SWITCHING

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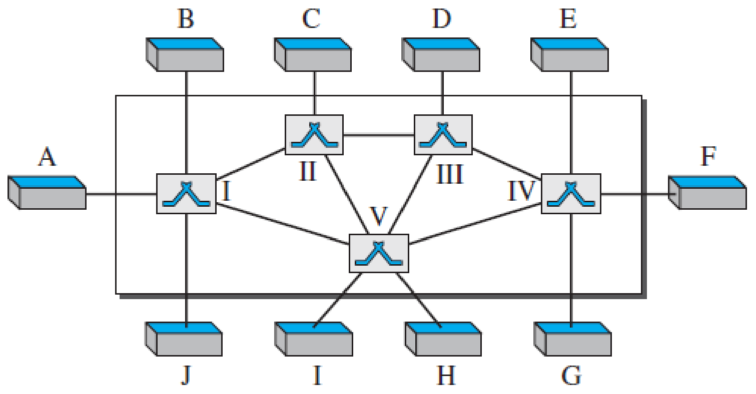
INTRODUCTION

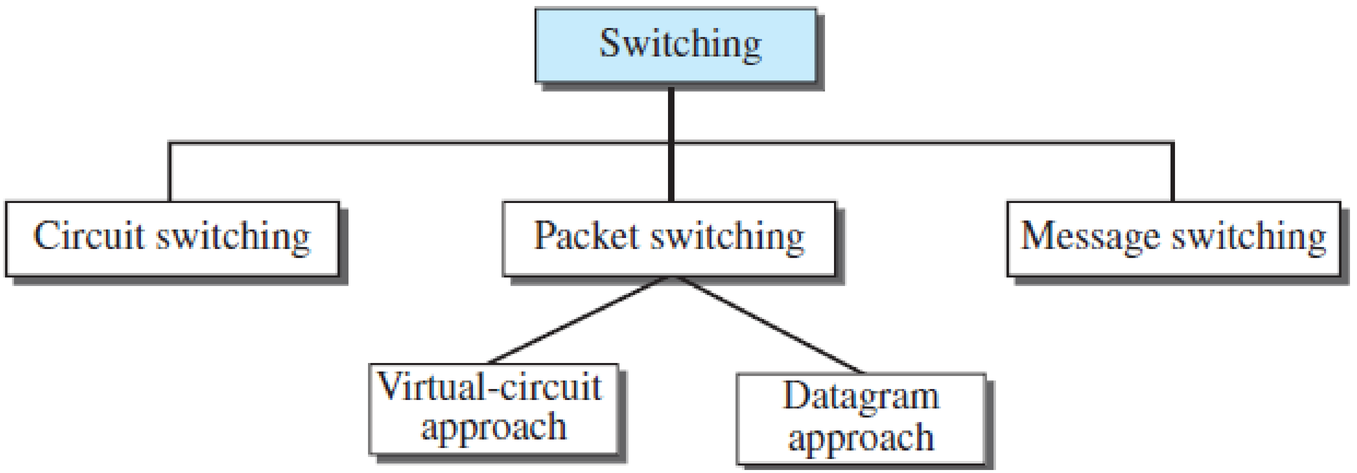
- A **switched network** consists of a series of interlinked nodes, called ***switches.*** Switches are devices capable of creating temporary connections between two or more devices linked to the switch. In a switched network, some of these nodes are connected to the end systems (computers or telephones, for example). Others are used only for routing. 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.

Figure 8.1 *Switched network*



THREE METHODS OF SWITCHING

Figure 8.2 *Taxonomy of switched networks*



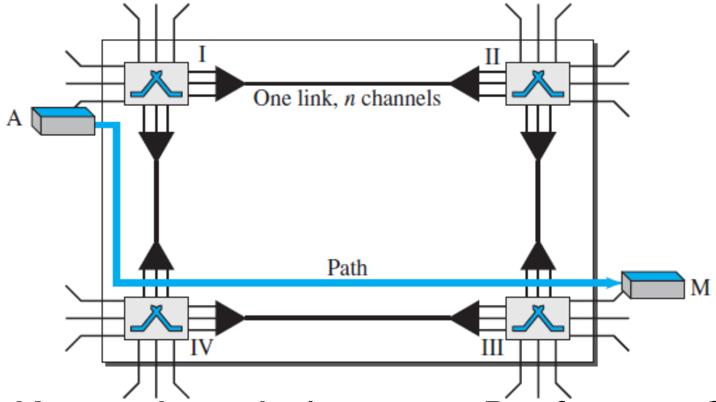
SWITCHING AND TCP/IP LAYERS

- Physical Layer: Circuit Switching
- Data-Link Layer: Packet Switching - Virtual-circuit Approach
- Network Layer: Packet Switching - Datagram Approach
- Application Layer: Message switching

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. The figure below 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.

Figure 8.3 *A trivial circuit-switched network*

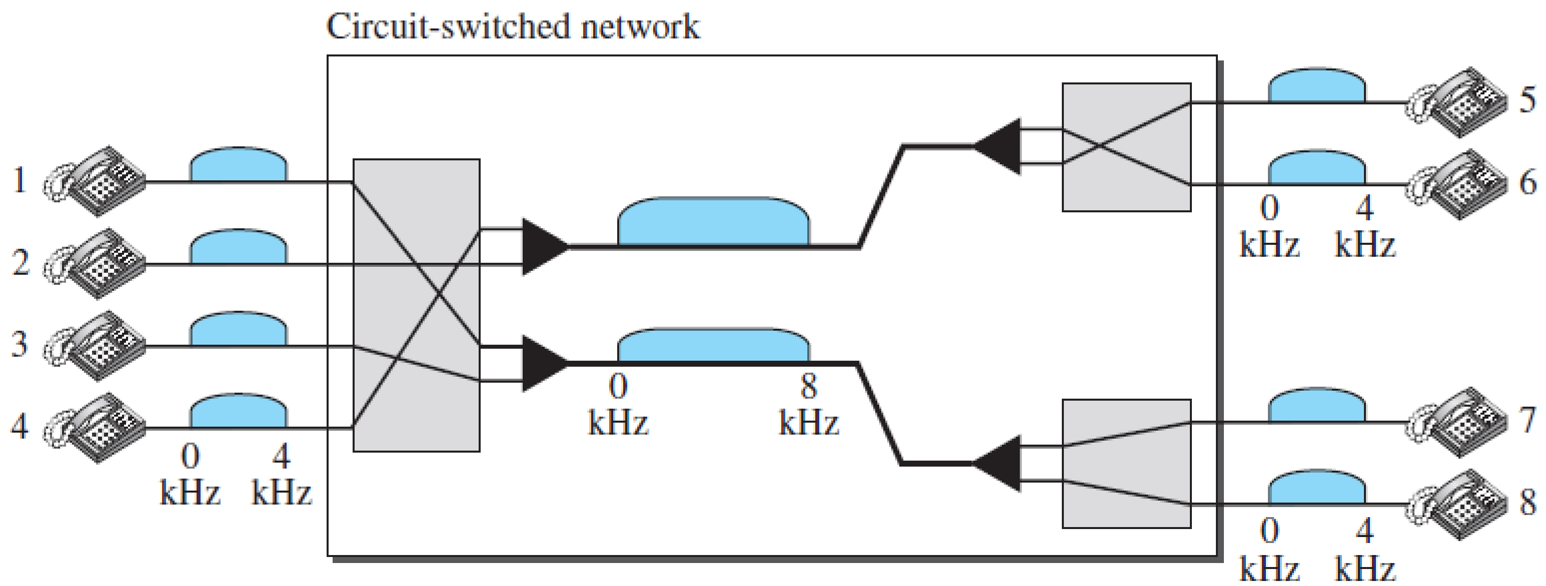


CIRCUIT-SWITCHED NETWORKS

- When end system A needs to communicate with end system M, system A needs to request a connection to M that must be accepted by all switches as well as by M itself. This is called the **setup phase**.
- A circuit (channel) is reserved on each link, and the combination of circuits or channels defines the dedicated path. After the dedicated path made of connected circuits (channels) is established, the **data-transfer phase** can take place. After all data have been transferred, the circuits are **torn down**.
- These resources, such as channels (bandwidth in FDM and time slots in TDM), switch buffers, switch processing time, and switch input/output ports, must remain dedicated during the entire duration of data transfer.
- Data transferred between the two stations is not packetized. There is no addressing involved during data transfer. Of course, there is end-to-end addressing used during the setup phase.

CIRCUIT-SWITCHED NETWORKS EXAMPLE

Figure 8.4 *Circuit-switched network used in Example 8.1*



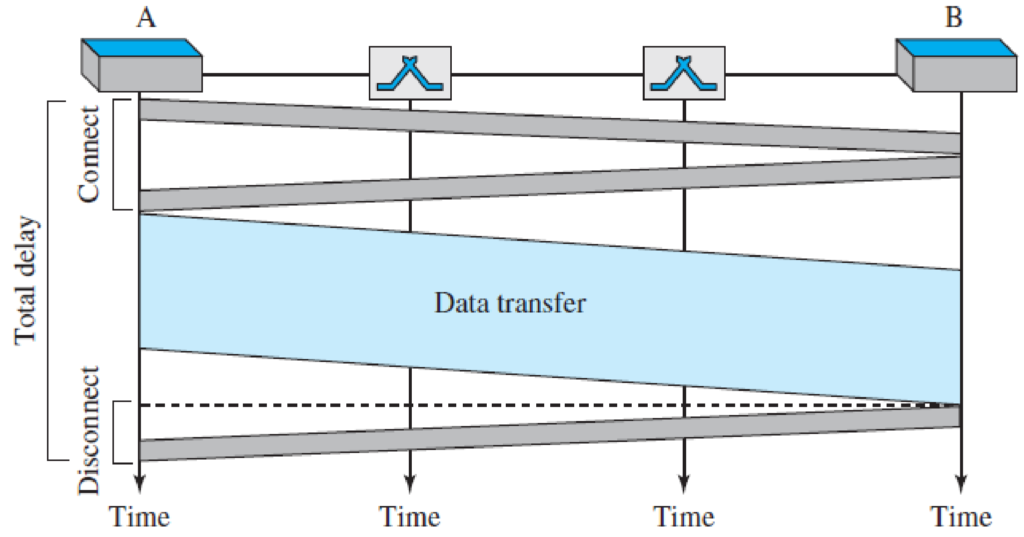
EFFICIENCY

- 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. The figure below shows the idea of delay in a circuit-switched network when only two switches are involved.

Figure 8.6 *Delay in a circuit-switched network*



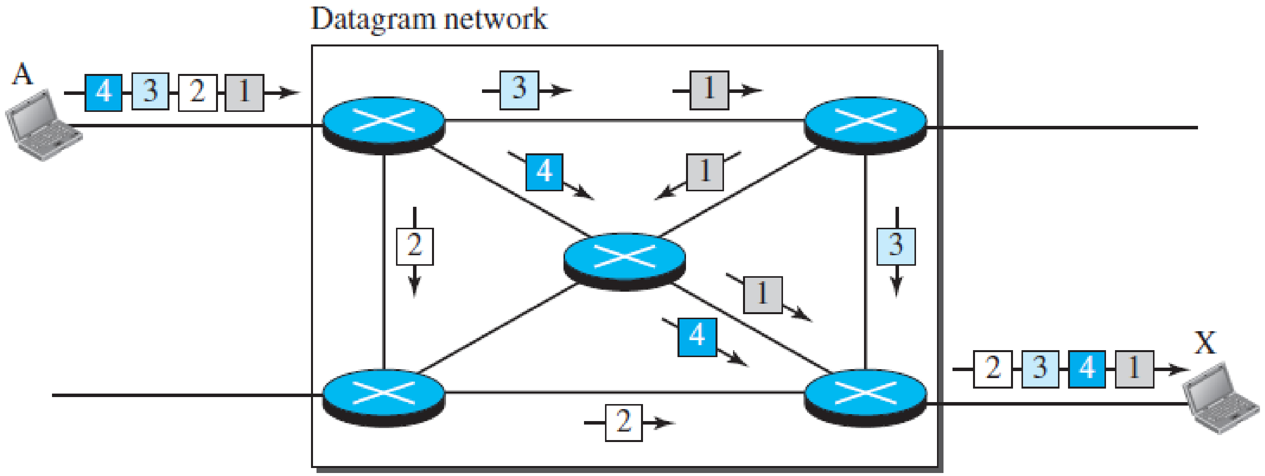
PACKET SWITCHING

- In data communications, we need to send messages from one end system to another. If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size. The size of the packet is determined by the network and the governing protocol.
- In packet switching, there is no resource allocation for a packet. This means that there is no reserved bandwidth on the links, and there is no scheduled processing time for each packet. Resources are allocated on demand. The allocation is done on a first-come, first-served basis. When a switch receives a packet, no matter what the source or destination is, the packet must wait if there are other packets being processed.
- We can have two types of packet-switched networks: datagram networks and virtual-circuit networks.

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. The switches in a datagram network are traditionally referred to as routers.

Figure 8.7 *A datagram network with four switches (routers)*



DATAGRAM NETWORKS

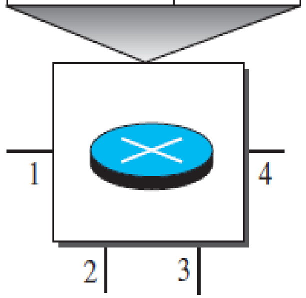
- This approach can cause the datagrams of a transmission to arrive at their destination out of order with different delays between the packets. Packets may also be lost or dropped because of a lack of resources. In most protocols, it is the responsibility of an upper-layer protocol to reorder the datagrams 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

- In this type of network, each switch (or packet switch) has a routing table that 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.
- 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.

Figure 8.8 *Routing table in a datagram network*

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



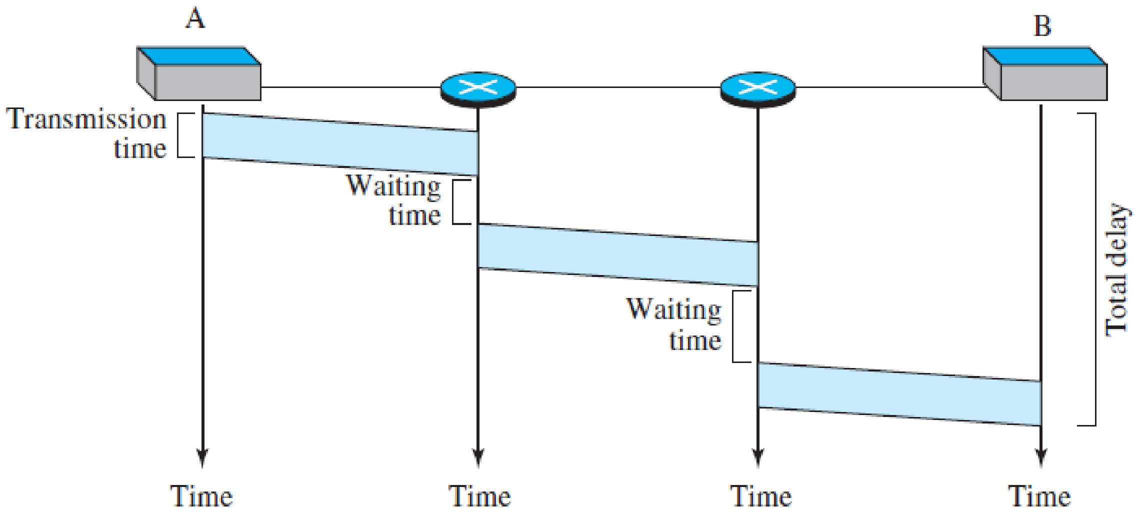
EFFICIENCY

- 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.
- 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.

Figure 8.9 *Delay in a datagram network*

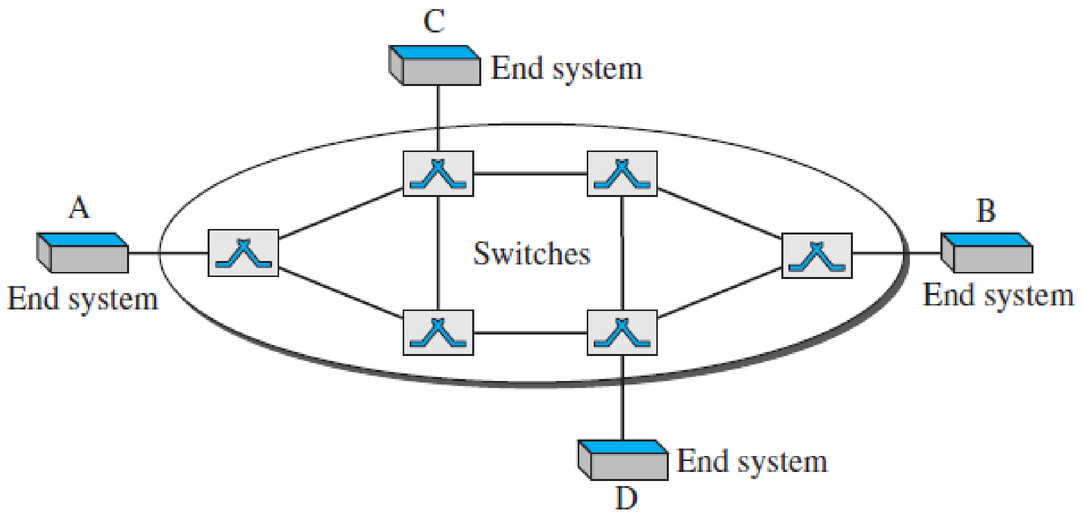


$$\text{Total delay} = 3T + 3\tau + w_1 + w_2$$

VIRTUAL-CIRCUIT NETWORKS

- 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.

Figure 8.10 *Virtual-circuit network*



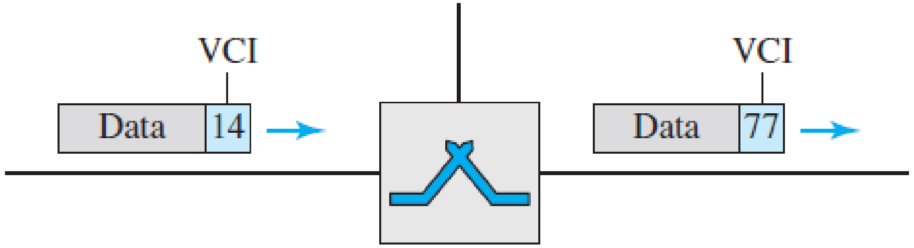
VIRTUAL-CIRCUIT NETWORKS - CHARACTERISTICS

- As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
- Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
- 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 the next switch should be and the channel on which the packet is being carried), not end-to-end jurisdiction.
- As in a circuit-switched network, all packets follow the same path established during the connection.
- A virtual-circuit network is normally implemented in the data-link layer.

ADDRESSING

- **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. A global address in virtual-circuit networks is used only to create a virtual-circuit identifier.
- **Virtual-Circuit Identifier**: The identifier that is actually used for data transfer is called the virtual-circuit identifier (VCI) or the label. 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 8.11 *Virtual-circuit identifier*



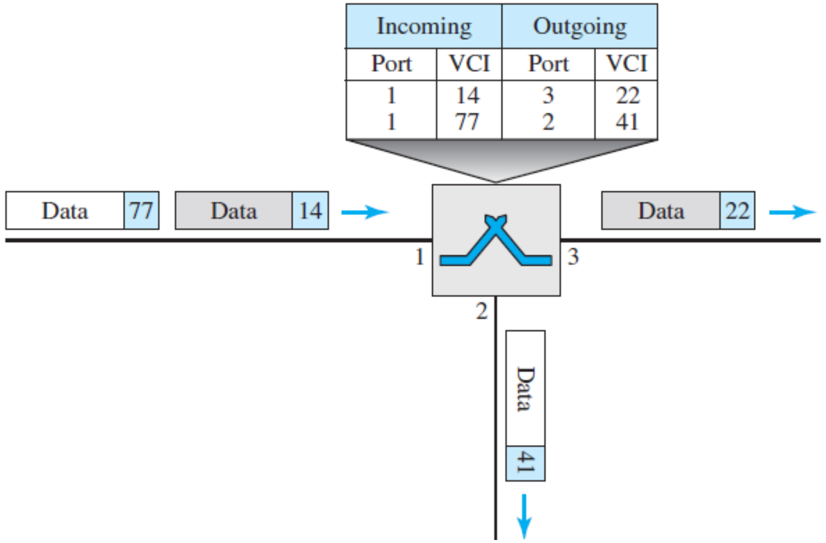
THREE PHASES

- As in a virtual-circuit network, a source and destination need to go through three phases: 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.

DATA-TRANSFER PHASE

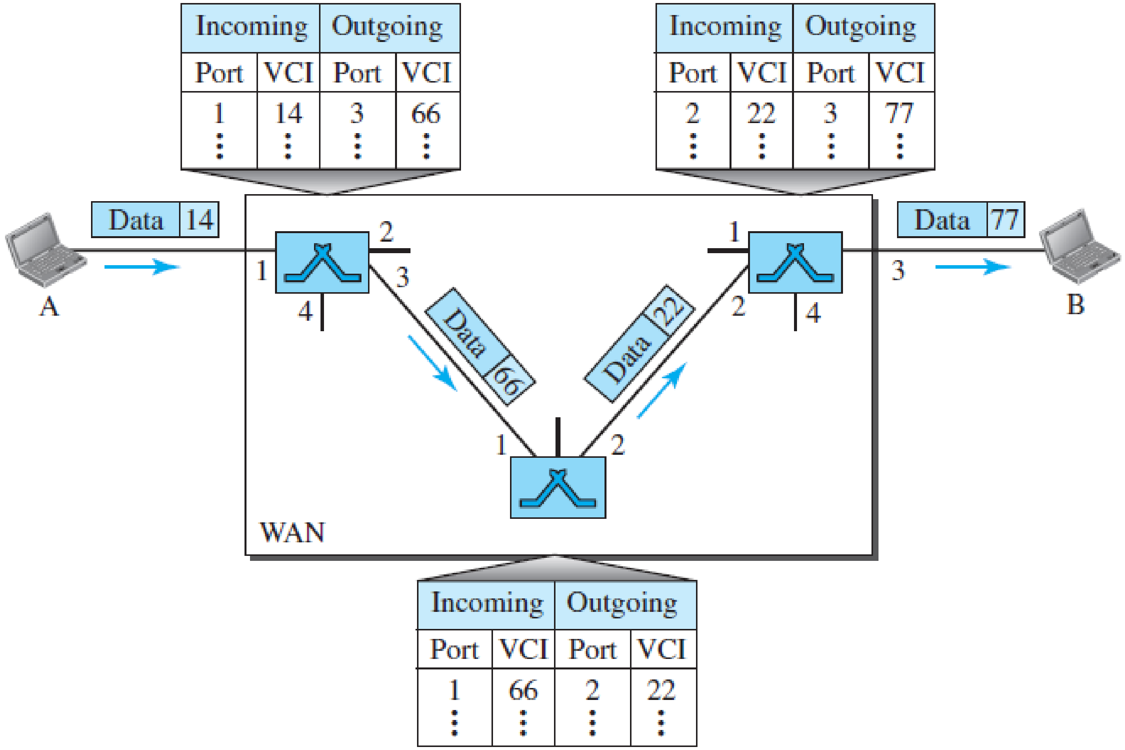
- To transfer a frame from a source to its destination, all switches need to have a table entry for this virtual circuit. The table, in its simplest form, has four columns. This means that the switch holds four pieces of information for each virtual circuit that is already set up.

Figure 8.12 *Switch and tables in a virtual-circuit network*



DATA-TRANSFER PHASE

Figure 8.13 *Source-to-destination data transfer in a virtual-circuit network*



DATA-TRANSFER PHASE

- The figure 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.
- The figure 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.

Figure 8.14 *Setup request in a virtual-circuit network*

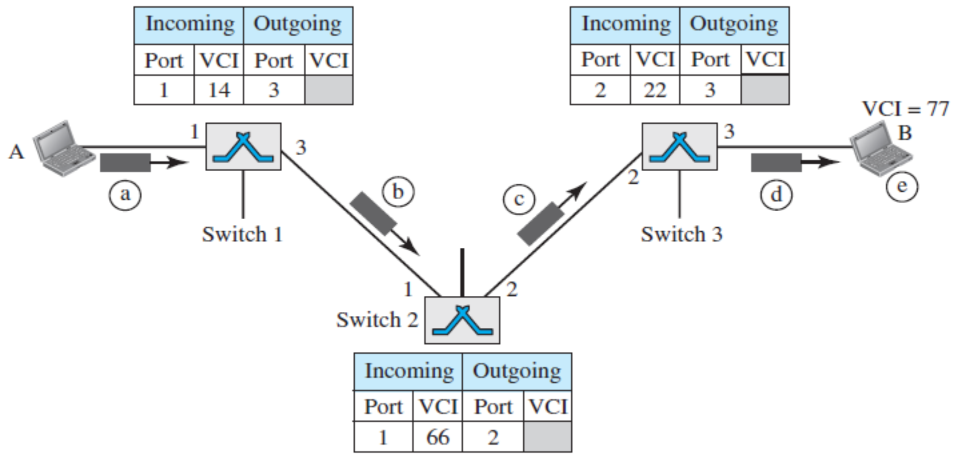
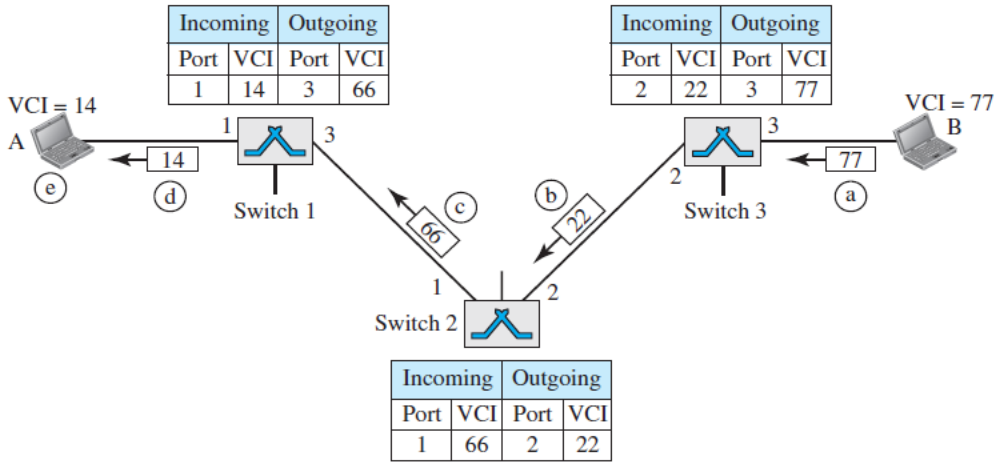


Figure 8.15 *Setup acknowledgment in a virtual-circuit network*



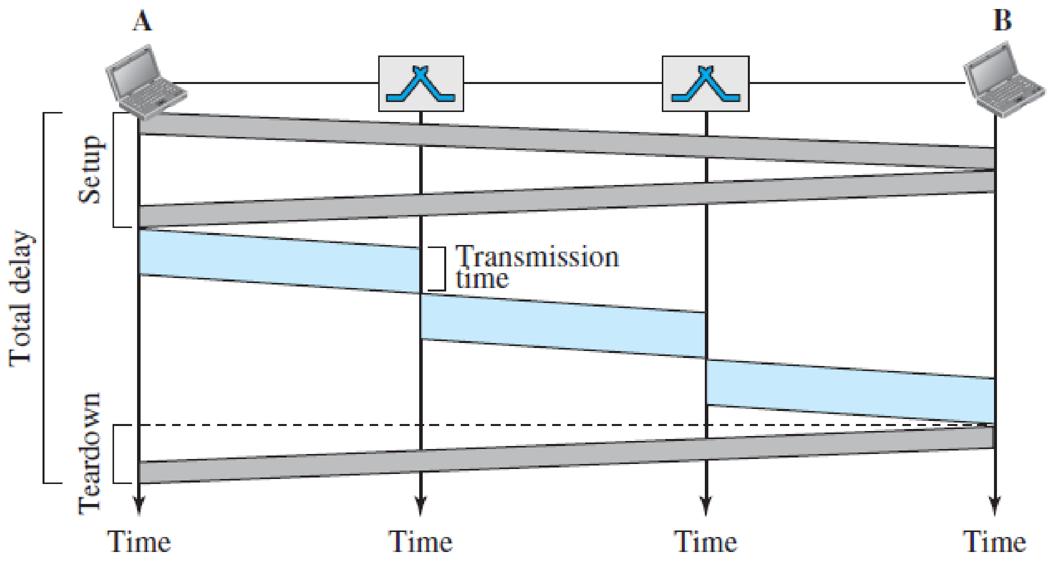
EFFICIENCY

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

DELAY

- 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.
- The 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.
- **Total Delay = $3T$ + 3τ + setup delay + teardown delay**

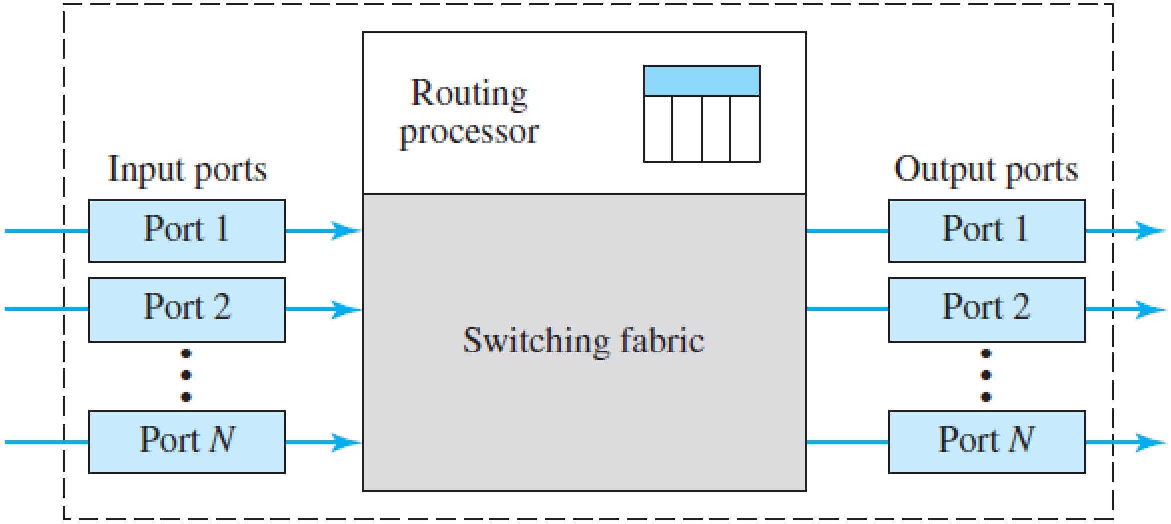
Figure 8.16 *Delay in a virtual-circuit network*



STRUCTURE OF PACKET SWITCHES

- A packet switch has four components: input ports, output ports, the routing processor, and the switching fabric.

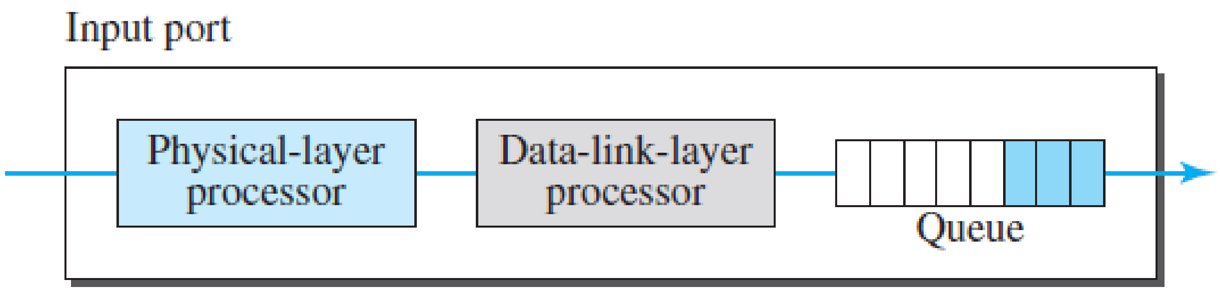
Figure 8.21 *Packet switch components*



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. In addition to a physical-layer processor and a data-link processor, the input port has buffers (queues) to hold the packet before it is directed to the switching fabric.

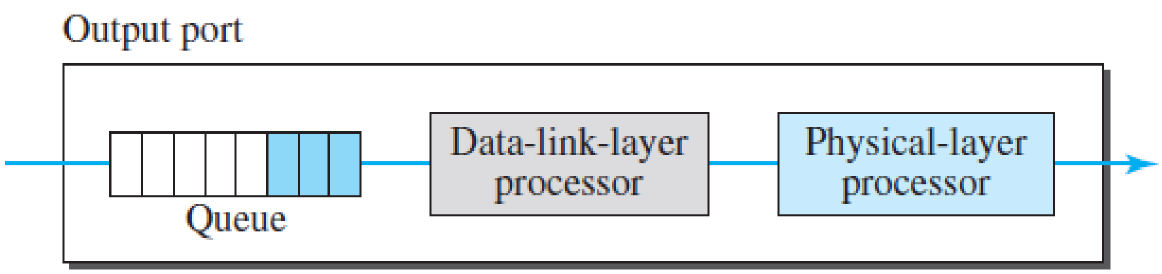
Figure 8.22 *Input port*



OUTPUT PORT

- 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.

Figure 8.23 *Output port*



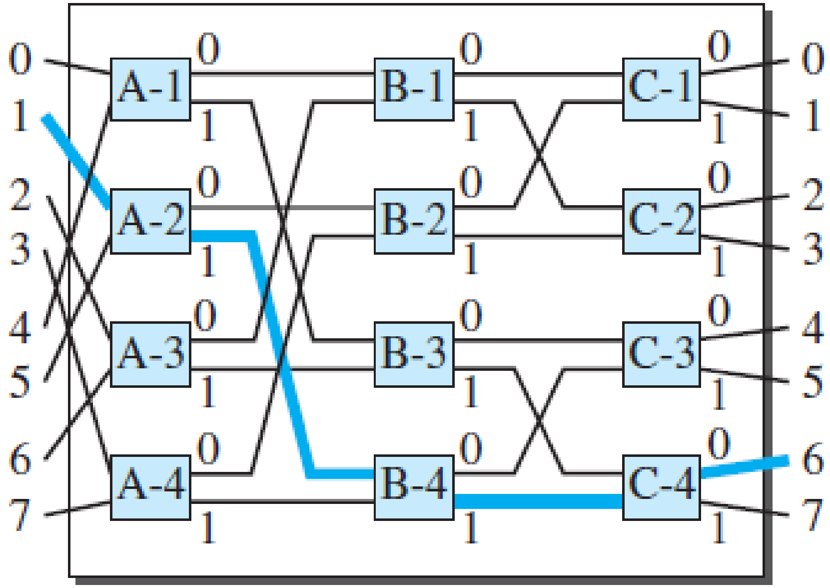
ROUTING PROCESSOR AND SWITCHING FABRICS

- 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.
- 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.

BANYAN SWITCH

- 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.

Figure 8.25 *Examples of routing in a banyan switch*



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