CPE 490: Information Systems Engineering I: Computer Networking

Chapter 1- Introduction

Professor Du

Department of Electrical and Computer Engineering
Stevens Institute of Technology
Email: xdu16@stevens.edu

Uses of Computer Networks

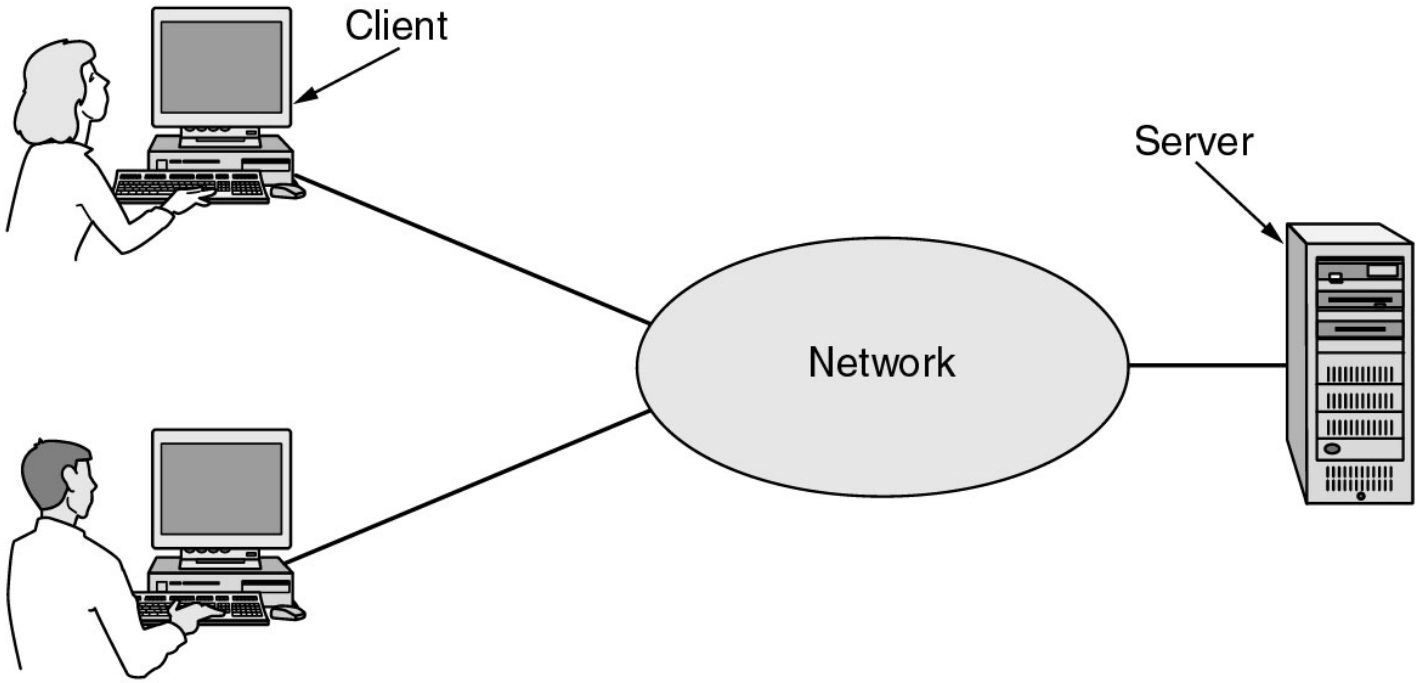
- Why people are interested in Computer Networks?
  - ✓ Sharing Resource – programs, equipment, data, etc.
    - E.g., sharing a printer.
  - ✓ Sharing Information – bank, company, etc.
  - ✓ A powerful communication medium among people.
    - Email, Messenger, Video Conference, Voice over IP, etc.
  - ✓ E-business & E-commerce – doing business with consumers over the Internet.
    - Online stores - books, computers, airline tickets, cars, etc.
    - Online banking.
    - Online auction – eBay, etc.
- What they can be used for?
  - ✓ Business Applications
  - ✓ Home Applications
  - ✓ Mobile Users

The Client – Server Model

- For large companies, the computers and employees may be scattered over dozens of offices and plants in many countries.
  - Remote data access is required.

- The data is stored on powerful computers with network connection – Servers
- Simpler computers used by employees – Clients
- Clients and Servers are connected by a network.

Business Applications of Networks



A network with two clients and one server.

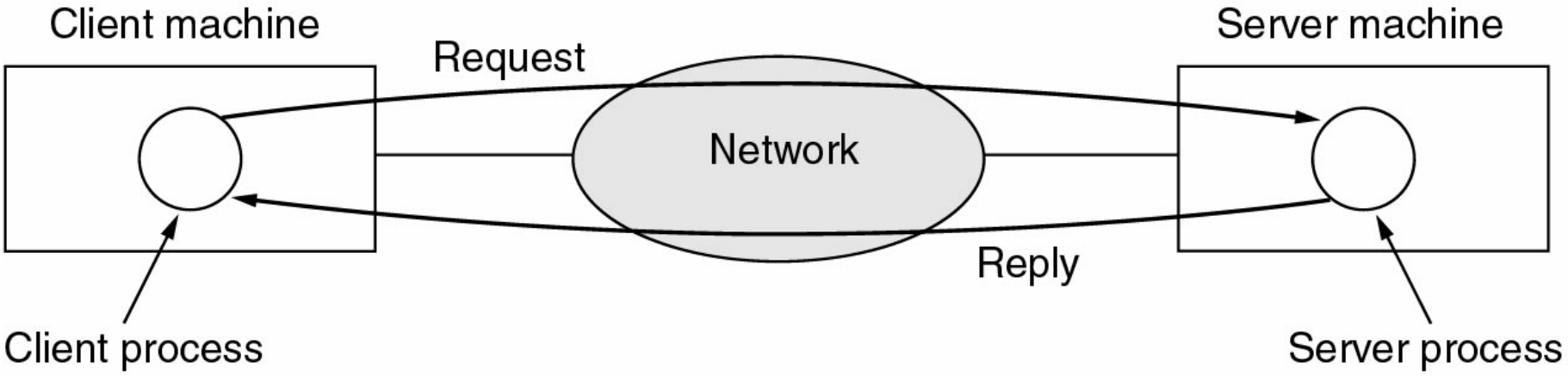
The Client – Server Model

- Two processes:
  - One on client machine – client process.
  - One on server machine – server process.

The communication procedure:

1. Client process sends a message over the network to the server process.
2. Client process waits for a reply message.
3. When the server process gets the request, it performs the requested work and sends back a reply.

Business Applications of Networks (2)



The client-server model involves requests and replies.

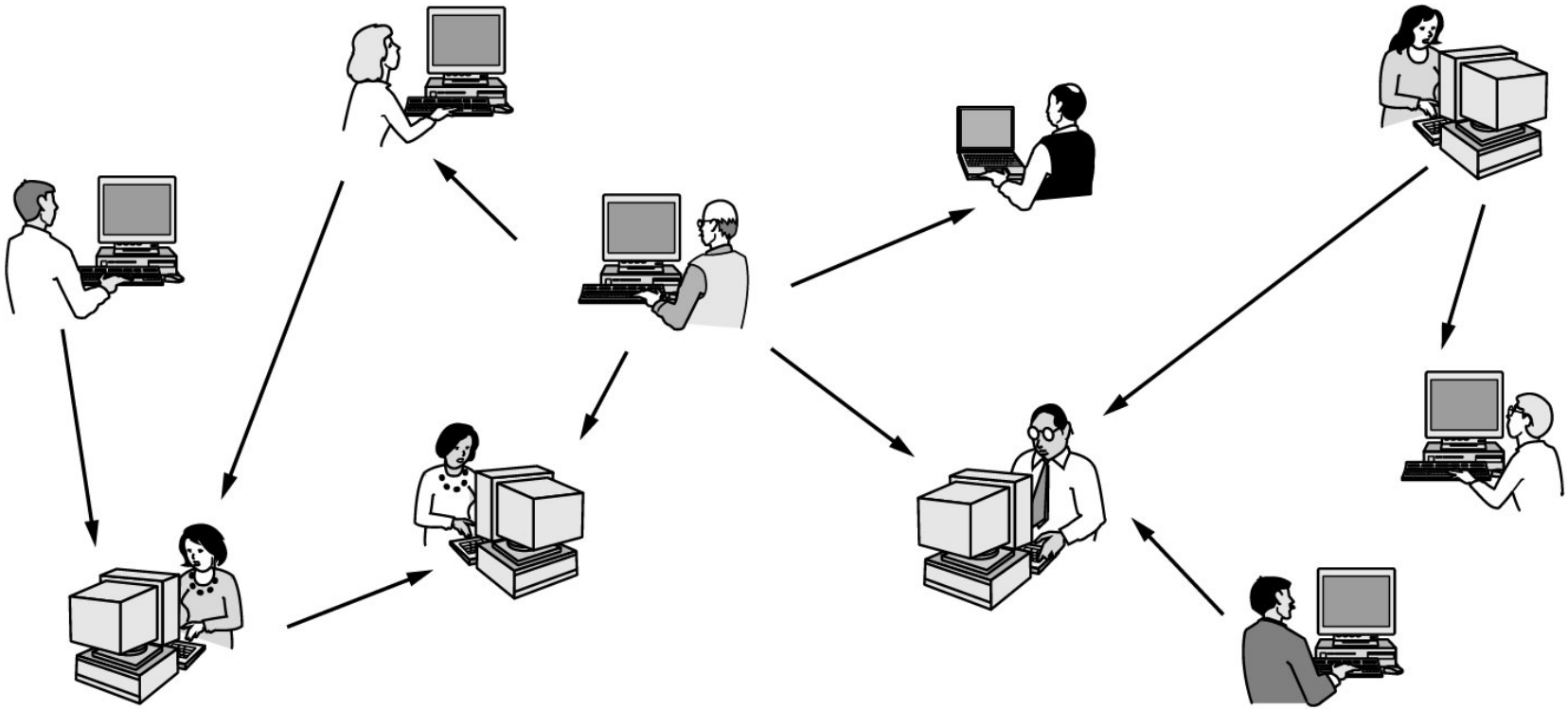
Home Network Applications

- Access to remote information
  - ✓ Web surfing – all kinds of information.
  - ✓ On-line digital library, such as IEEE, ACM.
  - ✓ Interaction between a person and a remote database.
- Person-to-person communication
  - ✓ Email – including text, picture, audio, video.
  - ✓ Instant messaging – Yahoo, MSN, etc.
  - ✓ Chat room – a multi-person version.
  - ✓ Newsgroup – discussion on certain topics.
  - ✓ Peer-to-peer communication (no fixed clients and servers)
    - Napster – with over 50 million music fans swapping music.
    - Families share photos.

Home Network Applications (2)

- Interactive entertainment
  - ✓ Game playing.
  - ✓ Video on demand – select any movie ever made.
- Electronic commerce
  - ✓ Online shopping.
  - ✓ Accessing to financial institutions
    - Paying bill online.
    - Online banking.
    - Online stock trading.
  - ✓ Online auction – second hand goods.

Home Network Applications (3)



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

Home Network Applications (4)

Tag	Full name	Example
B2C	Business-to-consumer	Ordering books on-line
B2B	Business-to-business	Car manufacturer ordering tires from supplier
G2C	Government-to-consumer	Government distributing tax forms electronically
C2C	Consumer-to-consumer	Auctioning second-hand products on-line
P2P	Peer-to-peer	File sharing

Some forms of e-commerce.

Mobile Network Users

- Wireless: Connecting to a network without wire line.
  - Wireless networking access.
- Mobility: Accessing information from various locations.
  - Portable devices, e.g., laptops, cell phones, PDAs.

Wireless	Mobile	Applications
No	No	Desktop computers with wired cable connection
No	Yes	A laptop with wired cable connection
Yes	No	Desktop computers with a wireless card
Yes	Yes	Cell phones

Combinations of wireless networks and mobile computing.

Mobile Network Users

- An example of achieving both wireless and mobility - A PDA used for rental car returning.
- The PDA
  - has a wireless networking card.
  - uses the license plate number of the car as input.
  - accesses the server to obtain rental information.
  - prints out the bill on the spot.
- Other examples.

Network Hardware

Taxonomy of Computer Networks:

Transmission Technology

- ✓ Broadcast links
- ✓ Point-to-point links

Network Scale

- ✓ Home Networks
- ✓ Local Area Networks
- ✓ Metropolitan Area Networks
- ✓ Wide Area Networks
- ✓ Wireless Networks
- ✓ Internetworks

Broadcast Networks

Types of transmission technology

- Broadcast links
  - A single communication channel is shared by all computers in the network.
  - Packets sent by any machine are received by all the others.
  - An address field within the packet specifies the receiver.
  - Broadcasting – transmission to all machines.
  - Multicasting – transmission to a subset of all machines.
- Point-to-point links
  - Point-to-point networks consist of many connections between individual pairs of machines, e.g., Internet.
  - Selecting the route (path) is an issue – routing.
  - Unicasting – Point-to-point transmission with one sender and one receiver.

Computer Networks

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

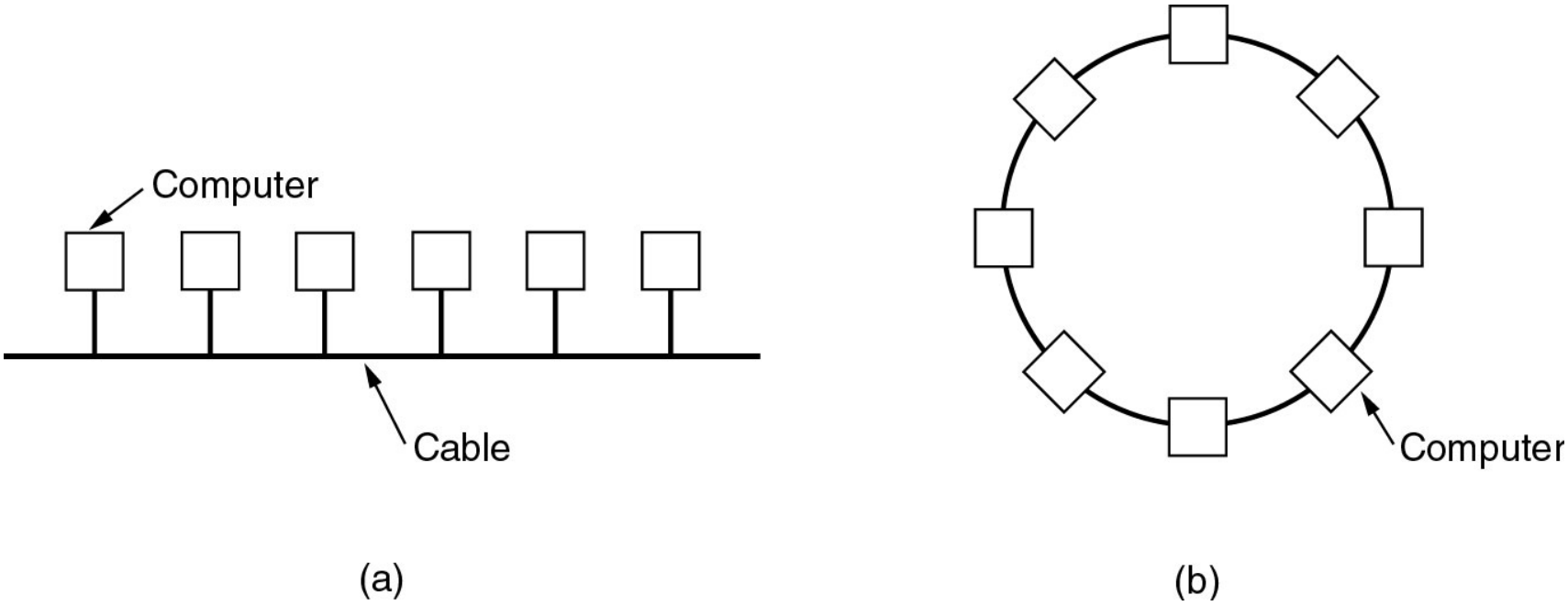
Personal Area Network – e.g., a wireless printer, mouse, keyboard and a computer.

Classification of interconnected processors by scale.

Local Area Networks (LANs)

- LANs are privately-owned networks
  - ✓ Within a single building or campus.
  - ✓ Up to a few miles in size.
- LANs are distinguished from other kinds of networks by three characteristics:
  - ✓ Size
    - LANs are restricted in size.
    - The worst-case transmission time is bounded and known in advance.
  - ✓ Transmission technology
    - Cable – 10 Mbps to 100 Mbps (1 Mbps = 1,000,000 bits/sec).
    - Low delay (microseconds or nanoseconds).
    - Few errors from transmission.
    - New LANs operate at up to 10 Gbps (1 Gbps = 1,000,000,000 bits/sec).
  - ✓ Topology
    - Bus
    - Ring

Local Area Networks



Two broadcast networks

(a) Bus

(b) Ring

Local Area Networks

Two broadcast networks – (a) Bus

- ✓ At any instant at most one machine is the master and is allowed to transmit.
- ✓ An arbitration mechanism is needed to resolve the conflicts
  - when two or more machines want to transmit at the same time.
  - centralized or distributed.
- ✓ The IEEE 802.3 - Ethernet is a bus-based broadcast network with distributed control.
  - 10 Mbps to 10 Gbps.

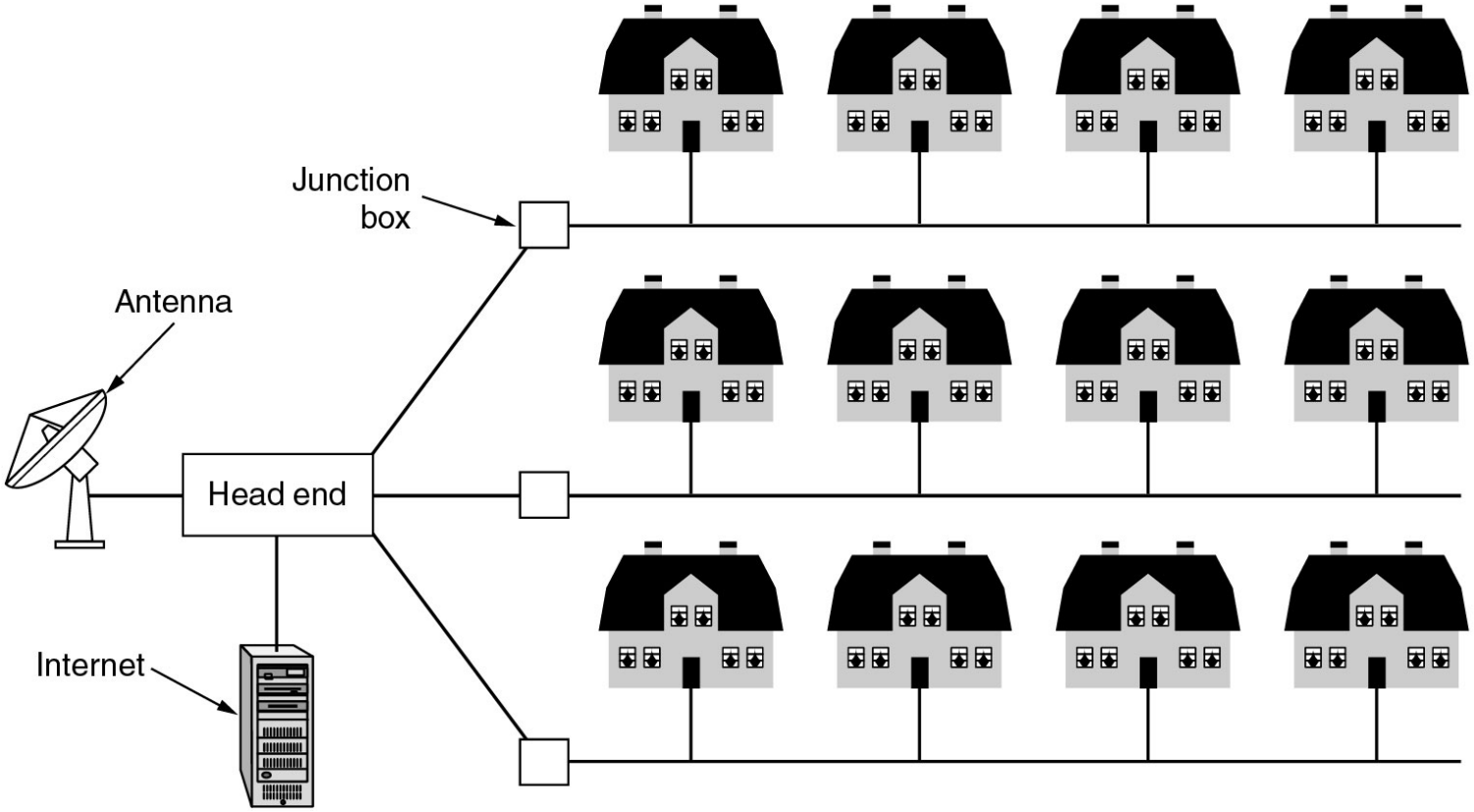
(b) Ring

- ✓ Each bit circumnavigates the entire ring without waiting for the rest of the packet.
- ✓ An arbitration mechanism is needed to resolve the concurrent transmission issue. E.g., round robin – each computer takes turn.
- ✓ IEEE 802.5 – the IBM token ring network.

Metropolitan Area Networks (MANs)

- A Metropolitan Area Network covers a city.
  - ✓ MANS use the cable TV network in many city.
    - E.g., Cable One in Fargo.
  - ✓ The cable TV network can also be used to provide Internet service.
  - ✓ Both TV signals and Internet are fed into the head end.
  - ✓ Another example of MANs
    - High-speed wireless Internet access networks
    - IEEE 802.16 (will be covered in Chap. 2)

Metropolitan Area Networks

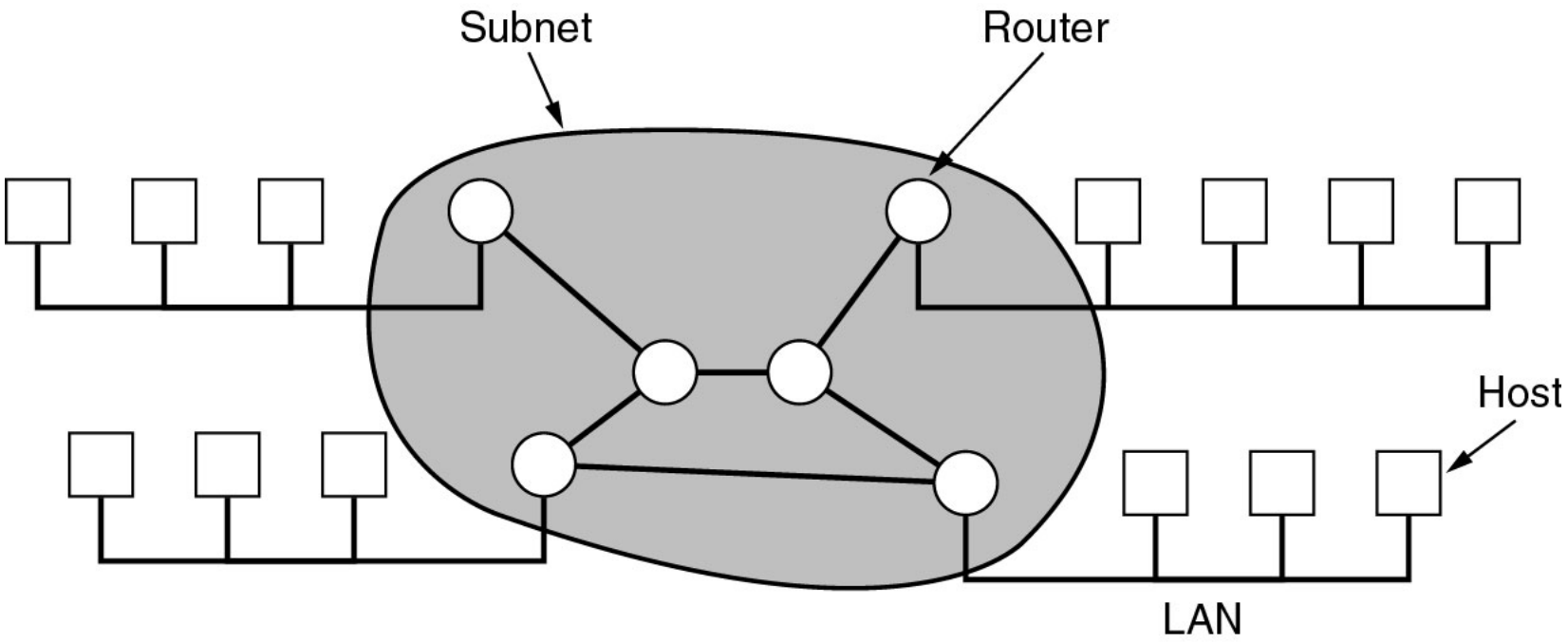


A metropolitan area network based on cable TV.

Wide Area Networks

- A Wide Area Network (WAN) spans a large geographic area.
  - ✓ A country or continent.
  - ✓ A WAN consists of several subnets.
  - ✓ A subnets consists of many computers – hosts.
  - ✓ The hosts are owned by the customers (personal computers).
  - ✓ The subnets are owned by a telephone company or Internet Service Provider (ISP).
  - ✓ The job of a subnet is to carry messages from host to host.
- A subnet consists of two distinct components:
  - ✓ Transmission lines
    - Move bits between computers.
    - Copper wire, optical fiber or radio links.
  - ✓ Switching elements
    - choose path (route) for data transmissions.
    - Specialized devices - routers.

Wide Area Networks

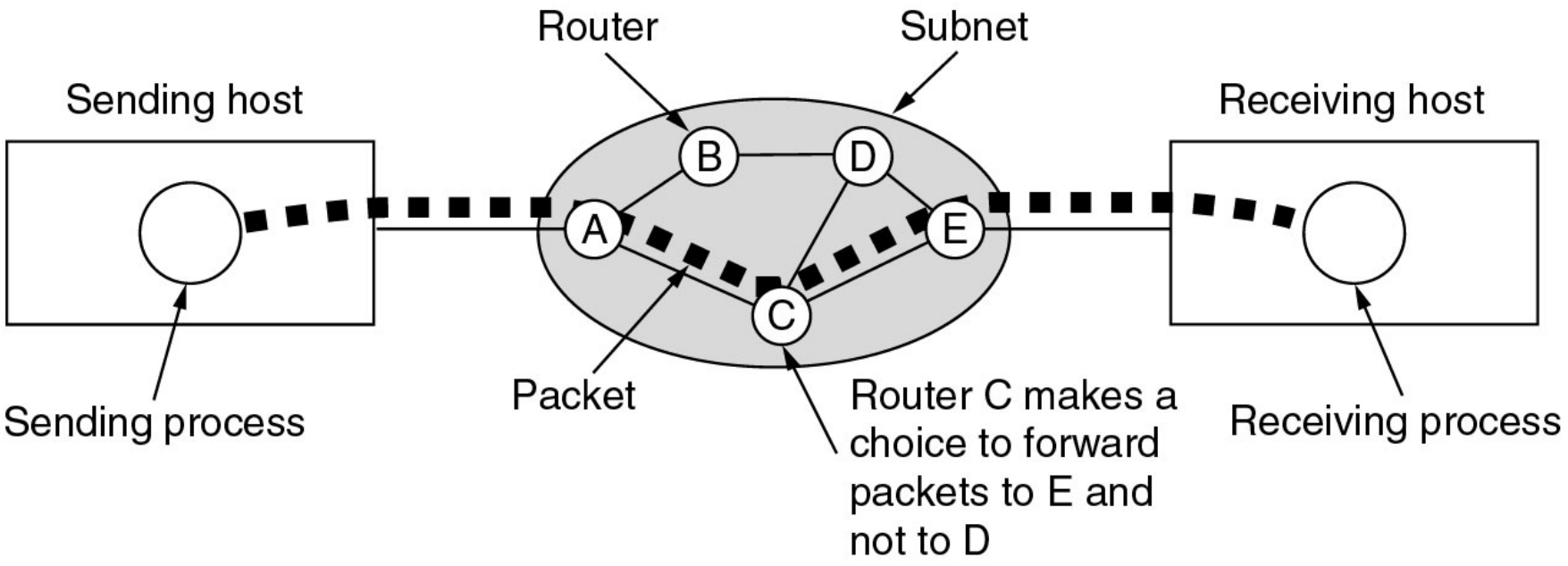


Relation between hosts on LANs and the subnet.

Wide Area Networks

- A packet may travel across several subnets before reaching the destination host.
- The store-and forward (packet switched) subnets are used in most WANs.
  - ✓ A packet is sent from one router to another via several intermediate routers.
  - ✓ The packet is received at each intermediate router in its entirely,
  - ✓ and stored there until the outgoing line is free.
  - ✓ A long message is divided into several packets for transmission.
  - ✓ Packets of the same message may travel via different routes.
  - ✓ Routing algorithms are used to select the route.

Wide Area Networks (2)



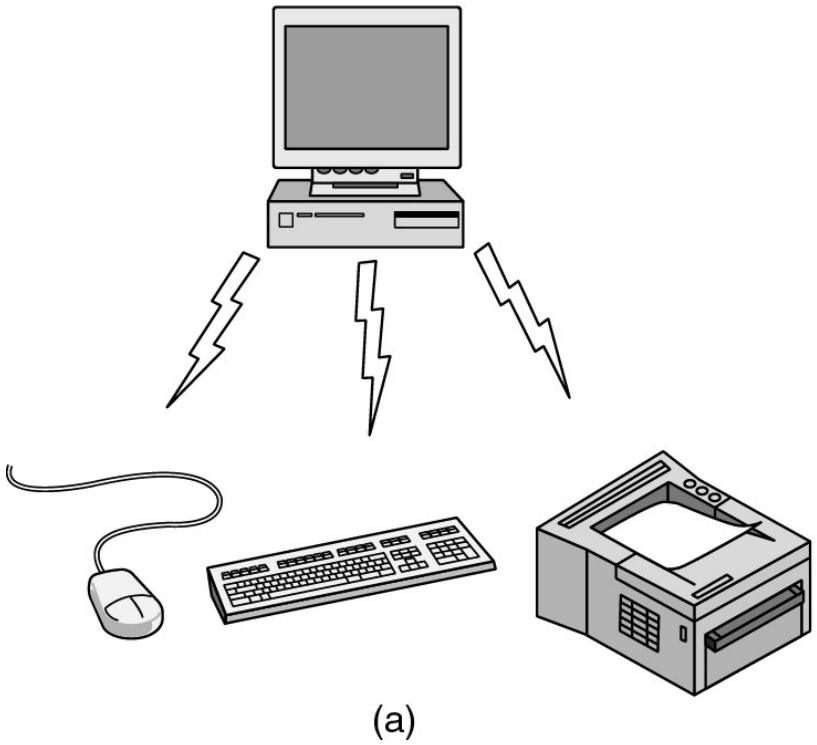
A stream of packets from sender to receiver.

Wireless Networks

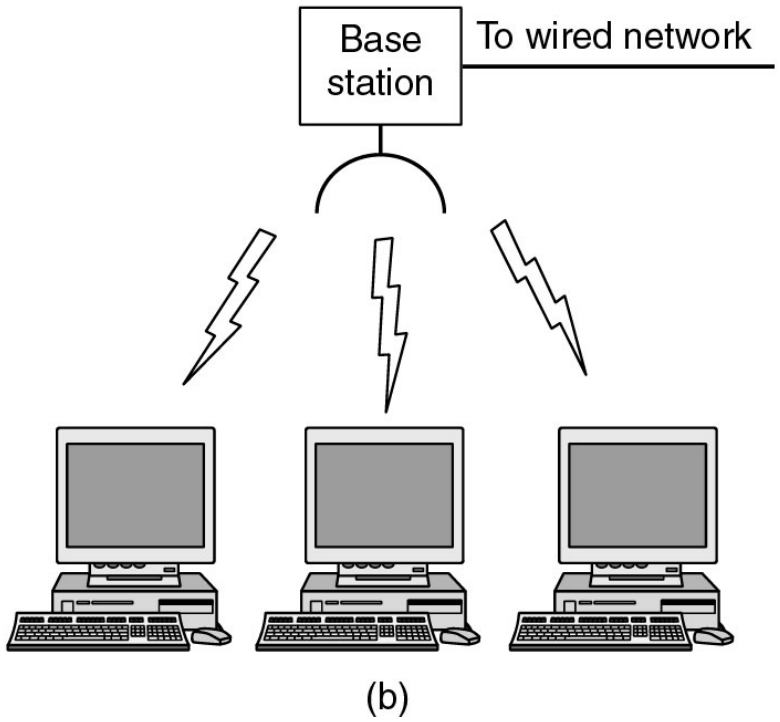
Categories of wireless networks:

- Cellular Networks
  - ✓ Providing cell phone service.
- WLANs (Wireless Local Area Networks)
  - ✓ IEEE 802.11; etc.
- WPANs (Wireless Personal Area Networks)
  - ✓ IEEE 802.15.1 (Bluetooth); 802.15.3; 802.15.4
- WMANs (Wireless Metropolitan Area Networks)
  - ✓ IEEE 802.16; etc.
- Wireless MANETs (Mobile Ad Hoc Networks)
- Wireless Sensor Networks

Wireless Networks (2)

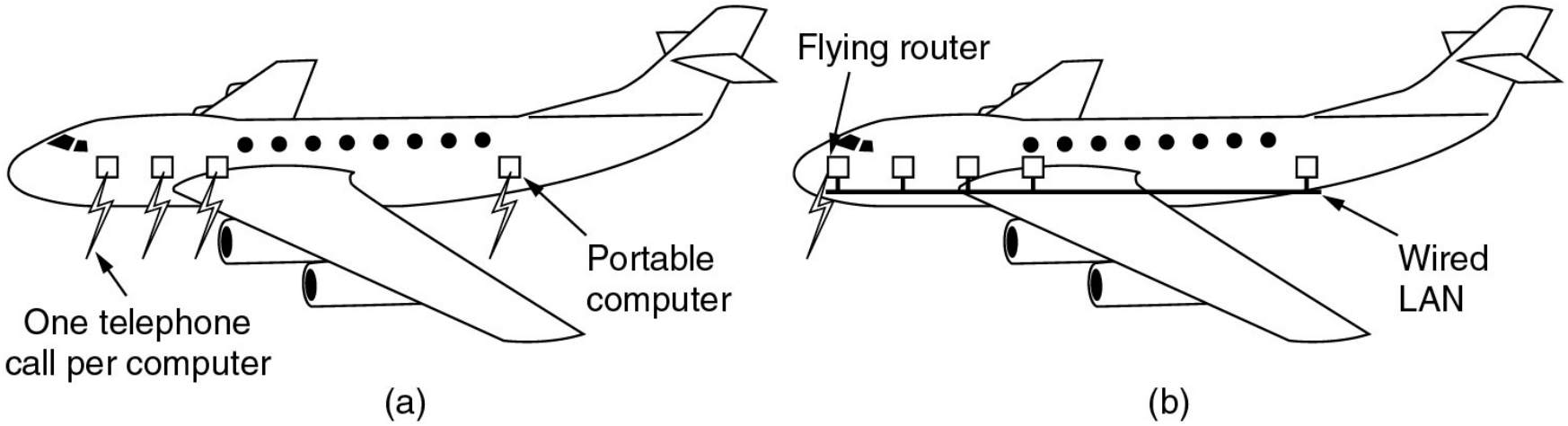


(a) Bluetooth configuration



(b) Wireless LAN

Wireless Networks (3)



(a) Individual mobile computers

(b) A flying LAN

Network Architecture and Software

- Protocol Hierarchies
- Design Issues for the Layers
- Connection-Oriented and Connectionless Services
- Service Primitives
- The Relationship of Services to Protocols

Protocol Hierarchies

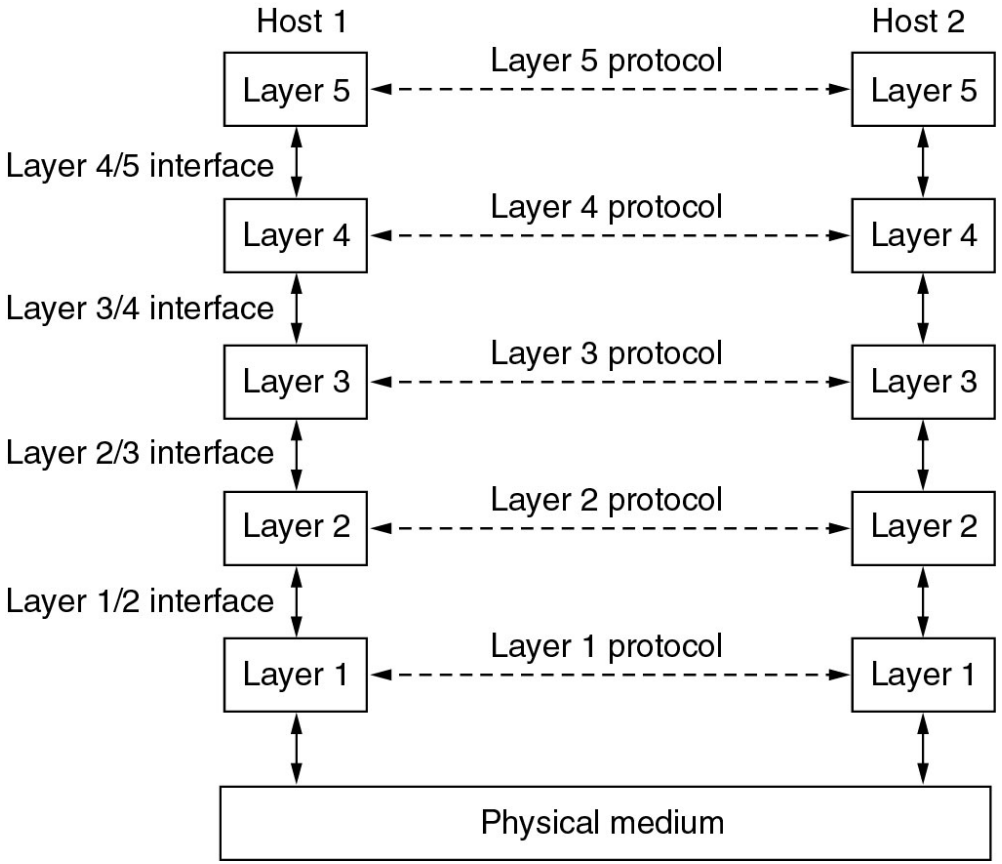
- Today's network software is highly structured.
- To reduce the design complexity, most networks are organized as a stack of layers (levels).
  - ✓ One layer build upon another.
  - ✓ The number of layers, the name, content and function of each layer - differ from network to network.
  - ✓ Each layer offers certain services to the higher layers
    - Shielding those layers from the details of the implementation of the services.
  - ✓ The concept of layering is similar to information hiding, abstract data type, etc.
- A protocol is an agreement between the (two or more) communicating parties on how communication is to proceed.
  - ✓ Behavior protocol – e.g., introducing a woman to a man.

Protocol Hierarchies (2)

The entities comprising the corresponding layers on different machines are called **peers**.

- Processes, hardware devices, or even human beings.
- Peers communicate by using the protocol.
- Dotted line – virtual comm.
- Solid lines – physical comm.
- **An interface** defines the primitive operations and services to the upper layer.
- A clear-cut interface is important.

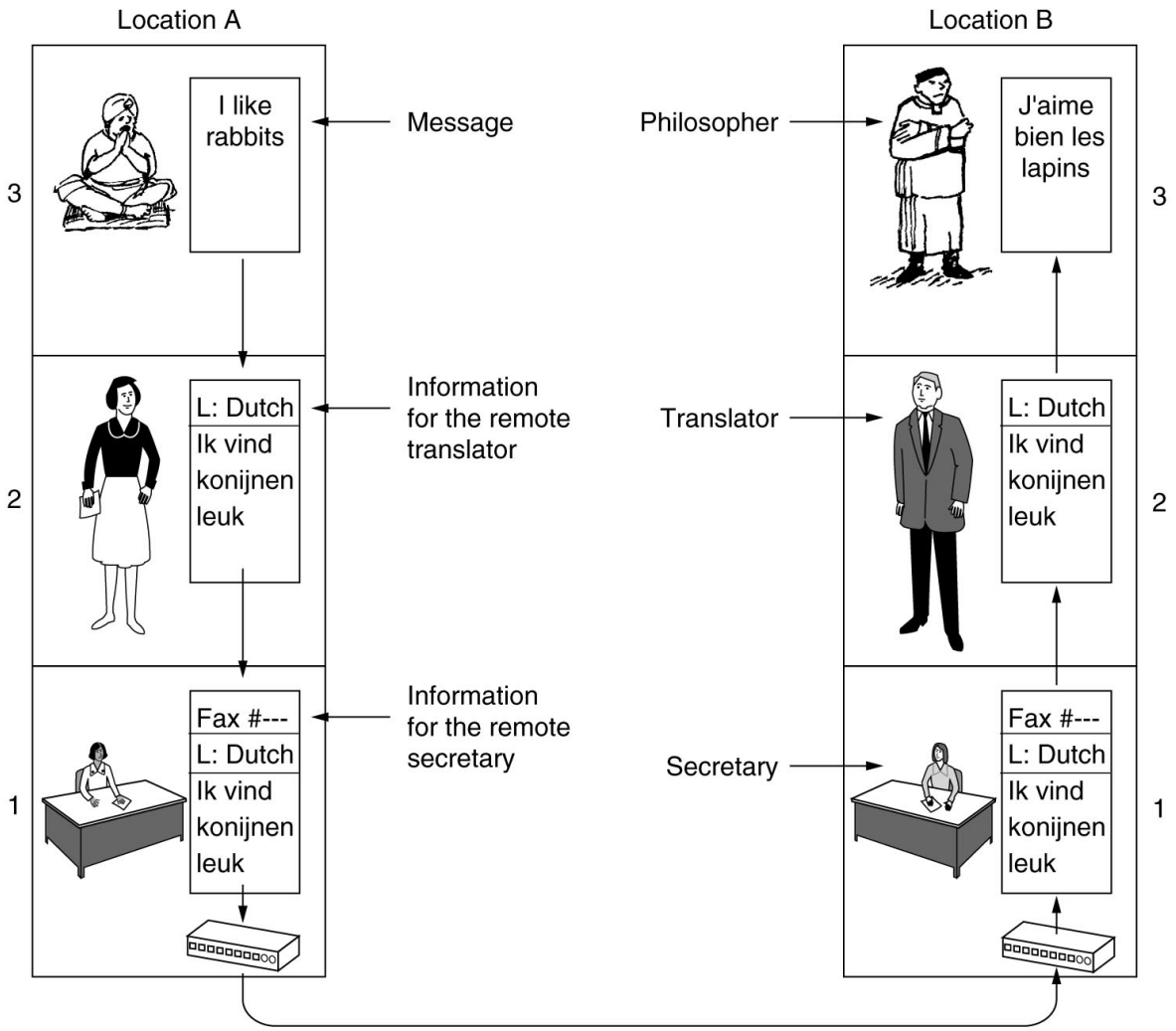
- A set of layers and protocols is called a **network architecture**.



Layers, protocols, and interfaces.

Protocol Hierarchies (3)

The philosopher-translator-secretary architecture.



Protocol Hierarchies (4)

- M - message
- H4 – header

Control info.

E.g., size, timestamp, sequence #, etc.

- Layer 3 breaks down a large message.
- T2 – trailer
- E.g., check sum.

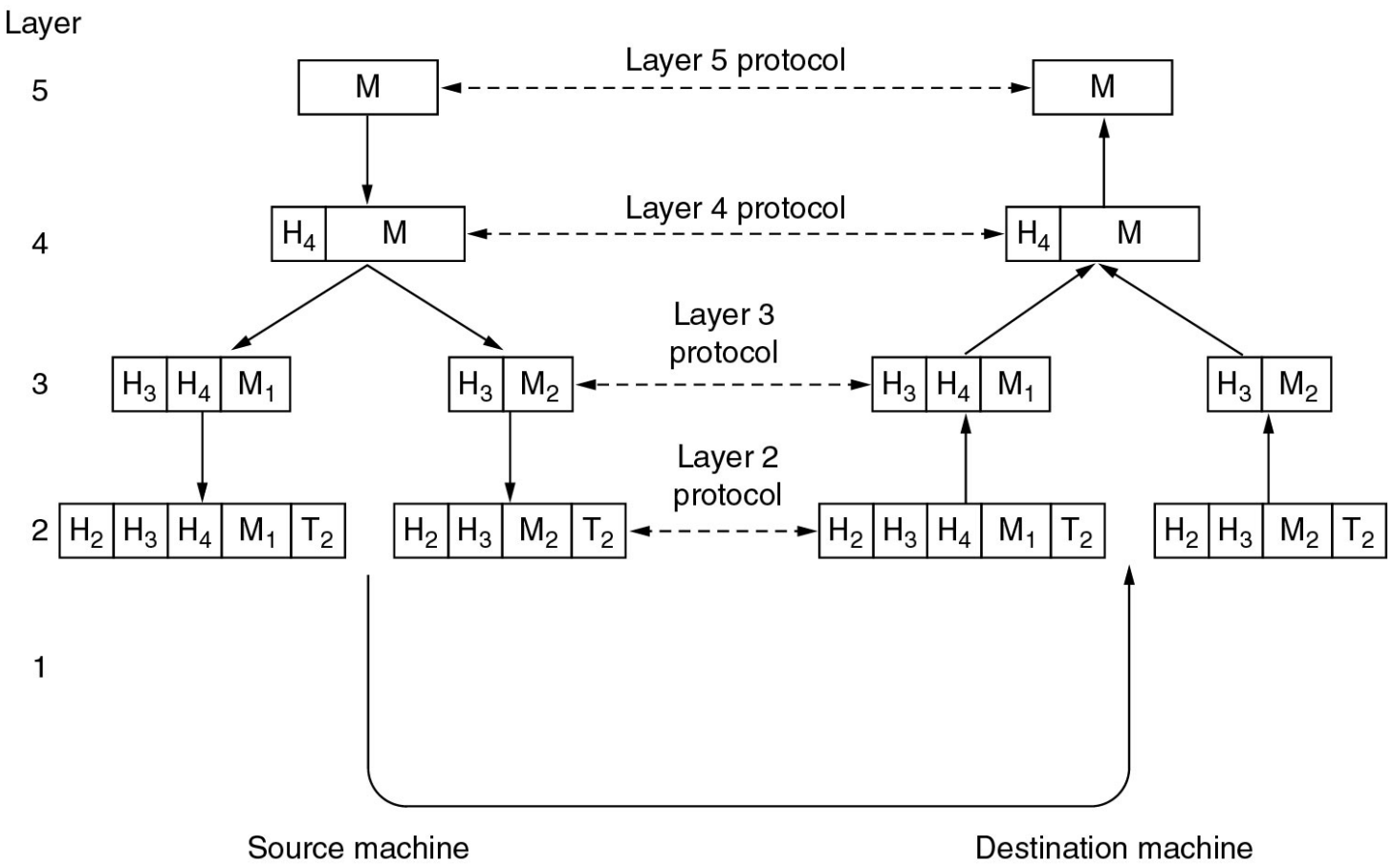


Fig. 1-15: Example information flow supporting virtual communication in layer 5.

Design Issues for the Layers

- Addressing
  - ✓ Every layer needs a mechanism for identifying senders and receivers.
    - To specify a machine or a process.
- Error Control
  - ✓ Physical communication circuits are not perfect.
    - Transmission errors could happen.
- Flow Control
  - ✓ How to keep a fast sender from swamping a slow receiver with data?

Design Issues for the Layers

- Multiplexing
  - ✓ Multiple connections have to be sent over a few physical links.

- Routing
  - ✓ When there are multiple paths between source and destination, a mechanism is needed to choose the route.
  - ✓ Routing protocols – e.g., OSPF, BGP, etc.

Connection-Oriented and Connectionless Services

- Connection-Oriented Services
  - ✓ Modeled after telephone system.
  - ✓ The user first establishes a connection, uses the connection, and then releases the connection.
  - ✓ The sender and receiver can negotiate parameters, such as max. message length, quality of service (QoS).
  - ✓ Reliable Connection-Oriented Services – Using Ack.

Connection-Oriented and Connectionless Services

- Connectionless Services – Datagram Services
  - ✓ No connection needs to be setup
  - ✓ unreliable services – similar to first-class mails.
  - ✓ Acknowledged datagram service
    - with Ack but without connection.
  - ✓ Request – reply service
    - The sender transmits a request.
    - The receiver replies the answer.
    - E.g., database query.

Service Primitives

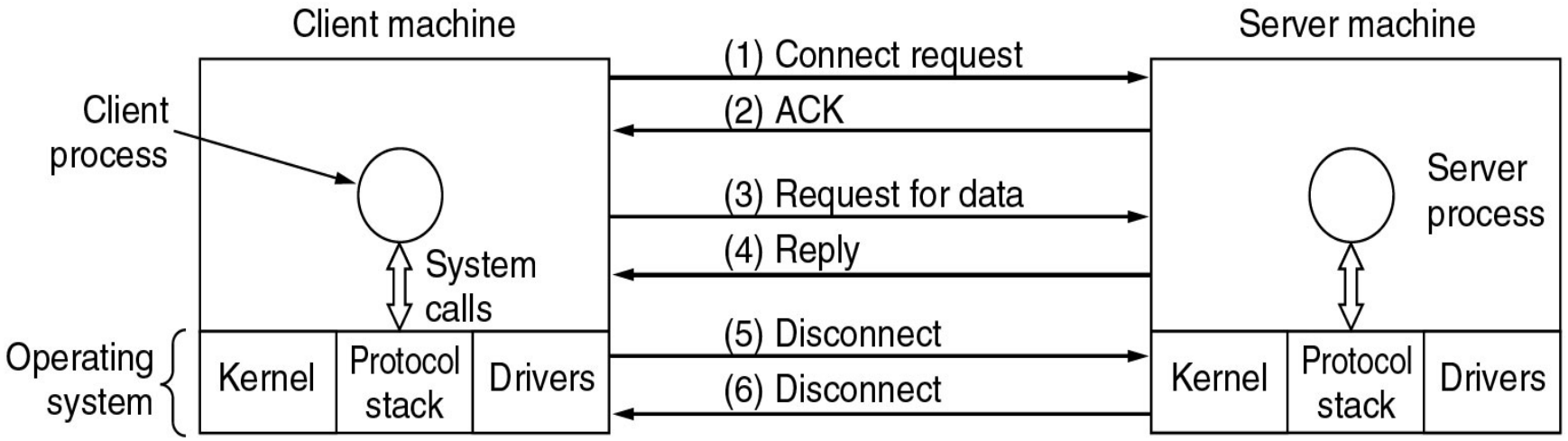
Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

Five service primitives (operations) for implementing a connection-oriented service.

The procedure:

- The server executes LISTEN – The server is blocked until a request for connection appears.
- The client executes CONNECT – to establish a connection.
- The server sends back an Ack.
- The client and server can communicate with each other - SEND, RECEIVE.
- When all the communication is done, the connection is released – DISCONNECT.

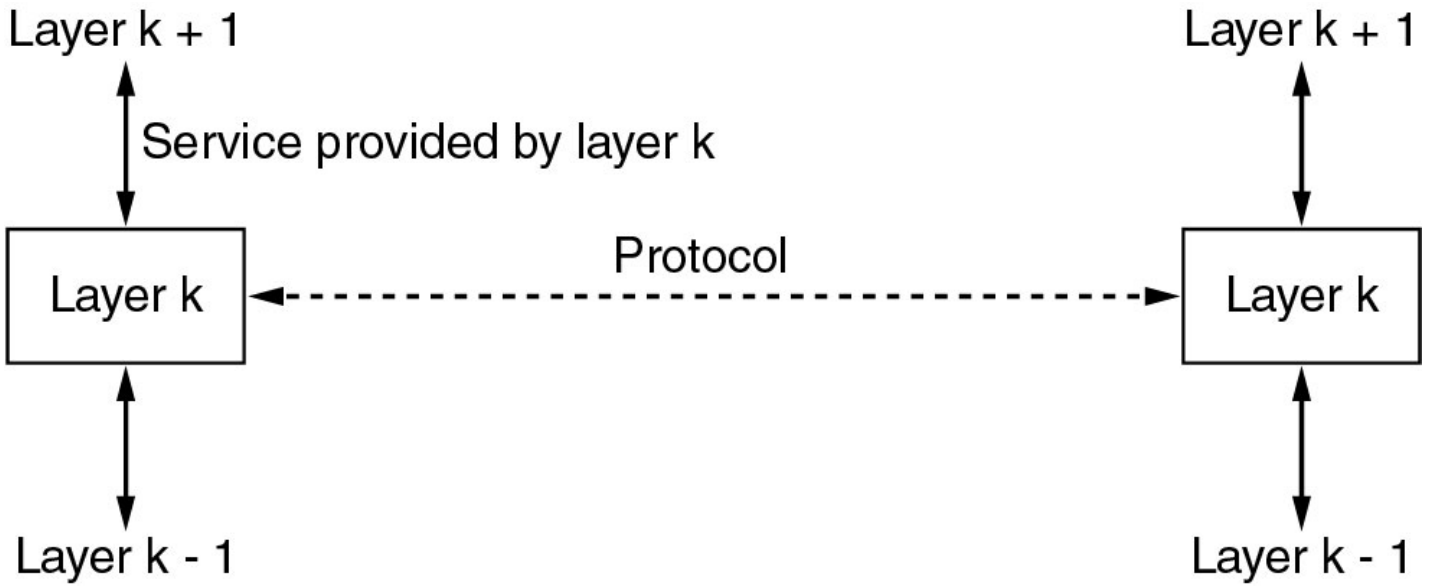
Service Primitives (2)



Packets sent in a simple client-server interaction on a connection-oriented network.

Services to Protocols Relationship

- A service is a set of primitives (operations) that a layer provides to the layer above it.
- A protocol is a set of rules governing the format and meaning of the packets that are exchanged by the peer entities within a layer.



The relationship between a service and a protocol.

Reference Models

- The OSI Reference Model
- The TCP/IP Reference Model
- A Comparison of OSI and TCP/IP
- A Critique of the OSI Model and Protocols
- A Critique of the TCP/IP Reference Model

The OSI Reference Model

- The OSI (Open System Interconnection) Reference Model is
  - ✓ based on a proposal developed by the ISO (International Standards Organization).
- Seven Layers
- The Physical Layer
  - ✓ Transmission of raw bits (1 or 0) over a communication channel.
  - ✓ Design Issues
    - How many volts should be used to represent a 1 (and 0)?
    - Transmission proceed simultaneously in both direction?
    - and so on.

The OSI Reference Model

- The Data Link Layer
  - ✓ Providing services to the Physical and Network Layers
    - To transform a raw transmission facility into a line that appears free of undetected transmission errors to the network layer
    - Having the sender break up the input data into data frames
    - A typical data frames ranges from a few hundred to thousand bytes.
    - If the service is reliable, the receiver sends back ACK frame.
  - ✓ Error Control
    - ✓ Detecting and correcting transmission errors.
  - ✓ Flow Control
    - How to keep a fast transmitter from drowning a slow receiver?
  - ✓ Medium Access Control
    - For broadcast networks.

The OSI Reference Model

- The Network Layer
  - ✓ The Network Layer controls the operation of the subnet.
  - ✓ The inter-connection of heterogeneous networks (subnets).
    - The addressing, the lower layer protocols may differ.
  - ✓ Routing
    - How packets are routed from source to destination?
    - Routes can be based on static tables, or determined dynamically.
  - ✓ Congestion Control
    - Congestion happens when too many packets are present in a subnet at the same time.
  - ✓ Quality of Service
    - Delay, bandwidth, jitter, etc.

The OSI Reference Model

- The Transport Layer
  - ✓(sender) accepts data from above, and splits it into smaller units if needed, then passes them to the network layer,
  - ✓(receiver) ensures the pieces all arrive correctly at the other end.
  - ✓is a true end-to-end layer – between source and destination.
  - ✓In the lower layers, the protocols are between neighbor machines.
- The Session Layer
  - ✓Allows users on different machines to establish sessions.
  - ✓Session services
    - •Dialog control – keeping track of whose turn it is to transmit.
    - •Token management – preventing two parties from attempting the same critical operation at the same time.
    - •Synchronization – Checkpointing long transmissions to allow them to continue from where they were after a crash.

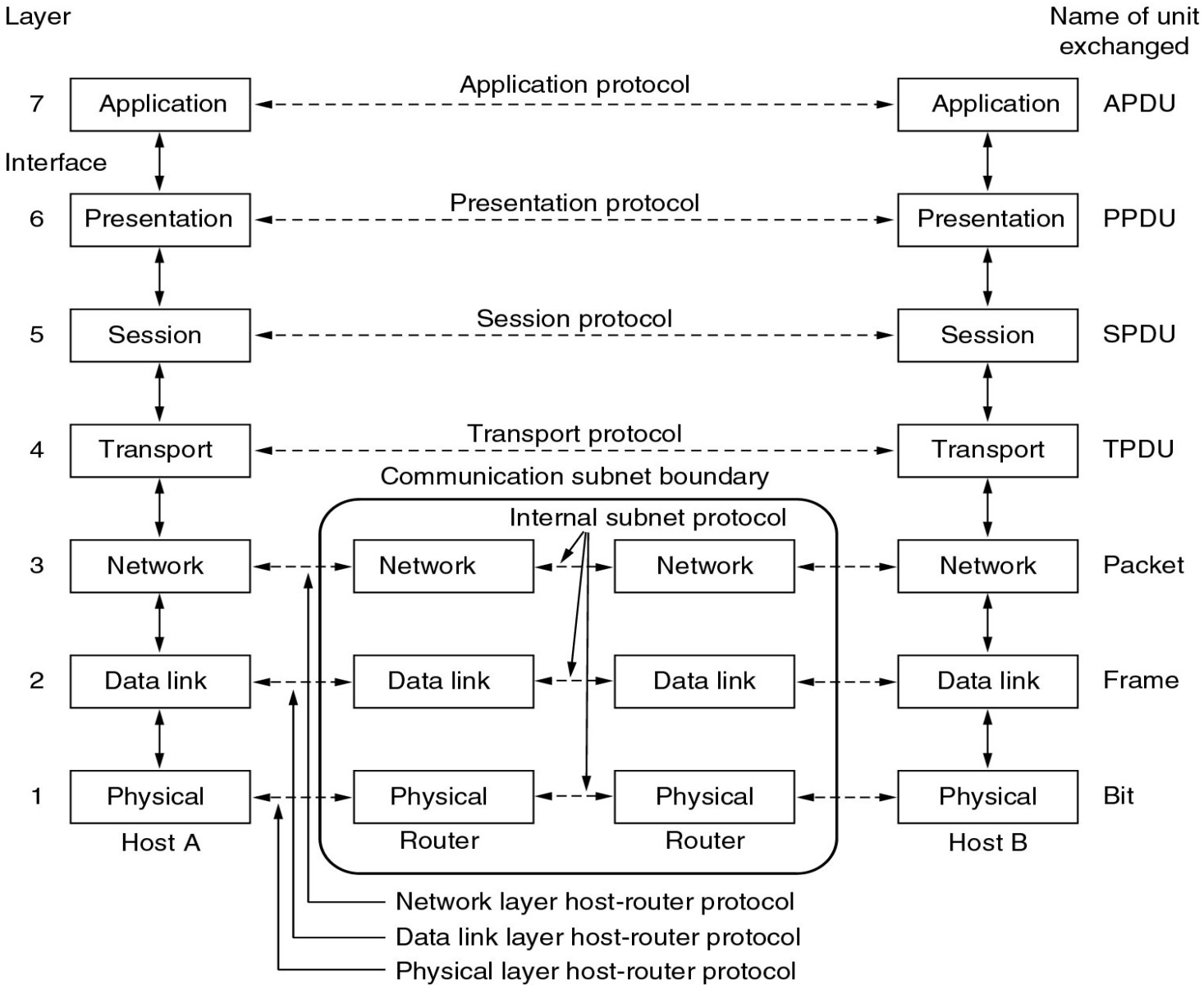
The OSI Reference Model

- The Presentation Layer
  - ✓ is concerned with the syntax and semantics of the information transmitted.
  - ✓ manages abstract data structures
    - To make it possible for computers with different data representations to communicate.
  - ✓ allows higher-level data structures (e.g. banking records) to be defined and exchanged.
- The Application Layer
  - ✓ contains a variety of commonly-used protocols, such as
    - HTTP (HyperText Transfer Protocol) - WWW.
    - FTP – file transfer.
    - SMTP - email.

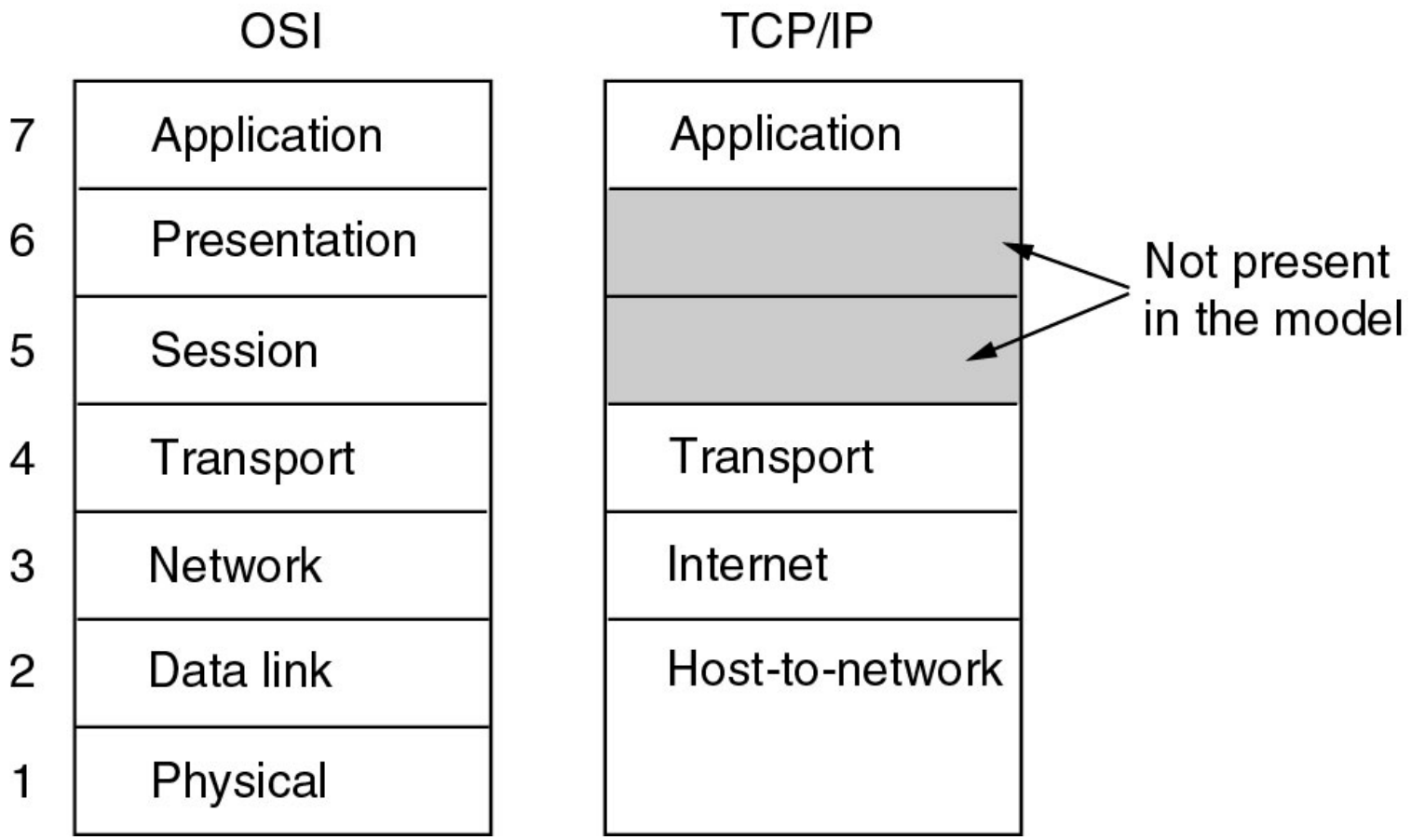
Reference Models

The OSI reference model.

• PDU – Protocol Data Unit.



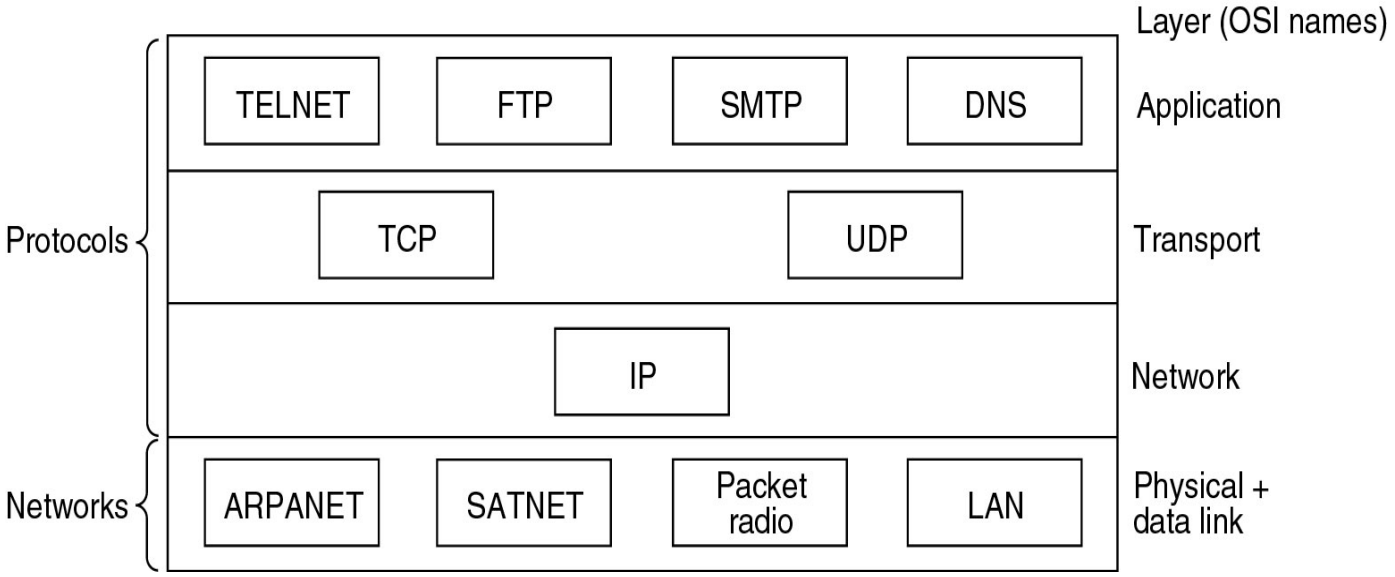
Reference Models (2)



The TCP/IP reference model.

The TCP/IP Reference Model

- ARPANET
  - ✓ A research network sponsored by the DoD.
  - ✓ Connected hundreds of univ. and government networks using leased telephone lines.
  - ✓ A new architecture was needed – TCP/IP Reference Model
    - when satellite and radio networks were added.



Protocols and networks in the TCP/IP model initially.

The TCP/IP Reference Model

- One major design goal was that
  - ✓ Connections remain intact as long as the source and destination machines were functioning
    - even if some machines or transmission lines in between were down.
- The Host-to-Network Layer
  - ✓ The TCP/IP model does not specify this layer.
- The Internet Layer
  - ✓ A packet-switching network based on a connectionless layer.
  - ✓ defines an official packet format and protocol – IP (Internet Protocol).
  - ✓ delivers IP packets.
  - ✓ is similar in functionality to the OSI network layer.

The TCP/IP Reference Model

- The Transport Layer
  - ✓ TCP (Transmission Control Protocol).
    - A reliable connection-oriented protocol.
    - It fragments the incoming byte stream into fixed-size packets and passes them to the internet layer.
    - TCP also handles flow control and congestion control.
  - ✓ UDP (User Datagram Protocol).
    - An unreliable, connectionless protocol.
    - UDP is widely used for applications in which prompt delivery is more important than accurate delivery, e.g., speech and video.
- The Application Layer
  - ✓ contains a variety of higher-layer protocols, such as
    - TELNET – remote login, virtual terminal.
    - DNS (Domain Name System) – mapping host names onto IP addresses.

Comparing OSI and TCP/IP Models

Concepts central to the OSI model

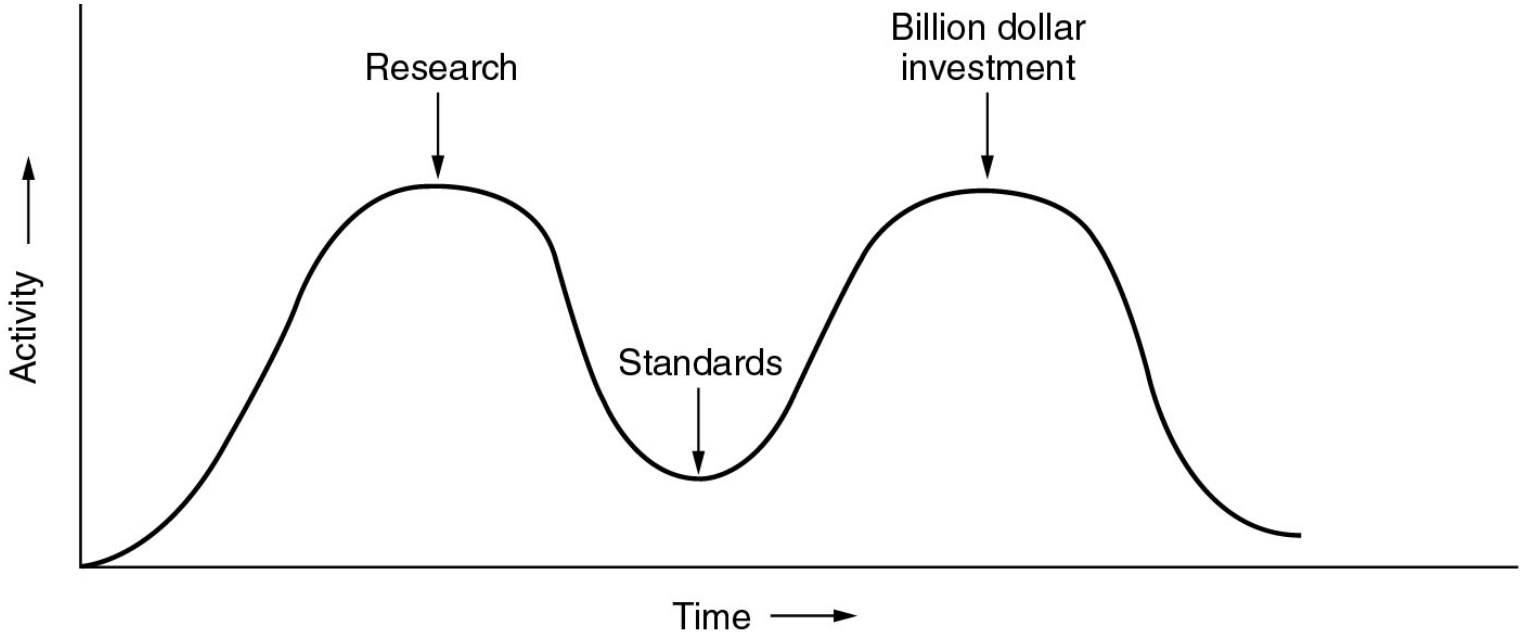
- Services
- Interfaces
- Protocols

A Critique of the OSI Model and Protocols

Why OSI did not take over the world?

- Bad timing
  - ✓ The competing TCP/IP protocols were already in wide use by research univ. by the time OSI protocols appeared.
- Bad technology
  - ✓ Both the model and protocols are flawed.
  - ✓ Seven layers was more political than technical
    - The session and presentation layers are nearly empty.
- Bad implementations
  - ✓ The OSI model is too complex.
    - Difficult to implement and inefficient in operation.
  - ✓ While the 1st implementation of TCP/IP was
    - part of Berkeley UNIX
    - good and free.
- Bad politics
  - ✓ Government bureaucrats pushed the standard down to researchers.

Bad Timing



- If the standards are written too early, before the research is finished, the subject may still be poorly understood.
- If the standards are written too late, so many companies may have already made major investments, and the standards are ignored.

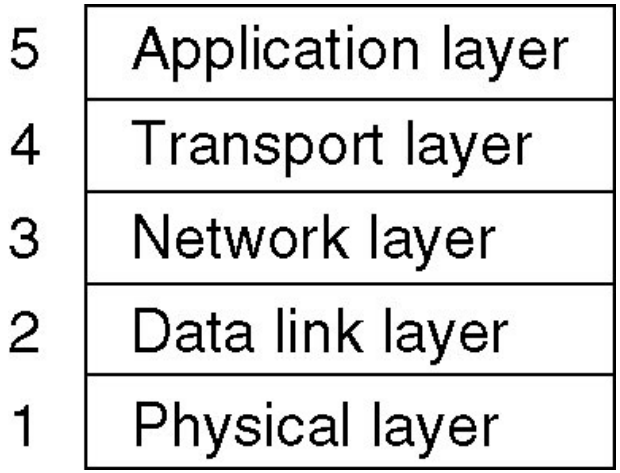
The apocalypse of the two elephants.

A Critique of the TCP/IP Reference Model

Problems:

- Service, interface, and protocol not distinguished
- Not a general model
- Host-to-network “layer” not really a layer
- No mention of physical and data link layers
- Minor protocols deeply entrenched, hard to replace

Hybrid Model

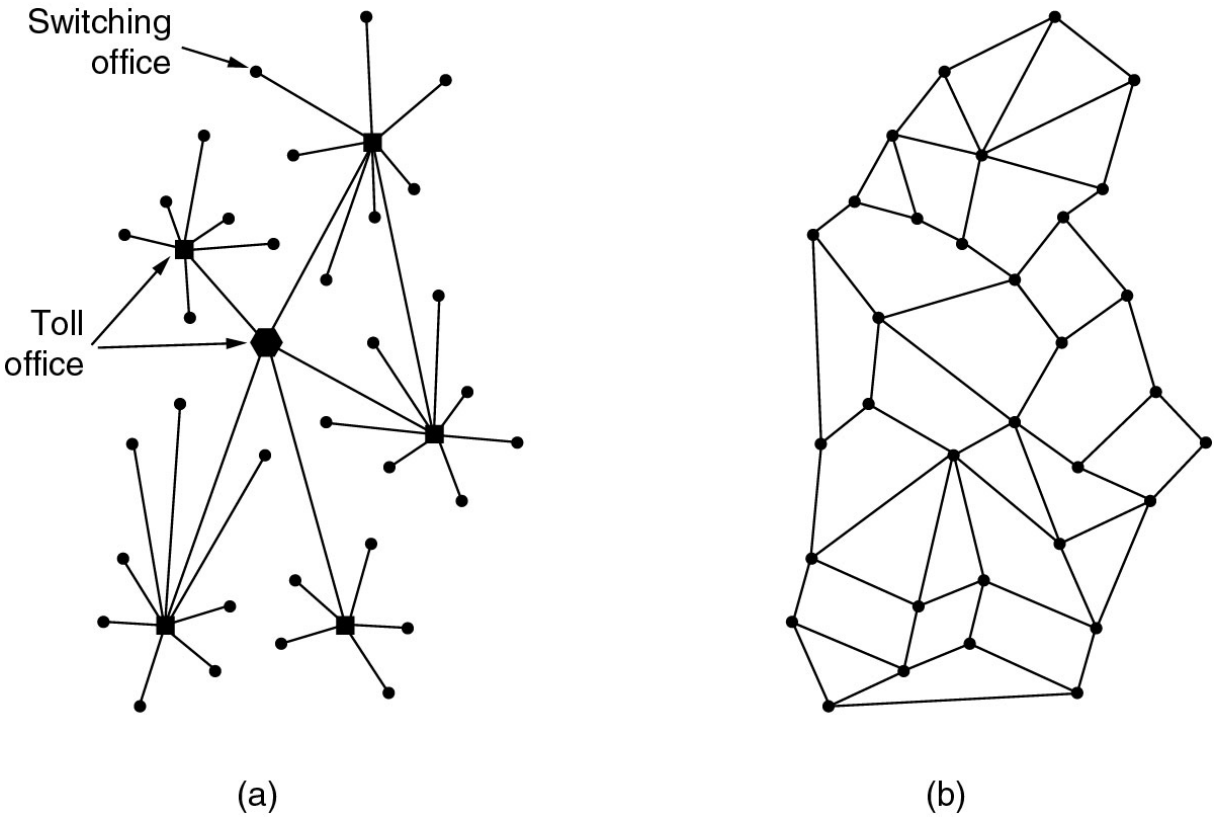


The hybrid reference model to be used in this book.

Example Networks

- The Internet
  - ARPANET
  - NSFNET
- Connection-Oriented Networks:
  - X.25
    - The first public data network – based on telephone systems.
    - A computer first places a telephone call to set up connection with a remote computer.
    - A data packet has a 3-byte header + up to 128 bytes of data.
  - Frame Relay
    - Replaced X.25 in the 1980s.
    - without error control and flow control.
    - Packets were delivered in order.
    - It is still in use in places today.
  - ATM (Asynchronous Transfer Mode)
- Ethernet
- Wireless LANs: 802.11

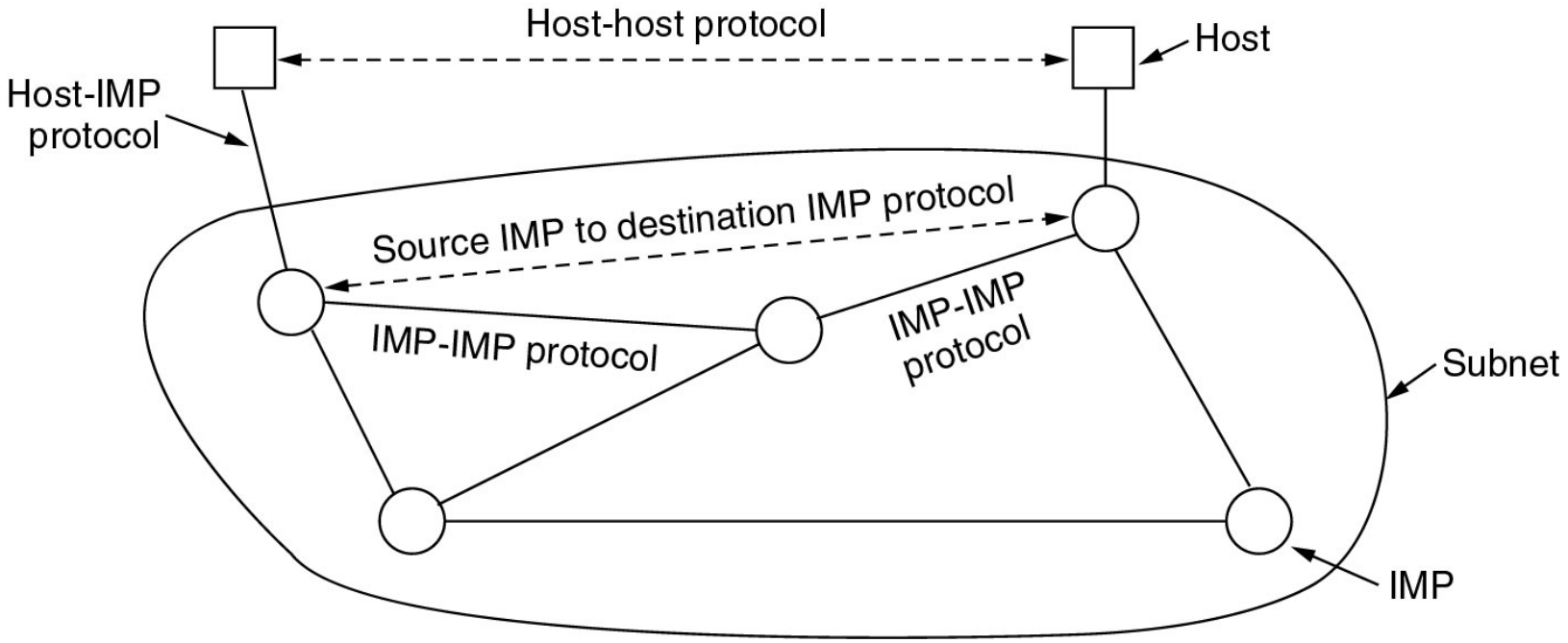
The ARPANET



(a) Structure of the telephone system.

(b) Baran's proposed distributed switching system.

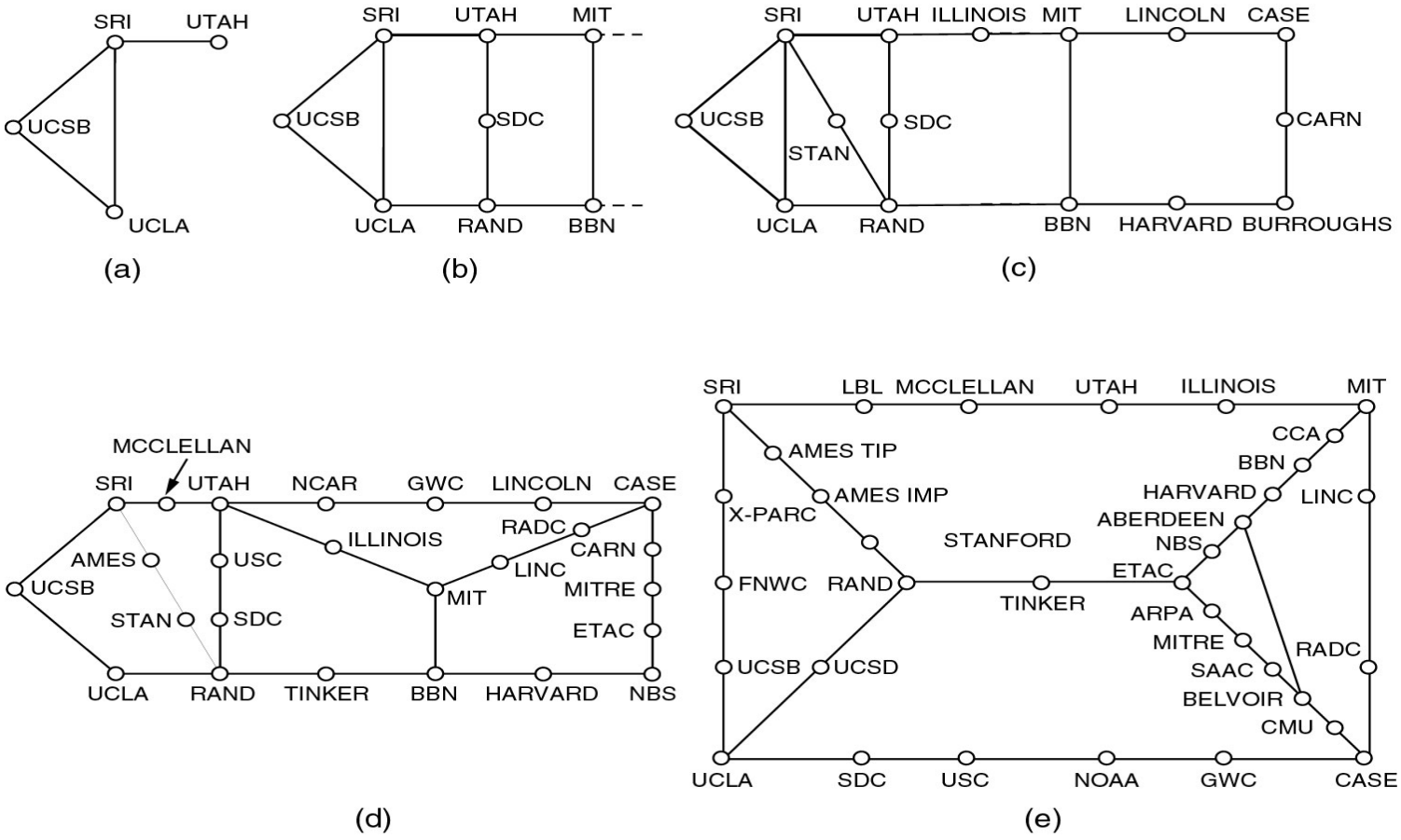
The ARPANET (2)



The original ARPANET design.

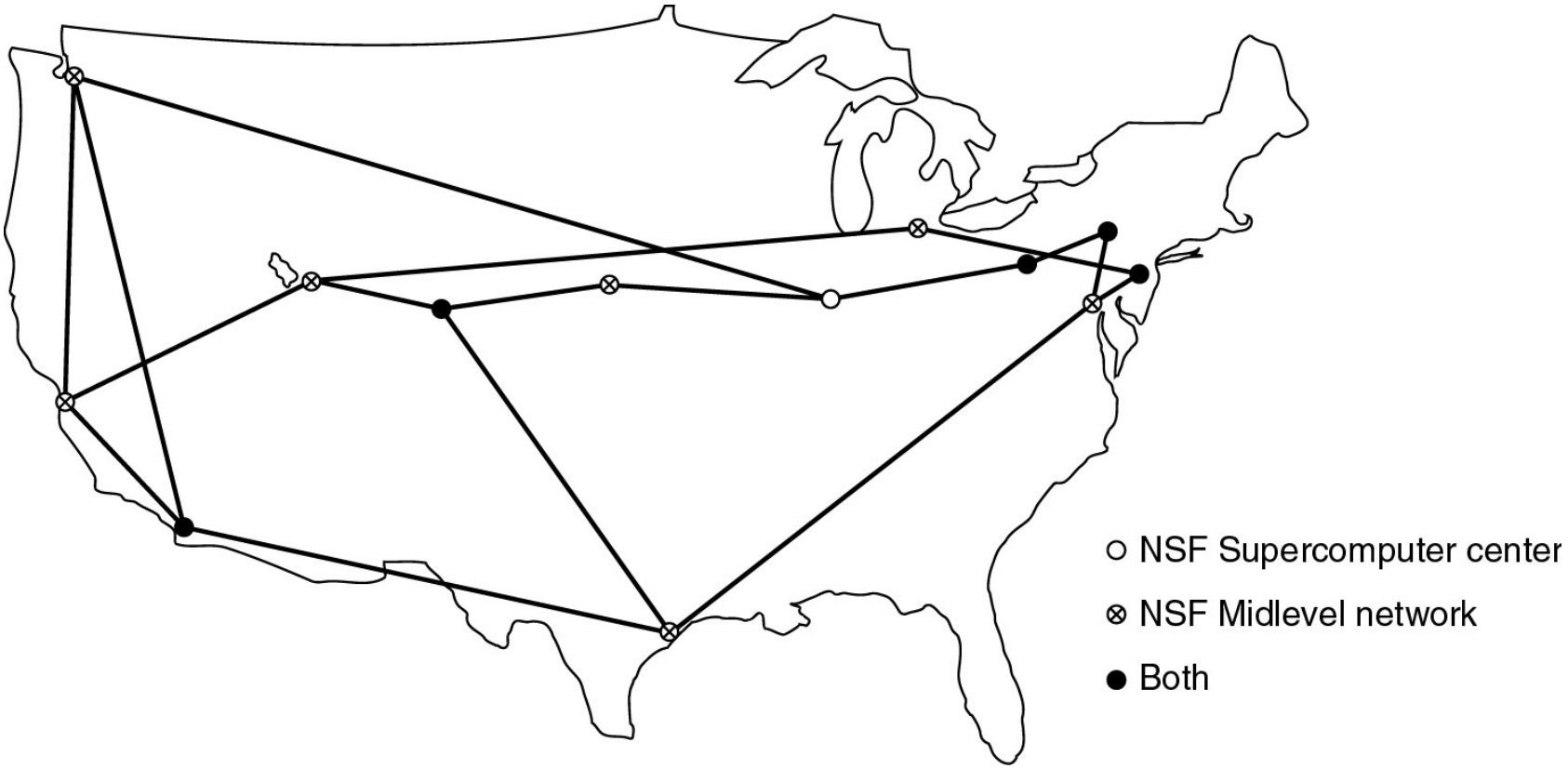
IMP (Interface Message Processors) – minicomputers.

The ARPANET (3)



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

NSFNET



The NSFNET backbone in 1988.

Internet Usage

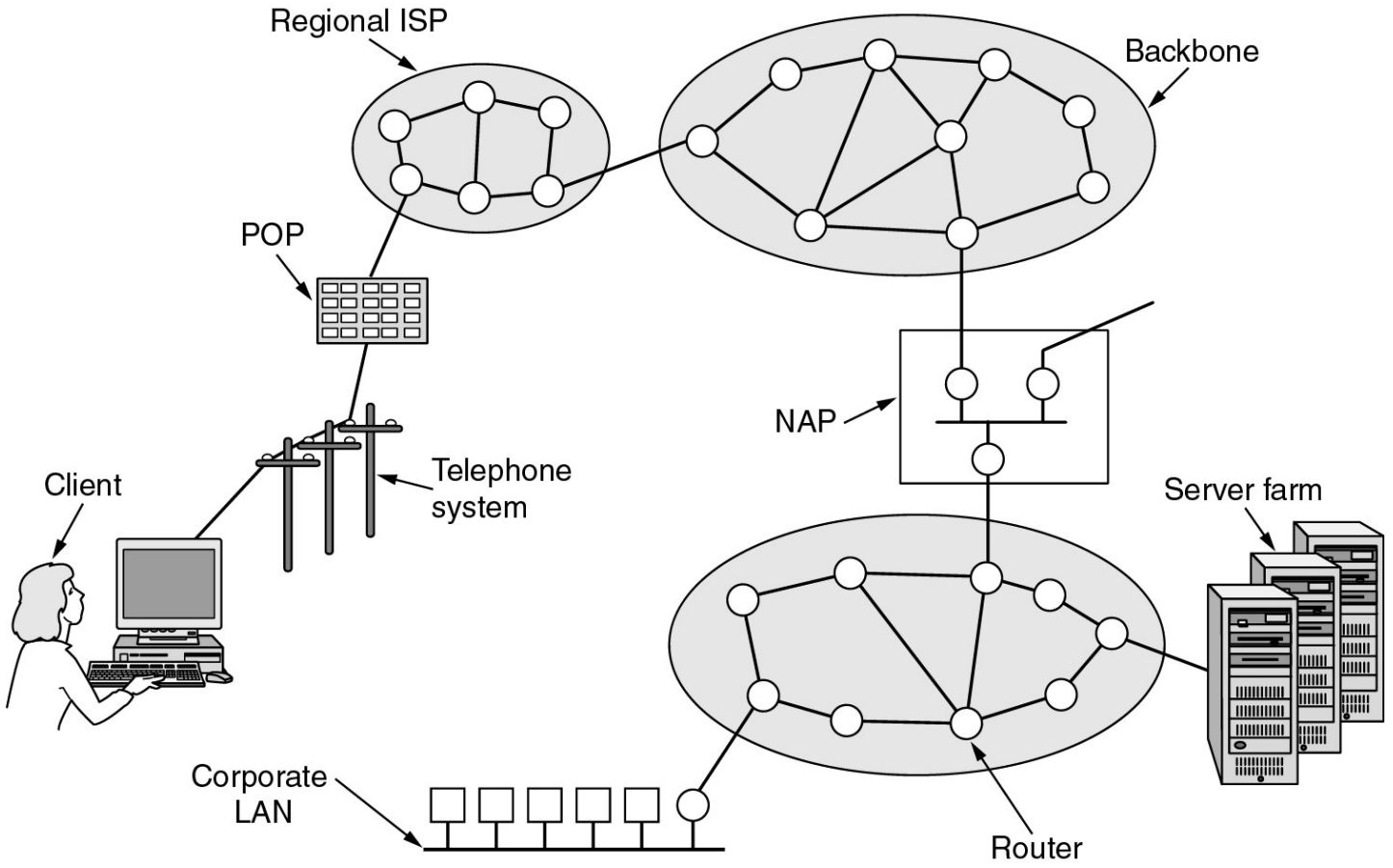
Traditional applications (1970 – 1990)

- E-mail
- News
- Remote login
- File transfer

New applications

- E-business
- Online gaming
- Online auction, etc.

Architecture of the Internet



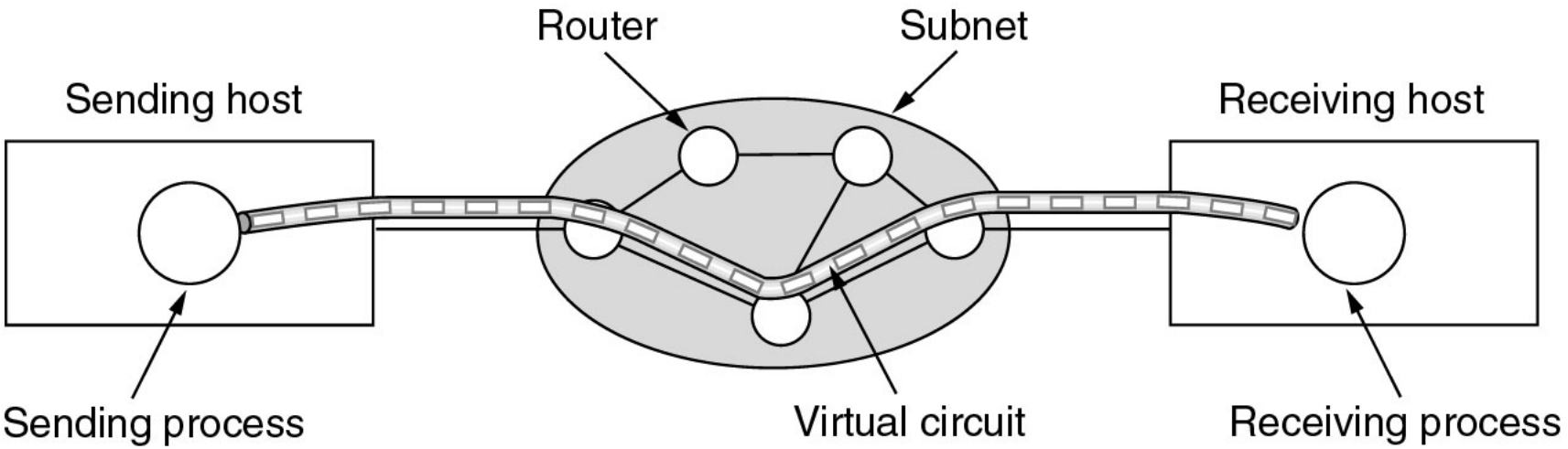
POP (Point of Presence) – located in the telephone switching office.

NAP (Network Access Point) – a room full of routers.

ATM (Asynchronous Transfer Mode)

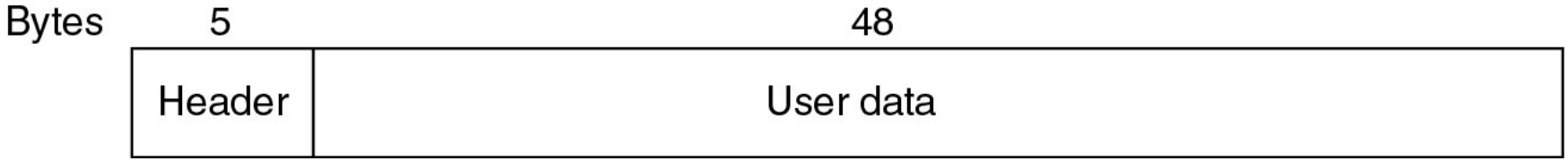
- ATM networks are connection-oriented
  - Sending data requires setting up a connection.
  - A setup packet travels through the subnets, and all the routes in the path reserve resources for the connection – Virtual Circuits (VC).
- An ATM packet has a fixed-size - 53 bytes, and is called Cell.
  - header (5 bytes) + data (48 bytes)
  - Cell routing is done in hardware – faster than software routing.
  - The most common speeds for ATM networks are 155 Mbps and 622 Mbps.
- The ATM reference model
  - Different from OSI model and TCP/IP model.
  - Three layers: the physical, ATM and ATM Adaptation Layer (AAL).
  - The ATM layer deals with cells and cell transport.
  - The AAL layer provides interface services to various applications.
    - E.g., file transfer and video on demand have different requirements on error handling, timing, etc.
  - Control plane deals with connection management.
  - User Plane deals with data transport, flow control, error control, etc.
  - The layer and plane management functions relate to resource mgmt. and interlayer coordination.

ATM Virtual Circuits



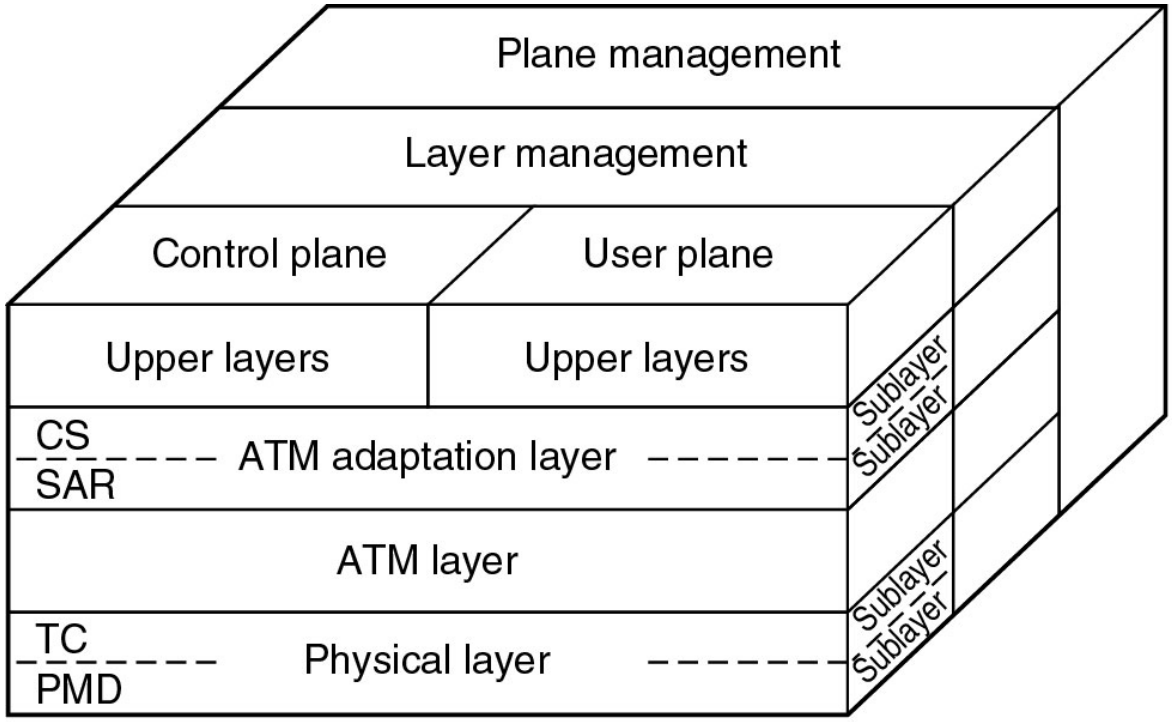
A virtual circuit.

ATM Virtual Circuits (2)



An ATM cell.

The ATM Reference Model



CS: Convergence sublayer
SAR: Segmentation and reassembly sublayer
TC: Transmission convergence sublayer
PMD: Physical medium dependent sublayer

The ATM reference model.

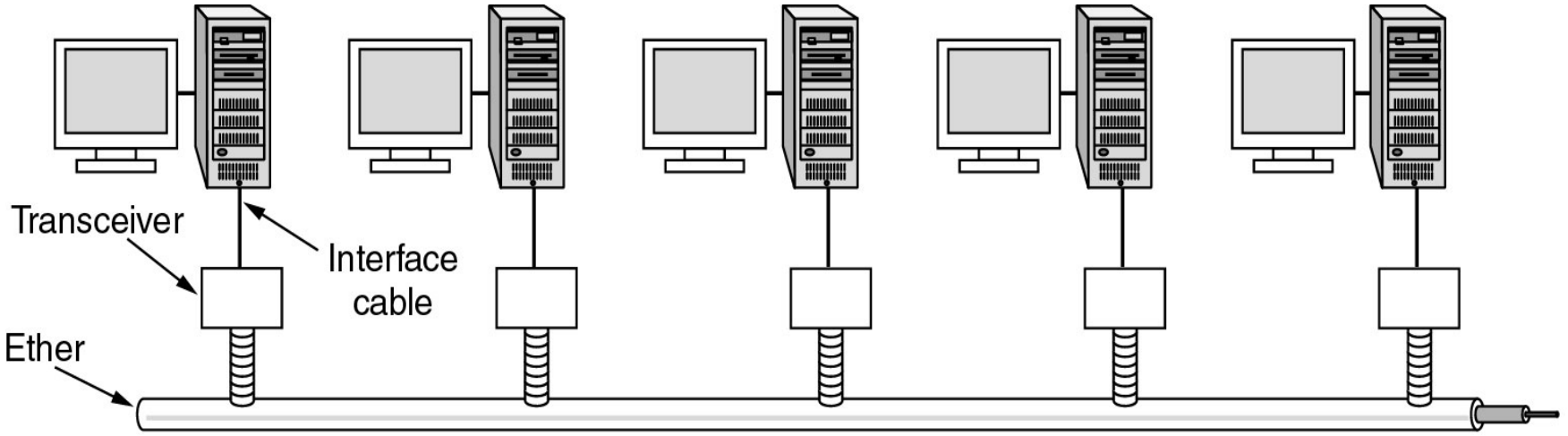
The ATM Reference Model (2)

OSI layer	ATM layer	ATM sublayer	Functionality
3/4	AAL	CS	Providing the standard interface (convergence)
		SAR	Segmentation and reassembly
2/3	ATM		Flow control Cell header generation/extraction Virtual circuit/path management Cell multiplexing/demultiplexing
2	Physical	TC	Cell rate decoupling Header checksum generation and verification Cell generation Packing/unpacking cells from the enclosing envelope Frame generation
1		PMD	Bit timing Physical network access

The ATM layers and sublayers and their functions.

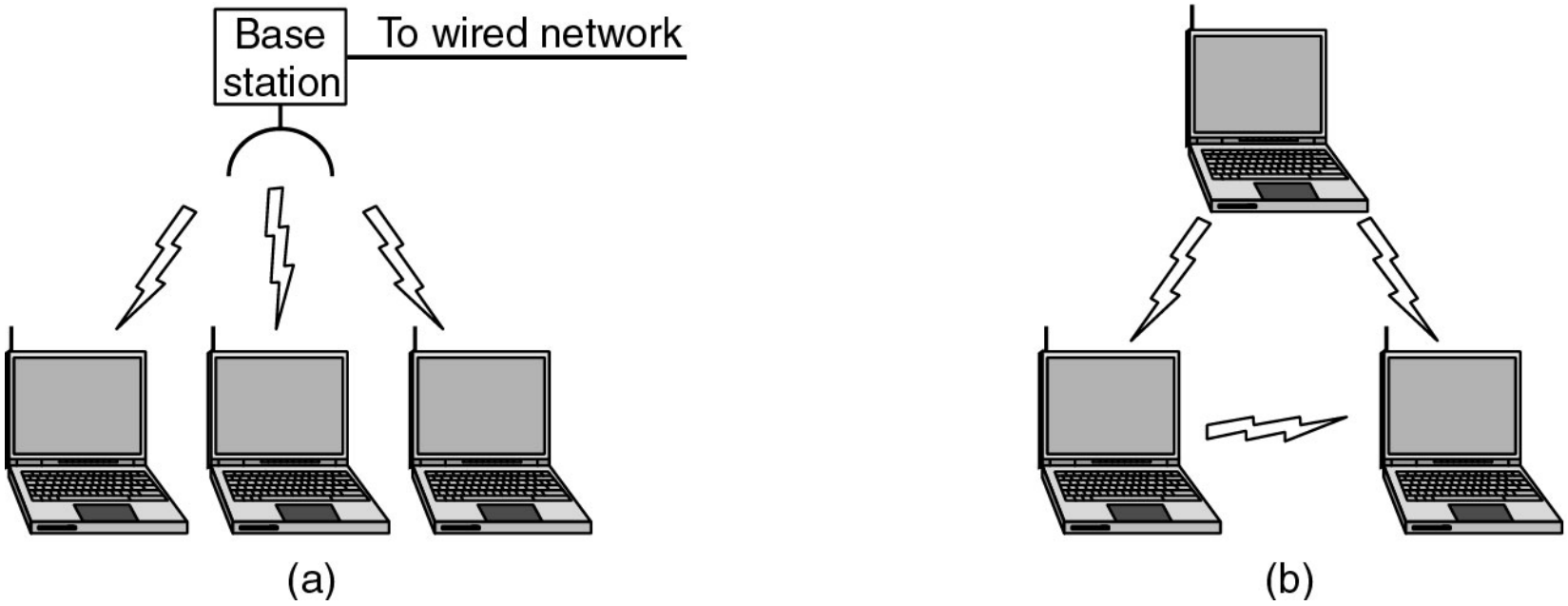
Ethernet

- Ethernet (IEEE 802.3) is the most popular LAN.
- Using thick coaxial cables up to 2.5 km long.
- Up to 256 computers can be attached to the system via transceiver screwed onto the cable.
- Transmission speed varies from 10 Mbps to 10 Gbps.



Architecture of the original Ethernet.

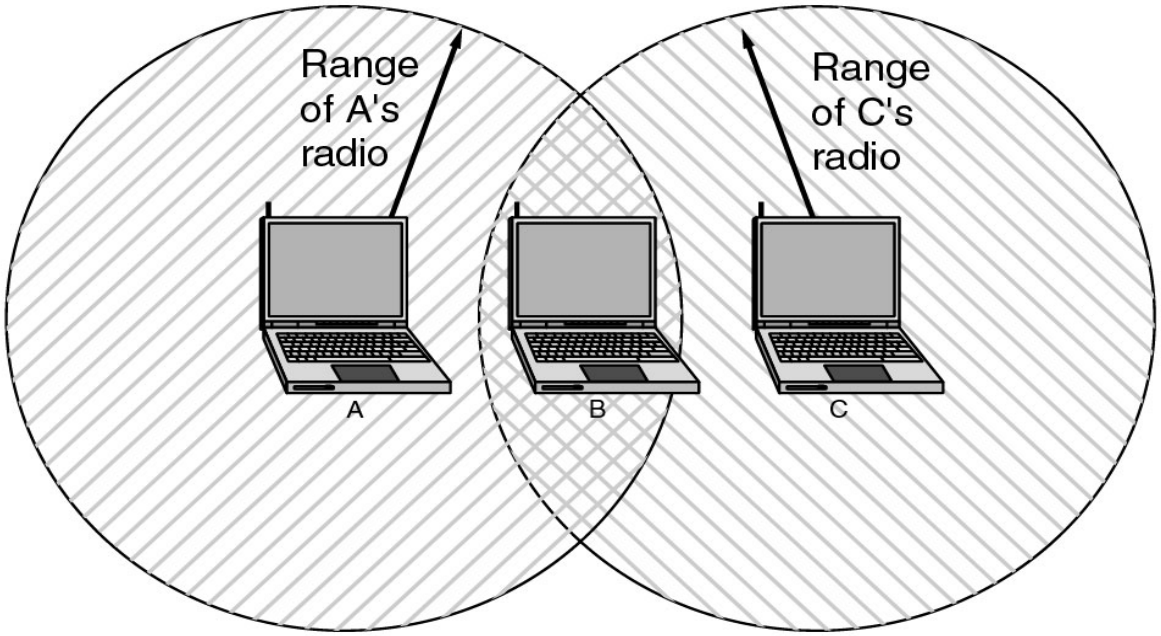
Wireless LANs



(a) Wireless networking with a base station (access point).

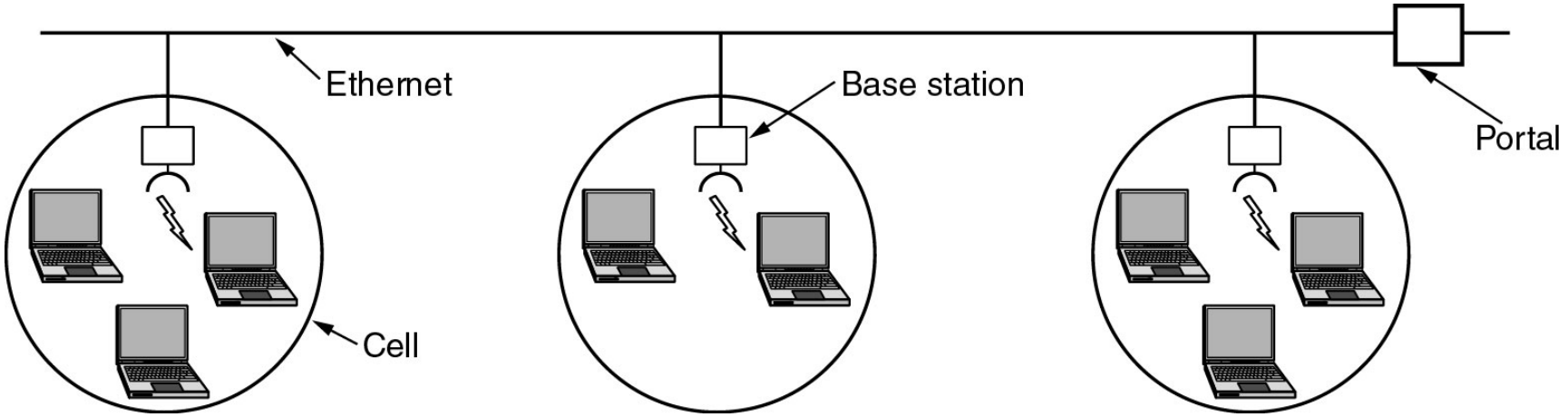
(b) Ad hoc networking.

Wireless LANs (2)



The range of a single radio may not cover the entire system.

Wireless LANs (3)



A multi-cell 802.11 network.

Network Standardization

- Who's Who in the Telecommunications World
- Who's Who in the International Standards World
- Who's Who in the Internet Standards World

ITU (International Telecommunication Union)

- Main sectors
  - ✓ Radiocommunications (ITU-R)
  - ✓ Telecommunications Standardization (ITU-T)
  - ✓ Development (ITU-D)
- Classes of Members
  - ✓ National governments – most countries in the world.
  - ✓ Sector members
    - Telephone companies, vendors, media companies, etc.
    - E.g., AT&T, Cisco, Nortel, HP, Sun, AOL, CBS.
  - ✓ Associate members
    - smaller organizations interested in a particular study group.
  - ✓ Regulatory agencies – who watch over telecom business.
    - ✓ E.g., the US Federal communications Commission (FCC).

IEEE 802 Standards

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
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)
802.16 *	Broadband wireless
802.17	Resilient packet ring

The 802 working groups. The important ones are marked with *. The ones marked with ↓ are hibernating. The one marked with † gave up.

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

The principal metric prefixes.