Republic of Iraq
Middle Technical University
Technical Engineering College of Artificial Intelligence
Cybersecurity Engineering Technology Department

Computer Network Fundamentals

Chapter Three

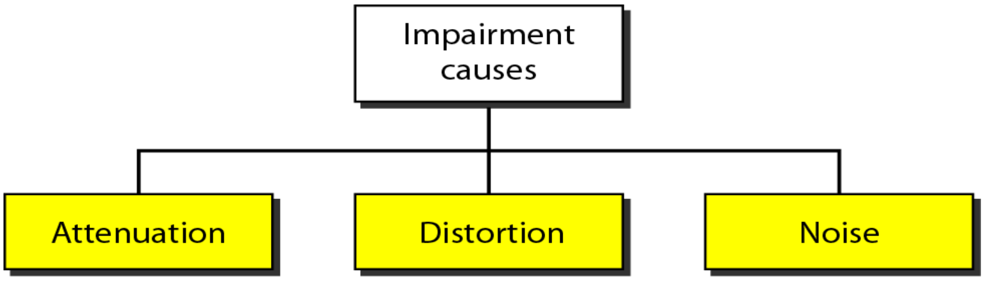
Transmission Media & Multiplexing

((Physical Layer))

Prepared By:
Associate Prof. Dr. Mahmoud Shuker Mahmoud
mahmoud.shukur@mtu.edu.iq

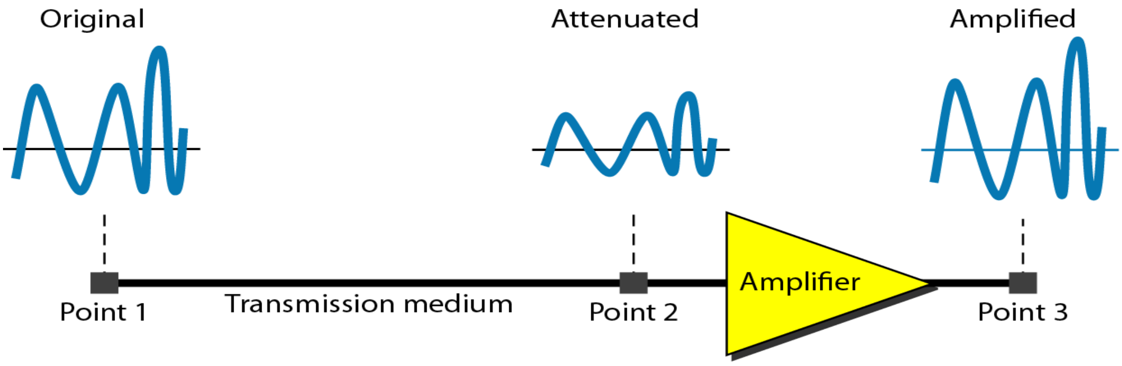
3.1- Transmission Impairment

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are ***attenuation***, ***distortion***, and ***noise***



Attenuation

Attenuation means a loss of energy. When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium. That is why a wire carrying electric signals gets warm. Some of the electrical energy in the signal is converted to heat. To compensate for this loss, amplifiers are used to amplify the signal.



To show that a signal has lost or gained strength, engineers use the unit of the *decibel*. The **decibel (dB)** *measures the relative strengths of two signals or one signal at two different points*. Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.

$$\mathbf{dB = 10\ Log_{10}\ (P_2 / P_1)}$$

Example:

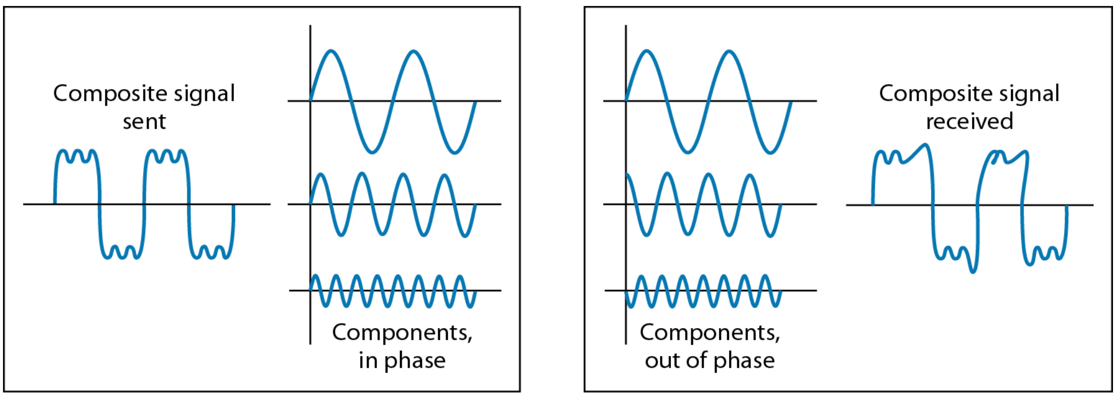
Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is (1/2)P1. In this case, the attenuation (loss of power) can be calculated as follows:

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

Distortion

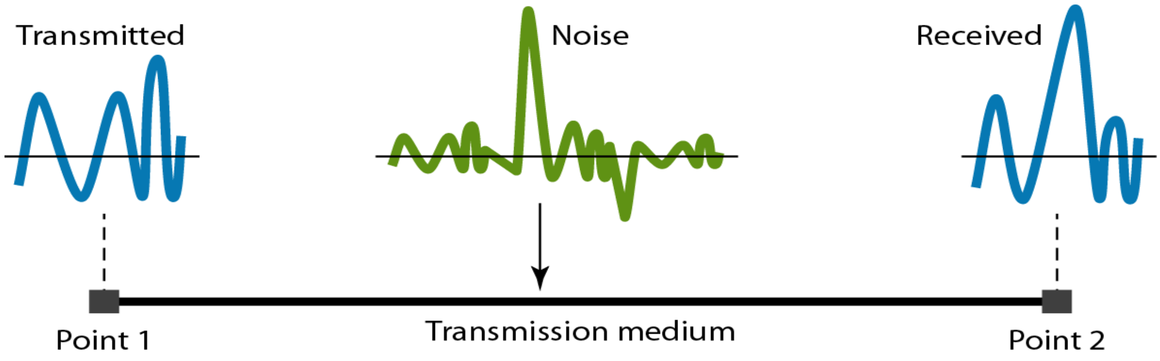
Distortion means that the signal changes its form or shape. Distortion can occur in a composite signal made of different frequencies. Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination. Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration. In other words, signal components at the receiver have phases different from what they had at the sender. The shape of the composite signal is therefore not the same.



At the sender At the receiver

Noise

Noise is another cause of impairment. Several types of noise, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal. Thermal noise is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter. Induced noise comes from sources such as motors and appliances. These devices act as a sending antenna, and the transmission medium acts as the receiving antenna. Crosstalk is the effect of one wire on the other. One wire act as a sending antenna and the other as the receiving antenna. Impulse noise is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.



Signal-to-Noise Ratio (SNR)

It is the term useful to find the bit rate of the signal and it is defined as the ratio of the signal power to the noise power as shown below:

$$\textbf{SNR} = \frac{\textbf{average signal power}}{\textbf{average noise power}}$$

Because SNR is the ratio of two powers, it is often described in decibel units, $\boldsymbol{SNR_{dB}}$ and defined as:

$$\mathbf{SNR_{dB} = 10\ log_{10}\ SNR}$$

Example:

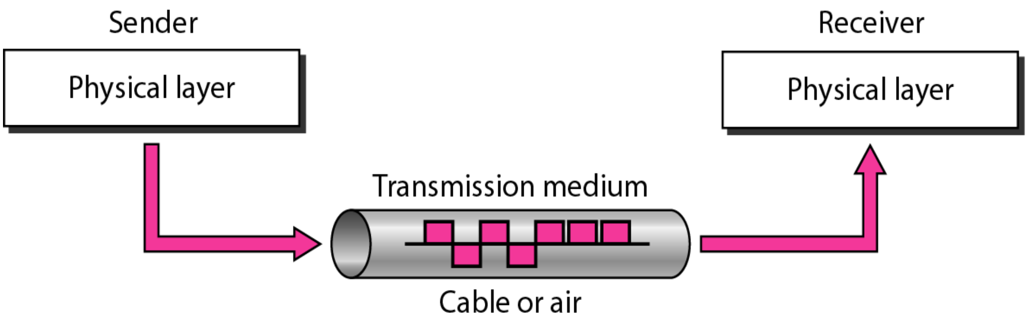
The power of a signal is 10 mW and the power of the noise is 1 μW; what is the value of SNR_{dB}

SNR = (10000 μW) / (1 μW) =10000

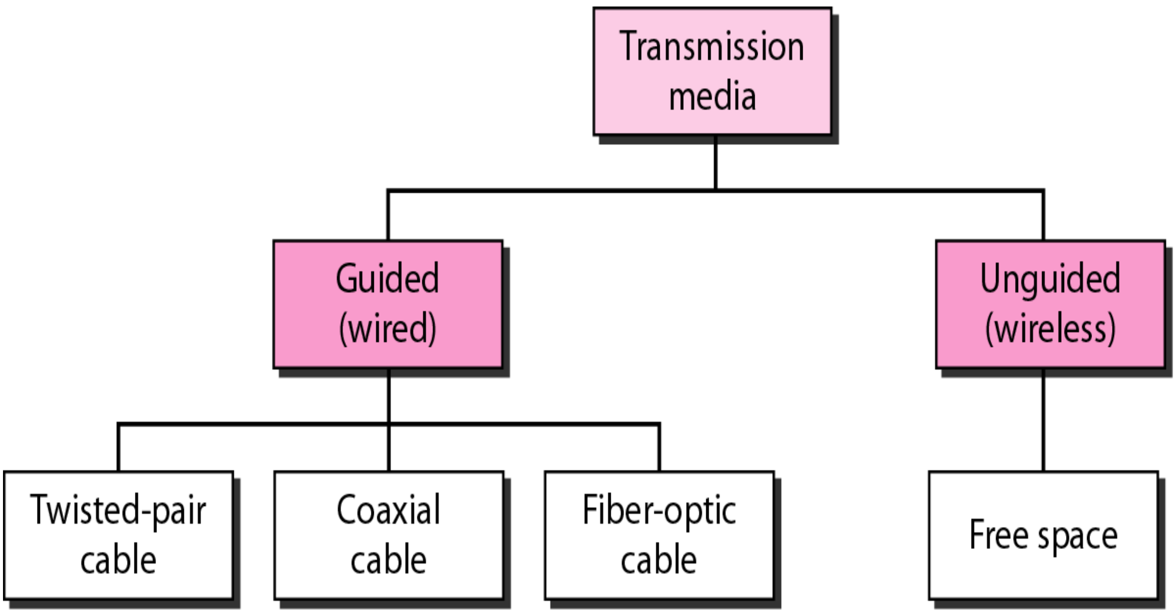
$SNR_{dB} = 10 \log_{10} (10000) = 10 \log_{10} (10^4) = 40$ dB

3.2- Transmission Media

We discussed many issues related to the physical layer in the previous sections. Now we will discuss transmission media. Transmission media are actually located below the physical layer and are directly controlled by the physical layer. You could say that transmission media belong to layer zero.



A transmission medium can be broadly defined as anything that can carry information from a source to a destination. 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.
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, as illustrated in the figure shown below.

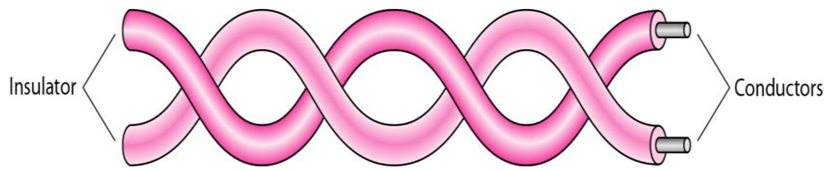


3.2.1- Guided Media

Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable. A signal traveling along any of these media is directed and contained by the physical limits of the medium. Twisted-pair and coaxial cable use metallic (copper) conductors that accept and transport signals in the form of electric current. Optical fiber is a cable that accepts and transports signals in the form of light.

Twisted Pair

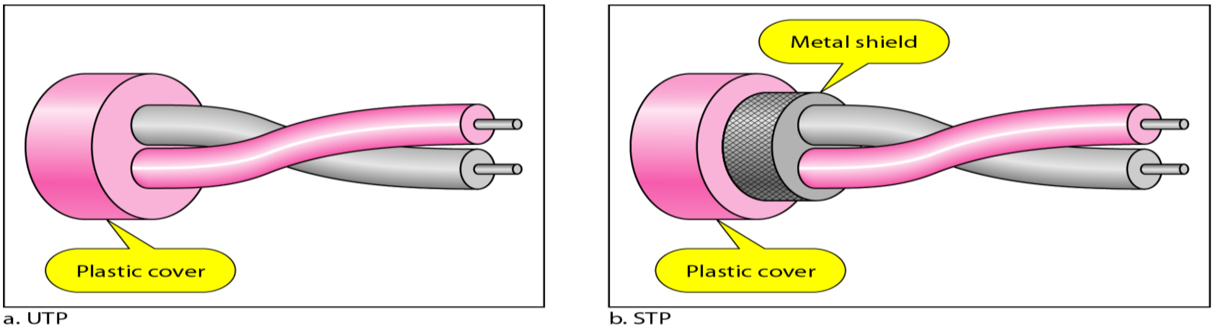
A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together, as shown in Figure below.



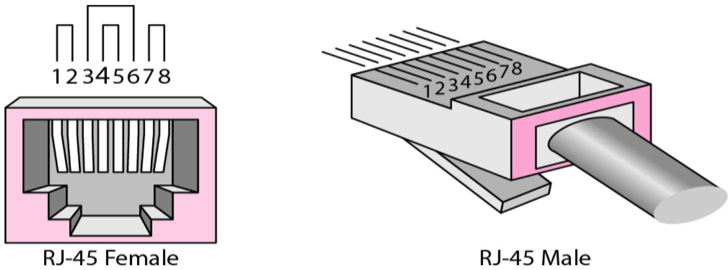
One of the wires is used to carry signals to the receiver, and the other is used only as a ground reference. The receiver uses the difference between the two.
In addition to the signal sent by the sender on one of the wires, interference (noise) and crosstalk may affect both wires and create unwanted signals. Twisting makes it probable that both wires are equally affected by external influences (noise or crosstalk). This means that the receiver, which calculates the difference between the two, receives no unwanted signals. The unwanted signals are mostly canceled out.

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.

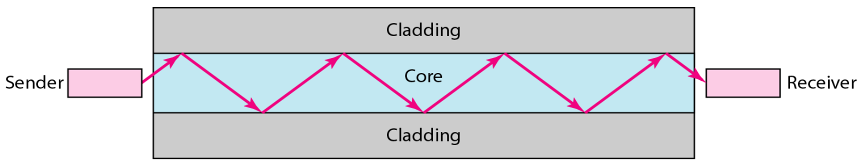


The most common UTP connector is RJ45 (RJ stands for registered jack), as shown below. The RJ45 is a keyed connector, meaning the connector can be inserted in only one way.

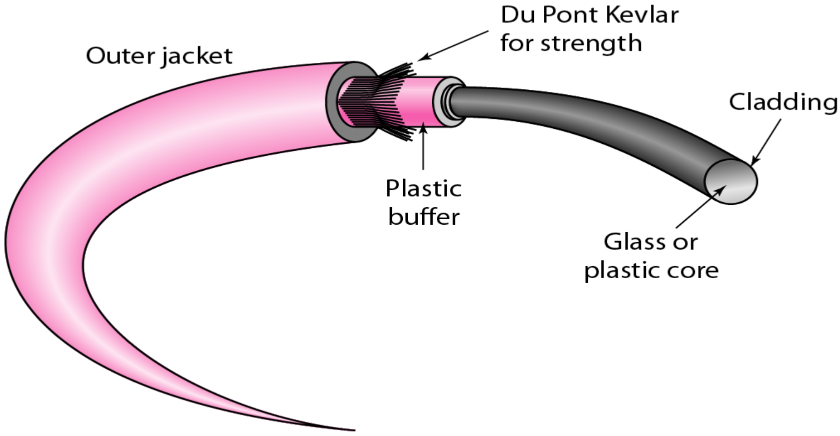


Fiber-Optic Cable

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 core is surrounded by a cladding of less dense glass or plastic. The difference in density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it, as shown in figure below.



Current technology supports two modes (multimode and single mode) for propagating light along optical channels, each requiring fiber with different physical characteristics.



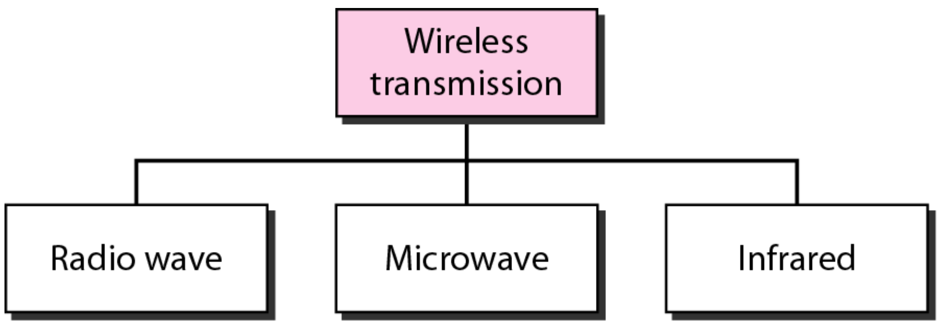
Different between single mode and multiple mode fiber optic

Single mode	Multiple mode
1:small core	1:larger core
2:less dispersion	2:greater dispersion and therefore ,loss of signal
3:sutible for long distant	3:large distant but shorter than single mode
4|:use lasers as light source	4:use LED as source of light

3.2.2- Unguided Media: Wireless

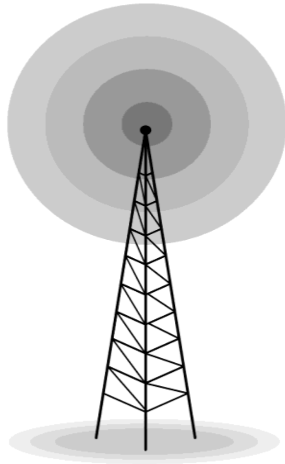
Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as *wireless communication*. Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.

We can divide wireless transmission into three broad groups: ***radio waves,*** **microwaves**, and ***infrared waves.***

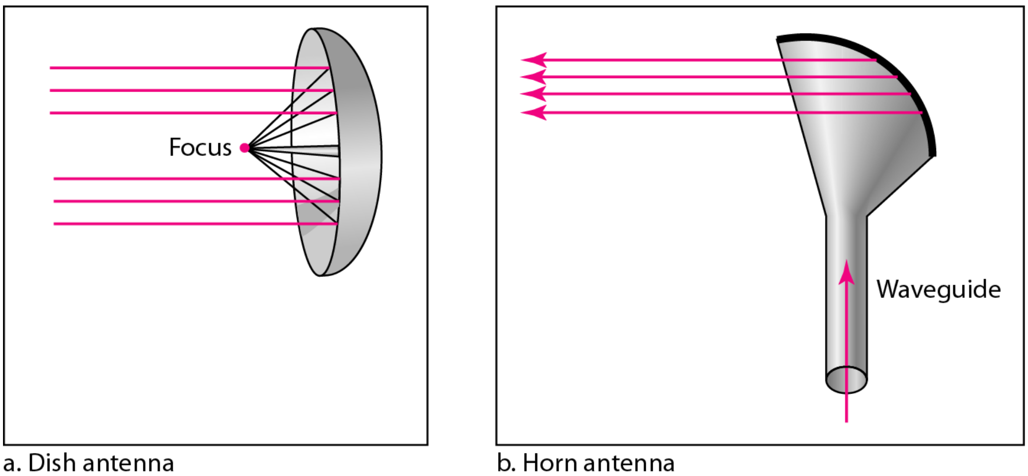


Radio Waves

Although there is no clear-cut demarcation between radio waves and microwaves, electromagnetic waves ranging in frequencies between **3 kHz and 1 GHz** are normally called radio waves; waves ranging in frequencies between 1 and 300 GHz are called microwaves.



However, the behavior of the waves, rather than the frequencies, is a better criterion for classification. Radio waves, for the most part, are ***Omni-directional***. 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. While the Microwaves are ***unidirectional***. When an antenna transmits microwave waves, they can be narrowly focused. This means that the sending and receiving antennas need to be aligned.

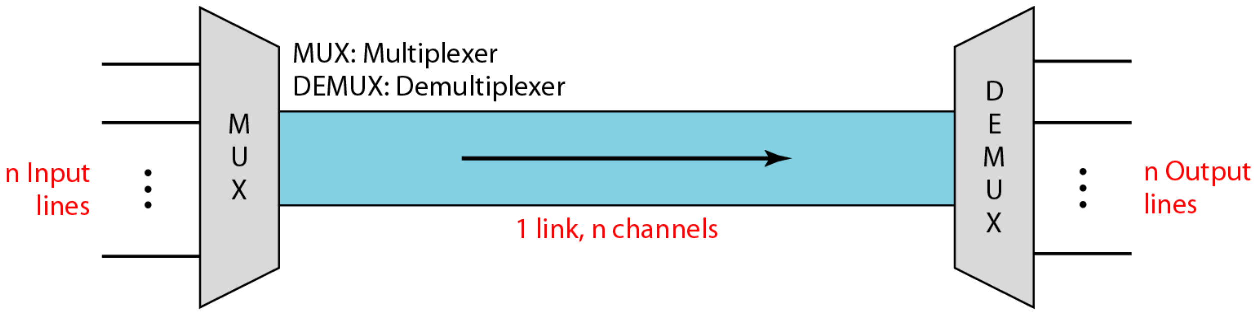


3.3- Multiplexing

Whenever the transmission capacity of a medium linking two devices is greater than the transmission needs of the devices, the link ***can be shared***, much as a large water pipe can carry water to several separate houses at once. *Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.*

As data and telecommunications usage increases, so does ***traffic***. We can accommodate this increase by continuing to add individual lines each time a ***new channel*** is needed, **or** we can ***install higher capacity links*** and use each to carry multiple signals.

Today's technology includes ***high-bandwidth media*** such as *optical fiber*, and *terrestrial and satellite microwaves*. Each of these has a carrying capacity far in excess of that needed for the average transmission signal, ***if the transmission capacity*** of a link is greater than the transmission needs of the devices connected to it, the excess capacity is ***wasted.*** An efficient system maximizes the utilization of all facilities. In addition, the expensive technology involved often becomes cost-effective only when links are shared.



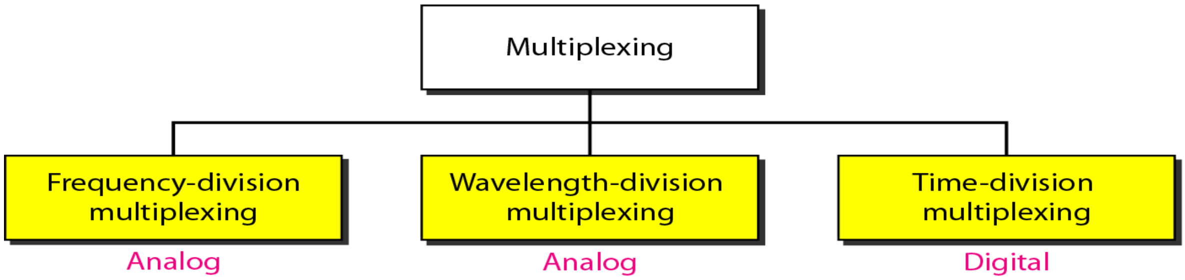
In a multiplexed system, ***n*** devices share the capacity of one link; The devices on the left direct their transmission streams to a **Multiplexer (MUX)** which combines them into a single stream (lots of to one). At the receiving end, that stream is fed into a **Demultiplexer (DEMUX),** which separates the stream back into its component transmissions (one-to-many) and directs them to their intended receiving devices.

3.3.1- Types of Multiplexing

Signals are multiplexed using ***three*** basic techniques:

- **Frequency Division Multiplexing (FDM)**
- **Wavelength Division Multiplexing (WDM)**
- **Time Division Multiplexing (TDM)**

TDM is further subdivided into ***synchronous TDM*** (usually called TDM) and ***asynchronous TDM***, also called statistical TDM or concentrator (See Figure (2))



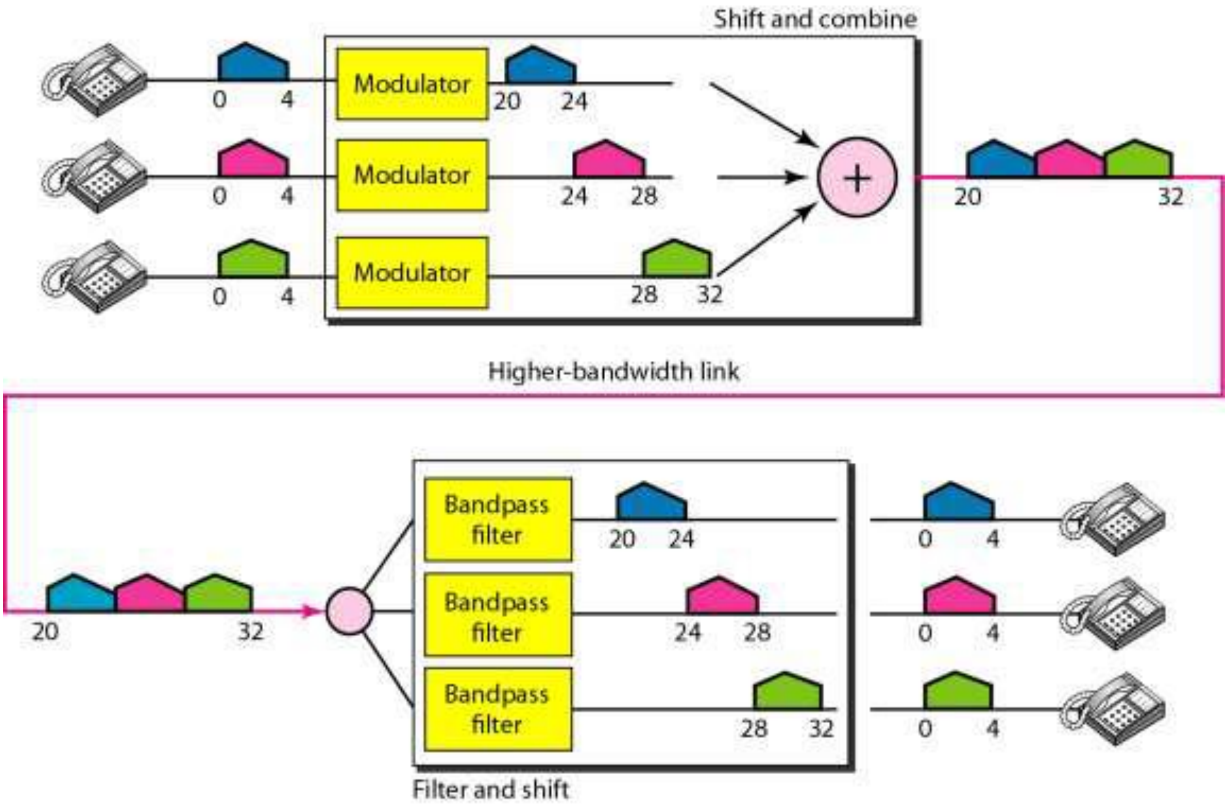
Frequency-Division Multiplexing (FDM)

Frequency-division multiplexing (FDM) is an ***analog technique*** that can be applied when the bandwidth of a link is greater than the combined bandwidth of the signals to be transmitted. In FDM, ***signals*** generated by each sending device ***modulate with*** 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 enough bandwidth to accommodate the modulated signal. These bandwidth ranges are the channels through which the various signals travel. Channels must be separated by strips of unused bandwidth (***guard bands***) to prevent signals from overlapping. In addition, carrier frequencies must not interfere with the original data frequencies.

A familiar application of FDM is cable television. The coaxial cable used in a cable television system. Today, a new and more efficient method is being developed to implement FDM over fiber-optic cable. Called ***Wavelength Division Multiplexing (WDM)***, it uses essentially the same concepts as FDM but incorporates the range of frequencies in the visible light spectrum.

Example 1

Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the multiplexer process and de multiplexer process in frequency domain (configuration using the frequency domain). Assume there are no guard bands.



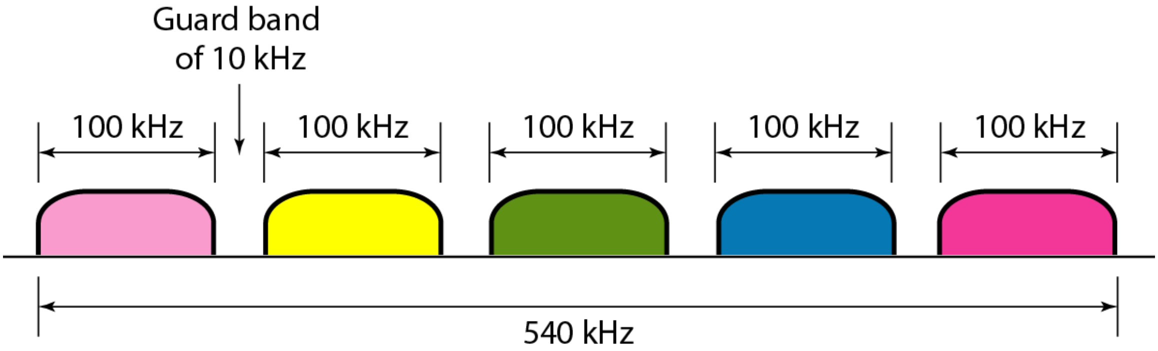
Example 2

Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?

Solution

For five channels, we need at least four guard bands. This means that the required bandwidth is at least as shown in Figure below.

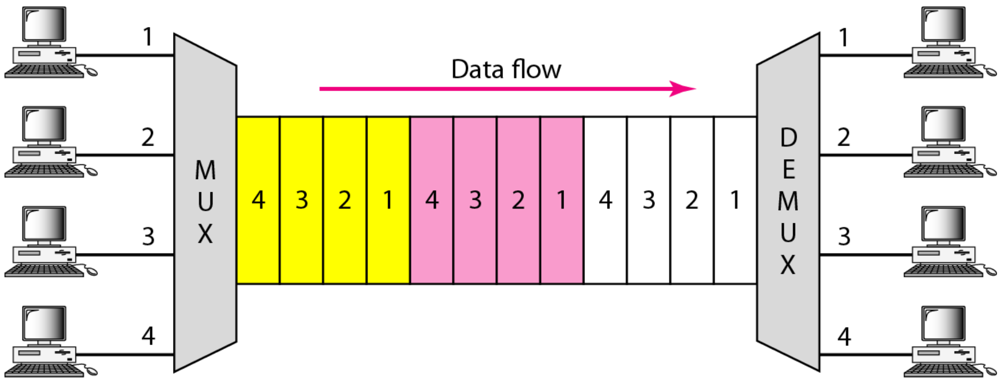
$$5 \times 100 + 4 \times 10 = 540 \text{ kHz},$$



Time-Division Multiplexing (TDM)

Time-division multiplexing (TDM) is a ***digital process*** that can be applied when the data rate capacity of the transmission medium is greater than the data rate required by the sending and receiving devices. In such a case, multiple transmissions can occupy a single link by *subdividing* them and *interleaving* the portions.

Note that the same link is used as in the FDM. Here however, the link is shown *sectioned by time rather than frequency*.



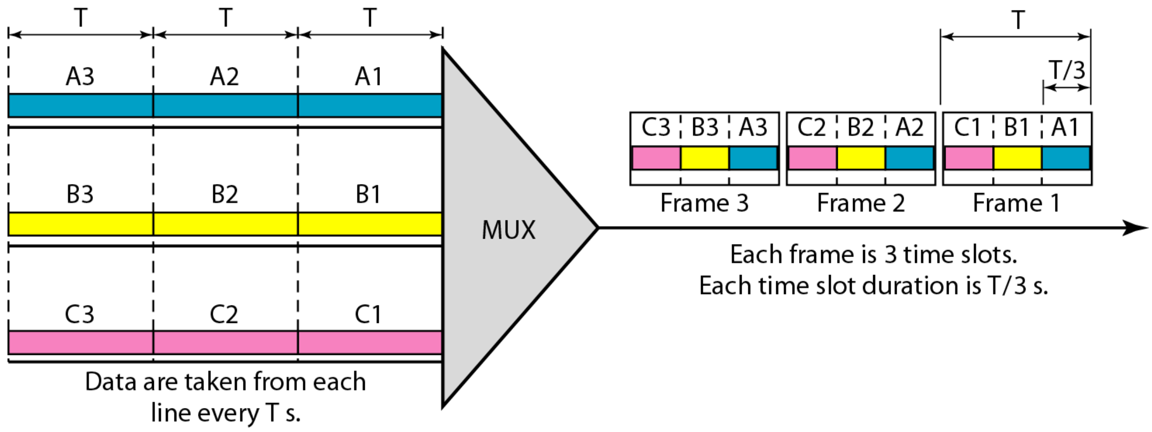
TDM can be implemented in two ways: ***synchronous TDM*** and ***asynchronous TDM***.

a) <u>Synchronous TDM</u>

Here ***synchronous means*** *that the multiplexer allocates exactly the same time slot to each device at all times, whether or not a device has anything to transmit*. **Time slot** A, for example, is assigned to device **A** alone and cannot be used by any other device. Each time its allocated time slot comes up, a device has the opportunity to send a portion of its data. If a device is unable to transmit or does not have data to send, its time slot remains **empty**.

Time slots are grouped into *frames*. In a system with ***n*** input lines, each frame has at least ***n*** slots. With each slot allocated to carry data from a specific input line. If all the input devices sharing a link are transmitting at the *same data rate*, each device has *one time slot per frame*. However, ***it is possible to*** accommodate varying data rates. A transmission with two slots per frame will arrive twice as quickly as one with one slot per frame.

In Figure below, we show three input lines multiplexed onto a single path using synchronous TDM. In this example, all of the inputs have the same data rate, so the number of time slots in each frame is equal to the number of input lines.



<u>Example 3</u>

Four channels are multiplexed using TDM. If each channel sends 100 bytes/sec and we multiplex 1 byte per channel.

1- Show the frame traveling on the link

2- The size of the frame

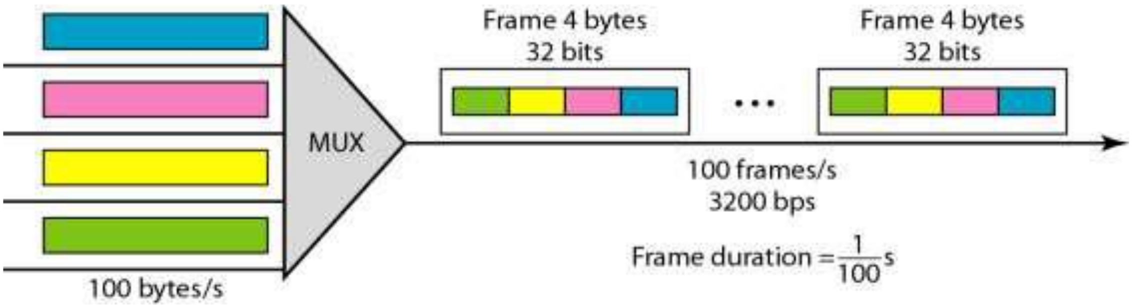
3- The frame rate

4- The duration of a frame

5- Bit rate for the link.

Solution

1-



2- Size of frame=input multiplexer*number of channels

Frame size=1 *4=4 byte or 32 bits

3-Because each channel is sending 100 bytes/s and a frame carries 1 byte from each channel, the frame rate must be 100 frames per second.

4-The duration of a frame is therefore 1/100 s.

5-The link is carrying 100 frames per second, and since each frame contains 32 bits, the bit rate is 100 x 32, or 3200 bps.

This is actually 4 times the bit rate of each channel, which is 100 x 8 =800 bps.

Example 4

Four channels are multiplexed using TDM. If each channel sends 1k bits/s and we multiplex 1 bit per channel find:

(a) The input bit duration.

(b) The output bit rate.

(c) The output bit duration.

(d) The output frame rate.

Solution

We can answer the questions as follows:

a. The duration of 1 bit before multiplexing is 1/1 kbps, or 0.001 s (1 ms).

b. The rate of the link is 4 times the rate of a connection, or 4 kbps.

c. The duration of each time slot is one-fourth of the duration of each bit before multiplexing, or 1/4 ms or 250 μs.

Note that we can also calculate this from the data rate of the link, 4 kbps. The bit duration is the inverse of the data rate, or 1/4 kbps or 250 μs.

d. The frame rate is always the same as any input rate =1k bps.

Example 5

Four channels synchronous TDM with a data stream for each input 1Mbps and the unit of data is 1 bit. Find:

(a) The input bit duration

(b) The output bit duration

(c) The output bit rate
(d) The output frame rate.

Solution

a. The input bit duration=1/input bit rate=1/1Mps=1 μs.

b. The output bit duration =1/number of input channel=1/4 μs.
c. The output bit rate =number of channel*rate of channel=1Mbps*4=4 Mbps or it is the inverse of the output bit duration or 1/(1/4μs) or 4 Mbps.
d. The frame rate is always the same as any input rate =1 Mbps.

b) Asynchronous TDM

Synchronous TDM ***does not guarantee*** that the full capacity of a link is used. In fact, it is more likely that only a portion of the time slots is in use at a given instant. ***Because the time*** slots are pre-assigned and fixed whenever a connected device is not transmitting the corresponding slot is ***empty*** and that much of the path is ***wasted.*** For example, imagine that we have multiplexed the output of 20 identical computers onto a single line. Using synchronous TDM, the speed of that line must be at least 20 times the speed of each input line. But what if only 10 computers are in use at a time? Half of the capacity of the line is wasted.

Asynchronous time-division multiplexing, or *statistical time-division multiplexing*, is designed to avoid this type of waste. As with the term *synchronous,* the term ***asynchronous means*** something different in multiplexing than it means in other areas of data communications. Here it means flexible or not fixed.

Like synchronous TDM, asynchronous TDM allows a number of lower speed input lines to be multiplexed to a single higher speed line. ***Unlike*** synchronous TDM, however, in asynchronous TDM the total speed of the input lines can be greater than the capacity of the path. In a ***synchronous system***, if we have ***n*** input lines, the frame contains a fixed number of at least ***n*** time slots. In an asynchronous system, if we have ***n*** input lines, the frame contains no more than *m* slots, with *m* less than *n*. In this way, asynchronous TDM supports the same number of input lines as synchronous TDM with a lower capacity link. Or given the same link, asynchronous TDM can support more devices than synchronous TDM.

The number of time slots in an asynchronous TDM frame (m) is based on a statistical analysis of the number of input lines that are likely to be transmitting at any given time. Rather than being pre-assigned, each slot is available to any of the attached input that has data to send. The multiplexer scans the input line, accept portions of the data until a frame is filled, and then sends the frame across the link. If there are not enough data to full all the slots in a frame, the frame is transmitted only partially filled; thus, full link capacity may not be used 100 percent of the time.
Figure below illustrate the difference in operation between synchronous and asynchronous TDM.

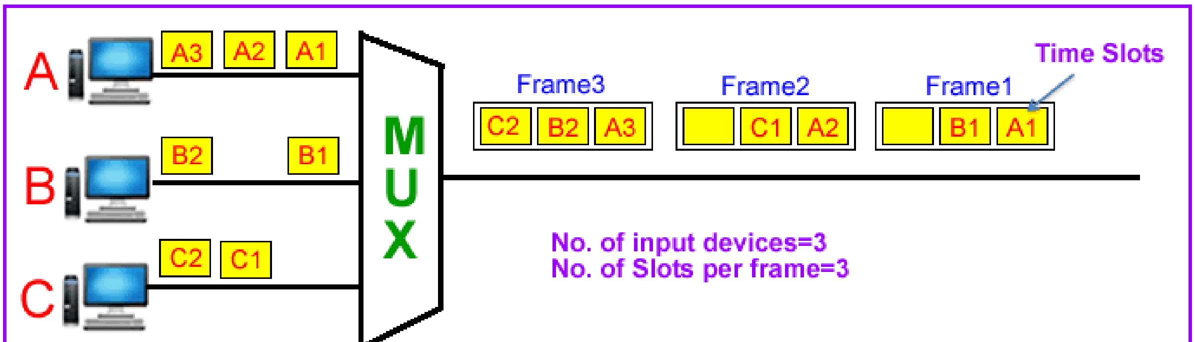


Fig: Synchronous TDM

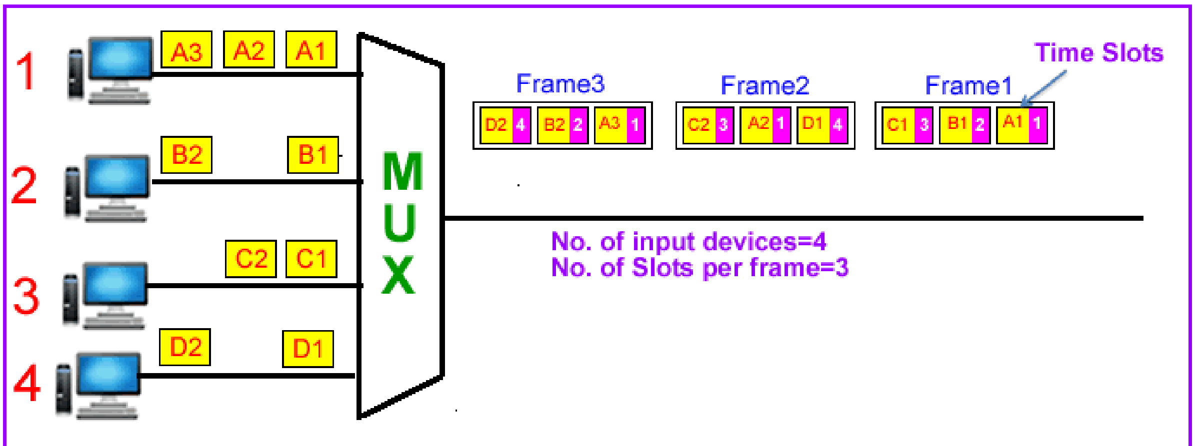


Fig: Statistical TDM