

WAN TECHNOLOGY AND PROTOCOLS

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LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- ◆ Define circuit switching and describe the key elements of circuit-switching networks.
- ◆ Define packet switching and describe the key elements of packet-switching technology.
- ◆ Discuss the relative merits of circuit switching and packet switching and analyze the circumstances for which each is most appropriate.
- ◆ Describe the features and characteristics of ATM networks.

Part Two describes how information can be encoded and transmitted over a communications link. We now turn to the broader discussion of networks, which can be used to interconnect many devices. The chapter begins with a general discussion of switched communications networks. The remainder of the chapter focuses on wide area networks and, in particular, on traditional approaches to wide area network design: circuit switching and packet switching.

Since the invention of the telephone, circuit switching has been the dominant technology for voice communications, and it has remained so well into the digital era. This chapter looks at the key characteristics of a circuit-switching network.

Around 1970, research began on a new form of architecture for long-distance digital data communications: packet switching. Although the technology of packet switching has evolved substantially since that time, it is remarkable that (1) the basic technology of packet switching is fundamentally the same today as it was in the early 1970s networks, and (2) packet switching remains one of the few effective technologies for long-distance data communications.

This chapter provides an overview of packet-switching technology. We will see, in this chapter and later in this part, that many of the advantages of packet switching (flexibility, resource sharing, robustness, responsiveness) come with a cost. The packet-switching network is a distributed collection of packet-switching nodes. Ideally, all packet-switching nodes would always know the state of the entire network. Unfortunately, because the nodes are distributed, there is a time delay between a change in status in one portion of the network and knowledge of that change elsewhere. Furthermore, there is overhead involved in communicating status information. As a result, a packet-switching network can never perform “perfectly,” and elaborate algorithms

are used to cope with the time delay and overhead penalties of network operation. These same issues will appear again when we discuss internetworking in Part Five.

9.1 SWITCHED COMMUNICATIONS NETWORKS

For transmission of data¹ beyond a local area, communication is typically achieved by transmitting data from source to destination through a network of intermediate switching nodes; this switched network design is typically used to implement LANs as well. The switching nodes are not concerned with the content of the data; rather, their purpose is to provide a switching facility that will move the data from node to node until they reach their destination. Figure 9.1 illustrates a simple network. The devices attached to the network may be referred to as *stations*. The stations may be computers, terminals, telephones, or other communicating devices. We refer to

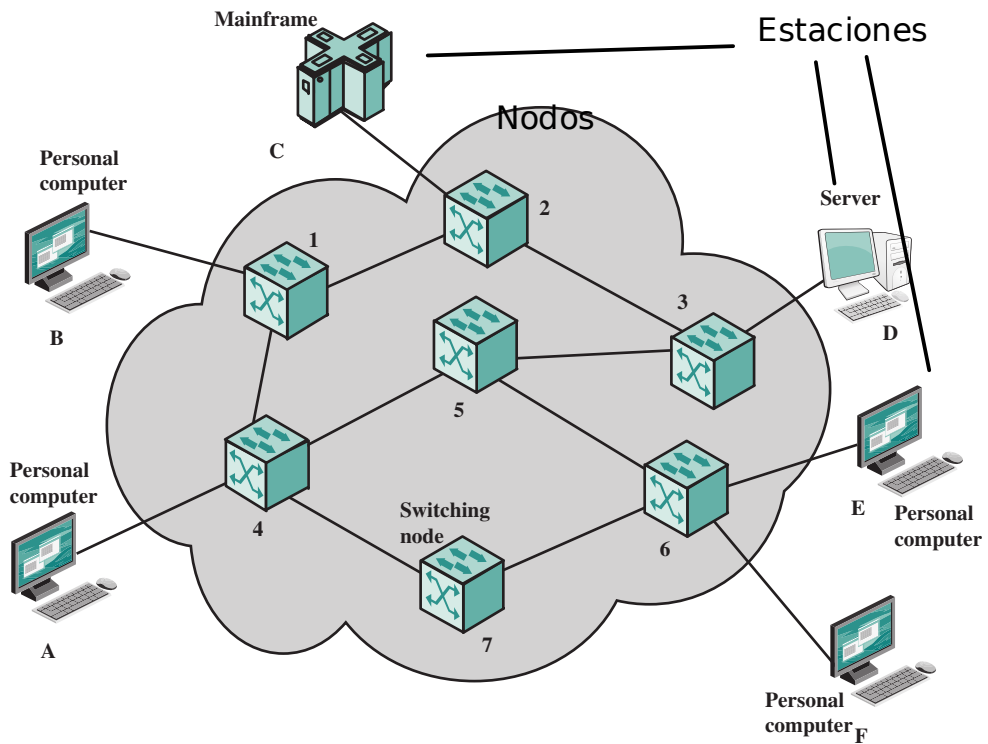


Figure 9.1 Simple Switching Network

¹We use this term here in a very general sense, to include voice, image, and video, as well as ordinary data (e.g., numbers, text).

colección de nodos unidos=
red de comunicaciones.

the switching devices whose purpose is to provide communication as *nodes*. Nodes are connected to one another in some topology by transmission links. Each station attaches to a node, and the collection of nodes is referred to as a *communications network*.

In a *switched communication network*, data entering the network from a station are routed to the destination by being switched from node to node.

Ruteado de nodo a nodo para llegar a destino...

EXAMPLE 9.1 In Figure 9.1, data from station A intended for station F are sent to node 4. They may then be routed via nodes 5 and 6 or nodes 7 and 6 to the destination. Several observations are in order:

1. Some nodes connect only to other nodes (e.g., 5 and 7). Their sole task is the internal (to the network) switching of data. Other nodes have one or more stations attached as well; in addition to their switching functions, such nodes accept data from and deliver data to the attached stations.
2. Node–station links are generally dedicated point-to-point links. Node–node links are usually multiplexed, using either frequency-division multiplexing (FDM) or time-division multiplexing (TDM).
3. Usually, the network is not fully connected; that is, there is not a direct link between every possible pair of nodes. However, it is always desirable to have more than one possible path through the network for each pair of stations. This enhances the reliability of the network.

Two different technologies are used in wide area switched networks: circuit switching and packet switching. These two technologies differ in the way the nodes switch information from one link to another on the way from source to destination.

2 Tecnologías : Conm. de Paquetes y Conm. de Circuitos.

9.2 CIRCUIT-SWITCHING NETWORKS

Communication via circuit switching implies that there is a dedicated communication path between two stations. That path is a connected sequence of links between network nodes. On each physical link, a logical channel is dedicated to the connection. Communication via circuit switching involves three phases, which can be explained with reference to Figure 9.1.

1. **Circuit establishment.** Before any signals can be transmitted, an end-to-end (station-to-station) circuit must be established. For example, station A sends a request to node 4 requesting a connection to station E. Typically, the link from A to 4 is a dedicated line, so that part of the connection already exists. Node 4 must find the next leg in a route leading to E. Based on routing information and measures of availability and perhaps cost, node 4 selects the link to node

Pensar en una llamada telefónica.

5, allocates a free channel (using FDM or TDM) on that link, and sends a message requesting connection to E. So far, a dedicated path has been established from A through 4 to 5. Because a number of stations may attach to 4, it must be able to establish internal paths from multiple stations to multiple nodes. How this is done is discussed later in this section. The remainder of the process proceeds similarly. Node 5 allocates a channel to node 6 and internally ties that channel to the channel from node 4. Node 6 completes the connection to E. In completing the connection, a test is made to determine if E is busy or is prepared to accept the connection.

2. Data transfer. Data can now be transmitted from A through the network to E. The transmission may be analog or digital, depending on the nature of the network. As the carriers evolve to fully integrated digital networks, the use of digital (binary) transmission for both voice and data is becoming the dominant method. The path is A-4 link, internal switching through 4, 4-5 channel, internal switching through 5, 5-6 channel, internal switching through 6, 6-E link. Generally, the connection is full duplex.

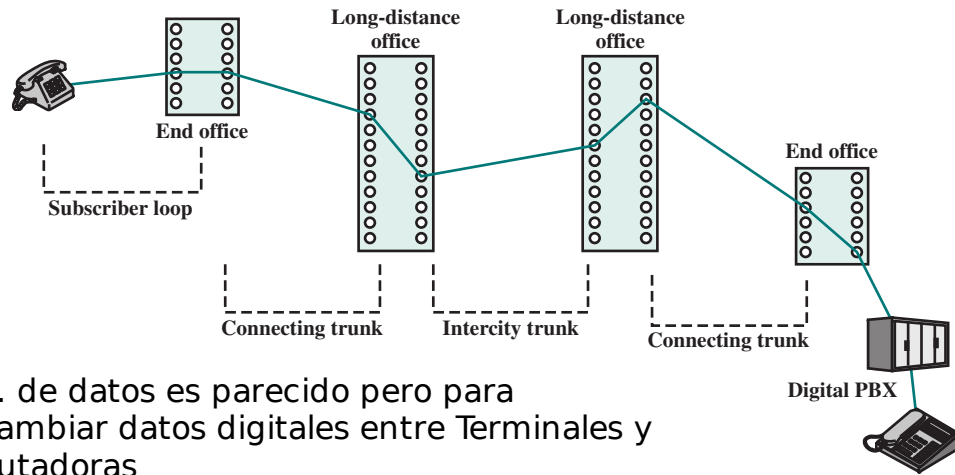
3. Circuit disconnect. After some period of data transfer, the connection is terminated, usually by the action of one of the two stations. Signals must be propagated to nodes 4, 5, and 6 to deallocate the dedicated resources.

Note that the connection path is established before data transmission begins. Thus, channel capacity must be reserved between each pair of nodes in the path, and each node must have available internal switching capacity to handle the requested connection. The switches must have the intelligence to make these allocations and to devise a route through the network.

Circuit switching can be rather inefficient. Channel capacity is dedicated for the duration of a connection, even if no data are being transferred. For a voice connection, utilization may be rather high, but it still does not approach 100%. For a client/server or terminal-to-computer connection, the capacity may be idle during most of the time of the connection. In terms of performance, there is a delay prior to signal transfer for call establishment. However, once the circuit is established, the network is effectively transparent to the users. Information is transmitted at a fixed data rate with no delay other than the propagation delay through the transmission links. The delay at each node is negligible.

Circuit switching was developed to handle voice traffic but is now also used for data traffic. The best-known example of a circuit-switching network is the public telephone network (Figure 9.2). This is actually a collection of national networks interconnected to form the international service. Although originally designed and implemented to service analog telephone subscribers, it handles substantial data traffic via modem and is gradually being converted to a digital network. Another well-known application of circuit switching is the private branch exchange (PBX), used to interconnect telephones within a building or office. Circuit switching is also used in private networks. Typically, such a network is set up by a corporation or other large organization to interconnect its various sites. Such a network usually consists of PBX systems at each site interconnected by dedicated, leased lines obtained from one of the carriers, such as AT&T. A final common example of the application of circuit switching is the data switch. The data switch is similar to the

PBX: Private branch exchange: Centralita privada



Com. de datos es parecido pero para intercambiar datos digitales entre Terminales y Computadoras

Figure 9.2 Example Connection Over a Public Circuit-Switching Network

PBX but is designed to interconnect digital data processing devices, such as terminals and computers.

A public telecommunications network can be described using four generic architectural components:

- **Subscribers:** The devices that attach to the network. It is still the case that most subscriber devices to public telecommunications networks are telephones, but the percentage of data traffic increases year by year. **recordar ADSL**
- **Subscriber line:** The link between the subscriber and the network, also referred to as the **subscriber loop** or **local loop**. Almost all local loop connections use twisted-pair wire. The length of a local loop is typically in a range from a few kilometers to a few tens of kilometers.
- **Exchanges:** The switching centers in the network. A switching center that directly supports subscribers is known as an end office. Typically, an end office will support many thousands of subscribers in a localized area. There are over 19,000 end offices in the United States, so it is clearly impractical for each end office to have a direct link to each of the other end offices; this would require on the order of 2×10^8 links. Rather, intermediate switching nodes are used.
- **Trunks:** The branches between exchanges. Trunks carry multiple voice-frequency circuits using either FDM or synchronous TDM. We referred to these as carrier systems in Chapter 8.

Subscribers connect directly to an end office, which switches traffic between subscribers and between a subscriber and other exchanges. The other exchanges are responsible for routing and switching traffic between end offices. This distinction is shown in Figure 9.3. To connect two subscribers attached to the same end office, a circuit is set up between them in the same fashion as described before. If two subscribers connect to different end offices, a circuit between them consists of a chain of circuits through one or more intermediate offices. In the figure, a connection is established between lines a and b by simply setting up the connection through the end office. The

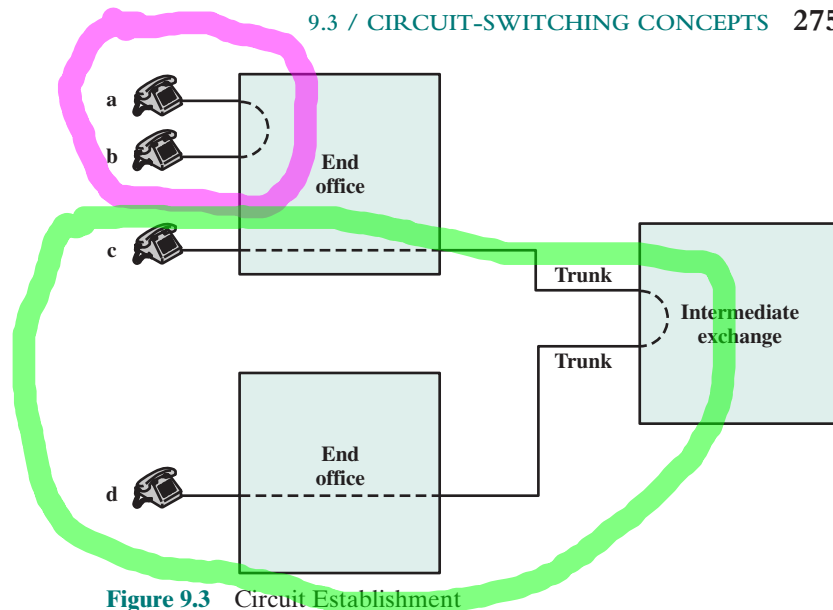


Figure 9.3 Circuit Establishment

Mortal la variación en la demora para enlaces de voz!

connection between c and d is more complex. In c's end office, a connection is established between line c and one channel on a TDM trunk to the intermediate switch. In the intermediate switch, that channel is connected to a channel on a TDM trunk to d's end office. In that end office, the channel is connected to line d.

Circuit-switching technology has been driven by those applications that handle voice traffic. One of the key requirements for voice traffic is that there must be virtually no transmission delay and certainly no variation in delay. A constant signal transmission rate must be maintained, because transmission and reception occur at the same signal rate. These requirements are necessary to allow normal human conversation. Further, the quality of the received signal must be sufficiently high to provide, at a minimum, intelligibility.

Circuit switching achieved its widespread, dominant position because it is well suited to the analog transmission of voice signals. In today's digital world, its inefficiencies are more apparent. However, despite its inefficiencies, circuit switching will remain an attractive choice for both local area and wide area networking. One of its key strengths is that it is transparent. Once a circuit is established, it appears as a direct connection to the two attached stations; no special networking logic is needed at the station.

9.3 CIRCUIT-SWITCHING CONCEPTS

The technology of circuit switching is best approached by examining the operation of a single circuit-switching node. A network built around a single circuit-switching node consists of a collection of stations attached to a central switching unit. The central switch establishes a dedicated path between any two devices that wish to communicate. Figure 9.4 depicts the major elements of such a one-node network. The dotted lines inside the switch symbolize the connections that are currently active.

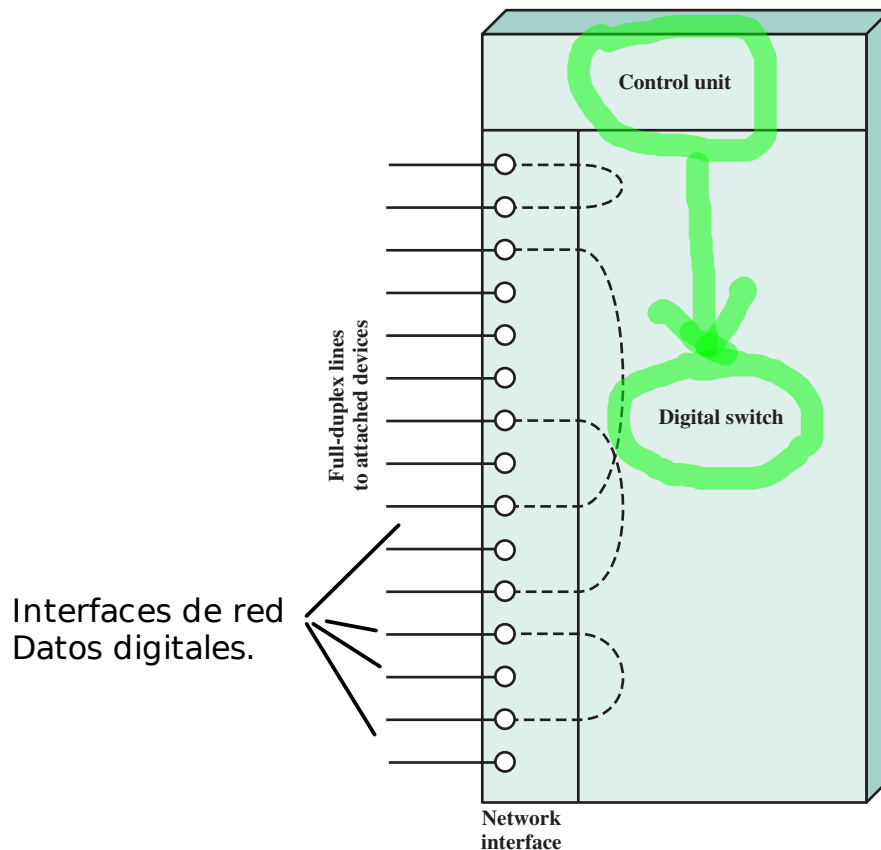


Figure 9.4 Elements of a Circuit-Switch Node

The heart of a modern system is a digital switch. The function of the digital switch is to provide a transparent signal path between any pair of attached devices. The path is transparent in that it appears to the attached pair of devices that there is a direct connection between them. Typically, the connection must allow full-duplex transmission.

The network interface element represents the functions and hardware needed to connect digital devices, such as data processing devices and digital telephones, to the network. Analog telephones can also be attached if the network interface contains the logic for converting to digital signals. Trunks to other digital switches carry TDM signals and provide the links for constructing multiple-node networks.

The control unit performs three general tasks. First, it establishes connections. This is generally done on demand, that is, at the request of an attached device. To establish the connection, the control unit must handle and acknowledge the request, determine if the intended destination is free, and construct a path through the switch. Second, the control unit must maintain the connection. Because the digital switch uses time-division principles, this may require ongoing manipulation of the switching elements. However, the bits of the communication are transferred transparently (from the point of view of the attached devices). Third, the control

3 tareas de la unidad de control

unit must tear down the connection, either in response to a request from one of the parties or for its own reasons.

An important characteristic of a circuit-switching device is whether it is blocking or nonblocking. Blocking occurs when the network is unable to connect two stations because all possible paths between them are already in use. A blocking network is one in which such blocking is possible. Hence a nonblocking network permits all stations to be connected (in pairs) at once and grants all possible connection requests as long as the called party is free. When a network is supporting only voice traffic, a blocking configuration is generally acceptable, because it is expected that most phone calls are of short duration and that therefore only a fraction of the telephones will be engaged at any time. However, when data processing devices are involved, these assumptions may be invalid. For example, for a data entry application, a terminal may be continuously connected to a computer for hours at a time. Hence, for data applications, there is a requirement for a nonblocking or “nearly nonblocking” (very low probability of blocking) configuration.

We turn now to an examination of the switching techniques internal to a single circuit-switching node.

Space Division Switching

Space division switching was originally developed for the analog environment and has been carried over into the digital realm. The fundamental principles are the same, whether the switch is used to carry analog or digital signals. As its name implies, a space division switch is one in which the signal paths are physically separate from one another (divided in space). Each connection requires the establishment of a physical path through the switch that is dedicated solely to the transfer of signals between the two endpoints. The basic building block of the switch is a metallic crosspoint or semiconductor gate that can be enabled and disabled by a control unit.

EXAMPLE 9.2 Figure 9.5 shows a simple **crossbar matrix** with 10 full-duplex I/O lines. The matrix has 10 inputs and 10 outputs; each station attaches to the matrix via one input and one output line. Interconnection is possible between any two lines by enabling the appropriate crosspoint. Note that a total of 100 crosspoints is required.

The crossbar switch has a number of limitations:

- The number of crosspoints grows with the square of the number of attached stations. This is costly for a large switch.
- The loss of a crosspoint prevents connection between the two devices whose lines intersect at that crosspoint.
- The crosspoints are inefficiently utilized; even when all of the attached devices are active, only a small fraction of the crosspoints are engaged.

To overcome these limitations, multiple-stage switches are employed.

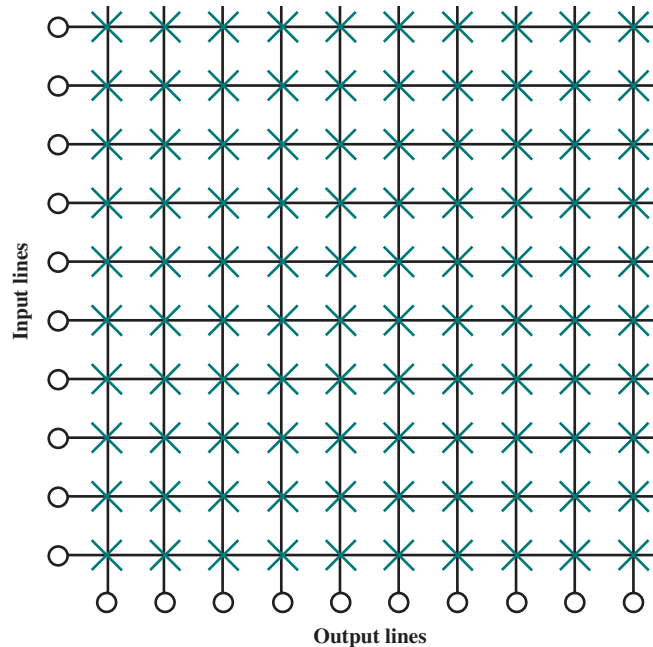


Figure 9.5 Space Division Switch

EXAMPLE 9.3 Figure 9.6 is an example of a three-stage switch.

A multiple-stage switch has two advantages over a single-stage crossbar matrix:

- The number of crosspoints is reduced, increasing crossbar utilization. In Examples 9.2 and 9.3, the total number of crosspoints for 10 stations is reduced from 100 to 48.
- There is more than one path through the network to connect two endpoints, increasing reliability.

Of course, a multistage network requires a more complex control scheme. To establish a path in a single-stage network, it is only necessary to enable a single gate. In a multistage network, a free path through the stages must be determined and the appropriate gates enabled.

A consideration with a multistage space division switch is that it may be blocking. It should be clear from Figure 9.5 that a single-stage crossbar matrix is nonblocking; that is, a path is always available to connect an input to an output. That this may not be the case with a multiple-stage switch can be seen in Figure 9.6. The heavier lines indicate the lines that are already in use. In this state, input line 10, for example, cannot be connected to output line 3, 4, or 5, even though all of these output lines are available. A multiple-stage switch can be made nonblocking

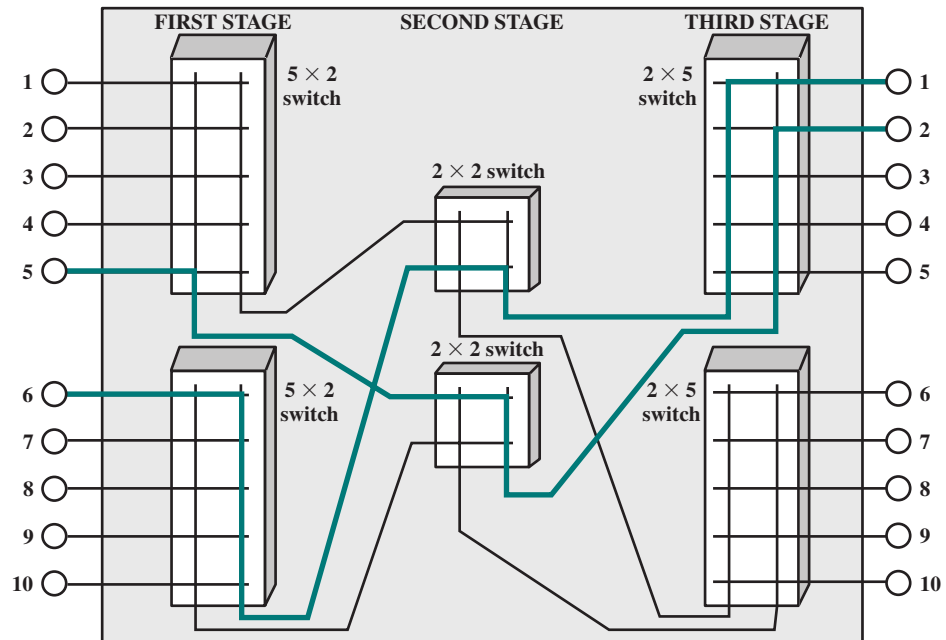


Figure 9.6 Three-Stage Space Division Switch

Control?

by increasing the number or size of the intermediate switches, but of course this increases the cost.

Time-Division Switching

The technology of switching has a long history, most of it covering an era when analog signal switching predominated. With the advent of digitized voice and synchronous TDM techniques, both voice and data can be transmitted via digital signals. This has led to a fundamental change in the design and technology of switching systems. **Instead of the relatively dumb space division approach, modern digital systems rely on intelligent control of space and time-division elements.**

Virtually all modern circuit switches use digital time-division techniques for establishing and maintaining "circuits." Time-division switching involves the partitioning of a lower-speed bit stream into pieces that share a **higher-speed stream** with **other bit streams**. The individual pieces, or slots, are manipulated by control logic to route data from input to output.

ver que dice "circuitos"

Time-Slot Interchange

The basic building block of many time-division switches is the time-slot interchange (TSI) mechanism. A TSI unit operates on a synchronous TDM stream of time slots, or channels, by interchanging pairs of slots to achieve a full-duplex operation. Figure 9.7a shows how the input line of device *I* is connected to the output line of device *J*, and vice versa.

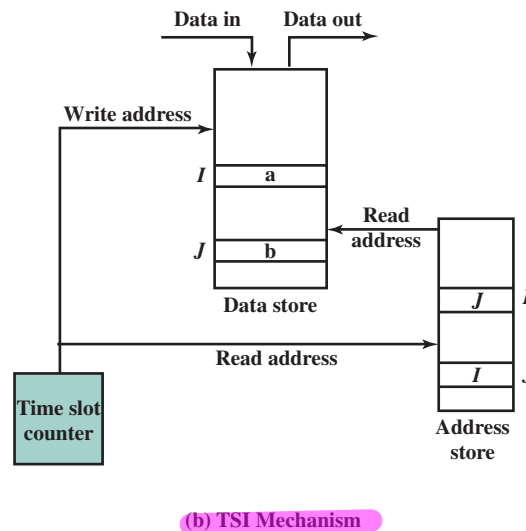
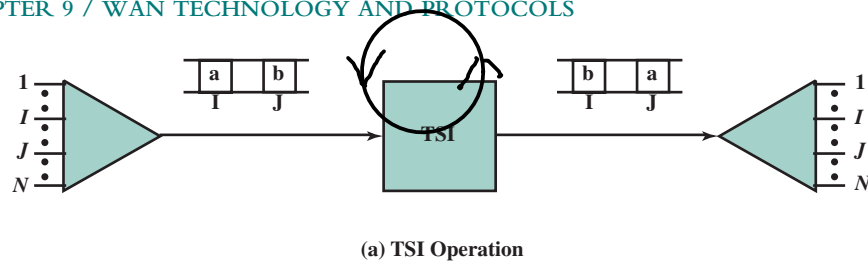


Figure 9.7 Time-Slot Interchange

The input lines of N devices are passed through a synchronous time-division multiplexer to produce a TDM stream with N slots. To allow the interchange of any two slots, to create a full-duplex connection, the incoming data in a slot must be stored until the data can be sent out on the correct channel in the next TDM frame cycle. Hence, the TSI introduces a delay and produces output slots in the desired order. The output stream of slots is then demultiplexed and routed to the appropriate output line. Because each channel is provided a time slot in each TDM frame, whether or not it transmits data, the size of the TSI unit must be chosen for the capacity of the line, not for the actual data rate.

Figure 9.7b shows a mechanism for implementing TSI. A random access data store whose width equals one time slot of data and whose length equals the number of slots in a frame is used. An incoming TDM frame is written sequentially, slot by slot, into the data store. An outgoing data frame is created by reading slots from the memory in an order dictated by an address store that reflects the existing connections. In the figure, the data in channels I and J are interchanged, creating a full-duplex connection between the corresponding stations.

TSI is a simple, effective way to switch TDM data. However, the size of such a switch, in terms of the number of connections, is limited by the amount of latency that can be tolerated. The greater the number of channels, the greater the average delay that each channel experiences.

efectivo , pero incluye latencia..(hay procesamiento)

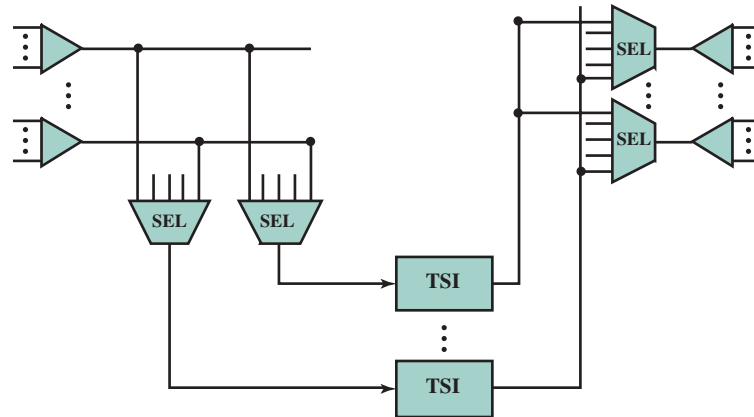


Figure 9.8 A Time-Multiplexed Switch

divido para disminuir el trafico de cada uno

Time-Multiplexed Switching

To overcome the latency problems of TSI, contemporary time-division switches use multiple TSI units, each of which carries a portion of the total traffic. To connect two channels entering a single TSI unit, their time slots can be interchanged, as just described. However, to connect a channel on one TDM stream (going into one TSI) to a channel on another TDM stream (going into another TSI), some form of space division switching is needed. Naturally, we do not wish to switch all of the time slots from one TDM stream to another; we would like to do it one slot at a time. This technique is known as **time-multiplexed switching (TMS)**.

One means of implementing a TMS switch is the crossbar switch discussed earlier. This requires the crosspoints to be manipulated at each time slot. More commonly, the TMS switch is implemented using digital selectors. The selector (SEL) device selects an input line based on a channel assignment provided from a store controlled by a time-slot counter.

To reduce or eliminate blocking, multiple stage networks can be built by concatenating TMS (S) and TSI (T) stages. Systems are generally described by an enumeration of their stages from input to output using the symbols T and S. Figure 9.8 shows an example of a three-stage switch implemented with SEL units.

No bloqueo: etapas Tiempo y Espacio.

9.4 SOFTSWITCH ARCHITECTURE

The latest trend in the development of circuit-switching technology is generally referred to as the softswitch. In essence, a softswitch is a general-purpose computer running specialized software that turns it into a smart phone switch. Softswitches cost significantly less than traditional circuit switches and can provide more functionality. In particular, in addition to handling the traditional circuit-switching functions, a softswitch can convert a stream of digitized voice bits into packets. This opens up a number of options for transmission, including the increasingly popular voice over IP (Internet Protocol) approach.

En esencia, un softswitch es una computadora de uso general ejecutando software especializado que lo convierte en un switch x software

<https://www.khomp.com/es/ss7-y-sigtran-protocolos/>

El Sistema de Señalización por Canal Común, o Signalling System Number 7 (SS7), es un conjunto de protocolos diseñados para que las redes de telefonía puedan intercambiar información y que las llamadas puedan transitar de manera transparente entre los teléfonos y sean correctamente tarifadas.

En otras palabras, el SS7 es el responsable directo de interconectar los teléfonos entre sí y también las centrales telefónicas y las operadoras.

In any telephone network switch, the **most complex element** is the software that **controls call processing**. This software performs call routing and implements call-processing logic for hundreds of custom-calling features. Typically, this software runs on a proprietary processor that is integrated with the physical circuit-switching hardware. A more flexible approach is to physically separate the call-processing function from the hardware-switching function. In softswitch terminology, the physical-switching function is performed by a **media gateway (MG)** and the call-processing logic resides in a **media gateway controller (MGC)**.

Figure 9.9 contrasts the architecture of a traditional telephone network circuit switch with the softswitch architecture. **In the latter case, the MG and MGC are distinct entities and may be provided by different vendors.** To facilitate interoperability, ITU-T has issued a standard for a media gateway control protocol between the MG and MGC: H.248.1 (*Gateway Control Protocol, Version 3, 2005*). RFC 2805 (*Media Gateway Control Protocol Architecture and Requirements, 2000*) provides an overview of media gateway concepts.

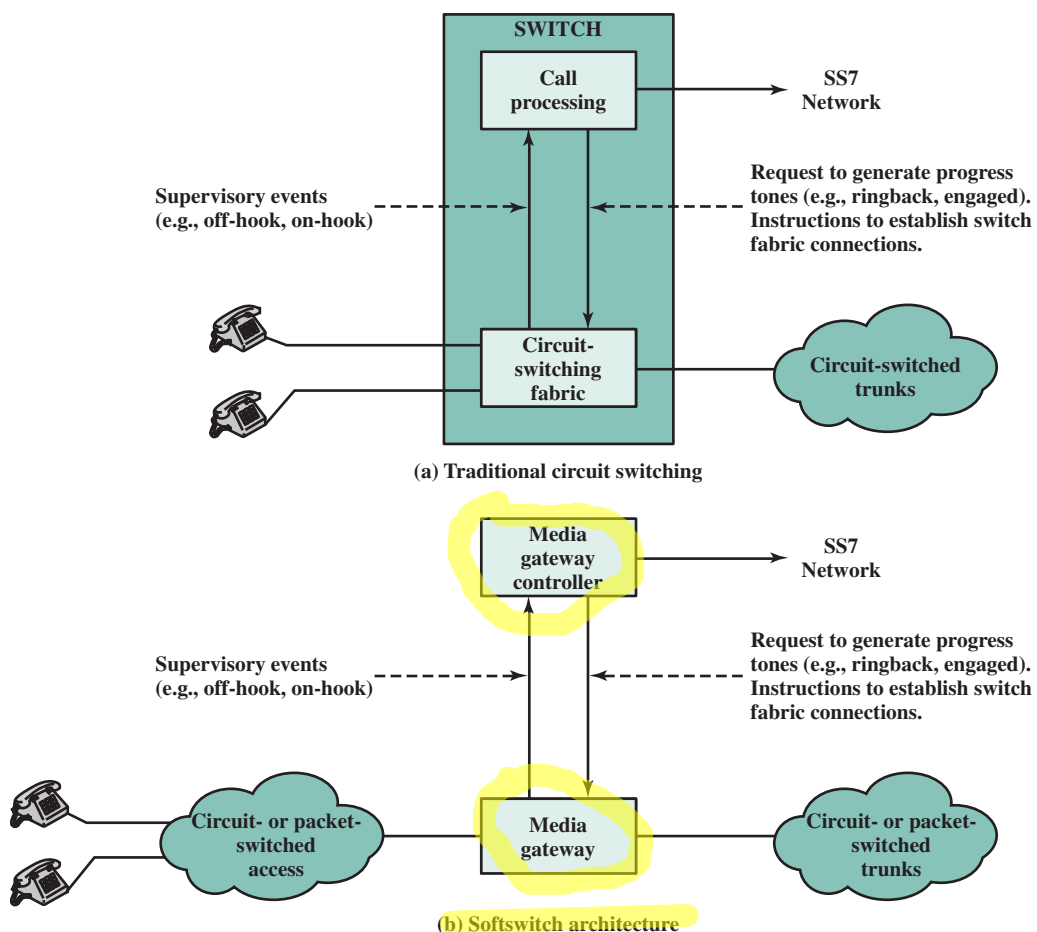


Figure 9.9 Comparison between Traditional Circuit Switching and Softswitch

9.5 PACKET-SWITCHING PRINCIPLES

origen:
voz

+ datos

The long-haul circuit-switching telecommunications network was originally designed to handle voice traffic, and the majority of traffic on these networks continues to be voice. A key characteristic of circuit-switching networks is that resources within the network are dedicated to a particular call. For voice connections, the resulting circuit will enjoy a high percentage of utilization because, most of the time, one party or the other is talking. However, as the circuit-switching network began to be used increasingly for data connections, two shortcomings became apparent:

Problema 1

- In a typical user/host data connection (e.g., personal computer user logged on to a database server), much of the time the line is idle. Thus, with data connections, a circuit-switching approach is inefficient.

Problema 2

- In a circuit-switching network, the connection provides for transmission at a constant data rate. Thus, each of the two devices that are connected must transmit and receive at the same data rate as the other. This limits the utility of the network in interconnecting a variety of host computers and workstations.

To understand how packet switching addresses these problems, let us briefly summarize packet-switching operation. Data are transmitted in short packets. A typical upper bound on packet length is 1000 octets (bytes). If a source has a longer message to send, the message is broken up into a series of packets (Figure 9.10). Each packet contains a portion (or all for a short message) of the user's data plus some control information. The control information, at a minimum, includes the information that the network requires to be able to route the packet through the network and deliver it to the intended destination. At each node en route, the packet is received, stored briefly, and passed on to the next node.

overhead =>

Let us return to Figure 9.1, but now assume that it depicts a simple packet-switching network. Consider a packet to be sent from station A to station E. The packet includes control information that indicates that the intended destination is E. The packet is sent from A to node 4. Node 4 stores the packet, determines the

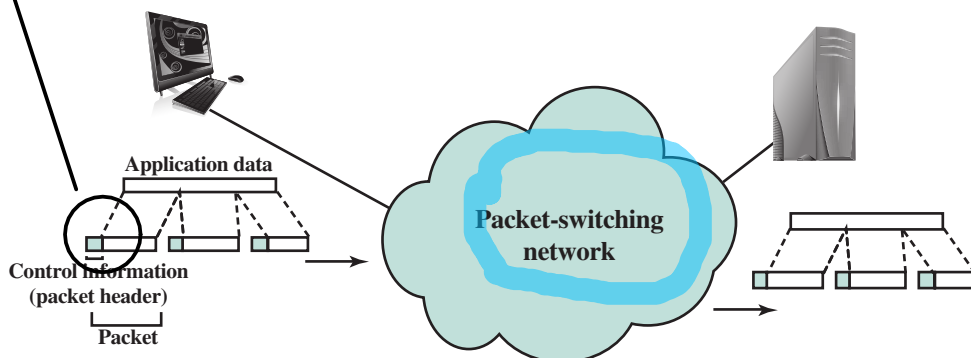


Figure 9.10 The Use of Packets