

Chapter 1

Introduction

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Computer Networks

- A computer network is an interconnected collection of autonomous computers.
- Networking Goals:
 1. Resource sharing - e.g., shared printer, shared files.
 2. Increased reliability - e.g., one failure does not cause system failure.
 3. Economics - e.g., better price/performance ratio.
 4. Communication - e.g., e-mail.

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Uses of Computer Networks

- Business Applications
- Home Applications
- Mobile Users
- Social Issues

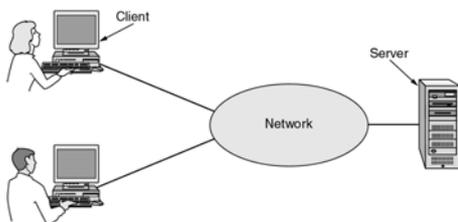
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Business Applications of Networks

- Business Applications
 - Resource sharing
 - Communication
 - Business with other companies
 - Business with consumers
- A client is a program requesting services. A server is a program providing services.

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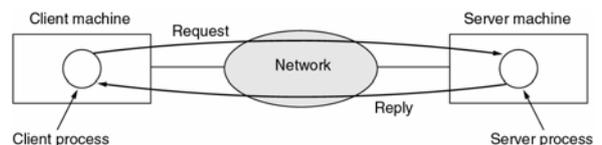
Business Applications of Networks



A network with two clients and one server.

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Business Applications of Networks



The client-server model involves requests and replies.

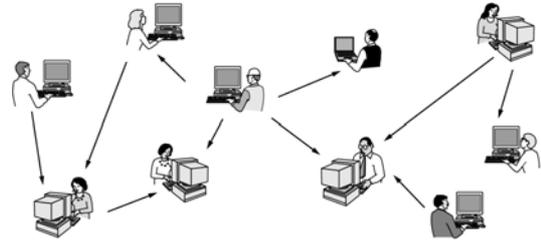
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Home Network Applications

- Access to remote information
- Person-to-person communication
- Interactive entertainment
- Electronic commerce

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Home Network Applications



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

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Home Network Applications

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.

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Mobile Network Users

Wireless	Mobile	Applications
No	No	Desktop computers in offices
No	Yes	A notebook computer used in a hotel room
Yes	No	Networks in older, unwired buildings
Yes	Yes	Portable office; PDA for store inventory

Combinations of wireless networks and mobile computing.

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Mobile Network Users

- **WAP** (Wireless Application Protocol) is the merger of cell phones and PDAs into tiny wireless computers.
- M-commerce (mobile-commerce)
 - Wireless PDAs for banking and shopping
 - Electronic wallet
- Personal area networks and wearable computers
 - A watch running Linux with wireless connectivity

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Social Issues

- Content
- Employee rights versus employer rights
- Government versus citizen
- Junk mail (spam)
- Identity theft
- Many problems could be solved if the computer security is taken seriously.

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How is a Network built?

- A network includes:
 - Special purpose **hardware** devices that:
 - Interconnect transmission media
 - Control transmission of data
 - Run protocol software
 - Protocol **software** that:
 - Encodes and formats data
 - Detects and corrects problems encountered during transmission

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Network Hardware

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

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Network Hardware

- Types of transmission technology
 - Broadcast links
 - Point-to-point links
- Messages on networks are called **packets**.
- Broadcasting – a packet transmitted is received by every machine
- Multicasting is transmission to a subset of the machines.

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Network Hardware

- **Point-to-point** networks consist of many connections between individual pairs of machines.
- Point-to-point transmission with one sender and one receiver is sometimes called **unicasting**.
- The **personal area networks** are meant for one person.

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Network Classification

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

Classification of interconnected processors by scale.

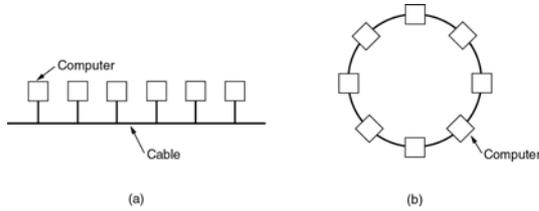
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Local Area Networks

- **Local area networks (LANs)** are privately-owned networks within a single building or campus of up to a few kilometers in size.
- LANs are distinguished by three characteristics:
 - (Restricted in) Size
 - Transmission technology: 10 Mbps to 10 Gbps (1 Mbps = 1,000,000 bits/sec, 1 Gbps = 1,000,000,000 bits/sec).
 - Topology: bus and ring

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Local Area Networks



Two broadcast networks

(a) Bus: Ethernet – IEEE 802.3

(b) Ring: IEEE 802.5, FDDI

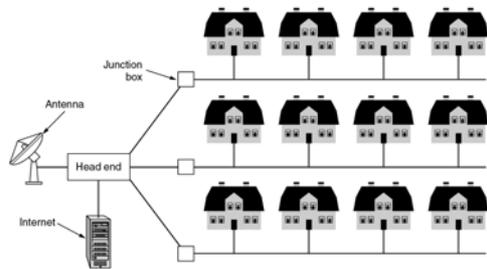
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Metropolitan Area Networks

- A **metropolitan Area Networks (MAN)** is a network that interconnects users with computer resources in a geographic area or region such as a city.
- Deployment
 - Cable television
 - Wireless: IEEE 802.16

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Metropolitan Area Networks



A metropolitan area network based on cable TV.

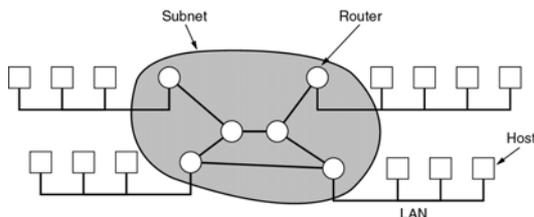
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Wide Area Networks

- A **wide area network (WAN)** spans a large geographical area, often a country and continent.
- It contains a collection of machines (**hosts**).
- The hosts are connected by a communication **subnet**.
- The subnet consists of two components:
 - Transmission lines
 - Switching elements: router

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Wide Area Networks



Relation between hosts on LANs and the subnet.

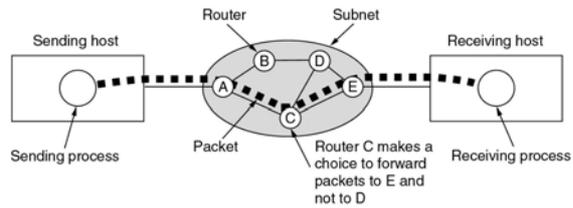
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Wide Area Networks

- A packet is sent in the subnet by a **store-and-forward** or **packet-switched**.
- The small packets with the same size are called **cells**.
- How a packet is routed is decided by the **routing algorithm**.

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Wide Area Networks



A stream of packets from sender to receiver.

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Wireless Communication

- Wireless communication is not a new idea.
 - Native American smoke signal
 - Chinese Beacon fire
 - Wireless telegraph using Morse Code
- Modern digital wireless systems have better performance, but the basic idea is the same.

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Wireless Networks

- Categories of wireless networks:
 - System interconnection
 - Wireless LANs
 - Wireless WANs

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System Interconnection

- System interconnection is all about interconnecting the components of a computer using short-range radio.
- Some companies got together to design a short-range wireless network called **Bluetooth** to these components.
- Bluetooth allows digital cameras, headsets, scanners, and other devices to connect to a computer in a short range.

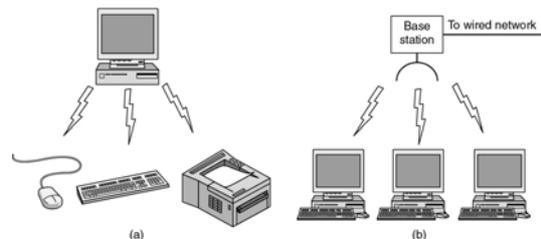
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Bluetooth Standard

- The Bluetooth document is adopted by **IEEE** (Institute of Electrical and Electronics Engineers) **802.15** as a basis for wireless personal area networks.
 - Work at 2.4 GHz
 - Transfer up to 2 Mbps
 - 10 meters range

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Wireless Networks



(a) Bluetooth configuration
(b) Wireless LAN

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Wireless LANS

- The wireless local area networks (LANs) are systems in which every computer has a radio modem and antenna with which it can communicate with other systems.
- Wireless LANs are common in small offices and homes.
- There is a standard for wireless LANs, called **IEEE 802.11**.

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Wireless WANS

- The wireless wide area networks (WANs) are systems used in the wide area.
- The radio network used for cellular telephones is an example of a low-bandwidth (low transfer rate) wireless system.
 - First generation: analog for voice
 - Second generation: digital for voice
 - Third generation: digital for voice and data

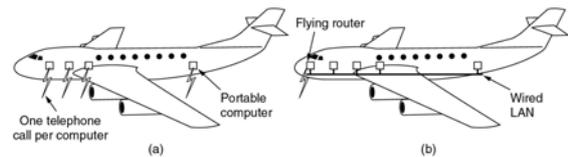
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Wireless WANS

- High-bandwidth wide area wireless networks are also being developed.
- A standard for it, called **IEEE 802.16**, has also been developed.
 - Work at 10-to-66 GHz
 - Transfer up to 155 Mbps
 - 30 miles range

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Wireless Networks



(a) Individual mobile computers
(b) A flying LAN

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Wireless WANS

- High-bandwidth wide area wireless networks are also being developed.
- A standard for it, called **IEEE 802.16**, has also been developed.
 - Work at 10-to-66 GHz
 - Transfer up to 155 Mbps
 - 30 miles range

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Home Network Categories

- Computers (desktop PC, PDA, shared peripherals)
- Entertainment (TV, DVD, VCR, camera, stereo, MP3)
- Telecomm (telephone, cell phone, intercom, fax)
- Appliances (microwave, fridge, clock, furnace, airco)
- Telemetry (utility meter, burglar alarm, babycam).

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Home Network Properties

- The network and devices have to be easy to install.
- The network and devices have to be foolproof in operation.
- Low price is essential for success.
- The main application is likely to involve multimedia.
- It must be possible to start out with one or two devices and expand the reach of the network gradually.
- Security and reliability will be very important.

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Internetworks

- Different networks are connected by means of machines called **gateways**.
- A collection of interconnected networks is called an **internetwork** or **internet**.
- A common form of internet is a collection of LANs connected by a WAN.

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Network Software

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

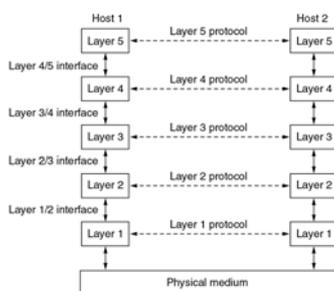
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Protocol Hierarchies

- To reduce design complexity, most networks are organized as a stack of **layers** or **levels**.
- A **protocol** is an agreement between the communication parties.
- The entities comprising the corresponding layers on different machines are called **peers**.
- The **physical medium** is the place through which actual communication occurs.
- Between each pair of adjacent layers is an **interface**. It defines which primitive operations and services the lower layer makes available to the upper one.

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Network Software Protocol Hierarchies



Layers, protocols, and interfaces.

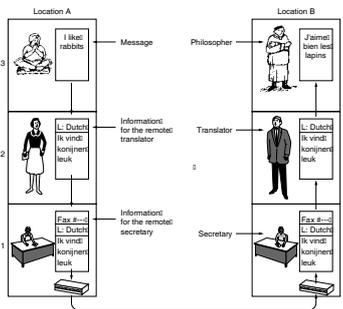
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Network Architecture

- A **network architecture** is a set of layers and protocols used to reduce network design complexity.
- A protocol stack is a list of protocols used by a certain system, one protocol per layer.

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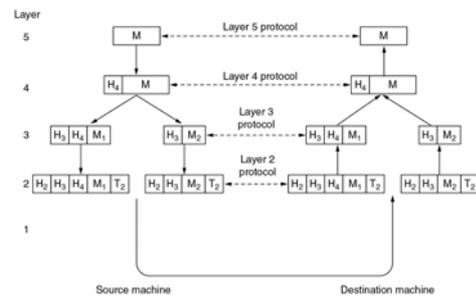
Protocol Hierarchies



The philosopher-translator-secretary architecture.

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Protocol Hierarchies



Example information flow supporting virtual communication in layer 5.

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Design Issues for the Layers

- Addressing: a specific destination needs to be specified.
- Error Control: errors need to be detected and corrected.
- Flow Control: A fast sender is kept from swamping a slow receiver with data.
- Multiplexing: the same connection is used for multiple, unrelated conversations.
- Routing: a route must be chosen for a packet to transmit.

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Connection-Oriented and Connectionless Services

- **Connection-oriented**: connection needs to be established before communication: telephone
- **Connectionless (datagram)**: connection needs not to be established before communication: postal system
- Each service can be characterized by a **Quality of Service (QoS)**.
- **Request-reply**: the sender transmits a request; the reply contains the answer.

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Connection-Oriented and Connectionless Services

- Reliable communication is communication where messages are guaranteed to reach their destination complete and uncorrupted and in the order they were sent.
- Why is unreliable communication used?
 - Reliable communication is not available.
 - The delay in a reliable service might not be acceptable such as real-time applications.

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Connection-Oriented and Connectionless Services

	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

Six different types of service.

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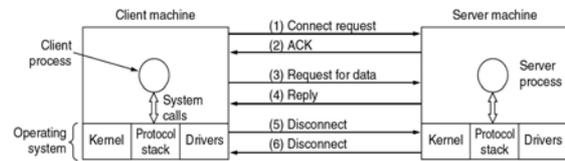
Service Primitives

- A service is specified by a set of **primitives** (operations) available to a user process to access the 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

Five service primitives for implementing a simple connection-oriented service. 49

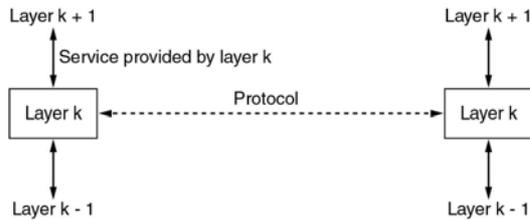
Service Primitives



Packets sent in a simple client-server interaction on a connection-oriented network. 50

Services to Protocols Relationship

- Services* relate to the interfaces between layers. *Protocol* relate to the packets sent between peer entities.



The relationship between a service and a protocol. 51

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

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Reference Model

- The **OSI (Open Systems Interconnection) 7-Layer Reference Model [ISO,1984]** is a guide that specifies what each layer should do, but not how each layer is implemented.
- The **TCP/IP Reference Model** is not of much use but the protocols associated with it are widely used.

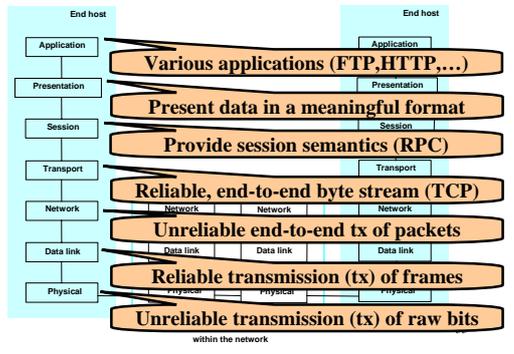
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Reference Model

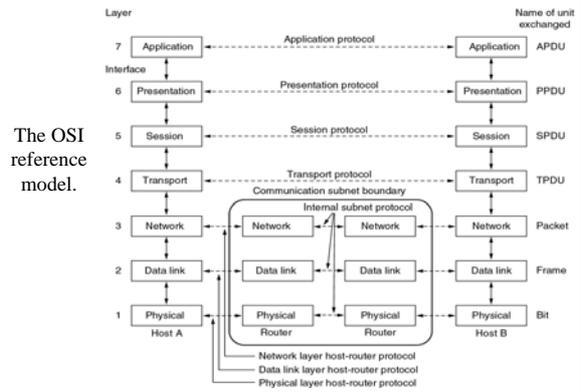
- OSI Reference Model
 - Physical Layer** - transmission of raw bits over a physical channel.
 - Data Link Layer** - provide an error-free point-to-point link to transmit data and control frames (sequencing frames, retransmission) between two directly connected nodes.
 - Network Layer** - provide a point-to-point link between any two switching nodes (routing, congestion control).
 - Transport Layer** - provide a link between any two hosts (connection-oriented or connectionless).
 - Session Layer** - manage conversation between two peer session entities.
 - Presentation Layer** - present data in a meaningful format (compress, encode, and convert data).
 - Application Layer** - a variety of user applications (e-mail, ftp, etc.).

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ISO 7-Layer Reference Model

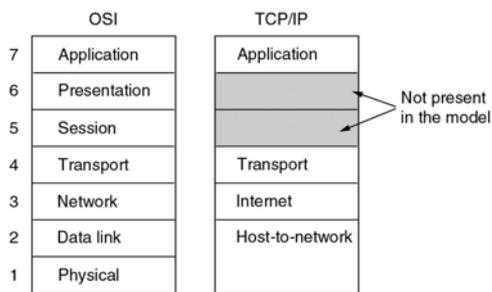


Reference Models



The OSI reference model.

Reference Models



The TCP/IP reference model.

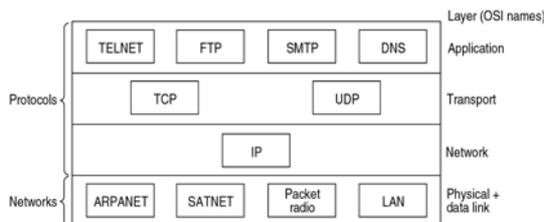
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TCP/IP Reference Model

- **TCP/IP Reference Model**
 - The **internet layer** defines an official packet format and protocol called **IP (Internet Protocol)** and specifies how IP packets are routed from the source to the destination.
 - The **transport layer** is designed to allow peer entities to talk.
 - **TCP (Transmission Control Protocol)** is a reliable connection-oriented protocol that allows a byte stream to be delivered.
 - **UDP (User Datagram Protocol)** is an unreliable, connectionless protocol for applications.
 - The **application layer** contains all the higher-level protocols.
 - The **host-to-network layer** points out that the host has to connect to the network.

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Reference Models



Protocols and networks in the TCP/IP model initially.

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Comparing OSI and TCP/IP Models

Concepts central to the OSI model

- Services
- Interfaces
- Protocols

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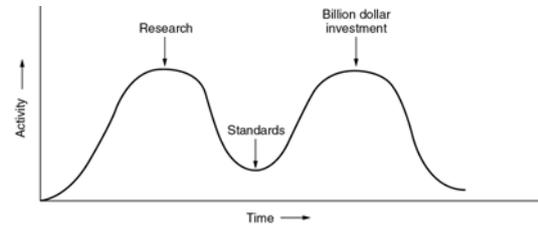
A Critique of the OSI Model and Protocols

Why OSI did not take over the world

- Bad timing
- Bad technology
- Bad implementations
- Bad politics

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Bad Timing



The apocalypse of the two elephants.

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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

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Hybrid Model

5	Application layer
4	Transport layer
3	Network layer
2	Data link layer
1	Physical layer

The hybrid reference model to be used in this book.

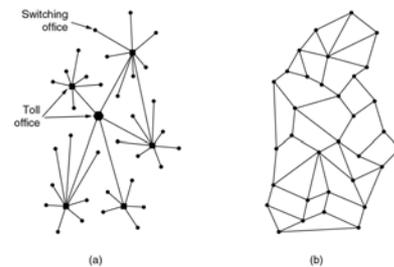
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Example Networks

- The Internet
- Connection-Oriented Networks:
X.25, Frame Relay, and ATM
- Ethernet
- Wireless LANs: 802.11

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The ARPANET



(a) Structure of the telephone system.

(b) Baran's proposed distributed switching system.

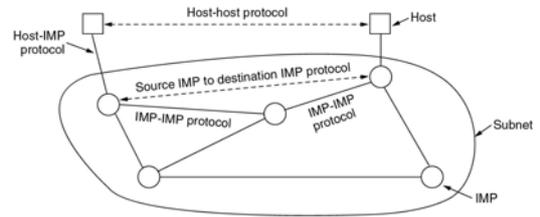
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The Internet

- **Interface Message processor (IMP)** is a processor-controlled switch used in packet-switched networks to route packets to their proper destination.
- **DNS (Domain Name System)** was created to organize machines into domains and map host names onto IP addresses.
- **ISPs (Internet Service Providers)** are companies that offer individuals and other companies access to the Internet.
- An **intranet** is a private internet designed for use by everyone within an organization.

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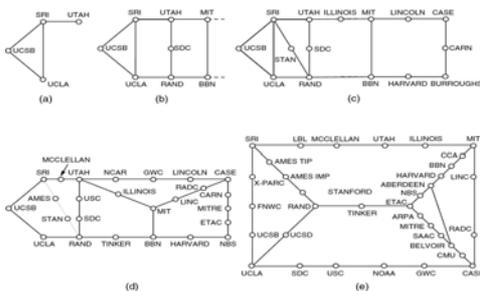
The ARPANET



The original ARPANET design.

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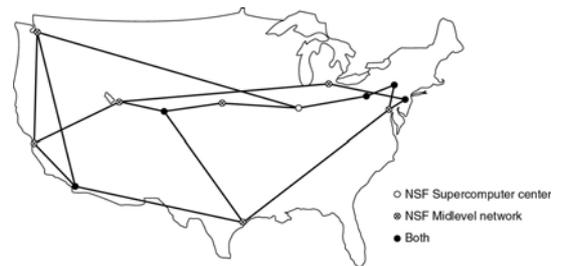
The ARPANET



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

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NSFNET



The NSFNET backbone in 1988.

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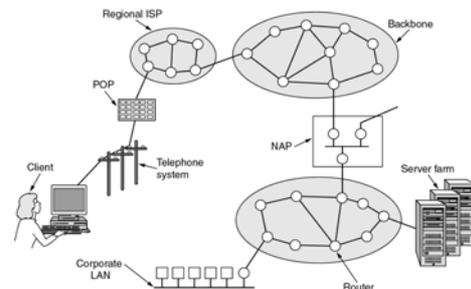
Internet Usage

Traditional applications (1970 – 1990)

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

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Architecture of the Internet



Overview of the Internet.

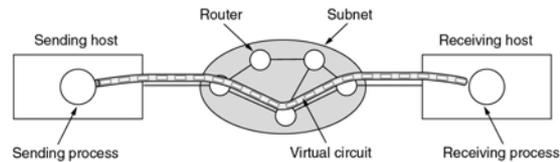
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Connection-Oriented Networks

- The **X.25** protocol, adopted as a standard by the Consultative Committee for International Telegraph and Telephone (CCITT), is a connection-oriented network protocol.
- **Frame relay** is connection-oriented network with no error control and no flow control.
- **ATM (asynchronous transfer mode)** is a dedicated-connection switching technology that organizes digital data into 53-byte cell units and transmits them over a physical medium using digital signal technology.

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ATM Virtual Circuits



A virtual circuit.

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ATM Virtual Circuits



An ATM cell.

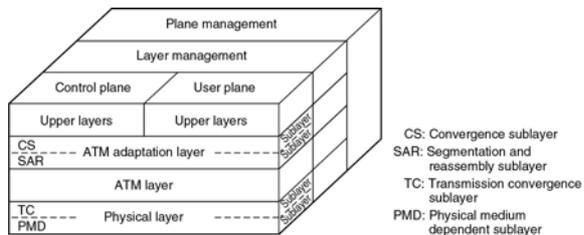
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ATM Reference Model

- The physical layer deals with the physical medium.
 - The PMD (Physical Medium Dependent) sublayer interfaces to the actual cable.
 - The TC (Transmission Convergence) sublayer converts back forth a bit stream to a cell stream.
- The ATM layer deals with cells and cell transport.
- The ATM adaptation layer deals with segmentation and re-assembly.
 - The SAR (Segmentation And Reassembly) sublayer breaks up packets into cells and put them back.
 - The CS (Convergence Sublayer) is used to offer different kind of services to the upper layers.

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The ATM Reference Model



The ATM reference model.

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The ATM Reference Model

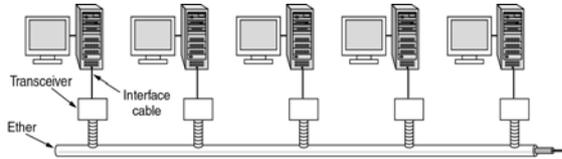
OSI layer	ATM layer	ATM sublayer	Functionality
3/4	AAL	CS SAR	Providing the standard interface (convergence) Segmentation and reassembly
2/3	ATM		Flow control Cell header generation/extraction Virtual circuit/path management Cell multiplexing/demultiplexing
2		TC	Cell rate decoupling Header checksum 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.

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Ethernet

Ethernet is the most widely-installed local area network (LAN) technology



Architecture of the original Ethernet.

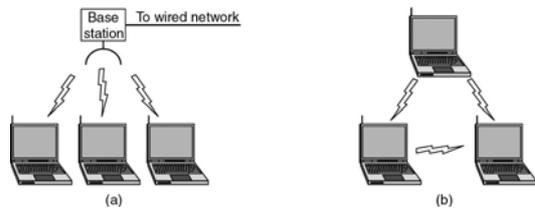
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Wireless LAN: 802.11

- A wireless LAN is one in which a mobile user can connect to a local area network (LAN) through a wireless (radio) connection.
- A standard, IEEE 802.11, specifies the technologies for wireless LANs.
- It is designed to work in two modes:
 - In the presence of a base station: **access point**
 - In the absence of a base station: **ad hoc networking**

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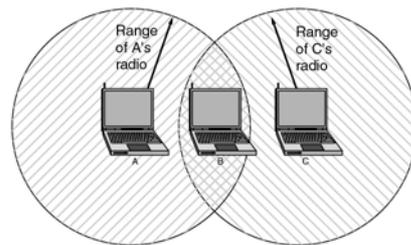
Wireless LANs



- (a) Wireless networking with a base station.
 (b) Ad hoc networking.

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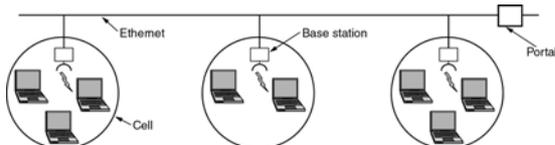
Wireless LANs



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

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Wireless LANs



A multicell 802.11 network.

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Network Standardization

- Who's Who in the Telecommunications World: **ITU**
- Who's Who in the International Standards World: **ISO, ANSI, NIST, IEEE**
- Who's Who in the Internet Standards World
 - **IAB (Internet Architecture Board)**
 - A **Request for Comments (RFC)** is a formal document from the Internet.
 - **IRTF (Internet Research Task Force)**
 - **IETF (Internet Engineering Task Force)**

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Telecommunications World - ITU

- Main sectors
 - Radiocommunications (ITU-R)
 - Telecommunications Standardization (ITU-T)
 - Development (ITU-D)
- Classes of Members
 - National governments
 - Sector members
 - Associate members
 - Regulatory agencies

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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.

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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	fermi	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	0.00000000000000000000001	yocto	10 ²⁴	1,000,000,000,000,000,000,000,000	Yotta

- The metric prefixes are typically abbreviated by their first letters, with the units greater than 1 capitalized.
- m is for milli and μ is for micro.
- For storage, Kilo means 2¹⁰. For communication, 1-Kbps means 1000 bits per second.

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