MULTIPLEXING AND MULTIPLE ACCESS

Specific objectives

By the end of the lesson the learner should be able to:

i) Define multiplexing as applied in data communication
ii) Describe different types of multiplexing
iii) Describe application of different types of multiplexing

Multiplexing is a technique through which one or many signals are transmitted concurrently over a single data link. A multiplexed system consists of n number devices that share the capacity of a link, so a link means multiple paths can have multiple channels.

Many devices pass their transmission streams to multiplexers which are all merged into a single stream. And a single stream on the receiver is directed to the de-multiplexer which is then transmitted to the component transmission and sent to the integrated receiver.

Multiplexing is sending process of multiple signals or streams of information over a circuit at the same time in the form of a single, complex signal and then recovering the separate signals at the receiving end.

Types of Multiplexing

The basic type of Multiplexing involves frequency division. (FDM), time division (TDM), and wavelength division (WDM), with TDM and WDM Optical circuits are being widely used by telephone and data service providers. Multiplexing is usually divided into four parts.

1. Frequency Division Multiplexing (FDM)
2. Wavelength Division Multiplexing (WDM)
3. Time division Multiplexing (TDM)
4. Code Division Multiplexing (CDM)

1. Frequency Division Multiplexing (FDM)

FDM which is an analog technique which is implemented when the link bandwidth of the path is more than the bandwidth of the merge transmit signal. Each sending device produces signals that are modulated at different carrier frequencies.

To hold the modulated signal, the carrier frequencies are separated by sufficient bandwidth known as the guard band.

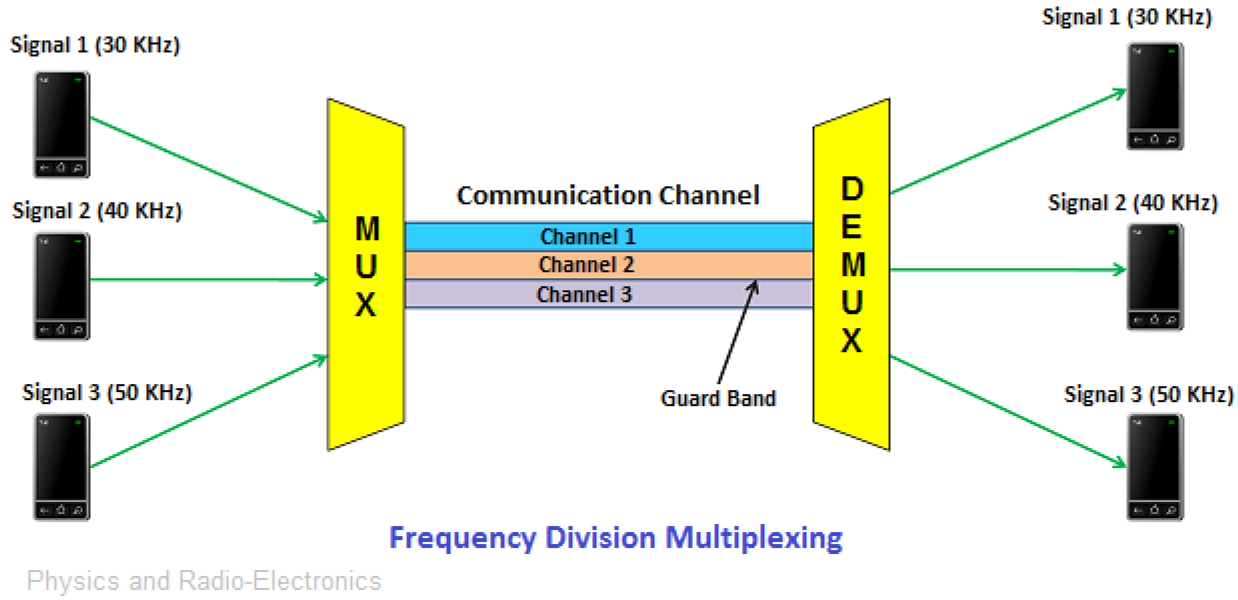

Fig 6.1 Frequency Division Multiplexing

Advantages and Disadvantages of Frequency Division Multiplexing (FDM)

Advantages of Frequency Division Multiplexing (FDM)

1. It transmits multiple signals simultaneously.
2. In frequency division multiplexing, the demodulation process is easy.
3. It does not need Synchronization between transmitter and receiver.

Disadvantages of Frequency Division Multiplexing (FDM)

It needs a large bandwidth communication channel.
There also bandwidth wastage in the form of guard band as well as during idle times when the channel allocated devices are not communication.

Applications of Frequency Division Multiplexing (FDM)

1. Frequency division multiplexing is used for FM and AM radio broadcasting.
2. It is used in first generation cellular telephone.
3. It is used in television broadcasting.

2. Wavelength Division Multiplexing (WDM)

Introduction:

The WDM is the short form of Wavelength Division Multiplexing. This optical multiplexing uses different frequencies at different wavelengths to transmit data separately over multiple channels.

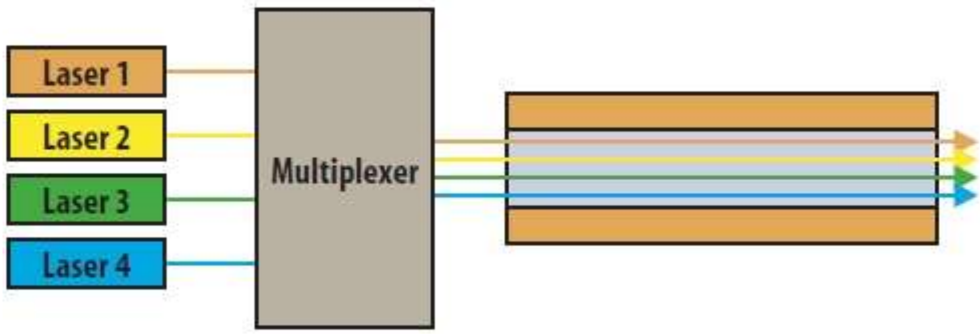

Fig 6.2 a Wavelength Division Multiplexing

The WDM assigns unique frequencies of light having certain bandwidth to different optical signals. The multiplexed wavelengths are transmitted over single fiber. At the de-multiplexer end, these signals are selected using tuner of desired bandwidth.

Wavelength Division Multiplexing (WDM) Working and Applications

Wavelength division multiplexing (WDM) is a technique modulating various data streams, i.e. optical carrier signals of varying wavelengths in terms of colours of laser light onto a single optical fiber. Wavelength division multiplexing WDM is similar to frequency-division multiplexing (FDM) but referencing the wavelength of light to the frequency of light. WDM is done in the Infrared (IR) portion of the electromagnetic spectrum instead of taking place at radio frequencies (RF). Each IR channel carries several RF signals combined with frequency-division multiplexing (FDM) or time-division multiplexing (TDM). Each multiplexed infrared channel is separated or de-multiplexed into the original signals at final point. Data in different formats and at different speeds can be transmitted simultaneously on a single fiber by using FDM or TDM in each IR channel in combination with WDM. It allows network capacity to be gradually and cost effectively increased.

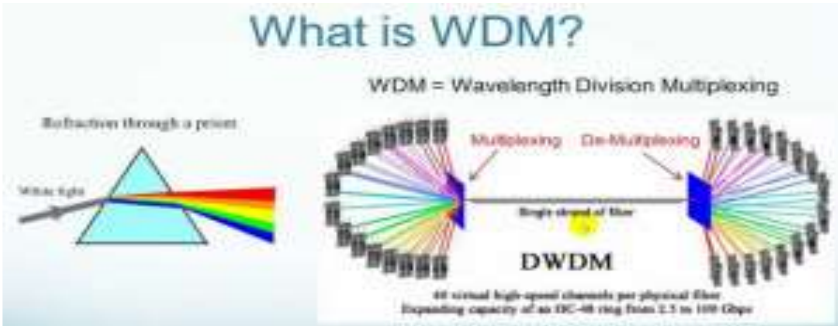

Fig 6.2 b Wavelength Division Multiplexing (WDM)

What is Wavelength Division Multiplexing?

WDM enables bi-directional communication and multiplies signal capacity. Each laser beam is modulated by separate set of signals. Since wavelength and frequency have an inverse relationship (shorter wavelength means higher frequency), the WDM and FDM both contains the same technology in them. At the receiving end, Wavelength-sensitive filters, IR analog of visible-light color filters are used. The first WDM technique was conceptualized in the early 1970s. Later, Wave division multiplexing (WDM) systems were able to handle 160 signals that will expand a 10 Gbit/second system with a single fiber optic pair of conductors to more than 1.6 Tbit/second (i.e. 1,600 Gbit/s). The first WDM systems were two-channel systems that used 1310nm wavelengths. Shortly afterwards came multi-channel systems that used the 1550nm region – where the fiber attenuation is lowest.

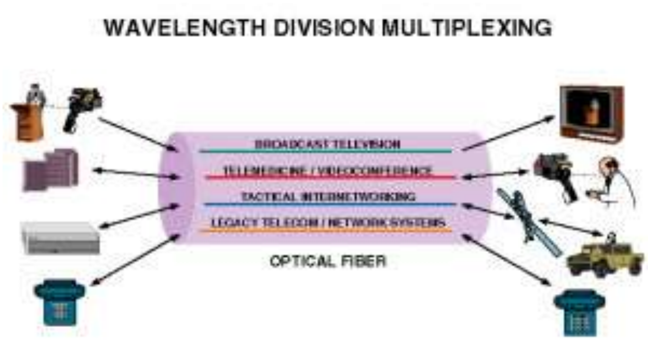

Fig 6.3 WDM through Optical Fibre

Wavelength division multiplexing systems can combine signals with multiplexing and split them apart with a de-multiplexer. WDM systems are popular with telecommunications companies because they allow them to expand the capacity of the network without laying more fiber by using WDM and optical amplifiers. These two devices work as add-drop multiplexer (ADM), i.e. simultaneously adding light beams while dropping other light beams and rerouting them to other destinations and devices and this type of filtering of light beams were made possible with e talons, devices called Fabry-Perot interferometers using thin-film-coated optical glass.

In general, WDM systems use single-mode optical fiber (SMF) in which only a single ray of light having a core diameter of 9 millionths of a meter (9 µm). Other systems with multi-mode fiber cables (MM Fiber) which are also called as premises cables have core diameters of about 50 µm. Present modern systems can handle up to128 signals and can expand a basic 9.6 Gbps fibre system to a capacity of over 1000 Gbps. It is mostly used for optical fiber communications to transmit data in several channels with slight variation in wavelengths. WDM can increase the total bit rate of point-to-point systems.

Uses of Wavelength Division Multiplexing:

- WDM multiply the effective bandwidth of a fiber optic communications system
- A fiber optic repeater device called the erbium amplifier can make WDM a cost-effective and it is the long-term solution.
- This reduces the cost and increases the capacity of the cable to carry data.
- Wavelength Division Multiplexing (WDM) uses multiple wavelengths (colors of light) to transport signals over a single fiber.
- It uses light of different colours to create a number of signal paths.
- It uses Optical prisms to separate the different colours at the receiving end and optical prisms does not require power source.
- These systems used temperature stabilized lasers to provide the needed channels count.

WDM systems are divided according to wavelengths – WDM (CWDM) and dense WDM (DWDM). CWDM operates with 8 channels (i.e., 8 fiber optic cables) which is called as the “C-Band” or “erbium window” with wavelengths about 1550 nm (nanometers or billionths of a meter, i.e. 1550 x 10-9 meters). DWDM also operates in the C-Band but with 40 channels at 100 GHz spacing or 80 channels at 50 GHz spacing. Mostly WDM systems are operated on single-mode fiber optical cables having a core diameter of 9 µm. Wavelength division multiplexing is a technique where optical signals with different wavelengths are combined, transmitted and separated.

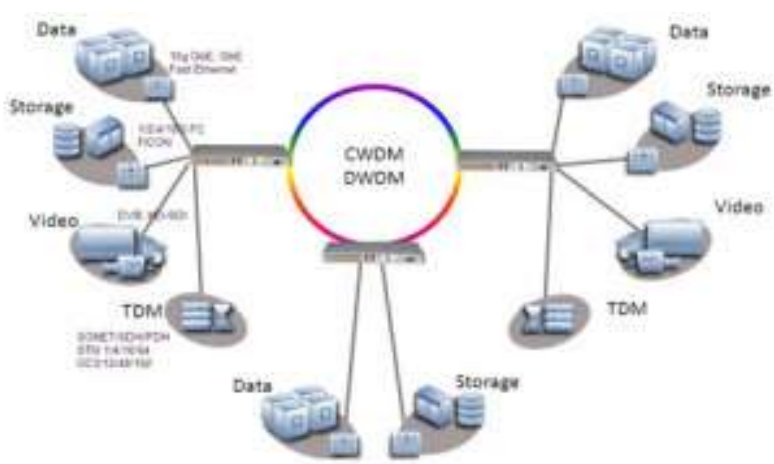

Fig 6.4 CWDM and DWDM

Each colour obtained from the prism is capable of carrying 10Gbps to 40Gbps. A 16 colour solution, based on 10Gbps per colour, yields a total network capacity of 160Gbps. Each colour can come off the network at multiple nodes and all these nodes are terminated in one or more data centres by allowing for resilient routing between circuits and also for 'on ramp' services.

As shown in figure, wavelength division multiplexing in optical fiber, the input signals are assigned a wave length that are combined on one fiber for transmission and separated before receiving.

Dense Wavelength-division Multiplexing (DWDM) :

Dense Wavelength Division Multiplexing (DWDM) is a technology that allows multiple signals simultaneously that are to be transmitted on a single fiber at different wavelengths and it is also an optical multiplexing technology used to increase bandwidth over existing fiber networks. Due to the wide amplification bandwidth of erbium-doped fiber amplifiers, all channels can often be amplified in a single device. DWDM systems feature high channel count and longer reach.

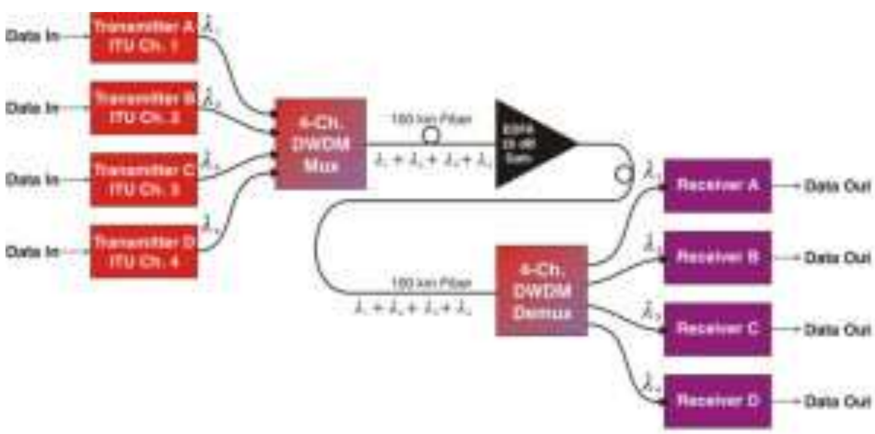

Fig 6.5 Dense Wavelength Division Multiplexing

In this technology, another fiber is not required and because of DWDM, single fibers have been able to transmit data at up to 400 GB/s of speed. This technology offers excellent performance characteristics including narrow channel separation and wide channel bandpass in the range of frequencies which are passed through a filter.

What is the difference between CWDM and DWDM?

1. **CWDM** means Coarse Wavelength Division Multiplexing
- CWDM is defined by wavelengths
- CWDM is short-range communications.
- It uses wide-range frequencies and spreads wavelengths

DWDM means Dense Wavelength Division Multiplexing.

- DWDM is defined in terms of frequencies.
- DWDM is designed for long transmissions where wavelengths are packed tightly.

Dense Wavelength Division Multiplexing (DWDM) is a technique or technology for transmission of huge information or data over long distances.

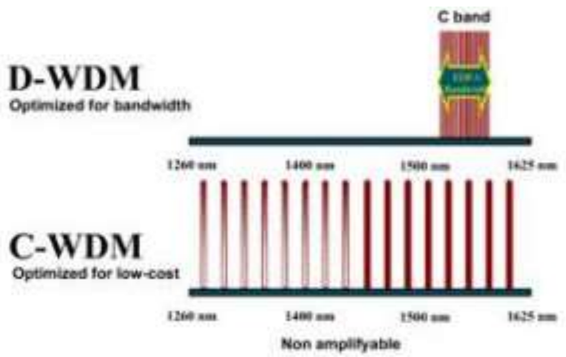

Fig 6.6 Difference between CWDM and DWDM

Thus, the technology of sending signals through different wavelengths of light into fibers is nothing but wave length division multiplexing in fiber optic communication. In this, multiple optical carrier signals are multiplexed on a single optical fiber using different wavelengths of laser light to different signals.

DWDM System Advantages

- Less fiber cores to transmit and receive high capacity data
- A single core fiber cable could divided into multiple channels instead of using 12 fiber core.
- Easy network expansion, especially for limited fiber resource, no need extra fiber but add wavelength, Low cost for expansion, because no need to replace many components such as optical amplifiers, Can move to STM-64 when economics improve
- DWDM systems capable of longer span lengths, TDM approach using STM-64 is more costly and more susceptible to chromatic and polarization mode dispersion

DWDM Disadvantages

- Not cost-effective for low channels, low channel recommend CWDM
- Complicated transmitters and receivers
- Wide-band channel, CAPEX and OPEX high
- The frequency domain involved in the network design and management, increase the difficulty for implementation

Summary

Even through there is so many disadvantages of DWDM system, however, technology are improving, the transmission efficiency will improve, and the DWDM system will be more cost-effective, especially many Chinese venders are able to provide DWDM turnkey solutions for the service provider, Internet companies, Data center, etc

Benefits or advantages of WDM

- Following are the benefits or **advantages of WDM**:

  ➡Full duplex transmission is possible.

  ➡Easier to reconfigure.

  ➡Optical components are similar and more reliable.

  ➡It provides higher bandwidth.

  ➡This could be the best approach as it is simple to implement.

  ➡High security

Others are

- low cost
- Long distance communication with low signal loss

Drawbacks or disadvantages of WDM

Following are the **disadvantages of WDM**:

➡Signals cannot be very close.

➡Light wave carrying WDM are limited to 2-point circuit.

➡Scalability is a concern as OLT (Optical Line Termination) has to have transmitter array with one transmitter for each ONU (Optical Network Unit). Adding a new ONU could be problem unless transmitters were provisioned in advance. Each ONU must have a wavelength specific laser.

➡Cost of system increases with addition of optical components.

➡Inefficiency in BW utilization, difficulty in wavelength tuning, difficulty in cascaded topology

WDM combines multiple optical WDM data streams over a single fiber through the use of multiple wavelengths of light. Each individual WDM data stream is sent to a separate laser that transmits a unique wavelength of light.

Advantages of Wavelength Division Multiplexing (WDM)

3. Time division Multiplexing (TDM)

Time-division multiplexing (TDM) is a method of combining several independent data streams into a single data stream by merging the signals according to a defined sequence. Each independent data stream is retrieved at the receiving end based on sequence and time.

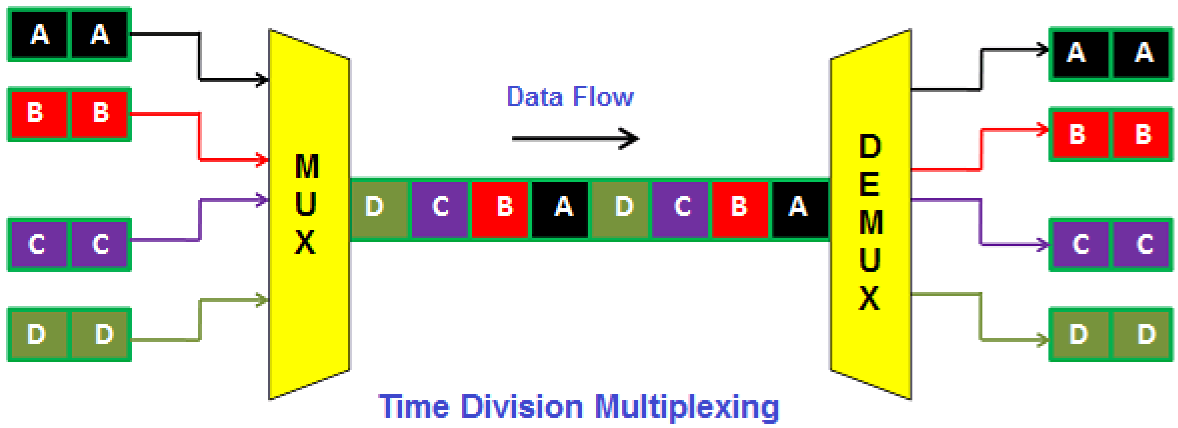

Fig 6.7 Synchronous Time Division Multiplexing

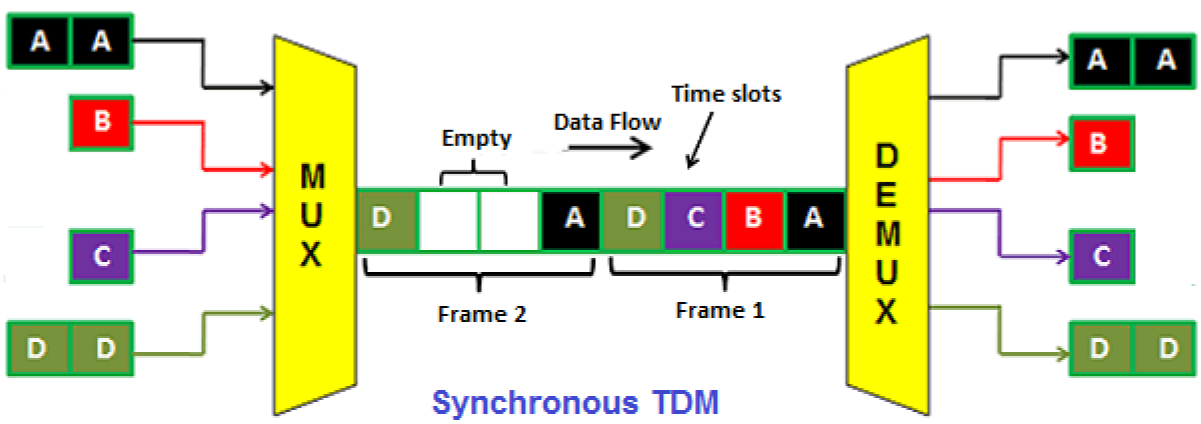

Fig 6.8 Empty spaces in Synchronous Time Division Multiplexing

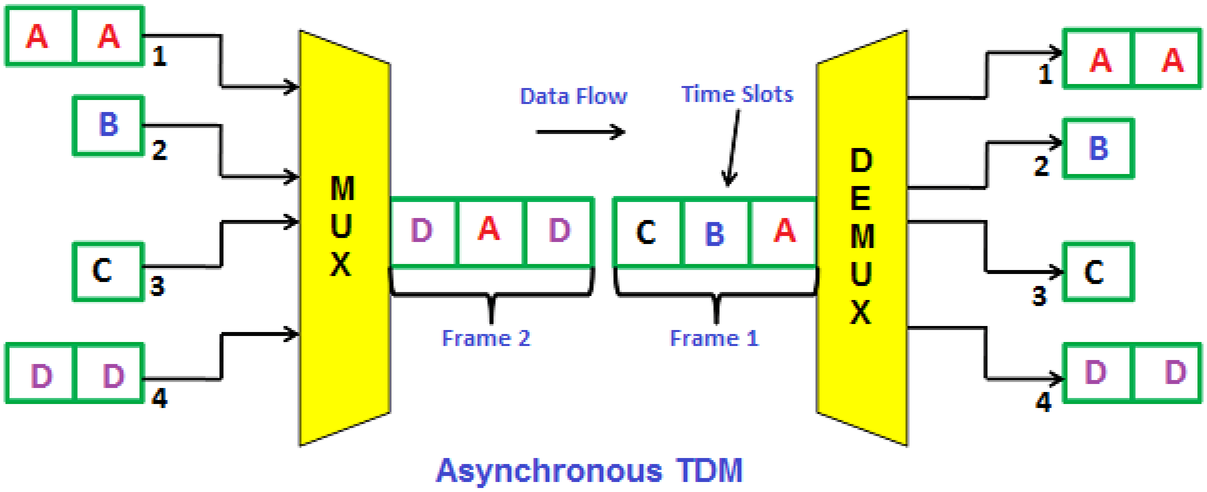

Fig 6.10 Asynchronous Time Division Multiplexing ATDM

Synchronous optical network (SONET), asynchronous transfer mode (ATM) and Internet protocol (IP) use TDM techniques. As per modern telecommunications networks, by the SONET network element TDM signals are converted from electrical to optical signals, for transport over optical fiber.

Advantages and Disadvantages of Time Division Multiplexing (TDM)

Advantages of Time Division Multiplexing (TDM)

1. Full bandwidth is utilized by a user at a particular time jn ATDM.
2. The time division multiplexing technique is more flexible than frequency division multiplexing.
3. In time division multiplexing, the problem of crosstalk is minimal.

Disadvantages of Time Division Multiplexing (TDM)

In time division multiplexing, synchronization is required.

4. Code division multiplexing (CDM)

CDM is a multiplexing technique that uses spread spectrum communication. In spread spectrum communications, a narrowband signal is spread over a larger band of frequency or across multiple channels via division. It does not constrict bandwidth's digital signals or frequencies. It is less susceptible to interference, thus providing better data communication capability and a more secure private line.

Code Division Multiple Access

When CDM is used to allow multiple signals from multiple users to share a common communication channel, the technology is called Code Division Multiple Access (CDMA). Each group of users is given a shared code and individual conversations are encoded in a digital sequence. Data is available on the shared channel, but only those users associated with a particular code can access the data.

Concept

Each communicating station is assigned a unique code. The codes stations have the following properties −

- If code of one station is multiplied by code of another station, it yields 0.
- If code of one station is multiplied by itself, it yields a positive number equal to the number of stations.

The communication technique can be explained by the following example −

Consider that there are four stations w, x, y and z that have been assigned the codes c_w , c_x, c_y and c_z and need to transmit data d_w , d_x, d_y and d_z respectively. Each station multiplies its code with its data and the sum of all the terms is transmitted in the communication channel.

Thus, the data in the communication channel is $d_w . c_w + d_x . c_x + d_y . c_y + d_z . c_z$

Suppose that at the receiving end, station z wants to receive data sent by station y. In order to retrieve the data, it will multiply the received data by the code of station y which is d_y.

$$\text{data} = (d_w . c_w + d_x . c_x + d_y . c_y + d_z . c_z) . c_y$$
$$= d_w . c_w . c_y + d_x . c_x . c_y + d_y . c_y . c_y + d_z . c_z . c_y$$
$$= 0 + 0 + d_y . 4 + 0 = 4d_y$$

Thus, it can be seen that station z has received data from only station y while neglecting the other codes.

Summary

Advantages of multiplexing

1. Multiple signals can be sent simultaneously over a single communication channel.
2. Effective use of channel bandwidth
3. Multiplexing reduces cost
4. Multiplexing reduces circuit complexity

Applications of Multiplexing

1. Communication system
2. Computer memory
3. Telephone systems
4. TV broadcasting
5. Telemetry
6. Satellites

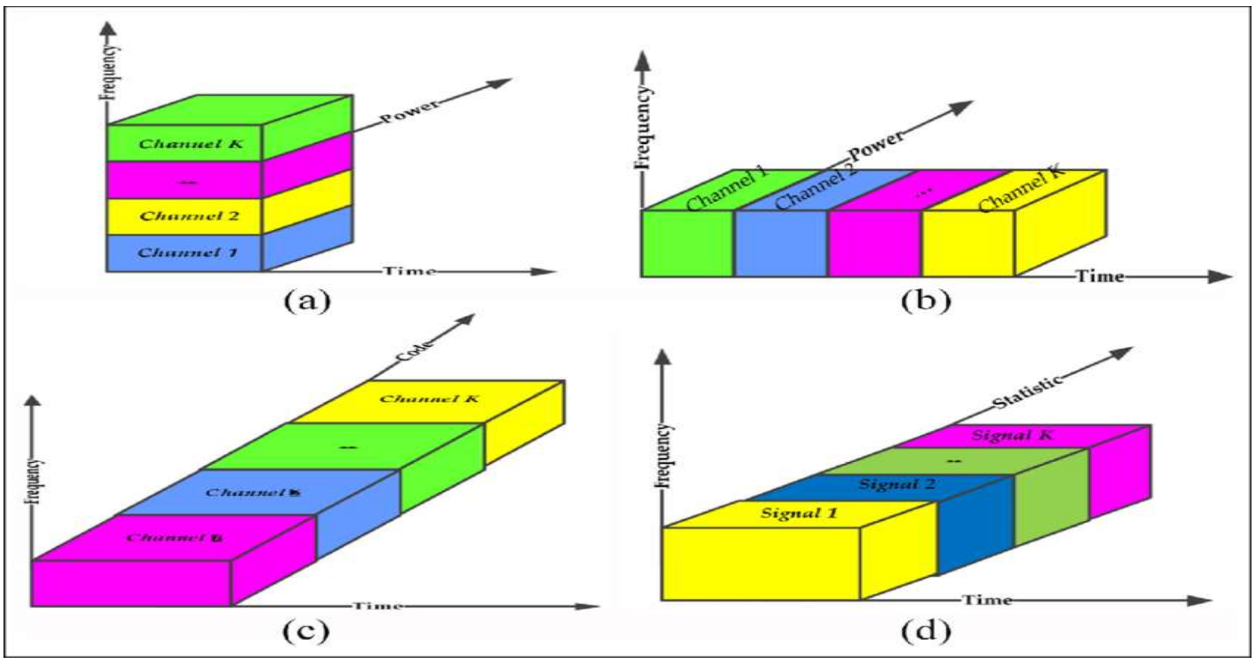

Fig 6.11 (a) FDM, (b) TDM, (c) CDM (d) Statistic

T-carrier and E-carrier systems comparison

- Note 1: The designators for T-carrier in the North American Digital multiplex hierarchy correspond to the designators for the digital signal (DS) level hierarchy.
- Note 2: T-carrier systems were originally designed to transmit digitized voice signals. Current applications also include digital data transmission.
- Note 3: Historically, if an "F" precedes the "T", optical fiber cables are utilized at the same rates.
- Note 4: The North American and Japanese hierarchies are based on multiplexing 24 voice-frequency channels and multiples thereof, whereas the European hierarchy is based on multiplexing 32 voice-frequency channels and multiples thereof. *See table below.*
- Note 5: Will be directed to this table by certain Network+ books. *See table below.*

T-carrier and E-carrier systems	**North American**	**Japanese**	**European (CEPT)**
Level zero (channel data rate)	64 kbit/s (DS0)	64 kbit/s	64 kbit/s
First level	1.544 Mbit/s (DS1) (24 user channels) (T1)	1.544 Mbit/s (24 user channels)	2.048 Mbit/s (32 user channels) (E1)
(Intermediate level, T-carrier hierarchy only)	3.152 Mbit/s (DS1C) (48 Ch.)	–	–
Second level	6.312 Mbit/s (DS2) (96 Ch.) (T2)	6.312 Mbit/s (96 Ch.), or 7.786 Mbit/s (120 Ch.)	8.448 Mbit/s (128 Ch.) (E2)
Third level	44.736 Mbit/s (DS3) (672 Ch.) (T3)	32.064 Mbit/s (480 Ch.)	34.368 Mbit/s (512 Ch.) (E3)
Fourth level	274.176 Mbit/s (DS4) (4032 Ch.)	97.728 Mbit/s (1440 Ch.)	139.264 Mbit/s (2048 Ch.) (E4)
Fifth level	400.352 Mbit/s (DS5) (5760 Ch.)	565.148 Mbit/s (8192 Ch.)	565.148 Mbit/s (8192 Ch.) (E5)

Note 1: The DS designations are used in connection with the North American hierarchy only. Strictly speaking, a DS1 is the data carried on a T1 circuit, and likewise for a DS3 and a T3.

Multiple Access Techniques

Overview

In wireless systems, just like wired systems, the users of channels need special mechanisms to avoid interference and collisions. The three mechanisms used most commonly are *frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA).*

Analogy

Before going into the details, an example may help. Suppose you are in a party where multiple people want to talk to each other. In an FDMA scheme, the different groups will break up into small subgroups and each subgroup will communicate in parallel. In a TDMA scheme, the people who want to talk to each other will take turns (i.e., use time slices). In CDMA, everyone will start talking at once, but only some people will understand each other because of a code. For example, people speaking Spanish will be tuned to Spanish only, French to French, etc.

The three multiple access techniques (FDMA, TDMA, and CDMA) are illustrated in Figure 1.

- In an FDMA scheme, the different cellular users are assigned different frequencies and each user communicates in parallel on a different frequency.
- In a TDMA scheme, the users take turns, i.e., they are assigned different time slices.
- In CDMA, everyone talks at once by using a code. For example, a user u1 uses code c1, u2 uses c2, etc. In this case, the listener has to know the code of the sender, otherwise she gets a background noise signal.

FDMA is used in older 1G systems but TDMA and CDMA are competing in the 2G and 3G systems, with CDMA being favored for 3G.

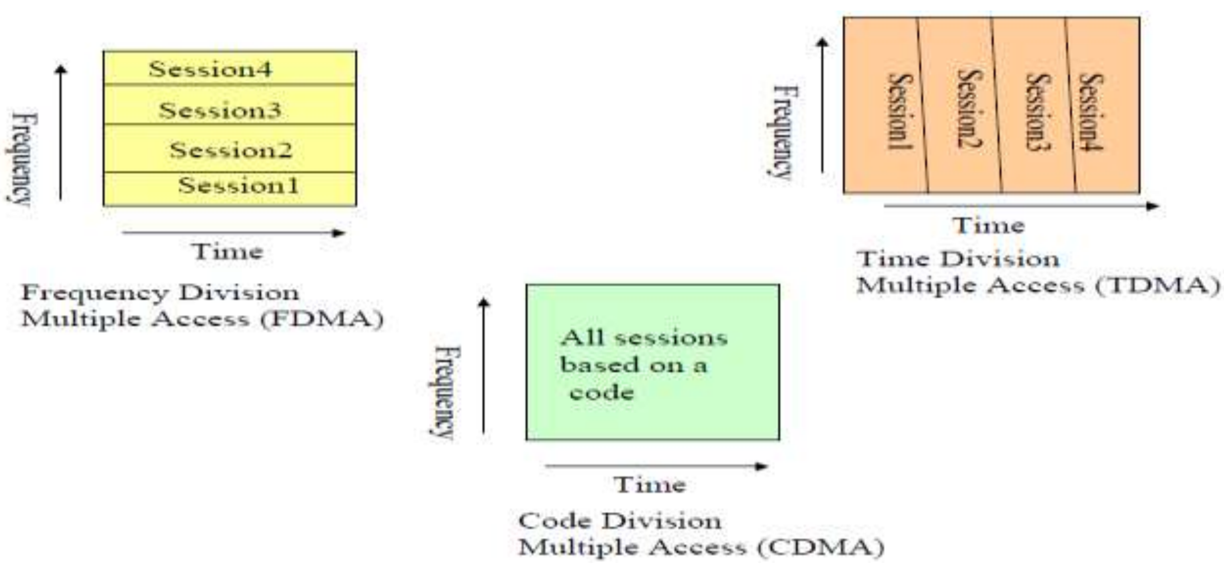

Fig 6.12 Multiple Access Techniques

Frequency Division Multiple Access (FDMA)
In this case, the frequency spectrum is subdivided so that each user gets a *dedicated channel.* This is one of the simplest and oldest schemes. However, it is *not very efficient* because a channel could be wasted if no one in that channel is talking. For example, FM radio divides the spectrum into 30 Khz channels, and FDMA divides each 30 Khz channel into 3 users (10 Khz each).
Base station cost for FDMA is high with very limited capacity. Due to these limitations, very few wireless systems use FDMA at present. Most applications of FDMA are in satellites.

Time Division Multiple Access (TDMA)
In this case, frequency bands available to the network are divided into time slots, with each user having access to one time slot at regular intervals. TDMA thereby makes more efficient use of available bandwidth than FDMA. TDMA has been available since 1992, with numerous modifications and improvements made since then.
The basic idea of TDMA is quite simple. Each subscriber transmits at different times; thus the data bits or small clumps of bits from different sources are interleaved on the same communication medium. Framing is used to identify which bits belong to which source so that the signals can be separated at the receiving side.

In cellular phone systems, the communication is divided into 6 millisecond (ms) frames, each divided into 1 ms time slots for 6 users. Each time slot has a header and data. Errors may corrupt headers and cause loss of time slots. In some cases the whole frame is lost. Call quality of TDMA is similar to FDMA but it can handle more calls. Several extensions of TDMA have been proposed and implemented (it can support 15 users per voice channel).

Code Division Multiple Access (CDMA) Technology
CDMA differs from the other two technologies by its use of coding techniques for transmitting voice or data over the air. Rather than dividing the RF spectrum into separate user channels by frequency slices or time slots, CDMA technology separates users by *assigning them digital codes* within the same broad spectrum. The receivers only tune to those codes and ignore the others. The assigning of codes to different users is also known as *spread spectrum,* a technique very heavily used in wireless LANs as well as cellular networks.
Spread spectrum transmits different data bits on different signals, based on a secret scheme. The receiver must know the code to understand the signal.

Specific characteristics of CDMA are:

- Groups of bits from digitized speech are tagged with a unique code that is associated with a cellular call.
- Several cellular calls are combined and transmitted over 1.25MHz and then reassembled on the receiver side.
- Receiver detects a signal by tuning to correct phase position between incoming and locally generated signals from code.
- Speech coder operates at a variable rate (fully when user is talking).
- It adjusts for near-far power adjustments (nearer stations generate less powerful signals).
- When powered on, the mobile system knows the CDMA frequency, so it tunes to that frequency and searches for a pilot signal (pilot signals represent base stations).
- Mobile station will pick the strongest pilot and register.
- When moving from cell to cell, new pilot is picked up.

Note

CDMA and its variants are at present very popular and are targeted as the core technologies for the 3G wireless systems.

CDMA Versus TDMA

There are conflicting performance claims for CDMA and TDMA. The debate is raging because hardware vendors have chosen sides and consequently the standardizing bodies have been lobbied hard. The primary motivation for this level of debate is that vendors want their selection to become the industry standard.

Since both TDMA and CDMA have become TIA (Telecom Industry Association) standards – IS-54 and IS-95, respectively – the debate goes on to determine which standard is better.

Technically speaking, CDMA has the following advantages over TDMA.

- **Call clarity:** CDMA appears to be better but is questioned.
- **Network capacity**: In CDMA, the same frequency can be reused in adjacent cells because the user signals differentiate from each other by a code. Thus frequency reuse can be very high and many more users (up to 10 times more) can be supported as compared to TDMA.
- **Privacy**: Privacy is inherent in CDMA since spread spectrum modulates data to signals randomly (you cannot understand the signal unless you know the randomizing code).
- **Reliability and graceful degradation**: CDMA-based networks only gradually degrade as more users access the system. This is in contrast to the sudden degradation of TDMA based systems. For example, if the channel is divided between ten users, then the eleventh user can get a busy signal in a TDMA system.

- This is not the case with CDMA because there is no hard division of channel capacity – CDMA can handle users as long as it can differentiate between them. In case of CDMA, the noise and interference increases gradually as more users are added because it becomes harder to differentiate between various codes.
- **Frequency diversity**: CDMA uses spread spectrum, thus transmissions are spread over a larger frequency bandwidth. Consequently, frequency-dependent transmission impairments that occur in certain frequency ranges have less effect on the signal.
- **Environmental**: Since existing cells can be upgraded to handle more users, the need for new cell towers decreases.
- **Maturity:** TDMA is very mature (in use since 1992) but CDMA is catching up.
- **Economy:** TDMA allows same equipment for multiple users.

Note

Although the TDMA-versus-CDMA debate continues, CDMA is taking a clear lead in future cellular networks, as the 3G and 3G+ systems are almost exclusively based on CDMA.

https://www.elprocus.com/understanding-wavelength-division-multiplexing-wdm/

http://www.fowiki.com/b/dwdm-disadvantages-and-dwdm-advantages/

https://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-WDM.html

https://www.tutorialspoint.com/code-division-multiplexing