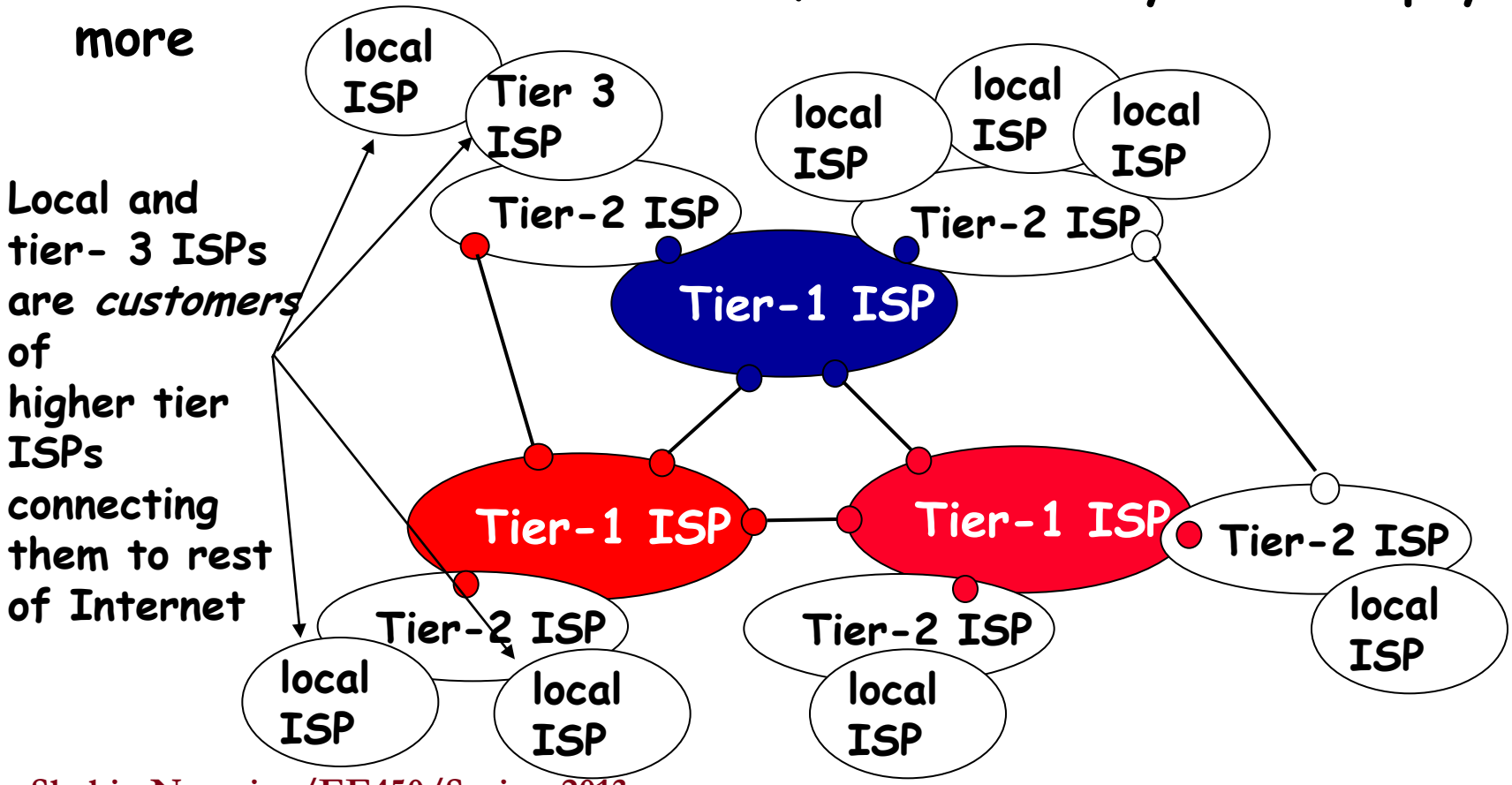
Internet Structure: Tier-2

- Tier-2 are smaller (often regional) ISPs
  - A Tier-2 connects to one or more tier-1 ISPs as their customer (paying to Tier-1s,) they possibly have private connectivity to other tier-2 ISPs



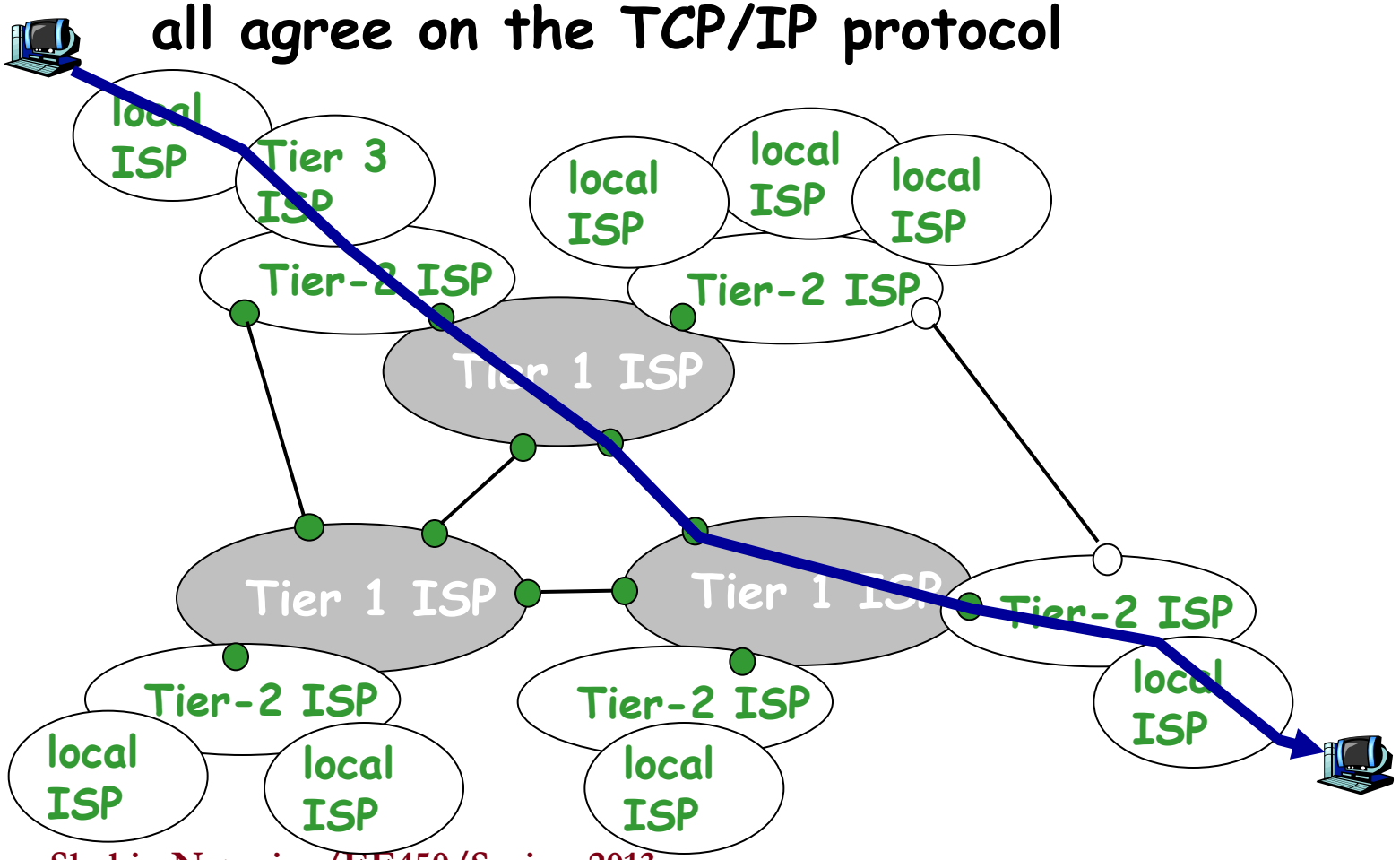
Internet Structure: Tier-3

- "Tier-3 ISPs or local ISPs are the last hop ("access") network and are the closest to end systems
- They can be directly connected to tier-1 to have faster and more reliable connection, however they have to pay more



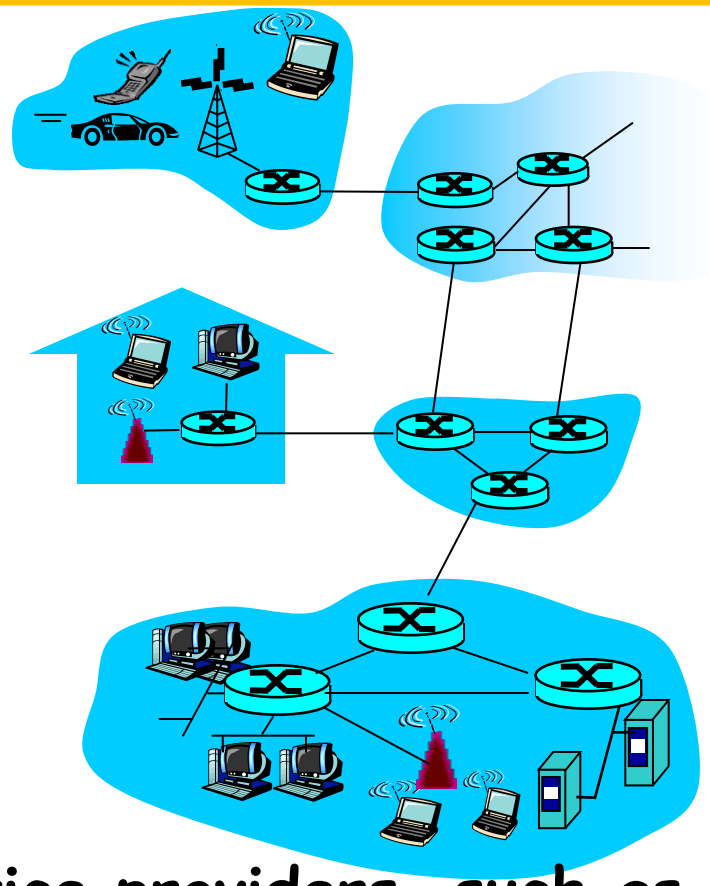
Internet structure: network of networks

- A packet passes through many networks (from node to node) and traverses multiple tiers
- Note that they use different technologies but they all agree on the TCP/IP protocol



Network Structure – A Closer Look

- **Network edge**
  - Applications and hosts
- **Access networks**
  - Are the smaller tiers, with wired or wireless communication links



- **Network core:**
  - Are ISPs or backbone service providers, such as tier-1
  - Interconnected routers mostly via fiber optics
  - Network of networks

Network Edge: Reliable Data Transfer Service (Connection-Oriented Service)

Goal: data transfer between end systems

- *Handshaking* (to ensure reliable transmission) setup (prepare for) data transfer ahead of time
  - Hello, initial establishment
  - *set up "state"* in two communicating hosts
- Supported by TCP/IP - Transmission Control/ Internet Protocol

- Applications using TCP (all for reliable service) : are HTTP [Hyper Text Transfer Protocol] (web), FTP (file transfer), Telnet [Terminal Network] (remote login), SMTP [simple mail transport] (email)

Network Edge: Reliable Data Transfer Service (Connection-Oriented Service)

TCP (Transport Control Protocol) service [RFC 793]

- *Reliable, in-order* byte-stream data transfer
  - Loss: acknowledgements and retransmissions
- *Flow control:*
  - Sender won't overwhelm receiver with too many packets that the receiver cannot handle
- *Congestion control:*
  - Senders "slow down (or stop) sending rate" when network is congested

Network Edge: Best Effort (Unreliable) Data Transfer Service (Connectionless)

UDP (User Datagram Protocol) Service [RFC768]

- Goal is still data transfer between end systems, however supported by
  - Connectionless
  - Unreliable data transfer
  - No flow control
  - No congestion control
- UDP (User Datagram Protocol) does not do any of above that TCP does

- Applications using UDP
  - Streaming media
  - Teleconferencing, DNS (Domain Name Service), internet telephony

Dialup Connection

- Dialup customers are residential customers (service providers are AOL, Netzero, Earthlink, etc.)
- The Internet speed with this type of connection can be at most 56kbps
- Both packet and circuit switching techniques, use switching from node to node, however
  - In packet switching the traffic is stored in every node, processed and fwded to another node
  - In circuit switching, once the path is set, there is no processing any longer
- During Internet connections, packets can be slowed down or congested in the nodes (or they are stored in the node and are waiting to be fwded) however ISP has this shared pool of modems; ISP does not want to hold the modem in this case (inactive case) for a long time, instead it prefers to disconnect from PSTN and make its modem free for its other dialup based customers

T-Carrier

- In telecommunications, T-carrier, sometimes abbreviated as *T-CXR*, is the generic designator for any of several digitally multiplexed telecommunications carrier systems originally developed by Bell Labs and used in North America, Japan, and Korea
- The basic unit of T-carrier system is DS-0 (DS0 or Digital Signal 0) which is a single channel of 64Kpbs

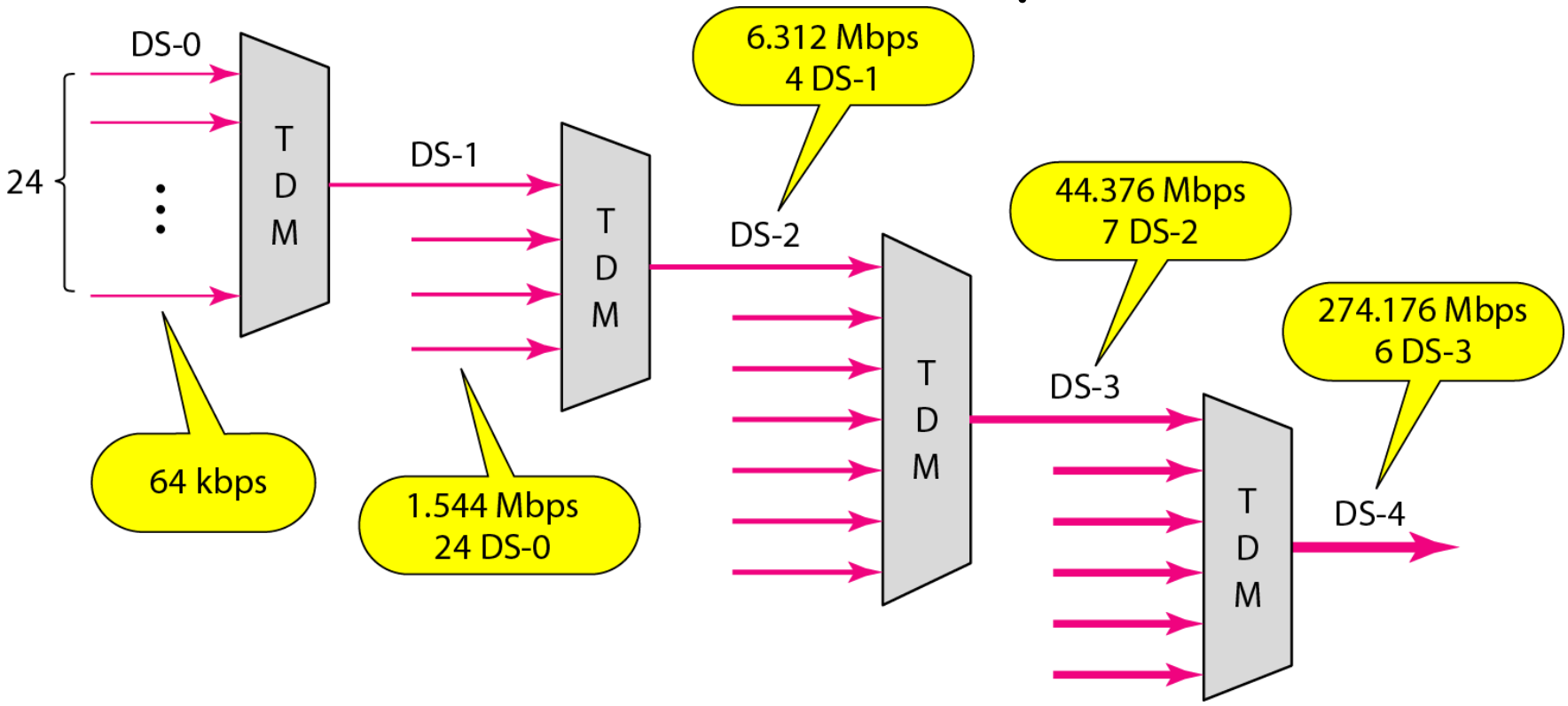
Service	*Line*	*Rate (Mbps)*	*Voice Channels*
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

T1 Lines and Customers

- Digital signal 1 (DS1, or DS-1, a.k.a. T1)
  - A widely used standard in telecommunications in North America, Japan, S Korea to transmit voice and data between devices (E1 is for other parts)
- The rate of T1 is 1.544 Mbps and its for business customers (they have dedicated access)
- 24 DS0 can be used to make a T1 line
- A CSU/DSU (Channel Service Unit/Data Service Unit) is a digital-interface device used to connect a Data Terminal Equipment device (DTE), such as a router, to a digital circuit, e.g. a T1 or T3 line
  - CSU/DSU is like the MODEM which is needed for PSTN, but for T1 it is digital

T3

- T3 is bigger than T1, 45Mbps, also a dedicated connection each T3=28 T1s
- T3 Also needs CSU/DSU
- T3 customers are medium size corporations



Optical Carrier Specifications

- **Optical Carrier** (OC) is a standard that describes a range of digital signals that can be carried on **SONET** fiber optic network
  - SONET stands for **Synchronous Optical NETwork**

- The OC standard link speeds range from 51.8Mbps for OC-1 to 39.8Gbps
  - The speed of OC-n is n×51.8Mbps
    - Example: OC-3 speed is 155Mbps
  - Bigger companies use higher OCs (i.e., higher n)