UNIT - II
Multiple Access and Duplexing Techniques

MULTIPLE ACCESS TECHNIQUES

Multiple Access is a technique used to allow multiple users to access the channel at the same time without any interference.

The Multiple Access Techniques are as follows:

I. Frequency Division Multiple Access (FDMA)
II. Time Division Multiple Access (TDMA)
III. Code Division Multiple Access (CDMA)
IV. Space Division Multiple Access (SDMA)
V. Wavelength Division Multiple Access (WDMA)

Frequency Division Multiple Access (FDMA)

- Frequency division multiple access (FDMA) assigns unique frequency band or channel to individual users on demand to users who request service in which no other user can share the same frequency band.
- Features are :-
    - The FDMA channel carries only one phone circuit at a time.
    - If an FDMA channel is not in use, then it sits idle and cannot be used by other users to increase or share capacity. It is essentially a wasted resource.
    - After the assignment of a voice channel, the base station and the mobile transmit simultaneously and continuously.

- The bandwidths of FDMA channels are relatively narrow (30 kHz) as each channel supports only one circuit per carrier That is, FDMA is usually implemented in narrowband systems.
- The symbol time is large as compared to the average delay spread. This implies that the amount of intersymbol interference is low and, thus, little or no equalization is required in FDMA narrowband systems.
- Even though no two users use the same frequency band at the same time, guard bands are introduced between frequency bands to minimize adjacent channel interference.
- Since the user has his portion of the bandwidth all the time, FDMA does not require synchronization or timing control, which makes it algorithmically simple.

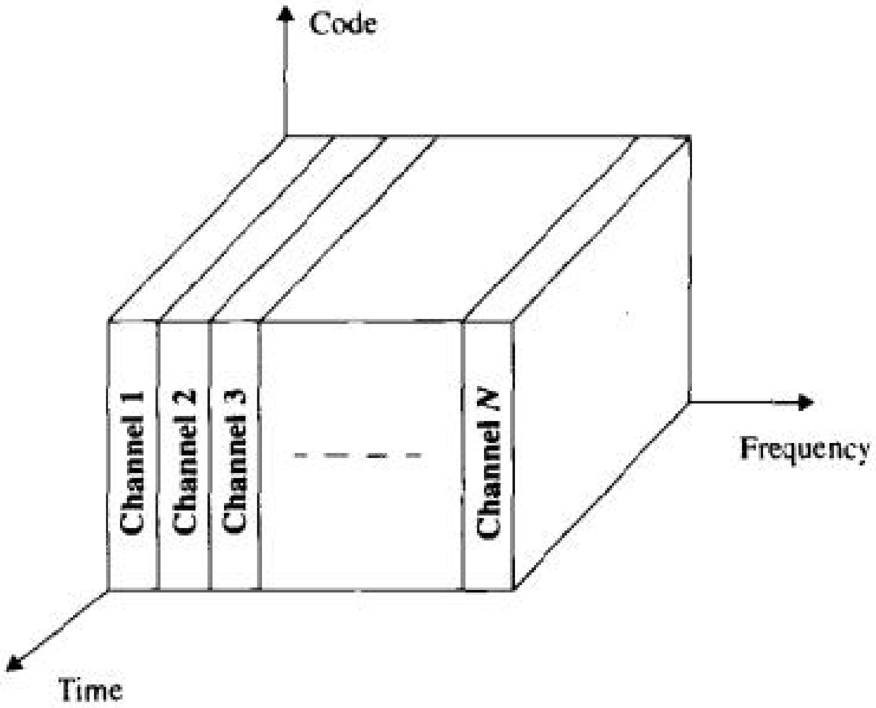
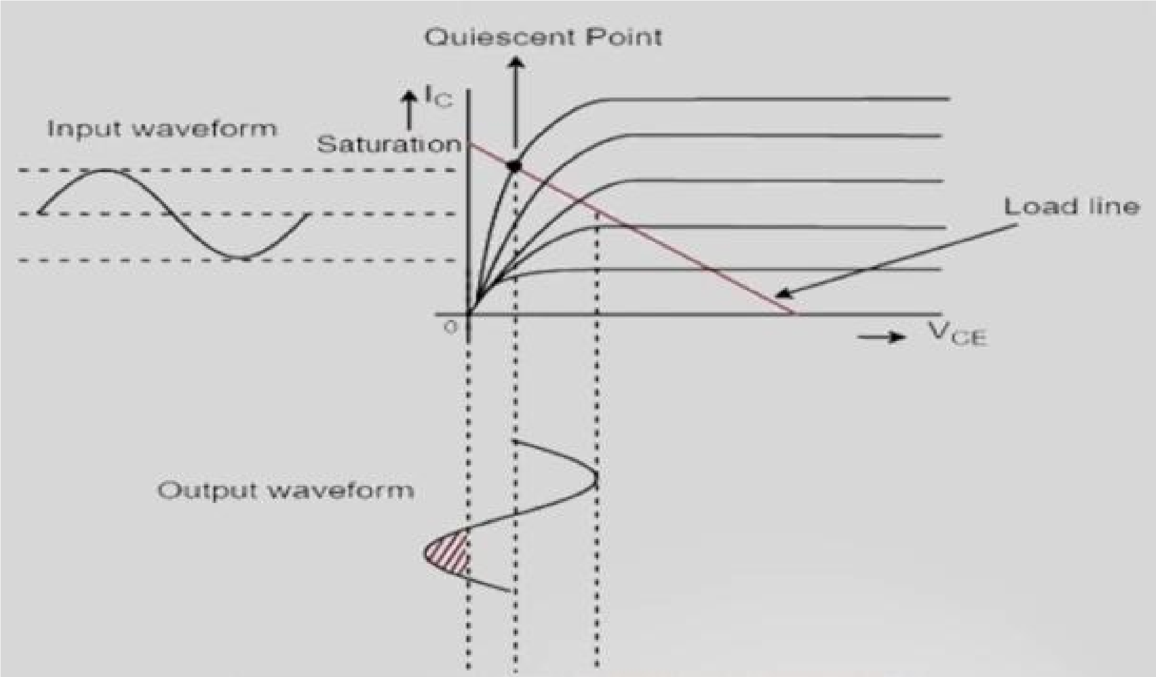


Figure 8.2

FDMA where different channels are assigned different frequency bands.

Nonlinear Effects in FDMA

- In a FDMA system, many channels share the same antenna at the base station.
- The power amplifiers or the power combiners, when operated at or near saturation for maximum power efficiency, are nonlinear.
- The non linearities cause signal spreading in the frequency domain and generate intermodulation (IM) frequencies.
- IM is undesired RF radiation which can interfere with other channels in the FDMA systems.
- Spreading of the spectrum results in adjacent-channel interference.
- Intermodulation is the generation of undesirable harmonics.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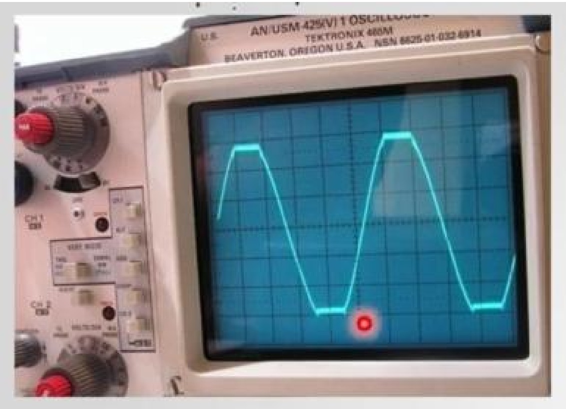
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FDMA vs TDMA

- The complexity of FDMA mobile systems is lower when compared to TDMA systems, though this is changing as digital signal processing methods improve for TDMA.
- Since FDMA is a continuous transmission scheme, fewer bits are needed for overhead purposes (such as synchronization and framing bits) as compared to TDMA.
- FDMA systems have higher cell site system costs as compared to TDMA systems, because of the single channel per carrier design, and the need to use costly bandpass filters to eliminate spurious radiation at the base station.
- The FDMA mobile unit uses duplexers since both the transmitter and receiver operate at the same time. This results in an increase in the cost of FDMA subscriber units and base stations.
- FDMA requires tight RF filtering to minimize adjacent channel interference.

FDMA usage by AMPS

- The first U.S. analog cellular system, the Advanced Mobile Phone System(AMPS), is based on FDMA/FDD.
- A single user occupies a single channel while the call is in progress, and the single channel is actually two simplex channels which are frequency duplexed with a 45 MHz split.
- When a call is completed, or when a handoff occurs, the channel is vacated so that another mobile subscriber may use it.
- Multiple or simultaneous users are accommodated in AMPS by giving each user a unique channel.
- Voice signals are sent on the forward channel from the base station to mobile unit, and on the reverse channel from the mobile unit to the base station.
- In AMPS, analog narrowband frequency modulation(NBFM) is used to modulate the carrier.

Number of Channels supported in FDMA System

The number of channels that can be simultaneously supported in a FDMA system is given by

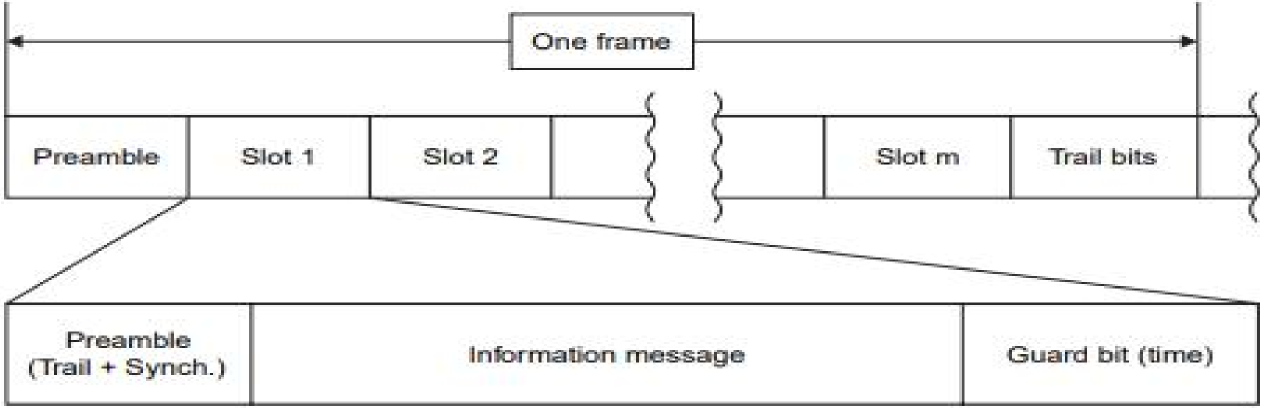
$$N = \frac{B_t - 2B_{guard}}{B_c}$$

Where, B_t is the total spectrum allocation , B_{guard} is the guard band allocated at the edge of the allocated spectrum, and B_c is the channel bandwidth.

Time Division Multiple Access (TDMA)

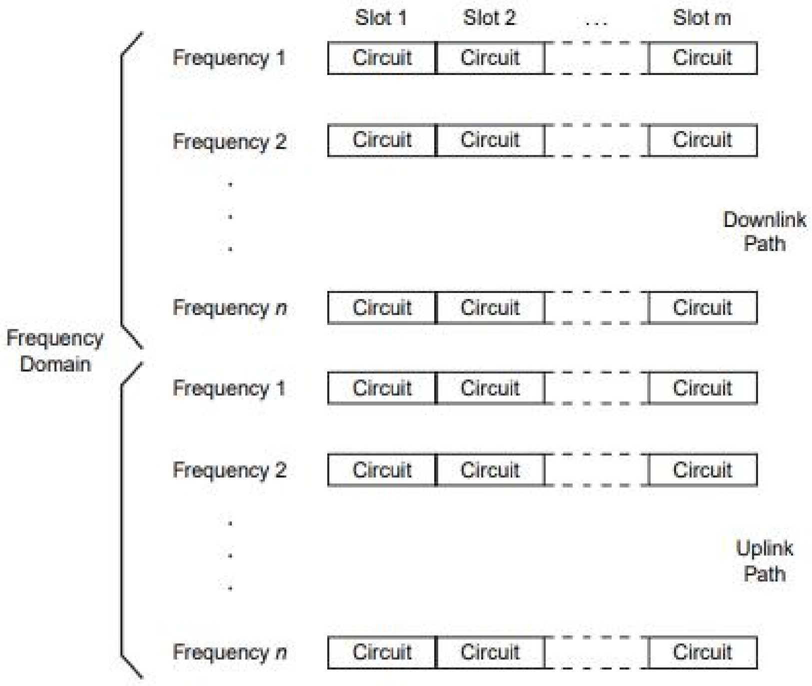
- In a TDMA system, each user uses the whole channel bandwidth for a fraction of time compared to an FDMA system where a single user occupies the channel bandwidth for the entire duration.
- In a TDMA system, time is divided into equal time intervals, called *slots*. User data is transmitted in the slots. Several slots make up a frame.
- To prevent synchronization errors and inter-symbol interference due to signal propagation time differences, guard intervals are introduced between time slots.

- Each user is assigned a frequency and a time slot to transmit data.
- The preamble carries the address and synchronization information that both the base station and mobile stations use for identification.



TDMA/FDD channel architecture

- For two-way communication, the uplink and downlink time slots, used for transmitting and receiving data, respectively, can be on the same frequency band (TDMA frame) or on different frequency bands.
- The data is transmitted via a radio-carrier from a base station to several active mobiles in the downlink. In the reverse direction (uplink), transmission from mobiles to base stations is time-sequenced and synchronized on a common frequency for TDMA.



Advantages of TDMA

- TDMA permits a flexible bit rate, not only for multiples of the basic single channel rate but also submultiples for low bit rate broadcast-type traffic.
- TDMA, when used exclusively and not with FDMA, utilizes bandwidth more efficiently because no frequency guard band is required between channels..
- TDMA offers the opportunity for frame-by-frame monitoring of signal strength/bit error rates to enable either mobiles or base stations to initiate and execute handoffs.
- TDMA transmits each signal with sufficient guard time between time slots to accommodate time inaccuracies because of clock instability, delay spread, transmission delay because of propagation distance, and the tails of signal pulse because of transient responses.

Disadvantages of TDMA

- For mobiles and particularly for hand-sets, TDMA on the uplink demands high peak power in transmit mode, that shortens battery life.
- TDMA requires a substantial amount of signal processing for matched filtering and correlation detection for synchronizing with a time slot.
- TDMA requires synchronization. If the time slot synchronization is lost, the channels may collide with each other.
- One complicating feature in a TDMA system is that the propagation time for a signal from a mobile station to a base station varies with its distance to the base station.

Synchronous TDMA frame

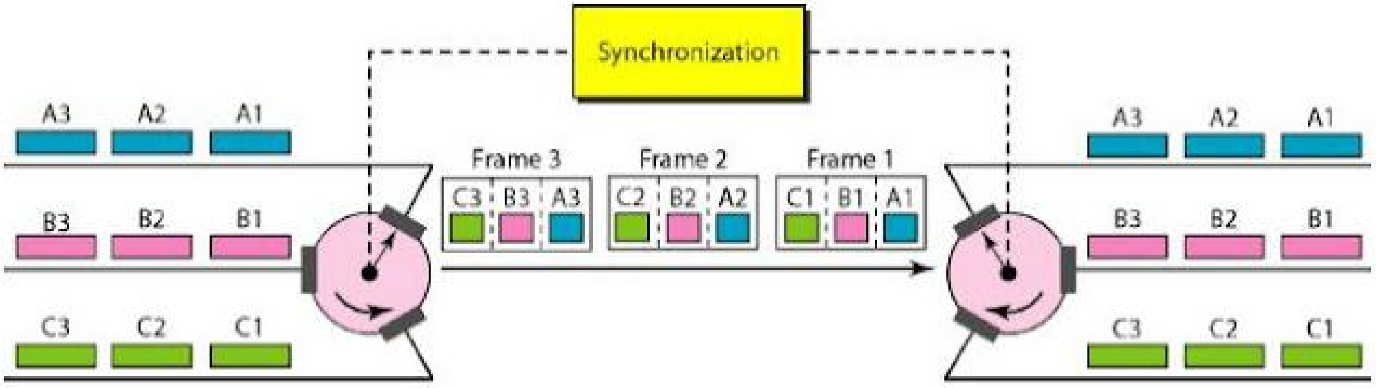
- Multiplexer allocates same time slots to each device without considering fact that device contains data or not.
- Number of slots per frame are equal to number of input lines i.e., If it contains n input lines, then it must have n slots in one frame.
- Number of time slots in a frame as always based on number of input lines.
- Usage of devices is less.
- There is no guarantee that full capacity link is used.

Asynchronous TDMA frame

- Multiplexer does not allocates same time slots to each device without considering fact that device contains data or not.
- Number of slots per frame are less than number of input lines i.e., If there are n input lines, then there are m slots in one frame (m<n).
- Number of time slots in a frame as always based on statistical analysis of number of input lines that are likely to be transmitting at any given time.
- Usage of Devices is more.
- There is guarantee that full capacity link is used.

Interleaving

TDM can be visualized as two fast-rotating switches, one on the multiplexing side and the other on the demultiplexing side.



Interleaving

- The switches are synchronized and rotate at the same speed, but in opposite directions.
- On the multiplexing side, as the switch opens in front of a connection, that connection has the opportunity to send a unit onto the path. This process is called interleaving.
- On the demultiplexing side, as the switch opens in front of a connection, that connection has the opportunity to receive a unit from the path.

Data Rate Management

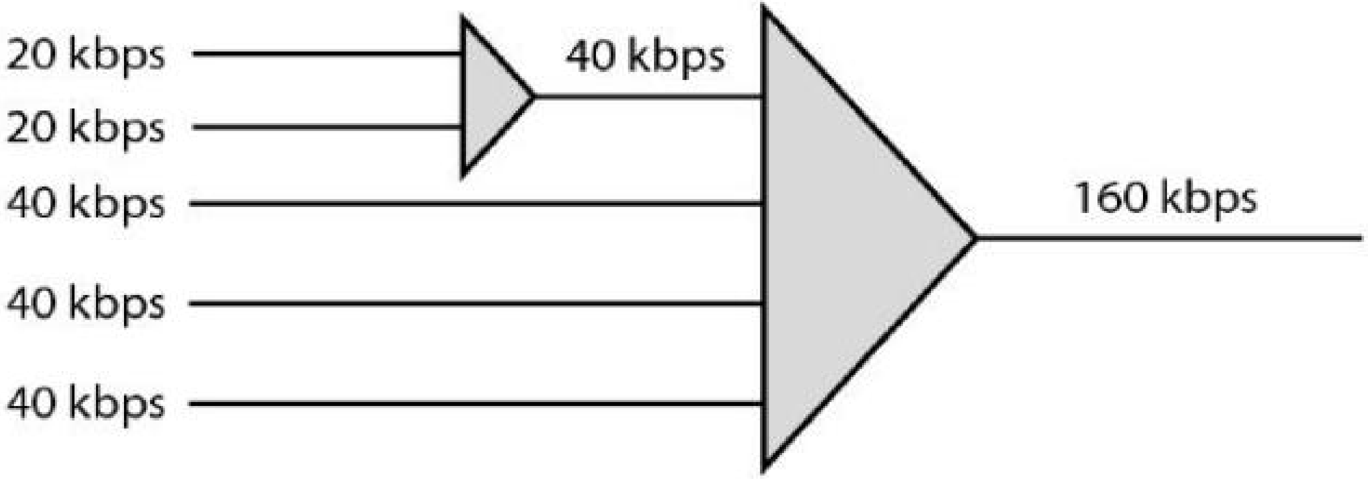
One problem with TDM is how to handle a disparity in the input data rates.

If data rates are not the same, three strategies, or a combination of them, can be used.

- → Multilevel multiplexing,
- → Multiple-slot allocation,
- → Pulse stuffing.

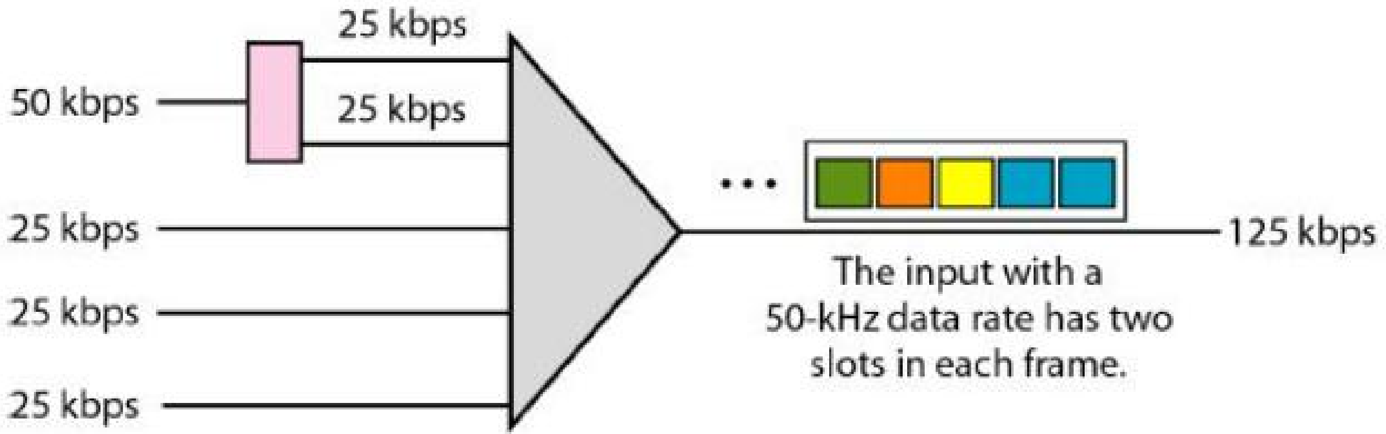
Multilevel Multiplexing

Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others.



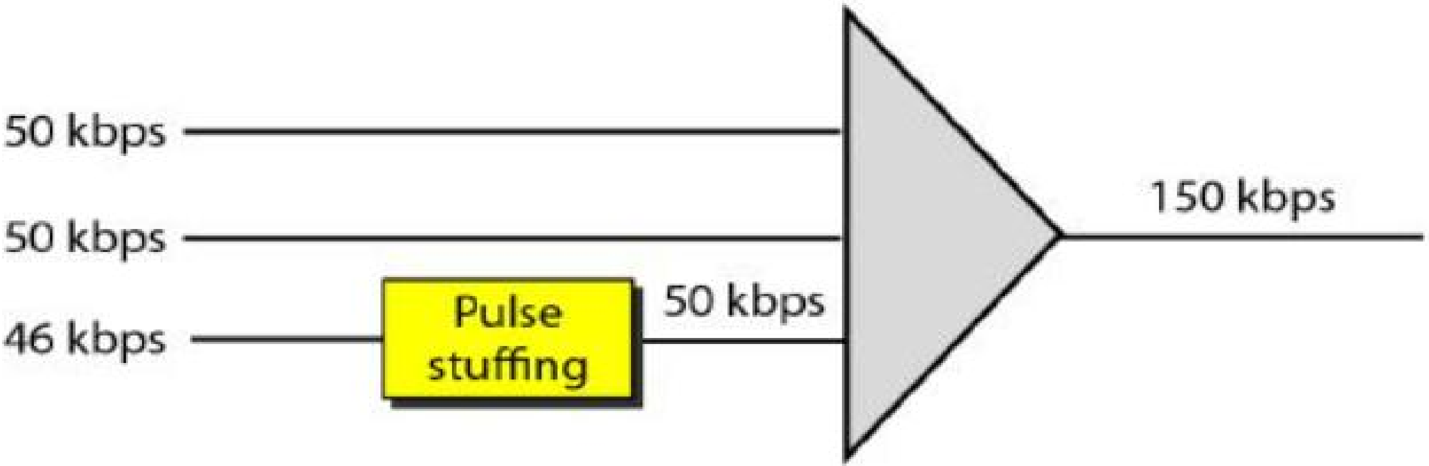
Multiple-Slot Allocation

Multiple Multiplexing is a technique to allot more than one slot in a frame to a single input line.



Pulse Stuffing

Sometimes the bit rates of sources are not multiple integers of each other. Then to make the data rate compatible dummy bits are added to input lines.This technique is called pulse stuffing, bit padding, or bit stuffing.



Code Division Multiple Access (CDMA)

- Unlike other systems such as TDMA and FDMA, code division multiple access (CDMA) does not assign a specific frequency to each user. Instead, every channel uses the entire spectrum.
- CDMA uses spread spectrum technology to transmit data. This technology permits several phones to send and receive through a single channel. Each part of these separate conversations is labeled with a specific digital code.
- Individual conversations are encoded with a pseudo random digital sequence. As the narrow-band transmission frequency is spread over the entire wideband spectrum, the technique is also called as spread spectrum.

- The transmissions are differentiated through a unique code that is independent of the data being transmitted, assigned to each user.
- CDMA was first used during World War II by the English Allies to foil attempts by the German army to jam the transmissions of the Allies. The Allies decided to transmit signals over several frequencies in a specific pattern, instead of just one frequency, thereby making it very difficult for the Germans to get hold of the complete signal.

CDMA Capacity

The factors deciding the CDMA capacity are –

- ❑ Processing Gain
- ❑ Signal to Noise Ratio
- ❑ Voice Activity Factor
- ❑ Frequency Reuse Efficiency

Capacity in CDMA is soft, CDMA has all users on each frequency and users are separated by code. This means, CDMA operates in the presence of noise and interference.

Processing Gain: CDMA is a spread spectrum technique. Each data bit is spread by a code sequence. This means, energy per bit is also increased. This means that we get a gain of

P(gain) = 10log (W/R), where

- W is Spread Rate
- R is Data Rate

For CDMA, P(gain) = 10 log (1228800/9600) = 21dB

This is a gain factor and the actual data propagation rate.

On an average, a typical transmission condition requires a signal to the noise ratio of 7 dB for the adequate quality of voice. Translated into a ratio, signal must be five times stronger than noise.

Actual processing gain = P (gain) - SNR

= 21 – 7 = 14 dB

CDMA uses variable rate coder.

The Voice Activity Factor of 0.4 is considered = -4dB.

Hence, CDMA has 100% frequency reuse. Use of same frequency in surrounding cells causes some additional interference.

In CDMA, frequency reuse efficiency is 0.67 (70% eff.) = -1.73dB

Two types of spread spectrum systems are widely in use today:

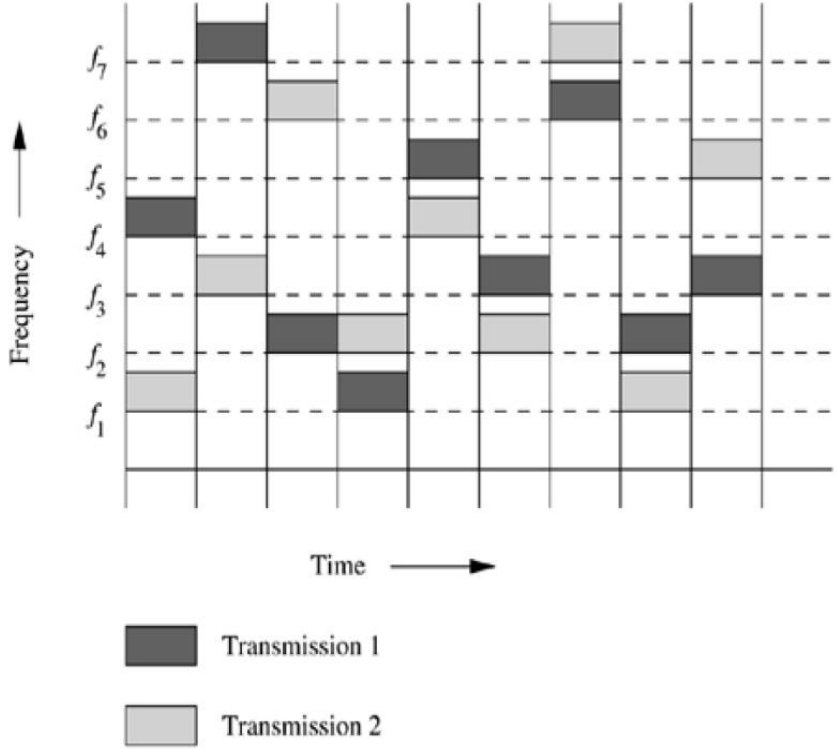
Frequency hopping spread spectrum

Frequency hopping spread spectrum (FHSS) is a simple technique in which the transmission switches across multiple narrow-band frequencies in a pseudorandom manner, that is, the sequence of transmission frequencies is known both at the transmitter and the receiver, but appears random to other nodes in the network.

The process of switching from one channel to the other is termed frequency hopping. The radio frequency signal is de-hopped at the receiver by means of a frequency synthesizer controlled by a pseudo-random sequence generator.

The figure shows two simultaneous transmissions. The first transmission (darker shade in figure) uses the hopping sequence f4 f7 f2 f1 f5 f3 f6 f2 f3 and the second transmission uses the hopping sequence f1 f3 f6 f2 f4 f2 f7 f1 f5 .

Frequency hopped systems are limited by the total number of frequencies available for hopping.



FHSS can be classified into two types:

Fast FHSS

In fast FHSS, the dwell time on each frequency is very small, that is, the rate of change of frequencies is much higher than the information bit rate, resulting in each bit being transmitted across multiple frequency hops.

Slow FHSS

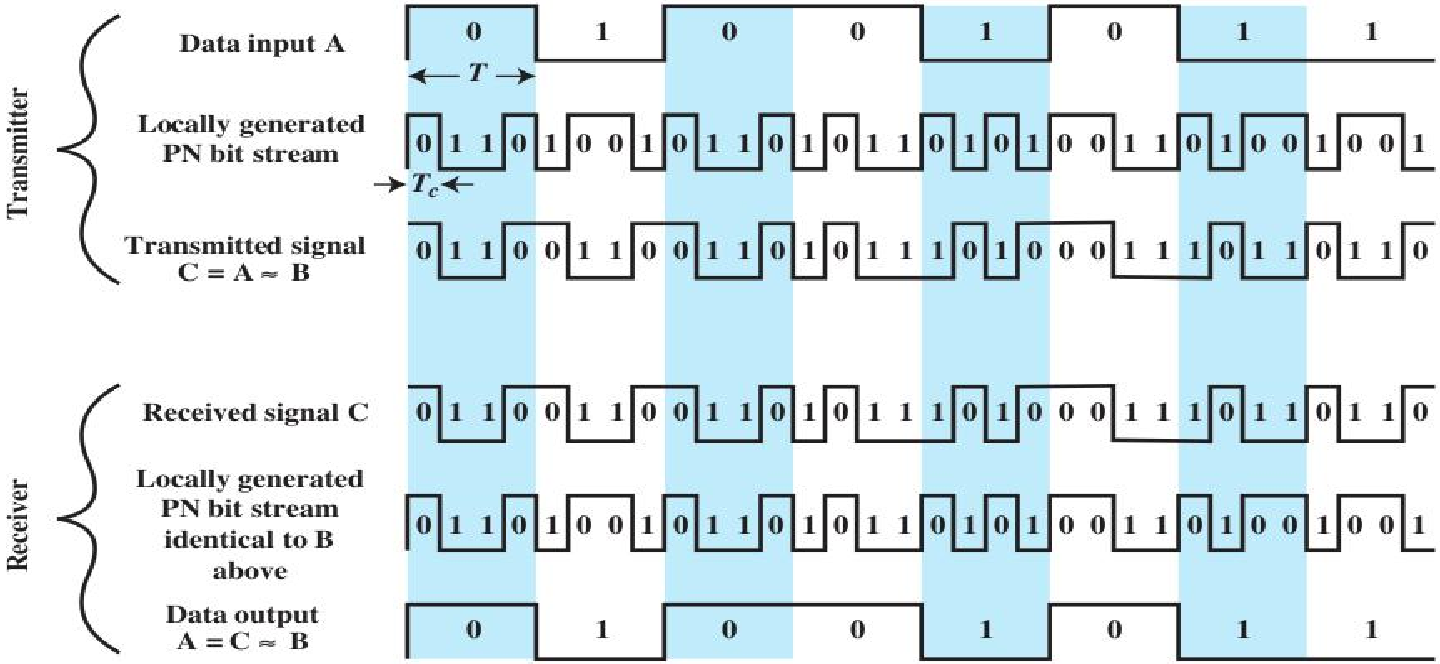
In slow FHSS, the dwell time on each frequency is high, hence multiple bits are transmitted on each frequency hop.

FHSS is now used mainly for short-range radio signals, particularly those in the unlicensed bands.

Direct Sequence Spread Spectrum

- In DSSS, each node is assigned a specific n-bit code, called a *chipping code*, where n is known as the chipping rate of the system. These codes assigned to the nodes are orthogonal to each other, that is, the normalized inner product of the vector representations of any two codes is zero. Each node transmits using its code.
- At the receiver, the transmission is received and information is extracted using the transmitter's code. For transmitting a binary 1, the sender transmits its code; for a binary 0, the one's complement of the code is transmitted. Hence, transmission of a signal using CDMA occupies n times the bandwidth that would be required for a narrow-band transmission of the same signal.

ILLUSTRATION OF DSSS



Direct sequence spread spectrum applications:

DSSS is used in a number of areas where its properties have enabled it to provide some unique advantages over other techniques.

- Covert communications
- CDMA cell phone technology
- Satellite based navigation systems

CDMA Near Far Problem

The near far problem is an issue that is encountered in CDMA when strong signals close to the base station need to be serviced along with weak ones far away.

This problem arises because handsets may be anywhere within the particular cell boundaries. Some handsets will be close to the base station, whereas others will be much further away.

In a free space scenario signals decay according a an inverse square law - in other words double the distance and the strength falls away to a quarter.

$$\text{Signal} = k / d^2$$

Where:

k = constant

d = distance

In cellular applications this situation may be worse. The effects of objects and other obstructions in the signal propagation path mean that in reality a signal decays at a greater rate than the simple inverse square law. It is somewhere between a law that follows a curve of an inverse of the distance to the power three or four. Many system planners may use a law of around $1 / d^{3.4}$.

The result of this is that signals within a cell will have a huge variation in signal strengths. However for CDMA to operate correctly, the receiver must be able to receive all the required signals within the same channel bandwidth and it must be able to decode them.

Drawbacks caused by the CDMA near far problem

- Reduced data capacity: The power control mechanism requires data to be sent in both directions across the radio interface. This utilises data capacity that could be otherwise used for carrying revenue earning data.
- High power handset power consumption at cell edges: In order to be able to maintain the required signal level at the base station when the handset is close to the edge of the cell, it will be required to transmit at a high power level. This will reduce battery life. Other cellular systems might not require such high signal levels at the base station and may be able to conserve battery power as a result.

Solution to the CDMA Near Far Problem:

The problem is commonly solved by dynamic output power adjustment of the transmitters. That is, the closer transmitters use less power so that the SNR for all transmitters at the receiver is roughly the same.

Other possible solutions are:-

1. Increased receiver dynamic range - Use a higher resolution ADC. Increase the dynamic range of receiver stages that are saturating.
2. Dynamic output power control – Nearby transmitters decrease their output power so that all signals arrive at the receiver with similar signal strengths.
3. TDMA – Transmitters use some scheme to avoid transmitting at the same time.

Advantages of CDMA

- Better system capacity: The system capacity improvement is mainly contributed by improved coding gain/modulation density and reuse of the same spectrum in every cell.
- More cost effective: CDMA requires fewer, less-expensive cells and no costly frequency reuse pattern. The average power transmitted by a CDMA mobile is about 6- 7mW, which is less than one tenth of the average power typically required by FM and TDMA phones. It will result in a longer battery life.
- Improved quality of service: CDMA provides robust operation in fading environments by using a RAKE receiver, improved signal processing techniques and soft handoffs.
- Degree of built-in privacy.

Disadvantages of CDMA

- The code length must be carefully selected. A large code length can induce delay or may cause interference.
- Time synchronization is required.
- Gradual transfer increases the use of radio resources and may reduce capacity.
- As the sum of the power received and transmitted from a base station needs constant tight power control. This can result in several handovers.

Space Division Multiple Access (SDMA)

The narrow beam of radio waves is aimed at particular part of space. The same channel is reused over the another narrow beam aimed at another part of the space. This division of space in different directions of base station through highly directional beams is called Space Division Multiple Access (SDMA).

SDMA is used for allocating a separate space to users in a wireless network.

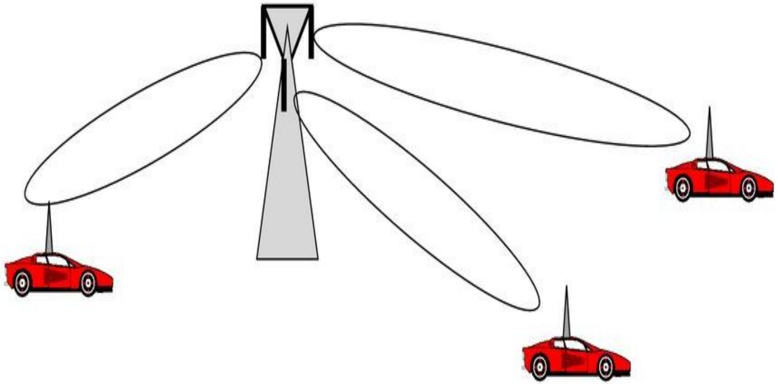
It follows a multiple input and multiple output architecture (MIMO).

MIMO is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver).

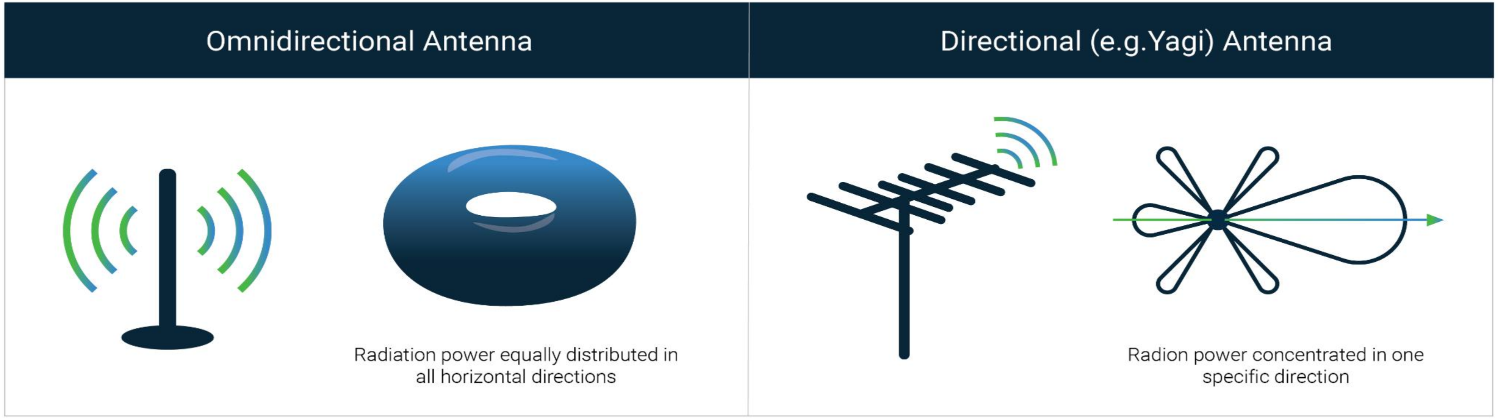
Since in general we want to have an interference free environment for the users who want to transmit their information on the common medium.

Thus we want to make sure that at least one of the following occurs:

1. No two users transmit at the same time.
2. No two users use the same frequency.
3. No two users should transmit in the same space.
   a. Multiple directional antennas
   b. All users are separated by a certain distance (spatially apart) known as the reuse distance.
   c. These users can transmit at the same time using the same frequency.
   d. Directional antennas/Spot beams are used.



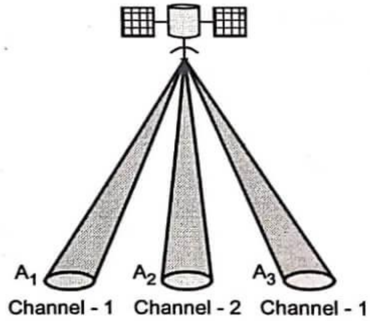
- Instead of having an omnidirectional antenna, we have multiple directional antennas whose coverage is a spot beam



Role of SDMA in Wired and Wireless Communications

- SDMA can be used for mobile communication and satellite communication. The satellite dish antennas transmit signals to various zones on earth's surface. These antennas are highly directional. Hence same frequency can be used for multiple surface zones.

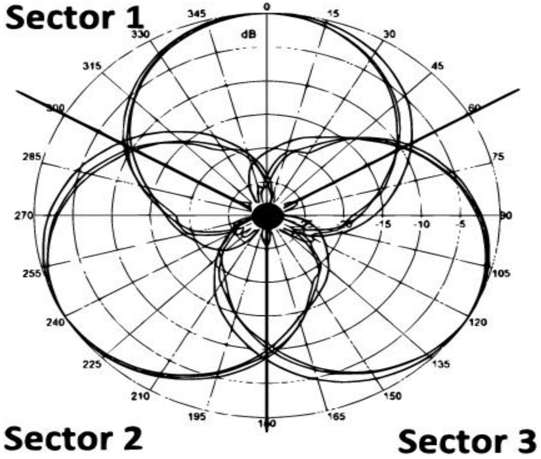
As shown in Fig, area A1 and area A3 are physically apart. Hence same channel-1 is used to send signals to A1 and A3 with the help of highly directional antennas.There will be no signal interface between the signals of areas A1 and A3

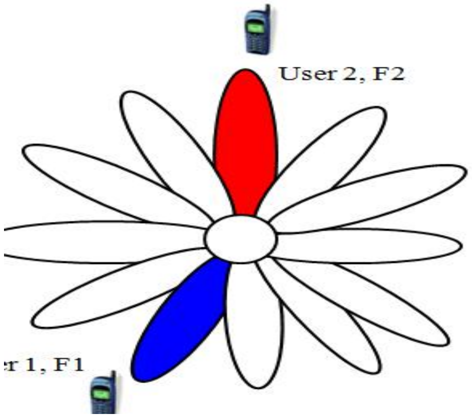


Space Division Multiple Access

SDMA techniques use smart antennas to establish such narrow beamwidth. A smart antenna is an antenna with a digital signal processing capability to transmit and receive in an adaptive and spatially sensitive manner. Some examples of smart antennas are the following:

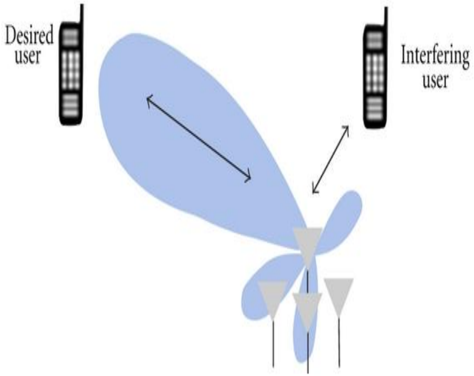
1. *Sectored antennas:* The simplest form of smart antenna is the sectored antenna. This antenna provides significant capacity gains simply by dividing the service area of each Base station into more than three angular sections with a significant amount of isolation between them.





2. *Switched beam antennas:* These are the next type of smart antennas. These antennas have a number of fixed beams that cover 360 degree and are typically narrower than sectored antennas. The receiver selects the beam that provides the best signal and interference reduction.

3. *Adaptive antennas (High sensitivity reception):* The most advanced example is the adaptive antenna. This antenna dynamically adjusts its pattern to minimize the effects of noise, interference and multipath. With adaptive antenna , there is one beam for each user.



Multiple antennas in SDMA protect quality of radio signal, safeguard against interference and also save power.

Advantages of SDMA

- → SDMA is a purely optical path
- → SDMA is frequency reuse
- → Increased spectral efficiency
- → SDMA is usually combined with other multiplexing techniques to better utilize the individual physical channel such as FDMA, TDMA, CDMA

Disadvantages of SDMA

- → SDMA is very expensive and complicated to construct and design
- → There are also high insertion losses since each input must have the capability to be split to any output.
- → The reverse link may be a problem like an interference problem
- → Different propagation path exists from user to the base

Reverse link - Mobile station will transmit to base station.

DUPLEXING TECHNIQUES

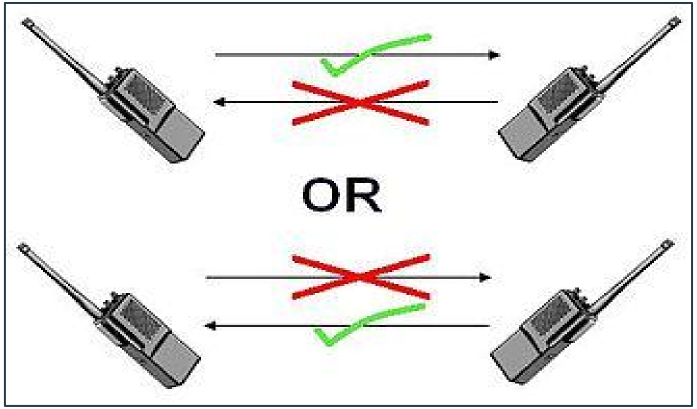
DUPLEX COMMUNICATION SYSTEM

A duplex communication system is a point-to-point system composed of two or more connected parties or devices that can communicate with one another in both directions.

Duplex systems are employed in many communications networks, either to allow for simultaneous communication in both directions between two connected parties or to provide a reverse path for the monitoring and remote adjustment of equipment in the field.

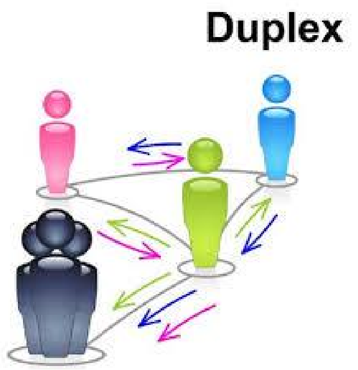
There are two types of duplex communication systems: full-duplex (FDX) and half-duplex (HDX).

In a half-duplex or semi-duplex system, both parties can communicate with each other, but not simultaneously; the communication is one direction at a time. An example of a half-duplex device is a walkie-talkie, a two-way radio that has a push-to-talk button.



In a full-duplex system, both parties can communicate with each other simultaneously. An example of a full-duplex device is telephone service; the parties at both ends of a call can speak and be heard by the other party simultaneously

Duplexing can be divided based on time or frequency slots. If it is divided based on frequency it is known as Frequency Division Duplexing (FDD) and if it is divided based on time slots it is known as Time Division Duplexing (TDD).

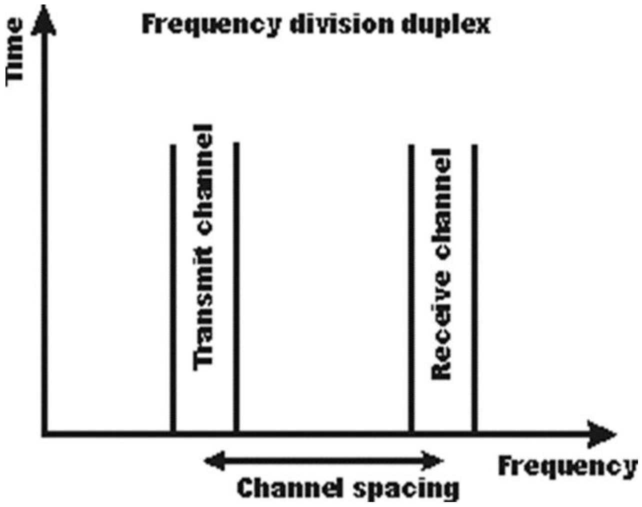


Both FDD and TDD are two spectrum usage techniques, used in mobile or fixed wireless broadband links .

The *main aim* is the smooth flow of data in both directions simultaneously without any noticeable interruptions.

Frequency Division Duplexing (FDD)

- FDD allows uplink and downlink transmission at the same time, but over a different frequency band. These bands are separated by a large margin in order to avoid leakage. The difference between assigned frequencies for uplink and downlink is called *frequency split or frequency offset*, remains constant.
- The method is frequently used in ham radio operation, where an operator is attempting to use a repeater station.
- The repeater station must be able to send and receive a transmission at the same time and does so by slightly altering the frequency at which it sends and receives.
- This mode of operation is referred to as *duplex mode* or *offset mode*.



Advantages of FDD

- It is proven technology for voice traffic. It is designed for symmetric traffic and do not require guard time like TDD.
- It uses paired spectrum on continuous basis for both the directions and hence it can achieve higher rates for similar distances as TDD system.
- Frequency-division duplex systems can extend their range by using sets of simple repeater stations because the communications transmitted on any single frequency always travel in the same direction.
- Due to above, FDD system requires fewer base stations compare to TDD as it covers larger distances with same rates as of TDD.
- Due to requirements of less number of Base Stations, overall deployment, operation and maintenance costs are less.

Disadvantages of FDD

- In FDD, frequencies are allocated dedicatedly. This leads to wastage of spectrum when it is not used. Moreover guard band is used between uplink and downlink to avoid interference, this part is wasted as it is not used for useful traffic.
- FDD can not be deployed where spectrum is unpaired.
- Though it saves in number of Base Station requirements, hardware costs associated with FDD are higher.

Time Division Duplexing (TDD)

Time division duplex (TDD) refers to duplex communication where uplink is separated from downlink by the allocation of different time slots in the same frequency band.

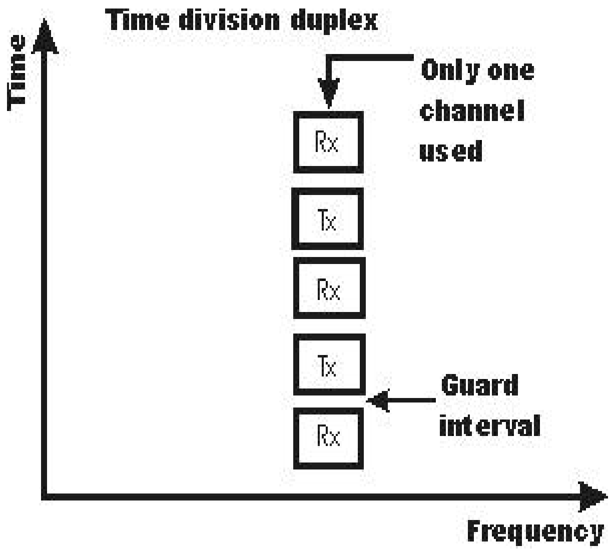
Each time slot may be 1 byte long or could be a frame of multiple bytes.

- Used in IEEE 802.16 WiMAX, 3G TD-SCDMA and 4G TDD LTE etc.
- Users are allocated different time slots for uplink(UL) and downlink (DL) transmission.
- This method is highly advantageous in case there is an asymmetry in the uplink and downlink data rates.
- Time slots could be dynamically allocated and variable in length based on network needs.
- A guard period is needed to ensure that UL and DL transmissions do not collide.

Q. Why is TDD not suitable for use over long distances?

TDD requires a guard period between the uplink and downlink transmissions during which the signal can travel between transmitter and receiver before the direction of the communication is reversed.
However this gap is proportional to the distance between Tx and Rx.

It takes 3.3 microseconds to travel a kilometre, 5.4 microseconds to travel 1 mile. As the guard time increases , the channel efficiency falls.



Q. How TDD supports asymmetry in uplink and downlink data rates?

In many cases, the capacity(data travelling in one direction) is greater in downlink direction. Using a TDD system it is possible to change the capacity in either direction relatively easily by changing the number of time slots allocated to each direction.

Advantages of TDD

- TDD requires single channel for both uplink and downlink, hence it is spectrum efficient topology.
- It has a provision to allocate any number of time slots for uplink and downlink directions.
- It is used for dynamic resource requirements based on application and quality of service. This is possible due to dynamic allocation of time slots without changing the bandwidth once allocated.
- Due to channel reciprocity, channel equalizer algorithms are simpler in TDD as compared to FDD.

Disadvantages of TDD

- As TDD operates based on allocated time slots, it requires stringent phase/time synchronization to avoid interference between UL (Uplink) and DL (Downlink) transmissions.

- As TDD supports lesser distances compare to FDD, it needs more base stations to achieve given coverage area.

- Due to requirements of more Base stations (or eNBs) , deployment and operating costs are higher in TDD.

Therefore, TDD systems are often used in scenarios where short distances are required, with the possibility of unbalanced data traffic. FDD schemes are better over greater distances and where the traffic is balanced.

References

- Wireless Communications by Theodore S. Rappaport (z-lib.org)
- Data communication and Networking by Behrouz A. Forouzan
- Ad Hoc Wireless Networks Architectures and Protocols C. Siva Ram Murthy BS Manoj
- Wireless Communication and Networking by Vijay. K Garg
- TDMA:Difference b/w Synchronous TDM and Asynchronous TDM
- CDMA: CDMA Capacity, DSSS Applications
- Near far problem: About the Problem, Solution
- SDMA: SDMA, Different types of smart antennas, Advantages and disadvantages of SDMA
- WDMA: A WDMA Network for Computer Communication
- Duplex

THANK YOU!