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

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

  $= 1 / 10^3 \text{ sec}$

  = 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?

Calculating Propagation Delay:

Propagation Delay = (Distance) / (Propagation speed)

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

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

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

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

$= 25 \text{ ms}$

Calculating Transmission Delay:

Transmission delay (T) = File size / Bandwidth

= 1000 bits / 1 Mbps

= 1000 bits / 10^6 bits per sec

= 1 / 10^3 sec

= 1 ms

Calculating Total Delay:

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?

Calculating Propagation Delay:

Propagation Delay = (Distance) / (Propagation speed)

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

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

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

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

$= 25 \text{ ms}$

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

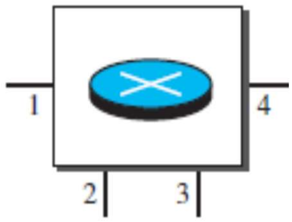
= 1103 ms

(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

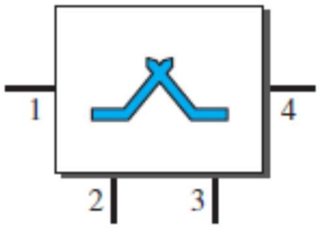
Packet 2: 3

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

4.	**Design a three-stage, 200 × 200 switch (N = 200) with k = 4 and n = 20.** **<u>Solution</u>** **First stage has N/n crossbars of n × k crosspoints.** **Middle stage k crossbars, each of size (N/n) × (N/n).** **Third stage has N/n crossbars, each of size k × n.** No. of crossbars in the first stage = N/n = 200 / 20 = 10 crossbars, each of size 20 × 4 No. of crossbars in the second stage = 4 crossbars, each of size 10 × 10. No. of crossbars in the third stage = 10 crossbars, each of size 4 × 20. The total number of crosspoints = $2kN + k(N/n)^2$ $= 2 * 4 * 200 + 4(200/20)^2$ = 2000 crosspoints $\frac{N}{n}(n \times k) + k\left(\frac{N}{n} \times \frac{N}{n}\right) + \frac{N}{n}(k \times n) = 2kN + k\left(\frac{N}{n}\right)^2$ The total number of crosspoints = 10 (20 *4) + 4 (10 * 10) + 10 (4 * 20) = 800 + 400 + 800 = 2000 crosspoints This is 5 percent of the number of crosspoints in a single-stage switch (200 × 200 = 40,000).
5.	**Redesign the previous three-stage, 200 × 200 switch, using the Clos criteria with a minimum number of crosspoints.** **<u>Solution</u>** **First stage has N/n crossbars of n × k crosspoints.** **Middle stage k crossbars, each of size (N/n) × (N/n).** **Third stage has N/n crossbars, each of size k × n.** **The number of middle-stage switches must be at least 2n – 1.** **$k \geq 2n - 1$** **According to Clos criterion: $n = (N/2)^{1/2}$** **Total number of crosspoints $\geq 4N[(2N)^{1/2} - 1]$**

We let $n = (200/2)^{1/2}$

$n = 10$

We calculate $k = 2n – 1$

$= (2 * 10) - 1$

$= 19$

Number of crossbars in the first stage = N / n

= 200/10

= 20 crossbars, each with 10×19 crosspoints.

No. of crossbars in the second stage = 19 crossbars, each with 20×20 crosspoints.

No. of crossbars in the third stage = 20 crossbars each with 19×10 crosspoints.

The total number of crosspoints $= 20(10 \times 19) + 19(20 \times 20) + 20(19 \times 10)$

$= 15200$

Total number of crosspoints $\geq 4N [(2N)^{1/2} - 1]$

$= 4 * 200 ((2*200)^{1/2} – 1)$

$= 4 * 200 (20-1)$

$= 4 * 200 (19)$

$= 15200$

If we use a single-stage switch, we need $200 \times 200 = 40{,}000$ crosspoints.

The number of crosspoints in this three-stage switch is 24 percent that of a single-stage switch.

The extra crosspoints are needed to prevent blocking.

6. **We need a three-stage space-division switch with N = 100. We use 10 crossbars at the first and third stages and 4 crossbars at the middle stage.**

a. Draw the configuration diagram.

b. Calculate the total number of crosspoints.

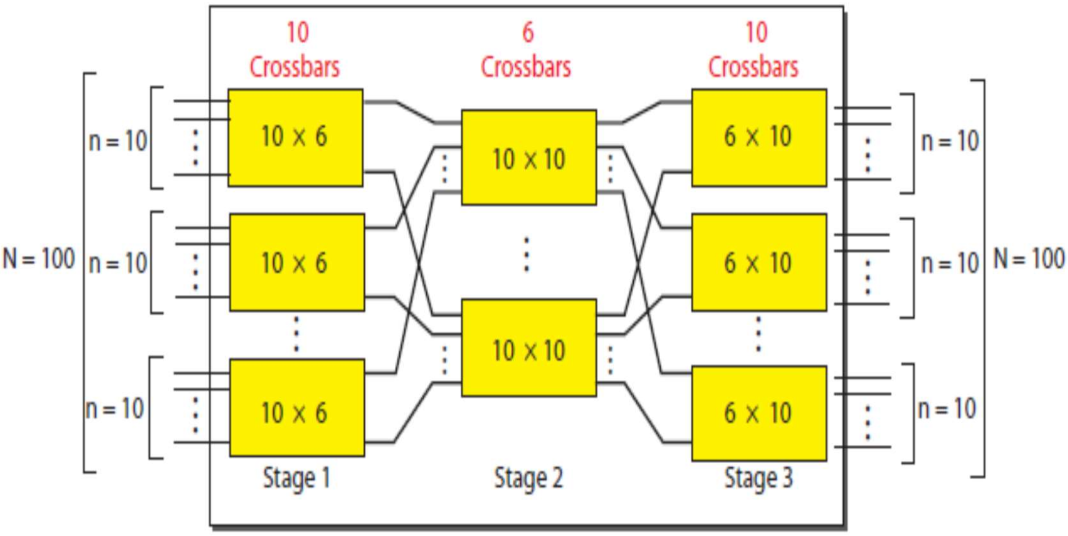
c. Find the possible number of simultaneous connections.

d. Find the possible number of simultaneous connections if we use a single crossbar (100 × 100).

e. Find the blocking factor, the ratio of the number of connections in part c and in part d.

<u>Solution</u>

a. Draw the configuration diagram.



b. Calculate the total number of crosspoints.

Number of crossbars in the first stage = N / n

= 100/10

= 10 crossbars, each with 10 × 6 crosspoints.

No. of crossbars in the second stage = 6 crossbars, each with 10 × 10 crosspoints.

No. of crossbars in the third stage = 10 crossbars each with 6 × 10 crosspoints.

The total number of crosspoints = 10 (10 × 6) + 6 (10 × 10) + 10 (6 × 10)

= 600 + 600 + 600

= 1800

	c. Find the possible number of simultaneous connections. Only six simultaneous connections are possible for each crossbar at the first stage. This means that the total number of simultaneous connections is 60. **d. Find the possible number of simultaneous connections if we use a single crossbar (100 × 100).** If we use one crossbar (100 × 100), all input lines can have a connection at the same time, which means 100 simultaneous connections. **e. Find the blocking factor, the ratio of the number of connections in part c and in part d.** The blocking factor is 60/100 or 60 percent.