Computer Network
(CSE 3034)

Text book: Computer Networks by Andrew S. Tanenbaum

Introduction to the course

Syllabus :

- Introduction(Chapter 1)
- The Physical Layer(Chapter 2)
- The Data Link Layer(Chapter 3)
- The Medium Access Control Sublayer(Chapter 4)
- The Network Layer(Chapter 5)
- The Transport layer(Chapter 6)
- The Application layer(Chapter 7)
- Network security(Chapter 8)

Introduction

What is Computer Network?

Computer Network :

- Formed by merging of computers and communication technology.

Computation/processing of data

Exchange of information

- Collection of autonomous computers interconnected by a single technology to carry out computation/processing of data and exchange of information.
  - Copper wire
  - Fibre optics
  - Microwave
- Wired (or cabled), Wireless
- Internet (Network of networks)
- Though looks same computer network is different from a distributed system.

Distributed System :

–*High degree of cohesiveness and transparency*

–A software system built on top of a network

WWW a distributed systems run on the top of Internet.

Uses of Computer Network

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

Uses of Computer Network (cont.)

Business Applications

Goals of Networks in this application :

- *Resource sharing :* Programs, equipment, and especially data available to anyone on the network without regard to the physical location of the resource and the user

  Ex: (i) Sharing of physical equipment like printer, CD burner, etc.

  (ii) Sharing of customer records, inventories, accounts, financial statements, etc.

- *Establish a **computer-assisted communication** between individuals.*

  Ex : (i) Electronic mail (i.e. e-mail).

  (ii)VoIP (i.e. Voice over internet Protocol) /Videoconferencing.

- *Doing business electronically.*

  Ex : E-commerce

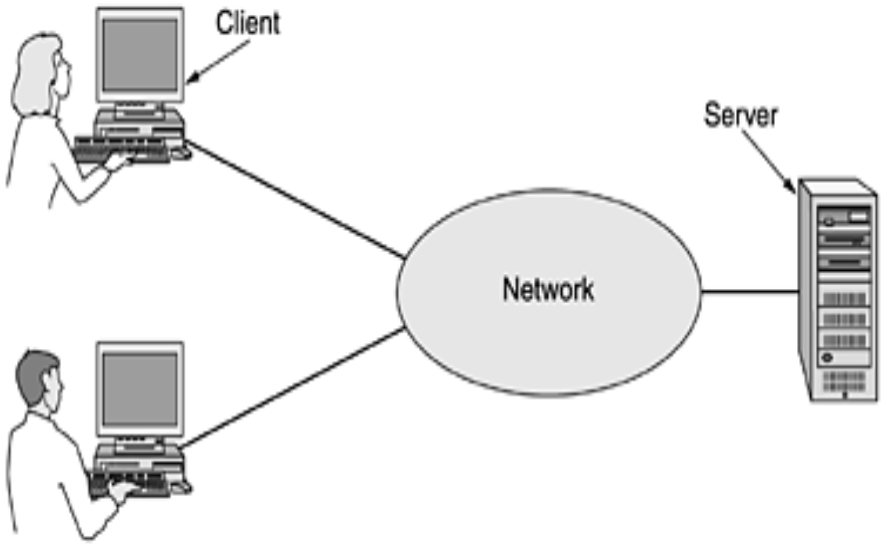
  - Individual - company
  - Company - company

Uses of Computer Network (cont.)

Business Applications

Structure :

- The establishment varies from a single office in a single building to dozens of offices scattered over more than one place.
- Configured in the form of client-server model.



A network with two clients and one server

Server :

- Powerful computer where most of the data associated with an organization/company are stored.
- Physical equipment that is shared is also connected to the server system.
- Maintained by a system administrator.

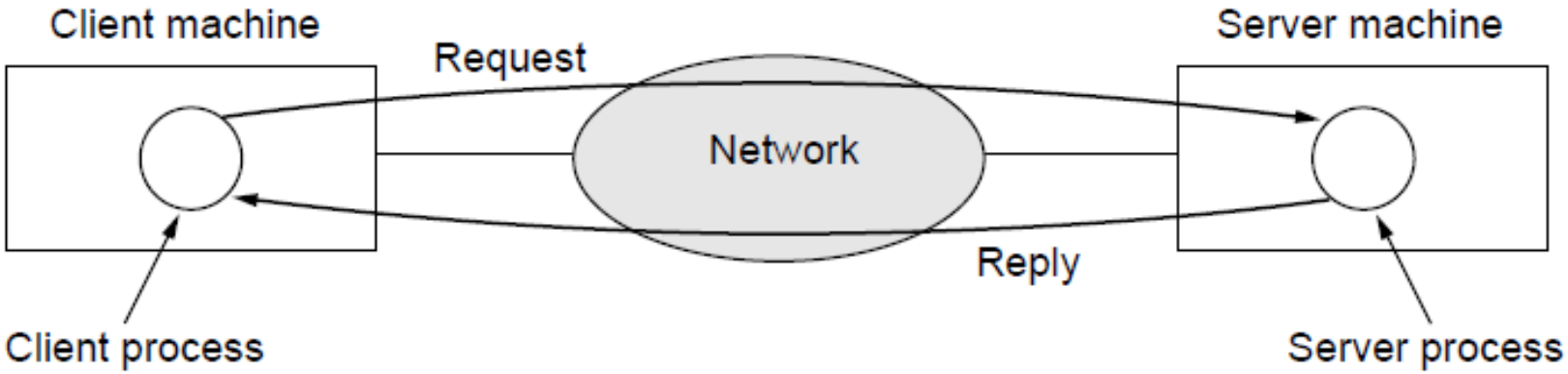
Client :

- Simpler computer systems used by employees of an organization/company/individual being connected to the same network.

Uses of Computer Network (cont.)

Business Applications

Communication in client – server model :



Client process : Sending message over the network to server & waits reply from server

Server process : Performs the requested work or looks up the requested data and sends back a reply to client.

Uses of Computer Network (cont.)

Home Applications

In 1977 Ken Olsen, President,

Digital Equipment Corporation (DEC), Second Largest Computer Company (after IBM) said

"There is no reason for any individual to have a computer in his home"

(Initially for word processing)

Now : Why do people buy computers for home use?

Biggest Reason is Internet access.

Uses of Computer Network (cont.)

Home Applications

Popular uses of the **internet access** for home users :

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

Uses of Computer Network (cont.)

Home Applications

Internet access for home users : Access to remote information

- Surfing the web is done for variety of reasons:
  - Arts, Business, Cooking, Government, Health, History, Hobbies, Recreation, Science, Sports, Travel, …
- E-Newspaper
- Online Digital Libraries (magazines/journal)
  (e.g. www.ieee.org)

Uses of Computer Network (cont.)

Home Applications

Internet access for home users : Person – to – person communication

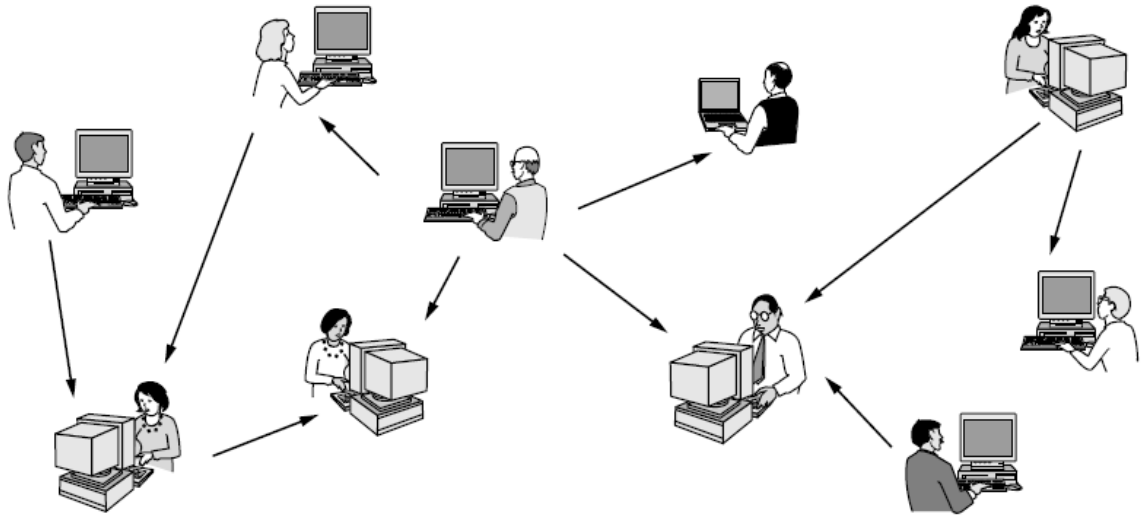
- Video conferencing/chating
- Instant Messaging (Whats app,Twitter)
- Telelearning
- Social Networking:
  - Facebook

Person - to – person communication often goes by the name of peer - to - peer communication

Uses of Computer Network (cont.)

Home Applications

Peer – to – peer communication (different from client –server model)



Example :

- BitTorrent
- Sharing Music and Videos (Napster)
- Email, etc.

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

Uses of Computer Network (cont.)

Home Applications

Internet access for home users : Interactive entertainment

- MP3 and DVD-quality movies
- TV shows – IPTV (IP TeleVision)
- Interactive Live TV
- Multiperson real-time simulation games
- Smart Home Monitoring

Uses of Computer Network (cont.)

Home Applications

Internet access for home users : Electronic commerce

- Online shopping from home
- Online consultation about product with support team
- Payment of bills
- Managing bank accounts and financial investments
- Online auction of second hand goods – in the form of peer to peer system

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

Uses of Computer Network (cont.)

Mobile Users

- Mobile computers (handheld and laptops)
  - Fastest growing segments in computer history.
  - Individuals are able to use their mobile devices to:
    - Read and send email,
    - Tweet,
    - Watch Movies,
    - Download Music,
    - Play Games,
    - Serf the Web
- Internet connectivity allows for those applications to be easily built
  - Wireless Networks (Cars, Boats, and Airplanes can not have wired Connections)
  - Cellular Networks
  - Wireless hotspots (802.11 Standard).
  - Wireless Networking vs. Mobile Wireless Networks

Uses of Computer Network (cont.)

Mobile Users

Combinations of wireless networks and mobile computing

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

Uses of Computer Network (cont.)

Mobile Users

- Smart Phones – Integration of Internet with Telephony
  - Driving the wireless-mobile applications
  - 3G & 4G cellular networks provides fast data services
  - GPS is a standard feature
  - m-commerce (mobile commerce)
- Sensor Networks
  - Notes that Sense/gather data about state of the physical world.
  - It is revolutionizing science
- Wearable Computers
  - Implantable Devices
    - Pacemakers, Insulin pumps, …
    - Controllable wirelessly

Network Hardware

There is no generally accepted taxonomy into which all computer networks fit, but two dimensions stand out as important: **transmission technology** and **scale**.

Transmission technology : Two types of transmission technology are in widespread use.

1. Broadcast links.
2. Point to point links.

Network Hardware(cont.)

Broadcast network

- Single communication channel that is shared by all the machines connected to the network.
- Messages (in the form of **packets**) sent by one machine are received by all other machines belonging to the network.
- Upon receiving a packet, a machine checks the address field.
  - If the packet is intended for the receiving machine, that machine processes the packet;
  - If the packet is intended for some other machine, it is just ignored.
- Multicast : Transmission to a subset of machines

Broadcast transmission

Multicast transmission

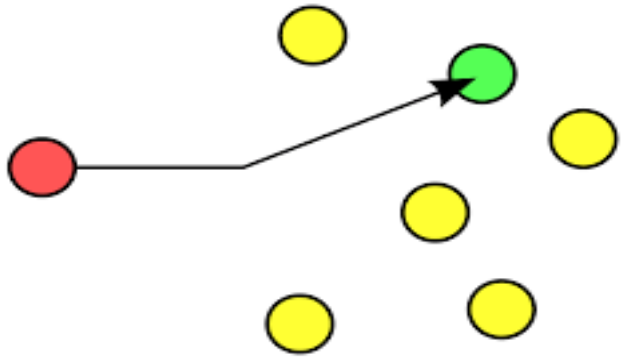
Network Hardware (cont.)

Point to point network

- Multiple individual pairs of machine communicate with each other.
  - Single hop : Directly, One route
  - Multi hop : Through one/more intermediate machines, Multiple routes possible

(Finding good one is important)

- Intermediate machines only forward the data packets from source to destination.
- **Unicast transmission**



Unicast transmission

Network Hardware (cont.)

Classification of network based on size of the network:

- Computer networks are also classified based on the size, no. of machines and distance among machines of a network.

- Personal Area Network (PAN)
- Local Area Network (LAN)
- Metropolitan Area Network (MAN)
- Wide Area Networks (WAN)
- The internet

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

Classification of interconnected processors by scale

Network Hardware (cont.)

Local Area Networks (LANs):

- Privately owned
- Established within a single building or campus
- Widely used to connect personal computers and workstations in company offices and factories for share resources (e.g., printers) and exchange information.

Characteristics based on which different from other networks

(1) Size : Restricted and small

(2) Transmission technology :

Medium of communication : Mostly use **co-axial cable**

Speed : **10 Mbps to 100 Mbps**

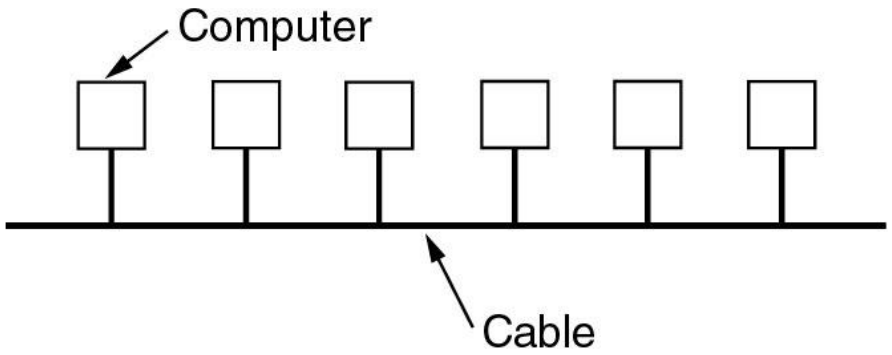
Delay : low (**microseconds/nanoseconds)**

Transmission error : **Less**

(3) Topology : BUS , RING, STAR, MESH.

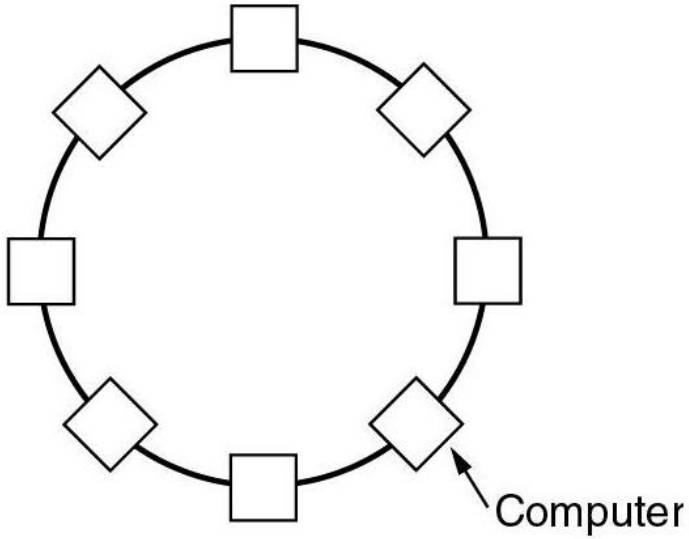
Network Hardware (cont.)

Local Area Networks (LANs):



BUS

- At any instant at most one machine is the master and is allowed to transmit.
- Conflicts may occur when two more machines try to transmit simultaneously.
  (Requires proper arbitration mechanism)
- Ex : Ethernet (or IEEE 802.3)



RING

- Each bit propagates around on its own, not waiting for the rest of the packet to which it belongs.
- Each bit circumnavigates the entire ring.
- Conflict due to simultaneous accesses to the ring can be avoided by arbitration mechanism.

Ex : IEEE 802.5 and FDDI

Network Hardware (cont.)

Local Area Networks (LANs):

Categorized as **static or dynamic** based on the channel allocation strategy among the users wants to transmit their data.

Static :

- Uses a **round-robin algorithm (i.e. each machine is allowed to broadcast only when its time slot comes up)**
- Wastage of channel capacity (a drawback)

Dynamic :

- Centralized (**a bus arbitration unit used to determine who goes next)**
- Decentralized (each machine must decide for itself whether to transmit)

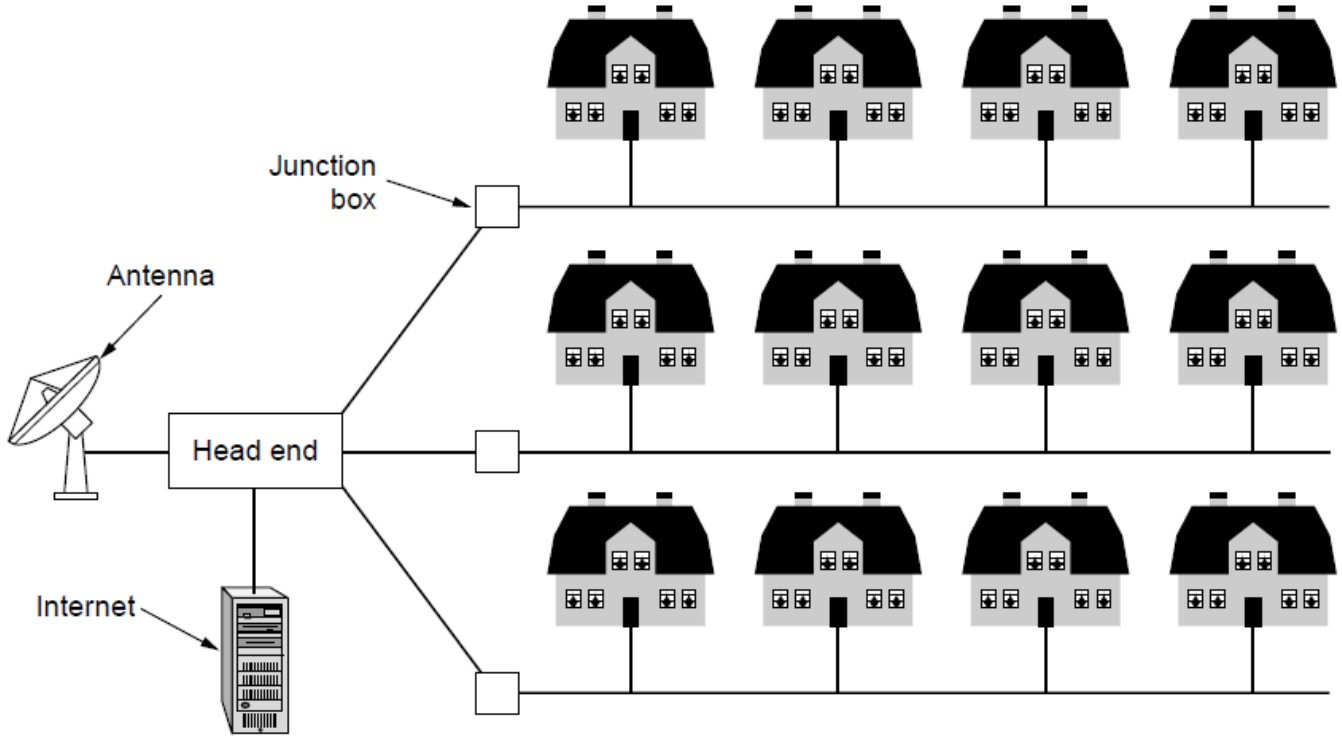
Network Hardware (cont.)

Metropolitan Area Network (MAN)

- Covers a city
- Ex : Cable television network

(Initially for TV signal transmission, currently for internet along with TV transmission)

- Concept : A large antenna was placed on top of a nearby hill or big building and then signal is piped to the subscribers' houses.

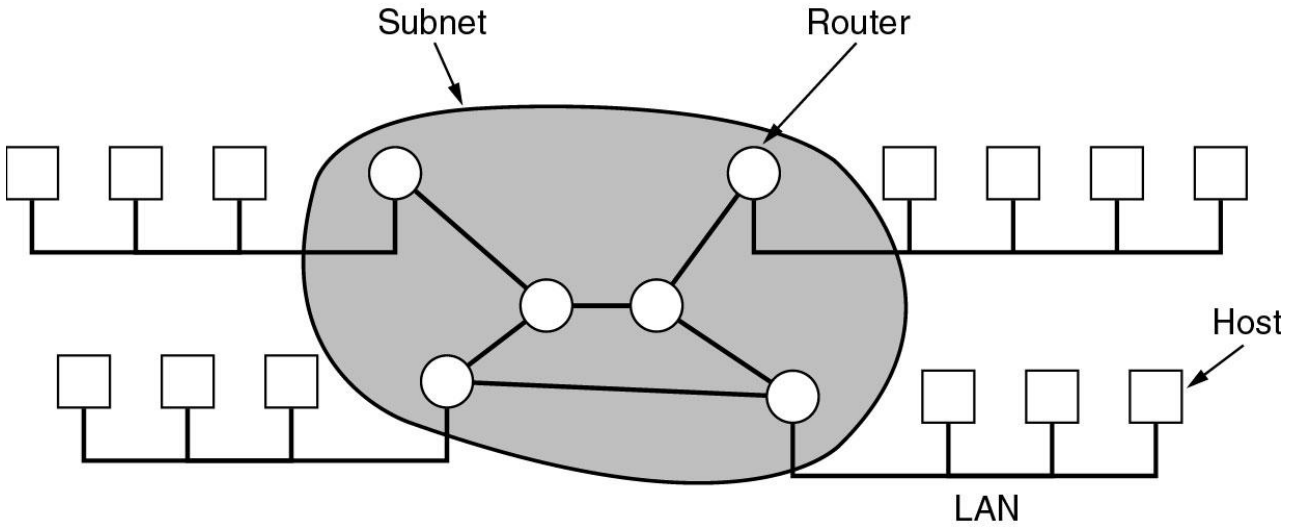


A metropolitan area network based on cable TV

Network Hardware (cont.)

Wide Area Network (WAN)

- Spans a large geographical area, often a country or continent.
- Establish communication link between two machines (say **host computers)** belonging to two different networks.
- Major constituents of such a network
  - **Host** : Owned by customers
  - **Communication subnet** : Owned by the network service providers



Relation between hosts on LANs and the subnet

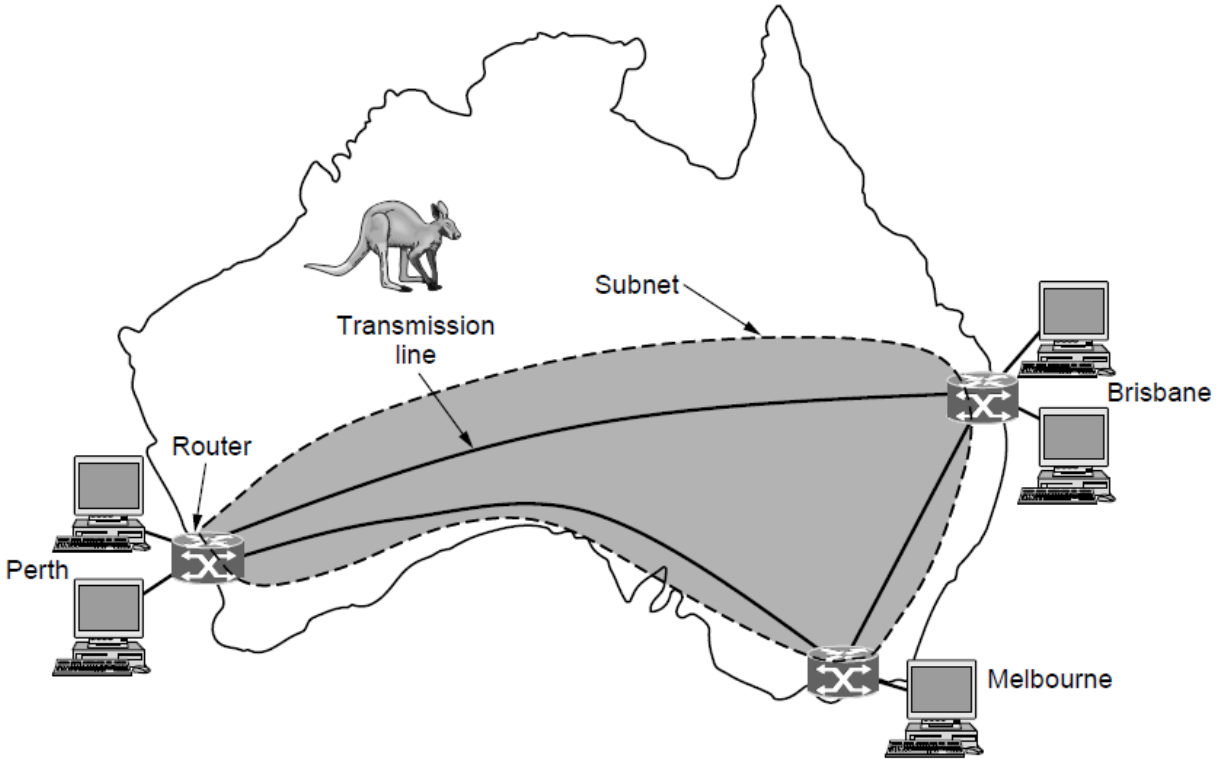
Network Hardware (cont.)

Wide Area Network (WAN)

Subnet :

Comprises of two components.

- Transmission lines :
  - Used to move data packets between two machines
    (Copper wire, optical fiber)
- Switching elements :
  - Popularly known as routers.
  - Connect more than two transmission lines.
  - Store -and-forward.



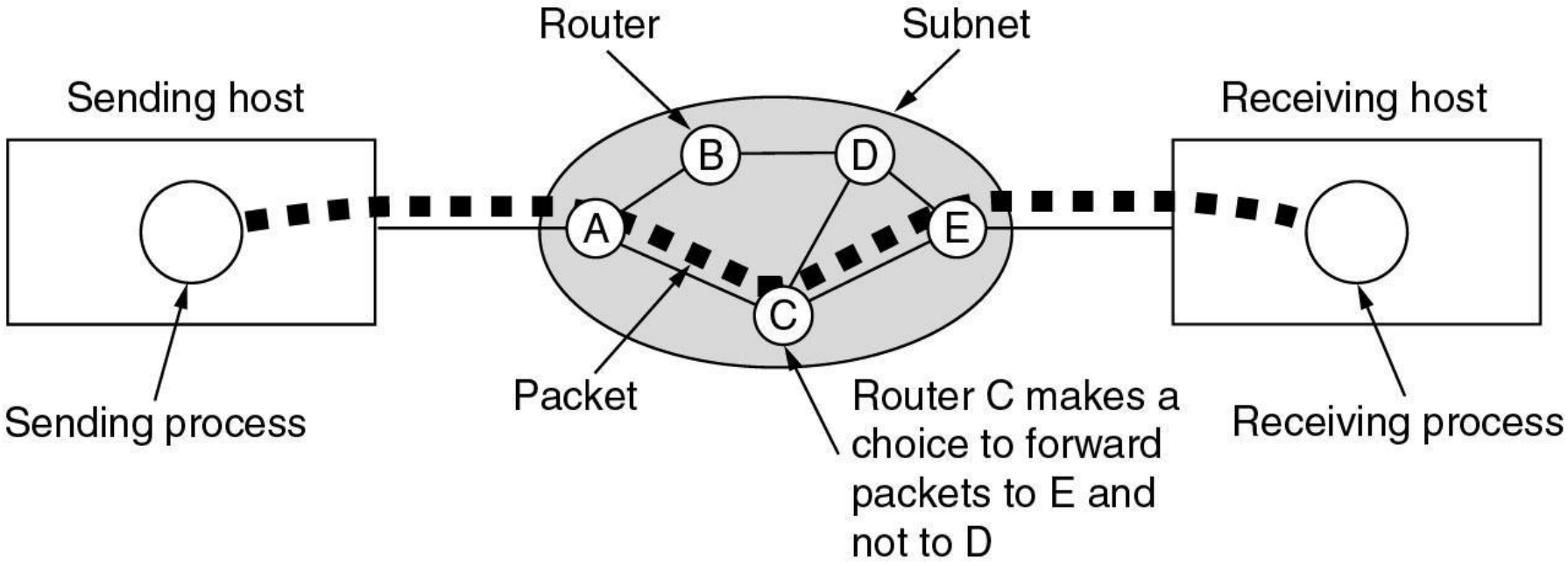
WAN that connects three branch offices in Australia

Network Hardware (cont.)

Wide Area Network (WAN)

The **WAN** often also referred as **packet switched network,** since the packets in the network are moved from one transmission line to other through the switching element (or router).

An example :



- Routing decisions are made locally.
- How A makes that decision is called the routing algorithm.

  (Instead of ABDE it is ACE)

Network Hardware (cont.)

Wireless network

- Transmission line : Wireless (or radio channel)
- Wireless networks can be divided into three main categories:
  1. System interconnection.
  2. Wireless LANs.
  3. Wireless WANs.

Network Hardware (cont.)

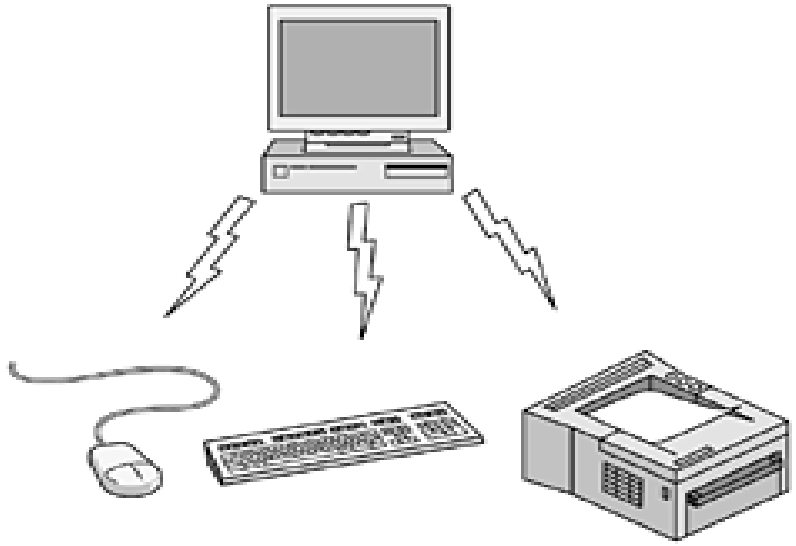
Wireless network

System interconnection :

- Uses **short range radio communication** technology (e.g. Bluetooth) to make interconnection between different digital machines in a room.
- Can be referred as a **PAN**.

Example:

A computer CPU and its subordinates like mouse, keyboard and monitor can be connected through a blue-tooth based network system.



A Bluetooth configured network

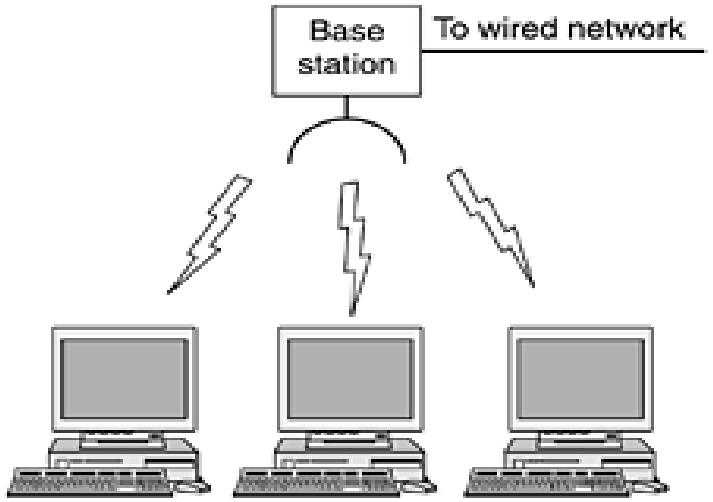
Network Hardware (cont.)

Wireless network

Wireless LANS :

- Every computer/computing machines should have **a radio modem and antenna.**
- Requires a **base station.**
- Follows the standard IEEE 802.11

Example : Offices, Hostels, Conference rooms etc.



An example of Wireless LAN

Network Hardware (cont.)

Wireless network

Wireless WANS :

- Structure is same as WLAN except to geographical area of coverage (quite a more than that in WLANs)
- Lesser speed than WLANs.
- Distance between base station and computing device is more than that in WLANs.

Example : Cellular networks (3G & 4G) meant for both voice and data.

High bandwidth wireless MANs are also being available in certain cities. A standard for it, called IEEE 802.16, has also been developed.

Note : Almost all wireless networks hook up to the wired network at some point to provide the internet service.

Network Hardware (cont.)

Home network

- Properly not categorized as a form of computer network.
- Smart home and IoT (a possibility).
- Requires smart devices that are capable to communicate with each other and (or) access internet.

Examples of smart devices in home :

1. Computers (desktop PC, notebook PC, PDA, shared peripherals).
2. Entertainment (TV, DVD, VCR, camcorder, camera, stereo, MP3).
3. Telecommunications (telephone, mobile telephone, intercom, fax).
4. Appliances (microwave, refrigerator, clock, furnace, airco, lights).
5. Telemetry (utility meter, smoke/burglar alarm, thermostat, babycam).

Network Hardware (cont.)

Home network

Home networking has some fundamentally different properties than other network types.

- The network and devices have to be easy to install.
- The network and devices have to be fool proof in operation.
- Low price is essential for success.
- The main application is likely to involve multimedia, so the network needs sufficient capacity.
- 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.

Network Software

The network software structure plays an important role in the operation of the network.

- Protocol hierarchies
- Design issues for the layers
- Connection-oriented versus connectionless service
- Service primitives
- Relationship of services to protocols

Network Software

Protocol Hierarchies

- A stack of layers or levels, each one built upon the one below it.
- Number of layers, the name of each layer, the contents of each layer, and the function of each layer differ from network to network.
- Lower layer provides service to higher layers.
- interaction/conversation between n layer of a machine with n layer of another machine carried following a set of rules and convention (normally known as **protocol**).

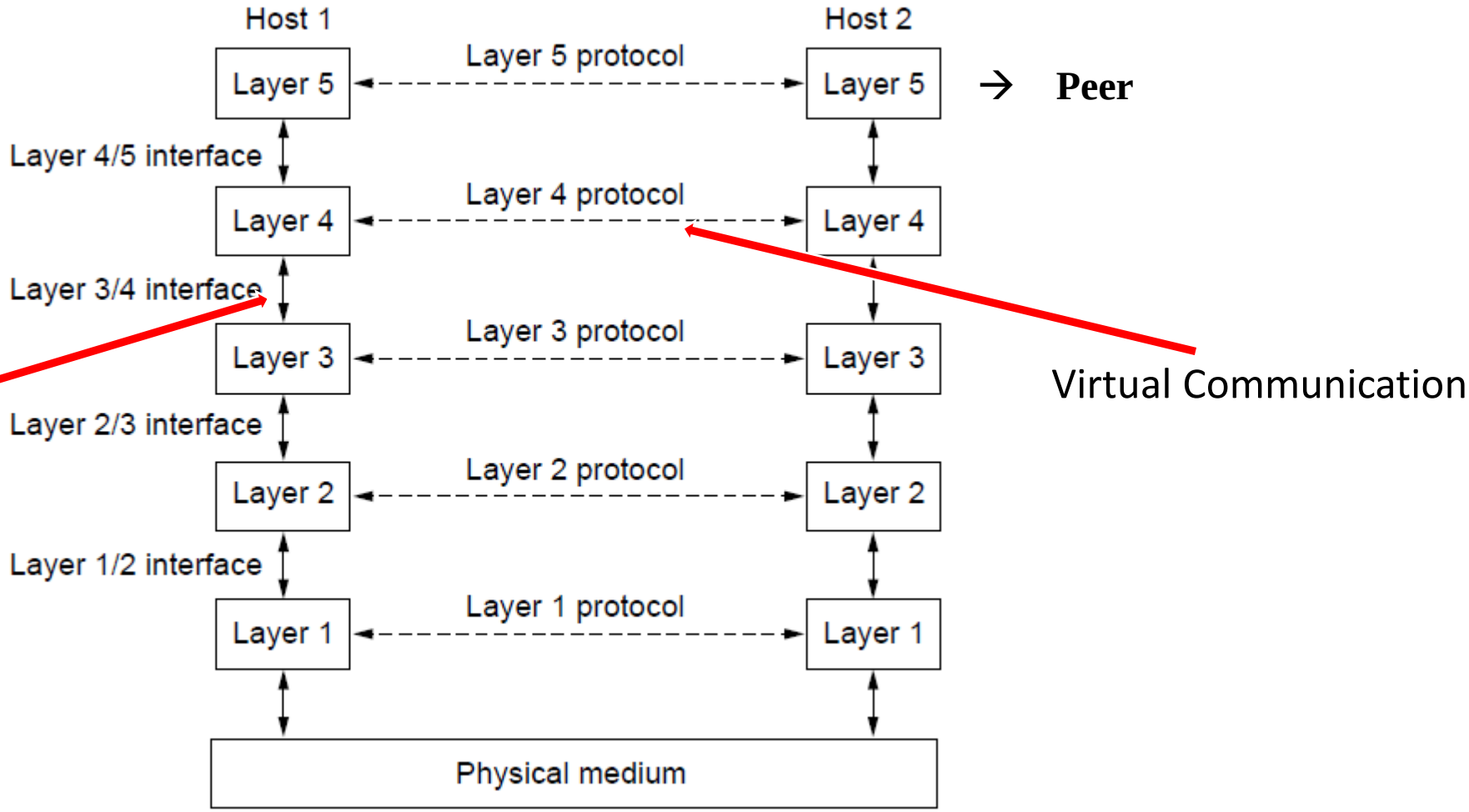
Network Software (cont.)

Protocol Hierarchies

- **Protocol** – An agreement between the communicating parties on how communication is to proceed.
- **Peers** – Entities comprising corresponding layers on different machines (e.g. hardware devices).
  - Peers use the protocol to communicated with each other.
- No data is directly transferred from layer n on one machine to layer n on another machine.
  - Each Layer passed data and control information to the layer immediately below it until the lowest layer is reached.
  - Below layer 1 is the physical medium through which actual communication occurs.
  - Between each pair of adjacent layers is an interface
- **Interface -** It defines which primitive operations and services the lower layer makes available to the upper one.

Network Software (cont.)

Protocol Hierarchies



Layers, protocols, and interfaces in a network

Network Software (cont.)

Protocol Hierarchies

Layering

- To make things simple: modularization container
- Different layer has different functions
- Create layer boundary such that
  - **description of services can be small**
  - **number of interactions across boundary are minimized**
  - **potential for interface standardized**
- Different level of abstraction in the handling of data (e.g., syntax, semantics)
- Provide appropriate services to upper layer
- Use service primitives of lower layer

Network Software (cont.)

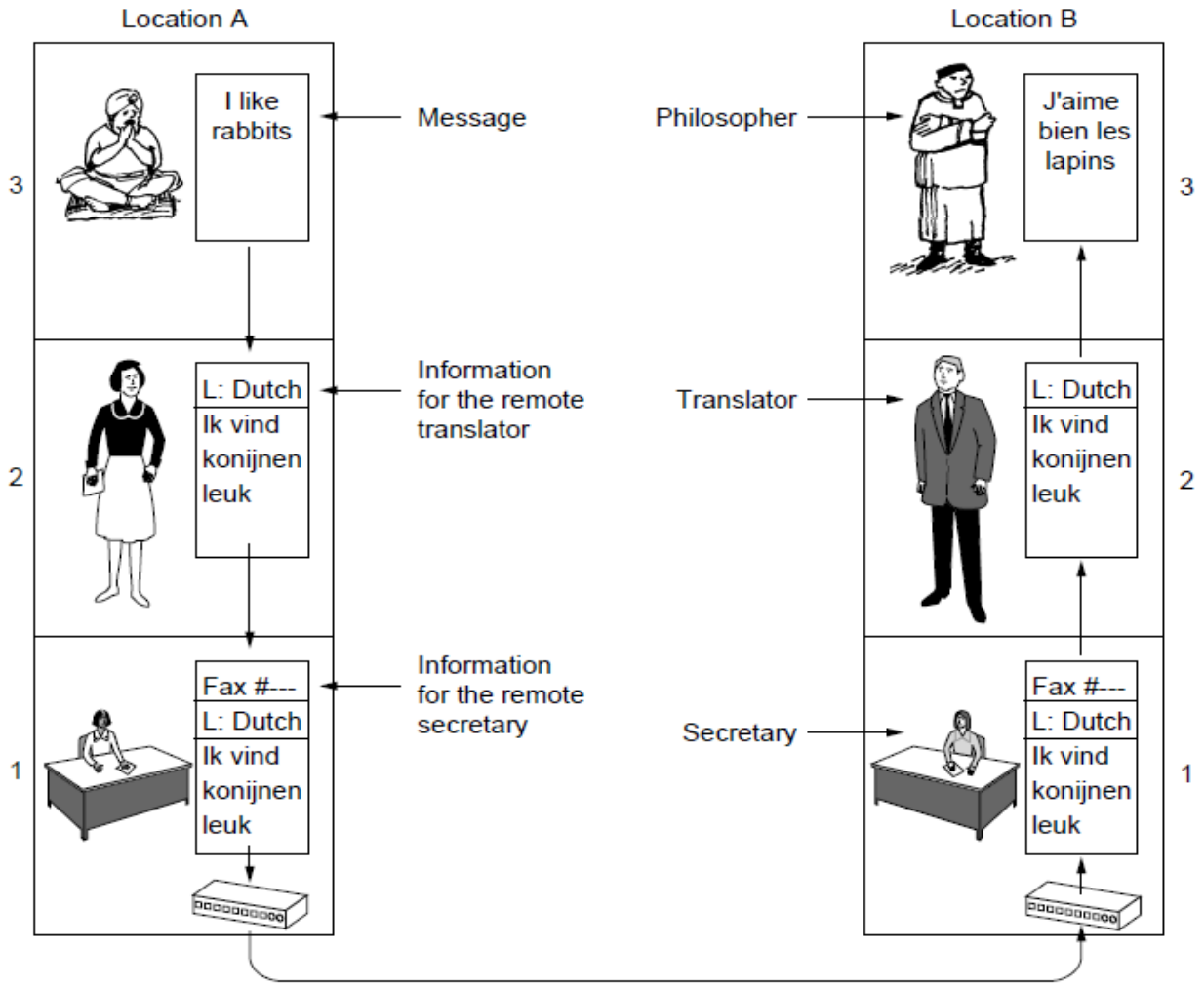
Protocol Hierarchies

- **Network Architecture:**
  - A set of layers and protocols.
  - The specification of the network architecture must contain enough information to allow an implementation of the program or the hardware for each layer so that it will obey appropriately the protocol.
- **Protocol Stack:**
  - The list of protocols used by a certain system – one protocol per layer.

Network Software (cont.)

Protocol Hierarchies

An analogy example:



The philosopher-translator-secretary architecture

Layer3 :

Two philosophers having no common language want to communicate with each other.

Layer2:

Each philosophers engages a translator.

Layer1:

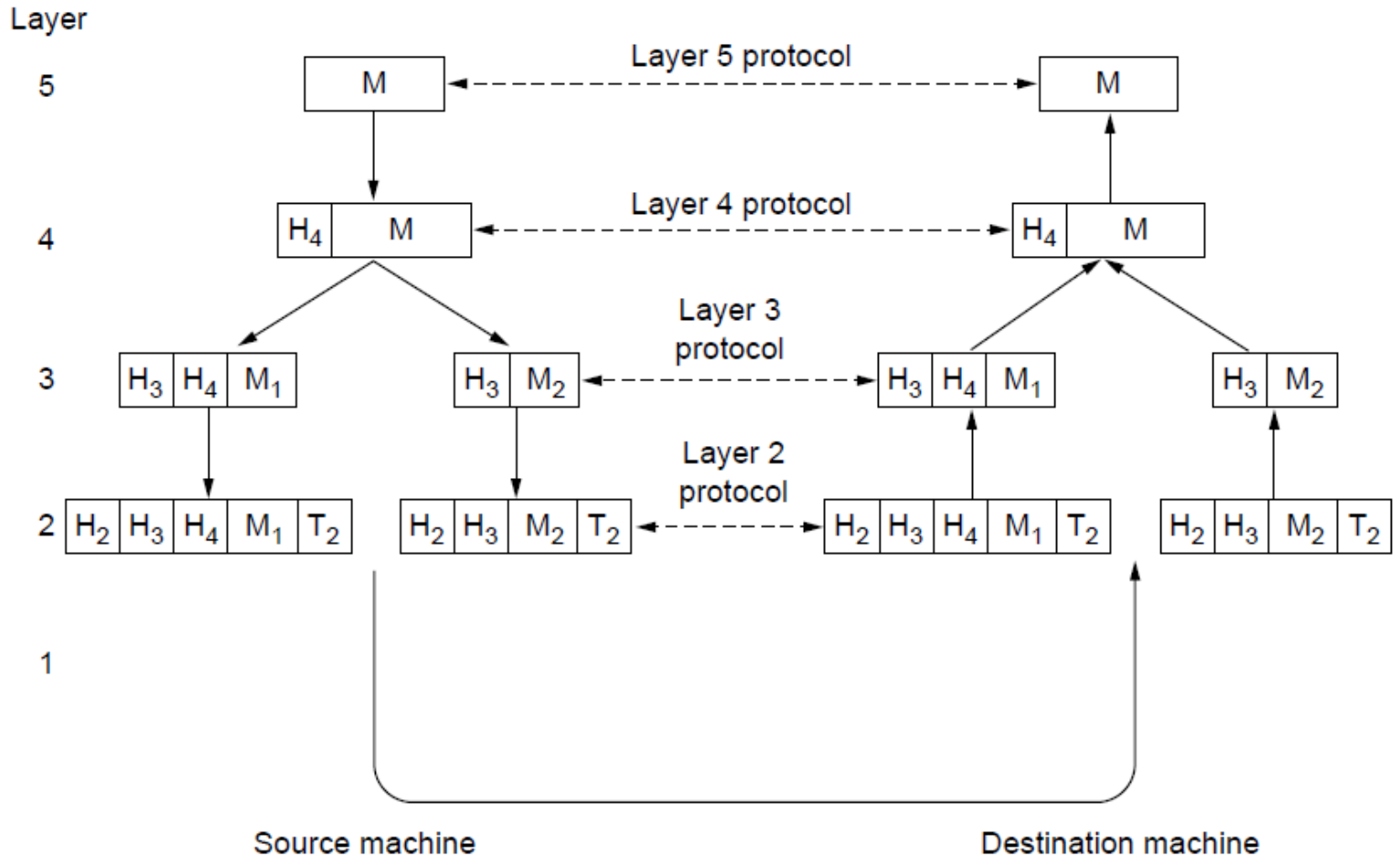
Each translator takes the help of a secretary to transmit the message using the medium (e.g. Fax).

Note : Each protocol is completely independent of each other as long as interfaces are not changed.
(e.g. in layer1 the medium can be a telephone call or e-mail without the notice of translator)

Network Software (cont.)

Protocol Hierarchies

A technical example:



Example information flow supporting virtual communication in layer 5.

Network Software (cont.)

Protocol Hierarchies

Illustration of technical example:

Let a message 'M' produced in layer 5 in source machine is to be transmitted to layer 5 in destination machine.

Step 1 : Message 'M' from layer 5 given to layer 4.

Step 2 : In layer 4 a **header** (i.e. control information like sequence number) is added in front of the message and then given to layer 3. No restriction in size of message.

Step 3 : In layer 3 (if required) the message gets broken into small packets along with the prepend of layer 3 header to each packet following which the packets passed to layer 2. Restriction in size of message. (In the picture the message 'M' is divided into 'M_1' and 'M_2' .)

Step 4 : Layer 2 adds not only a header to each piece, but also a trailer, and gives the resulting unit to layer 1 for physical transmission.

At the receiving machine the message 'M' moves upward from layer to layer, with headers being stripped off as it progresses.

The peer process abstraction is crucial to all network design.

Level 4 protocol conceptually think of their communication as being "horizontal":

SendToOtherSide or *GetFromOtherSide* even though though these procedures actually communicate with lower layers across the 3/4 interface, not with the other side.

Network Software (cont.)

Key design Issues for the Layers

Addressing : Multiple computers and processes: addressing

- Identify senders and receivers (Ex : telephone number, e-mail address, IP address,…)

Error Control : Physical communication medium is not ideal : possibility of error at the receiving end

- error detection
- error correction

Flow control : A fast sender can communicate with slow receiver : proper handshaking before data transmission.

- feedback/acknowledgement from the receiver
- agreed upon transmission rate

Multiplexing and Demultiplexing : Scarcity of separate channels for each source destination pair in the network.

- Multiplexing at one(i.e. transmitting) end
- De-multiplexing at other(i.e. receiving) end

Routing : Possibility of multiple paths between source and destination: appropriate route using suitable routing algorithm

- High level: London -> France or Germany -> Rome
- Low level: many available circuits

Network Software (cont.)

Other design Issues for the Layers

Reliability:

- Network must operate correctly although it is made up of a collection of components that are themselves unreliable.

Protocol Layering:

- Networks grow larger over time and new designs emerge that need to connected to the existing networks.

Scalable:

- Designs that continue to work well when the network gets large.

Congestion:

- The problem may occur when the network is oversubscribed because to many computers want to send too much traffic and the network will not be able to deliver them all.
- Overloading problem of the network.
- One strategy is for each computer to reduce its demand.

Quality of Service:

- Additional Resources (other then Bandwidth),
- Real-time delivery (for applications that require high throughput),
- Live Video,

Network Security:

- How good is the network against different kinds of threats

Network Software (cont.)

Connection-Oriented and Connectionless Services

- Layers can offer two different types of service to the layers above them.
  - Connection-oriented
  - Connectionless
- Importance : Quality of service in terms of reliability.
- Reliability :
  - Accompanies an acknowledgement from the receiver to the sender after reception ensuring the information transmitted has not been lost.
  - In certain cases the unreliable service is also acceptable since acknowledgment introduces overhead and delays.

Network Software (cont.)

Connection-Oriented Service

- Modeled after telephone system: Pickup-the-phone, Dial the number, Talk, Hang-up
- In connection oriented service
  - Establishes a connection,
  - Uses a connection (sender pushes objects in at one end and the receiver takes them out at the other end).
  - Releases the connection
  - In some cases when connection is established, the sender, receiver, and a subnet conduct a negotiation about the parameters to be used:
    - Maximum message size,
    - Quality of service required
- Can be used in both reliable and unreliable form depending on requirement.

Network Software (cont.)

Connection-Oriented Service

- Reliable connection-oriented service: Two forms
  1. Message Sequences
  2. Byte Streams

- Message Sequences:
  - Message boundaries are preserved.
  - Example: Two 1024 byte messages are sent, they arrive as two distinct 1024-byte messages; Never as one 2048-byte message.

- Byte Streams:
  - Message is send as a stream of bytes with no concepts of message boundaries.
  - Example: When a 2048-byte message arrives at the receiver there is no way to tell if they were sent as
    - One 2048-byte message,
    - Two 1024-byte message, or 2048 1-byte messages.

- Unreliable connection-oriented service:
  - It is preferable for telephone users to hear a bit of noise on the line from time to time than to experience a delay waiting for acknowledgements.
  - Example : Digital voice transmission

Network Software (cont.)

Connectionless Service

- Modeled after a postal system.
  - Each message carries the full destination address
  - Each one is routed through the intermediate nodes inside the system independent of all the subsequent messages.
  - Possibility of arrival of second message prior to first message at the receiving end.
- Mostly used in unreliable form.
- Popularly known as **datagram** service.
  - Analogous to telegram service
  - Common example : E-mail
- Certain scenario appreciate acknowledgement from the receiver.

Network Software (cont.)

Connectionless Service

- Unreliable connectionless service :
  - The sender of such kind of messages does not worry for acknowledgement from the receiver.
  - Example : Junk e-mail
- Acknowledgement based connectionless service :
  - The sender in this service can be acknowledged by the receiver.
  - Example : Registered mail
- Request-reply connectionless service :
  - The sender transmits a single datagram containing a request; the reply contains the answer.
  - Example : Answering to queries through mail

Network Software (cont.)

Summary of connection oriented and connectionless service

	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 services offered by network layers

Network Software (cont.)

Service primitives

- Set of **primitives (operations)** available to a user process to access the service.
- Primitives for connection-oriented service are different from those of connectionless service.

Example : Minimum service primitives required to implement a reliable byte stream in a client-server environment

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

Network Software (cont.)

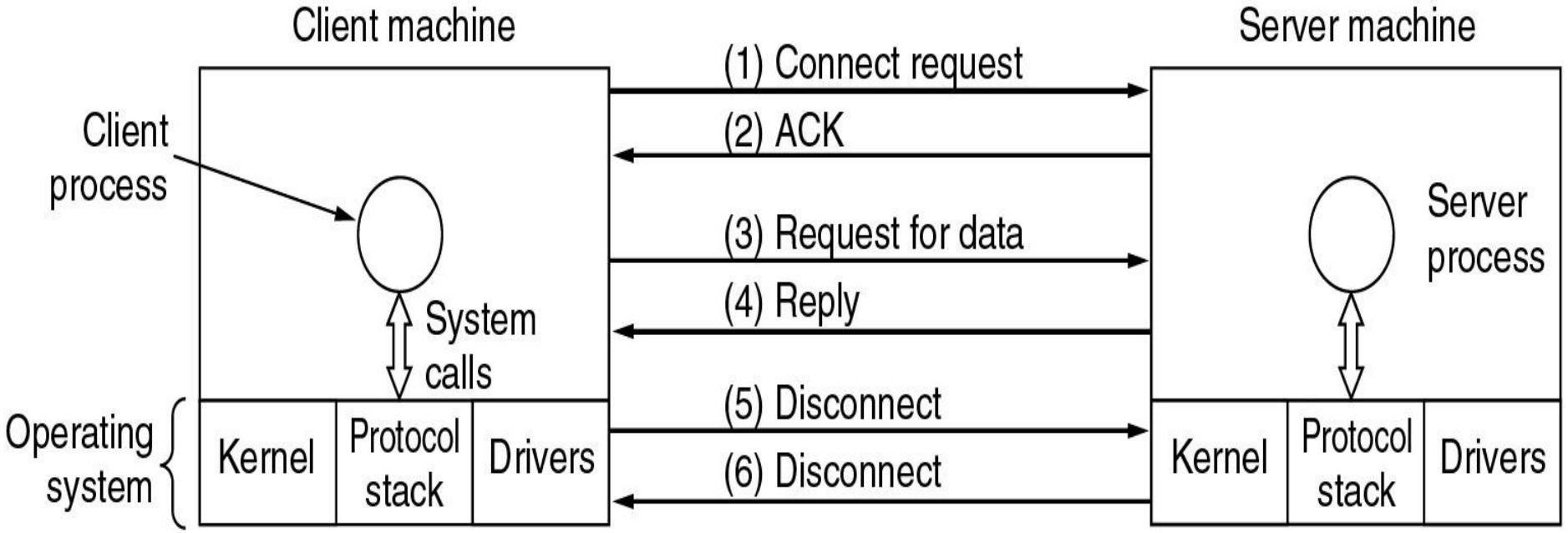
Service primitives

- First, the server executes **LISTEN** to indicate that it is prepared to accept incoming connections. After executing the primitive, the server process is blocked until a request for connection appears.
- Next, the client process executes **CONNECT** to establish a connection with the server. The client process is suspended until there is a response.
- The next step is for the server to execute **RECEIVE** to prepare to accept the first request.
- Then the client executes **SEND** to transmit its request followed by the execution of **RECEIVE** to get the reply.
- After receiving the reply from server, If the client has additional requests, it can make them now. If it is done, it can use **DISCONNECT** to terminate the connection.

Network Software (cont.)

Service primitives

If the protocol stack is located in the operating system, the primitives are normally system calls.



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

Network Software (cont.)

Service primitives

1. Server executes LISTEN to indicate that it is prepared to accept incoming connections.
   - Blocking system call.
   - The server process is blocked until a request for connection appears.
2. Client process executes CONNECT to establish a connection (1) with the server.
   - Specifies who to connect to (parameter giving the server’s address).
   - OS sends a packet to the peer asking it to connect.
   - Client process is suspended until there is a response.
3. The packet is processed at the server.
   - OS sees that the packet is requesting a connection upon reception of the packet.
   - OS checks to see if there is a listener and if so it unblocks it.
   - Sends an acknowledgement (2) back to the client process to accept the connection.
   - The arrival of this response then releases the client.
   - At this point both client and server are running and they have connection established.

Network Software (cont.)

Service primitives

4. The server will execute RECEIVE to prepare to accept the first request.
   - Server does this immediately upon being released from the LISTEN, before acknowledgment can get back to the client.
   - The RECEIVE is a blocking call.

5. The client will execute SEND to transmit its request (3) followed by RECEIVE to get the reply.
   - The arrival of the request packet at the Server unblocks it so it can handle the request.
   - After the server has done the work it will issue a SEND to return the answer to the client (4).
   - The arrival of the this packet unblocks the client which can now inspect the answer.
   - If further request are required it can make them now.

Network Software (cont.)

Service primitives

6. When the client is done it executed DISCONNECT to terminate the connection (5).
   - Initial DICONNECT is a blocking call, suspending the client and sending a packet to the server saying that the connection is no longer needed.
   - When the server gets the packet it also issues a DISCONNECT of its own, acknowledging the client and releasing the connection (6).
   - When the server’s packet gets back to the client machine, the client process is released and the connection is broken.

Network Software (cont.)

Service primitives

- Many things can go wrong:
  - Timing (e.g., CONNECT is done before LISTEN)
  - Packets can get lost, …
- Why not using connectionless service:
  - Only two (2) packets would be needed (i.e. request and reply) vs. six (6).
  - If large messages then chances of transmission errors, lost packets, etc.
- Example:
  - If the reply consisted of hundreds of packets, some of which could be lost during transmission, how would the client know if some pieces were missing?
  - How would the client know whether the last packet actually received was really the last packet sent?

Note : However, in the case where the number of information packets to be communicated are very less and/or the loss of information is acceptable the system can make use of service primitives associated to a connectionless service.

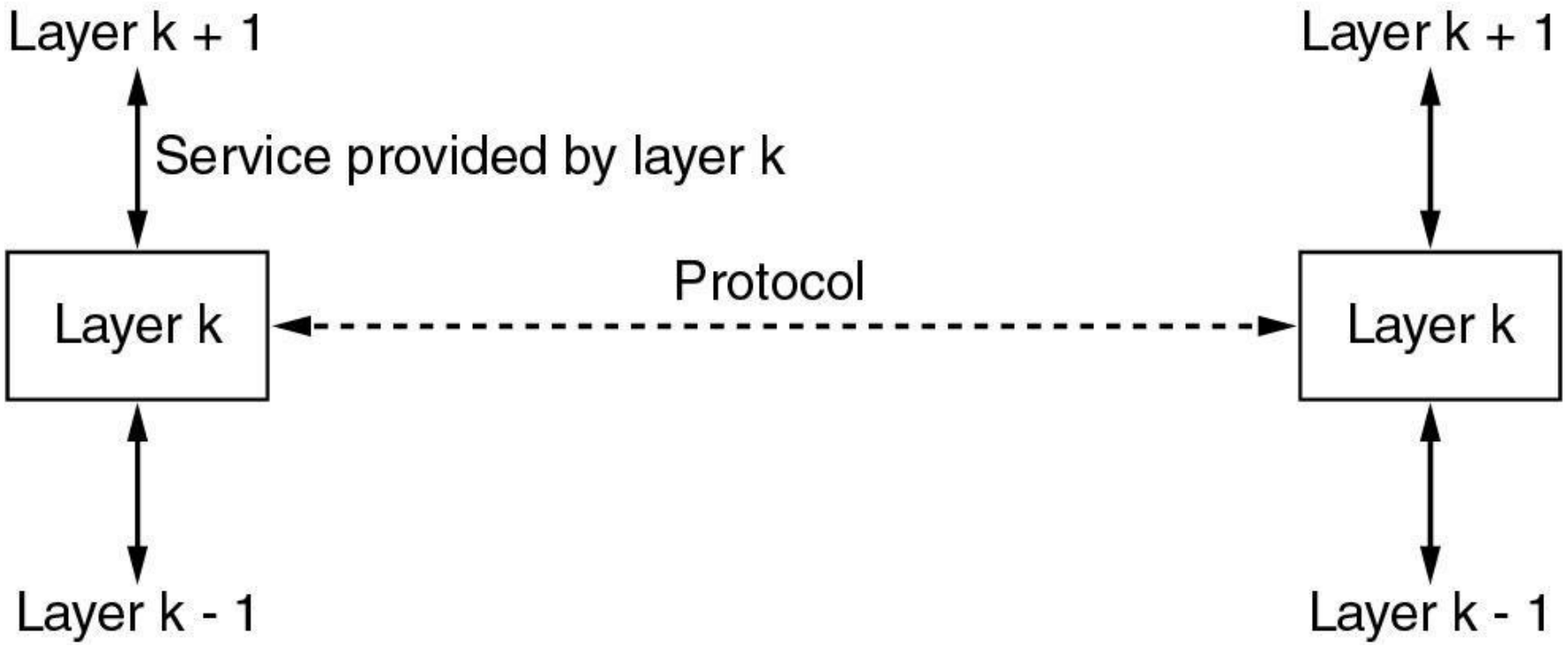
Network Software (cont.)

Relationship of Services to Protocols

- A *service* is a set of primitives (operations) that a layer provides to the layer above it.
  - Services relate to interfaces between layers
  - The service defines what operations the layer is prepared to perform on behalf of its users, but it does not say anything at all about how these operation are implemented.
- A *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.
  - Protocols relate to the packets send between peer entities on different machines.
  - Entities use protocols to implement their service definitions.
  - They are free to change their protocols at will, provided they do not change the service visible to their users.

Network Software (cont.)

Relationship of Services to Protocols



The relationship between a service and a protocol.

Reference Models

- OSI reference model :
  - Although the protocols associated with the OSI model are rarely used any more, the model itself is actually quite general and still valid.
- TCP/IP reference model :
  - The model itself is not of much use but the protocols are widely used.

Reference Models(cont.)

The OSI Reference Model

- Designed in 1983 based on a proposal developed by the International Standards Organization (ISO).
- Revised in 1995, then after, the model is called the ISO **OSI (Open Systems Interconnection)**.
- Deals with connecting open systems (systems that are open for communication with other systems).
- Based on **seven layers**.

Reference Models(cont.)

The OSI Reference Model

Principles :

- Layers created where different abstraction needed.
- Each layer performs well-defined function.
- Function of layer chosen with definition of international standard protocols in mind.
- Minimize information flow across interfaces between boundaries.
- Number of layers optimum.

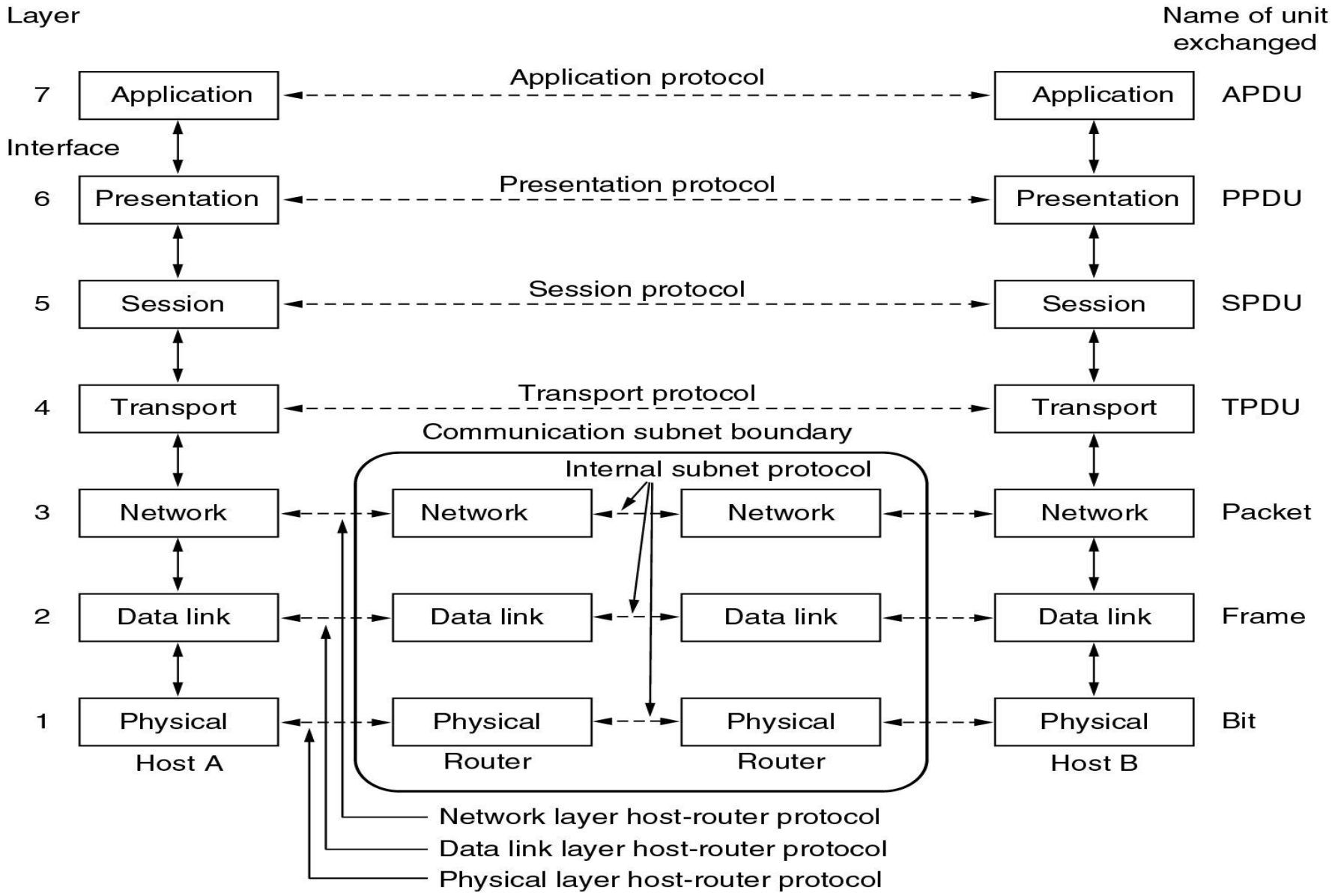
Layers :

1. Physical Layer
2. Data Link Layer
3. Network Layer
4. Transport Layer
5. Session Layer
6. Presentation Layer
7. Application Layer

Reference Models(cont.)

The OSI Reference Model

Structure of
OSI reference model.



Reference Models(cont.)

The OSI Reference Model

Physical Layer:

- Concerned with transmitting raw bits over a communication channel.
- Converts data from the upper layers into '1's and '0's for transmission over media.
- Defines how data is encoded onto the media to transmit the data.
- Defined on this layer: Cable standards, wireless standards, and fiber optic standards.
- Copper wiring, fiber optic cable, radio frequencies, anything that can be used to transmit data is defined on the Physical layer of the OSI Model.

Design issues :

- Ensuring that when one side sends a 1 – bit of information it is received as 1-bit (not as 0-bit or 2-or more- bits).
- What type of signal should be used to represent "1" and "0"?
- How many nano seconds a bit lasts?
- Whether transmission can occur simultaneously in both direction?
- How many pins the network connector has?
- What each pin is used for?

Reference Models(cont.)

The OSI Reference Model

Data Link Layer:

- Transforms the raw data bits to a data frame (few hundred/thousand bits)
- Responsible for sequential transmission of frames from node to node or computer to computer
- In reliable service the receiver confirms correct receipt of each frame by sending back an *acknowledgment frame*.
- Protocols defined include Ethernet Protocol and Point-to-Point Protocol (PPP)
- Two sub layers: Logical Link Control (LLC) and the Media Access Control (MAC)
  - Logical Link Control (LLC)
    - –Flow control, Error control
  - Media Access Control (MAC)
    - –Determines which computer has access to the network media at any given time
    - –Determines where one frame ends and the next one starts, called frame synchronization

Reference Models(cont.)

The OSI Reference Model

Network Layer:

- Controls the operation of the subnet.
- Responsible for moving (or routing) packets (data) from one end of the network to the other, called *end-to-end communications.*
- Determines how packets to be *routed* from source (in one network) to destination (in another network).
  - *Static table (rarely changed)*
  - *Dynamic table (Often changed to avoid failed components) : Route can be determined at the start of each conversion (or) new route for each packet depending on network load.*
- Responsible for congestion handling : If too many packets are present in the subnet at the same time, they will get in each other's way forming bottlenecks.
- Deals with quality of service (i.e. jitter, transit time, delay etc.)
- Handles the issues raised due to different physical addresses of machines belonging to different networks.

Reference Models(cont.)

The OSI Reference Model

Network Layer types :

In datagram networks

- Provides both routing and data forwarding

In connection-oriented network

- Separate data plane and control plane
- Data plane only forwards and schedules data (touches every byte)
- Control plane responsible for routing, call establishment, call-teardown (doesn't touch data bytes)

In Internet

- Network layer is provided by Internet Protocol
- Found in all **end-systems** and **intermediate systems**
- Packet-forwarding, routing, scheduling
- Unique IP addresses

Reference Models(cont.)

The OSI Reference Model

Transport Layer:

- Accepts data from higher levels and splits it into smaller segments that can be sent to network layer.
- Also, reassembles data segments into data for the use of higher layers.
- Puts segments in correct order (called sequencing), so they can be reassembled in correct order at destination.
- Concerned with the reliability of the transport of sent data.
- May use a *connection-oriented protocol* such as TCP to ensure destination has received segments.
- May use a *connectionless protocol* such as UDP to send segments without assurance of delivery.
- It is a true end-to-end layer; it carries data all the way form the source to the destination.
    - In the lower layers (i.e. 1 to 3), the protocols are between each machine and its immediate neighbours (may be routers), and not between the ultimate source and destination machines.

Reference Models(cont.)

The OSI Reference Model

Session Layer:

- Allows users on different machines to establish *sessions* between them.
- Services:

  Dialog control - Keeping track of whose turn is it to transmit

  Token management – Preventing two parties from attempting the same critical operation simultaneously

  Synchronization – Check pointing long transmissions to allow them to pick up form where they left off in the event of a crash and subsequent recovery.
- Establishes, manages, and terminates connections
- Provides duplex, half-duplex, or simplex communications between devices
- Internet – doesn’t have a standard session layer

Reference Models(cont.)

The OSI Reference Model

Presentation Layer:

- Concerned with the syntax and semantics of the information transmitted.
- Since different computer may deal with different data representations a standard encoding is done, thus handles three primary tasks:

  –Translation , –Compression , –Encryption

  Ex : ASCII
- Internet

  –no standard presentation layer

Application Layer:

- Contains all services or protocols needed by application software or operating system to communicate on the network

  Example : **HTTP (Hyper Text Transfer Protocol**), which is the basis for the World Wide Web.

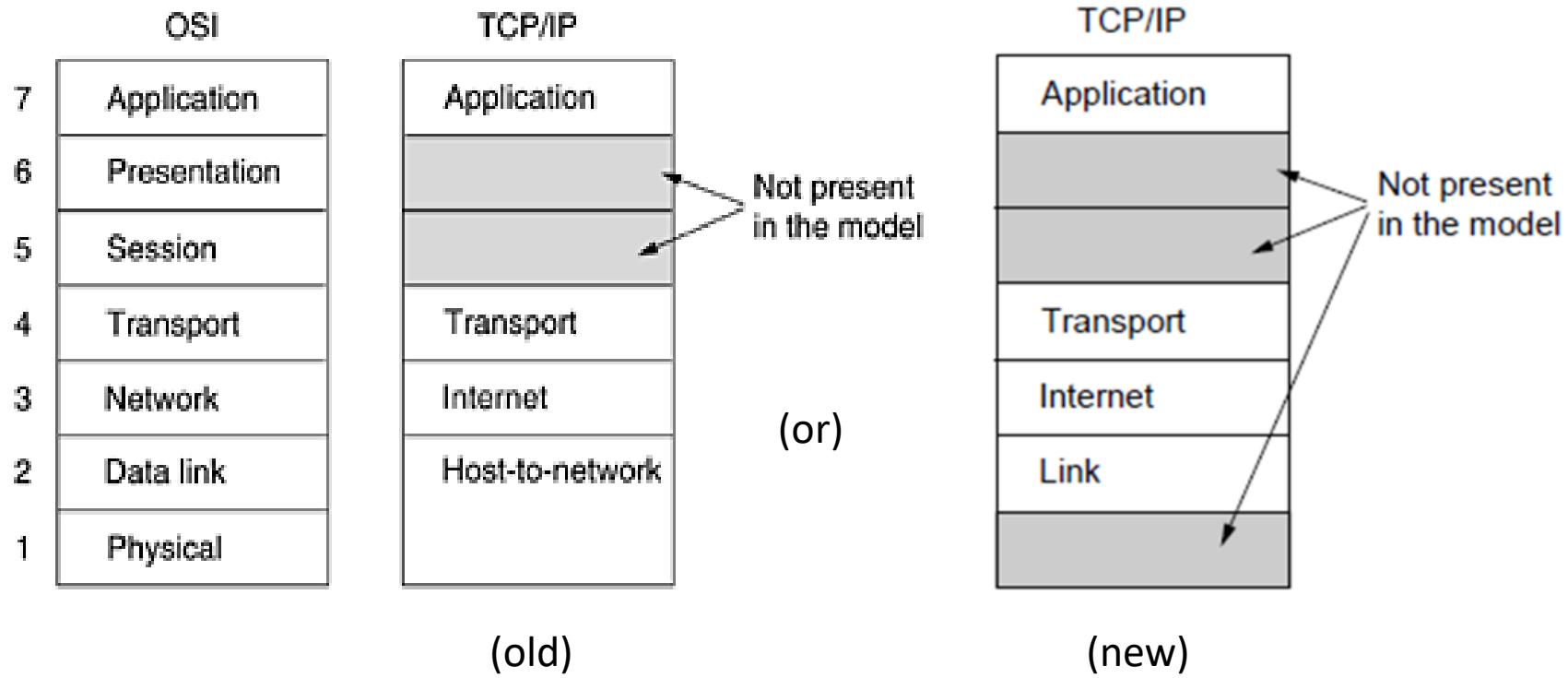
Reference Models(cont.)

The TCP/IP Reference Model

- Proposed earlier to OSI model.
- Used in **ARPANET**(grandparent of all wide area computer) and it's successor **the internet**
  (Also used in private networks)
- Designed to support/interconnect different types of network (e.g. interconnection of radio network and computer network).
- Four protocol layers :
  - Host-to-network/link
  - **Internet**
  - **Transport**
  - **Application**
- Design criteria:
  - Network be able to survive loss of subnet hardware without existing conversations being broken off.
  - Applications with divergent requirements were supported ranging from file transfer to real-time speech transmission.

Reference Models(cont.)

The TCP/IP Reference Model



Note :

When TCP/IP is compared to OSI it can be seen that the host-to-network layer is equivalent to the combination of physical and data link layer. Also, the internet layer is equivalent to the network layer, and the application layer is roughly doing the job of the session, presentation, and application layers

Reference Models(cont.)

The TCP/IP Reference Model

Link Layer :

- Describes what links such as serial lines and classic Ethernet must do to meet the needs of this connectionless internet layer.
- It is not actual layer in the classical sense of the term rather is an interface between hosts and transmission links.

Internet Layer :

- Permit hosts to inject packets into any network and have them travel independently to the destination (potentially on a different network).
- The packets may arrive in a completely random order from the original and the higher layer must rearrange them – if in-order of delivery is desired.

  (An analogy example : Letters dropped in the post box in sequence may not reach in the same sequence)
- Defines an official packet format and protocol called IP (Internet Protocol).
- Packet routing is a major issue and IP has not proven effective at avoiding congestion.

Reference Models(cont.)

The TCP/IP Reference Model

Transport Layer :

- Allow peer entities on the source and destination hosts to carry on a conversation.
- Uses either of the two types of transport protocol (i.e. TCP and UDP).

TCP(Transmission Control Protocol) :

- A reliable connection-oriented protocol.
- Allows a byte stream originating on one machine to be delivered without error on any other machine in the internet.
- It fragments the incoming byte stream into discrete messages and passes each one on to the internet layer.
- At the destination, the receiving TCP process reassembles the received messages into the output stream.
- TCP also handles flow control to make sure a fast sender cannot swamp a slow receiver with more messages than it can handle.

UDP(User Datagram Protocol):

- An unreliable, connectionless protocol for applications that do not want sequencing or flow control and wish to provide their own.
- Also widely used for one-shot, client-server-type request-reply queries and applications in which prompt delivery is more important than accurate delivery, such as transmitting speech or video.

Reference Models(cont.)

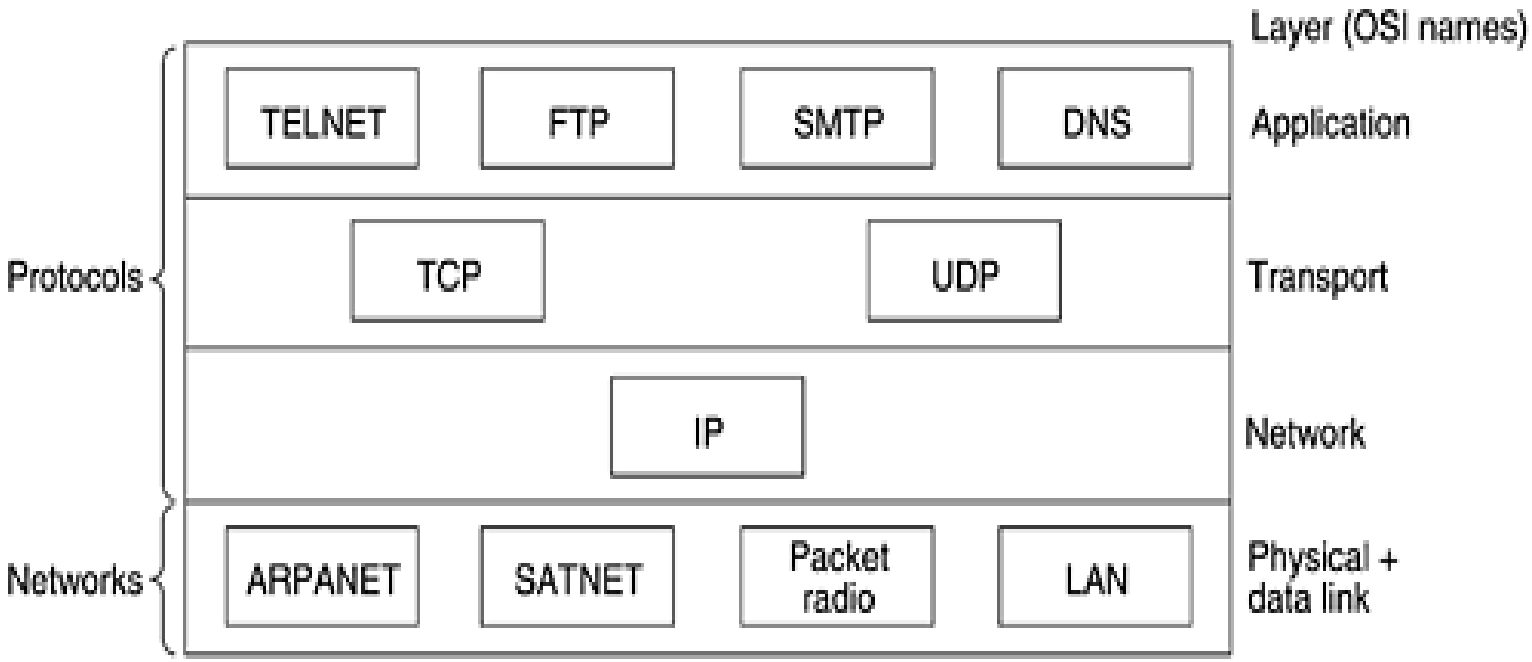
The TCP/IP Reference Model

Application Layer :

- Define the rules when implementing specific network applications.
- Applications simply include any session and presentation functions that they require.
- Rely on the underlying layers to provide accurate and efficient data delivery.
- Typical protocols:
  - FTP – File Transfer Protocol (For file transfer)
  - Telnet – Remote terminal protocol (For remote login on any other computer on the network)
  - SMTP – Simple Mail Transfer Protocol (For mail transfer)
  - HTTP – Hypertext Transfer Protocol (For Web browsing)

Reference Models(cont.)

The TCP/IP Reference Model



Protocols and networks in the TCP/IP model initially

Reference Models(cont.)

A Comparison of the OSI and TCP/IP Reference Models

Similarities :

1. Both lie on the concept of a stack of independent protocols.
2. Functionality of the layers is roughly similar (for example in both models, the layers above transport are application-oriented users of the transport service).

Differences :

OSI reference model	TCP/IP reference model
Uses 7 different layers.	Uses 4 different layers.
Supports both connectionless & connection oriented service in the network layer but only connection oriented service in transport layer.	Supports only connectionless service in the network layer but both connectionless & connection oriented service in transport layer.
Clearly distincts service, interface & protocol.	Doesn't clearly distinguish service, interface & protocol.
Protocols are better hidden and can be replaced relatively easily as the technology changes.	Protocols are not hidden and can not be replaced easily as the technology changes (e.g. Replacing IP with a different protocol is virtually impossible).
The reference model was devised before the corresponding protocols were invented.	The protocols came first, and the model was really just a description of the existing protocols since the protocols fit perfectly.

Example networks

The computer networks that are functioning in the current scenario are associated with so many attributes like size, technology, goals etc.

- Internet
  - ARPANET
  - NSFNET
- Connection oriented network : ATM
- Ethernet
- Wireless LANs: 802.11

Example networks (cont.)

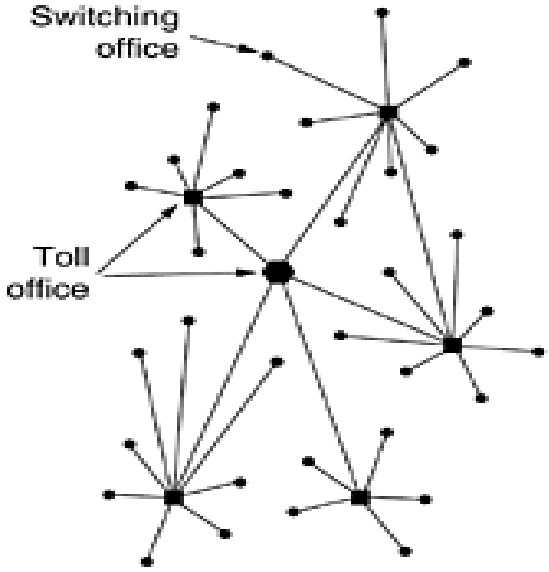
The Internet

- Never be considered as a single network rather than a vast collection of different networks that use certain common protocols and provide certain common services.
- Not planned by anyone and not controlled by anyone.
- Revolutionized many aspects of our daily lives.
- People use internet for various reasons.
- History :
  - ARPANET
  - NSFNET

Example networks (cont.)

ARPANET

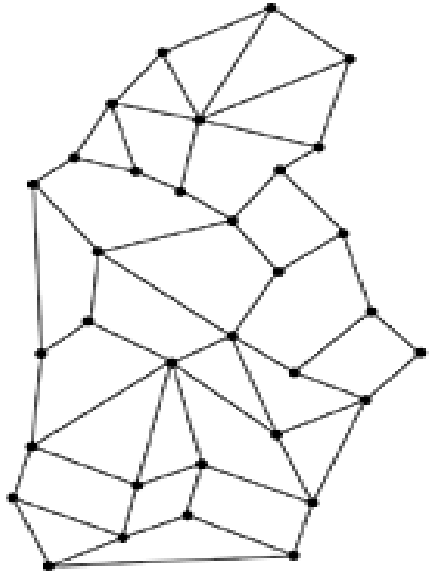
- Started with the want from DoD in late 1950 to develop a command-and-control network.
- In the beginning uses the base of existing public telephone network.
- Issue : Structure is vulnerable (i.e. destroy of toll offices fragments the system into isolated islands).



Structure of the telephone system

- Around 1960 the DoD awarded a contract to the RAND Corporation.
- Paul Baran, proposed the incorporation of digital packet switching technology in a highly distributed and fault tolerant system.

(Idea was dismissed)



Baran's proposed distributed switching system

Example networks (cont.)

ARPANET

- Following several years, **ARPA (Advanced Research Projects Agency)** is created to find the solution related to design of the command and control network.
- In 1967, Lary Roberts (director of ARPA) presented an idea (Wesley clark) in the form of paper related to building of a packet switched subnet, where each host has it's own router.
- Following to this, the practical implementation of a network is determined by Roberts with a name **ARPANET**.
- A consulting firm named BBN had contracted to make practical implementation of ARPANET.
  - Built subnet
  - Wrote the subnet software
  - Transmission line leased from telephone companies.

Example networks (cont.)

ARPANET

Concept :

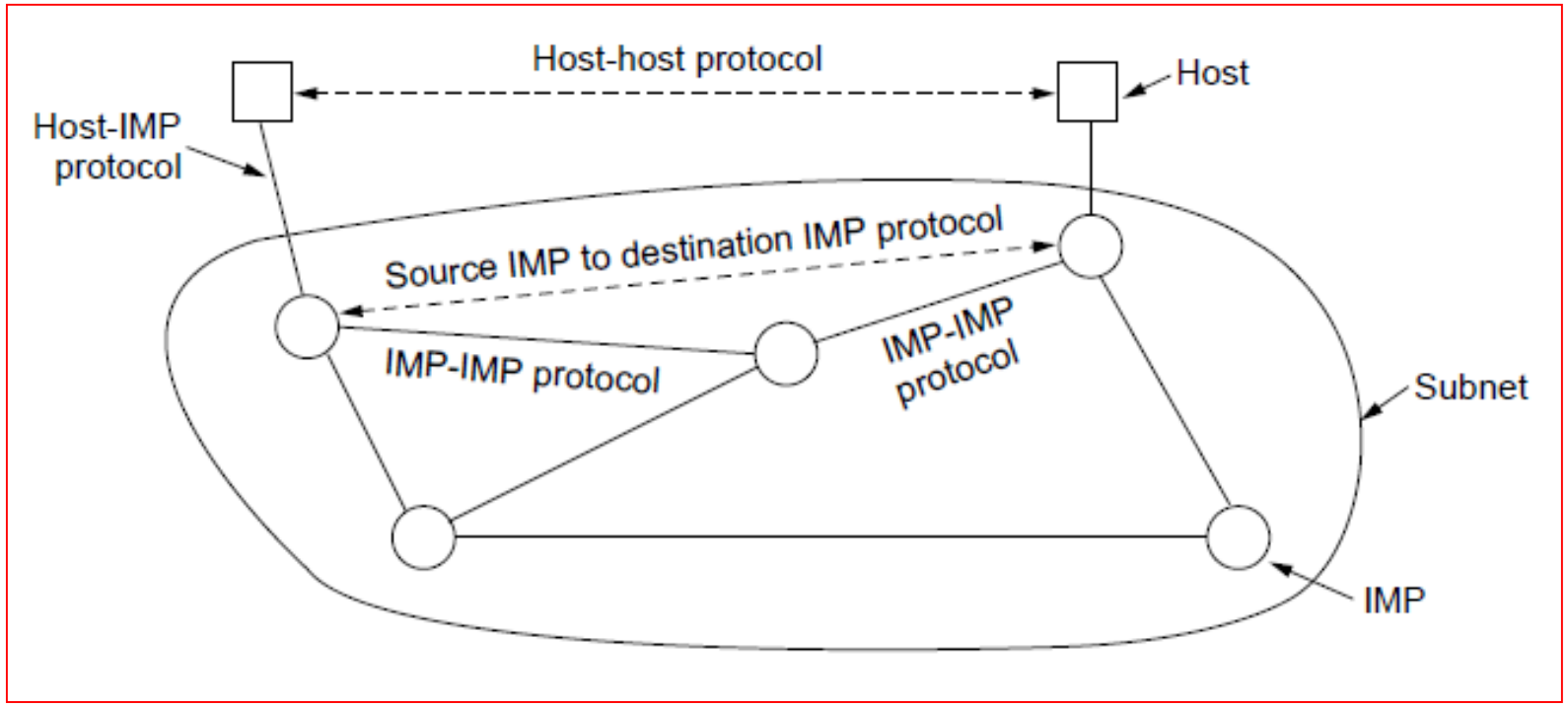
- Subnet consists of minicomputers called **IMPs (Interface Message Processors).**
- 56-kbps transmission lines.
- Each IMP connected to at least two other IMPs.
- Datagram subnet (if some lines and IMPs were destroyed, messages could be automatically rerouted along alternative paths).
- Each node consists of an IMP and a host, in the same room, connected by a short wire.
- A host can send messages of up to 8063 bits to its IMP.
- IMPs break these up into packets of at most 1008 bits and forward them independently toward the destination.
- Each packet was received in its entirety before being forwarded.
- Store-and-forward packet-switching network.

Example networks (cont.)

ARPANET

Software :

- Subnet software : required at the IMP end of the host-IMP connection
  - IMP-IMP protocol
  - Source IMP to destination IMP protocol
- Host software : Required at the host end of the host-IMP connection
  - Host-host protocol
  - Application software



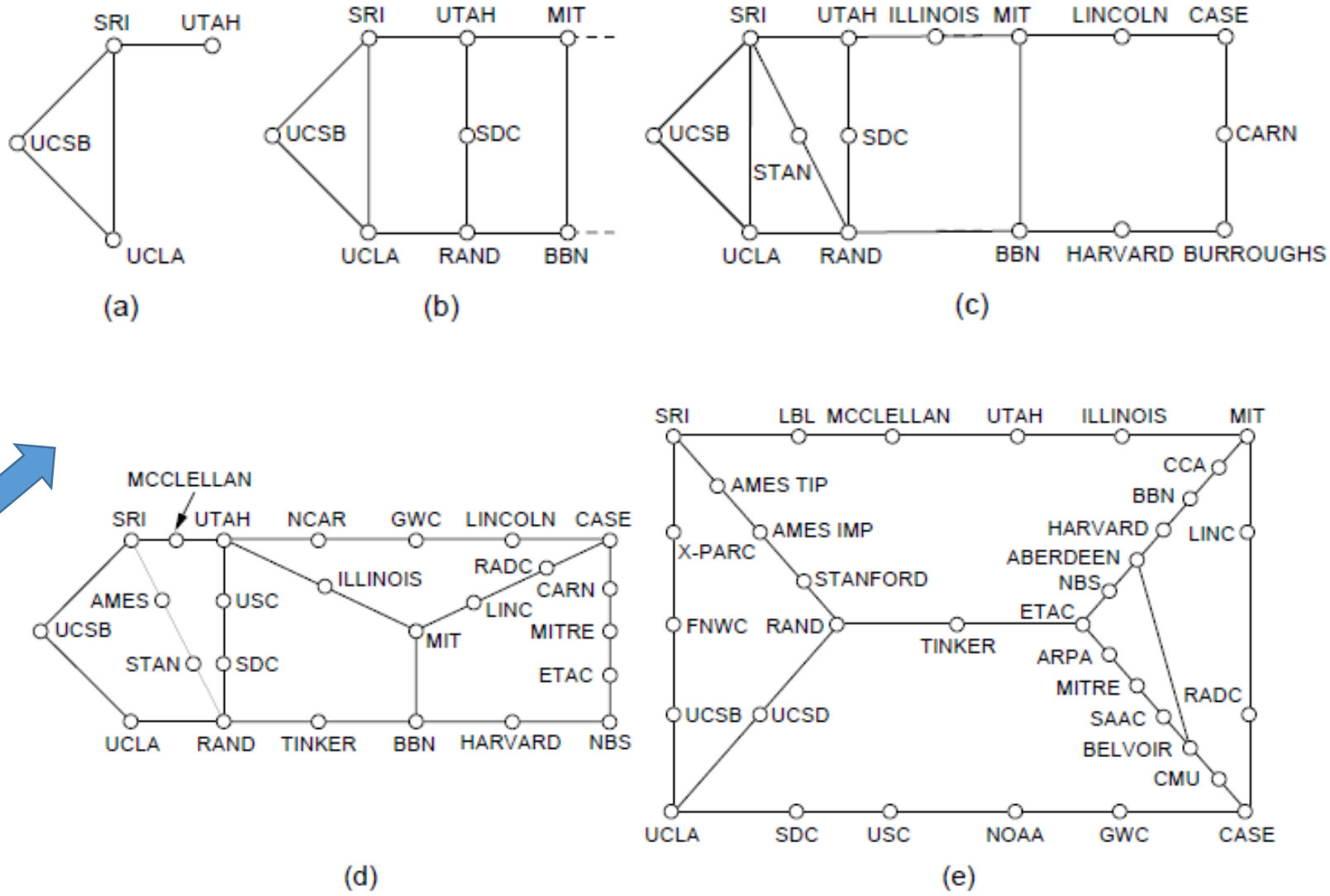
The original ARPANET design

Example networks (cont.)

ARPANET

Growth :

- An experimental network implemented in December 1969 with four nodes: at UCLA, UCSB, SRI, and the University of Utah. (a)
- Installation of more IMPs make the ARPANET to grew rapidly. (b), (c), (d), (e)



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

Example networks (cont.)

ARPANET

Use of TCP/IP :

- ARPANET protocols were not suitable for running over multiple networks.
- Leads to invention and implementation of **TCP/IP**.
- In 1980s, many additional networks, especially LANs, were connected to the ARPANET.

Use of DNS :

- Increase in scale of network → Difficulty in identifying hosts
- Development of **DNS (Domain Name system).**
- Host names mapped to IP addresses.
- DNS is still used in internet.

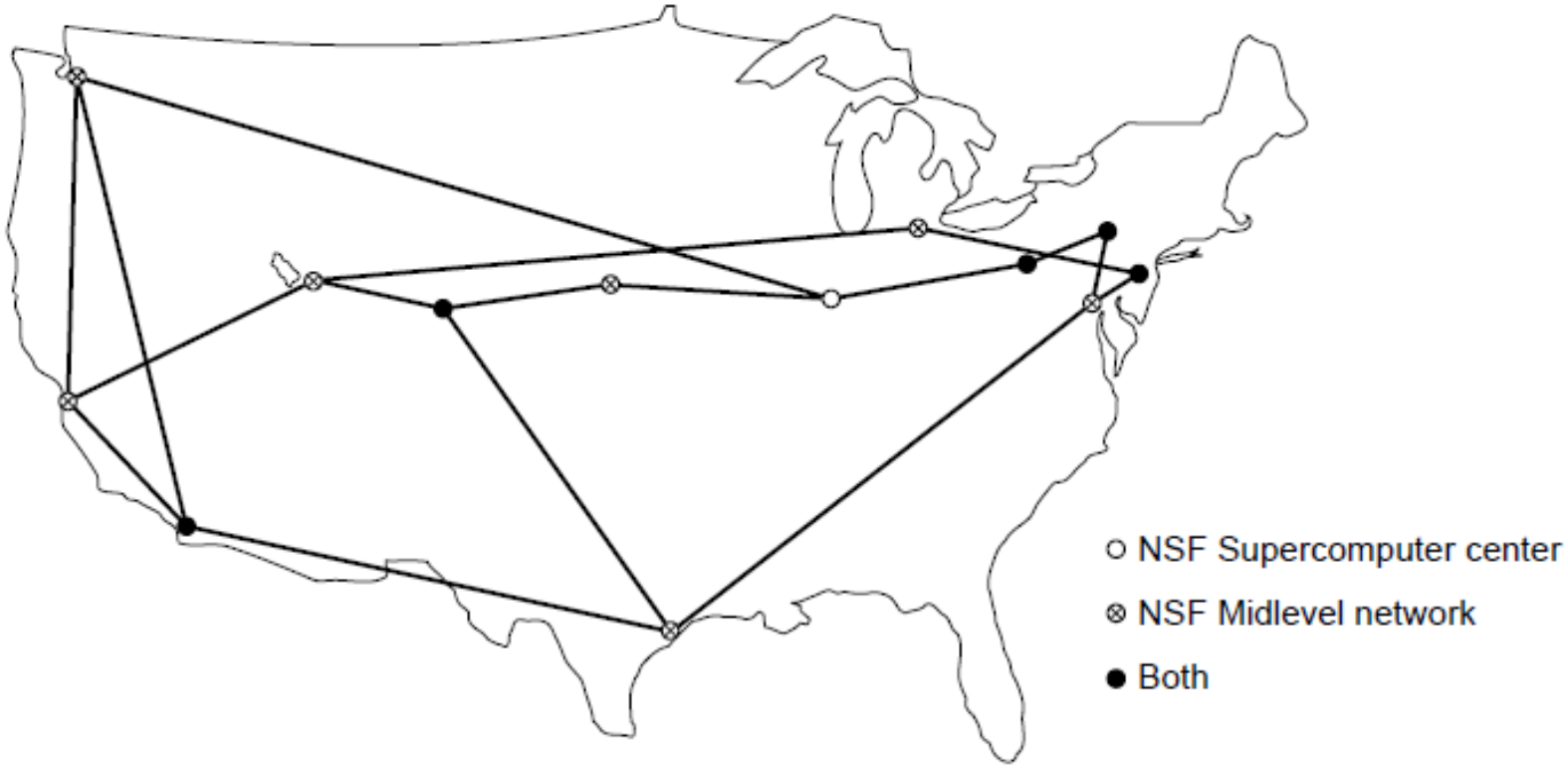
Example networks (cont.)

NSFNET

- Late 1970's : NSF (the U.S. National Science Foundation) had taken a response to design a successor to the ARPANET.
- Open to all university research groups.
- Initial step to built a backbone network to connect its six supercomputer centres.
- Each supercomputer was attached with a microcomputer called a **fuzzball**.
- **Fuzzballs** were connected with 56-kbps leased lines and formed the subnet.
- TCP/IP was used from the beginning.
- Regional networks also connected to the backbone getting the financial support from NSF.
  - Allow users at thousands of universities, research labs, libraries, and museums to access any of the supercomputers and to communicate with one another.
- Combined structure of backbone and regional networks named as **NSFNET**.
- **NSFNET** was also connected with ARPANET through link between fuzzball and IMP.

Example networks (cont.)

NSFNET



The NSFNET backbone in 1988

Example networks (cont.)

NSFNET

NSFNET to ANSNET:

- By 1990s version 2 backbone designed and implemented with the use of fiber channel to provide a speed of 1.5 Mbps.
- NSF with non government organizations forms **ANS (Advanced Networks and Services).**
- In 1990s, ANS took over the NSFNET and renamed it **ANSNET** with a speed 45 Mbps.

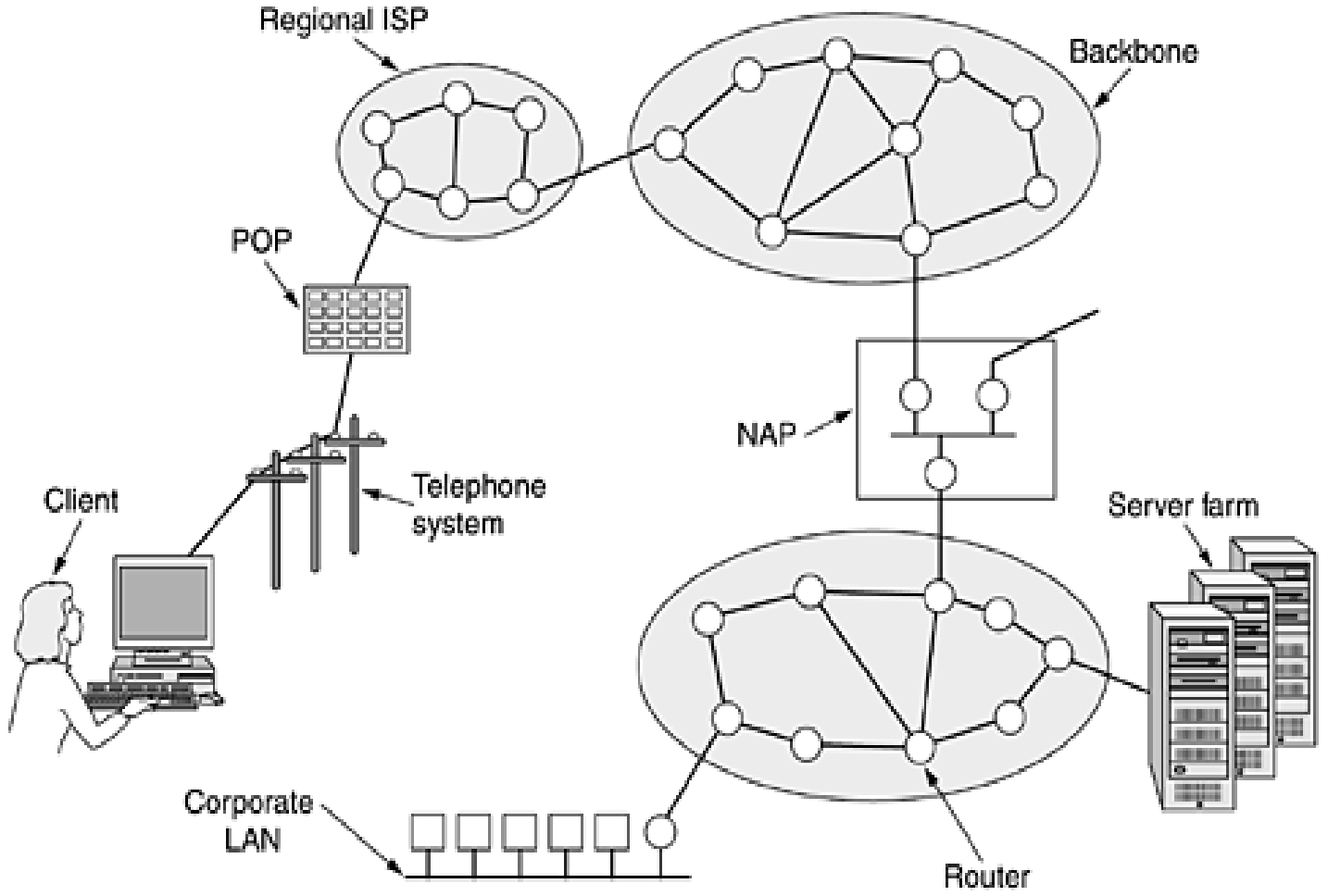
NAP (Network Access Point):

- Four different network operators get contract from NSF to set up **NAPs** for providing communication service between regional networks.
- Network operators also provide backbone service to regional networks.
- A packet originating on any regional network had a choice of backbone carriers to get from its NAP to the destination's NAP.
- More than one backbone like competitive structure came into action.

Example networks (cont.)

Architecture of the Internet

- Client machine gets connected to Regional ISP through POP centre.
  - Dial up service (for telecom company as ISP).
  - Direct cable (ISP other than telecom company).
- ISP's regional network consists of interconnected routers in cities.
- If destination host served by same ISP, then packet delivered to destination host, else forwarded to ISP's backbone operator.
  - If destination host directly connected to backbone, then Packet delivered to host, else forwarded to other ISP regional network/ other backbone (through NAP).
- Packet delivered to host.



Overview of the Internet

Example networks (cont.)

Internet usage

Definition :

A machine is on the Internet if it runs the TCP/IP protocol stack, has an IP address, and can send IP packets to all the other machines on the Internet.

1970 – early 1990 : The Internet and its predecessors had four main applications.

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

- Until the early 1990s, the Internet was largely populated by academic, government, and industrial researchers.
- **WWW (World Wide Web)** changed all that and brought millions of new, non-academic users to the net.
- Together with the **browser,** the WWW made it possible for a site to set up a number of pages of information with embedded links between pages.
  - For example, many companies have a home page with entries pointing to other pages for product information, price lists, customer support and more.
- With the facility available in home, the network character has taken the shape of public utility.

Example networks (cont.)

Connection-Oriented Network: ATM

- Telephone companies were supporting the connection-oriented network because of two reasons:
  1) Quality of service
  2) Billing
- **X.25** (1970s) and **frame delay** (1980s) : works on synchronous transmission characteristics.
- In early 1990s, **ATM (Asynchronous Transfer Mode)** network designed to work with asynchronous transmission system.
- Merging of voice, data, cable television and many more signals into a single integrated system that could do everything for everyone.
- Initially not happened due to bad timing, technology and implementation, however later on, found to be successful.

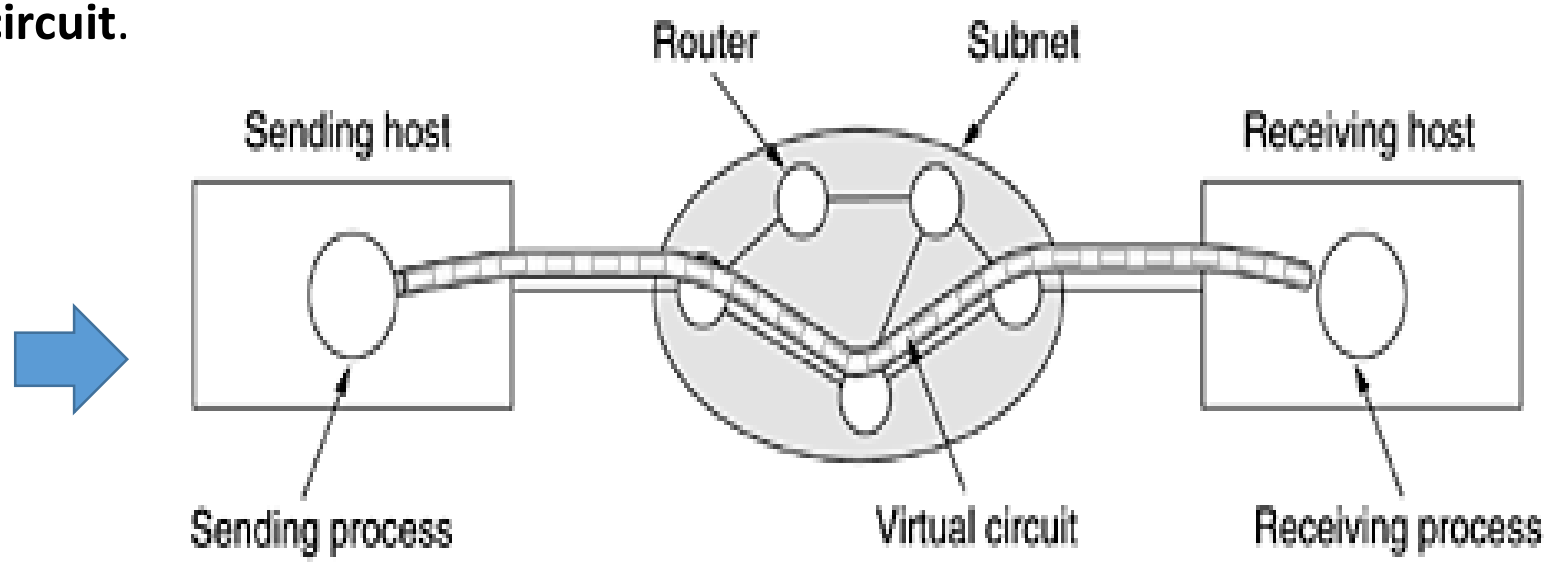
Example networks (cont.)

Connection-Oriented Network: ATM

ATM Virtual Circuits:

- Set up packet transmission prior to sending of data from source host to destination host.
- Routers in the path followed by set up packet make an entry to their routing table indicating path information till the end of the data transmission.
- Connection between two hosts through subnet/routers van be temporary/permanent and is referred as **ATM virtual circuit**.

A virtual circuit in ATM network



Example networks (cont.)

Connection-Oriented Network: ATM

Connection identifier, ATM cell, Information flow

- Each connection, temporary or permanent, has a unique **connection identifier**.
- The information in ATM is transmitted in the form of small, fixed-size packets called **cells**.
- The cells are 53 bytes long, of which 5 bytes are header and 48 bytes are payload.

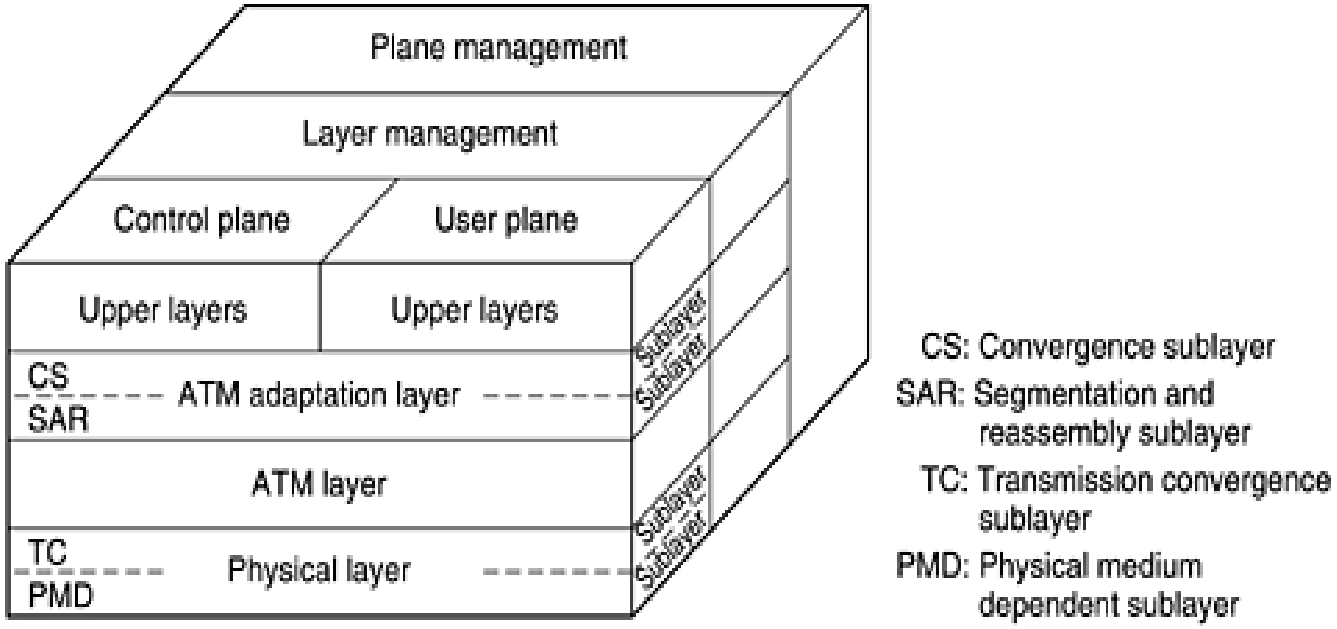
An ATM cell

- Part of the header is the connection identifier to identify the source and destination host for a packet.
- Helps the router to know how to route each incoming cell.
- Cells transmitted in a sequence order.
- Most common speeds for ATM networks are 155 Mbps and 622 Mbps.

Example networks (cont.)

The ATM Reference Model

- ATM has its own reference model, different from the OSI model and also different from the TCP/IP model.
- Three layers, the physical, ATM, and ATM adaptation layers with a flexibility for an user defined upper layer(s) above that.



The ATM reference model

Example networks (cont.)

The ATM Reference Model

Physical layer :

- Deals with the physical medium: voltages, bit timing, and various other issues.
- No specific rules for the cells regarding the chose of transmission medium.
- ATM cells can be sent on a wire or fibre by themselves.
- ATM cells can also be packaged inside the payload of other carrier systems.
- Two sub layers.

- PMD (Physical Medium Dependent) sub layer:

  - Make the bits on and off to move through transmission medium (say cable)/carrier.
  - Handles the bit timing.
  - For different carriers and cables, this layer will be different.

- TC (Transmission Convergence) sub layer:

  - Converts the cells into bit stream in transmitting end and the reverse in receiving end.
  - Handles all the issues related to telling where cells begin and end in the bit stream.

Example networks (cont.)

The ATM Reference Model

ATM layer :

- Deals with cells and cell transport.
- Defines the layout of a cell and tells what the header files mean.
- Deals with establishment and release of virtual circuits.
- Handles congestion control issues.

ATM adaption layer :

- Allow users to send packets larger than a cell.
- The ATM interface segments these packets, transmits to lower layer.
- Reassembles the segments (if any) at the other end.
- Two sub layers.

- SAR (Segmentation And Reassembly) sub layer:

  - Breaks up packets into cells on the transmission side and puts them back together again at the destination.

- CS (Convergence Sub layer):

  - Handles different kinds of services to different applications (e.g., file transfer and video on demand have different requirements concerning error handling, timing, etc.).

Example networks (cont.)

The ATM Reference Model

User defined upper layer :

- User plane deals with data transport, flow control, error correction, and other user functions.
- Control plane is concerned with connection management.
- Layer and plane management functions relate to resource management and interlayer coordination.

Example networks (cont.)

The ATM Reference Model

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

The ATM layers and sub layers, and their functions

Example networks (cont.)

Ethernet

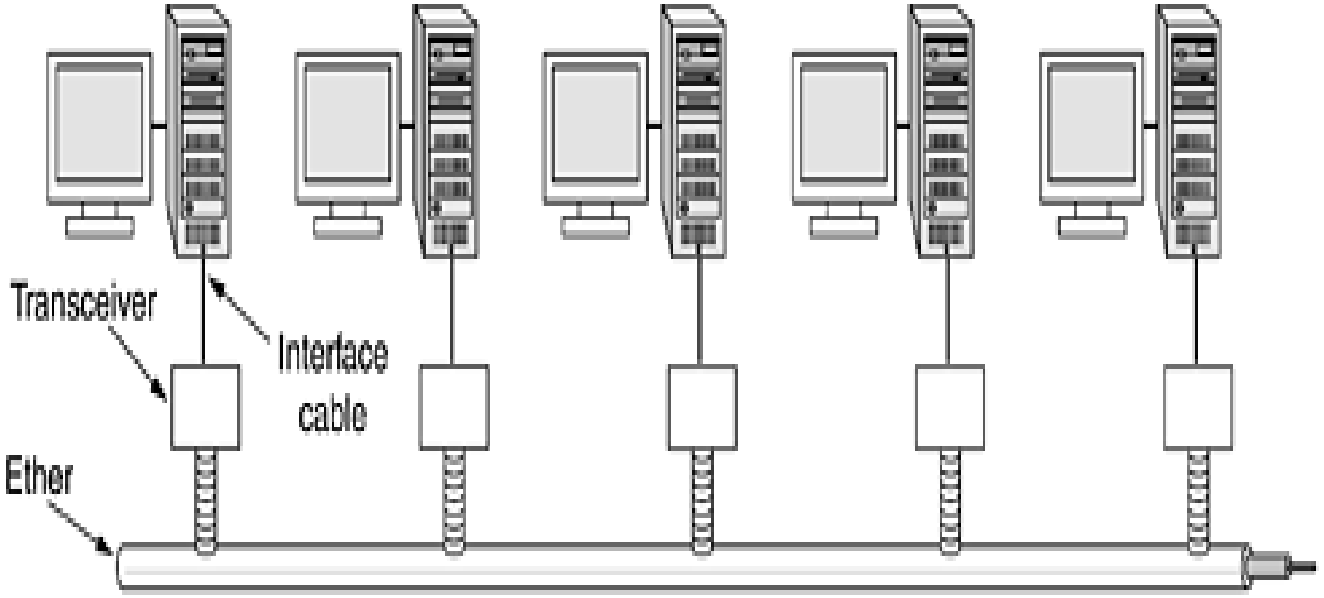
- Most popular local area network.
- Implemented in Xerox PARC (Palo alto Research centre) in 1976.
- Named after the ***luminiferous ether***, through which electromagnetic radiation was once thought to propagate.
- Considered as a suceeder to ALOHANET.
- Uses thick coaxial cable (the ether) as transmission medium.
- Cable length : 2.5 km

  (Repeaters at every 500m)
- 256 machines can be connected.
- Speed : 2.94 Mbps.

- Prior to Ethernet (in 1970s)
- Uses short range radio devices.
- Communication between user terminals through central computer.
- Uses two frequencies.
  1. Upstream (user terminal to central computer)
  2. Downstream (Central computer to user terminal).
- Worked fine with low traffic.
- Poor performance with heavy traffic in upstream.

Example networks (cont.)

Ethernet



Architecture of the original Ethernet

Example networks (cont.)

Ethernet

Advantage of Ethernet over ALOHANET :

- Before transmitting, a computer first listened to the cable to see if someone else was already transmitting.
- If so, the computer held back and wait until the current transmission finished.
- Avoids interfering with existing transmissions, giving a much higher efficiency.
- (ALOHANET : Not possible to sense the transmission line.)
- Still a possibility of simultaneous transmission ?
- Can be resolved with random wait time which can be doubled if still collision chance is there.

Example networks (cont.)

Ethernet

Ethernet as IEEE standard :

- Following to success in implementation of Ethernet the speed enhanced to 10 Mbps in 1978.
- In 1983, considered as **IEEE 802.3** standard.
- In the due course of time with the improvement in technology it provides higher speed (100 Mbps).

Other IEEE standards for LAN : IEEE 802.4, IEEE 802.5

- **802.4** : Token bus introduced by General motors, BUS topology
- **802.5** : Token ring introduced by IBM, RING topology
- **Token** : A short packet and is used to make a turn for a computer being allowable for transmission of its data.
- A computer could only send if it possessed the token, thus avoiding collisions.
- In due course of time 802.4 has vanished from sight .
- 802.5 had its existence and still in use at some IBM site (popular in the name **IBM token ring).**

In the war of LAN, Ethernet has taken the highest utility in compare to others like token bus and token ring.

Example networks (cont.)

Wireless LANs: 802.11

- To equip both the office and the notebook computers with short-range radio transmitters and receivers and to allow them to communicate.
- **Issue in the beginning : Some systems faces problem because of technical incompatibility between devices.**

  Example: A computer equipped with a brand X radio could not work in a room equipped with a brand Y base station.
- **Issue solved through standardisation of Wireless LAN (IEEE 802.11).**
- Popular in the term **WIFI**.

Example networks (cont.)

Wireless LANs: 802.11

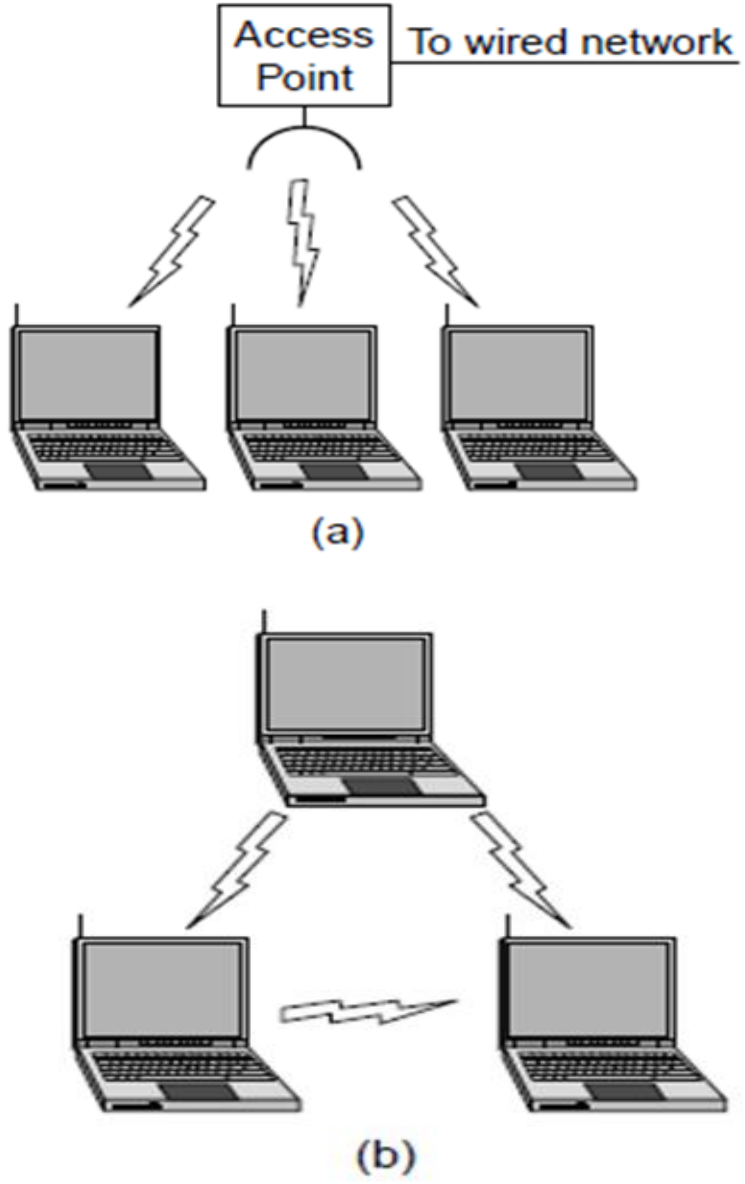
The proposed standard had to work in two modes:

(a) In the presence of a base station.

- All communication was to go through the base station, called an **access point**.

(b) In the absence of a base station.

- The computers would just send to one another directly.
- This mode is now sometimes called **ad hoc networking**.



Example networks (cont.)

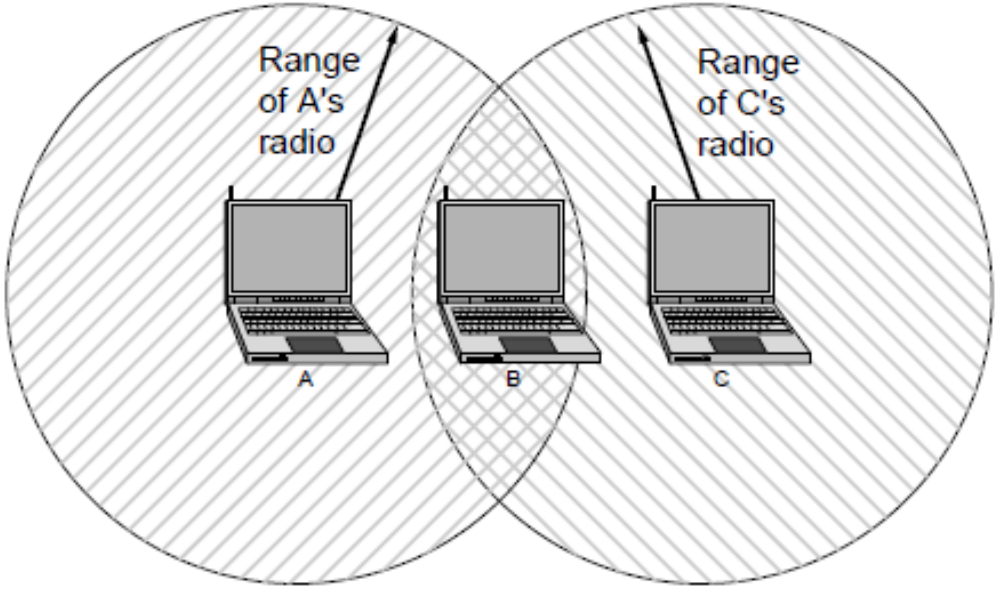
Problems encountered during implementation of Wireless LANs: 802.11

Carrier sense before transmission :

- Though works in Ethernet to avoid simultaneous transmission may not work always in 802.11.

Example :

Let’s assume that computer A is transmitting to computer B, but the radio range of A's transmitter is too short to reach computer C. If C wants to transmit to B it can listen to the ether before starting, but the fact that it does not hear anything does not mean that its transmission will succeed.



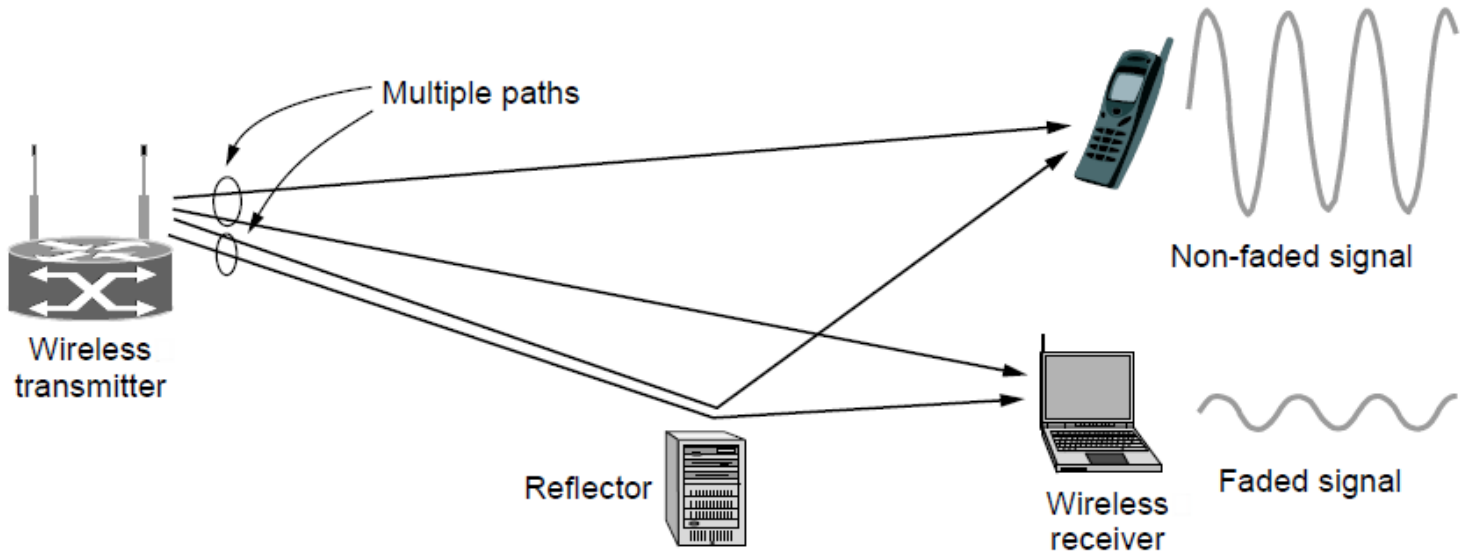
The range of a single radio may not cover the entire system

Example networks (cont.)

Problems encountered during implementation of Wireless LANs: 802.11

Multipath fading:

- A radio signal can be reflected off solid objects.
- Same signal may be received multiple times (along multiple paths).
- May lead to interference what is called **multipath fading**.



Example networks (cont.)

Problems encountered during implementation of Wireless LANs: 802.11

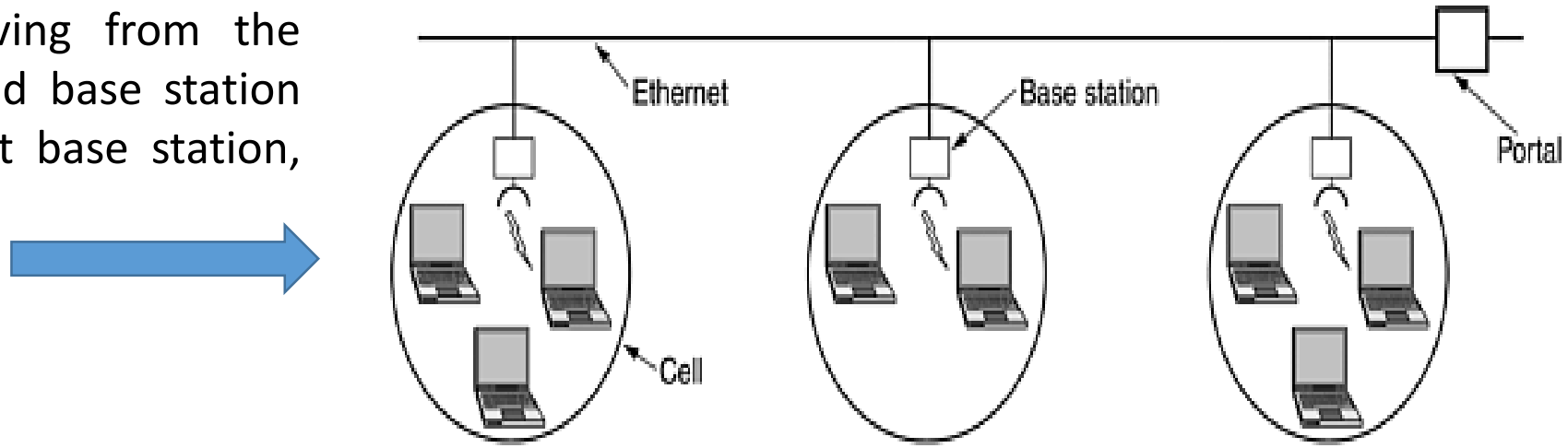
Compatibility with software :

- Software is not aware of mobility of computer system compatible with other device.

Example :
Many word processors have a list of printers that users can choose from to print a file. When the computer on which the word processor runs is taken into a new environment, the built-in list of printers becomes invalid.

Hand off:

- A notebook computer moving from the range of one ceiling-mounted base station into the range of a different base station, requires hand off.



A multi-cell 802.11 network

Example networks (cont.)

Versions of 802.11

Though the problem cited earlier were solved in the due course of time dissatisfaction lies among users with speed.

- The initial standard (i.e. 802.11 in 1997) ran at either 1 Mbps or 2 Mbps.

  (Frequency hopping and signal spreading technology)

- **802.11a** and **802.11b** (1999)

802.11a : Speed up to 54 Mbps (wider frequency band **)**

802.11b : 11 Mbps (same frequency band as 802.11 but different modulation technique**)**

Besides these 802.11g (2003) is also used currently in some networks that employs OFDM transmission.