Computer Networks

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Course Information

- **Instructor**: Dr. Xiqun Lu (email: xqlu@zju.edu.cn)
- **Class Time**: Tuesday 10:00-12:25 (Room 310, No.4 Building at YuQuan Campus)
- **Experiment Time**: Tuesday 14:00-16:15 (Room 304, the West Wing of Cao Guang-Biao Building at YuQuan Campus)
- **TextBook**: A.S. Tanenbaum, and D.J. Wetherall, Computer Networks, 5th Edition, Prentice Hall, 2013.
- **Grading**
  - Homework 15%, quiz 10%, experiment 25%, final exam 50%.
- 计算机网络课程网上作业系统
  - http://10.214.0.253/network/exercise/index.php
  - 登录名：学号，密码（passwd）：学号的后四位

What will be taught in this courses?

- In this course, we try to provide you the principles and practical insights you will need to understand not only today's network, but tomorrow's as well.

Outline

- Uses of Computer Networks
- Types of Computer Networks
- **Network Technology: from local to global**
- **Examples of Networks**
- **Network Protocols**
- **Reference Models**
- **Standardization**
- Policy, Legal and Social Issues
- **Metric Units**

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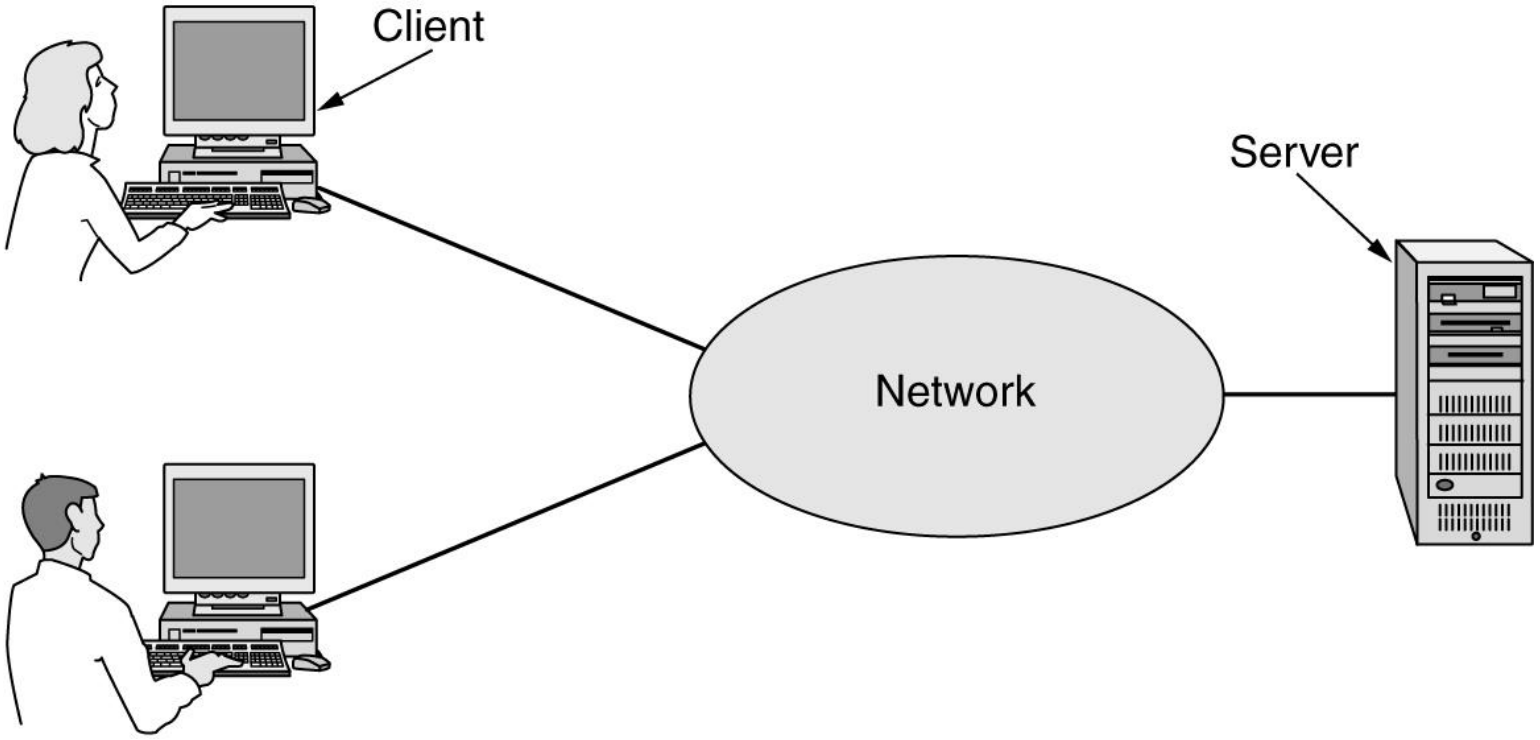
Uses of Computer Networks

- Computer network
  - Large number of separate but interconnected computers do a job
  - Collection of interconnected, autonomous computing devices
  - Interconnected computers can exchange information
- Example: the Internet
- Network uses
  - Access to information
  - Person-to-person communication
  - Electronic commerce
  - Entertainment
  - The Internet of Things

Network Uses: Access to Information I

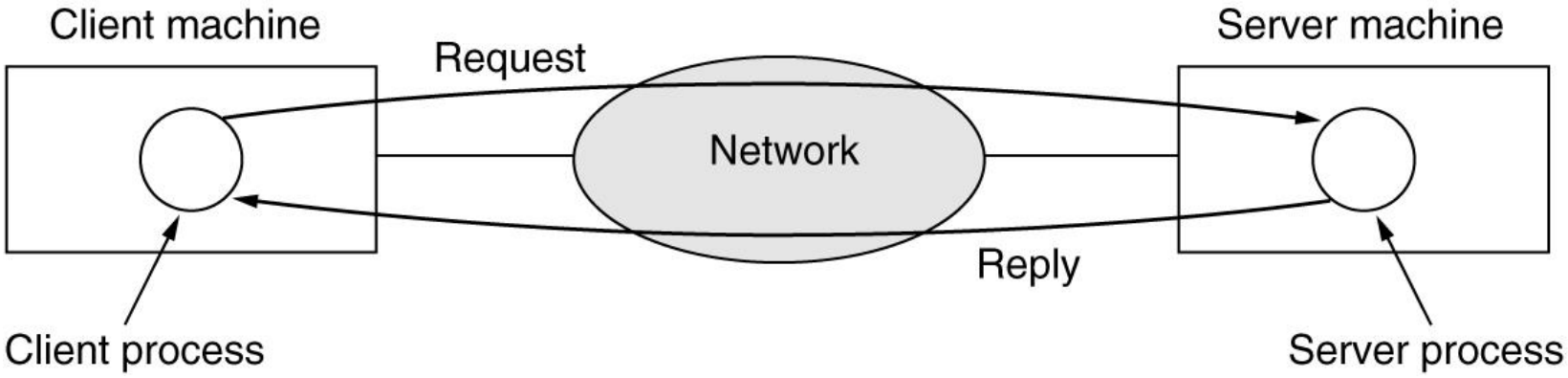
- Web browser and smart phones retrieve information from various Web sites
- Social media platforms support targeted behavioral advertising
- Online digital libraries and retail sites host digital content
- Client-server model forms the basis of network usage
- Web applications: Server generates Web pages in response to client requests
- Peer-to-peer communication: Individuals form a loose group to communicate with others in the group

Network Uses: Access to Information II



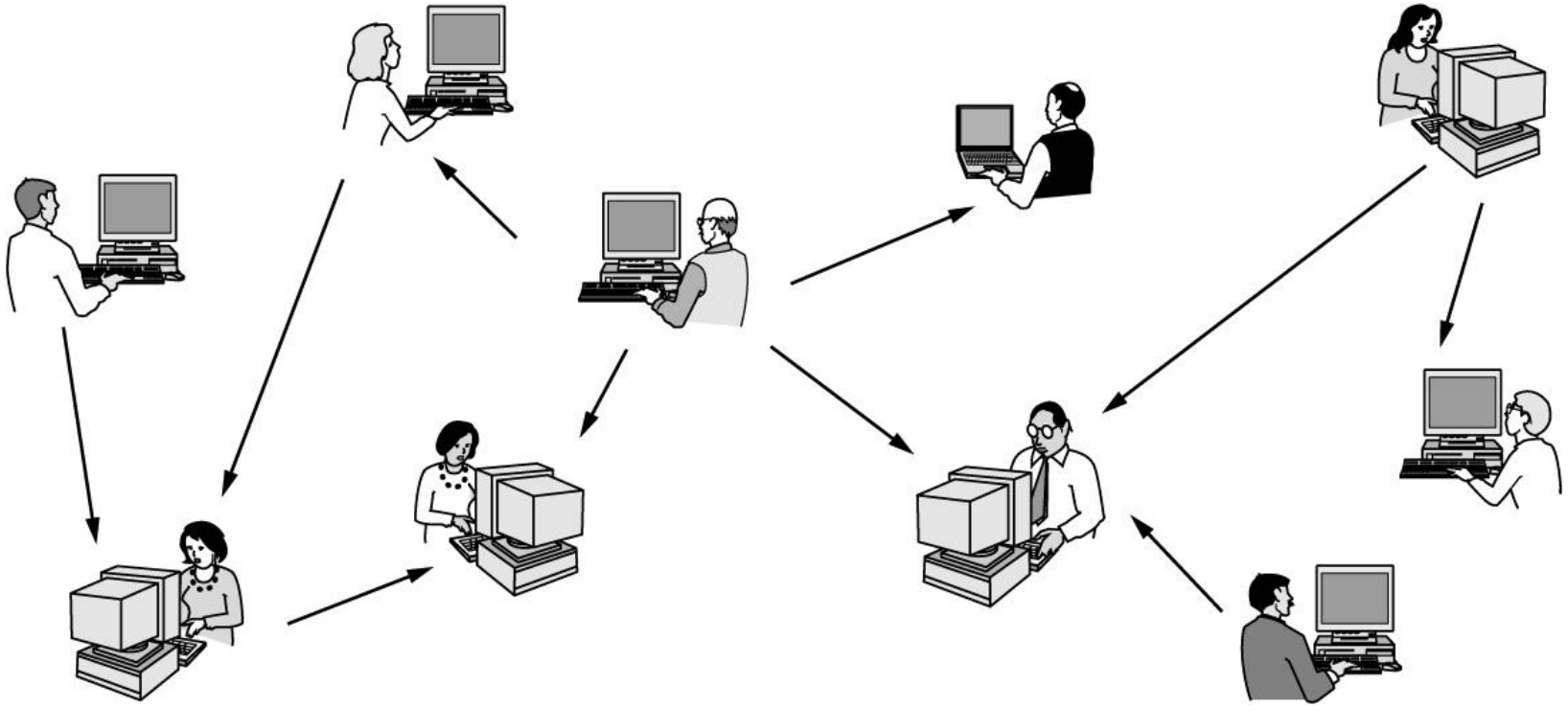
In the client-server model, a client explicitly requests information from a server that hosts that information.

Network Uses: Access to Information III



Communication takes the form of the client process sending a message over the network to the server process. The client process then waits for a reply message.

Network Uses: Access to Information IV



In a peer-to-peer system, there are no fixed clients and servers.

Network Uses: Person-to-Person Communication

- Instant messaging
  - Allows two people to type messages at each other in real time
- Twitter multi-person messaging service
  - Allows people to send short messages to their circle of friends or other followers or the whole world
- Social network applications
  - Information flow driven by the relationships that people declare between each other
- Wiki content is a collaborative Web site the members of a community edit

Network Uses: Electronic Commerce I

- Online shopping and financial institution transactions follow client-server model
- Online auctions follow peer-to-peer model
  - Consumers act as buyers and sellers
  - Central server holds the database of products for sale

Network Uses: Electronic Commerce II

Tag	Full name	Example
B2C	Business-to-consumer	Ordering books online
B2B	Business-to-business	Car manufacturer ordering tires from a supplier
G2C	Government-to-consumer	Government distributing tax forms electronically
C2C	Consumer-to-consumer	Auctioning second-hand products online
P2P	Peer-to-peer	Music or file sharing; Skype

Some forms of e-commerce have acquired little tags based on the fact that “to” and “2” are pronounced the same.

Network Uses: Entertainment

- IPTV (IP Television) systems
  - TV shows based on IP technology instead of cable TV or radio transmissions
- Media streaming applications
  - Internet-provided radio stations, TV shows, and movies
  - Content usually moves wirelessly between devices
- Game playing using multi-person real-time simulation
- Virtual worlds provide a persistent setting
  - Thousands of users experience a shared reality with three-dimensional graphics

Network Uses: The Internet of Things

- Ubiquitous computing
  - Computing embedded in everyday life
  - Home security systems wired with door and window sensors
  - Sensors folded into a smart home monitor
  - Smart refrigerators
- IoT (Internet of Things)
  - Sensing and communication take place over the Internet
  - Poised to connect every electronic device to the Internet
- Power-line networks
  - Send information throughout the house over the electric wires

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Types of Computer Networks

- Mobile and broadband access networks
  - Networks used to access the Internet
- Data-center networks
  - Networks that house data and applications
- Transit networks
  - Networks that connect access networks to data centers
- Enterprise networks
  - Networks used on campuses, in office buildings, or at other organizations

Broadband Access Networks

- Home network use
  - Listen to, look at, and create music, photos, and videos
  - Access information, communicate with other people, buy products and services
- Metcalfe's law
  - Explains how tremendous Internet popularity comes from its size
- Broadband access networks
  - Delivered to homes using copper, coaxial cable, or **optical fiber**
  - Broadband Internet speeds: gigabit per second to individual homes

Mobile and Wireless Access Networks
(1 of 3)

- Wireless hotspots are based on the 802.11 standard
- Wireless networking and mobile computing
  - Related but not identical
- Smartphones combine aspects of mobile phones and mobile computers
- Text messaging or texting short message
- GPS (Global Positioning System): locates a device
- Geo-tagging: annotating photos and videos with the location where they were made

Mobile and Wireless Access Networks
(2 of 3)

Wireless	Mobile	Typical applications
No	No	Desktop computers in offices
No	Yes	A laptop computer used in a hotel room
Yes	No	Networks in unwired buildings
Yes	Yes	Store inventory with a handheld computer

Although wireless networking and mobile computing are often related, they are not identical.

Mobile and Wireless Access Networks
(3 of 3)

- M-commerce (mobile-commerce) uses mobile phones
- NFC (Near Field Communication)
  - Allows mobile device to act as an RFID smartcard and interact with a nearby reader for payment
- Sensor networks use nodes gathering and relaying information about the physical state of the world
  - Nodes may be embedded in familiar devices (cars or phones)
  - Nodes may be small, separate devices
  - Provide a wealth of data on behavior
  - Example: wireless parking meters

Content Provider Networks

- Data-center network
  - Internet services are served from ‘‘the cloud’’
  - Serves the increasingly growing demands of cloud computing
  - Moves large amounts of data between servers in the data center
  - Moves data between the data center and the rest of the Internet
- Data center network challenges
  - Network throughput and energy usage scaling
  - ‘‘Cross-section bandwidth”
- CDN (Content Delivery Network)
  - Large collection of servers, geographically distributed so content is close to the users requesting it

Transit Networks

- Transit network
  - Carry traffic between the content provider and the ISP (Internet Service Provider) when they are not directly connected
  - Typically charge both the ISP and the content provider for carrying traffic from end-to-end
  - Traditionally called backbone networks because they carry traffic between two endpoints
- Two trends
  - Consolidation of content in a handful of large content providers
  - Expansion of the footprint of individual access ISP networks

Enterprise Networks

- Allows resource sharing for devices and information
- **VPN**s (Virtual Private Networks)
  - Connect individual networks at different sites into one logical network
  - Act as a communication medium among employees
- Allows IP telephony or VoIP (Voice over IP)
  - Internet technology and computer networks for telephone calls
- Allows desktop sharing
  - Remote workers can see and interact with a computer screen
- Allows electronic business communication

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Network Hardware

- There is no generally accepted taxonomy into which all computer networks fit, but two dimensions stand out as important: **transmission technology** and **scale**.
- Broadly, *two types of transmission technology* are in widespread use
  - **Broadcast links** (Multicasting多播)
    - The communication channel is shared by all the machines on the network.
    - An address field within each packet specifies the intended recipient.
    - A wireless network is a common example of a broadcast link
    - Allow the possibility of addressing a packet to all destinations by using a special code in the address field.
  - **Point-to-point links** (Unicasting单播)
    - Point-to-point links connect individual pairs of machines.
    - To go from the source to the destination on a network made up of point-to-point links, short messages, called **packets** in certain contexts may have to first visit one or more intermediate machines.
    - Often multiple routes, of different lengths, are possible, so finding good ones is important in point-to-point networks.

Network Hardware

- An alternative criterion for classifying networks is **scale**.
- **Distance** is important as a classification metric because different technologies are used at different scales.

Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	Local area network
100 m	Building	
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1000 km	Continent	
10,000 km	Planet	The Internet

Figure 1-6. Classification of interconnected processors by scale.

Network Hardware: Communication Links

- There are many types of communication links, which are made up of different types of physical media, such as
  - Twisted Pair (telephone)
  - Coaxial cable (TV)
  - Fiber optics (the backbone the PSTN, Public Switched Telephone Network)
  - Radio spectrum (cellphone)

- Different links can transmit data at different rates, with **the transmission rate** of a link measured in *bits/second*.

Network Hardware: PAN

- Personal Area Network — let devices communicate over the range of a person.
- A common example is a wireless network that connects a computer with its peripherals.

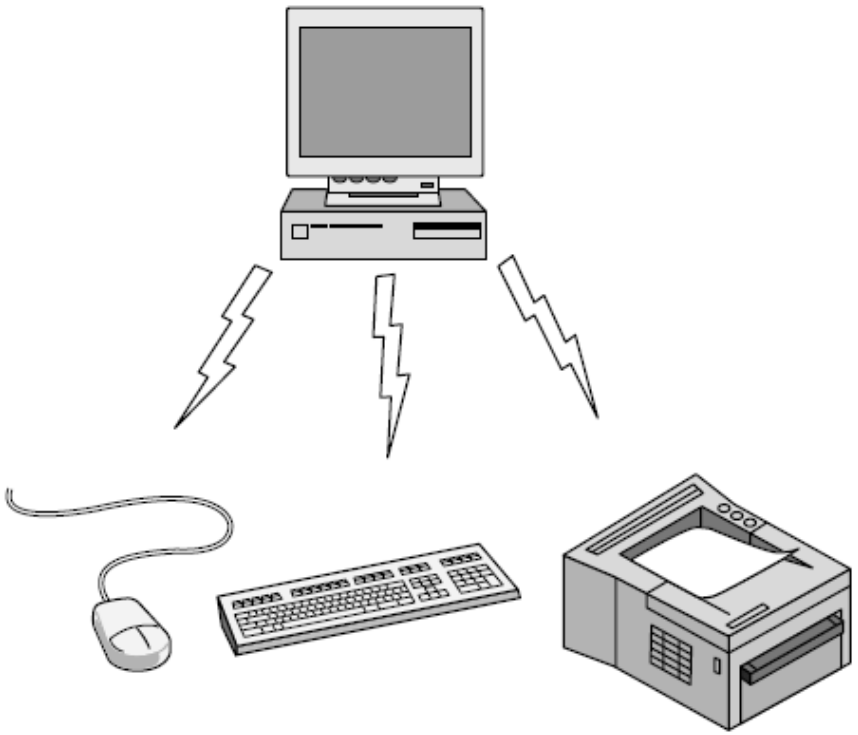


Figure 1-7. Bluetooth PAN configuration.

Bluetooth networks use **the master-slave paradigm**. The system unit (the computer) is normally the master, talking to the mouse, keyboard, est., as slaves. The master tells the slaves what addresses to use, when they can broadcast, how long they can transmit, what frequencies they can use, and so on.

Network Hardware: LAN

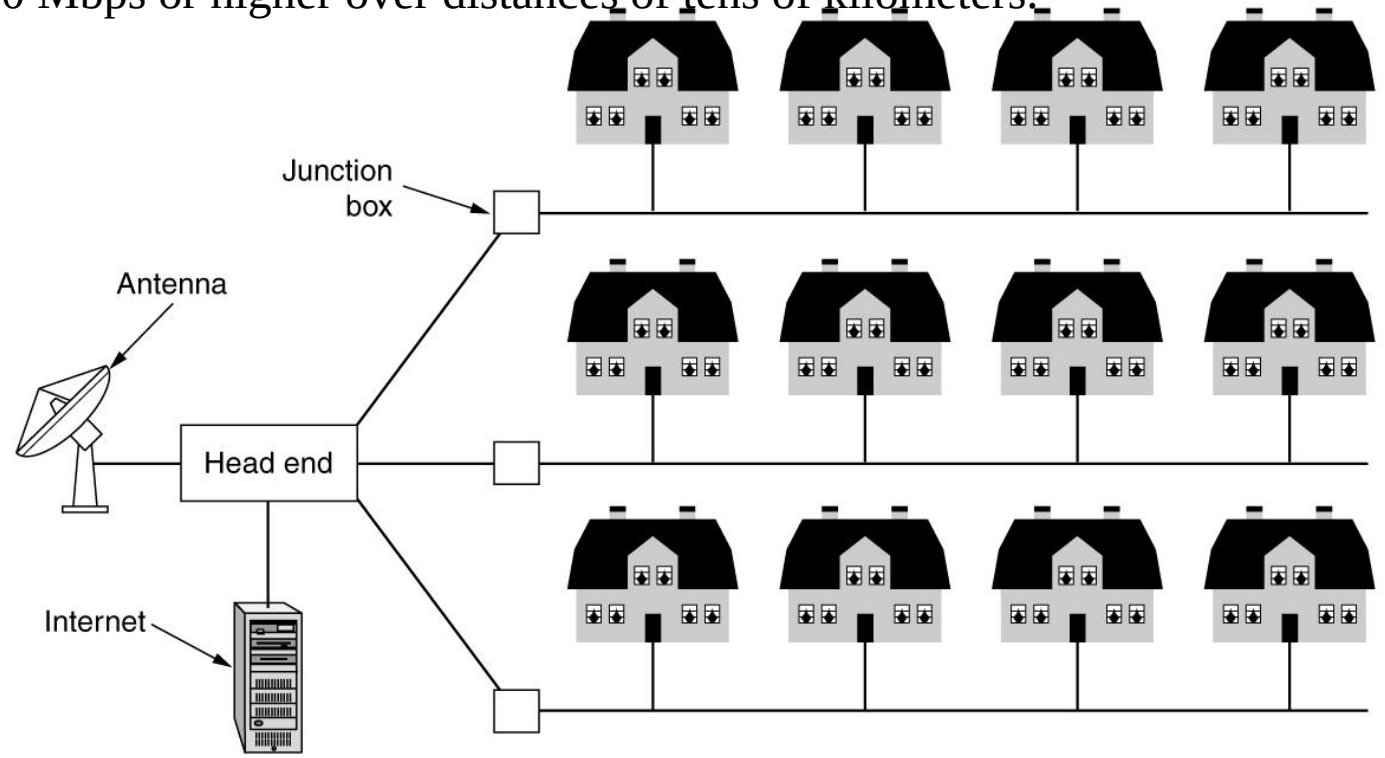
- Both wireless and wired broadcast networks can be divided into **static** and **dynamic** designs, depending on how the channel is allocated.
  - Static: time slot (TDM) and FDM
  - Dynamic allocation methods for a common channel are either **centralized** or **decentralized**.
    - In the centralized channel allocation method, there is a single entity, for example, the base station in cellular network, which determines who goes next.
    - In the decentralized channel allocation method, there is no central entity; each machine must decide for itself whether to transmit or not.

Home Networks [8]

- Home network LAN
  - Broad, diverse range of Internet-connected devices
  - Characteristics: manageable, dependable, and secure
- Internet of things
  - Allows almost any device to connect
- Required home network properties
  - Easy to install
  - Secure and reliable
  - Interfaces work between all products
  - Reduced consumer device costs

Network Hardware: MAN

- A MAN (Metropolitan Area Network) covers a city.
  - Wired example: **cable television**
  - Wireless example: IEEE 802.16 (WiMax, 不成功案例)
    - A long-distance cousin of the 802.11 WiFi protocol
    - WiMax operates independently of the cellular network and promises speeds of 5 to 10 Mbps or higher over distances of tens of kilometers.



Network Hardware: WAN

- A WAN (Wide Area Network) spans a large geographical area, often a country or continent.
- In most WANs, the subnet consists of two distinct components: **transmission lines** and **switching elements**.

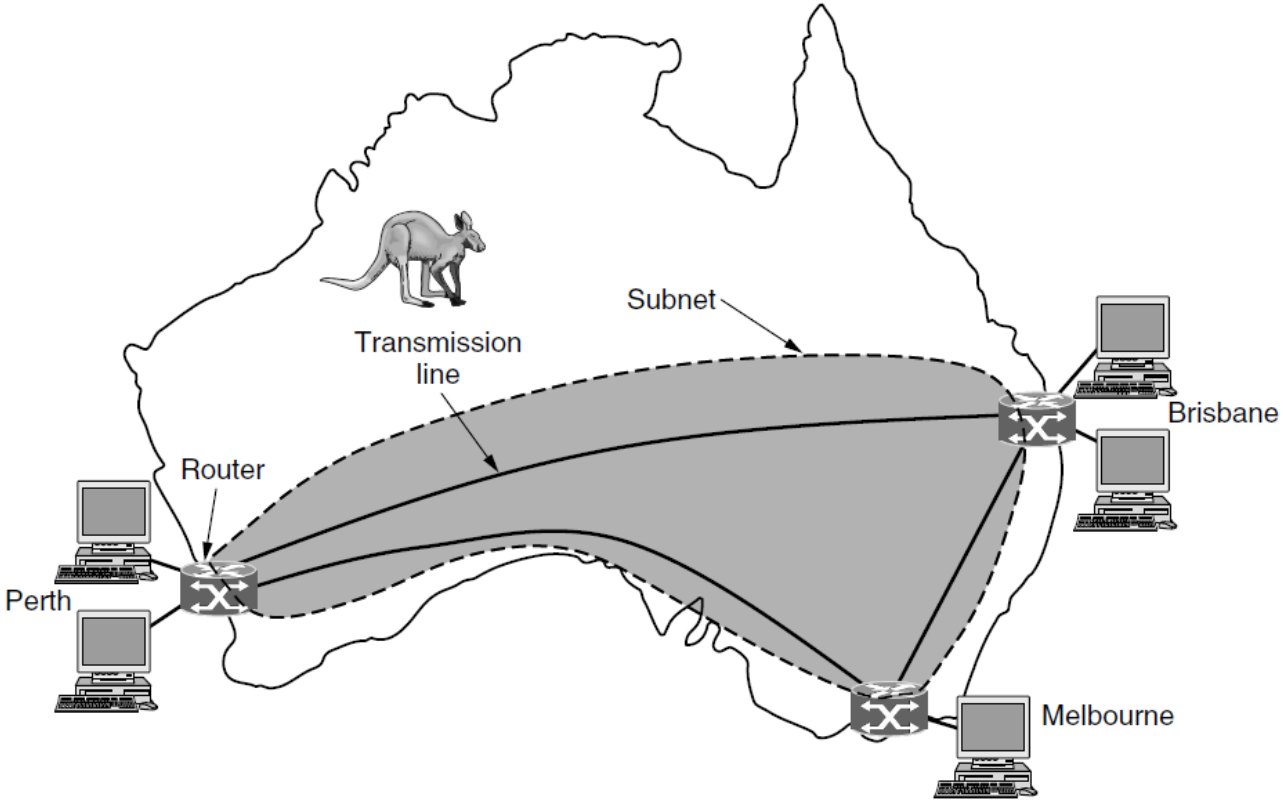
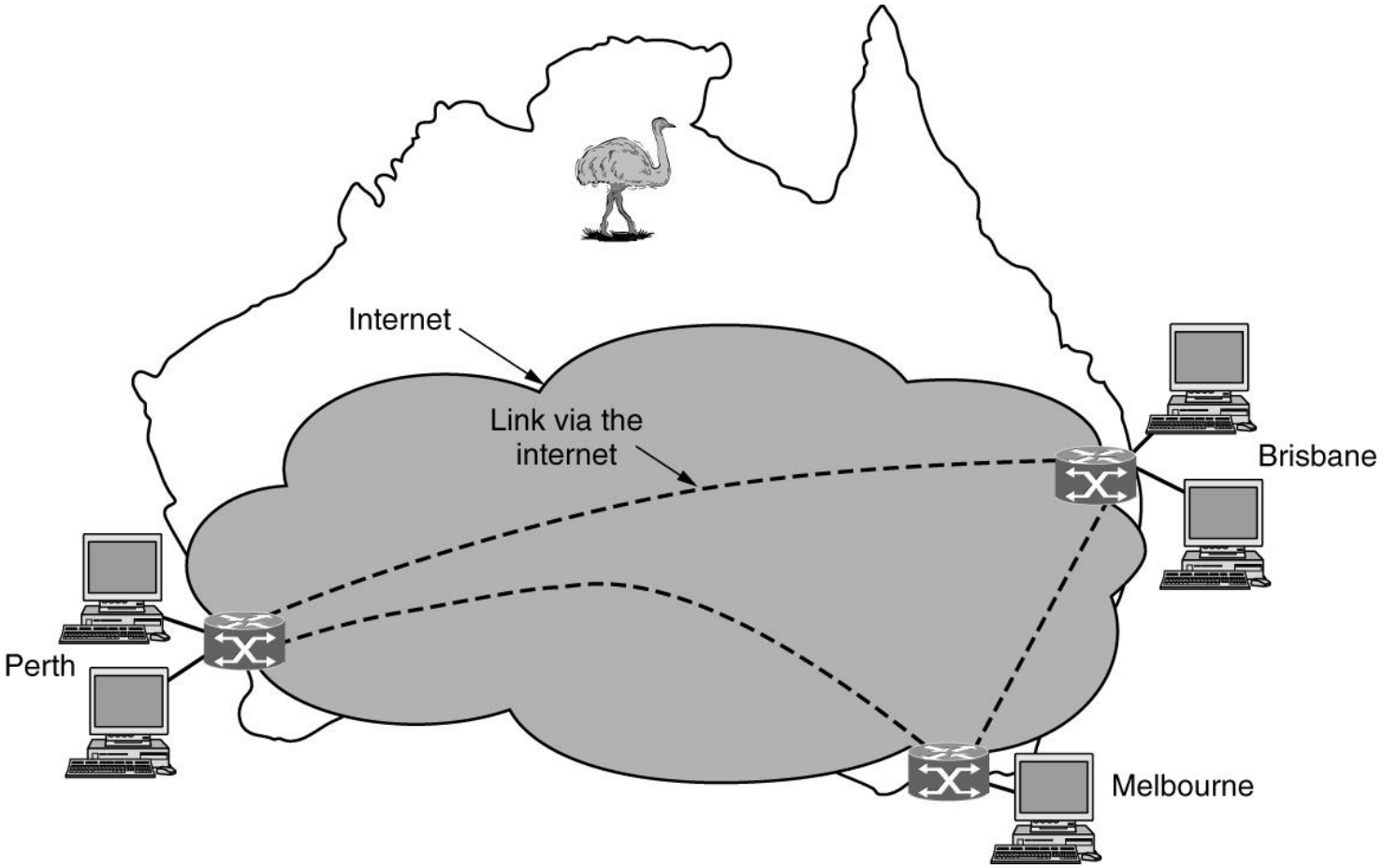


Figure 1-10. WAN that connects three branch offices in Australia.

Network Hardware: WAN

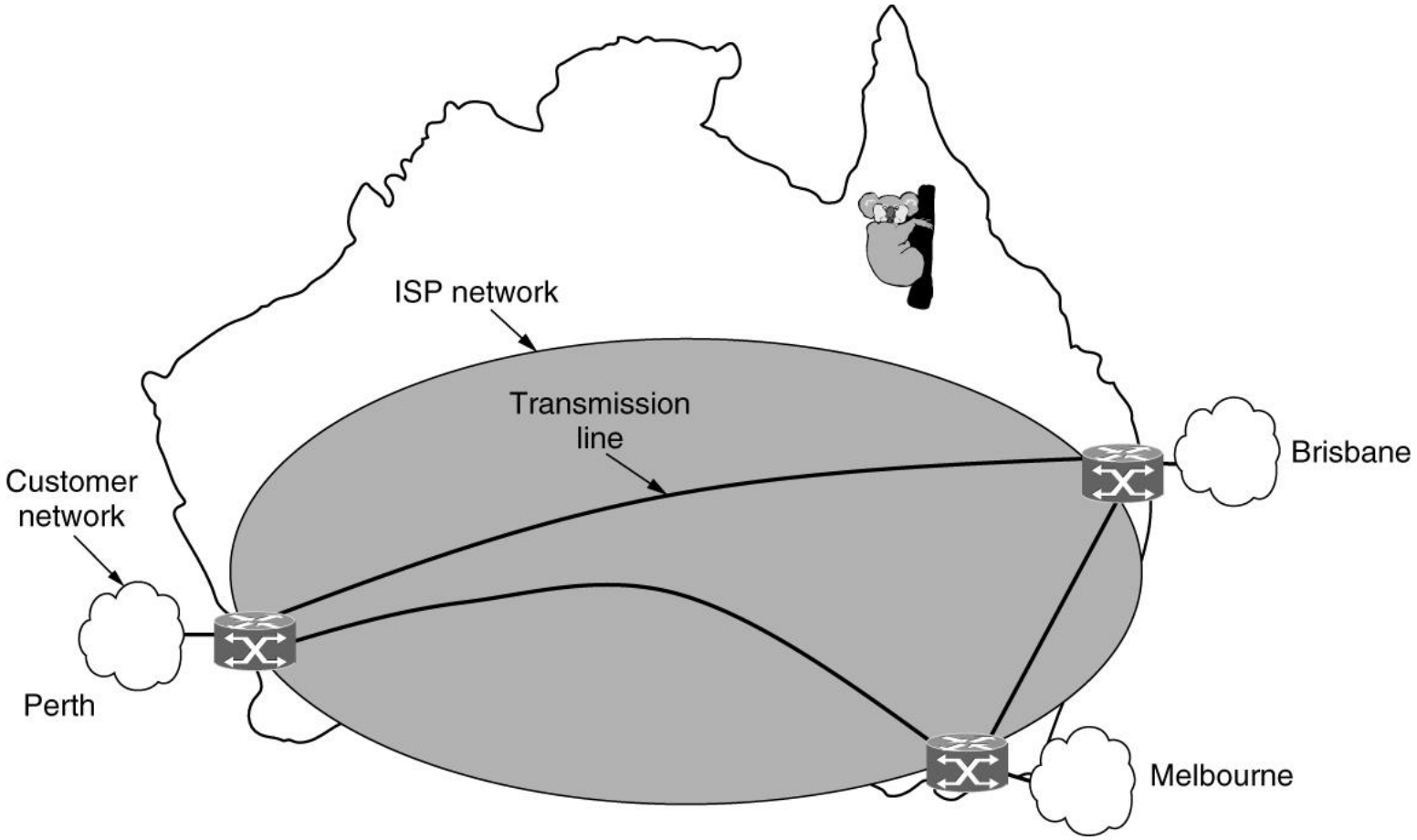
- Many WANs will in fact be internetworks, or composite networks that are made up of more than one network.
- Two varieties of WANs
  - VPN (Virtual Private Network)
    - Advantage: reuse of resource
    - Disadvantage: a lack of control over the underlying resources
  - ISP (Internet Service Provider)
    - **The routing algorithm** — how the network makes the decision as to which path to use
    - **The forwarding algorithm** — how each router makes the decision as to where to send a packet next.
- The cellular telephone network is an example of a WAN that uses wireless technology.

Network Hardware: WAN: VPN [8]



This wide area network illustrates how hosts in Perth, Brisbane, and Melbourne can communicate via the Internet.

Network Hardware: WAN: ISP [8]



This wide area network illustrates how hosts in Perth, Brisbane, and Melbourne can communicate via an ISP.

Network Hardware: Internetworks [8]

- Internetwork or internet
  - A collection of interconnected networks
- Network combines subnets and hosts
  - Subnet can be described as a ISP network (Figure 1-11)
  - Internetwork might be described as a WAN network (Figure 1-9)
- An internet
  - Interconnection of distinct, independently operated networks
  - Connecting a LAN and a WAN or connecting two LANs
  - Gateway device makes a connection between two or more networks

Network Hardware: the Internet

- The Internet is arguably the **largest** engineering system ever created by mankind, with hundred of millions of connected computers, communication links, and switches; hundreds of millions of users who connect intermittently via cell phones and PDAs; and devices such as sensors, webcams, game consoles, picture frames, and even washing machines being connected to the Internet. [2]
  - The Internet is a network of networks.
  - The Internet provides services to distributed applications

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Examples of Networks

- The Internet
  - The ARPANET
  - NSFNET
  - The Internet architecture
- Mobile networks
  - Mobile network architecture
  - Packet switching and circuit switching
  - Early generation mobile networks: 1G, 2G, and 3G
  - Modern mobile networks: 4G and 5G
- Wireless networks (WiFi)

Example Networks: Internet (I)

- Internet is a network of interconnected computers that is now global
- Internet born in 1969 - called ARPANET
- 1969 ARPANET was connection of computers at UCLA, Stanford, UCSB, Univ. of Utah

Example Networks: Internet (II)

- Internet - 1970s
  - 1972 - Telnet developed as a way to connect to remote computer
  - 1972 – Email introduced
    - 1977 - U. Wisconsin has first “large” Email system - 100 users
  - 1973 - ARPANET goes international
  - 1973 - File Transfer Protocol (FTP) established

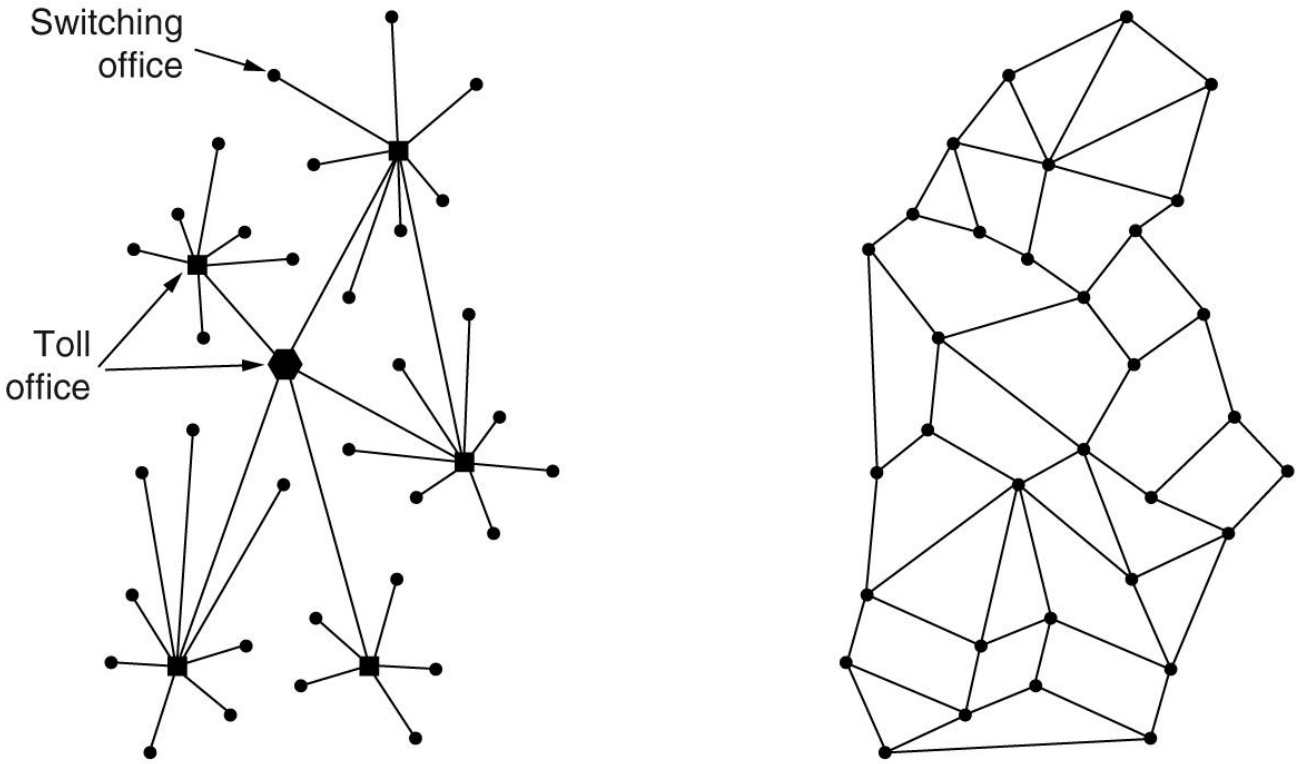
Example Networks: Internet (III)

- Internet - 1980s
  - 1984 - Domain Name Server introduced
    - allows naming of hosts, no longer numeric
  - 1986 - NSFNET created
    - in 1990, becomes backbone of modern Internet when ARPANET is decommissioned
    - Completely privatized by 1995
    - 56 K interconnection initially, increased rapidly

Example Networks: Internet (IV)

- Internet 1990s
  - 1991 - Tim Berners-Lee releases **World Wide Web**!
    - TBL is computer programmer at CERN, a physics lab in Europe (new book *Weaving the Web* by TBL)
  - 1993 - Mosaic (becomes Netscape) designed by graduate students at University of Illinois
    - first point-and-click browser
    - later developed into Netscape Navigator
- These are the two most significant events in the formation of the WWW

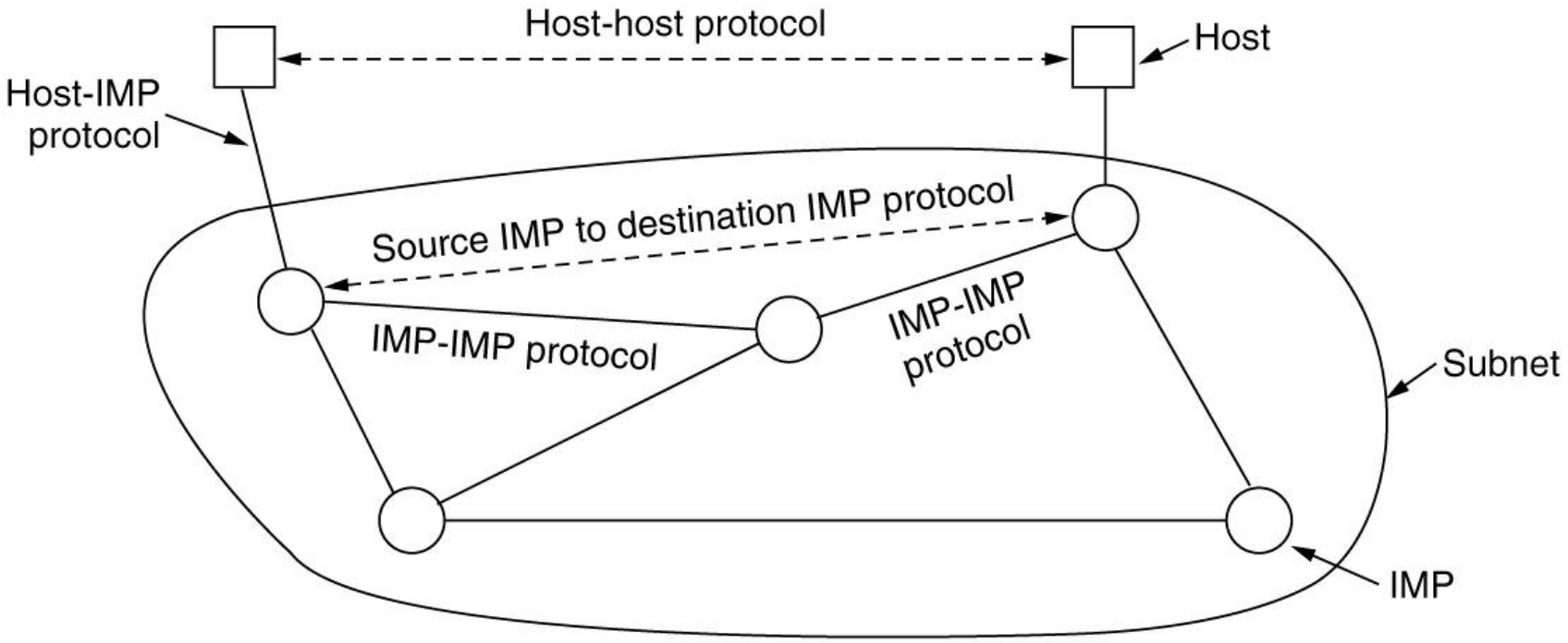
Examples of Networks: the Internet



(a) Hierarchy (b) Distributed

Figure (a) represents an unsecure network with little redundancy. Figure (b) illustrates a more secure packet-switched network that was initially dismissed as a solution.

Examples of Networks: the Internet: ARPANET

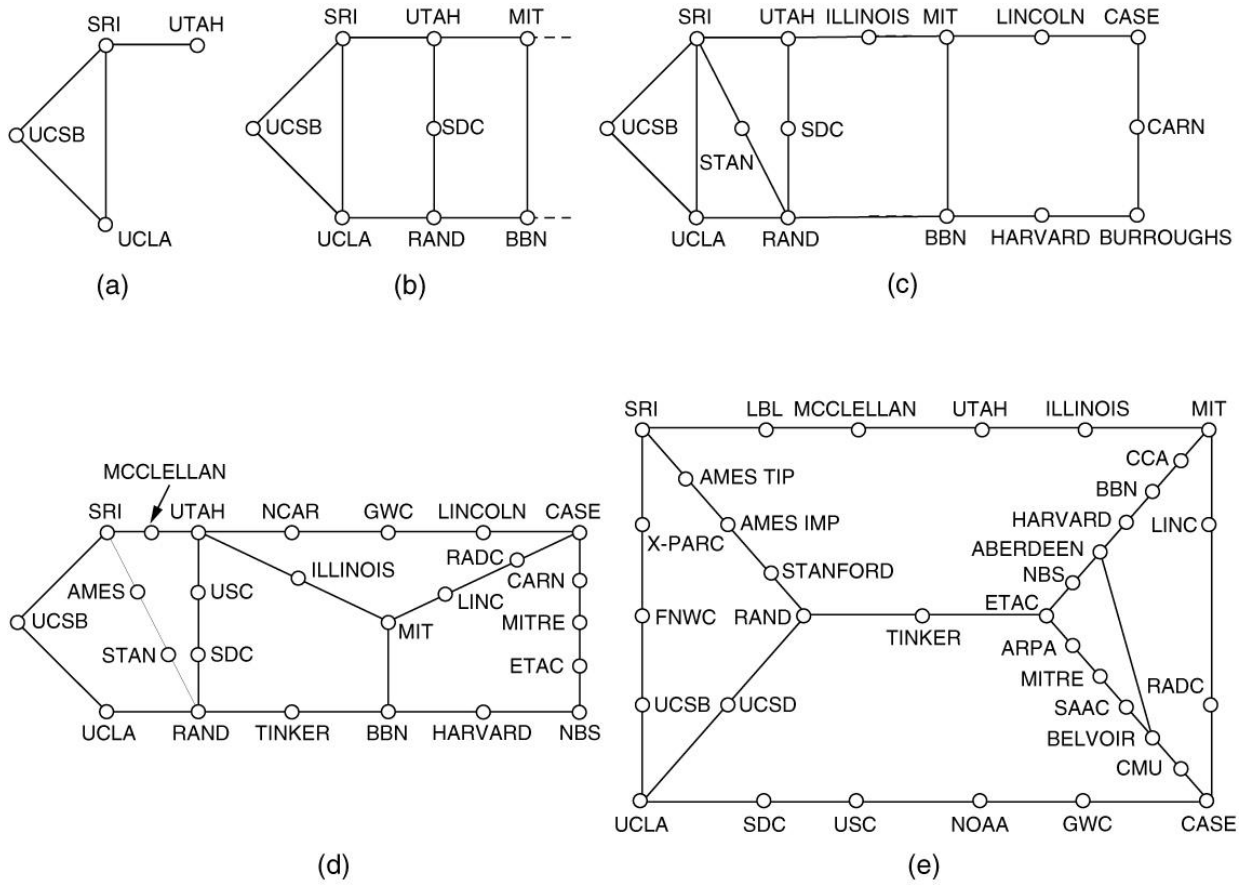


♦Internet born in 1969 - called ARPANET

♦1969 ARPANET was connection of computers at UCLA, Stanford, UCSB, Univ. of Utah

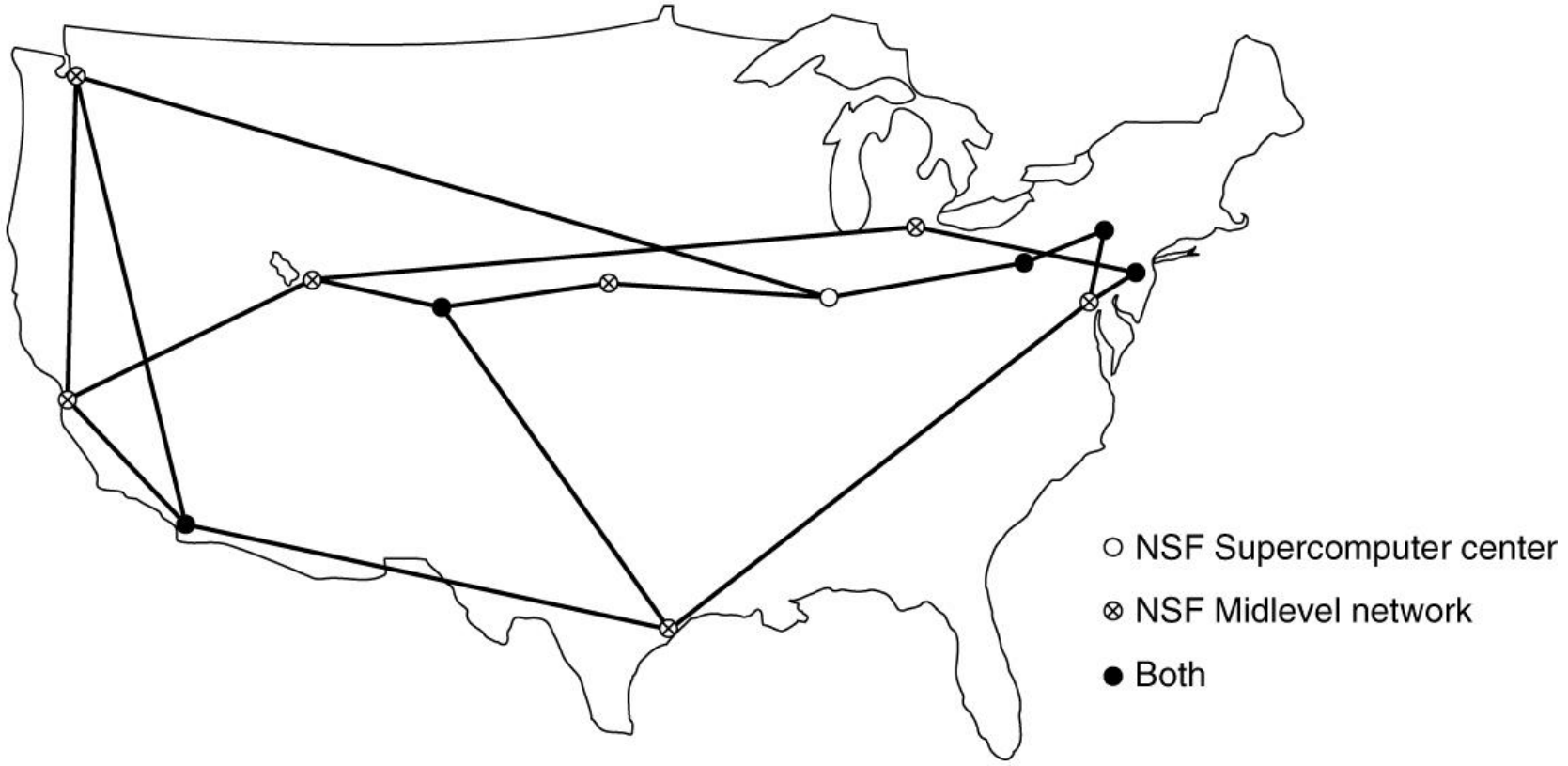
♦The original ARPANET software was split into two parts: subnet and host. The subnet software consisted of the IMP end of the host-IMP connection, the IMP-IMP protocol, and a source IMP to destination IMP protocol designed to improve reliability.

Examples of Networks: the Internet : ARPANET



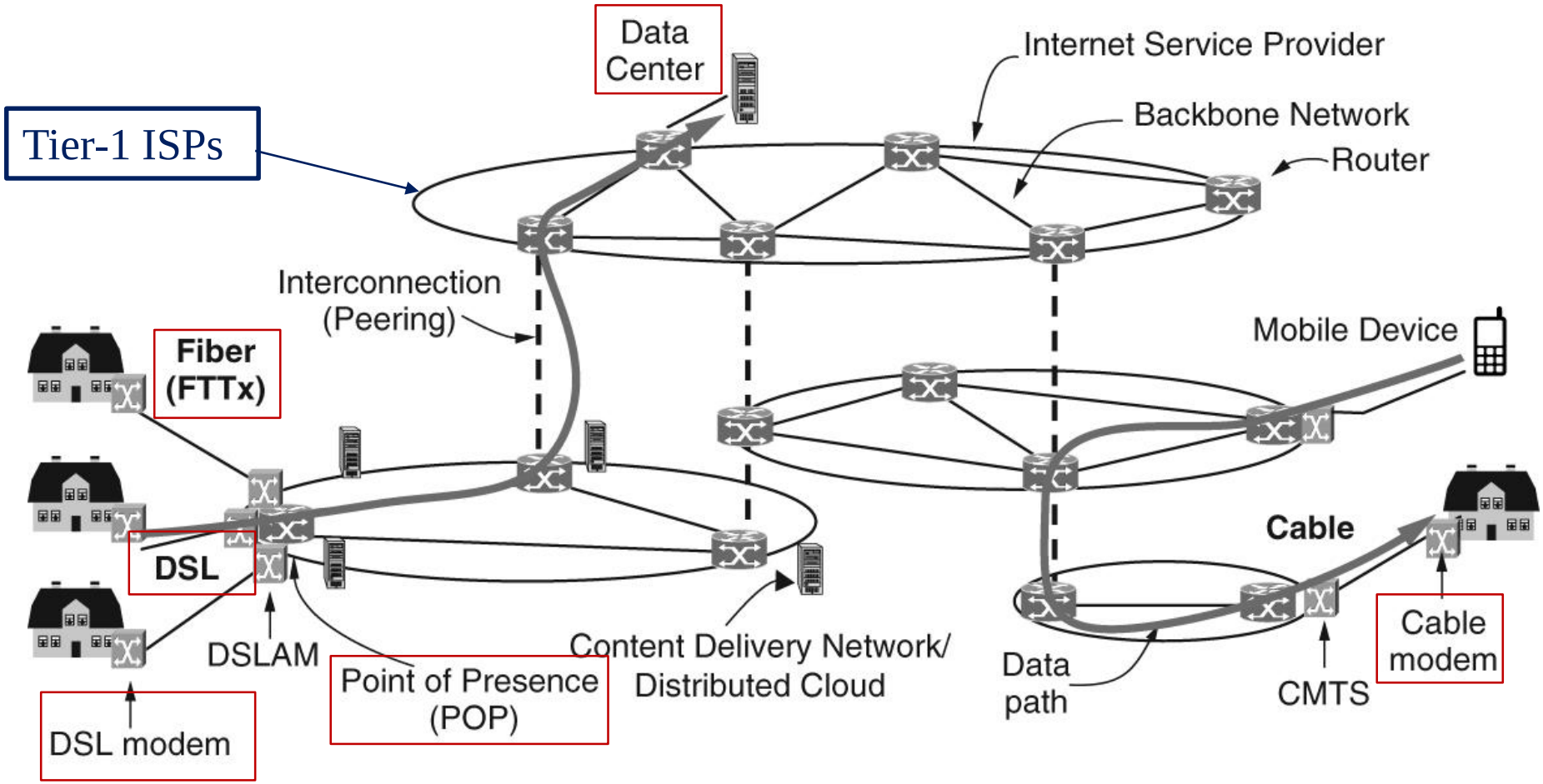
Growth of the number of nodes on ARPANET. (a) December 1969. (b) July 1970. (c) March 1971. (d) April 1972. (e) September 1972.

Examples of Networks: the Internet: NSFNET



NSFNET was a backbone network designed to be a successor to the ARPANET that would be open to all university research groups, allowing them to communicate without having to contract with the Department of Defense.

Examples of Networks: the Internet's Architecture

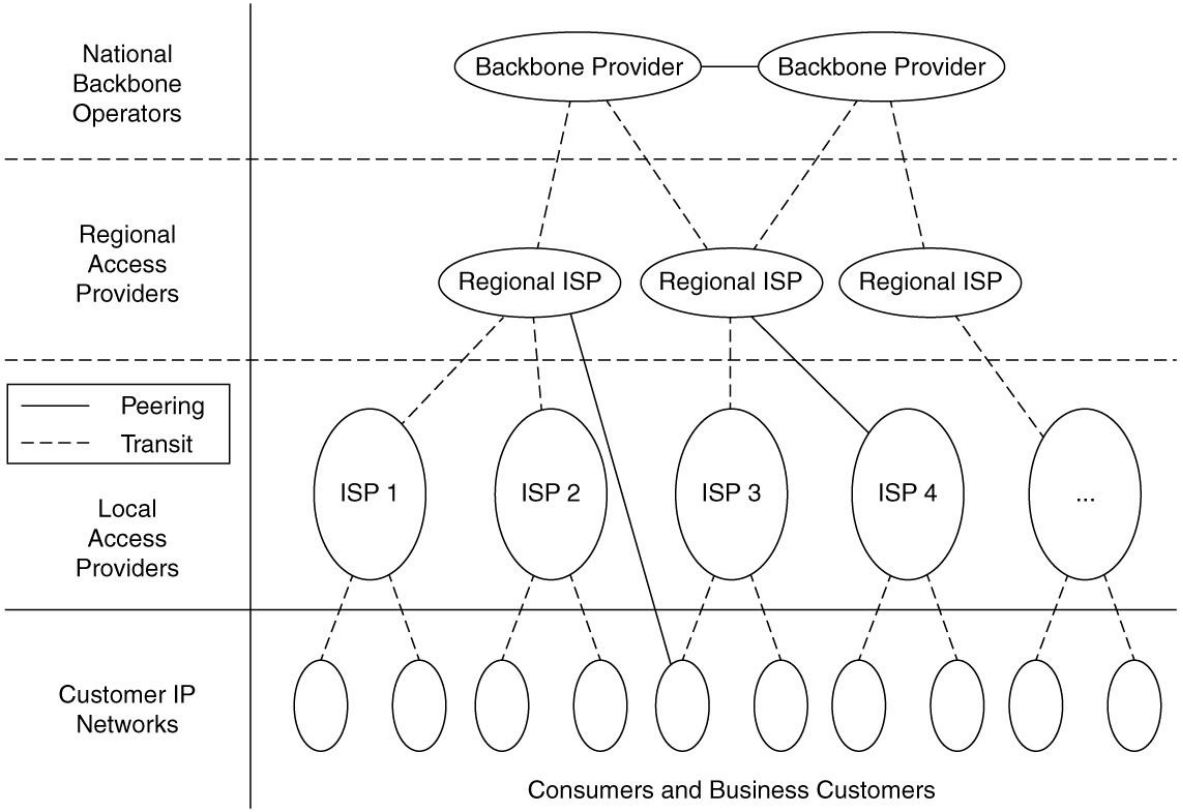


A common method for connecting to the Internet from your home is to send signals over the cable television infrastructure.

Examples of Networks: the Internet's Architecture

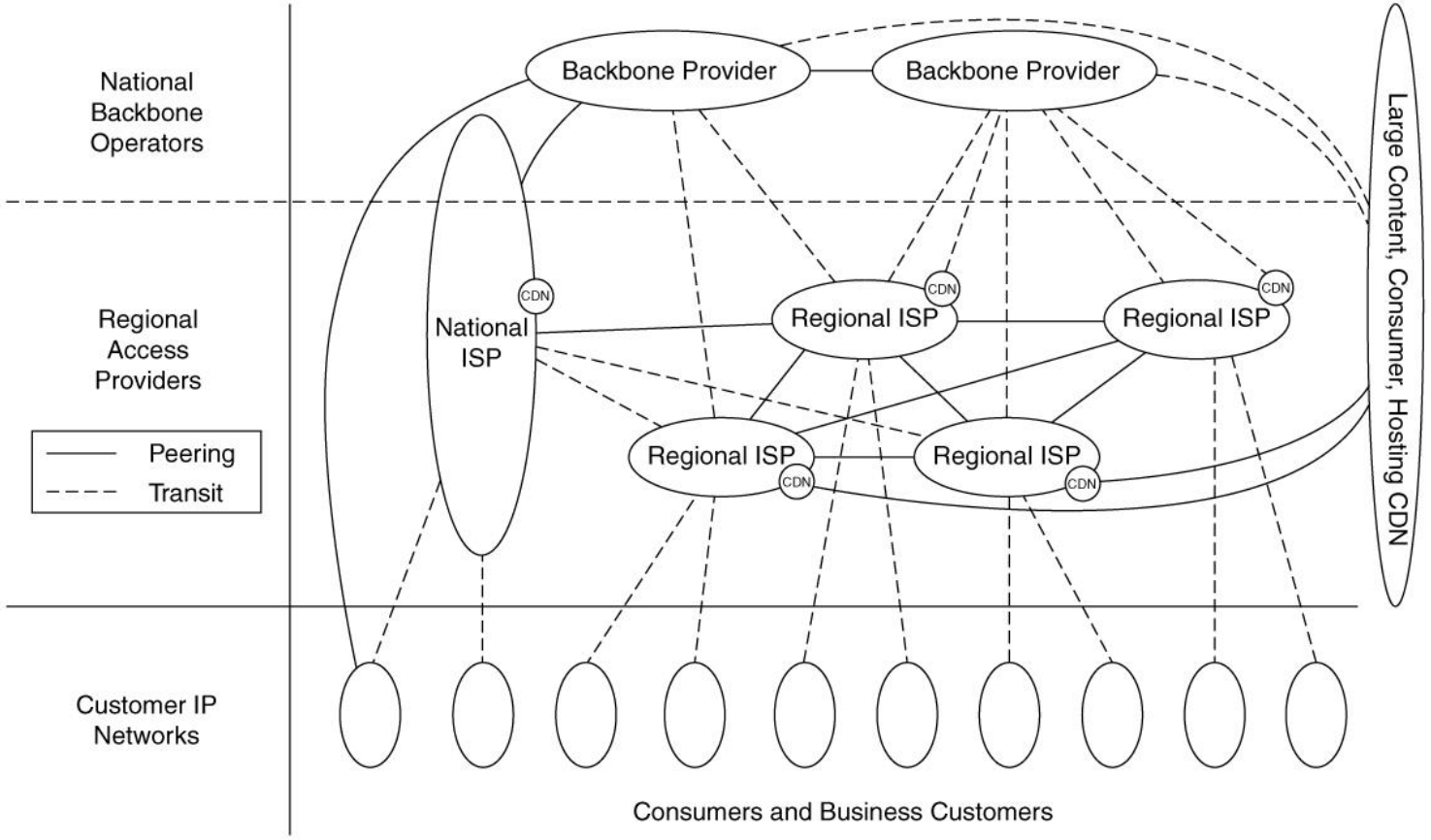
- Cable television infrastructure connects to the Internet
- HFC (Hybrid Fiber-Coaxial) network is a single integrated infrastructure
  - Uses packet-based transport called **DOCSIS** (Data Over Cable Service Interface Specification)
- DOCSIS transmits a variety of data services, including television channels, high-speed data, and voice
  - Device at the home end is called a cable modem
  - Device at the cable headend is called the CMTS (Cable Modem Termination System)
  - Modem is short for "**mo**dulator **dem**odulator"

Examples of Networks: the Internet's Architecture

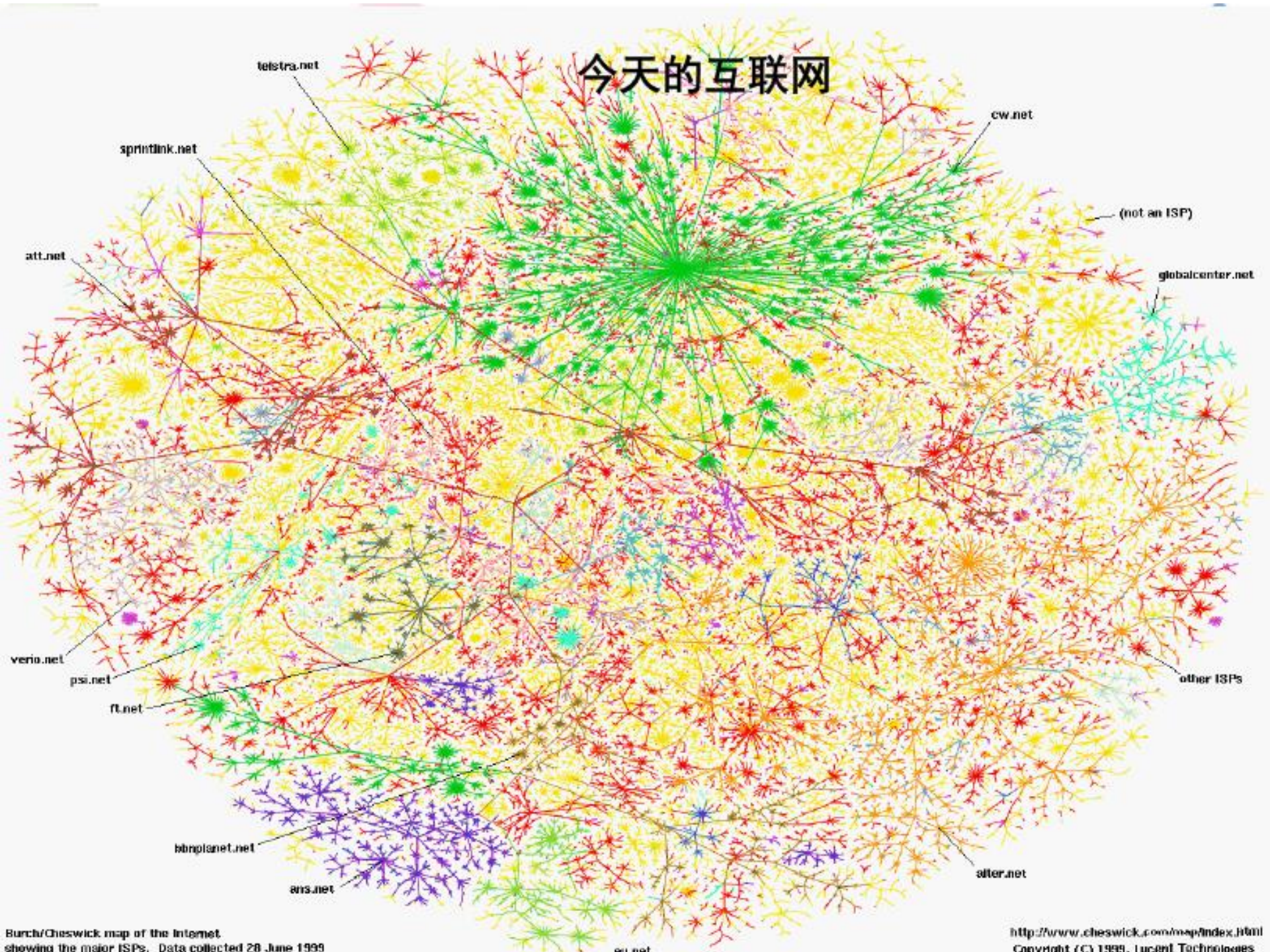


Conventionally, the Internet architecture has been viewed as a hierarchy, with the tier-1 providers at the top of the hierarchy and other networks further down the hierarchy, depending on whether they are large regional networks or smaller access networks.

Examples of Networks: the Internet's Architecture



Over the past decade, the conventional hierarchy has evolved and "flattened" dramatically.


今天的互联网
telstra.net
sprintlink.net
cw.net
(not an ISP)
att.net
globalcenter.net
verio.net
psi.net
ft.net
other ISPs
bbnplanet.net
ans.net
alter.net
Burch/Cheswick map of the Internet
showing the major ISPs. Data collected 28 June 1999
http://www.cheswick.com/map/index.html
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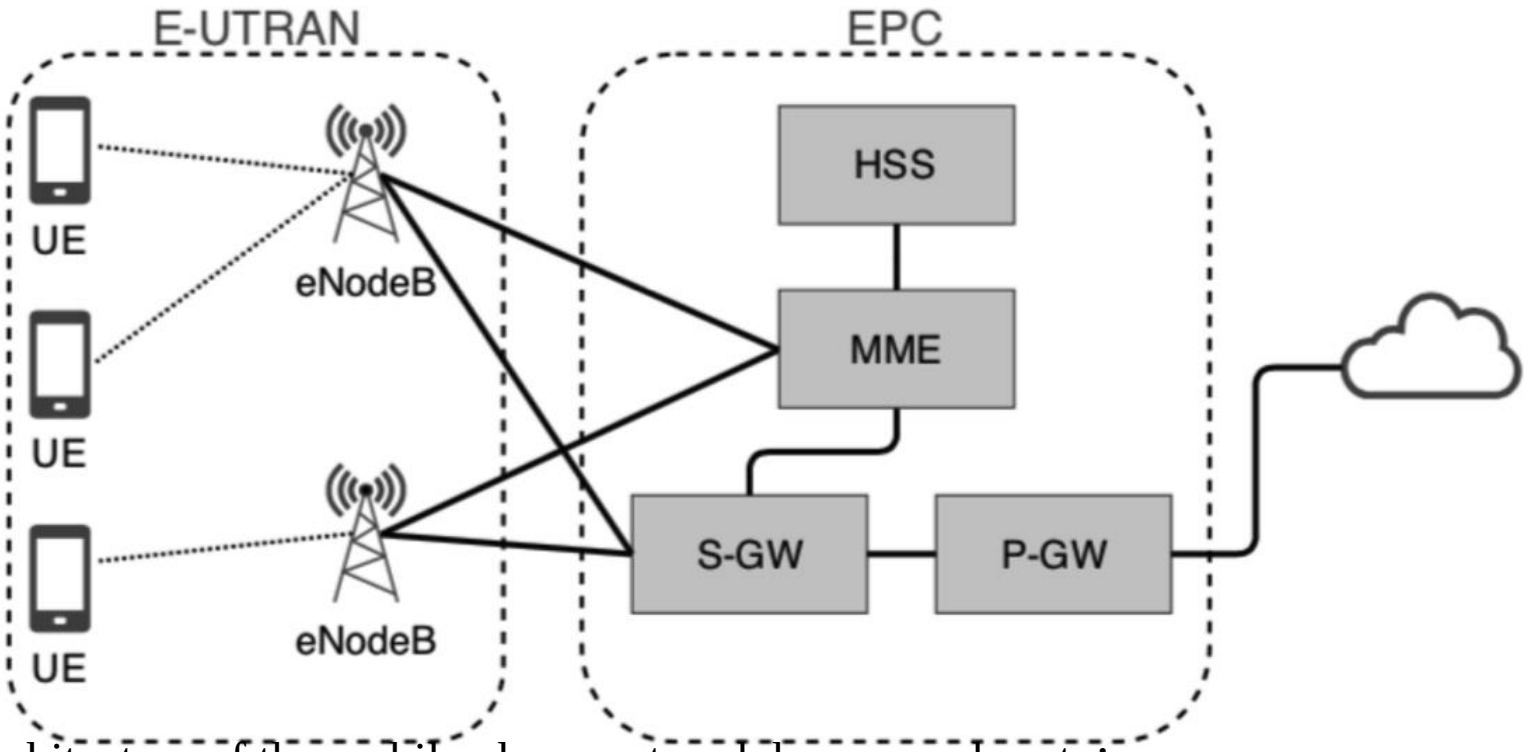
Examples of Networks: Mobile Networks

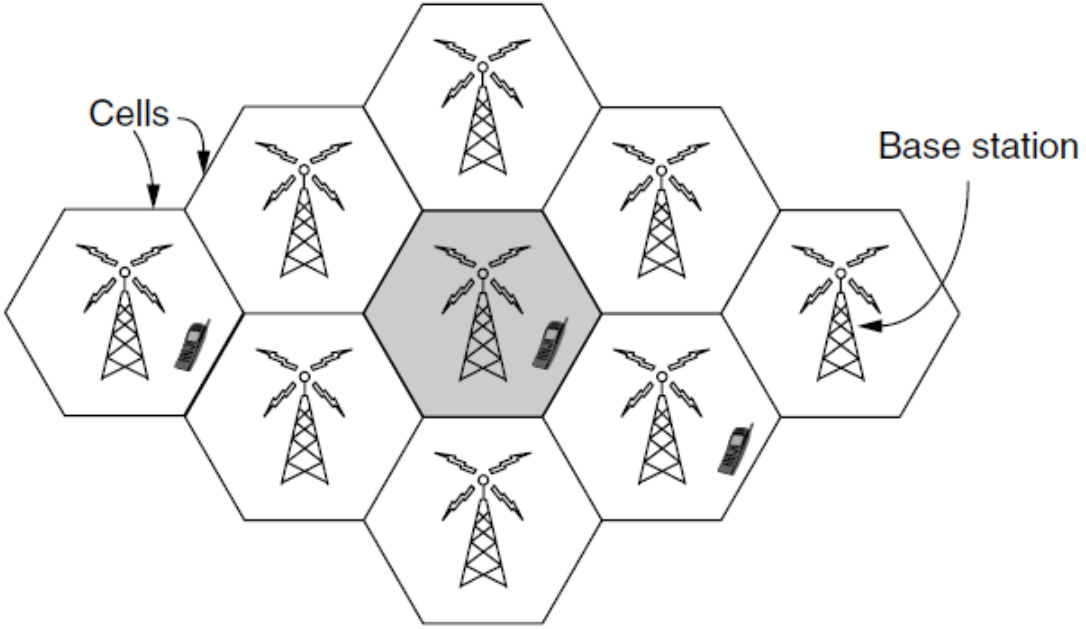


The architecture of the mobile phone network has several parts:

- E-UTRAN (Evolved UMTS Terrestrial Radio Access Network) between the mobile devise and the cellular base station (eNodeB)
- EPC (Evolved Packet Core) — the core network, in 4G networks, the core network became packet-switched.
  - ♥ S-GW (Serving Network Gateway)
  - ♥ P-GW (Packet Data Network Gateway) deliver data packets to and from mobiles and interface to external packet networks such as the Internet.
  - ♥ HSS (Home Subscriber Server)

Examples of Networks: Mobile Networks

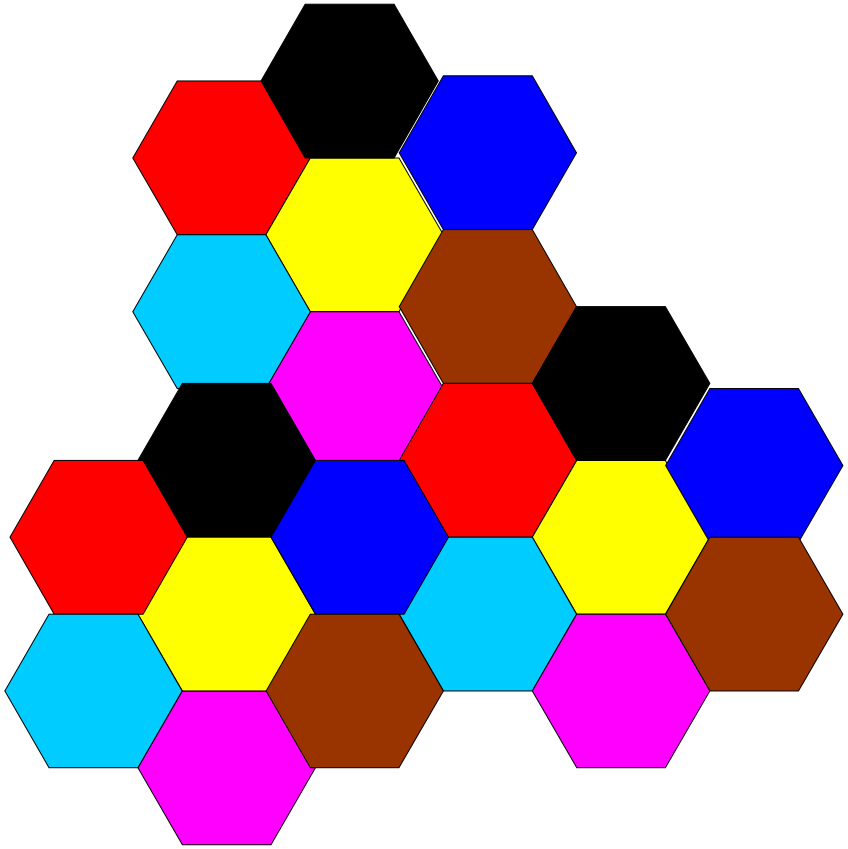
- The scarce resource in mobile phone system is radio spectrum.
  - Governments **license** the right to use parts of the spectrum to the mobile phone network operators, often using a spectrum auction in which network operators submit bids.
  - It is the scarcity of spectrum that led to the cellular network design



Within a cell, users are assigned channels that do not interfere with each other, and **frequency reuse** in the neighboring cells.

Mobile Networks: Cellular Concept

- Proposed by Bell Labs in 1947 — Geographic service divided into smaller "**cells**"
- Neighboring cells do not use same set of frequencies to prevent interference.
- Often approximate coverage area of a cell by an idealized **hexagon**
- Increase system capacity by **frequency reuse**.



Modern 3G systems allow each cell to use all frequencies, but in a way that results in a tolerable level of interference to the neighboring cells.

Examples of Networks: Mobile Networks

- Handover
  - Soft handover

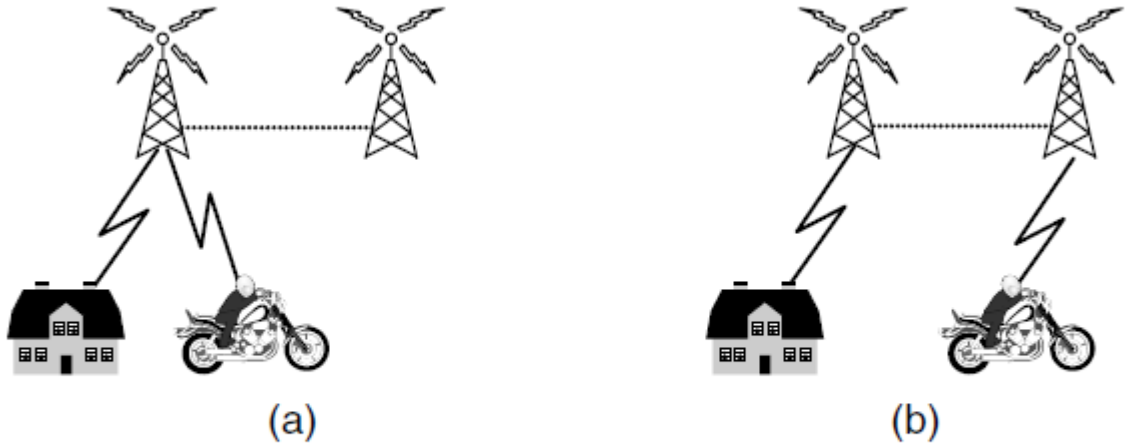


Figure 1-32. Mobile phone handover (a) before, (b) after.

- SIM (Subscriber Identity Module) — a removable chip
  - SIM cards can be switched to different handsets to active them
  - Provides a basis for security

Evolution of Mobile Networks (I)

- First-Generation (1G) Mobile Phones: Analog Voice
  - AMPS (Advanced Mobile Phone System, 1982)
- Second-Generation (2G) Mobile Phones: Digital Voice
  - DAMPS
  - GSM (Global System for Mobile Communications, 1991)
  - IS-95 (CDMA)
- Third-Generation (3G) Mobile Phones: Digital Voice + Data
  - UMTS (2001)
  - CDMA2000

Evolution of Mobile Networks (II)

- 4G
  - Later 4G known as LTE (Long Term Evolution) technology
  - Offers faster speeds
  - Emerged in the late 2000s
  - Quickly became the predominant mode of mobile Internet access in the late 2000s
  - Outpacing competitors like 802.16 (WiMax)
  - Uses frequency bands up to 20 MHz
- 5G technologies are promising faster speeds
  - Up to 10 Gbps
  - Set for large-scale deployment in the early 2020s
  - Operate in much higher frequency bands, of up to 6 GHz
- Main distinction: frequency spectrum they rely on

Mobile Networks: Packet Switching vs. Circuit Switching

- Packet switching comes from the Internet community
  - Connectionless networks
  - Every packet is routed *independently*
  - If some routers go down during a session, no harm will be done as long as the system can dynamically reconfigure itself
- Circuit switching comes from telephone companies
  - Connection-oriented networks
  - Caller must dial the called party's number and wait for a connection before talking or sending data
  - Route maintained until call is terminated
  - Can support quality of service more easily

Example of Networks: Wireless LANs (802.11 WiFi)

- Equip both a local area and a computer with **short-range** radio transmitters and receivers to allow them to talk.
- In the early state, wireless LANs are not compatible.
  - In the mid 1990s, the industry decided to set up a wireless LAN **standard**.
  - 802.1, 802.2, 802.3 up to 802.10, so the wireless LAN standard was dubbed **802.11** (**WiFi**).
- 802.11 systems operate in *unlicensed bands* such as the **ISM** (Industrial, Scientific, and Medical) bands defined by ITU-R (e.g., 902-928 MHz, 2.4-2.5 GHz, 5.725-5.825 GHz).
  - All devices are allowed to use this spectrum provided that they *limit their transmit power* to let different devices coexist. This means that 802.11 radios may find themselves competing with cordless phones, garage door openers, and microwave ovens.

Example of Networks: Wireless LANs (802.11 WiFi)

- 802.11 networks are made up of clients, such as laptops and mobile phones, and infrastructure called **APs** (**Access Points**) that is installed in buildings.
  - APs ~ base stations
- The access points connected to the wired network, and all communication between clients goes through an access point. It is also possible for clients that are in radio range to talk directly, such as two computers in an office without an access point.

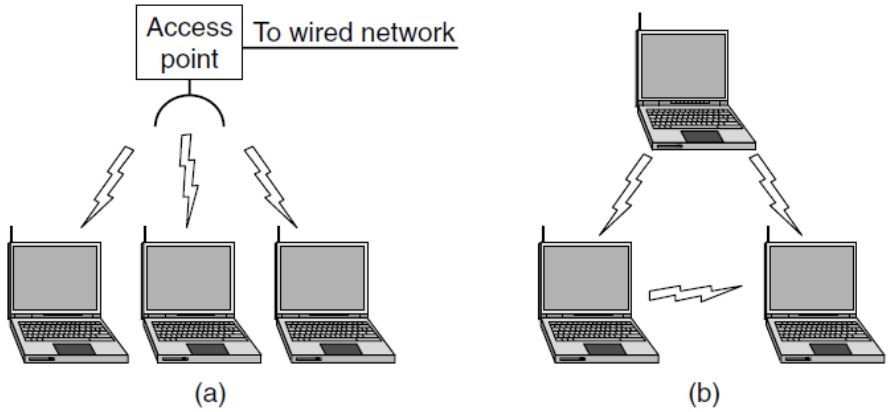


Figure 1-33. (a) Wireless network with an access point. (b) Ad hoc network.

Example of Networks: Wireless LANs (802.11 WiFi)

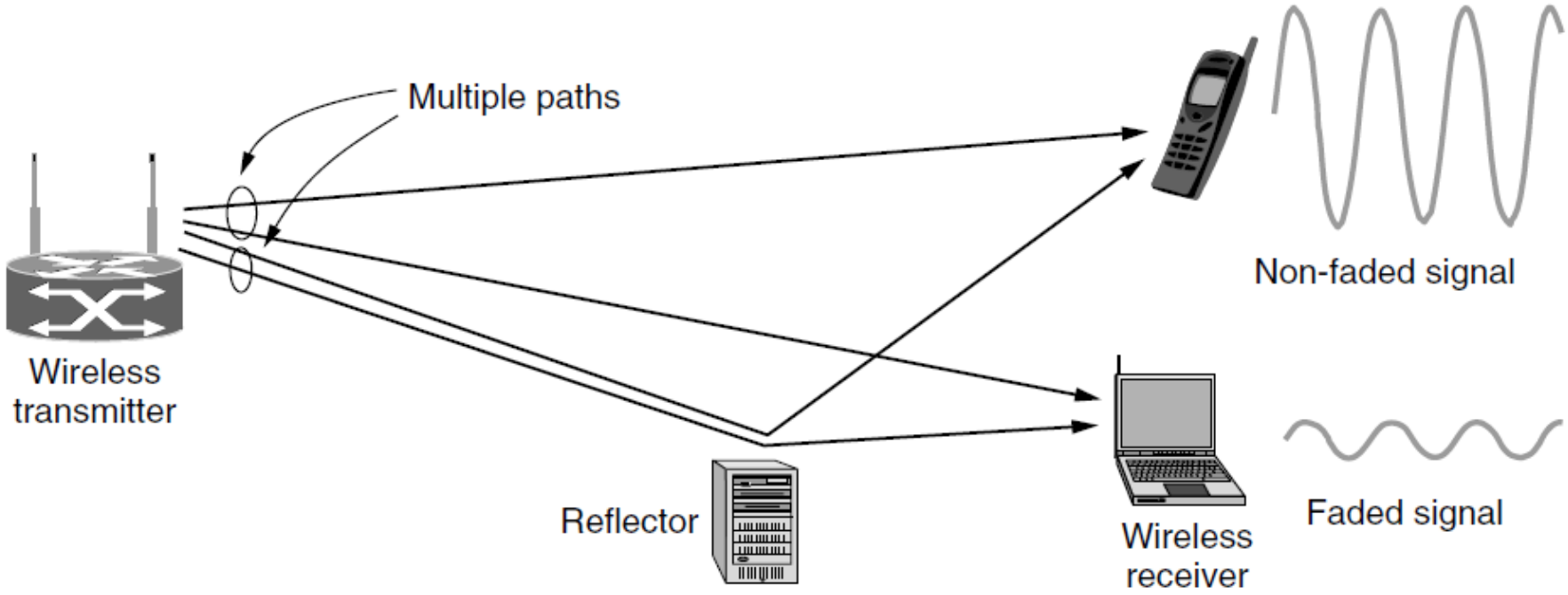


Figure 1-34. Multipath fading.

Multiple echoes of a transmission may reach a receiver along different paths. The echoes can cancel or reinforce each other, causing the received signal to fluctuate greatly. This phenomenon is called **multipath fading**.

Example of Networks: Wireless LANs (802.11 WiFi)

- The key idea for overcoming variable wireless conditions is **path diversity**, or the sending of information along *multiple*, *independent paths*.
  - Using different frequencies across the allowed band (using different frequencies to transmit the same signal)
  - Following different spatial paths between different pairs of antennas (**MIMO**),
  - Repeating bits over different periods of time.

Evolution of 802.11

- 802.11 (1997) defined a wireless LAN that ran at either 1 Mbps or 2 Mbps by hopping between frequencies or spreading the signal across the allowed spectrum.
- 802.11b (1999) standard running at rates up to 11 Mbps by extending the spread spectrum design.
- 802.11a (1999) and 802.11g (2003) standards switched to a different modulation scheme called **OFDM** (Orthogonal Frequency Division Multiplexing). Bit rates up to 54 Mbps.
- 802.11n (2009) uses wider frequency bands and up to four antennas per computer to achieve rates up to 450 Mbps
- 802.11 ac can run at 3.5 Gbps
- 802.11 ad can run at 7 Gbps

Example of Networks: Wireless LANs (802.11 WiFi)

- Multiple Transmissions
  - To deal the **collision** problem when multiple transmissions are sent at the same time
  - **CSMA** (**Carrier Sense Multiple Access**) drew from an early wireless network developed in Hawaii and called **ALOHA**.
    - Computer wait for a short **random** interval before transmitting, and defer their transmissions if they hear that someone else is already transmitting.
    - After any collision, the sender then waits another, longer, random delay and retransmits the packet.

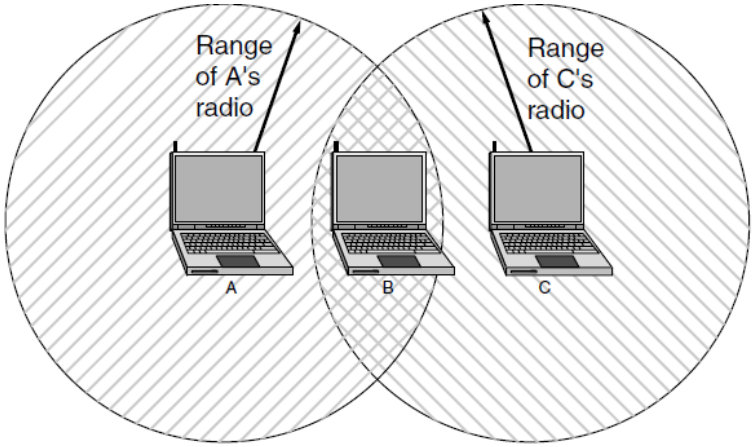


Figure 1-35. The range of a single radio may not cover the entire system.

Example Networks: Wireless LANs 802.11 (WiFi) (VI)

- Mobility
  - The solution is that an 802.11 network can consists of multiple cells, each with its own access point, and a distribution system that connects the cells.
  - Support **nomadic** clients that go from one fixed location to another.
- Security
  - **WEP** (Wired Equivalent Privacy, broken in 2001)
  - In the 802.11i standard, use some different cryptographic called **WiFi Protected Access** (**WPA**)
  - WiFi Protected Access (WPA) replaced by **WPA2** and **802.1X**
- 802.11 has caused a revolution in wireless networking that is set to continue. Beyond buildings, it is starting to be installed in trains, planes, boats, and automobiles so that people can surf the internet wherever they go.

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Network Protocols [8]

- Design goals
  - Reliability (ability to recover from errors, faults, or failures)
  - Resource allocation (sharing access to a common, limited resource)
  - Evolvability (allowing for incremental deployment of protocol improvements over time)
  - Security (defending the network against various types of attacks)
- Network protocol design: **layering**
- Connection-oriented vs. connectionless service
- Specific service primitives

Design Goals (1 of 4) [8]

- Reliability
  - Make a network operate correctly even though it is comprised of a collection of components that are themselves unreliable
    - Error detection finds errors in received information
    - Error correction corrects a message by recovering the possibly incorrect bits
  - Find a working path through a network using routing
    - Routing allows network to automatically make the decision

Design Goals (2 of 4) [8]

- Resource allocation
  - Scalable designs continue to work well when network gets large
  - **Statistical multiplexing**: sharing based on the statistics of demand
- An allocation problem that occurs at every level
  - Keeping a fast sender from swamping a slow receiver with data
  - Use flow control
- Congestion problem
  - Occurs when too many computers want to send too much traffic, and the network cannot deliver it all
- Quality of service reconciles competing demands

Design Goals (3 of 4) [8]

- Evolvability
  - Design issue concerns the evolution of the network
  - Over time, networks grow larger and new designs emerge that need to be connected to the existing network
  - Use protocol **layering** structuring mechanism to support change by dividing the overall problem and hiding implementation details
  - Use addressing or naming mechanism to identify the senders and receivers involved in a particular message
  - Different network technologies often have different limitations
  - Overall topic is called internetworking

Design Goals (4 of 4) [8]

- Security
  - Confidentiality mechanisms defend against eavesdropping on communications
  - Authentication mechanisms prevent someone from impersonating someone else
  - Integrity mechanisms prevent surreptitious changes to messages

Protocol Layering

- Networks organized as a stack of layers or levels
  - Each layer built upon the one below it
- Communication between corresponding layers
  - Use a common protocol referred to as a "layer n protocol"
  - Below layer 1 is the physical medium through which actual communication occurs
  - Interface lies between each pair of adjacent layers
- Network architecture: a set of layers and protocols
- **Protocol stack**: a list of the protocols used by a certain system, one protocol per layer
  - A **protocol** defines the *format* and the *order* of messages exchanged between two or more communication entities, as well as the *actions* taken on the transmission and/or receipt of a message or other event. [2]

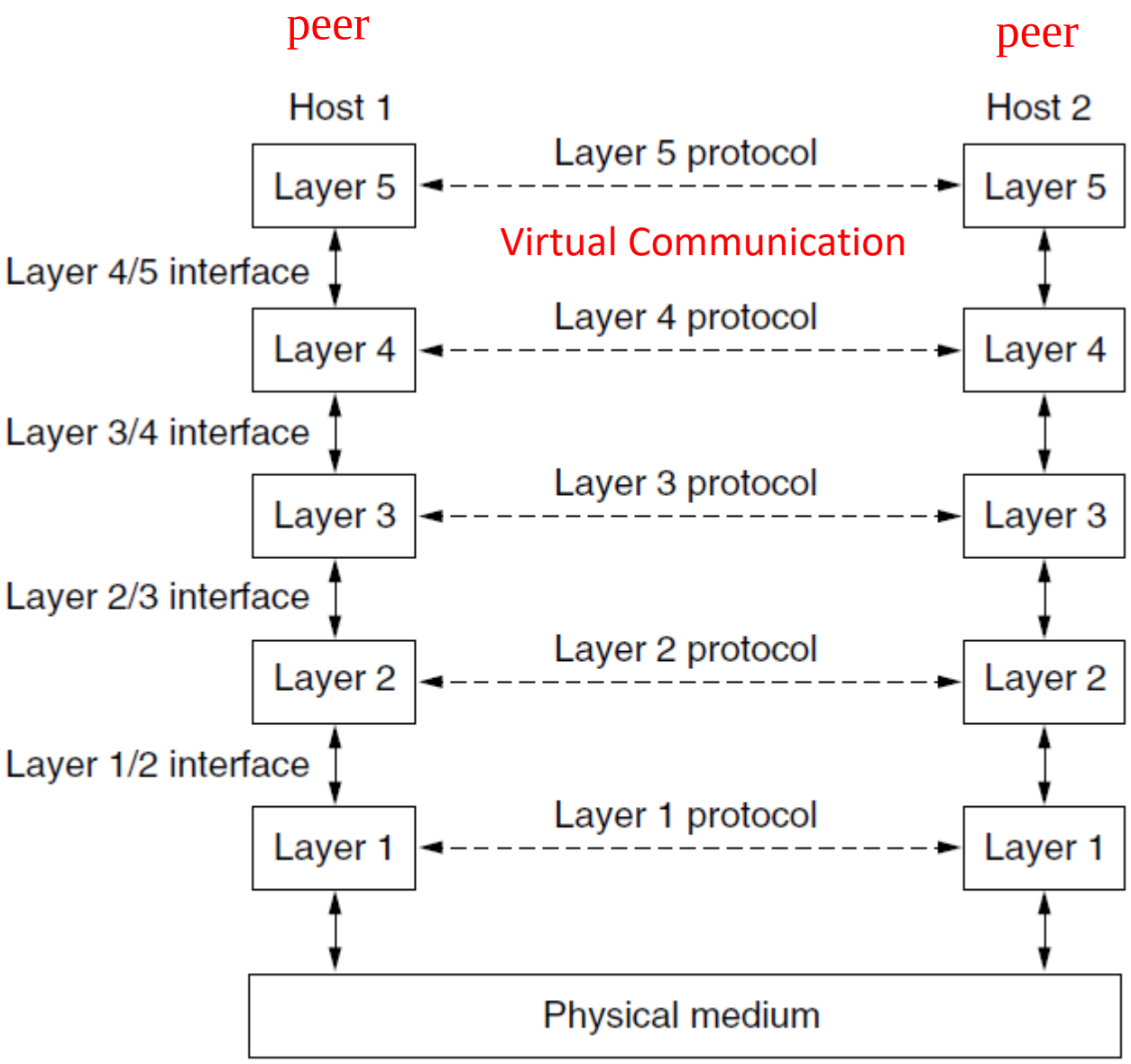

Figure 1-13. Layers, protocols, and interfaces.

1) Each layer passes data and control information to the layer immediately below it, until the lowest layer is reached.
2) The physical medium is where the actual communication occurs.
3) Between each pair of adjacent layers is an **interface**. The interface defines which **primitive operations** and **services** the lower layer makes available to the upper one.

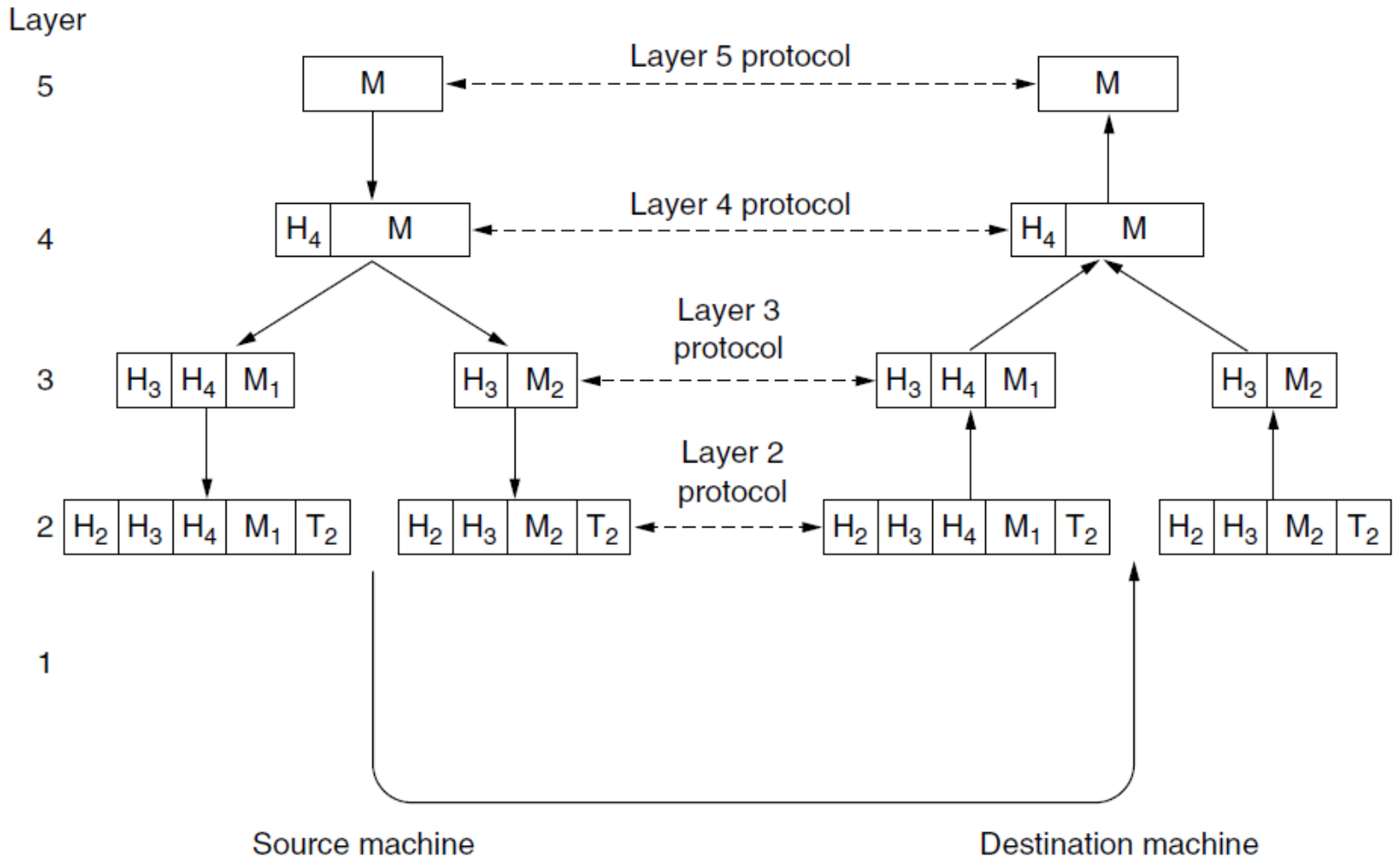

Figure 1-15. Example information flow supporting virtual communication in layer 5.

In many networks, layer 3 usually break up the incoming messages into smaller units, packets, prepending a layer 3 header to each packet.
Layer 2 adds to each piece not only a header but also a trailer.
The lower layers of a protocol hierarchy are frequently implemented in hardware or firmware.

Connection-Oriented vs. Connectionless Service

- Layers can offer two different types of service to the layers above them: connection-oriented and connectionless.
- Connection-oriented service is modeled after the telephone system
  - The service user first establishes a connection, uses the connection, and then releases the connection.
  - tube
- Connectionless service is modeled after the postal system
  - A packet is a message at the network layer. There are two ways to send the packet:
    - Store-and-forward switching
    - Cut-through switching
- Reliability characterizes connection-oriented and connectionless services
  - Reliable connection-oriented service has two minor variations: message sequences and byte stream
  - Unreliable connectionless service is called Datagram service.

Connections and Reliability

	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Movie download
	Unreliable connection	Voice over IP
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Text messaging
	Request-reply	Database query

Six common connection-oriented and connectionless services.

Service Primitives

- A service is formally specified by a set of primitives (operations) available to user processes to access the service.
  - These primitives tell the service to perform some action or report on an action taken by a peer entity.
  - If the protocol stack is located in the operating system, the primitives are normally **system calls**.

Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
ACCEPT	Accept an incoming connection from a peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

Figure 1-17. Six service primitives that provide a simple connection-oriented service.

Service Primitives

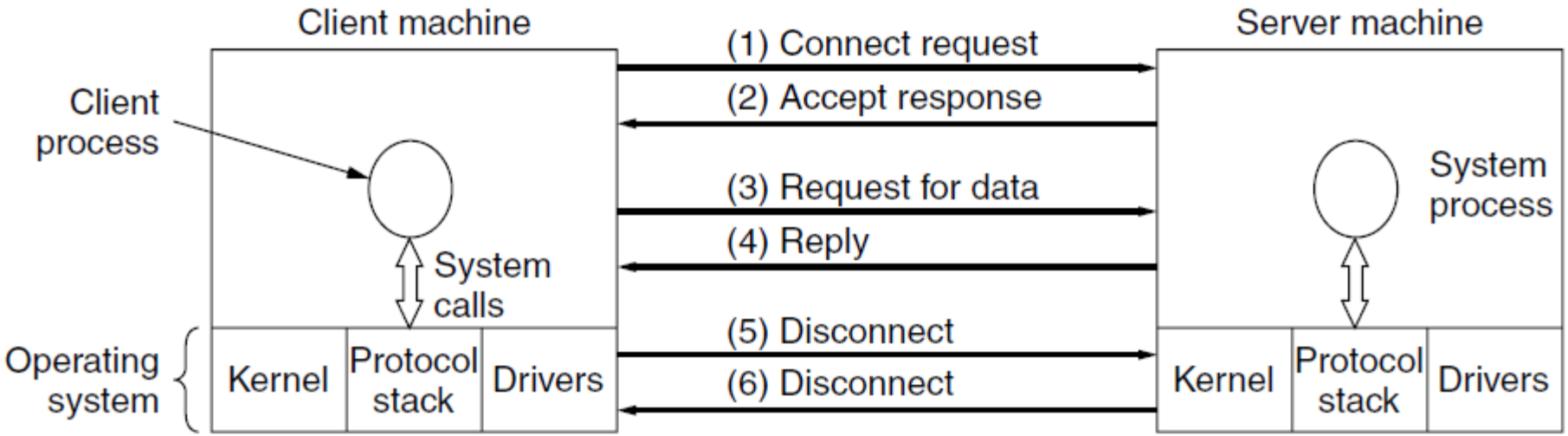

Figure 1-18. A simple client-server interaction using acknowledged datagrams.

Services vs. Protocols (I)

- A service is a set of primitives (operations) that a layer provides to the layer above it.
  - Services related to the interface between layers
- A protocol is a set of rules governing the format and meaning of the packet, or message that are exchanged by the peer entities within a layer.
  - Protocols relate to the packets sent between peer entities on different machines.
- Entities use protocols to implement their service definitions. They are free to change their protocols at will, provided they do not change the service visible to their users.

Services vs. Protocols (II)

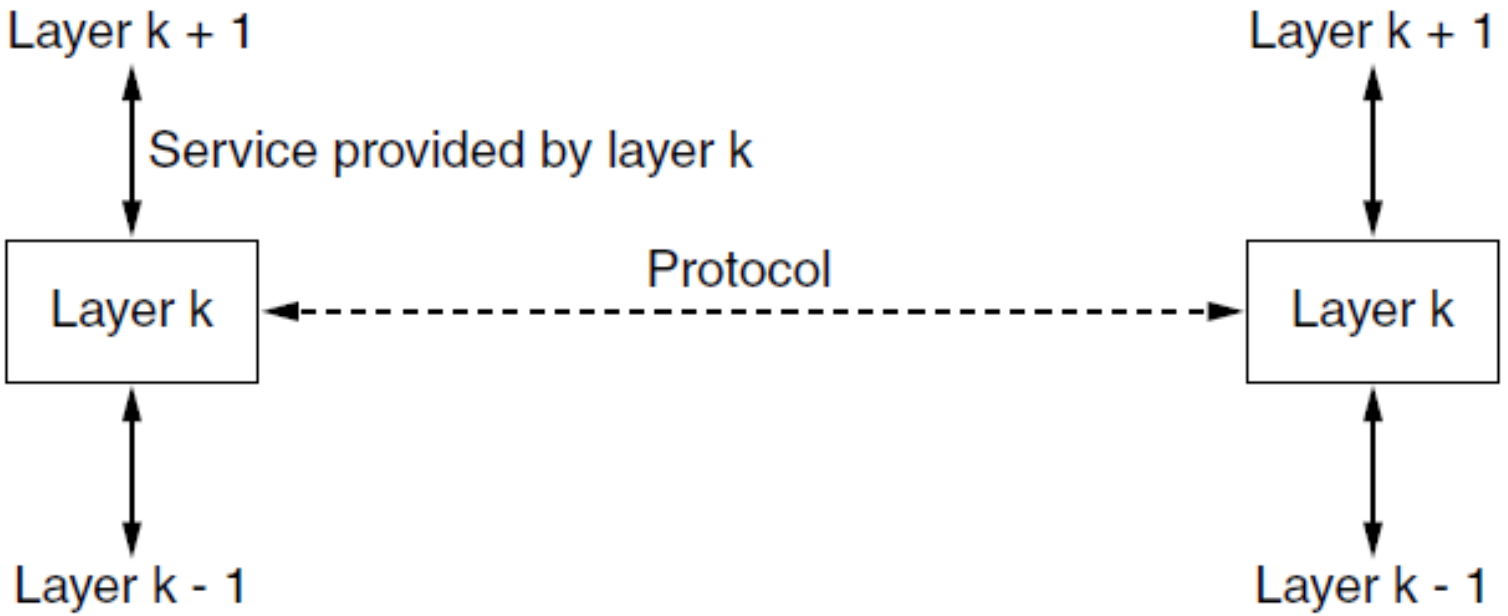

Figure 1-19. The relationship between a service and a protocol.

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Reference Models

- The OSI reference model
  - **The OSI model** is a first step toward international standardization of the protocols used in the various layers.
  - The OSI reference model has **seven** layers.
    - The physical layer
    - The data link layer
    - The network layer
    - The transport layer
    - The session layer
    - The presentation layer
    - The application layer
  - The OSI model itself is **NOT** a network architecture because it does not specify the exact services and protocols to be used in each layer.

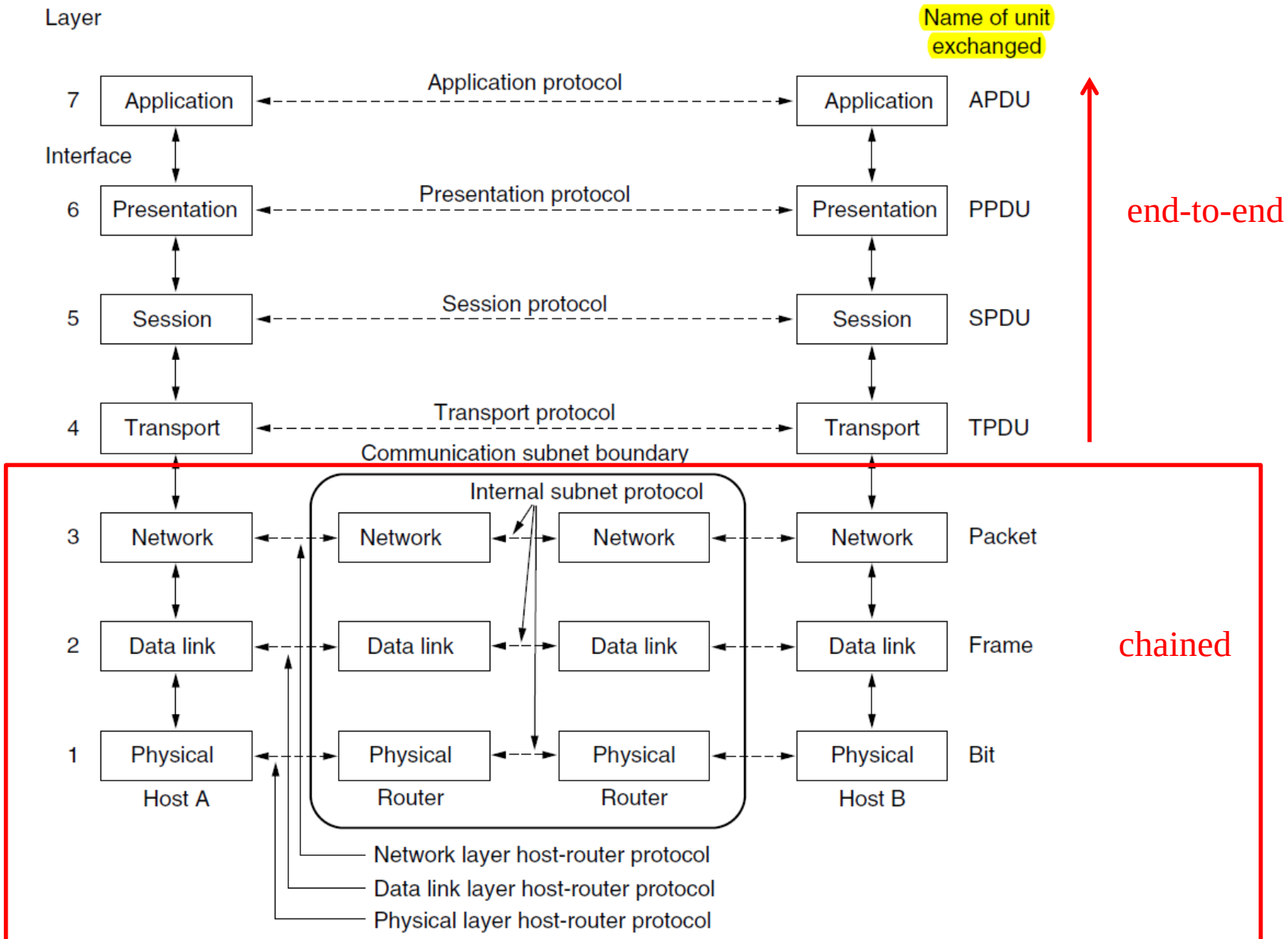

Figure 1-20. The OSI reference model.

The Reference Model: OSI: Physical Layer

- The physical layer
  - The lowest layer in our protocol model, is the foundation on which the network is built.
  - These design issues largely deal with mechanical, electrical, and timing interfaces, as well as the physical transmission medium.
- We will talk about
  - The theoretical basis for data communication (Fourier analysis, bandwidth-limited signals)
  - Physical media fall into three categories: **guided media** (wired, twisted-pair wire, fiber) and **unguided media** (wireless), **satellite**.
  - Digital modulation and multiplexing
    - **TDM**, **FDM**, **CDM**
  - Introduce three typical communication systems: PSTN and mobile phone system, cable network

The Reference Model: OSI: Data Link Layer

- Three main functions of the data link layer
  - Framing: the sender breaks up the input data into data **frames** (typically a few hundred or a few thousand bytes) and transmit the frames sequentially.
  - Error control: error detection and how handle with errors?
  - Flow control: how to keep a faster transmitter from drowning a slow receiver in data.
- Examples of link layer protocols include Ethernet, WiFi and the Point-to-Point Protocol (PPP)
- Broadcast networks have an additional issue in the data link layer: how to control access to the **shared** channel.
  - A special sublayer of the data link layer — **the medium access control** sublayer will deal with this problem.

The Reference Model: OSI: Network Layer

- The Network Layer
  - is concerned with getting packet from source to destination
  - is the lowest layer that deals with end-to-end transmission
- What we will talk about
  - Routing algorithms (Link-state, Distance-vector)
  - Congestion control algorithms
  - Quality of services
  - The Internet protocol: IPv4, IPv6, ICMP
  - Routing in the Internet: OSPF, BGP

The Reference Model: OSI: Transportation Layer

- The transport layer
  - The transport layer is a true end-to-end layer
    - In the lower layers, each protocols is between a machine and its immediate neighbors, and not between the ultimate source and destination machines.
    - The difference between layers 1 through 3, which are chained, and layers 4 through 7 which are end-to-end.
  - Connectionless Transport Protocol: **UDP**
  - Connection-Oriented Transport Protocol: **TCP**

The Reference Model: OSI: Session Layer and Presentation Layer *

- The session layer
  - The session layer offers various services, including dialog control (keeping track of whose turn it is to transmit), token management (preventing two parties from attempting the same critical operation simultaneously), and synchronization (checkpointing long transmissions to allow them to pick up from where they left off in the event of a crash and subsequent recovery)
- The presentation layer
  - The presentation layer is concerned with the syntax and semantics of the information transmitted.
  - To make it possible for computers with different internal data representations to communicate, the data structures to be exchanged can be defined in an abstract way.

The Reference Model: OSI: Application Layer

- The application layer contains a variety of protocols that are commonly needed by users.
  - HTTP (Hyper Text Transfer Protocol) is basis of the World Wide Web.
  - Email (SMTP)
  - File transfer (FTP)

The TCP/IP Reference Model

- Internet's grandpa — the ARPANET (Advanced Research Projects Agency)
  - A research network sponsored by the DoD (U.S. Department of Defense): it eventually connected hundreds of universities and government installations, using leased telephoned lines.
  - When satellite and radio network were added later, the existing protocols had trouble interworking with them, so a new reference architecture was need.
  - One of the major design goals: the ability to connect multiple networks in a seamless way.
  - The DoD wanted connections to remain intact as long as the source and destination machines were functioning.

The TCP/IP Reference Model

- The TCP/IP reference model

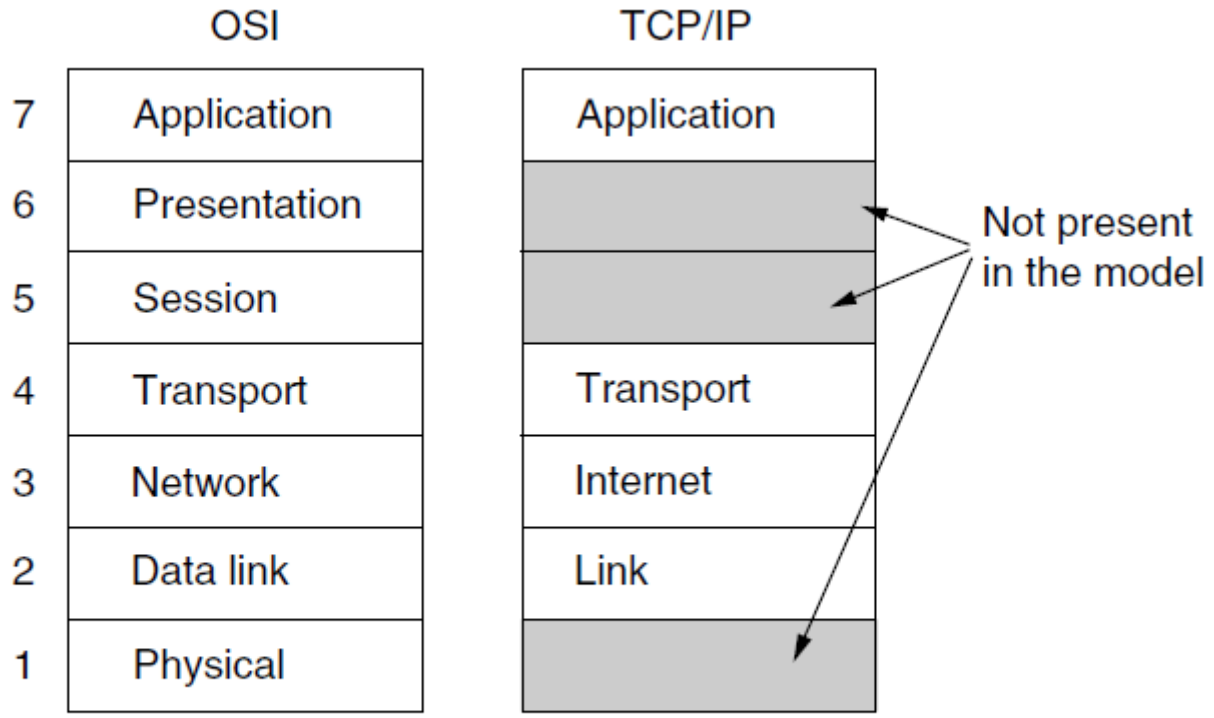

Figure 1-21. The TCP/IP reference model.

The TCP/IP Reference Model (I)

- The link layer
  - It is not really a layer at all, but rather an **interface** between hosts and transmission lines.
  - A **packet-switching** network based on a connectionless layer that runs across different networks.
- The Internet layer
  - As corresponding roughly to the OSI network layer
  - The internet layer defines an official packet format and protocol called **IP** (**Internet Protocol**), plus a companion protocol called **ICMP** (**Internet Control Message Protocol**) that helps it function.
  - The job of the internet layer is to deliver IP packets where they are supposed to go.
    - Packet routing is clearly a major issue here, as is congestion.

The TCP/IP Reference Model (II)

- The transport layer
  - It is designed to allow peer entities on the source and destination hosts to carry on a conversation, just as in the OSI transport layer.
  - Two end-to-end transport protocols
    - **TCP** (**Transmission Control Protocol**) is a *reliable* **connection-oriented** protocol that allow a byte stream originating on one machine to be delivered without error on any other machine in the internet.
      - Segment the incoming byte stream into discrete messages and passes each one on to the internet layer. At the destination, the receiving TCP process reassembles the received messages into the output stream.
      - Flow control
    - **UDP** (**User Datagram Protocol**) is an *unreliable*, **connectionless** protocol
      - It is widely used for one-shot, client-server-type request-reply queries and applications in which prompt delivery is more important than accurately delivery.

The TCP/IP Reference Model (III)

- The application layer
  - Virtual terminal (TELNET)
  - File transfer (FTP)
  - Electronic mail (SMTP)
  - DNS (map host names onto their network address)
  - HTTP
  - RTP (for delivering real-time media such as voice and movies)

The TCP/IP Reference Model (IV)

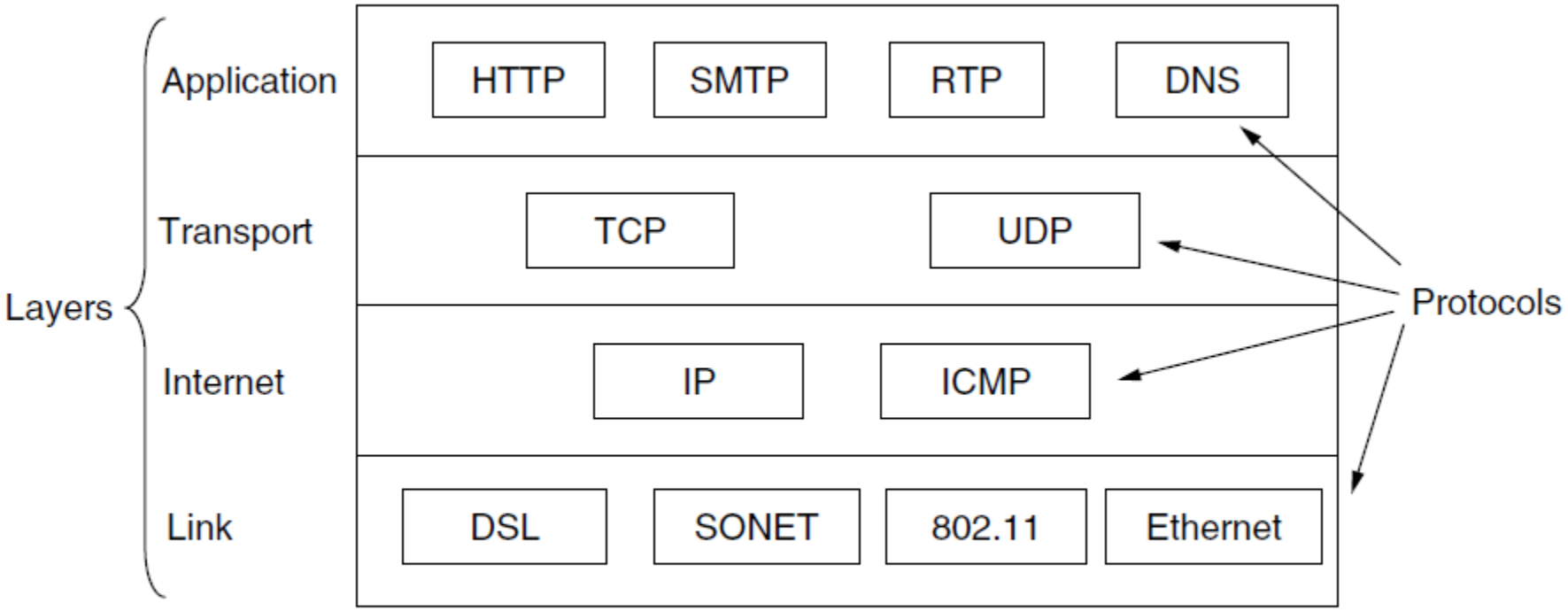

Figure 1-22. The TCP/IP model with some protocols we will study.

The Model Used in This Book

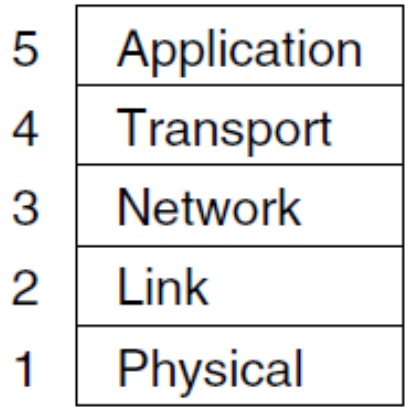

Figure 1-23. The reference model used in this book.

The OSI vs. TCP/IP

- The OSI reference model was devised before the corresponding protocols were invented. While for TCP/IP, the protocols came first, and the model as really just a description of the existing protocols.
- The OSI model supports both connectionless and connection-oriented communication in the network layer, but only connection-oriented communication in the transport layer. **The TCP/IP model supports only one mode in the network layer (connectionless) but both in the transport layer**.

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Standardization

- Standards define what is needed for interoperability: no more, no less.
- Standards fall into two categories: de facto and de jure.
  - De facto (Latin for “from the fact”)
    - HTTP, Bluetooth
  - De jure (Latin for “by law”) — International standardization authorities are generally divided into two classes: those established by treaty among national governments, and those comprising voluntary, non-treaty organizations
    - ISO, ITU (International Telecommunication Union), NIST, IEEE, W3C (World Wide Web Consortium)

Number	Topic
802.1	Overview and architecture of LANs
802.2	Logical link control
802.3 *	Ethernet
802.4 †	Token bus (was briefly used in manufacturing plants)
802.5 †	Token ring (IBM's entry into the LAN world)
802.6 †	Dual queue dual bus (early metropolitan area network)
802.7 †	Technical advisory group on broadband technologies
802.8 †	Technical advisory group on fiber-optic technologies
802.9 †	Isochronous LANs (for real-time applications)
802.10 †	Virtual LANs and security
802.11 *	Wireless LANs (WiFi)
802.12 †	Demand priority (Hewlett-Packard's AnyLAN)
802.13	Unlucky number; nobody wanted it
802.14 †	Cable modems (defunct: an industry consortium got there first)
802.15 *	Personal area networks (Bluetooth, Zigbee)
802.16 †	Broadband wireless (WiMAX)
802.17 †	Resilient packet ring
802.18	Technical advisory group on radio regulatory issues
802.19	Technical advisory group on coexistence of all these standards
802.20	Mobile broadband wireless (similar to 802.16e)
802.21	Media independent handoff (for roaming over technologies)
802.22	Wireless regional area network

WiFi Alliance — Interoperability within the 802.11 standard

The important ones are marked with *. The ones marked with † gave up and stopped.

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Policy, Legal, and Social Issues (1 of 3)

- Online speech
  - Communications Decency Act protects some platforms from federal criminal prosecution
  - DMCA takedown notices (after the Digital Millennium Copyright Act) threaten legal action
- Net neutrality
  - ISPs should provide equal quality of service to a given type of application traffic, regardless of who is sending that content
  - No blocking, no throttling, no paid prioritization, transparency
  - Does not prevent an ISP from prioritizing any traffic
  - Zero rating: ISP might charge its subscribers according to data usage but grant an exemption for a particular service

Policy, Legal, and Social Issues (2 of 3)

- Security
  - DDoS (Distributed Denial of Service) attack
  - Botnets
  - Spam email
  - Phishing
- Privacy
  - Profiling and tracking users by collecting data about their network behavior over time
  - Storing **cookies** in Web browser
  - Browser fingerprinting
  - Mobile services location privacy

Policy, Legal, and Social Issues (3 of 3)

- Disinformation
  - Ill-considered, misleading, or downright wrong information
  - Fake news
  - Challenges
    - How does one define disinformation in the first place?
    - Can disinformation be reliably detected?
    - What should a network or platform operator do about it once it is detected?

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Metric Units

Exp.	Explicit	Prefix	Exp.	Explicit	Prefix
10^{-3}	0.001	milli	10^{3}	1,000	Kilo
10^{-6}	0.000001	micro	10^{6}	1,000,000	Mega
10^{-9}	0.000000001	nano	10^{9}	1,000,000,000	Giga
10^{-12}	0.000000000001	pico	10^{12}	1,000,000,000,000	Tera
10^{-15}	0.000000000000001	femto	10^{15}	1,000,000,000,000,000	Peta
10^{-18}	0.000000000000000001	atto	10^{18}	1,000,000,000,000,000,000	Exa
10^{-21}	0.000000000000000000001	zepto	10^{21}	1,000,000,000,000,000,000,000	Zetta
10^{-24}	0.000000000000000000000001	yocto	10^{24}	1,000,000,000,000,000,000,000,000	Yotta

Figure 1-39. The principal metric prefixes.

Quantitative Metrics of the Performance of Packet-Switching Networks

- **Delay**
  - *Processing delay*: the time required to examine the packet's header and determine where to direct the packet
  - *Queuing delay*: depends on the number of earlier-arriving packets
  - *Transmission delay* (or *the store-and-forward delay*): L(the length of packet in bits)/R(the transmission rate of a link)
  - *Propagation delay* is the distance between two routers divided by the propagation speed.
- **Loss**: in reality a queue preceding a link has finite capacity.
- **Throughput**: depends on the transmission rate of *the bottleneck link* in the network.

WireShark [7]

- **Wireshark** is the world's foremost and widely-used **network protocol analyzer**. It lets you see what's happening on your network at a microscopic level and is **the de facto (and often de jure) standard** across many commercial and non-profit enterprises, government agencies, and educational institutions.

Main Points

- Protocol layer
  - OSI reference model (7 layers: application layer, presentation layer, session layer, transport layer, network layer, link layer and physical layer)
  - The TCP/IP reference model (4 layers: application, transport, internet, link)
  - The reference model used in this book (5 layers: application, transport, network, link, physical)

- The history of the Internet (ARPANET(1969) → NSFNET(1986) → Internet)
  - Leonard Kleinrock (packet-switching 1961-1964)
  - Ray Tomlinson (the 1st email program in 1972)
  - Vinton Cerf and Robert Khan (TCP/IP, 1974)
  - Tim Berners-Lee (Web, 1989)
  - Marc Andreessen (GUI browser Mosaic, 1993)

- The performance metrics of network: *delay*, *loss*, *throughput*.
  - Metric units

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