Switching

INTRODUCTION

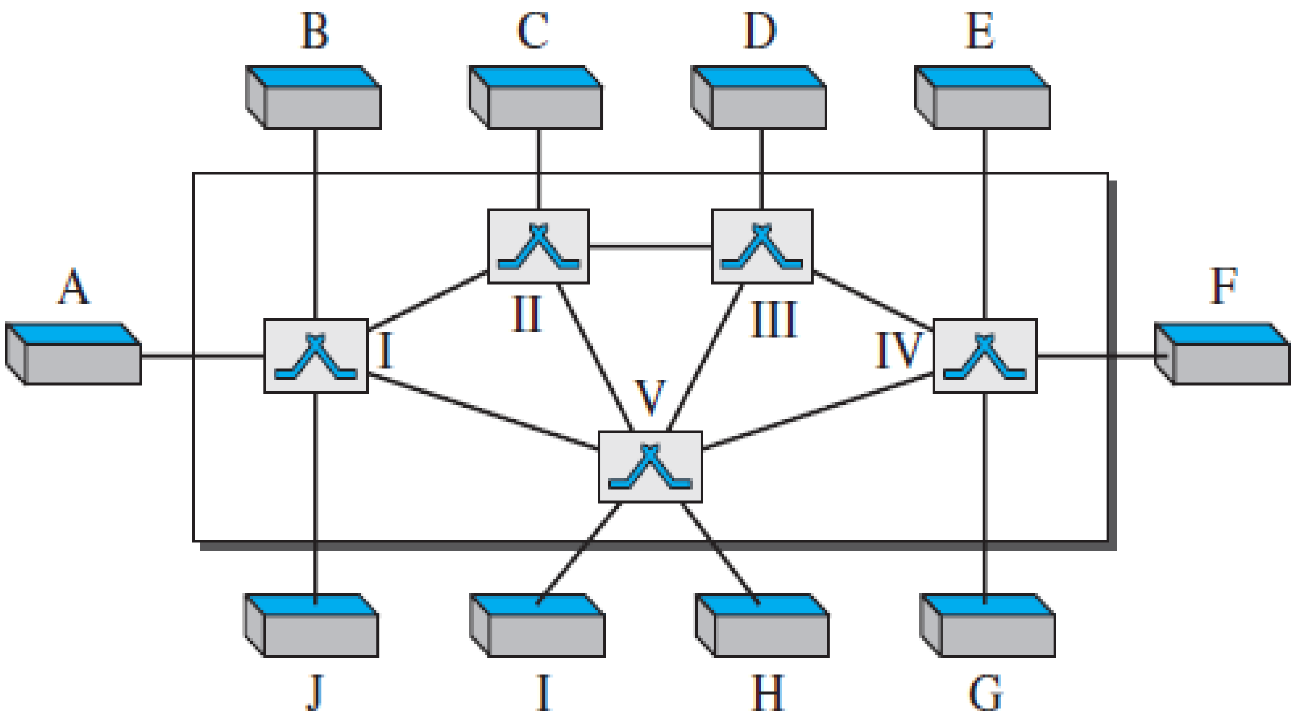
- A network is a **set of connected devices**.
- **Problem:** How to connect them to make **one-to-one communication possible**?
- **One solution** - make **a point-to-point** connection
  - Between each pair of devices (mesh topology) or
  - Between a central device and every other device (star topology).
  - **Impractical and wasteful** for very large networks.
  - **Number and length of the links** require too much infrastructure to be cost-efficient, and **majority of those links** would be **idle** most of the time.
- **Other solution** - make a **multipoint connections**, such as a bus, are ruled out because
  - Distances between devices
  - Total number of devices increase beyond the capacities of media and equipment.
- A better solution is **switching.**

Switched network

- It is 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.**
- Some switches are connected to end systems (Ex: Computers or telephones).
- Others are used only for **routing**.

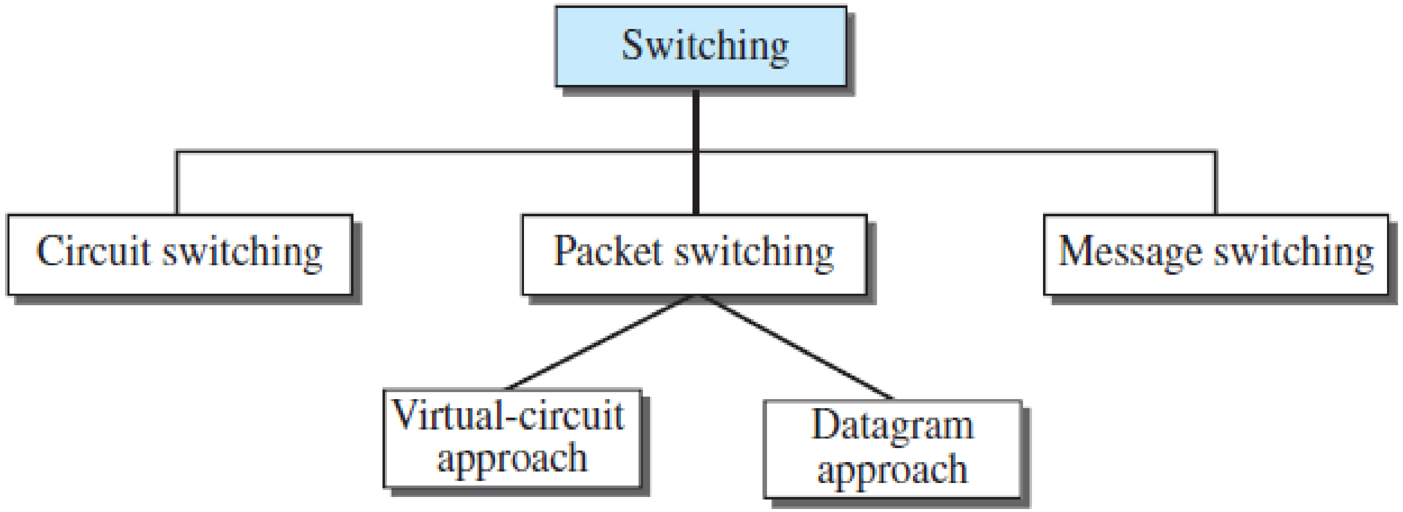
Switched network cont..

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



Three Methods of Switching

- **Three types** of switching:
  1. **Circuit switching**
  2. **Packet switching**
  3. **Message switching.**
- First two are commonly used today.



- Third has been phased out in general communications but still has networking applications.
- Packet switching can further be divided into two subcategories
  1. **Virtual-circuit approach**
  2. **Datagram approach**

Switching and TCP/IP Layers

- Switching can happen at **several layers of TCP/IP protocol suite**.
- **Switching at Physical Layer**
  - Only circuit switching occur.
  - There are no packets exchanged.
  - Switches allow signals to travel in one path or another.
- **Switching at Data-Link Layer**
  - Packet switching occur.
  - Term packet means frames or cells.
  - Packet switching is done using a virtual-circuit approach.

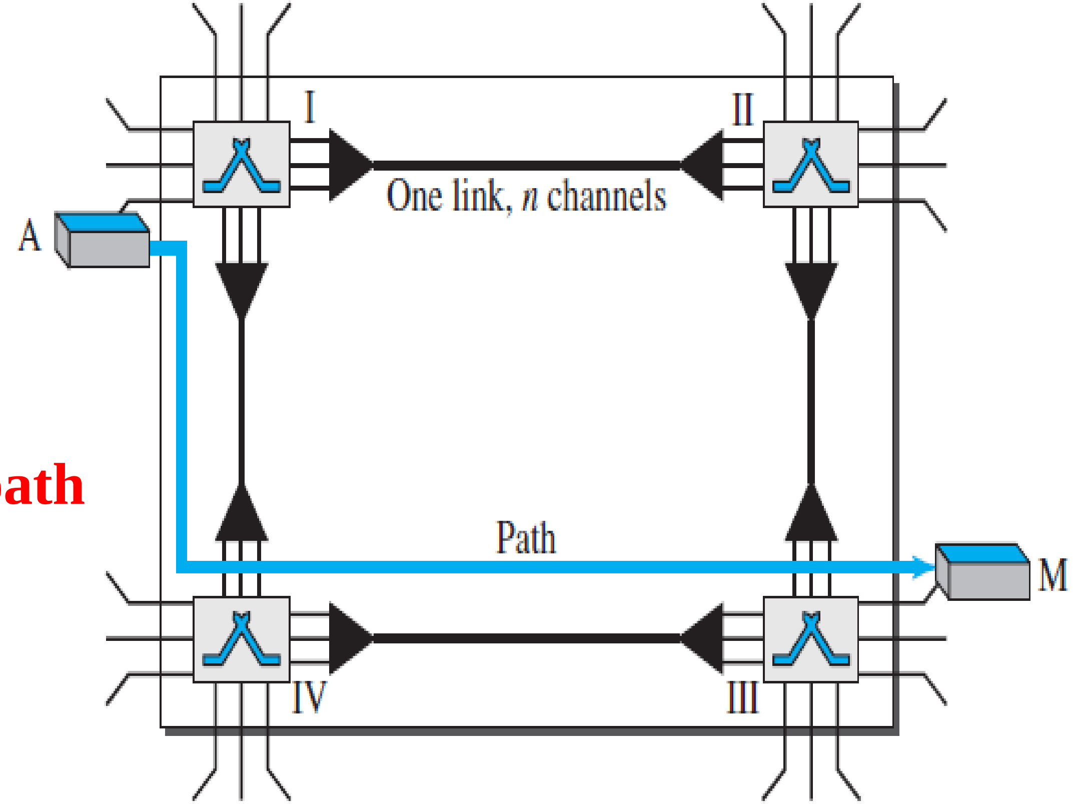
Switching and TCP/IP Layers cont..

- **Switching at Network Layer**
  - **Packet switching** occur.
  - Either virtual-circuit approach or datagram approach can be used.
  - Currently Internet uses datagram approach, but the tendency is to move to a virtual-circuit approach.
- **Switching at Application Layer**
  - Only message switching.
  - Communication occurs by exchanging messages.
  - Communication using e-mail is a kind of message-switched communication, but we do not see any network that can be called a message-switched network.

CIRCUIT-SWITCHED NETWORKS

Circuit-Switched Networks

- Consists of a **set of switches** connected by **physical links**.
- **Each link** is divided into **n channels** by using FDM or TDM. **Ex**: n=3.
- A connection between two stations is a **dedicated path made of one or more links.**
- Each connection uses only **one dedicated channel on each link.**



- Network with two end systems (A and M), four switches and four links.
- End systems, such as computers or telephones, are directly connected to a switch.

Circuit-Switched Networks cont..

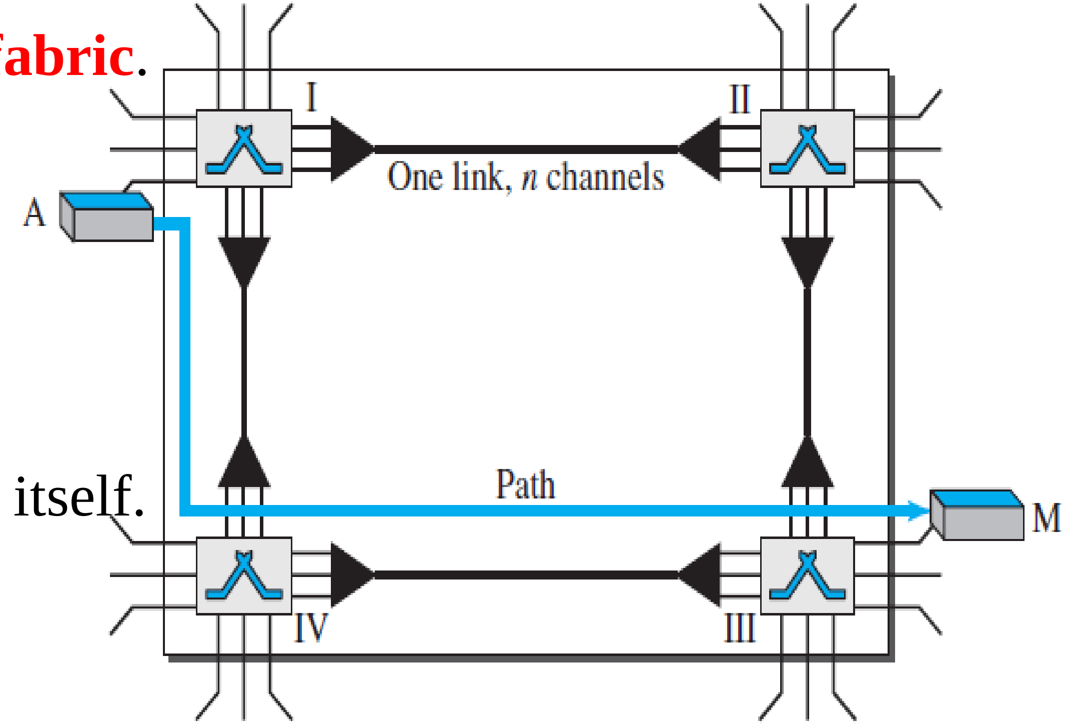
- **Multiplexing** can be implicitly included in **switch fabric**.
- Multiplexing symbols are used to **highlight the division of link into channels.**
- When **A** needs to communicate with **M**,

A needs to request a connection to **M**

that must be accepted by **all switches** as well as by M itself.

This is called **setup phase**;

- A circuit (channel) is reserved on each link.
- Combination of circuits or channels defines dedicated path.
- After the dedicated path is established, data-transfer phase can take place.
- After all data have been transferred, circuits are torn down.



Circuit-Switching

- It is takes place at **physical** layer.
- Resources need to be reserved during setup phase.
    - Before starting communication, stations must make a reservation for resources to be used during communication.
    - **Resources** are:
        1. **Channels (bandwidth in FDM and time slots in TDM),**
        2. **Switch buffers,**
        3. **Switch processing time, and**
        4. **Switch input/output ports**
- Resources must remain dedicated for entire duration of data transfer until teardown phase.

Circuit-Switching cont..

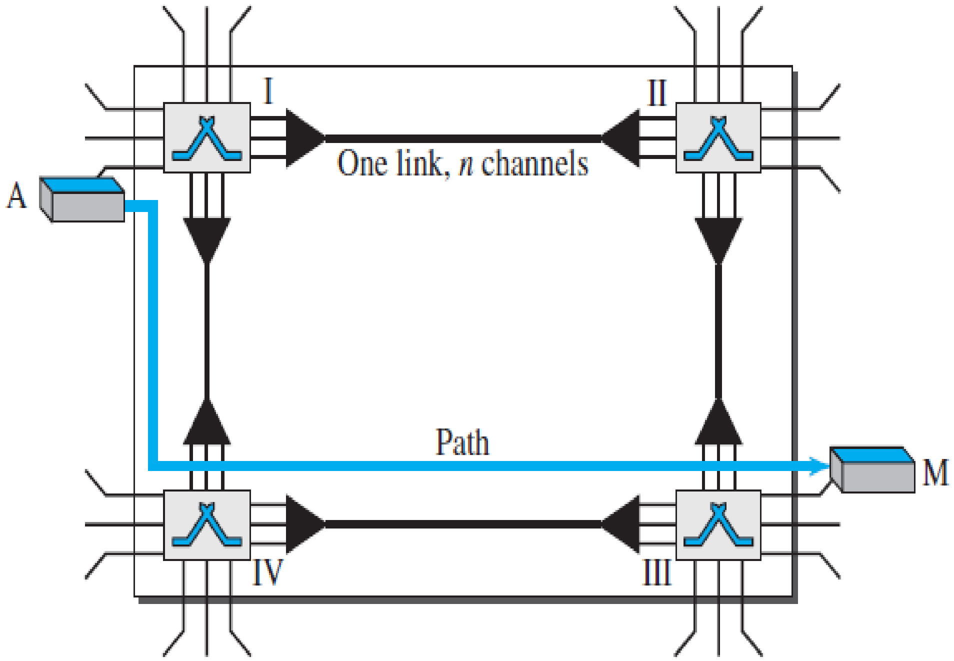
- Data transferred between two stations are not packetized (physical layer transfer of signal).
- Data are a continuous flow sent by source station and received by destination station, although there may be periods of silence.
- There is no addressing involved during data transfer.
- Switches route data based on their occupied band (FDM) or time slot (TDM).
- End-to-end addressing is required for creating a connection between two end systems.
- **Example:**
  - Addresses of computers assigned by administrator in a TDM network
  - Telephone numbers in an FDM network.

Three Phases in Circuit-Switched Network

- Communication in a circuit-switched network requires three phases:
  1. **Connection setup**
  2. **Data transfer**
  3. **Connection teardown.**
- **Connection Setup Phase**
  - Creating dedicated channels between switches.
  - Before two parties (or multiple parties) can communicate, a dedicated circuit (combination of channels in links) needs to be established.
  - End systems are directly connected to a switches through dedicated lines.
- **Data-Transfer Phase**
  - After the establishment of dedicated circuit (channels), two parties can transfer data.
- **Teardown Phase**
  - When one of the parties needs to disconnect, a signal is sent to each switch to release resources.

Connection Setup Phase Example:

- When A needs to connect to M, it sends a setup request to switch I that includes address of M.
- Switch I finds a channel between itself and switch IV that can be dedicated for this purpose.
- Switch I then sends 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.
- To making a connection, an ack from system M needs to be sent in opposite direction to system A.
- Connection established only after system A receives this ack.

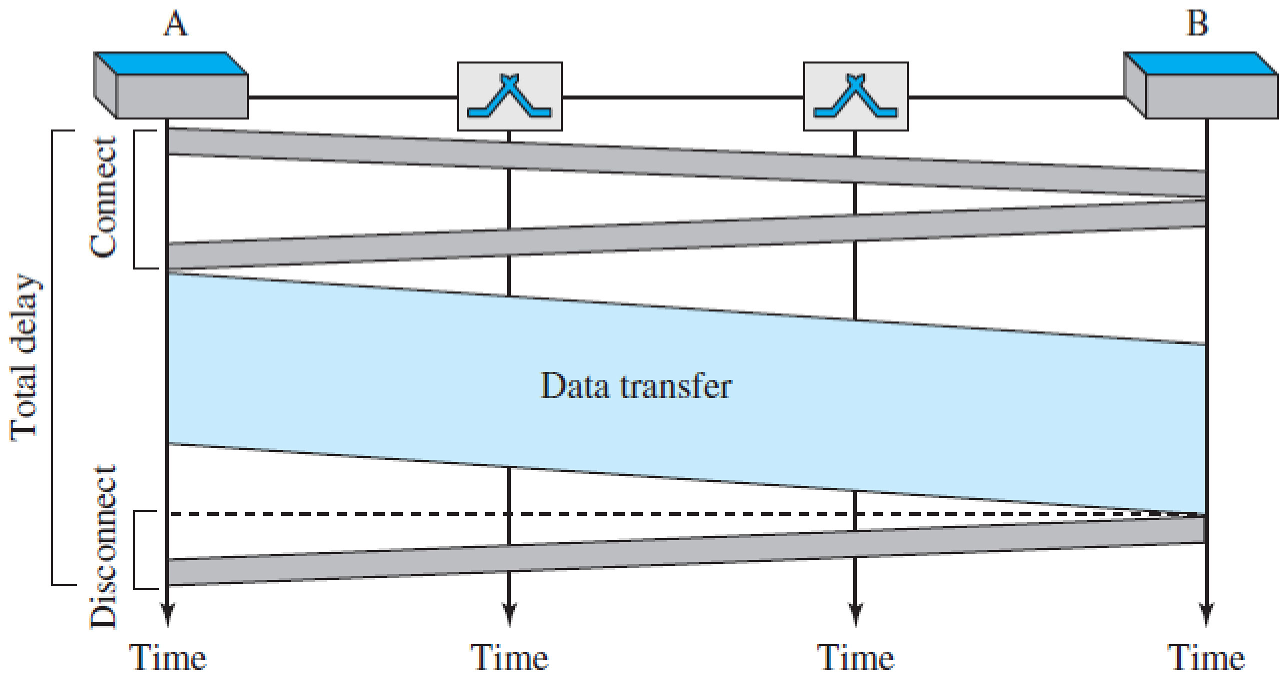


Efficiency of Circuit-switched networks

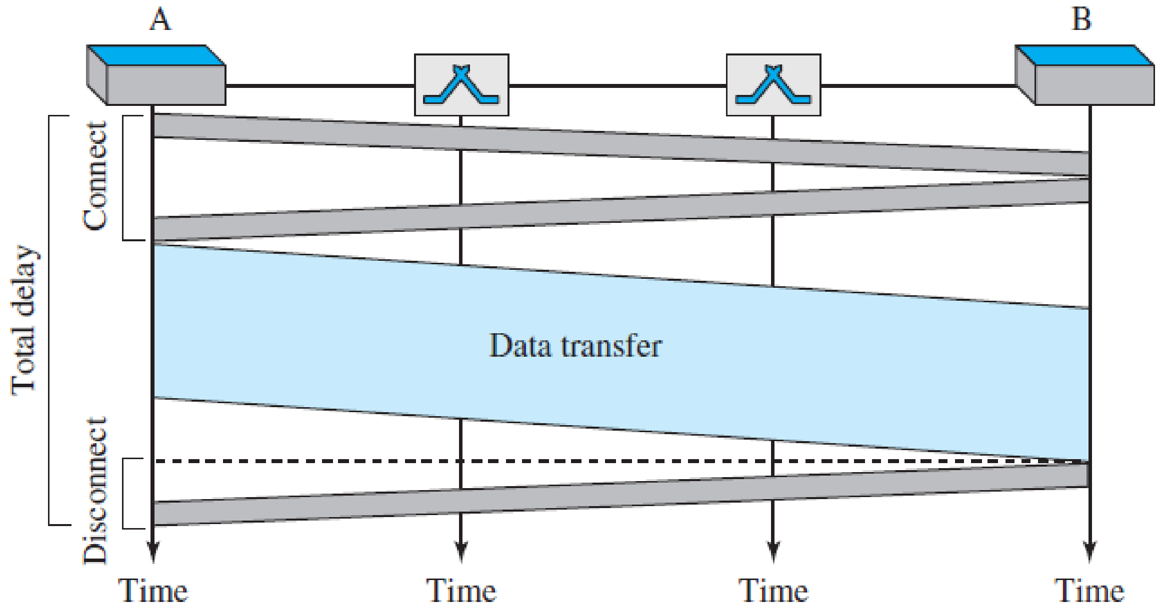
- Less efficient than other two types of networks because,
  - Resources are allocated during entire duration of connection.
  - These resources are unavailable to other connections.
- **Example:**
  - In telephone network, people terminate communication when they have finished their conversation.
  - In computer networks, a computer can be connected to another computer even if there is no activity for a long time.

Delay of Circuit-switched networks

- Delay is minimal.
- Data are not delayed at each switch.
- There is no waiting time at each switch.
  - Resources are allocated for the duration of connection.
- **Total delay is due to time needed to**
  1. Create the connection
  2. Transfer data
  3. Disconnect the circuit.



Delay of Circuit-switched networks



- **Delay caused by setup is sum of four parts**:
    1. Propagation time of source request (slope of first gray box)
    2. Transfer time of request signal (height of first gray box)
    3. Propagation time of ack from destination (slope of second gray box)
    4. Transfer time of ack signal(height of second gray box).
- **Delay due to data transfer is sum of two parts**:
    1. Propagation time (slope of colored box) and
    2. Data transfer time (height of colored box), which can be very long.
- Third box shows time needed to tear down the circuit.
- Here, receiver requests disconnection, which creates maximum delay.

PACKET SWITCHING

- To send messages from one end system to another.
  - Message is divided into fixed or variable sized packets.
- Packet size is determined by network and governing protocol.
- No resource reservation for a packet.
  - No reserved bandwidth on links
  - No scheduled processing time for packet.
- Resources are allocated on demand.
- Allocation is done on a first-come, first-served basis (FCFS).
- Lack of reservation may create delay.
  - When a switch receives a packet, packet must wait if there are other packets being processed.
- Two types:
  1. Datagram networks
  2. Virtual-circuit networks.

Datagram Networks

- Datagram switching is done at the network layer.
- Each packet is treated independently.
- Packets are referred as datagrams.
- Switches are referred as routers.
- Networks are sometimes referred to as connectionless networks.
  - Switch (packet switch) does not keep information about the connection state.
- There are no setup or teardown phases.

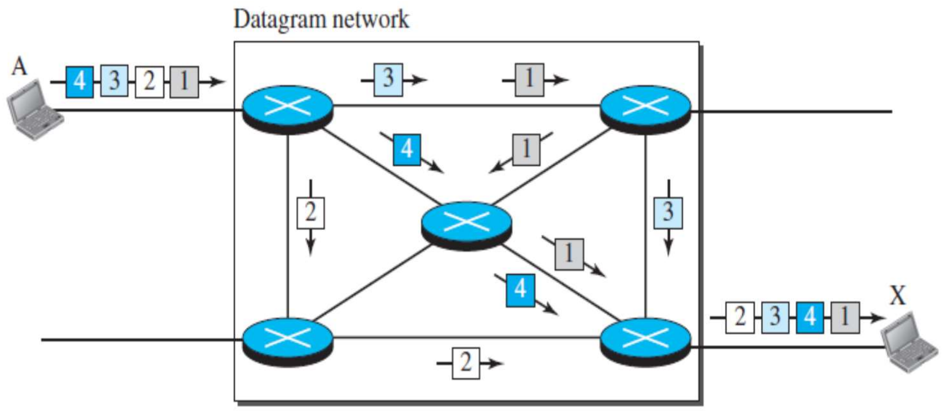


Fig: ***A datagram network with four switches (routers) used to deliver four packets***

Example:

- All four packets (or datagrams) belong to same message, but may travel different paths to reach their destination.
- Datagrams arrives at their destination in 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, upper-layer protocols reorder the datagrams or ask for lost datagrams before passing them on to the application.

Routing Table

- In a datagram network, each switch (or packet switch) has a routing table which is based on destination address.
- Routing tables are dynamic and are updated periodically.
- Destination addresses and the corresponding forwarding output ports are recorded in the tables.
- It 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.

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

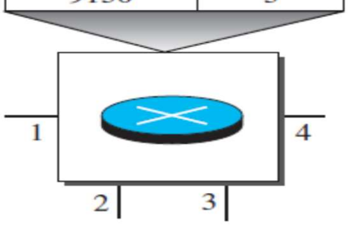


Fig: Routing table in a datagram network

Destination Address

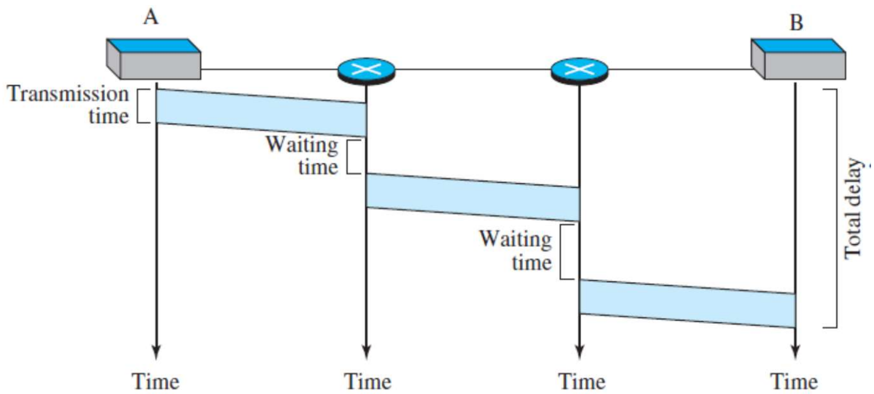
- Every packet carries a header that contains, among other information, destination address of packet.
- When the switch receives the packet, this destination address is examined;
- Routing table is consulted to find the corresponding port through which the packet should be forwarded.
- This address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

Efficiency of a datagram network

- It 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 of a datagram network

- There may be greater delay 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.
- Delay is not uniform for the packets of a message.
  - All packets not necessarily travel through the same switches.



- Packet travels through two switches. There are three transmission times (3T), three propagation delays (slopes 3τ of the lines), and two waiting times (w1 + w2).
- We ignore the processing time in each switch. The total delay is

$$\textbf{Total delay} = 3T + 3\tau + w1 + w2$$

Virtual-Circuit Networks

- It is a cross between circuit-switched n/w and datagram n/w.
- It has some characteristics of both.
  1. Setup and teardown phases in addition to data transfer phase, as in circuit-switched n/w.
     - It creates a virtual circuit, not a real circuit, between source and destination.
  2. Resources can be allocated during setup phase, as in circuit-switched n/w, or on demand, as in datagram n/w.
  3. Data are packetized and each packet carries an address in header, as in datagram n/w. However, address in header has local control (it defines what the next switch should be and the channel on which the packet is being carried), not end-to-end control.
  4. All packets follow same path established during the connection, as in circuit-switched n/w.
  5. Virtual-circuit n/w is implemented in DLL, while circuit-switched n/w is implemented in physical layer and datagram n/w in network layer.

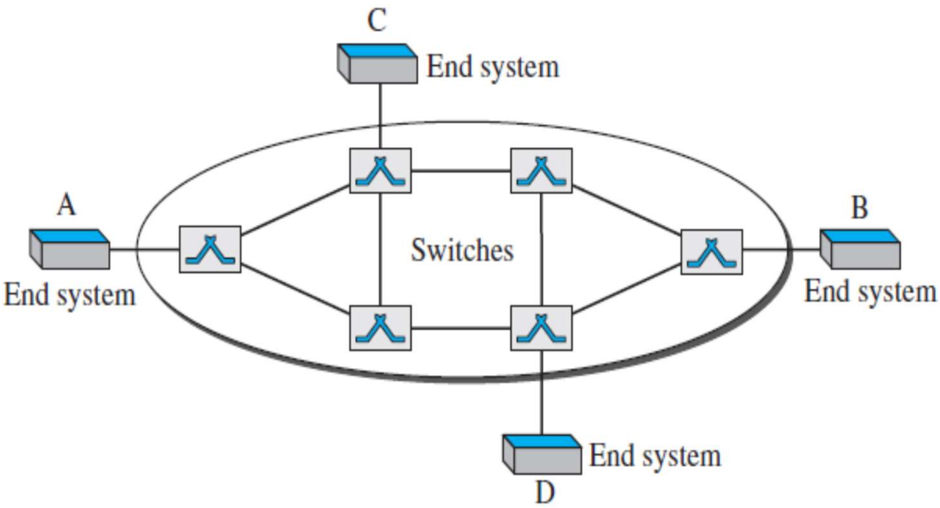


Fig: virtual-circuit network

- 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

- Two types:
  1. Global
  2. 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.
- It is used only to create a virtual-circuit identifier.

Local Addressing (Virtual-Circuit Identifier)

- Identifier that is used for data transfer is called virtual-circuit identifier (VCI) or label.
- It 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 the switch, it has a different VCI.
- VCI does not need to be a large number since each switch can use its own unique set of VCIs.

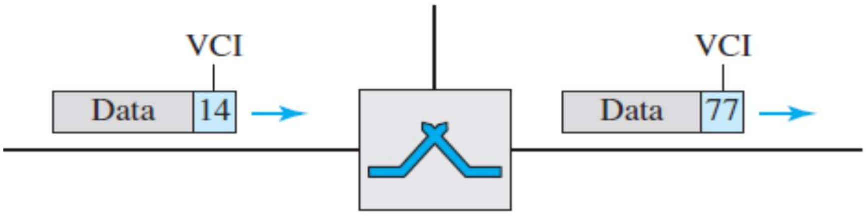


Fig. shows how the VCI in a data frame changes from one switch to another

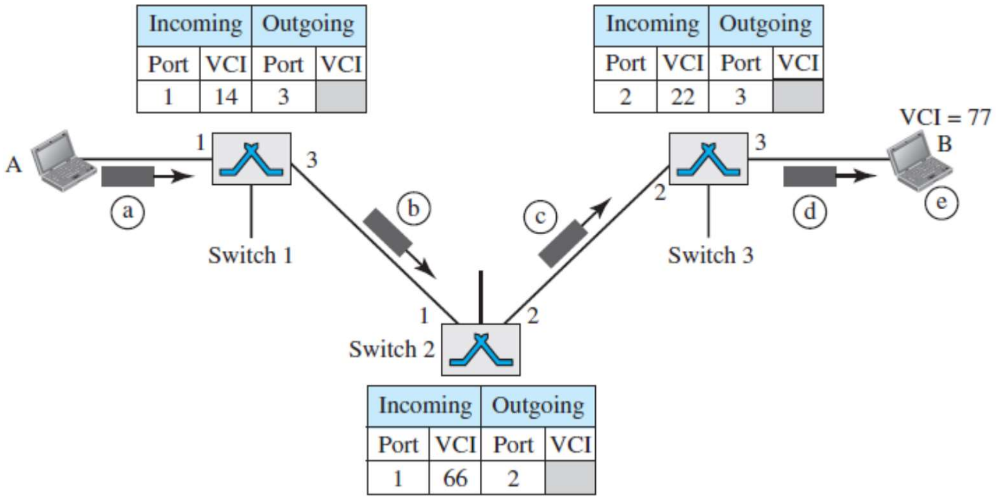
Three Phases

- Three phases.
  1. Setup phase
     - Source and destination use their global addresses to help switches make table entries for the connection.
  2. Teardown phase
     - Source and destination inform the switches to delete the corresponding entry.
  3. Data transfer phase
     - Data transfer occurs between these two phases.

Setup Phase

- In this phase, a switch creates a table entry for a virtual circuit using global addresses of source and destination.
- Two steps are required to create a virtual circuit between source A and destination B.
  - Setup request
  - Acknowledgment.

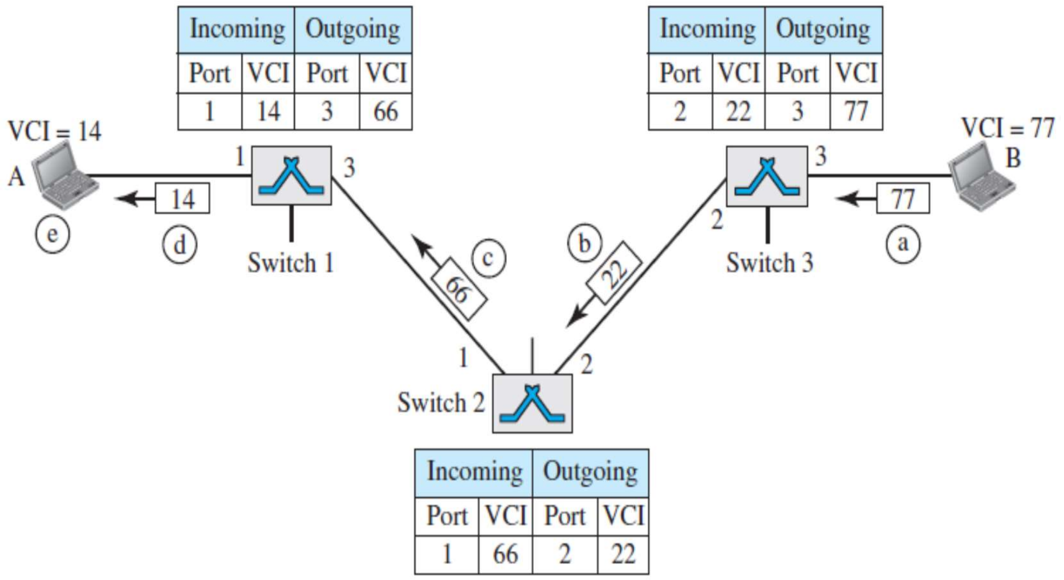
1. Setup Request



- A setup request frame is sent from source to destination.
  a. Source A sends a setup frame to switch 1.
  b. Switch 1 receives setup frame.
    - It knows that a frame going from A to B goes out through port 3.
    - Switch acts as a packet switch;
    - It has a routing table which is different from switching table.
    - Assume that it knows the output port.
    - Switch creates an entry in its table for this virtual circuit, but it is only able to fill three of the four columns.
    - Switch assigns incoming port (1) and chooses an available incoming VCI (14) and outgoing port (3).
    - It does not yet know the outgoing VCI, which will be found during the acknowledgment step.
    - Switch then forwards the frame through port 3 to switch 2.
  c. Switch 2 receives setup request frame.
    - Same events happen here as at switch 1.
    - Three columns of the table are completed: in this case, incoming port (1), incoming VCI (66), and outgoing port (2).
  d. Switch 3 receives setup request frame.
    - Again, three columns are completed: incoming port (2), incoming VCI (22), and outgoing port (3).
  e. Destination B receives setup frame.

- 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.

2. Acknowledgment



- A special frame, called acknowledgment frame, completes the entries in switching tables.

a. Destination sends an acknowledgment to switch 3.

- Ack carries global source and destination addresses so the switch knows which entry in the table is to be completed.
- Frame also carries VCI 77, chosen by the destination as incoming VCI for frames from A.
- Switch 3 uses this VCI to complete outgoing VCI column for this entry.
- Note: 77 is incoming VCI for destination B, but outgoing VCI for switch 3.

b. Switch 3 sends an ack 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 ack 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. Source uses this as outgoing VCI for the data frames to be sent to destination B.

Teardown Phase

- Source A sends a special frame called a teardown request after sending all frames to B.
- Destination B responds with a teardown confirmation frame.
- All switches delete the corresponding entry from their tables.

Data-Transfer Phase

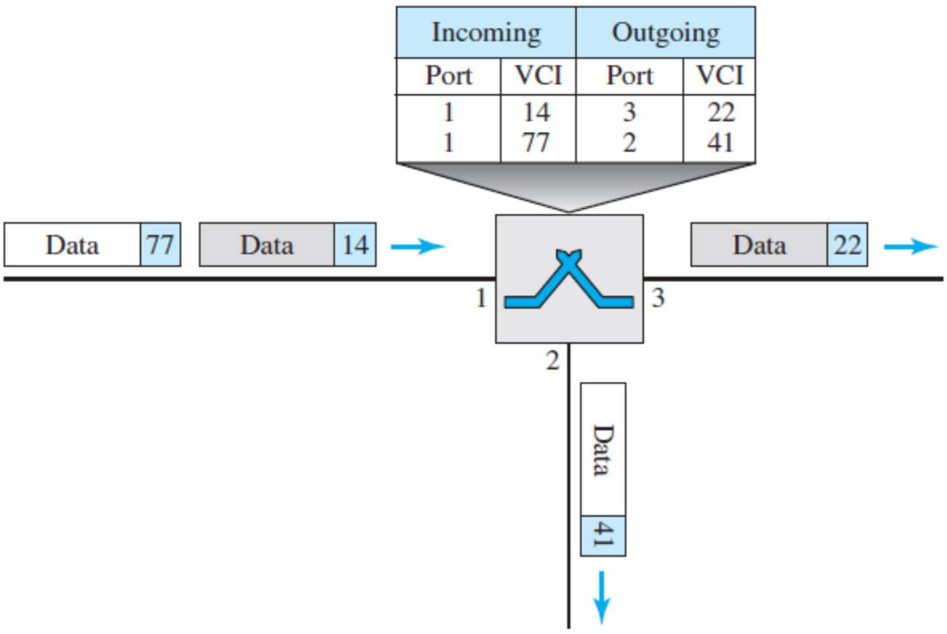


Fig. shows a switch and its corresponding table.

- To transfer a frame, all switches need to have a table entry for this virtual circuit.
- Table has four columns.
- Switch holds four pieces of information for each virtual circuit that is already set up.
- Above figure shows a frame arriving at port 1 with a VCI of 14.
- When the frame arrives, switch looks in its table to find port 1 and a VCI of 14.
- When it is found, switch knows to change the VCI to 22 and send out the frame from port 3.
- Each switch changes the VCI and routes the frame.
- Data-transfer phase is active until the source sends all its frames to the destination.
- Procedure at the switch is the same for each frame of a message.

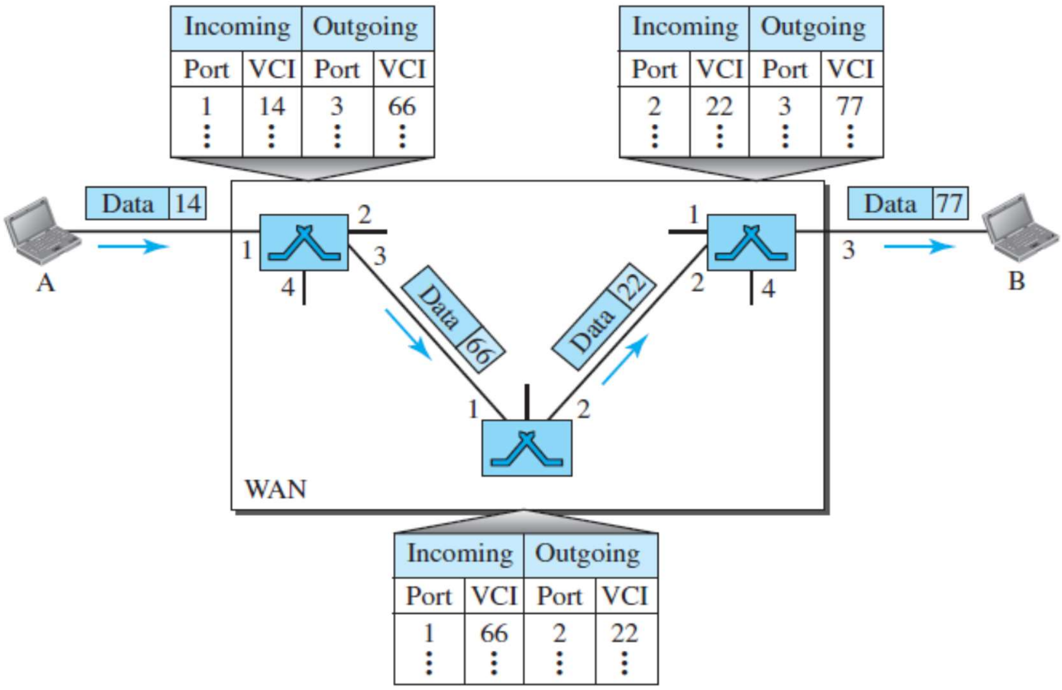


Fig. Source-to-destination data transfer in a virtual-circuit network

Efficiency

- Resource reservation can be made during setup phase.
  - Delay for each packet is same.
- Resource reservation can be on demand during data-transfer phase.
  - Each packet may encounter different delays.
- One big advantage is - resource allocation is on demand.
  - Source can check the availability of the resources, without actually reserving it.

Delay in Virtual-Circuit Networks

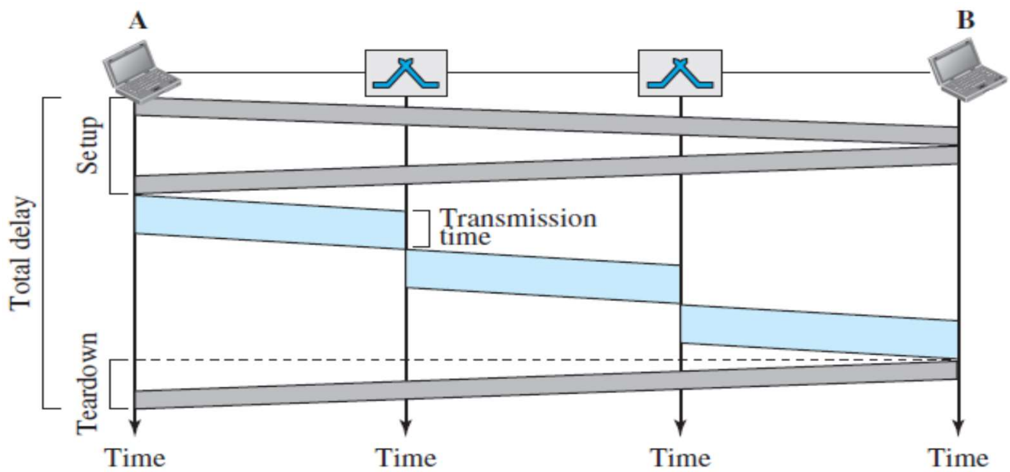


Fig. shows the delay for a packet traveling through two switches

- 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.
- Packet is traveling through two switches (routers).
- There are three transmission times (3T), three propagation times (3τ), 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.

Total delay = 3*T* + 3τ + setup delay + teardown delay

1.	**A path in a digital circuit-switched network has a data rate of 1 Mbps. The exchange of 1000 bits is required for the setup and teardown phases. The distance between two parties is 5000 km. Answer the following questions if the propagation speed is 2×10^8 m:** a. **What is the total delay if 1000 bits of data are exchanged during the data-transfer phase?** b. **What is the total delay if 100,000 bits of data are exchanged during the data-transfer phase?** c. **What is the total delay if 1,000,000 bits of data are exchanged during the data-transfer phase?** d. **Find the delay per 1000 bits of data for each of the above cases and compare them. What can you infer?** **Solution** **Given:** Total bandwidth or data rate = 1 Mbps Distance between two parties = 5000 km 1000 bits is required for the setup and teardown phases Propagation speed = 2×10^8 m/s **Formulas:** **Total time taken to transmit a message = Connection set up time + Transmission delay + Propagation delay + Tear down time** where- **Transmission delay = Message size / Bandwidth** **Propagation delay = Distance between 2 hops / Propagation speed** **1 km = 1000 m =10^3 m** **1 ms = 10^{-3} s** **1 s = 1000 ms** • We assume that the setup phase is a two-way communication and the teardown phase is a one-way communication. • These two phases are common for all three cases.

- The delay for these two phases can be calculated as three propagation delays and three transmission delays.

Calculating Propagation Delay:

Propagation Delay = (Distance) / (Propagation speed)

$= 5000 \text{ km} / 2 \times 10^8 \text{ m/s}$

$= 5000 * 10^3 \text{ m} / 2 \times 10^8 \text{ m/s}$

$= 2500 / 10^5 \text{ s}$

$= 25 * 10^{-3} \text{ s}$

$= 25 \text{ ms}$

Three propagation delays = 3 * 25 ms

= 75 ms

Calculating Transmission Delay:

Transmission delay (T) = File size / Bandwidth

= 1000 bits / 1 Mbps

$= 1000 \text{ bits} / 10^6$ bits per sec

$= 1 / 10^3$ sec

= 1 ms

Three transmission delays = 3 * 1 ms

= 3 ms

The delay for the setup phase and the teardown phase:

= Three propagation delays + Three transmission delays

= 75 ms + 3 ms

= 78 ms

- We assume that the data transfer is in one direction.
- The total delay is then delay for setup and teardown + propagation delay + transmission delay.

	(i). What is the total delay if 1000 bits of data are exchanged during the data-transfer phase? **<u>Calculating Propagation Delay:</u>** **Propagation Delay = (Distance) / (Propagation speed)** $= 5000\ km / 2 \times 10^8\ m/s$ $= 5000 * 10^3\ m / 2 \times 10^8\ m/s$ $= 2500 / 10^5\ s$ $= 25 * 10^{-3}\ s$ $= 25\ ms$ **<u>Calculating Transmission Delay:</u>** Transmission delay (T) = File size / Bandwidth = 1000 bits / 1 Mbps $= 1000$ bits / 10^6 bits per sec $= 1 / 10^3$ sec = 1 ms **<u>Calculating Total Delay:</u>** Total delay = Delay for setup & teardown + Propagation delay + Transmission delay = 78 ms + 25 ms + 1 ms = 104 ms **(ii). What is the total delay if 100,000 bits of data are exchanged during the data-transfer phase?** **<u>Calculating Propagation Delay:</u>** **Propagation Delay = (Distance) / (Propagation speed)** $= 5000\ km / 2 \times 10^8\ m/s$ $= 5000 * 10^3\ m / 2 \times 10^8\ m/s$ $= 2500 / 10^5\ s$ $= 25 * 10^{-3}\ s$ $= 25\ ms$

Calculating Transmission Delay:

Transmission delay (T) = File size / Bandwidth

= 100,000 bits / 1 Mbps

= 100,000 bits / 10^6 bits per sec

= 1 / 10 sec

= 0.1 * 1000 ms

= 100 ms

Calculating Total Delay:

Total delay = Delay for setup and teardown + Propagation delay + Transmission delay

= 78 ms + 25 ms + 100 ms

= 203 ms

(iii). What is the total delay if 1,000,000 bits of data are exchanged during the data-transfer phase?

Calculating Propagation Delay:

Propagation Delay = (Distance) / (Propagation speed)

= 5000 km / 2 $\times 10^8$ m/s

= 5000 * 10^3 m / 2 $\times 10^8$ m/s

= 2500 / 10^5 s

= 25 * 10^{-3} s

= 25 ms

Calculating Transmission Delay:

Transmission delay (T) = File size / Bandwidth

= 1,000,000 bits / 1 Mbps

= 1,000,000 bits / 10^6 bits per sec

= 1 sec

= 1 * 1000 ms

= 1000 ms

Calculating Total Delay:

Total delay = Delay for setup and teardown + Propagation delay + Transmission delay

= 78 ms + 25 ms + 1000 ms

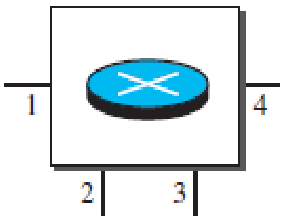
= 1103 ms

(iv). **Find the delay per 1000 bits of data for each of the above cases and compare them. What can you infer?**

- In case a, we have 104 ms.
- In case b we have 203/100 = 2.03 ms.
- In case c, we have 1103/1000 = 1.101 ms.
- The ratio for case c is the smallest because we use one setup and teardown phase to send more data.

2. Figure shows a switch (router) in a datagram network.

Destination address	Output port
1233	3
1456	2
3255	1
4470	4
7176	2
8766	3
9144	2



Find the output port for packets with the following destination addresses:.

a. **Packet 1: 7176**

b. **Packet 2: 1233**

c. **Packet 3: 8766**

d. **Packet 4: 9144**

<u>Solution</u>

Packet 1: 2

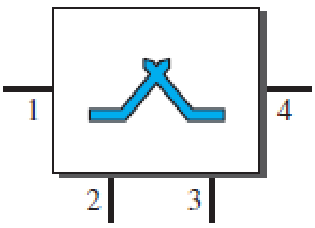
Packet 2: 3

Packet 3: 3

Packet 4: 2

3. **Figure shows a switch in a virtual-circuit network.**

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	22
2	71	4	41
2	92	1	45
3	58	2	43
3	78	2	70
4	56	3	11



Find the output port and the output VCI for packets with the following input port and input VCI addresses:

a. **Packet 1: 3, 78**

b. **Packet 2: 2, 92**

c. **Packet 3: 4, 56**

d. **Packet 4: 2, 71.**

<u>Solution</u>

a. **Packet 1: 3, 78**

Output port and the output VCI : 2, 70

b. **Packet 2: 2, 92**

Output port and the output VCI : 1, 45

c. **Packet 3: 4, 56**

Output port and the output VCI : 3, 11

d. **Packet 4: 2, 71**

Output port and the output VCI : 4, 41

Define the following parameters for a switching network:
N= number of hops between two given end systems
L= message length in bits
B= data rate in bits per second (bps), on all links
P= packet size
H= overhead (header) bits per packet
S= call setup time (circuit switching or virtual circuit) in seconds
D= propagation delay per hop in seconds

For N=4, L=3200, B=9600, p=1024, H=16, S=0.2, D=0.001, compute the end-to-end delay for circuit, virtual-circuit, and packet switching. Assume there are no acknowledgements, and no queuing delay.

circuit:
Latency = SetupTime + TransmitTime + PropagationTime + QueuingDelay
= (S) + (Size/Bandwidth) + (N*D) + 0
= S + L/B + N*D= 0.2 + 3200/9600 + 4*0.001 =537ms

packet:
Latency = TransmitTime + PropagationTime + QueuingDelay
= (Size/Bandwidth) + (N*D) + 0, where Size=(number-of-packets)*(overhead+size-of-packet)
= (L/P)*(H+P)/B+N*D=(3200/1024)*(16+1024)/9600+4*0.001=343 ms

virtual circuit:
Latency = SetupTime + TransmitTime + PropagationTime + QueuingDelay
= (S) + (Size/Bandwidth) + (N*D) + 0, where Size=(number-of-packets)*(overhead+size-of-packet)
= S + (L/P)*(H+P)/B + N*D =0.2 + (3200/1024)*(16+1024)/9600 + 4*0.001=543 ms

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:

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

We assume that the delay for each switch (including waiting and processing) is 3, 10, 20, 7, and 20 ms 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.

Solution:

The arrival timed is calculated as:

First: (3200 Km) / (2×10^8 m/s) + (3 + 20 + 20) = 59.0 ms

Second: (11700 Km) / (2×10^8 m/s) + (3 + 10 + 20) = 91.5 ms

Third: (12200 Km) / (2×10^8 m/s) + (3 + 10+ 20 + 20) = 114.0 ms

Fourth: (10200 Km) / (2×10^8 m/s) + (3 + 7 + 20) = 81.0 ms

Fifth: (10700 Km) / (2×10^8 m/s) + (3 + 7 + 20 + 20) = 103.5 ms

The order of arrival is: $\boxed{3 \rightarrow 5 \rightarrow 2 \rightarrow 4 \rightarrow 1}$