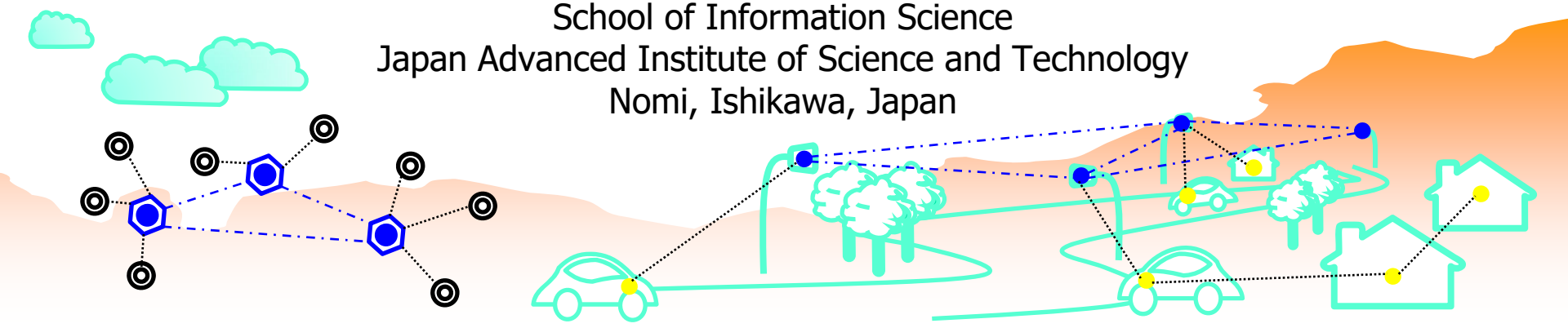
I226
Computer Networks

Course Description

Assoc. Prof. Yuto Lim

School of Information Science
Japan Advanced Institute of Science and Technology
Nomi, Ishikawa, Japan



Instructor's Profile

Associate Professor

Yuto LIM

B.Eng. (1998), M.IT (2000), Ph.D. (2005)
Regular Members of IEEE, IEICE, IPSJ
Publication: Journal (60+), Int. Conf. (100+), Local Conf. (98+), Patent (8+), Standardization (18+)

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- Current Research Interests
  - Wireless, Sensor, Ad Hoc, IoT, Home Networks, Cyber-Physical Systems, Energy Distribution, Quantum Networks, Communication Protocol Standardization, Network Softwarization, Optical Wireless Communication, AI Empowered Wireless, Network Emulation
- Past Research Experience
  - 2D Communication System, WMN, MANET, Game Theory, Multihop Wireless Networks, VANET, ATM
- Recent Professional Activities
  - Steering Committee of IPSJ MBL, IEICE IN, IEICE RCC
  - Associate Editor of IJAIS + Reviewer of IEEJ, IEICE, IEEE
  - TPC of ICAIT, ICMU, SoSE, IWCMC
- Motto
  - For forthcoming research on wireless, sensor, and energy (WiSE)
- Hobby and Sport
  - Traveling, Watching Movie, Shogi, Bowling, Badminton

Course Overview

- Course structure

	Chapter
General and concept	1
Protocol stack	2, 3, 4, 5, 6, 7
Interconnection, security, traffic	8, 9, 10
Design, implementation, management	11,12
Latest topics	13

- Related course
  - I441 Advanced Computer Networks (Shinoda)
  - I450 Network Design Laboratory (Lim)
  - I649E Advanced Wireless Networks (Lim)
- Reference
  - A.S. Tanenbaum, “Computer networks,” Prentice Hall (Main)
  - W. Stallings, “Data and computer communications,” Prentice Hall
  - B.A. Forouzan, “Data communications and networking” McGraw-Hill
  - W.R. Stevens, “TCP/IP illustrated, vol. 1: The protocols,” Addison-Wesley

Assessment and Schedule

- Assessment

Assignment	= 30%
Mid-term Examination	= 30%

Final Examination	= 40%

- Schedule

12 Oct (Wednesday)	10:50 ~ 12:30	Chapter 1 Introduction
17 Oct (Monday)	09:00 ~ 10:40	Chapter 2 Physical Layer
19 Oct (Wednesday)	10:50 ~ 12:30	Chapter 3 Data Link Layer
24 Oct (Monday)	09:00 ~ 10:40	Chapter 4 Network Layer I
26 Oct (Wednesday)	10:50 ~ 12:30	Chapter 5 Network Layer II
31 Oct (Monday)	09:00 ~ 10:40	Chapter 6 Transport Layer
02 Nov (Wednesday)	10:50 ~ 12:30	Chapter 7 Application Layer and Network Programming Basics
07 Nov (Monday)	09:00 ~ 10:40	Mid-term Examination
07 Nov (Monday)	13:30 ~ 15:10	Chapter 8 Name Service and Internetworking
09 Nov (Wednesday)	10:50 ~ 12:30	Chapter 9 Wide-area Networks and Security
14 Nov (Monday)	09:00 ~ 10:40	Chapter 10 Traffic and Communication Engineering
16 Nov (Wednesday)	10:50 ~ 12:30	Chapter 11 Design of Network Equipments and Protocols
21 Nov (Monday)	09:00 ~ 10:40	Chapter 12 Design, Implementation, and Operation of Network Systems
21 Nov (Monday)	13:30 ~ 15:10	Chapter 13 Latest Topics
05 Dec (Monday)	09:00 ~ 10:40	Final Examination

Assignment (30%)

For lecture slide, please go to http://www.jaist.ac.jp/is/labs/lim-lab/course/I226E/index.php
User Name: student Password: comnet

Course Aim and Grading System

- Course Aim
  - To provide the basic technology and concepts for computer networks
  - To provide a wide-range of general knowledge on computer networks
  - To provide the basic network programming skills
- Grading System

Excellent	A	80% ~ 100%
Good	B	70% ~ 79%
Fair	C	60% ~ 69%
Fail	F	0% ~ 59%

- Study Tips and Tricks
  - Try to understand all the technologies and concepts for computer networks
  - Try to work hard with **your own understandings** on the given assignment

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Chapter 1
Introduction

Assoc. Prof. Yuto Lim

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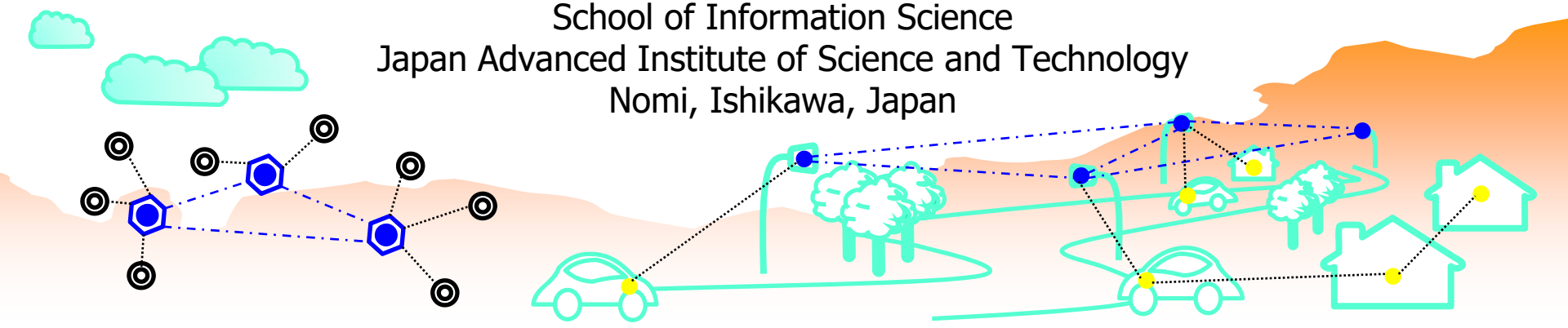


Objectives of this Chapter

- Give an understanding what computer networks are, what their network hardware concepts
- Furnish a basic knowledge on network protocol and architecture
- Offer an insight of layer design issues, the OSI model and its service primitives
- Explain the TCP/IP protocol and the success of the nimble Internet today

Outline

- What is Network, Computer Network?
- Network Hardware: Concepts
- Switching System
- Network Software: Protocol Hierarchies
- Network Architecture
- Design Issues for the Layers
- Connection-oriented and Connectionless
- Service Primitives
- OSI Reference Model
- Role of Each Layer
- TCP/IP Protocol Suite

What is a Network?

- Quoted from Oxford Dictionaries site:
  - An arrangement of intersecting horizontal & vertical lines
  - A complex system of railways, roads, etc
  - A group of broadcasting stations that connect to broadcast a program simultaneously
  - A group of people who interact together
  - A number of interconnected computers, operations, etc
- Network is a set of devices (nodes) connected by media links

Figure: Example of a basic network

  - A node can be a computer, printer, or any other device that is capable of sending and/or receiving data
  - A link that connecting the nodes is called communication channel

What is a Network? (cont.)

- Networks use distributed processing, a task is divided among multiple computers
- Advantages of distributed processing:
  - Security/encapsulation, e.g., User access to ATM of a bank
  - Distributed databases, e.g., User access to Internet website
  - Faster problem solving, e.g., Multiple PCs break secret code
  - Security through redundancy, e.g., a backup PC is used
  - Collaborative processing, e.g., Multiuser for gaming
- To achieve effective and efficient in a network, three criteria must meet:
  - Performance – transit time (time required for a message to travel from one device to another)
  - Reliability – frequency of failure
  - Security – protecting data from unauthorized access

Benefits of a Network

- Resource sharing
  - Physical resources, i.e., printers, scanners & CD-ROM drives
  - Logical resources (software), i.e., databases and applications
- Remote Access and File Transfer
  - FTP and Telnet (remote login) commands
- Communications
  - Service that includes e-mail, chat, teleconferencing, etc
- Savings
  - All above-mentioned services save money, energy, and resource

Computer Network & Distributed System

- Computer network is a collection of computing devices that are connected in various ways in order to communicate and share resources
- Does the Internet or the WWW is a computer network?
  - Internet is not a single network but a network of networks
  - WWW is a distributed system that runs on top of Internet
- Distributed system is a collection of independent computers appears to its users as a single coherent system

Computer Network	Distributed System
Multiple autonomous computers are visible	Autonomous computers are not visible
User oriented management A user physically logs into a particular machine and explicitly submit jobs remotely, moves files around and generally handles all management personally, being aware of its location on the network	System oriented management A user remotely logs in to a distributed system not being aware which processor, memory or storage being used. Nothing has to be done explicitly, all automatically done by the system
Computers are connected in the same physical location, using different styles, e.g., ring, star, etc	Distributed system can be considered as a type of computer network but in a large scale. Different computers are connected at different physical locations across cities, states, etc

Usages of Computer Networks: Business

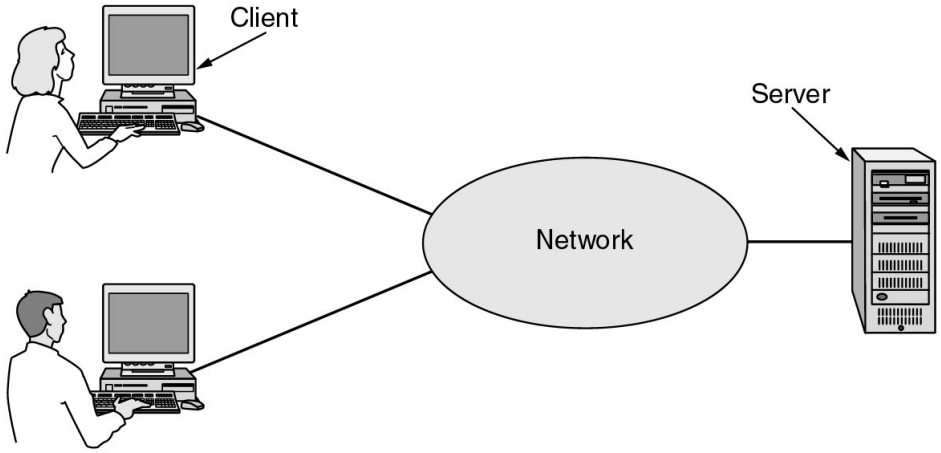


Figure: A network with two clients and one server

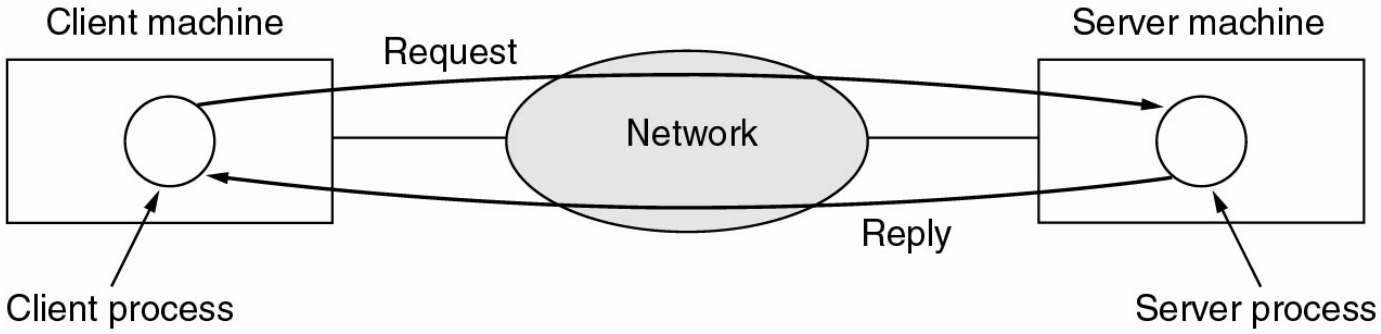


Figure: The client-server model involves requests and replies

Usages of Computer Networks: Others

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

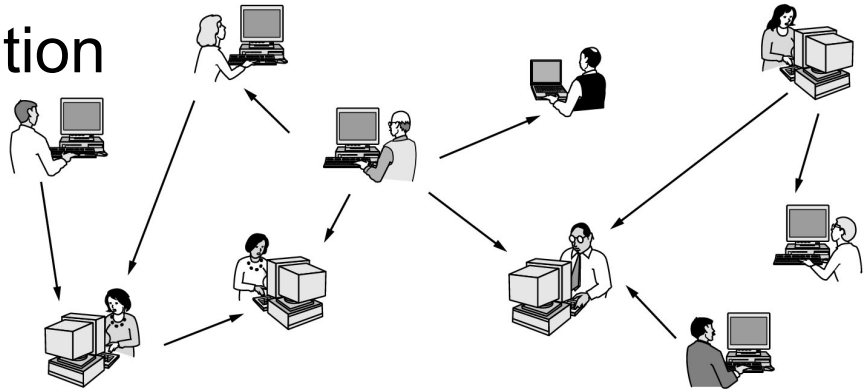


Figure: In peer-to-peer system there are no fixed clients and servers

Table: Some forms of e-commerce

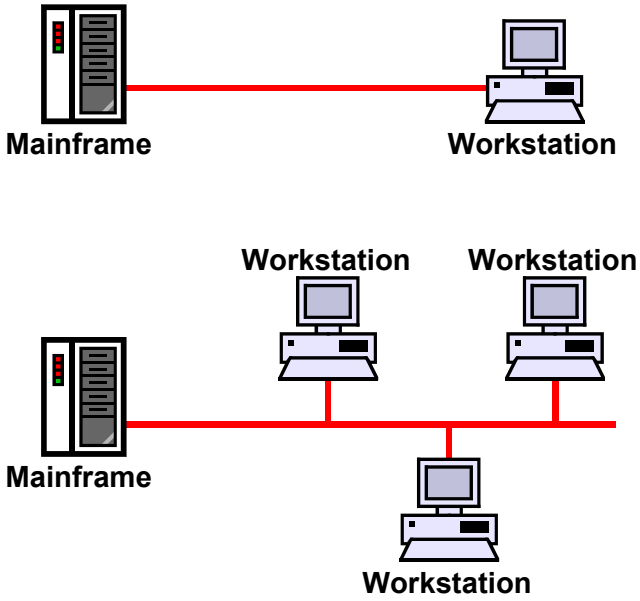
Tag	Full name	Example
B2C	Business-to-consumer	Ordering books on-line
B2B	Business-to-business	Car manufacturer ordering tires from supplier
G2C	Government-to-consumer	Government distributing tax forms electronically
C2C	Consumer-to-consumer	Auctioning second-hand products on-line
P2P	Peer-to-peer	File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

Network Hardware: Concepts

- General concepts are
  - Line configuration
  - Transmission mode
  - Form of communication
  - Topology
  - Types of networks

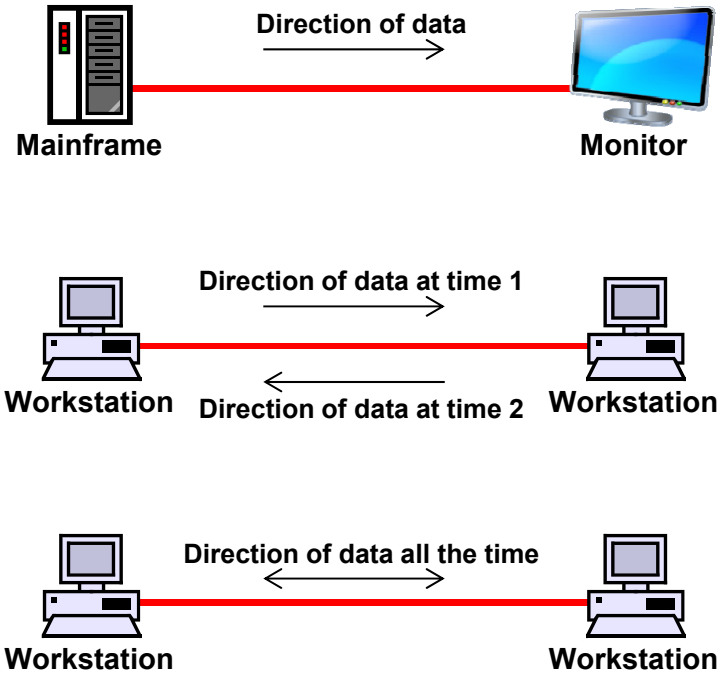
Line Configuration

- Definition: the way two or more communication devices attach to a link
- Two possible line configurations
  - Point-to-point
  - Point-to-multipoint
- Point-to-point configuration
  - A dedicated link between two devices
  - The entire capacity of the channel is reserved for transmission between those two devices
- Point-to-multipoint configuration
  - One in which more than two specific devices share a single link
  - The capacity is shared either spatially or temporally



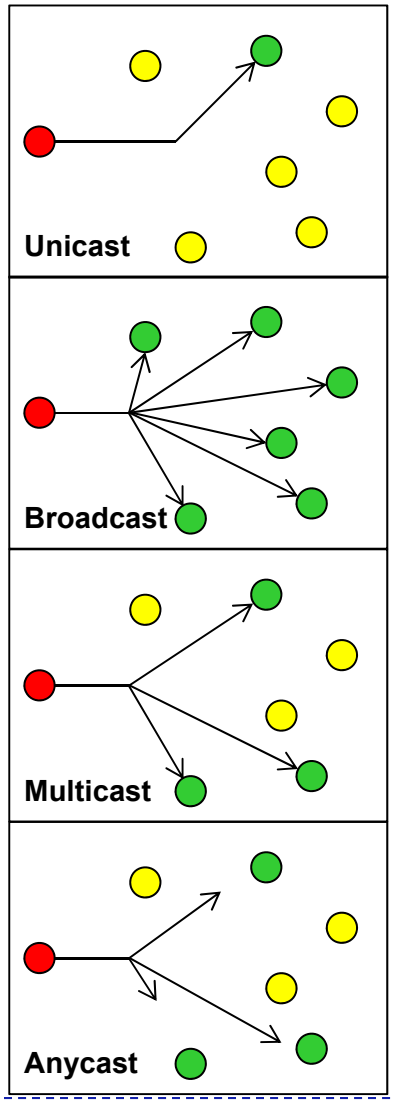
Transmission Mode

- Definition: the direction of signal flow between two linked devices
- Three types of transmission modes
  - Simplex mode: only one of the two stations on a link can transmit; the other can only receive
  - Half-duplex mode: each station can both transmit and receive, but not at the same time
  - Full-duplex mode: both stations can transmit and receive simultaneously



Form of Communication

- Unicast
  - Data is sent from only one sender to only one receiver
  - E.g., HTTP, SMTP, Telnet, SSH, POP3
- Broadcast
  - Data is sent from just one computer but is received by all the computers connected to the network
  - E.g., DHCP, ARP
- Multicast
  - There may be more than one senders and the data sent is meant for a set of receivers
  - E.g., video transmission network
- Anycast
  - Data from one sender are routed to the topologically nearest node in a group of potential receivers
  - E.g., DNS, IPv6 Translation, Content Delivery Networks



Topology

- Definition: the way a network laid out, either logically or physically
- Two or more devices connect to a link; two or more links form a topology
- Five possible basic topologies:
  - Ring, Star, Mesh, Tree, Bus

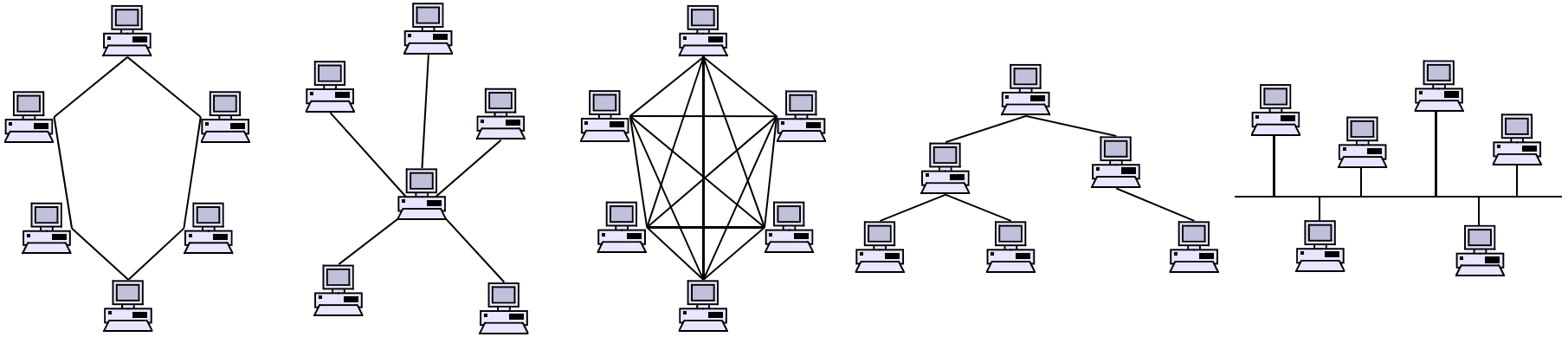
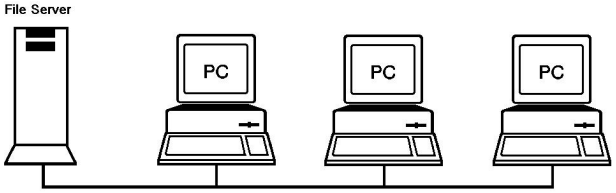


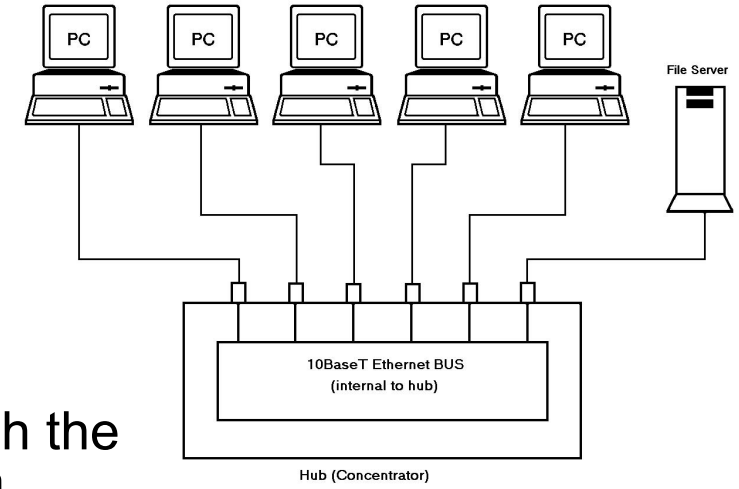
Figure: Various topologies

Bus Topology

- In a Bus topology, all devices attach to the same transmission medium, which has a physical beginning and end



- Bus topology is implemented using electrical cable (coaxial) and the ends of the cable must be terminated with a terminating resistor that matches the impedance of the cable
- Bus topology is considered a multipoint system because all devices tap into the same backbone cable
- E.g., Ethernet 10Base2 or 10Base5
- In Ethernet, each device connects to the coaxial through T-connector (BNC). The devices both transmit and receive through the same connector. Therefore, Ethernet is a logical as well as physical bus



Types of Networks

- Network is categorized by its size, its ownership, the distance it covers, and its physical architecture
- Three primary types of networks:
  - Local Area Network (LAN) privately links the devices in a single place, e.g., office
  - Metropolitan Area Network (MAN) a means of connecting a number of LANs into a larger network, so that resources may be shared LAN-to-LAN and device-to-device
  - Wide Area Network (WAN) long-distance transmission of data, voice, image, and video information over large geographical areas, e.g., country

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

Figure: Classification of interconnected processors by scale

Typical LAN

- LAN consists of a small group of computers (but can reach thousands), including client and server nodes
- LANs are distinguished by their size, transmission technology and physical topology

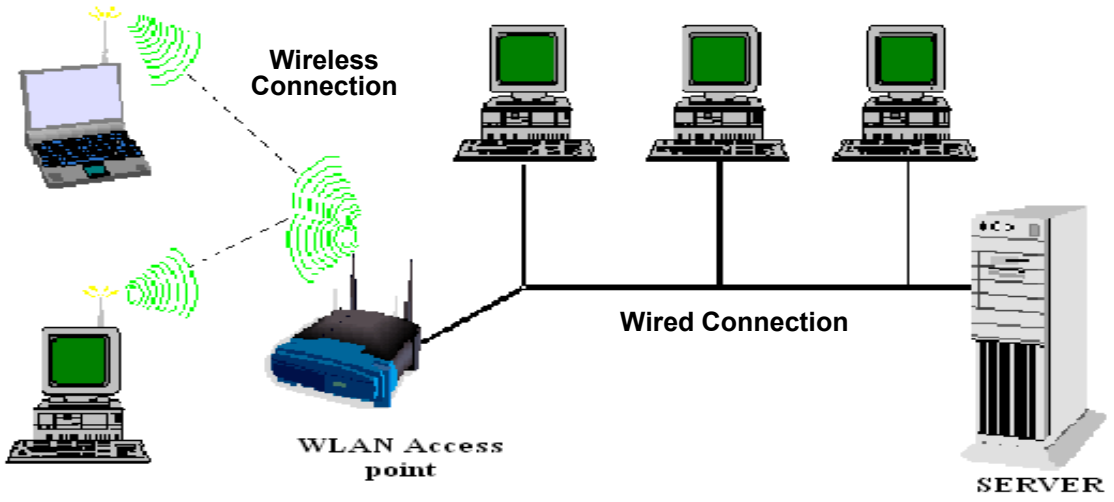
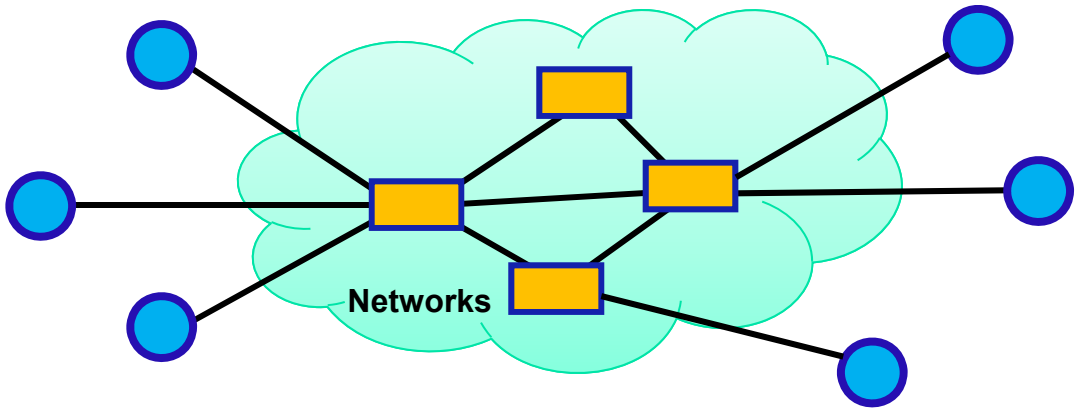


Figure: LAN consists of wireless and wired connections

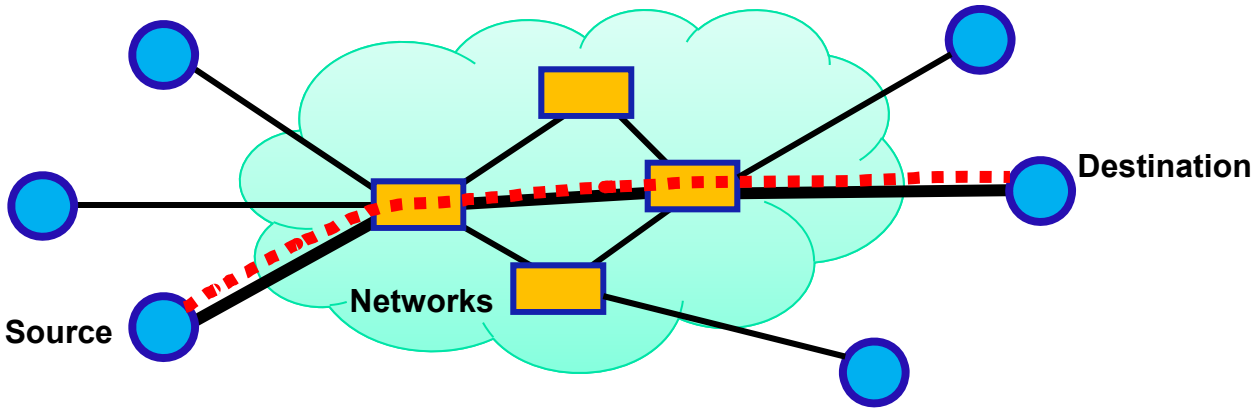
- Today, most LANs use fixed wiring and wireless connections
- The advantage of a WLAN is that WLAN does not need to be a 'hard-wired' connection between the computers. This allows users' computers to easily join and leave the network, and move around

Switching System



- Need to share network resources
- How? Switched network
  - Node “A” gets resources sometimes
  - Node “B” gets them sometimes
- Intermediate nodes act as “Routers” or “Switches”
- What mechanisms can share resources?
  - Circuit switching
  - Packet switching

Circuit Switching



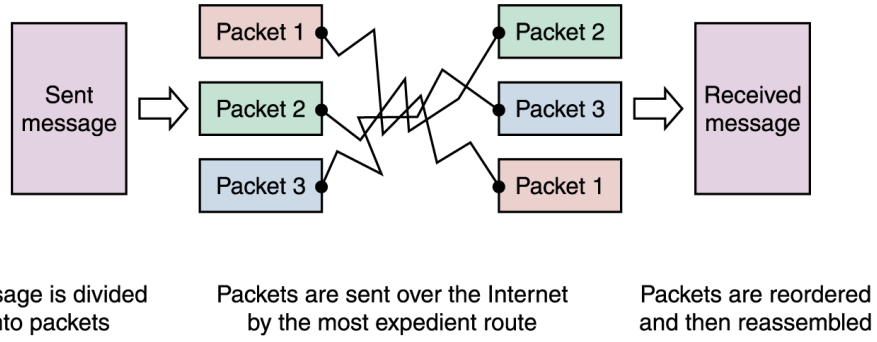
- Uses a dedicated communications path established for duration of conversation. E.g., telephone network
- Operation
  - Source establishes a connection (circuit) to the destination
  - Each router (switch) along the way may reserve some bandwidth for the data flow
  - Source sends the data over the circuit
  - No need to include the destination address with the data since the routers know the path

Shortcomings of Circuit Switching

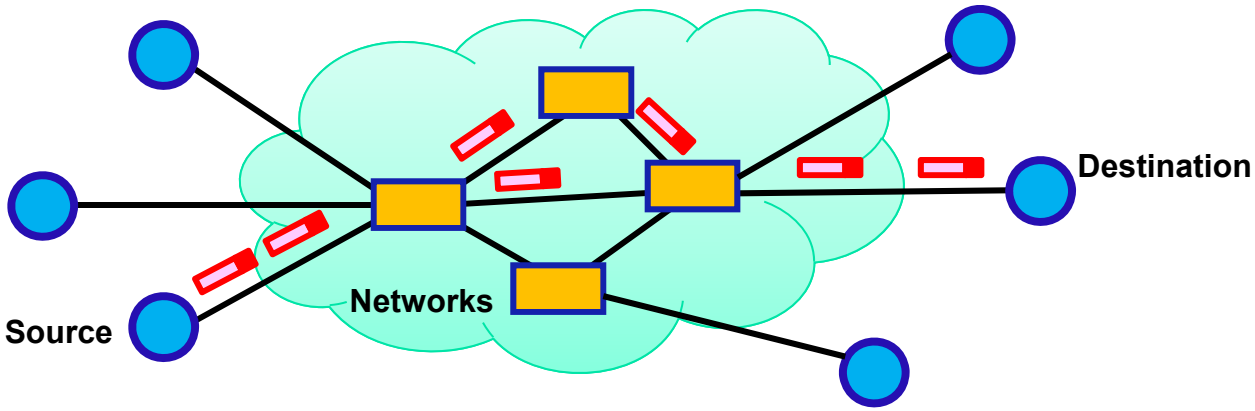
- What about many connections?
  - Many wires (e.g., those big 200-pair cables)
- Circuits has some very attractive properties
  - Fast and simple data transfer, once the circuit has been established
  - Predictable performance since the circuit provides isolation from other users
  - Guaranteed bandwidth
- But it also has some shortcomings
  - How about bursty traffic? Circuit will be idle for significant periods of time
  - How about users with different bandwidth needs? Do they have to use multiple circuits
- Alternative solution: packet switching

Packet Switching

- Data sent out of sequence
- Small chunks (packets) of data at a time
- Packets passed from node to node between source and destination
- Used for terminal to computer and computer to computer communications
- Analogy: a letter in surface mail



Packet Switching (cont.)



- Operation
  - Source sends information as self-contained packets that have an address
  - Source may have to break up single long message in many short packets
  - Each packet travels independently to the destination host
  - Routers and switches use the address in the packet to determine how to forward the packets

Network Software: Protocol Hierarchies

- Network software is designed carefully as a stack of layers, each one built upon the one below it
- Each layer that acts as a virtual machine is to offer certain services to the higher layer
- Layer *N* on one machine carries on a conversion with layer *N* on another machine
- The rules used in this conversion are collectively known as the layer *N* protocol
- Protocol is an agreement between the communicating machines on how communication is to proceed
- Between each pair of adjacent layers is an interface, which defines that primitive operations and services the lower layer makes available to the upper one

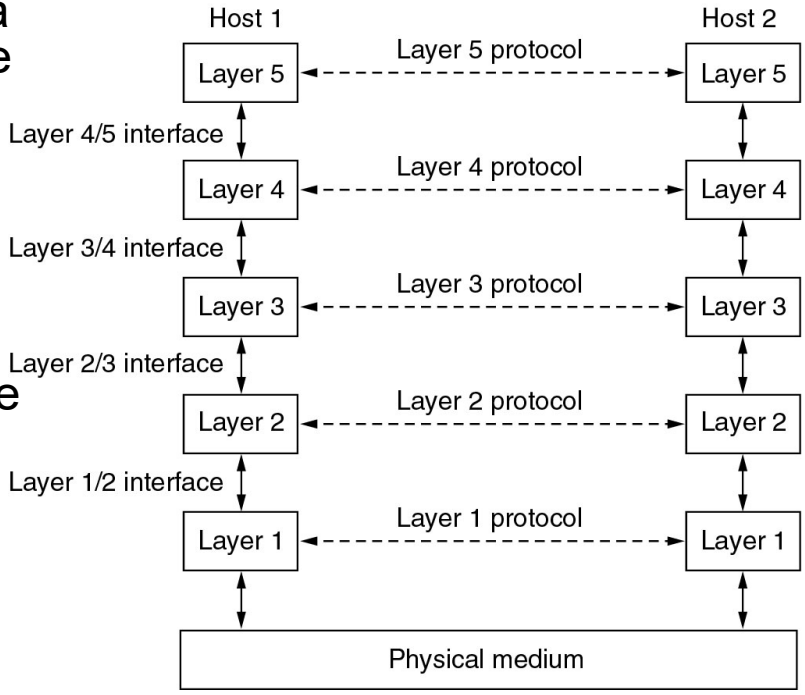


Figure: Layers, protocols, and interfaces

Note:
Virtual communication is shown by dotted lines
Physical communication is shown by solid lines

Network Architecture

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

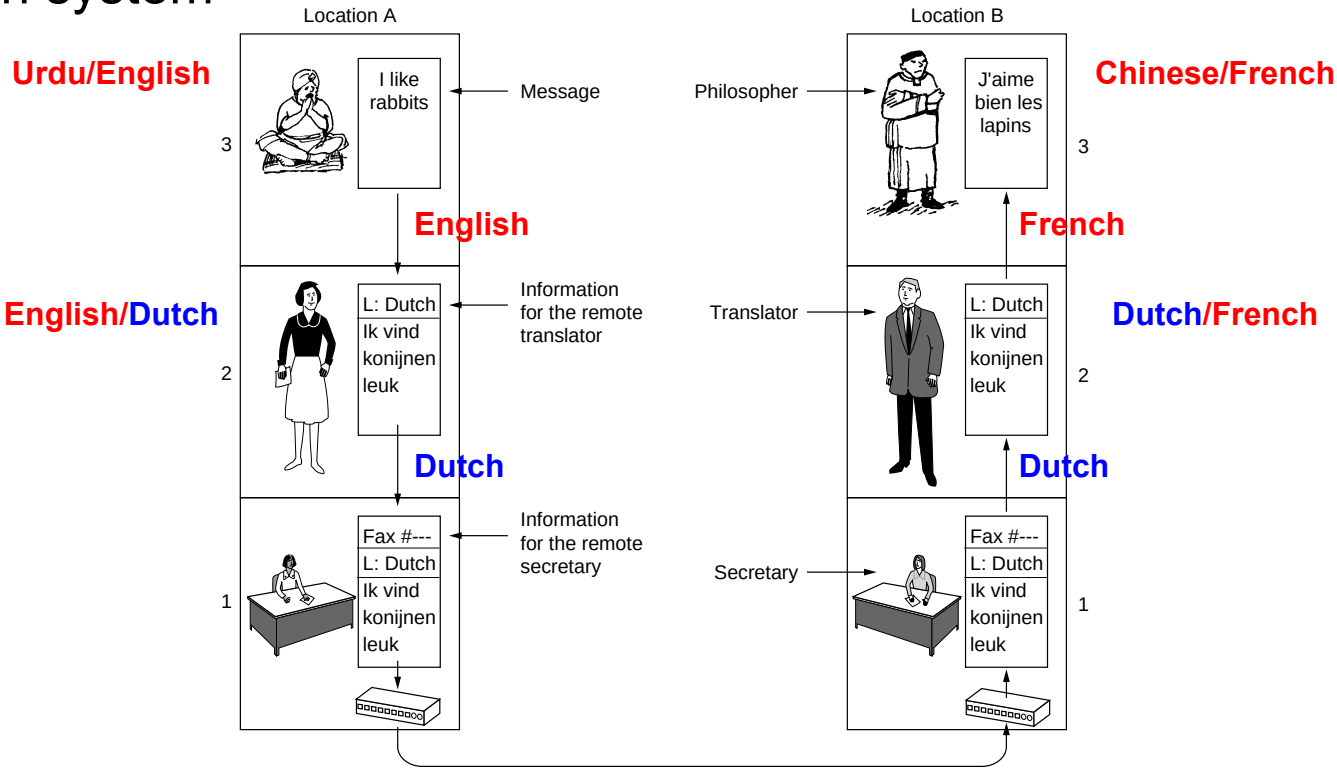


Figure: The philosopher-translator-secretary architecture

Network Architecture (cont.)

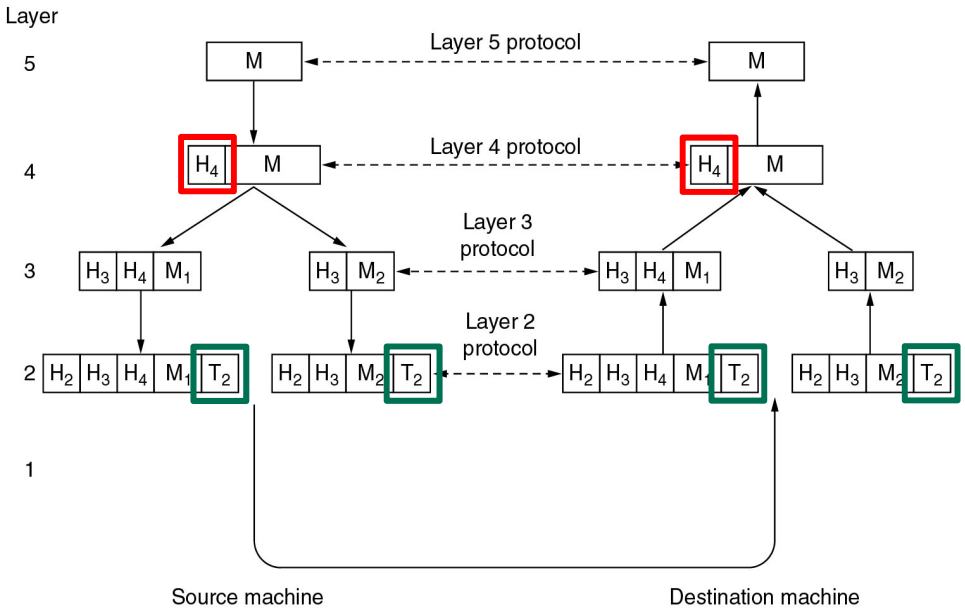


Figure: Example information flow supporting virtual communication in layer 5

- How to provide communication to the top layer of the 5-layer network?
- Solution: Layer 4 puts a header in front of the message to identify the message from layer 5 and passes the result to layer 3. Header includes control information, sequence numbers, sizes, times, and other control fields

- Layer 3 must break up the incoming message into smaller packets. E.g., $M = M_1 + M_2$
- Layer 2 adds a header and a trailer, and gives the resulting unit to layer 1 for physical transmission

Design Issues for the Layers

- Addressing – it is needed for one machine to specify with whom it wants to talk (a specific destination)
- Error control – it is important because physical hardware is not perfect. Error-detecting and error-correcting codes are used
- Flow control – it deals with a possible loss of message sequencing
- Multiplexing – it is needed in the physical layer, where all the traffic has to be sent over at most a few hardware
- Routing – a route must be chosen for multiple paths between source and destination

Connection-oriented & Connectionless

- Connection-oriented service includes the establishment of a logical connection between 2 processes
  - establish logical connection
  - transfer data
  - terminate connection
- Connectionless service involves sending of independent messages

	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

Figure: Six different types of service

Service Primitives

- Service is specified by a set of primitives (operations) available to a user process to access the service
- These primitives tell the service to perform action or report on the action taken by a peer entity
- The primitives for connection-oriented service are different from those of connectionless 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

Figure: Five service primitives for implementing a simple connection-oriented service

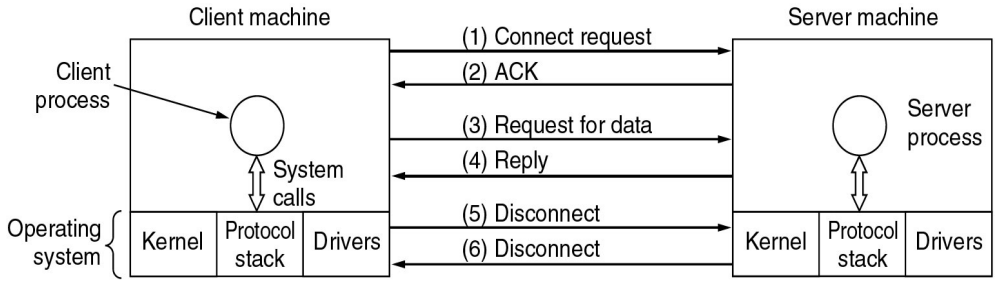


Figure: Packets sent in a simple client-server interaction on a connection-oriented network

Relationship of Services to Protocols

- Service is a set of primitives that a layer provides to the layer above it
- Protocol is a set of rules governing the format and meaning of the packets or messages that are exchanged by the peer entities within a layer
- Services relate to the interfaces between layers. In contrast, protocols relate to the packets sent between peer entities on different machines

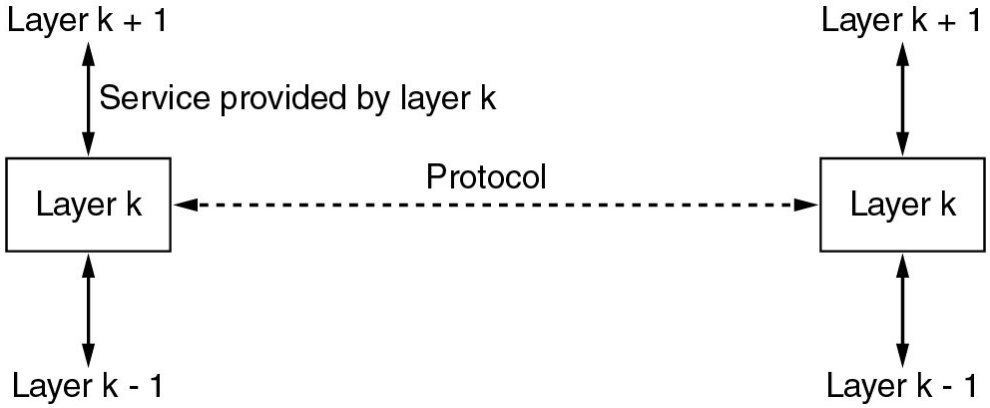


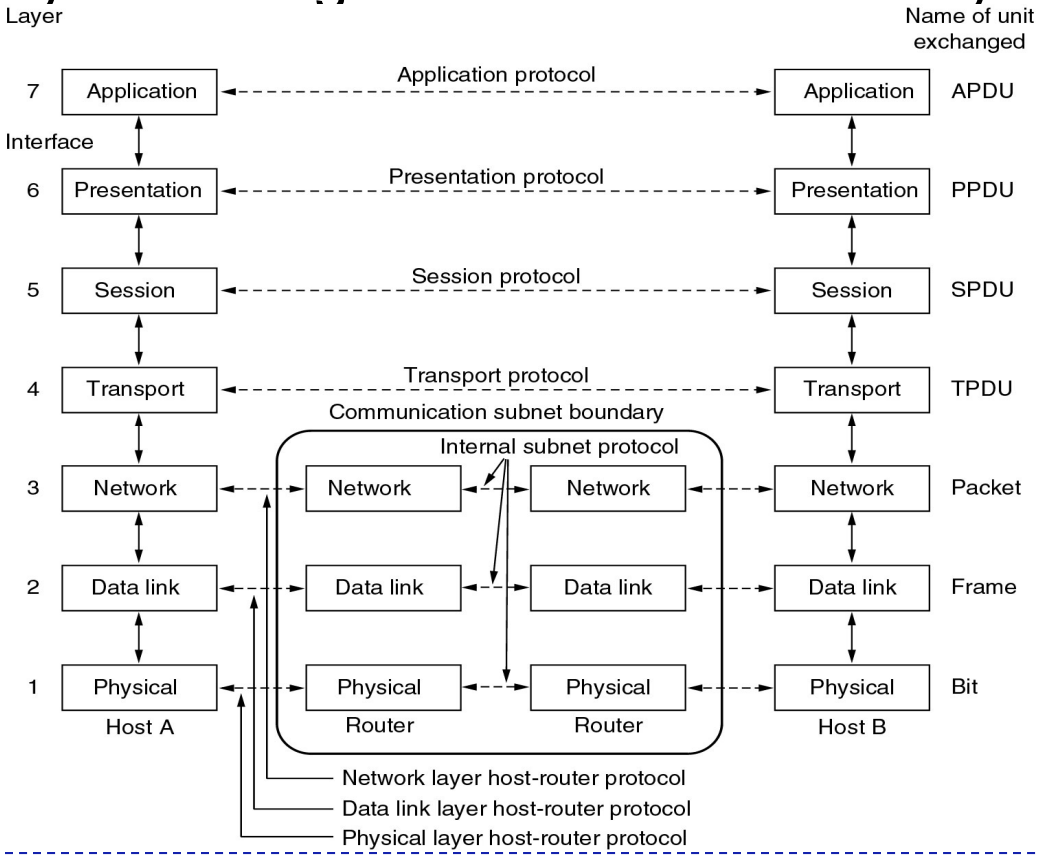
Figure: Relationship between a service and a protocol

OSI Model

- International Standards Organization (ISO) 1947 – Multinational body dedicated to worldwide agreement on International Standards
- ISO Standard that covers all aspects of network communication is Open System Interconnection (OSI) Model
- Open System – A model that allows two different systems to communicate regardless of their underlying network
- Purpose of the OSI Model
  - Open communication between different systems without requiring changes to the underlying hardware and software
- OSI Model is not a Protocol. It is a model for understanding and designing a network architecture that is flexible, robust, and interoperable

OSI Reference Model

- Layered framework for the design of network systems that allows communication across all types of computer systems regardless of their underlying architecture



7. Application (Text, Numbers)
6. Presentation (Raw Data)
5. Session (Dialog units)
4. Transport (Segment)
3. Network (Packets)
2. Data Link (Frames)
1. Physical (Bits)

Figure: The OSI reference model

OSI Reference Model (cont.)

- As the message travels from A to B, it may pass through many intermediate nodes, which involve only the first three layers of the OSI Model
- In developing the OSI model, designers identified which networking functions had related uses and collected those functions into discrete groups that became the layers
- Each layer defines a family of functions distinct from other layers
- By defining and localizing functionality, designers created an architecture that is both comprehensive and flexible
- The OSI model allows complete transparency between incompatible systems

OSI Reference Model (cont.)

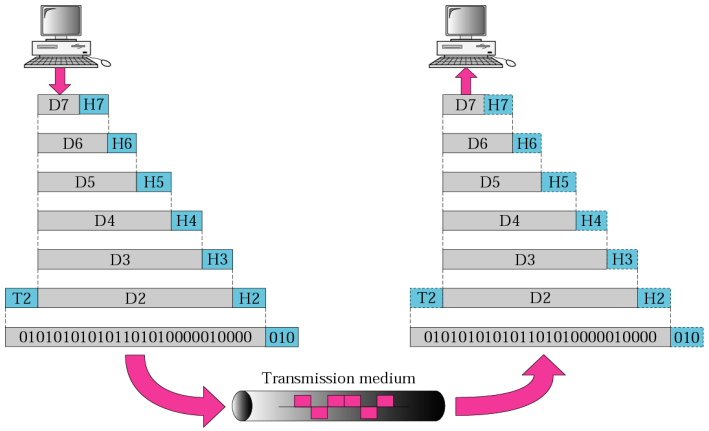


Figure: An exchange using the OSI model

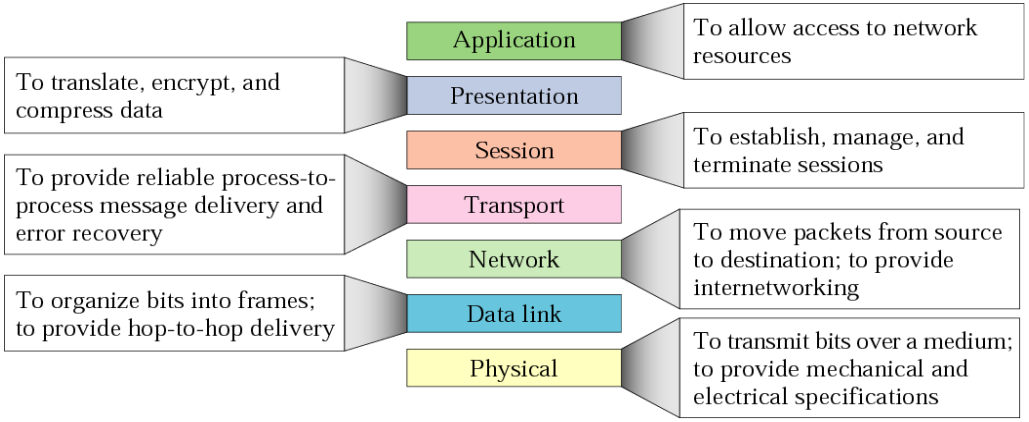


Figure: Summary of layer functions

- Data Encapsulation
  - Protocol data unit (PDU) conception – each protocol on the different layer has its own format
  - Headers are added while a packet is going down the stack at each layer
  - Trailers are usually added on the second layer

OSI Model as Standardization Framework

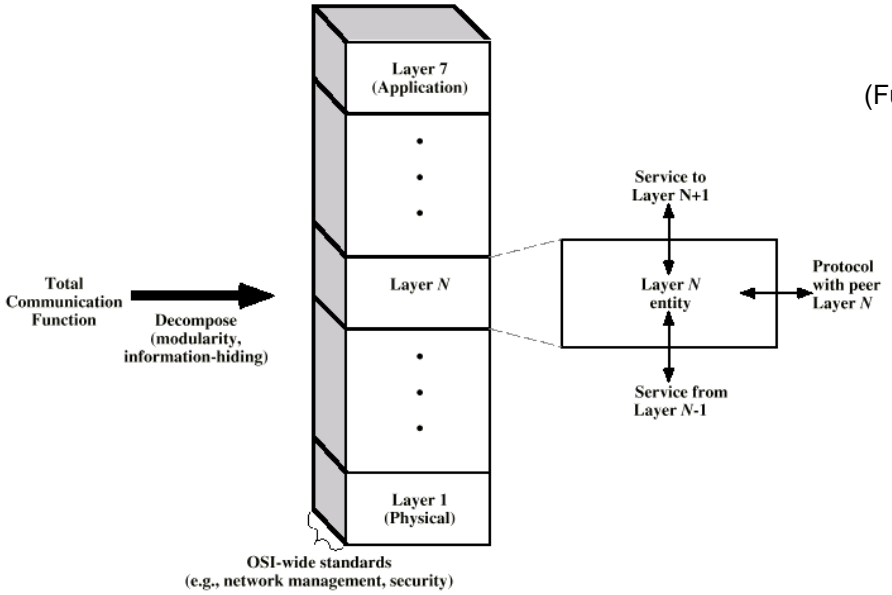


Figure: The OSI reference model as a framework for standardization

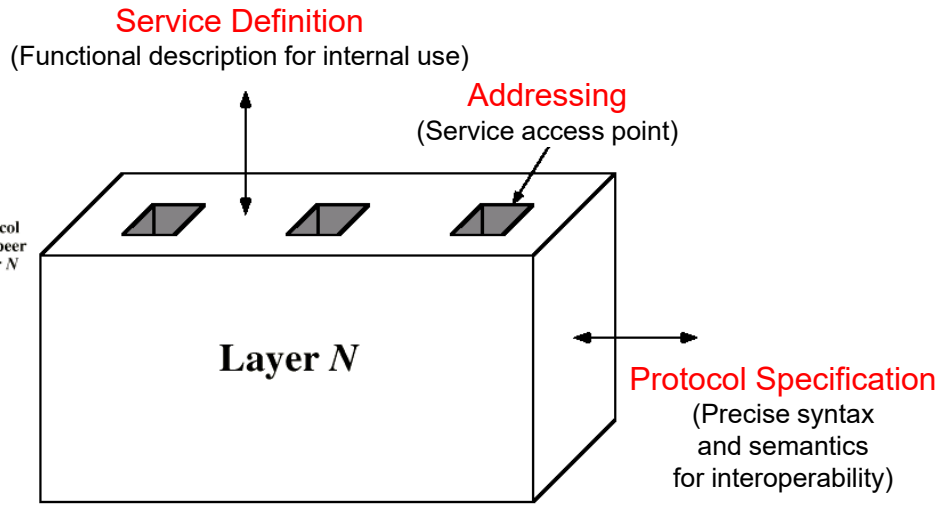


Figure: Layer specific standards

- Protocol Specification
  - Operates between the same layer on two systems
  - May involve different operating system
  - Protocol specification must be precise
- Service Definition – Function types that can be provided
- Addressing - Referred as service access point (SAP)

Service Primitive Types of OSI Model

- Services between adjacent layers expressed in terms of primitives and parameters
- Primitives specify function to be performed
- Parameters pass data and control information

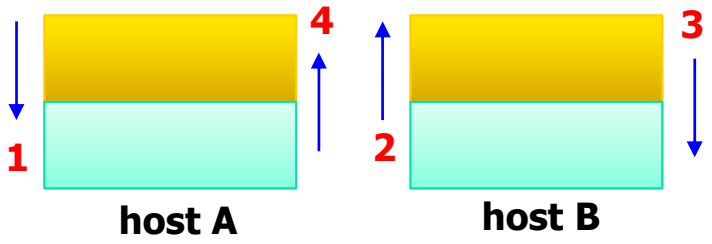


Figure: service primitives between adjacent layers of the OSI reference model

1. REQUEST	A primitive issued by a service user to invoke some service and to pass the parameters needed to specify fully the requested service
2. INDICATION	A primitive issued by a service provider either to: indicate that a procedure has been invoked by the peer service user on the connection and to provide the associated parameters, or notify the service user of a provider-initiated action
3. RESPONSE	A primitive issued by a service user to acknowledge or complete some procedure previously invoked by an indication to that user
4. CONFIRM	A primitive issued by a service provider to acknowledge or complete some procedure previously invoked by a request by the service user

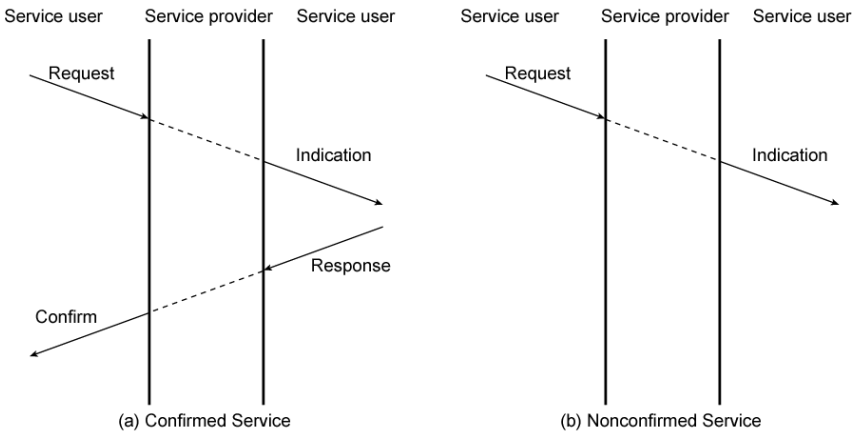
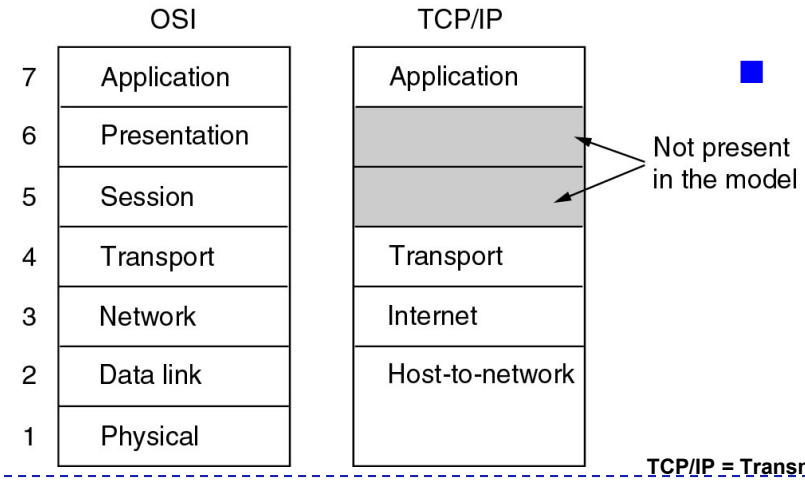


Figure: Timing sequence for service primitives

TCP/IP Reference Model

- TCP/IP is a set of protocols that defines how all transmissions are exchanged across the Internet
- In 1969, ARPA established ARPANET for early research on how computers can communicate across a network became TCP/IP
- TCP/IP was developed before the OSI model, and it widely used in the Internet today

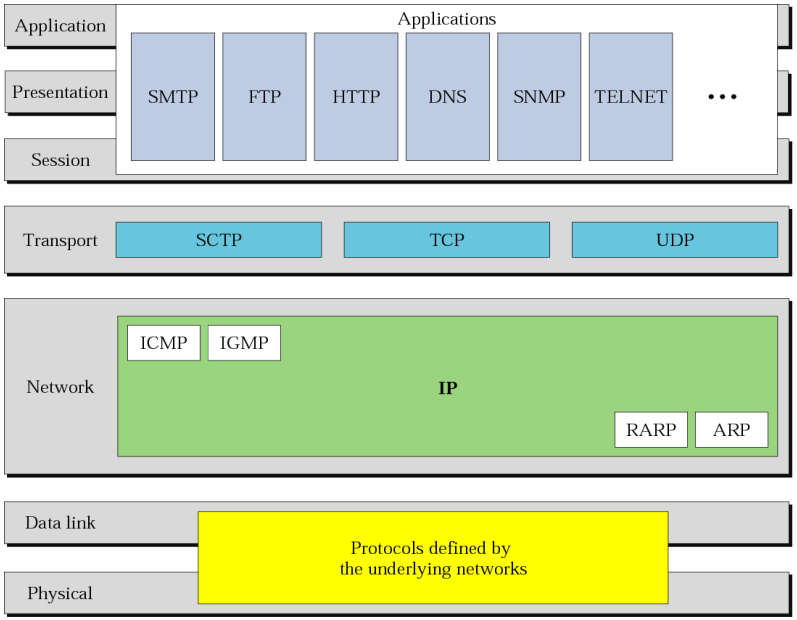


- Layers that covered in this course
  - Physical (Physical standards)
  - Data Link (Network interface)
  - Network (Interconnectivity)
  - Transport (Transport functions)
  - Application (Session, presentation, and application of OSI)

TCP/IP = Transmission Control Protocol/Internet Protocol
ARPA = Advanced Research Project Agency
ARPANET = ARPA Network

 Figure: The TCP/IP reference model

TCP/IP Protocol Suite



5. Application (Message)

4. Transport (Segment or User Datagram)

3. Network (Datagram)

2. Data Link (Frame)

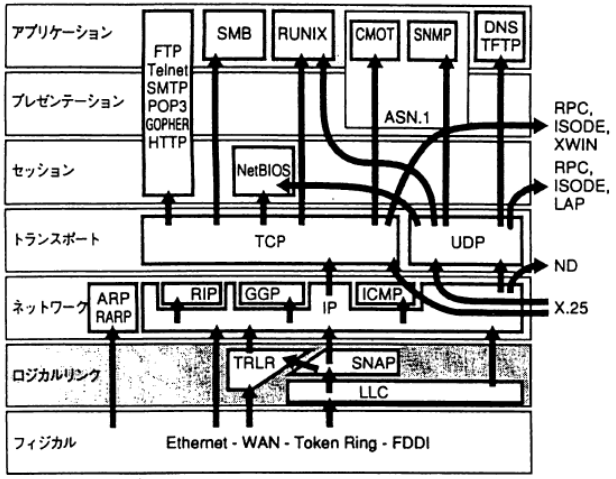
1. Physical (Bit)

Figure: TCP/IP and the OSI model

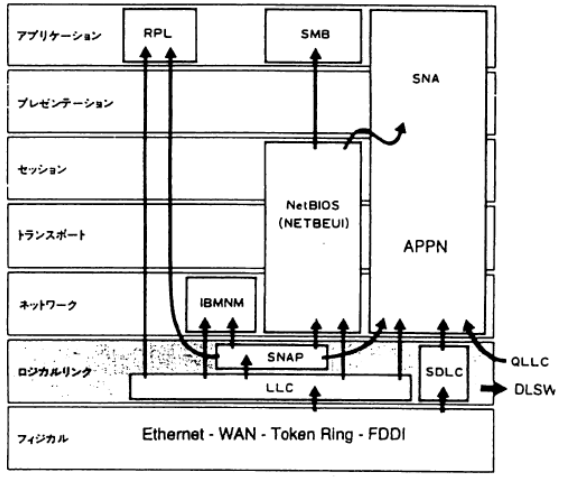
- Transmission control protocol (TCP)
  - It provides a reliable connection, which is a temporary logical association between two machines
  - Logical connection refers to a given pair of port values
  - Header format is a minimum of 20 octets, which contains source and destination ports
- User datagram protocol (UDP)
  - It does not guarantee delivery, no preservation of sequence, and no protection against duplication
  - Because it is connectionless, it adds a port addressing capability to IP. Therefore, the header format is only 8 octets

Other Protocol Suites

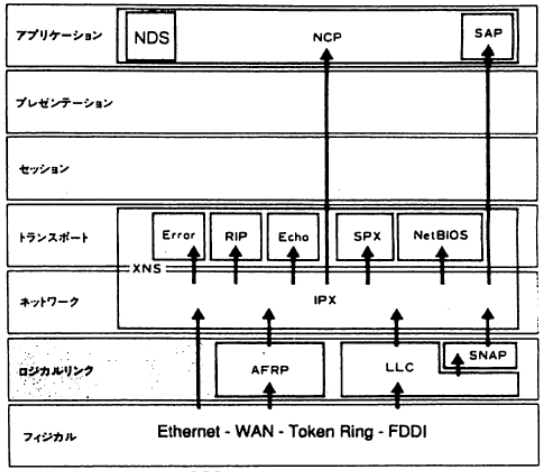
- TCP/IP
- IBM
- Novell NetWare
- AppleTalk
- DECnet
- SNA
- XNS
- X.25



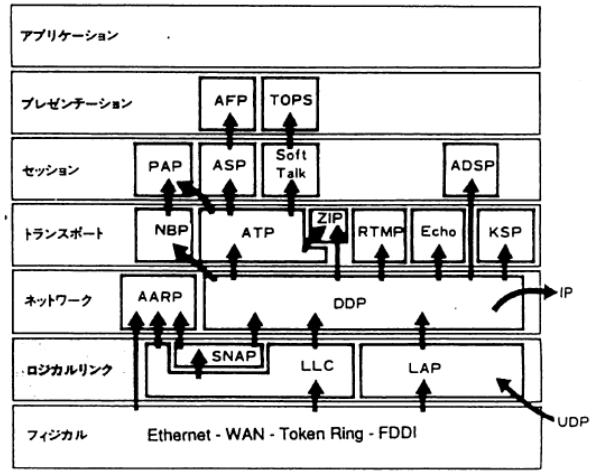
TCP/IP



IBM



Novell NetWare



AppleTalk

ARPANET

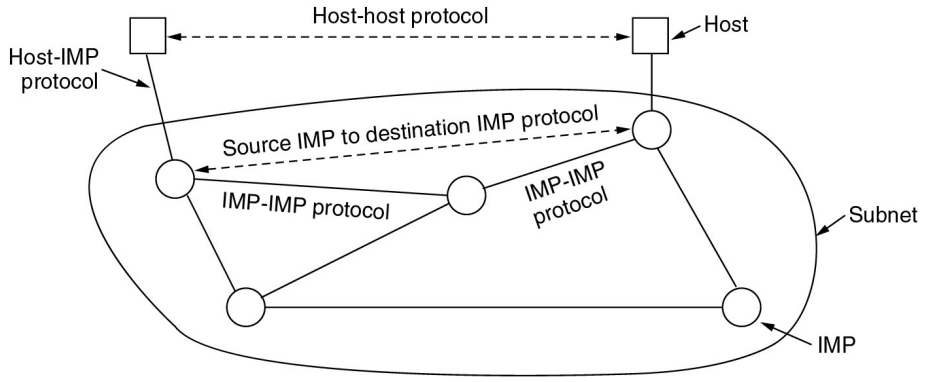


Figure: Original ARPANET design

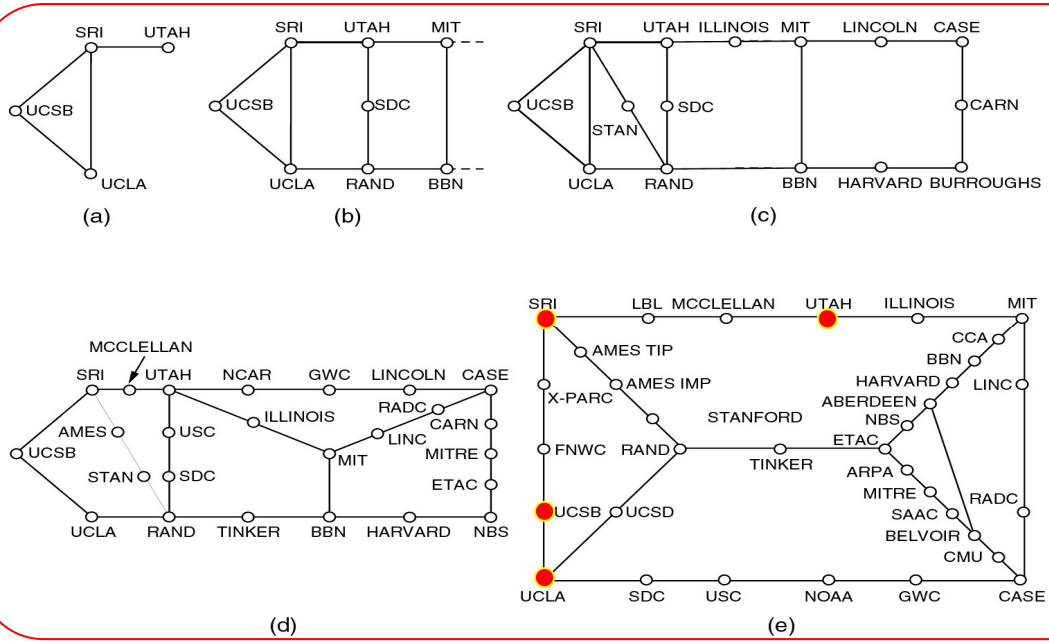


Figure: Growth of the ARPANET
(a) December 1969
(b) July 1970
(c) March 1971
(d) April 1972
(e) September 1972

Internet

- Internet evolved from ARPANET
  - First operational packet network
  - Applied to tactical radio & satellite networks
  - Had a need for interoperability

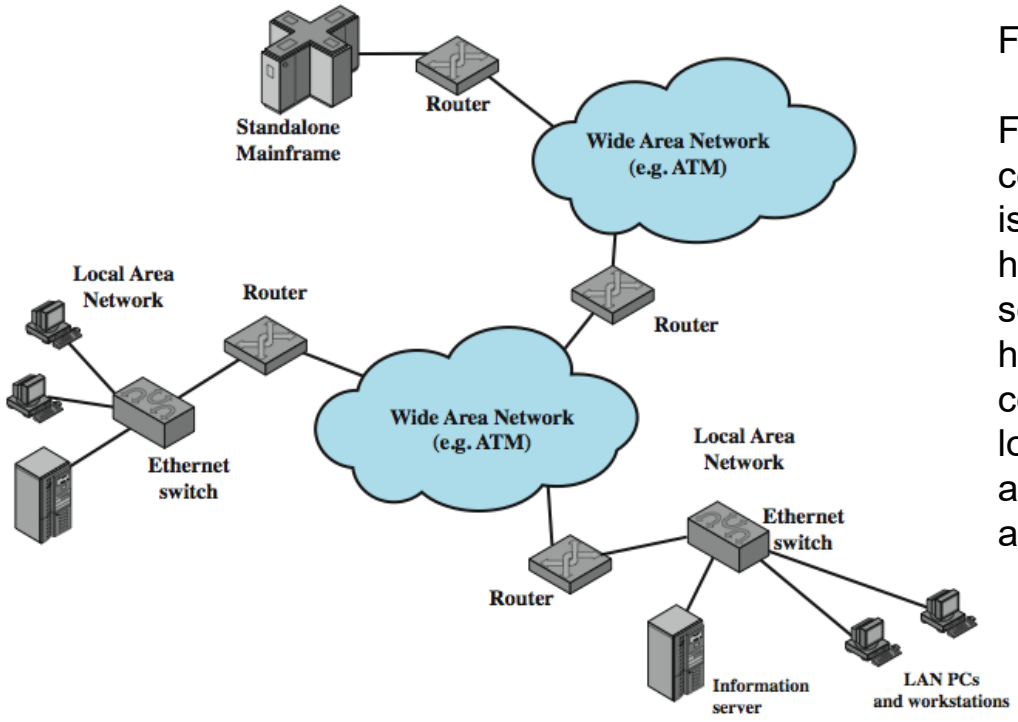


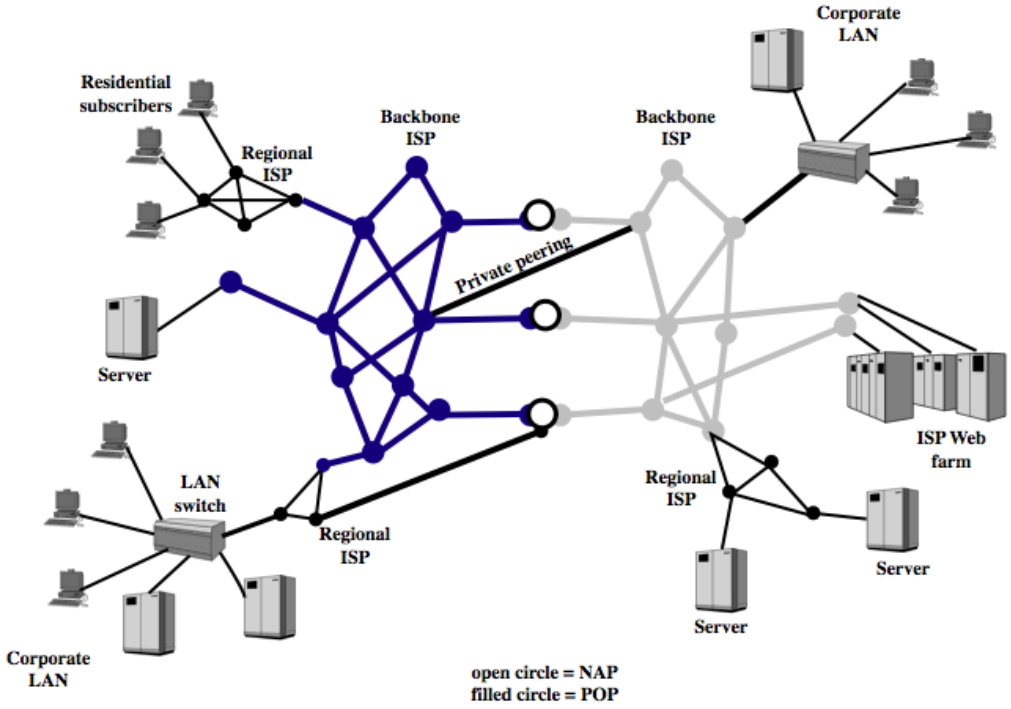
Figure: Internet elements

Figure illustrates the key elements that comprise the Internet, whose purpose is to interconnect end systems, called hosts; including PCs, workstations, servers, mainframes, and so on. Most hosts that use the Internet are connected to a network, such as a local area network (LAN) or a wide area network (WAN). These networks are in turn connected by routers.

Internet Architecture

Internet today is made up of thousands of overlapping hierarchical networks, an overview of the common, general characteristics can be made.

Figure illustrates the hosts grouped into LANs, linked to an Internet service provider (ISP) through a point of presence (POP) by a dedicated line. Network access point (NAP) is connecting several high-level networks.



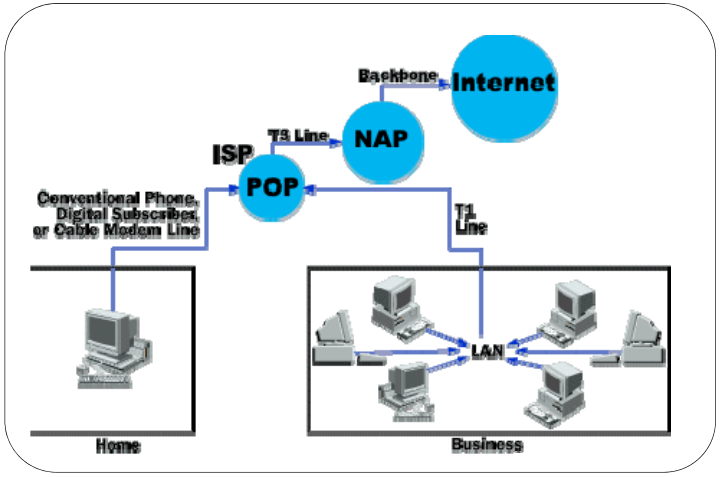


Figure: Internet architecture

Analogy: Postal Delivery Service

IP packet	letter
(start) Program →	(start) Person →
Protocol Stack →	Letter →
Output Buffer →	Mailbox→
Cable →	Postman →
Router →	Local Postal Office →
Cable →	Postman →
Backbone Router →	Central Postal Office →
Cable →	Postman →
Router →	Local Postal Office →
Cable →	Postman →
Computer →	Home →
Input Buffer →	Mailbox →
Protocol Stack →	Letter →
Program (end)	Person (end)

Announcement

- Next is Chapter 2 Physical Layer
- 09:00 ~ 10:40 on 17 October (Monday)