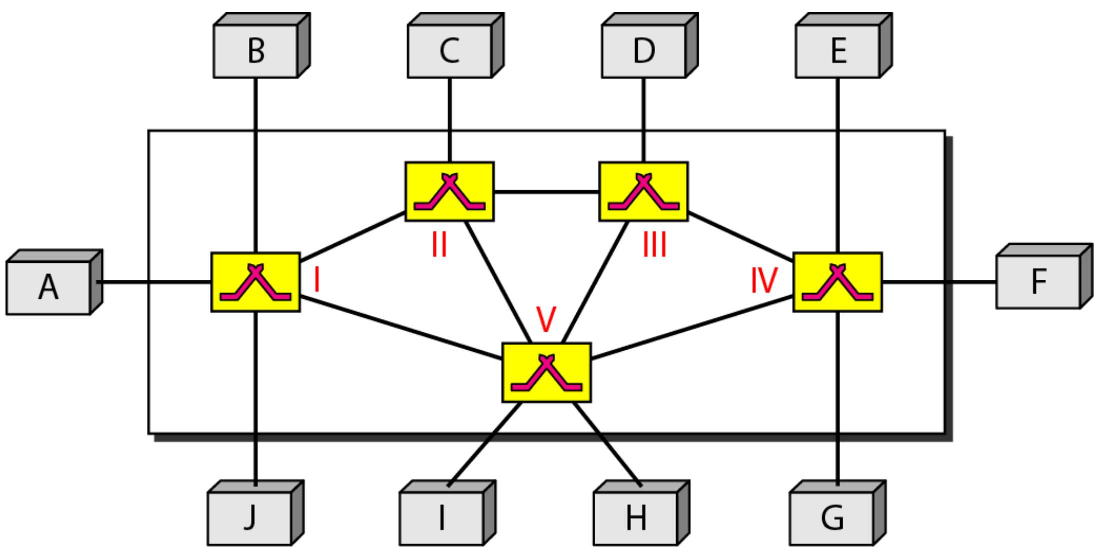
CSE 365: Communication Engineering

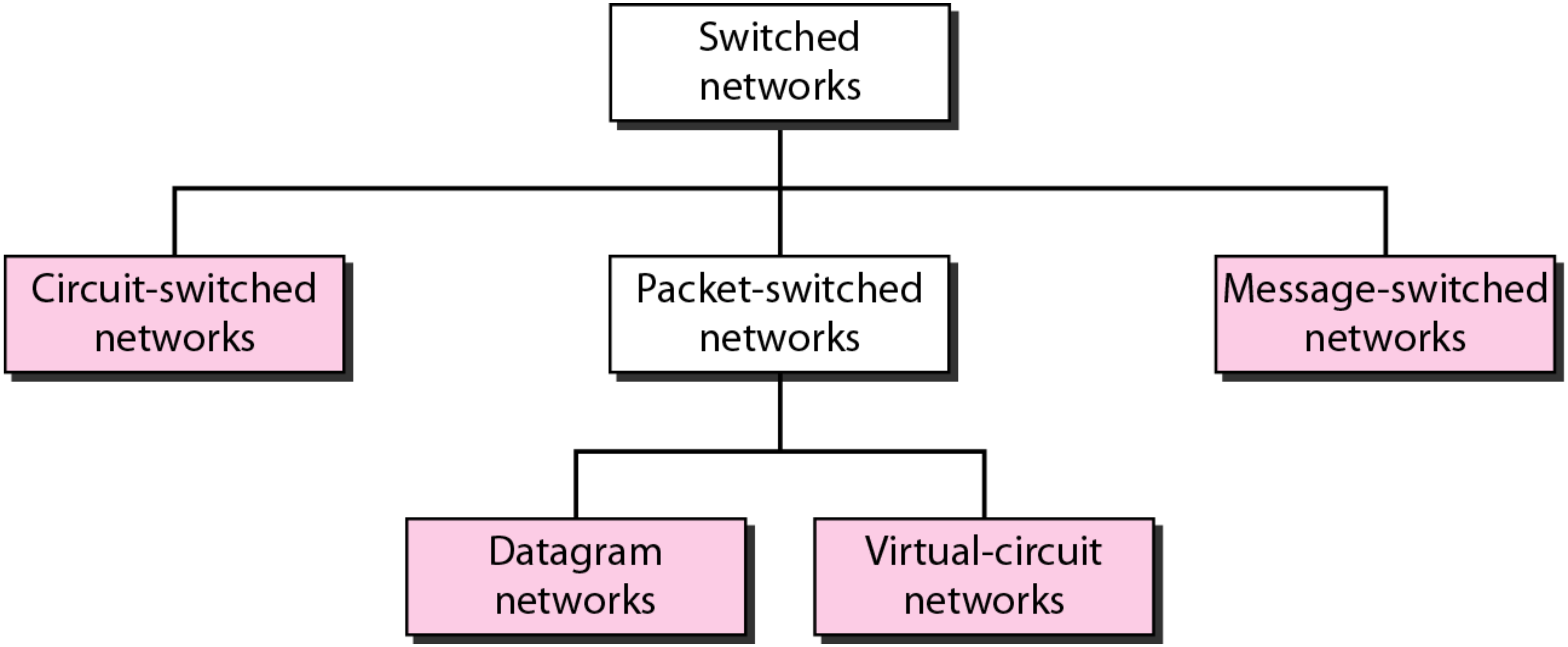
Chapter 8: Switching

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.



Taxonomy of Switched Networks



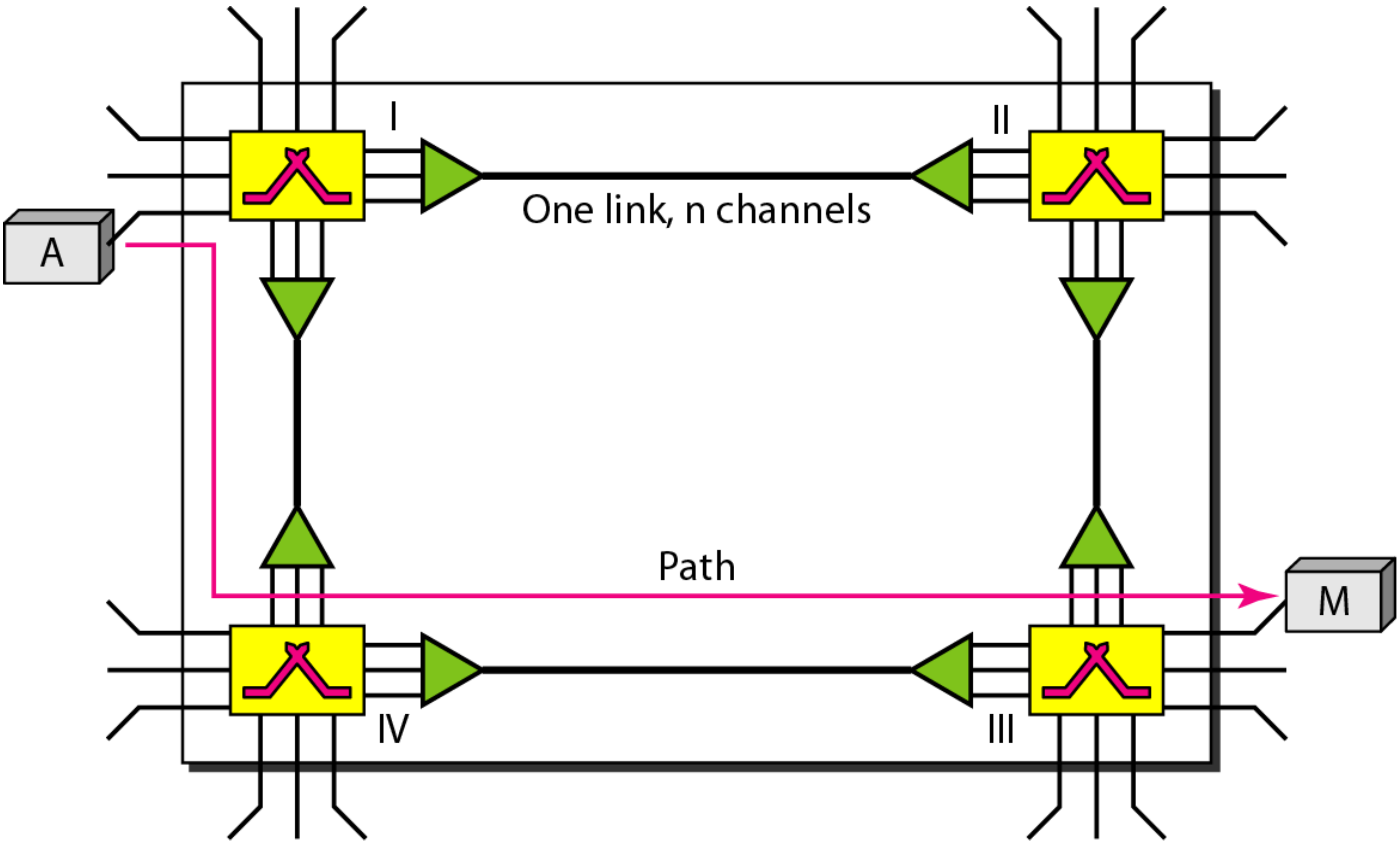
Switching and TCP/IP Layers

- Switching at Physical layers:
  - Circuit switching.
- Switching at Data-link layers:
  - Packet switching (Virtual-circuit approach)
- Switching at Network layers:
  - Packet switching (Virtual-circuit approach or Datagram approach)
- Switching at Application layers:
  - Message switching

Circuit-Switched Network

- A circuit-switched network is made of a set of switches connected by physical links, in which each link is divided into *n* channels by using FDM or TDM.
- A connection between two stations is a dedicated path made of one or more links.
- Before starting communication, the station make a reservation for the resources.
- Telephone network uses circuit-switched network.

Circuit-Switched Network



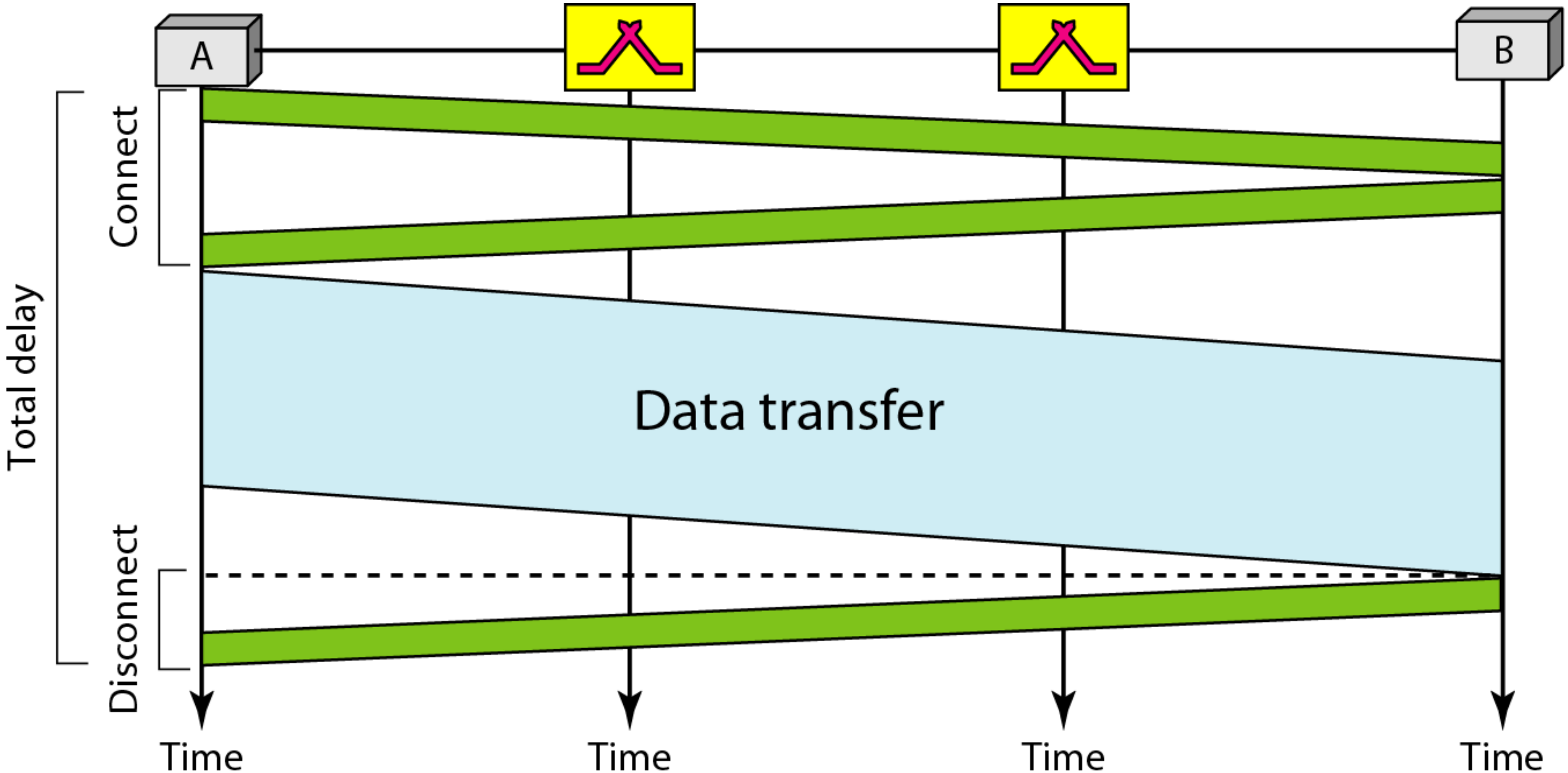
Three Phases

- The actual communication in a circuit-switched network requires three phases:
- *Setup Phase:* Before the two parties can communicate, a dedicated circuit needs to be established.
  - A sends a setup request to M
  - M sends an acknowledgement
- *Data Transfer Phase:* After the establishment of the dedicated circuits, 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.

Important points

- Switching take place at physical layer
- Reservation for the resources
  - Such as bandwidth in FDM and time slot in TDM
  - Switch buffer
  - Switch processing time
  - Switch I/O ports
- Data transferred are not packetized, continuous flow
- No addressing involved during data transfer

Delay in a Circuit-switched Network

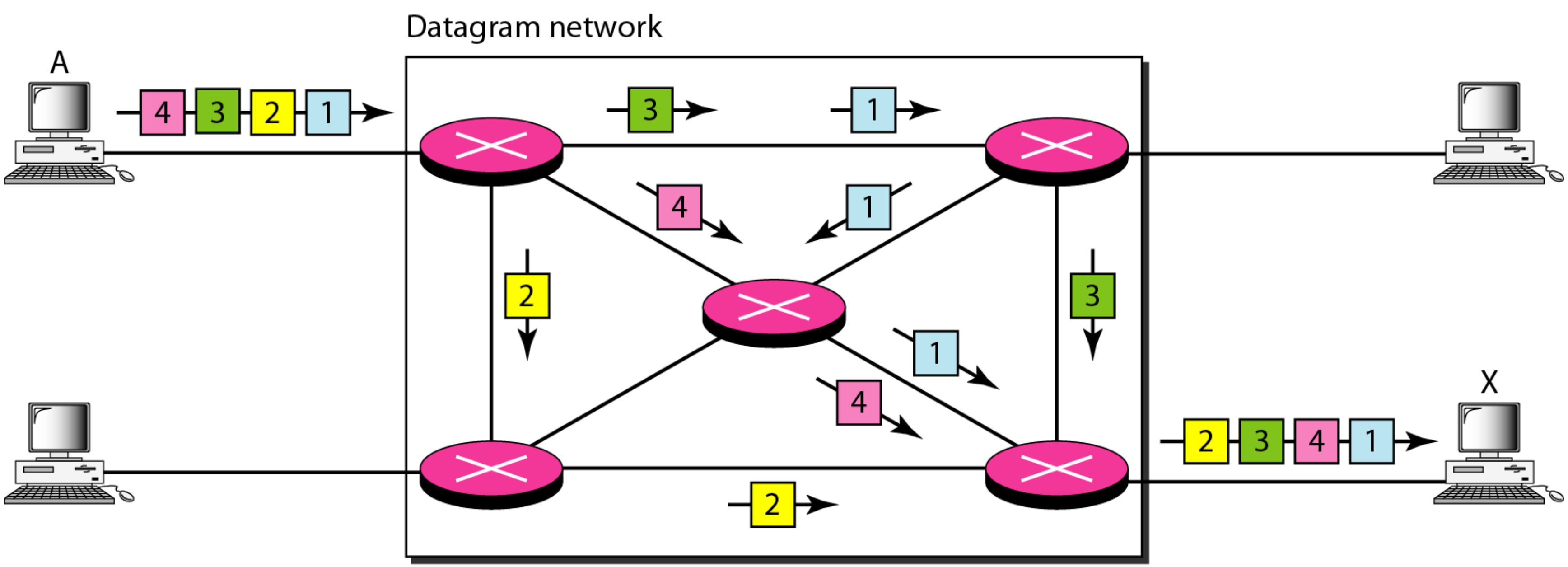


Packet Switching

- In a *packet-switched network*, the message needs to be divided into packets of fixed or variable size.
- There is no resource reservation; resources are allocated on demand.
- The allocation is done on a first-come, first-served basis.
- When a switch receives a packet, the packet must wait if there are other packets being processed.
- Two types: *Datagram networks* and *Virtual-circuit networks*.

Datagram Network

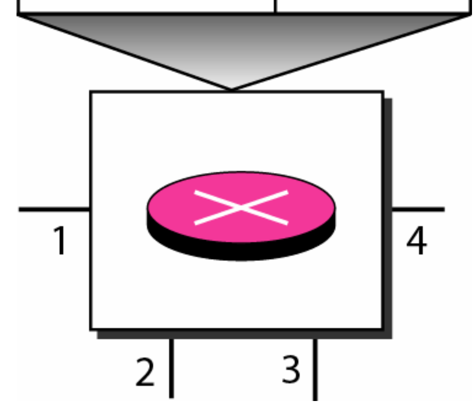
- Packets are referred to as *datagrams*.
- Done at *network layers.*
- The switches are referred to as *routers*.



Datagram Network

- Datagram networks are sometimes referred to as *Connectionless Networks*.
- There are no setup or teardown phases.
- *Routing Table:*
  - Each switch (or packet switch/router) has a routing table based on the destination address.
  - The routing tables are dynamic and are updated periodically.
- *Destination Address:* The destination address in the header of a packet in a datagram network remains the same during the entire journey of the packet.

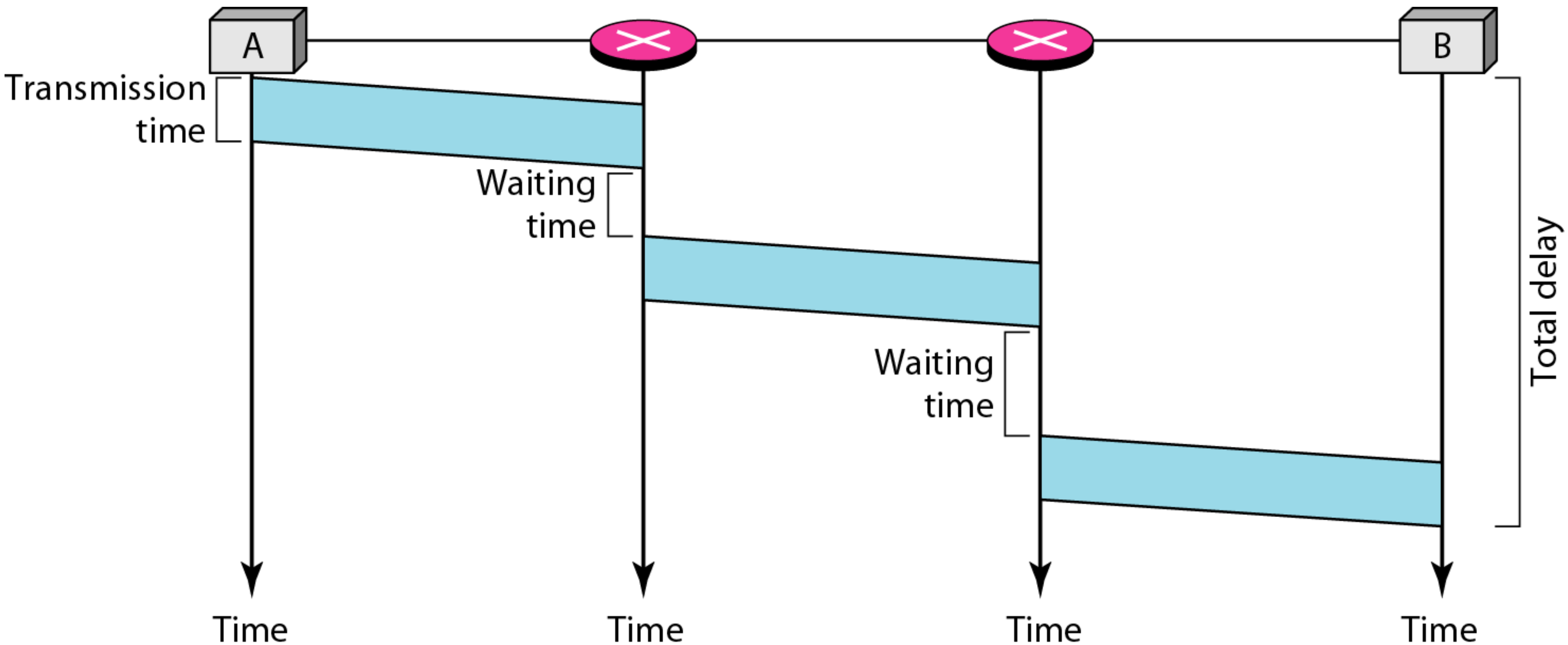
Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3



Datagram Network

- *The efficiency is better* than a circuit switched network as resources are allocated on demand.
- May have *a greater delay* than circuit switched networks.
- Although there are *no setup and teardown phases*, each packet may experience *a wait* at a switch before it is forwarded.

Delay in a Datagram Network



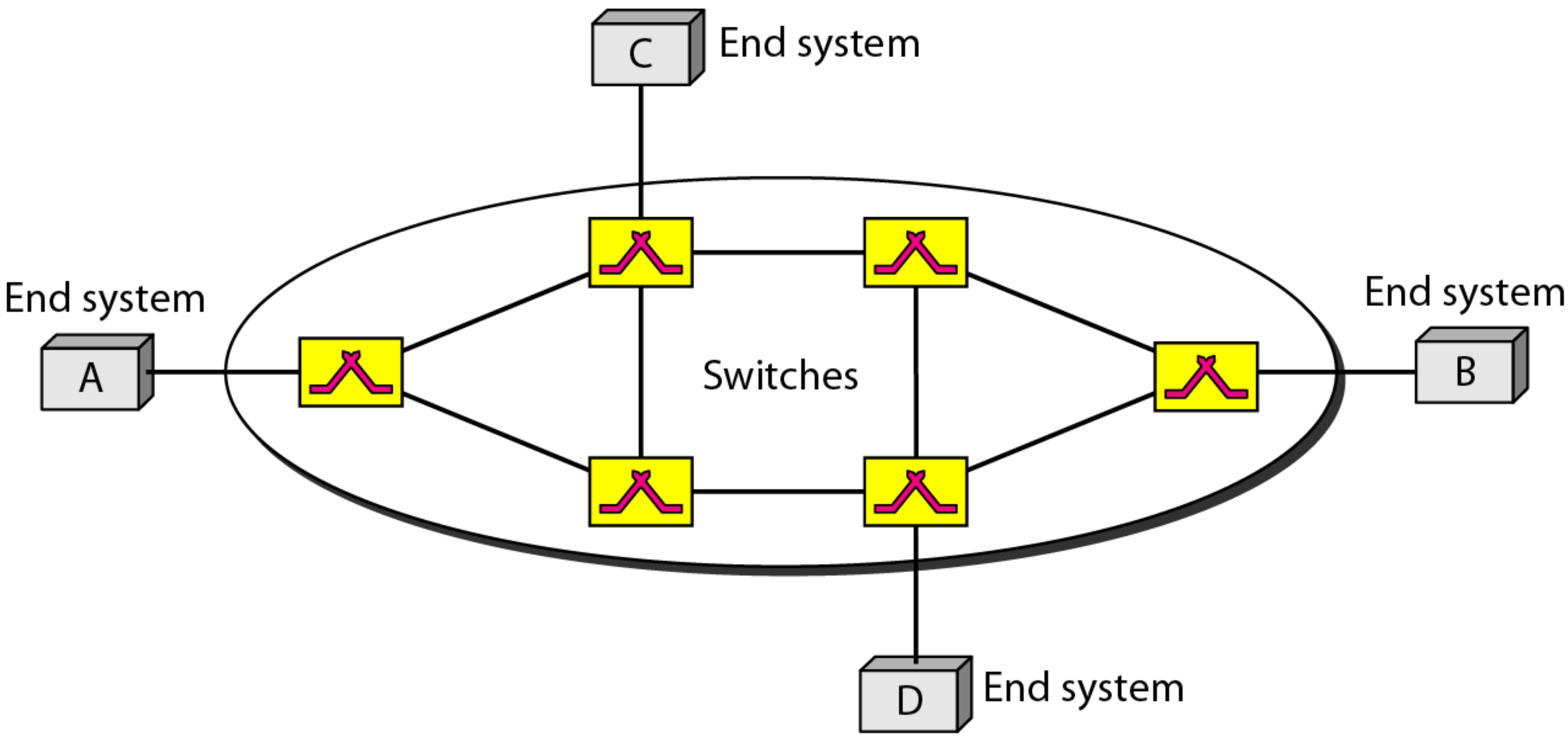
Total delay = Three transmission times + three propagation delays + two waiting times

$= 3T + 3\,\tau + w_1 + w_2$

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. It has three phases (circuit-switched)
  2. Resources can be allocated during the setup phase (circuit-switched) or on demand (datagram)
  3. Data are packetized and each packet carries an address in the header (datagram), but follows local jurisdiction
  4. All packets follow the same path established during the connection (circuit-switched)
  5. Implemented in the data link layer.

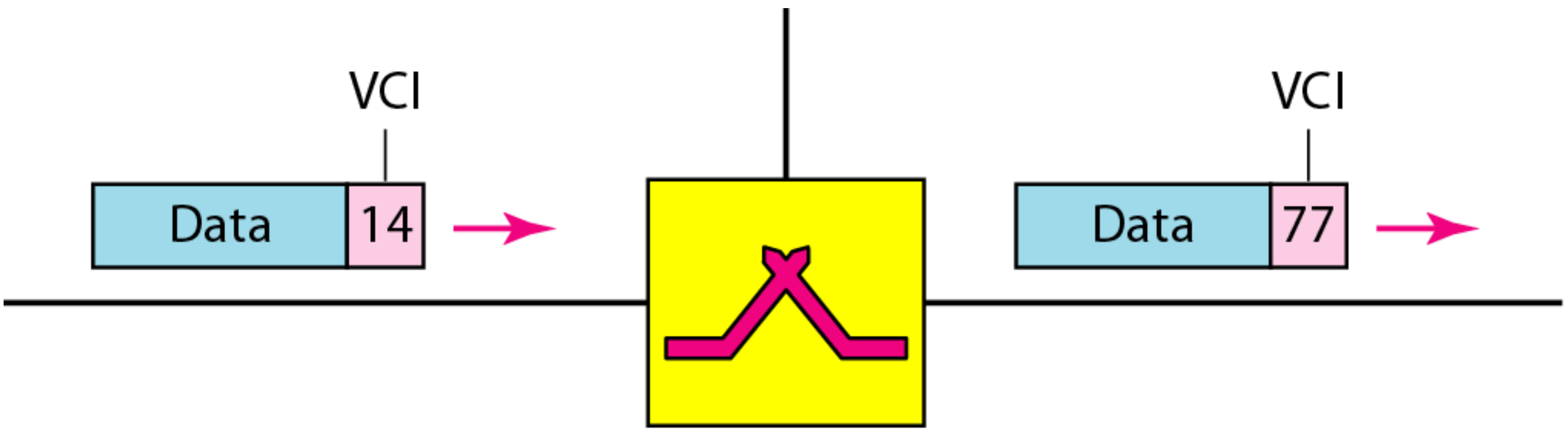
Virtual-Circuit Networks



Addressing

- In a virtual-circuit network, two types of addressing are involved: *Global* and *Local* (virtual-circuit identifier).
- Global Addressing: an address that can be unique in the scope of the network or internationally if the network is part of an international network.
- 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.

Virtual-Circuit Identifier

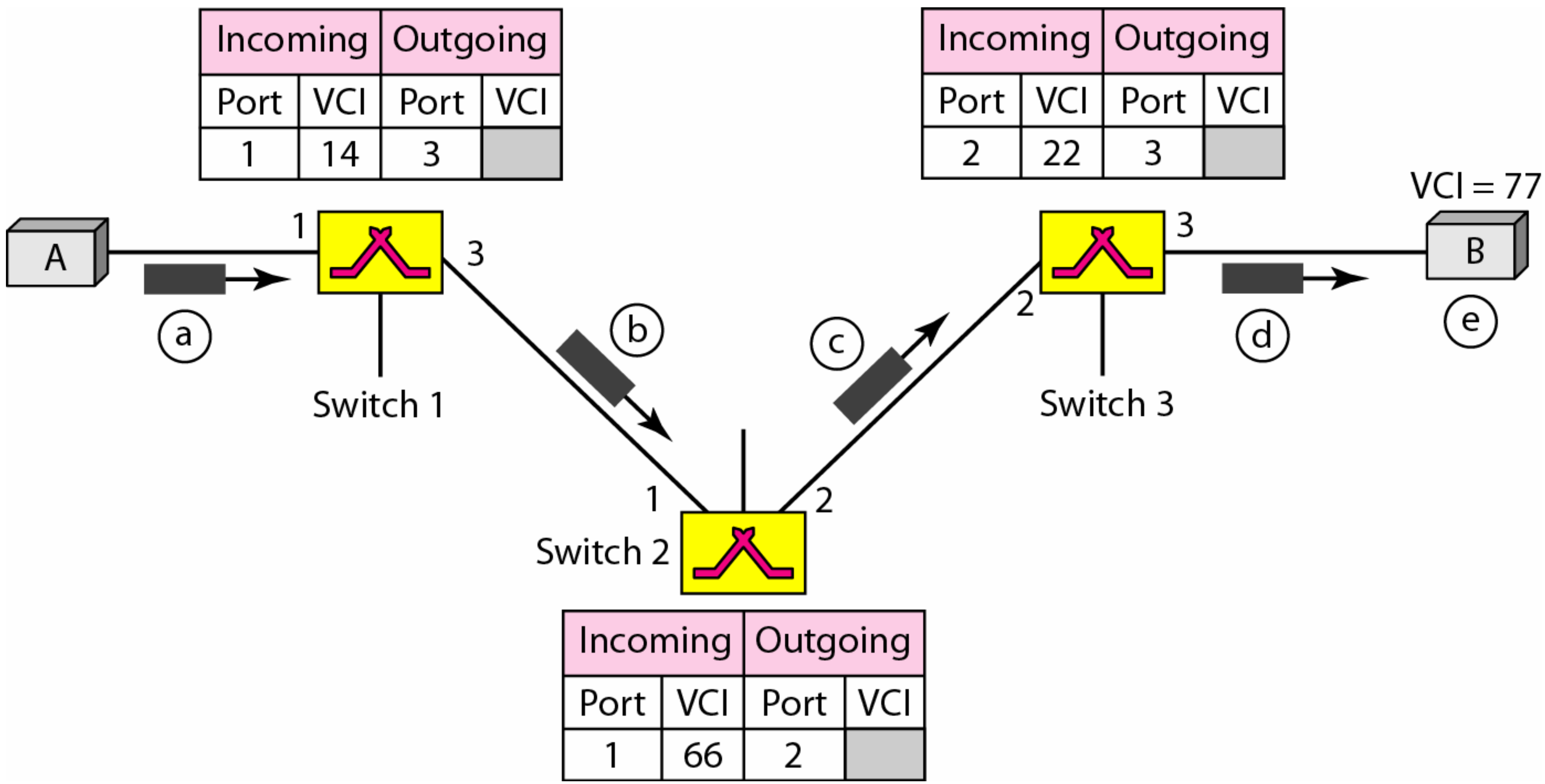


Three Phases

- In a virtual-circuit network, a source and destination need to go through three phases:
  - Setup Phase
  - Data Transfer Phase
  - Teardown Phase
- Setup Phase: Two steps are required-
  1) Setup Request: A setup request frame is sent from the source to the destinations
  2) Acknowledgement: A special frame, acknowledgement frame completes the entries in the switching table
- Data Transfer Phase: Once Setup phase completes, data transfer phase becomes straightforward.
- Teardown Phase: After sending all frames, a special frame is send to end the connection

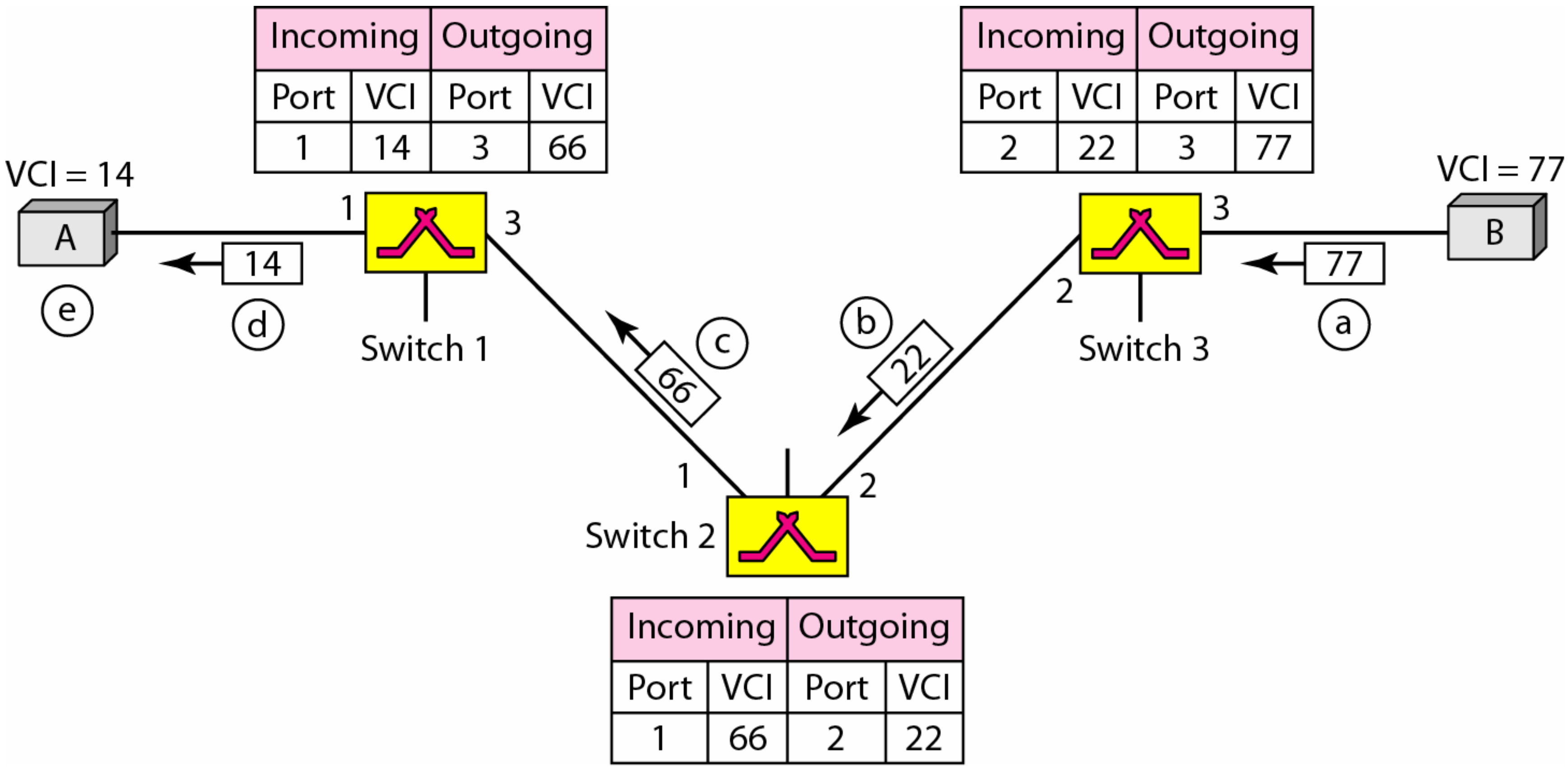
Setup Request in a Virtual-Circuit Network

Setup Request: A setup request frame is sent from the source to the destinations



Setup Acknowledgement in a Virtual-Circuit Network

Acknowledgement: A special frame, acknowledgement frame, completes the entries in the switching table



Switch and Tables in a Virtual-Circuit Network

Once Setup phase completes, data transfer phase becomes straightforward.

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

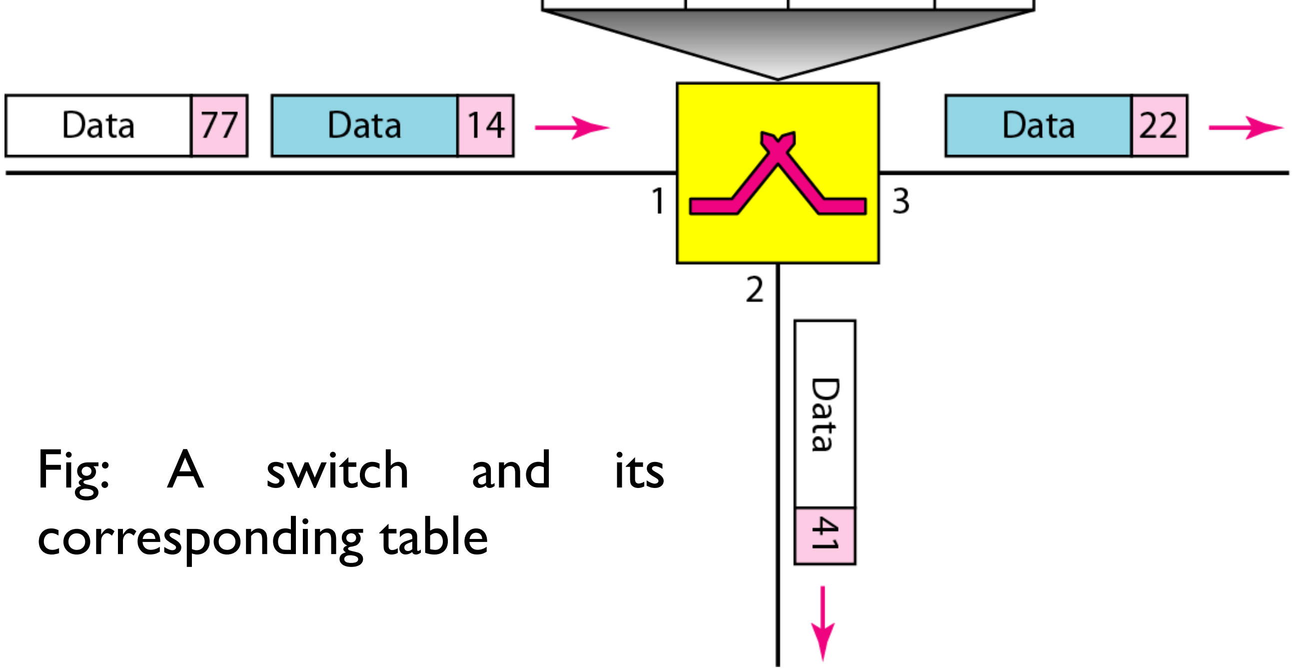
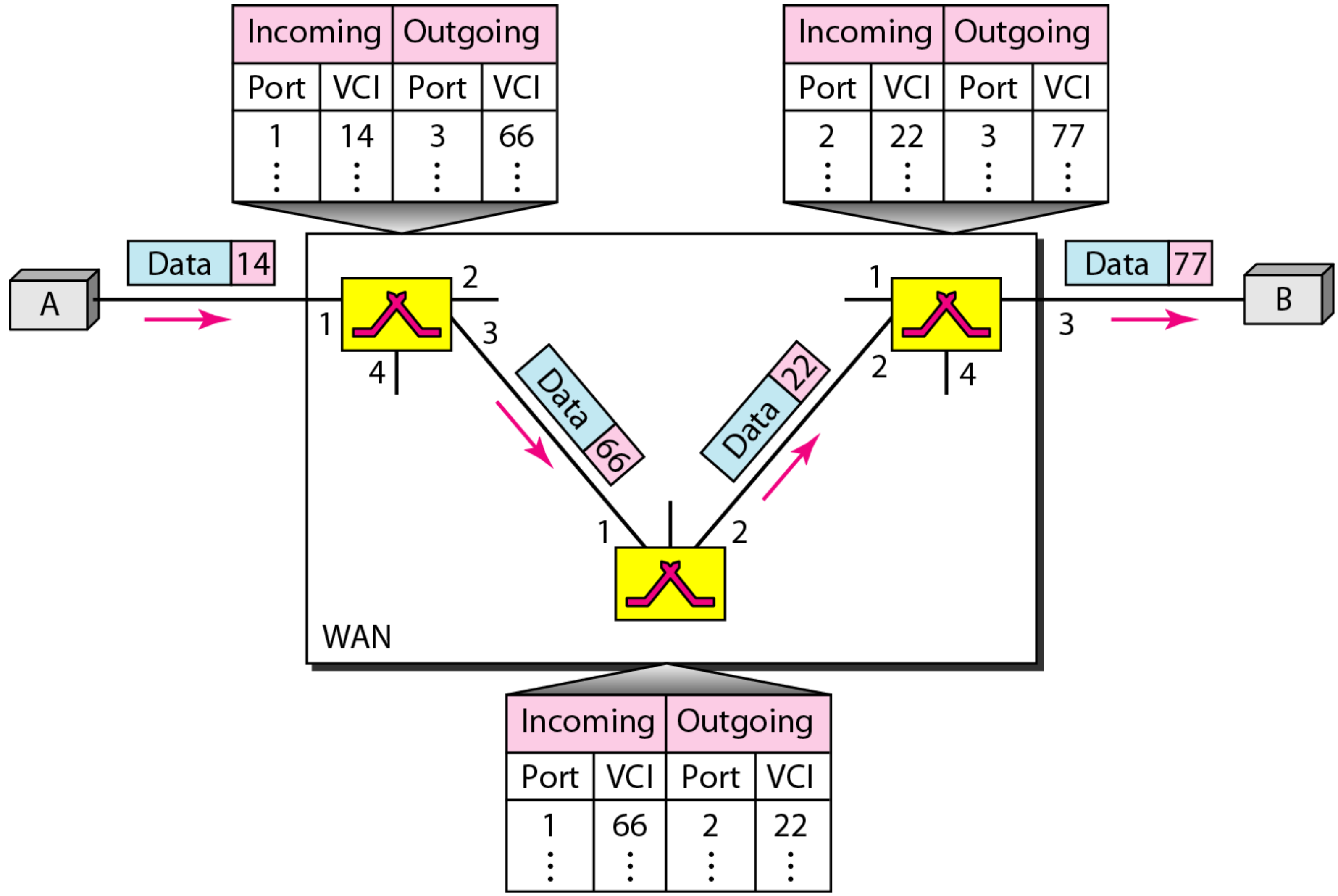
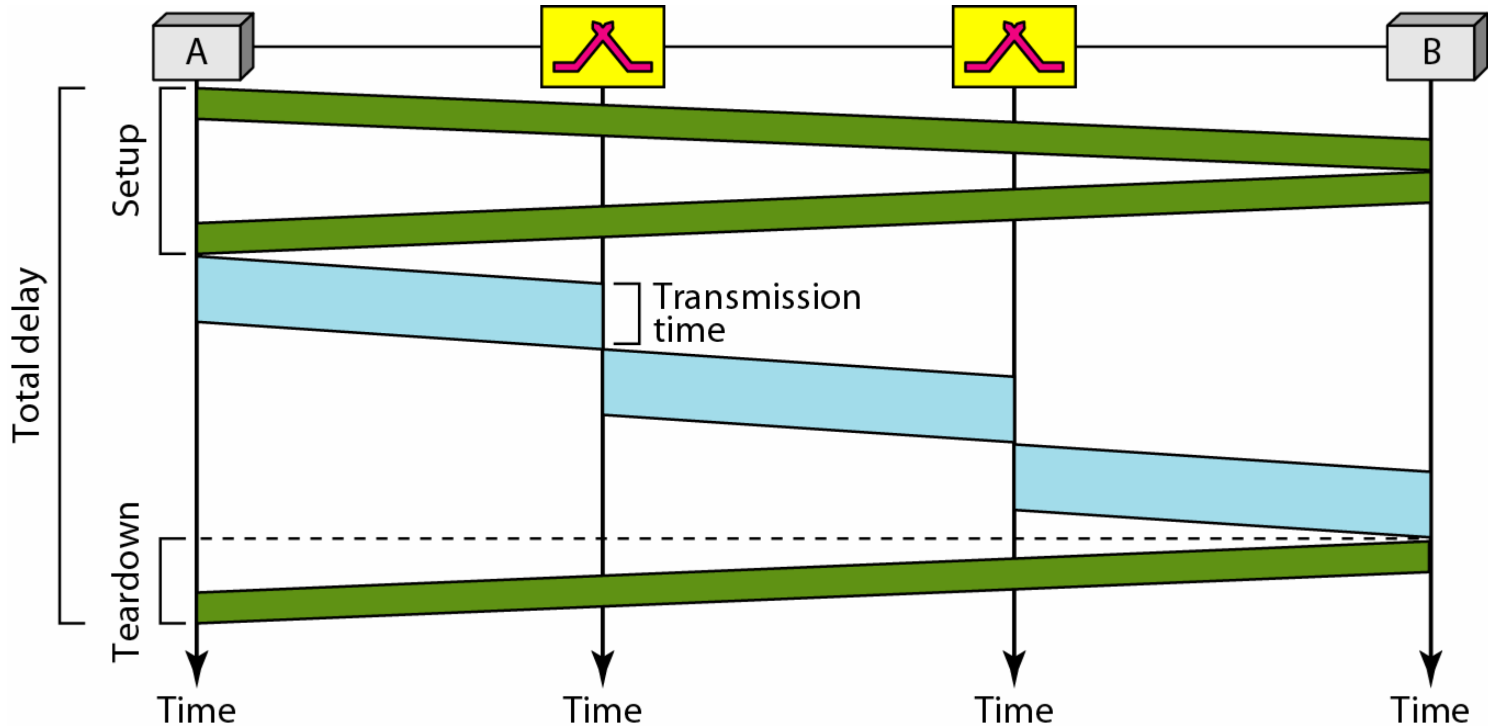


Fig: A switch and its corresponding table

Source-to-destination data transfer in a Virtual-Circuit Network



Delay in a Virtual-Circuit Network



Total delay = Three transmission times (*3T*) +
three propagation delays (*3 τ*) +
setup delay + teardown delay

Structure of a Switch: Circuit Switch

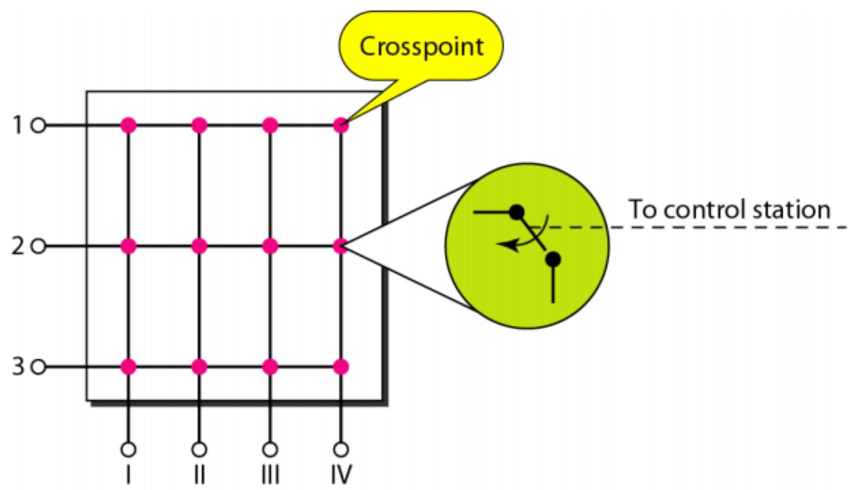
Circuit switching today can use either of two technologies:

- Space-Division Switch
- Time-Division Switch

- Space-Division Switch
  - The paths in the circuit are separated from one another spatially
  - Originally designed for use in analog networks but is used currently in both analog and digital networks.
  - It has evolved through a long history of many designs.

Crossbar Switch

- A crossbar switch connects *n* inputs to *m* outputs in a grid, using electronic micro-switches (transistors) at each crosspoint.
- The major limitation of this design is the number of crosspoints required.
- To connect *n* inputs to *m* outputs using a crossbar switch requires $n \times m$ crosspoints.

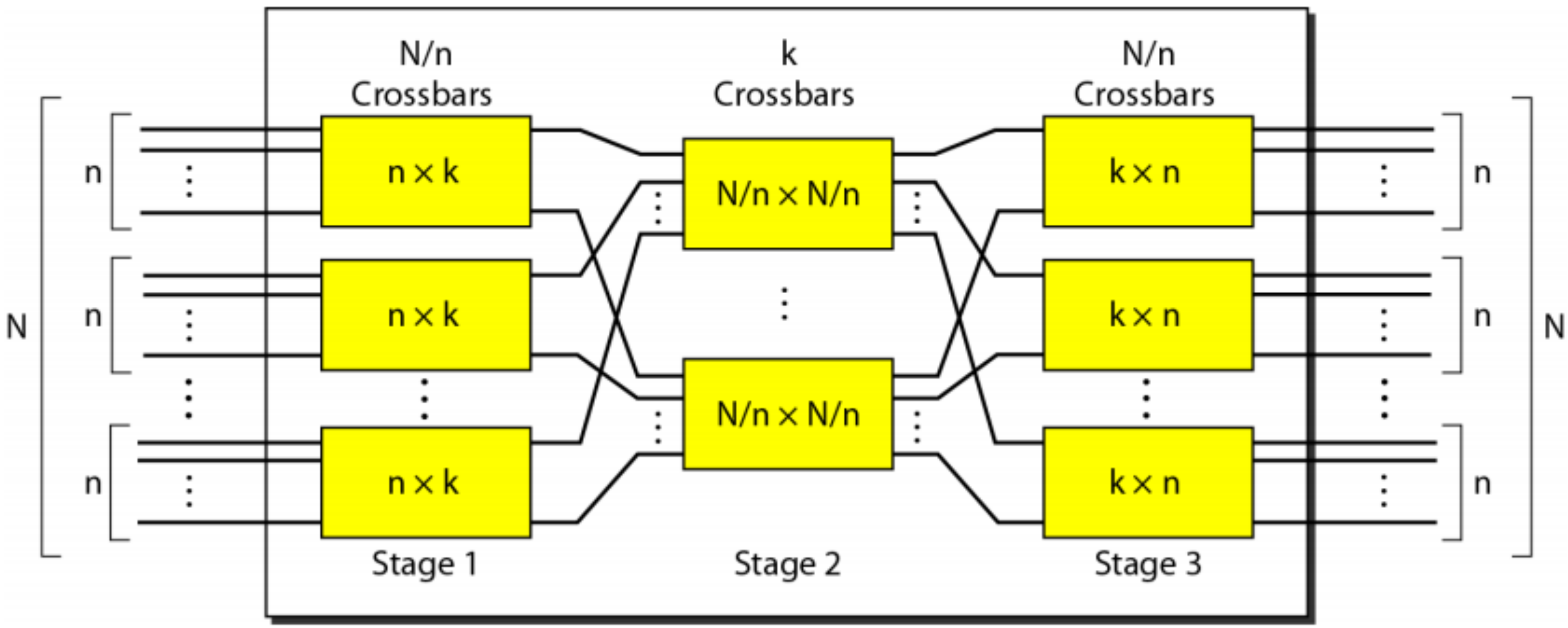


Example

- For example, to connect 1000 inputs to 1000 outputs requires a switch with 1000000 crosspoints.
- A crossbar switch with this number of crosspoints is impractical.
- Fewer than 25% of the crosspoints are in use at any given time.

Multistage Switch

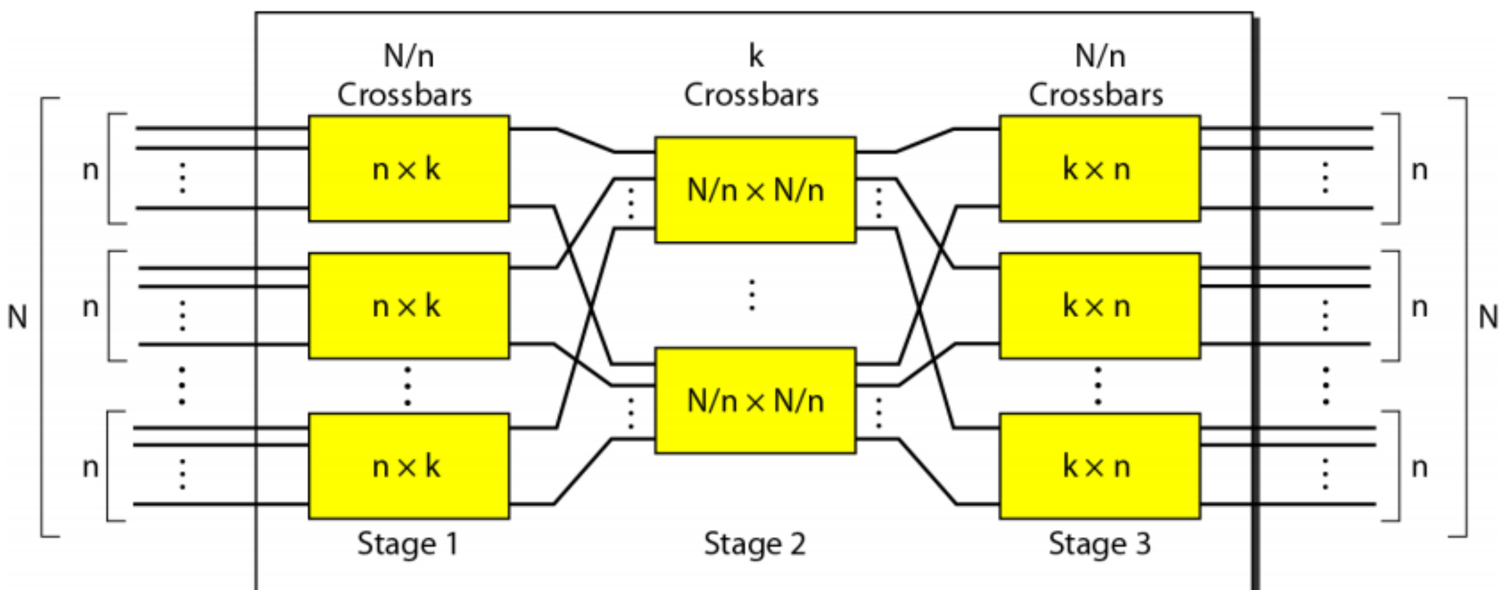
- The solution to the limitations of the crossbar switch is the multistage switch, which combines crossbar switches in several (normally three) stages



Multistage Switch

- To design a three-stage switch:

1) We divide the N input lines into groups, each of n lines. For each group, we use one crossbar of size $n \times k$, where k is the number of crossbars in the middle stage. In other words, the first stage has N/n crossbars of $n \times k$ crosspoints.
2) We use k crossbars, each of size $(N/n) \times (N/n)$ in the middle stage.
3) We use N/n crossbars, each of size $k \times n$ at the third stage.



Multistage Switch

- We can calculate the total number of crosspoints as follows:

$$\frac{N}{n}(n \times k) + k\left(\frac{N}{n} \times \frac{N}{n}\right) + \frac{N}{n}(k \times n) = 2kN + k\left(\frac{N}{n}\right)^2$$

In a three-stage switch, the total number of crosspoints is

$$2kN + k\left(\frac{N}{n}\right)^2$$

which is much smaller than the number of crosspoints in a single-stage switch (N^2).

Example 8.3

Design a three-stage, 200 × 200 switch (N = 200) with k = 4 and n = 20.

Solution:

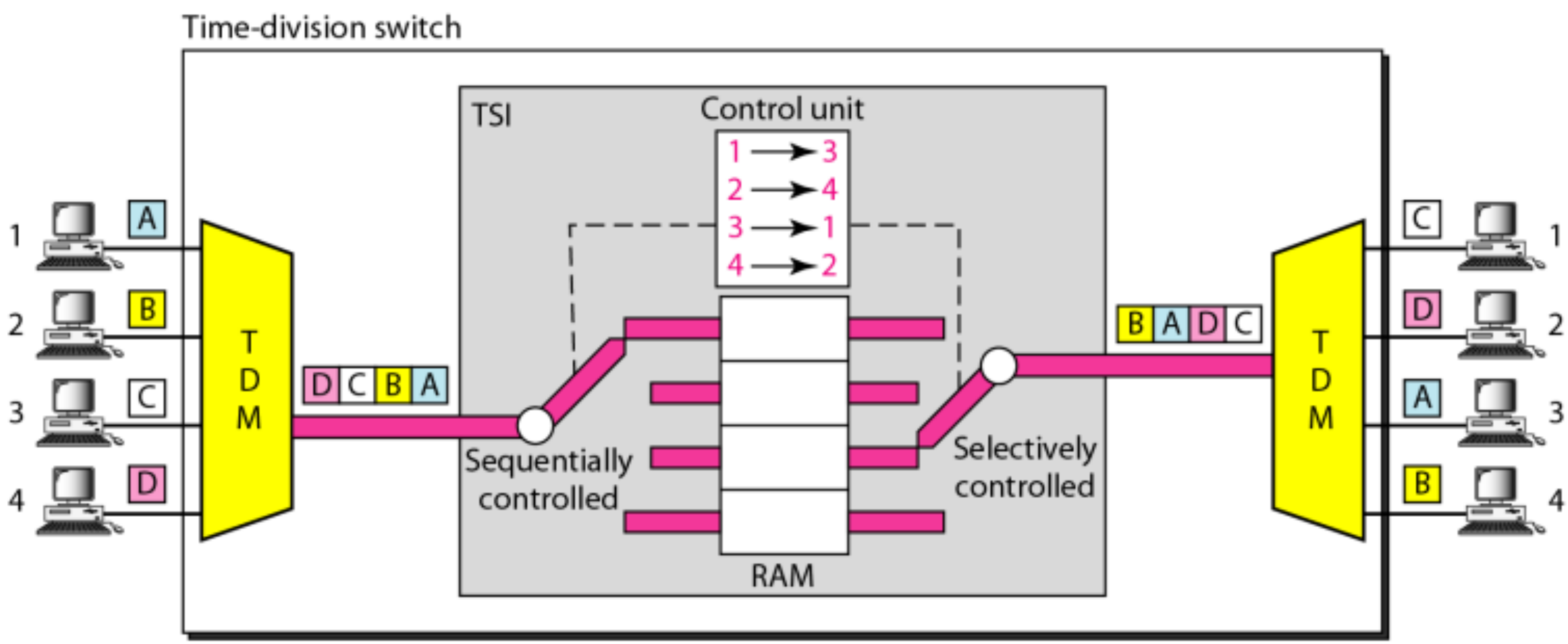
- In the first stage we have N/n or 10 crossbars, each of size 20 × 4.
- In the second stage, we have 4 crossbars, each of size 10 × 10.
- In the third stage, we have 10 crossbars, each of size 4 × 20.
- The total number of crosspoints is $2kN + k(N/n)^2$, or 2000 crosspoints.
- This is 5 percent of the number of crosspoints in a single-stage switch (200 × 200 = 40,000).

Blocking

- The multistage switch has one drawback—*Blocking* during periods of heavy traffic.
- The whole idea of multistage switching is to share the crosspoints in the middle-stage crossbars.
- Sharing can cause a lack of availability if the resources are limited and all users want a connection at the same time.
- Blocking refers to times when one input cannot be connected to an output because there is no path available between them—all the possible intermediate switches are occupied.

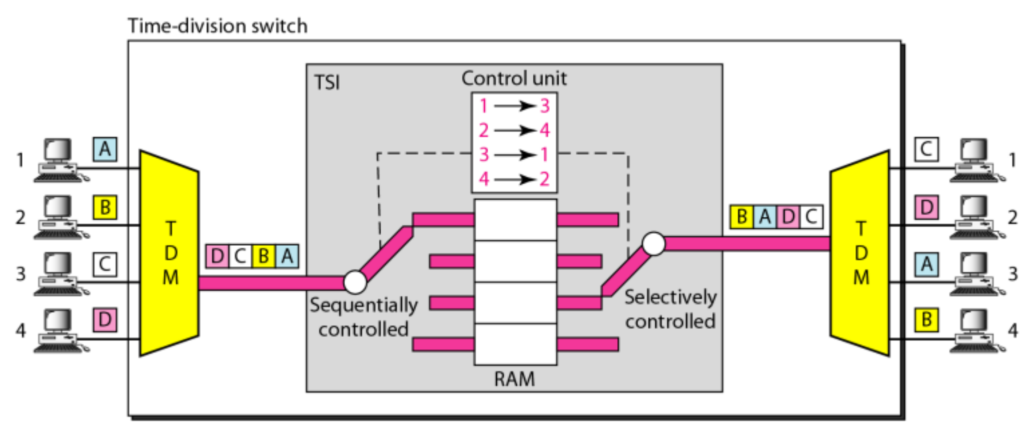
Time-Division Switch

- Time-division switching uses time-division multiplexing (TDM) inside a switch.
- The most popular technology is called the Time-Slot Interchange (TSI).



TSI

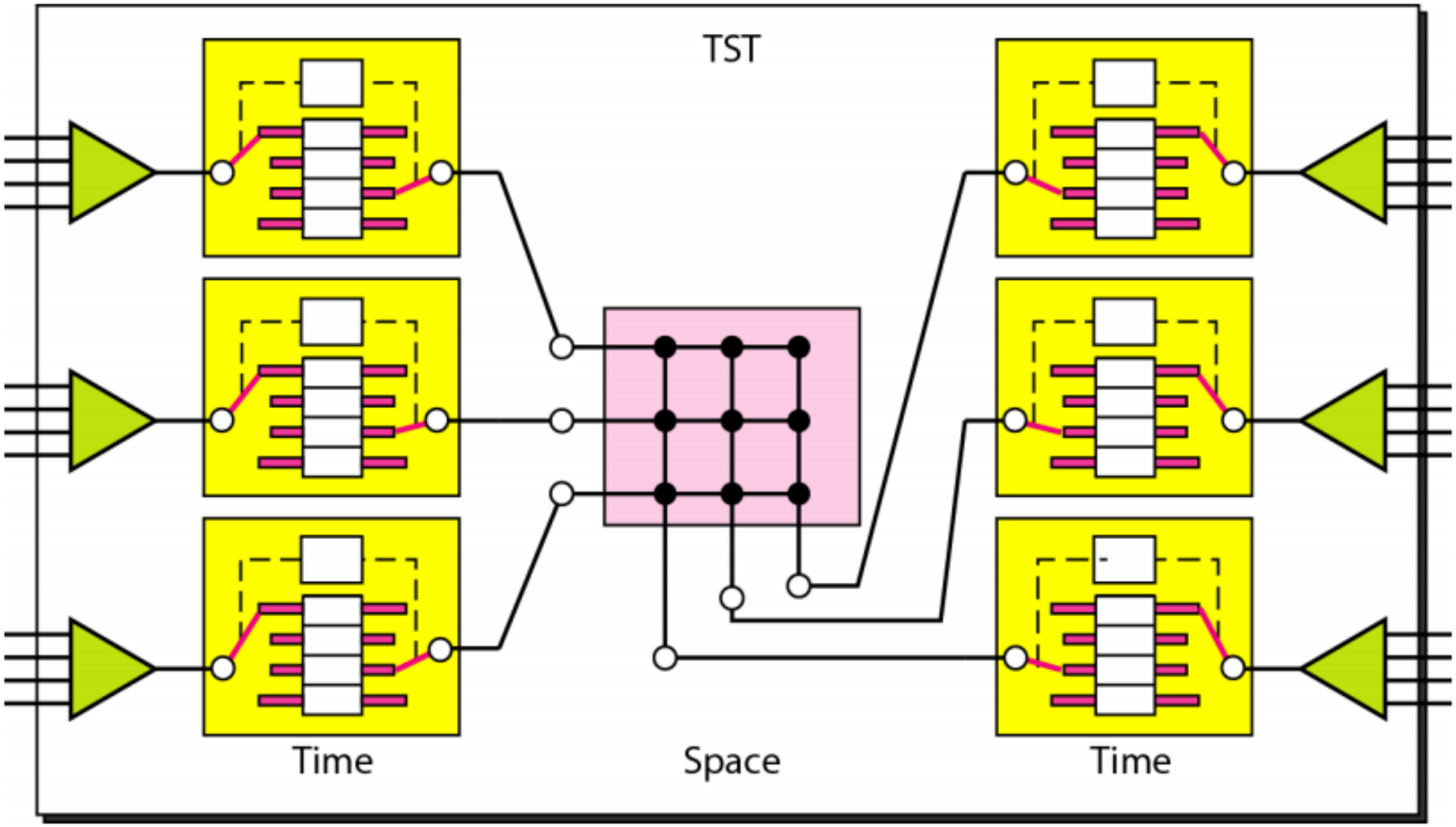
- TSI - a system connecting four input lines to four output lines (in the figure).
- Each input line wants to send data to an output line according to the following pattern: (1→3), (2→4), (3→1), and (4→ 2), in which the arrow means "to."
- A TDM multiplexer, a TDM demultiplexer, a control unit and a RAM with several memory locations.
- The size of each location is the same as the size of a single time slot.
- The number of locations is the same as the number of inputs.
- The RAM fills up with incoming data from time slots in the order received. Slots are then sent out in an order based on the decisions of a control unit.



Time- and Space-Division Switch Combinations

- The advantage of space-division switching is that it is instantaneous.
- Its disadvantage is the number of crosspoints required to make space-division switching acceptable in terms of blocking.
- The advantage of time-division switching is that it needs no crosspoints.
- Its disadvantage, in the case of TSI, is that processing each connection creates delays. Each time slot must be stored by the RAM, then retrieved and passed on.
- In a third option, we combine space-division and time-division technologies to take advantage of the best of both.

Time-Space-Time (TST) switches

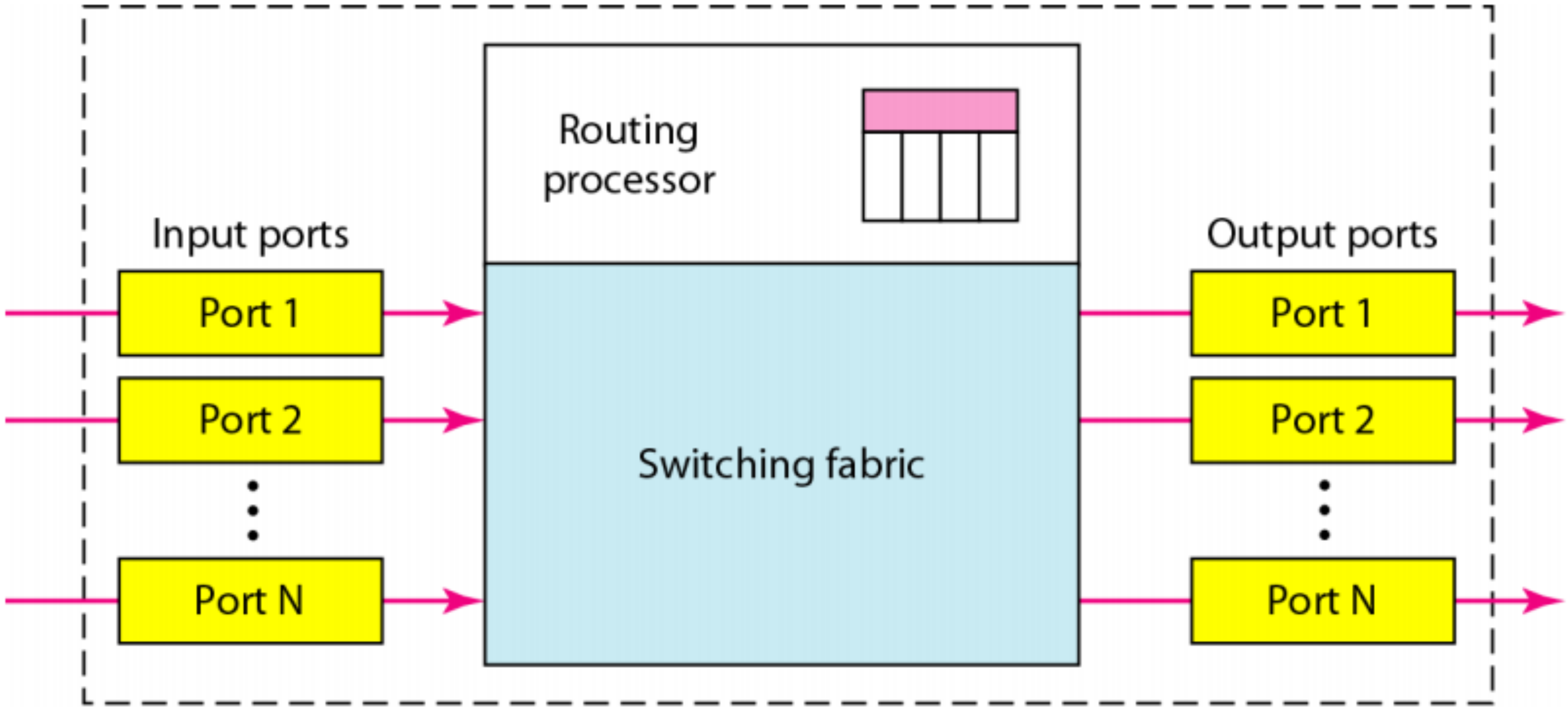


The result is that the average delay is one-third of what would result from using one time-slot interchange to handle all 12 inputs.

Structure of Packet Switches

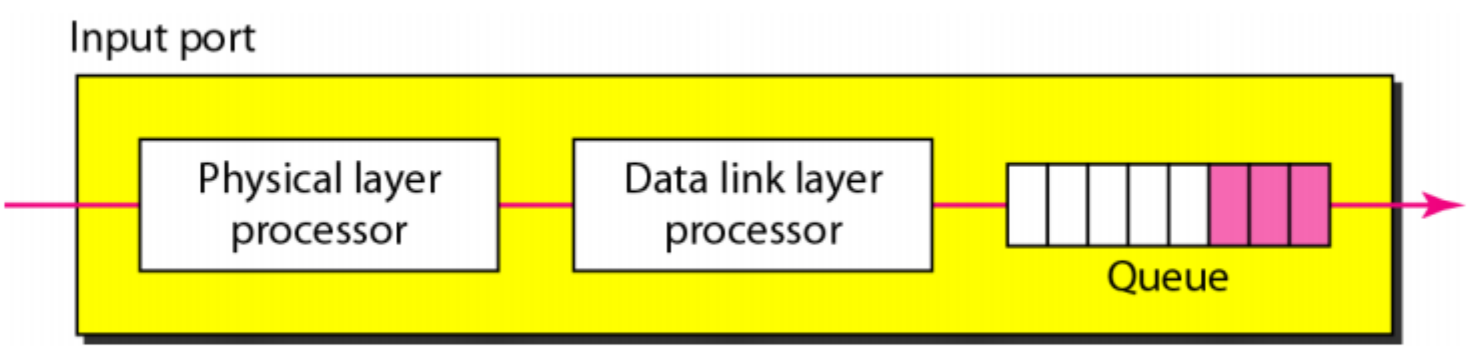
- A switch used in a packet-switched network has a different structure from a switch used in a circuit-switched network.
- A packet switch has four components:
  - input ports,
  - output ports,
  - the routing processor, and
  - the switching fabric

Structure of a Packet Switch



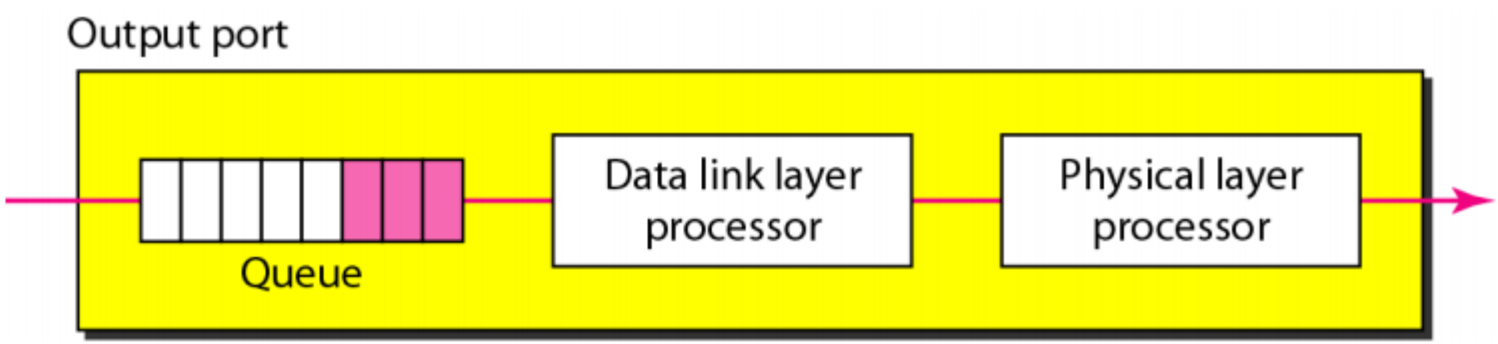
Input Ports

- An input port performs the physical and data-link functions of the packet switch.
- The bits are constructed from the received signal.
- The packet is decapsulated from the frame.
- Errors are detected and corrected.
- The packet is now ready to be routed by the network layer.
- The input port has buffers (queues) to hold the packet before it is directed to the switching fabric.



Output Ports

- The output port performs the same functions as the input port, but in the reverse order.
- First the outgoing packets are queued, then the packet is encapsulated in a frame, and finally the physical-layer functions are applied to the frame to create the signal to be sent on the line.



Routing Processor

- The routing processor performs the functions of the network layer.
- The destination address is used to find the address of the next hop and, at the same time, the output port number from which the packet is sent out.
- This activity is sometimes referred to as *table lookup* because the routing processor searches the routing table.

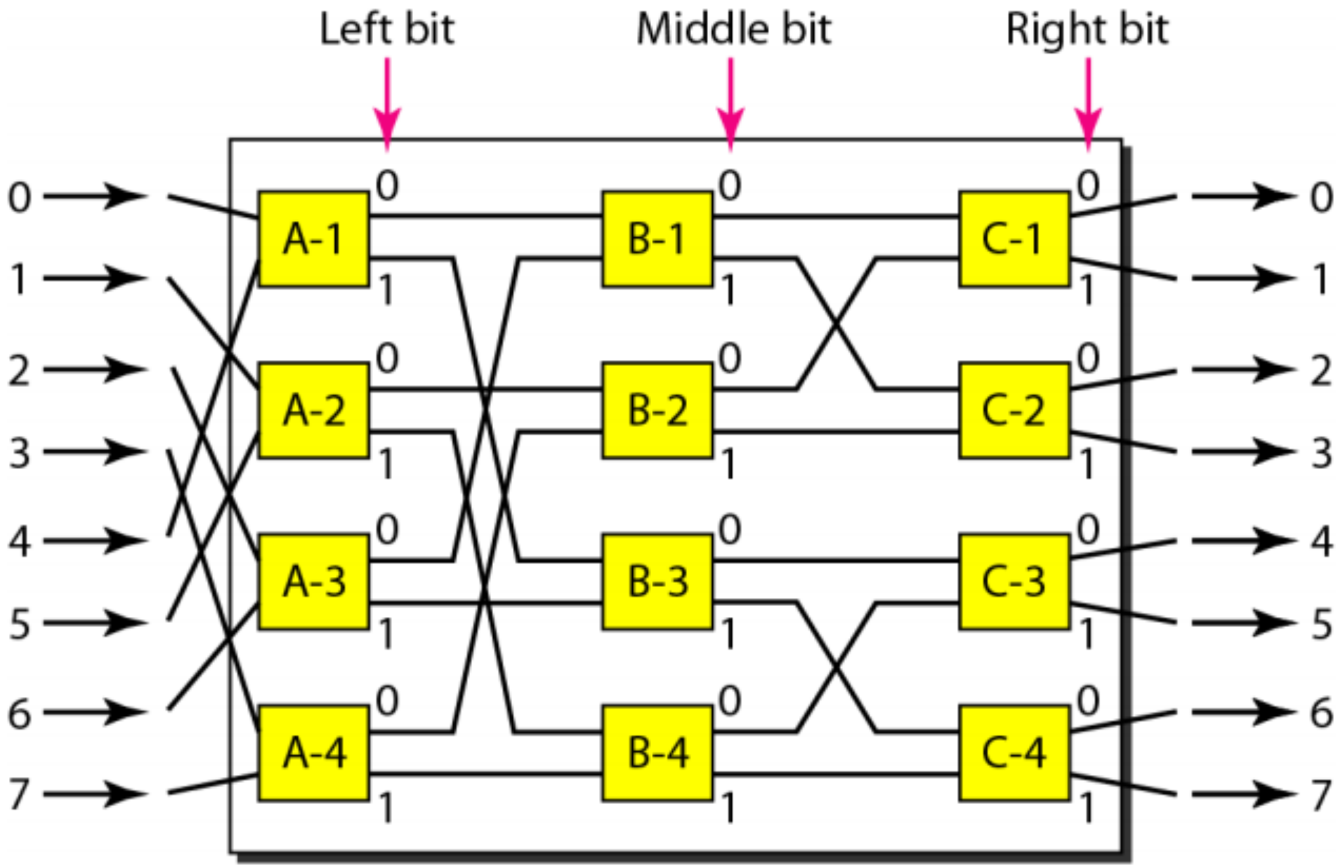
Switching Fabrics

- The most difficult task in a packet switch is to move the packet from the input queue to the output queue.
- The speed with which this is done affects the size of the input/output queue and the overall delay in packet delivery.
- In the past, when a packet switch was actually a dedicated computer, the memory of the computer or a bus was used as the switching fabric.
- The input port stored the packet in memory; the output port retrieved the packet from memory.
- Today, packet switches are specialized mechanisms that use a variety of switching fabrics.
- ***Crossbar Switch:*** The simplest type of switching fabric is the crossbar switch.

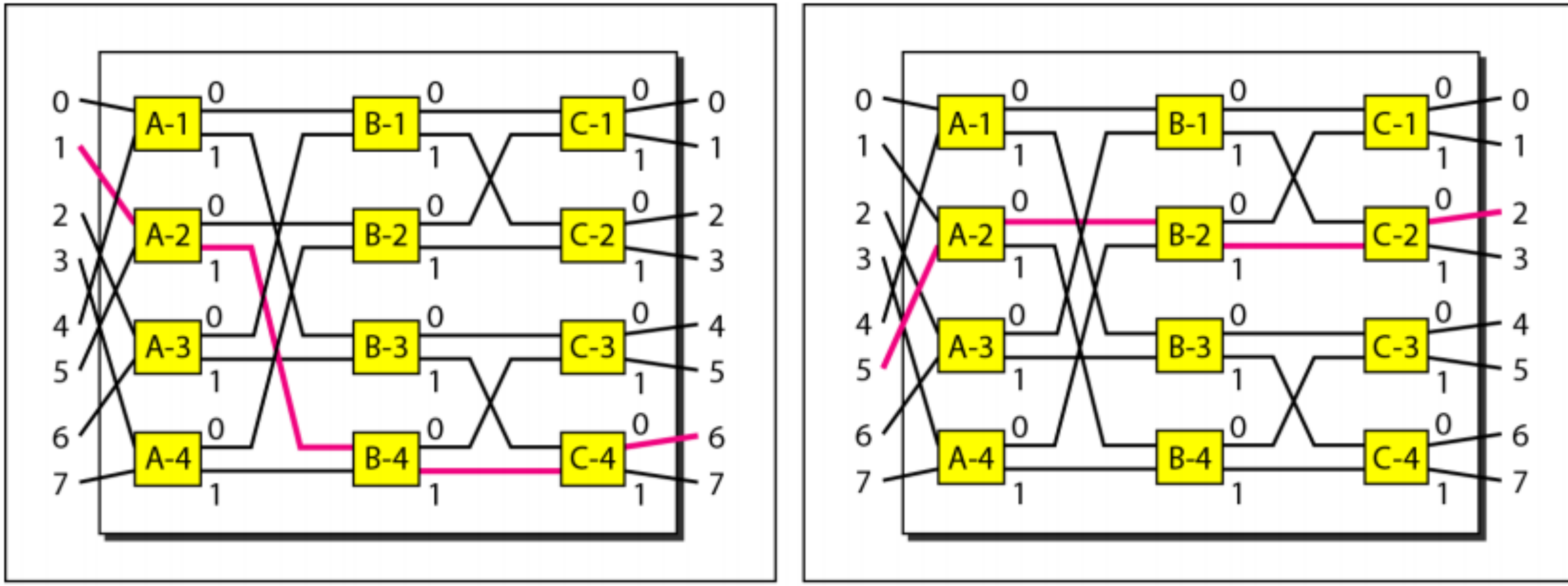
Banyan Switch

- A more realistic approach than the crossbar switch is the banyan switch (named after the banyan tree).
- A banyan switch is a multistage switch with microswitches at each stage that route the packets based on the output port represented as a binary string.
- For n inputs and n outputs, we have $log_2 n$ stages with n/2 microswitches at each stage. The first stage routes the packet based on the high-order bit of the binary string. The second stage routes the packet based on the second high-order bit, and so on.
- The next figure shows a banyan switch with eight inputs and eight outputs. The number of stages is $\log_2(8) = 3$.

A Banyan Switch



Routing in a Banyan Switch



a. Input 1 sending a cell to output 6 (110)

b. Input 5 sending a cell to output 2 (010)

- In part a; a packet has arrived at input port 1 and must go to output port 6 (110 in binary). The first microswitch (A-2) routes the packet based on the first bit (1), the second microswitch (B-4) routes the packet based on the second bit (1), and the third microswitch (C-4) routes the packet based on the third bit (0).