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

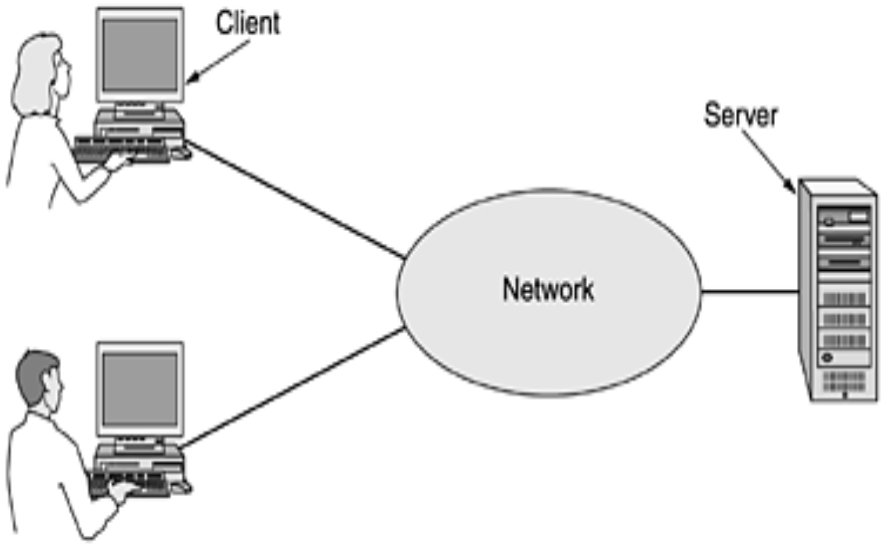
  - Individual - company
  - Company - company

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.

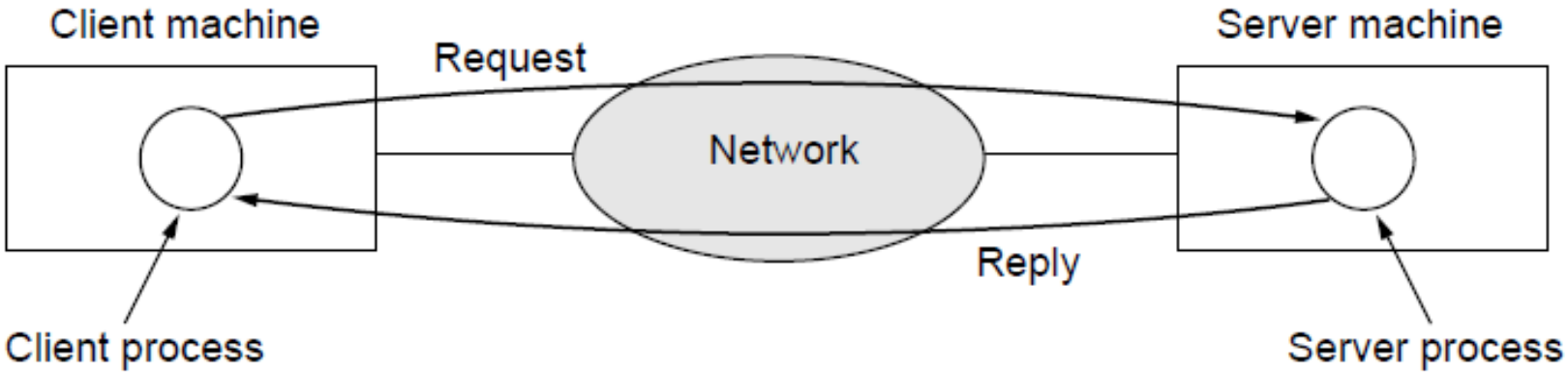
Client :

- 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

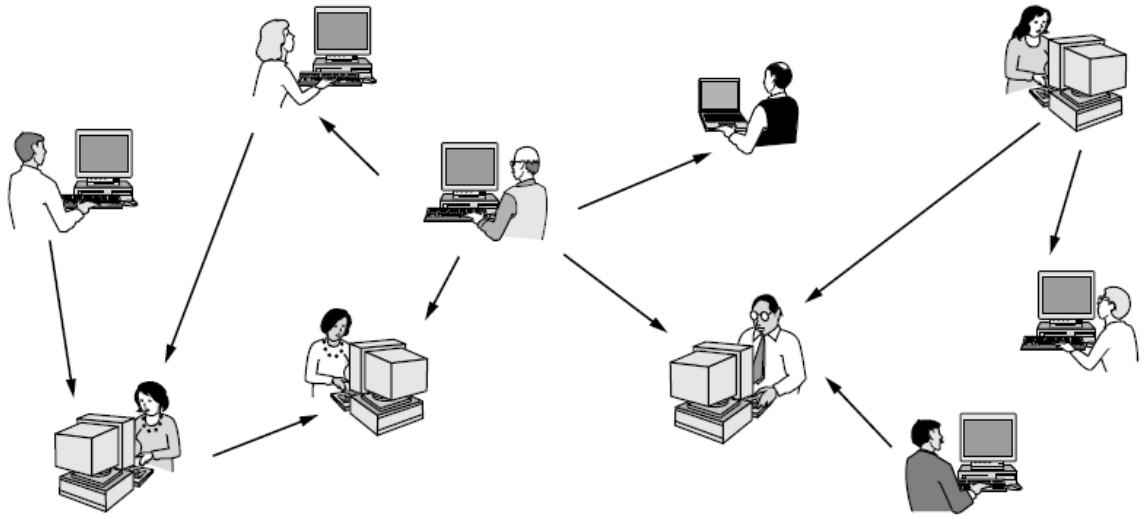
- Video conferencing/chating
- Instant Messaging (Whats app,Twitter)
- Telelearning
- Social Networking:
  - Facebook

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

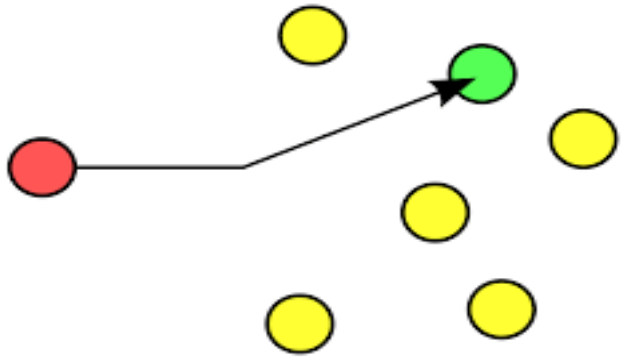
Network Hardware (cont.)

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**

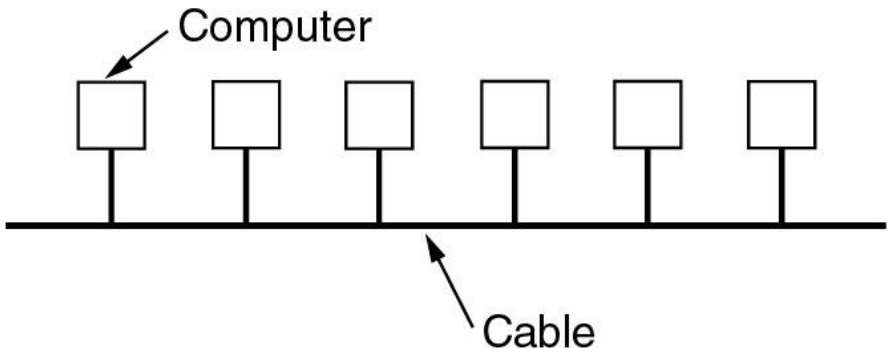
Delay : low (**microseconds/nanoseconds)**

Transmission error : **Less**

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

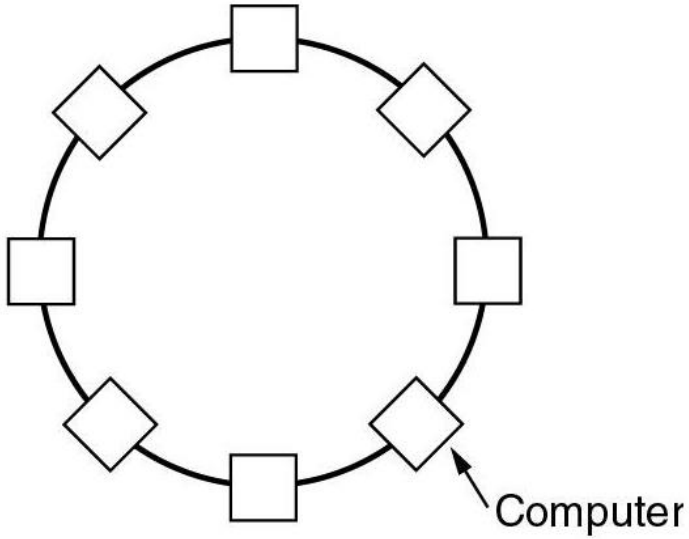
Network Hardware (cont.)

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)

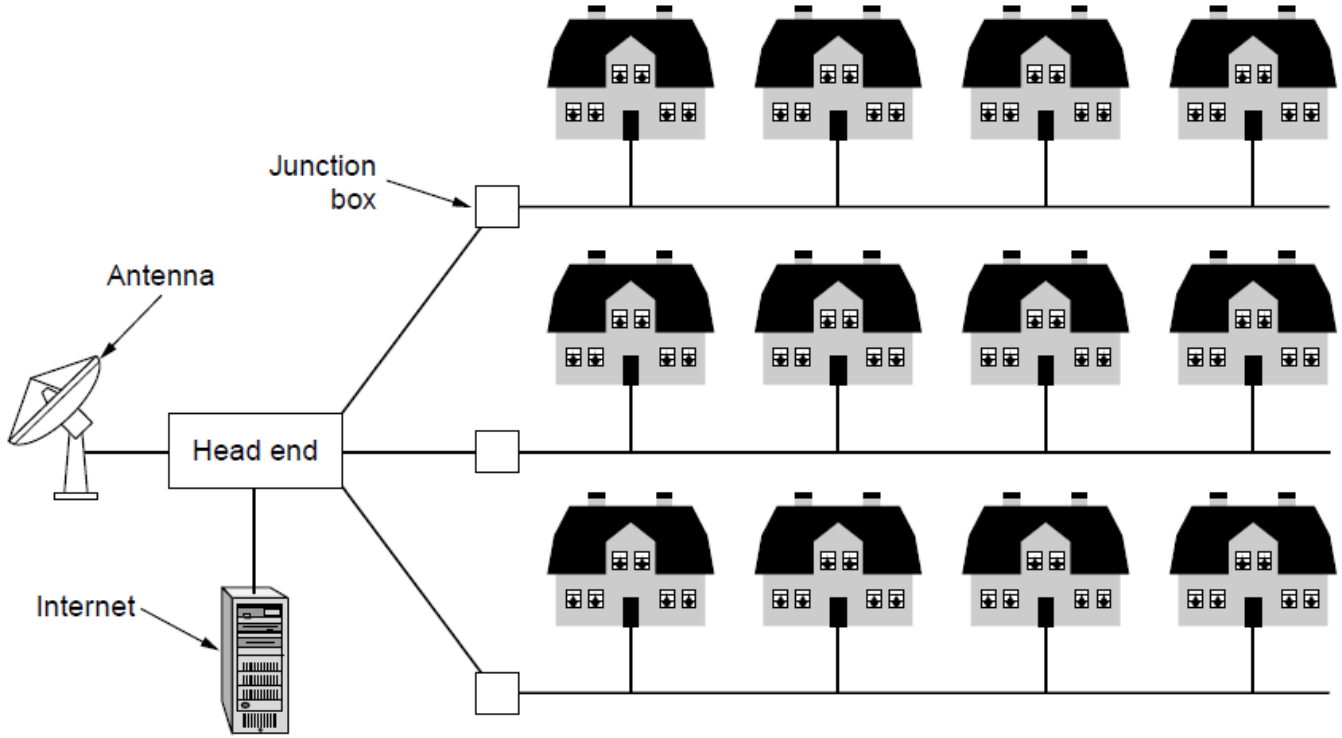
Network Hardware (cont.)

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.

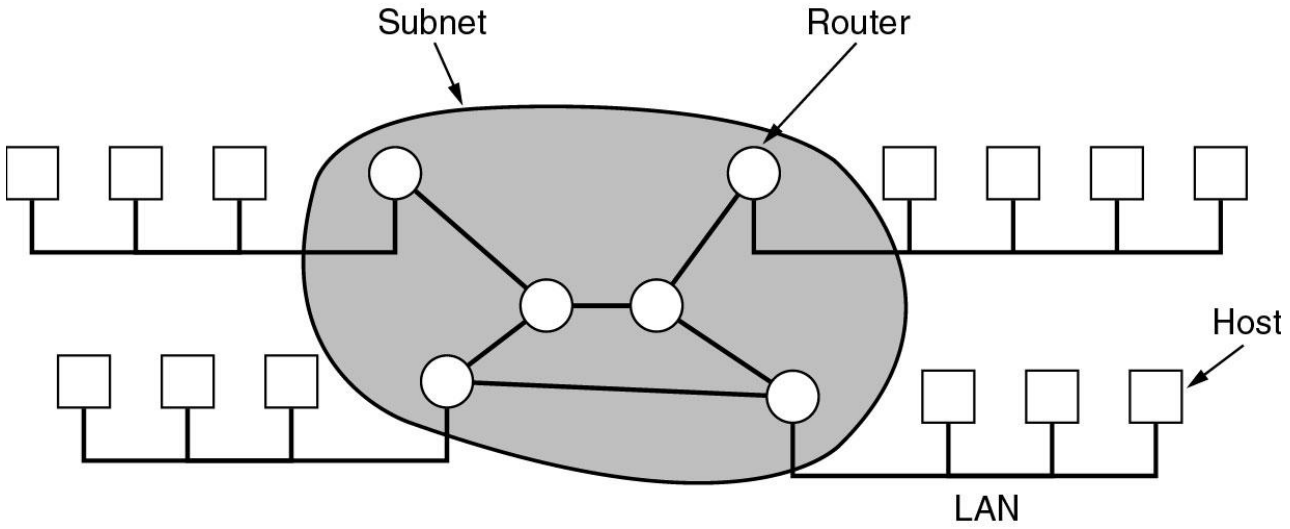


A metropolitan area network based on cable TV

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

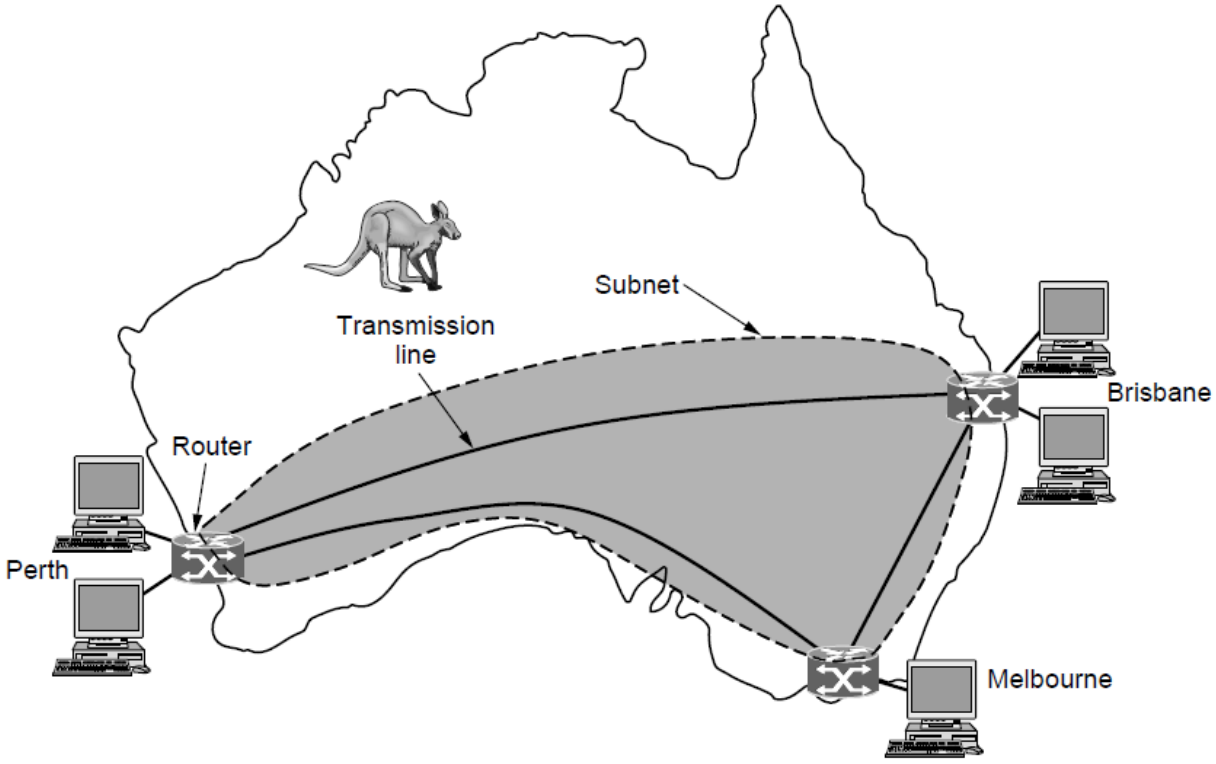
Network Hardware (cont.)

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.



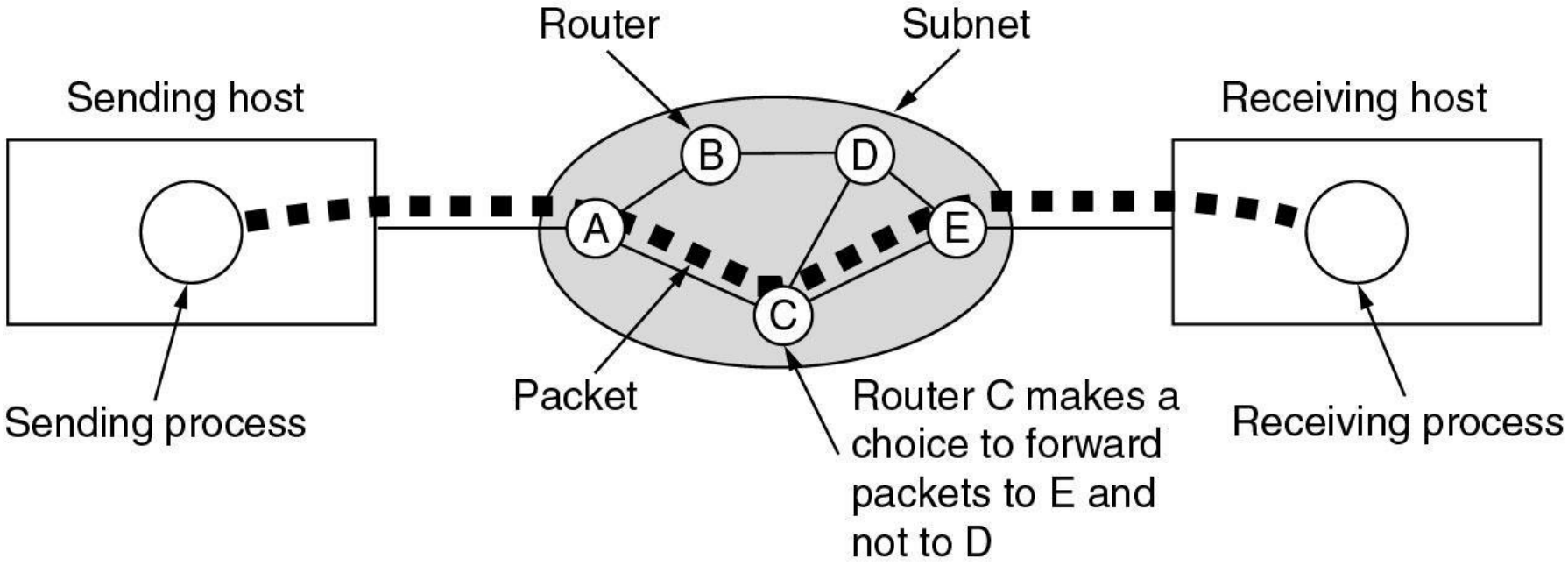
WAN that connects three branch offices in Australia

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.)

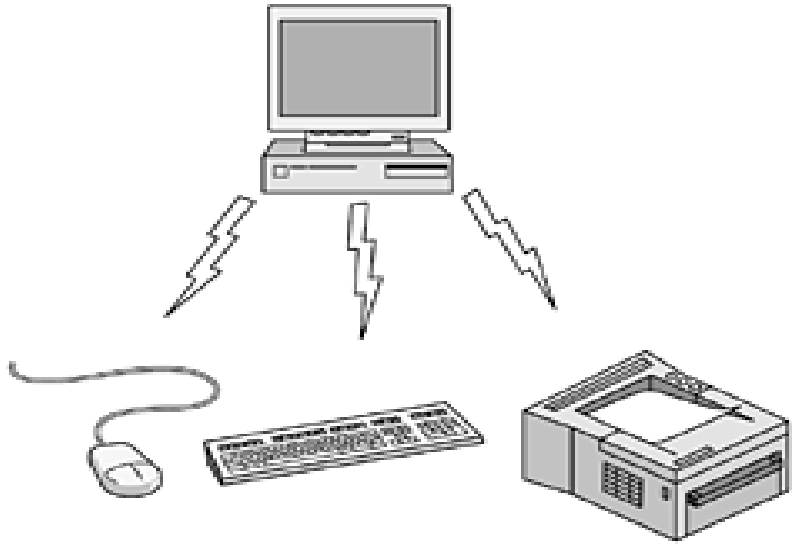
Wireless network

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

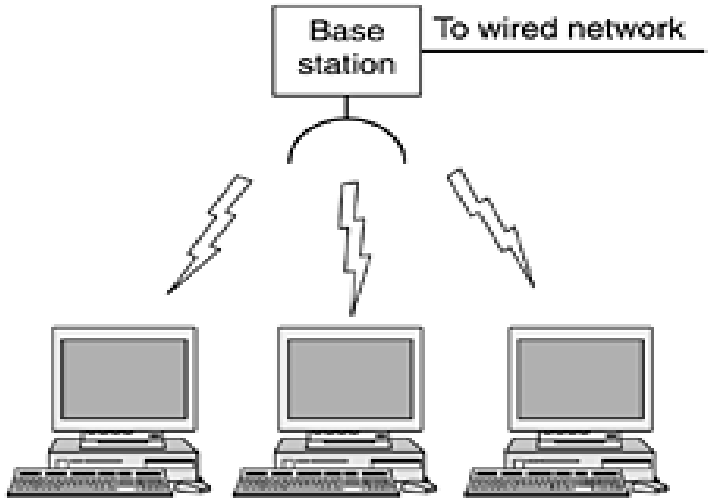
Network Hardware (cont.)

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**).

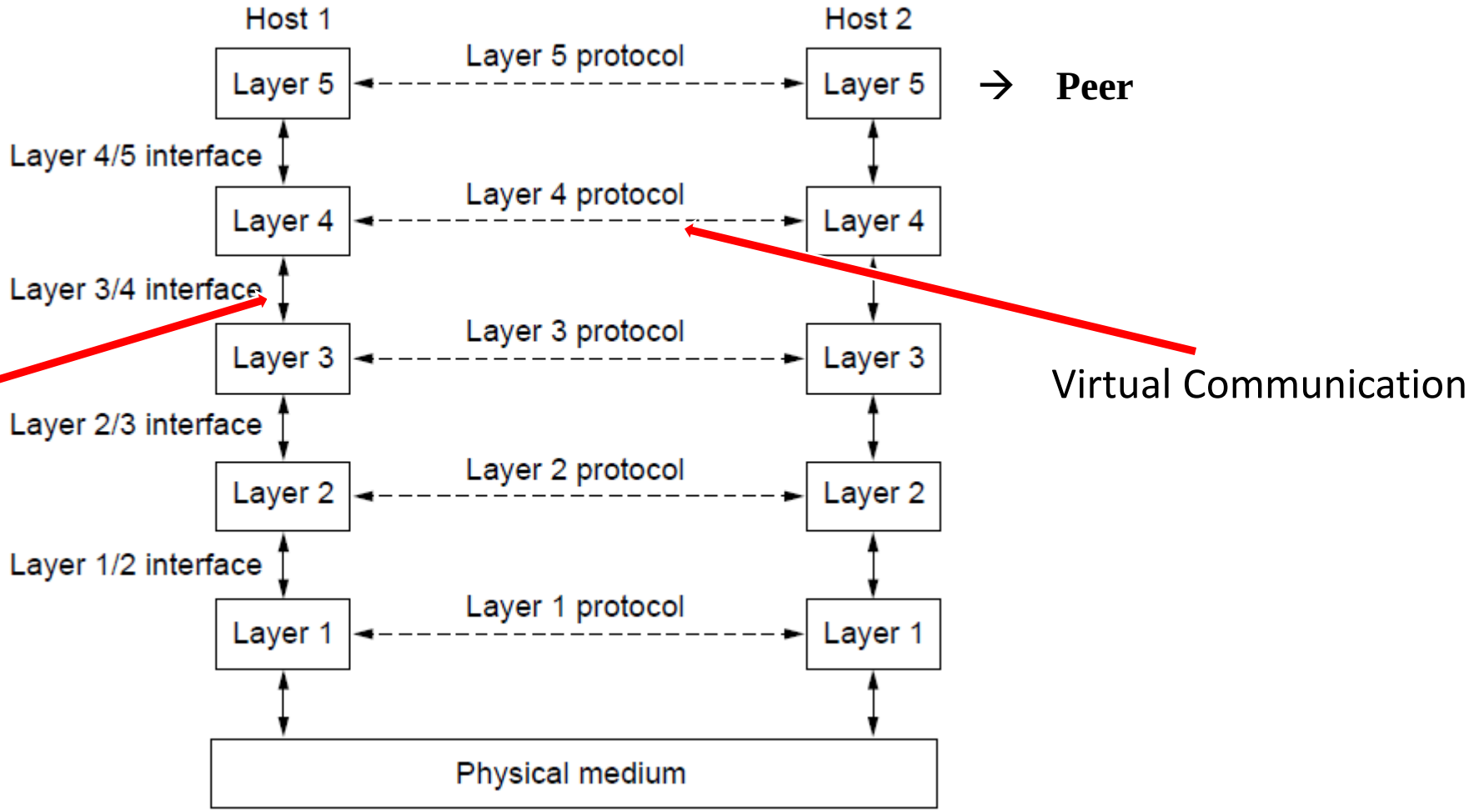
Network Software (cont.)

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.)

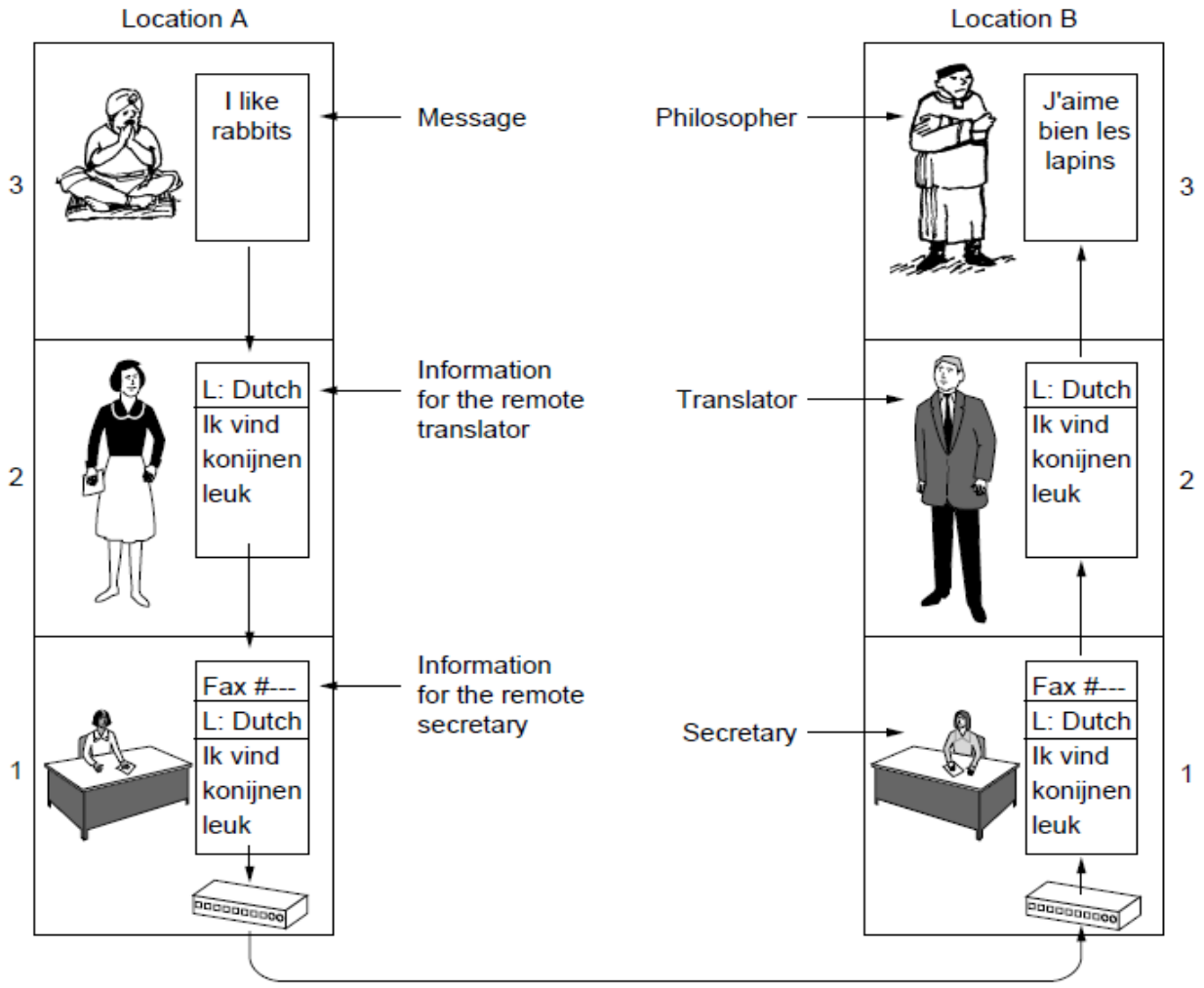
Protocol Hierarchies

- **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:

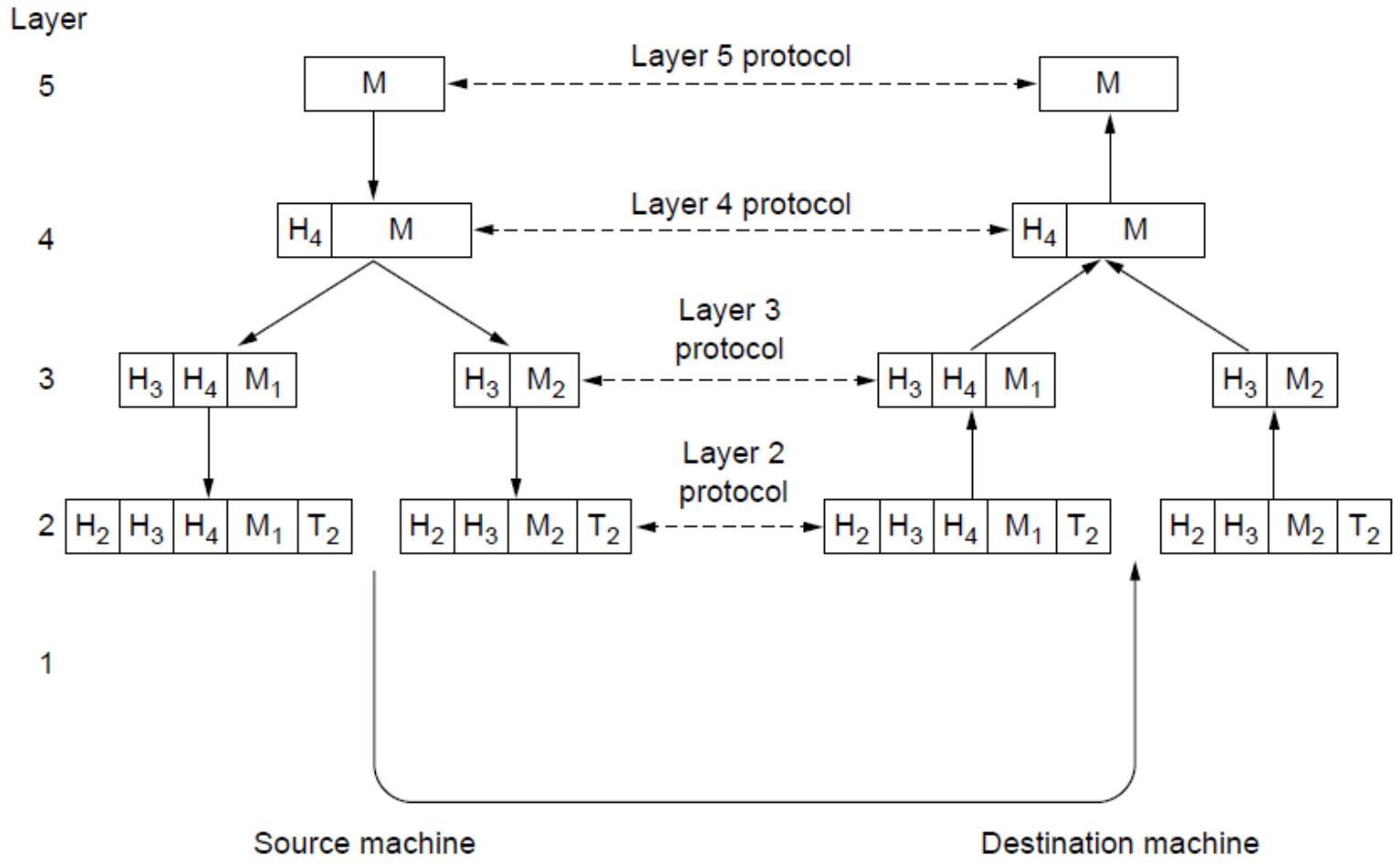
Each translator takes the help of a secretary to transmit the message using the medium (e.g. Fax).

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.)

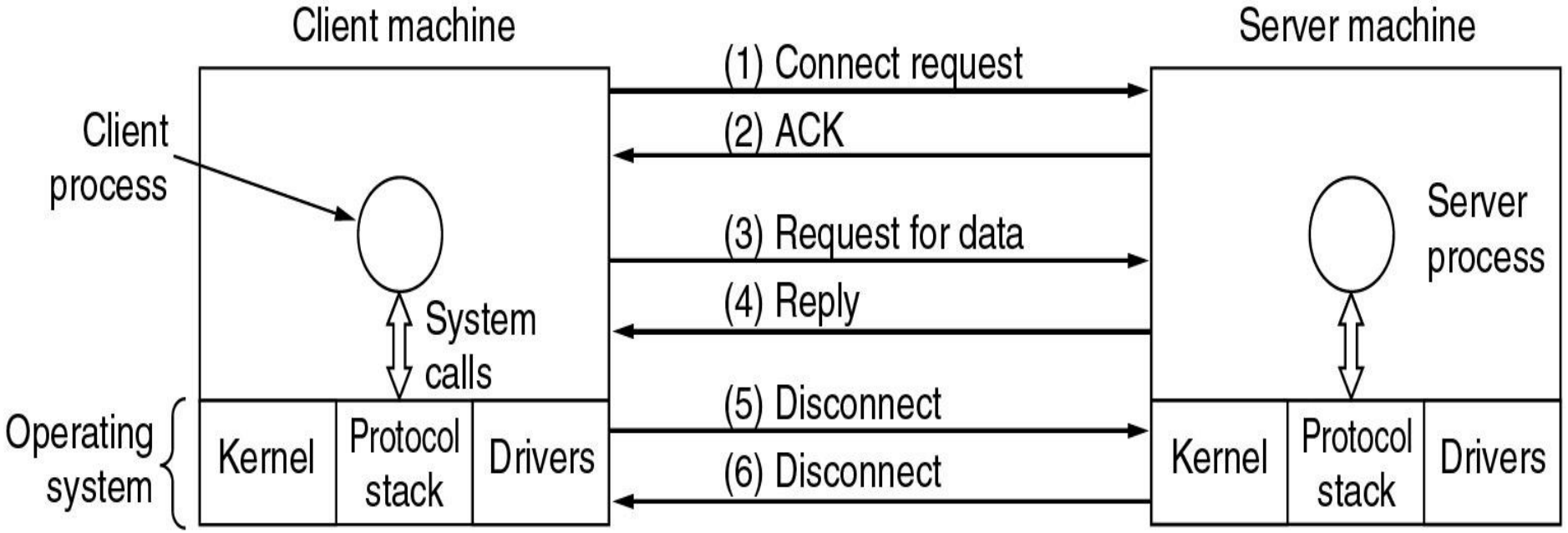
Service primitives

- 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.

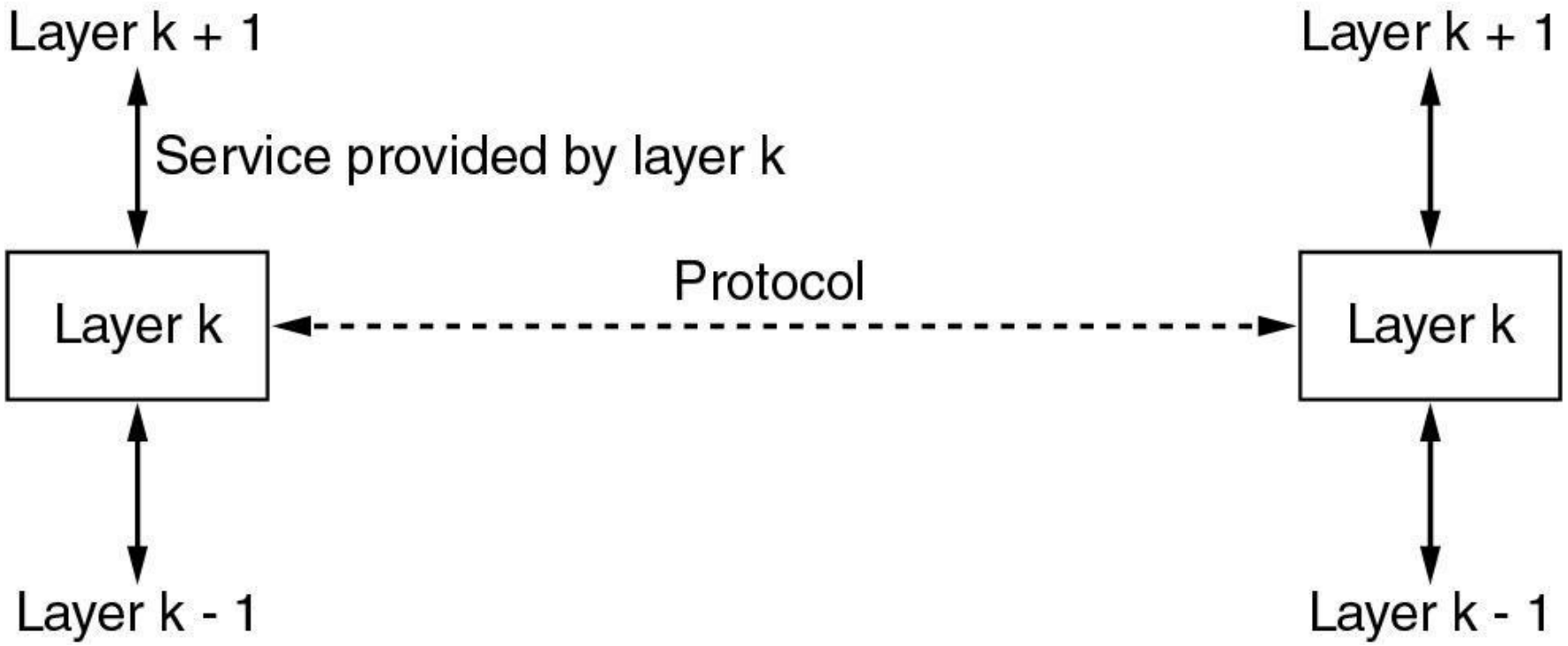
Network Software (cont.)

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.