BEng Course B38CN: Introduction to Communications and Networks

Chapter 1. Introduction

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Topics

- Ch1 Introduction
- Ch2 The Physical Layer
- Ch3 The Data Link Layer
- Ch4 The Medium Access Control Sublayer
- Ch5 The Network Layer
- Ch6 The Transport Layer

Reference Books

- Andrew S. Tanenbaum, “Computer Networks”, 4th edition, Pearson Education International, 2003.
- Alberto Leon-Garcia, “Communication Networks: Fundamental Concepts and Key Architectures”, 2nd edition, McGraw Hill, 2004.
- Other textbooks related to Digital Communications and Networks.

Assessment (100%)

- Exam (70%): 2 hour written exam (3 questions from 4, each 25 marks);
- Coursework (30%):
  1) Coursework questions (55%): similar to exam questions/style; issued near the end of the course.
  2) Tutorial solutions: 45%.

	T1	T2	T3	T4	T5	T6
Question numbers	9	9	10	7	6	5
Full mark	9	9	9	7	6	5

Note: Print your solutions in A4 papers.

General marking criteria for tutorials:

a) Hand in timely and answer 1 question correctly: 1;

b) Hand in timely and answer 2-9 questions correctly: 2-9;

c) Otherwise: 0.

Teaching staff

- **Instructor**

  Sheng Tong

- **Teaching assistant**

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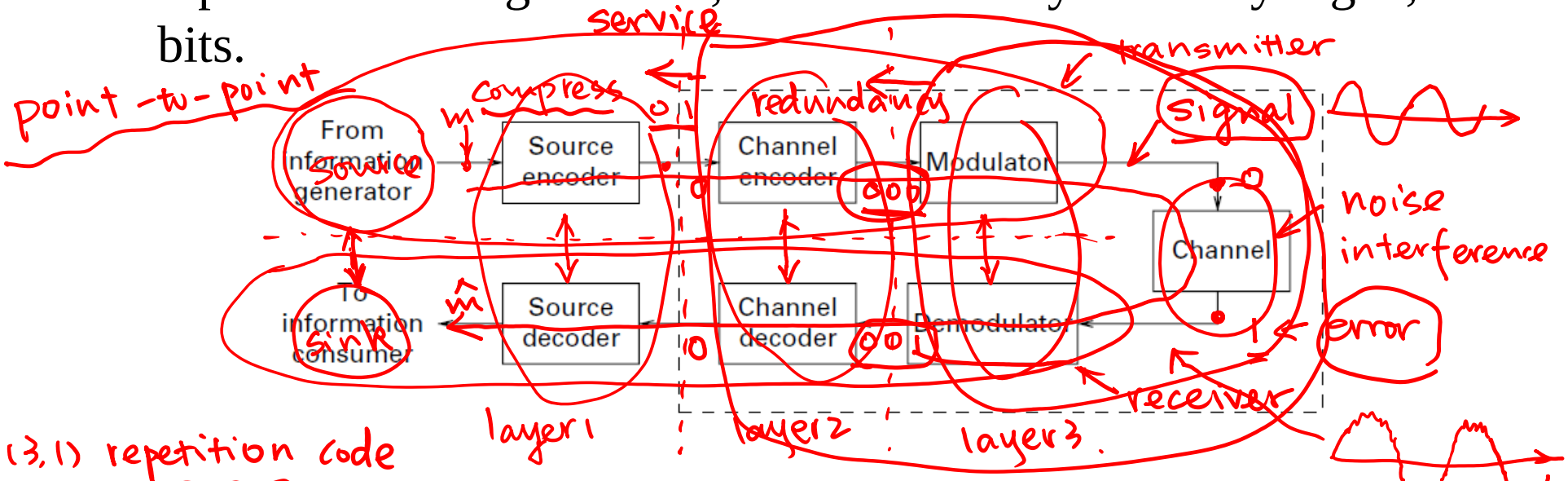
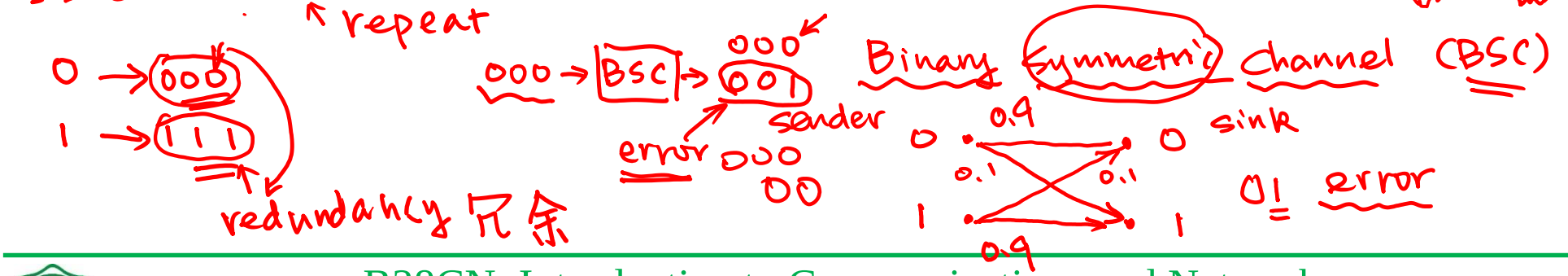
What is communication?

- We define communication as information transfer between different positions in space or time.
- Information refers to all standard formats, such as voice, audio, video, data files, web pages, etc.
- Examples:
  - Telephone conversation, accessing a website, tuning to a TV station
  - Accessing a storage device (e.g., CD, DVD, or hard drive)
- The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point.

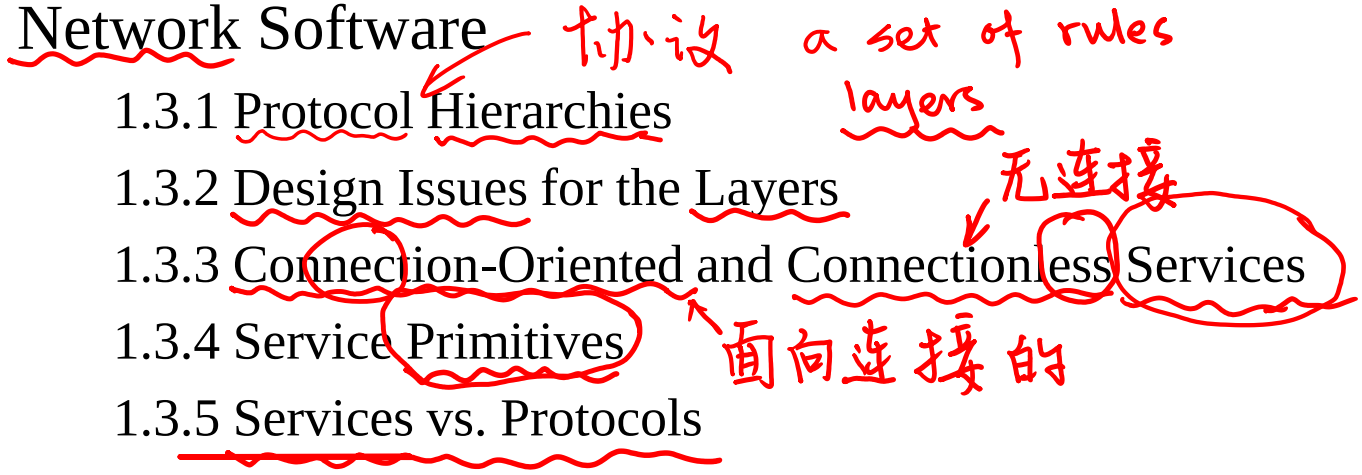
Components of a digital communication system

- In digital communication, the information being transferred is represented in digital form, most commonly as binary digits, or bits.





Contents (1/2)



Contents (2/2)

1 Mega 兆 = 10^6 milli - 10^{-3}

1. Introduction

- The **subjects** of this module: the design and organization of computer networks.
- Computer network: a collection of *autonomous* computers *interconnected* by a *single* technology.
- Interconnection of two computers: be able to exchange information.
- Connection medium: copper wire, fiber optics, microwaves, infrared, communication satellites, etc.

1.1 Uses of Computer Networks

- **Applications**: business, home, mobile users, social issues
- **Business applications**:
  - Resource sharing: to make all programs, equipments, and especially data available to anyone on the network.
  - Communicaton medium among people: e-mail, online document, video conferencing, etc.
  - Business with other companies: suppliers and customers.
  - Business with consumers over Internet: e-commerce.

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

Fig. 1.1: Some forms of e-commerce.

Client-Server Model

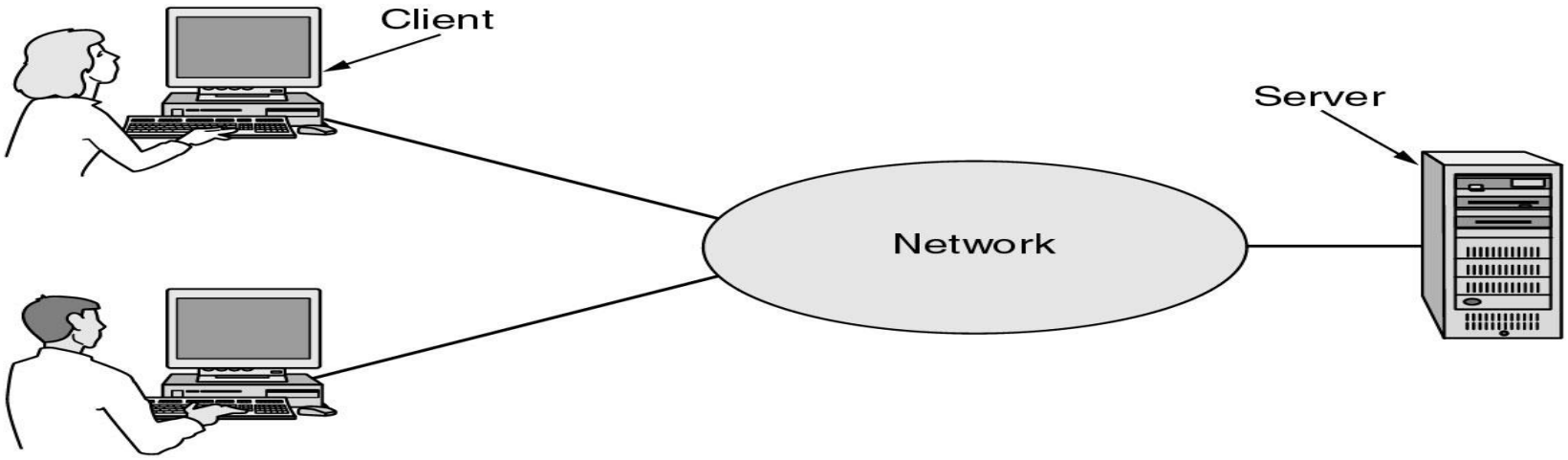


Fig. 1.2: A network with two clients and one server.

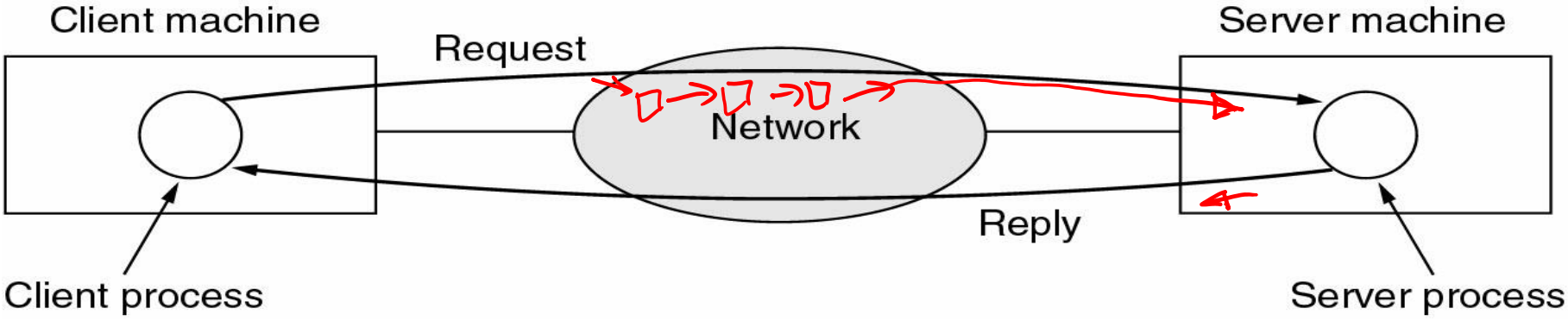


Fig. 1.3: The client-server model involves requests and replies.

Other Applications

- **Home applications**:
  - Access to remote information: interacts between a person and a remote database.
  - Person-to-person (peer-to-peer) communication: e-mail, instant messaging.
  - Interactive entertainment: video, game playing.
  - E-commerce: home shopping, online banking.
- **Mobile users**:
  - Wireless networks: cell phones, PDAs
  - Mobile-commerce
  - Mobile maps
  - Personal area networks and wearable computers
- **Social issues**: newsgroups, bulletin boards.

1.2 Network Hardware

- Classification of networks by **transmission technology**:
  - **Broadcast** networks: have a single communication channel that is shared by all the machines on the network.
  - **Point-to-point (unicast)** networks: consist of many connections between individual pairs of machines.
- Classification of networks by **scale (distance)**:
  - Personal area network (PAN)
  - Local area network (LAN)
  - Metropolitan area network (MAN)
  - Wide area network (WAN)
  - The Internet

Classification of Networks by Scale

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

Fig. 1.4: Classification of interconnected processors by scale.

Local Area Networks (LANs)

LANs distinguish themselves from other networks by 3 characteristics:

- Size: restricted to up to a few kilometers.
- Transmission technology: broadcast link, consisting of a cable to which all the machines are attached.
- Topology:
  - **Bus** (linear cable) network: At any instant, at most one machine is allowed to transmit, while all other machines are required to refrain from sending.
  - **Ring** network: Each bit propagates around on its own, not waiting for the rest of the packet to which it belongs.

  ⇨ An arbitration mechanism is needed to resolve conflicts when two or more machines want to transmit simultaneously.

LANs Examples

- Bus network example: IEEE 802.3 (Ethernet)
- Ring network example: IEEE 802.5 (the IBM token ring)

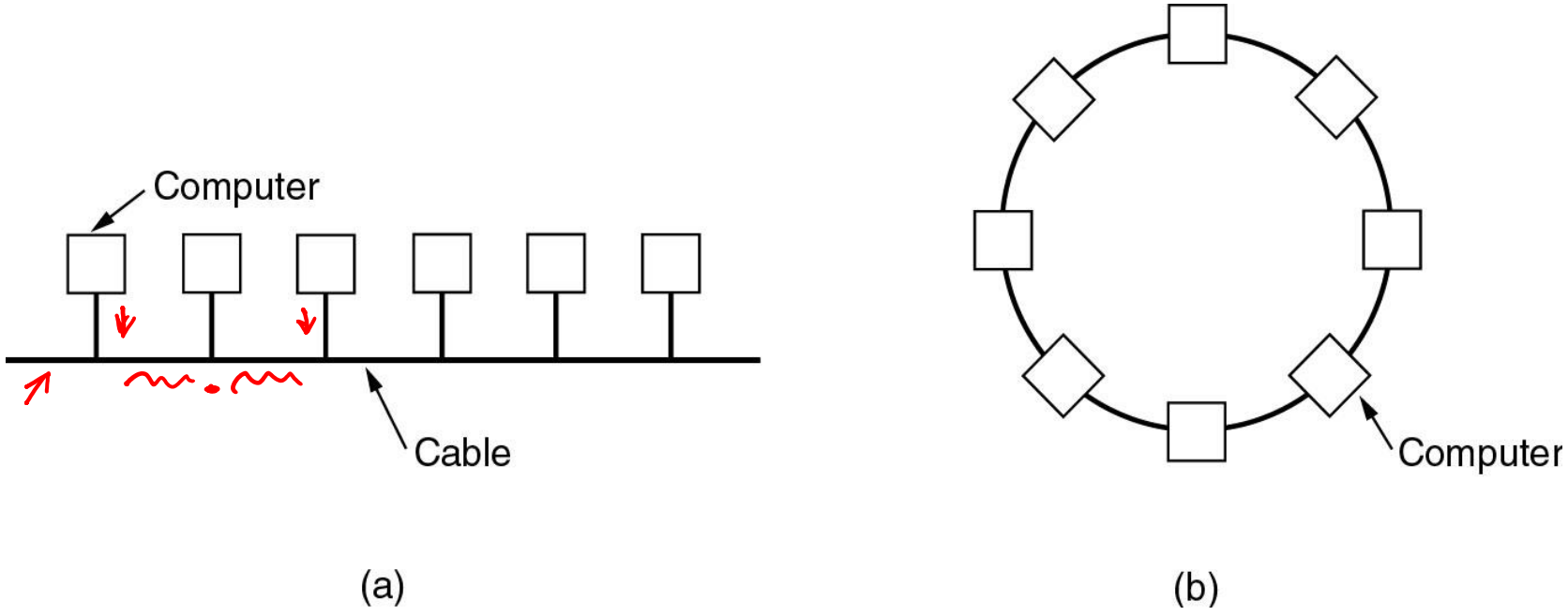


Fig. 1.5: Two broadcast networks: (a) Bus. (b) Ring.

Metropolitan Area Networks (MANs)

- A MAN intends to cover a city.

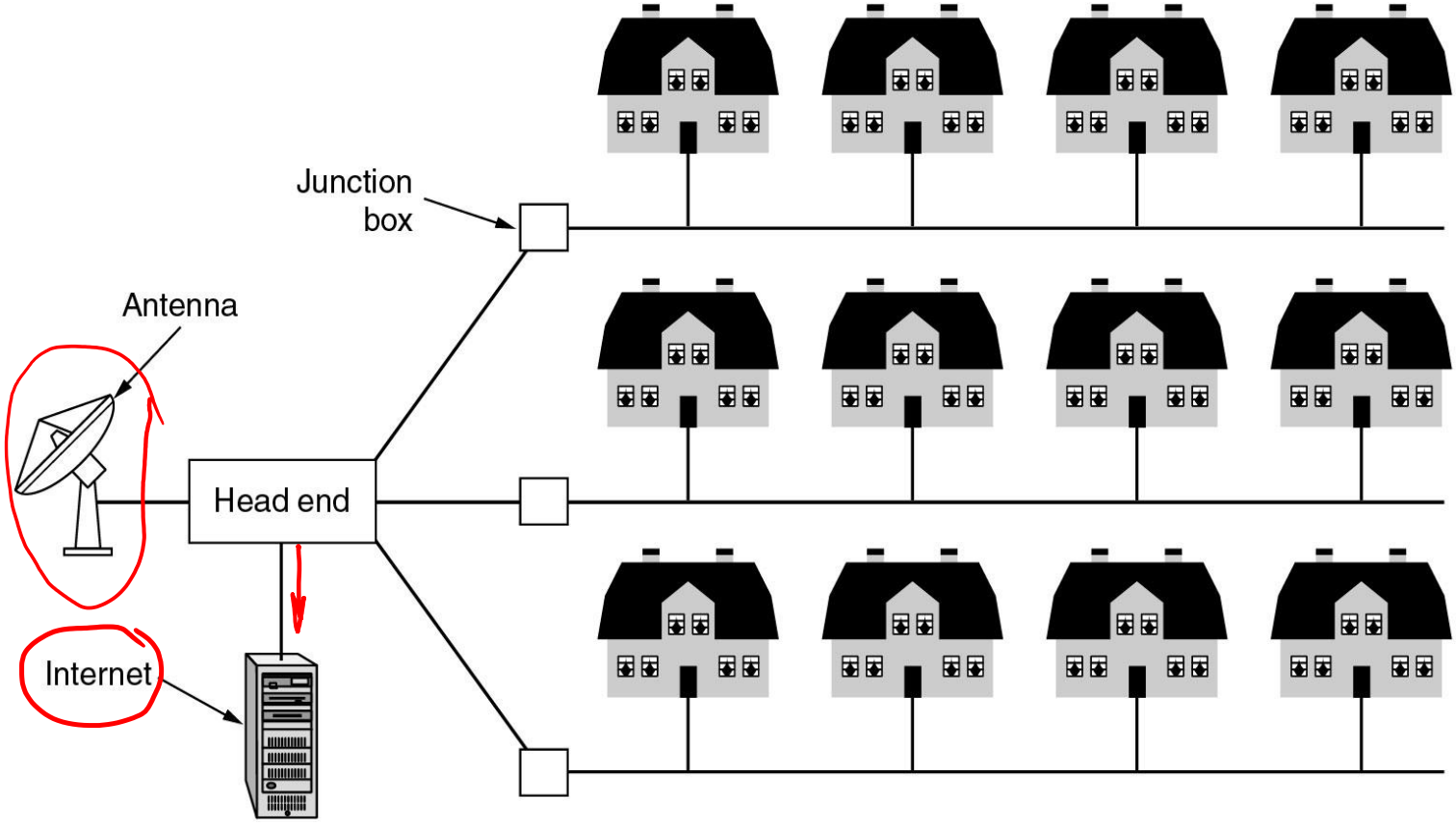


Fig. 1.6: A MAN based on cable TV.

Wide Area Networks (WANs)

- A WAN spans a large geographical area, often a country or continent.
  - **Hosts**: machines running application programs, owned by the customers.
  - **Subnet**: consists of **transmission lines** and **switching elements** (**routers**), owned and operated by a telephone company or Internet service provider.

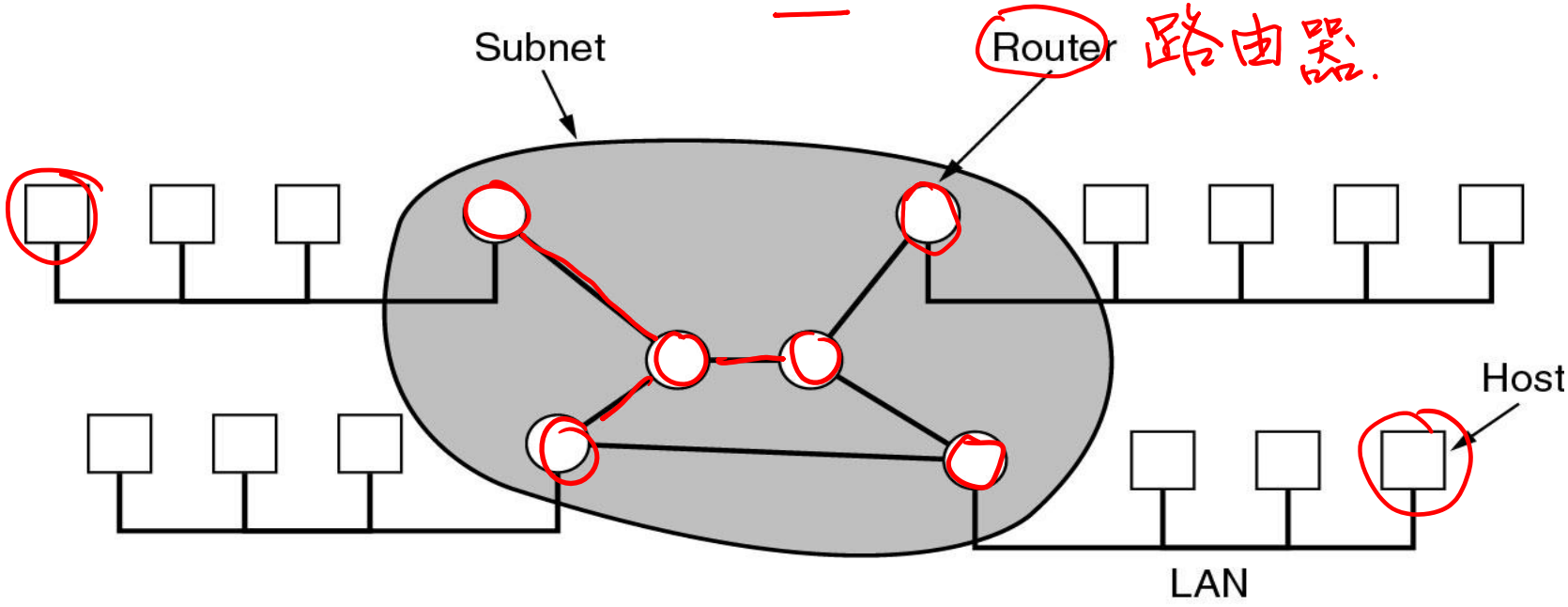


Fig. 1.7: Relation between hosts on LANs and the subnet.

Packet-Switched Subnet

- **Packet-switching (store-and-forward)**: When a packet is sent from one router to another via one or more intermediate routers, the packet is received at each intermediate router in its entirety, stored there until the required output line is free, and then forwarded.

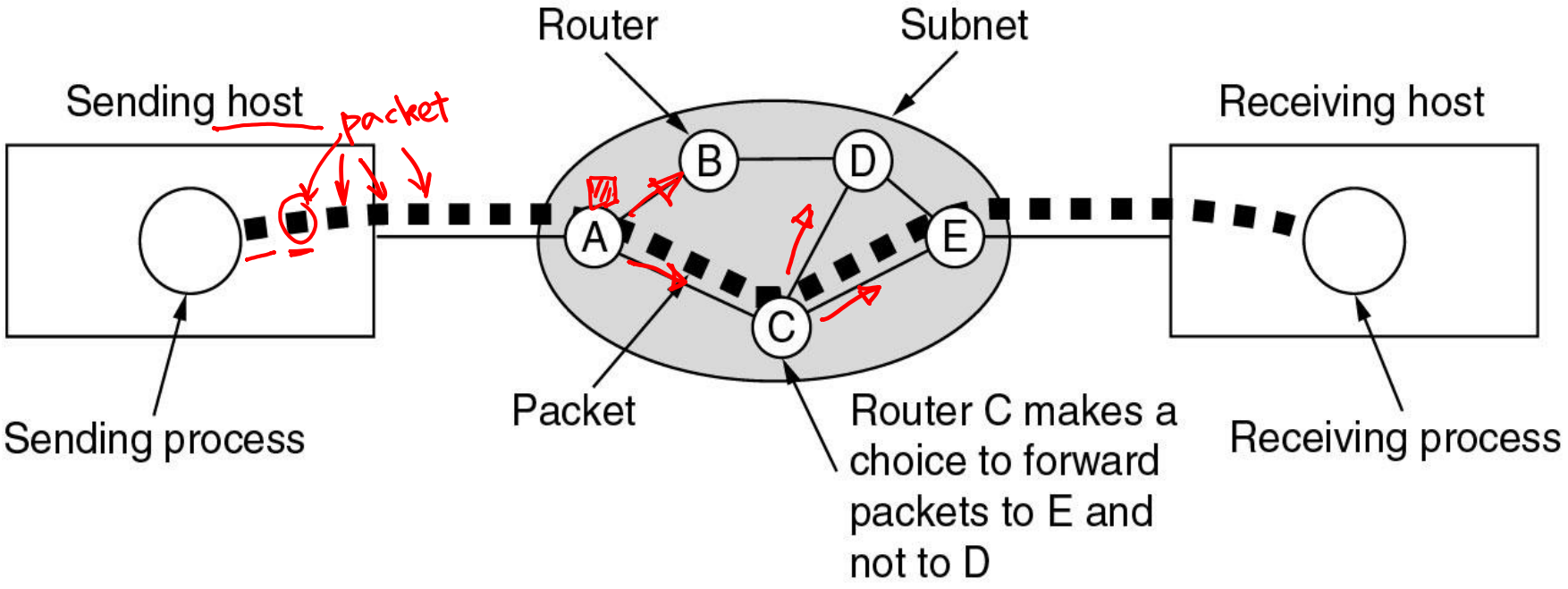


Fig. 1.8: A stream of packets from sender to receiver.

Wireless Networks

- In wireless networks, the transmission occurs through unguided media.
- Three main categories:
  - **System interconnection**: interconnecting the components of a computer using short-range radio, e.g., Bluetooth.
  - **Wireless LANs**: IEEE 802.11. Computers (with a radio modem and antenna) communicate through a base station that is placed on the ceiling, or directly in a peer-to-peer fashion (e.g., home networks).
  - **Wireless WANs**: cellular telephone networks.

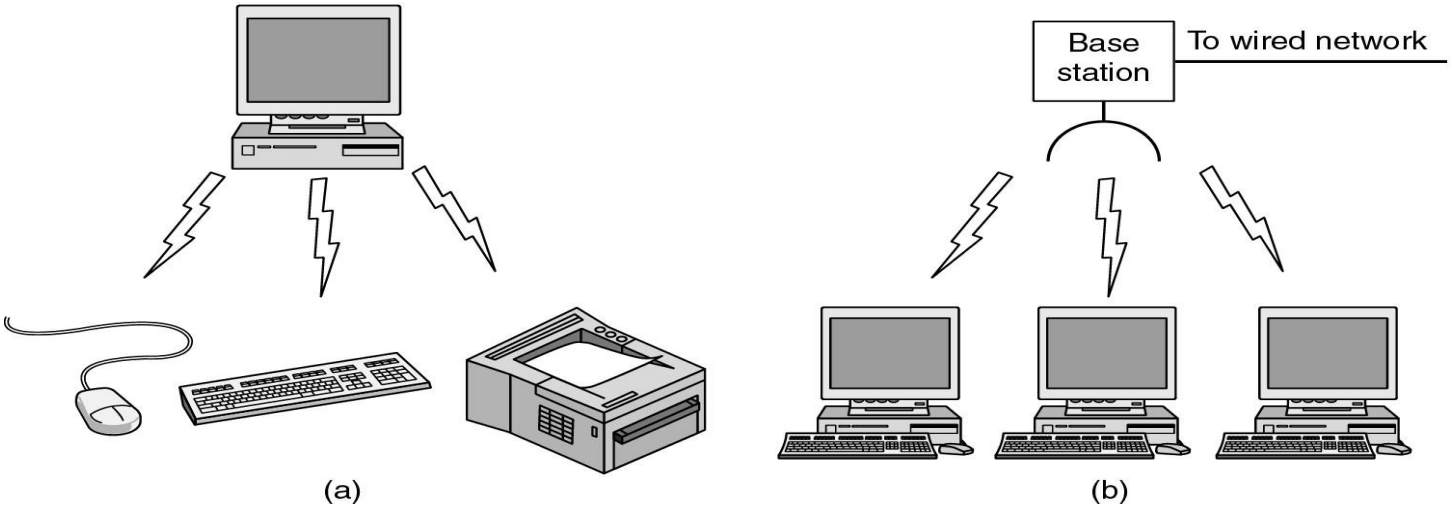


Fig. 1.9: (a) Bluetooth configuration. (b) Wireless LAN.

Home Networks

- Every device in the home will be capable of communicating with every other device, and all of them will be accessible over the Internet.
- Main categories:
  - Computers (desktop PC, PDA, shared peripherals)
  - Entertainment (TV, DVD, VCR, camera, stereo, MP3)
  - Telecomm (telephone, cell phone, fax)
  - Appliances (microwave, fridge, clock, furnace)
  - Telemetry (utility meter, burglar alarm)
- Specific requirements:
  - Easy to install and expand
  - Better performance and low price
  - Sufficient capacity
  - Secure and reliable

Internetworks

- The assumption so far is that a network is **homogeneous**: There is hardly any variation in hardware and software. In practice, large networks can only be constructed by **interconnecting** different kinds of networks⇨ **internet(work)**.
- Examples:
  - Connecting a collection of different kinds of LANs within a department.
  - Connecting LANs to each other through a WAN. The WAN acts as a subnet.
  - Connecting WANs to each other (the Internet).

1.3 Network Software

1.3.1 Protocol Hierarchies

1.3.2 Design Issues for the Layers

1.3.3 Connection-Oriented and Connectionless Services

1.3.4 Service Primitives

1.3.5 Services vs. Protocols

1.3.1 Protocol Hierarchies

- Protocol Hierarchy: structures the services that a network must offer in terms of a stack of layers or levels; fundamental to *all* software that makes a computer network run.
- Layer: offers certain services to the higher layers, shielding those layers from the details of how the offered services are actually implemented.
- Protocol: an agreement between the communicating parties on how communication is to proceed.
- Peers: the entities comprising the corresponding layers on different machines, can be processes, hardware devices, or even human beings.
- Interface: defines which primitive operations and services the lower layer makes available to the upper one.

Protocol Hierarchies

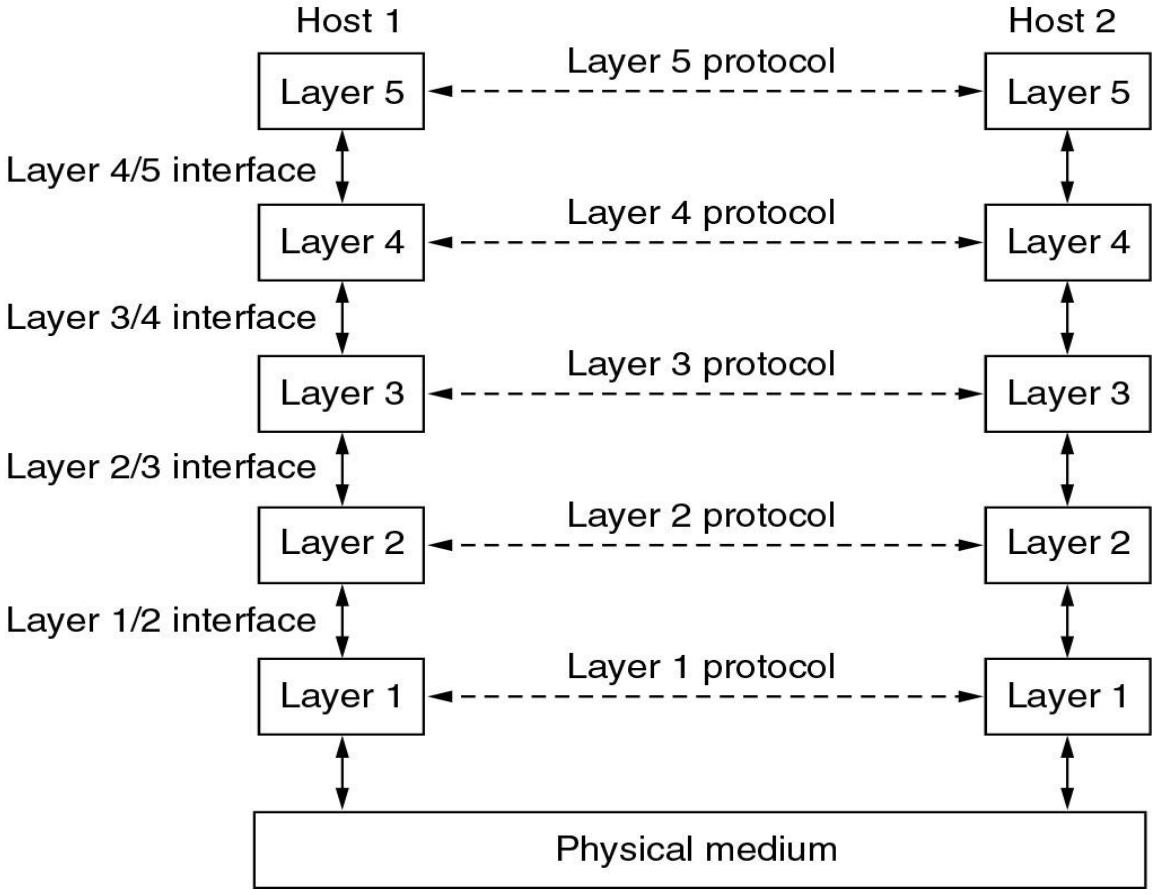


Fig. 1.10: Layers, protocols, and interfaces.

Layers: An Example

- Network architecture: a set of layers and protocols.
- Protocol stack: a list of protocols (one protocol per layer) used by a certain system.

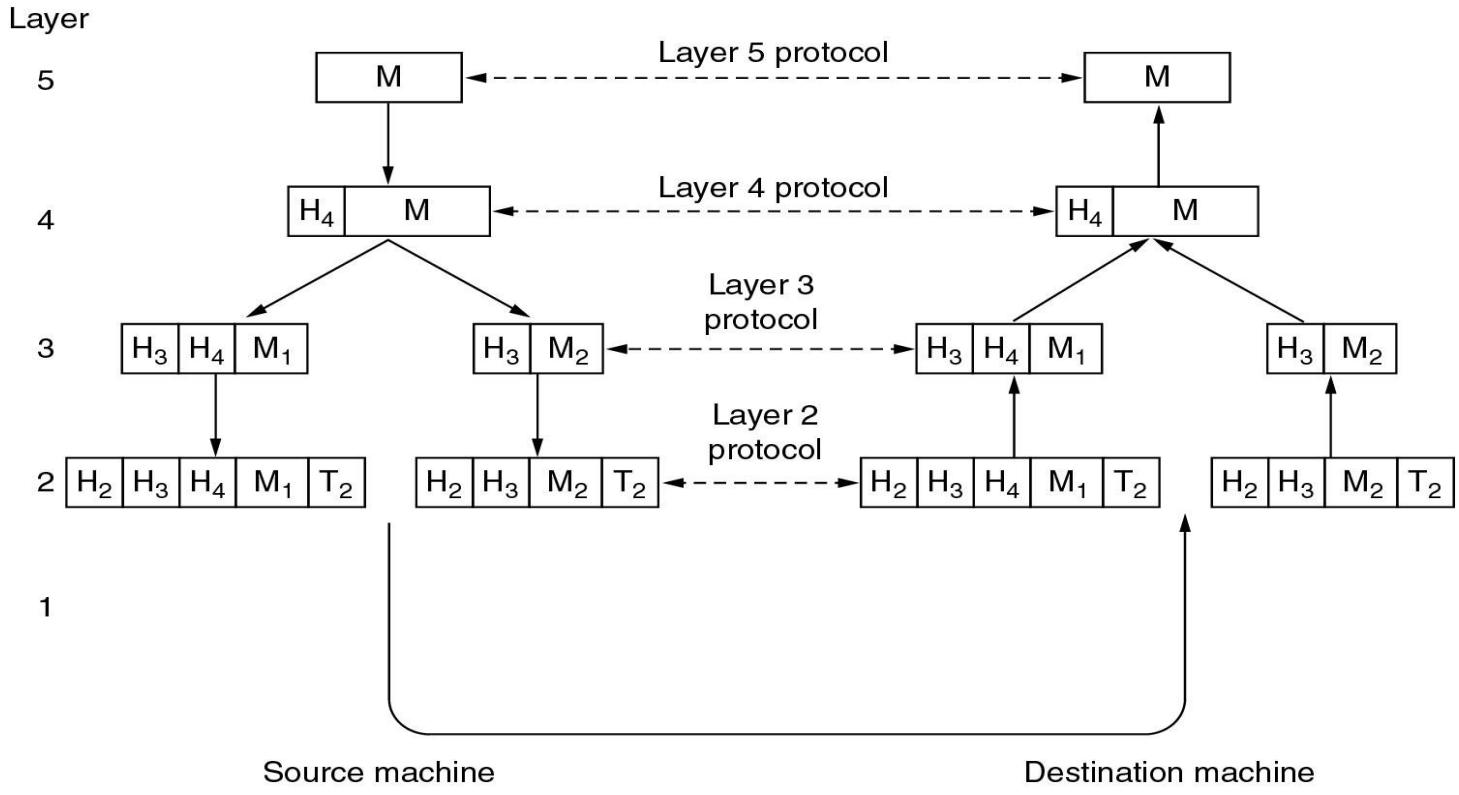


Fig. 1.11: Example information flow supporting virtual communication in layer 5.

1.3.2 Design Issues for the Layers

- Problem 1: multiples destinations.
  - ⇨ **Addressing**: specify a destination with whom a process wants to talk.
- Problem 2: Physical communication circuits are not perfect.
  - ⇨ **Error control**: error detecting and/or error correcting.
- Problem 3: How to keep a fast sender from swamping a slow receiver with data?
  - ⇨ **Flow control**
- Problem 4: the inability of all processes to accept arbitrarily long messages.
  - ⇨ **Multiplexing/Demultiplexing**: mechanisms for disassembling, transmitting, and then reassembling messages.
- Problem 5: multiple paths between source and destination.
  - ⇨ **Routing**

1.3.3 Connection-Oriented and Connectionless Services

- Two types of service layers can offer to the layers above them:
  - **Connection-oriented** (telephone system model): establish a connection, use the connection to communicate, and then release the connection.
  - **Connectionless** (postal system model): Each message carries the full destination address. Each one is routed to the destination through the system independent of all the others.
- Quality of service (QoS):
  - **Reliability**: Reliable service (acknowledged); Unreliable service (not acknowledged).
  - **Data in order**: With connection-oriented, in general yes; With connectionless, very often not.

Service Examples

	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Remote login
	Unreliable connection	Digitized voice
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Registered mail
	Request-reply	Database query

Fig. 1.12: Six different types of service.

1.3.4 Service Primitives

- A service is formally specified by a set of primitives (operations) available to a user (client) process to access the service.
- The set of primitives available depends on the nature of the service provided.
- Examples of service primitives for a simple connection-oriented service:

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

Fig. 1.13: Five service primitives for implementing a simple connection-oriented service.

Client-Server Process

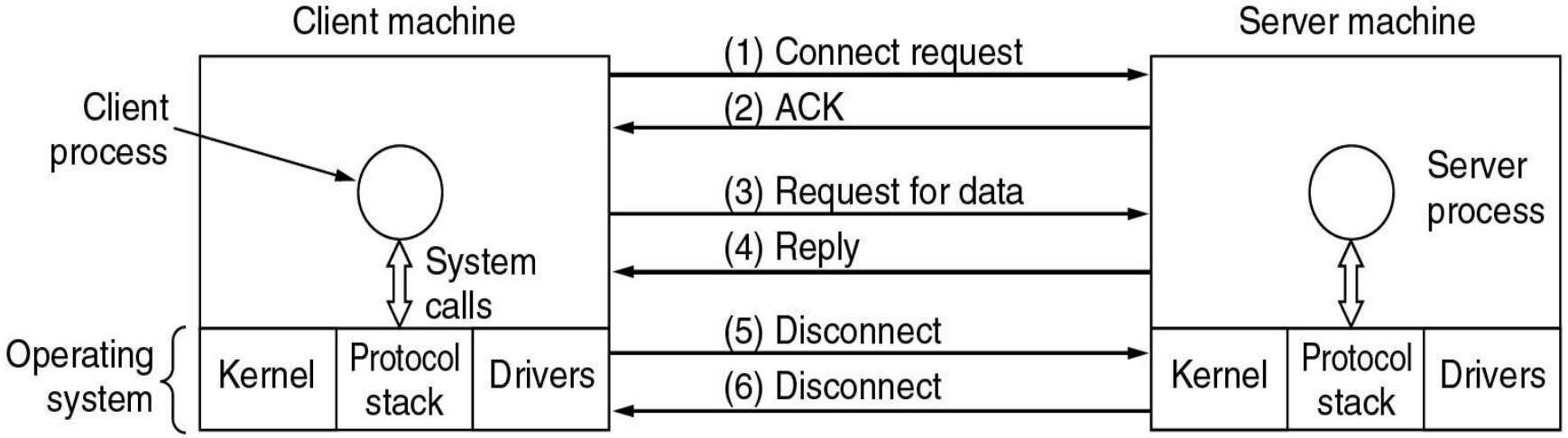


Fig. 1.14: Packets sent in a simple client-server interaction on a connection-oriented network.

	1	2	3	4	5	6	7	8
Server	Listen		Receive			Send (4)		Disconnect (6)
Client		Connect (1)(2)		Send (3)	Receive		Disconnect (5)	

Fig. 1.15: Relation between Fig. 1.13 and Fig. 1.14.

1.3.5 Services vs. Protocols

- **Service**: a set of primitives (operations) that a layer provides to the layer above it. A service relates to an interface **between** two layers **within** an entity.
- **Protocol**: a set of rules governing the format and meaning of the packets or messages that are exchanged **between** the peer entities on different machines **within** a layer.
- A protocol relates to the implementation of the service and as such is not visible to the user of the service.

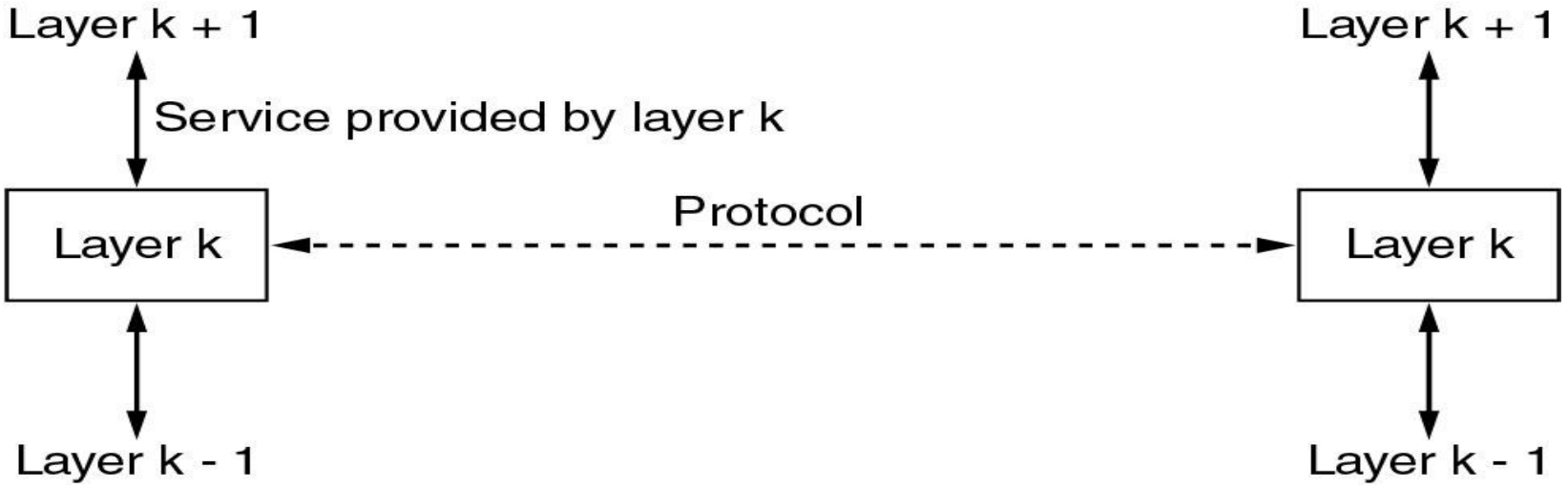


Fig. 1.16: The relationship between a service and a protocol.

1.4 Reference Models

1.4.1 The ISO OSI Reference Model

1.4.2 The TCP/IP Reference Model

1.4.3 A Comparison of the OSI and TCP/IP Reference Models

- **Two Network architectures:**
  - OSI reference model: the protocols are rarely used anymore, while the model itself is quite general and still valid.
  - TCP/IP reference model: the protocols are widely used, while the model itself is not of much use.

1.4.1 The ISO OSI Reference Model

- ISO: International Standards Organization
- OSI: Open Systems Interconnection
  - Open systems: systems that are open for communication with other systems.
- Seven layers
  - The lower 3 layers provide transmission through the subnet.
  - The upper 4 layers provide host-to-host (end-to-end) communications.
- The OSI model itself is not a network architecture.
  - It does not specify the exact services and protocols to be used in each layer.
  - It just tells what each layer should do.

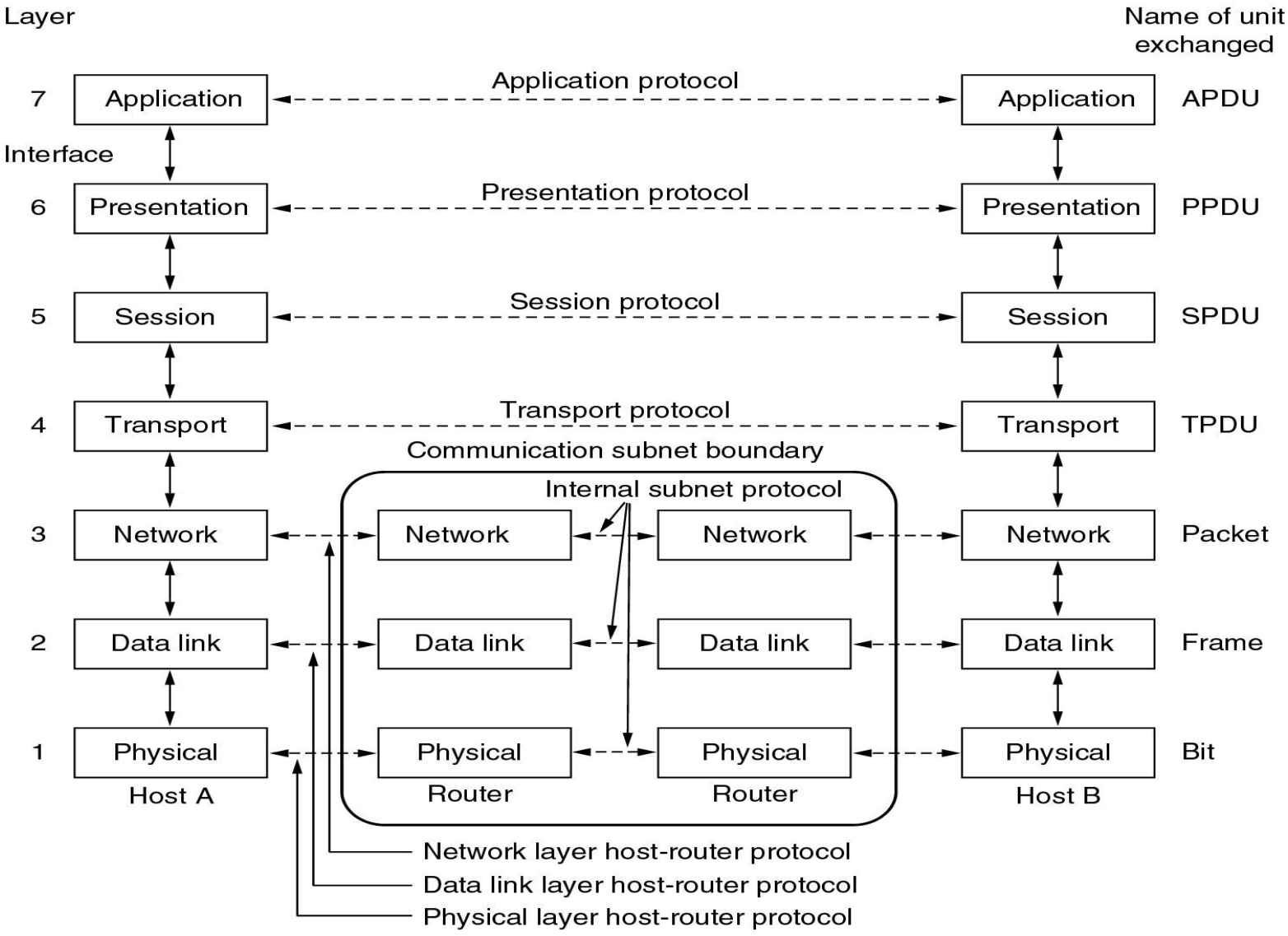


Fig. 1.17: The OSI reference model (minus the physical medium).

The OSI Physical Layer

- Describes the transmission of raw bits over a communication channel.
- The design issues largely deal with mechanical, electrical, and timing interfaces, and the physical transmission medium, which lies below the physical layer.
  - Electrical system parameters: voltage levels, signal durations.
  - Mechanical: socket type, number of pins for the network connector, what each pin is used for.
  - Physical: How to set up (initiate/establish) and release the physical connection?
  - Timing: May the transmission proceed simultaneously in both directions?

The OSI Data Link Layer

- Provides services to the network layer by using the services provided by the physical layer.
- **Framing**: breaks up the input data into data frames (blocks of bytes) and transmits the frames sequentially.
- **Error control**: Detects and, if necessary, corrects errors.
- **Flow control**: keeps a fast transmitter from drowning a slow receiver in data; lets the transmitter know how much buffer space the receiver has at the moment.
- **Multiple access**: controls access to the shared channel in broadcast networks.
  - Medium access control (MAC) sublayer

The OSI Network Layer

- Provides services to the transport layer by using the services provided by the data link layer.
- Controls the operation of the communication subnet.
- **Routing**: determines how packets are routed (selecting paths across a network) from source to destination.
- **Congestion control**: controls traffic congestion between nodes.
- **QoS**: e.g., delay and jitter.
- **Internetworking**: transfers packets from one network to another; deals with differences in addressing, packet size, and protocols etc.

The OSI Transport Layer

- Provides services to the session layer and ultimately to the users of the network by using the services provided by the network layer.
- Accepts data from session layers, split up into smaller units if necessary, pass to the network layer, and ensure that the pieces all arrive correctly at the other end.
- The heart of the whole protocol hierarchy. Isolates the upper layers from the technology, design, and imperfections of the subnet.
- A true end-to-end layer, all the way from the source to the destination.
- The lower 3 layers are chained, in which the protocols are between each machine and its immediate neighbors (routers), since the ultimate source and destination machines may be separated by many routers. The upper 4 layers are end-to-end.
- The bottom 4 layers are transport service provider. The upper layer(s) are the transport service user. It forms the boundary between the provider and user of the reliable data transmission service.

The OSI Session Layer

- Allows users on different machines to establish “sessions” between them; Used to control the manner in which data are exchanged.
- Other services:
  - **Dialog control**: keeps track of whose turn it is to transmit.
  - **Token management**: prevents two parties from attempting the same critical operation at the same time.
  - **Synchronization**: checkpoints long transmissions to allow them to continue from where they were after a crash.

The OSI Presentation Layer

- Provides the application layer with independence from differences in the representation of data.
- Deals with the syntax and semantics of the information transmitted; ensures that messages can be understood at both ends.
- Manages abstract data structures and allows higher level data structures to be defined and exchanged.
- Neither the session layer nor the presentation layer are much used in practice.

The OSI Application Layer

- Provides services that are frequently required by applications that involve communications.
- Examples:
  - World Wide Web (WWW): Hyper Text Transfer Protocol (HTTP)
  - E-mail: Simple Mail Transfer Protocol (SMTP)
  - File transfer: File Transfer Protocol (FTP)
  - Network news: Network News Transfer Protocol (NNTP)
  - Virtual terminal (remote log-in): TELecommunication NETwork |(TELNET), rlogin, Secure SHell (SSH).
  - Name services: Domain Name System (DNS).

Headers and Trailers

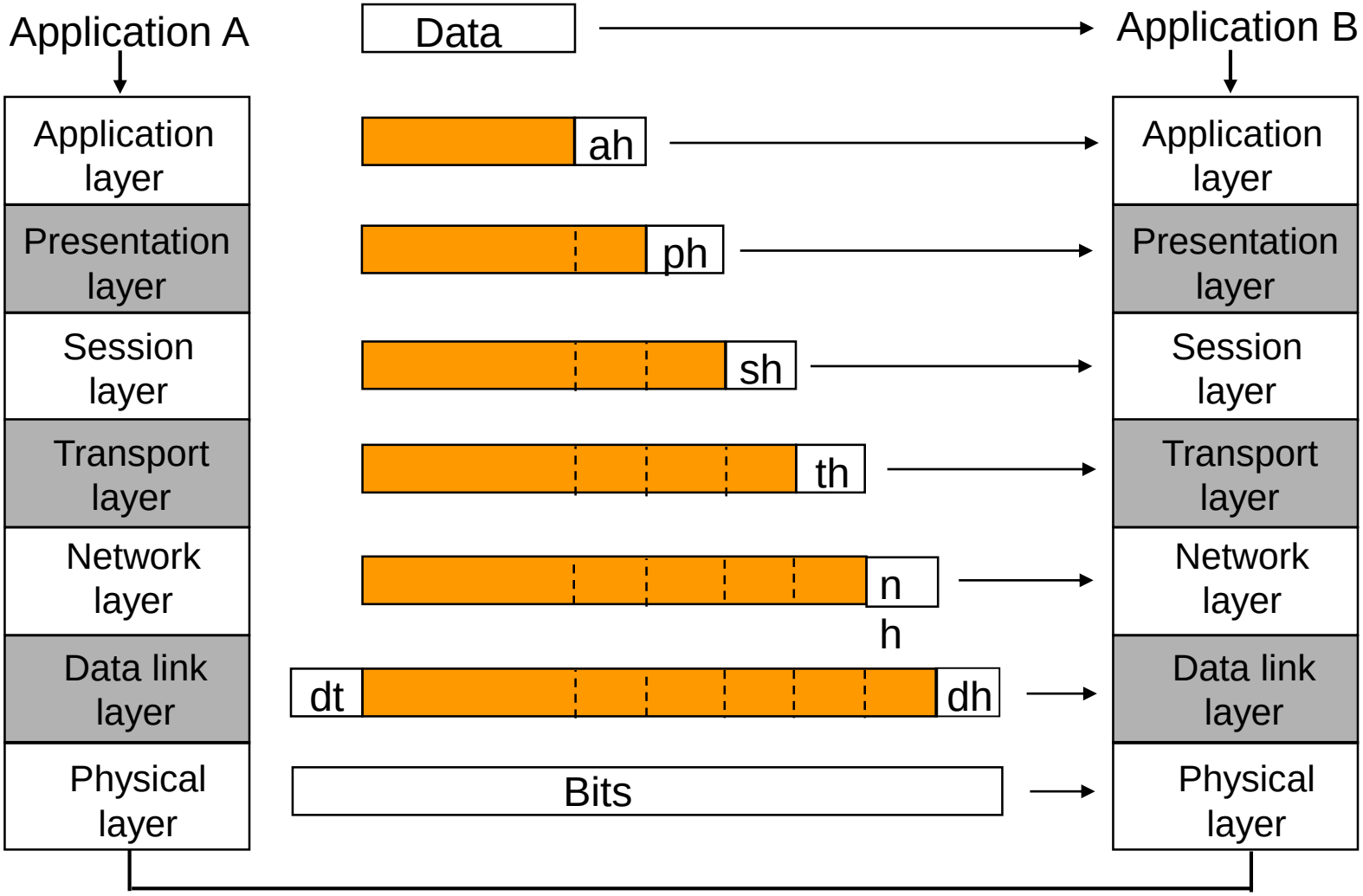


Fig. 1.18: Headers and trailers are added to a block of data as it moves down the layers.

1.4.2 The TCP/IP Reference Model

- The reference model used in the ARPANET and the worldwide Internet.
- Four layers: roughly equivalent to the OSI model without the session and presentation layers.

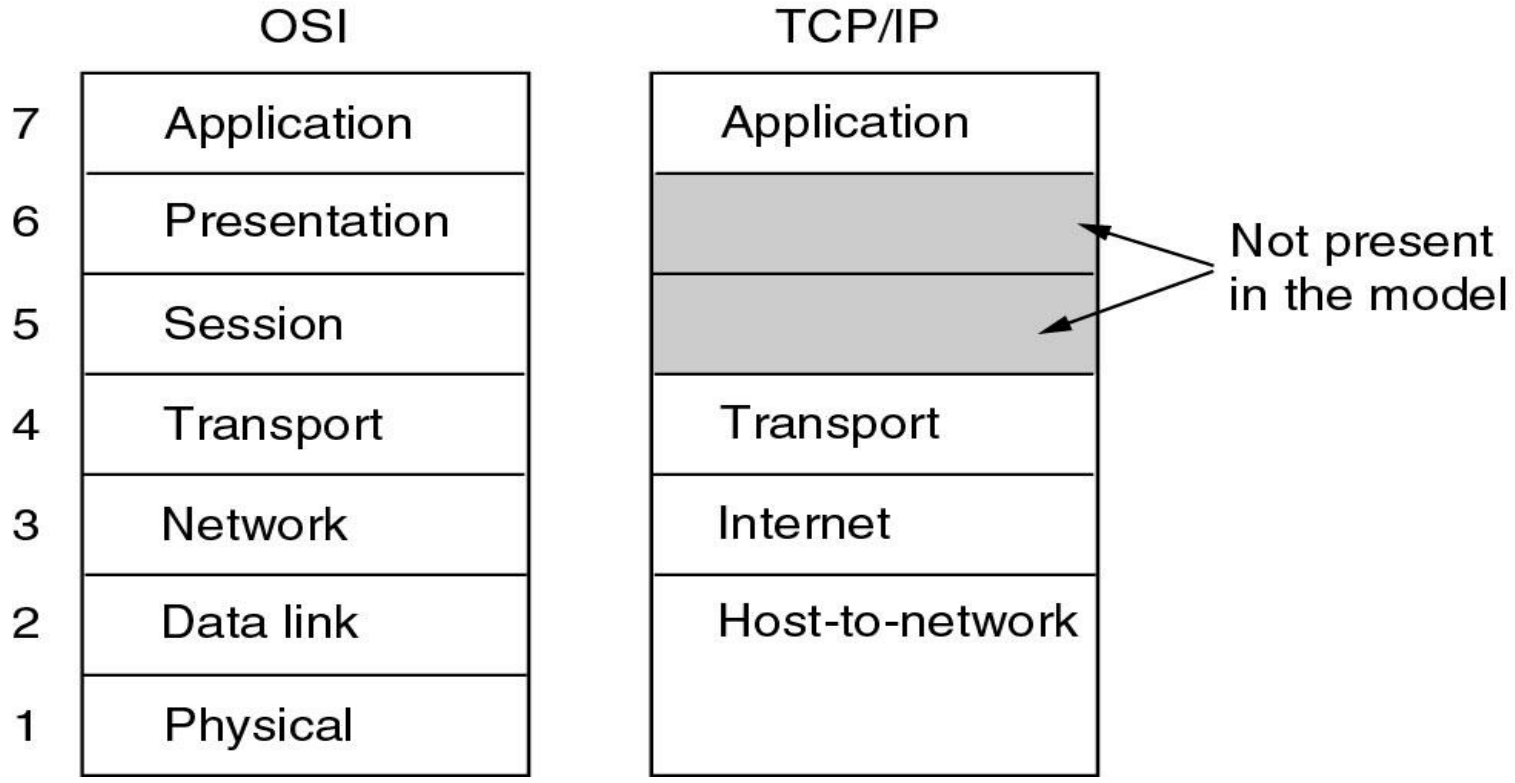


Fig. 1.19: The TCP/IP reference model.

The TCP/IP Host-to-Network Layer

- Incorporates the functions of the physical layer and data link layer in the OSI model.
- Not specified in the TCP/IP model.
- The TCP/IP model only points out that the host has to connect to the network using some protocol so it can send IP packets to it.
- Protocols can vary from host to host and network to network.

The TCP/IP Internet Layer

- Similar to the OSI network layer in functionality.
- Handles the transfer of packets across multiple networks independently through the use of gateways/routers.
  - Packet routing
  - Congestion control
- Defines an official packet format and protocol called Internet Protocol (IP).
- Provides a single service: best-effort **connectionless** packet transfer (packet-switching network).

The TCP/IP Transport Layer

- Similar to the OSI transport layer in functionality.
- It is designed to allow peer entities on the source and destination hosts to carry on a conversation.
- Two end-to-end transport protocols:
  - Transmission Control Protocol (TCP): a **reliable connection-oriented** protocol that allows an error-free delivery of a byte stream from one machine to another in the Internet.
  - User Datagram Protocol (UDP): an **unreliable connectionless** protocol used for applications that require prompt/quick but not necessarily reliable delivery, such as transmitting speech or video.

The TCP/IP Application Layer

- Incorporates the functions of the top three OSI layers.
- The TCP/IP application layer programs are intended to run directly over the transport layer.
- Contains all the higher-level protocols required by applications, e.g.,
  - TELNET: virtual terminal protocol, allows remote log-in onto a distant machine.
  - FTP (File Transfer Protocol): provides a way to move data efficiently from one machine to another.
  - SMTP: electronic mail (e-mail).
  - DNS (Domain Name System): mapping host names onto their network addresses.
  - NNTP (Network News Transfer Protocol): moving USENET news articles around.
  - HTTP: WWW page fetching.

The TCP/IP Protocols

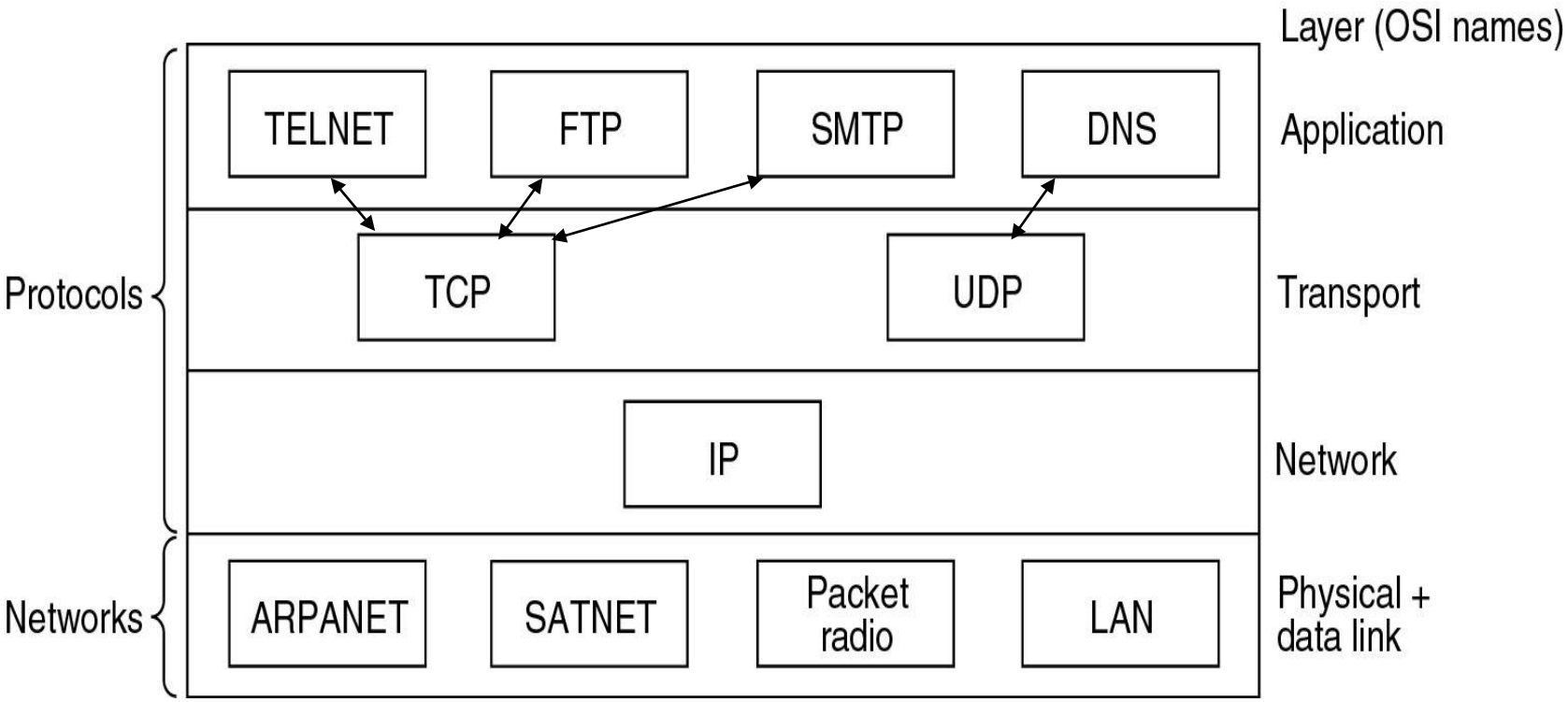


Fig. 1.20: Protocols and networks in the TCP/IP model initially.

1.4.3 A Comparison of the OSI and TCP/IP Reference Models

- **In common**:
  - Both are based on the concept of a stack of independent protocols.
  - The functionality of the layers is roughly similar.
    - The layer(s) above transport layer are transport service user.
    - The layers up through and including the transport layer are end-to-end.
  - Both have a network, transport, and application layer.
- **Differences**:
  - Central concepts
  - Model/protocol design ordering
  - Number of layers
  - Connection-oriented vs. connectionless services
  - TCP/IP reference model does not have session and presentation layers.

Differences between the OSI and TCP/IP Reference Models (1/3)

- Central concepts
  - OSI model:
    - Services: tell what the layer does and define the layer's semantics.
    - Interfaces: tell the processes above the layer how to access it; specify what the parameters are and what results to expect.
    - Protocols: tell the communicating parties how to proceed communication.
  - TCP/IP model: does not clearly distinguish the above three concepts.

⇨ The protocols in the OSI model are better hidden than in the TCP/IP model and can be replaced relatively easily as the technology changes.

Differences between the OSI and TCP/IP Reference Models (2/3)

- Model/protocol design ordering
  - OSI model:
    - Devised before the corresponding protocols were invented.
    - Not biased toward one particular set of protocols, a fact that made it quite general.
  - TCP/IP model:
    - The protocols came first. The model was really just a description of the existing protocols.
    - The protocols can fit the model perfectly. The model did not fit any other protocol stacks and, hence, was not useful for describing non TCP/IP networks.

Differences between the OSI and TCP/IP Reference Models (3/3)

- The number of layers
  - OSI model: 7 layers.
  - TCP/IP model: 4 layers.
- Connection-oriented vs. connectionless services
  - OSI model: supports both in the network layer, but only connection-oriented service in the transport layer.
  - TCP/IP model: supports only connectionless service in the network layer, but supports both modes in the transport layer.

A Critique of the OSI Model and Protocols

- Why did not the OSI model take over the world?
  - Bad timing
  - Bad technology: both the model and protocols are flawed.
    - Session and presentation layers are nearly empty, whereas the data link and network layers are overful.
    - The model and the associated service definitions and protocols are too complex and incomprehensible.
    - Some functions, such as addressing, flow control, and error control, appear again and again in each layer.
  - Bad implementations (bad quality): huge, unwieldy, and slow.
  - Bad politics: government bureaucrats.

Bad Timing of the OSI Model

- The time at which a standard is established is absolutely critical to its success.
- The standards should be written in the trough in between the two “elephants”.
- The interval between the two elephants should be reasonably long, not too short. Otherwise, the people developing the standards may get crushed.
- The standard OSI protocols got crushed. TCP/IP protocols were already there.

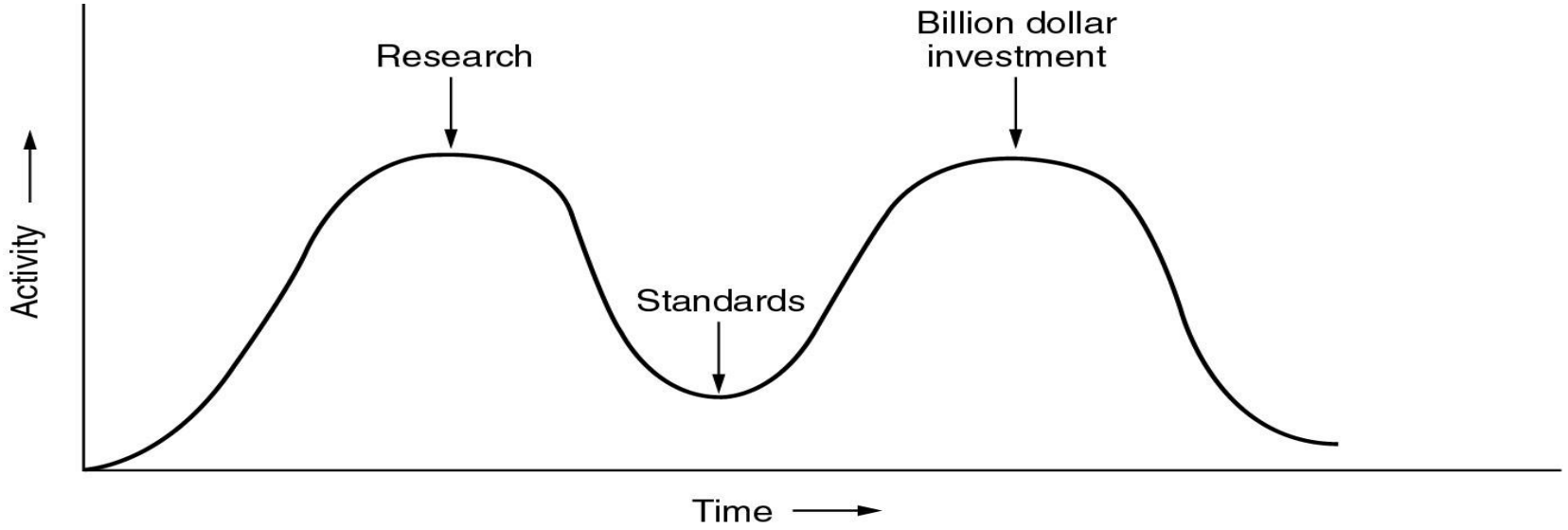


Fig. 1.21: The apocalypse of the two elephants.

A Critique of the TCP/IP Model

- The concepts of service, interface, and protocol are not clearly distinguished.
- Not a general model at all.
- The host-to-network layer is not really a layer. It is an interface between the network and data link layers.
- Does not distinguish (or even mention) the physical and data link layers.
- Many of the protocols, other than the IP and TCP protocols, were ad hoc, deeply entrenched, and hard to replace.

Hybrid Reference Model

- A modified OSI model without the session and presentation layers.
- Concentrates primarily on the TCP/IP and related protocols, as well as newer ones, such as IEEE 802.

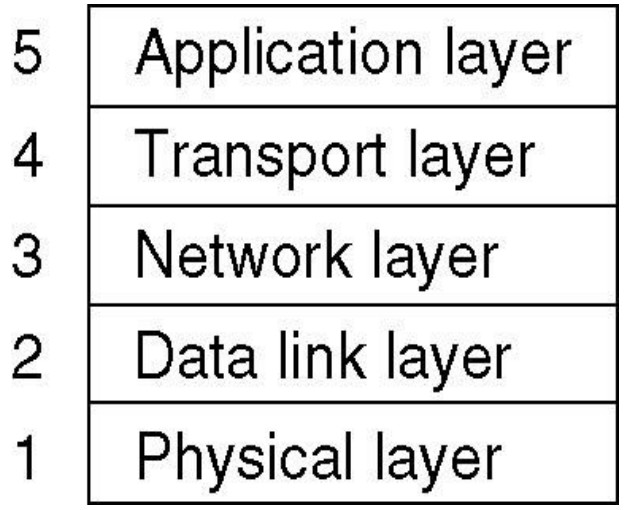


Fig. 1.22: The hybrid reference model to be used.

1.5 Example Networks

1.5.1 The Internet

1.5.2 A Connection-Oriented Network: ATM

1.5.3 Ethernet

1.5.4 Wireless LANs: IEEE 802.11

1.5.1 The Internet

- The Internet is a vast collection of different networks that use certain common protocols and provide certain common services. It is not a network at all.
- The TCP/IP reference model and protocols stack are the glue that holds the Internet together.
- Four main applications: E-mail, news, remote login, and file transfer.
- History:
  - The ARPANET: Advanced Research Projects Agency Network (1969-1980).
  - The NSFNET: National Science Foundation Network (1988-).
  - When the NSFNET and ARPANET were interconnected, the number of networks, machines, and users connected to them grew exponentially.
  - In the mid-1980s, people began viewing the collection of networks as an internet, and later as the Internet.

The ARPANET

- Datagram subnet:
  - Consists of minicomputers called Interface Message Processors (IMPs).
  - Each IMP is connected to at least two other IMPs for high reliability.
  - The first electronic store-and-forward packet-switching network.

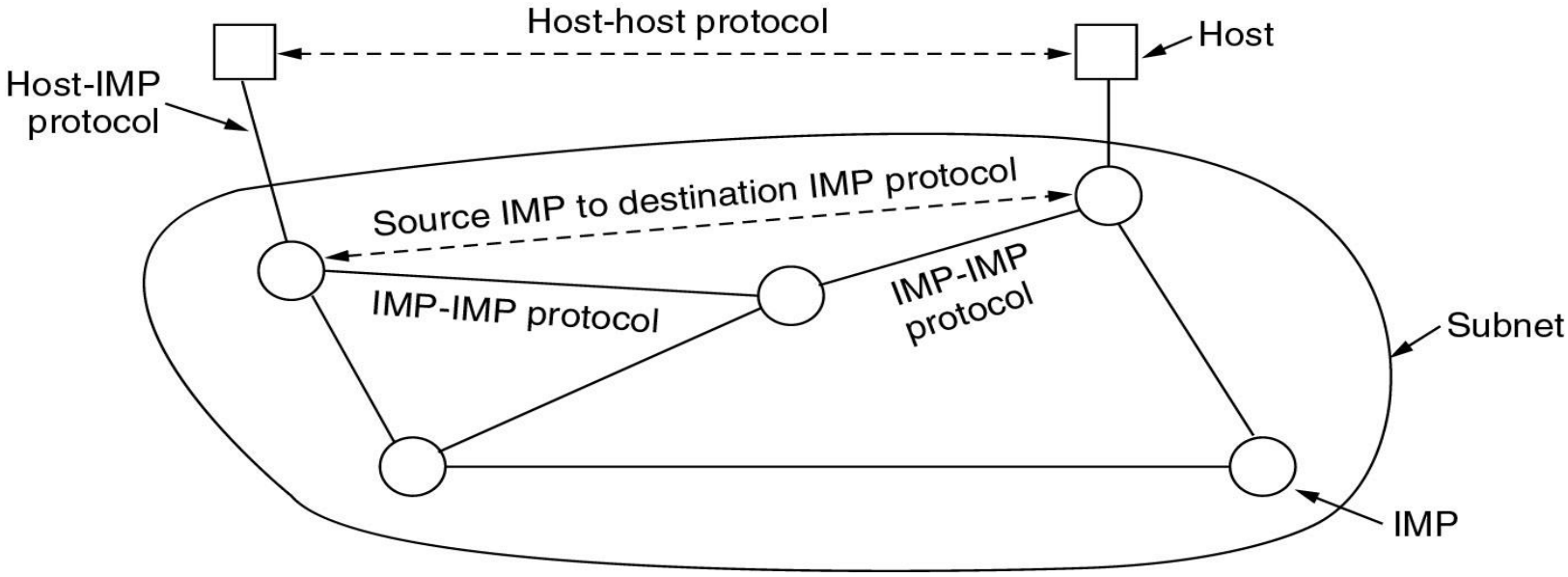


Fig. 1.23: The original ARPANET design.

The NSFNET

- Consists of the backbone network and the regional network.
- Connected to the ARPANET through a link between an IMP and a fuzzball.

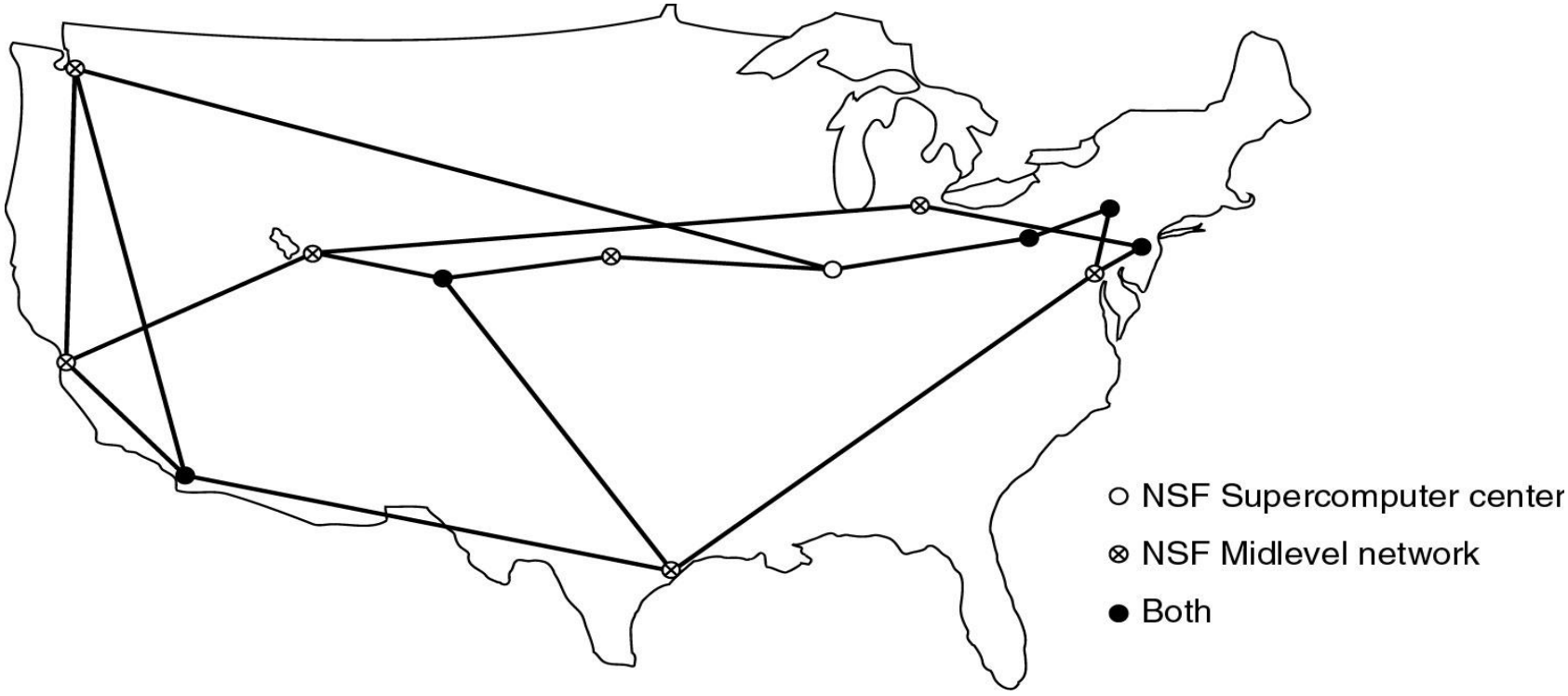


Fig. 1.24: The first NSFNET backbone in 1988.

Architecture of the Internet

- POP (Point of Presence), ISP (Internet Service Provider), and NAP (Network Access Point)

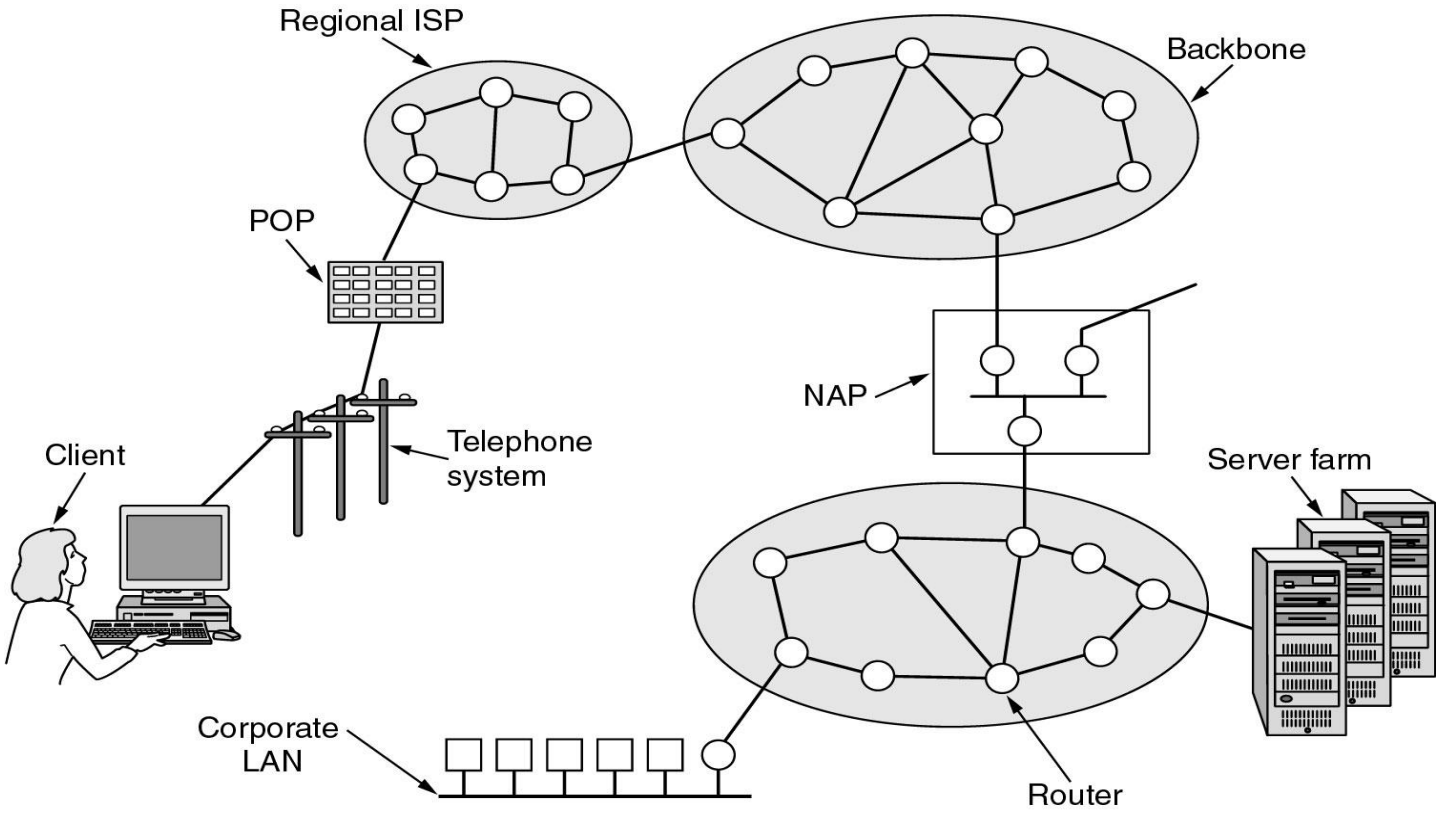


Fig. 1.25: Overview of the Internet.

1.5.2 A Connection-Oriented Network: ATM

- Asynchronous Transfer Mode (ATM): widely used within the telephone system, often for moving IP packets.
- Connections are often called virtual circuits; Each connection, temporary or permanent, has a unique connection identifier.

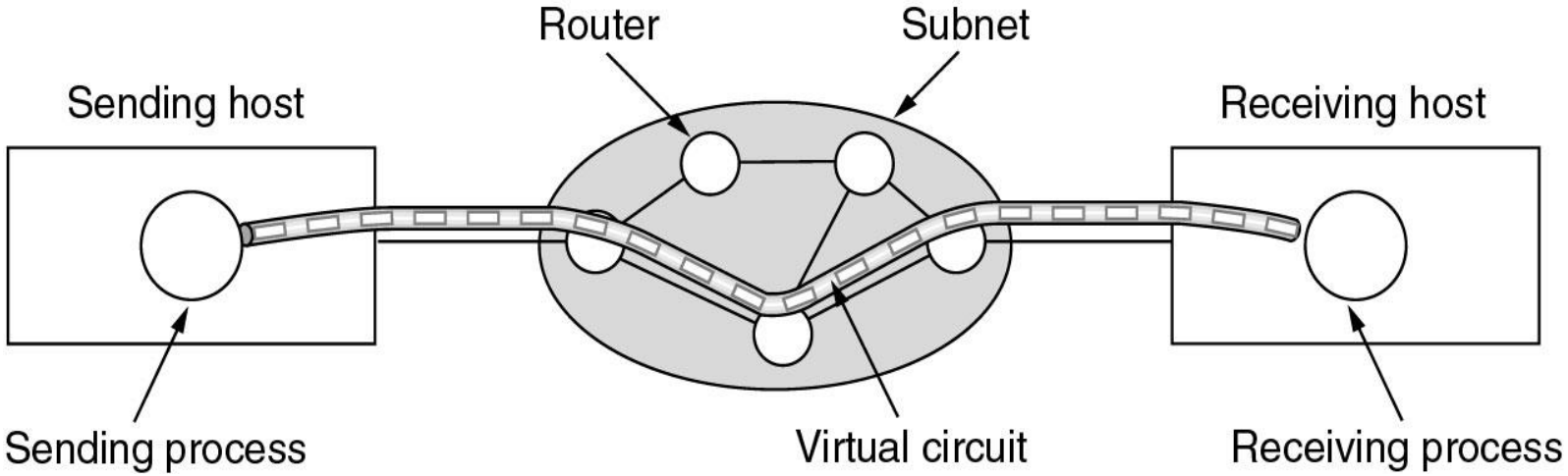


Fig. 1.26: A virtual circuit in the ATM network.

An ATM Cell

- The basic idea behind ATM is to transmit all information in small, fixed-size packets called cells.
- Advantages for having small, fixed size cells:
  - Can easily be handled by hardware routers; Software routers are not necessary.
  - The hardware can be set up to copy one incoming cell to multiple output lines.
  - Makes guaranteeing QoS easier, since small cells do not block any line for very long.
- A cell: 53 bytes=5 bytes (header)+48 bytes (payload/user data).

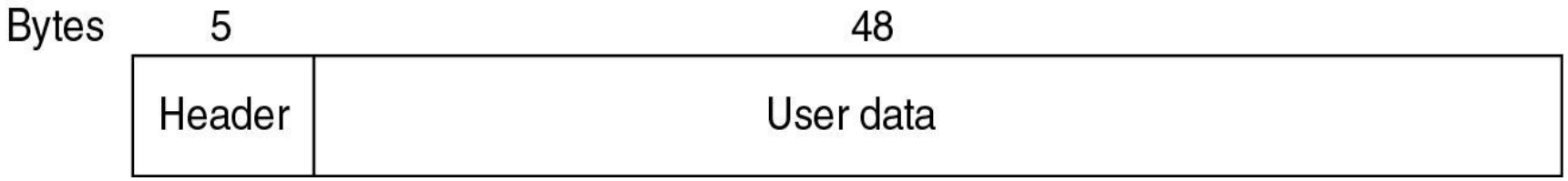


Fig. 1.27: An ATM cell.

The ATM Reference Model (1/2)

- Three layers: the physical, ATM, and ATM adaptation layers.
- Three dimentional:
  - User plane: deals with data transport, flow control, error correction, and other user functions.
  - Control plane: connection management.
  - Layer and plane management: resource management and interlayer coordination.

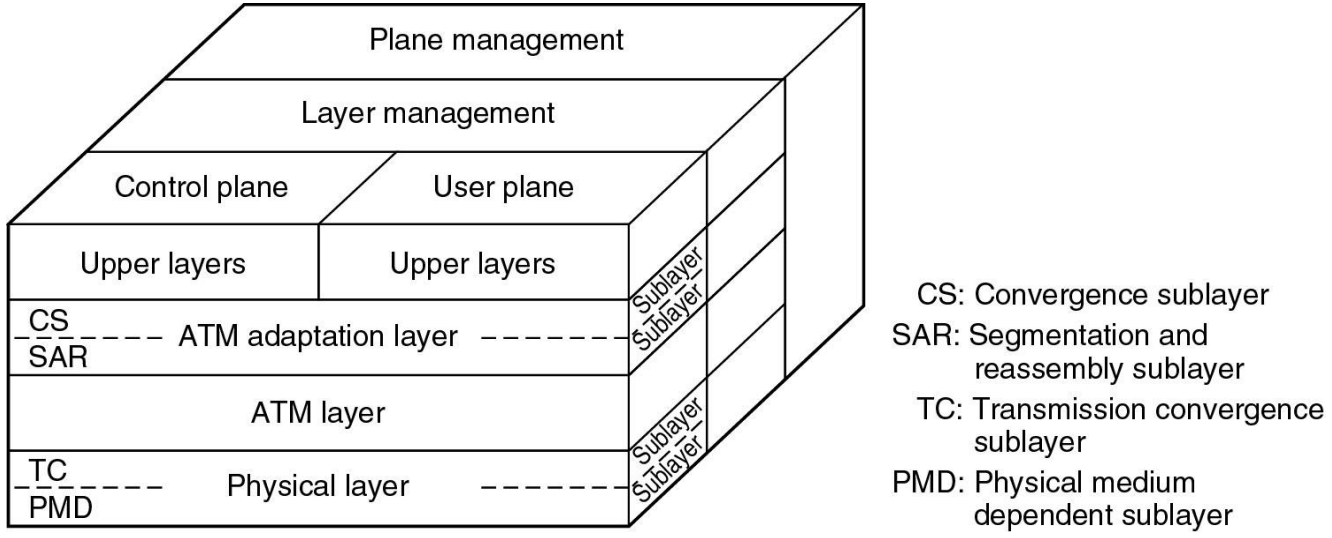


Fig. 1.28: The ATM reference model.

The ATM Reference Model (2/2)

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

Fig. 1.29: The ATM layers and sublayers, and their functions.

1.5.3 Ethernet

- The transmission medium: a thick coaxial cable (the ether) up to 2.5 km long (with repeaters every 500 meters).
- Up to 256 machines could be attached to the system via transceivers screwed onto the cable.
- Multidrop cable: a cable with multiple machines attached to it in parallel.

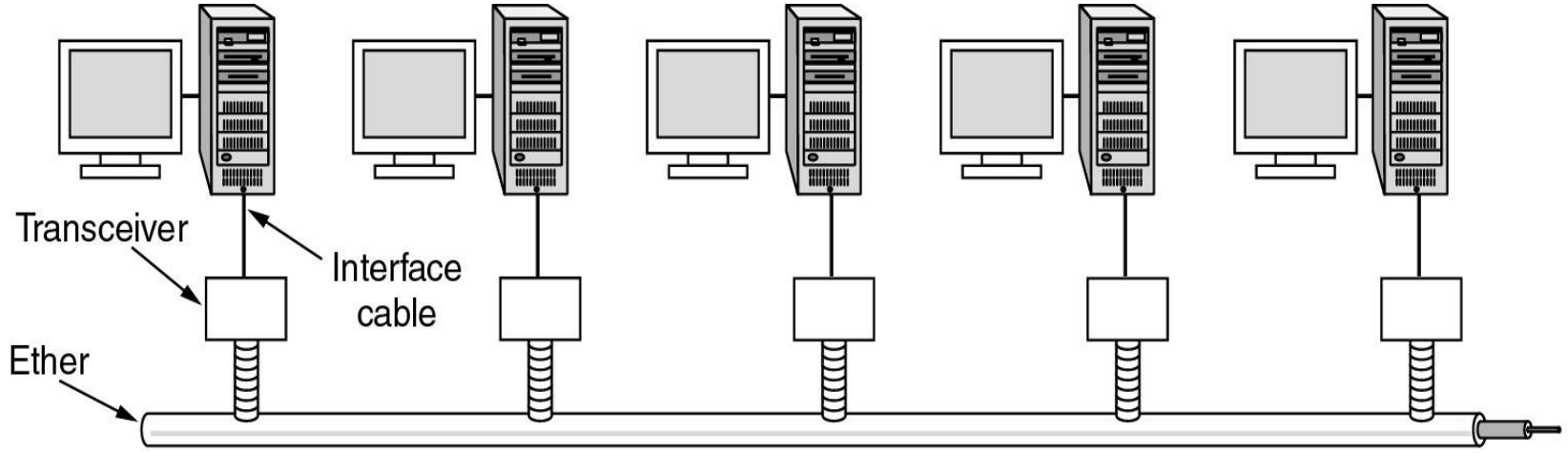


Fig. 1.30: Architecture of the original Ethernet.

1.5.4 Wireless LANs: IEEE 802.11

- The standard has two modes:
  - In the presence of a base station (access point): all communications go through the base station.
  - In the absence of a base station: the computers just send to one another directly.

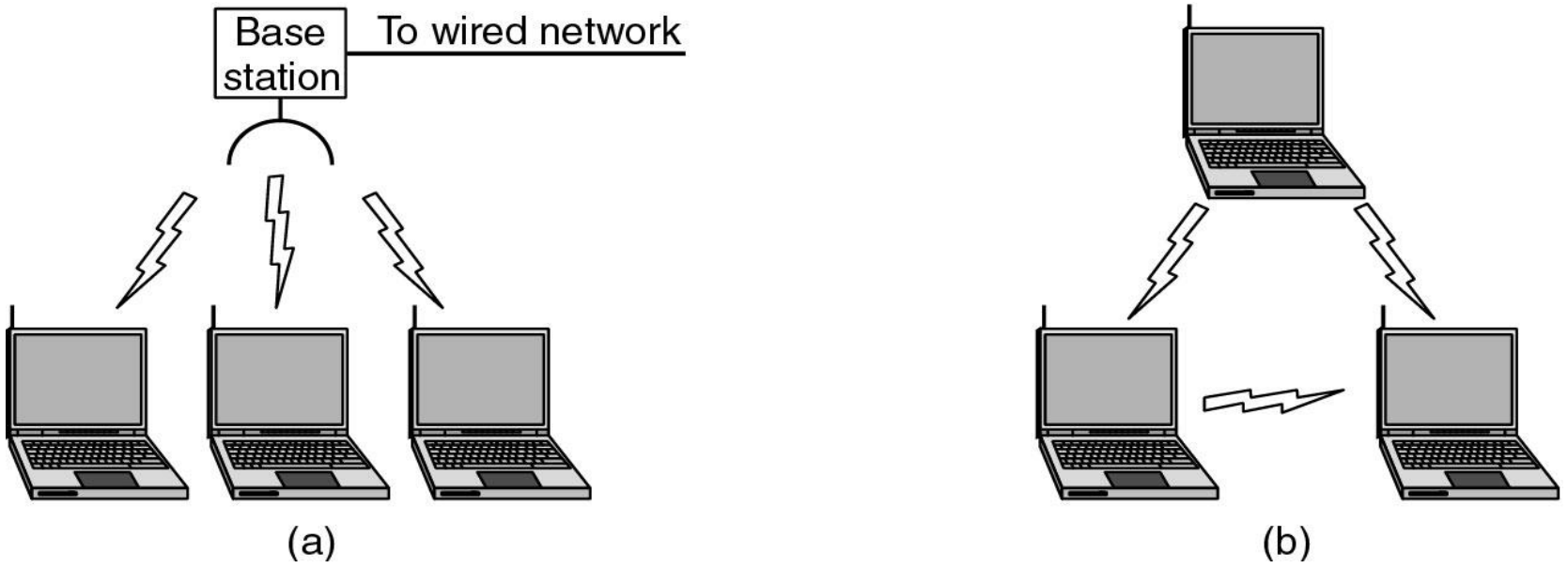


Fig. 1.31: (a) Wireless networking with a base station. (b) Ad hoc networking.

Wireless LANs

- IEEE 802.11 is compatible with Ethernet above the data link layer.
- Problems to be solved compared with Ethernet:
  - The range of a single radio may not cover the entire system.
  - A radio signal can experience multipath fading.
  - A great deal of software is not aware of mobility.
  - Hand-off is necessary when a laptop computer is moved away from one base station to another.

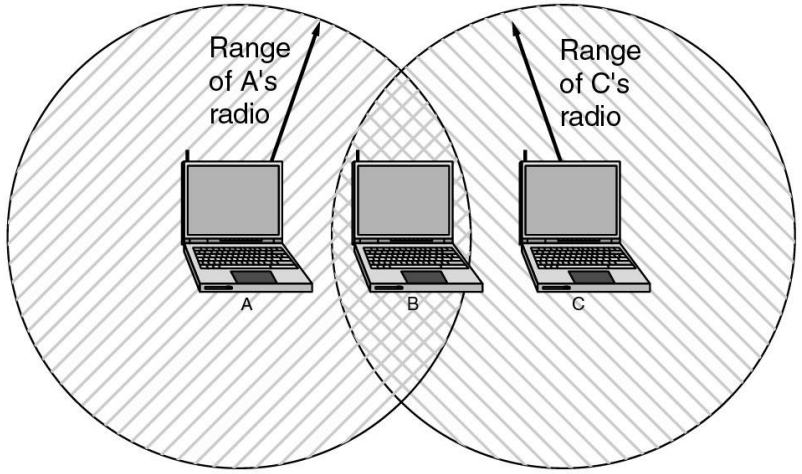


Fig. 1.32: The range of a single radio may not cover the entire system.

1.6 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

Fig. 1.33: The principal metric prefixes.