

Computer Networks

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1 Introduction

Today, we can use desktop computers, notebooks and even smartphones to access Google searching engine, watch Youtube videos and make LINE calls. One important infrastructure for making them real is the Internet. Internet is a global network of computers and communication devices (including transceivers, routers, gateways, wireless access points and others). Internet is also a network of computer networks.

1.1 Local area networks

In the early days, around 1970s, computer manufacturers (like IBM and DEC) and universities developed their own local area networks. Each of these networks were designed independently. Their routing methods, message formats and even the medium access methods are different. In the end, it was not possible to send a message from one network to another.

1.2 Internetworking

Around the middle of 1970s, the computer industry started to call for unification of the standards for computer networks. Gateway technologies were developed to bridge the networks of different standards. Eventually, a true open system of network of computer network (i.e. Internet) was formed in the middle of 1980s.

Today, a computer is able to communicate with other computer as long as both computers have been connected to the Internet. After iPhone has been introduced to the market in 2006, many new cell phones have been designed with notebook capability. WiFi network card is embedded. Thus, the scale of the Internet is now extended to cover those mobile devices, like cell phones and Pads.

1.3 Internet and telecommunication network

Today, two major networks supporting data communication are the Internet and the telecommunication network. Clearly, telecommunication network used to support voice communication. Owing to the advancement in communication technologies, many technologies have been applied to both the advancement of the Internet and the advancement of the telecommunication

network. One notable collection of technologies is wireless communication. While many technologies have been applied to both networks, one should be noted that the specifications and the standards of both networks are not the same. In other words, they are different systems.

Here, it is important to point out that many technologies developed for Internet have also been applied in telecommunication (i.e. telephone) networks. The terms WiFi and WiMAX are used for referring the generations of the wireless communication technologies for Internet. The terms 3G, 4G and 5G are used for referring the generations of the communication technologies for mobile phones.

1.4 Internet and post office

Essentially, the generic service¹ supported by the Internet is the same as the service supported by the network of post offices, as shown in Figure 1. The clients to be served by the Internet are computers, mobile devices and cell phones. The clients to be served by the network of post offices are individuals, firms, organizations, schools and others. Their similarities are depicted in the following table.

Postal Service	Internet Services (TCP/IP)
Network of post offices	Internet
Letter	Data
Envelope	Header of a datagram
Envelope with letter	Datagram
Sender postal address	Source IP address
Receiver postal address	Destination IP address
Sender name	Source port number with or without session ID
Receiver name	Destination port number with or without session ID
Post office	Router and gateway
Post office ID	MAC address of a router, gateway or cell phone
Postal address	MAC address of a router, gateway or cell phone

¹Here, the generic service of the Internet is simply referred to the service supported by the core technologies specified in the TCP/IP.

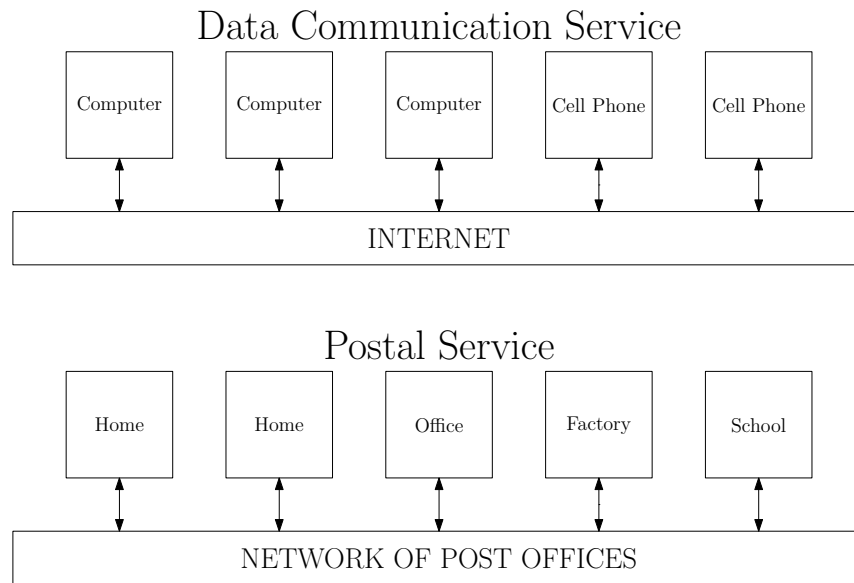


Figure 1: Data communication service versus postal service.

1.5 Further readings

To have a comprehensive account for computer networking, one could refer to the following textbooks.

- Kurose, James F. *Computer Networking: A top-down approach featuring the Internet*, 3E. Pearson Education India, 2005.
- Stallings, William. *Computer Networking with Internet Protocols and Technology*. Upper Saddle River, NJ, USA: Pearson/Prentice Hall, 2004.
- Stallings, William. *Data and Computer Communications*. Pearson Education India, 2007.

2 Computer Network

Computer network is a network of computers. It could be a private network of computers, sometimes called local area network (LAN). It could be the public network connecting all the computers in the world, called the Internet. One

original purpose of a computer network is to share computational resources amongst the computers connected in the network. For instance, in a research lab located in New Mexico of US, there is a supercomputer that can do large scale scientific computation. A research team in UCLA would like to access this supercomputer for solving a research problem. Without computer network, the researchers had to take the data and drove all the way from LA to New Mexico for accessing such a computer. Clearly, it was not convenient. Thus, it came to the idea of computer network – networking computational resources for sharing. While the motivation is simple, the technologies for making it work are enormous.

Computer network embraces a collection of technologies that enable communication amongst computers. Those technologies are usually named as protocols or in more general term called standards. There protocols include the binary code of a character, to the format of an address of a computer, to the steps for making a secure connection between two computers. To start with, let us have two simple examples.

2.1 Three browsers two websites

Suppose that I have a notebook with WiFi connection. Now, I am sitting in a cafe in Taipei. I open three browsers. One of them is connecting to the NCHU server browsing the latest news. One is connecting to the NCHU server browsing seminar information. The third browser is connecting to Youtube for video watching. Technically, the action 'browse' refers to a sequence of messages passing back and forth.

1. User keys in the url `https://www.nchu.edu.tw/news/id/1` on the address bar and presses return.
2. The browser composes a request message sending to the NCHU web server asking for sending back a specific file (yet another message).
3. Once the request message has arrived the web server, the web server reads the message and figure out what action it should do.
4. The web server in response with the message (i.e. the results of the action) sending back to the browser.
5. The browser reads the message and formats the results as a webpage to the user.

The 2nd and the 4th steps will need the help of the operating system. Precisely, in the 2nd step, the browser (as an application system) requests the operating system to help sending out the message to the Internet. In the 4th step, the operating system sends the message to the corresponding browser once it has received the message.

2.2 Problems aroused and solutions

Even for this simple situation, it raises a number of problems to be solved.

Problem 1 *In the cafe, there is only one access point (AP) which is connected to the Internet. There are many notebooks around. How does the access point help these notebooks to sending out the messages to the Internet?*

Problem 2 *Even though the URL has been keyed, how does the Internet know where the message should be sent to? In other words, which physical machine the NCHU web server is located?*

Problem 3 *Once the 'latest news' and the 'seminar information' have been received, how does the operating system know which browser shows 'latest news' and which browser shows the 'seminar information'?*

Problem 4 *Video file is usually a big file, in the order of magnitude megabytes. So, it is inefficient to send a big file over the Internet. Not just traffic jams could be caused, it could also lead to file lost. So, how does the Internet handle the transmission of a big file?*

While all these problems are essential in computer communication, the solutions for solving such problems are very intuitive.

MAC Address To solve the first problem, the solution is to assign for each notebook and the access point a unique address, the MAC address. The MAC address can allow the AP to differentiate which message is sent from which machine, and which message is sent to which machine. Once a computer has been connected to a network, either wired or wireless, the computer will have to report to the network management system its MAC address. Note that MAC address is different from IP address. MAC address, while it is called address, should better be called as a machine ID. Today, this address is assigned by the manufacturer

before the mobile device has been released to the marker. This address is unique. Different devices have different MAC address. For an ad hoc wireless network of notebooks, the notebooks can then communicate each other by their MAC addresses.

IP Address To solve the second problem, the solution is to assign for each computer an IP address. The address of a computer on the Internet space. It acts like the postal address of a physical location. To send a message from one machine to another, we simply specify the sender IP address and the destination IP address. The routers in the Internet can read the IP address of the message and route it to its destination. On the other hand, the routers can route back an error message to the sender if the message is failed to be routed. Moreover, the destination server can send the reply message back to the sender computer by specifying the sender IP address.

Session ID To solve the third problem, the solution is to assign for each browser (each process)² a session ID. The message composed by the operating system will add the session ID in the message. While the web server has received the message, processed the request and then composed the reply message, the session ID will be added in the reply message. Therefore, the notebook operating system is able to differentiate which message to be shown in which browser (which process).

Sequence ID To solve the forth problem, the solution is to chop the big file into small message files. Each of these message files are then sent to the Internet with the sender and destination IP address, the receiver MAC address, the session ID. Now, one more information is added. It is the sequence ID. The sequence IDs are used for the application system to reconstruct the big file.

For some machines, it might consist of more than one server, say web server together with mail server. So, it causes another problem.

Problem 5 *If a machine has more than one server, how does the network operating system know which server queue the message has to be put?*

²This technique is in fact applied in process management in an operating system. Each process running in a computer is assigned with a unique process ID. This process ID is used for assigning the file IDs of all temporary files to be accessed by the same process and the process IDs of all the background processes created by this process.

In such case, one more ID called port number is needed.

Port Number For a server machine, it could consist of many servers, like web server, mail server, FTP server and etc. Each server has its own server queue. The port number is able to let the network operating system (NOS) in the machine to efficiently pass to its corresponding server queue once the message has arrived.

These IDs are sufficient for identifying which message to be sent to which process, to which computer and to which server queue. To make it possible, two more problems have to be solved.

Problem 6 *Seamlessly, the AP is connected to more than one notebooks helping them sending and receiving messages to and from the Internet simultaneously. As a matter of fact, the AP can only serve one notebook (one device) at a time. That is to say, in each moment, only one device can actually be connected with the AP sending a message to it or receiving message from it. In each moment, the AP can only connect and communicate with one notebook to send the message to. So, how does the AP manage this physical connection?*

Problem 7 *The routing of a message is relied on a specific network of computers. Normally, we call them routers. Each router is usually connected to at least one other network. Once a message has arrived a router, how does the router forward this message to the other routers?*

Problem 6 is usually attributed as the medium access control (MAC) problem. The access point is treated as a medium for the notebooks to send and receive messages to and from the Internet. Problem 7 is attributed as the routing problem. The solutions for the MAC problem depend very much on the actual structure of the computers being connected. The solutions for the routing problem are a bit interesting. They are heuristic and sometimes designed by trial-and-error.

MAC In the WiFi environment, computers can send and receive messages via an access point (AP). In each moment, it is clear that only one machine can connect to the access point to send or receive a message. The mechanism to determine which computer is allowed to connect is defined by a medium access control (MAC) protocol. There are many

MAC protocols which are developed for various local area networks (LANs) of different topologies.

For the aforementioned wireless LAN, the medium access control is based on a simple method carrier-sense multiple access with collision avoidance (CSMA/CA)³, see Figure 2. If a notebook NB-X needs to send a frame of data to the AP (the request-for-webpage message to AP and let the AP forwards it to the Internet), it sends out a RTS (ready-to-send) message together with its MAC address (source MAC address) and the AP MAC address (destination MAC address)⁴. If the AP is idle, it responses by sending a message CTS (clear-to-send) together with its MAC address and the NB-X MAC address. Then, NB-X can send the frame of data to the AP. Once, the AP has successfully received the frame, it replies by sending acknowledgement (ACK) message to NB-X.

It is possible that NB-X does not receive any CTS message. One reason is because the AP is busy. Another reason is because another notebook, say NB-Y, also sends out a RTS message. Multiple RTS messages in the air will interfere each others. The resultant messy signal becomes noise. Thus, the AP does not have any response simply because it cannot sense any signal. In either case, NB-X waits for a random time and sends the RTS message again.

Suppose that the webpage has arrived the AP, the AP needs to forward it to NB-X. The AP does the same thing. It first sends out a RTS message together with its MAC address (sender MAC address) and the NB-X MAC address (destination MAC address). If NB-X is idle, NB-X responses by sending a CTS message together with its MAC address and the AP MAC address. Then, the AP sends the frame of the webpage message to NB-X. Finally, NB-X sends ACK message to the AP once the frame has been received successfully.

In fact, the request-for-webpage message to be forwarded to the Internet is an IP datagram, see Figure 3. It consists of the data (i.e. request-for-webpage message) to be sent to the NCHU web server, the sequence ID,

³This method is applied not just to notebook-AP connection, but also notebook-notebook connection.

⁴Note that this message together with the MAC addresses is broadcasted in the air in a specific form of radio signal. Thus, all devices in the LAN are able to hear the message. However, only the device with the AP MAC address can receive.

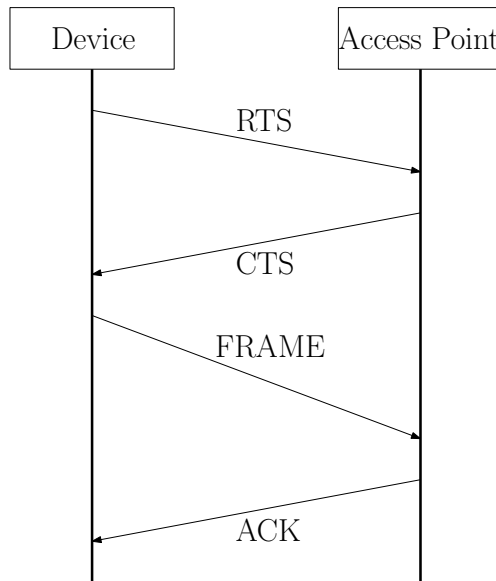


Figure 2: Carrier-sense multiple access with collision avoidance.

Source IP Address	Source Port	Session ID	Sequence ID	Data
Destination IP Address	Destination Port			

Figure 3: The IP datagram to be forwarded by the router to the Internet.

the session ID, the source and destination port numbers, the source and destination IP addresses. This datagram is eventually routed to the NCHU web server.

Routing Algorithms There are many routing algorithms the routers can implement. One approach is to maintain a router table. The table reveals the topology of the network of routers the router can reach. If a router needs to forward a datagram, it determines from the table the shortest path to route the datagram to its destination. By that, the router is able to determine which neighbor routers the datagram should be forwarded. If the destination IP address does not exist in the router table, the router forwards it to a higher level (domain level) router and let it forward the datagram through the network of domain routers.

The above approach applies to a stable network with fixed topology. For a network with dynamic topology, the above routing algorithm

could not be implemented efficiently. For a network of notebooks, the notebooks move arbitrarily. Due to limit of transmission range, only two notebooks within the transmission range are able to communicate. In this moment, these two notebooks are neighbors. In another moment, these two notebooks could be distance apart. Then, these two notebooks are not neighbors. The network topology changes. In this regard, the router table will have to be updated frequently if the above routing algorithm is applied. It thus leads to very high overhead is too high. To this end, another routing algorithm is more suitable for this kind of network, flooding. The datagram (resp. message) is simply forwarded to all the neighbor notebooks. Each neighbor notebook checks if its IP (resp. MAC) address is the destination IP (resp. MAC) address. If it is not, the neighbor notebook floods the datagram to all its neighbor notebooks.

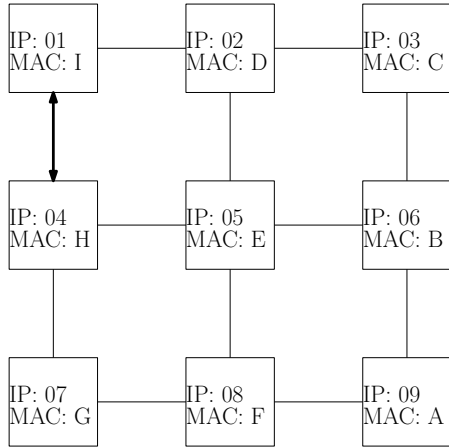
2.3 IP address versus MAC address

It should be noted that routing of a datagram is based on the information of the source and destination IP addresses. Sending of a frame of message from a computer to another computer within a LAN is based on the information of the source and destination MAC addresses. In principle, each computer in a Internet-connected LAN will be assigned with an IP address during the time it is connected to the LAN. This IP address could be a temporary IP address. The table mapping between the IP addresses and the MAC addresses is maintained by the routers in the LAN. Once the computer has been disconnected from the LAN, its IP address will be released.

If a LAN is an isolated private network and the computers have no need to access Internet, it is in principle to use their MAC addresses for communication amongst the computers. For some networks of mobile devices which are communicated by Bluetooth or Zigbee technologies, it is also possible to use the MAC addresses for communication.

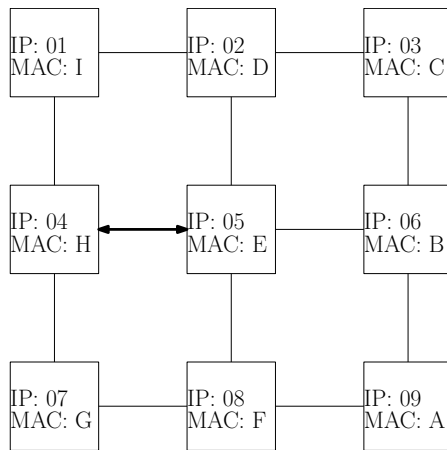
Figure 4 shows an example how a packet is formatted during routing. Here, device with IP:01 and MAC:I is going to send a data to the device with IP:09. Once it has made connection with the device (IP:04, MAC:H), it generates the following packet and then forwards it to the device.

MAC:I MAC:H IP:01 IP:09 XXXXXXXXXXXXXXXXXXXX



MAC:I MAC:H IP:01 IP:09 XXXXXXXXXXXXXXXXXXXX

(a) Packet is forwarded from IP01 to IP04.



MAC:H MAC:E IP:01 IP:09 XXXXXXXXXXXXXXXXXXXX

(b) Packet is forwarded from IP04 to IP05.

Figure 4: A message is forwarded from IP01 to IP09.

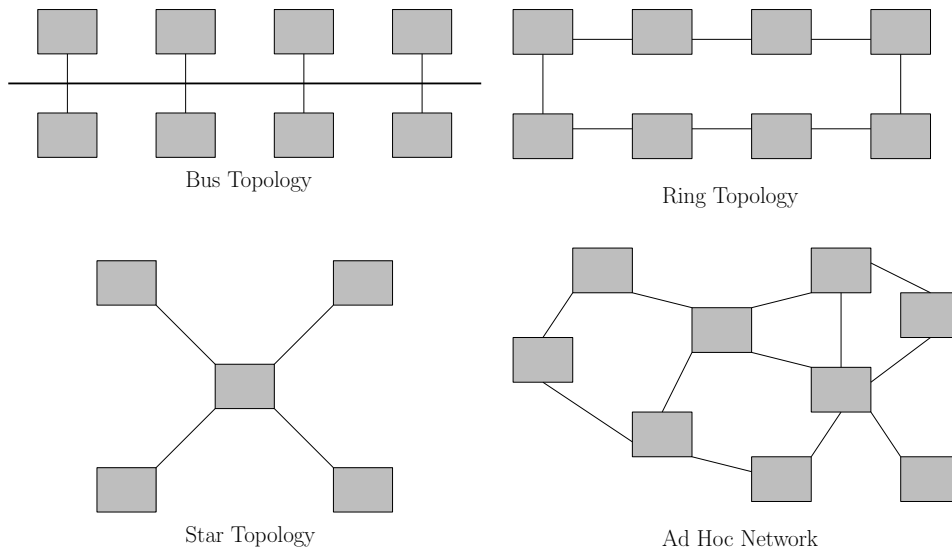


Figure 5: A few network topologies.

Once the IP:04 device has received the packet and checked that it is not the destination, it forwards the datagram to a neighbor device, say the one with IP:05 and MAC:E. The following packet is then sent out.

MAC:H MAC:E IP:01 IP:09 XXXXXXXXXXXXXXXXXXXX

So, the only change is the source and destination MAC addresses. The source and destination IP addresses have not been changed.

2.4 Network topologies

Network topology usually refers to the structure of a local area network (LAN), not the structure of Internet. Figure 5 shows four examples. As their structures are different, they usually have different medium access control (MAC) protocol and packet routing protocol.

2.4.1 Bus

For the bus structure, all computers are connected to a common medium called bus. To control the medium access, one method is based on the

carrier-sense multiple access with collision avoidance (CSMA/CA) protocol, see Figure 2. These ideas are the network design behind Ethernet⁵ and wireless LAN (i.e. so-called WiFi network).

The initial version of CSMA/CA was designed by a group of researchers in University of Hawaii for a wireless data communication network called AlohaNET in 1971. As Hawaii is a state of many remote islands, lining cables to connect the computers in Hawaii was not practical in the 1970s. Thus, the group decided to build a wireless network. University of Hawaii is treated as the center to co-ordinate the computers to communicate among each other. Its role is basically the same as what we call the access point in today WiFi network.

2.4.2 Ring

In the ring structure, the computers are connected in a ring shape. Each computer can only communicate with two neighbor computers. The MAC protocol for this structure is called *token ring*. The essential idea of token ring medium access control is to let each computer take turn to send a message.

Each computer is initially assigned with a number. Then, a special message with a token inside is composed. The token is started as '1'. The number in the token indicates which computer can send message. Suppose now that C1 needs to send a message. It composes the message with the destination number, say C3, and passes it to C2. C2 checks that the token is '1' and the destination is not C2, it passes the message to C3. Now, C3 checks that it is the destination. It then downloads the message, increments the token number by one, i.e. '2'. Clearly, C3 has no right to send, it then passes the message to C4 and so on.

2.4.3 Mobile ad hoc network

Nowadays, many vehicles have been equipped with a computer inside. These computers thus form a mobile ad hoc network. As the vehicles in the network are moving around, the network has no fixed structure. Communication between two computers can only be possible if they are within the transmission range. So, a computer can have many neighbor computers if there are many

⁵It should be noted that the CSMA/CA protocol is not the only MAC protocol Ethernet can implement. Ethernet can also implement the token ring protocol under the bus structure. The network of this kind is called Ethernet ring.

computers in its transmission range. In other case, it can have no neighbor computer if there is no computer in its transmission range. Routing algorithms for this kind of networks are still underway.

3 Telecommunication Network

Internet and telecommunication network are two different networks. Internet is the infrastructure for computers communication, while telecomm network is for communication amongst mobile phones and landline phones. The operation principles of computer network and telecomm network are similar but not the same. However, many technologies behind them are similar. For example, each computer connected to the Internet has a unique IP address for sending or receiving messages. Each smartphone connected to the telecomm network has a unique phone number for making phone calls. The carrier frequency in telecomm network is different from the carrier frequency in WiFi.

Today, each telecommunication firm (or operator) provides many services to her subscribers, including voice service, cellular data service and many others. Voice service and cellular data service are two important services for almost all subscribers, through the 4G/5G cellular network and the landline network.

3.1 Voice service

Voice call is the fundamental service that every telecommunication network has to support. While a caller X has to make a call to Y, the caller X simply keys in the phone number of Y. As the voice call is a real-time service, it is not allowed to have lag during the call. Thus, the switching centers of the telecommunication firm will make a dedicated path for X and Y. This dedicated path is called a circuit. Resources along the path are allocated for X and Y to ensure high quality voice call, such as zero time lag and zero noise. This method of switching is called **circuit switching**.

3.2 Data service

Sending and receiving digital data is another service provided by telecommunication firms. Sending a page of document from one facsimile machine

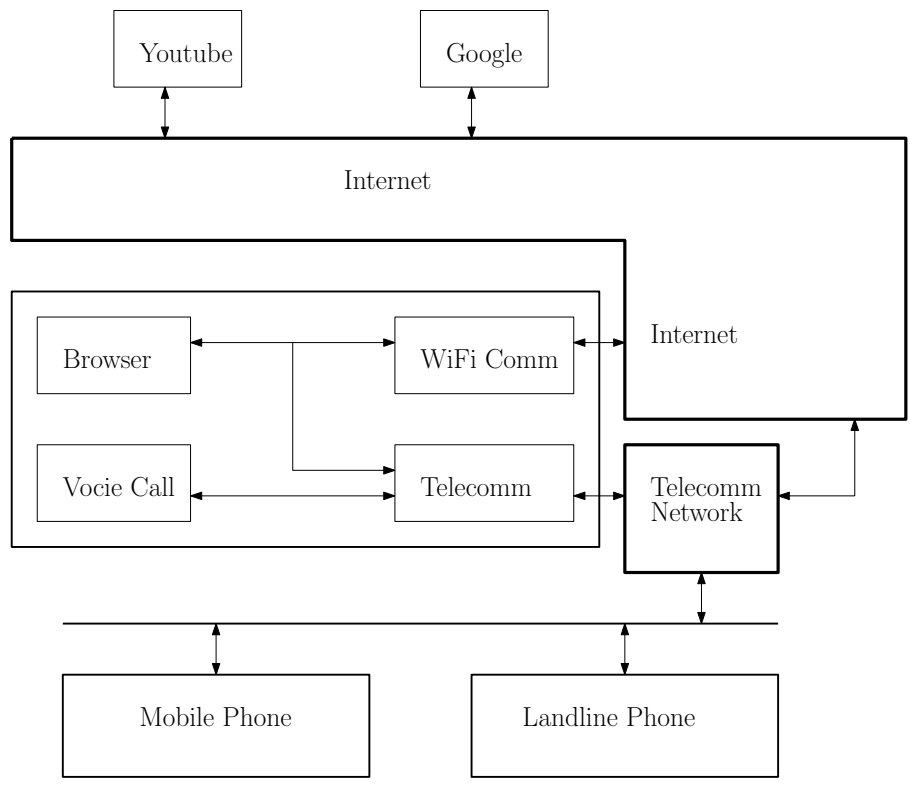


Figure 6: Smartphone is able to connect to the Internet and telecomm network.

to another facsimile machine would need to use the data service. Messaging a photo to your friend will need to use the data service. To support data service, the mechanism is based on the idea of **packet switching**.

The document or file is chopped into multiple small segments. Each segment is encapsulated in a stream of binary bits called packet. These packets are thus routed to the destination phone. Finally, the file is reconstructed in the receiver phone. In contrast to voice call, data service has no need to be real-time. Packet switching, instead of circuit switching, is already good enough to support such service.

Here, two points should be noted. First, the idea of packet switching is also applied in Internet. However, the industrial standard (equivalently, the technologies) for telecommunication networks supporting data services is not the same as the standard for the Internet. Second, almost all public telecommunication networks are now connected to the Internet via a machine called gateway, see Figure 6. One of its tasks is to convert the format of the packet to be passed from the telecommunication network (resp. Internet) to the Internet (resp. telecommunication network).

3.3 iPhone setting

Suppose you have subscribed both the voice service and data service from a telecommunication firm. You can set your phone as shown in the following.

WiFi	OFF
Bluetooth	OFF
Cellular	ON
Personal Hotspot	OFF
Carrier	ON

The carrier must be ON. Then, you phone can connect to the telecommunication network. To enjoy the data service, 'Cellular' has to be ON. To let the phone to connect to a WiFi network, WiFi has to be ON. It should be noted that the phone can still access to the Internet if WiFi is OFF.

3.4 Network of 2 PCs

Suppose you would like to have a network of two remote computers. One is located at home and the other is located in your office. To make communication between these two computers possible, one would need to have

two modems. The modem⁶ is connected on one side to the computer and the other side to the telecommunication network. In this regard, sending message from one computer to the other is possible. Before doing this, it has to be sure that you have subscribed telecommunication services for your home and your office.

4 Switching

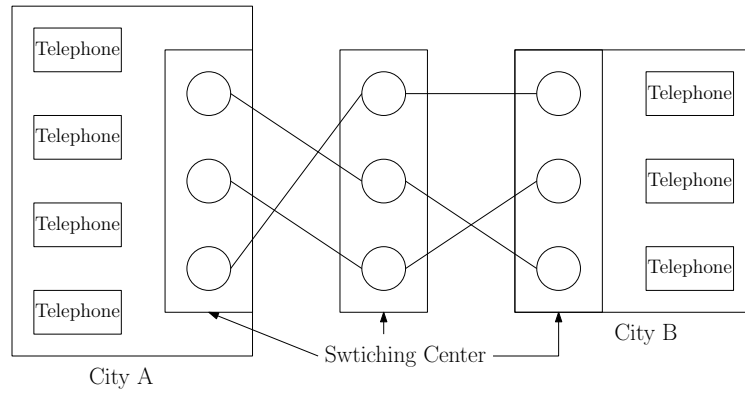
Switching technology refers to the method to pass a data (resp. voice) message to from one device to another. Here, a device could be a computer or a smartphone.

4.1 Circuit switching

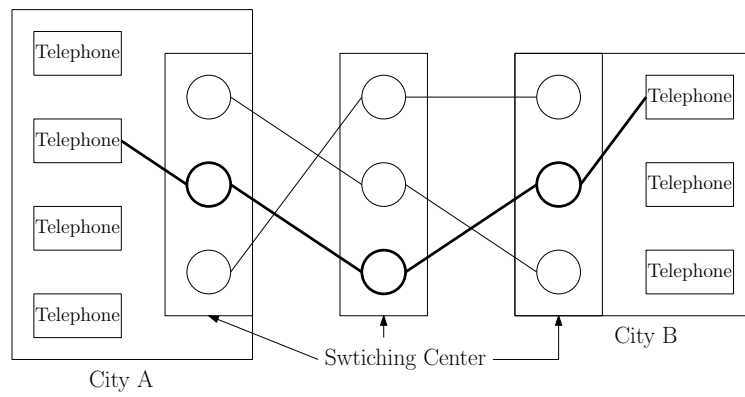
As mentioned in the mechanism how voice is sent over the telecommunication network, the technology is based on circuit switching. Figure 7 shows the idea behind circuit switching. In the early twentieth century, once a telephone user in City A would like to make a call to a telephone user in City B, the telephone user will need to ask an operator in the city switching center to make connection. The operator will then inform an operator in City B switching center to make connection to the corresponding telephone user in City B. Once it is done, the telephone users could talk to each other via this dedicated path. This connection path is called a circuit.

Once a device X needs to send a data (resp. voice) message to another device Y, the network (resp. telecommunication network) will instruct the intermediate nodes, the routers in the network (resp. the switches in the telecommunication network), to reserve resource and then form a circuit (i.e the dedicated path) for the devices X and Y. Then, devices X and Y can communicate with each other over this circuit seemingly like no disturbance from other devices. Apart from handling voice call over the telecommunication network, circuit switching can support other real-time mission critical tasks which demand excellent quality of communication with no delay.

⁶The full name of modem is modulator-demodulator.



(a) Network of switching centers.



(b) Circuit for voice service.

Figure 7: The operators in the switching centers connect a circuit to support voice call between two telephones.

4.2 Message switching

In message switching, a message is forwarded from one node to another based on the idea of store-and-forward. Usually, it is assumed that the message is not a short message. Thus, the time spent on receiving a message is not instantaneously. Once a message is sent to a node, say Y, its bits will be stored in node Y. Until the complete bit stream has been received, the message is then forwarded to a neighbor node for routing. In contrast to circuit switching, there is no dedicated circuit to be set up in message switching.

As the entire message is forwarded from one node to another, the time spent on sending a message from one device to another depends on the path that the message has travelled. The message could take a long time to arrive the destination device if there are too many nodes along the path.

4.3 Packet switching

Message switching is aimed at sending the entire message from node to node. Packet switching is aimed at sending part of the message from one node to another. First, the message is chopped into small segments. Next, each segment is assigned with a sequence ID and encapsulated in a packet. Finally, these packets are sent to the network. In the receiver side, the packets are then decapsulated and the message is reconstructed.

For some applications, like streaming, the entire file is not possible to be sent from the video server to the user computer. Clearly, the video file must be chopped into segments and sent to the user computer in forms of packets. The video is thus reconstructed in the user computer and shown on the video viewer.

4.4 Comparisons

For comparison, the differences amongst different switching methods are depicted in the following table, Table 4.4. In the table, one point is needed to be noted. Nowadays, an *virtual circuit* is in fact realized based upon the packet switching technology.

Table 1: Comparisons amongst different switching methods.

Switching	Size	Speed	Note
Circuit	Unlimited	Very fast	Real/virtual circuit for voice and data service
Message	Single file	Slow	Store-and-forward for data service
Packet	~ 64K byte	Fast	Support for data service

5 Packet Loss

A packet can be lost due to various reason. In this section, only two simple reasons are given. One is due to channel noise and the other is due to time-to-live.

5.1 Channel noise

Applying which switching method is sometimes related to the channel noise. It should be noted that each packet or message is actually a stream of bits. This stream of bits will be physically embedded in a very high frequency electrical signal (resp. radio signal). This signal is called the carrier signal and the frequency is called the carrier frequency. The signal will then be transmitted through a cable (resp. the air) to the other device. If the channel is fiber optics, there is another mechanism for sending the stream of bits.

To start with, let us introduce how digital data is transmitted by radio signal. By that, some key terms are introduced. Suppose a stream of 20 bits is going to be transmitted.

Source:10101101100110101101

1. A sequence of electrical signals is generated to represent the bits, see Figure 8a.
2. The electrical signal is thus multiplied with a carrier signal as shown in Figure 8b. For illustration, the frequency of the carrier signal is 200Hz. In reality, this frequency is around 2.4 GHz or higher.

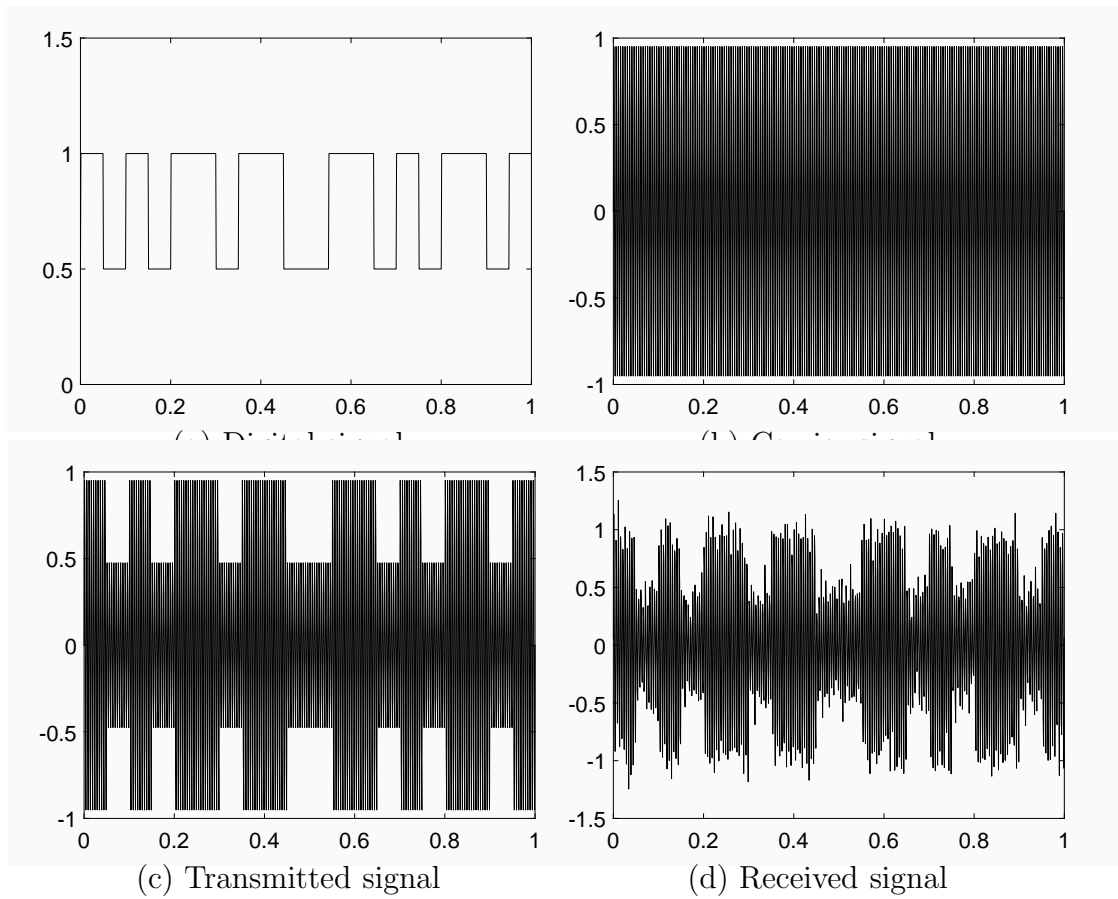


Figure 8: Digital data transmission via radio signal.

3. The radio signal (i.e. electromagnetic wave) is generated and emitted to the air, see Figure 8c.
4. In the presence of noise, the signal received is a noisy radio signal as shown in Figure 8d.

A few points should be noted. (1) The data transmission rate, i.e. say 10 mega bits per second (10 Mbps), depends partly from the carrier frequency. (2) The data transmission rate cannot be higher than the carrier frequency. (3) In wireless communication, the bit error rate (a measure of the noise effect of a channel) depends on the distance between two devices. One factor is due to the fact that particles, like water molecules and dusts, in the air could

absorb the energy of the radio signal and end up with signal deterioration. Another factor is the background radiation (from microwave oven and sun light) which is a source of noise corrupting the radio signal.

As a result, the reconstructed bit stream could be erroneous. In this example, the 6th and the 13th bits are incorrect.

Source: 10101101100110101101

Destination: 10101001100100101101

Similar situation exists when the digital signal is transmitted over a cable or a fibre optic. In either cases, error detection and correction is an important problem in data transmission.

Problem 8 *In the above example, as we know the correct bit stream, we know which bits are incorrect. However, the destination device cannot have such information. The stream of bits received is the only information it has. Error detection and error correction turn out to be two big problems to the engineers. Thanks to the pioneer engineers, many error detection and correction methods have been developed.*

Error Detection & Correction Once a stream of bits has been received, the destination device can detect if there is any incorrect bit. If there is, the device can try to correct the error. Note that all these methods have one limitation. They can only correct erroneous bit stream with a few error bits. If there are too many error bits, the only way is to ask the source device to re-send.

To this end, one should realize that it is not recommended to apply message switching for a long data over a wireless medium. The reconstructed bit stream could have too many error bits. The data transmission might not be successful even after a number re-send. Message switching is thus suitable for wired network with very low bit error rate.

5.2 Time-To-Live (TTL)

For a packet to be sent, there are at least two possible reasons making it disappear. The first one is definitely the channel noise. Suppose that a datagram is going to be sent from device X to a neighbor device Y. If the channel is too noisy, the datagram cannot be reconstructed in device Y. As

a result, device X cannot receive the ACK frame. Normally, each device will set a waiting time, say 1 second. After one second, the ACK has not been received, the packet is treated as loss.

Another factor leading to packet loss is a bit funny. Let say a datagram has been routed to a router K. Router K will check the destination IP address. If the destination IP address is one of its neighbor, the router forwards the datagram to the neighbor. If it is not, the router guesses which neighbor router is closer to the destination IP address and then the datagram is forwarded to it. For the latter case, it is not guaranteed that the guess is correct. It might happen that the guess is wrong and the datagram is again forwarded to another router which is far away from the destination IP address. In the end, the datagram could be forwarded in the Internet forever.

Owing to solve this problem, apart from the source IP address and the destination IP address have to be specified in the IP datagram. In fact, one more information has to be added. It is the time-to-live (TTL) information. For instance, the TTL is set to 15 by the source device. Once, the datagram has arrived a router (or other devices for doing routing), the value of TTL will be decremented by one. If the datagram has been forwarded for 15 times, the TTL will then be decremented to zero. In such case, the datagram will not be forwarded and deleted. This is the second reason leading to packet loss.

6 Protocol

Protocol refers to a collection of technologies and standards to ensure both voice and data communication amongst devices connected to a network. One might also call these technologies and standards the rules or agreements.

The frequency of the carrier signal is specified in the protocol. The format of the electrical signal representing '0' and '1' signals is specified in the protocol. The method to control medium access and the format of binary stream of the packet are specified in one of the MAC protocols. The method of embedding this binary bit stream in radio signal and the method to correct erroneous bits are specified in the data-link level and physical level protocols.

Device manufacturers can thus follow these standards to design and make the communication devices, like routers, built-in network cards and the chips for WiFi communication. Today, the widely adopted protocol for Internet is called TCP/IP. TCP refers to transmission control protocol. IP refers to

internetworking protocol.

There are many protocols for telecommunication networks and Internet. Earlier in the text, it is mentioned that telecommunication network and Internet are two different networks. One reason is that the protocols for telecommunication network are not the same as the protocols for Internet. The carrier frequency for cellular networks is not the same as the carrier frequency for WiFi networks.

7 Applications

The ultimate purposes of these protocols are developed to support 'data' communication. The source device (with a unique IP address) generates a stream of bits in which the 'Data' is encapsulated as shown in Figure 3. Once the stream of bits is received at the destination device (the device with the corresponding destination IP address), the 'Data' is reconstructed. So, we can now use the Internet to develop applications.

7.1 Simple example: File transfer

Suppose that I want to share technical reports to my friends. The size of each technical report is over 1MByte. It is definitely larger than the size of the 'Data' that can be encapsulated in an IP datagram. So, I need to develop an application program. The program is applied to chop a report file into a number of segments. Each segment is small enough to be encapsulated in the datagram. Apart from file chopping, I also need to add extra information to let the application program running in the destination computer know what is going on with these segments. So, here is a method developed for sending large file. It is assumed that an application program named APP21 is running as a background process in both the source computer and destination computer.

Source Computer

Step 1: Chop the file into segments of no more than 512 bytes.

Step 2: Number each segment with a sequence ID, starting from 1, and a number (say APP21) representing the application program.

Summary data:

APP21 SID000 50KByte 100 Segments

Segment 001:

APP21 SID001 xxx

Segment 002:

APP21 SID002 yyy

Figure 9: Segments to be generated.

Step 3: Generate a summary data for the file, including (i) memory size of the file (ii) the total number of segments to be sent. Number the summary with the sequence ID 0. Again, the number APP21 is added, see Figure 9.

Step 4: Request the operating system to send out the segments.

Once the segments have been received in the destination IP address, the operating system identifies from 'APP21' that the data is sent to the background process APP21.

Destination Computer

Step 1: Puts the segments one by one in temporary memory location.

Step 2: Checks for the segment with SID000 and the information in the segment.

Step 3: Reconstructs the file in accordance with the sequence IDs.

Step 4: Generates an acknowledgement data and sends it to the source computer.

7.2 Application-layer protocols

To make the above application work, one would need to have a program (i.e. APP21) to be developed. This program must be installed and running

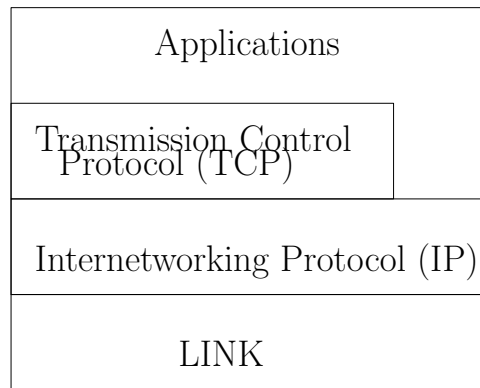


Figure 10: Protocol stack.

persistently in both the source and destination computers. Together with the program, one needs to design the format of the data to be encapsulated in the datagram. Therefore, the APP21 running in the source computer can generate the right format of data to be sent. The program APP21 in the destination side is able to understand the meaning of the data received.

Nowadays, many applications have been developed by using the services provided by the Internet. Notable applications include file transfer, email, world wide web and voice transfer (LINE and Whatsapp). Their corresponding protocols are called file transfer protocol (FTP), simple mail transfer protocol (SMTP), hypertext transfer protocol (HTTP) and voice over Internet protocol (VOIP). As these protocols are developed for common applications, they are collectively called the application layer protocols, or simply application protocols. They have been filed to be standards and listed with numbers. In fact, many technology firms have developed their own protocols for different applications. Even though, those protocols have not been filed as standards.

Figure 10 shows the protocol stack. In the bottom layer is the LINK layer. Medium access control, the format of the packet to be send to the destination MAC address, error detection and so on are specified in the LINK layer. The second bottom layer is the internetworking protocol (IP) layer. On top of it is the transmission control protocol layer. Applications are developed by using the services provided either or both by TCP layer and IP layer.

8 Additional Concepts

8.1 Process ID

As mentioned in the conclusion of the chapter *Computer Networks*, the essential service of the Internet is to deliver a message without error from the computer corresponding to the source IP address to the computer corresponding to the destination IP address. Once the message has been received, it will be pass to the operating system. The operating system identifies from its PORT ID as well as its Session ID and passes the message to the corresponding process running in the computer.

In the area of computer science, each program running in a computer is called a process. Each process is assigned with a unique number called Process ID. For instance, you have invoked two Chrome applications. Each browser will be associated with an unique process ID. The operating system could thus generate different session IDs for messages to be sent from different browsers.

Application	Process ID	Session ID
Browser X	111	333
Browser X	111	351
Browser X	111	091
Browser Y	272	444
Browser Y	272	301
WORD	101	–

As a process can send more than one message to the Internet, different message could be assigned with different session ID. This table is maintained by the operating system. The operating system can thus generate the IP datagram for a process and pass it to the network card.

Remember that there are background processes running in a computer as well. For instance, one background process is in charge of the operating system update. This process will also be assigned with an unique process ID. This ID can let it connects with the remote server to download the updated patches for operating system update.

8.2 Client-Server Computing: Layered Model

In the *Operating System* chapter, the concept of client-server computing has been introduced. The operating system plays a role as a server while the

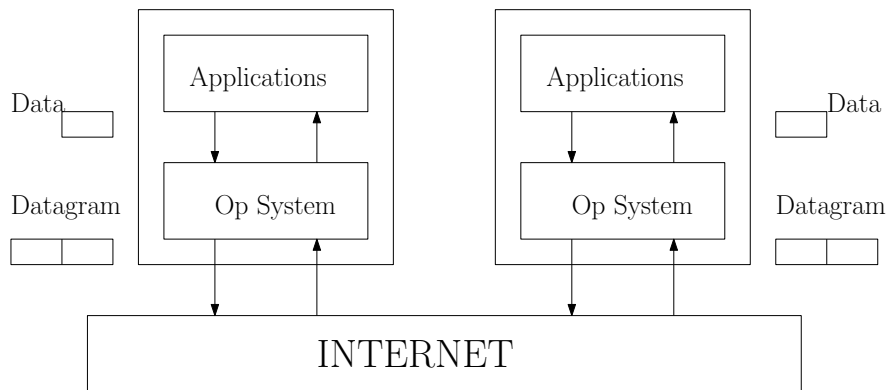


Figure 11: Lower layer provides services to the upper layer.

application system plays a role as a client. The operating system provides services to the application systems.

As a matter of fact, this concept can now be extended to describe the role of Internet. But now, the operating system plays a role as a client while the Internet plays a role as a server. The Internet provides message deliver service to the operating systems.

To make it clear! One should understand that the design of this giant computing system is based upon the concept of client-server computing.

1. **Server: Internet; Client: Operating Systems.** Internet serves all the operating systems in which their computers are connected to the Internet.
2. **Server: Operating System; Client: Application Systems.** An operating system serves all the application systems running in the computer.
3. **Server: Application System; Client: Users.** An application system serves all its users who invoke the application system.
4. **Server: User; Client: Customers.** A user of the application system could be a staff in a firm. He or she works on something to serve for his or her clients (other staffs in the firm or the customers of the firm).

Note that each server does not serve one client only. It serves multiple clients. This layered structure tells us one important phenomena. Some systems (resp. people) play both roles as client and server.

8.3 Networking Models

In the literature, there are many layered structures for the TCP/IP model. In the book authored by Andrew S. Tanenbaum⁷, the author states five-layer model. In the book authored by William Stallings⁸, the author states another five-layer model. The open system for interconnection (OSI) model from the International Organization for Standardization (ISO) states a seven-layer model.

Tanenbaum	Stalling	OSI Model
		Application
Application	Application	Presentation Session
Transport	Transport	Transport
Internet	Internet	Network
Network Access	Data Link	Data Link
Physical	Physical	Physical

The bottom four layers could be interpreted as the TCP/IP layer. Presentation layer in the OSI model consists of protocols for character encoding, like ASCII code, and the encryption methods.

These models are reference models for the understanding of the technologies embraced. Besides, it provides the complete picture of the technologies supporting the computer network. Lower layers provides services to the higher layer. For example, the technologies developed in the physical and data link layers are used for providing services for the Internet layer.

8.4 Port number

In the above networking models, one should see that the layer above the Internet layer is called transport layer. The protocols developed in the layer are responsible for port to port message delivery. That is why it is called transport layer.

In convention, each port is associated with one and only one application protocol. For instance, the message to be delivered for the application systems developed by using hypertext transfer protocol (HTTP) will be assigned

⁷Tanenbaum, Andrew S., *Computer Networks*, Prentice Hall, 2003.

⁸Stallings, William, *Data and Computer Communications*, Prentice Hall, 2007.

with Port 80. The message to be delivered for the application systems developed by using file transfer protocol (FTP) will be assigned with Port 20 or Port 21.

A port number specified in TCP is encoded by a 16 bits long binary number. Therefore, we could have altogether 65535 TCP ports. Many of them have not be used. For any future developed application protocol, developer can select then a number from these port numbers for the application protocol.

9 Hypertext Transfer Protocol (HTTP)

In its initial design, one application of Internet is to let people sharing their information or knowledge, in form of web pages. A web page is just like a newspaper article or a technical report. These web pages are collectively called the web resources. The technologies supporting this information sharing application are embraced under the hypertext transfer protocol (HTTP).

Hypertext is a technical term for a document file (equivalently a web page) which contains data other than text. They could be an image, photo, video, audio data and/or links (so-called the hyperlinks) to other information sources. The location of a web resource is called *uniform resource locator* (URL). For instance, the following is the URL of the course homepage.

`http://john.digi-pack.io/CS/cs2022fall.html`

To make it work, we need three things. First, a program file contains the information to be shared and to be displayed. Second, a web server manages the requests from the browsers in remote locations and the files to be delivered to the browsers. Third, a reader (i.e. browser) interprets the program file and then generates the output (i.e. webpage) in accordance with the layout specified in the program. The first two are located in the server side. The third is located in the client side.

The language for generating such program file is a programming language called hypertext markup language (HTML). It is a very simple language for formatting a webpage. Precisely, it is the programming language for *static* webpage.

Today, a website could have many dynamic webpages with various effects. It is because many advanced programming languages have been developed. These languages could support more sophisticated formatting features.

Moreover, many more (web) technologies have been developed for advanced uses. Integrated with other protocols, applications like webmail (Gmail for instance), online shopping platform (PC Home for instance) and cloud platform (Google Cloud for instance) are developed. As an introductory course, they will not be covered here. Only the basic HTML will be introduced.

9.1 Web server

A web server is a program managing all the web resources available in the machine and handling all the requests from the remote clients for the resources to be delivered. Technical, the web server composes the message to be delivered by the Internet to the IP address corresponding to the remote client.

While it is located in the server side and its name is called web server, this program is an application system (or application in short) no matter from the perspective of the networking models or from the perspective of the operating system. That is the reason why HTTP is classified as an application protocol.

Today, there are many web server available. One popular web server is called Apache. It is used to be running on Unix or Linux platform only. Now, it is also running in Windows operating system. Nginx is another popular web server which can be running in Unix, Linux and Windows operating systems. Precisely, the features of Nginx are more than a web server. It also bundles other features in it. Microsoft has developed a web server called Internet Information Server (IIS).

9.2 Browser

A web browser, like Chrome or Internet Explorer, is an application system which is able to interpret an html file, formate the page layout and then display the web page on the browser window. A browser usually has the following user interface.

- Back and forward buttons.
- A reload button.
- A stop button to stop loading a page.

- An address bar to input the URL.

One should be noted that Microsoft Edge in Windows 10 operating system is not just a browser. It has been bundled a number of application systems inside. Apart from web browser, it also includes a PDF reader and others.

9.3 Hypertext markup language (HTML)

Hypertext markup language (HTML) is a programming language for making a web page. With reference to a report, this language can help us to format (1) the layout of a web page, (2) the title of the page, the size of a section or a subsection, (3) the font type of the characters, (4) tables to be included, (5) item listing and so on.

9.3.1 Program structure

The structure of an HTML program consists of two parts, the header and the body. All of them have to be embraced inside the `<html>` opening tag and the `</html>` closing tag. Below is a part of the codes for the course homepage.

```
<html>
<header>
  <title>Introduction to Computer Science</title>
  <meta http-equiv="Content-Type" content="text/html">
  <meta name="keywords" content="John Sum">
  <style type="text/css">
    body { color: black; background: #ffeedd;}
    body { font-family: Garamond, "Times New Roman";}
    body { margin-left: 10%; margin-right: 10%;}
    p { margin-top: 0.75em; margin-bottom: 0em}
  </style>
</header>

<body>
  <h1>INTRODUCTION TO COMPUTER SCIENCE</h1>
  <hr>
  <h3>COURSE OBJECTIVES</H3>
  .....
```

```

.....
<h3>LANGUAGE OF INSTRUCTION</H3>
.....
.....
<h3>PRE-REQUISITES</h3>
.....
.....
<H3>COURSE CONTENTS</H3>
.....
</body>
</html>

```

The information to be put inside the header tags include (1) the title of the page which will be displayed on the tab of the page, (2) the keywords of the page which can let the search engine to tag this paper, (3) the color of the characters and the background color, (4) the font of the character and (5) the page layout. Inside the body tags, the content to be displayed and the format of text content will be specified.

9.3.2 Section heading

Section headings could simply be formatted by the <H1> tags, as shown in the above program segment. Subsection headings could be formatted by the <H2> or <H3> tags. Section heading tags not just specify the font size of the text inside the tags, they also specify how much the vertical space above and the space below the heading should be reserved.

9.3.3 Font type and font size

In a document, some words might be in bold or italic for emphasizing the importance of those words. To do so, we can use and <i> tags. Here is an example.

```

<html>
  <header>
    .....
    .....
  </header>

```

```

<body>
<h2>About Me</h2>
I am a <b>professor</b> in NCHU.

I am a <i>professor</i> in NCHU.

I am a <i><b>professor</b></i> in NCHU.

I am a <font size="8"><b>professor</b></font>
</body>
</html>

```

The last line, the word 'professor' will be displayed in bold face and italic.

The font size of text can be formatted by using the tags like `<small>` and `<Large>`. Moreover, font size can also be specified by using `` tag, as shown on the last line of code in the `<body>`.

9.3.4 Listing

To list a number of items, we can use the `` or `` tag. The former tag is used for ordered listing and the latter tag is used for unordered listing. Below is an example. For the first listing, there will be listed with numbers '1', '2' and '3'. For the second listing, the items will be listed with bullets.

```

<html>
<header>
.....
.....
</header>

<body>
<h2>About Me</h2>
<ol>
<li> I am a <b>professor</b> in NCHU.
<li> I am a <i>professor</i> in NCHU.
<li> I am a <i><b>professor</b></i> in NCHU.
</ol>

<ul>

```

```

<li> I am a <b>professor</b> in NCHU.
<li> I am a <i>professor</i> in NCHU.
<li> I am a <i><b>professor</b></i> in NCHU.
</ul>

</body>
</html>

```

For advanced usage, one can also add a sub-listing (resp. sub-sub-listing) for an item (resp. an item in a sub-listing). This sub-listing (resp. sub-sub-listing) can also be ordered or unordered.

9.3.5 Table

<table> tag is a very useful tag. First, it can help us to add table in a web page. Second, it can be used for formatting the layout of a web page.

Table of data: Below is a simple example showing how data can be displayed in a table.

```

<center>
<table>
<tr> <td></td> <td>John</td> <td>Mary</td> </tr>
<tr> <td>Age</td> <td>35</td> <td>28</td> </tr>
<tr> <td>Income</td> <td>10K</td> <td>20K</td></tr>
</table>
</center>

```

The center tag is used for centering the table. This table will be displayed like the following.

	John	Mary
Age	35	28
Income	10K	20K

Text formatting: Below is an example showing how table tag can be used for formatting the layout of some text in the page.

```

<table>
<tr>

```

```

    <td width=100>Instructor:</td>
    <td><a href="https://john.digi-pack.io/">John Sum</a>,
    <a href="http://itm.nchu.edu.tw/">ITM</a> </td>
</tr>
<tr>
    <td>Office:</td>
    <td>Room 821, CSSM Building </td>
</tr>
<tr>
    <td width>Time:</td>
    <td>Friday 09:10-12:00 </td>
</tr>
<tr>
    <td>Classroom:</td>
    <td>CS121, CSSM Building</td>
</tr>
<tr>
    <td>URL:</td>
    <td>john.digi-pack.io/CS/cs2022fall.html</td>
</tr>
</table>

```

This table consists of two columns and five rows. Due to the page width, I have removed the information about the email addresses. The names of the professor and his affiliation are different from the names shown in the course homepage.

On the first row, the parameter width inside the first `<td>` is to let us specify the width of the first column. This technique is not limited to the first column. The width of any column can be specified in the same manner.

9.3.6 Hyperlink

In the above table example, I have added two hyperlinks. One is linked to my homepage and the other is linked to the homepage of ITM.

```

<a href="https://john.digi-pack.io/">John Sum</a>
<a href="http://itm.nchu.edu.tw/">ITM</a>

```

The tag for this function is called the anchor tag, `<a>`. The text to be highlighted for linking to other URL is embraced inside the tag. Here, 'John

Sum' and 'ITM' are the text to be highlighted. The URL the text to be linked to is specified in the parameter 'href', namely hyperlink reference.

The anchor tag can also be used for linking other URLs, like a document, an image, a video and audio file. If those files are stored in the same directory as the web page, we can simply put the filename inside the quote of the parameter href.

```
<a href="johnface.jpg">John Sum</a>  
<a href="assignment01.docx">Assignment 1</a>  
<a href="assignment02.docx">Assignment 2</a>
```

For sure, one needs to upload those files to the web server. Otherwise, the page will show broken links.

9.3.7 Misc

HTML provides a lot more functions for advanced usages. One of them is the FORM. In my publication page, you might find that there is a text box linking to Google Scholar.

<https://john.digi-pack.io/publication.html>

Moreover, photo can also be displayed on a web page by using the tag . Student can take a look on the web pages in my homepage for other features. For more information regarding HTML, one can search over the Internet for tutorials on HTML programming.

9.3.8 Editor for generating HTML program

To prepare an HTML program, there are many possible ways. As it is a program file, you can use any program editor to edit this program and then save it as an HTML file. In Windows operating system, you can use WordPad or Notepad. These editors are text editors. Notepad will automatically save the file as a text file. WordPad will not do it automatically. You need to select the file type as a text file when you are saving the HTML program.

9.4 Interpreter

Once an html program (e.g. index.html) has been received, the browser interprets the program line by line and then converts each line of code to the corresponding machine code for text display on the browser window. This

mode of conversion is called interpretation. The program doing this is called the interpreter.

A browser must have this interpreter. If the HTML interpreter cannot convert any line of code, it could ignore the line and then proceed to convert the next line of code. For some cases, it generates machine code for displaying error message.

It should be noted that another type of converter is called compiler. It converts the entire program to an executable file. In case there is an error in a line of code, compiler will not do the conversion. Error message will thus be reported.

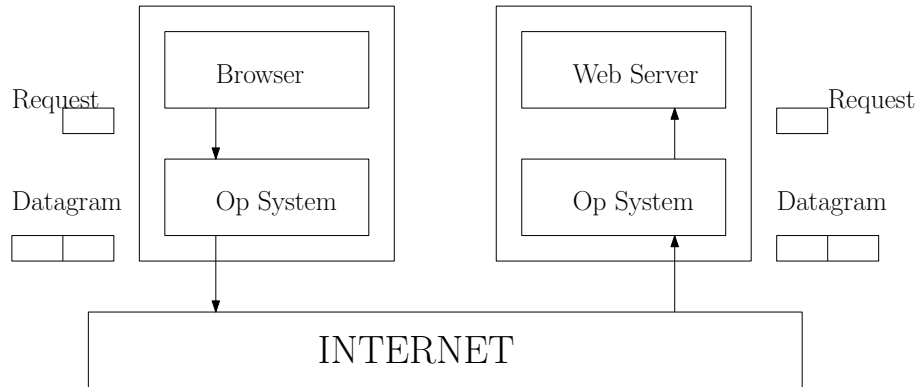
9.5 Web Browsing

Once all the necessary (HTML) files and the image files have been available on the web server, user could browse the web page by using the web browser. The mechanism is illustrated in Figure 12.

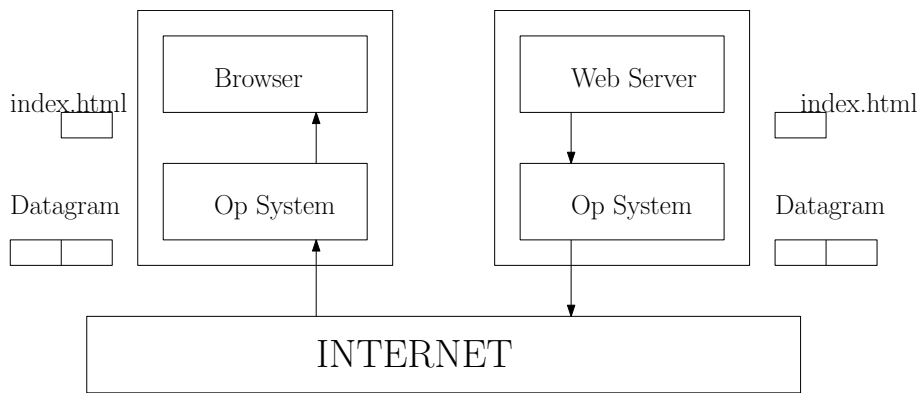
Browser side: Once a user has invoked a browser and entered the URL at the address bar, the browser creates a request message with the URL information inside and pass it to the operating system. Upon receiving the request message, the operating system creates the datagram for the message with (i) source and destination IP addresses, (ii) port number 80 (this number is assigned for HTTP applications), (iii) session ID and other relevant information. The datagram will then pass to the Internet for delivery.

Web server side: Once the datagram has arrived the destination IP address. The operating system of the destination machine will decapsulate the datagram and pass the message to the web server. The web server checks that it is a request for a URL. The web server thus creates a reply message in which the HTML file is included and passes it to the operating system. The operating system then creates a datagram and passes it to the Internet.

Browser side: On the browser machine, the operating system decapsulates the datagram sent from the web server machine and passes the HTML file to the browser. The browser interprets the file and displays the contents in its window.



(a) From browser to web server.



(b) From web server to browser.

Figure 12: Browsing a web page.

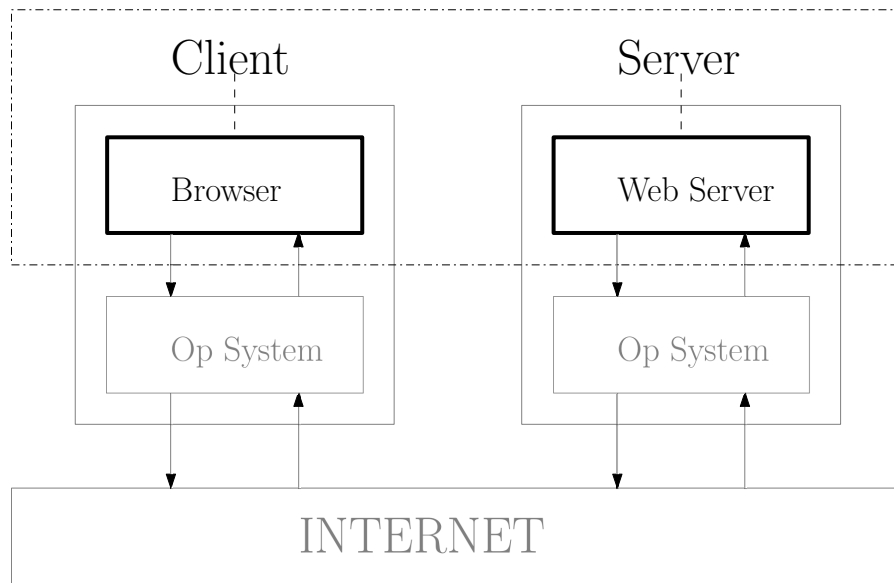


Figure 13: Client-server computing: From application-level perspective.

From application-level point of view, the interaction is also considered as client-server computing, Figure 13. Browser is the client and the web server is the server. The web server serves the browsers which request for services.

10 Other Internet Applications

Web browsing (or web applications) is just one simple application of the Internet. For half a century, many applications have been developed. Clearly, new applications are under development as well. It is not possible to introduce all them in this course. Here, only a few of them are introduced.

10.1 File transfer

File transfer is an important application. As mentioned earlier, the message (or data) encapsulated in a packet is far smaller than a file like a document or a video. A document file could be larger than one mega bytes. In such case, it is needed to chop the file into small segments. The segments are put in the packets and sent to destination IP address. Once the packets have

arrived the destination machine, the machine will need to extract the file segments from the packets and reconstruct the file.

The technologies for this application is embraced in the protocol called file transfer protocol (FTP) which was initially released in 1971 and later in 1980 for TCP/IP version. The software supporting this application is called FTP server. One usage of FTP server is for archiving technical reports.

For each FTP server, there is a default account for public access. In accordance with the protocol, this account name is set to 'anonymous'. The password of this account is nothing (or empty). Let say a FTP server called `ftp.nchu.edu.tw`. It is available for public access.

```
C:\Users\John Sum>ftp ftp.nchu.edu.tw
Connected to ftp.nchu.edu.tw
220 (vsFTPd 3.0.2)
Username: anonymous
Password:
230 Login successful.
ftp>
*
*** Upload or download files ***
*
ftp>quit
C:\Users\John Sum>
```

Once the ftp prompt has been shown, you can enter commands. Again, the set of commands is defined in the protocol. In the FTP environment, you can create a directory and upload your file here. To upload a file, the command 'put' is used. To download a file, you can use the command 'get'. The set of commands can be recalled by typing 'help' on the ftp prompt.

Clearly, this manual way of ftp access is not user friendly for many users. Application systems are thus developed for this file transfer application. FileZilla is one of them⁹.

10.2 Electronic mail (Email)

Another important application on Internet is email. The protocol supporting this application is called simple mail transfer protocol (SMTP) which was

⁹URL: <https://en.wikipedia.org/wiki/FileZilla>.

introduced in 1981. Nowadays, almost all webmail systems are developed based upon this protocol. Two notable inventions in SMTP is the symbol @ and the format of an email address, like `pfsun@nchu.edu.tw`.

The characters on the left hand side of @ is the account name of the user who is able to access the SMTP server, yet another application system. The characters on the right hand side of @ is the domain name. As one domain usually has one mail server, email messages will be automatically routed to the mail server once it has arrived the machine corresponding to `nchu.edu.tw`. In NCHU, the mail server handling the emails for the teaching staff is named `dragon.nchu.edu.tw`. So, it is no different to send the email to `pfsun@nchu.edu.tw` or `pfsun@dragon.nchu.edu.tw`.

11 Other Communication Networks

Telephone network and Internet are just two exemplar communication networks. In reality, there are many other communication networks in the world.

11.1 Existing networks

Here, let us name a few.

- ATM network: Network connecting the automatic teller machines and the banking systems.
- Vehicle network: Network connecting the computers in vehicles.
- Sensor network: Network connecting sensors for monitoring a specific area its temperature, humidity, PM2.5 and so on. These networks are usually applied for environmental monitoring. Some of them are deployed on land and some of them are deployed under the sea.
- Personal area network (PAN): Network connecting your cell phone and wearable devices. One application of PAN is for health care monitoring.
- Amazon GO, Google Home: Network of home appliances and the voice command interfacing device.

Each of these networks has its own communication protocol. Today, these technologies are rather mature.

Still, scientists and engineers have long time ago forseen the increasing demand of network traffic and started to develop alternative communication networks to supplement the Internet. In recent years, Google and Facebook have also involved in developing such networks. Google launched a project called Project Loon¹⁰. Facebook launched a project called Aquila¹¹.

11.2 Networks under development

For the Project Loon, big balloons are sent up to the sky. Each balloon has been equipped with a wireless communication device. Thus, the balloons are able to form big wireless communication network. On one hand, each balloon acts as a router for routing messages and connecting to some Internet base stations. On the other hand, each balloon acts as an access point for the devices on ground.

For the project Aquila, unmanned flying vehicles are deployed in the sky. Similarly, each flying vehicle is equipped with a wireless communication device. So that, it can connect to other flying vehicle to form a mobile wireless network. Again, each flying vehicle acts as a router for routing message and as an access point for the ground devices and Internet base stations.

These two networks are still under development. These projects have at least two goals. First, they could supplement the Internet by handling part of the traffic load. Second, the networks could cover the areas in which the existing communication networks cannot cover, like desert, mountains and sea. Currently, users in these areas can only access the telephone networks or Internet via satellites. It is way more expensive.

11.3 Network for outerspace communication

For more than a decades, there have been a lot of researches on the development of outerspace communication network. Imagine that you would like to send an email from the earth to Mars. How could it be possible? Scientists and engineers are now working on it.

One approach is to let spacecrafts act as carriers and routers. At the same time, satellites are put in orbiting at every planet in the solar system. Those spacecrafts and satellites act as base stations for routing messages.

¹⁰URL: https://en.wikipedia.org/wiki/Loon_LLC.

¹¹URL: https://en.wikipedia.org/wiki/Facebook_Aquila.

12 Conclusions

In simple words, computer network is simply a network for sending data from one computer to another computer. The technologies (or the protocols) developed are to ensure that the data received in the destination computer is identical to the data sent from the source computer. The global network is computer networks becomes to day Internet. Applications can thus be developed on top of Internet for various purposes, such as file transfer and send mail.

Additional concepts on computer networks have been introduced. The mechanism how an operating system manages the sessions by using process IDs is elucidated. An application of Internet, namely HTTP, has been described and how to encode a webpage by using HTML is introduced. Finally, some other Internet applications like file transfer and sending email are mentioned. Other communication networks are introduced.

To extend the coverage of the communication networks is a never-stop project. It relies on the effort of the scientists and engineers to make it real. Internet is just part of it. I must say that we should appreciate all those engineers and scientists who have involved in the development of Internet. Radio engineers, electrical engineers and even scientists developed many technologies to ensure smooth transmission of physical signals (i.e. electrical signal or radio signal). Computer scientists and mathematicians developed error detection and correction technologies. Moreover, they developed many encryption technologies to ensure network security. Building of such a extraordinary Internet is one of the mega project in the 20 century.

Finally, I would like to highlight that the role of the Internet is essentially the same as the role of a third part logistic (3PL) firm, see Table 2. The Internet is helping to deliver a data from one computer to another. A 3PL firm is helping to deliver a product from one firm to another. Many problems aroused in network operations design are also encountered in the operations design in the 3PL firm.

13 Review Questions

13.1 Question 1

1. What is the use of IP address?

Table 2: Internet versus 3PL.

Internet	3PL
A Computer	A Firm
IP address	Postal address of a firm
Message routing	Product routing
Processor	Factory
Memory	Warehouse
Logic gates	Tools/Machines
Switches	Workers
Registers	Working space for semi-products
Control unit	Operations manager
A memory address	A location in the warehouse
A memory space	A space for storing a product
Data specification	Product specification
Operating system (OS)	Executives (Top/Senior/Middle)
Set of instructions	Set of services (resp. productions)
An instruction	A service request
A micro-program	An operation procedure
Levels of programming	Levels of management
Micro-instructions design	Operating procedure design
Processor design	Factory design
Memory device design (Design for efficiently storage & retrieval of data)	Warehouse design (Design for efficiently storage & retrieval of products)
Architecture design	Organization design
Program design	Operations design
Computer designers	Executives (Top/Senior/Middle)

2. What is the use of MAC address?
3. What is the use of PORT ID?
4. What is the use of session ID?
5. What do TCP and IP stand for?
6. What is the use of domain name system (DNS)?
7. Once a device, like smartphone and notebook, has been manufactured, it will be assigned with unique address (or ID). What is the name of this address (or ID) and what is it used for?
8. In simple words, what is the ultimate goal of technologies developed behind TCP/IP?
9. What is the format of an IP datagram?
10. Describe the mechanism of CSMA/CA in medium access control.
11. You are now in Taiwan. Your telephone service is subscribed from a Taiwan telecom firm. You have set your phone WiFi OFF but cellular ON. Describe the mechanism how the browser in your cell phone can connect to Google.
12. Imagine that you are now in HK. Your telephone service is subscribed from a Taiwan telecom firm. In HK, you set your phone WiFi OFF but cellular ON. Describe the mechanism how the browser in your cell phone can connect to Google.
13. Without connecting to the Internet, is it possible to connect notebooks to form a local area network for data communication?
14. Name three application protocols and describe what applications they support.
15. Describe under what conditions, a packet can be lost.
16. Search over the Internet and find in which year the APARNET project was launched.

17. In telephone network, after a caller has dialed and connected to another phone, both phone users can talk to each other. Which switching method is applied to make this connection?
18. VOIP is a protocol (i.e. a collection of technologies) for sending voice signal from one computer to another over the Internet. Which switching method is applied to make this connection?
19. What is the key difference between message and packet switching?
20. Is encryption technology embraced in TCP or IP?
21. Is HTTP embraced in TCP or IP?

13.2 Question 2

1. How does an operating system identify which process a message should be pass to?
2. Which system is going to create the datagram?
3. In this chapter, it has introduced two perspectives on client-server computing. What are they?
4. To make a web application work, we need at least two software. What are they?
5. The above two software have to be designed in accordance with an application protocol. What is it?
6. What is the protocols developed in the transport layer responsible for?
7. What editors can be used for creating an HTML file?
8. What is the program structure of a HTML program?
9. Describe the differences between `` and `` tags.
10. Describe the use of `<th>` in the table environment.
11. In which machine the HTML file should be uploaded?
12. The translator in the browser is an interpreter or a compiler?

13. What is the default port number of HTTP applications?
14. Describe how a file is transferred from the FTP server to the client computer.
15. Name a few existing communication networks and describe what they are used for.
16. State two goals that the projects Loon and Aquila would like to achieve.