

Module 2

Circuit and Packet Switching

Switching

- **Need for switching:**

Whenever we have many devices, the interconnection between them becomes more difficult as the number of devices increases.

- Some of the conventional ways of interconnecting devices are;
 - Point-to-point connection between devices as in a mesh topology.
 - Connection between a central device and every other device as in star topology.
 - Bus topology, not practical if the devices are at great distances.
- **All these techniques require extensive cabling, dependence on a central server or a central bus.**
- The better solution to this interconnectivity problem is **switching**.

Switching

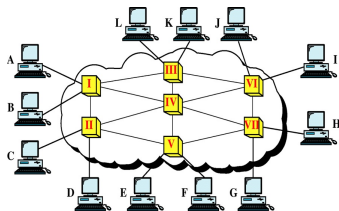
- **Switched Network:**
A switched network consists of a series of interlinked nodes, called switches.

Switching

- **Switched Network:**
A switched network consists of a series of interlinked nodes, called switches.
- **Switch:**
A switch is a hardware/software device that creates temporary connections between two or more systems.

Switching

- **Switched Network:**
A switched network consists of a series of interlinked nodes, called switches.
- **Switch:**
A switch is a hardware/software device that creates temporary connections between two or more systems.
- Some of the switches are connected to the end systems (computers or telephones) and others are used only for routing.



- In this diagram, A to L are the end systems (stations).
The switches(nodes) are labeled I, II, III, etc. Each switch is connected to multiple links.

Switching

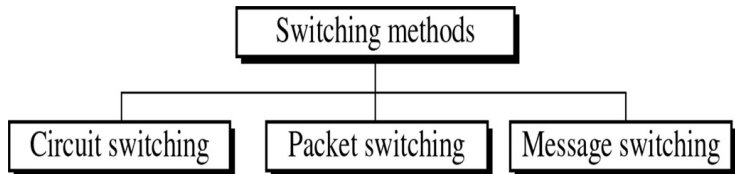


Figure 1 : Classification of switching methods

Switching

- **Circuit switching:**
 - Circuit-switching takes place at the physical layer in the OSI model.
 - A dedicated path is established between two end stations.
 - Before communication between two computers starts, they must reserve the resources such as channels, switch buffers, switch processing time, and these must be reserved during the entire duration of data transfer.
 - In case data transfer is by FDM, a bandwidth must be reserved and if it is by TDM, a time slot must be reserved.
 - Data is sent in a continuous flow from source to destination.
Data is not broken up into packets.
 - During the setup phase addressing is involved, but once data transmission begins, addressing is not involved.

Switching

Time-division

- Each circuit allocated certain time slots



Frequency-division

- Each circuit allocated certain frequencies



Figure 2 : Circuit switching: Multiplexing a Link

Switching

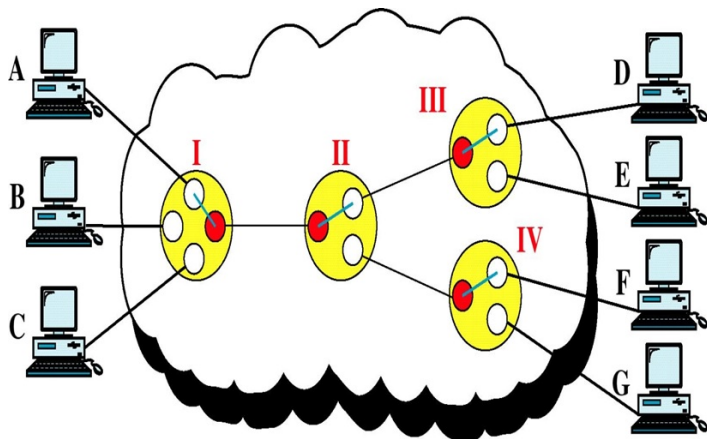


Figure 3 : Circuit switched Network

Switching

- Phases in Circuit switching:

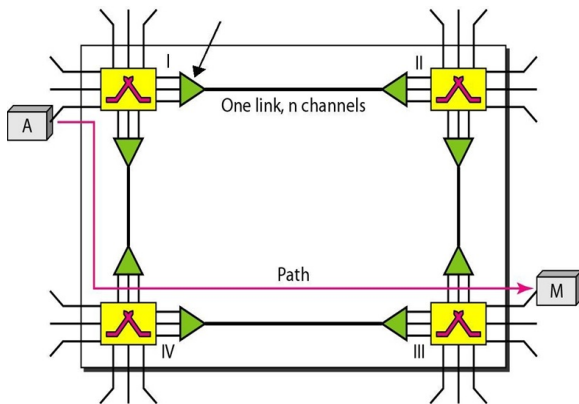
The actual communication in circuit switching requires three phases;

- connection setup or circuit establishment
- data transfer
- connection teardown or circuit disconnect

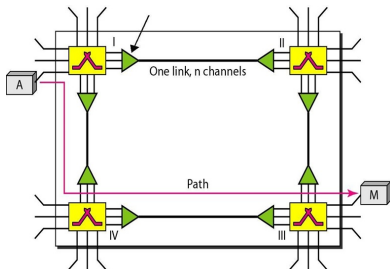
Switching

- Connection Setup Phase

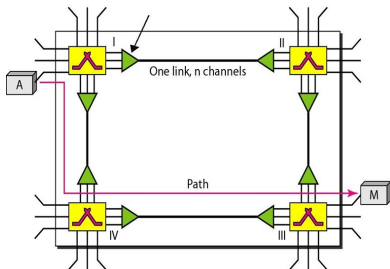
Connection setup means creating dedicated channels between the switches



- Before the two systems can communicate, a dedicated circuit (i.e. a combination of channels and links) must be established.
- For example, in the given Fig, when system *A* needs to communicate to system *M*, it sends a setup request to switch I. This request contains the address of system *M*.

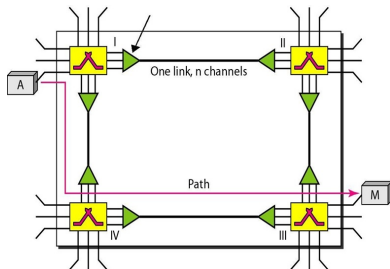


- Before the two systems can communicate, a dedicated circuit (i.e. a combination of channels and links) must be established.
- For example, in the given Fig, when system *A* needs to communicate to system *M*, it sends a setup request to switch I.
This request contains the address of system *M*.



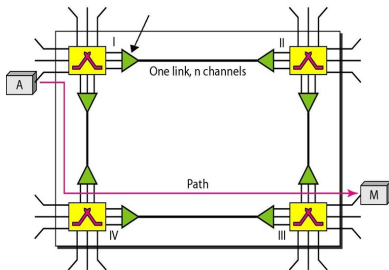
- Switch I finds a channel between itself and switch IV.

- Before the two systems can communicate, a dedicated circuit (i.e. a combination of channels and links) must be established.
 - For example, in the given Fig, when system A needs to communicate to system M, it sends a setup request to switch I.
- This request contains the address of system M.



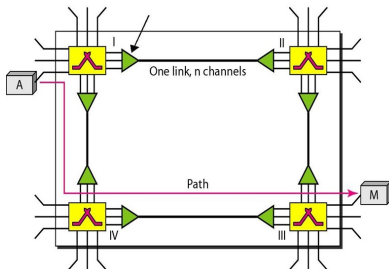
- Switch I finds a channel between itself and switch IV.
- Switch I then sends the request to switch IV.

- Before the two systems can communicate, a dedicated circuit (i.e. a combination of channels and links) must be established.
 - For example, in the given Fig, when system *A* needs to communicate to system *M*, it sends a setup request to switch I.
- This request contains the address of system *M*.



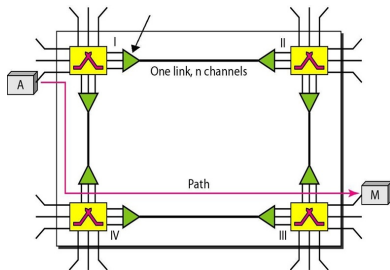
- Switch I finds a channel between itself and switch IV.
- Switch I then sends the request to switch IV.
- Switch IV finds a dedicated channel between itself and switch III.

- Before the two systems can communicate, a dedicated circuit (i.e. a combination of channels and links) must be established.
 - For example, in the given Fig, when system *A* needs to communicate to system *M*, it sends a setup request to switch I.
- This request contains the address of system *M*.



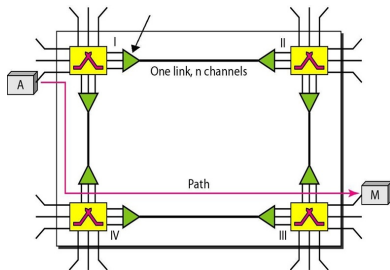
- Switch I finds a channel between itself and switch IV.
- Switch I then sends the request to switch IV.
- Switch IV finds a dedicated channel between itself and switch III.
- Switch III informs system *M* that system *A* wants to communicate.

- Before the two systems can communicate, a dedicated circuit (i.e. a combination of channels and links) must be established.
 - For example, in the given Fig, when system A needs to communicate to system M, it sends a setup request to switch I.
- This request contains the address of system M.



- Switch I finds a channel between itself and switch IV.
- Switch I then sends the request to switch IV.
- Switch IV finds a dedicated channel between itself and switch III.
- Switch III informs system M that system A wants to communicate.
- System M then sends an acknowledgement in the opposite direction to system A.

- Before the two systems can communicate, a dedicated circuit (i.e. a combination of channels and links) must be established.
 - For example, in the given Fig, when system A needs to communicate to system M, it sends a setup request to switch I.
- This request contains the address of system M.



- Switch I finds a channel between itself and switch IV.
- Switch I then sends the request to switch IV.
- Switch IV finds a dedicated channel between itself and switch III.
- Switch III informs system M that system A wants to communicate.
- System M then sends an acknowledgement in the opposite direction to system A.
- Once A receives the acknowledgment, the connection is established.

Switching

- **Data Transfer Phase:**

Once a dedicated path is established between the two systems, data transfer can take place.

Switching

- **Data Transfer Phase:**

Once a dedicated path is established between the two systems, data transfer can take place.

- **Tear-down Phase:**

When one of the systems needs to disconnect (after data transfer is completed or after a time-out event), a signal is sent to each switch to release the resources.

Switching

- Issues in Circuit Switching:

- Circuit-switched networks are not as efficient as packet and message switched networks.
- A channel is a resource and it is allocated during the entire duration of the connection.
- These resources are not available to other systems.
That is, once a dedicated path is established between two computers, the path may remain connected even when no data transmission is taking place.

Switching

- Delay:

The total delay is due to the time needed to create a connection, transfer data, and disconnect the circuit.

Switching

- **Delay:**
The total delay is due to the time needed to create a connection, transfer data, and disconnect the circuit.
- The delay caused by the setup is the sum of
 - (i) Propagation time of the source computer request
 - (ii) Signal transfer time of the request
 - (iii) Propagation time of the acknowledgement from the destination to the source
 - (iv) Signal transfer time of the acknowledgment

Switching

- **Delay:**
The total delay is due to the time needed to create a connection, transfer data, and disconnect the circuit.
- The delay caused by the setup is the sum of
 - (i) Propagation time of the source computer request
 - (ii) Signal transfer time of the request
 - (iii) Propagation time of the acknowledgement from the destination to the source
 - (iv) Signal transfer time of the acknowledgment
- The delay due to transfer is the sum of two parts
 - (i) propagation time
 - (ii) data transfer time.

Switching

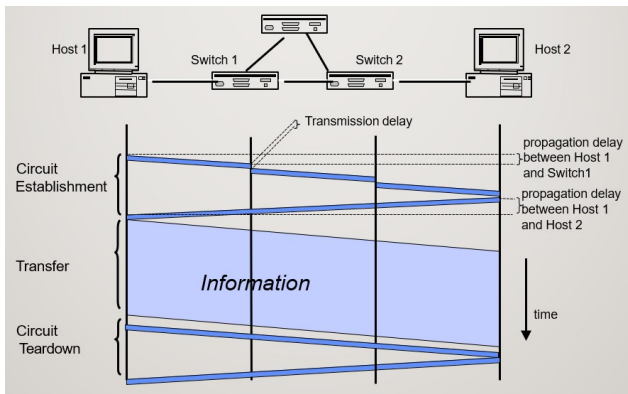


Figure 4 : Timing in circuit switching

Switching

- Total Delay:

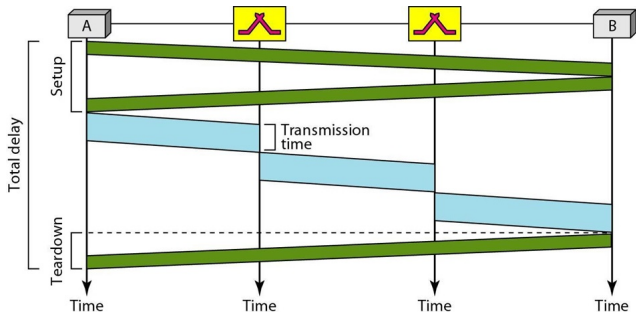


Figure 5 : Delay in circuit switched network for one single packet

Switching

- Advantages:

- Since a circuit is dedicated to a data transmission there is no interference and no sharing of data.
- The full bandwidth of the channel is guaranteed for the duration of the call.

Switching

- **Disadvantages:**

- Takes a relatively long time to setup the circuit.
- A channel is reserved for the duration of the connection even if no data transfer is taking place.

The channel may not be utilized to its maximum.

- Transmission takes place at a constant rate. The two devices that are interconnected must transmit and receive at the same rate.
- Inflexible, once a circuit has been established, that path is taken by all parts of the transmission whether or not it remains the most efficient path.
- Circuit switching treats all transmission as equal. There is no priority among transmission of data.

Switching

- **Exercise1:** How long does it take to send a file of 640,000 bits (1 byte = 8bits) from host *A* to host *B* over a circuit-switched network?
Assume that, all links are 1.536 *Mbps*, each link uses TDM with 24 slots/sec and 500ms to establish end-to-end circuit (setup time including propagation delay).

Switching

- **Exercise1:** How long does it take to send a file of 640,000 bits (1 byte = 8bits) from host *A* to host *B* over a circuit-switched network?

Assume that, all links are 1.536 *Mbps*, each link uses TDM with 24 slots/sec and 500ms to establish end-to-end circuit (setup time including propagation delay).

- **Solution:**

Single circuit speed = $1.536 \text{ Mbps} / 24 = 64 \text{ kbps}$

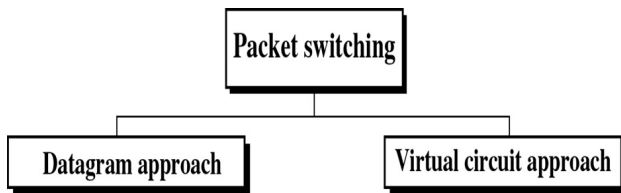
File Transmission time = $500 \text{ ms} + \text{filesize} / \text{speed}$

= $0.5 \text{ sec} + 640000 \text{ bits} / 64 \text{ kbps}$

= 10.5 sec

Packet Switching

Packet Switching



Packet Switching

- Datagram Networks or Connectionless Network: Characteristics
 - Create Packets
 - No resource allocation

Packet Switching

- **Datagram Networks or Connectionless Network: Characteristics**
 - Create Packets
 - No resource allocation
- **Create Packets:**
 - Before transmission, a message is broken down into smaller segments called packets of a particular size.
 - This size may be fixed or variable.
 - The size of the packet is determined by the network and the protocol.
 - Typically, packet size is 1000 bytes.
 - Each packet contains users data and some control information

Packet Switching

- **Datagram Networks or Connectionless Network: Characteristics**
 - Create Packets
 - No resource allocation
- **Create Packets:**
 - Before transmission, a message is broken down into smaller segments called packets of a particular size.
 - This size may be fixed or variable.
 - The size of the packet is determined by the network and the protocol.
 - Typically, packet size is 1000 bytes.
 - Each packet contains users data and some control information
- **No resource allocation:**
 - In packet switching, there is no resource allocation for a packet.
 - This means that there is no reserved bandwidth on the links, and there is no scheduled processing time for each packet.
 - Resources are allocated on demand.
 - The allocation is done on a first-come, first-served basis

- **Store-and-Forward:**

The packets are passed from node to node and the nodes may store the data briefly before passing it to the next node.

- **Store-and-Forward:**

The packets are passed from node to node and the nodes may store the data briefly before passing it to the next node.

- **Delay:**

When a switch receives a packet, the packet must wait if there are other packets being processed. This can create a delay. A switch uses its routing table to decide the port that is to be used.

- **Store-and-Forward:**

The packets are passed from node to node and the nodes may store the data briefly before passing it to the next node.

- **Delay:**

When a switch receives a packet, the packet must wait if there are other packets being processed. This can create a delay. A switch uses its routing table to decide the port that is to be used.

- **Packets are independent entities:**

In a datagram network, each packet is treated independently of all others. Even if a packet is part of a multipacket transmission, the network treats it as though it existed alone.

Packets in this approach are referred to as datagrams.

- **Store-and-Forward:**

The packets are passed from node to node and the nodes may store the data briefly before passing it to the next node.

- **Delay:**

When a switch receives a packet, the packet must wait if there are other packets being processed. This can create a delay. A switch uses its routing table to decide the port that is to be used.

- **Packets are independent entities:**

In a datagram network, each packet is treated independently of all others. Even if a packet is part of a multipacket transmission, the network treats it as though it existed alone.

Packets in this approach are referred to as datagrams.

- **Different Routes:** The different packets of a message may follow different routes before they reach the destination. This may happen because a link is already involved in carrying packets from other sources and there is not enough bandwidth to carry more packets.

- Variable Delay due to different paths:

Since the packets can follow different routes there is a variable amount of delay and the packets may arrive out of order at the destination. Some packets may also be lost.

- **Variable Delay due to different paths:**

Since the packets can follow different routes there is a variable amount of delay and the packets may arrive out of order at the destination. Some packets may also be lost.

- **Reordering of datagrams:**

An upper-layer protocol will reorder the datagrams or ask for lost datagrams before passing them on to the application layer.

The Internet Protocol (IP) transports data in packets called datagrams.

- **Variable Delay due to different paths:**

Since the packets can follow different routes there is a variable amount of delay and the packets may arrive out of order at the destination. Some packets may also be lost.

- **Reordering of datagrams:**

An upper-layer protocol will reorder the datagrams or ask for lost datagrams before passing them on to the application layer.

The Internet Protocol (IP) transports data in packets called datagrams.

- **Connectionless:** Datagram networks are also called connectionless networks. It means that a switch does not keep information about the connection state. There are no setup or teardown phases.

Packet Switching

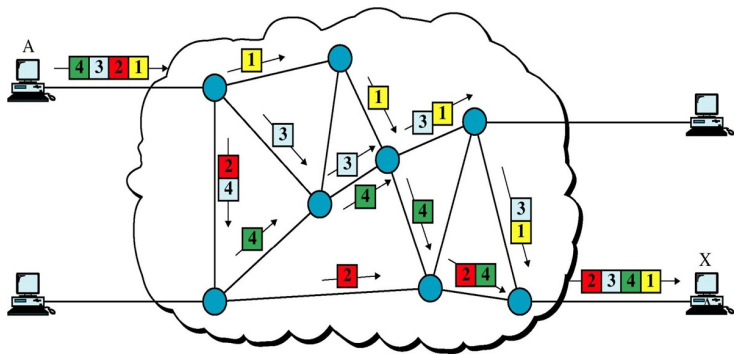
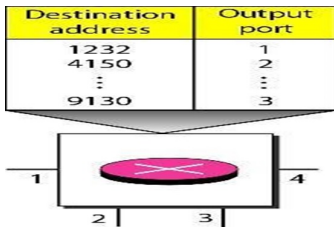


Figure 6 : Datagram approach

- **Role of routing table in datagram approach:**

- In a datagram network, each switch has a routing table that is updated periodically.
- The destination addresses and the corresponding forwarding ports are stored in the tables.
- Each packet in a datagram network carries a header. This header contains data, and the destination address.
- When a switch receives a packet, it checks the destination address, and from the routing table finds the corresponding port through which the packet should be forwarded.



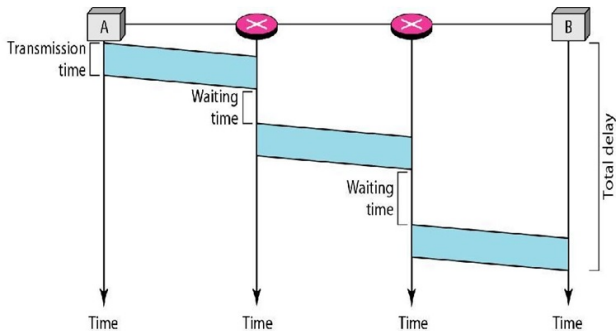


Figure 7 : Delay in a datagram network for one single packet

- Advantages:

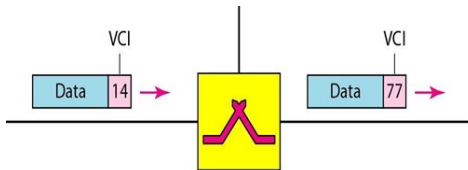
- Packet-switching is more economical than transmission over private/dedicated lines if the data transmission is short.
- Different packets can travel along different routes till they reach their destination. Thus, a failure in one switch/node or a particular link does not affect data communication.
- Packets are accepted even when network is busy.
- Priority scheme can be used (some packets/messages have a higher priority than others)

Virtual Circuit Approach

- **Virtual Circuit Approach:**

Virtual circuit networks involve two addresses;

- **Global address:** A source or a destination must have a global address i.e., an address that is unique in the scope of the network.
- **Virtual-Circuit Identifier(VCI):** The identifier that is actually used for data transfer is called the virtual-circuit identifier.
 - A VCI is a small number that has only switch scope;
 - It is used between two switches.
 - When a frame arrives at a switch, it has a VCI; when it leaves, it has a different VCI.
 - The VCI in a data frame changes from one switch to another as shown in Fig.



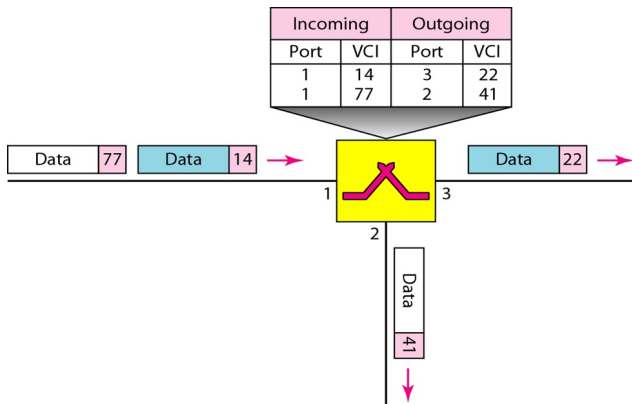


Figure 8 : Switch and tables in a virtual circuit network

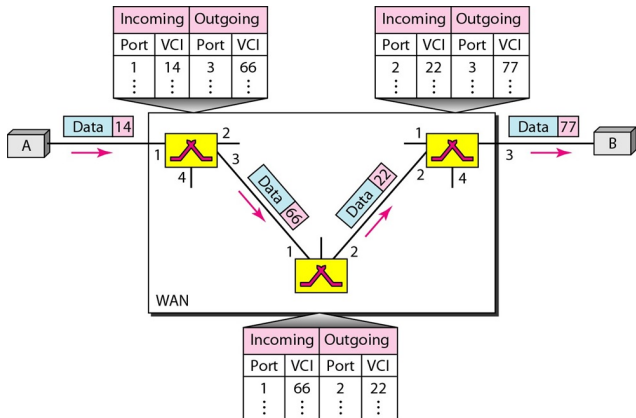


Figure 9 : Source to destination data transfer in a virtual circuit network

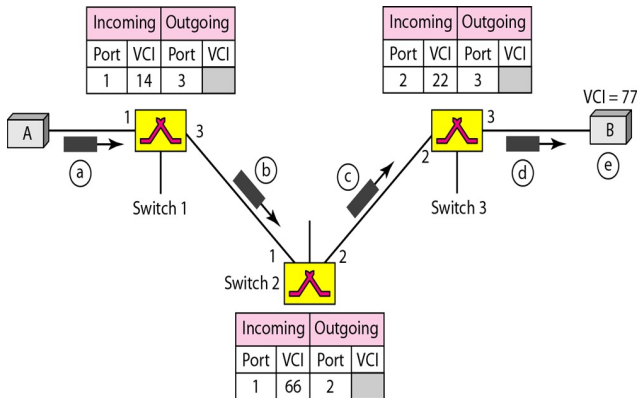


Figure 10 : Setup request in a virtual-circuit network

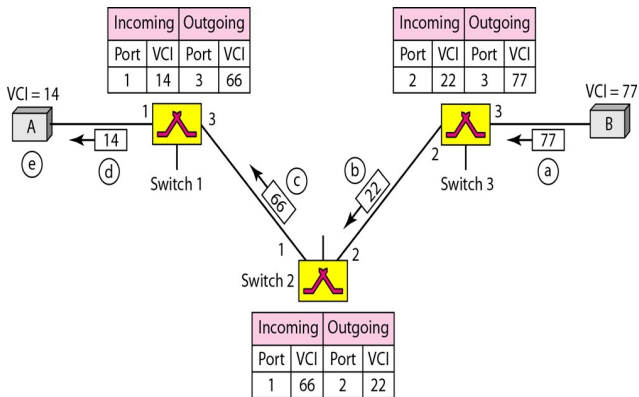


Figure 11 : Setup acknowledgement in a virtual-circuit network

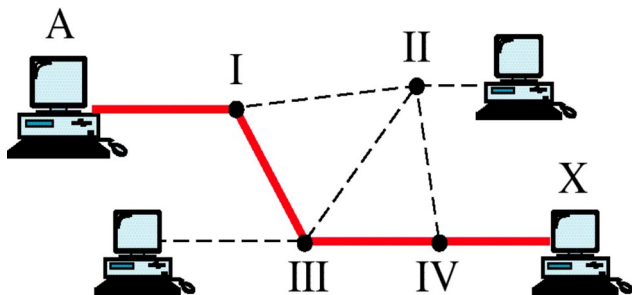


Figure 12 : Connection establishment

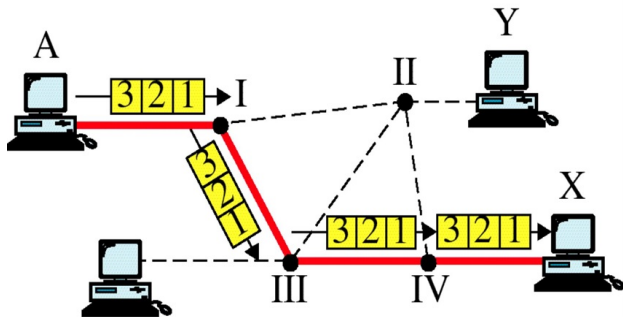


Figure 13 : Data transfer

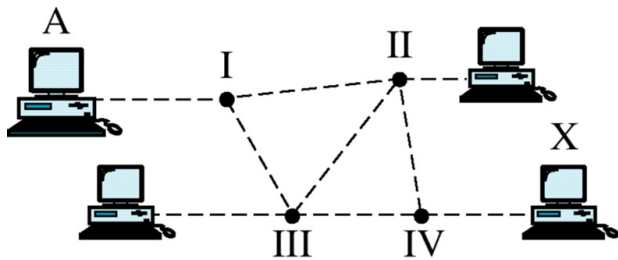


Figure 14 : Connection release

Packet Switching

- In virtual-circuit switching, all packets belonging to the same source and destination travel the same path; but the packets may arrive at the destination with different delays if resource allocation is on demand.

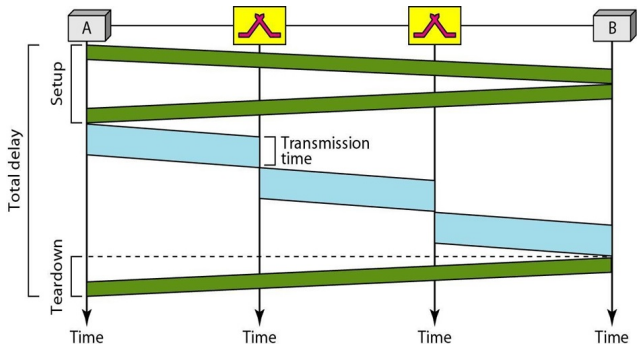


Figure 15 : Delay in a virtual circuit switching for one single packet

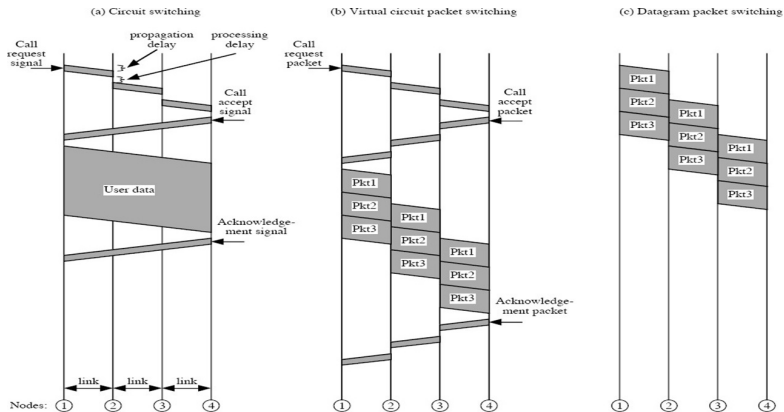


Figure 16 : Event timing for circuit switching and packet switching

Circuit Switching	Datagram Packet Switching	Virtual Circuit Packet Switching
Dedicated transmission path	No dedicated path	No dedicated path
Continuous transmission of data	Transmission of packets	Transmission of packets
Fast enough for interactive	Fast enough for interactive	Fast enough for interactive
Messages are not stored	Packets may be stored until delivered	Packets stored until delivered
The path is established for entire conversation	Route established for each packet	Route established for entire conversation
Call setup delay; negligible transmission delay	Packet transmission delay	Call setup delay; packet transmission delay
Busy signal if called party busy	Sender may be notified if packet not delivered	Sender notified of connection denial
Overload may block call setup; no delay for established calls	Overload increases packet delay	Overload may block call setup; increases packet delay
Electromechanical or computerized switching nodes	Small switching nodes	Small switching nodes
User responsible for message loss protection	Network may be responsible for individual packets	Network may be responsible for packet sequences
Usually no speed or code conversion	Speed and code conversion	Speed and code conversion
Fixed bandwidth	Dynamic use of bandwidth	Dynamic use of bandwidth
No overhead bits after call setup	Overhead bits in each packet	Overhead bits in each packet

Figure 17 : Comparison

- **Exercise1:** Five equal size datagrams belonging to the same message leave for the destination one after another. However, they travel through different paths as shown in the following table.

Assume that, the delay for each switch(including waiting and processing time) is 3, 10, 20, 7 and 20ms respectively. Assuming that, the propagation speed is 2×10^8 m/s. Find the order the datagrams arrive at the destination and the delay for each. Ignore any other delays in transmission.

Datagram	Path Length	Visited Switches
1	3200 Km	1,3,5
2	11,700 Km	1,2,5
3	12,200 Km	1,2,3,5
4	10,200 Km	1,4,5
5	10,700 Km	1,4,3,5

Performance Metrics

Performance Metrics

- **Bandwidth:**
One characteristic that measures network performance is bandwidth.

Performance Metrics

- **Bandwidth:**

One characteristic that measures network performance is bandwidth.

- **Bandwidth in Hertz**

Bandwidth in hertz is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass.

Example: bandwidth of a subscriber telephone line is 4 kHz.

- **Bandwidth in Bits per Seconds**

The term bandwidth can also refer to the number of bits per second that a channel, a link, or even a network can transmit.

For example, one can say the bandwidth of a Fast Ethernet network (or the links in this network) is a maximum of 100 Mbps. This means that this network can send 100 Mbps.

Performance Metrics

- **Throughput:**

The throughput is a measure of how fast we can actually send data through a network.

- Although, bandwidth in bits per second and throughput seem the same but they are different.
- A link may have a bandwidth of B bps, but we can only send T bps through this link with T always less than B .
- In other words, the bandwidth is a potential measurement of a link; the throughput is an actual measurement of how fast we can send data.
For example: we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link.

Performance Metrics

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Performance Metrics

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

$$\text{Throughput} = \frac{12000 \times 10000}{60} = 2 \text{ Mbps}$$

The throughput is almost one-fifth of the bandwidth in this case.

Performance Metrics

- Latency(Delay)

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

Performance Metrics

- Latency(Delay)

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

- Thus latency is made of four components:

- (1) propagation time
- (2) transmission time
- (3) queuing time
- (4) processing delay

Latency = propagation time + transmission time + queuing time + processing delay

Performance Metrics

- **Propagation Time:** Propagation time measures the time required for a bit to travel from the source to the destination.
The propagation time is calculated by dividing the distance by the propagation speed.

$$\text{Propagation time} = \frac{\text{Distance}}{\text{Propagation speed}}$$

- The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal
For example, in a vacuum, light is propagated with a speed of 3×10^8 mls. It is lower in air; it is much lower in cable.

Performance Metrics

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 mls in cable.

Performance Metrics

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 mls in cable.

Solution

We can calculate the propagation time as

$$\text{Propagation Time} = \frac{12000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

Performance Metrics

- **Transmission Time:**

The first bit may take a time equal to the propagation time to reach its destination; the last bit also may take the same amount of time.

- However, there is a time between the first bit leaving the sender and the last bit arriving at the receiver.
- The first bit leaves earlier and arrives earlier; the last bit leaves later and arrives later.
- The time required for transmission of a message depends on the size of the message and the bandwidth of the channel.

$$\text{Transmission Time} = \frac{\text{Message Size}}{\text{Bandwidth}}$$

Performance Metrics

What are the propagation time and the transmission time for a 5-Mbyte message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

Performance Metrics

What are the propagation time and the transmission time for a 5-Mbyte message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

Solution

We can calculate the propagation and transmission times as

$$\text{Propagation Time} = \frac{12000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission Time} = \frac{5,000,000 \times 8}{10^6} = 40 \text{ s}$$

Note that in this case, because the message is very long and the bandwidth is not very high, the dominant factor is the transmission time, not the propagation time.

The propagation time can be ignored.

Performance Metrics

- **Queuing Time:**

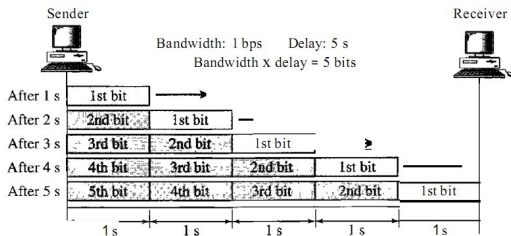
The third component in latency is the queuing time, the time needed for each intermediate or end device to hold the message before it can be processed.

- The queuing time is not a fixed factor; it changes with the load imposed on the network.
- When there is heavy traffic on the network, the queuing time increases. An intermediate device, such as a router, queues the arrived messages and processes them one by one. If there are many messages, each message will have to wait.

Performance Metrics

- **Bandwidth-Delay Product:**

Bandwidth and delay are two performance metrics of a link. However, what is very important in data communications is the product of the two, the bandwidth-delay product.



Performance Metrics

- The product of bandwidth and delay is the number of bits that can fill the link.
- This measurement is important if we need to send data in bursts and wait for the acknowledgment of each burst before sending the next one.
- To use the maximum capability of the link, we need to make the size of our burst 2 times the product of bandwidth and delay;
- The sender should send a burst of data of $(2 \times \text{bandwidth} \times \text{delay})$ bits.
- The sender then waits for receiver acknowledgment for part of the burst before sending another burst.
- The amount $2 \times \text{bandwidth} \times \text{delay}$ is the number of bits that can be in transition at any time.



Performance Metrics

- **Jitter:**
Another performance issue that is related to delay is jitter. We can roughly say that jitter is a problem if different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive (audio and video data).
- If the delay for the first packet is 20 ms, for the second is 45 ms, and for the third is 40 ms, then the real-time application that uses the packets endures jitter.

*Thank you
&
Queries*