# Chapter One
# Introduction to Computer Networks

# Main Contents

- Functions of computer network in Information Age
- Concept of computer networks
- History of computer networks
- Constitution of computer networks
- Definition of computer networks
- Classification of computer networks
- Topological structure of computer networks
- Performance indicators of computer networks
- Architecture of computer networks★

# 1.Functions of computer network in Information Age

- 21st century is information age, information collection, production, storage, transfer, retrieval and utility cannot break away from the computer network, many countries have spent heavily to build the "Information Superhighway" as well as the information industry, and put it as the basic national policy.
- The important feature of the 21st century is: Digitization, Networking, Informatization, which is the age look upon Networking as the core.
- " Three networks " refers to the Telecommunication networks, Cable television networks and Computer networks, which plays the core role. "Convergence of three networks - Triple Play" refers to the Telecommunication net-works and the Cable television networks have gradually converged in-to the modern Computer networks.

  (Example: Mobile Internet, IPTV)
- Networks have changed the way people work and lifestyle, its main two functions are: Connectivity and Sharing.

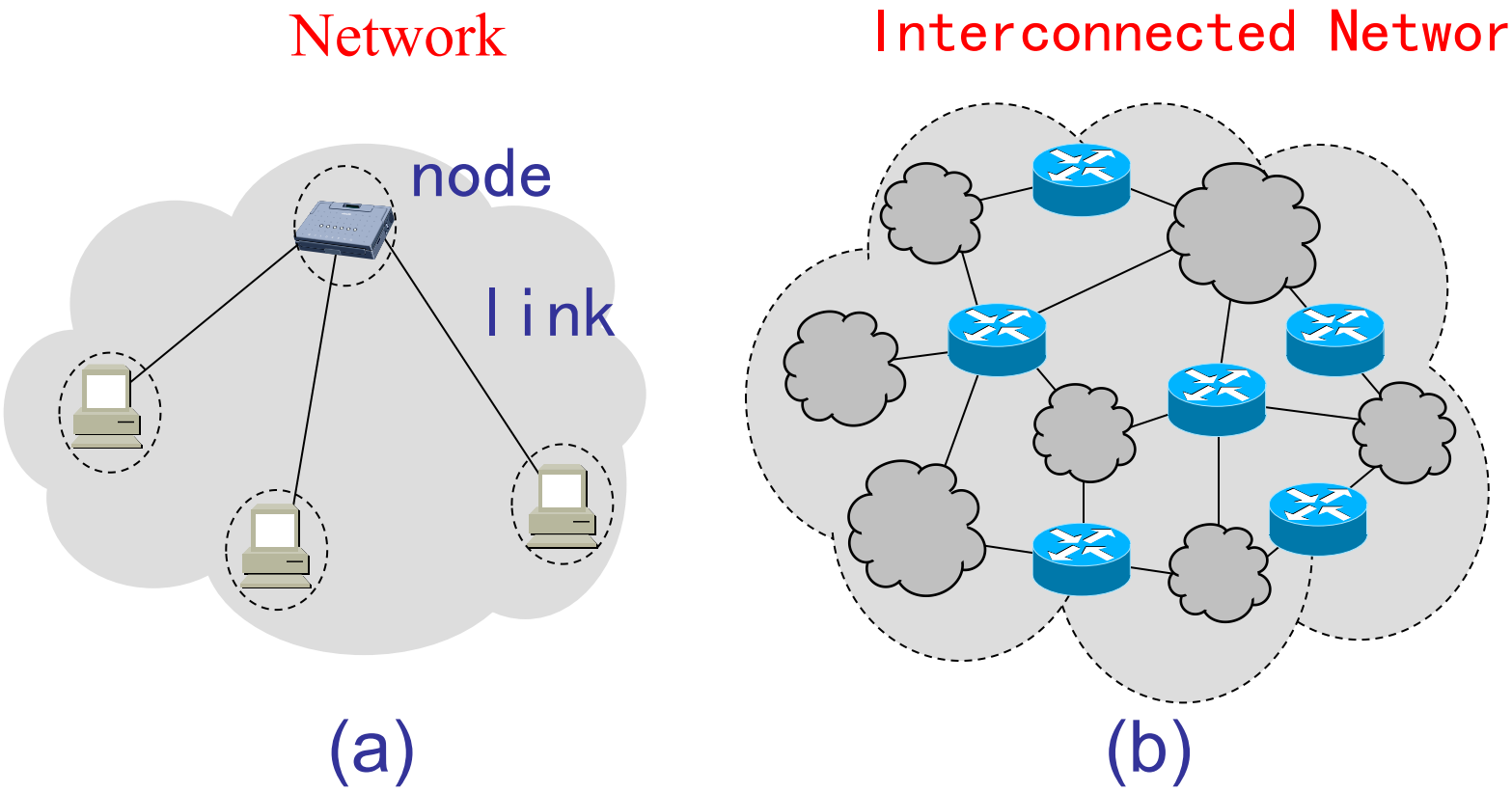
# 1.Functions of computer network in Information Age

- Three types of convergence for computer networks and communication systems
  - Technological Convergence
    - Computers & Modems, VoIP, Cell Phone
  - Protocol Convergence
    - TCP/IP Protocol
  - Industrial Convergence
    - Computers & Communications

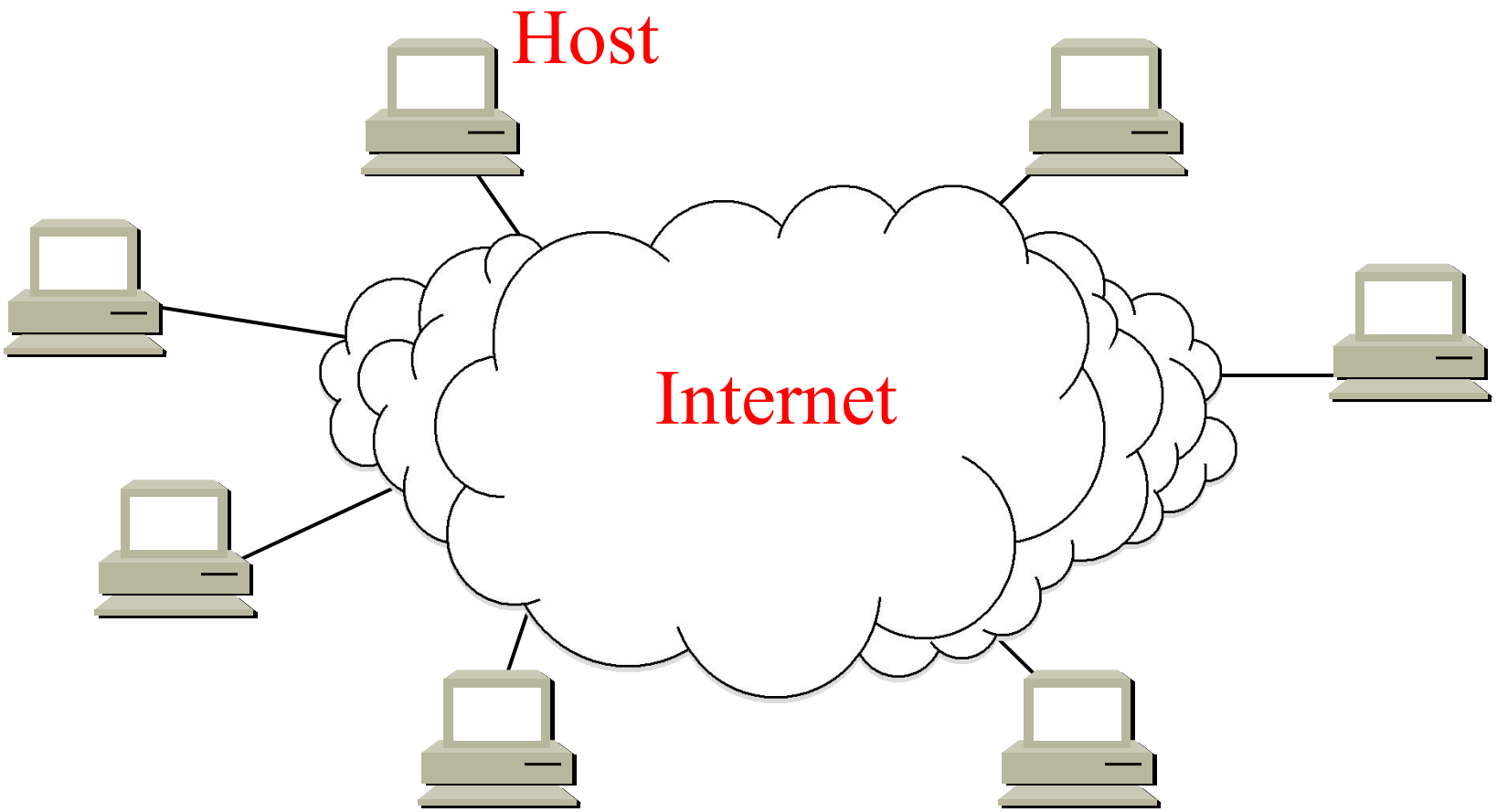
# 2. Concept of computer networks

- **Network**: composed by the **nodes** and the **link**s of these nodes. It could be a computer, hubs, switches, routers, etc.
- **Interconnected Network**: network and the network can be connected through a router, constitute a greater network coverage, so is a "**network of networks**".
- **Internet**: the world's largest Interconnected Network (millions of users), usually expressed by "cloud". **Network connect the computers, the Internet connect interconnected networks.**
- **Host**: Computers which connected on the Internet.
- **Internet** (Terminology), and **the internet** (General meaning)

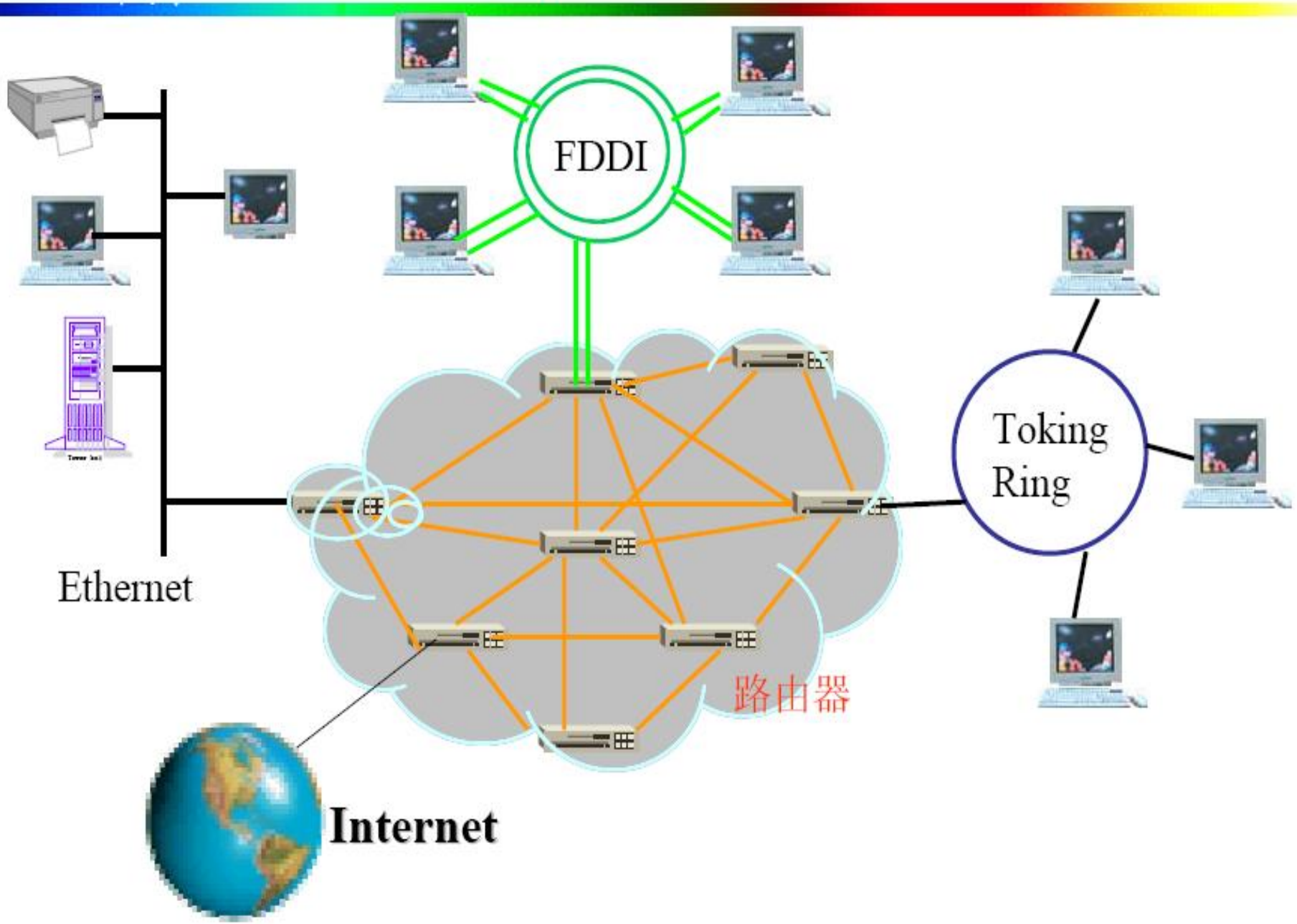
# 2. Concept of computer networks



# 2. Concept of computer network



# Typical Computer Networks



# 3. History of computer networks

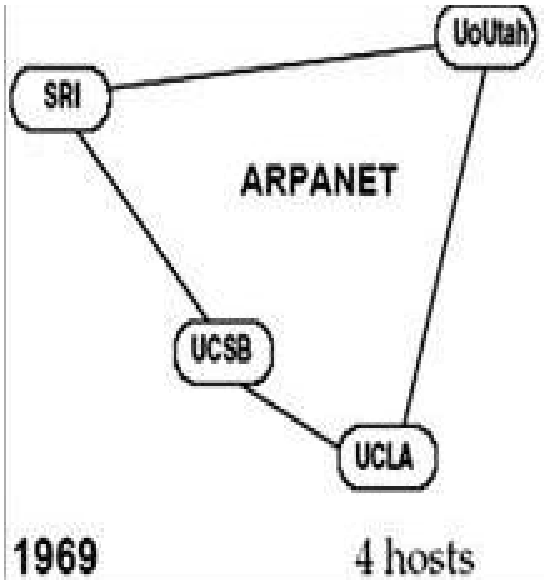
## The origin of Internet

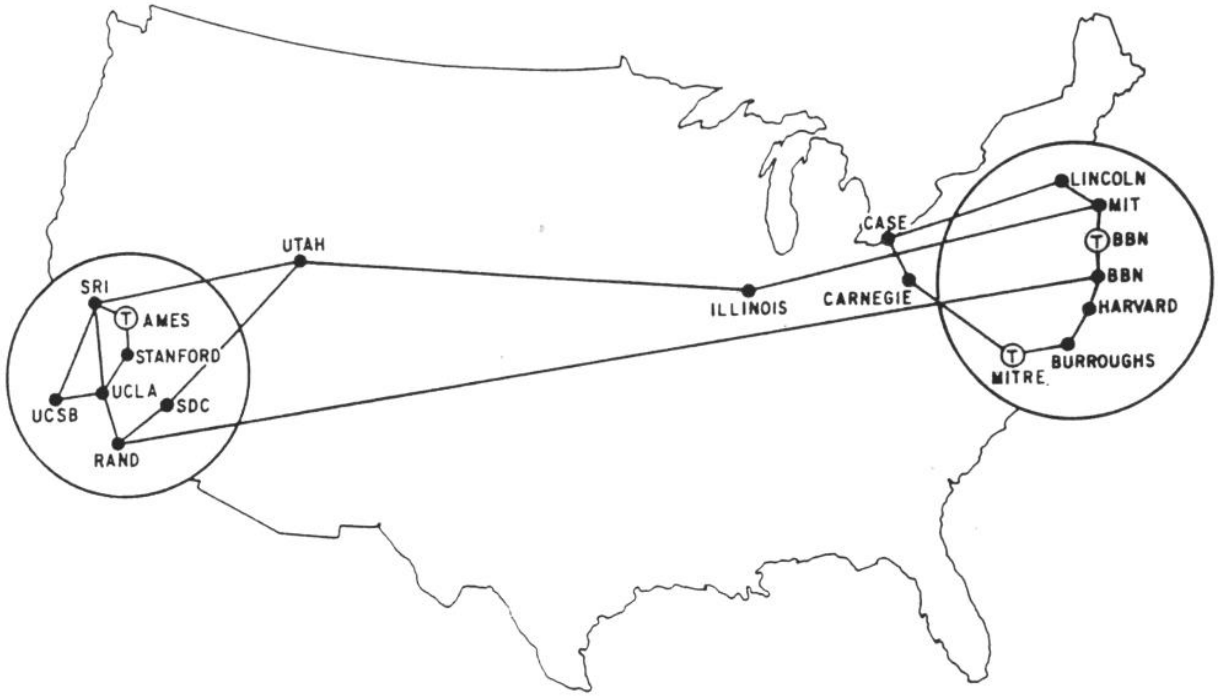
In 1962, the department of defense to ensure local defense force and overseas defense forces in the former Soviet Union still has the ability of survival after a nuclear attack and counterattack ability.It puts forward a decentralized command system, which can maintain interconnection between each command points.

In 1969, the department of defense advanced research projects agency (DARPA) has funded a project called ARPANET network, the numbers of computer hosts which located in the University of Los Angeles (UCLA) was connected, using packet switching technology, interchanger and communication cables.

**ARPANET is the earliest prototype of Internet.**

# ARPANET network



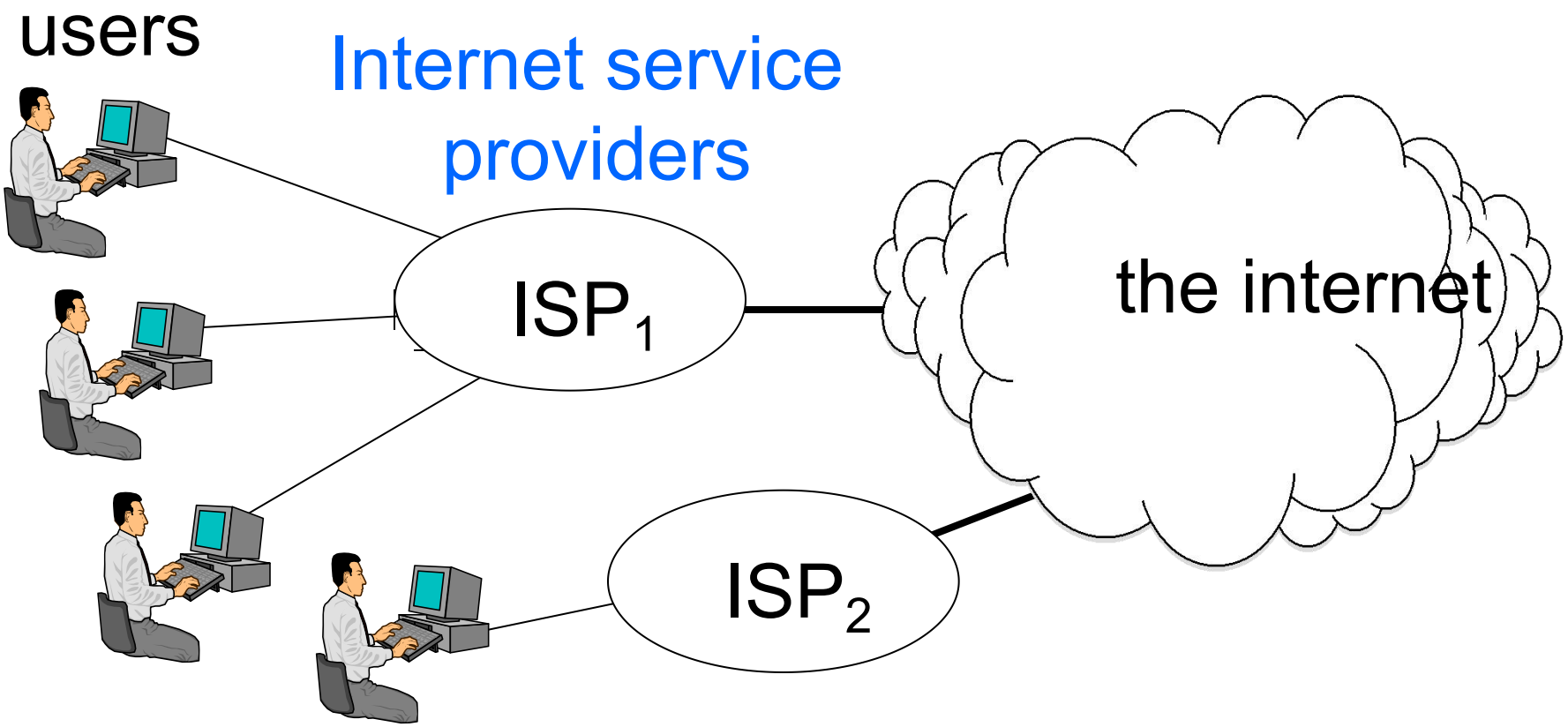

MAP 4 September 1971

# 3. History of computer networks

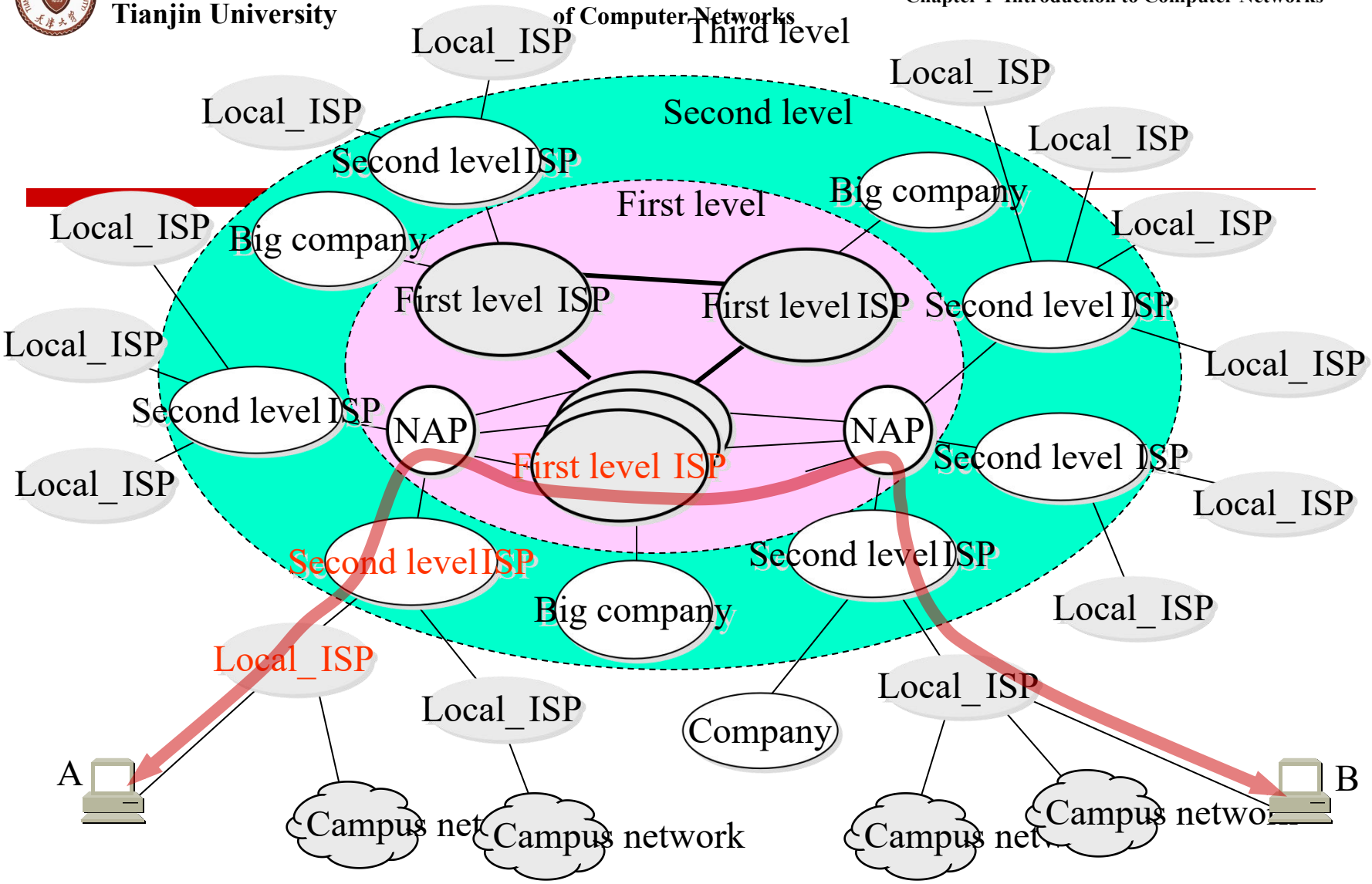
- **Three stages of the development of computer network**

  - **Stage 1: The first stage is the process from a single ARPANET network development to the Internet. < 1983, TCP/IP protocol become standard on the ARPANET, people consider 1983 as the birth of the Internet time >**
  - **Stage 2: The characteristics of the second phase is completed Tertiary structure (three levels) of the Internet. < the 3 levels computer network is divided into Backbone, Regional network and Campus network (or Enterprise network) >**
  - **Stage 3: The characteristics of the third stage is gradually formed a Multi-level (Multi-layered) structure of ISP's Internet. < in the ISP (Internet Service Provider) and Internet Service providers NAP (Network Access Point) >**

# Users surf the internet through ISP

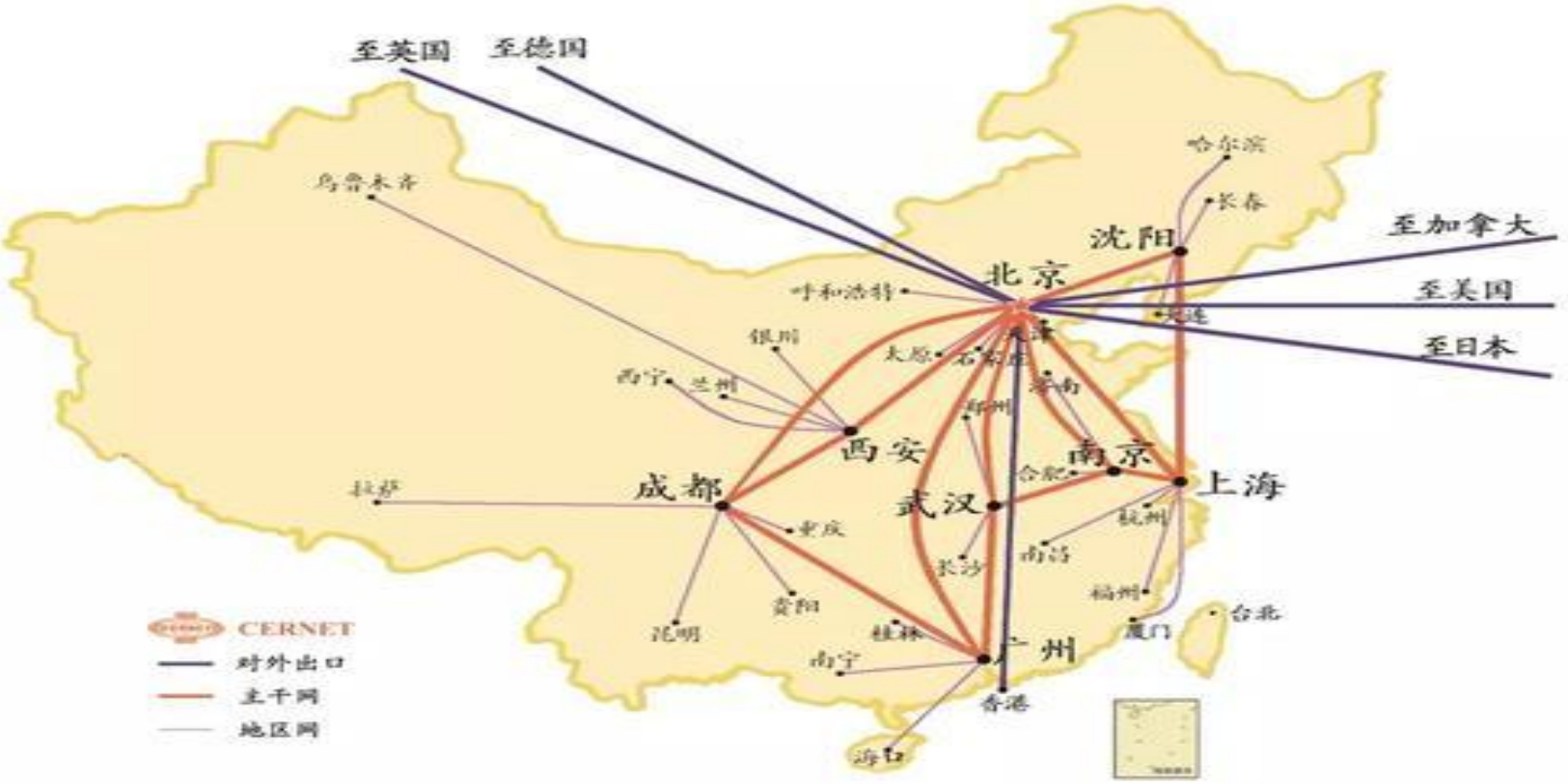



According to the differrence of the service coverage area size and the number of IP addresses , ISPs are divided into different levels.



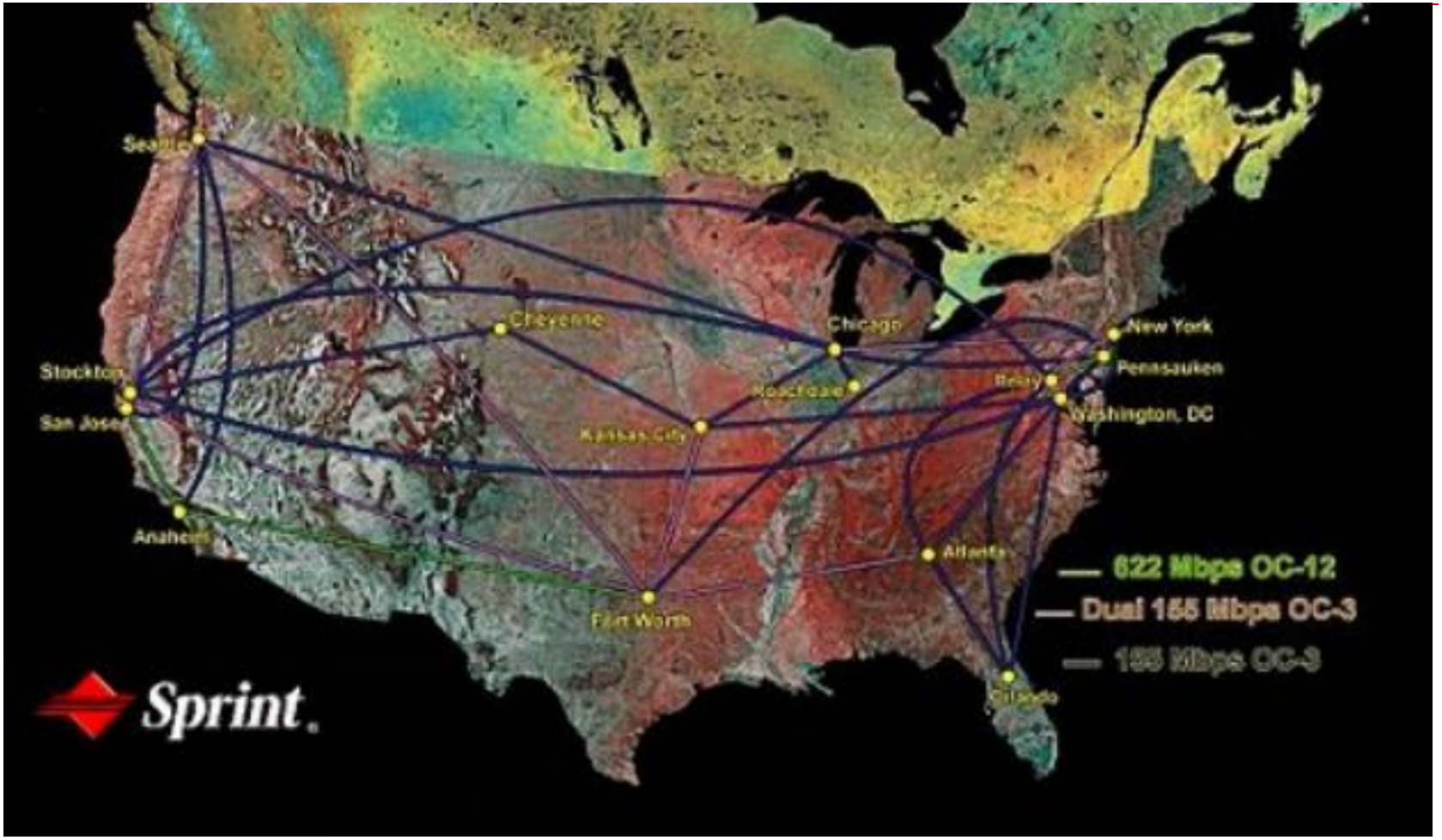

Host A → Local_ISP → Second level ISP → NAP → First level ISP → NAP → Second level ISP → Local_ISP → Host B

# Example of First level ISP： Backbone network of China




Four networking company of P.R. China: 中国科技网（CSTNET）、中国公用计算机互联网（CHINANET）、中国教育和科研计算机网（CERNET）、中国金桥信息网（CHINAGBN）

# Example of First level ISP： Backbone network of USA




Three Telecommunication Company of USA: AT&T(GSM), Verizon & Sprint(CDMA)

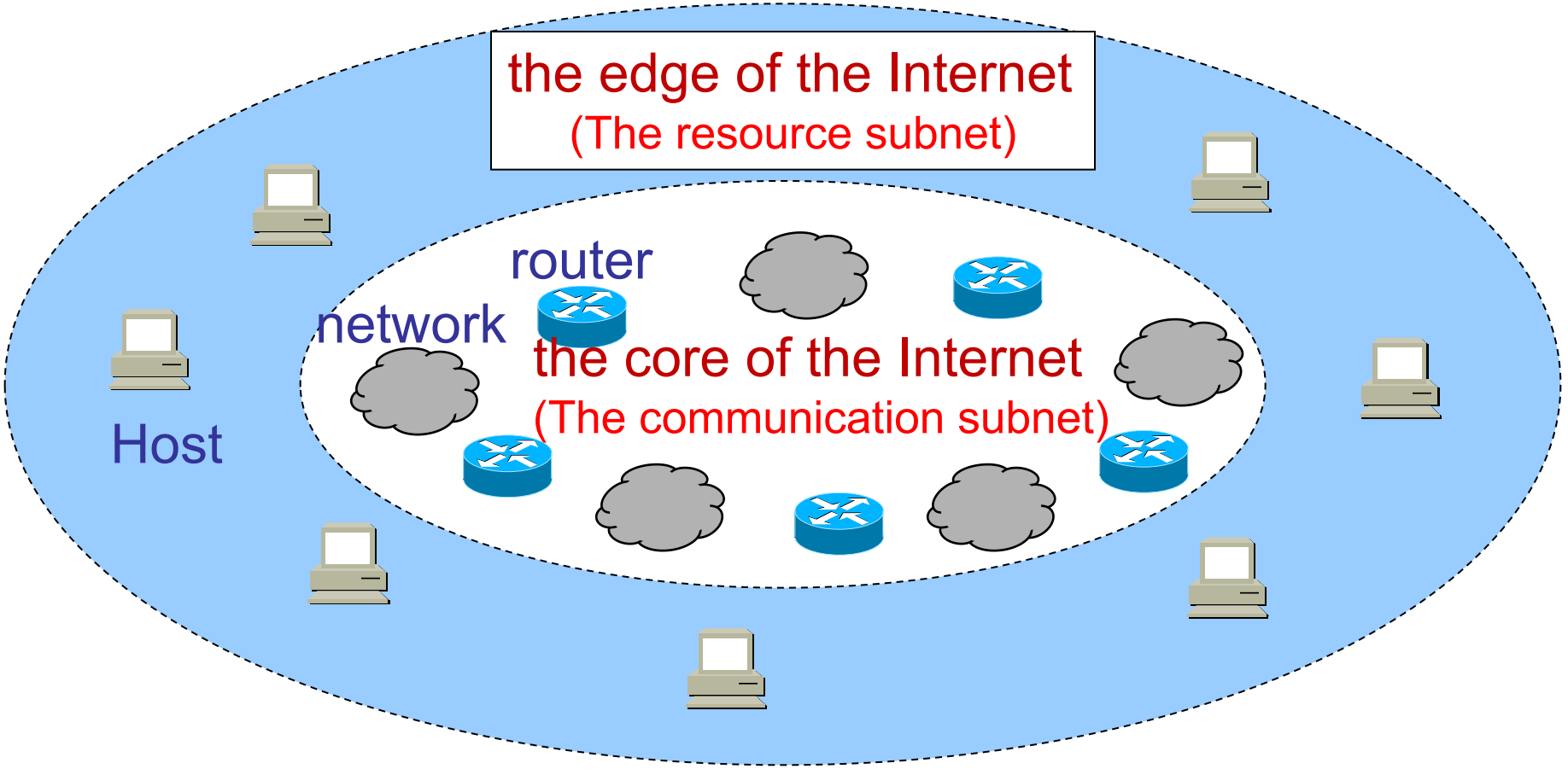
# The general situation of the development of the Internet

| | Networks | Host | Users | Management institutions |
|---|---|---|---|---|
| 1980 | 10 | $10^2$ | $10^2$ | $10^0$ |
| 1990 | $10^3$ | $10^5$ | $10^6$ | $10^1$ |
| 2000 | $10^5$ | $10^7$ | $10^8$ | $10^2$ |
| 2005 | $10^6$ | $10^8$ | $10^9$ | $10^3$ |

# 4. Constitution of computer networks

- According to the working style:
  - Edge - consists of all the Host connected to the Internet. This part is the user use, directly used to communicate (send data, audio or video) and resource sharing.
  - Core - made up of a large number of network and the network router. This section is to provide service for the edges provide connectivity and exchange (support data connection and exchange).
- According to the logical structure:
  - Resource Subnet - to be responsible for the entire network data processing, that is, to the network users with a variety of network resources and network services, mainly including the Host and the terminal
  - Communication Subnet – consist of communication control processor, communication lines, and other communications equipment, its task is network data transmission

# The edge and the core of the Internet



# 4. Constitution of computer networks

## Edge part (Resource subnet)

- At the edge of the Internet, the Internet is connected to all of the Host. These Hosts are also called the "End system".
- Host A and Host B are communicating, in fact, refers to: a program running on Host A is communicating a program running on Host B".
- That is, "a process on Host A is communicated with another process on Host B". Or refers to as the "progress communications between computers"

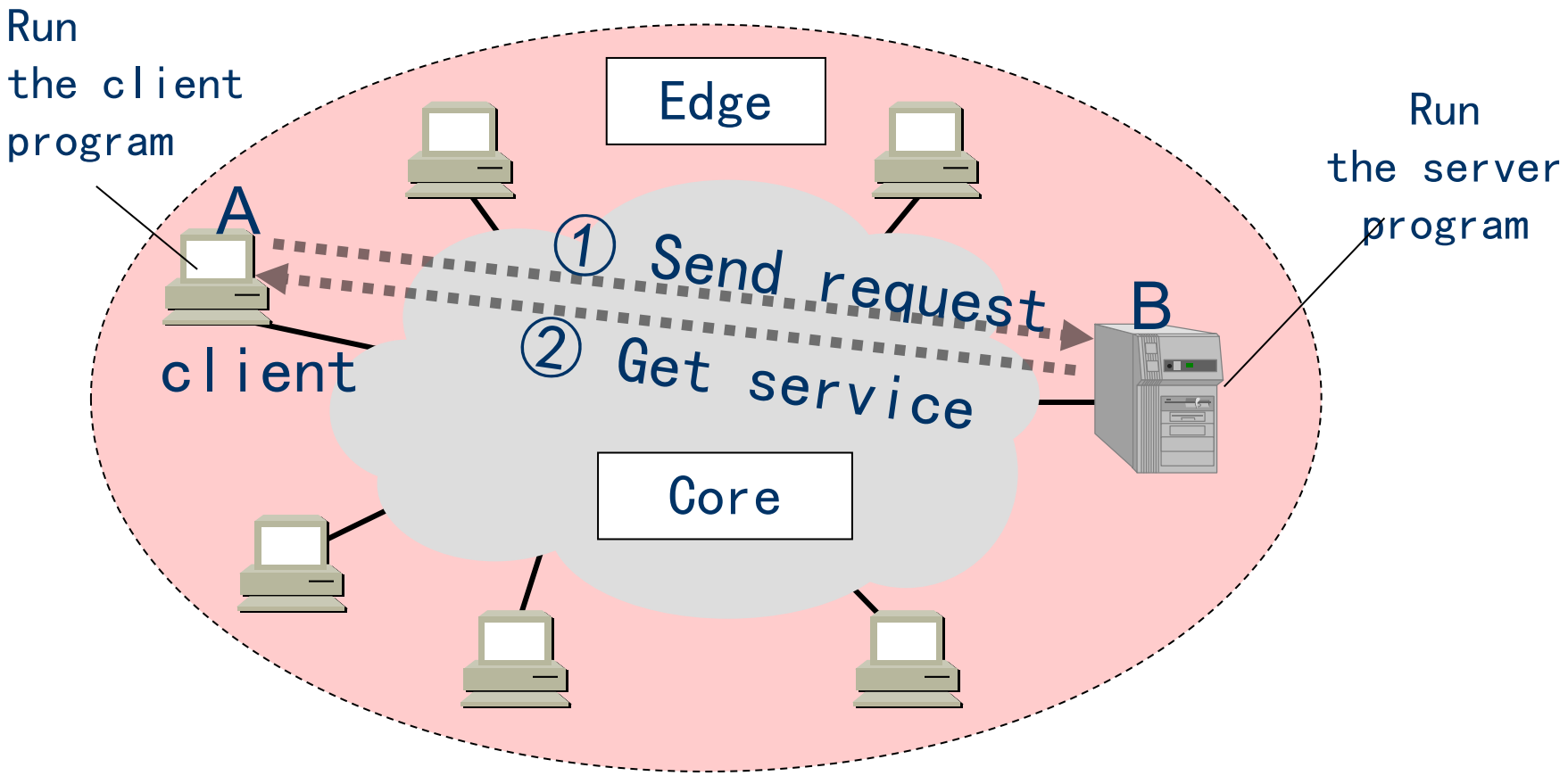
# Edge part (Resource subnet)

- Communication methods between the program in the network edge of the end system can be divided into two categories:
  - Client/Server (C/S model, including B/S model)
    - Examples: Web browser/server, E-mail client / server
  - Peer to Peer (P2P model)
    - Examples: Emule, BT, PT software

# Client/Server Model

- The client and the server are two applications processes involved in communication.
- What the client server describes is the relationship between processes and services.
- The customer is the service requester, the server is the service provider.

# Client/Server Model

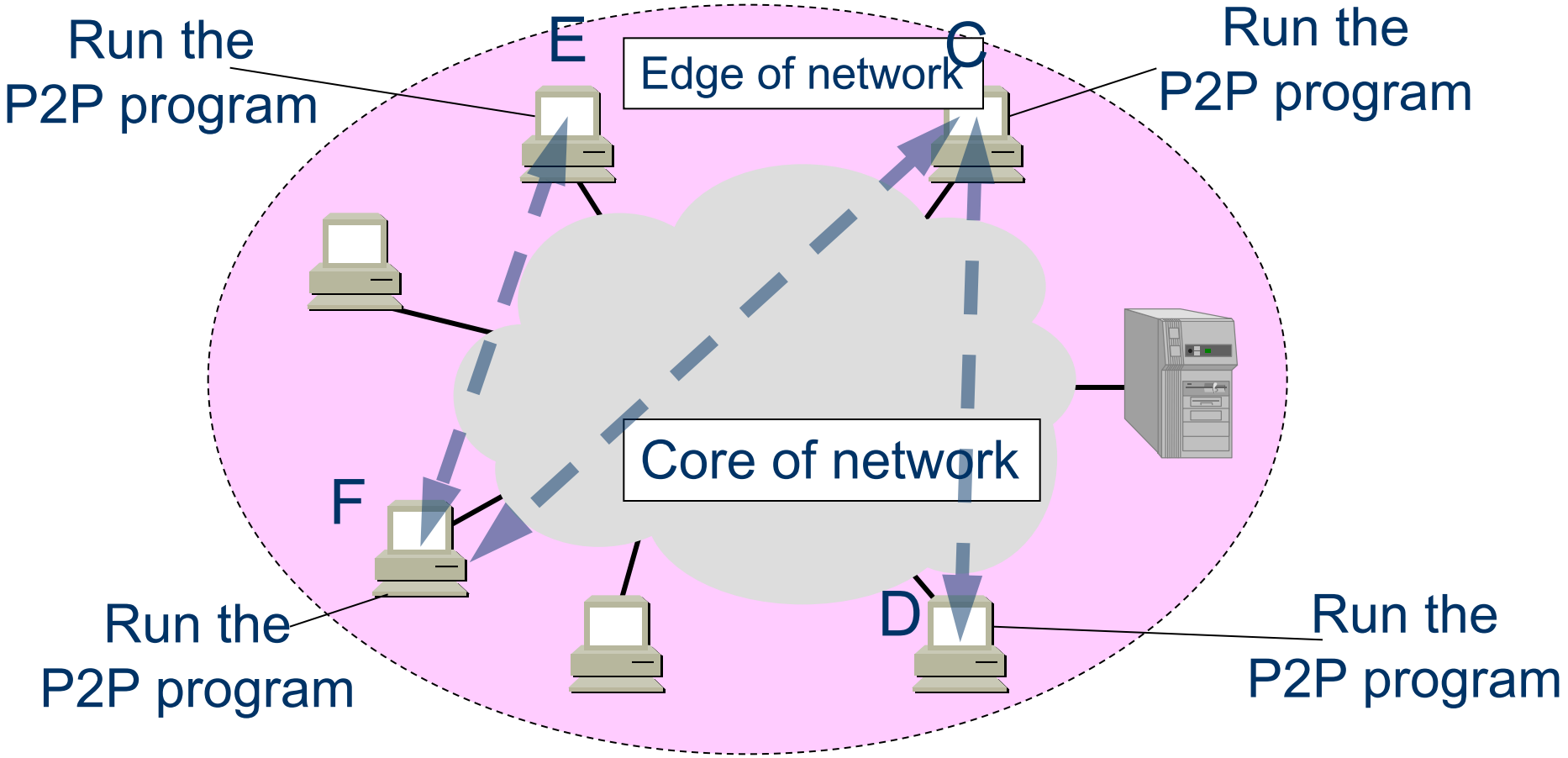



Customer A sends a request to the server B,
Server B provides services to the customer A.

# Peer to Peer Model

- A Peer-to-Peer connection (abbreviated as P2P) refers to the two host in the communication does not distinguish between which a service request or service provider.
- As long as two Hosts are running the peer to peer (P2P) software, they can be equal, peer to peer communication.
- Both sides can download each other has been stored in the hard drive to share the document.
  - In essence, the P2P connection is still the way of C/S connection, while for each Host in a peer connection, it is the client as well as the server.
  - For example, when C Host requests D services, C is the customer, D is the server. But if C is also providing services to F, then the C also plays the role of the server, see below.

# Peer to Peer Model



# Edge part (Resource subnet)

- Target
  - Transfer data between the end systems (Hosts)
- Research questions and applications
  - TCP services (TCP transmission control protocol)
    - Reliable data transmission, flow control, congestion control (HTTP, FTP, Telnet, SMTP)
  - UDP services (UDP user data packet protocol)
    - Unreliable data transmission, no flow control, no congestion control (DNS, Streaming media, IP phone)

# 4. Constitution of computer networks

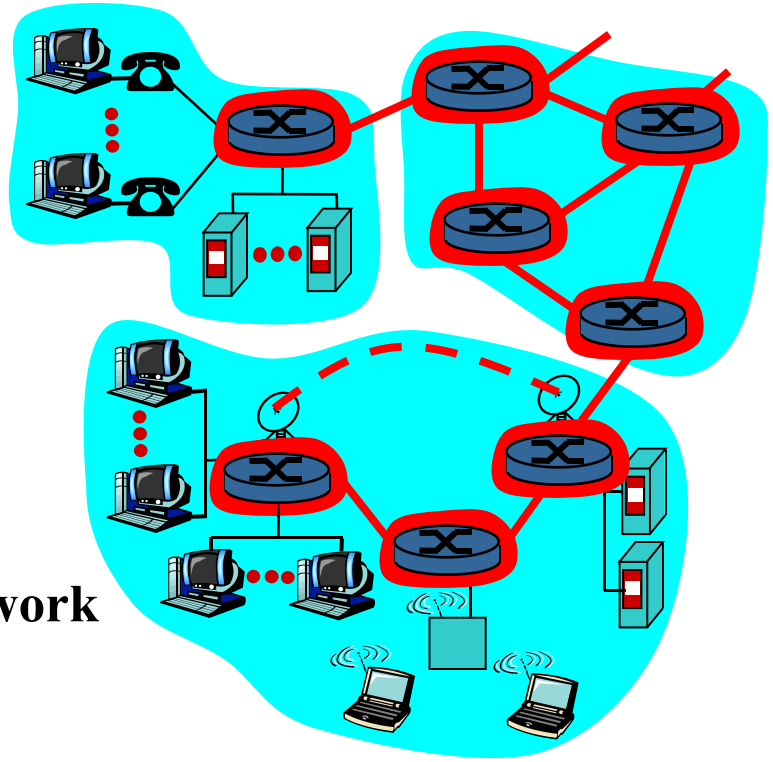
- **Core part (Communication subnetwork)**
  - The core of the network is the most complex part of the Internet.
  - The core part of the network to provide connectivity to a large number of Host on the edge of the network, so that any one of the edge of the Host are able to communicate with other Host (that is, send or receive various forms of data).
  - In the core of the network of networks, in addition to the network, and the router has the special role.
  - Router is the key component of Packet Switching , which is the most important function of network core.

# Core part (Communication subnet)

- **Basic questions**
  - How data transmitted through the router connected network.
- **Two solutions**
  - Circuit switching
    - Call dedicated circuit

    (Circuit-switched Network)
  - Packet switching
    - Data is transmitted by the network to the "block" of the "block".

    (Packet-switched Network)



# Definition and characteristics of Circuit switching

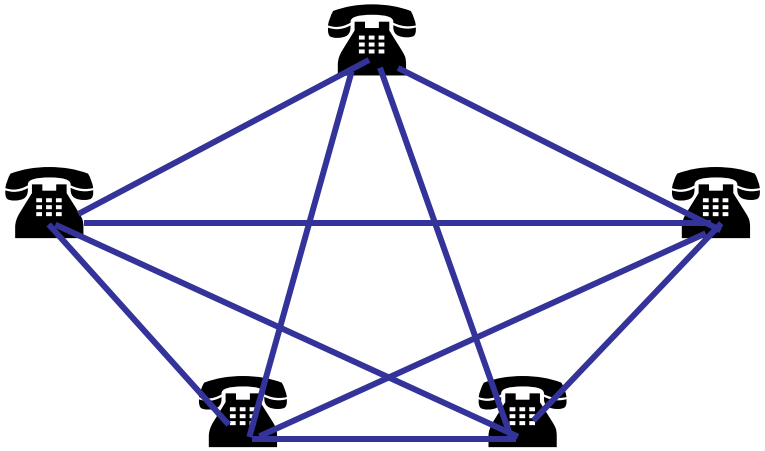
- Three stages of circuit switching:
  - Establish connection
  - Communication
  - Release connection
- This must be referred to as circuit switching by the three steps"building up connection", "call", "release connection" .
- The important feature of circuit switching is that the two users are always occupying the communication resources at whole time. Therefore the efficiency of the resource utilization is low.

# Typical representative example of circuit switching—— Switched telephone network

Two telephones can be connected to each other by a pair of wires.

# More telephones are connected to each other.

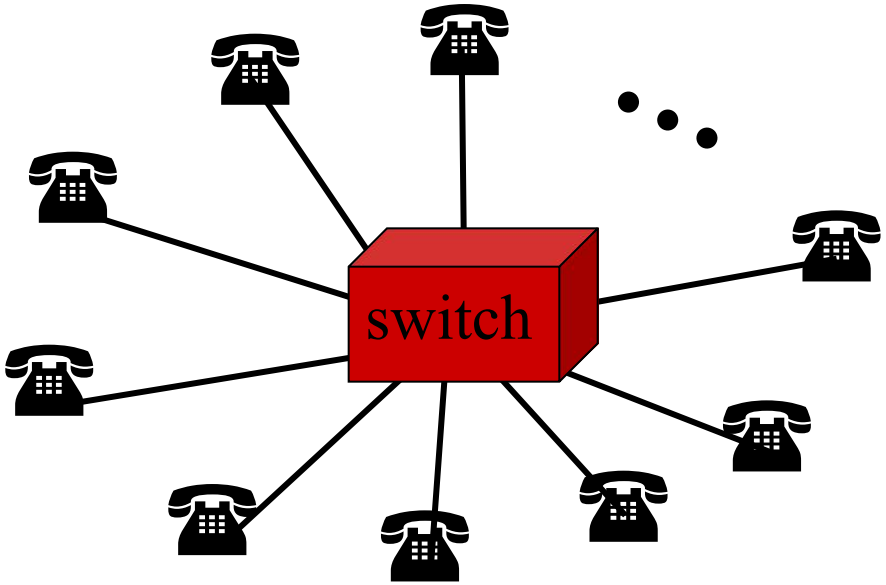
- Five phones are connected each other, 10 pairs of wires are required.



- N phones are connected each other, N (N - 1) /2 pairs of wires are required.
- When the number of the telephone is very large, the number of wires required for this connection is proportional to the square of the number of the telephones.

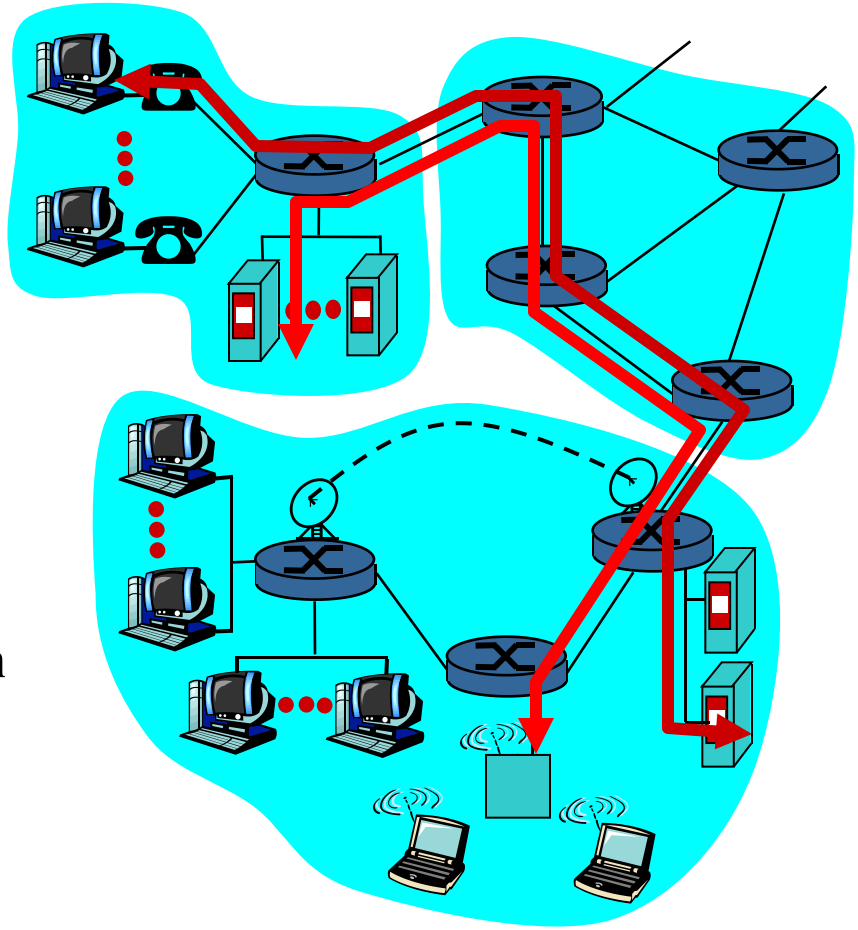
# Solutions: use the switch

- When the number of the telephone is increased, the switch is used to complete the switching task and reduce the number of wires.



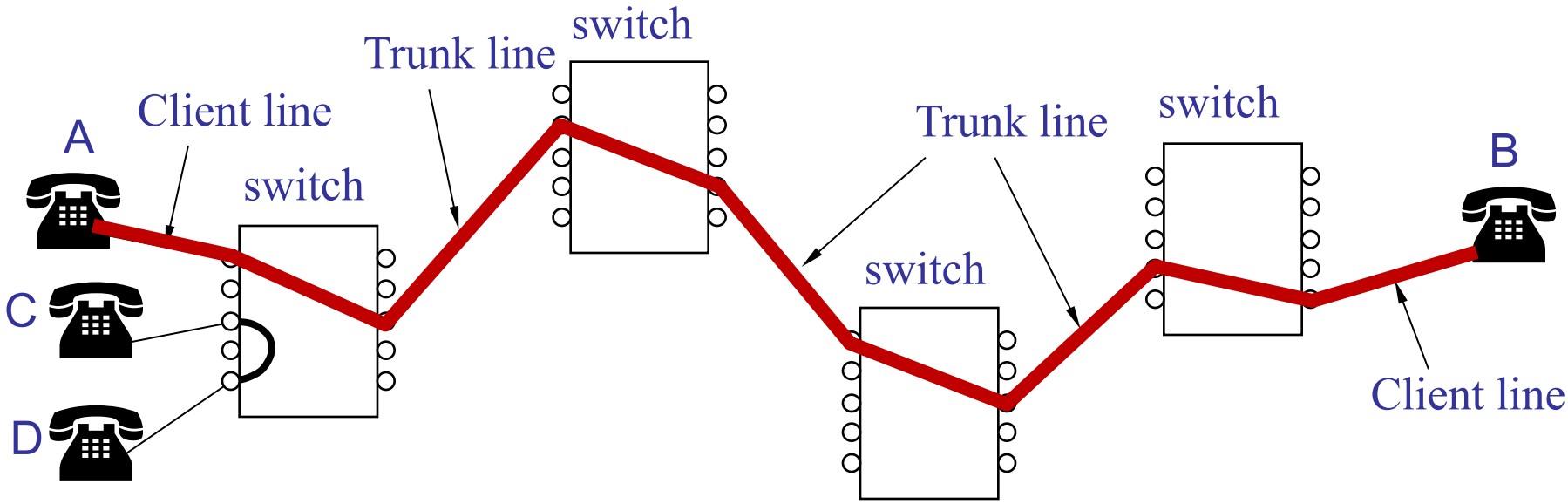
# The meaning of "switching"

- Here, the switching meaning is to transfer a telephone line to another phone line, so that they connect.
- From the point of view of the distribution of the communication resources, the switching is to dynamically allocate resources for transmission lines in a way.



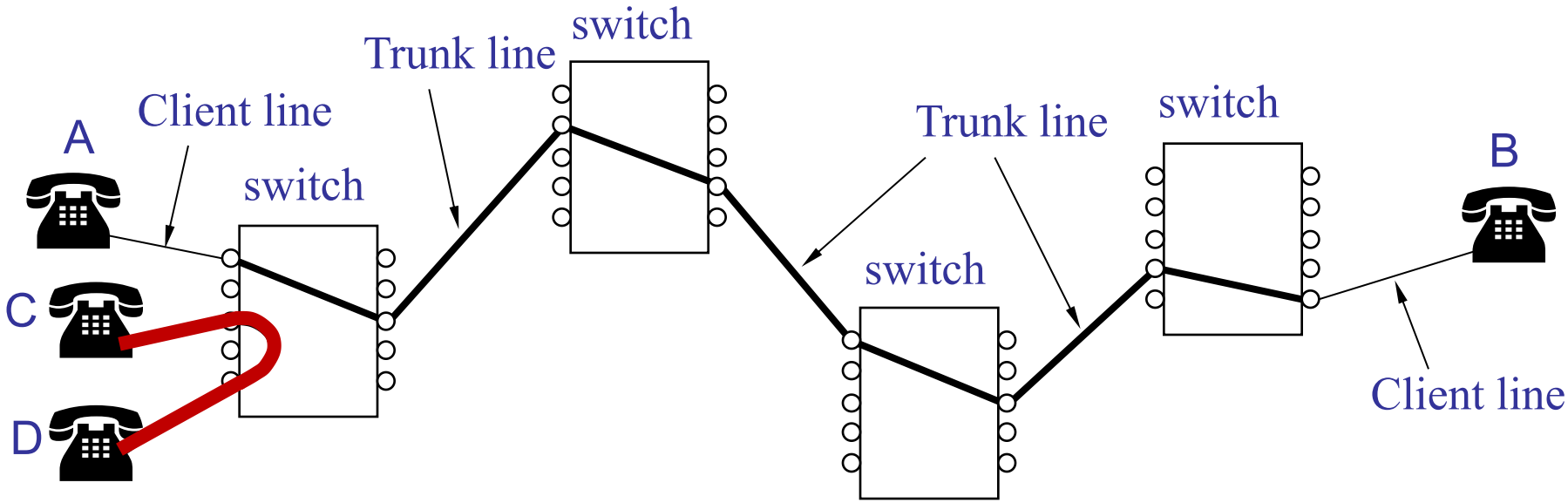
# Circuit Switching Example

- A and B talk through four switches
- Talk by the connection from A to B



# Circuit Switching Example

- C and D talk through a local switch.
- Talk by the connection from C to D



# Message/Packet switching

- The technology of Message/Packet switching is to divide the data into a number of messages/packets as independent units. The technology has the advantages of high efficiency, high error correction rate.Therefore it is widely used in computer and communication field. Store and forward switching is the core of the technology.
- Message/Packet concept
  - Message is a block of data to be sent.The message is to be stored and transmitted.
  - Packet is defined as the packet is divided into a number of Data Segments, and each Data segment is composed of a packet after adding some necessary control information into the header.
  - Packet= Header + Data Segment

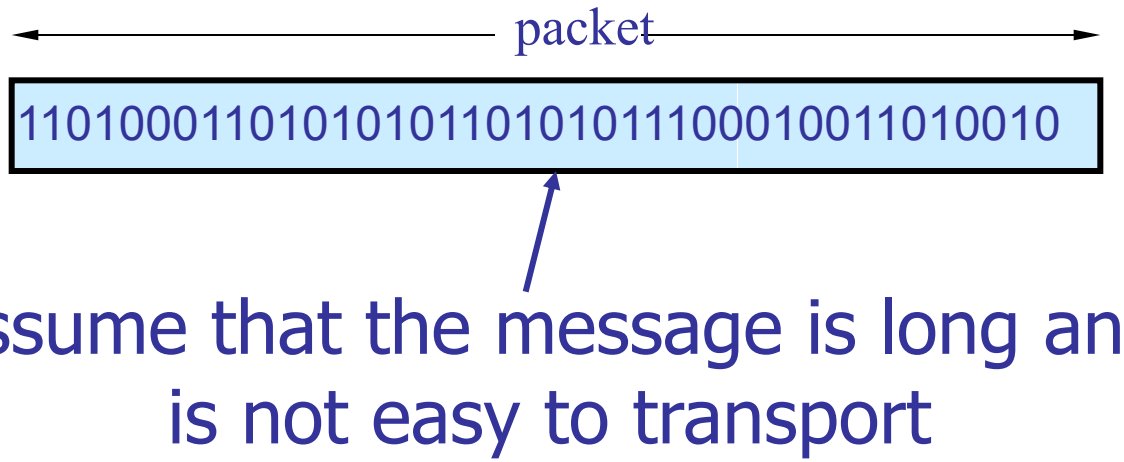
# The importance of the Header

- Each header contains the control information such as address.
- In packet-switching networks according to the received packet address information in the first, the node switchings transmit the packet to the next nodes.
- By this way of store and forward switching, the last packet can reach the final destination.

# The first process of Packet switching:

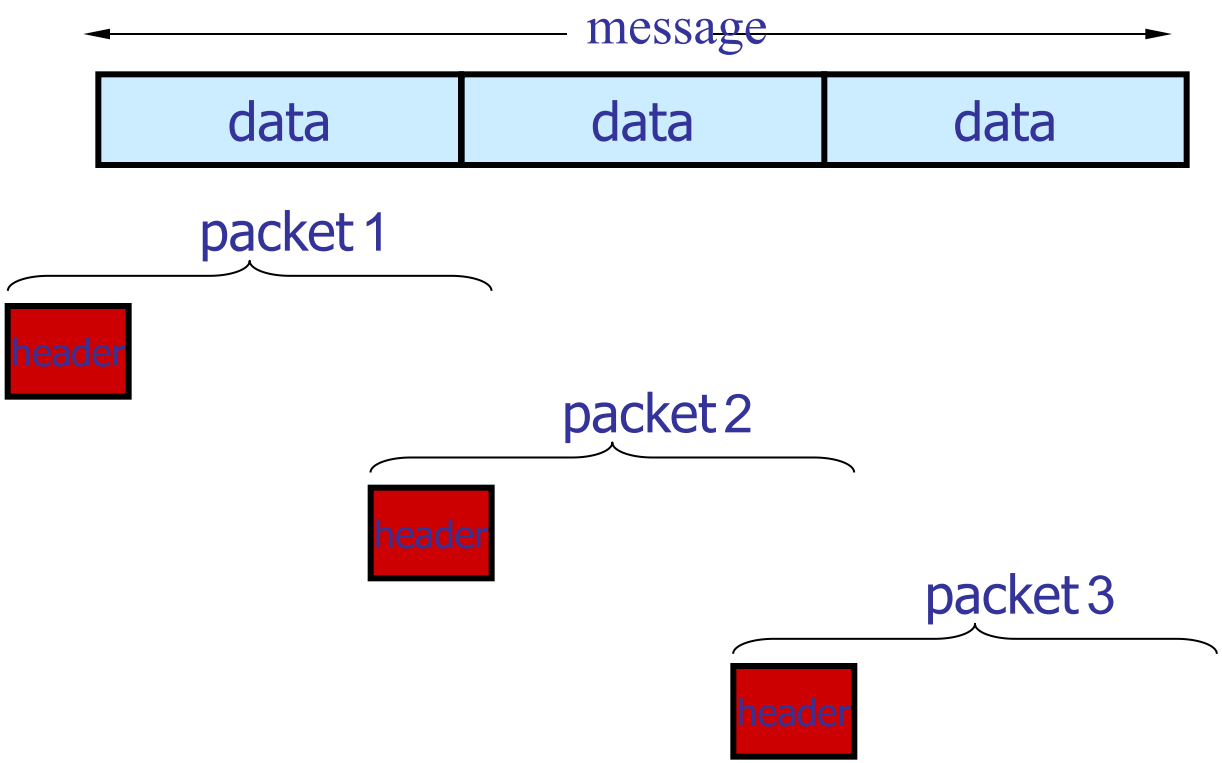
## 1. Divide the Data segments

- In the sender, the longer message is firstly divided into short, fixed-length data segment.



# The second process of Packet switching:

## 2. Add the headers in order to form packets

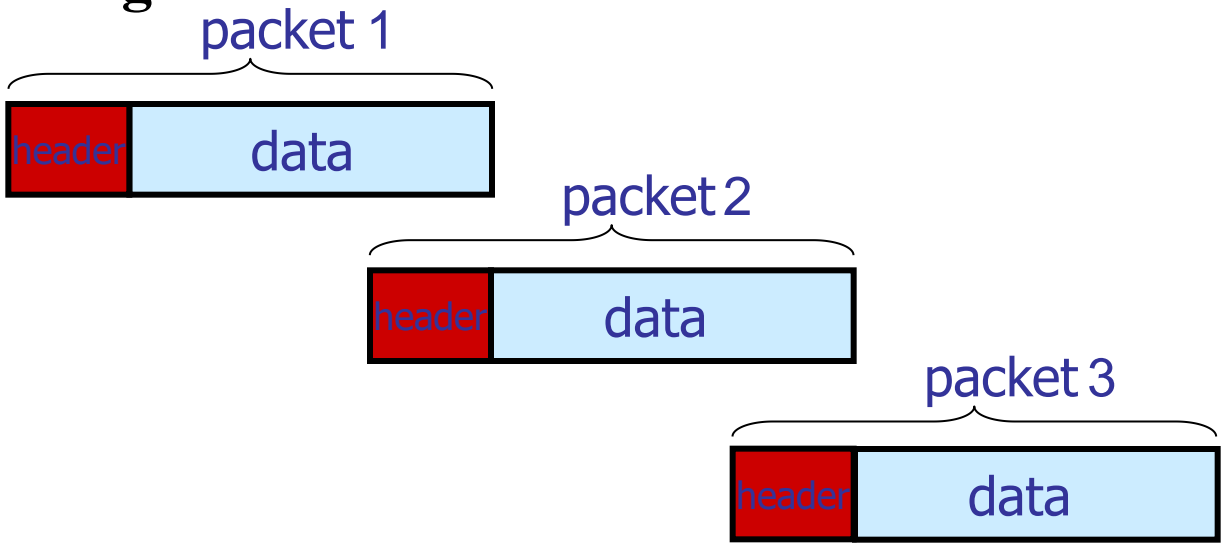



Attention:the message mentioned now is on the left

# The third process of Packet switching:

## 3.Transmitting the packet data unit

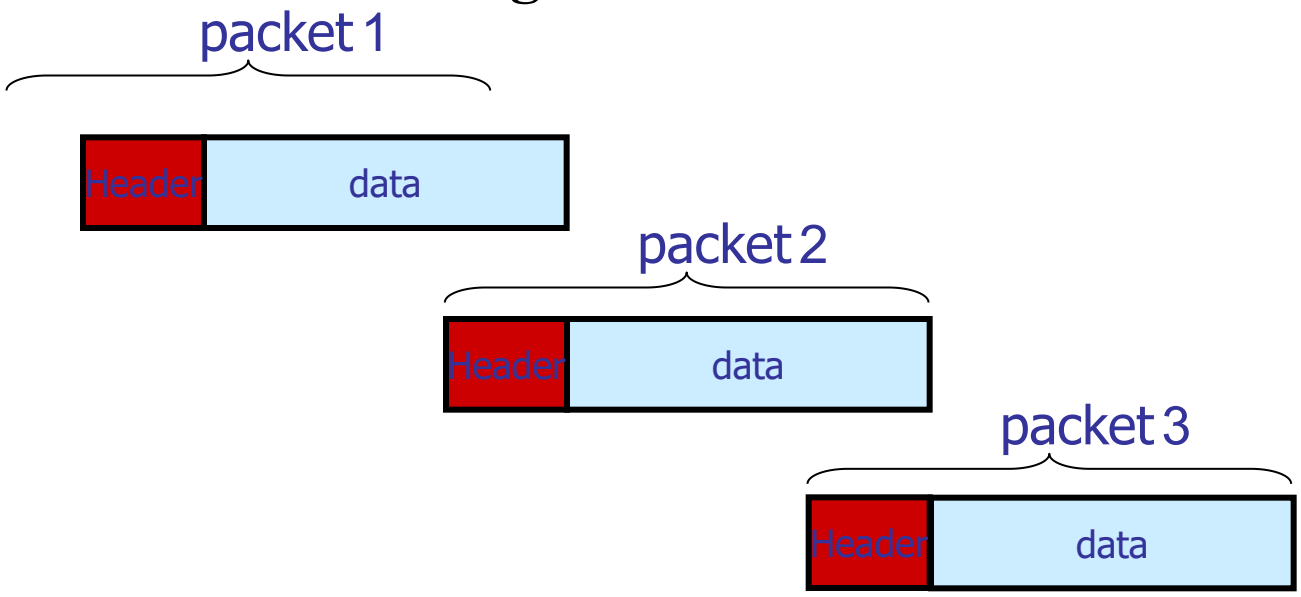
- Packet switching network takes "packet" as the data transmission unit.
- Send each packet to the receiving end in turn and here assuming that the receiver is on the left



# The fourth process of Packet switching:

## 4. Remove headers after receiving packets

- Remove header and return to message after receiving packets in the receiving end.




Received data

# The fifth process of Packet switching:

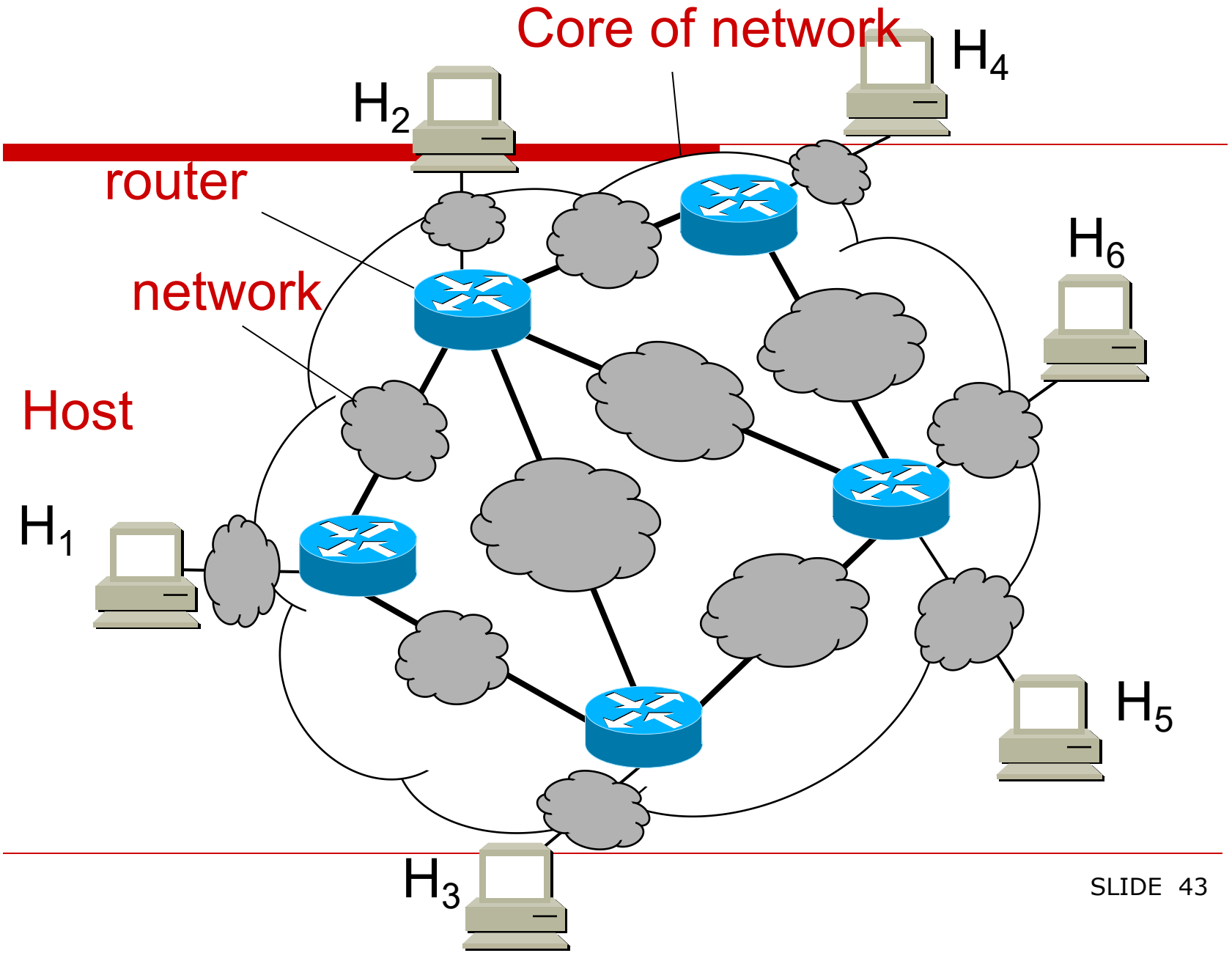
## 5.Return to the original message

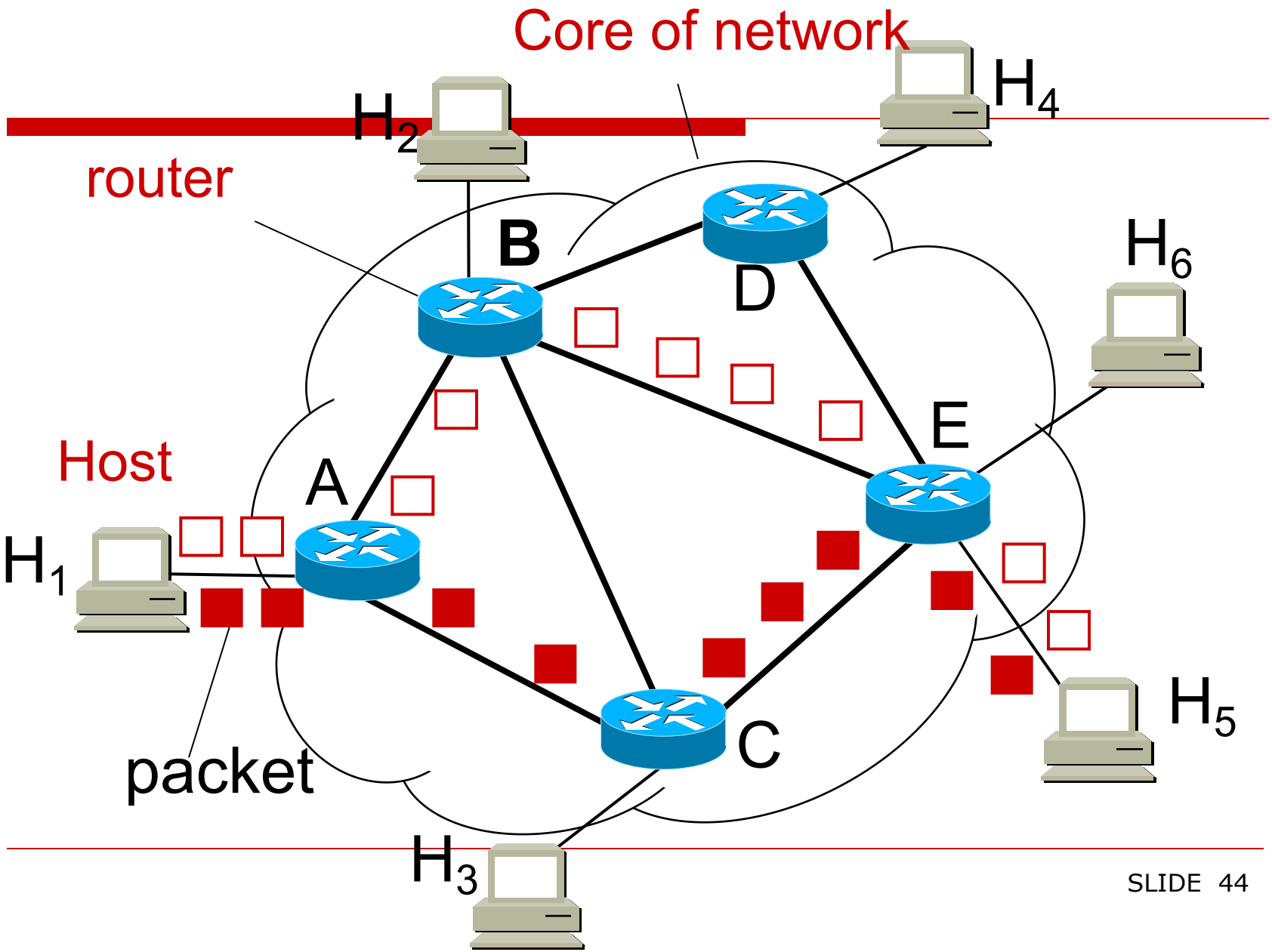
- Finally, the data receiving end return to the original message according to the received data.


- Here we assume that the packets does not appear to be any errors in the transmission process, and are not discarded when forwarding.

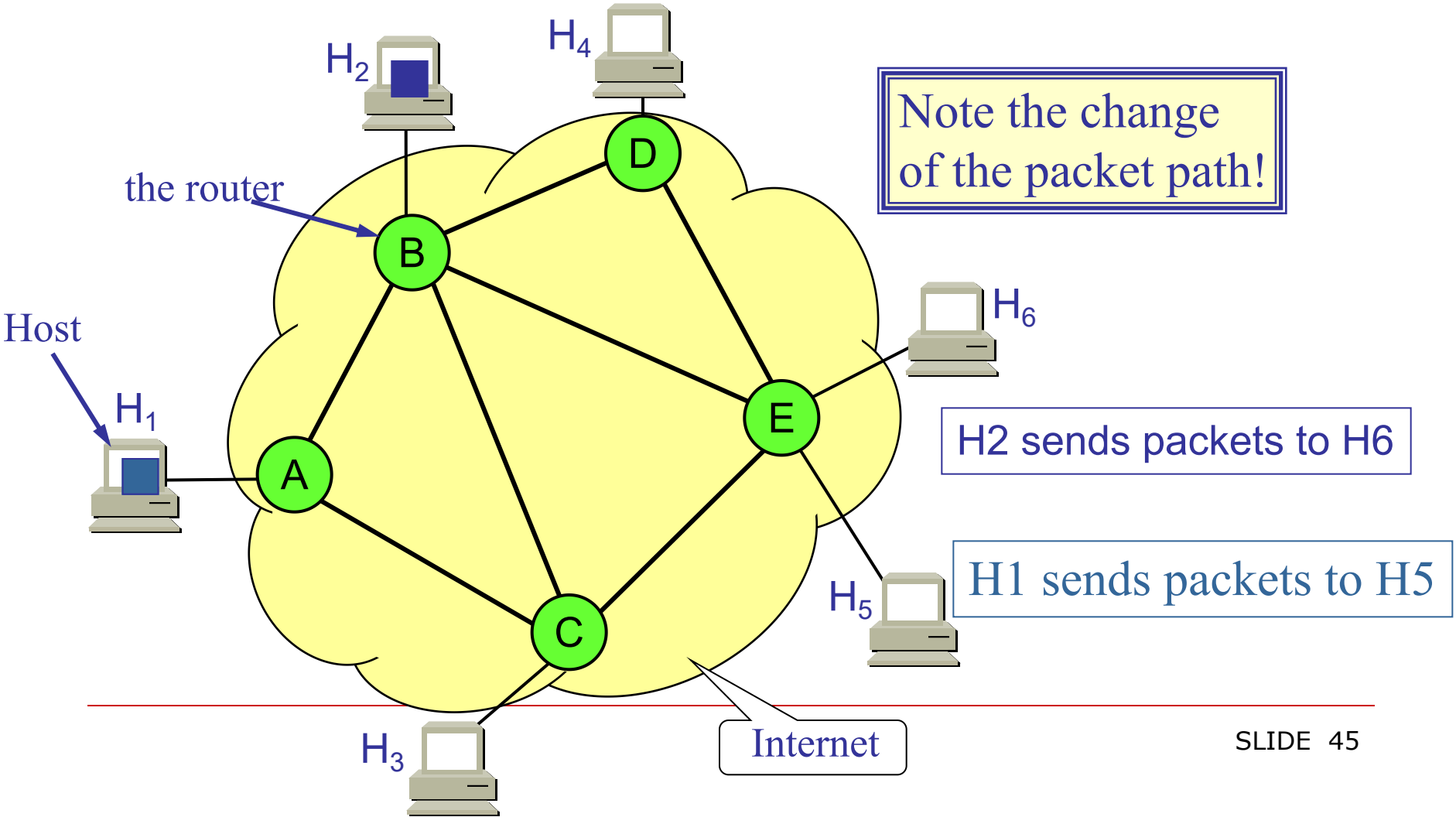
# Examples of Message/Packet switching

- Typical Message switching - Telegraph communication, due to the long delay of packet switching, ranging from a few minutes to a few hours. Now the message exchange is less used.
- Typical Packet switching - Router

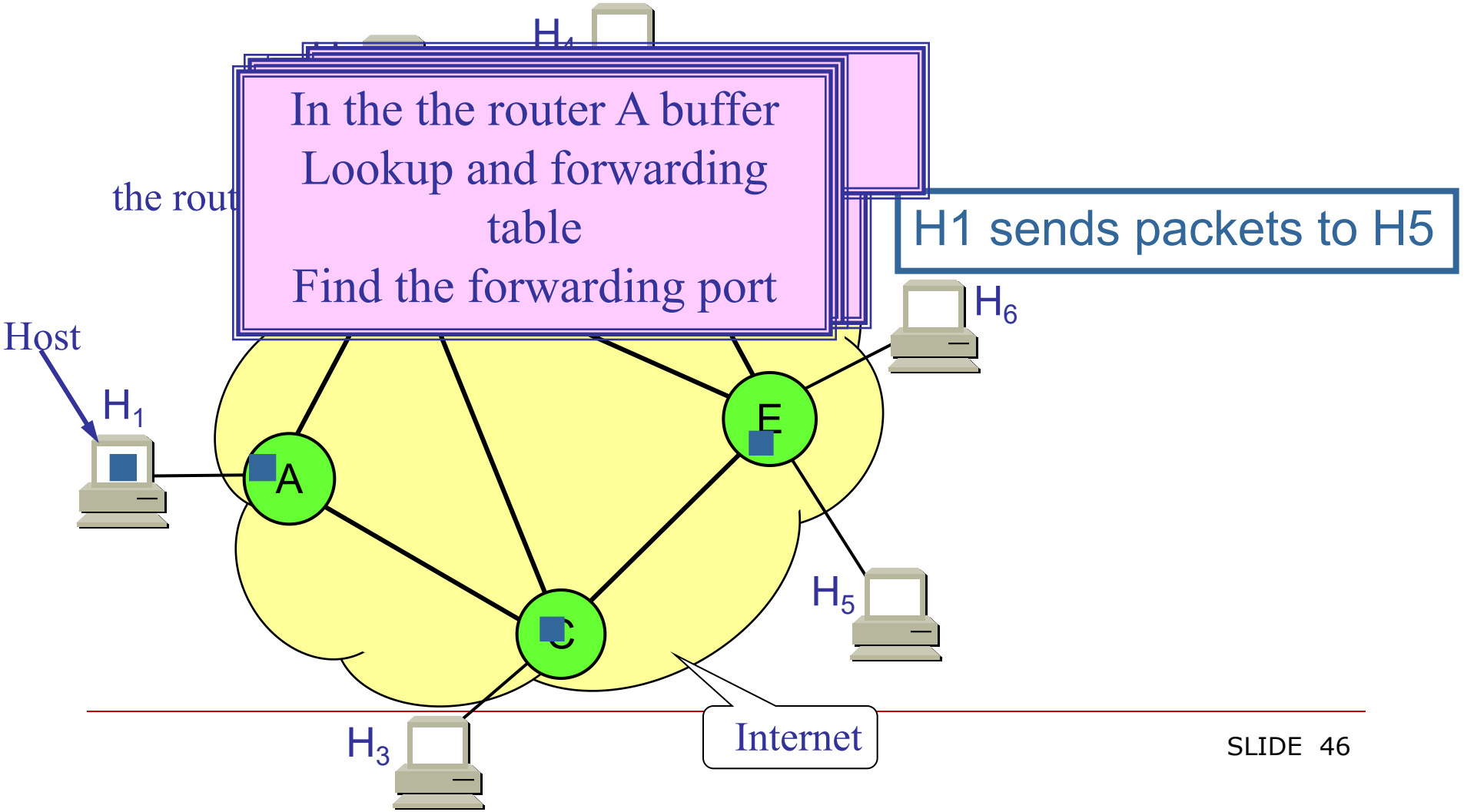

Core of network
H2
H4
router
network
H6
Host
H1
H5
H3


Core of network
H2
H4
router
B
D
H6
Host
A
E
H1
H5
C
packet
H3

# Schematic diagram of Packet switching network



# Note that packets' store-and-forward process



# Router

- There is no direct connection between the input and output ports in the router.
- The process of router deal with the packets is:
  - Firstly input the received packets into the cache (temporary storage);
  - Lookup the forwarding table, find out which port forwarding according to a destination address;
  - Send packets to the appropriate port in order to finish forwarding tasks.

# The different roles of Hosts and Routers

- The hosts are the information processing units for the users, they can exchange information with other hosts through the network (i.e. it sends the packets to the network, and receive packets from the network ).
- Routers are used to store and forward packets, in order to deliver the packets to the destination hosts (i.e. packet switching).

# Advantages of Packet switching

- **High efficiency**
  - Dynamic allocation of transmission bandwidth, the communication link is a period of time.
- **Flexibility**
  - Lookup routing and the packets as the transmission unit .
- **Rapid/Speed**
  - it can quickly send packets to other hosts without establishing a connection at first.
- **Reliability**
  - Guarantee the reliability of the network protocol, and the distributed routing protocol make the network have a sound survivability.

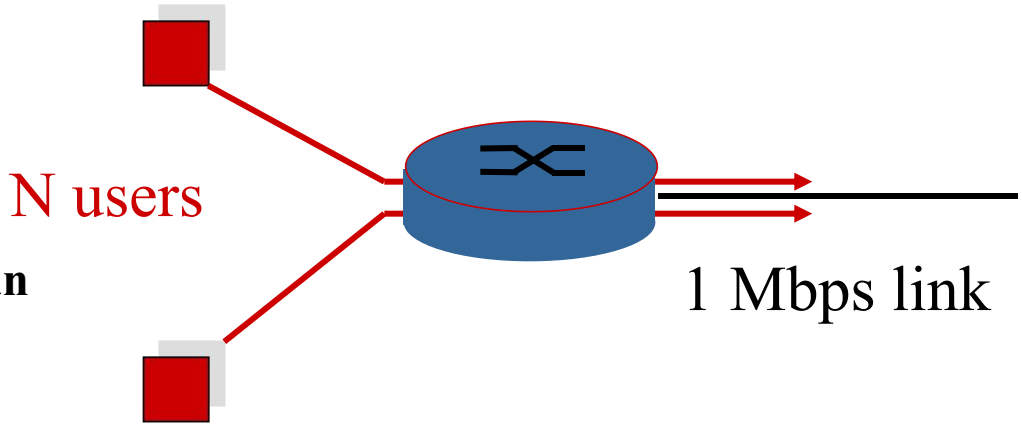
# Shortcomings of packet switching

- The packet has to be queued in each node in store-and-forward progress, which may cause the certain delay.
- The packet has to take the header (as the essential and necessary control information) therefore may cause a certain overhead (expenditure).

# Packet switching vs. Circuit switching

## which supports more users to use the network?

- 1 Mbps link
- Each user:
  - When it is active - 100 kbps
  - 10% time is active
- Circuit switching:
  - Up to 10 users
- Packet switching
  - Empirical statistics can reach 35 users
  - It is assumed that the probability of more than 11 simultaneous users is less than 0.0004 (0.04%).



# Whether packet switching is a "strong winner" or not compared with circuit switching?

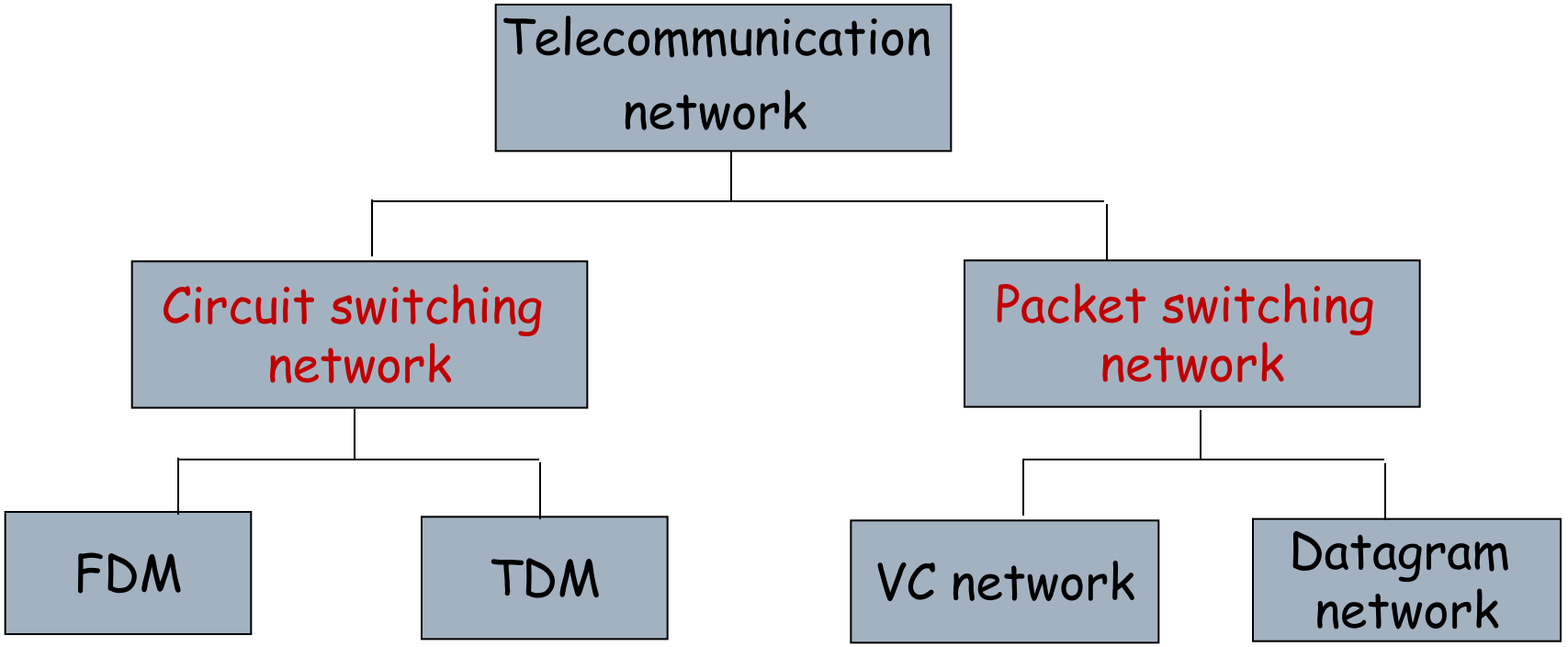
- Extremely effective to burst data
  - Resource sharing
  - Relatively simple, no need to call establishment
- Too much congestion: Time delay and Packet loss
  - Need the reliable protocol to transfer reliable data and make congestion control
- Question: how to provide the similar circuit-like behaviors?
  - Bandwidth guarantee for Audio / Video applications
  - Still as an unsolved problem nowadays

# Packet switching network: Forwarding

- **Objective: move packets from source to destination through routers.**
  - **Some routing selection algorithms (Chapter 4)**
- **Datagram network:**
  - **The destination address in the packet determine the next hop**
  - **Routing could change in the process of the session**
  - **Analogy: Driving cars, asking for directions**
- **Virtual circuit network:**
  - **Each packet carries a label (virtual circuit ID), the label decides the next hop**
  - **Fixed path is set up when a call established, and remains unchanged during call process**
  - **Routers keep awake at each call state**

# Telecommunication network

## Classification according to Data exchange methods

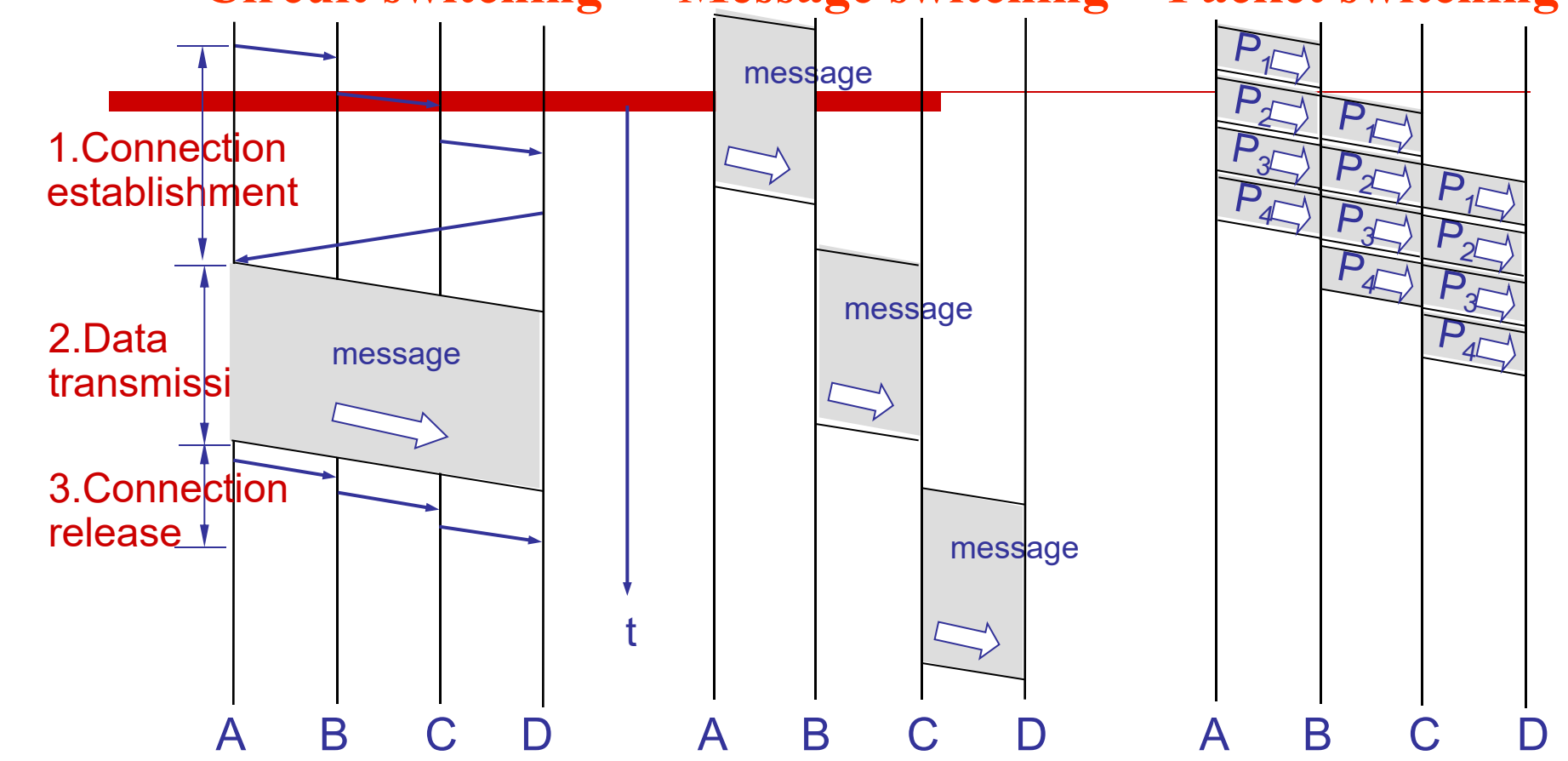


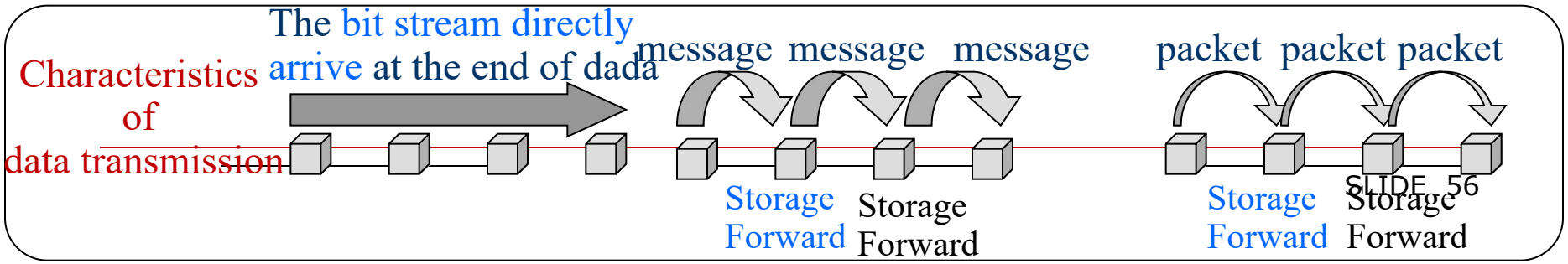

- A datagram network is not connection-oriented, is no connection.
- The Internet provides a connection-oriented application service
- (TCP) and connectionless service (UDP).

# Summary: From Circuit switching to Packet switching

- Three data exchange methods in core part (Communication sub network) of computer network
  - Circuit switching – the bit stream of the entire message is from the source point to the end point, as a pipeline transmission;
  - Message switching- the entire message is transmitted to the adjacent node, then stored down before lookup the forwarding table, finally transmitting to the next node;
  - Packet Switching - Single packet (only part of the whole message) is transmitted to the adjacent node, which is stored in this node and then switching to the next code after lookup the forwarding table;

# Comparison of three kinds of data switching modes



# Comparison and range of applications of three kinds of data switching modes

- Circuit switching requires exclusive physical line. If needed to send large amount of data, and the transmission time is much longer than the established time, the transmission rate is faster than others;
- Since Message/Packet switching does not need to pre-allocate transmission bandwidth, the channel utilization of the whole network can be improved when transmitting burst data;
- Compared with Message switching, because the length of a packet is often far less than the length of the whole message, so Packet switching's delay is less than Message switching.It also has better flexibility;

# The development of computer network in China

- 中国公用计算机互联网 **CHINANET—1994.9**
- 中国教育和科研计算机网 **CERNET**（高校、研究所）
- 中国科学技术网 **CSTNET**（中科院）
- 中国联通互联网 **UNINET**（中国联通）
- 中国网通公用互联网 **CNCNET**（中国电信）
- 中国国际经济贸易互联网 **CIETNET**
- 中国移动互联网 **CMNET**（中国移动）
- 中国长城互联网 **CGWNET**
- 中国卫星集团互联网 **CSNET** （35颗卫星的北斗卫星导航系统，已经于2020年全部建成）

# 5. Definition of computer network

- Early definition - A collection of interconnected, autonomous computers
- Definition 1 - Computer network is the information system that uses the communication lines (networking equipment) to connect the geographically dispersed computer systems and realizes the information resources sharing according to some protocol for data communication.
- Definition 2 – is an interconnection of computers and computing equipment using either wires or radio waves and can share data and computing resources.
- The simplest computer network = two nodes (computers) + one link
- Distinction between telephone communication, computer communication and data communication:
  - Telephone communications emphasize the communication agents are human beings
  - Computer communications (i.e., computer networks) emphasize the programs (processes) which running on the computers are the communication agents.
  - Data communications emphasize the communication contents are data (when in computer communication)

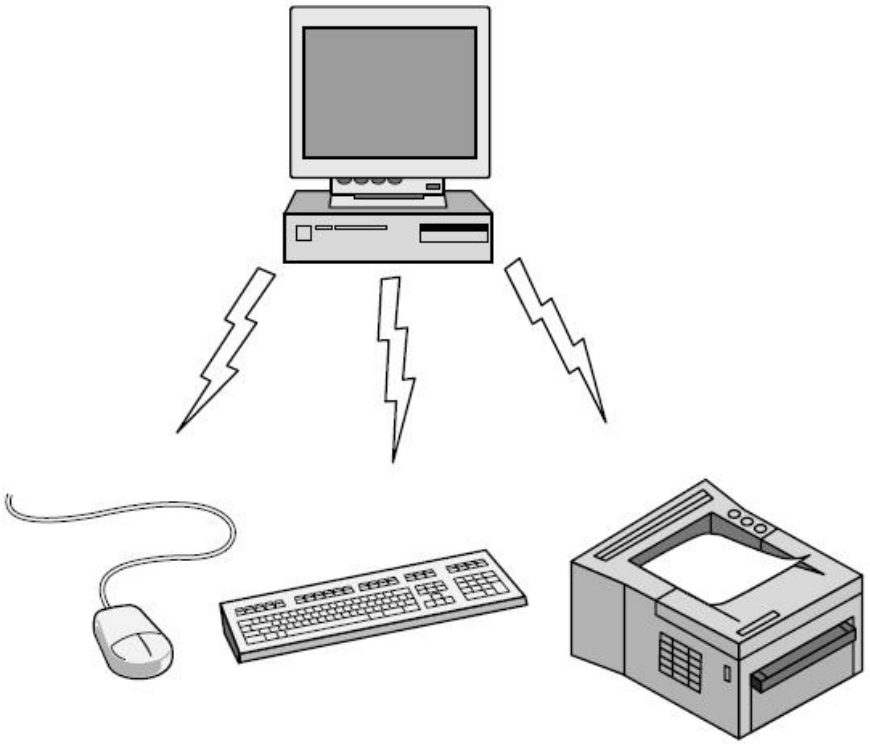
# 6. Classification of computer networks

- 1. Classified by function scope (Distance)
  - PAN (Personal Area Network)
  - LAN (Local Area Network)
  - MAN (Metropolitan Area Network)
  - WAN (Wide Area Network)
  - Internet (World largest WAN)

# 1) Classified by function scope (Distance)

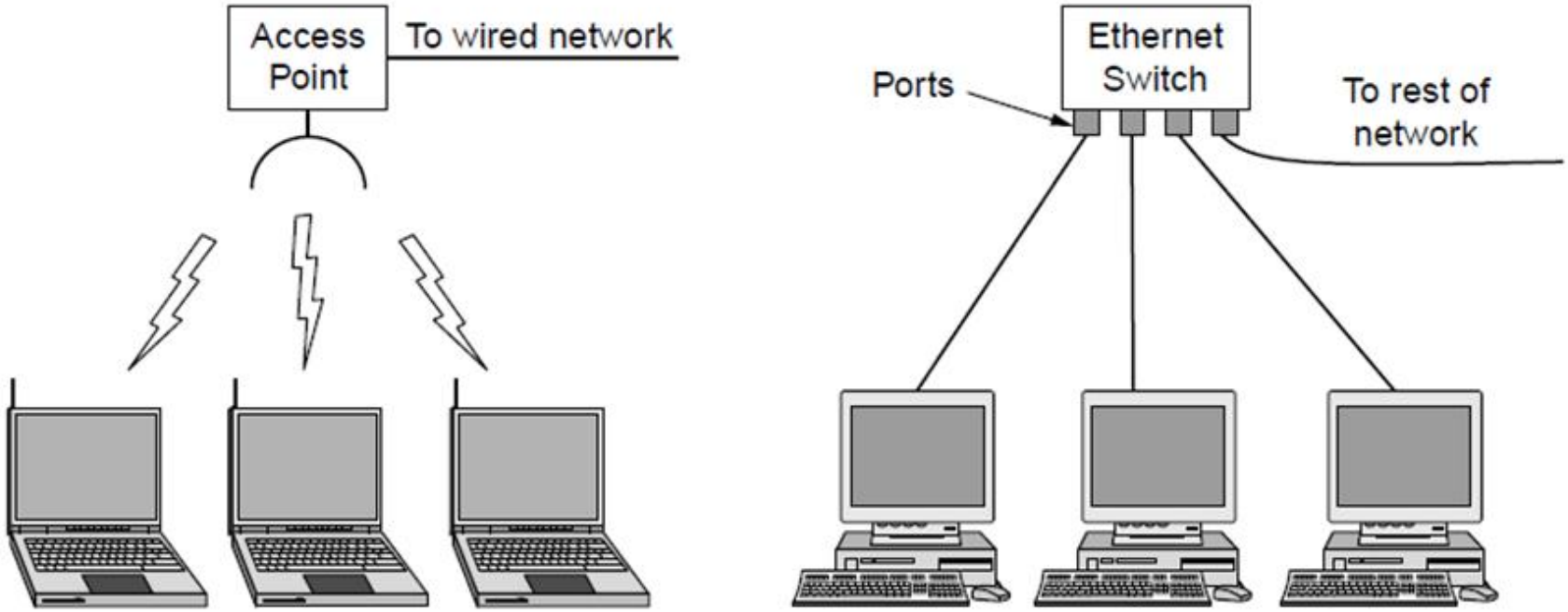
| Interprocessor distance | Processors located in same | Example |
|---|---|---|
| 1 m | Square meter | Personal area network |
| 10 m | Room | Local area network |
| 100 m | Building | |
| 1 km | Campus | |
| 10 km | City | Metropolitan area network |
| 100 km | Country | Wide area network |
| 1000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

# PAN (Personal Area Network)



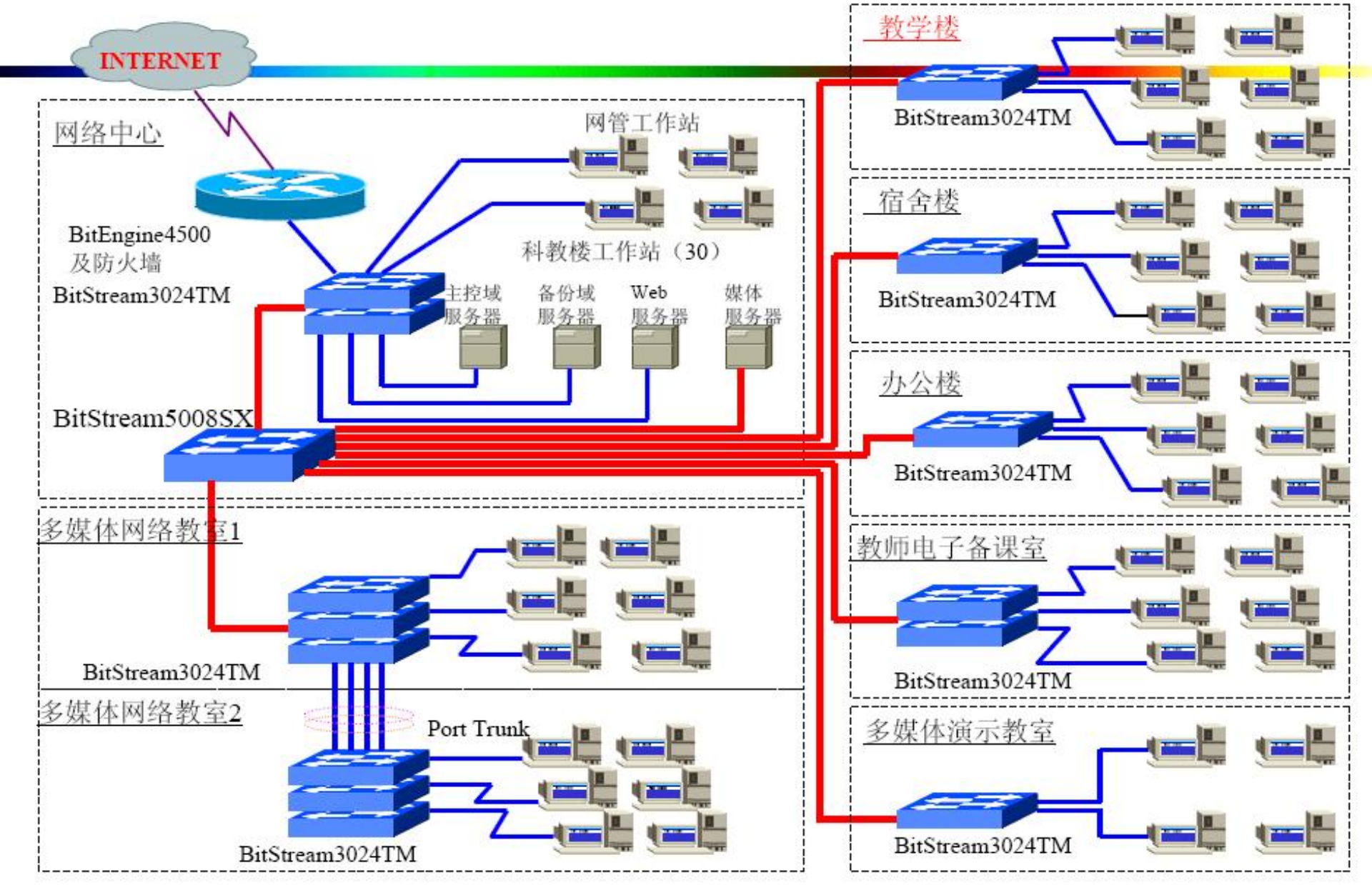
Bluetooth PAN configuration

# LAN (Local Area Network)

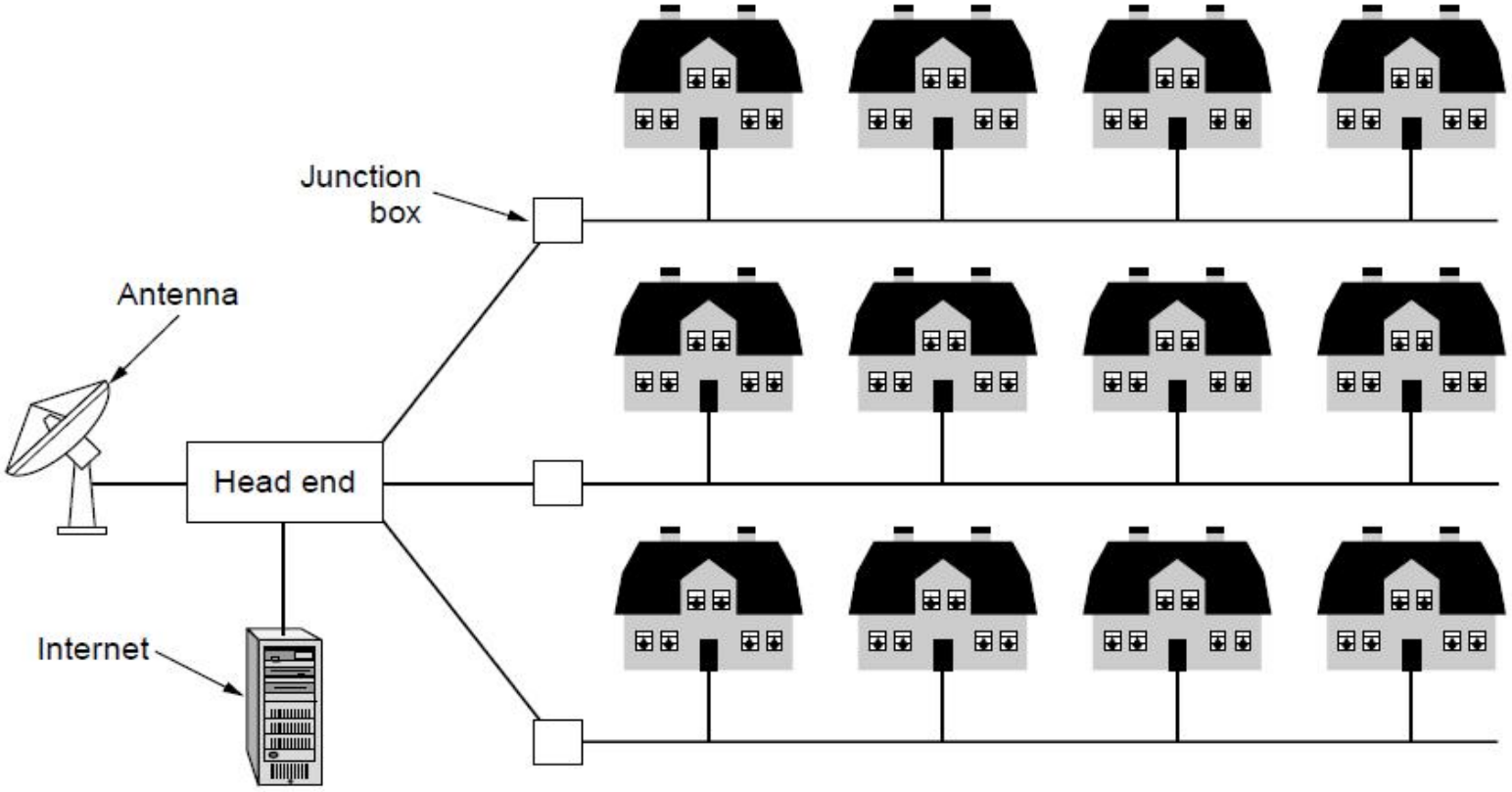



Wireless and wired LANs.
(a) 802.11. (b) Switched Ethernet.

# Example of LAN－Campus network

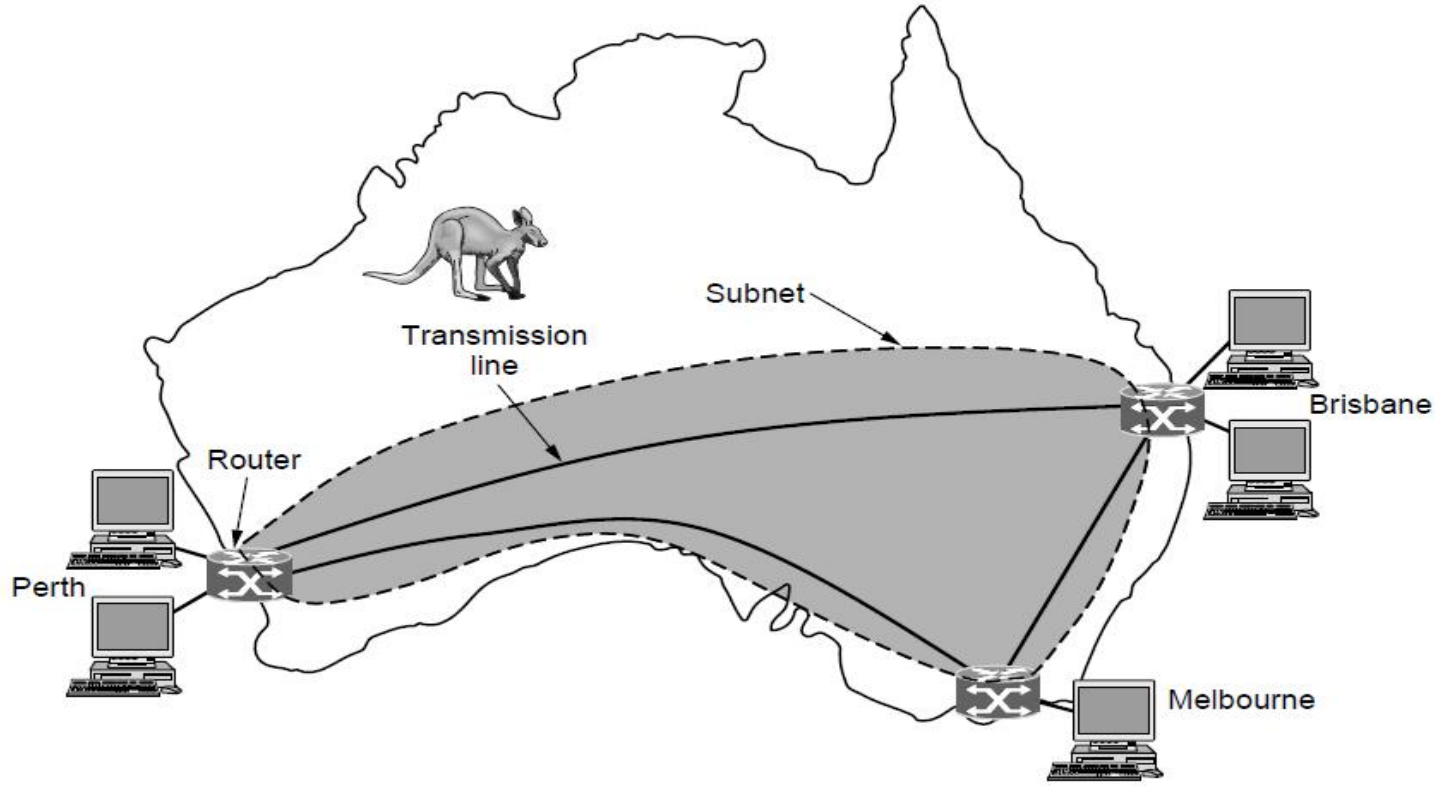


# MAN (Metropolitan Area Network)



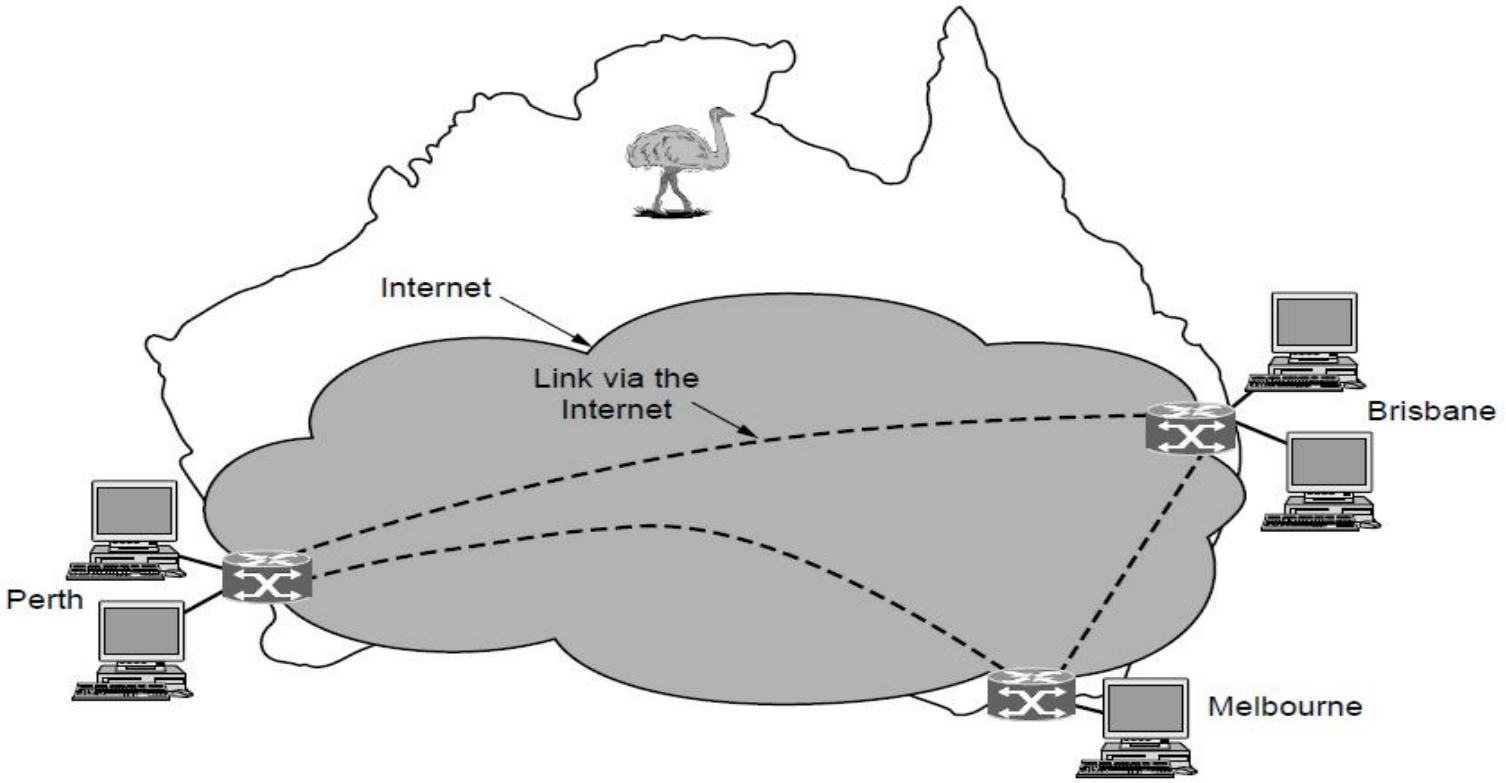

A metropolitan area network based on cable TV.

# WAN 1 (Wide Area Network 1)



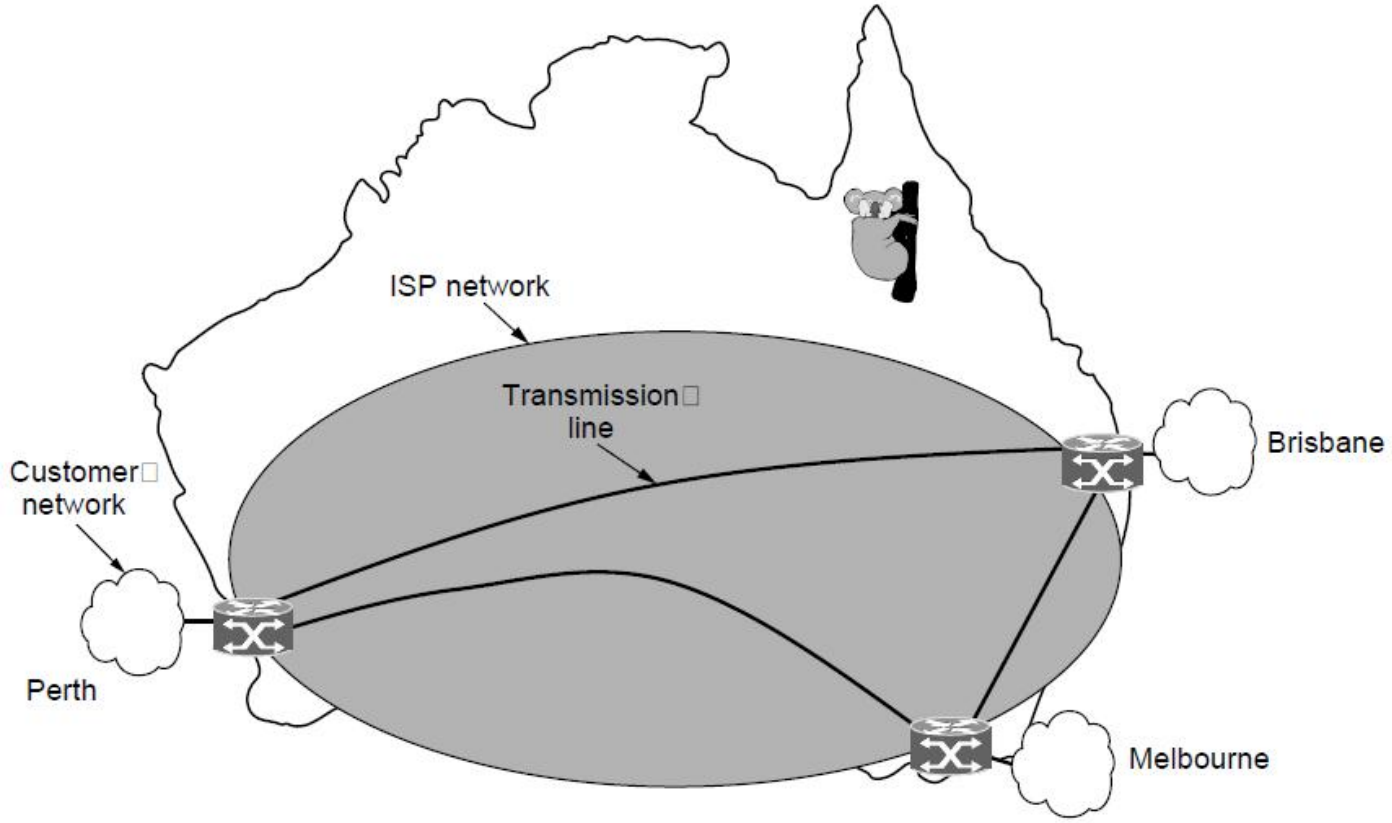

WAN that connects three branch offices in Australia

# WAN 2 (Wide Area Network 2)



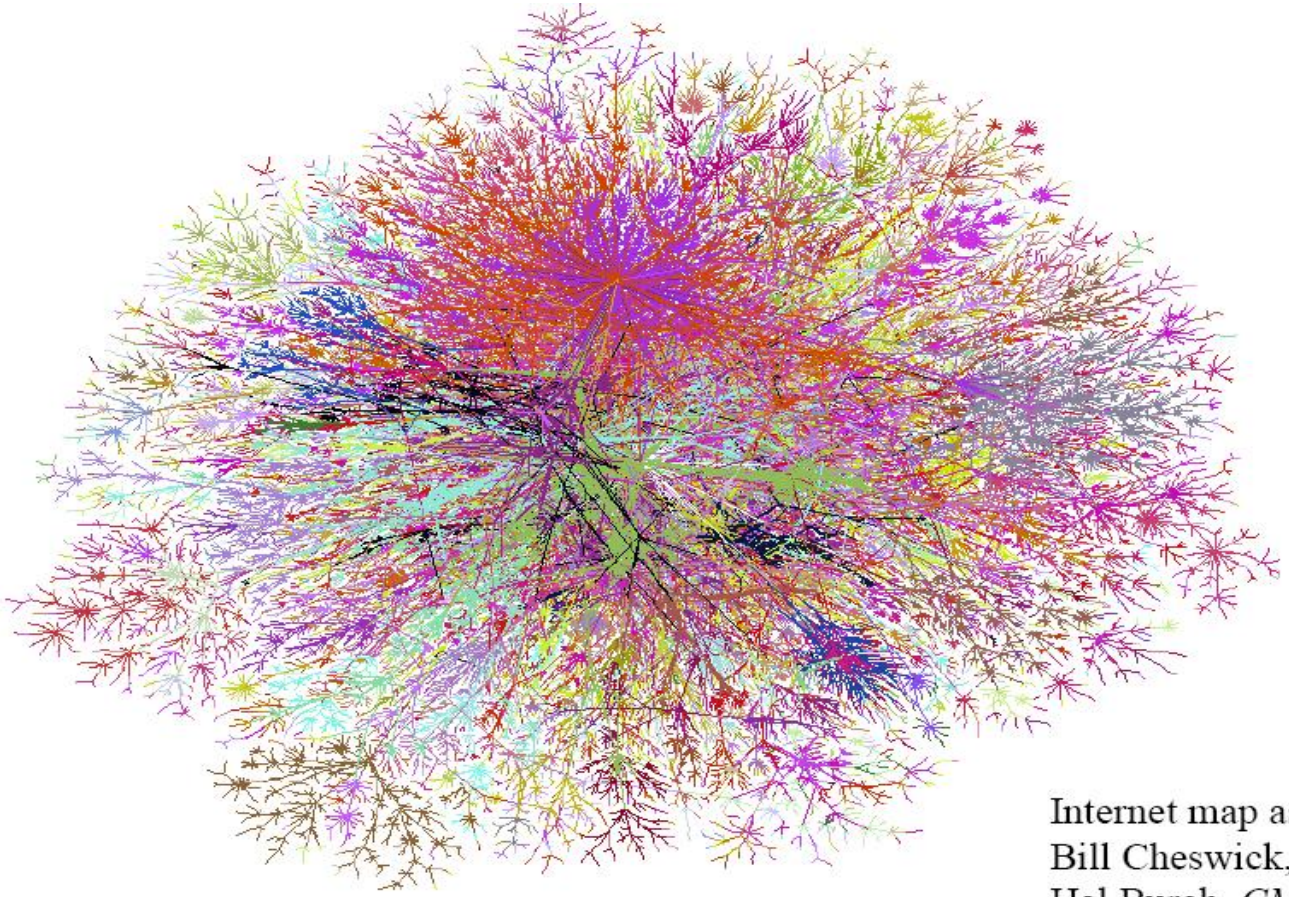

WAN using a virtual private network.

# WAN 3 (Wide Area Network 3)




WAN using an ISP network.

# Internet



Internet map as of 1998 by
Bill Cheswick, *Bell Labs*
Hal Burch, *CMU*

# 6. Classification of computer networks

## 2) Classified by various users

- **Public Networks - which is provided by the telecommunication department or the company that is engaged in professional telecom operators, provides a network of public services, such as X.25, Chinapac, ChinaDDN, group, Chinanet, and data, which is provided by China Telecom ".**
- **Private Networks – it is established by Government, industry, enterprises and institutions and the academic community, the enterprise and the service sector. Examples of private network, representatives of the education research network CERNET, Chinese Academy of Sciences CASNET, China economic information network CEINET and the network of all levels of government departments and so on.**

# 6. Classification of computer networks

## 3) Classified by information exchange objects (based on TCP/IP protocol )

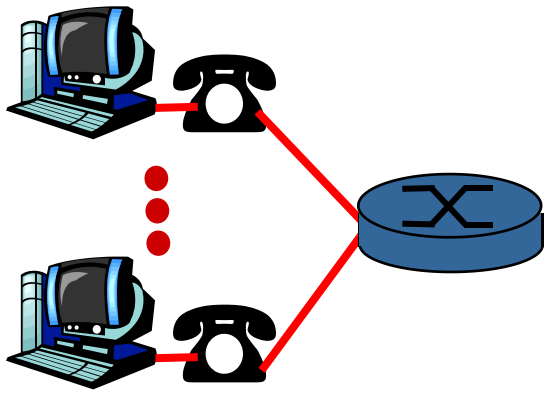
- **Internet** - is the world's only international interconnection network based on TCP / IP, the national and regional public data network. Such as the Chinese Internet Chinanet.
- **Intranet** - The protocol set as the basis of enterprises, enterprise dedicated network.It is through the TCP/IP (Firewall) to implement the separation and through the proxy server (Server Proxy), encryption and other measures to ensure the internal information communication and access security. In this sense, Intranet is a kind of application of Internet technology in special network.
- **Extranet** - is to expand the scope of the Intranet's connectivity to the outside of the company's business contacts with partners, suppliers, customers, and consultants.

# 6. Classification of computer networks

- 4) Classified by users' access method (residential access point form)
  - Point to point access - Modem, ADSL
  - Electronic cable / Optical cable access
    - HFC network (Hybrid Fiber－Coaxial),
    - FTTx network (Fiber-to-the-x network)

# Point to point access

- **Modem dialing**
  - Up to 56Kbps, direct access to the router (less)
  - Can not surf the Internet and make a phone call at the same time: not always online.

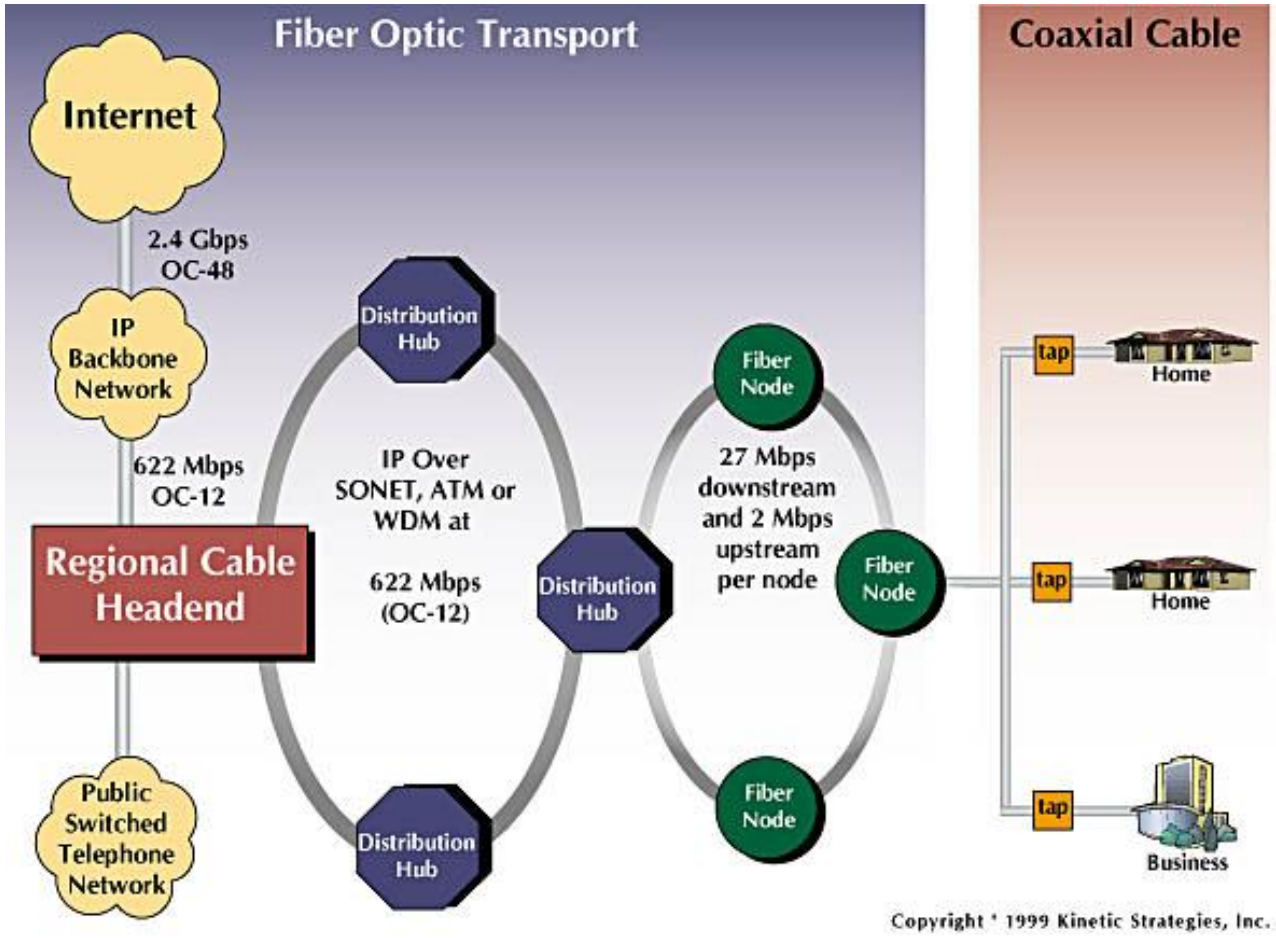


- **ADSL: Asymmetric digital subscriber line**
  - The maximum reach to 1 Mbps uplink (today is < 512 Kbps).
  - The maximum reach to 8 Mbps downlink (today is < 2 Mbps)
  - FDM: 50 kHz - 1 MHz for downlink
    4 kHz - 50 kHz for uplink
    0 kHz - 4 kHz for common phone

# Electric cable/Optical cable access

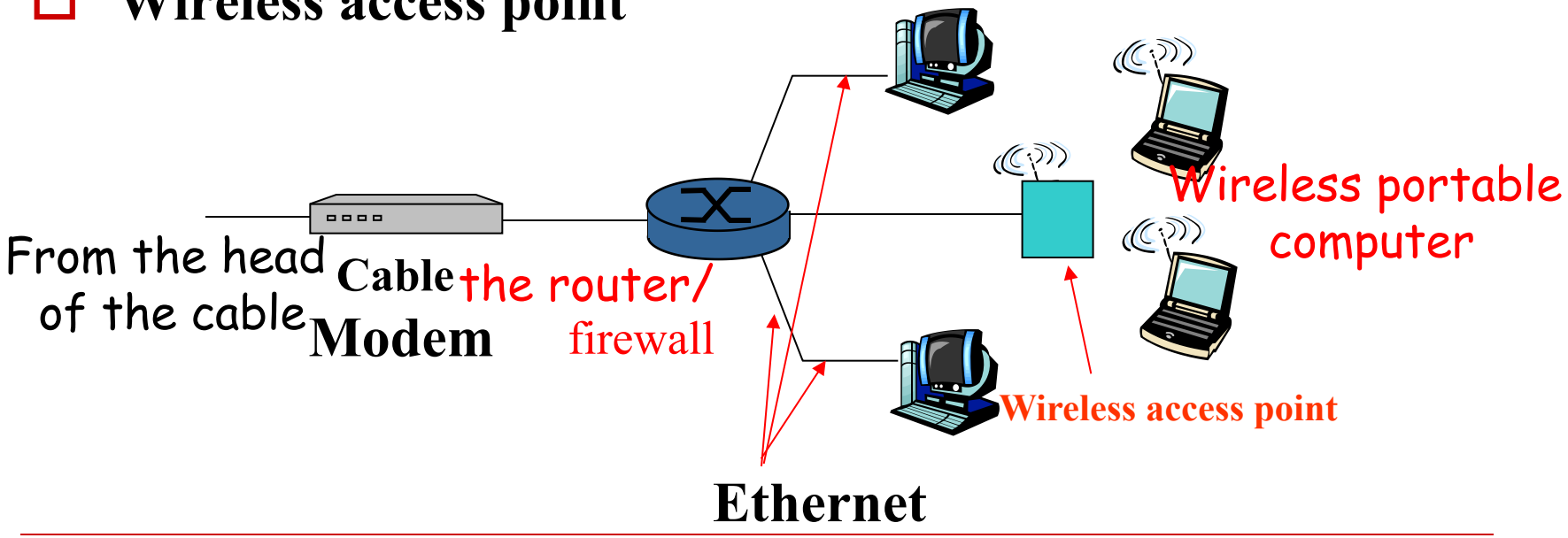
- **HFC: Hybrid Fiber Coaxial**
  - **Asymmetric: up to 30Mbps downlink, up to 2 Mbps**
- **Cable and cable network will be home to the IPS router**
  - **Family shared access to router**
- **Deployment: Cable TV company**

# HFC Network


Fiber Optic Transport
Coaxial Cable
Internet
2.4 Gbps
OC-48
IP
Backbone
Network
622 Mbps
OC-12
Regional Cable
Headend
Public
Switched
Telephone
Network
Distribution
Hub
IP Over
SONET, ATM or
WDM at
622 Mbps
(OC-12)
Distribution
Hub
Distribution
Hub
Fiber
Node
27 Mbps
downstream
and 2 Mbps
upstream
per node
Fiber
Node
Fiber
Node
tap
Home
tap
Home
tap
Business
Copyright ' 1999 Kinetic Strategies, Inc.

# Typical family network

- ADSL or Cable modem
- Router/ the Firewall /NAT
- Ethernet
- Wireless access point



# 6. Classification of computer networks

## 5) Other classification methods

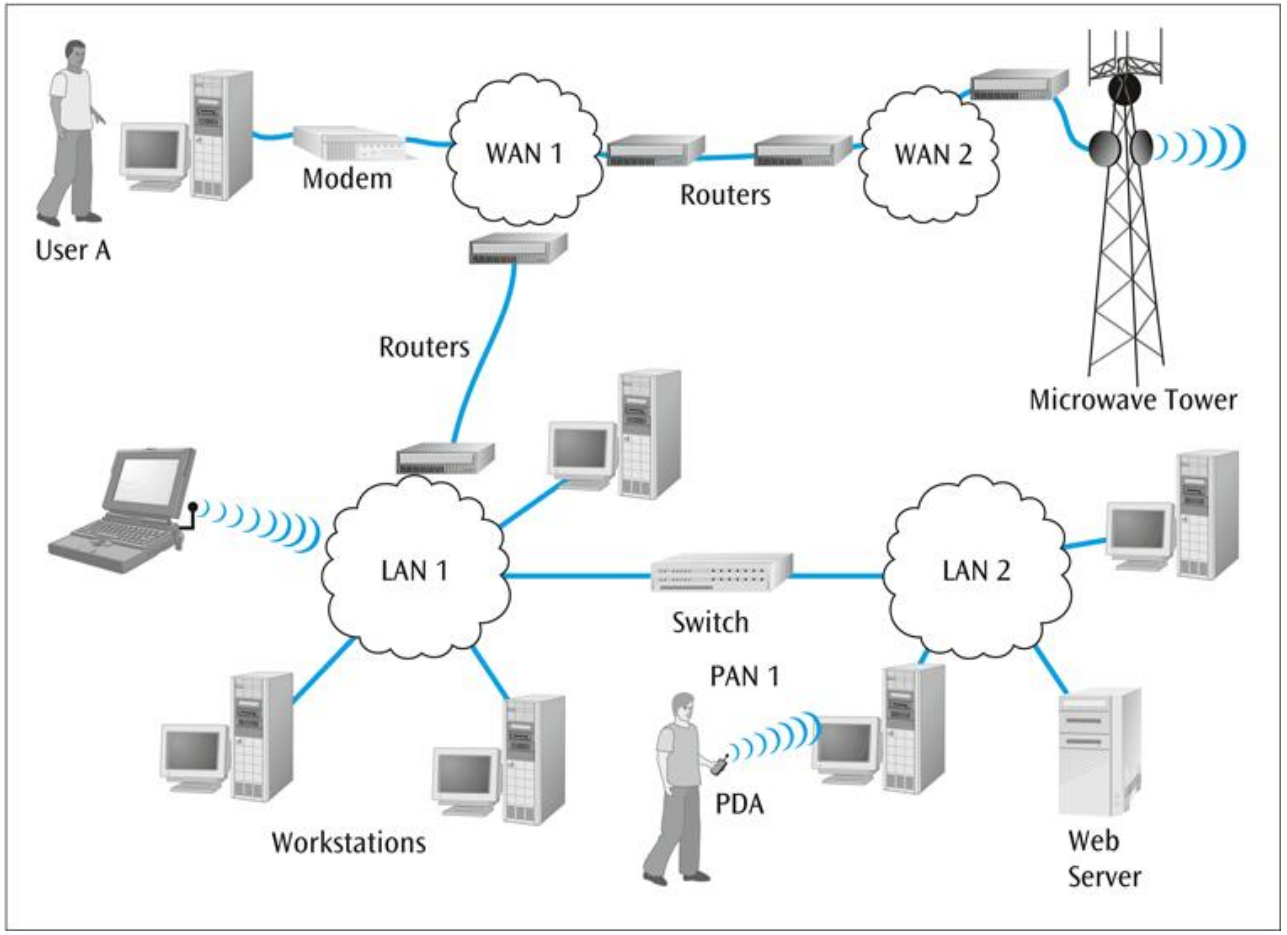
- Classified by Application data properties
  - Data communication network
  - Multimedia network, or integrated services digital network (ISDN short for Integrated Service Network Digital)
- Classified by the Main network technology
  - X.25 based network
  - ATM (Asynchronous Transfer Mode) network
  - Frame relay network
  - Satellite communication network
  - Wired / wireless network
  - Fixed / mobile network

# The Big Picture of Networks

- Networks are composed of many devices, including:
  - LANs
    - Workstations (computers, tablets, wireless phones, etc)
    - Servers
    - Network switches
    - Routers (LAN to WAN and WAN to WAN)
  - WANs
    - Nodes
    - High-speed transmission line
    - Sub-network (Cloud)

# The Big Picture of Networks

**Figure 1-1**
*An overall view of the interconnection between different types of networks*



# Common Examples of Communications Networks

- The desktop computer and the Internet
- A laptop computer and a wireless connection
- Cell phone networks
- Industrial sensor-based systems
- Mainframe systems
- Satellite and microwave networks

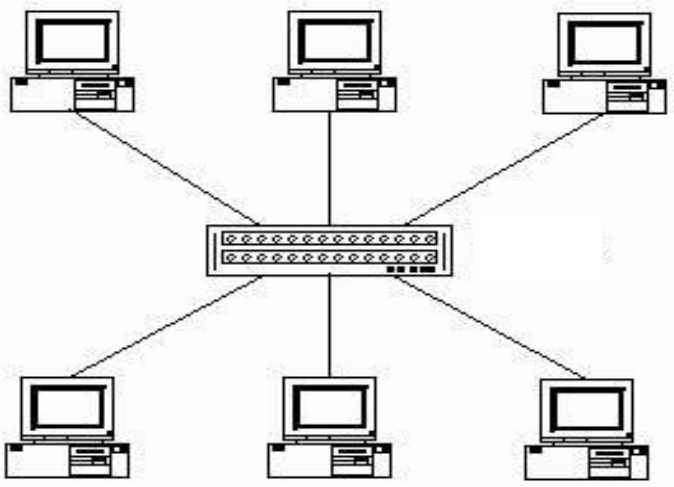
**(more details illustrated in English textbook)**

# 7.Topological structure of computer network

- **Network topology is the geometry style of all the interconnection nodes in a network.**
- **The three basic topology of the network are Star, Bus and Ring type. Any kinds of network system regulates their own network topology.**

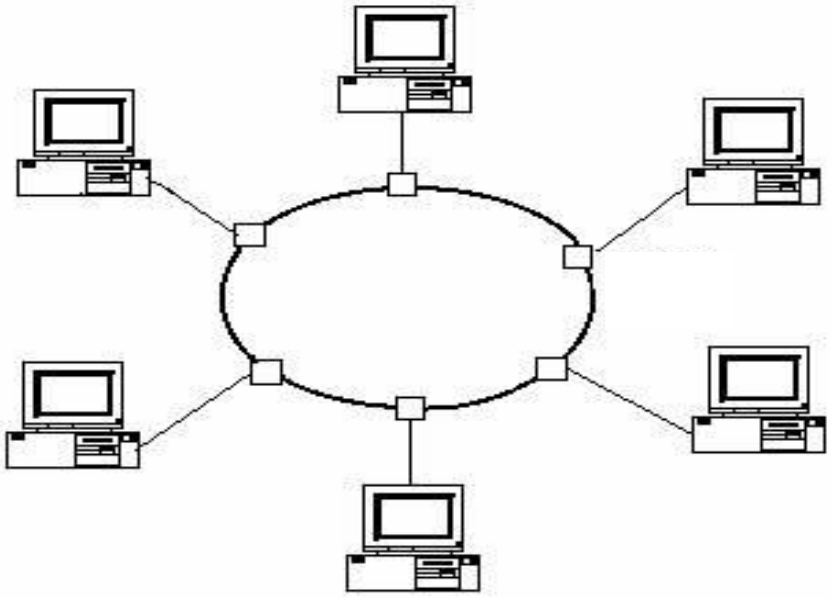
# Star Topology

- **Star topology, node will be divided into endpoints and intermediate node , each endpoint must be connected to intermediate nodes point-to-point. Any two between end nodes to realize data exchange and communication through intermediate nodes.**
- **In the communication of nodes, the network must use the appropriate access control policies and methods to solve the problem of communication between nodes.**
- **In the star network of distributed access control strategy, the intermediate nodes are network switching equipment, which uses the storage forwarding mechanism to provide the transmission path and the forwarding service for the network nodes. In addition, the intermediate node can also be forwarded to all the nodes according to the need of the data, so as to realize the broadcast transmission.**

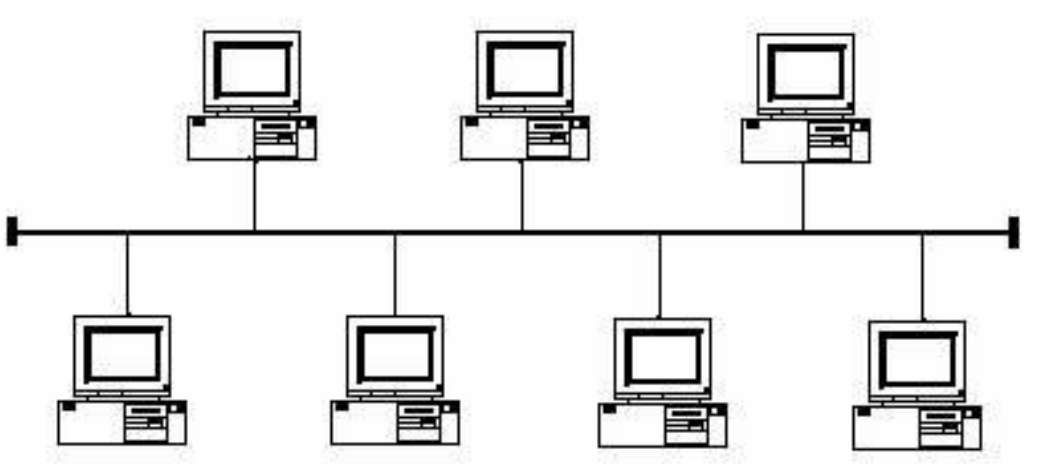


# Ring topology

- **Ring topology, each node through the transceiver connected into the network, between the transceiver by point-to-point link connecte into a closed ring network. The transmitting node transmits the data frame along the loop way. Each pass through a node, the node must judge whether the data frame is transmitted tc the node, if it is sent to the node, then the data frame is copied. Then pass the data frame to tl downstream node. When the data frame is transmitted through each node, the data frame is removed from the loop by the sending node. In this way, the "broadcast" transmission can be realized through the data frame.**
- **In ring network, the access control method is based on token access control. It is a distributed access control technology, which is used to control the medium access of each node and the token control mechanism.**



# Bus topology



- All of the nodes in the network are directly connected to the same transmission medium, which is called the bus. Each node will use the bus to transmit data according to a certain access rule. The data frame transmitted by the transmitting node is transmitted along the bus. The data frame is received by all the nodes on the bus, and if it is sent to the node, the data frame is reserved or the data frame is discarded.
- The “Broadcast" transmission of the bus network is dependent on the basic characteristics of the data signal along the bus to the two ends.
- All the nodes in the bus network share a bus, a node only allows one node to send data, the other node can only be in the receiving state. In order to enable the nodes to use the bus in order and reasonably, a proper access control strategy must be adopted to control the access of the nodes to the bus.

# 8. Performance indicators of computer networks

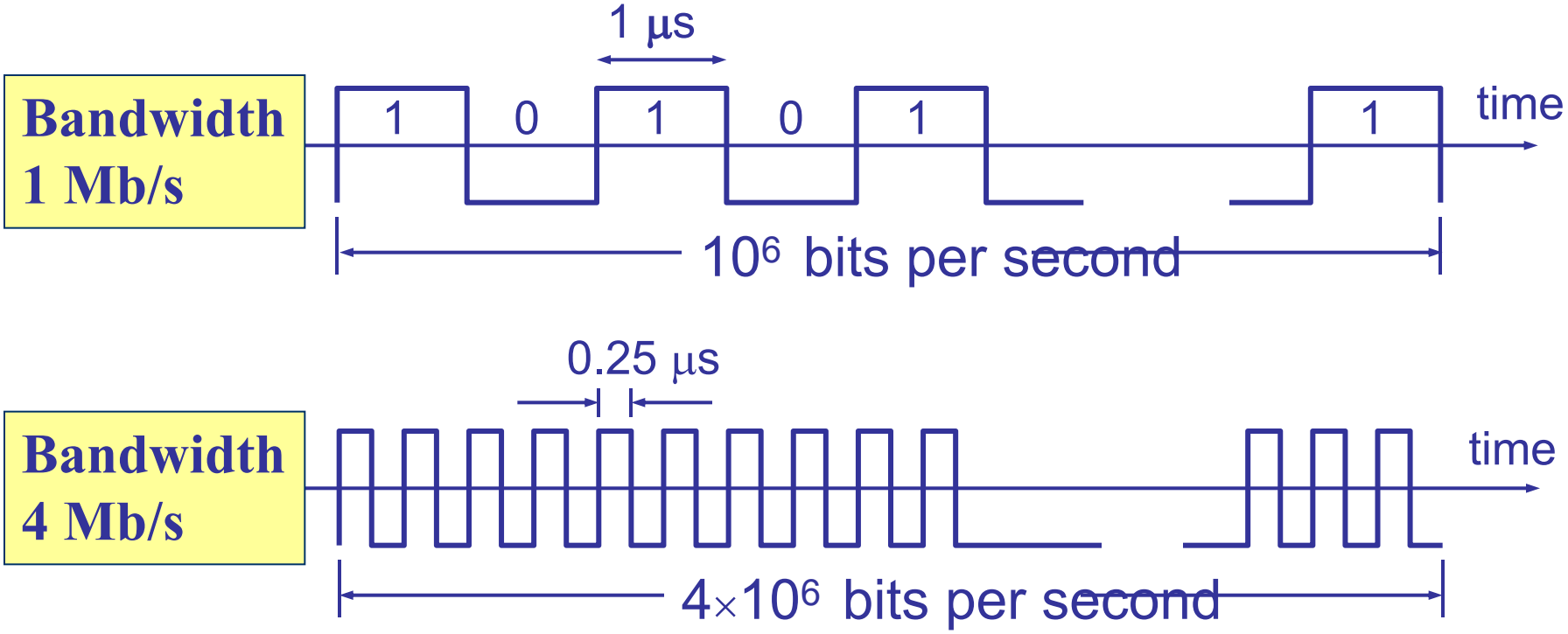
- **Bit rate** - refers to the rate of Host in a digital channel that is connected to a data on a computer network. The speed of the unit is b/s or bps, Kb/s, Mb/s, Gb/s. 0/1 1bit=1. Note: bit 1Byte=8, the rate unit are KB/s, MB/s, GB/s.
- **Bandwidth** - represents the ability of transmitting data in a network communication line capable of the network bandwidth is expressed in the unit time from a point to another point through the highest data rate". Remember as b/s, note that is not the signal bandwidth (band width), Hz. Signal bandwidth is the frequency range of the signal which contains different frequency components, such as 3.2kHz (range from 300Hz to 3.4kHz), which is the analog signal (continuous changed signal).
- **Throughput** - the amount of data that is expressed in a network (channel, interface) through a network within a unit time, such as the 100Mb/s of the Ethernet, which is typically only 70Mb/s.
- **Delay** - Time that data transmitted from one end to the other of the network .

  Total delay=Transmission delay + Propagation delay + Processing delay + Queuing delay.

  Note: in the computer world, it is based on binary $K = 2^{10} = 1024$, $M = 2^{20}$, $G = 2^{30}$, $T = 2^{40}$, $P = 2^{50}$, $E = 2^{60}$, $Z = 2^{70}$, $Y = 2^{80}$ (the Big Data >= PB)

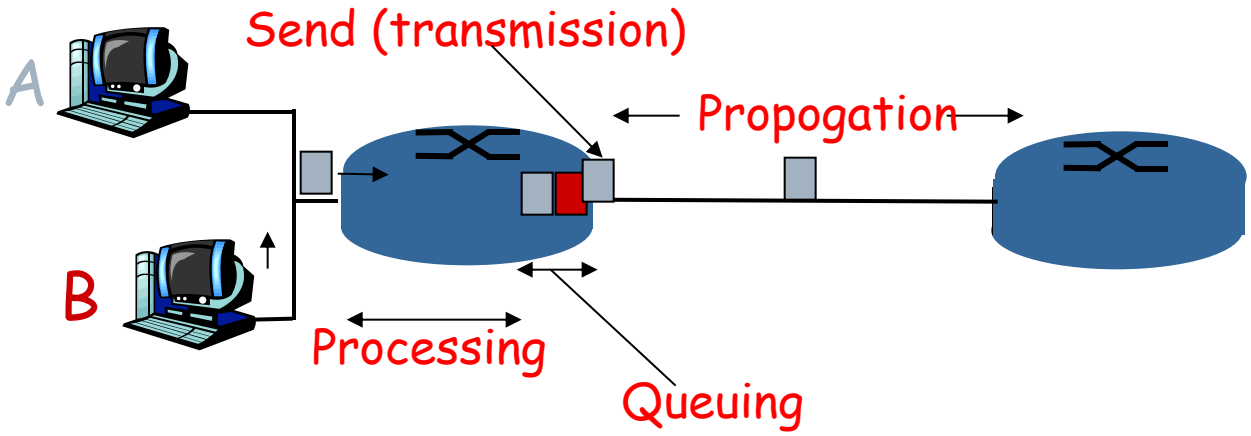
# Digital signal flow with time changed

- The width of the signal becomes narrower with the increase of bandwidth on the time axis.



# Four sources of Packet Switching Delay

- **1 Processing delay:**
  - Check bit error
  - Decide output link
- **2 Queuing delay**
  - Waiting for output link to transmit
  - Depending on the level of congestion in router



# Four sources of Packet Switching Delay

## 3 Sending delay:

R= sending rate (bps)

Data L= frame length (bit)

Time to send bits into the link = L/R

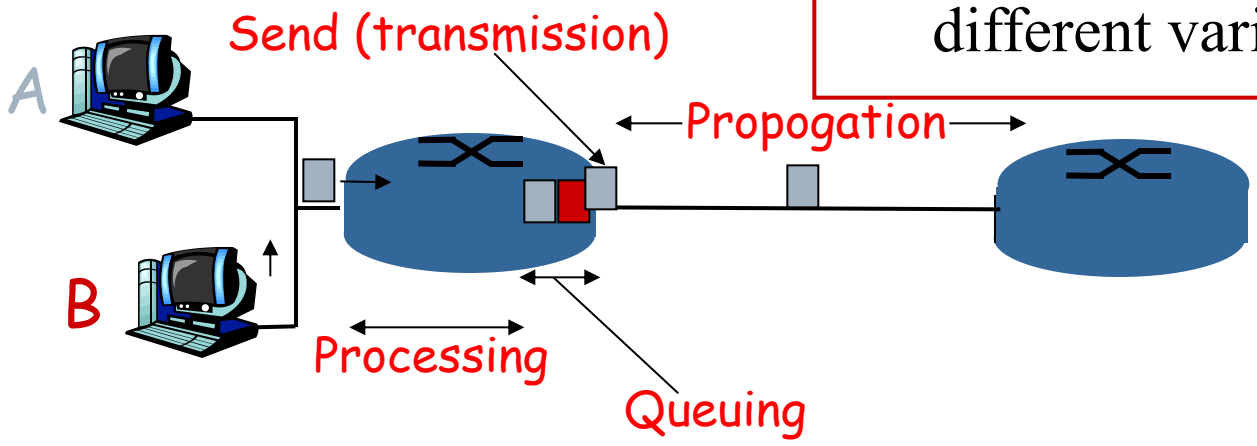
## 4 Propogation delay:

d = channel length

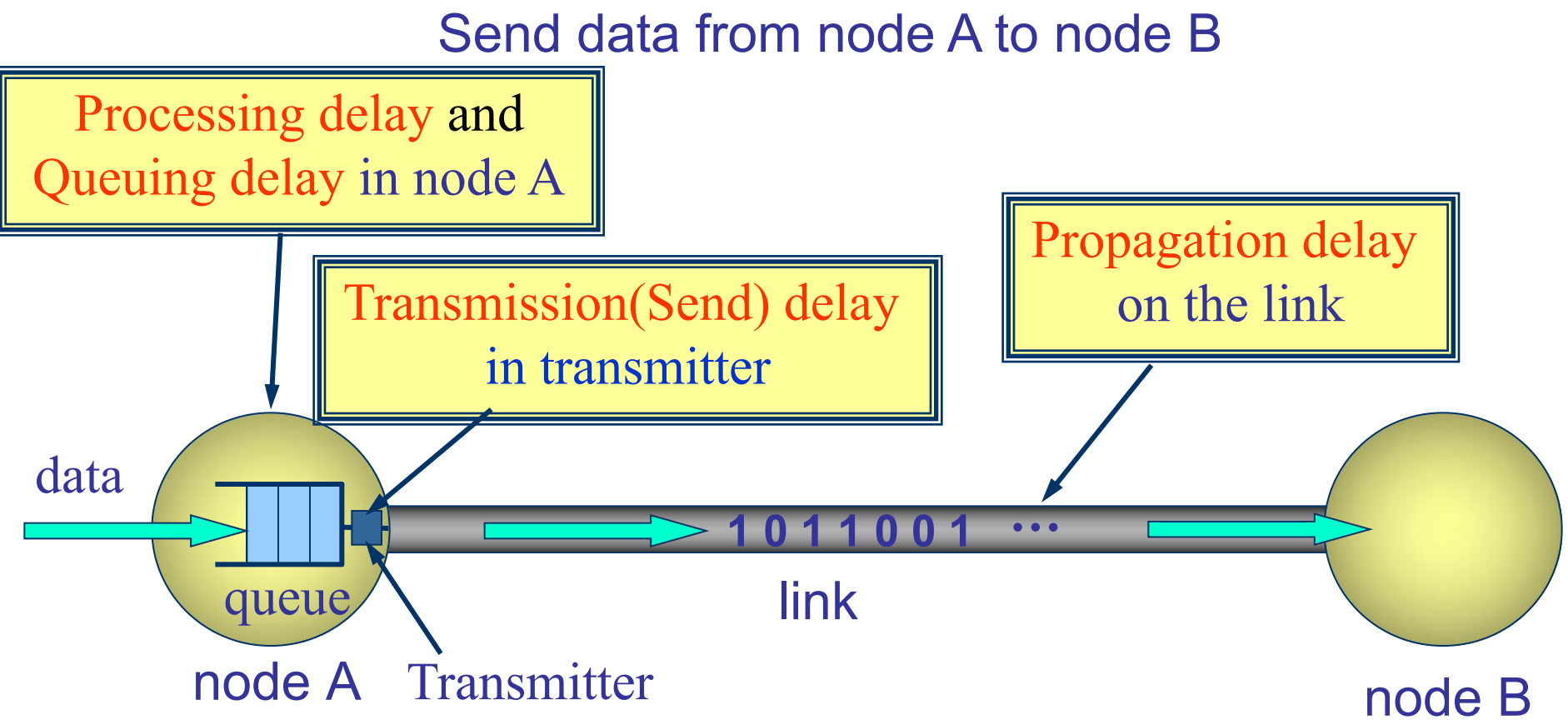
s = ~$2x10^8$ (m/s) in the channel.

Propagation delay = d/s

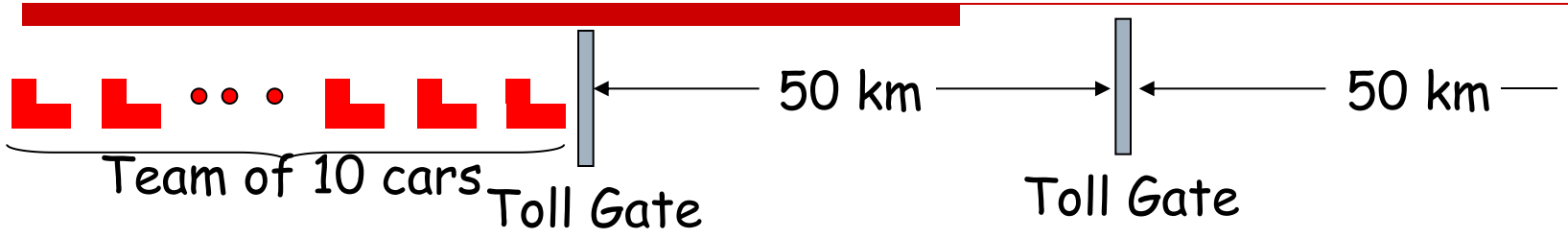
Note: s and R are very different variables!



# Four sources of Packet Switching Delay



# Car Team Analogy Example




- Car speed at 100 km/hr
- Toll station each 6 sec serves a car (processing + queuing + send delay)
- Car - bits; Team - packet
- Question: How long car team will gather in the second row of the Toll Gate?
- Through the toll gate to the highway "launch" the entire fleet of the departure time = 6*10 = 60 sec=1min (processing + queuing + send delay)
- In the last time, the time of the last car from the first to the second toll gate: 50km/ (100km/hr) = 30min (transmission delay)
- Answer: 31 minutes

# Total delay in a node

$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

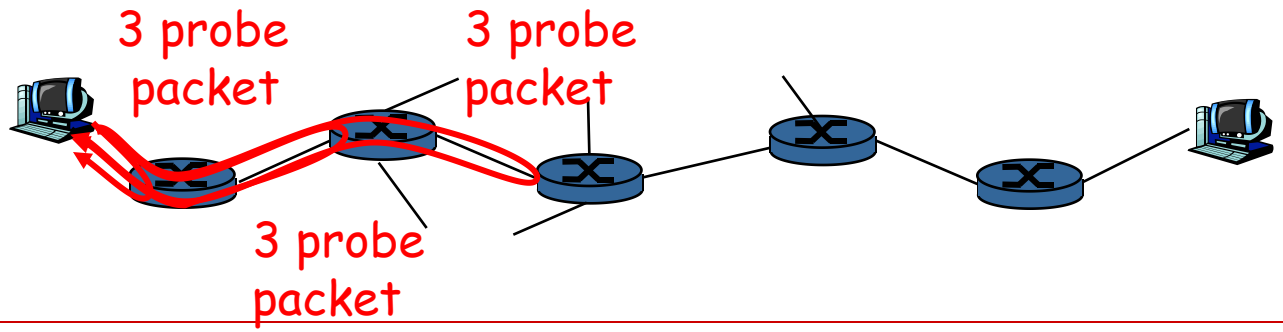
- **Dproc = Processing delay**
  - Usually a few milliseconds or less
- **Dqueue = Queuing delay**
  - Depends on the degree of congestion
- **Dtrans = Transmission delay (Send delay)**
  - = L/R, very big for the low speed link
- **Dprop = Propagation delay**
  - = d/s, a few milliseconds to hundreds of milliseconds

# Some wrong concept illustration

- For high-speed network link, we can only improve the Transmission rate (Send rate) of data, while not the Propagation rate of bit on the link.
- Increasing the link Bandwidth (Sending rate) reduces the Transmission (Send) delay of data, while does not affect its Propagation delay.

# Real Time delay and Routing

- What is "real" Internet delay and packet loss?
- Traceroute program: to provide a time delay measurement from the source to the destination, the destination along the end-to-end Internet path. For each node i:
  - Send 3 packets, the packet is in the destination on the path to reach the router I
  - Router i will return packet to the sender
  - The measurement of the time interval between the transmission and response.



# traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link

* means no reponse (probe lost, router not replying)

# 8. Performance indicators of computer networks

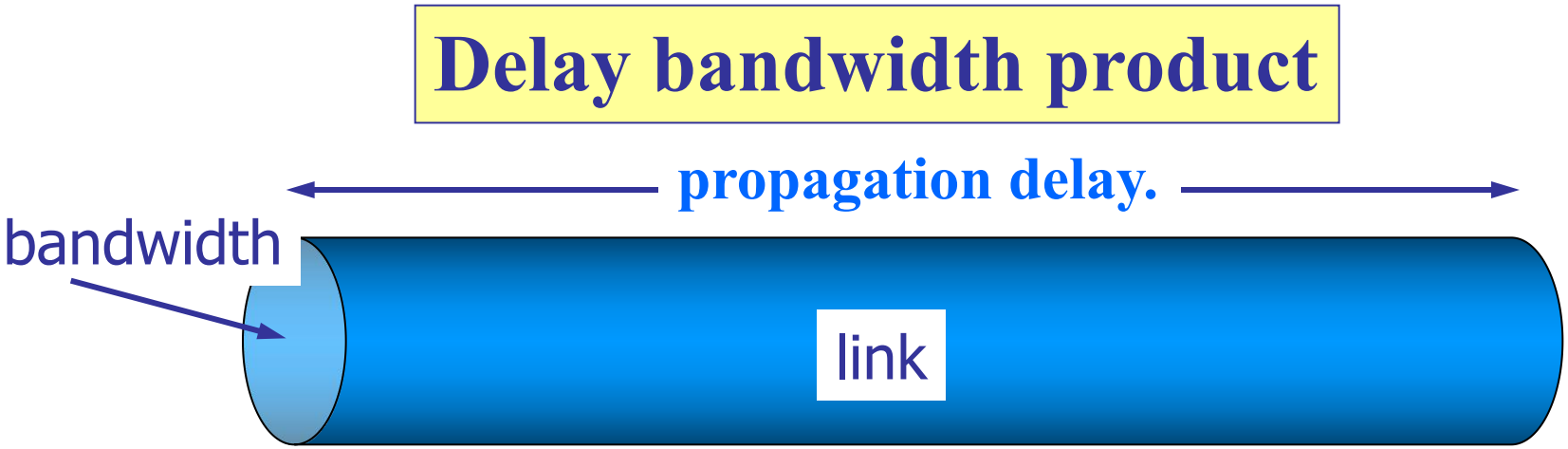
- **Time delay bandwidth product** - time delay bandwidth product = Propagation delay × Bandwidth;

  Example: propagation delay 20ms, bandwidth 10Mb/s, the time delay bandwidth product =$2*10^5$bit, that is, the link length of 200000 bits.

- **RTT (Round trip time)** - start from a sender to transmit data, to the sender received confirmation from the recipient, a total experience of time. RTT in the preceding example 40ms, round-trip link length is 40 million bits, including each node processing delay, queuing delay and forwarding data when the transmission delay.

- **Utilization rate**: the high rate of the channel or network utilization will produce very large delays (similar to the super highway)

# Delay bandwidth product




**Delay bandwidth product = Propagation delay × Bandwidth;**

The delay bandwidth product of the link is also known as the link length of the bit as a unit.

# Utilization rate

- **Channel utilization rate - is the time percentage of a certain channel is to be occupied. The channel utilization rate is zero when the channel is fully spare.**
- **Network utilization rate - is the weighted average value of total network channel utilization rates.**
- **According to the queuing theory, it is not means the better with the channel utilization rate is higher, similar to high speed highway.**

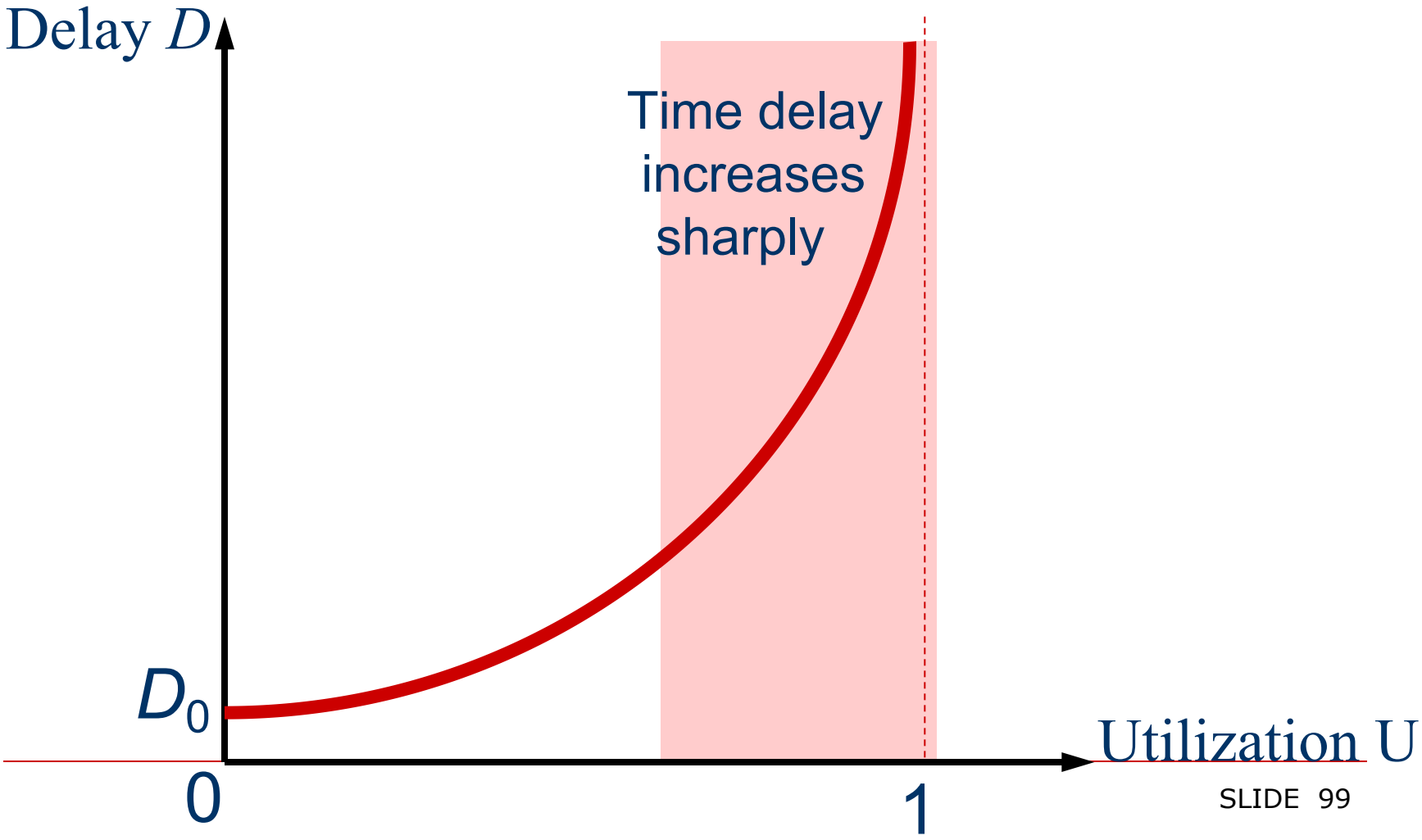
# Relationship between Time delay and Network utilization rate

- According to the theory of queuing theory, when the utilization rate of a certain channel increases, the time delay of the channel increases rapidly.
- If $D_0$ represents the network time delay when network is spare, D represents the current network delay, the relationship between D and $D_0$ can be expressed in the following simple formula:

$$D = \frac{D_0}{1 - U}$$

**U is the network utilization rate, the value is from 0 to 1. If U is too high,it will produce too much time delay, U generally not more than 50%**

# Relationship between Time delay and Network utilization rate



# Non-performance characteristics of computer networks

- Cost (fixed cost + maintenance)
- Quality (network service quality QoS)
- Standardization
- Reliability
- Extensibility and Scalability
- Easy to manage and maintain

# ★9. Architecture of computer networks

- The computer network system structure is the abstraction of the composition, relationship and basic working principles of the computer network systems.
- Network structure is very complex, while network architectures must be resolved:
  - Exchange information between multiple computers: information format (semantic), exchange style (grammar)?
  - What kind of network equipment internal structure (composition and relationship) can achieve the purpose of information exchange between computers?
  - How to realize the resources sharing (resource definition, publishing, search, access and utilization) between network applications

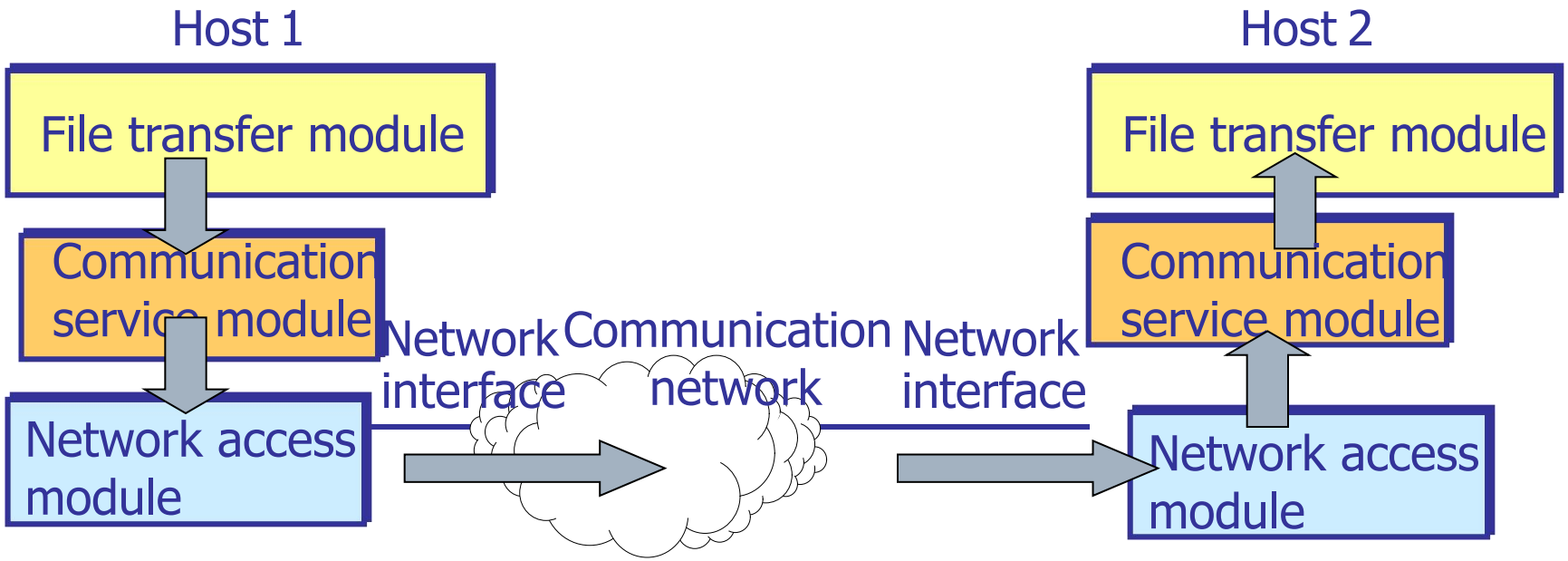
# Classification method & Hierarchical structure concept of the Computer network structure

- To simplify the description of complex systems, the system is decomposed into a number of sub-systems, and then it is necessary to divide the system into several sub-systems, so as to simplify the study of a complex system into several interrelated but more tractable sub-systems.
- Computer network uses the hierarchical structure concept, that is, any computer network equipment is composed of a number of layers and the layer may be a number of sub layer (that is, sub system) system, each layer to complete the function of the network, the lower level to provide a certain service".
- Special note: computer network system structure is a macro structure, can be said to be an abstract structure, so the actual work of the network structure can only from the macro point of view, from the abstract sense of the whole network communication process into a corresponding level to compare with the standard system structure, it is difficult to compare network in a specific network equipment and system structure one than in a network device, because it involves a number of hierarchical structure of the system.

# Hierarchy concept of the computer network

- Host 1 send files to Host 2 through the network.
- To do the following work.
- The first type of work is directly related to the transport document.
  - Make sure that the other party is ready to receive and store documents.
  - File format for both sides to coordinate well.
- Two Host file transfer module as the top layer. The rest of the work is in charge of the following modules.

# Finally design a network access module




The network access module is responsible for the work related to the details of the network interface.
For example, the frame format, frame length, etc..

# Benefits of the hierarchical (or layered) structure & Number of the layers

- **Benefits**
  - Each layer is independent.
  - Good flexibility.
  - Structure can be splited.
  - Easy to implement and maintain.
  - Can promote standardization work.
- **Number of the layers**
  - If the number of layers is not enough, each layer will be too complicated.
  - If there is too much layers, it will meet more difficulties in the engineering tasks to description and synthesis of the function of the system.

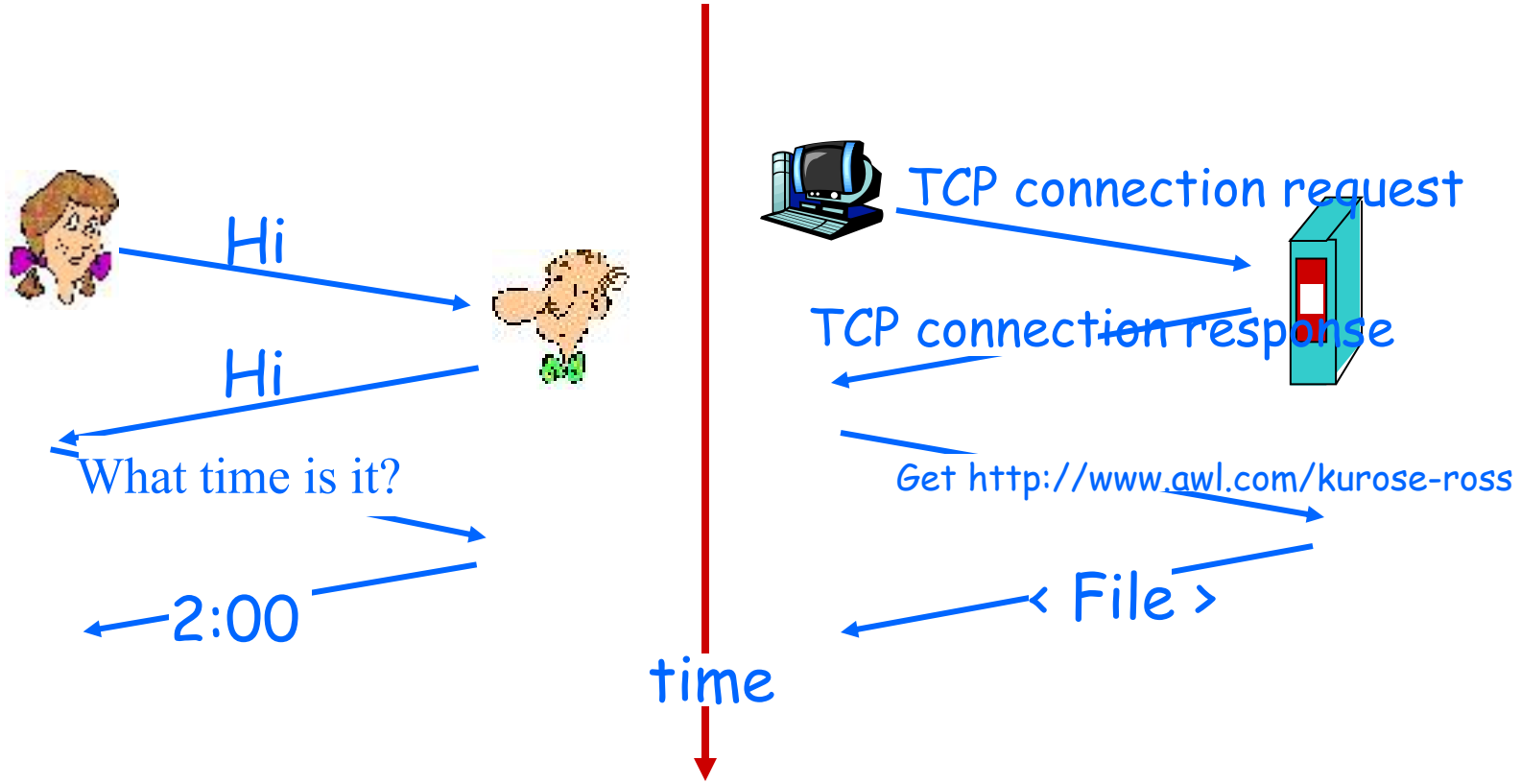
# ★9.Architecture of computer network - Protocol

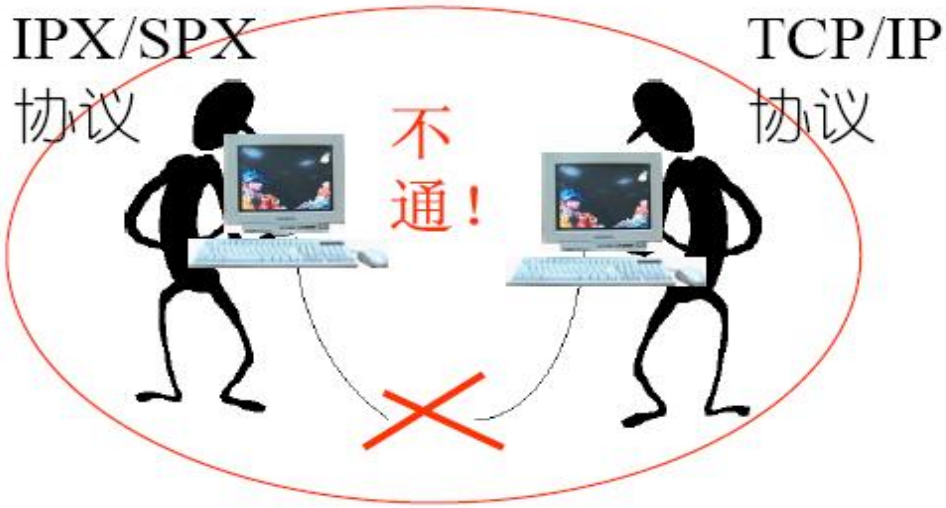
- In order to achieve communication, the two entities must have the same language, communicate what, how and when to communicate. A collection of these rules is called the protocol, and it can be defined as a collection of data exchange rules between the two entities.
- Data exchange in computer networks must comply with the agreement in advance. These rules explicitly specify the format of the exchange data and the related synchronization issues.
- Network protocol - is defined as the rule, standard and convention in order to implement the network data exchange.

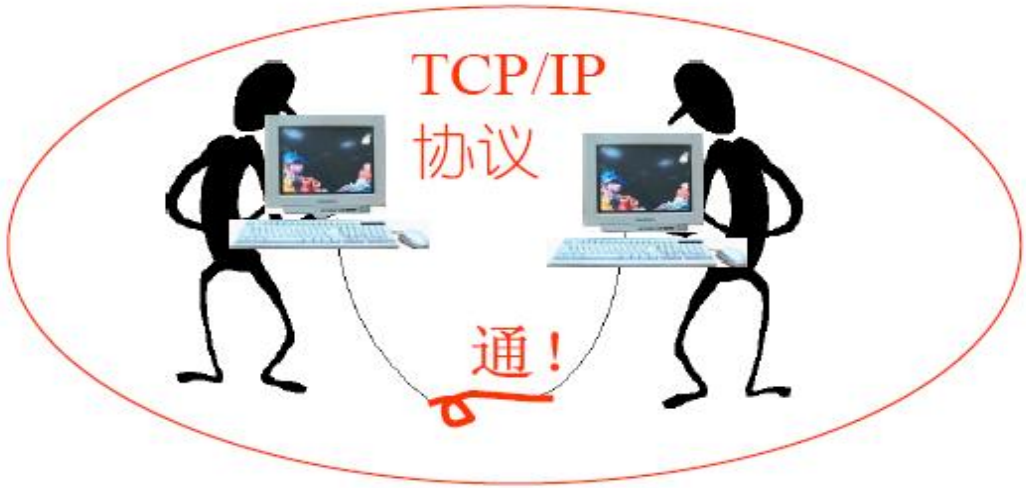
# ★9.Architecture of computer network -Protocol

- Three basic elements of a protocol
  - Syntax: How to speak?
    - including data format, encoding and signal level, etc.
  - Semantics : What to speak?
    - includes control information for coordinating synchronization and error handling.
  - Synchronous (Time): When to speak?
    - includes speed matching and event implementation sorting.

# Comparison between human language and computer network protocol




IPX/SPX
协议
不
通！
TCP/IP
协议


TCP/IP
协议
通！

# ★9.Architecture of computer networks-Implementation

- The architecture of computer network (Architecture) is the collection of all layers and protocols of computer network. Computer network architecture is the precise definition of the function of the computer network and its components.
- Implementation is to solve the problems of what kind of hardware or software is used to accomplish these functions.
- Architecture is abstract, and the implementation is concrete, it is the real running operations of computer hardware and software. (seen Richard Stevens: Unix Network Programming or TCP/IP Illustrated Vol. 2/3)

# ★9.Architecture of computer network-Hierarchical (layered) structure of network protocol

- In actual data communication, data is not directly transmitted to another machine from the N layer of a machine, but the data and control information to the next layer, until the bottom layer. The lowest layer is the physical medium, which carries on the actual communication.
- Each layer performs a certain function , each layer provides a certain service to its upper layer, and the details of how to implement the service to the upper layer, that is, the low layer protocol is transparent to the upper level. Between two adjacent layers for the inter layer interface. The rules that must be followed by a peer to peer user calls which are called peer-to-peer layer protocol.

# ★9.Architecture of computer network- Two International Standard (Reference Model)

- A reference model that describes the layers of hardware and software necessary to transmit data between two points or for multiple devices / applications to interoperate
- Reference models are necessary to increase likelihood that different components from different manufacturers will converse
- Some of the world's major standards organizations have done fruitful work in this area, and a series of international standard OSI/RM reference models for data communication and computer networks have been developed.
- The organization of standard international OSI of law is not recognized by the market.
- Non-international standard TCP/IP is now the most widely used.
  - TCP/IP is often referred as the international standard in fact.

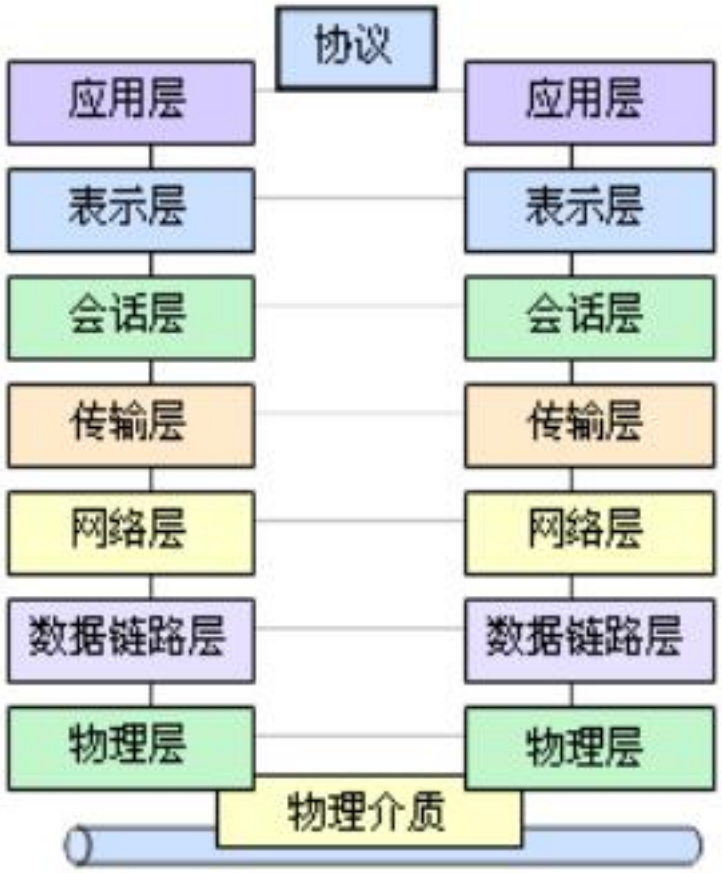
# ★9.Architecture of computer networks— OSI/RM

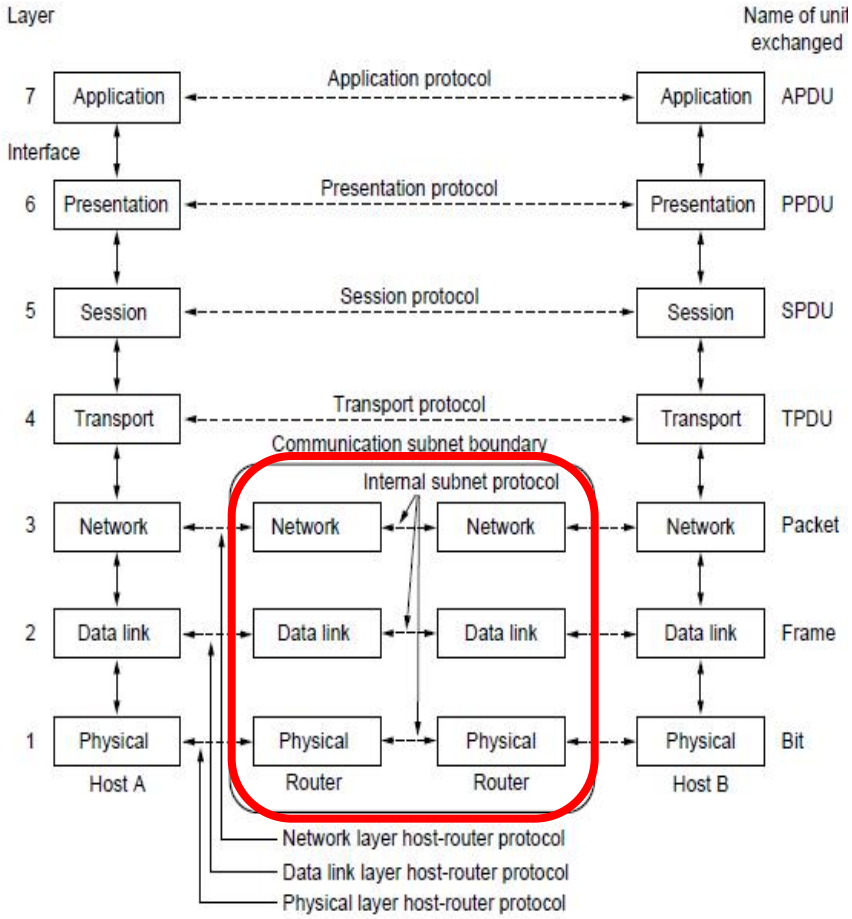
- International Standard Organization (ISO) established in 1977 set up a sub-committee to study the architecture of network communication, and put forward the Open System Interconnection Reference Model <OSI/RM>
- The so-called "Open" means any two system as long as the reference model and have the relevant standards, are able to interconnect. OSI uses a hierarchical structure of the construction technology.
- The task of the ISO sub committee is to define a set of functions and services to be performed by each layer.

# ★9.Architecture of computer networks— OSI/RM

- The OSI reference model consists of Seven layers, from the lowest to highest layer respectively.
  - Physical layer
  - Data link layer
  - Network layer
  - Transport layer
  - Session layer
  - Presentation layer
  - Application layer

# ★9.Architecture of computer networks— OSI/RM



# ★9.Architecture of computer networks— OSI/RM

## OSI/RM - Reference model and the correspondence relationship between network composition

- The data communication in the computer network (data communication for short) contains network communication and data communication. Network communication is run in communication subset (the three layers under OSI/RM, and don't need the layers above); which used to build network path for data communication between both communication sides. Data communication is run in resource subnet (four layers above the OSI/RM), and is run only after the network communication process is completed. That is the network communication of the nethermost three layers should be operated first, then the above four layers can be used for user conversation, and transmit data to the user.
- The more specific classification: 1~3 layer is mainly responsible for communication function, and belong to the communication subnet layer. 5~7 layer belong to the resource subnet layer. The transport layer plays the role of link up the bottom three layers and upset three layers.

# ★9.Architecture of computer networks— OSI/RM

## ☐ OSI / RM - Reference model

① **Physical Layer - Provide electronic, functional, and normative features for create, maintain and dismantle of physical link that transmit data needed; Provide transmission unstructured bit stream on the transmission medium and physical link failure detection.**

② **Data Link Layer - Provide point-to-point error-free transmission function for the network layer entity, and control the flow.**

③**Network Layer - Provide end-to-end exchange of network data transmission function for the transport layer entity, which help the transport layer get rid of route selection, exchange way, congestion control and so forth network transmission details. Establish, maintain and dismantle one or more communication paths for the transport layer entities. Report the unrecoverable errors of the network transmission.**

④ **Transport Layer - Provide transparent and reliable data transmission service for the session layer entity, and ensure the end-to-end data integrity. Choose the network layer can provide the most suitable service. Provide the function of establish, maintain and dismantle of transmission connection.**

# ★9.Architecture of computer networks— OSI/RM

- **OSI / RM - Reference model**

⑤ **Session Layer - Provide the function of establish, maintain and end the session for the presentation layer entity of mutual cooperation. Complete the correspondence between the logical names and physical names in the communication process. Provide session management services.**

⑥**Presentation Layer: Provide a set of services to explain the meaning of information exchange for the application layer progress, such as the code conversion, format conversion, text compression, and text encryption and decryption, etc.**

⑦**Application Layer: Provide OSI customer service, such as transaction processing program, E-mail and network management procedure, etc.**

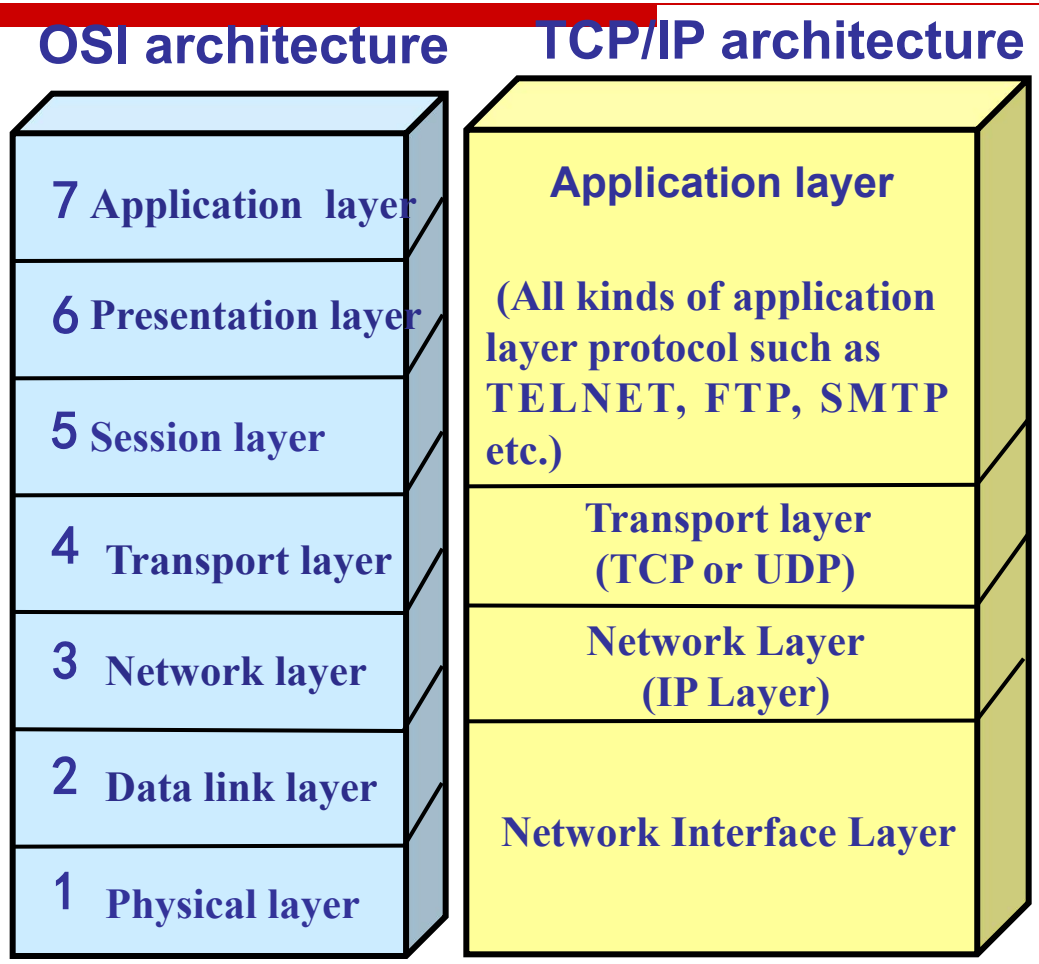
# ★9.Architecture of computer networks— OSI/RM

- The characteristics of the OSI Seven-layered protocol architecture:
  - The concept description is clearly and completely
  - The theory is also perfect
  - Too complex, and not practical enough
- So the more concise TCP/IP Protocol Suite (architecture) was introduced, and so far has been used widely.

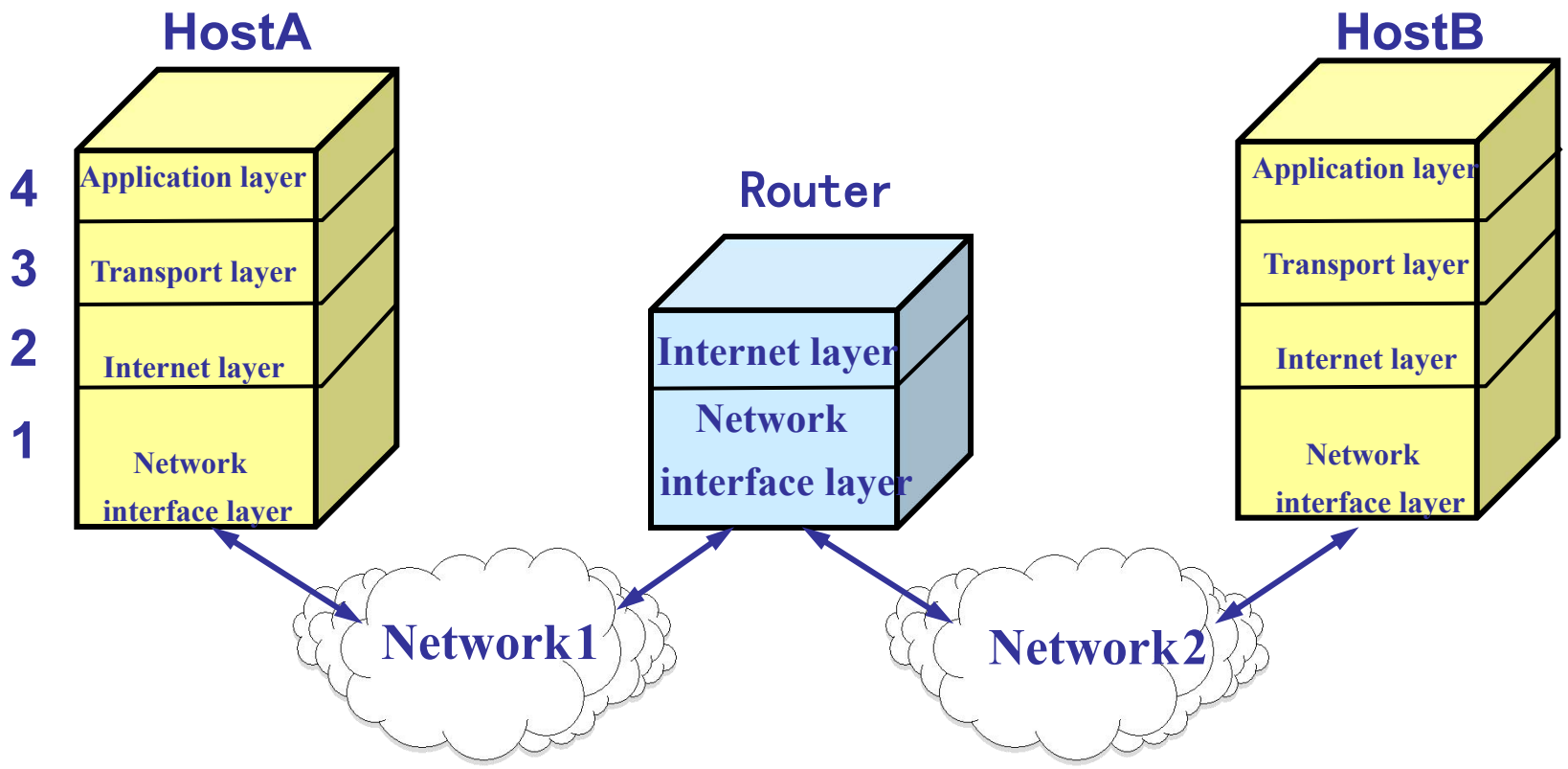
# ★9.Architecture of computer networks— TCP/IP

- **TCP/IP Protocol suite is a four-layered network architecture**
- **TCP/IP architecture comprises four layers:**
  - **Application layer**
    - **Which is correspond to the above three layers of OSI**
  - **Transport layer**
  - **Network layer**
  - **Network interface layer**
    - **Which is correspond to the two bottom layers of OSI**

# ★9.Architecture of computer networks— TCP/IP



# ★9.Architecture of computer networks— TCP/IP

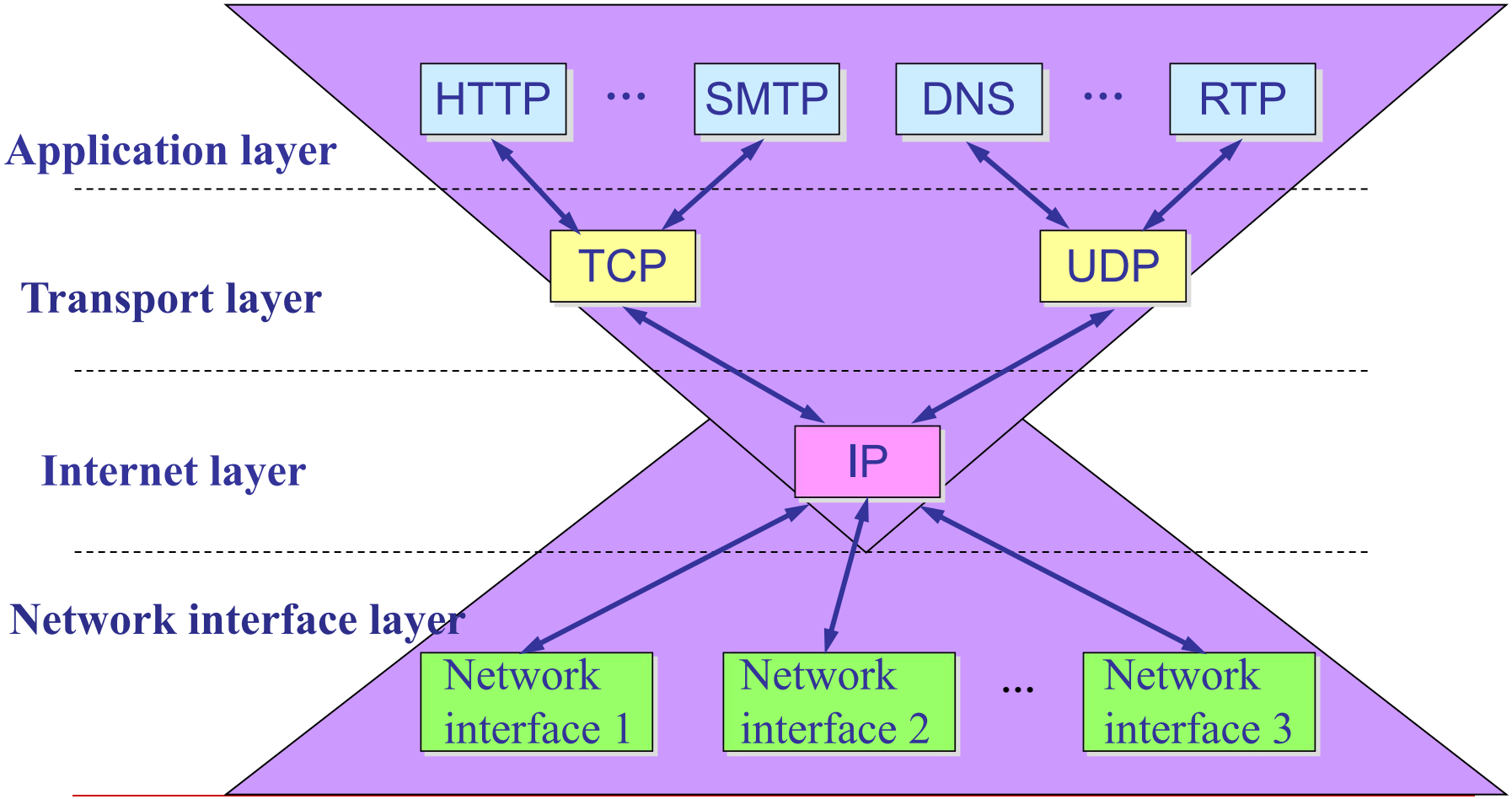


# ★9.Architecture of computer networks— TCP/IP

## TCP/IP The main function of each layer:

- **Application layer** - Provide direct services for the user application process
- **Transport layer** - Responsible for providing services to the communication process between the two Host.
  - **TCP protocol**: A connection-oriented, provide reliable transmission, the data transmission unit is packet (segment); **UDP protocol**: no connection, the data transmission unit is the user data packets, and can't guarantee the correctness of data transmission, only can provide " best effort transmission ".
- **Network layer**: Responsible for the group exchange, and encapsulate transport layer user's packet segment into group/packet, called IP data package, then transmission.
- **Network Interface Layer (Undefined)**: The link layer assembles the IP data into **frame** from the upper network layer, and add the head, that is the data control information. The size of frame is a few hundred KB to 1024KB generally; the data transmission unit of **physical layer** is **bit**, what need to consider is how to represent transmitted signal "1" or "0", and don't need to understand the meaning of bit.
- **In short, in the various of protocols used for in Internet, the most common is the TCP / IP protocol suite.**

# ★9.Architecture of computer networks— TCP/IP

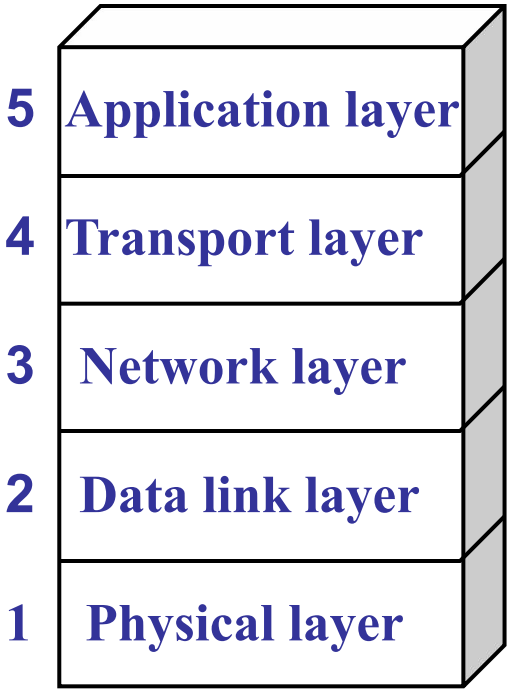


# ★9.Architecture of computer networks — Five-layered Protocol Architecture

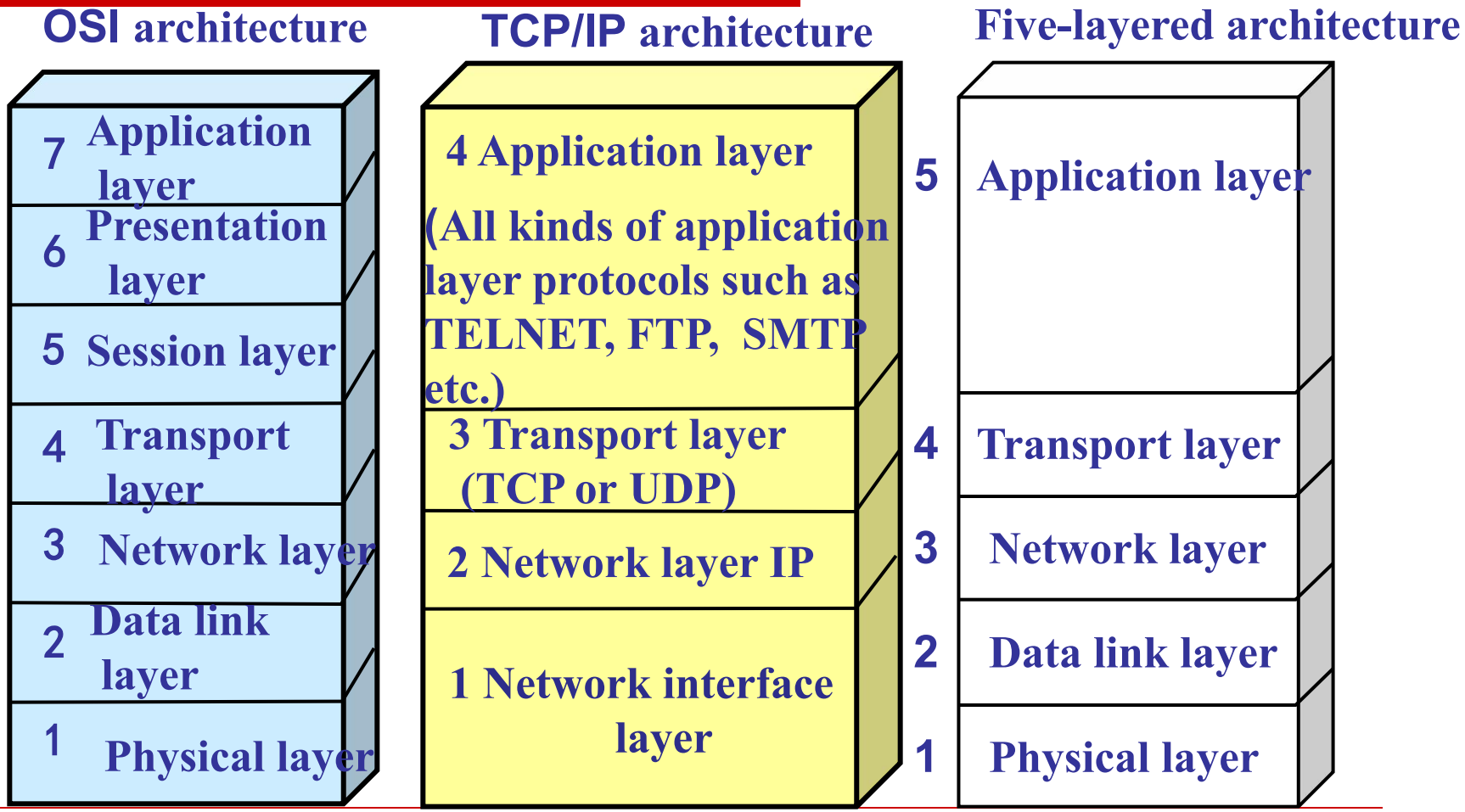
- TCP/IP protocol is defined as four-layered architecture, while the lowermost network interface layer has not specific definition.
- Therefore many researchers often compromised the process and integrated the merits of OSI and TCP/IP, then some kind of five-layered protocol architecture (which has become a consensus in this field). (which can be seen in page 15, 18 of Curt. M. White's English textbook, it divided the network interface layer into network access layer and physical layer)

# ★9.Architecture of computer networks — Five-layered Protocol Architecture

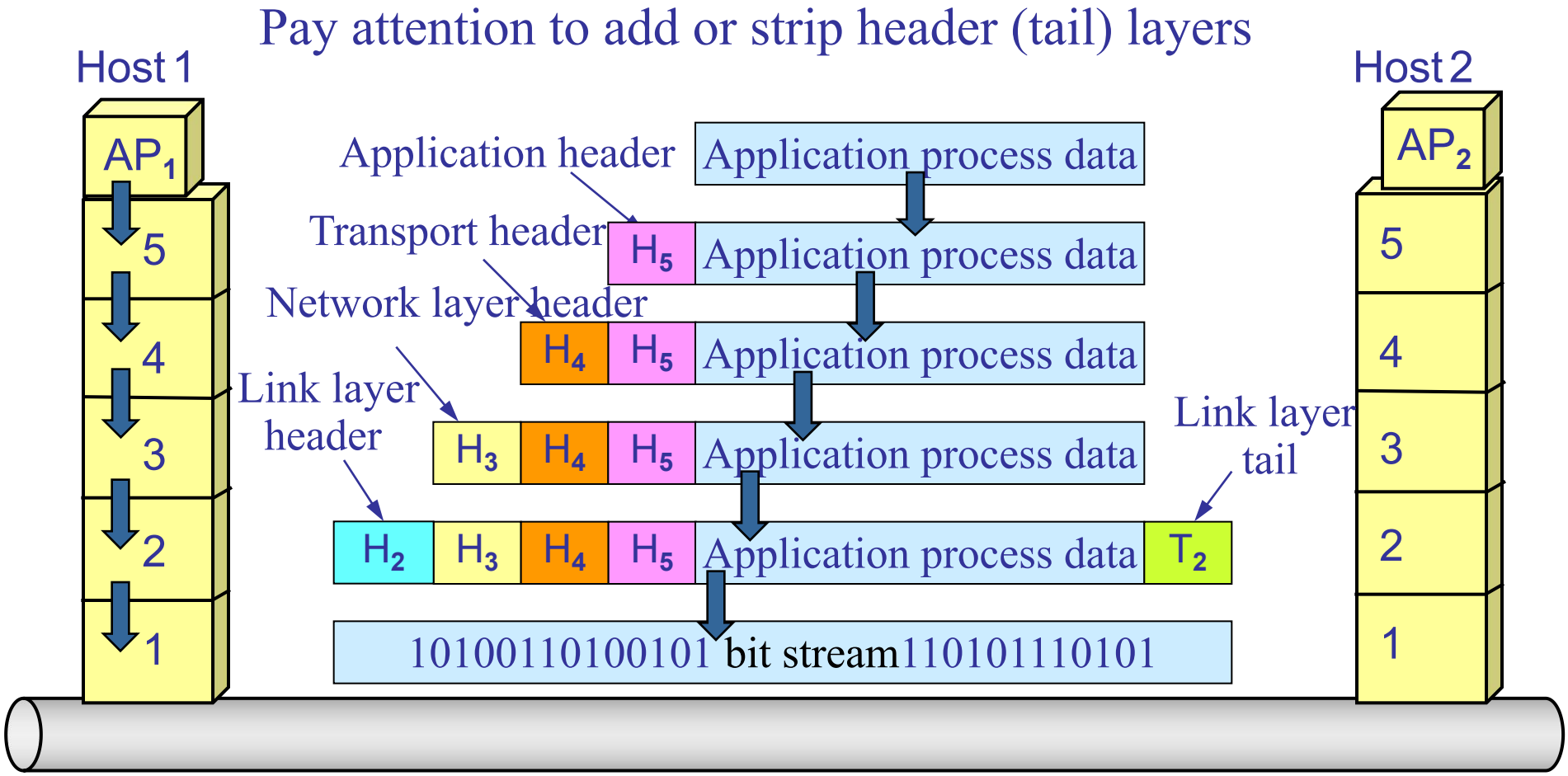
- **Application layer:** support network application
  - FTP, SMTP, HTTP
- **Transport layer**: data transmission between hosts
  - TCP, UDP
- **Network layer**: the data packet path selection from source to destination address
  - IP, Routing protocol
- **Data link layer** (**Network access layer**): transfer data between neighborhood network elements
  - PPP, Ethernet
- **Physical layer**: "Online" bit stream



# ★9.Architecture of computer networks — Five-layered Protocol Architecture

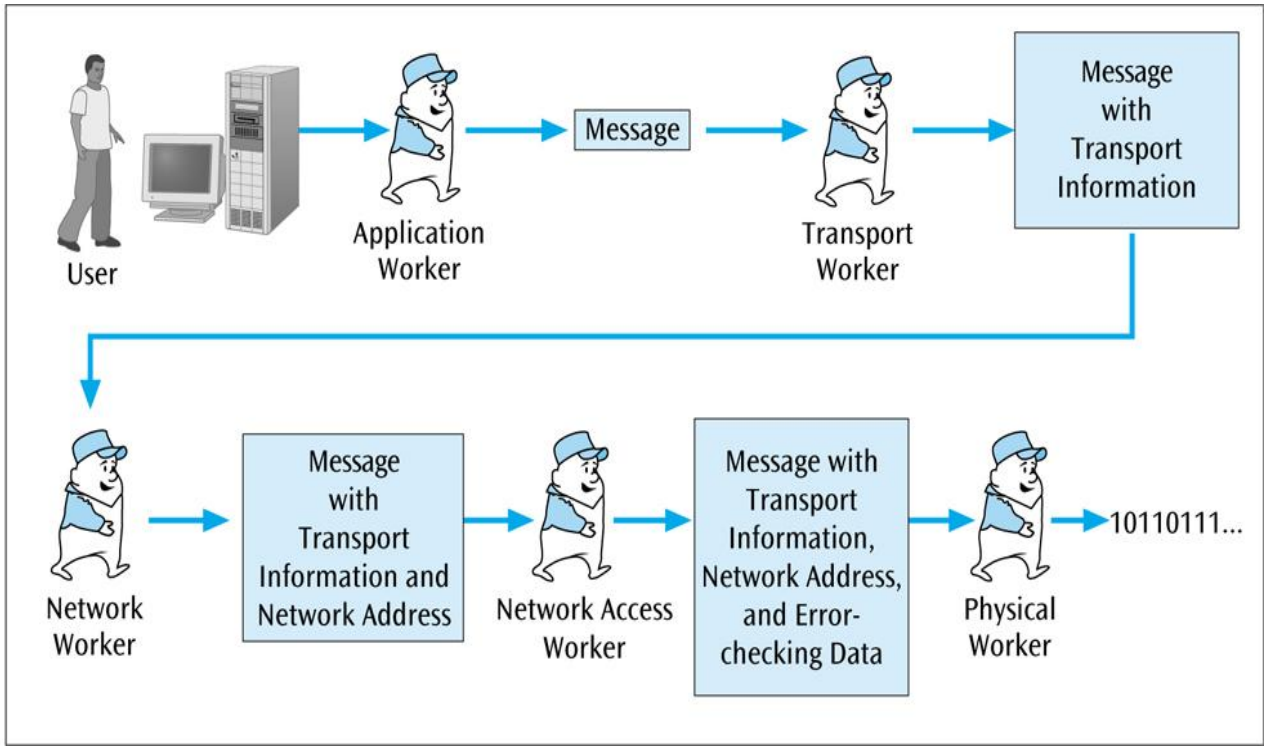


# ★9. Architecture of computer networks– Data transmission style of five-layered protocol architecture (from H1 to H2)



# The TCP/IP Protocol Suite (Five-layered)

Figure 1-11 "Network workers" perform their job duties at each layer in the model

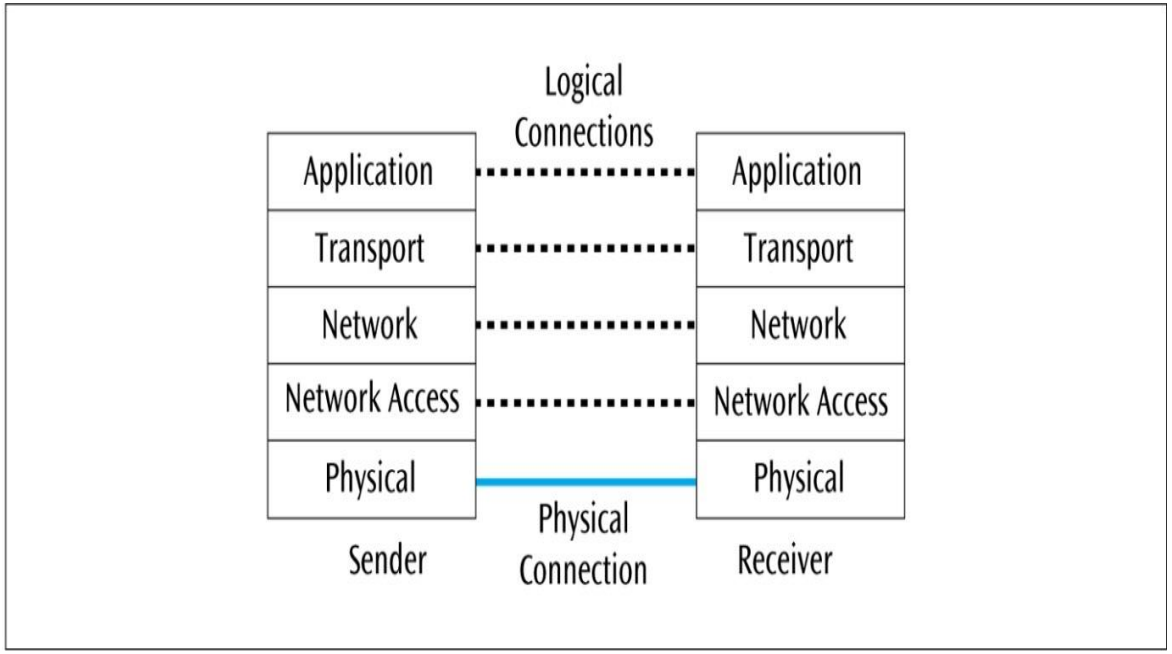


# Logical and Physical Connections

- A logical connection is one that exists only in the software, while a physical connection is one that exists in the hardware
- Note that in a network architecture, only the lowest layer contains the physical connection, while all higher layers contain logical connections

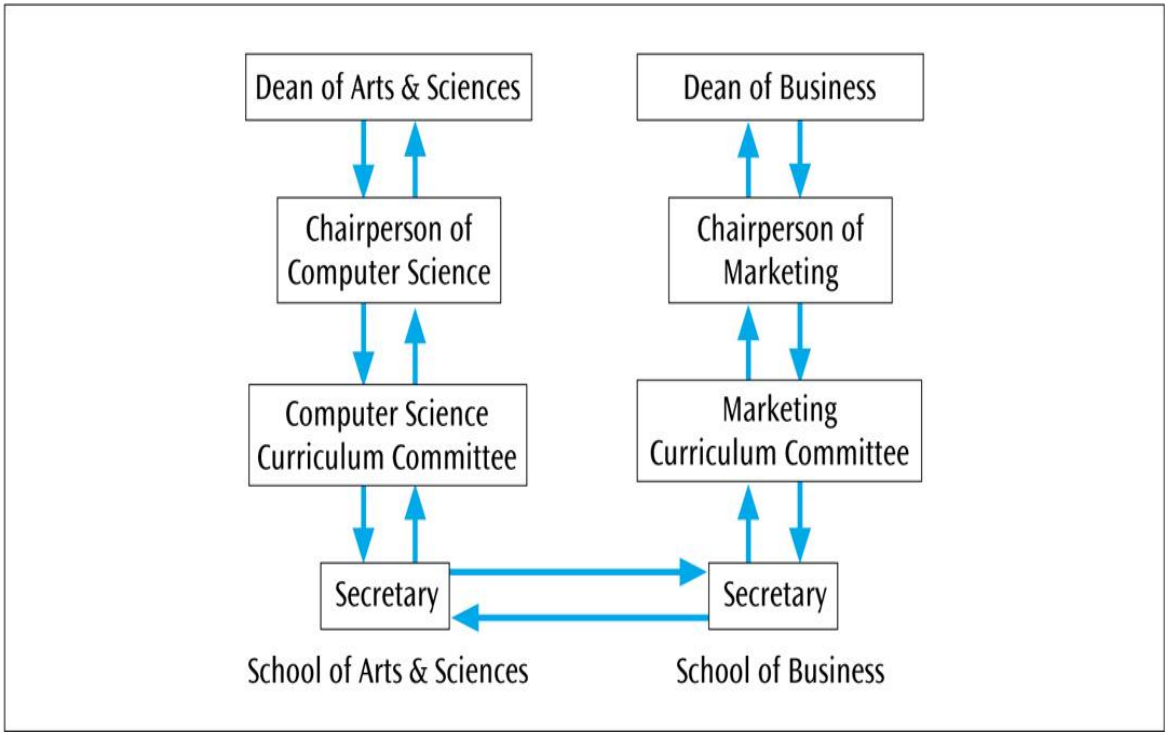
# Logical and Physical Connections

Figure 1-13 Sender and receiver communicating using the TCP/IP protocol suite



# Logical and Physical Connections

Figure 1-14 Flow of data through the layers of bureaucracy



# The TCP/IP Protocol Suite in Action

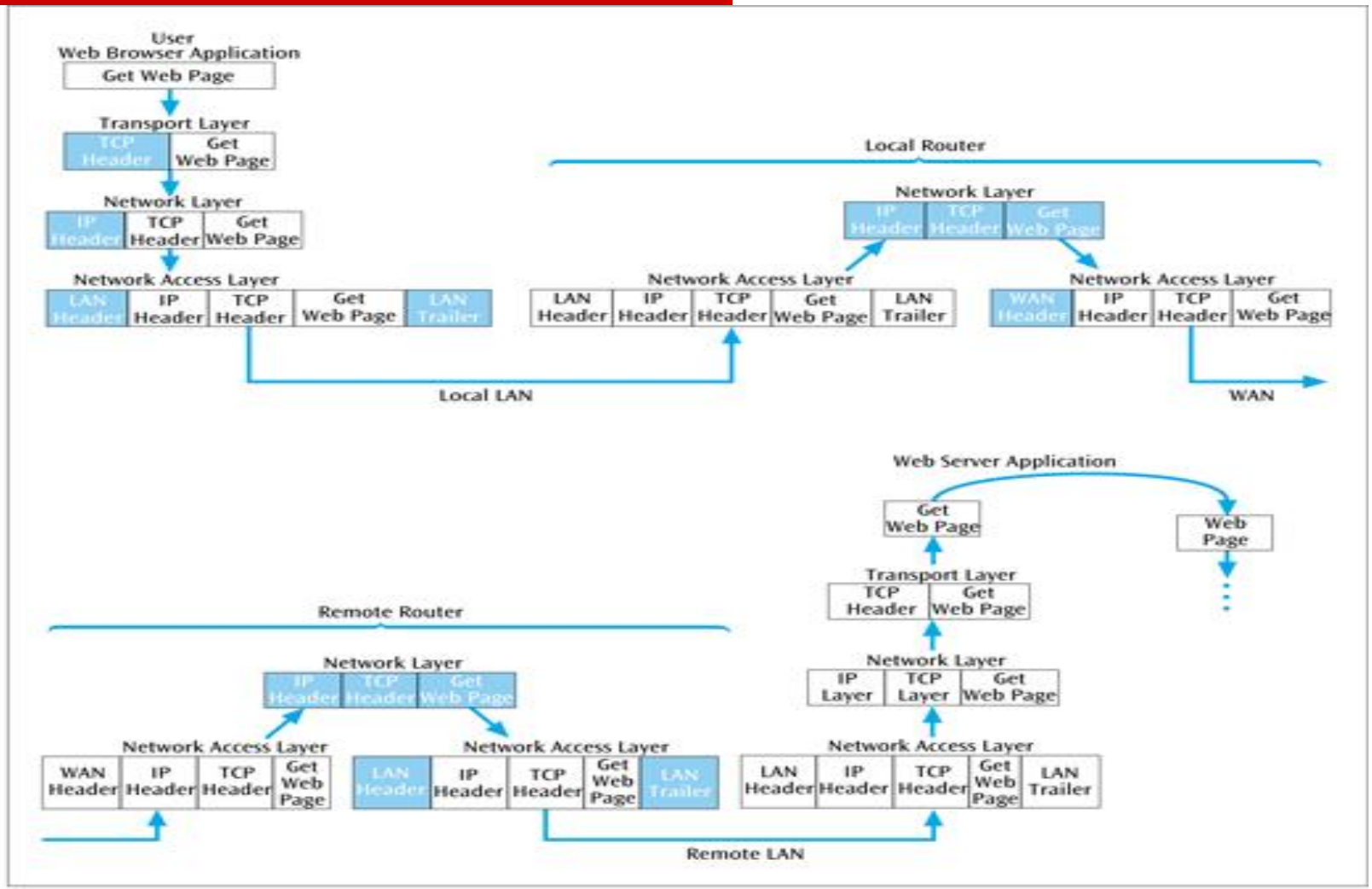



Figure 1-16 Path of a Web page request as it flows from browser to Internet Web server and back

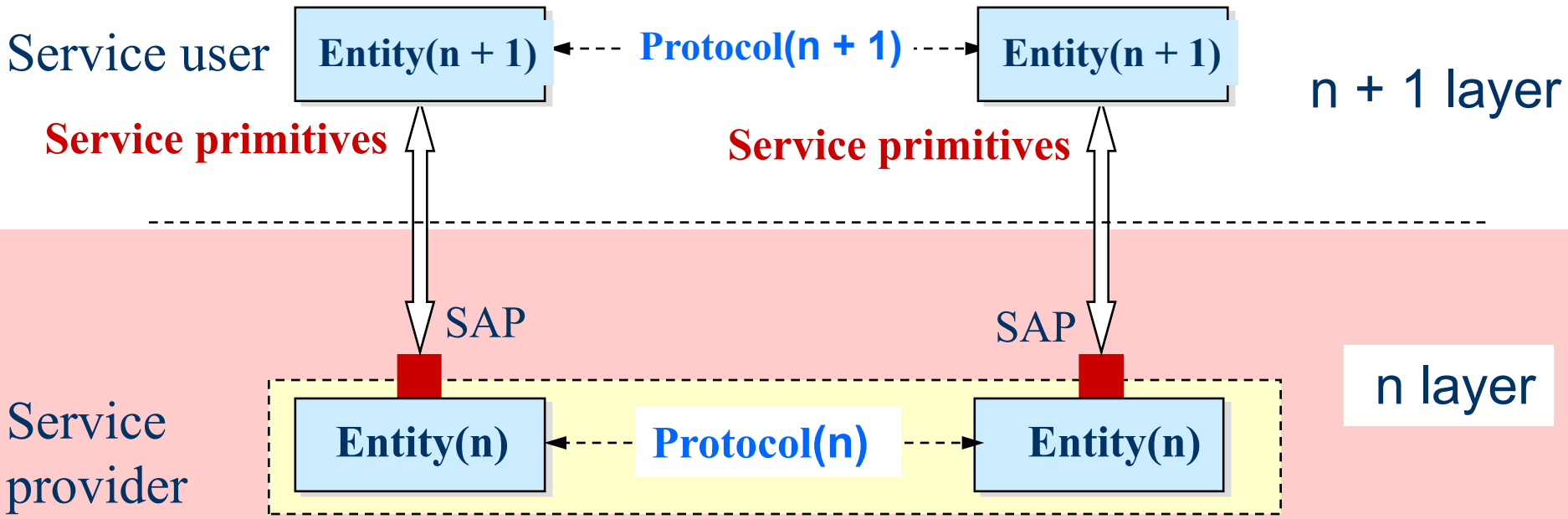
# Some basic concepts need to be emphasized in network architecture

- **Entity** represents any hardware or software process that can send or receive information。
- **Protocol** is the set of rules of communication that control two peer entities.
- Under the control of protocol, the communication between the two peer entities can provide services to the upper layer
- To implement same layer protocol, it also need the services provided by the bottom layer.

# Some basic concepts need to be emphasized in network architecture (continue)

- This layer service user only can see the service and can not see the following protocol.
- The following protocol is transparent for the above service users.
- Protocol is "Horizontal", that is Protocol control the communication rules between peer entities.
- Service is "Vertical", and through interlayer interface that provided by the service from the lower to upper.
- The entitles adjacent local interaction from the same system is the SAP (Service Access Point)

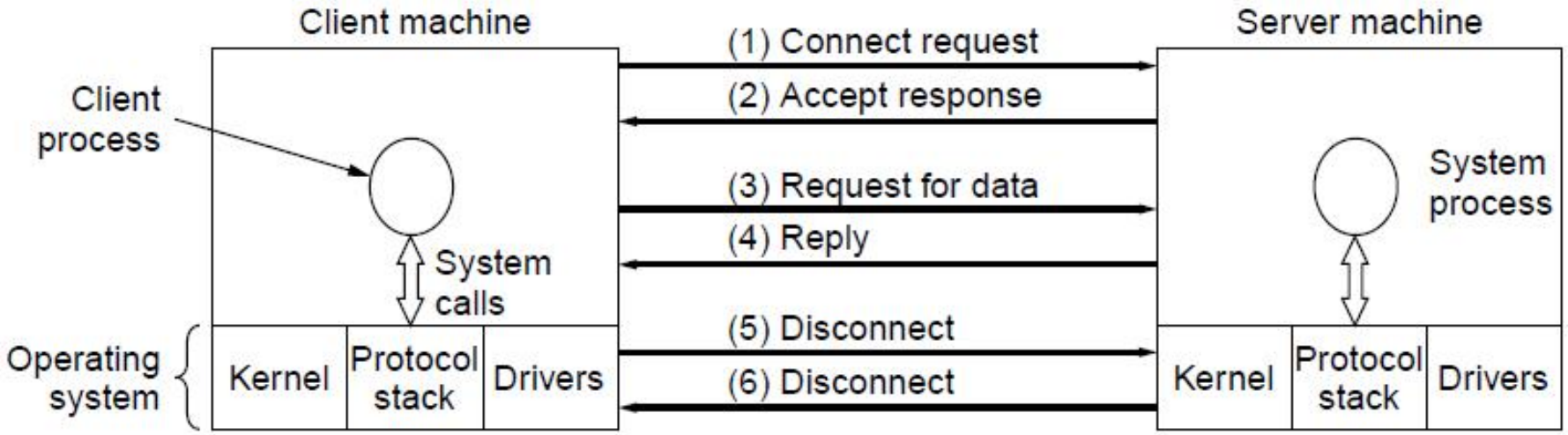
# Relations between Entity, Protocols, Services, and Service Access Points



# Service primitives (Exchange primitive)

| Primitive | Meaning |
|---|---|
| LISTEN | Block waiting for an incoming connection |
| CONNECT | Establish a connection with a waiting peer |
| ACCEPT | Accept an incoming connection from a peer |
| RECEIVE | Block waiting for an incoming message |
| SEND | Send a message to the peer |
| DISCONNECT | Terminate a connection |

# Service primitives (Exchange primitive)



# The famous example of network protocol 【Example1-1】

- Blue Army1 and Blue Army 2 combat with White Army. Blue Army 1 and Blue Army 2 occupy the east peak and west peak separately, and White Army occupies the valley. The balance of power is: single Blues Army 1 or Blue Army 2 can not beat the White Army, but the Blue Army 1 and Blue Army 2 fight tighter can beat White Army. Blue Army 1 intends to attack the White Army in next day noon. Then send messages to the Blue Army 2 with computer. But the communication line is so bad, there is a high probability of error or loss of message (no phone can be used). Therefore require the friendly force that receive the message must return a confirmation message. But this confirmation message also may be wrong or missing. Whether can design a protocol that enable Blue Army 1 and Blue Army 2 work together and achieve a certain (I.e. 100% instead of 99.999% ...) win?

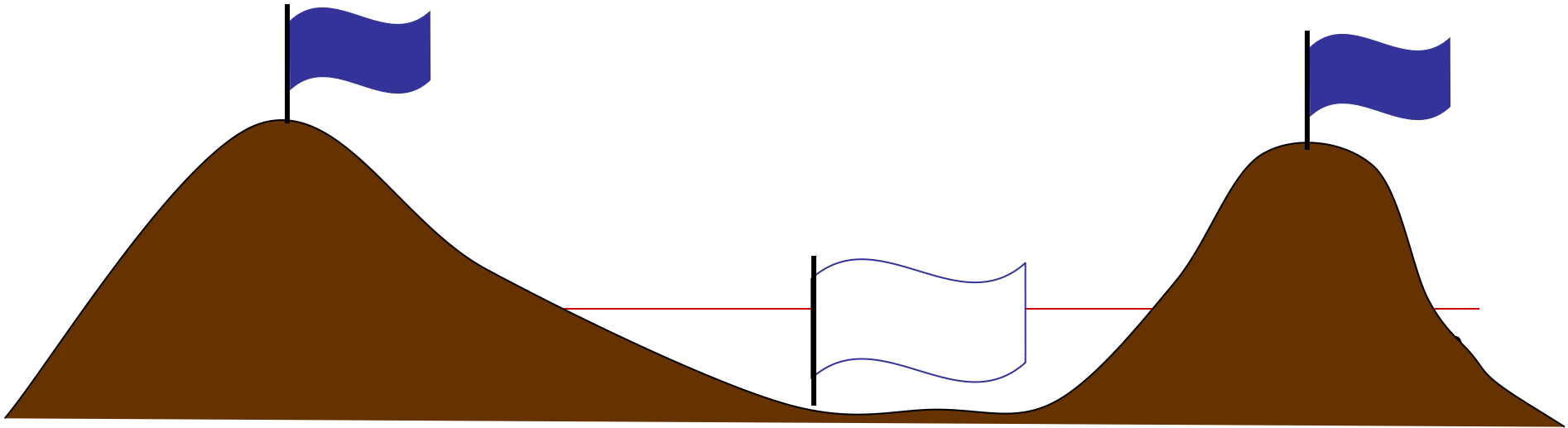
Tomorrow noon attack, how?

Agree

Such an agreement can not be achieved!

Receive "a

Receive : receive "agree"

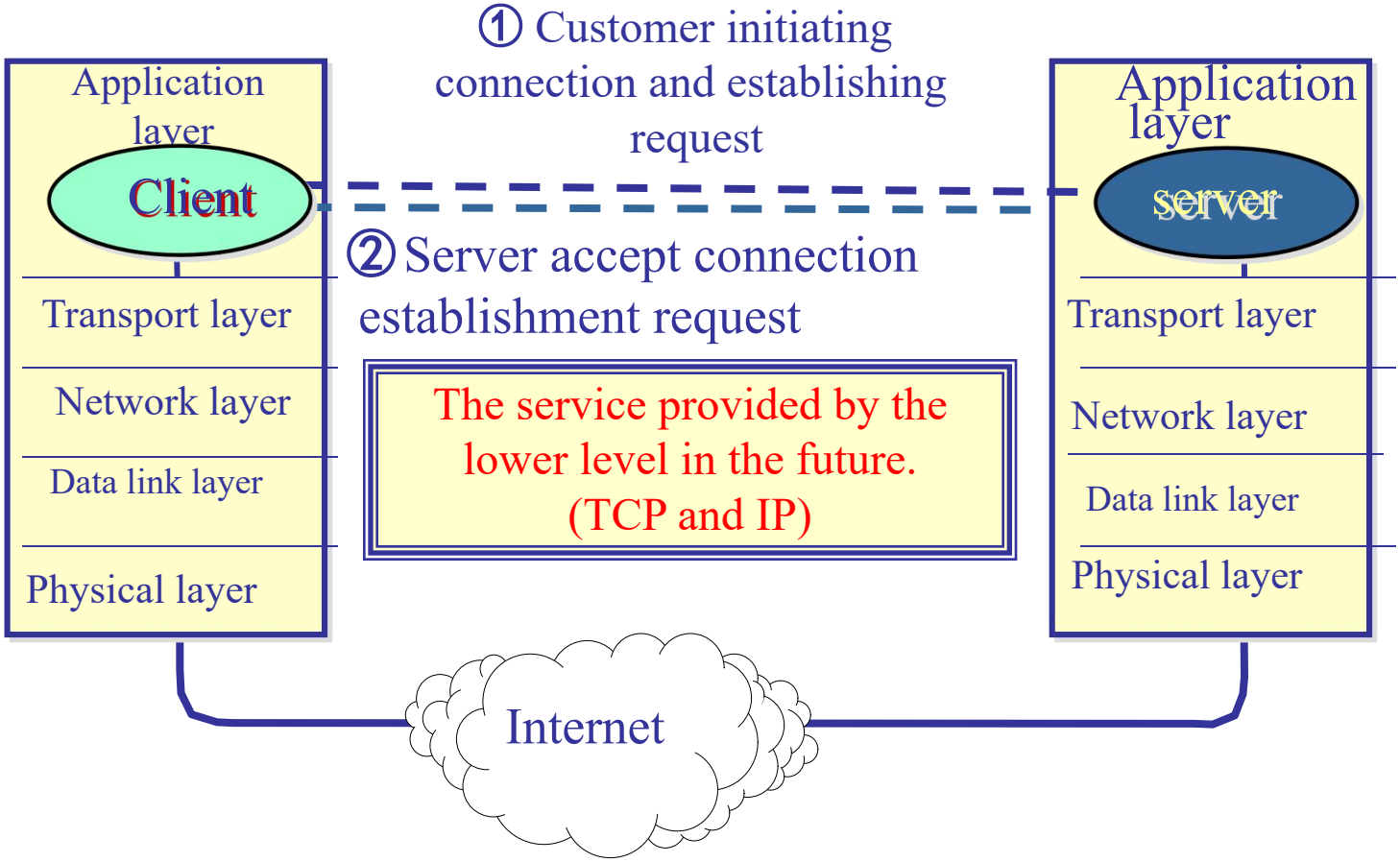


# The famous example of network protocol 【Example1-1】

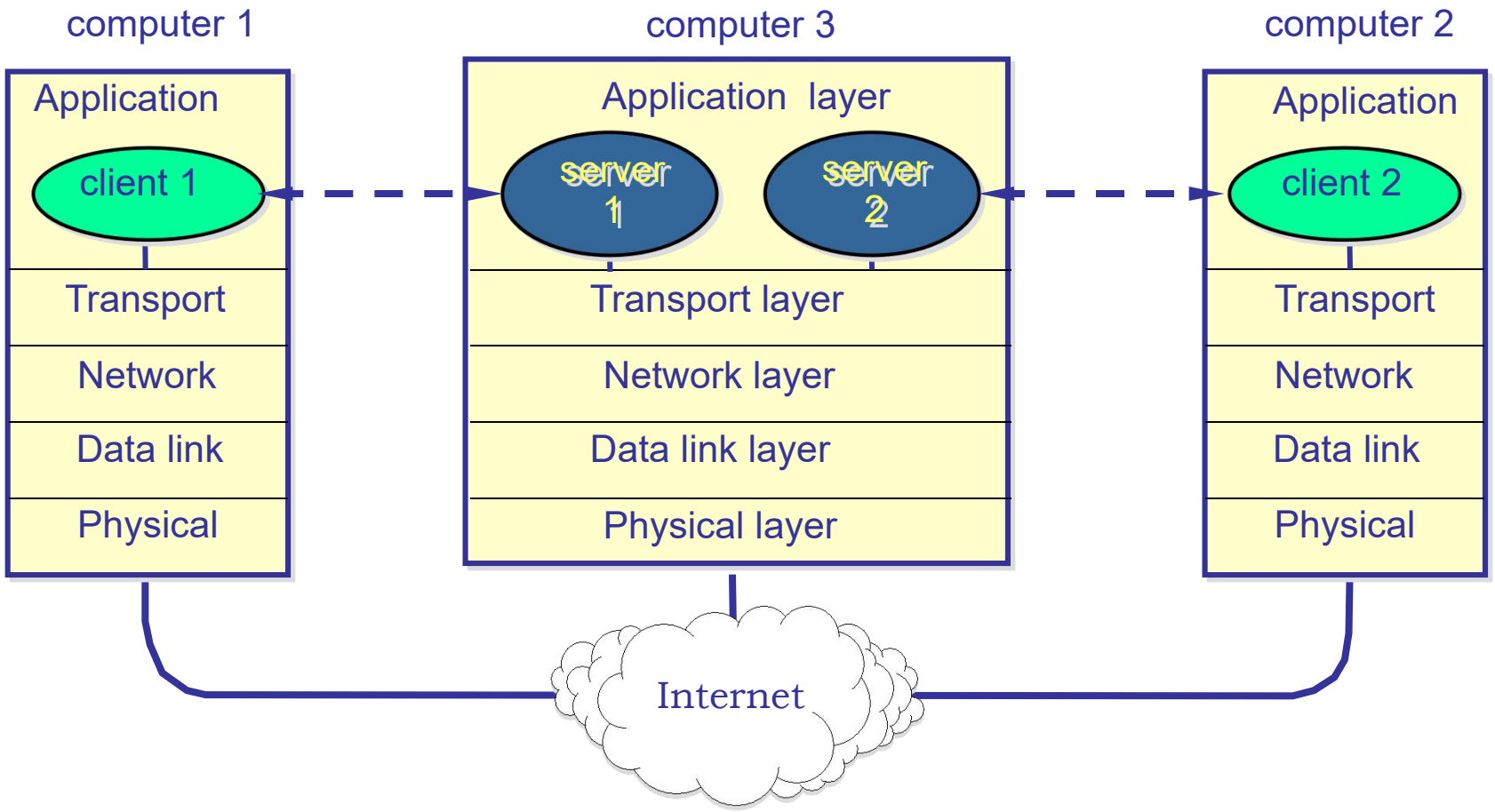
## Conclusion

- This is an infinite loop, the two sides of Blue Army always unable to determine whether the other part receive the last message.
- There is no protocol can guarantee Blue Army 100% winning.
- That is to say many problems should be considered in the protocol design process.

# 【Example 1-2】The client and server processes use TCP/IP protocol to communicate (client/server)



# A powerful computer can run multiple server processes at the same time.



# Summary

- Functions of computer network in the information age (two functions)
- Concept and History of computer networks (three stages)
- Constitution of Computer networks (two parts)
- Characteristics and comparison of three kinds of data switching modes (Packet Switching is most important)
- Definition and classification of computer networks ( the scope of the role, users, information exchange and access the four aspects of the way)
- Topological structure of computer networks (the basic features of the three structures)
- Performance indicators of computer networks (Time delay and Network utilization rate)
- Architecture of Computer network (Layered, Protocol, OSI and TCP/IP protocol suite, the structure and main functions of the protocols in different layer)

# Homework

- English Book (8th Edition)
  - Read Chapter One
  - Case Study 1 - Network Layouts in Action & The TCP/IP Protocol Suite in Action (page 21)
- Chinese Book p39-40 (8th Edition)
  - Homework
    - Exercise One
      - 2,3,8,10,11,13,15,17,18,19,22,24,29,34,35