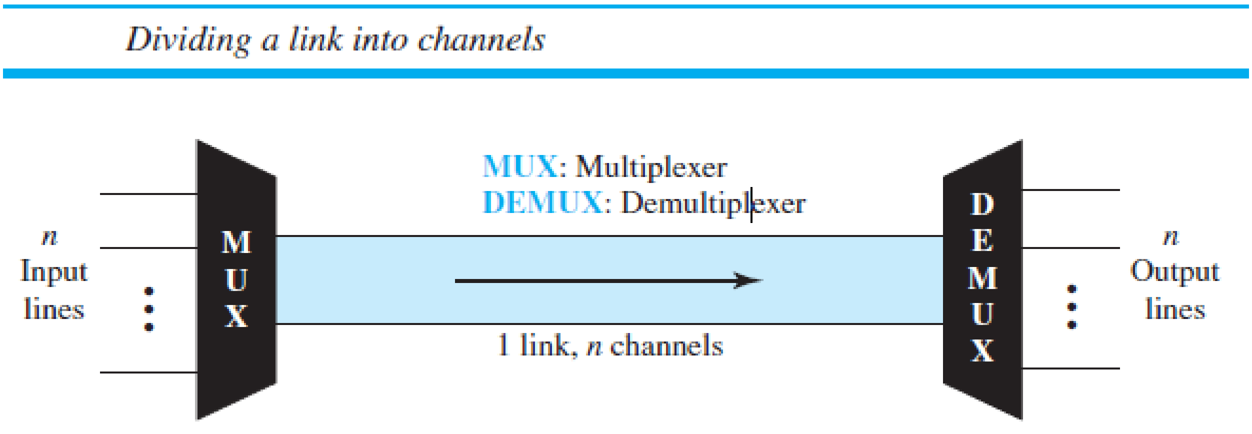
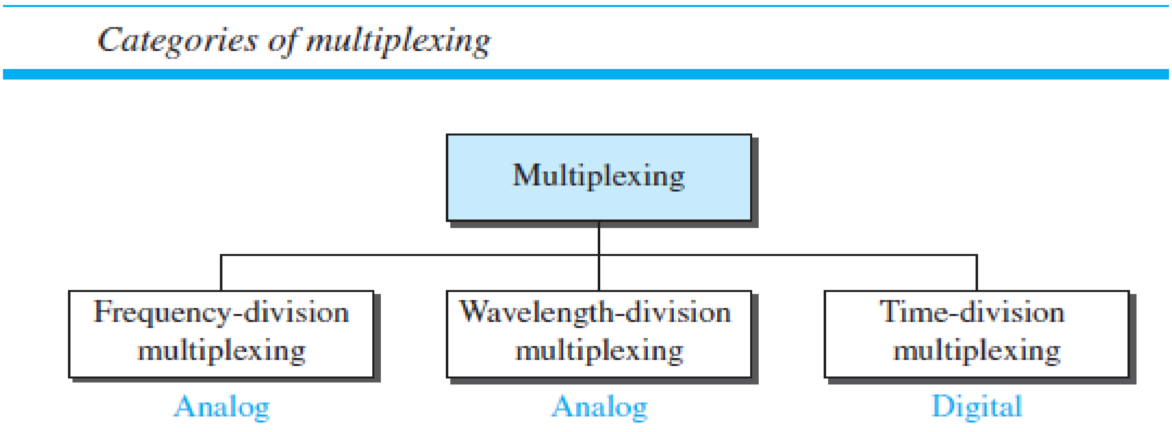
UNIT II

- **MULTIPLEXING**

Multiplexing is the set of technique that allow the simultaneous transmission of multiple signals across a single data link.In a multiplexed system, n lines share the bandwidth of one link.



The lines on the left direct their transmission streams to a multiplexer (MUX), which combines them into a single stream (many-to-one). At the receiving end, that stream is fed into a demultiplexer (DEMUX), which separates the stream back into its component transmissions (one-to-many) and directs them to their corresponding lines. In the figure, the word link refers to the physical path. The word channel refers to the portion of a link that carries a transmission between a given pair of lines. One link can have many (n) channels.
There are three basic multiplexing techniques: frequency-division multiplexing, wavelength-division multiplexing, and time-division multiplexing.



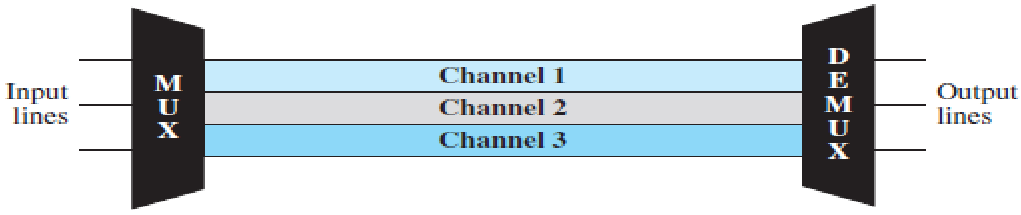
- **Frequency-Division Multiplexing(FDM)**

Frequency-division multiplexing (FDM) is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.
In FDM, signals generated by each sending device modulate different carrier frequencies. These modulated signals are then combined into a single composite signal that can be transported by the link. Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal. These bandwidth ranges are the channels through which the various signals travel

Channels can be separated by strips of unused bandwidth—guard bands—to prevent signals from overlapping.

FDM is an analog multiplexing technique that combines analog signals.

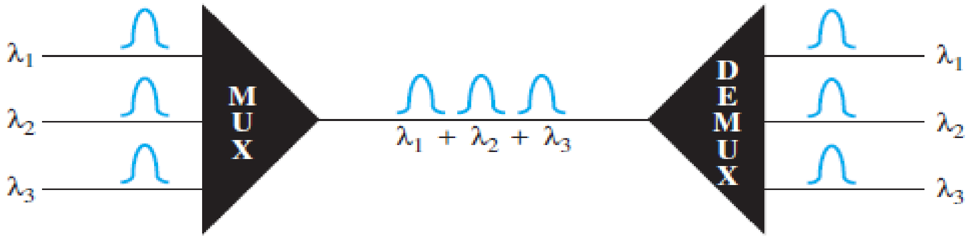
Frequency-division multiplexing



- **Wavelength-division multiplexing (WDM)**

Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable. The optical fiber data rate is higher than the data rate of metallic transmission cable, but using a fiber-optic cable for a single line wastes the available bandwidth. Multiplexing allows us to combine several lines into one.Very narrow bands of light from different sources are combined to make a wider band of light. At the receiver, the signals are separated by the demultiplexer. WDM is an analog multiplexing technique to combine optical signals.

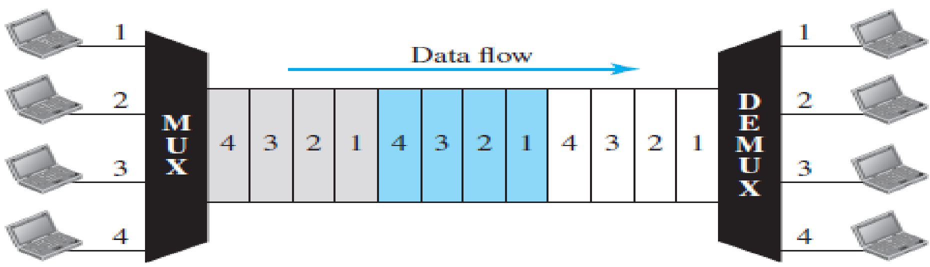
Wavelength-division multiplexing



- **Time-division multiplexing (TDM)**

Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link. Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link.

TDM



TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one. TDM is divided into two different schemes: synchronous and statistical.

Synchronous TDM:

In synchronous TDM, each input connection has an allotment in the output even if it is not sending data. In synchronous TDM, the data rate of the link is n times faster, and the unit duration is n times shorter.

statistical time-division multiplexing:

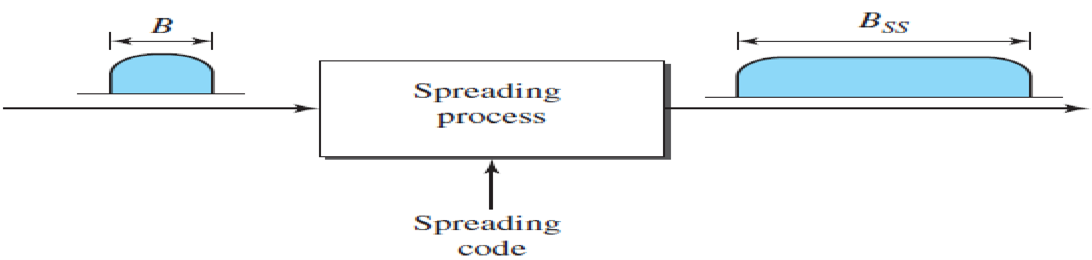
In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth efficiency. Only when an input line has a slot's worth of data to send is it given a slot in the output frame. In statistical multiplexing, the number of slots in each frame is less than the number of input lines. The multiplexer checks each input line in round robin fashion; it allocates a slot for an input line if the line has data to send; otherwise, it skips the line and checks the next line.

- **Spread Spectrum:**

Spread spectrum achieves its goals through two principles: 1) The bandwidth allocated to each station needs to be, by far, larger than what is needed. This allows redundancy.

2) The expanding of the original bandwidth B to the bandwidth Bss must be done by a process that is independent of the original signal. In other words, the spreading process occurs after the signal is created by the source.

Spread spectrum

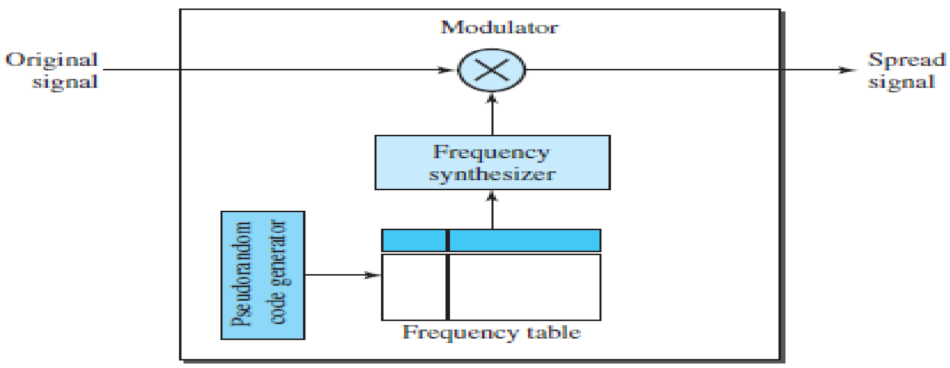


There are two techniques to spread the bandwidth: frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS).

- **frequency hopping spread spectrum (FHSS)**

The frequency hopping spread spectrum (FHSS) technique uses M different carrier frequencies that are modulated by the source signal. At one moment, the signal modulates one carrier frequency; at the next moment, the signal modulates another carrier frequency.

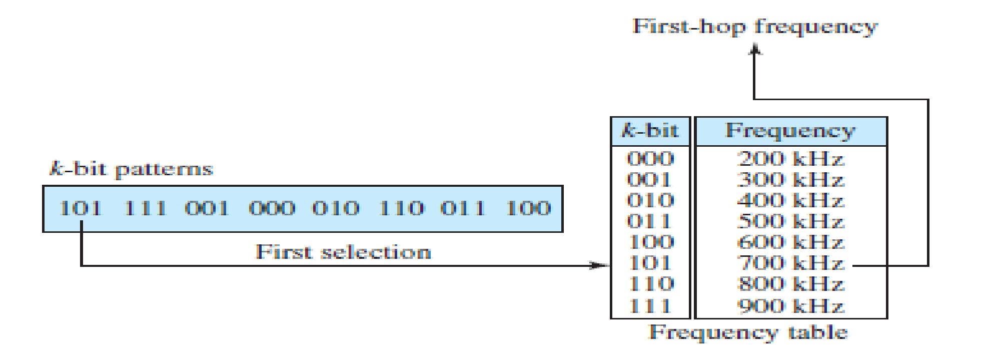
Frequency hopping spread spectrum (FHSS)



A pseudorandom code generator, called pseudorandom noise (PN), creates a k-bit pattern for every hopping period T_h. The frequency table uses the pattern to find the frequency to be used for this hopping period and passes it to the frequency synthesizer. The frequency synthesizer creates a carrier signal of that frequency, and the source signal modulates the carrier signal.

Suppose we have decided to have eight hopping frequencies. This is extremely low for real applications and is just for illustration. In this case, M is 8 and k is 3. The pseudorandom code generator will create eight different 3-bit patterns. These are mapped to eight different frequencies in the frequency table (see Figure)

Frequency selection in FHSS



- **Direct sequence spread spectrum (DSSS)**

The direct sequence spread spectrum (DSSS) technique also expands the bandwidth of the original signal, but the process is different. In DSSS, we replace each data bit with n bits using a spreading code. In other words, each bit is assigned a code of n bits, called chips, where the chip rate is n times that of the data bit.

DSSS

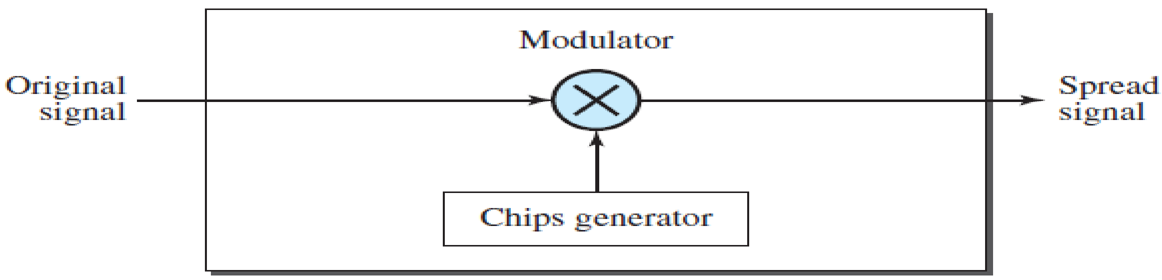
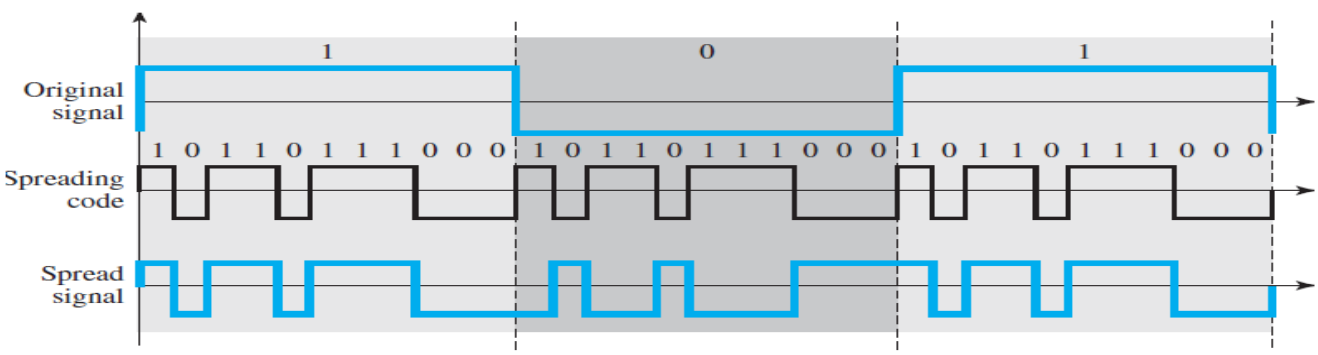


Figure shows the chips and the result of multiplying the original data by the chips to get the spread signal.

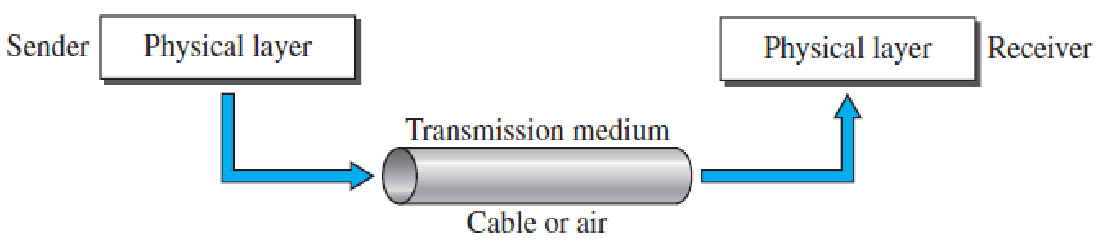
DSSS example



Transmission Media

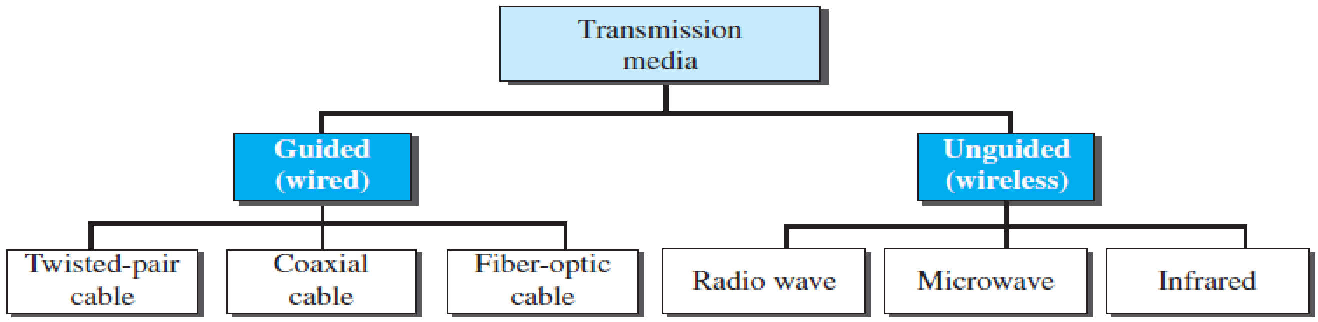
Transmission media are actually located below the physical layer and are directly controlled by the physical layer. In data communications the definition of the information and the transmission medium is more specific. The transmission medium is usually free space, metallic cable, or fiber-optic cable. The information is usually a signal that is the result of a conversion of data from another form.

Transmission medium and physical layer



In telecommunications, transmission media can be divided into two broad categories: **Guided and Unguided**. Guided media include twisted-pair cable, coaxial cable, and fiber-optic cable. Unguided medium is free space.

Classes of transmission media



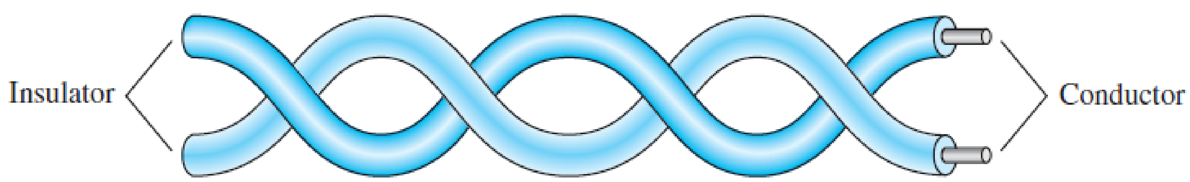
- **Guided media**

Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable.

1) Twisted-pair cable

A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together.

Twisted-pair cable



One of the wires is used to carry signals to the receiver, and the other is used only as a ground reference. The receiver uses the difference between the two. In addition to the signal sent by the sender on one of the wires, interference (noise) and crosstalk may affect both wires and create unwanted signals.By twisting the pairs, a balance is maintained.

Unshielded Versus Shielded Twisted-Pair Cable

The most common twisted-pair cable used in communications is referred to as unshielded twisted-pair (UTP). IBM has also produced a version of twisted-pair cable for its use, called shielded twisted-pair (STP). STP cable has a metal foil or braided mesh covering that encases each pair of insulated conductors. Although metal casing improves the quality of cable by preventing the penetration of noise or crosstalk, it is bulkier and more expensive.

The most common UTP connector is RJ45 (RJ stands for registered jack).

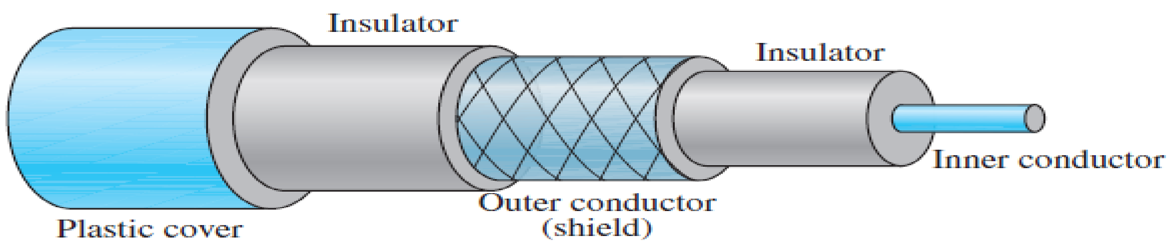
A twisted-pair cable can pass a wide range of frequencies.

Twisted-pair cables are used in telephone lines to provide voice and data channels.

2) **Coaxial cable**

Coaxial cable (or coax) carries signals of higher frequency ranges than those in twisted pair cable, in part because the two media are constructed quite differently. Instead of having two wires, coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which is, in turn, encased in an outer conductor of metal foil, braid, or a combination of the two. The outer metallic wrapping serves both as a shield against noise and as the second conductor, which completes the circuit. This outer conductor is also enclosed in an insulating sheath, and the whole cable is protected by a plastic cover.

Coaxial cable

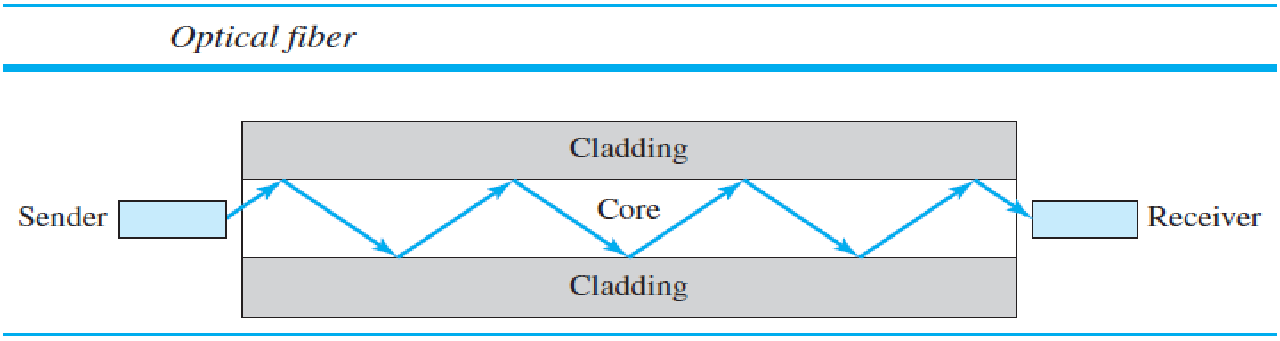


To connect coaxial cable to devices, we need coaxial connectors. The most commontype of connector used today is the Bayonet Neill-Concelman (BNC) connector.

Coaxial cable was widely used in analog telephone networks where a single coaxial network could carry 10,000 voice signals.Cable TV networks also use coaxial cables.

3) **Fiber-optic cable**

A fiber-optic cable is made of glass or plastic and transmits signals in the form of light. Optical fibers use reflection to guide light through a channel. A glass or plastic coreis surrounded by a cladding of less dense glass or plastic. The difference in density of thetwo materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it.Fiber-optic cable is often found in backbone networks because its wide bandwidth is cost-effective. Some cable TV companies use a combination of optical fiber and coaxial cable, thus creating a hybrid network.



Advantages and Disadvantages of Optical Fiber

Advantages

Fiber-optic cable has several advantages over metallic cable (twisted-pair or coaxial).

❑Higher bandwidth. Fiber-optic cable can support dramatically higher bandwidths (and hence data rates) than either twisted-pair or coaxial cable. Currently, data rates and bandwidth utilization over fiber-optic cable are limited not by the medium but by the signal generation and reception technology available.

❑Less signal attenuation. Fiber-optic transmission distance is significantly greater than that of other guided media. A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted-pair cable.

❑Immunity to electromagnetic interference. Electromagnetic noise cannot affect fiber-optic cables.

❑Resistance to corrosive materials. Glass is more resistant to corrosive materials than copper.

❑Light weight. Fiber-optic cables are much lighter than copper cables.

❑Greater immunity to tapping. Fiber-optic cables are more immune to tapping than copper cables. Copper cables create antenna effects that can easily be tapped.

Disadvantages

There are some disadvantages in the use of optical fiber.

❑Installation and maintenance. Fiber-optic cable is a relatively new technology. Its installation and maintenance require expertise that is not yet available everywhere.

❑Unidirectional light propagation. Propagation of light is unidirectional. If we need bidirectional communication, two fibers are needed.

❑Cost. The cable and the interfaces are relatively more expensive than those of other guided media. If the demand for bandwidth is not high, often the use of optical fiber cannot be justified.

- **Unguided medium**

Unguided medium transport electromagnetic waves without using a physical conductor.

This type of communication is often referred to as wireless communication.

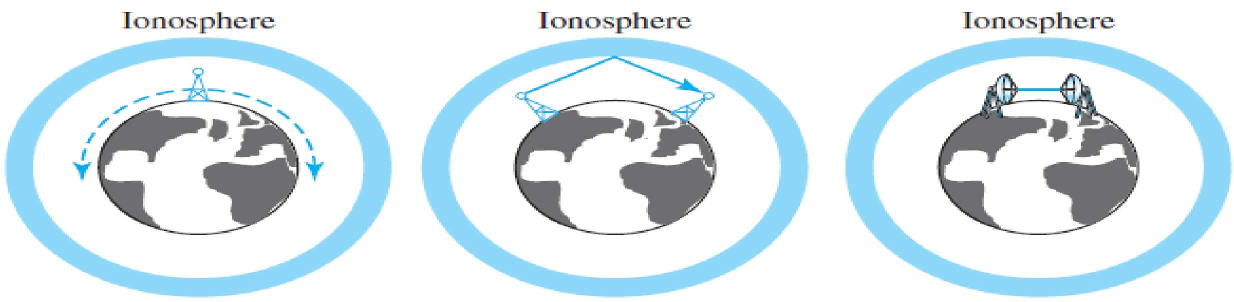
Unguided signals can travel from the source to the destination in several ways: ground propagation, sky propagation, and line-of-sight propagation.

In **ground propagation**, radio waves travel through the lowest portion of the atmosphere, hugging the earth.

In **sky propagation**, higher-frequency radio waves radiate upward into the ionosphere (the layer of atmosphere where particles exist as ions) where they are reflected back to earth.

In **line-of-sight**propagation, very high-frequency signals are transmitted in straight lines directly from antenna to antenna.

Propagation methods



Ground propagation (below 2 MHz) | Sky propagation (2–30 MHz) | Line-of-sight propagation (above 30 MHz)

1) Radio waves

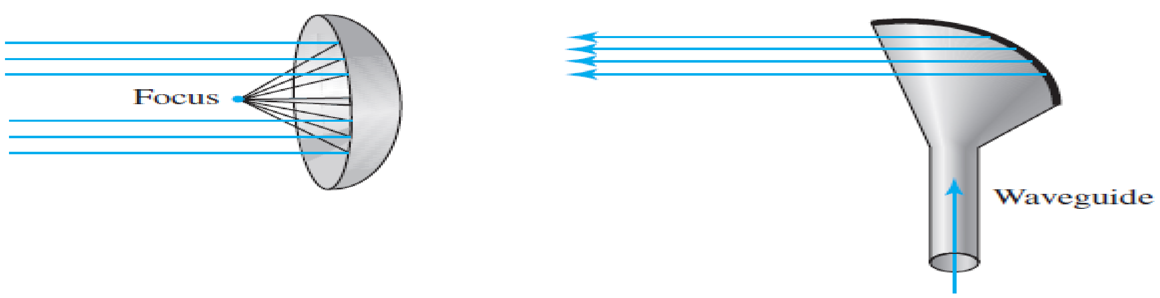
The waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves. Radio waves, for the most part, are omnidirectional. When an antenna transmits radio waves, they are propagated in all directions. This means that the sending and receiving antennas do not have to be aligned. A sending antenna sends waves that can be received by any receiving antenna.
Radio waves, particularly those waves that propagate in the sky mode, can travel long distances. This makes radio waves a good candidate for long-distance broadcasting such as AM radio.
Radio waves, particularlythose of low and medium frequencies, can penetrate walls. AM and FM radio, television, maritime radio, cordless phones, and paging are examples of multicasting.

2) Microwaves

Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves.
Microwaves are unidirectional.When an antenna transmits microwaves, they can be narrowly focused. This means that the sending and receiving antennas need to be aligned.
The following describes some characteristics of microwave propagation:

- ❑ Microwave propagation is line-of-sight. Since the towers with the mounted antennas need to be in direct sight of each other, towers that are far apart need to be very tall. The curvature of the earth as well as other blocking obstacles do not allow two short towers to communicate by using microwaves. Repeaters are often needed for long distance communication.
- ❑ Very high-frequency microwaves cannot penetrate walls. This characteristic can be a disadvantage if receivers are inside buildings.
- ❑ The microwave band is relatively wide, almost 299 GHz. Therefore wider subbands can be assigned, and a high data rate is possible.
- ❑ Use of certain portions of the band requires permission from authorities.

Unidirectional antennas



a. Parabolic dish antenna | b. Horn antenna

Microwaves, due to their unidirectional properties, are very useful when unicast (one-to-one) communication is needed between the sender and the receiver. Microwaves are used for unicast communication such as cellular telephones, satellite networks, and wireless LANs.

3) **Infrared waves**

Infrared waves, with frequencies from 300 GHz to 400 THz (wavelengths from 1 mmto 770 nm), can be used for short-range communication. Infrared waves, having high frequencies, cannot penetrate walls.

This advantageous characteristic prevents interference between one system and another; a short-range communication system in one room cannot be affected by another system in the next room. When we use our infrared remote control, we do not interfere with the use of the remote by our neighbors. However, this same characteristic makes infrared signals useless for long-range communication.

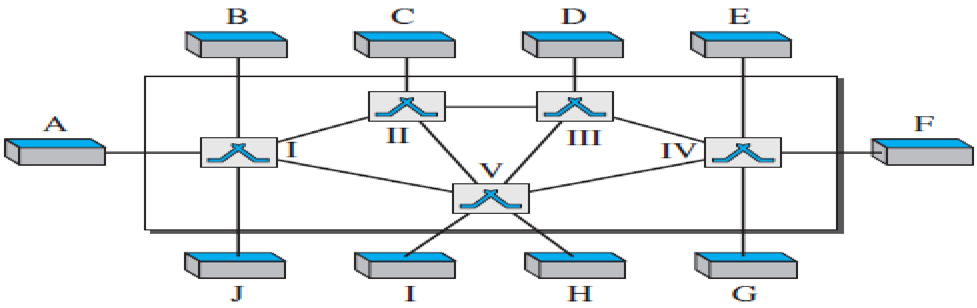
Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.

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. 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.

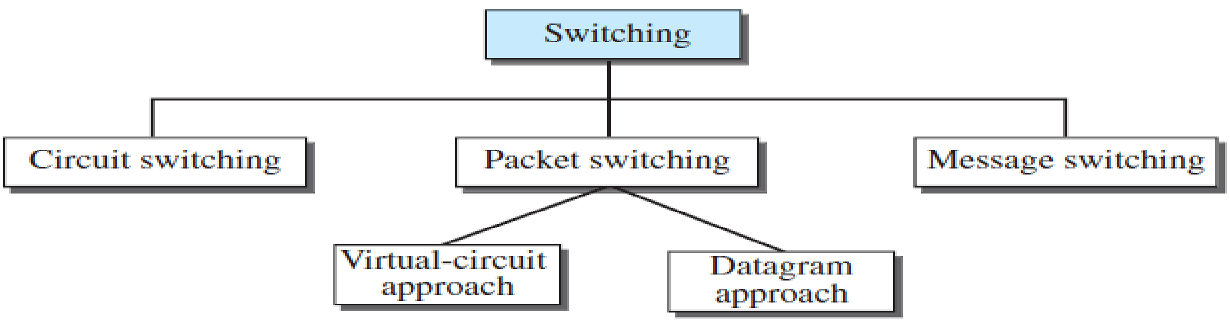
The end systems (communicating devices) are labeled A, B, C, D, and so on, and the switches are labeled I, II, III, IV, and V. Each switch is connected to multiple links.

Switched network



There are three methods of switching: **circuit switching**, **packet switching**, and **message switching**.

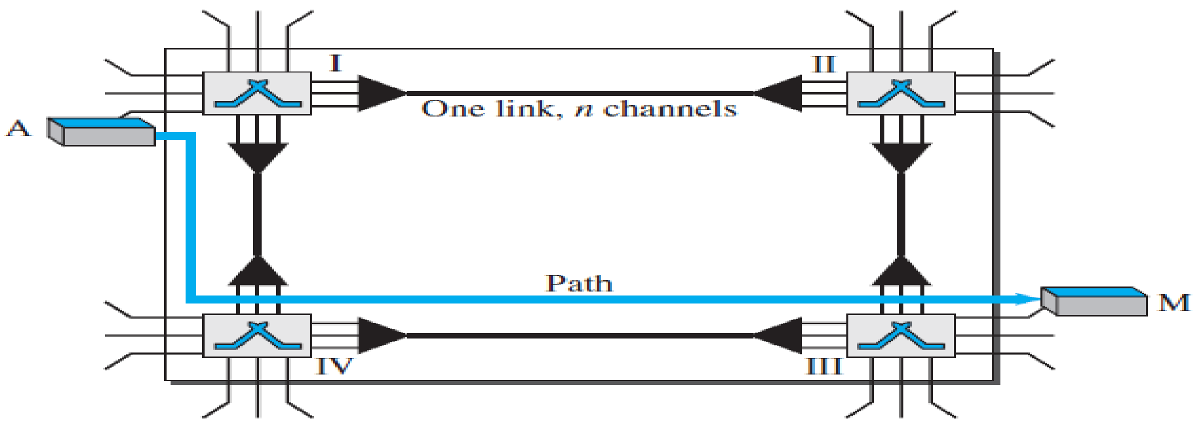
Taxonomy of switched networks



1) circuit-switched network

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.

A trivial circuit-switched network



The end systems, such as computers or telephones, are directly connected to a switch. Circuit switching takes place at the physical layer.

❑Before starting communication, the stations must make a reservation for the resources to be used during the communication. 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 until the teardown phase.

❑ Data transferred between the two stations are not packetized (physical layer transfer of the signal). The data are a continuous flow sent by the source station and received by the destination station, although there may be periods of silence.

❑There is no addressing involved during data transfer. The switches route the data based on their occupied band (FDM) or time slot (TDM). Of course, there is end-to end addressing used during the setup phase, as we will see shortly.

In circuit switching, the resources need to be reserved during the setup phase; the resources remain dedicated for the entire duration of data transfer until the teardown phase.

Setup Phase

Before the two parties (or multiple parties in a conference call) can communicate, a dedicated circuit (combination of channels in links) needs to be established. The end systems are normally connected through dedicated lines to the switches, so connection setupmeans creating dedicated channels between the switches.

Data-Transfer Phase

After the establishment of the dedicated circuit (channels), the two parties can transfer data.

Teardown Phase

When one of the parties needs to disconnect, a signal is sent to each switch to releasethe resources.

2) Packet-switched network

In data communications, we need to send messages from one end system to another. Ifthe 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 thatthere 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. As withother systems in our daily life, this lack of reservation may create delay. For example, if we do not have a reservation at a restaurant, we might have to wait.

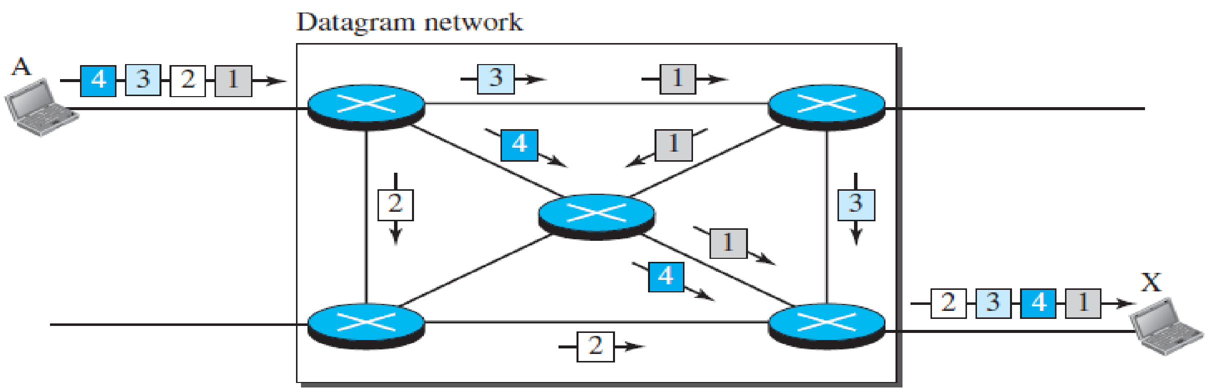
There are two types of packet-switched networks: datagram networks and virtual circuit networks.

a) Datagram networks

In a datagram network, each packet is treated independently of all others. Packets in this approach are referred to as datagrams.

Datagram switching is normally done at the network layer.The datagram networks are sometimes referred to as connectionless networks. Theterm connectionless here means that the switch (packet switch) does not keep informationabout 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.

A datagram network with four switches (routers)

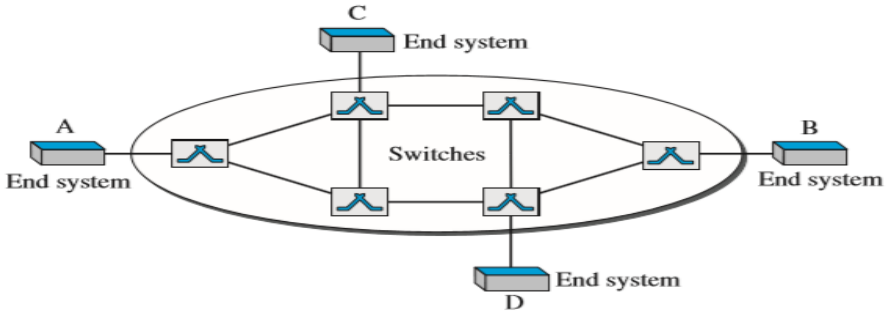


In this type of network, each switch (or packet switch) has a routing table which is based on the destination address. The routing tables are dynamic and are updated periodically. The destination addresses and the corresponding forwarding output ports are recorded in the tables.

The destination address in the header of a packet in a datagram network remains the same during the entire journey of the packet.

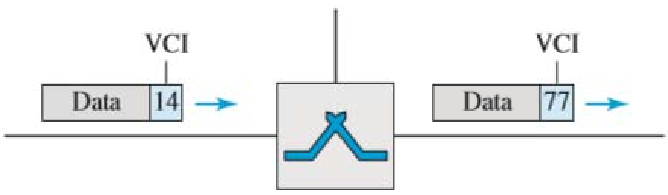
Virtual-Circuit Network

Virtual-circuit network



1) A virtual-circuit network is a cross between a circuit-switched network and a datagram network.
2) It has some characteristics of circuit-switched network and a datagram network.
3) As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
4) Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
5) As in a datagram network, data are packetized and each packet carries an address in the header.
6) As in a circuit-switched network, all packets follow the same path established during the connection.
7) A virtual-circuit network is normally implemented in the data-link layer, while a circuit-switched network is implemented in the physical layer and a datagram network in the network layer. But this may change in the future.
8) In a virtual-circuit network, two types of addressing are involved: global and local (virtual-circuit identifier).
9) 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 or internationally if the network is part of an international network.
10) Virtual-Circuit Identifier:- The identifier that is actually used for data transfer is called the virtual-circuit identifier(VCI) or the label.
11) In virtual-circuit switching, all packets belonging to the same source and destinationtravel the same path, but the packets may arrive at the destination with different delays if resource allocation is on demand.

Virtual-circuit identifier



Data-Transfer Phase

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.

Setup Request

A setup request frame is sent from the source to the destination.

Acknowledgment

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

Teardown Phase

In this phase, source A, after sending all frames to B, sends a special frame called a teardown request.

- **STRUCTURE OF A SWITCH**

We use switches in circuit-switched and packet-switched networks.

Structure of Circuit Switches

Circuit switching today can use either of two technologies: the space-division switch or the time-division switch.

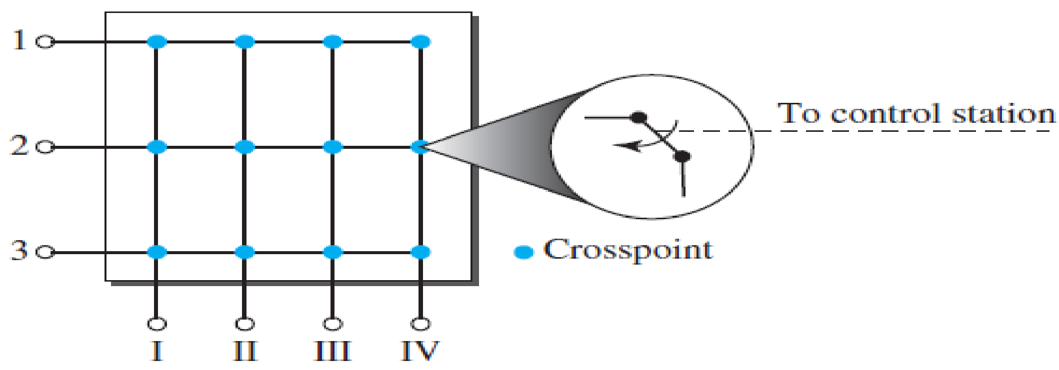
1) **space-division switch**

In space-division switching, the paths in the circuit are separated from one another spatially. This technology was originally designed for use in analog networks but is used currently in both analog and digital networks.

a) **crossbar switch**

A crossbar switch connects n inputs to m outputs in a grid, using electronic microswitches (Transistors) at each crosspoint. The major limitation of this design is the number of crosspoints required. To connect n inputs to m outputs using acrossbar switch requires n × m crosspoints.

Crossbar switch with three inputs and four outputs

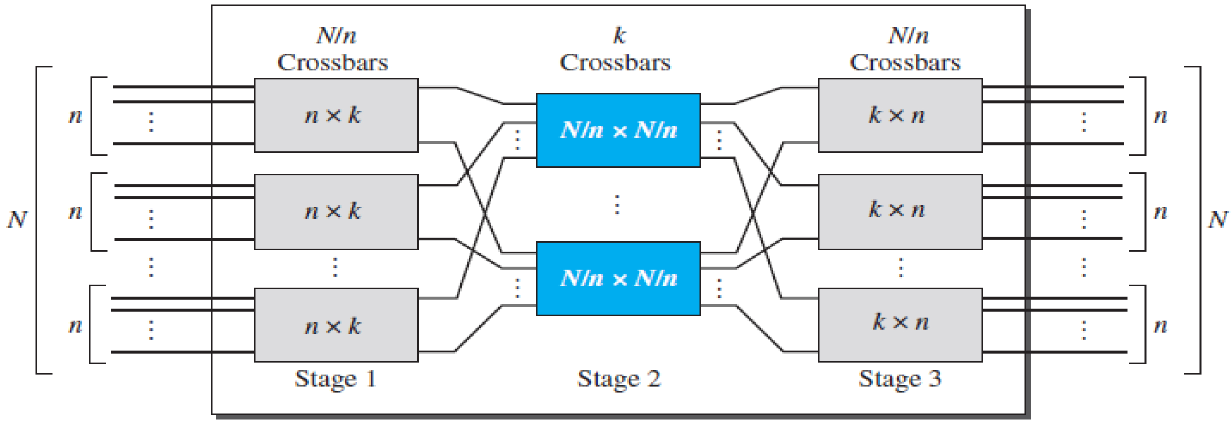


b) **Multistage Switch**

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

In a single crossbar switch, only one row or column (one path) is active for any connection. So we need N × N crosspoints. If we can allow multiple paths inside the switch, we can decrease the number of crosspoints. Each crosspoint in the middle stage can be accessed by multiple crosspoints in the first or third stage.

Multistage switch



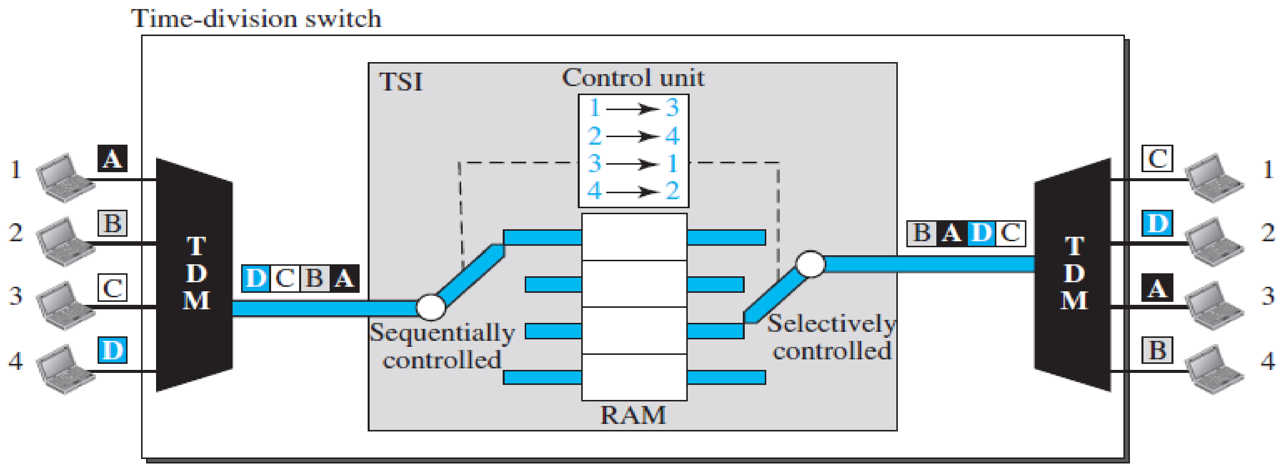
2) Time-Division Switch

Time-division switching uses time-division multiplexing (TDM) inside a switch. Themost popular technology is called the **time-slot interchange (TSI).**

Time-Slot Interchange

Figure shows a system connecting four input lines to four output lines. Imagine that 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."

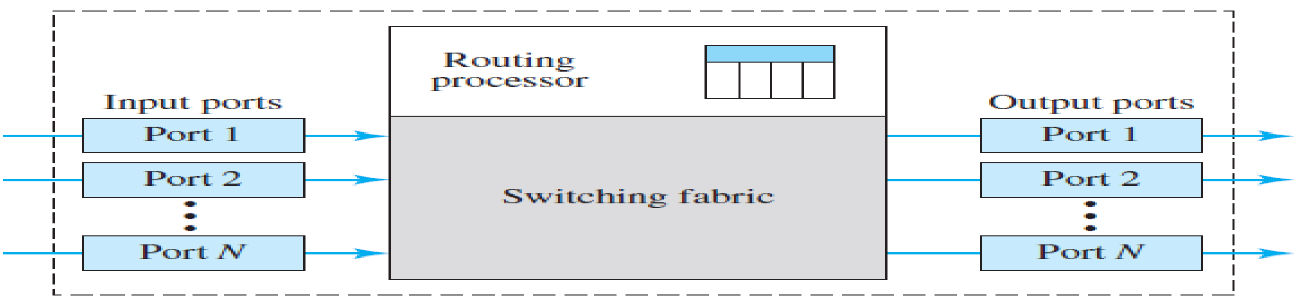
Time-slot interchange



Structure of Packet Switches

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

Packet switch components



Error Detection and Correction

- **Types of Errors**

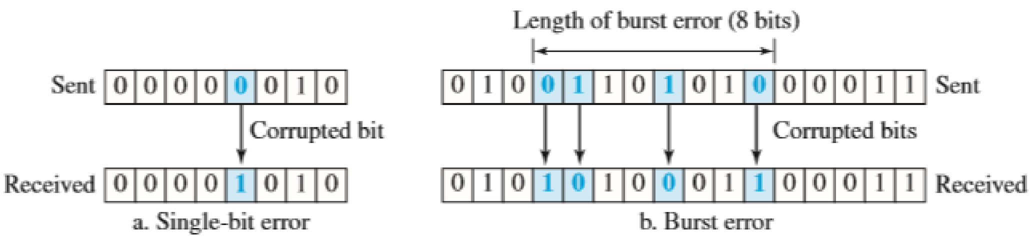
Whenever bits flow from one point to another, they are subject to unpredictable changes because of interference. This interference can change the shape of the signal.

The term **single-bit error** means that only 1 bit of a given data unit (such as a byte, character, or packet) is changed from 1 to 0 or from 0 to 1.

The term **burst error** means that 2 or more bits in the data unit have changed from 1 to 0 or from 0 to 1.

A burst error is more likely to occur than a single-bit error because the duration of the noise signal is normally longer than the duration of 1 bit, which means that when noise affects data, it affects a set of bits.

Single-bit and burst error



Redundancy

The central concept in detecting or correcting errors is redundancy. To be able to detect or correct errors, we need to send some extra bits with our data. These redundant bits are added by the sender and removed by the receiver. Their presence allows the receiver to detect or correct corrupted bits.

Redundancy is achieved through various coding schemes.

The coding schemes is divided into two broad categories: **block coding and convolution coding.**

BLOCK CODING

In block coding, the message is divided into blocks, each of k bits, called **datawords**. We add r redundant bits to each block to make the length n = k + r.

The resulting n-bit blocks are called **codewords**.

The block coding process is one-to-one; the same dataword is always encoded as the same codeword.

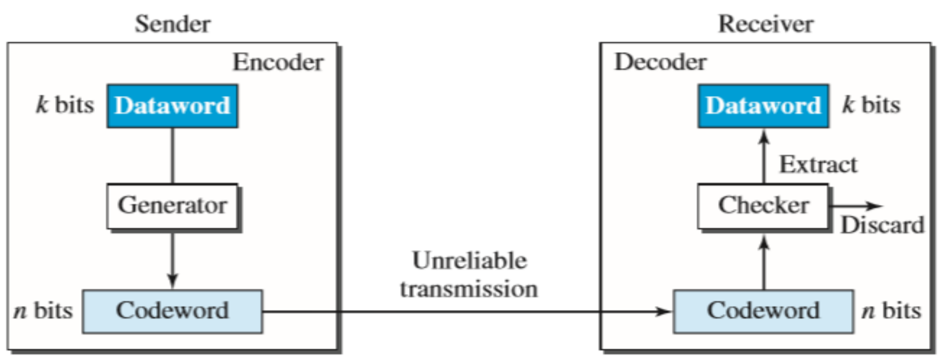
If the receiver receives an invalid codeword, this indicates that the data was corrupted during transmission.

Error Detection

If the following two conditions are met, the receiver can detect a change in the original codeword:
1. The receiver has (or can find) a list of valid codewords.
2. The original codeword has changed to an invalid one.

An error-detecting code can detect only the types of errors for which it is designed; other types of errors may remain undetected.

Process of error detection in block coding



Hamming Distance

One of the central concepts in coding for error control is the idea of the Hamming distance. The Hamming distance between two words (of the same size) is the number of differences between the corresponding bits.

The Hamming distance between two words x and y as d(x, y).

The Hamming distance between the received codeword and the sent codeword is the number of bits that are corrupted during transmission. For example, if the codeword 00000 is sent and 01101 is received, 3 bits are in error and the Hamming distance between the two is d(00000, 01101) = 3. In other words, if the Hamming distance between the sent and the received codeword is not zero, the codeword has been corrupted during transmission.

CYCLIC CODES

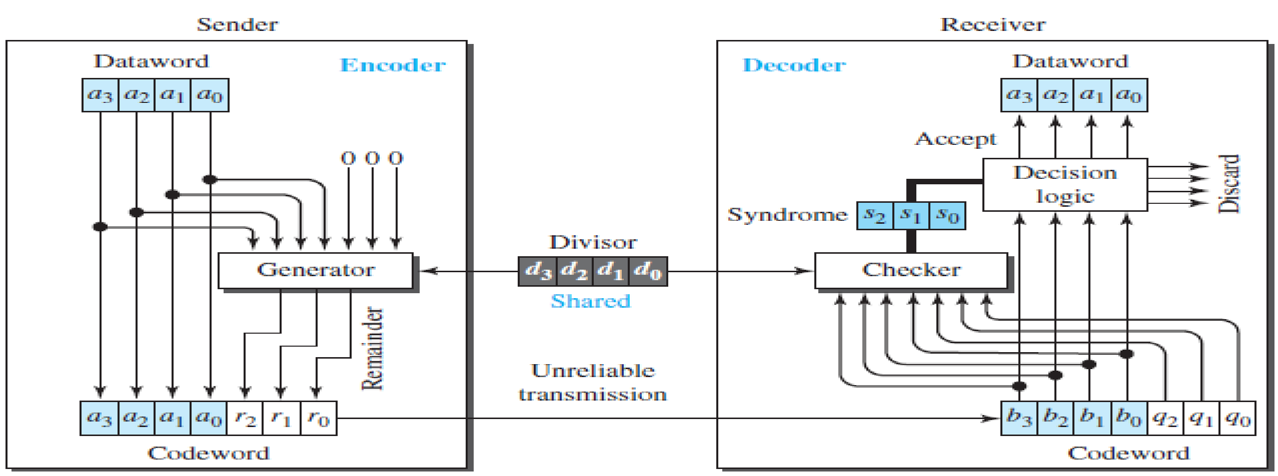
In a cyclic code, if a codeword is cyclically shifted (rotated), the result is another codeword. For example, if 1011000 is a codeword and we cyclically left-shift, then 0110001 is also a codeword. In this case, if we call the bits in the first word a0 to a6, and the bits in the second word b0 to b6, we can shift the bits by using the following:

b1 = a0 b2 = a1 b3 = a2 b4 = a3 b5 = a4 b6 = a5 b0 = a6

Cyclic Redundancy Check:

Cyclic codes are created to correct errors. Cyclic redundancy check (CRC) is the subset of cyclic codes which is used in networks such as LANs and WANs.

CRC encoder and decoder

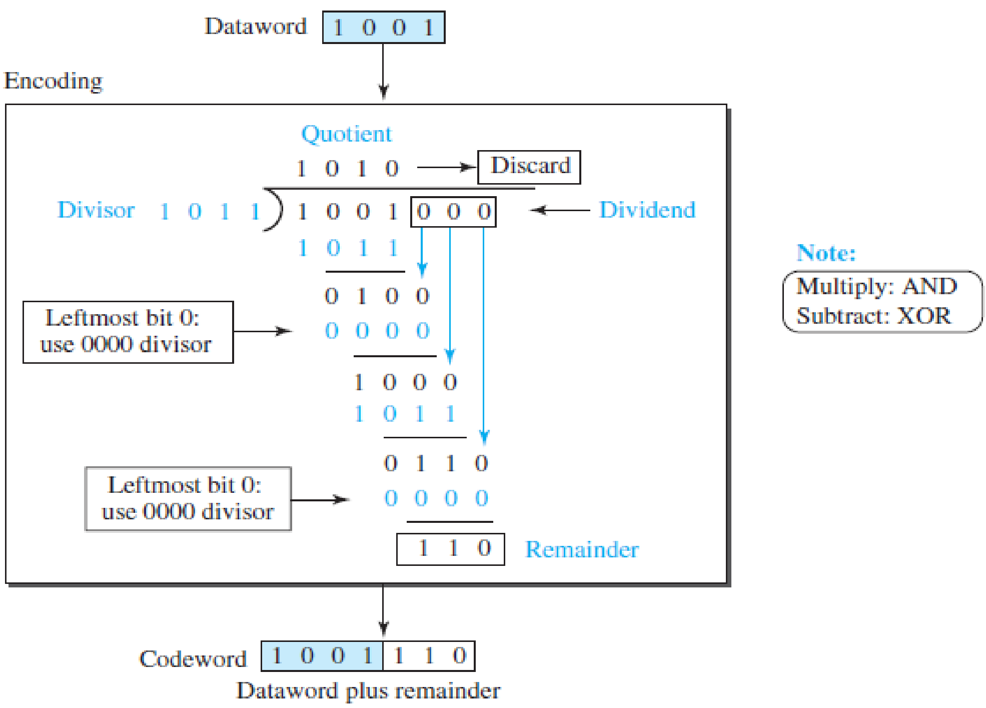


In the encoder, the dataword has k bits (4 here); the codeword has n bits (7 here). The size of the dataword is augmented by adding n - k (3 here) 0s to the right-hand side of the word. The n-bit result is fedinto the generator.

The decoder receives the codeword (possibly corrupted in transition). A copy of all n bits is fed to the checker, which is a replica of the generator. The remainder produced by the checker is a syndrome of n - k (3 here) bits, which is fed to the decision logic analyzer. The analyzer has a simple function. If the syndrome bits are all 0s, the 4 leftmost bits of the codeword are accepted as the dataword (interpreted as no error); otherwise, the 4 bits are discarded (error).

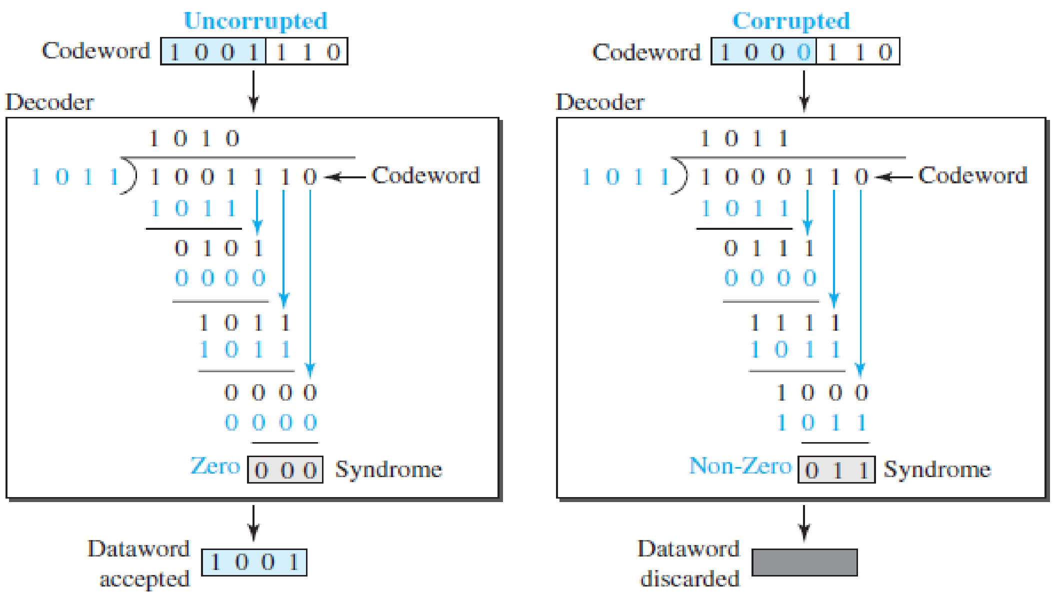
Encoder:

Division in CRC encoder



Decoder:

Division in the CRC decoder for two cases



CHECKSUM:

Checksum is an error-detecting technique that can be applied to a message of anylength. In the Internet, the checksum technique is mostly used at the network and transport layer rather than the data-link layer.

At the source, the message is first divided into m-bit units. The generator then createsan extra m-bit unit called the checksum, which is sent with the message. At thedestination, the checker creates a new checksum from the combination of the messageand sent checksum. If the new checksum is all 0s, the message is accepted; otherwise,the message is discarded.

Traditionally, the Internet has used a 16-bit checksum.

Procedure to calculate the traditional checksum

Sender	*Receiver*
1. The message is divided into 16-bit words.	1. The message and the checksum are received.
2. The value of the checksum word is initially set to zero.	2. The message is divided into 16-bit words.
3. All words including the checksum are added using one's complement addition.	3. All words are added using one's complement addition.
4. The sum is complemented and becomes the checksum.	4. The sum is complemented and becomes the new checksum.
5. The checksum is sent with the data.	5. If the value of the checksum is 0, the message is accepted; otherwise, it is rejected.

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