UNIT- 2

Physical Layer and Overview of PL Switching

Objectives:

Build an understanding of the fundamental concepts of multiplexing and switching.

Syllabus:

Physical Layer: Multiplexing- frequency division multiplexing, synchronous time division multiplexing, statistical time division multiplexing, Introduction to switching - circuit switched networks, datagram networks, virtual circuit networks.

Outcomes:

Students will be able to

- Identify the different types of multiplexing and their functions within a network
- Compare and contrast different multiplexing techniques
- Enumerate the techniques of switching
- Compare different switching techniques
- Explain the concept of switching, and identify and analyze the different types of delay in switched networks

Learning Material

MULTIPLEXING

Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals cross a single data link.

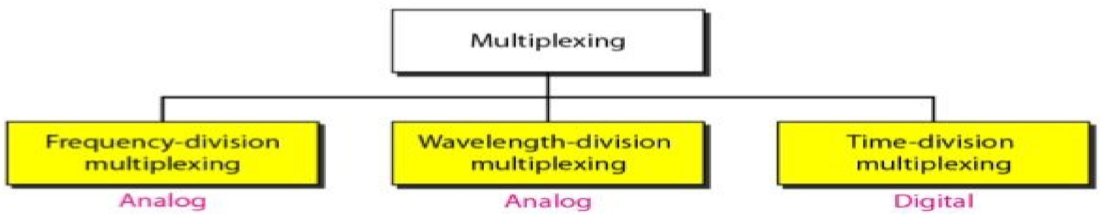


Figure : *Categories of multiplexing*

Frequency-Division Multiplexing

Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted. In FOM, signals generated by each sending device modulate different carrier frequencies.

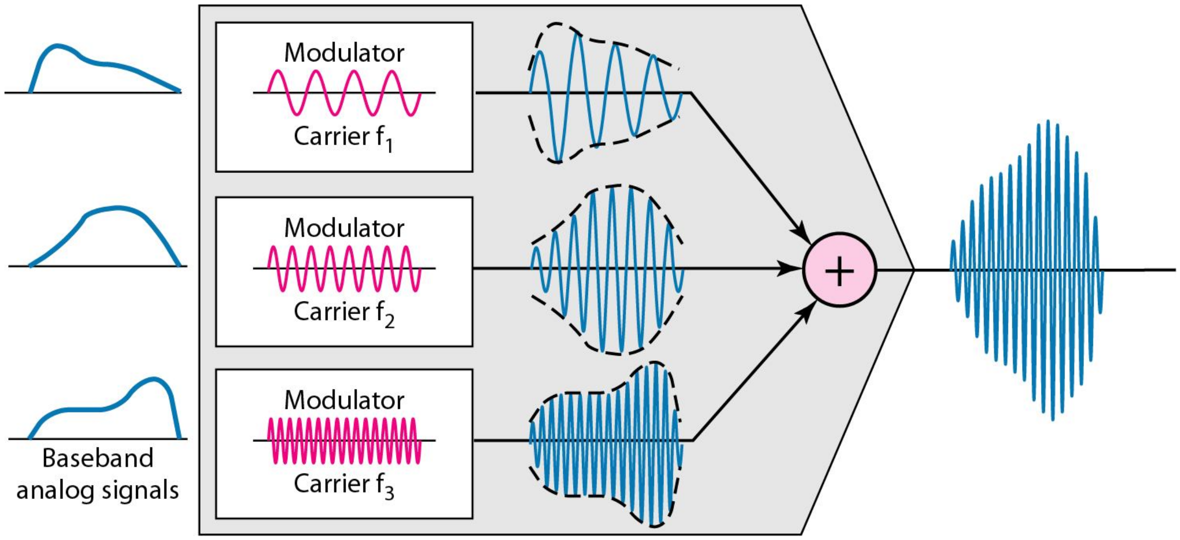
- These modulated signals are then combined into a single composite signal that can be transported by the link. Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal. These bandwidth ranges are the channels through which the various signals travel. Channels can be separated by strips of unused bandwidth-guard bands-to prevent signals from overlapping. In addition, carrier frequencies must not interfere with the original data frequencies.

- Figure 1 gives a conceptual view of FDM. In this illustration, the transmission path is divided into three parts, each representing a channel that carries one transmission.

- We consider FDM to be an analog multiplexing technique; however, this does not mean that FDM cannot be used to combine sources sending digital signals. A digital signal can be converted to an analog signal before FDM is used to multiplex them.

Multiplexing Process

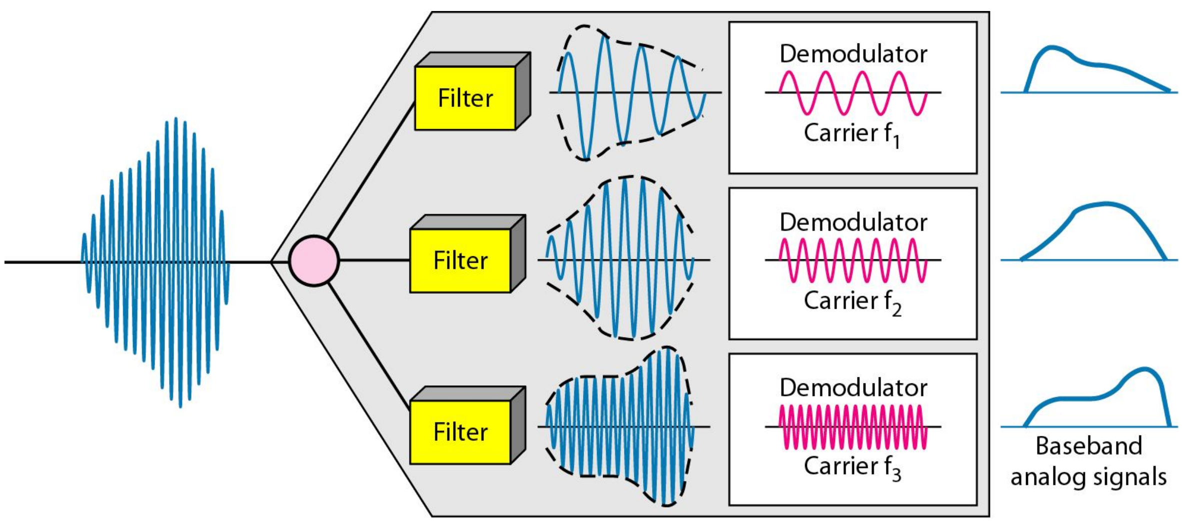
Figure 2 is a conceptual illustration of the multiplexing process. Each source generates a signal of a similar frequency range. Inside the multiplexer, these similar signals modulates different carrier frequencies *(/1,12,* and *h).* The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.



Demultiplexing Process

The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals. The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines.

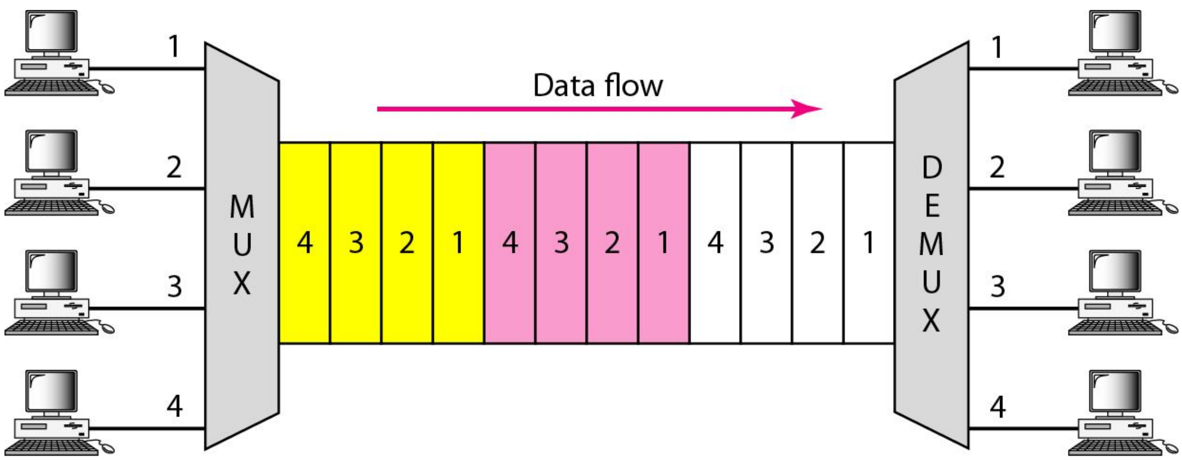
- Figure 3 is a conceptual illustration of demultiplexing process.



Synchronous Time-Division Multiplexing

Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link. Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link.

- Figure gives a conceptual view of TDM. Note that the same link is used as in FDM; here, however, the link is shown sectioned by time rather than by frequency. In the figure, portions of signals 1,2,3, and 4 occupy the link sequentially.

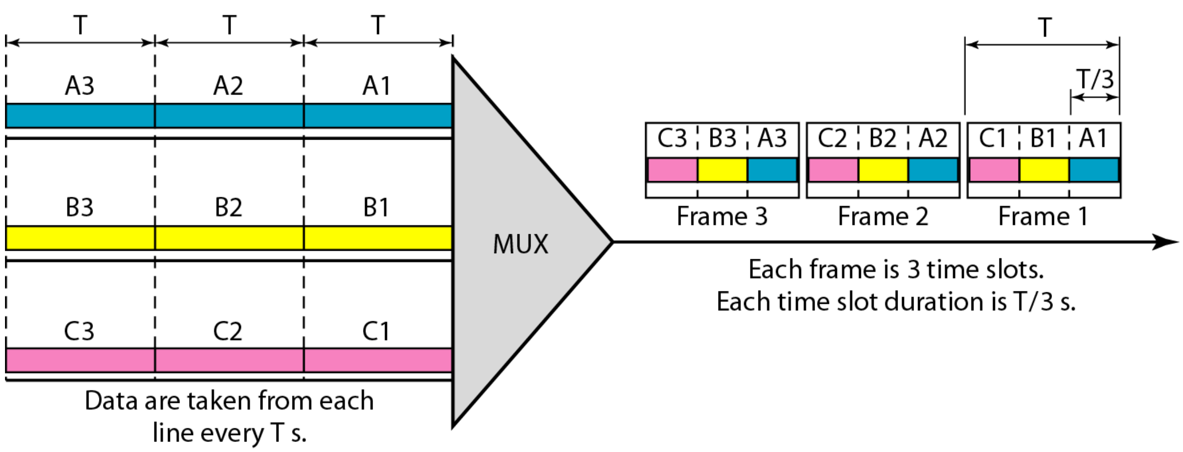


Note that in Figure we are concerned with only multiplexing, not switching. This means that all the data in a message from source 1 always go to one specific destination, be it 1, 2, 3, or 4. The delivery is fixed and unvarying, unlike switching. We also need to remember that TDM is, in principle, a digital multiplexing technique.

- Digital data from different sources are combined into one timeshared link. However, this does not mean that the sources cannot produce analog data; analog data can be sampled, changed to digital data, and then multiplexed by using TDM. We can divide TDM into two different schemes: synchronous and statistical.

- In synchronous TDM, each input connection has an allotment in the output even if it is not sending data. Time Slots and Frames In synchronous TDM, the data flow of each input connection is divided into units, where each input occupies one input time slot. A unit can be 1 bit, one character, or one block of data. Each input unit becomes one output unit and occupies one output time slot.

- However, the duration of an output time slot is n times shorter than the duration of an input time slot. If an input time slot is T s, the output time slot is Tin s, where n is the number of connections. In other words, a unit in the output connection has a shorter duration; it travels faster. Figure 7 shows an example of synchronous TDM where n is 3.



- In synchronous TDM, a round of data units from each input connection is collected into a frame (we will see the reason for this shortly). If we have n connections, a frame is divided into n time slots and one slot is allocated for each unit, one for each input line. If the duration of the input unit is T, the duration of each slot is Tin and the duration of each frame is T (unless a frame carries some other information, as we will see shortly).

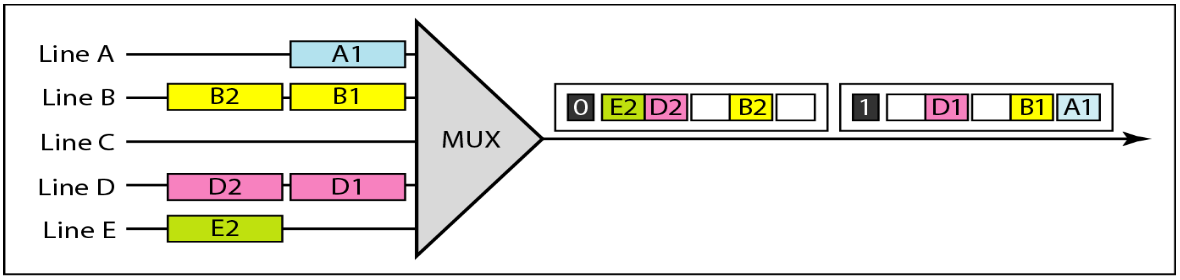
- The data rate of the output link must be n times the data rate of a connection to guarantee the flow of data. In Figure 7, the data rate of the link is 3 times the data rate of a connection; likewise, the duration of a unit on a connection is 3 times that of the time slot (duration of a unit on the link). In the figure we represent the data prior to multiplexing as 3 times the size of the data after multiplexing. This is just to convey the idea that each unit is 3 times longer in duration before multiplexing than after. Time slots are grouped into frames. A frame consists of one complete cycle of time slots, with one slot dedicated to each sending device. In a system with n input lines, each frame has n slots, with each slot allocated to carrying data from a specific input line.

Statistical Time-Division Multiplexing

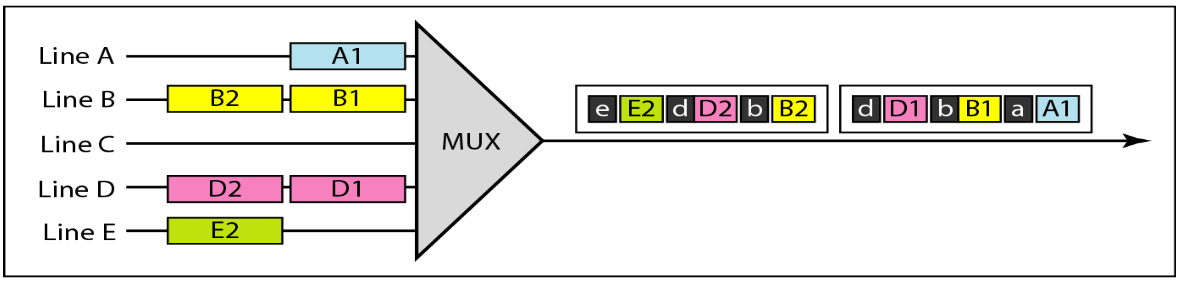
Addressing:

Figure a also shows a major difference between slots in synchronous TDM and statistical TDM. An output slot in synchronous TDM is totally occupied by data; in statistical TDM, a slot needs to carry data as well as the address of the destination. In synchronous TDM, there is no need for addressing; synchronization and pre assigned relationships between the inputs and outputs serve as an address.

- We know, for example, that input 1 always goes to input 2. If the multiplexer and the demultiplexer are synchronized, this is guaranteed. In statistical multiplexing, there is no fixed relationship between the inputs and outputs because there are no pre assigned or reserved slots.
- We need to include the address of the 35 receiver inside each slot to show where it is to be delivered. The addressing in its simplest form can be n bits to define N different output lines with n =10g2 N. For example, for eight different output lines, we need a 3-bit address.



a. Synchronous TDM



b. Statistical TDM

Slot Size

Since a slot carries both data and an address in statistical TDM, the ratio of the data size to address size must be reasonable to make transmission efficient. For example, it would be inefficient to send 1 bit per slot as data when the address is 3 bits.

This would mean an overhead of 300 percent. In statistical TDM, a block of data is usually many bytes while the address is just a few bytes.

No Synchronization Bit

There is another difference between synchronous and statistical TDM, but this time it is at the frame level. The frames in statistical TDM need not be synchronized, so we do not need synchronization bits.

Bandwidth

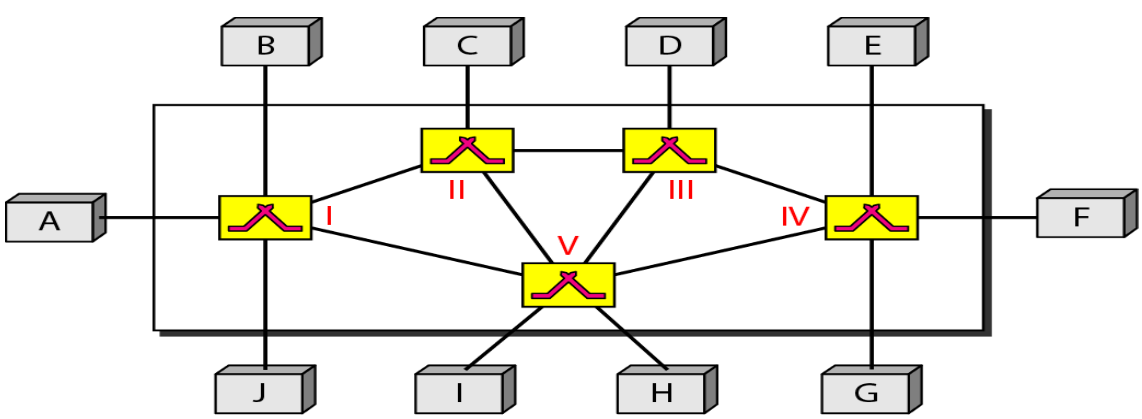
In statistical TDM, the capacity of the link is normally less than the sum of the capacities of each channel. The designers of statistical TDM define the capacity of the link based on the statistics of the load for each channel.

- If on average only *x* percent of the input slots are filled, the capacity of the link reflects this. Of course, during peak times, some slots need to wait.

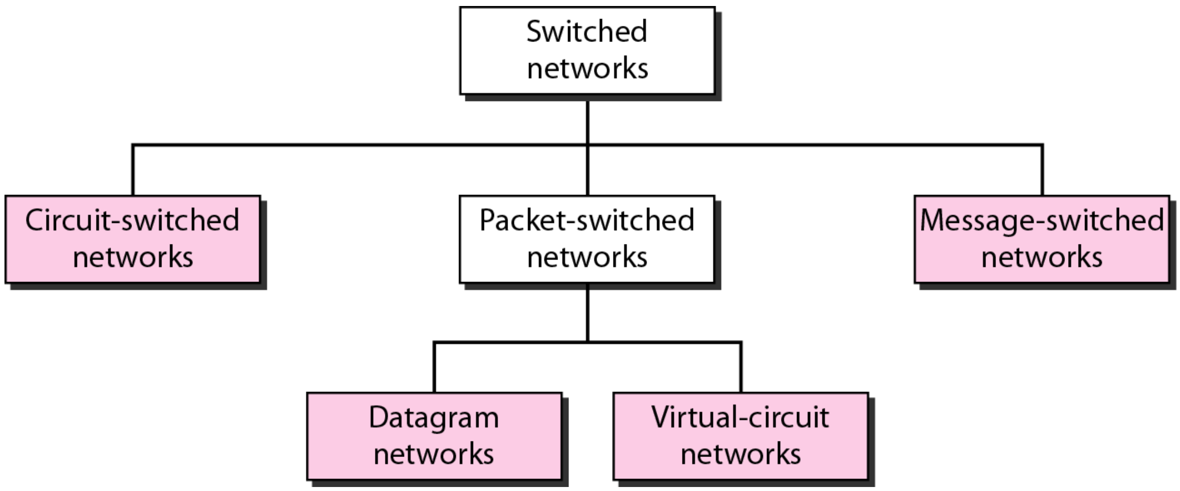
Switching

A network is a set of connected devices. Whenever we have multiple devices, we have the problem of how to connect them to make one-to-one communication possible. One solution is to make a point-to-point connection between each pair of devices (a mesh topology) or between a central device and every other device (a star topology). These methods, however, are impractical and wasteful when applied to very large networks. The number and length of the links require too much infrastructure to be cost-efficient, and the majority of those links would be idle most of the time.

- Other topologies employing multipoint connections, such as a bus, are ruled out because the distances between devices and the total number of devices increase beyond the capacities of the media and equipment.
- A better solution is switching. A switched network consists of a series of interlinked nodes, called switches. Switches are devices capable of creating temporary connections between two or more devices linked to the switch.
- In a switched network, some of these nodes are connected to the end systems (computers or telephones, for example). Others are used only for routing. Figure shows a switched network.



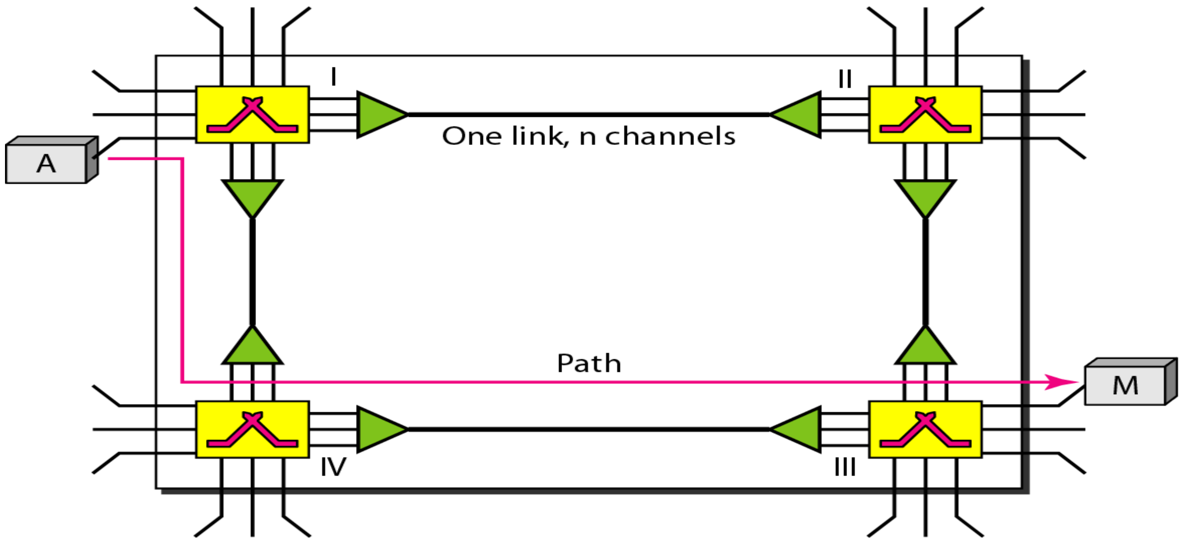
- The end systems (communicating devices) are labeled A, B, C, D, and so on, and the switches are labeled I, II, III, IV, and V. Each switch is connected to multiple links.



2.2.1 CIRCUIT-SWITCHED NETWORKS

A circuit-switched network consists of a set of switches connected by physical links. A connection between two stations is a dedicated path made of one or more links. However, each connection uses only one dedicated channel on each link. Each link is normally divided into *n* channels by using FDM or TDM

- Figure shows a trivial circuit-switched network with four switches and four links. Each link is divided into *n* (*n* is 3 in the figure) channels by using FDM or TDM.



Three Phases

The actual communication in a circuit-switched network requires three phases: connection setup, data transfer, and connection teardown.

Setup Phase:

- Before the two parties (or multiple parties in a conference call) can communicate, a dedicated circuit (combination of channels in links) needs to be established. The end systems are normally connected through dedicated lines to the switches, so connection setup means creating dedicated channels between the switches.
- For example, in Figure, when system A needs to connect to system M, it sends a setup request that includes the address of system M, to switch I. Switch I finds a channel between itself and switch IV that can be dedicated for this purpose. Switch I then sends the request to switch IV, which finds a dedicated channel between itself and switch III. Switch III informs system M of system A's intention at this time.
- In the next step to making a connection, an acknowledgment from system M needs to be sent in the opposite direction to system A. Only after system A receives this acknowledgment is the connection established. Note that end-to-end addressing is required for creating a connection between the two end systems. These can be, for example,

the addresses of the computers assigned by the administrator in a TDM network, or telephone numbers in an FDM network.

Data Transfer Phase:

- After the establishment of the dedicated circuit (channels), the two parties can transfer data.

Teardown Phase:

- When one of the parties needs to disconnect, a signal is sent to each switch to release the resources.

Efficiency:

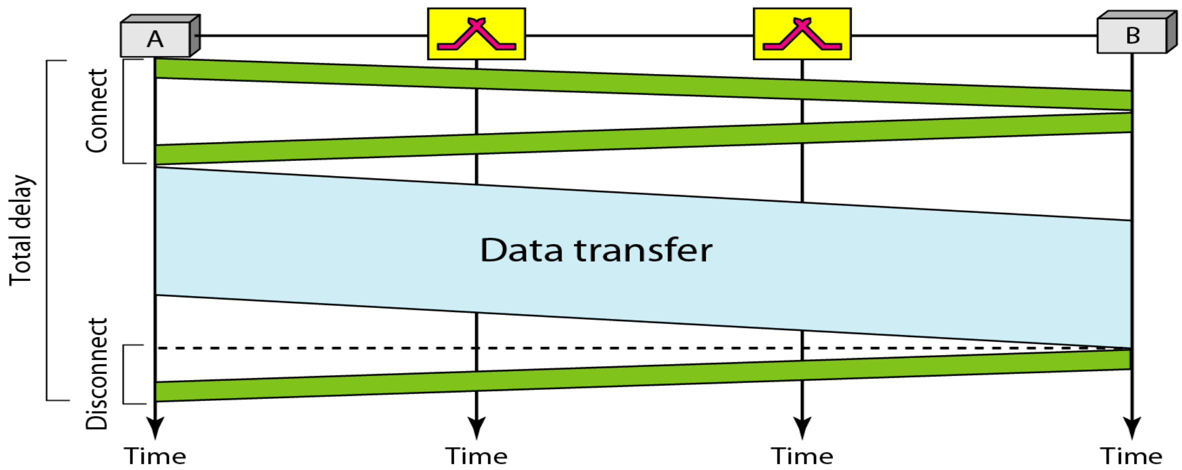
It can be argued that circuit-switched networks are not as efficient as the other two types of networks because resources are allocated during the entire duration of the connection. These resources are unavailable to other connections.

- In a telephone network, people normally terminate the communication when they have finished their conversation. However, in computer networks, a computer can be connected to another computer even if there is no activity for a long time. In this case, allowing resources to be dedicated means that other connections are deprived.

Delay :

Although a circuit-switched network normally has low efficiency, the delay in this type of network is minimal. During data transfer the data are not delayed at each switch; the resources are allocated for the duration of the connection.

- Figure 8.6 shows the idea of delay in a circuit-switched network when only two switches are involved. As Figure shows, there is no waiting time at each switch. The total delay is due to the time needed to create the connection, transfer data, and disconnect the circuit.



- The delay caused by the setup is the sum of four parts: the propagation time of the source computer request (slope of the first gray box), the request signal transfer time (height of the first gray box), the propagation time of the acknowledgment from the destination computer (slope of the second gray box), and the signal transfer time of the acknowledgment (height of the second gray box). The delay due to data transfer is the sum of two parts: the propagation time (slope of the colored box) and data transfer time (height of the colored box), which can be very long.

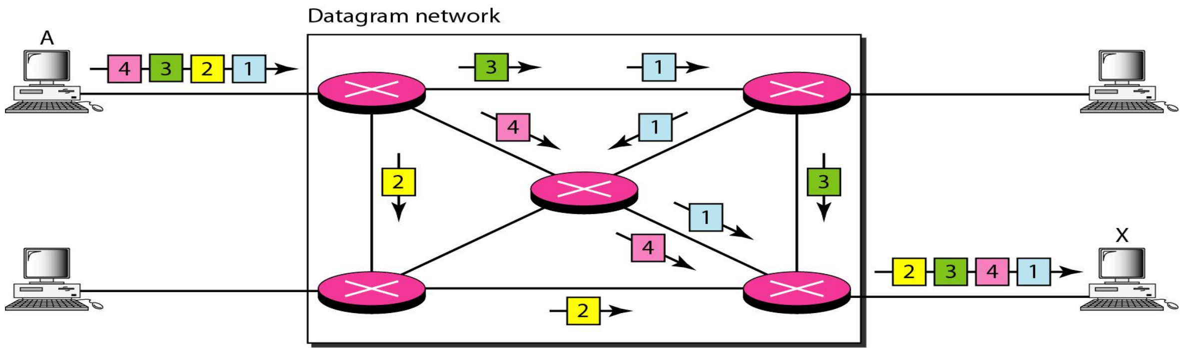
- The third box shows the time needed to tear down the circuit. We have shown the case in which the receiver requests disconnection, which creates the maximum delay.

2.2.2 DATAGRAM NETWORKS

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.

- Datagram switching is normally done at the network layer. We briefly discuss datagram networks here as a comparison with circuit-switched and virtual-circuit switched networks

- Figure shows how the datagram approach is used to deliver four packets from station A to station X. The switches in a datagram network are traditionally referred to as routers. That is why we use a different symbol for the switches in the figure.



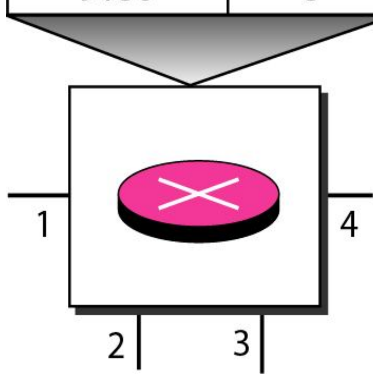
- In this example, all four packets (or datagrams) belong to the same message, but may travel different paths to reach their destination. This is so because the links may be involved in carrying packets from other sources and do not have the necessary bandwidth available to carry all the packets from A to X.
- This approach can cause the datagrams of a transmission to arrive at their destination out of order with different delays between the packets. Packets may also be lost or dropped because of a lack of resources. In most protocols, it is the responsibility of an upper-layer protocol to reorder the datagrams or ask for lost datagrams before passing them on to the application.
- The datagram networks are sometimes referred to as connectionless networks. The term *connectionless* here means that the switch (packet switch) does not keep information about the connection state. There are no setup or teardown phases. Each packet is treated the same by a switch regardless of its source or destination.

Routing Table

- If there are no setup or teardown phases, how are the packets routed to their destinations in a datagram network? In this type of network, each switch (or packet switch) has a routing table which is based on the destination address. The routing tables are dynamic and are updated periodically.

- The destination addresses and the corresponding forwarding output ports are recorded in the tables. This is different from the table of a circuit switched network in which each entry is created when the setup phase is completed and deleted when the teardown phase is over. Figure shows the routing table for a switch.

Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3



Destination Address

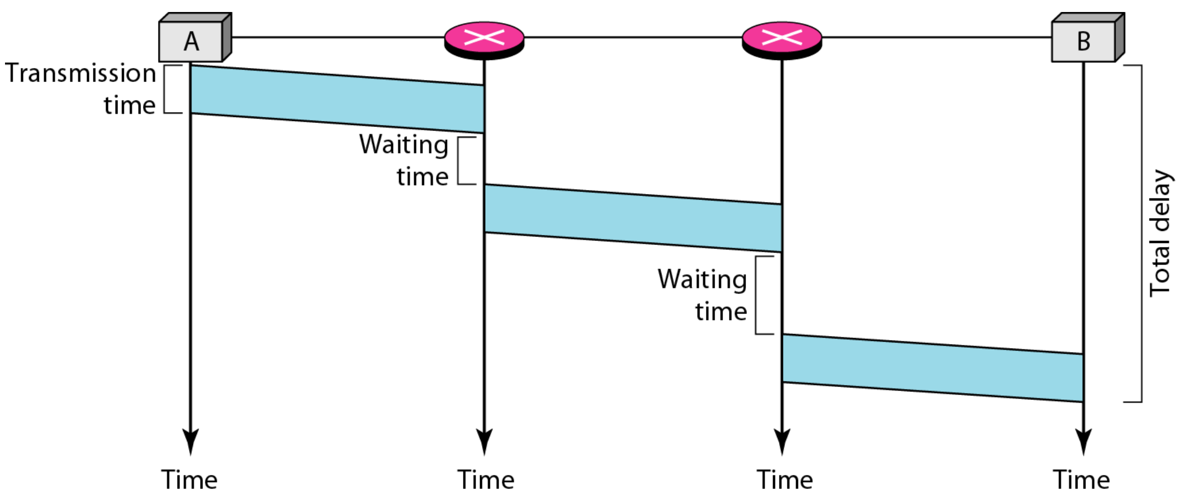
- Every packet in a datagram network carries a header that contains, among other information, the destination address of the packet. When the switch receives the packet, this destination address is examined; the routing table is consulted to find the corresponding port through which the packet should be forwarded.
- This address, unlike the address in a virtual-circuit-switched network, remains the same during the entire journey of the packet.

Efficiency

The efficiency of a datagram network is better than that of a circuit-switched network; resources are allocated only when there are packets to be transferred. If a source sends a packet and there is a delay of a few minutes before another packet can be sent, the resources can be reallocated during these minutes for other packets from other sources.

Delay

There may be greater delay in a datagram network than in a virtual-circuit network. Although there are no setup and teardown phases, each packet may experience a wait at a switch before it is forwarded. In addition, since not all packets in a message necessarily travel through the same switches, the delay is not uniform for the packets of a message.



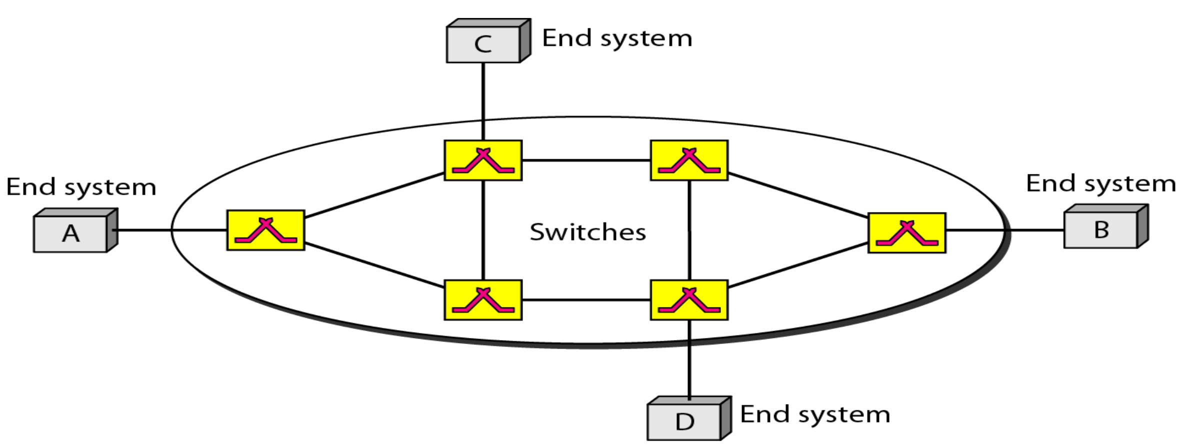
The packet travels through two switches. There are three transmission times *(3T),* three propagation delays (slopes 3't of the lines), and two waiting times (WI + *w2)'* We ignore the processing time in each switch. The total delay is Total delay =*3T* + 3t + WI + W2

2.2.3 VIRTUAL-CIRCUIT NETWORKS:

A virtual-circuit network is a cross between a circuit-switched network and a datagram network. It has some characteristics of both.

1. As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
2. Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
3. As in a datagram network, data are packetized and each packet carries an address in the header. However, the address in the header has local jurisdiction (it defines what should be the next switch and the channel on which the packet is being canied), not end-to-end jurisdiction. The reader may ask how the intermediate switches know where to send the packet if there is no final destination address carried by a packet. The answer will be clear when we discuss virtual-circuit identifiers in the next section.
4. As in a circuit-switched network, all packets follow the same path established during the connection.
5. A virtual-circuit network is normally implemented in the data link layer, while a circuit-switched network is implemented in the physical layer and a datagram network in the network layer. But this may change in the future.

Figure is an example of a virtual-circuit network. The network has switches that allow traffic from sources to destinations. A source or destination can be a computer, packet switch, bridge, or any other device that connects other networks.

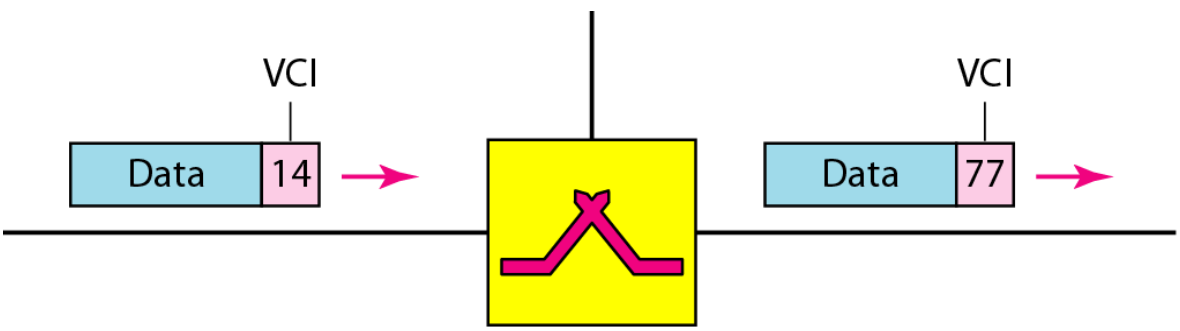


Addressing

In a virtual-circuit network, two types of addressing are involved: global and local (virtual-circuit identifier).

Global Addressing: A source or a destination needs to have a global address-an address that can be unique in the scope of the network or internationally if the network is part of an international network. However, we will see that a global address in virtual-circuit networks is used only to create a virtual-circuit identifier, as discussed next.

Virtual-Circuit Identifier: The identifier that is actually used for data transfer is called the virtual-circuit identifier (VCI). A VCI, unlike a global address, is a small number that has only switch scope; it is used by a frame between two switches. When a frame arrives at a switch, it has a VCI; when it leaves, it has a different VCI. Figure shows how the VCI in a data frame changes from one switch to another. Note that a VCI does not need to be a large number since each switch can use its own unique set of VCI's.



Three Phases

As in a circuit-switched network, a source and destination need to go through three phases in a virtual-circuit network: setup, data transfer, and teardown. In the setup phase, the source and destination use their global addresses to help switches make table entries for the connection. In the teardown phase, the source and destination inform the switches to delete the corresponding entry. Data transfer occurs between these two phases.

- We first discuss the data transfer phase, which is more straightforward; we then talk about the setup and teardown phases.

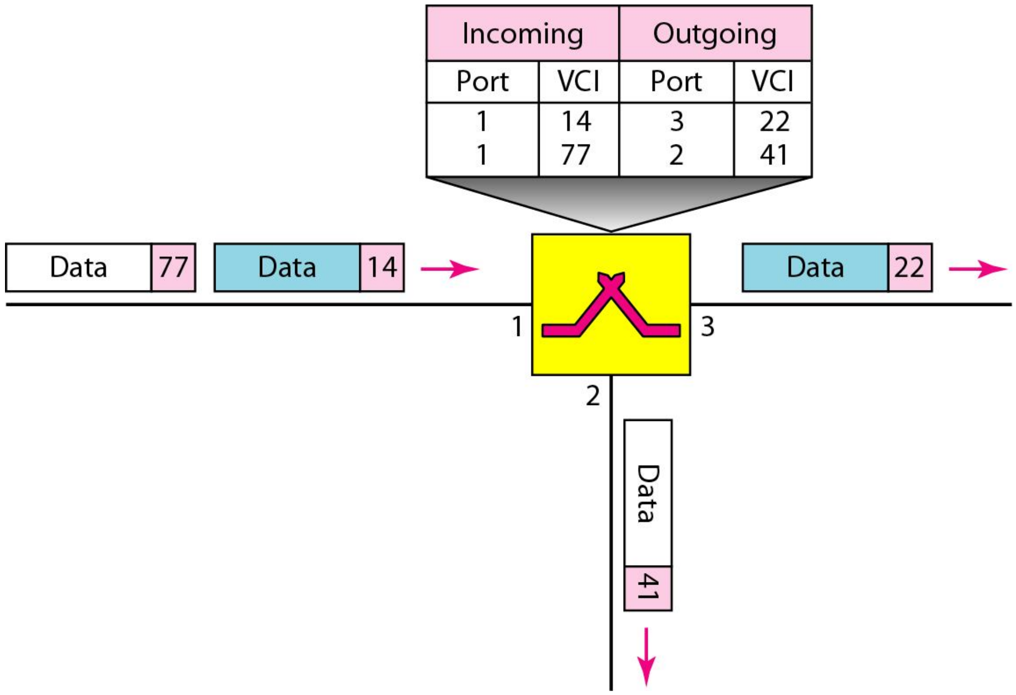
Data Transfer Phase :

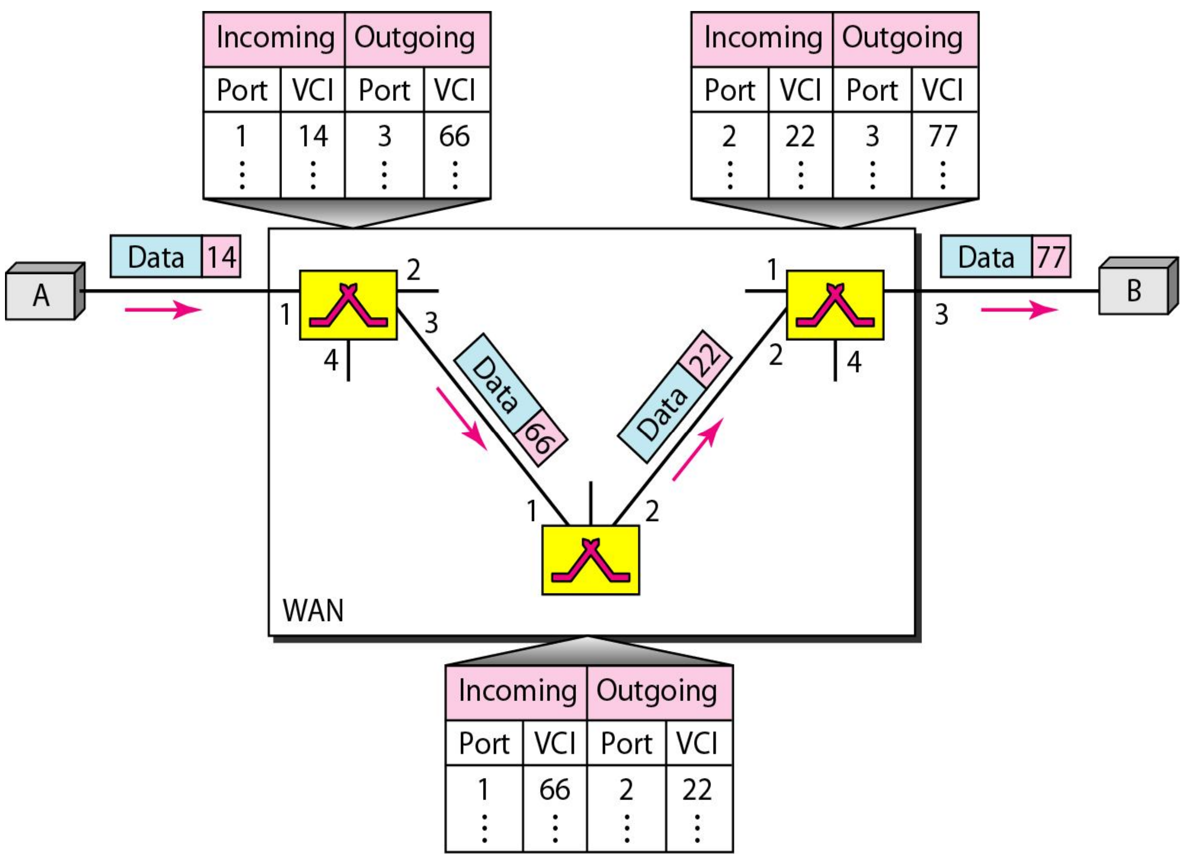
To transfer a frame from a source to its destination, all switches need to have a table entry for this virtual circuit. The table, in its simplest form, has four columns. This means that the switch holds four pieces of information for each virtual circuit that is already set up.

- Figure 2 shows such a switch and its corresponding table. And also shows a frame arriving at port 1 with a VCI of 14. When the frame arrives, the switch looks in its table to find port 1 and a VCI of 14. When it is found, the switch knows to change the VCI to 22 and send out the frame from port 3.
- Figure 3 shows how a frame from source A reaches destination B and how its VCI changes during the trip. Each switch changes the VCI and routes the frame. The data transfer phase is active until the source sends all its frames to the destination. The procedure at the switch is the same for each frame of a message. The process creates a virtual circuit, not a real circuit, between the source and destination.

Setup Phase:

In the setup phase, a switch creates an entry for a virtual circuit. For example, suppose source A needs to create a virtual circuit to B. Two steps are required: the setup request and the acknowledgment.

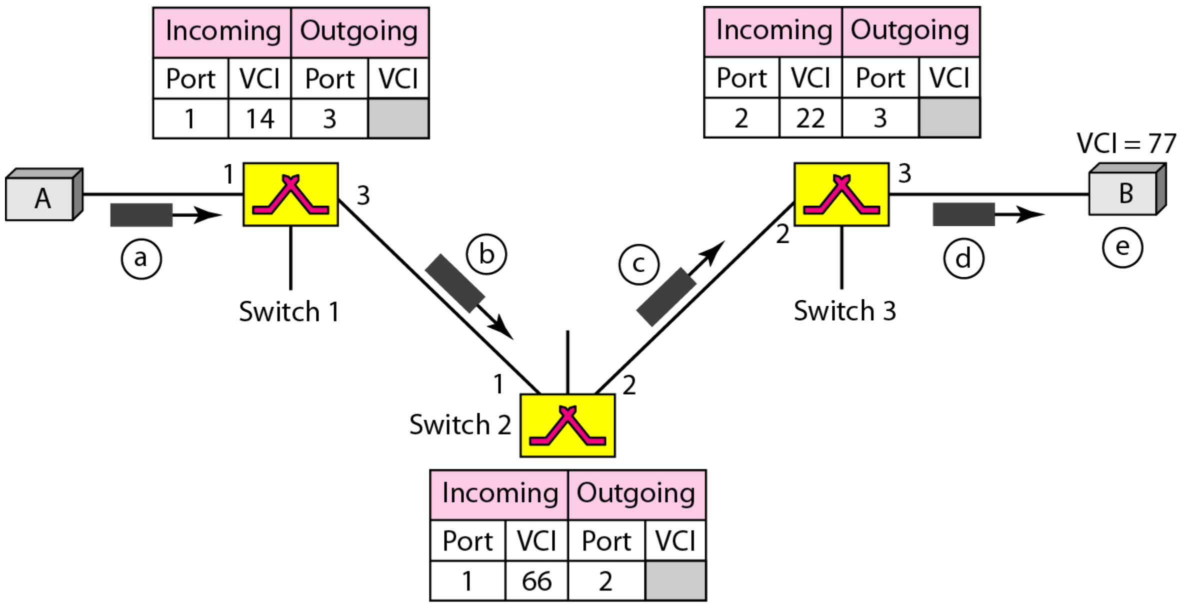

Incoming
Outgoing
Port
VCI
Port
VCI
1
14
3
22
1
77
2
41
Data
77
Data
14
Data
22
1
3
2
Data
41


Incoming
Outgoing
Port
VCI
Port
VCI
1
14
3
66
Incoming
Outgoing
Port
VCI
Port
VCI
2
22
3
77
A
Data
14
1
2
3
4
Data
66
1
2
Data
22
1
2
3
4
Data
77
B
WAN
Incoming
Outgoing
Port
VCI
Port
VCI
1
66
2
22

Setup Request :

A setup request frame is sent from the source to the destination.

Figure 4 shows the process.



a. Source A sends a setup frame to switch 1.

b. Switch 1 receives the setup request frame. It knows that a frame going from A to B goes out through port 3.

The switch, in the setup phase, acts as a packet switch; it has a routing table which is different from the switching table. For the moment, assume that it knows the output port. The switch creates an entry in its table for this virtual circuit, but it is only able to fill three of the four columns. The switch assigns the incoming port (1) and chooses an available incoming VCI (14) and the outgoing port (3). It does not yet know the outgoing VCI, which will be found during the acknowledgment step. The switch then forwards the frame through port 3 to switch 2.

c. Switch 2 receives the setup request frame. The same events happen here as at switch 1; three columns of the table are completed: in this case, incoming port (l), incoming VCI (66), and outgoing port (2).

d. Switch 3 receives the setup request frame. Again, three columns are completed: incoming port (2), incoming VCI (22), and outgoing port (3).

e. Destination B receives the setup frame, and if it is ready to receive frames from A, it assigns a VCI to the incoming frames that come from A, in this case 77. This VCI lets the destination know that the frames come from A, and not other sources.

Acknowledgment A special frame, called the acknowledgment frame, completes the entries in the switching tables. Figure 8.15 shows the process.

a. The destination sends an acknowledgment to switch 3. The acknowledgment carries the global source and destination addresses so the switch knows which entry in the table is to be completed. The frame also carries VCI 77, chosen by the destination as the incoming VCI for frames from A. Switch 3 uses this VCI to complete the outgoing VCI column for this entry. Note that 77 is the incoming VCI for destination B, but the outgoing VCI for switch 3.

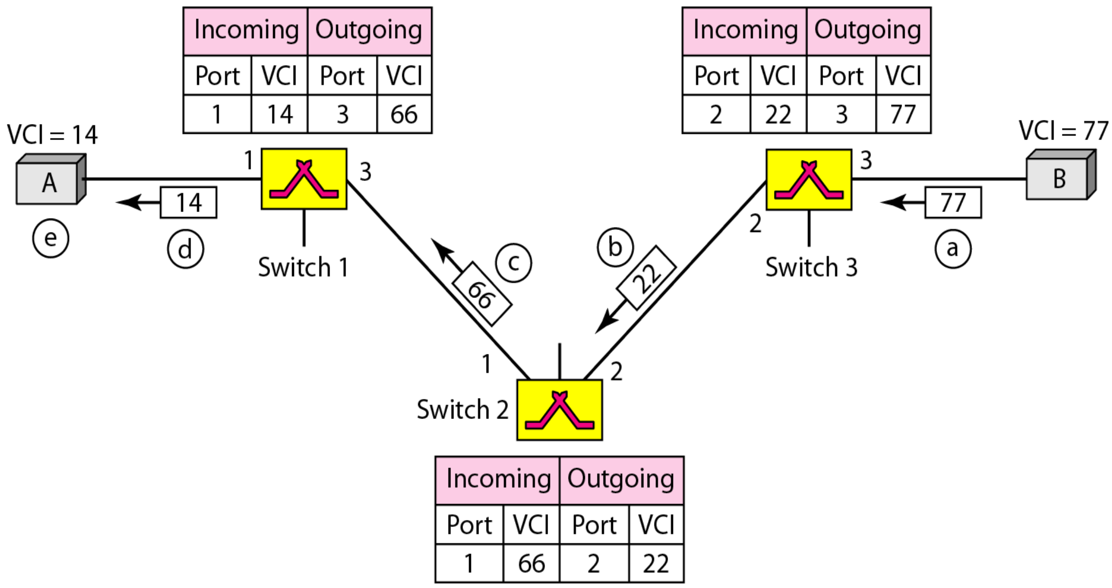
b. Switch 3 sends an acknowledgment to switch 2 that contains its incoming VCI in the table, chosen in the previous step. Switch 2 uses this as the outgoing VCI in the table.

c. Switch 2 sends an acknowledgment to switch 1 that contains its incoming VCI in the table,

chosen in the previous step. Switch 1 uses this as the outgoing VCI in the table.

d. Finally switch 1 sends an acknowledgment to source A that contains its incoming VCI in the table, chosen in the previous step.

e. The source uses this as the outgoing VCI for the data frames to be sent to destination B.



Teardown Phase :

In this phase, source A, after sending all frames to B, sends a special frame called a *teardown request.* Destination B responds with a teardown confirmation frame. All switches delete the corresponding entry from their tables.

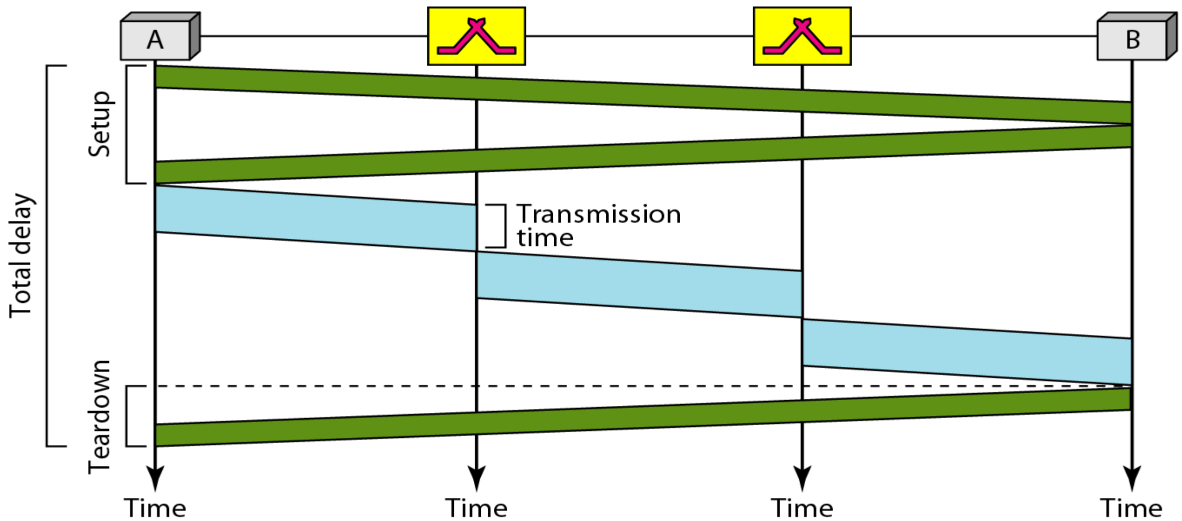
Efficiency

As we said before, resource reservation in a virtual-circuit network can be made during the setup or can be on demand during the data transfer phase. In the first case, the delay for each packet is the same; in the second case, each packet may encounter different delays.

- There is one big advantage in a virtual-circuit network even if resource allocation is on demand. The source can check the availability of the resources, without actually reserving it. Consider a family that wants to dine at a restaurant. Although the restaurant may not accept reservations (allocation of the tables is on demand), the family can call and find out the waiting time. This can save the family time and effort.

Delay in Virtual-Circuit Networks

In a virtual-circuit network, there is a one-time delay for setup and a one-time delay for teardown. If resources are allocated during the setup phase, there is no wait time for individual packets. Below Figure shows the delay for a packet traveling through two switches in a virtual-circuit network.



The packet is traveling through two switches (routers). There are three transmission times *(3T),* three propagation times (3't), data transfer depicted by the sloping lines, a setup delay (which includes transmission and propagation in two directions), and a teardown delay (which includes transmission and propagation in one direction). We ignore the processing time in each switch. The total delay time is

Total delay = *3T*+ 3't + setup delay + teardown delay

UNIT-II
Assignment-Cum-Tutorial Questions
SECTION-A

Objective Questions

1) The sharing of a medium and its link by two or more devices is called ______ [ ]
   a)Fully duplexing
   b) Multiplexing
   c) Both a and b
   d) None of the mentioned

2) Multiplexing is used in ______ [ ]
   a) Packet switching b) Circuit switching
   c) Data switching d) None of the mentioned

3)Which multiplexing technique transmits digital signals ? [ ]
   a) FDM b) TDM c) WDM d) None of the mentioned

4)Multiplexing can provide [ ]
   a) Efficiency b) Privacy c) Anti jamming d) Both a and b

5)The state when dedicated signals are idle are called [ ]
   a) Death period b) Poison period
   c) Silent period d) None of the mentioned

6)In TDM, slots are further divided into [ ]
   a) Seconds b) Frames c) Packets d) None of the mentioned

7)In TDM Data rate management is done by which of these strategies
   a) Multilevel multiplexing b) Multi-slot allocation [ ]
   c) Pulse stuffing d) all of the above

8) Method(s) to move data through a network of links and switches[ ]
   a)Packet switching b)Circuit switching
   c)Line switching d) Both a and b

9.______ is an analog multiplexing technique that combines analog signals

10.______ is an analog multiplexing technique to combine optical signals.

Multiple Choice Questions

1) If there are n signal sources of same data rate than TDM link has ______ slots [ ]

a)n b)n/2 c)n*2 d) 2^n

2) If link transmits 4000frames per second, and each slot has 8 bits,the transmission rate of circuit this TDM is [ ]

a)32kbps b)500bps c)500kbps d) None of the mentioned

3) In TDM, the transmission rate of the multiplexed path is usually _______ the sum of the transmission rates of the signal sources. [ ]

a) Greater than b) Lesser than

c)Equal to d) Equal to or greater than

4) What are the phases in circuit switching? [ ]

a) Setup, data transfer, teardown

b) request-connect, data sending-acknowledgment, request-disconnect

c) send-connect, data transfer, request-disconnect

d) none of above

5) Which of these statements is true about packet switching networks?

a)Resource allocation is done for a packet beforehand [ ]

b) Bandwidth is reserved on the links

c) Scheduled processing for a packet

d) Resource allocation is done on demand

6) What are the components of a packet switch? [ ]

a) input ports, output ports, a router processor, a switching fabric

b) input ports, output ports, a router processor.

c) input ports, output ports, a switching fabric

d) input ports, output ports, a router processing, a switching fabric, a memory chip

7) How switching is performed in the internet? [ ]

a) data gram approach to circuit switching at datalink layer

b) Virtual circuit approach to message switching at network layer

c) datagram approach to message switching at datalink layer

d) datagram approach to packet switching at network layer [ ]

8) Which of these is correct for synchronous Time Division Multiplexing

a) Data rate of link is n times faster and the unit duration is n times longer

b) Data rate of link is n times slower and the unit duration is n times shorter

c) Data rate of link is n times slower and the unit duration is n times longer

d) Data rate of link is n times faster and the unit duration is n times shorter

9) Multiplexing technique that shifts each signal to a different carrier frequency [ ]

a) FDM b)TDM c)Either a or b d) Both a and b

10) Which of these multiplexing techniques is digital for combining several low- rate channels into high-rate one [ ]

a)FDM b)WDM c)TDM d) None of the above

SECTION-B

SUBJECTIVE QUESTIONS

1. Describe the functioning of FDM
2. Discuss the various approaches to packet-switching
3. Compare and contrast a circuit-switched network and a packet switched network
4. Draw the diagram of a datagram network with four switches. And explain how will it work
5. Explain the process of TDM with an example.

Problems:

1. Assume that a voice channel occupies a bandwidth of 4 kHz. We need to multiplex 10 voice channels with guard bands of 500 Hz using FDM. Calculate the required bandwidth.
2. Two channels, one with a bit rate of 100 kbps and another with a bit rate of 200kbps, are to be multiplexed. How it can be achieved? What is the frame rate? What is the frame duration? What is the bit rate of the link?

SECTION-C

Questions testing the analyzing / evaluating ability of students

1. Assume that a voice channel occupies a bandwidth of 4kHz. We need to combine three voice channels into a link with a bandwidth of 12kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.