UNIT-I

THE CELLULAR CONCEPT-SYSTEM DESIGN FUNDAMENTALS

Introduction – Frequency Reuse - Channel Assignment Strategies - **Handoff Strategies:** Prioritizing Handoffs, Practical Handoff Considerations. **Interference And System Capacity**: Co-Channel Interference And System Capacity-Channel Planning For Wireless Systems, Adjacent Channel Interference, Power Control For Reducing Interference, Trunking And Grade Of Service. **Improving Coverage And Capacity In Cellular Systems:** Cell Splitting, Sectoring.

1.1 The Cellular Concept - Introduction

1. Explain the concept of cellular topology and cell fundamentals. [Dec 2015, May 2023]

- ✓ For a given set of frequencies or radio channels can be reused without increasing the interference, the large geographical area covered by a single high power transmitter can be divided into a number of small areas, each allocated power transmitters with lower antennas can be used.
- ✓ The ***Hexagon shape*** was used for cell because it provides the most effective transmission.
- ✓ Each cellular base station is allocated a group of radio channels to be used with a small geographic area called a **cell.**
- ✓ A group of cells that use a different set of frequencies in each cell is called a ***cell cluster***.

Types of cell

- ✓ The physical size of a cell varies, depending on user density and calling patterns.

1. **Macro cells:**
   - ➢ They are large cells.
   - ➢ They have a radius between 1 mile and 15 miles.
   - ➢ Base station transmits power between 1W and 6W.
2. **Microcells:**
   - ➢ They are the smallest cells.
   - ➢ They have a radius between of 1500 feet or less.
   - ➢ Base station transmit powers between 0.1W and 1W.
   - ➢ They are used in high-density areas such as in large cities and inside the buildings.

Location of base station

- ➢ For location of the base station, designing a system using hexagonal-shaped cells.

1. ***Center-excited cell- Base station transmitters***:
   - ➢ They can be located in the center of the cell.
   - ➢ They use Omni directional antennas which radiate and receive signals equally well in all directions.
2. ***Edge- excited cell- Base station transmitters:***
   - ➢ They can be located in the edge of the cell.
   - ➢ They use sectored antennas which radiate for a particular direction.
3. ***Corner- excited cell- Base station transmitters:***

- They can be located in the corner of the cell.
- They use sectored directional antennas.

Cellular system

- ✓ Figure shows a basic cellular system.
- ✓ It consists of mobile stations, base stations and a mobile switching center (MSC).

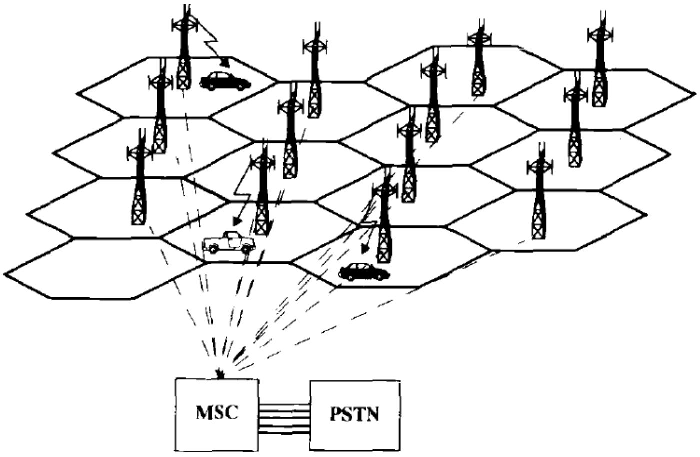

Figure: Cellular system

Mobile station:

- ✓ The mobile station contains a transceiver, an antenna, and control circuitry.
- ✓ It may be mounted in a vehicle or used as a portable hand-held unit.
- ✓ Each mobile communicates via radio with one of the base stations
- ✓ It may be handed off to any number of base stations throughout the duration of a call.

Base station:

- ✓ The base station consists of several transmitters and receivers which simultaneously handle full duplex communications.
- ✓ It has towers which support several transmitting and receiving antennas.
- ✓ It serves as a bridge between all mobile users in the cell.
- ✓ It connects the simultaneous mobile calls via telephone lines or microwave links to the MSC.

- ✓ The channels used for voice transmission from the base station to mobiles are called ***forward voice channels*** (FVC).
- ✓ The channels used for voice transmission from mobiles to the base station are called ***reverse voice channels*** (RVC).
- ✓ The two channels responsible for initiating mobile calls are the ***forward control channels*** (FCC) and ***reverse control channels*** (RCC).

Mobile Switching Center:

- ✓ The Mobile Switching Center is sometimes called a mobile telephone switching office (MTSO).
- ✓ It is responsible for connecting all mobiles to the PSTN in a cellular system.
- ✓ The MSC coordinates the activities of all of the base stations.
- ✓ It connects the entire cellular system to the PSTN.
- ✓ A typical MSC handles 100,000 cellular subscribers' and 5,000 simultaneous conversations at a time.
- ✓ It accommodates all billing and system maintenance functions.

1.2 Frequency Reuse

2. Discuss in detail about frequency reuse. [8m] [Dec 2014] (or)
Given a foot print by the service provider, prepare and illustrate the frequency planning addressing all practical limitations that can be envisaged. [Dec 2021]

- ✓ **Frequency reuse** is the process in which the same set of frequencies can be allocated to more than one cell and the cells are separated by sufficient distance.
- ✓ It is also known as **frequency planning.**
- ✓ The ability to reuse the frequencies to expand the total system capacity without the need to employ high power transmitters.
- ✓ Figure shows a geographic cellular radio coverage area.
- ✓ It contains three groups of cell called **clusters**.
- ✓ A cell cluster is outlined in bold and replicate over the coverage area.
- ✓ Each cluster has seven cells in it and all cells are assigned the same number of full duplex cellular telephone channels.
- ✓ Cells with the same letter use the same set of frequencies.
- ✓ The letters A, B, C, D, E, F and G denote the seven sets of frequencies.
- ✓ The actual radio coverage of a cell is known as the **foot print**. It is determined from field measurement or propagation prediction models.

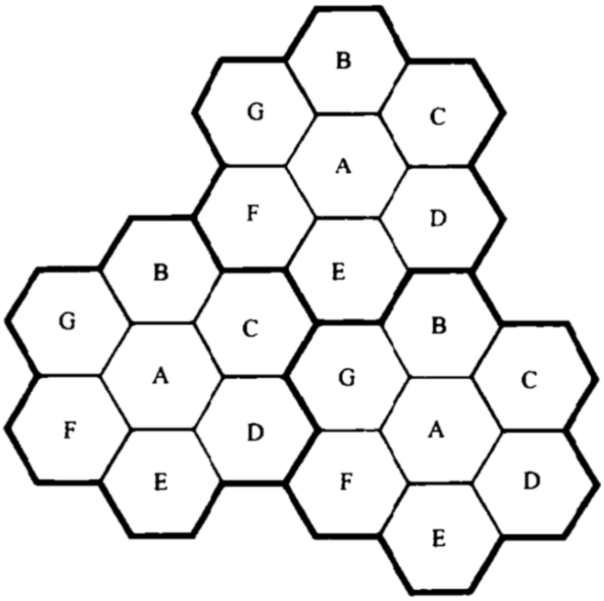

Figure: Illustration of the cellular frequency reuse concept.

<u>Capacity expansion by frequency reuse</u>

- ✓ Consider a cellular system which has a total of S duplex channels available for use.
- ✓ Let N be the cluster size in terms of the number of cells within it.
- ✓ Each cells is allocated a group of K channels $(K<S)$.
- ✓ The N cells which collectively use the complete set of available frequencies is called cluster.
- ✓ The cluster can be replicated many times to form the entire cellular communication systems.
- ✓ The N cells in the cluster would utilize all K available channels.
- ✓ For the total number of Channels C, the total number of available radio channels can be expressed as

$$S = KN$$

where,

$S \rightarrow$ Number of full duplex cellular channels available in the cluster

$K \rightarrow$ Number of channels in a cell

$N \rightarrow$ Number of cells in the cluster

- ✓ Let M be the number of times the cluster is replicated and C be the total number of channels used in the entire cellular system with frequency reuse.
- ✓ C is then the system capacity and is given by

$$C=MKN$$

$$C=MS$$

where,

$C \rightarrow$ Total channel capacity in a given area

$M \rightarrow$ Number of clusters in a given area

- ✓ The capacity of a cellular system is directly proportional to the number of times a cluster is replicated in a fixed service area.
- ✓ The cluster size factor N = 4, 7, or 12.
- ✓ If the cluster size N is reduced while the cell size is kept constant.
- ✓ More clusters are required to cover a given area and hence more capacity is achieved.
- ✓ The number of subscribers who can use the same set of frequencies in non-adjacent cells at the same area is dependent on the total number of cells in the area.
- ✓ The number of users use the same set of frequencies is called the ***Frequency Reuse Factor*** (FRF) and is defined as

$$FRF = \frac{N}{C}$$

where,

N $\rightarrow$ Cluster size

C $\rightarrow$ Total number of full duplex channels in an a cell.

<u>Rules for determining the nearest co-channel neighbors</u>

- ✓ To find the nearest co-channel neighbors of a particular cell:
  Step 1: Move I cells along any chain of hexagons.
  Step 2: Turn 60 degrees counter clockwise and more j cells.

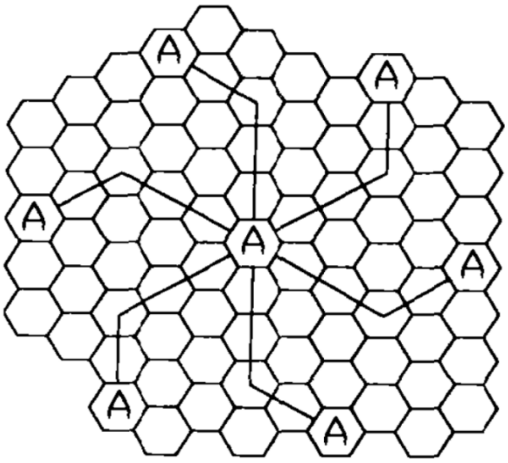

Figure: Method of locating co-channel cells in a cellular system.
In this example, N = 19 (i.e., i = 3, j = 2).

- ✓ Example for i = 3 and j = 2.

- ✓ The parameters i and j measure the number of nearest neighbor between co-channel cells.
- ✓ *N* is related to *I* and *j* by the equation

$$N = i^2 + ij + j^2$$

- ✓ As a distance between co-channel cell increases, co-channel interference will decrease.
- ✓ If cell size is fixed, the average signal-to-co-channel interference ratio will beindependent of the transmitted power of each cell.
- ✓ Co-channel reuse ratio,

$$Q = \frac{D}{R} = \sqrt{3N}$$

where,

Q $\rightarrow$ Co channel reuse ratio

D $\rightarrow$ Distance to the nearest co-channel cells

R $\rightarrow$ Radius of the cell

N $\rightarrow$ Number of cells in the cluster

- ✓ The advantages of Cellular Systems are,
  - ➢ The use of low power transmitter and
  - ➢ It allows frequency reuse for capacity improvement.

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<u>Problem:</u>

3. If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels, compute the number of channels available per cell if a system uses (a) 4-cell reuse, (b) 7-cell reuse (c) 12-cell reuse. If 1 MHz of the allocated spectrum is dedicated to control channels, determine an equitable distribution of control channels and voice channels in each cell for each of the three systems.[April/May 2019]

Given:

Total bandwidth =33 MHz

Channel bandwidth = 25 kHz x 2 simplex channels = 50 kHz/duplex channel

Total available channels = 33,000/50 = 660 channels

(a) For N= 4, total number of channels available per cell = 660/4 =165 channels.

(b) For N=7, total number of channels available per cell = 660/7 =95 channels.

(c) For N = 12, total number of channels available per cell = 660/12 = 55 channels.

- ✓ A 1 MHz spectrum for control channels implies that there are 1000/50 = 20 control channels out of the 660 channels available.
- ✓ To evenly distribute the control and voice channels, simply allocate the same number of channels in each cell wherever possible.
- ✓ Here, the 660 channels must be evenly distributed to each cell within the cluster.
- ✓ In practice, only the 640 voice channels would be allocated, since the control channels are allocated separately as 1 per cell.

(a) For N = 4, we can have 5 control channels and 160 voice channels per cell.

(b) For N = 7, we can have 4 cells with 3 control channels and 92 voice channels, 2 cells with 3 control channels and 90 voice channels, and 1 cell with 2 control channels and 92 voice channels could be allocated.

(c) For N = 12, we can have 8 cells with 2 control channels and 53 voice channels, and 4 cells with 1 control channel and 54 voice channels each.

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1.2 Channel Assignment Strategies (Or) Allocation Techniques

4. Briefly discuss the process of channel assignment in cellular networks. (or) Explain channel assignment in detail. [April/May 2018]

- ✓ For efficient utilization of the radio spectrum, a frequency reuse scheme is used. So that capacity is increased, interference is reduced.
- ✓ Channel assignment strategy improves the following performance of the system.
  - ➢ Used to manage calls when handoff is done.
  - ➢ Minimize connection set-up time
  - ➢ Adapt to changing load distribution
  - ➢ Fault tolerance
  - ➢ Scalability
  - ➢ Low computation and communication overhead
  - ➢ Minimize handoffs
  - ➢ Maximize number of calls that can be accepted concurrently
- ✓ Channel assignment strategies can be classified
  - (a) Fixed Channel assignment
  - (b) Dynamic Channel assignment
  - (c) Hybrid Channel Allocation schemes
    (HCA schemes: combining both FCA and DCA techniques)

(a) Fixed Channel assignment

- ✓ Channels are pre-allocated to the cells during planning phase.
- ✓ Each cell is allocated a predetermined set of voice channels.
- ✓ Any call attempt within the cell can only be served by the unused channels in that particular cell.
- ✓ If all the channels in that cell are occupied, the call is blocked and the subscriber does not receive service.
- ✓ Due to short term fluctuations in the traffic, FCA schemes are often not able to maintain high quality of service and capacity attainable with static traffic demands.
- ✓ One approach to address this problem is to borrow free channels from neighboring cells.

(b) Dynamic Channel assignment

- ✓ No pre-allocation:
  - ➢ In a dynamic channel assignment strategy, voice channels are not allocated to different cells permanently.
- ✓ Each time a call request is made, the serving base station requests a channel from the MSC.
- ✓ MSC then allocates a channel to the requested cell.
- ✓ The MSC only allocates a given frequency if that frequency is not currently in use in the cell or any other cell which falls within the limiting reuse distance.
- ✓ Dynamic channel assignment reduces blocking and increasing the capacity of the system.
- ✓ Dynamic channel assignment strategies require the MSC to collect real-time data on channel occupancy and traffic distribution on a continuous basis.
- ✓ Advantages of dynamic Channel assignment are
  - ➢ Increased channel utilization
  - ➢ Decreased probability of a blocked call.

- ✓ Disadvantages of dynamic Channel assignment are
  - ➢ Increases the storage
  - ➢ Increases computational load on the system

(c) Hybrid Channel Allocation (HCA)

- ✓ HCA schemes are the combination of both FCA and DCA techniques.
- ✓ In HCA schemes, the total number of channels available for service is divided into fixed and dynamic sets.
- ✓ The fixed set contains a number of nominal channels that are assigned to cells as in the FCA schemes
- ✓ The dynamic set is shared by all users in the system to increase flexibility.
- ✓ **Example:** When a call requires service from a cell and all of its nominal channels are busy, a channel from the dynamic set is assigned to the call.
- ✓ Request for a channel from the dynamic set is initiated only when the cell has exhausted using all its channels from the fixed set.
- ✓ Optimal ratio: ratio of number of fixed and dynamic channels.
- ✓ 3:1 (fixed to dynamic), provides better service than fixed scheme for 50% traffic.
- ✓ Beyond 50% fixed scheme perform better.
- ✓ For dynamic, with traffic load of 15% to 32%, better results are found with HCA.

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Comparison FCA and DCA

5. Compare FCA and DCA.

Attribute	Fixed Channel Allocation	Dynamic Channel Allocation
Traffic load	Fixed Channel Allocation is better under heavy traffic load	Dynamic Channel Allocation is better under light/moderate traffic load
Flexibility of channel allocation	Fixed Channel Allocation is less flexible	Dynamic Channel Allocation is more flexible
Reusability of channels	Fixed Channel Allocation has a maximum possibility.	Dynamic Channel Allocation has a limited possibility.
Temporal and spatial changes	Fixed Channel Allocation are very sensitive	Dynamic Channel Allocation are very insensitive
Grade of service	Fixed Channel Allocation is fluctuating	Dynamic Channel Allocation is stable.
Forced call termination	Large probability in Fixed Channel Allocation	Low/ Moderate probability in Dynamic Channel Allocation
Suitability of cell size	Fixed Channel Allocation uses macro cellular system	Dynamic Channel Allocation uses micro cellular system

Radio Equipment	Fixed Channel Allocation covers only the channels allotted to the cell.	Dynamic Channel Allocation has to cover all possible channel that could be assigned to the cell
Computational effort	In Fixed Channel Allocation, Computational effort is low.	In Dynamic Channel Allocation, Computational effort id high
Call setup delay	Low in Fixed Channel Allocation	Moderate/High in Dynamic Channel Allocation
Implementation complexity	Low in Fixed Channel Allocation	Moderate/High in Dynamic Channel Allocation
Frequency planning	Laborious and complex in Fixed Channel Allocation	None in Dynamic Channel Allocation
Signaling load	Low in Fixed Channel Allocation	Moderate/High in Dynamic Channel Allocation
Control	Centralized in Fixed Channel Allocation	Centralized, decentralized or distributed in Dynamic Channel Allocation

1.3 Hand Off Strategies

6. Explain the principle of cellular networks and various types of handoff techniques. (16m) [May 2016, May 2013] (or)
Explain in detail a handoff scenario at cell boundary. (6m) [Dec 2014, Dec 2019] (or)
Explain hand off strategies in detail. [May 2018, May 2019] (or)
(i) Explain with neat sketch, Handoff mechanism adopted in cellular communication detailing the condition for proper handoff.
(ii) Highlight the significance of prioritizing Handoffs and Practical Handoff consideration (6m) [May 2021, May 2023]

Hand off:

- ✓ When a mobile move into a different cell while a conversation is in progress, the MSC automatically transfers the call to a new channel belonging to the new base station is known as **hand off.**
- ✓ The handoff operation not only involves a new base station.
- ✓ It also requires that the voice and control signals be allocated to channels associated with the new base station.
- ✓ Handoff calls can be admitted at a higher priority than new calls.
- ✓ To manage the admission of requests based on priority, it is necessary to reserve capacity for admitting handoff requests.
- ✓ A particular signal level is specified as the minimum usable signal for acceptable voice quality at the base station receiver.
- ✓ A slightly stronger signal level is used as threshold at which a handoff is made.
- ✓ The time over which a call may be maintained within a cell, without handoff, is called the **dwell time**.

- ✓ Dwell time depends on
  - ➢ Propagation
  - ➢ Interference
  - ➢ Distance between the subscriber
  - ➢ Speed
- ✓ Handoff Margin ∆
  - ➢ Margin $\Delta = P_{handoff\ threshold} - P_{minimumusable\ signal}$ dB
  - ➢ ∆ is carefully selected
  - ➢ ∆ too large → unnecessary handoff → MSC loaded down
  - ➢ ∆ too small → not enough time to transfer → call dropped.

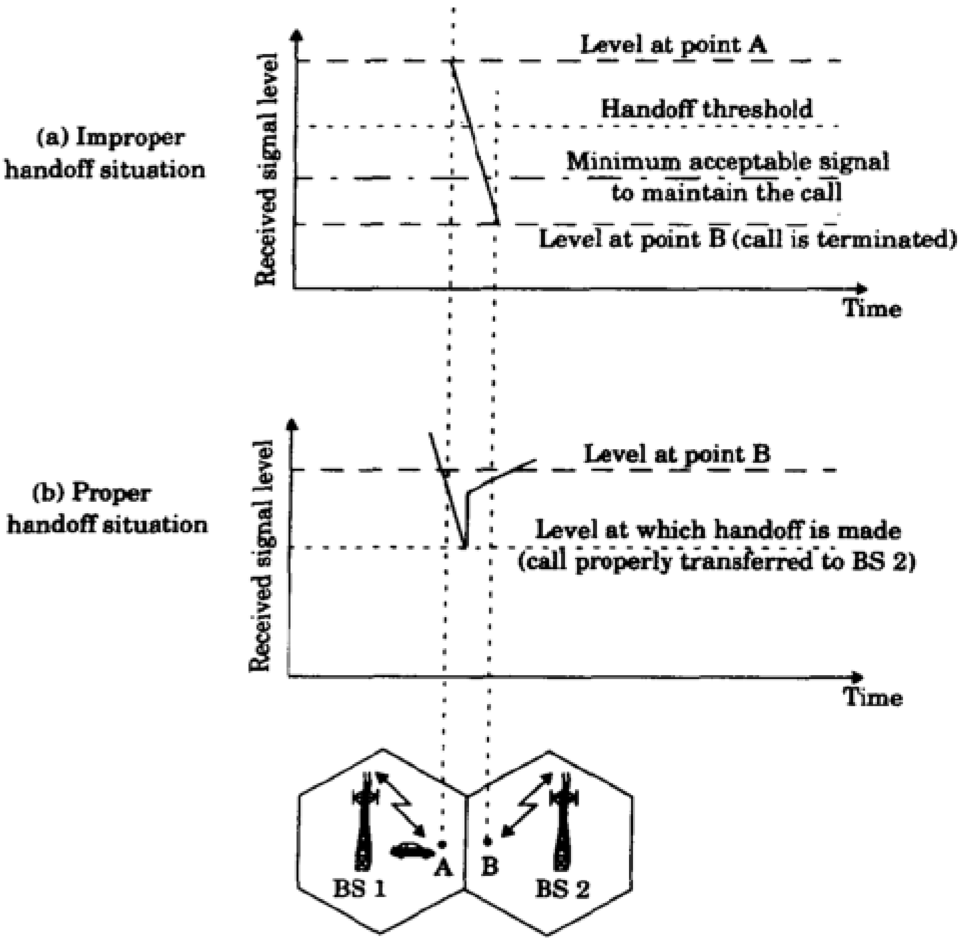

Figure: Illustration of a handoff scenario at cell boundary.

<u>Hand off methods</u>

1. Mobile Controlled Hand off (MCHO)
2. Network Controlled Hand off (NCHO) and
3. Mobile Assisted Hand off (MAHO)

1. MCHO

- ✓ Mobile controls the hand off.
- ✓ MCHO is a desirable method because it reduces the burden on the network.
- ✓ However, it increases the complexity of the mobile terminal.

2. NCHO

- ✓ In NCHO, the BSs or Access Points (APs) monitor the signal quality from the mobile and report the measurements to the MSC.

- ✓ The MSC is responsible for choosing the candidate AP and initiating the handoff.

3. MAHO

- ✓ In MAHO, the mobile measures the signal levels from the various Aps.
- ✓ The mobile collects a set of power levels from different APs and feeds it back to the MSC via the AP.

1.4.1 Prioritizing Handoffs

- Method for giving priority to handoffs are
  1. Guard channel concept.
  2. Queuing of handoff requests.

1. Guard channel concept

- Guard channel concept is a fraction of the total available channels in a cell is reserved exclusively for handoff requests from ongoing calls which may be handed off into the cell.

Disadvantage

- It reduces the total carried traffic as fewer channels are allocated to originating calls.

Advantage

- It is efficient spectrum utilization during dynamic channel assignment strategies.

2. Queuing of handoff requests

- Queuing of handoff requests decreases the probability of forced termination of a call due to lack of available channels.
- Queuing of handoffs is possible due to the fact that there is a finite time interval between the time the received signal level drops below the handoff threshold and the time the call is terminated due to insufficient signal level.
- The delay time and size of the queue is determined from the traffic pattern of the particular service area.

1.4.2 Practical Handoff Considerations

- In practical cellular systems, several problems arise.
- High speed vehicles pass through the coverage region of a cell within a matter of seconds, whereas users may never need a handoff during a call.
- The MSC can quickly become burdened if high speed users are constantly being passed between very small cells.
- To solve this problem, ***Umbrella cell approach*** is used.

<u>Umbrella cell approach</u>

- By using different antenna heights (same building or tower) and different power levels, it is possible to provide “large” and” small” cells which are co-located at a single location. This technique is called the umbrella cell approach.
- The umbrella cell approach is used to provide large area coverage to high speed users while providing small area coverage to users travelling at low speeds.

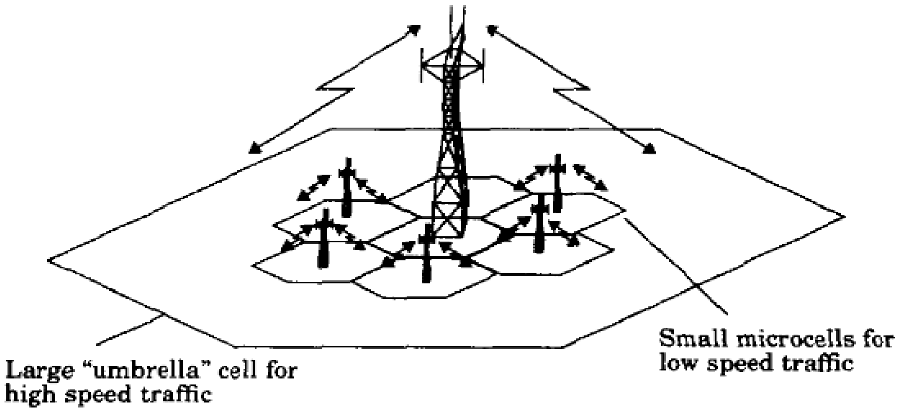

Figure: The umbrella cell approach.

- Figure illustrates an umbrella cell which is co-locates with some smaller microcells.
- The umbrella cell approach ensures that the number of handoffs is minimized for high speed users and provides additional microcell channels for pedestrian users.
- The speed of each user may be estimated by the base station or MSC by evaluating how rapidly the short-term average signal strength on the RVC changes over time, or more sophisticated algorithms may be used to evaluate and partition users.
- If a high speed user in the large umbrella cell is approaching the base station, and its velocity decreasing, the base station may decide to hand the user into the co-located microcell, without MSC intervention.

Cell Dragging

- Another practical handoff problem in microcell systems is known as cell dragging.
- Cell dragging results from users that provide a very strong signal to the base station.
- Such a situation occurs in an urban environment when there is a line-of-sight (LOS) radio path between the subscriber and the base station.
- As the user travels away from the base station at a very slow speed, the average signal strength does not decay rapidly.
- Even when the user has traveled well beyond the designed range of the cell, the received signal at the base station may be above the handoff threshold, thus a handoff may not be made.

Intersystem handoff:

During a call, if a mobile move from one cellular system to a different cellular system controlled by a different MSC, type of handoff is called intersystem handoff.

Types of Handoff

1. **Hard handover**

   - ✓ If the MSC monitors the strongest signal base station and transfer the call to that base station then it is called hard handoff.
   - ✓ The definition of a hard handover or handoff is one where an existing connection must be broken before the new one is established.
   - ✓ **Intra-frequency hard handovers** where the frequency channel remains the same.

2. Soft handover

- ✓ Mobile communicates with two or more cells at the same time and find which one is the strongest signal base station then it automatically transfers the call to that base station is called soft handoffs.
- ✓ The new 3G technologies use CDMA, it is not necessary to break the connection. This is called soft handover.
- ✓ Soft handoff is defined as a handover where a new connection is established before the old one is released.

3. Softer handover

- ✓ The third type of hand over is termed a softer handover, or handoff.
- ✓ In this instance a new signal is either added to or deleted from the active set of signals.
- ✓ It may also occur when a signal is replaced by a stronger signal from a different sector under the same base station.
- ✓ This type of handover or handoff is available within UMTS as well as CDMA2000.

Features of Handoff:

- ✓ Fast and lossless
- ✓ Minimal number of control signal exchanges.
- ✓ Scalable with network size.
- ✓ Capable of recovering from link failures.
- ✓ Efficient use of resources.

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1.4 Interference and System Capacity

7. Describe various interferences and increasing the system capacity of wireless cellular networks. (or)
Analyze the impact of both co-channel and adjacent chancel interference on system capacity in a cellular system. [May 2021] (or)
With neat sketch the first tier co-channel interference caused in a cluster size of 7.Also derive the expression that relates with the expression that relates the system capacity in terms of co-channel reuse ratio.[Nov/Dec 2021]

- ✓ Interference is the major limiting factor in the performance of cellular radio.
- ✓ It limits capacity and increases the number of dropped calls.

- ✓ Sources of interference include
  - ➢ Another mobile in the same cell
  - ➢ Call in progress in a neighboring cell,
  - ➢ Other base stations operating in the same frequency band,
  - ➢ Any non-cellular system which leaks energy into the cellular frequency band.

- ✓ Interference is more severe in urban areas due to

- Greater RF noise floor
- Large number of base stations and mobiles

- ✓ The two major types of interferences:
  1. Co-channel interference (CCI)
  2. Adjacent channel interference. (ACI)

- ✓ Adjacent channel interference is caused due to the signals that are adjacent in frequency.

1.5.1 Co-channel Interference and System Capacity

- ✓ Co-channel interference is caused due to the cells that reuse the same frequency set.
- ✓ The cells using the same frequency set are called co-channel cells.
- ✓ The interference between signals from the co-channel cells is called co-channel interference.
- ✓ Unlike thermal noise, co-channel interference cannot be overcome by increasing the carrier power of a transmitter
- ✓ This is because an increase in transmitter power increases the interference to neighboring co-channel cells.
- ✓ For similar sized cells, the co-channel interference is independent of the transmitted power and depends on the radius of the cell and the distance to the nearest co-channel cells.
- ✓ To reduce co-channel interference, co-channel cells must be physically separated.

- ✓ Co channel reuse ratio, $Q = D / R$

  where,

  $Q \rightarrow$ Co channel reuse ratio

  $D \rightarrow$ Distance to the nearest co-channel cells

  $R \rightarrow$ Radius of the cell

- ✓ It determines the spatial separation relative to the coverage distance of the cell.
- ✓ For a hexagonal geometry

$$Q = \frac{D}{R} = \sqrt{3N}$$

- ✓ Thus, a small value of Q provides larger capacity but higher co-channel interference.
- ✓ Hence there is a trade-off between capacity and interference.

Co-channel Reuse Ratio for Some Values of N

	Cluster Size (N)	Co-channel Reuse Ratio (Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

Calculation of signal-to-interference ratio (S/I or SIR)

- The signal-to-interference ratio for a mobile is

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_0} I_i}$$

where,

S $\rightarrow$ Desired signal power

I_i $\rightarrow$ Interference power caused by the i^th^ co-channel cell

i_0 $\rightarrow$ Number of co-channel interfering cells

- The average received power at a distance d is

$$P_r = P_0 \left(\frac{d}{d_0} \right)^{-n}$$

$$P_r\left(dBm\right) = P_0\left(dBm\right) - 10n\log\left(\frac{d}{d_0}\right)$$

where,

P_0 $\rightarrow$ Power received at a close-in reference point in the far field region of the antenna

d_0 $\rightarrow$ Small distance from the transmitting antenna

n $\rightarrow$ Path loss exponent.

- If D_i is the distance of the i^{th} interferer, the received power is proportional to $(D_i)^{-i_0}$.
- The path loss exponent, *n* ranges between 2 and 4.
- Thus the S/I for a mobile can be written as

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} \left(D_i\right)^{-n}}$$

- For only the first layer of equidistant interferers

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{\left(\sqrt{3N}\right)^n}{i_0} \qquad \because Q = \frac{D}{R} = \sqrt{3N}$$

- *S / I* is usually the worst casewhen a mobile is at the cell edge

$$\frac{S}{I} = \frac{R^{-4}}{2(D-R)^{-4} + 2(D+R)^{-4} + 2D^{-4}}$$

$$\frac{S}{I} = \frac{1}{2(Q-1)^{-4} + 2(Q+1)^{-4} + 2Q^{-4}}$$

- For a hexagonal cluster of cells

$$\frac{S}{I} = \frac{1}{6}\left(\frac{D}{R}\right)^{i_0} = \frac{1}{6}\left(\sqrt{3N}\right)^{i_0}$$

- Hence, S/I is independent of the cell radius.

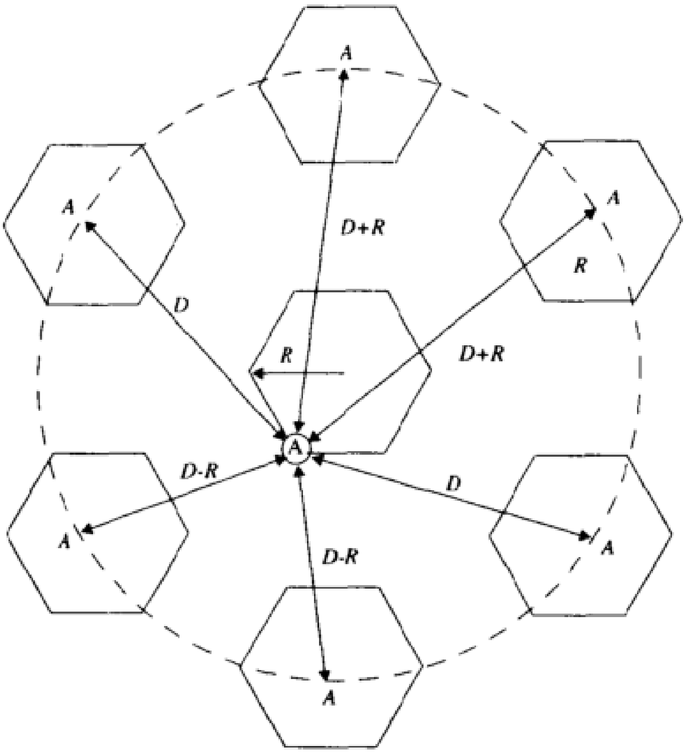


Figure: Illustration of the first tier of co-channel cells for a cluster size of N=7. When the mobile is at the cell boundary (point A), it experiences worst case co-channel interference on the forward channel. The marked distances between the mobile and different co-channel cells are based on approximations made for easy analysis.

1.5.2 Channel Planning for Wireless Systems

- Assigning the appropriate radio channels to each base station is an important process that is much more difficult in practice.
- The Equation $\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0}$ is a valuable rule for determining the appropriate frequency reuse ratio (or cluster size) and the appropriate separation between adjacent co-channel cells.
- But, the wireless engineer must deal with the real-world difficulties of radio propagation and imperfect coverage regions of each cell.

- Generally, the available mobile radio spectrum is divided into channels.
- These channels are made up of control channels (vital for initiating, requesting, or paging a call), and voice channels (dedicated to carrying revenue-generating traffic).
- Typically, about 5% of the entire mobile spectrum is devoted to control channels, which carry data messages that are very brief and bursty in nature.
- The remaining 95% of the spectrum is dedicated to voice channels.

- Control channels are vital in the successful launch of any call.
- The frequency reuse strategy applied to control channels is different and generally more conservative (e.g., is afforded greater S/I protection) than for the voice channels.

- One of the key features of CDMA systems is that the cluster size is N = 1, and frequency planning is not nearly as difficult as for TDMA.

- Propagation considerations require most practical CDMA systems to use some sort of limited frequency reuse.
- In the area of bodies of water, interfering cells on the same channel as the desired serving cell can create interference overload.

- In CDMA, a single 1.25 MHz radio channel carries the simultaneous transmissions of the single control channel with up to 64 simultaneous voice channels.
- The coverage region and interference levels are well defined when specific radio channels are in use than TDMA.
- The CDMA system has a dynamic, time varying coverage region which varies depending on the instantaneous number of users.
- This effect, known as a breathing cell, requires the wireless engineer to carefully plan the coverage and signal levels for the best and worst cases for serving cells.
- CDMA engineers must make difficult decisions about the power levels and thresholds assigned to control channels, voice channels.
- Also, threshold levels for CDMA handoffs, in both the soft handoff case and hard handoff case, must be planned and often measured carefully before turning up service.

1.5.3 Adjacent Channel Interference

- ✓ Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference.
- ✓ Adjacent channel interference results from imperfect receiver filters that allow nearby frequencies to leak into the passband.
- ✓ The problem can be severe if an adjacent channel user is transmitting in very close range to a subscriber's receiver.
- ✓ The near-far effect occurs when a mobile close to a base station radiates in the adjacent channel, while the subscriber is far away from the base station.
- ✓ Adjacent channel interference can be reduced by
  - Careful filtering
  - Careful channel assignments.
- ✓ The frequency separation between each channel in a cell should be made as large as possible.
- ✓ If the subscriber is at a distance d_1 and the interferer is at d_2, then signal-to-interference ratio is

$$\frac{S}{I} = \left(\frac{d_1}{d_2}\right)^{-n}$$

- ✓ The frequency separation between each channel in a cell should be made as large as possible while assigning them.

1.5.4 Power Control to Reduce Interference

- ✓ In practical systems, the power levels of every subscriber are under constant control by the serving base stations.
- ✓ Power control
- Reduces interference levels
- Prolongs battery life
- ✓ In CDMA spread spectrum systems, power control is a key feature to ensure maximal utilization of the system capacity.
- ✓ Reduced interference leads to higher capacity.

****

1.6 Trunking and Grade of Service

8. Describe the various terms involved in trunking and grade of service. (or)
Write short notes on i) Trunking ii) Grade of service of cell system. [Dec 2017, May 2019, Dec 2019]

- ✓ Cellular radio systems rely on trunking to accommodate a large number of users in a limited radio spectrum.
- ✓ The concept of trunking allows a large number of user to share the relatively small number of channels in a cell by providing access to each user, on demand, from a pool of available channels.
- ✓ In a trunked radio system, each user is allocated a channel on a per call basis.
- ✓ Upon termination of the call, the previously occupied channel is immediately returned to the pool of available channels.

- ✓ The time required to allocate a trunked radio channel to a requesting user is called **Set-up Time.**
- ✓ Call which cannot be completed at time of request due to congestion is called **Blocked Call or lost call**.
- ✓ Average duration of a typical call is called **Holding Time, H.**
- ✓ **Request Rate** is the average number of call requests per unit time.
  It is denoted by λ seconds^{-1}.
- ✓ **Traffic Intensity** is the measure of channel time utilization, which is the average channel occupancy measured in Erlangs.
- ✓ **Load** is the Traffic intensity across the entire trunked radio system, measured in Erlangs.
- ✓ A channel kept busy for one hour is defined as having a load of **one Erlang.**
- ✓ Grade of Service (GOS) is measure of congestion which is specified as the probability
  - ➢ Probability of a call being blocked (Erlang B)
  - ➢ Probability of a call being delayed beyond a certain amount of time (Erlang C)

- ✓ **The grade of service (GOS)** is a measure of the ability of a user to access a trunked system during the busiest hour.
- ✓ The grade of service is used to define the desired performance of a particular trunked system by specifying a desired likelihood of a user obtaining channel access given a specific number of channels available in the system.
- ✓ In order to obtain proper GOS, it is the necessary to estimate
- ➢ Maximum required capacity
- ➢ To allocate the proper number of channels.
- ✓ Each user generates a traffic intensity of A_u Erlangs given by

$$A_u = \lambda H$$

where,

$A_u \rightarrow$ Traffic intensity

$\lambda \rightarrow$ Average number of call requests per unit time

$H \rightarrow$ Average duration of a call

- ✓ Total offered traffic intensity A, is given as

$$A = UA_u$$

where,

$U \rightarrow$ Number of users in the system.

$A \rightarrow$ Total offered traffic.

- ✓ Traffic intensity per channel is given as

$$A_c = UA_u / C$$

where,

C $\rightarrow$ Number of trunked channels offered by a trunked radio system

- ✓ The Erlang B formula is given by

$$P_r[blocking] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = \text{GOS}$$

- ✓ The likelihood of a call not having immediate access to a channel is determined by the Erlang C formula

$$P_r[delay > 0] = \frac{A^c}{A^c + c!\left(1 - \frac{A}{C}\right)\sum_{k=0}^{C-1} \frac{A^k}{k!}}$$

****

1.6 Improving Capacity in Cellular Systems:

9. Explain some techniques intended to improve the coverage area and capacity of cellular system. (8m) [Nov 2015] (or)
Explain in detail how to improve coverage and channel capacity in cellular systems. (16m) [May 2016, Dec 2019] (or)
Define the methods of increasing the capacity of wireless cellular networks. (10M-May 2013) (or)
Explain the capacity improvement techniques used in cellular system. (10m) [May 2010, May 2019]
Write short notes on cell splitting [May 2019]

- ✓ Common Techniques used to expand the capacity of cellular systems are
  1. Cell splitting
  2. Sectoring
  3. Microcell Zoning

Cell splitting

- ✓ Cell splitting is the process of subdividing a congested cell into smaller cells with
  - ➢ its own base station
  - ➢ Corresponding reduction in antenna height
  - ➢ Corresponding reduction in transmitter power.

- ✓ Splitting of cells reduces the cell size and thus more number of cells has to be used.
- ✓ More number of cells => More number of clusters => More Channels => Higher capacity
- ✓ By defining new cells which have a smaller radius than the original cells and by installing these smaller cells (called microcells) between the existing cells, capacity increases due to the additional number of channels per unit area.
- ✓ Cells are split to add channels with no new spectrum usage

- ✓ Depending on traffic patterns, the smaller cells may be activated/deactivated in order to efficiently use cell resources.
- ✓ In the figure that the original base station A has been surrounded by six new microcell base stations.
- ✓ The smaller cells were added in such a way as to preserve the frequency reuse plan of the system.
- ✓ Cell splitting scales the geometry of the cluster.

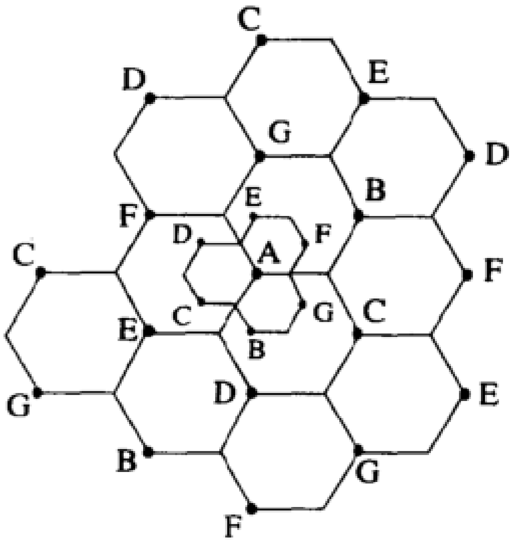


Figure: Illustration of cell splitting

- ✓ When new cell radius is half the original cell radius,

P_r [at old cell boundary] $\propto P_{t1}R^{-n}$

P_r [at new cell boundary] $\propto P_{t2}\left(R/2\right)^{-n}$

where,

$P_r \rightarrow$ Received power

$P_{t1} \rightarrow$ Transmit power of larger cell base station

$P_{t2} \rightarrow$ Transmit power of smaller cell base station

N $\rightarrow$ Path loss exponent

- ✓ Transmit power must be reduced by 12db in order to fill in the original coverage area with microcell while maintaining the S/I requirement.

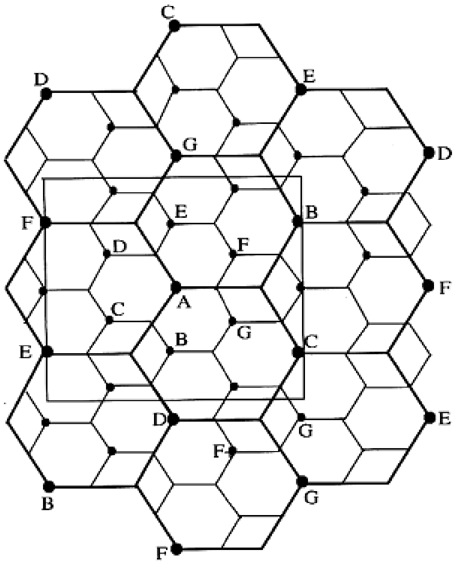
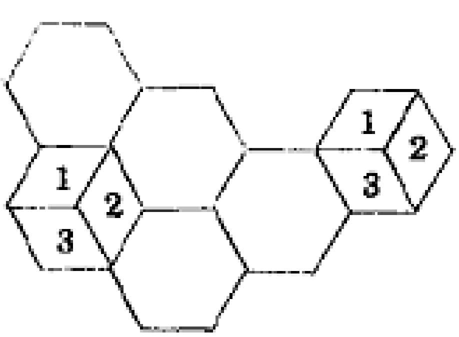


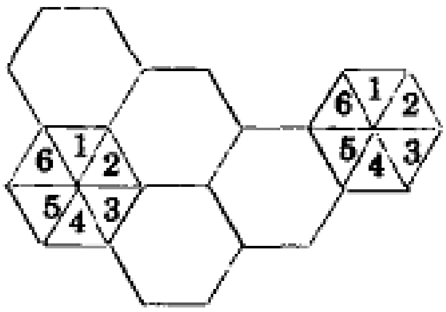
Figure: Illustration of cell splitting within a 3 km square centered base station A.

Sectoring

- ✓ The technique for decreasing co-channel interference and thus increasing system capacity by using directional antennas is called sectoring.
- ✓ The factor by which the co-channel interference is reduced depends on the amount of sectoring used.
- ✓ Cell Sectoring keeps R untouched and reduces D/R.
- ✓ Capacity improvement is achieved by reducing the number of cells per cluster, thus increasing frequency reuse.
- ✓ It is necessary to reduce the relative interference without decreasing the transmitter power.
- ✓ The co-channel interference may be decreased by replacing the single omni-directional antenna by several directional antennas, each radiating within a specified sector.
- ✓ A directional antenna transmits to and receives from only a fraction of the total number of co-channel cells. Thus co-channel interference is reduced.
- ✓ A cell is normally partitioned into three 120^0 sectors or six 60° sectors.



(a) 120^0 sectoring



(b) 60^0 sectoring

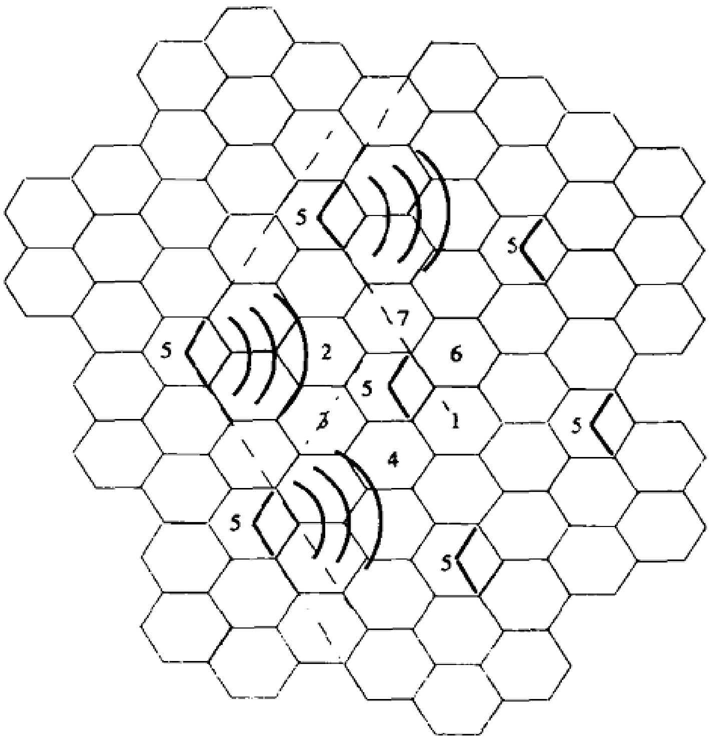


Figure: Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only 2 of them, interfere with the center cell. If omni-directional antennas were used at each base station, all 6 co-channel cells would interfere with the center cell.

Advantages

- ✓ It improves Signal-to-interference ratio.

Disadvantages

- ✓ Increased number of antennas at each base station.
- ✓ Decrease in trunking efficiency
- ✓ Increased number of handoffs.

Microcell Zoning

- ✓ Zone Concept
  - ➢ A cell is divided into microcell or zones.
  - ➢ Each microcell (Zone) is connected to the same basestation by coaxial cable, fiberoptic cable, or microwave link.
  - ➢ Each Zone uses a directional antenna
  - ➢ As mobile travels from one zone to another, it retains the same channel. i.e. Without handoff.
  - ➢ The base station simply switches the channel to the next zone site.
  - ➢ Mobile is served by the zone with the strongest signal.
- ✓ While the cell maintains a particular coverage area, the co-channel interference is reduced because:
  - ➢ The large central base station is replaced by several low powertransmitters.
  - ➢ Directional Antennas are used.
  - ✓ Decreased co-channel interference improves
  - ➢ Signal Quality
  - ➢ Capacity

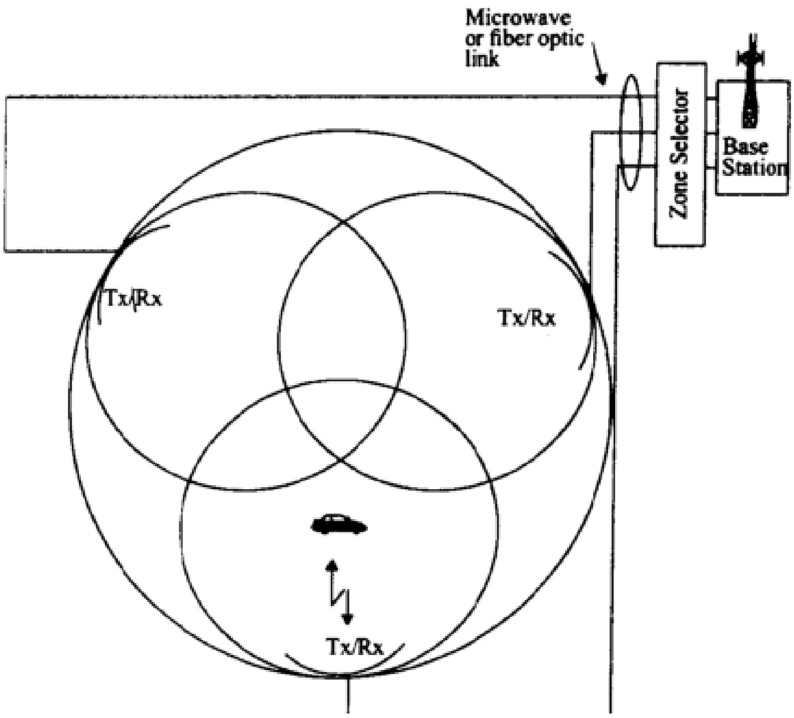


Figure: The microcell concept

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PROBLEMS

1. If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels, compute the number of channels available per cell if a system uses (a) 4-cell reuse, (b) 7-cell reuse (c) 12-cell reuse. If 1 MHz of the allocated spectrum is dedicated to control channels, determine an equitable distribution of control channels and voice channels in each cell for each of the three systems.

(**Apr/may 2010**, **Apr/ May 2017)**

Solution:

Given:

Total bandwidth =33 MHz

Channel bandwidth = 25 k}{z x 2 simplex channels = 50 kHz/duplex channel

Total available channels = 33,000/50 = 660 channels

(a) For N= 4,

Total number of channels available per cell = 660/4 = 165 channels.

(b) ForN=7,

Total number of channels available per cell = 660/7= 95 channels.

(c) For N = 12,

Total number of channels available per cell = 660/12 = 55 channels.

A 1 MHz spectrum for control channels implies that there are 1000/50 = 20 control channels out of the 660 channels available. It evenly distribute the control and voice channels, simply allocate the same number of channels in each cell wherever possible. Here, the 660 channels must be evenly distributed to each cell within the cluster. In practice, only the 640 voice channels would be allocated, since the control channels are allocated separately as 1 per cell.

(a) For N = 4, we can have 5 control channels and 160 voice channels per cell.

In practice, however, each cell only needs a single control channel (the control channels have a greater reuse distance than the voice channels).

Thus, one control channel and 160 voice channels would be assigned to each cell.

(b) For N = 7, 4 cells with 3 control channels and 92 voice channels, 2 cells with 3 control channels and 90 voice channels, and 1 cell with 2 control channels and 92 voice channels could be allocated.

In practice, however, each cell would have one control channel, four cells-4vould have 91 voice channels, andthree cells would have 92 voice channels.

(c) For N = 12, we can have 8 cells with 2 control channels and 53 voice channels, and 4 cells with 1 control channel and 54 voice channels each.

In an actual system, each cell would have 1 control channel, 8 cells would have 53 voice channels, and 4 cells would have 54 voice channels.

2.If a signal to interference ratio of 15 dB is required for satisfactory forward channel performance of a cellular system, what is the frequency reuse factor and cluster size that should be used for maximum capacity if the path loss exponent is (a) n = 4 , (b) nt = 3? Assume that there are 6 co-channels cells in the first tier, and all of them are at the same distance from the mobile. Use suitable approximations.

Solution:

(a) n = 4

First, let us consider a 7-cell reuse pattern.co-channel reuse ratio D/R = 4.583.

The sigal-to-noise interference ratio is given by S/I = (I/6)x(4.583) = 75.3 = 18.66 dB.

Since this is greater than the minimum required S/I, N = 7 can be used.

b) n=3

First, let us consider a 7-cell reuse pattern.

S/I = (l,6)x(4.583) = 16.04 = 12.05 dB.

Since this is less than the minimum required S/I, we need to use a larger N.

The next possible value of N is 12, (i = j = 2).

The corresponding co-channel ratio is given as D/R = 6.0.

The signal-to-interference ratio is given by

S/I = (1/6) x = 36 = 15.56 dB.

Since this is greater than the minimum required S/I, N = 12 can be used

3. A certain city has an area of 1,300 square miles and is covered by a cellular system using a 7-cell reuse pattern. Each cell has a radius of 4 miles and the city is allocated 40 MHz of spectrum with a full duplex channe] bandwidth of 60 kHz. Assume a GOS of 2% for an Erlang B system is specified. If the offered traffic per user is 0.03 Erlangs, compute (a) the number of cells in the service area, (b) the number of channels per cell, (c) traffic intensity of each cell, (d) the maximum carried traffic; (e) the total number of users that can be served for 2% GOS, (f') the number of mobiles per channel, and (g) the theoretical maximum number of users that could be served at one time by the system.[Nov/Dec 2019][Nov/Dec 2021]

Solution:

(a) Given:

Total coverage area = 1300 miles

Cell radius = 4 miles

The area of a cell (hexagon) can be shown to be 2.598 / R2, thus each cell covers 2.5981 x (4)2 = 41.57 sqm..

Hence, the total number of cells are = 1300/41.57 = 31 cells.

(b) The total number of channels per cell (C)

= allocated spectrum I (channel width x frequency reuse factor)

= 40, 000,000/ (60,000 x 7) = 95 channels/cell

(c) Given: C = 95, and GOS = 0.02

From the Erlang B chart, we havetraffic intensity per cell A = 84 Erlangs/cell

(d) Maximum carried traffic = number of cells x traffic intensity per cell

= 31 x 84 = 2604 Erlangs.

(e) Given traffic per user = 0.03 Erlangs

Total number of users = Total traffic / traffic per user

= 2604 / 0.02 = 86,800 users.

(f) Number of mobiles per channel = number of users/number of channels

= 86,800 / 666 = 130 mobiles/ehannel.

(g) The theoretical maximum number of served mobiles is the number of availablechannels in the system (all channels occupied)

= CxNc = 95 x 31 = 2945 users, which is 3.4% of the customer base.

4. A hexagonal cell within a 4-cell system has a radius of 1.387 km. A total of 60 channels are used within the entire system. If the load per user is 0.029 Erlangs, and λ = 1 calls/hour, compute the following for an Erlang C system that has a 5% probability of a delayed call:

(a) How many users per square kilometer will this system support?

(b) What is the probability that a delayed call will have to wait for more than 10 sec?

(c) What is the probability that a call will be delayed for more than 10 seconds?

Solution :

Given, Cell radius, R = 1.387 km

Area covered per cell is 2.598 x (1.387)2 = 5 sq kin

Number of cells per cluster = 4

Total number of channels = 60

Therefore, number of channels per cell = 60 / 4 = 15 channels.

(a) From Erlang C chart, for 5% probability of delay with C = 15, traffic intensity = 9.0 Erlangs.

Therefore, number of users = total traffic intensity/ traffic per user =9.0/0.029 = 310 users

= 310 users/S sq km = 62 users/sq km

(b) Given λ=1 = 1 , holding time

H = Au/λ = 0.029 hour = 104.4 seconds.

The probability that a delayed call will have to wait for more than 10 s is

Pr[delay > t | dleay |= exp(.—(C.-A)t / H) = exp(—(I5—9.0)I0/l04.4) = 56.29 %

(c) Given Pr delay >0] = 5% = 0.05

Probability that a call is delayed more than 10 seconds

Pr{delay> 10] = = 0.05 x 0.5629 = 2.81 %

5. **A digital mobile communication system has a forward channel frequency band ranging between 810 MHz to 826 MHz and a reverse channel band between 940 MHz to 956 MHz. Assume that 90 per cent of the band width is used by traffic channels. It is required to support at least 1150 simultaneous calls using FDMA The modulation scheme employed has a spectral efficiency of 1.68 bps / Hz. Assuming that the channel impairments necessitate the use of rate ½ FEC codes, find the upper bound on the transmission bit rate that a speech coder used in this system should provide?**

Solution :

Tbtal Bandwidth available for traffic channels = 0.9 x (810—826) = 14.4 MHz.

Number of simultaneous users = 1150.

Therefore, maximum channel bandwidth = 14.4 /1150 MHz = 12.5 kHz.

Spectral Efficiency = 1.68 bps/Hz.

Therefore, maximum channel data rate = 1.68 x 12500 bps = 21kbps.

FEC coder rate = 0.5.

Therefore, maximum net data rate = 21 x 0.5 kbps = 10.5 kbps.

Therefore, we need to design a speech coder with a data rate less than or equal to 10.5 kbps.

Consider the design of the U.S. digital cellular equalizer [Pro91]. If f = 900 MHz and the mobile velocity v = 80 km/hr, determine the following:

(a) the maximum Doppler shift

(b) the coherence time of the channel

(c) the maximum number of symbols that could be transmitted without updating the equalizer, assuming that the symbol rate is 24.3 ksymbols/sec

Solution to Example 6.3

(a) From equation (4.2), the maximum Doppler shift is given by

$$f_d = \frac{v}{\lambda} = \frac{(80,000/3600)\,\text{m/s}}{(1/3)\,\text{m}} = 66.67\ \text{Hz}$$

(b) From equation (4.40.c), the coherence time is approximately

$$T_c = \sqrt{\frac{9}{16\pi f_d^2}} = \frac{0.423}{66.67} = 6.34\ \text{msec}$$

Note that if (4.40.a) or (4.40.b) were used, T_C would increase or decrease by a factor of 2 – 3.

(c) To ensure coherence over a TDMA time slot, data must be sent during a 6.34 ms interval. For R_s=24.3 ksymbols/sec, the number of bits that can be sent is

$$N_b = R_s T_C = 24,300 \times 0.00634 = 154 \text{ symbols}$$

As shown in Chapter 10, each time slot in the U.S. digital cellular standard has a 6.67 ms duration and 162 symbols per time slot, which are very close to values in this example

7. The output of a speech coder has bits which contribute to signal quality with varying degree of importance. Encoding is done on blocks of samples of 20 ms duration (260 bits of coder output). The first 50 of the encoded speech bits (say type 1) in each block are considered to be the most significant and hence to protect them from channel errors are appended with 10 CRC bits and convolutionally encoded with a rate 1/ 2 FEC coder. The next 132 bits (say type 2) are appended with 5 CRC bits and the tast 78 bits (say type 3) are not error protected. Compute the gross channel data rate achievable.

Solution :

Number of type 1 channel bits to be transmitted every 20 ms

(5+l0x2) = 120 bits

Number of type 2 channel bits to be transmitted every 20 ms

132 +5 = 137 bits

Number of type 3 channel bits to be encoded = 78 bits

Total number of channel bits to be transmitted every 20 ms

120 + 137 +78 bits = 335 bits

Therefore, gross channel bit rate = 335/ (20 x I0-3) = 16.75 kbps.

8.

Example 8.2

If B_t is 12.5 MHz, B_{guard} is 10 kHz, and B_c is 30 kHz, find the number of channels available in an FDMA system.

Solution to Example 8.2

The number of channels available in the FDMA system is given as

$$N = \frac{12.5 \times 10^6 - 2(10 \times 10^3)}{30 \times 10^3} = 416$$

In the U.S., each cellular carrier is allocated 416 channels.

9. If GSM uses a frame structure where each frame consists of 8 time slots, andeach time slot contains 156.25 bits, and data is transmitted at 270.833 kbps inthe channel, find (a) the time duration of a bit, (b) the time duration of a slot,(c) the time duration of a frame, and (d) how long must a user occupying a singletime slot must wait between two simultaneous transmissions

Solution

(a) The time duration of a bit, $T_b = \frac{1}{270.833 \text{ kbps}} = 3.692\ \mu s.$

(b) The time duration of a slot, $T_{slot} = 156.25 \times T_b = 0.577$ ms.

(c) The time duration of a frame, $T_f = 8 \times T_{slot} = 4.615$ ms.

(d) A user has to wait 4.615 ms, the arrival time of a new frame, for its next transmission.

Example 8.5

If a normal GSM time slot consists of 6 trailing bits, 8.25 guard bits, 26 training bits, and 2 traffic bursts of 58 bits of data, find the frame efficiency.

Solution to Example 8.5

A time slot has $6 + 8.25 + 26 + 2(58) = 156.25$ bits.

A frame has $8 \times 156.25 = 1250$ bits/frame.

The number of overhead bits per frame is given by

$$b_{OH} = 8(6) + 8(8.25) + 8(26) = 322 \text{ bits}$$

Thus, the frame efficiency

$$\eta_f = \left[1 - \frac{322}{1250}\right] \times 100 = 74.24\ \%$$

11**. In a cellular system with total of 917 radio channels available for handling traffic. The area of a cell is 4 km2 and the total area is 1400 km2 with cluster of 7.**

(a) Calculate the system capacity.

(b) How many times signal can be replicated?

(c) Calculate the system capacity for N = 4.

(d) Compare the performance.

Solution:

(a) System capacity C = MKN

M = Number of times the cluster has to be replicated

$$M = \frac{A_{sys}}{A_{cluster}} = ?$$

$$A_{cluster} = N \times A_{singlecell} = 7 \times 4 = 28 \text{ km}^2$$

$$M = \frac{1400}{28} = 50$$

$$K = \text{Number of channels per cell}$$

$$K = \frac{S}{N} = \frac{917}{7} = 131 \text{ channels/cell}$$

$$\text{System capacity } C = MKN = 50 \times 131 \times 7$$

$$\boxed{C = 45850 \text{ channels}}$$

(b) $$M = \frac{A_{sys}}{A_{cluster}} = \frac{1400}{28} = 50$$

(c) For N = 4, $$A_{cluster} = N \times A_{cell} = 4 \times 4 = 16 \text{ km}^2$$

$$M = \frac{A_{sys}}{A_{cluster}} = \frac{1400}{16} = 87.5 \approx 87$$

$$C = MKN$$

$$K = \frac{S}{N} = \frac{917}{4} = 229.25 \approx 229 \text{ channels/cell}$$

$$C = MKN$$

$$C = 87 \times 229 \times 4 = 79692 \text{ channels}$$

(d) For N = 7, C = 45850 channels

For N = 4, C = 79692 channels

∴ The cluster size decreases, the capacity of the system increases.

---

12. For a cellular system with a total bandwidth of 15 MHz uses 10 KHz simplex channels to provide full duplex voice and control channels. For 12 cell reuse pattern and 1 MHz of the total bandwidth is allocated for control channels.

(a) Calculate the total available channels.

(b) Determine the number of control channels.

(c) Calculate the number of voice channels per cell.

$$(a) \quad \text{Total channels} = \frac{\text{Total bandwidth}}{\text{Channel bandwidth}}$$

$$\text{Channel bandwidth for duplex} = 10 \text{ KHz} \times 2$$

$$= 20 \text{ KHz/duplex channel}$$

$$\text{Total channels} = \frac{15{,}000 \text{ KHz}}{20 \text{ KHz}} = 750$$

$$(b) \quad \text{Number of control channels} = \frac{\text{Bandwidth of control channel}}{\text{Channel bandwidth}}$$

$$= \frac{1000 \text{ KHz}}{20 \text{ KHz}} = 50$$

$$(c) \quad \text{The number of voice channels per cell} = \frac{\text{Total channel} - \text{Number of control channel}}{\text{Cluster size}}$$

$$= \frac{750 - 50}{12} = \frac{700}{12} = 58.3 \approx 58$$

13. In the FDMA system, the total spectrum bandwidth is 12.5 MHz, each channel is 30 KHz. The edge guard spacing is 10 KHz. Find the total number of channels available in the system.

$$\text{Total number of available channels} = \frac{\begin{Bmatrix}\text{Spectrum} \\ \text{bandwidth}\end{Bmatrix} - 2 \times \begin{Bmatrix}\text{Guard} \\ \text{spacing}\end{Bmatrix}}{\text{Channel bandwidth}} \quad (\text{in KHz})$$

$$= \frac{12500 - 2 \times 10}{30}$$

$$= \frac{12480}{30}$$

$$\boxed{\text{Total channels} = 416 \text{ channels}}$$

14. Consider Global System for Mobile, which is a TDMA/FDD system that uses 25 MHz for the forward link, which is broken into radio channels of 200 kHz. If speech channels are supported on a single radio channel, and if no guard band is assumed, find the number of simultaneous users that can be accommodated in GSM.

Datas: 25 MHz for the forward linkradio channels of 200 kHz

$$N = \frac{25 \text{ MHz}}{(200 \text{ kHz})/8} = 1000$$

Thus, GSM can accommodate 1000 simultaneous users.

TWO MARKS

1. **What is multiple access technique? [May 2016, Nov 2013][April/May2023]**
   Multiple access or channel access method is based on a multiplexing method that allows several data streams or signals to share the same communication channel or physical medium.

2. **Write the applications of multiple access methods.**
   - ➢ The multiple access methods are used in
   - ✓ Satellite networks
   - ✓ Cellular and mobile communication networks
   - ✓ Military communication and
   - ✓ Underwater acoustic networks.
   - ✓

3. **What are the different types of multiple access schemes? [May 2012]**
   The different types of multiple access schemes are
   - ➢ Frequency Division Multiple Access (FDMA)
   - ➢ Time Division Multiple Access (TDMA)
   - ➢ Code Division Multiple Access (CDMA)

4. **State the difference between Narrowband and wideband systems. [Nov 2013, Nov 2012]**

NARROWBAND SYSTEMS	WIDEBAND SYSTEMS
In a narrowband system, the available radio spectrum is divided into a large number of narrowband channels.	In wideband system, a large number of transmitters are allowed to transmit on the same channels.

5. **Define FDMA.**
   In FDMA, the total bandwidth is divided into non-overlapping frequency sub bands. Each user is allocated a unique frequency sub band (channels) for the duration of the connection, whether the connection is in an active or idle state.

6. **What is the need of guard bands in FDMA?**
   The adjacent frequency bands in the FDMA spectrum are likely to interference with each other. Therefore it is necessary to include the guard bands between the adjacent frequency bands.

7. **Mention some features of FDMA.[Nov/Dec 2019]**
   - ✓ FDMA is relatively simple to implement.
   - ✓ To provide interference-free transmissions between the uplink and the downlink channels, the frequency allocations have to be separated by a sufficient amount (guard bands).

8. **Write the nonlinear effects in FDMA.**
   In FDMA system, many channels share same antenna at the base station. The power amplifiers and the power combiners used are nonlinear, and tend to generate inter modulation frequencies resulting in inter modulation distortion.

9. **Write the expression for number of channels used in FDMA system.**
   The number of channels that can be simultaneously supported in a FDMA system is given by

$$N_S = \frac{B_s - 2B_g}{B_c}$$

Where, B_s-Total spectrum allocation (or) system bandwidth

B_g-Guard band allocated at the edge of the allocated spectrum band and

B_g-Channel bandwidth

10. Write the formula for spectral efficiency of FDMA.

- ✓ The spectral efficiency of FDMA is given by

  $$\eta_{FDMA} = \frac{bandwidthavailablefordatatransmission}{systembandwidth}$$

  $$\eta_{FDMA} = \frac{N_{data}B_c}{B_s} < 1$$

  Where N_{data}=Number of data channels in the system.

  $N_{data} = N_S$-N_{ctl}

  $N_{ctl} =$ Number of allocated control channels

11. Mention the disadvantages of FDMA.

- ✓ This type of multiple access support is narrow band, and is not suitable for multimedia communications with various transmission rates.
- ✓ If a FDMA channel is not in use, then it is idle and cannot be used by other users to increase or share capacity. It is essentially a wasted resource.
- ✓ FDMA is an old and is used for the analog signal.

12. Define TDMA.

- ✓ Time Division Multiple Access (TDMA) systems divide the ratio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive.

13. What is W- TDMA?

- ✓ In wideband TDMA, transmission in each slot uses the entire frequency band.

14. Define N- TDMA.

- ✓ In narrow band TDMA, the whole frequency band is divided into sub band, transmission in each slot only uses the frequency width of one sub band.

15. Write the features of TDMA.

- ✓ TDMA shares a single carrier frequency with several users, where each user makes use of non-overlapping time slots.
- ✓ Data transmission for users of a TDMA system is not continuous, but occurs in bursts. This results in low battery consumption, since the subscriber transmitter can be turned off when not in use.
- ✓ Because of discontinues transmissions in TDMA, the handoff process is much simpler for a subscriber unit, since it is able to listen for other base stations during idle time slots.

16. What is frame efficiency in TDMA?

- ✓ The frame efficiency is the ***percentage***of bits per frame which contain transmitted data.

  The frame efficiency is given by

$$\eta_f = \left(1 - \frac{b_{OH}}{b_T}\right) \times 100\%$$

$b_{OH} =$ Number of overhead bits per frame and

$$b_T = \text{Number of total bits per frame}$$

17. What are the disadvantages of TDMA?[Nov/Dec 2019]

- ✓ High synchronization overhead is required in TDMA systems because of burst transmissions.
- ✓ In TDMA, the guard time should be minimized.

18. How does near/far problem influence TDMA systems? [Nov 2015]

The near-far problem is one of detecting or filtering out a weaker signal amongst stronger signals. The near-far problem is particularly difficult in CDMA systems where transmitters share transmission frequencies and transmission time. In contrast, FDMA and TDMA systems are less vulnerable.

19. State advantages of CDMA over FDMA. [Nov 2014]

CDMA sends digital signals spread out over a larger bandwidth constantly with each signal having a unique sequence code so that each call can be separated at the receiver. In theory, CDMA can carry 8-10 times the number of calls as FDMA, although probably not nearly that many times in the real world.

20. Define near-far problem in CDMA.

- ✓ Some of the mobile units are close to the base station while others are far from it. A strong signal received at the base from a near –in mobile unit and the weak signal from a far –end mobile unit. This phenomenon is called the near-far problem.

21. Write some features of CDMA.

- ✓ Many user of CDMA system share the same frequency.
- ✓ Channel data rates are very high in CDMA system.
- ✓ CDMA has more flexibility than TDMA in supporting multimedia service.

CELLULAR CONCEPT

22. Write the cellular concept. (or)
Why is cellular concept used for mobile telephony? [May 2017]

If a given set of frequencies or radio channels can be reused without increasing the interference, then the large geographical area covered by a single high power transmitter can be divided into a number of small areas, each allocated power transmitters with lower antennas can be used.

23. Why hexagon shape was selected for cell?

The Hexagon shape was chosen for cell because it provides the most effective transmission by approximating a circular pattern while eliminating gaps present between adjacent circles.

24. Differentiate between macro cells and microcells.

The physical size of a cell varies, depending on user density and calling patterns.

- ✓ Macro cells are large cells typically have a radius between 1 mile and 15 miles with base station transmit powers between 1W and 6W.
- ✓ Microcells are the smallest cells typically have a radius between of 1500 feet or less with base station transmit powers between 0.1W and 1W.

25. Mention the need of Pico cells.

- ✓ Cellular radio signal are to week to provide reliable communication at indoor, especially in well-shielded areas or areas with high levels of interference.

- ✓ To overcome this, very small cells called Pico cells are used in same frequencies as regular cells in the same areas.
- ✓

26. Define cell & cell cluster.

- ✓ Each cellular base station is allocated a group of radio channels to be used with a small geographic area called a cell.
- ✓ A group of cells that use a different set of frequencies in each cell is called a cell cluster.

27. Based on the location of BS, how cells are classified?

- ✓ When designing a system using hexagonal-shaped cells, main consideration is the location of the base station transmitters.
  - ➢ Center-excited cell- Base station transmitters can be located in the center of the cell and uses Omni directional antennas which radiate and receive signals equally well in all directions.
  - ➢ Edge- excited cell- Base station transmitters can be located in the edge of the cell and uses sectored antennas which radiate for a particular direction.
  - ➢ Corner- excited cell- Base station transmitters can be located in the corner of the cell and uses sectored directional antennas.

FREQUENCY REUSE

28. Define Frequency reuse. [May 2016, May 2013, Nov 2016, Nov/Dec 2017, April/May 2018, 2021], [Nov/Dec 2021][April/May 2023]

- ✓ The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency reuse or frequency planning.
- ✓ Physical separation of two cells is sufficiently wide; the same subset of frequencies can be used in both cells.
  - ▪ This is the concept of frequency reuse.
  - ▪ The same spectrum can support multiple users and available spectrum is efficiently utilized.

29. Define foot print.

- ✓ The actual radio coverage of a cell is known as the foot print. It is determined from field measurement or propagation prediction models.

30. Express the total number of channels available in cluster.

For total number of cellular channels available in a cluster can be expressed mathematically as ***S=Kn***

Where, S-Number of full-duplex cellular channels available in cluster.
K-Number of channels in a cell and
n-Number of cells in a cluster.

31. What are the rules used to determine the nearest co channel neighbors?

The following two-step rules can be used to determine the location of the nearest co channel cell:

Step 1: Move I cells along any chain of hexagons;

Step 2: Turn 60 degrees counter clockwise and more j cells.

32. Write the expression for cellular system capacity.

Let M be the number of times the cluster is replicated and C be the total number of channels used in the entire cellular system with frequency reuse. C is then the system capacity and is given by **C=MKn; C=MS**

Where C- Total channel capacity in a given area

M-Number of clusters in a given area

33. Define FRF.

The number of user use the same set of frequencies is called the frequency reuse factor (FRF) and is defined mathematically as

$$\mathbf{FRF} = \frac{\boldsymbol{N}}{\boldsymbol{C}}$$

Where N-Total number of full-duplex channels in an area

C-Total number of full-duplex channels in a cell.

HAND OFF

34. Write the advantages of cellular systems?

- ✓ The advantages of Cellular Systems:
  - The use of low power transmitter and
  - It allows frequency reuse for capacity improvement.

35. Define Dwell time.

The time over which a call may be maintained within a cell, without handoff, is called the dwell time.

36. What are the methods used for handoffs?

Depending on the information used and the action taken to initiate the handoff, the methods for handoff can be

- Mobile Controlled Hand off (MCHO)
- Network Controlled Hand off (NCHO) and
- Mobile Assisted Hand off (MAHO)

37. Write about umbrella cell approach and its usage.

- ✓ By using different antenna heights (same building or tower) and different power levels, it is possible to provide “large” and” small” cells which are co-located at a single location.
- ✓ The umbrella cell approach is used to provide large area coverage to high speed users while providing small area coverage to users travelling at low speeds.

38. Write a short note on hard handoff and Soft handoff.
What is soft handoff in mobile communication? [May 2016]

- ✓ **Hard Handoff:** If the MSC monitors the strongest signal base station and transfer the call to that base station then it is called hard handoff.
- ✓ **Soft handoff:** Mobile communicates with two or more cells at the same time and find which one is a strongest signal base station then it automatically transfers the call to that base station is called soft handoffs.

39. In a cellular network, among a handoff call and new call, which one is given priority? Why? [April 2017]

- ✓ Different systems have different methods for handling and managing handoff request.
- ✓ Some systems handle handoff in same way as they handle new originating call.
- ✓ In such system the probability that the handoff will not be served is equal to blocking probability of new originating call.

- ✓ But if the call is terminated abruptly in the middle of conversation then it is more annoying than the new originating call being blocked.
- ✓ So in order to avoid this abrupt termination of ongoing call handoff request should be given priority to new call this is called as handoff prioritization.

40. What are the techniques used to prioritize the handoff call and new call?

There are two techniques for this:

Guard Channel Concept

In this technique, a fraction of the total available channel in a cell is reserved exclusively for handoff request from ongoing calls which may be handed off into the cell.

Queuing

Queuing of handoffs is possible because there is a finite time interval between the time the received signal level drops below handoff threshold and the time the call is terminated due to insufficient signal level. The delay size is determined from the traffic pattern of a particular service area.

41. Mention the limitations of cellular communication systems? [June 2013]

Limitations of cellular communication systems

i. fixed network needed for the base stations
ii. handover (changing from one cell to another) necessary
iii. interference with other cells

42. What are the reasons for handover? [Nov 2013]

There are different reasons for handover:

i. When the phone is moving away from the area covered by one cell and entering the area covered by another cell, the call is transferred to the second cell, in order to avoid call termination.
ii. When the capacity for connecting new calls of a given cell is used up and an existing or new call from a phone is transferred to that cell in order to free-up some capacity in the first cell.

43. Write the features of handoff.

- ✓ Fast and lossless
- ✓ Minimal number of control signal exchanges.
- ✓ Scalable with network size.
- ✓ Capable of recovering from link failures and
- ✓ Efficient use of resources.

<u>CHANNEL ASSIGNMENT</u>

44. Name the two channels assignments.

- ✓ There are essentially two channels assignment approaches
  - ▪ Fixed channel assignment and
  - ▪ Dynamic channel assignment

45. What is FCA?

- ✓ In FCA, each cell is allocated a predetermined (permanently) set of voice channels. Any call attempt within the cell can only be served by the unused channels in that particular cell.

46. Define borrowing strategy.

- ✓ To improve utilization, a borrowing option may be considered borrowing strategy; a cell is allowed to borrow channels from a neighboring cell if all of its own channels are already occupied.

47. What do you meant by DCA? Give its advantages.

- ✓ In DCA, voice channels are not allocated to different cells permanently. Each time a cell request is made, the serving base station request a channel from the MSC.
- ✓ Dynamic channel assignment reduces the call blocking, which increases the trucking capacity of the system, since all available channel under the control of the MSC are accessible to the entire cell.

48. Define co-channel reuse ratio. [Nov 2015]

The co-channel reuse ratio Q is defined as

$$Q = \frac{D}{R}$$

Where,

D - Distance between centers of the nearest co-channel cells

R - Radius of the cell

49. Mention a few techniques used to expand the capacity of a cellular system. [May 2015]

Cell splitting, Sectoring, Coverage Zone approaches are the techniques used to expand the capacity of cellular system.

Cell splitting

- Cell-splitting is a technique which has the capability to add new smaller cells in specific areas of the system. i.e. divide large cell size into small size.

Sectoring

- use of directional antennas to reduce Co-channel interference.
- Coverage Zone approaches
- Large central BS is replaced by several low power transmitters on the edge of the cell.

50. Define co-channel Interference. [Nov 2015, May 2016]

- ✓ Co-channel interference is caused due to the cells that reuse the same frequency set.
- ✓ The cells using the same frequency set are called co-channel cells.
- ✓ The interference between signals from the co-channel cells is called co-channel interference.

51. Define adjacent channel Interference.

- ✓ Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference.
- ✓ Adjacent channel interference results from imperfect receiver filters that allow nearby frequencies to leak into the passband.

52. What do you mean by forward and reverse channel? [Nov/Dec 2017]

- ✓ The channels used for transmission from the base station to mobiles are called ***forward channels***
- ✓ The channels used for transmission from mobiles to the base station are called ***reverse channels***.

53. Differentiate between FDMA, TDMA and CDMA technologies.[April/May 2018]

S. No.	FDMA	TDMA	CDMA
1	Channel bandwidth is subdivided into number of sub channels	The radio spectrum is divided into time slots and each slot is allotted for only one user who can either transmit or receive.	Sharing of bandwidth and time takes place.
2	FDMA uses Narrow band Systems.	TDMA uses Narrow band Systems or wide band Systems	CDMA uses Wide band Systems.
3	FDMA is First generation wireless standard (1G).	TDMA is Second generation wireless standard (2G).	CDMA is third generation wireless standard (3G).
4	FDMA is use for the voice and data transmission	TDMA is used for data and digital voice signals	CDMA is use for digital voice signals and multimedia services.
5	Due to non-linearity of power amplifiers, inter-modulation products are generated due to interference between adjacent channels.	Due to incorrect synchronization there can be interference between the adjacent time slots.	Both type of interference will be present.
6	Synchronization is not necessary	Synchronization is necessary	Synchronization is not necessary
7	Code word is not required	Code word is not required	Code words are required
8	Guard bands between adjacent channels are necessary.	Guard times between adjacent time slots are necessary.	Guard bands and guard times are necessary.

54. How FDMA handles near-far problem?[April/May 2019]

The near-far problem is one of detecting or filtering out a weaker signal amongst stronger signals. The near-far problem is particularly difficult in FDMA systems where transmitters share transmission frequencies and transmission time.

55. What do you mean by mobile – assisted handoff? [April/May 2019]

In MAHO, the mobile measures the signal levels from the various APs using periodic beacon generated by the APs. The mobile collects a set of power levels from different APs and feeds it back to the MSC via the serving AP, for handoff decision making.

56. Write down the procedure involved in the determination of Co-Channel Cell. [April/May 2021]

Step 1: Move I cells along any chain of hexagons;

Step 2: Turn 60 degrees counter clockwise and more j cells.

57. What is the tradeoff that exists between system capacity and coverage? [Nov/Dec 2021]

Since network coverage depends on interference, reducing traffic load to values below network capacity with result in higher coverage. The overall performance under such circumstances can potentially be better than provided by lower-lying tradeoff points evaluated at maximum traffic load.

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QUESTION BANK

UNIT-I

THE CELLULAR CONCEPT-SYSTEM DESIGN FUNDAMENTALS

PART – A

1. What is multiple access technique?
2. What is the tradeoff that exists between system capacity and coverage?
3. Write down the procedure involved in the determination of Co-Channel Cell.
4. What do you mean by mobile – assisted handoff?
5. How FDMA handles near-far problem?
6. What do you mean by forward and reverse channel?
7. Mention the limitations of cellular communication systems?
8. What are the reasons for handover?
9. In a cellular network, among a handoff call and new call, which one is given priority? Why?
10. Define Frequency reuse.
11. Why is cellular concept used for mobile telephony?
12. What are the disadvantages of TDMA?
13. State the difference between Narrowband and wideband systems.
14. What are the different types of multiple access schemes?
15. Mention some features of FDMA.

PART – B & C

1. Explain the concept of cellular topology and cell fundamentals. [Dec 2015, May 2023]
2. Discuss in detail about frequency reuse. [8m] [Dec 2014, Dec 2021]
3. Explain channel assignment in detail. [April/May 2018]
4. Explain the principle of cellular networks and various types of handoff techniques. [May 2016, May 2013, Dec 2014, Dec 2019, May 2018, May 2019, May 2021, May 2023]
5. Describe various interferences and increasing the system capacity of wireless cellular networks. [May 2021, Dec 2021]
6. Write short notes on i) Trunking ii) Grade of service of cell system. [Dec 2017, May 2019, Dec 2019]
7. Explain in detail how to improve coverage and channel capacity in cellular systems. [Nov 2015, May 2016, Dec 2019, May 2013, May 2010, May 2019]

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SYLLABUS

EC3501 WIRELESS COMMUNICATION

COURSE OBJECTIVES:

- To study and understand the concepts and design of a Cellular System.
- To Study And Understand Mobile Radio Propagation And Various Digital Modulation Techniques.
- To Understand The Concepts Of Multiple Access Techniques And Wireless Networks

UNIT-I THE CELLULAR CONCEPT-SYSTEM DESIGN FUNDAMENTALS 9

Introduction-FrequencyReuse-Channel Assignment Strategies-**Handoff Strategies:**Prioritizing Handoffs, Practical Handoff Considerations. **Interference And System Capacity**: Co-Channel Interference And System Capacity-Channel Planning For Wireless Systems, Adjacent Channel Interference, Power Control For Reducing Interference, Trunking And Grade Of Service. **Improving Coverage And Capacity In Cellular Systems:** Cell Splitting, Sectoring.

UNIT-II MOBILE RADIO PROPAGATION 9

Large Scale Path Loss: Introduction To Radio Wave Propagation - Free Space Propagation Model – **Three Basic Propagation Mechanism:** Reflection – Brewster Angle- Diffraction- Scattering.**Small Scale Fading And Multipath:** Small Scale Multipath Propagation, Factors Influencing Small-Scale Fading, Doppler Shift, Coherence Bandwidth, Doppler Spread And Coherence Time. **Types Of Small-Scale Fading:** Fading Effects Due To Multipath Time Delay Spread, Fading Effects Due To Doppler Spread.

UNIT- III MODULATION TECHNIQUES AND EQUALIZATION AND DIVERSITY 9

Digital Modulation – **An Overview**: Factors That Influence The Choice Of Digital Modulation, **Linear Modulation Techniques:** Minimum Shift Keying (MSK), Gaussian Minimum Shift Keying(GMSK), **Spread Spectrum Modulation Techniques:** Pseudo- Noise (PN) Sequences, Direct Sequence Spread Spectrum (DS-SS)- Modulation Performance In Fading And Multipath Channels- **Equalization, Diversity And Channel Coding:** Introduction-Fundamentals Of Equalization- **Diversity Techniques:** Practical Space Diversity Considerations, Polarization Diversity, Frequency Diversity, Time Diversity.

UNIT- IV MULTIPLE ACCESS TECHNIQUES 9

Introduction: Introduction To Multiple Access- Frequency Division Multiple Access (FDMA)- Time Division Multiple Access(TDMA)- Spread Spectrum Multiple Access-Code Division Multiple Access(CDMA)- Space Division Multiple Access(SDMA)- **Capacity Of Cellular Systems:** Capacity Of Cellular CDMA, Capacity Of CDMA With Multiple Cells.

UNIT- V WIRELESS NETWORKING 9

Introduction: Difference Between Wireless And Fixed Telephone Networks, The Public Switched Telephone Network(PSTN), Development Of Wireless Networks: First Generation Wireless Networks, Second Generation Wireless Networks, Third Generation Wireless Networks, Fixed Network Transmission Hierarchy, TrafficRoutingInWireless Networks: Circuit Switching, Packet Switching-Personal Communication Services/ Networks(PCS/PCNs):Packet Vs Circuit Switching For PCN, Cellular Packet- Switched Architecture- Packet Reservation Multiple Access(PRMA)- Network Databases: Distributed Database For Mobility Management- Universal Mobile Telecommunication Systems(UMTS).

45 PERIODS

PRACTICAL EXERCISES: 30 PERIODS

1. Modeling of wireless communication systems using Matlab(Two ray channel and Okumura –Hata model)
2. Modeling and simulation of Multipath fading channel
3. Design, analyze and test Wireless standards and evaluate the performance measurements such as BER, PER, BLER, throughput, capacity, ACLR, EVM for 4G and 5G using Matlab
4. Modulation: Spread Spectrum – DSSS Modulation & Demodulation
5. Wireless Channel equalization: Zero-Forcing Equalizer (ZFE),MMSE Equalizer(MMSEE),Adaptive Equalizer (ADE),Decision Feedback Equalizer (DFE)
6. Modeling and simulation of TDMA, FDMA and CDMA for wireless communication

TOTAL:75 PERIODS

COURSE OUTCOMES :

Upon successful completion of the course the student will be able to:

CO1:Understand The Concept And Design Of A Cellular System.

CO2:Understand Mobile Radio Propagation And Various Digital Modulation Techniques.

CO3:Understand The Concepts Of Multiple Access Techniques And Wireless Networks

CO4:Characterize a wireless channel and evolve the system design specifications

CO5:Design a cellular system based on resource availability and traffic demands.

TEXT BOOK :

1. Rappaport,T.S.,-Wireless communications", Pearson Education, Second Edition, 2010.

REFERENCES :

1. Wireless Communication –Andrea Goldsmith, Cambridge University Press, 2011

2. Van Nee, R. and Ramji Prasad, ―OFDM for wireless multimedia communications, Artech House, 2000

3. David Tse and Pramod Viswanath, ―Fundamentals of Wireless Communication, Cambridge University Press, 2005.

4. Upena Dalal, ―Wireless Communication", Oxford University Press, 2009.

5. Andreas.F. Molisch, ―Wireless Communications", John Wiley – India, 2006.

6. Wireless Communication and Networks –William Stallings ,Pearson Education, Second Edition 2002.

UNIT-II
MOBILE RADIO PROPAGATION

Large Scale Path Loss: Introduction To Radio Wave Propagation - Free Space Propagation Model – **Three Basic Propagation Mechanism:** Reflection – Brewster Angle- Diffraction- Scattering. **Small Scale Fading And Multipath:** Small Scale Multipath Propagation, Factors Influencing Small-Scale Fading, Doppler Shift, Coherence Bandwidth, Doppler Spread And Coherence Time. **Types Of Small-Scale Fading:** Fading Effects Due To Multipath Time Delay Spread, Fading Effects Due To Doppler Spread.

2.1 Large Scale Path Loss: Introduction to Radio Wave Propagation
2.2 Free Space Propagation Model
2.3 Three Basic Propagation Mechanism:
2.4 Reflection
- 2.4.1 Reflection from dielectrics
- 2.4.2 Brewster Angle
- 2.4.3 Reflection from perfect conductors

2.6 Ground reflection (Two-ray model)
2.7 Diffraction
- 2.7.1 Fresnel Zone Geometry
- 2.7.2 Knife-edge diffraction model
- 2.7.3 Multiple Knife-edge diffraction

2.8 Scattering
- 2.8.1 Radar Cross Section Model

2.9 Small Scale Fading and Multipath: Small Scale Multipath Propagation
- 2.9.1 Factors Influencing Small-Scale Fading
- 2.9.2 Doppler Shift

2.10 Parameters of mobile multipath channels
- 2.10.1 Time dispersion parameters
- 2.10.2 Coherence Bandwidth
- 2.10.3 Doppler Spread and Coherence Time

2.11 Types of Small-Scale Fading:
- 2.11.1 Fading Effects Due To Multipath Time Delay Spread
  - 2.11.1.1 Flat fading
  - 2.11.1.2 Frequency selective fading
- 2.12.2 Fading Effects Due To Doppler Spread.
  - 2.12.2.1 Fast fading
  - 2.12.2.2 Slow fading

2.1 (Large Scale Path Loss) Introduction to Radio Wave Propagation

- The mechanisms behind electromagnetic wave propagation are reflection, diffraction, and scattering.
- Most cellular radio systems operate in urban areas where there is no direct line-of-sight path between the transmitter and the receiver.
- The presence of high rise buildings causes severe diffraction loss.
- Due to multiple reflections from various objects, the electromagnetic waves travel along different paths of varying lengths.
- The interaction between these waves causes multipath fading at a specific location.
- The strengths of the waves decrease as the distance between the transmitter and receiver increases.

- Propagation models have traditionally focused on predicting the average received signal strength.

- Propagation models that predict the mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance.
- These are useful in estimating the radio coverage area of a transmitter and are called ***large-scale propagation models***.
- Because, they characterize signal strength over large T-R separation distances (several hundreds or thousands of meters).

- On the other hand, propagation models that characterize the rapid fluctuations of the received signal strength over very short travel distances (a few wavelengths) or short time durations (on the order of seconds) are called ***small-scale or fading models***.

2.2 Free Space Propagation Model

1. **Explain how signal propagates against free space attenuation and reflection. [8m-May 2014]**
2. **How the received signal strength is predicated using the free space propagation model? Explain. [10m - Nov 2012]**
3. **Explain the free space path loss and derive the gain expression. [8m - May 2012] [Nov/Dec 2019]**
4. **Describe briefly about free space propagation model. [April/May 2018] [April/May 2019]**
5. **Derive the received power in dBm for a free space Propagation model. [April/May 2021][April/May 2023]**

- ✓ The **free space propagation model** is used to predict received signal strength.
- ✓ The transmitter and receiver should have a clear line-of-sight path between them.
- ✓ The free space **received power** is given by the **Friis free space equation**,

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \rightarrow (1)$$

where, $P_r(d)$ $\rightarrow$ Received power

P_t $\rightarrow$ Transmitted power

G_t $\rightarrow$ Transmitter antenna gain

G_r $\rightarrow$ Receiver antenna gain

d $\rightarrow$ T-R separation distance in meters

λ $\rightarrow$ Wavelength in meters

L $\rightarrow$ System loss factor

- The losses are usually due to
  a. Transmission line attenuation
  b. Filter losses
  c. Antenna losses in the communication system.
- ✓ The **gain** of an antenna is

$$G = \frac{4\pi A_e}{\lambda^2} \rightarrow (2)$$

where, G → Gain of an antenna

A_e → Effective aperture

Effective aperture, A_e is physical size of the antenna.

- ✓ **Wavelength** is $\lambda = \frac{c}{f} = \frac{2\pi c}{\omega_c}$ → (3)

where f → carrier frequency in Hertz

ω_c → Carrier frequency in radians per second

c → Speed of light given in meters/s.

- ✓ An **isotropic radiator** is an ideal antenna which radiates power with unit gain uniformly in all directions. It is used to reference antenna gains in wireless systems.
- ✓ The ***Effective Isotropic Radiated Power (EIRP)*** represents the maximum radiated power available from a transmitter in the direction of maximum antenna gain.

It is defined as $EIRP = P_t G_t$ → (4)

- ✓ The ***Effective Radiated Power (ERP)*** denotes the maximum radiated power as compared to a half-wave dipole antenna (Instead of an Isotropic antenna).
- ✓ Antenna gains are given in units of

dBi (***dB*** gain with respect to an ***i***sotropic antenna) or

dBd (***dB*** gain with respect to a hail-wave ***d***ipole antenna)

- ✓ The **path loss** is defined as the difference between the effective transmitted power and the received power.
- ✓ The path loss represents signal attenuation as a positive quantity measured in dB.
- ✓ The path loss for the free space model **when antenna gains are included** is given by

$$PL(dB) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right] \rightarrow (5)$$

- ✓ The path loss for the free space model **when antenna gains are excluded** is given by

$$PL(dB) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \rightarrow (6)$$

- ✓ **Far-field** or **Fraunhofer region:**

The far-field or **Fraunhofer region** of a transmitting antenna is defined as the region beyond the far-field distance d_f, which is related to the largest linear dimension of the transmitter antenna aperture and the carrier wavelength.

- ✓ The **Fraunhofer distance** is given by

$$d_f = \frac{2D^2}{\lambda} \rightarrow (7)$$

where, D → Largest physical linear dimension of the antenna.

d_f → Far-field distance

d_f must satisfy

$$d_f >> D \rightarrow (8)$$

$$d_f >> \lambda \rightarrow (9)$$

- ✓ The received power, $P_r(d)$ at any distance $d > d_0$, may be related to P_r at d_0.
- ✓ The received power in free space at a distance greater than d_0 is given by

$$P_r(d) = P_r(d_0)\left(\frac{d_0}{d}\right)^2, \qquad d \geq d_0 \geq d_f \qquad \rightarrow (10)$$

- ✓ ***dBm*** or ***dBW*** units are used to express received power levels.
- ✓ The **received power** in dBm, is given by

$$P_r(d)\ dBm = 10\log\left[\frac{P_r(d_0)}{0.001W}\right] + 20\log\left(\frac{d_0}{d}\right), \qquad d \geq d_0 \geq d_f \qquad \rightarrow (11)$$

$P_r(d_0)$ is in units of Watts.

******

Problem 1: A communication system has the following parameters: P_t =5W, G_t (db)=13dB, G_r (dB)=17dB, d =80km, f=3GHz. Determine the value of the received power. [6m - May 2013][April/May 2019]

Given

Transmitted power, P_t =5W

Transmitter antenna gain, G_t =13dB

Receiver antenna gain, G_r =17dB

T-R separation distance in meters, d =80Km

Frequency=3GHz

W.K.T., System loss factor, =1

To Find

Received power, $P_r(d)$

Solution

$$\lambda = \frac{c}{f} = \frac{3\times10^8\, m/s}{3\times10^9\, Hz} = 0.1m$$

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{5\times13\times17\times0.1^2}{(4\pi)^2(80\times10^3)^2\times1} = 10.9446\times10^{-12}W$$

*****

2.3 THREE BASIC PROPAGATION MECHANISM:

1. **In free space propagation describe how the signals are affected by reflection, diffraction and scattering. [16m - May 2016]**
2. **Explain in brief about the three propagation mechanisms which have impact on propagation in mobile environment. [8m - May 2015, 8m -Nov 2013, 8m-Nov 2012]**
3. **Explain the different types of multipath propagation in wireless communication. [10m - Nov 2014].**

- ✓ Reflection, diffraction, and scattering are the three basic propagation mechanisms which influence propagation in a mobile communication system.
- ✓ Received power (or its reciprocal, path loss) is the most important parameter predicted by large scale propagation models *(based on the physics of reflection, scattering, and diffraction.)*

- ✓ Small-scale fading and multipath propagation may also be described by the physics of these three basic propagation mechanisms.

- ✓ Reflection occurs when a propagating electromagnetic wave impinges upon an object which has very large dimensions when compared to the wavelength of the propagating wave.
- ✓ Reflections occur from the surface of the earth and from buildings and walls.

- ✓ Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities (edges).
- ✓ The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle, giving rise to a bending of waves around the obstacle, even when a line-of-sight path does not exist between transmitter and receiver.
- ✓ At high frequencies, diffraction, like reflection, depends on the geometry of the object, as well as the amplitude, phase, and polarization of the incident wave at the point of diffraction.

- ✓ Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large.

- ✓ Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the channel.
- ✓ In practice, foliage, street signs, and lamp posts induce scattering in a mobile communications system.

2.4 REFLECTION

- ✓ Reflection occurs when a propagating electromagnetic wave strikes upon an object which has very large dimensions when compared to the wavelength of the propagating wave.
- ✓ Reflections occur from the surface of the earth and from buildings and walls.
- ✓ When the radio wave propagating in one medium to another medium having different electrical properties, the wave is partially reflected and partially transmitted.
- ✓ If the plane wave incident on a perfect dielectric, part of the energy is transmitted into the second medium, and part of the energy is reflected back into the first medium, and there is no loss of energy in absorption.
- ✓ If the second medium is a perfect conductor, then all incident energy is reflected back into the first medium without loss of energy.
- ✓ The electric field intensity of the reflected and transmitted waves may be related to the incident wave in the medium of origin through the Fresnel reflection coefficient (Γ)
- ✓ The reflection coefficient is a function of the
  - (*i*) Material properties

(*ii*) Wave polarization
(*iii*) Angle of incidence
(*iv*) Frequency of propagating wave

2.4.1 Reflection from Dielectrics

- ✓ When an electromagnetic wave incident at an angle θ_i with the two dielectric media, part of the energy is reflected back to the first media at an angle θ_r and part of the energy is refracted (transmitted) into the second media at an angle θ_t .
- ✓ The plane of incidence is defined as the plane containing the incident, reflected and transmitted rays.

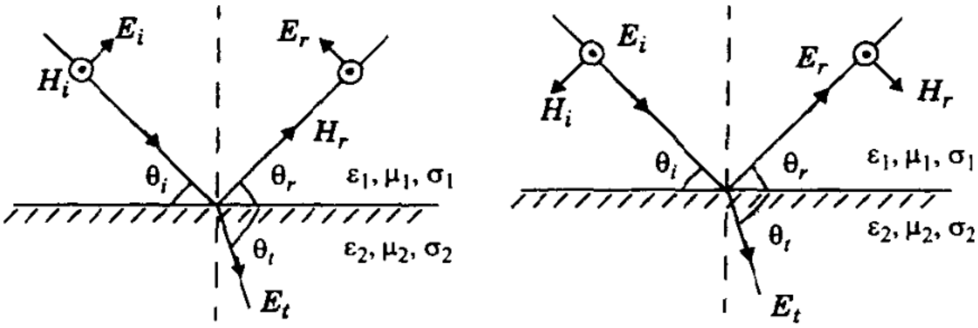

Figure 1.2: Geometry for calculating the reflection coefficients between two dielectrics

- ✓ In figure (a), the E-field polarization is parallel with the plane of incidence.*(That is, the E-field has a vertical polarization, or normal component, with respect to the reflecting surface.)*
- ✓ In figure (b), E field polarization is perpendicular to the plane of incidence. *(That is, the incident E-field is pointing out of the page towards the reader, and is perpendicular to the page and parallel to the reflecting surface.)*
- ✓ In figure, the subscripts ***i***, ***r***, ***t*** refer to the incident, reflected and transmitted fields, respectively.
- ✓ Parameters $\varepsilon_1,\ \mu_1,\ \sigma_1$ and $\varepsilon_2,\ \mu_2,\ \sigma_2$ represent the permitivity, permeability and conductance of the two media, respectively.

(i).For a Perfect Lossless Dielectric Material

- ✓ The dielectric constant of a perfect (lossless) dielectric is related to a relative value of permitivity, ε_r , such that $\varepsilon = \varepsilon_0 \varepsilon_r$, where ε_0 is a constant give by $8.85\times10^{-12}\ F/m$.

Permittivity $\varepsilon = \varepsilon_0 \varepsilon_r$

$\varepsilon_0 \Rightarrow$ constant = 8.85×10^{-12} F/*m*

$\varepsilon_r \rightarrow$ relative permittivity

(ii).For a Lossy Dielectric Material

- ✓ If a dilelectric material is lossy, it will absorb power and may be described by a complex dielectric constant given by
- ✓ The complex dielectric constant $\varepsilon = \varepsilon_0\, \varepsilon_r - j\, \varepsilon'$ because it absorbs power.

where,

$$\varepsilon' = \frac{\sigma}{2\pi f}$$

σ →Conductivity of the material

f→frequency

- ✓ The terms ε_r and σ are insensitive to frequency for good conductor ε_0 and ε_r are constant with frequency but σ may be sensitive to frequency for lossy dielectrics.
- ✓ A polarized wave is represented as a sum of vertical and horizontal components.

E-field in plane of incidence : $\Gamma_{\parallel} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_t - \eta_1 \sin\theta_i}{\eta_2 \sin\theta_t + \eta_1 \sin\theta_t}$

E-field not in plane of incidence : $\Gamma_{\perp} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_i - \eta_1 \sin\theta_t}{\eta_2 \sin\theta_i + \eta_1 \sin\theta_t}$

where η_i = intrinsic impedance of the i^{th} medium (i = 1, 2).

Intrinsic impedance, η = **Error!**

Velocity V = **Error!**

- ✓ The boundary conditions at the surface of incidence obey Snell's law is given by

$$\sqrt{\mu_1 \epsilon_1}\ \sin(90 - \theta_i) = \sqrt{\mu_2 \epsilon_2}\ \sin(90 - \theta_t)$$

Incident angle θ_i = θ_r reflected angle

$$E_r = \Gamma E_i$$

$$E_t = E_i + \Gamma E_i = E_i(1 + \Gamma)$$

Where Γ is either vertical or horizontal. Reflection coefficients for the vertical and horizontal polarization can be simplified to

$\Gamma_{\parallel}$ = **Error!**

and $\Gamma_{\perp}$ = **Error!**

For $\theta_i = 0$,

Γ = – 1 for both parallel and perpendicular polarization

2.4.2 Brewster angle

Define Brewster angle. [8m - May 2015, 8m - Nov 2013]

- ✓ The Brewster angle is the angle at which no reflection occurs in the medium of origin.
- ✓ It occurs when the incident angle is such that the reflection coefficient is equal to zero.
- ✓ The Brewster angle is given by

$$\sin(\theta_B) = \sqrt{\frac{\varepsilon_1}{\varepsilon_1 + \varepsilon_2}} \rightarrow (1)$$

- ✓ When the first medium is free space and the second medium has a relative permittivity ε_r, equation (1) can be expressed as

$$\sin(\theta_B) = \frac{\sqrt{\varepsilon_r - 1}}{\sqrt{\varepsilon_r^2 - 1}} \rightarrow (2)$$

- ✓ The Brewster angle occurs only for vertical (i.e. parallel) polarization.

2.4.3 Reflection from perfect conductors:

- ✓ Since electromagnetic energy pass through a perfect conductor a plane wave incident on a conductor has all of its energy reflected.
- ✓ As the electric field at the surface of the conductor must be equal to zero at all times in order to obey Maxwell's equations, the reflected wave must be equal in magnitude to the incident wave.
- ✓ For the case when E-field polarization is in the plane of incidence, the boundary conditions require that,

  $\theta_i = \theta_r \qquad \rightarrow (1)$

  and

  $E_i = E_r$ (E-field in plane of incidence) $\rightarrow (2)$

- ✓ Similarly, for the case when the E-field is horizontally polarized, the boundary conditions require that

  $\theta_i = \theta_r \qquad \rightarrow (3)$

  and

  $E_i = -E_r$ (E-field plane of incidence) $\rightarrow (4)$

- ✓ Referring to equations (1) to (4), we see that for a perfect conductor, $\Gamma_{\parallel} = 1$, and $\Gamma_{\perp} = 1$, regardless of incident angle.

2.5 DIFFRACTION

Q. Design a cellular network in a hilly terrain using knife edge diffraction geometry. [Nov/Dec 2021]

- ✓ Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities.
- ✓ The secondary waves resulting from the obstructing surface are present throughout the space and even behind the obstacle
- ✓ It gives `rise to a bending of waves around the obstacle, even when a line-of-sight path does not exist between transmitter and receiver.
- ✓ At high frequencies depends on the geometry of the object, as well as the amplitude, phase, and polarization of the incident wave at the point of diffraction.
- ✓ This phenomenon can be explained by the **Huygen's principle**, which states that all points on a wavefront acts as point sources for the production of secondary wavelets, and they combine to produce a new wavefront in the direction of propagation.

2.5.1 Fresnel Zone Geometry

- ✓ Consider a transmitter and receiver separated in free as shown in figure.
- ✓ Let an obstructing screen of height 'h' with infinite width be placed between them at a distance d_1 from the transmitter and d_2 from the receiver.
- ✓ Assuming $h \ll d_1, d_2$ and $h \gg \lambda$, then the difference between the direct path and the diffracted path called excess path length (Δ).
- ✓ From the geometry,

$$\Delta \approx \frac{h^2}{2} \frac{(d_1 + d_2)}{d_1 d_2}$$

$$\text{Phase difference } \phi = \frac{2\pi\Delta}{\lambda} \approx \frac{2\pi}{\lambda}\; l\; \frac{h^2}{2} \frac{(d_1 + d_2)}{d_1 d_2}$$

- Corresponding phase difference $\alpha = \beta + \gamma$

$$\alpha \approx h \frac{(d_1 + d_2)}{d_1 d_2}$$

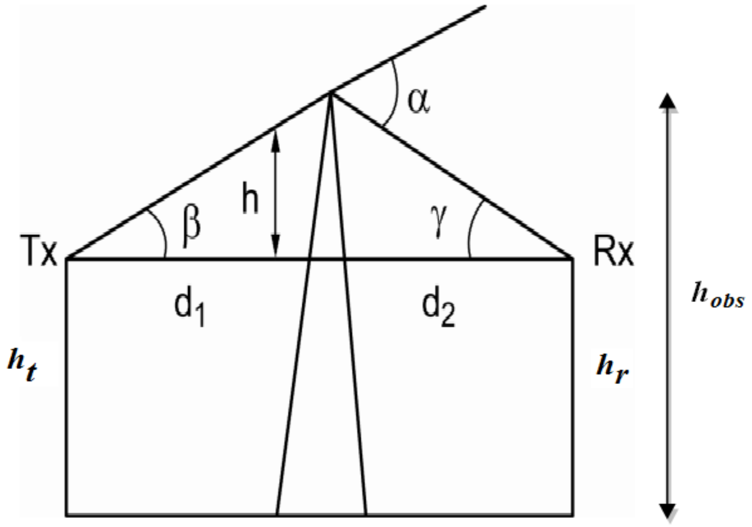

Figure 1.6: Knife edge model

The Fresnel Kirchhoff diffraction parameter is a dimensionless quantity.

- ✓ It characterizes the phase difference between two propagation paths.
- ✓ It is used to characterize diffraction losses in a general situation.
- ✓ It represents successive regions, where secondary waves have a path length from the transmitter and receiver which are $\frac{n\lambda}{2}$ greater than the total path length of a line of sight path.
- ✓ The concentric circles on the plane represent the loci of the origins of the secondary wavelet.
- ✓ The circles are called Fresnel zones.

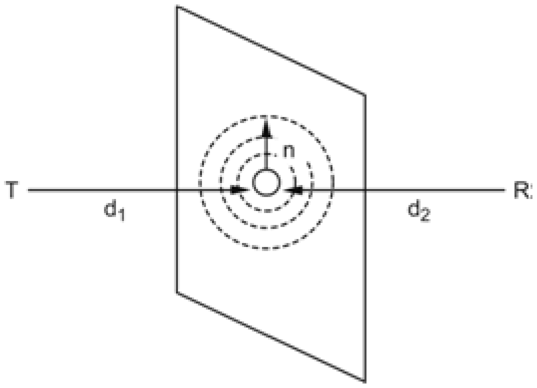

Figure 1.7: Fresnel zones

- ✓ The successive Fresnel zones have the effect of alternately providing constructive and destructive interference to the total received signal.
- ✓ The radius of the n[th] Fresnel Zone circle is denoted by r_n and can be expressed in terms of n, λ, d_1 and d_2.

r_n = **Error!**

- ✓ The excess total path length traversed by a ray of each circle is $\frac{n\lambda}{2}$.
- ✓ The received energy will be a vector sum of the energy contributions from all unobstructed Fresnel zones.

- ✓ The diffraction loss occurs from the blockage of secondary waves such that only a portion of energy is diffracted around an obstacle.
- ✓ That is, an obstruction causes a blockage of energy from some of the Fresnel zones, thus allowing only some of the transmitted energy to reach the receiver.

2.5.2 Knife Edge Diffraction Model

- ✓ When shadowing is caused by a single object such as hill or mountain, the attenuation caused by diffraction can be estimated by treating the obstruction as a diffracting knife edge.
- ✓ This is the simplest of diffraction models, and the diffraction loss in this case can be readily estimated using the classical Fresnel solution for the field behind a knife edge. (Figure 1.8)

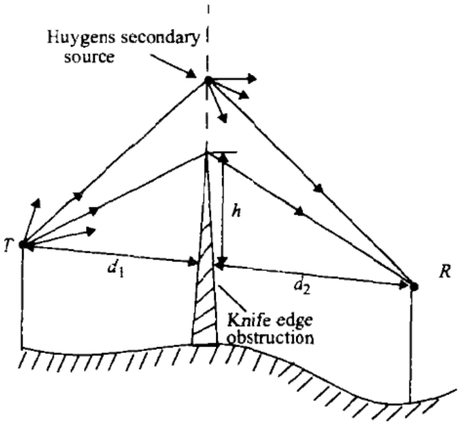

Figure 1.8: Illustration of knife-edge diffraction geometry.The rceiver R is locaated in the shadow.

- ✓ Consider a receiver at point R, located in the shadowed region (also called the diffraction zone).
- ✓ The field strength at point R is a vector sum of the fields due to all of the secondary Huygens sources in the plane above the knife edge.
- ✓ The electric field strength, E_d, of a knife edge diffracted wave is given by,

$$\frac{E_d}{E_o} = F(v) = \frac{(1+j)}{2}\int_v^{\infty} \exp((-j\pi t^2)/2)dt$$

where,

E_d - electric field strength of a knife edge diffracted wave

E_o - the free space field strength in the absence of both the ground and the knife edge

$F(v)$ - the complex Fresnel integral

v - Fresnel-Kirchoff diffraction parameter, $v = h\sqrt{\frac{2(d_1+d_2)}{\lambda d_1 d_2}} = \alpha\sqrt{\frac{2(d_1 d_2)}{\lambda(d_1+d_2)}}$

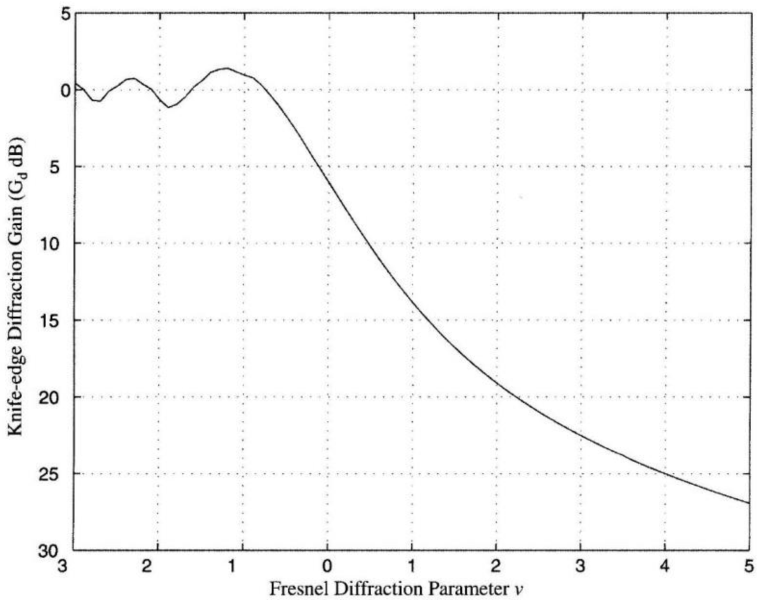

Figure 1.9: Knife edge diffraction gain as a function of Frenel diffraction parameter *v*.

- ✓ The diffraction gain due to the presence of a knife edge, as compared to the free space E-field, is given by

$$G_d(dB) = 20 \ \log|F(v)|$$

- ✓ A graphical representation of Gd (dB) as a function of u is given in Figure 1.9.

$$G_d(dB) = 0 \qquad v \le -1$$

$$G_d(dB) = 20 \ \log(0.5 - 0.62v) \qquad -1 \le v \le 0$$

$$G_d(dB) = 20 \ \log(0.5 \ \exp(-0.95v) \qquad 0 \le v \le 1$$

$$G_d(dB) = 20 \ \log(0.4 \ - \sqrt{0.1184 - (0.38 - 0.1v)^2} \qquad 1 \le v \le 2.4$$

$$G_d(dB) = 20 \ \log\left(\frac{0.225}{v}\right) \qquad v > 2.4$$

2.5.3 Multiple Knife-edge Diffraction

- ➢ In many practical situations, especially in hilly terrain, the propagation path may consist of more than one obstruction.
- ➢ Here the total diffraction loss due to all of the obstacles must be computed.
- ➢ Bullington suggested that the series of obstacles be replaced by a single equivalent obstacle.
- ➢ So that the path loss can be obtained using single knife-edge diffraction models.

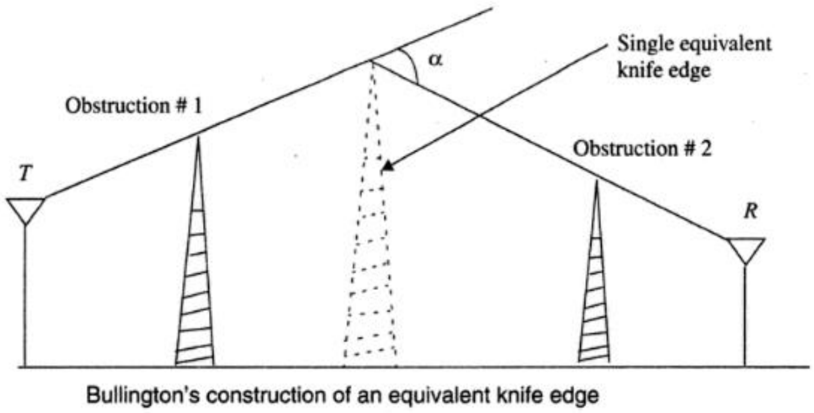

Figure 1.10: Bullington's construction of an equivalent knife edge

- This method, illustrated in Figure 1.10, oversimplifies the calculations and provides very optimistic estimates of the received signal strength.
- In a more rigorous treatment, Millington et. al., gave a wave-theory solution for the field behind two knife edges in series.
- This solution is very useful and can be applied easily for predicting diffraction losses due to two knife edges.
- However, extending this to more than two knife edges becomes a difficult mathematical problem.

2.6 Scattering

- The actual received signal in a mobile radio environment is stronger than what is predicted by reflection and diffraction models alone.
- This is because when a radio wave impinges on a rough surface, the reflected energy is spread out (diffused) in all directions due to scattering.
- Objects such as lamp posts and trees tend to scatter energy in all directions, thereby providing additional radio energy at a receiver.

- Flat surfaces that have much larger dimension than a wavelength may be modeled as reflective surfaces.
- Surface roughness is often tested using the Rayleigh criterion which defines a critical height *(h_c)* of surface protuberances for a given angle of incidence θ_i, given by

$$h_c = \frac{\lambda}{8 \ \sin\theta_i}$$

- A surface is considered smooth if its minimum to maximum protuberance h is less than h_c, and is considered rough if the protuberance is greater than h_c.
- For rough surfaces, the flat surface reflection coefficient needs to be multiplied by a scattering loss factor, ρ_s, to account for the diminished reflected field.
- Ament assumed that the surface height h is a Gaussian distributed random variable with a local mean and found ρ_s to be given by

$$\rho_s = \exp\left[-8\left(\frac{\pi\sigma_h \sin\theta_i}{\lambda}\right)^2\right]$$

- where σ_h is the standard deviation of the surface height about the mean surface height. The scattering loss factor derived by Ament was modified by Boithias [Boi87] to give better agreement with measured results, and is given in (3.63)

$$\rho_s = \exp\left[-8\left(\frac{\pi\sigma_h \sin\theta_i}{\lambda}\right)^2\right] I_0\left[8\left(\frac{\pi\sigma_h \sin\theta_i}{\lambda}\right)^2\right]$$

  where I_0 is the Bessel function of the first kind and zero order.
- The reflected E-fields for $h > h_c$ can be solved for rough surfaces using a modified reflection coefficient given as

$$\Gamma_{rough} > \rho_S \Gamma$$

2.6.1 Radar Cross Section Model

- In radio channels where large, distant objects induce scattering, knowledge of the physical location of such objects can be used to accurately predict scattered signal strengths.
- The radar cross section (RCS) of a scattering object is defined as the ratio of the power density of the signal scattered in the direction of the receiver to the power density of the radio wave incident upon the scattering object, and has units of square meters.
- Analysis based on the geometric theory of diffraction and physical optics may be used to determine the scattered field strength.

- For urban mobile radio systems, models based on the ***bistatic radar equation*** may be used to compute the received power due to scattering in the far field.
- The bistatic radar equation describes the propagation of a wave traveling in free space which impinges on a distant scattering object, and is then reradiated in the direction of the receiver, given by

$$P_R(dBm) = P_T(dBm) + G_T(dBi) + 20\ \log(\lambda) + RCS[dB\ m^2] \qquad (3.66)$$

$$-30\ \log(4\pi) - 20\ \log(d_T) - 20\ \log(d_R)$$

where d_T and d_R are the distance from the scattering object to the transmitter and receiver, respectively.

- In equation (3.66), the scattering object is assumed to be in the far field (Fraunhofer region) of both the transmitter and receiver.
- The variable RCS is given in units of $d_R.m^2$, and can be approximated by the surface area (in square meters) of the scattering object, measured in dB with respect to a one square meter reference.
- Equation (3.66) may be applied to scatterers in the far-field of both the transmitter and receiver and is useful for predicting receiver power which scatters off large objects, such as buildings, which are for both the transmitter and receiver.
- Several European cities were measured from the perimeter [Sei9l], and RCS values for several buildings were determined from measured power delay profiles. For medium and large size buildings located 510 km away, RCS values were found to be in the range of 14.1 $dB \cdot m^2$ to 55.7 $dB \cdot m^2$.

2.9 Small Scale Fading and Multipath: Small Scale Multipath Propagation

- Multipath in the radio channel creates small-scale fading effects. The three most important effects are:
    - Rapid changes in signal strength over a small travel distance or time interval.
    - Random frequency modulation due to varying Doppler shifts on different multipath signals.
    - Time dispersion (echoes) caused by multipath propagation delays.
- In built-up urban areas, fading occurs because the height of the mobile antennas are well below the height of surrounding structures, so there is no single line-of-sight path to the base station.
- Even when a line-of-sight exists, multipath still occurs due to reflections from the ground and surrounding structures.
- The incoming radio waves arrive from different directions with different propagation delays.
- The signal received by the mobile at any point in space may consist of a large number of plane waves having randomly distributed amplitudes, phases, and angles of arrival.
- These multipath components combine vectorially at the receiver antenna, and can cause the signal received by the mobile to distort or fade.
- Even when a mobile receiver is stationary, the received signal may fade due to movement of surrounding objects in the radio channel.

- If objects in the radio channel are static, and motion is considered to be only due to that of the mobile, then fading is purely a spatial phenomenon.
- The spatial variations of the resulting signal are seen as temporal variations by the receiver as it moves through the multipath field.
- Due to the constructive and destructive effects of multipath waves summing at various points in space, a receiver moving at high speed can pass through several fades in a small period of time. In a more serious case, a receiver may stop at a particular location at which the received signal is in a deep fade.
- Maintaining good communications can then become very difficult, although passing vehicles or people walking in the vicinity of the mobile can often disturb the field pattern, thereby diminishing the likelihood of the received signal remaining in a deep null for a long period of time.
- Antenna space diversity can prevent deep fading nulls.

2.9.1 Factors Influencing Small-Scale Fading

The following physical factors influence small-scale fading in the radio propagation channel:

(1) Multipath propagation

- ✓ The reflecting objects and scatterers in the channel create a constantly changing environment.

- ✓ This changing environment dissipates the signal energy in amplitude, phase and time.
- ✓ This effect results in multiple versions of the transmitted signal that arrive at the receiving antenna.
- ✓ These received signals displace with respect to one another in time and spatial orientation.
- ✓ The random phase and amplitudes of the different multipath components cause fluctuations in signal strength, includes small scale fading, signal distortion or both.
- ✓ Multipath causes signal spreading due to ISI.

(2) Speed of the mobile

- ✓ The relative motion between the base station and the mobile results in random frequency modulation due to different Doppler shifts on each of the multipath components.
- ✓ Doppler shift will be positive *(i.e., apparent receiving frequency is increased)* or negative, it depends on the mobile moving toward or away from the base station respectively.

(3) Speed of surrounding objects

- ✓ If objects in the radio channel are in motion, they induce a time varying Doppler shift on multipath components.
- ✓ If the surrounding objects move at a greater rate than the mobile, then this effect dominates fading.

(4) Transmission Bandwidth of the signal

- ✓ If the transmitted radio signal bandwidth is greater than the "bandwidth" of the multipath channel (quantified by coherence bandwidth), the received signal will be distorted.
- ✓ But, the received signal strength will not fade much over a local area.

2.9.2 Doppler Shift

- ✓ Consider a mobile moving at a constant velocity *v*, along a path segment having length *d* between points X and Y, while it receives signals from a remote source S, as illustrated in Figure.

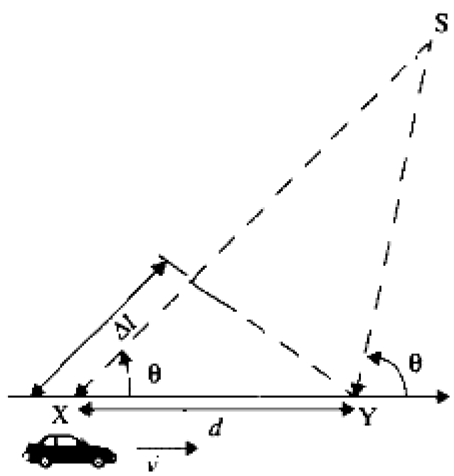

Figure: Illustration of Doppler effect.

- ✓ The difference in path lengths traveled by the wave from source S to the mobile at points X and Y is $\Delta l = d \cos\theta = v \Delta t \cos\theta$.
- ✓ where Δt is the time required for the mobile to travel from X to Y, and θ is assumed to be the same at points X and Y since the source is assumed to be very far away.
- ✓ The phase change in the received signal due to the difference in path lengths is therefore

$$\Delta\phi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}\cos\theta$$

- ✓ and hence the apparent change in frequency, or Doppler shift, is given by f_d where

$$f_d = \frac{1}{2\pi}.\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cos\theta$$

- ✓ Multipath components from a CW signal which arrive from different directions contribute to Doppler spreading of the received signal, thus increasing the signal bandwidth.

2.10 Parameters of mobile multipath channels

1. **Explain in detail about Small Scale Fading Parameters of Mobile Multipath Channels**
2. **Explain the time dispersion parameters of mobile multipath channels.**
3. **Discuss the impact of time dispersion parameter, Coherence Bandwidth , Doppler Spread and Coherence time on small scale fading. [April/May 2021]**

- ✓ Parameters of mobile multipath channel are,
  1. Time dispersion parameters
  2. Coherence bandwidth
  3. Doppler spread & Coherence time

2.10.1 Time dispersion parameters

- ✓ In multipath, the time difference between the arrival moment of the first multipath component and the last one is called ***delay spread***.
- ✓ The following multipath parameters are used to quantify the time dispersive properties of wide band multipath channels:
  - a. Mean excess delay ($\bar{\tau}$) (frequently used properties)
  - b. RMS delay spread (σ_τ)
  - c. Maximum Excess Delay (X dB)

a. Mean excess delay

- ✓ The **mean excess delay** is the first moment of the power delay profile (PDP).
- ✓ It is expressed as

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

b. RMS delay spread

- ✓ This parameter calculates the standard deviation value of the delay of reflections.
- ✓ The standard deviation value will be weighted proportional to the energy in the reflected waves.
- ✓ The ***rms*** **delay spread** is the square root of the second central moment of the power delay profile.

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)}$$

where,

σ_τ → *rms* delay spread

a_k → Amplitude

$P(\tau_k)$ → Relative power levels of the individual multipath components

τ_k → Excess delay

c. Maximum excess delay

- ✓ The **maximum excess delay** (X dB) of the power delay profile is defined to be the time delay during which multipath energy falls to X dB below the maximum.
- ✓ The maximum excess delay is defined $\tau_x - \tau_0$ as

  Where, τ_0 → First arriving signal

  τ_x → Maximum delay at which a multipath component is within X dB of the strongest multipath signal
- ✓ Maximum excess delay is sometimes called the ***excess delay spread***.

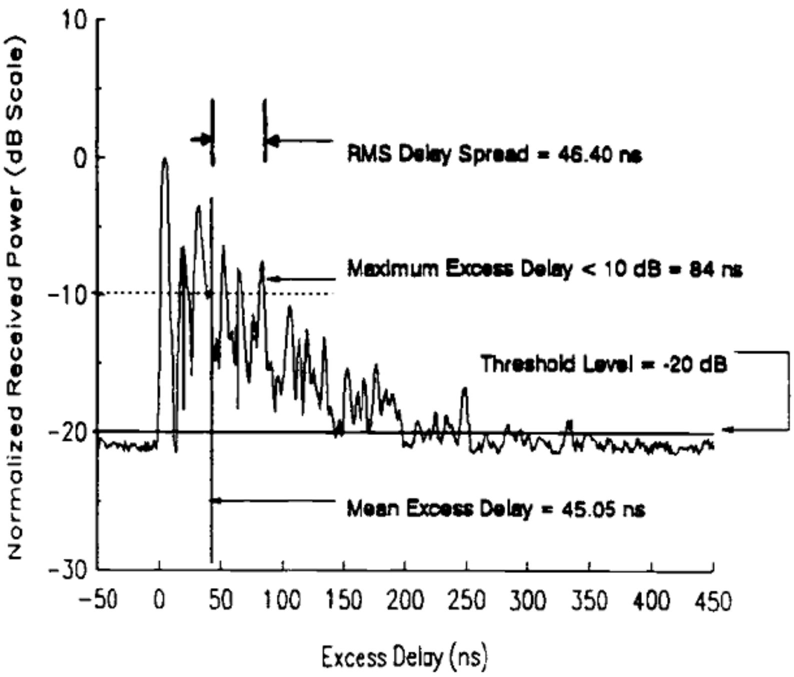

Figure 1.13: Measured multipath power delay profiles

2.10.2 Coherence Bandwidth

> 1. **Given that the coherence band width is approximately by equation** $B_c \approx \frac{1}{50\sigma_\tau}$.
> 2. **Show that a flat fading channel occurs when** $T_s \geq 100\sigma_\tau$ **. [April/May 2018]**

- ✓ **The maximum frequency separation for which the signals are still strongly correlated is called coherence bandwidth (B_c).**
- ✓ Coherence bandwidth, B_c, is derived from the rms delay spread.
- ✓ Coherence bandwidth is a statistical measure of the range of frequencies over which the channel is considered to be 'flat'.

- ✓ If frequency correlation function is above 0.9, then the coherence bandwidth is $B_c \approx \frac{1}{50\sigma_\tau}$
- ✓ If frequency correlation function is above 0.5. then the coherence bandwidth is $B_c \approx \frac{1}{5\sigma_\tau}$
- ✓ If the signal bandwidth larger than B_c is transmitted through the channel, it will subject to Frequency selective distortion.
- ✓ The channel will be referred as a frequency selective channel.
- ✓ If the signal bandwidth is larger than B_c, it will experience amplitude attenuation only with no distortion.
- ✓ This channel will be referred as a frequency non-selective fading channel.

2.10.3 Doppler Spread and Coherence Time

Derive the path loss for large scale propagation in a multipath wireless environment.-What is Doppler spread? [April 2010]

Doppler spread *(B_D)*

- ✓ **Doppler spread B_D is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero.**
- ✓ When pure dc signal is transmitted, then Doppler spectrum is $f_c, f_c + f_d, f_c - f_d$

where $f_d \rightarrow$ Doppler frequency.

- ✓ It describes the time varying nature frequency depressiveness of the channel
- ✓ If the baseband signal bandwidth is much greater than B_D, the effects of Doppler spread are negligible at the receiver.
- ✓ This is a slow fading channel.

Coherence time (T_C)

- ✓ **Coherence time is the time over which two signals are having strong potential for amplitude correlation.**
- ✓ Coherence time is the range of time over which similar fading occurs.
- ✓ The Doppler spread and coherence time are inversely proportional to one another.

$$Cohrence\ Time = \frac{1}{Doppler\ Spread}$$

$$T_c \approx \frac{1}{f_m}$$

Where,

$f_m \rightarrow$ Maximum Doppler Shift, $f_m = \frac{v}{\lambda}$

- ✓ The time over which the time correlation > 0.5, then the coherence time is

$$T_c \approx \frac{9}{16\pi f_m}$$

- ➢ Coherence time is defined as the geometric mean

$$T_c = \sqrt{\frac{9}{16\pi f_m^2}} = \frac{0.423}{f_m}$$

- ✓ If the reciprocal bandwidth of the baseband signal is greater than the coherence time of the channel, then the channel will change during the transmission of the baseband message, thus causing distortion at the receiver.

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2.11 TYPES OF SMALL-SCALE FADING:

1. **Explain in detail about types of Small Scale Fading. [May 2010]**
2. **Explain the types of small scale fading based on multipath time delay spread.**
3. **Explain the types of small scale fading based on Doppler spread.[April/May 2019]**
4. **Write down the small scale fading effects and also name the techniques that are used to mitigate the effects of small-scale fading. [Nov/Dec 2019][April/May 2023]**

- ✓ The type of fading in the signal propagating through a mobile radio channel depends on the nature of the **transmitted signal** with respect to the **characteristics of the channel**.
- ✓ The four different types of fading are

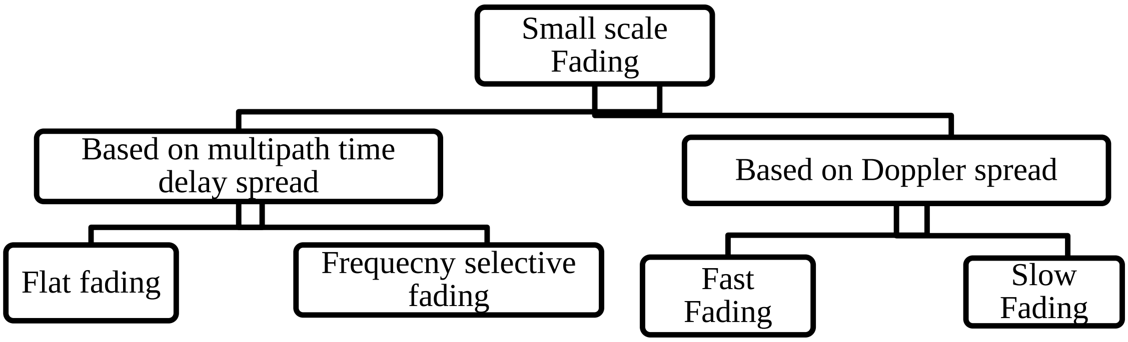

Figure 1.14: Types of small scale fading

2.11.1 Fading Effects Due To Multipath Time Delay Spread

1. **Examine the effectiveness of flat fading and frequency selective fading. [Nov/Dec 2019]**

- ✓ Time dispersion due to multipath causes the transmitted signal to undergo either ***flat*** or ***frequency selective fading***.

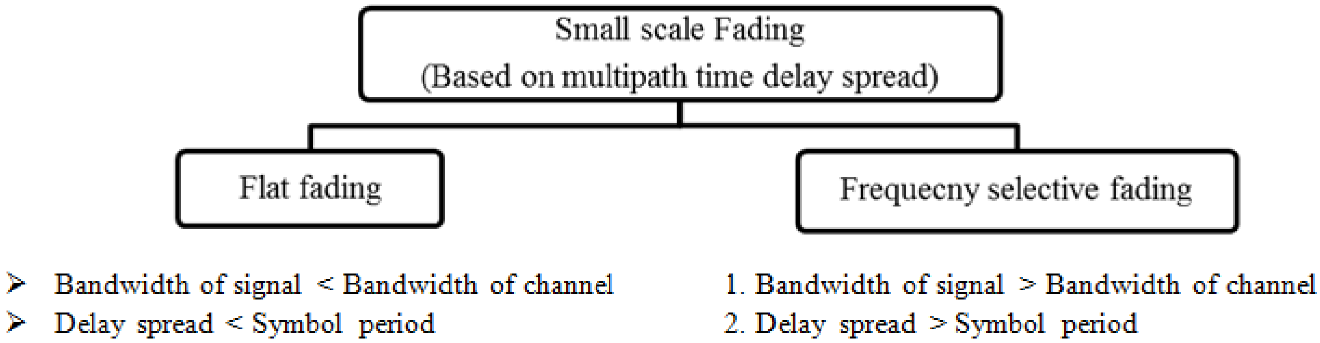

Figure 1.15: Types of small scale fading (Based on Multipath time delay spread)

2.11.1.1 Flat fading

Explain the flat fading channel characteristics with relevant diagrams. [April/May 2019]

- ✓ Flat fading affects all the frequencies in the given channel.
- ✓ Flat multipath fading changes the amplitude and rising & falling time of the signal.
- ✓ If mobile radio channel has a constant gain.

- ✓ If bandwidth of the transmitted signal is less than the bandwidth of the channel, then the received signal will undergo flat fading.

Channel impulse response

$$Mutipath\ delay\ spread \ll \frac{1}{Bandwidth\ of\ transmitted\ message\ waveform}$$

- ✓ ***Time characteristics***

Received signal changes with time due to fluctuations in the gain of the channel caused by multipath.

- ✓ ***Spectral characteristics***

Multipath structure of the channel is such that the spectral characteristics of the transmitted signal are preserved at the receiver.

- ✓ ***Channel characteristics***

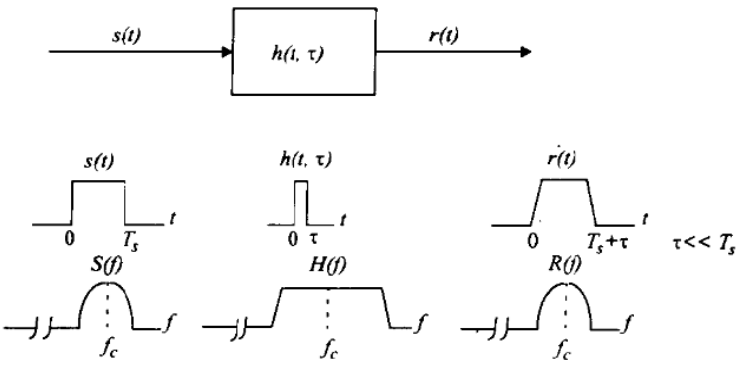

Figure 1.16: Flat fading channel characteristics

- ✓ The amplitude and channel gain varies with time, but the spectrum of the transmission is preserved.
- ✓ Flat fading channels are also known as amplitude varying channels (or) narrowband channels
- ✓ Flat fading channels cause deep fades and requires 20 or 30 dB more transmitter power to achieve low bit error rates.
- ✓ A signal undergoes flat fading if

$$B_S \ll B_c \text{ and } T_S \gg \sigma_\tau$$

where, B_s → Signal Bandwidth.

B_c → Coherence bandwidth

T_s → Reciprocal bandwidth (symbol period)

σ_τ → rms delay spread

2.11.1.2 Frequency selective fading

- ✓ Assume the channel possesses a constant-gain over a bandwidth that is smaller than the bandwidth of transmitted signal, then the channel creates frequency selective fading on the received signal.

Channel impulse response

$$\textit{Mutipath delay spread} \approx \frac{1}{\textit{Bandwidth of transmitted message waveform}}$$

Time characteristics

- ✓ For this, the received signal includes multiple versions of the transmitted waveform which are attenuated (delayed) and delayed in time.
- ✓ Hence the received signal is distorted.

Spectral characteristics

- ✓ Frequency selective fading is due to time dispersion of the transmitted symbols within the channel.
- ✓ Thus the channel induces Inter Symbol Interference (ISI).
- ✓ The received signal spectrum has greater gains than others.

Channel characteristics

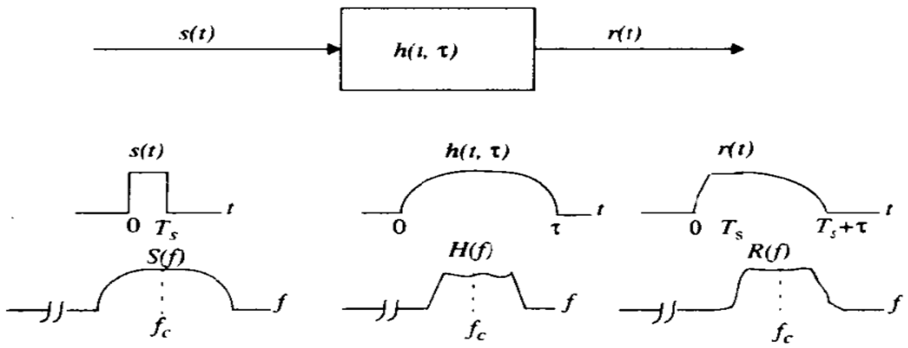

Figure 1.17: Frequency selective fading channel characteristics

- ✓ The gain is different for different frequency components.
- ✓ Frequency selective fading channels are also known as wideband channels
- ✓ Fading models are used to measure frequency.
- ✓ For Frequency selective fading, the spectrum S(f) of the transmitted signal bandwidth (B_S) which is greater than the coherence bandwidth (B_C)
- ✓ A signal undergoes frequency selective fading if

$$B_S > B_C \;\; and \;\; T_S > \sigma_C \, ,$$

where	B_s	→	Signal Bandwidth.
	B_c	→	Coherence bandwidth
	T_s	→	Reciprocal bandwidth
	σ_τ	→	rms delay spread

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2.12.2 Fading Effects Due To Doppler Spread.

Distinguish fast fading and slow fading in wireless channel and explain in detail.[Nov/Dec2017]

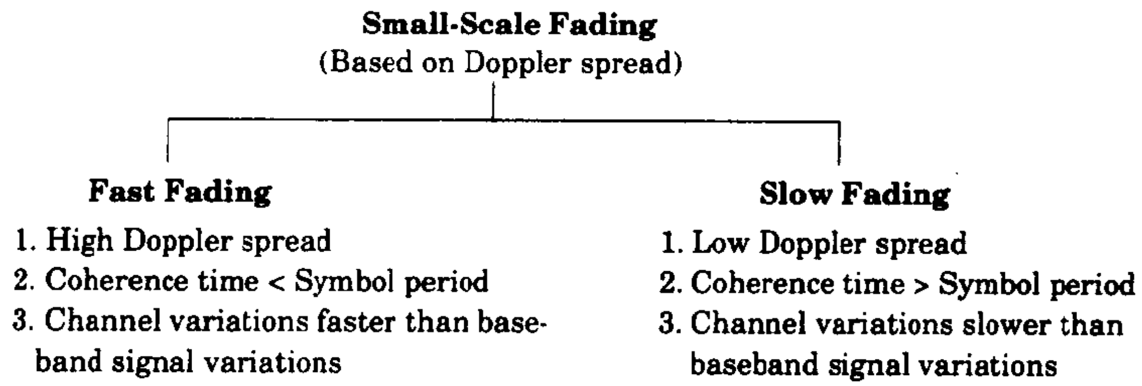


Figure 1.18: Types of small scale fading (Based on Doppler spread)

2.12.2.1 Fast Fading / Time Selective Fading

- ✓ In a fast fading channel, the channel impulse response changes rapidly within the symbol duration.
- ✓ The coherence time of the channel is smaller than the symbol period of the transmitted signal.
- ✓ This causes frequency dispersion due to Doppler spreading, which leads to signal distortion.
- ✓ In the frequency domain, signal distortion due to fast fading increases with increasing Doppler spread relative to the bandwidth of the transmitted signal.
- ✓ Therefore, a signal undergoes fast fading if

$T_S > T_C$ and $B_S < B_D$

- ✓ It should be noted that when a channel is specified as a fast or slow fading channel, it does not specify whether the channel is flat fading or frequency selective in nature.
- ✓ Fast fading only deals with the rate of change of the channel due to motion.
- ✓ In flat fading channel, the impulse response of the flat fading channel is a delta function (no time delay).
- ✓ Hence, a *flat fading, fast fading channel* is a channel in which amplitude of the delta function varying faster than the rate of change of the transmitted baseband signal.
- ✓ In case of a *frequency selective*, fast fading channel, the amplitudes, phases, and time delays of any one of the multipath components vary faster than the rate of change of the transmitted signal.
- ✓ In practice, fast fading only occurs for very low data rates.

2.12.2.1.2 Slow Fading

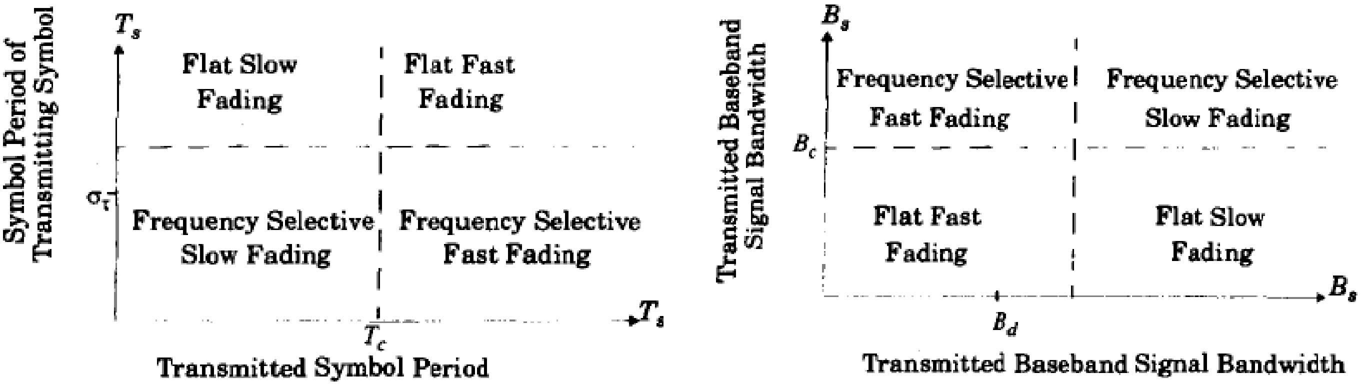
- ✓ In a slow fading channel, the channel impulse response changes at a rate much slower than the transmitted baseband signal *s(t)*.
- ✓ In this case, the channel is assumed to be static over one or several reciprocal bandwidth intervals.

- ✓ In the frequency domain, the Doppler spread of the channel is much less than the bandwidth of the baseband signals.
- ✓ Therefore, a signal undergoes slow fading if

$$T_S << T_c$$

$$B_S >> B_D$$

- ✓ The relation between the various multipath parameters and the type of fading experienced by the signal are summarized in Figure.



(a) (b)

Figure 1.19: Matrix illustrating type of fading experienced by a signal as a function of

(a) symbol period

(b) baseband signal bandwidth

State the difference between small-scale and large-scale propagation.

Sl. No.	LARGE-SCALE PROPAGATION	SMALL-SCALE PROPAGATION
1	Predicts mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance are useful in estimating the radio coverage area of a transmitter is called large-scale propagation	Rapid fluctuations of the received signal strength over very short travel distance/short duration are called Small-scale propagation.
2	As the mobile moves away from transmitter over large distances, the local average received signal will gradually decrease	As the mobile moves away from transmitter over small distances, , the received signal may fluctuate, giving rise to small scale fading
3	The local average signal is computed by large scale propagation models typically (Computed by averaging signal measurements over measurement track) cellular=> 1 GHz -2 GHz band→ power movement from 1m to 10m.	The received power may vary from [30/40 dB] when the receiver is moved by fraction of wavelength.

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Problems

1 **A mobile is located 10 Km away from a base station and uses a vertical λ/4 monopole antenna with a gain of 3 dB to receive cellular radio signals. The E-field at 1 km from the transmitter is measured to be 10^{-3} V/m. The carrier frequency used for this system is 1000 MHz.**

(a) Find the length and effective aperture of the receiving antenna

(b) Find the received power at the mobile using the two-ray ground reflection model assuming h_t is 50 m and h_r is 1.5 m above ground.

Given data

Transmitter-receiver distance = 10 Km

E-filed at 1 Km = 10^{-3} V/m

Frequency of operation = f = 1000 MHz

Solution:

(*a*) Length of antenna L $= \frac{\lambda}{4}$

Wavelength $\lambda = \frac{c}{f}$

$$= \frac{3 \times 10^8}{1000 \times 10^6} = 0.3\ m$$

Length L $= \frac{\lambda}{4}$

$$= \frac{0.3}{4} = 0.075\ m$$

Effective aperture of antenna $A_e = \frac{G\,\lambda^2}{4\,\pi}$

$$= \frac{(0.3)^2}{4\,\pi} = 0.015\ m^2$$

(*b*) Received Power $P_r(d) = \frac{|E|^2 G_r \lambda^2}{377\,(4\,\pi)}$ watts

Electric field $|E| = \frac{2\,E_o\ d_o}{d}\left(\frac{2\pi\, h_t\, h_r}{\lambda\ d}\right)$

$$= \frac{2 \times 10^{-3} \times 10^3}{10 \times 10^3}\left(\frac{2\pi(50)(1.5)}{0.3 \times 10 \times 10^3}\right)$$

Received Power $P_r = 3.14 \times 10^{11}$ watts

2 **Consider a transmitter which radiates a sinusoidal carrier frequency of 2000 MHz. For a vehicle moving 100 mph, compute the received carrier frequency if the mobile is moving**

(a) directly toward the transmitter

(b) away from the transmitter

(c) direction which is perpendicular to the direction of arrival of the transmitted signal.

Given Data:

Carrier frequency f_c = *2000MHz*

Vehicle speed V = *100 mph*

Solution:

(a) Doppler shift is positive for vehicle is moving towards the transmitter

$$\text{Received frequency } f = f_c + f_d$$

$$= 2000 \times 10^6 + \frac{V}{\lambda}$$

$$= 2000 \times 10^6 + \frac{100\times60\times60}{0.15}$$

$$= 2002 \text{ MHZ}$$

$$f = \frac{c}{\lambda}$$

$$\lambda = \frac{c}{f_c}$$

$$= \frac{3 \times 10^8}{2000 \times 10^6} = 0.15\text{m}$$

(b) Doppler shift is negative for vehicle is moving away from the transmitter

$$f = f_c - f_d$$

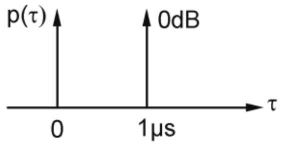
$$= 2000 \times 10^6 - \frac{V}{\lambda}$$

$$= 1997 \text{ MHZ}$$

(c) Vehicle is moving perpendicular to the angle of arrival of the transmitted signal

$\theta = 90°$ $\cos\theta = \cos 90° = 0$ there is no Doppler shift received frequency = transmitted frequency.

3 Compute the RMS delay spread for power delay profile



(a)

(b) If BPSK modulation is used, what is the maximum bit rate that can be sent through the channel?

Solution:

(a) RMS delay spread σ_τ = **Error!**

Mean excess delay $\bar{\tau}$ = **Error!**

$$= \frac{1\,(0) + 1\,(1)}{1+1} = \frac{1}{2}$$

$$= 0.5\ \mu s$$

$$\bar{\tau}^2 = \textbf{Error!}$$

$$= \frac{1(0)^2 + 1\,(1)^2}{1+1}$$

$$= \frac{1}{2} = 0.5\ \mu sec$$

$$\sigma_\tau = \textbf{Error!}$$

$$= \sqrt{0.5 - (0.5)^2} = 0.5\ \mu sec$$

(*b*) Bit rate R_b = symbol rate R_S

$$R_S = \frac{1}{T_s}$$

$$\frac{\sigma_\tau}{T_s} \leq 0.1$$

$$T_s \geq \frac{\sigma_\tau}{0.1} = \frac{0.5\ \mu s}{0.1} = 5\ \mu s$$

$$R_S = \frac{1}{T_s}$$

$$= \frac{1}{5 \times 10^6} = 200\ \text{ksps}$$

Bit rate R_b = 200 kbps

(*c*) Coherence bandwidth $B_C = \frac{1}{5\ \sigma_\tau}$

$$= \frac{1}{5(0.5 \times 10^{-6})} = 4\ \text{MHZ}$$

4 Calculate coherence time, Doppler spread for carrier frequency f_c = 1900 MHz and V = 50 m/s of moving vehicle distance of 10 m.

Solution:

(*a*) Coherence time $T_c = \frac{9}{16\,\pi f_m} = \frac{9\,\lambda}{16\,\pi\,V} = \frac{9\,c}{16\,\pi\,V f_c}$

Wavelength $\lambda = \frac{c}{f_c}$

$$V = f\lambda$$

Velocity $V = f_m\,\lambda$

$$f_m = \frac{V}{\lambda}$$

$$T_c = \frac{9 \times 3 \times 10^8}{16\,\pi(50 \times 1900 \times 10^6)} = 565\ \mu s$$

(*b*) Doppler spread $B_D = f_m = \frac{V}{\lambda} = \frac{V f_c}{c} = \frac{50 \times 1900 \times 10^6}{3 \times 10^8}$

$$B_D = 316.66 \text{ Hz}$$

5 Find the Fraunhofer (far-fied)distance for an antenna with maximum dimension of 1m and operating frequency of 9000 MHz. If antennas have unity gain, calculate the path loss.
[Nov 2013, April 2017, Nov 2012, Nov 2009, April/May 2021][Nov/Dec 2021]

Solution:

Operating frequency, f = 900 MHz

$$\lambda = c/f = \frac{3\times10^8 m/s}{900M} = 0.33m$$

Fraunhofer distance, $df = \frac{2d2}{\lambda} = \frac{2(1)}{0.33} = 6m$

Path loss $PL(dB) = -10log\left[\frac{(\lambda^2)}{(4\pi)^2 d^2}\right] = -10\log\left[\frac{(0.33^2)}{(4\times3.14)^2 \bullet 6^2}\right] = 47dB$

6 If a transmitter produces 50W of power, express the transmit power in units of (a) dBm, and (b) dBW. If 50W is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 1000m from the antenna. What is P_r(10km)? Assume unity gain for the receiver antenna. [Nov/Dec 2021][April/May 2022]

Solution:

Given:

Transmitter power, $P_t = 50W$

Carrier frequency, $f_C = 900\ MHz$

Using equation $P_r(d)dBm = 10\log\left[\frac{P_r(d_o)}{0.001\ W}\right] + 20\log\left(\frac{d_o}{d}\right)$

(a) Transmitter power,

$$P_t(d)dBm = 10\log\left[\frac{P_t(mW)}{1\ mW}\right] = 10\log\left[50\times10^3\right] = 47.0\ dBm$$

(b) Transmitter power,

$$P_t(dBW) = 10\log\left[\frac{P_t(W)}{1\ W}\right] = 10\log[50] = 17.0\ dBW$$

The received power can be determined using equation

$$P_t = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{50(1)(1)(1/3)^2}{(4\pi)^2(100^2)(1)} = (.5\times10^{-6})W = 3.5\times10^{-3} mW$$

$$P_r(\text{dBm}) = 10\log P_r(\text{mW}) = 10\log(3.5\times10^{-3}\text{ mW}) = -24.5\text{dBm}$$

The received power at 10m can be expressed in terms of dBm using equation $P_r(d)dBm = 10\log\left[\frac{P_r(d_o)}{0.001\ W}\right]$, where d_o = 100mand d = 10km.

$$P_r(10k\text{ m}) = P_r(100) + 20\log\left[\frac{100}{10000}\right]$$

$$= -24.5\ dBm - 40\ dB$$

$$= -64.5\ dBm$$

7. Determine the proper spatial sampling interval required to make small scale propagation measurement which assume that consecutive samples are highly correlated in time. How many samples will be required over *10m* travel distance if f_c*=1900 MHz* and v=50 m/s. How long would it take to make these measurements,

assuming they could be made in real time from a moving vehicle? What is the Doppler spread B_D for the channel? [April 2017][April/May 2019][Nov/Dec 2019]

Solution:

For correlation, ensure that the time between samples is equal to $T_C/2$, and use the smallest value of T_C for conservative design.

Using equation $T_C \approx \frac{9}{16\pi f_m}$

$$T_C \approx \frac{9}{16\ \pi\ f_m} = \frac{9\lambda}{16\ \pi\ v} = \frac{9c}{16\ \pi\ v\ f_c}$$

$$= \frac{9\times3\times10^8}{16\times3.14\times50\times1900\times10^6} = 565\ \mu s$$

Taking time samples at less than half , at 282.5 T_C corresponds to a spatial sampling interval of

$$\Delta x = \frac{vT_C}{2} = \frac{50\times565\mu s}{2} = 0.014125\ m = 1.41\ cm$$

Therefore, the number of samples required over a 10m travel distance is

$$N_x = \frac{10}{\Delta x} = \frac{100}{0.014125} = 701\ samples$$

The time taken to make this measurement is equal to $\frac{10}{50ms} = 0.2s$

The Doppler spread is $B_D = f_m = \frac{vf_c}{c} = \frac{50\times1900\times10^6}{3\times10^8} = 316.66\ Hz$

8. Consider a transmitter which radiates a sinusoidal carrier frequency of 1850 MHz. For a vehicle moving 60 mph, compute the received carrier frequency if the mobile is moving directly toward the transmitter. [April/May 2018]

Given Data:

Carrier frequency f_C = 1850MHz

Vehicle speed V = 60 mph

Solution:

Doppler shift is positive for vehicle is moving towards the transmitter

Received frequency $f = f_C + f_d$

$$= 1850 \times 10^6 + \frac{V}{\lambda}$$

$$= 1850 \times 10^6 + \frac{100\times60\times60}{0.15}$$

= 2002 MHZ

$$f = \frac{c}{\lambda}$$

$$\lambda = \frac{c}{f_C} = 0.15\text{m}$$

******

TWO MARKS

1. **What is meant by multipath propagation? [Nov/Dec 2017]**
Multipath propagation:
✓**Multipath** means the transmitted signal may arrive at the receiver over many paths.
✓The signal gets reflected and diffracted by different objects. So, each of the paths have a distinct amplitude, delay and direction of arrival.
✓This effect is known as multipath propagation
2. **What is the major advantage of wireless communication?**
Advantages of wireless communications:
✓ **Mobility:** The users have freedom to move.
✓ **Increased reliability:** Use of wireless technology eliminate cable failures, so overall reliability
✓ **Ease of installation:**
✓ **Rapid disaster recovery:** Accidents may happen due to fire, etc., the organization hot prepared to recover such natural disasters.
✓ **Low cost**
3. **What is the significance of propagation model?**
The major significance of propagation model is:
i. Propagation model predicts the parameter of receiver.
ii. It predicts the average received signal strength at a given distance from the transmitter.
4. **What are the types of propagation models?**
The two types of propagation models are

Large Signal Propagation Models	Small Scale Fading Models
They characterize signal strength over large transmitter-receiver separation distances. e.g., several hundred or 1000s of meters.	They characterize signal strength over short travel distance. e.g., mobile moves over small distance, for cellular and PCS frequencies in the 1 GHz to 2 GHz band, coverage area from 1 m to 10 m.

5. **Define large scale propagation. [Nov 2010]**
Large-scale propagation models predict the mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance, which are useful in estimating the radio coverage area of a transmitter and they characterize signal strength over large T-R separation distances.
6. **Define path loss. [Nov 2012]**
Path loss: The path loss is defined as the difference (in Db) between the effective transmitted power and the received power. Path loss may or may not include the effect of the antenna gains.
7. **What is free space propagation model?**
Free space propagation model: The free space propagation model is used to predict received signal strength, when the transmitter-receiver has a clear, line of sight path between them.
8. **What is free space propagation model? Write the expression for free space path loss. [June 2013][April/May 2023]**
Free space propagation model: The free space propagation model is used to predict received signal strength, when the transmitter-receiver has a clear, line of sight path between them.
The path loss for the free space model when antenna gains are included is given by

$$PL(dB) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right]$$

The path loss for the free space model when antenna gains are excluded is given by

$$PL(dB) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right]$$

9. Write an expression for free space propagation model.

The received power is given by the Friis free space equation as

$$P_{RX} = P_{TX} G_{RX} G_{TX}\left(\frac{\lambda}{4\pi d}\right)^2$$

where,
- P_{tx} → transmitted power
- P_{RX} → the received power
- G_{TX} → the transmitter antenna gain
- G_{RX} → the receiver antenna gain
- d → the transmitter-receiver separation distance in meter
- λ → Wavelength in meters

10. List the different types of propagation mechanisms. [Nov 2014]

The different types of propagation mechanisms include

- ✓ Reflection
- ✓ Diffraction
- ✓ Scattering

11. What is reflection?

Reflection:

Reflection occurs when a propagating electromagnetic wave impinges upon an object, which has very large dimension when compared to the wavelength of propagating wave.

12. What is diffraction?

Diffraction:

Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities

13. Which factors does diffraction depend on at high frequencies? [Nov/Dec 2019]

The amount of diffraction depends on the size of the obstacle or opening in relation to the wave length of the wave.

14. What is scattering?

Scattering:

Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength and where the number of obstacles per unit volume is large.

15. What is small-scale fading? [Nov/Dec 2021]

Small-scale fading, due to the constructive and destructive interference of the multiple signal paths between the transmitter and receiver. This occurs at the spatial scale of the order of the carrier wavelength, and is frequency dependent.

16. What is large scale fading?or shadow fading? Why it is called so? [Nov/Dec 2019]

Large-scale fading, due to path loss of signal as a function of distance and shadowing by large objects such as buildings and hills. This occurs as the mobile moves through a distance of the order of the cell size, and is typically frequency independent

17. State the difference between small-scale fading and large-scale fading. [May 2015, May 2013][April/May 2019]

Large-scale fading	Small-scale fading
The rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a long period of time or travel distance is known as	The rapid fluctuations of the amplitudes, phases; or multipath delays of a radio signal over a short period of time or travel distance is known as

large scale fading.	small scale fading.

18. Find the far-field distance for an antenna with maximum dimension of 2 m and operating frequency of 1GHz. [Nov 2015, Nov 2016]

Given:

Largest dimension of antenna, D = 2 meter

Operating frequency, f = 1GHz

To Find:

Far field distance, d_f

Solution:

$$\lambda = \frac{c}{f} = \frac{3\times10^8 m/s}{1\times10^9 Hz} m = 0.3\text{m}$$

Far field distance, $d_f = \dfrac{2D^2}{\lambda}$

$$= \frac{2(2)^2}{0.3} = 26.27\ m$$

19. Calculate the Brewster angle for wave impinging on ground having a permittivity ε_r = 5. [May 2016, Dec 2009]

Given:

Permittivity, ε_r =5

To find:

Brewster angle for wave

Solution:

$$\sin(\theta_i) = \frac{\sqrt{\varepsilon_r - 1}}{\sqrt{\varepsilon_r^2 - 1}} = \frac{\sqrt{(5)-1}}{\sqrt{(5)^2 - 1}} = \sqrt{\frac{4}{24}} = 0.4082$$

$$\theta_i = \sin^{-1}(0.4082) = 24.09^0$$

The Brewster angle for ε_r =5 is equal to 24.09^0

20. Calculate the Brewster angle for wave impinging on ground having a permittivity ε_r =4. (8m – May 2015, 8m – Nov 2013]

Given: Permittivity, ε_r =4

To find:

Brewster angle for wave

Solution:

$$\sin(\theta_i) = \frac{\sqrt{\varepsilon_r - 1}}{\sqrt{\varepsilon_r^2 - 1}} = \frac{\sqrt{(4)-1}}{\sqrt{(4)^2 - 1}} = \sqrt{\frac{3}{15}} = 0.577$$

$$\theta_i = \sin^{-1}(0.577) = 24.090$$

The Brewster angle for ε_r =4 is equal to 24.090

21. Interpret Snell's law. [May 2015, May 2013]

Snell's law state that

$$\sqrt{\mu_1\varepsilon_1}\sin(90-\theta_i) = \sqrt{\mu_2\varepsilon_2}\sin(90-\theta_t)$$

μ_1, μ_2 → Permittivity of two media

$\varepsilon_1, \varepsilon_2$ → Permeability of two media

θ_i → Incident angle, θ_t → Transmitted angle

22. List the advantages and disadvantages of 2 ray ground reflection model in the analysis of model in the analysis of path loss. [Dec 2012]

Advantages of 2 ray model:

- The 2 Ray model gives more accurate prediction at a long distance than the free space model.
- models predicts the mean received power at distance
- The 2 Ray model is used for mobile radio channels

Disadvantages of **2 ray model**:

- The formula is not applicable for short distances like 10 meters. Not accurate for a distance less than approximately 4.7 Km for GSM 1800.
- The two-ray model does not give a good result for a short distance due to the oscillation caused by the constructive and destructive combination of the two rays.
- Generally, the transmitter antenna height will be at least 10 meters to clear trees and buildings.

23. What are the three most important effects of small-scale multipath propagation? State the propagation Effects in mobile radio. [May 2014]

The three most important effects of small-scale multipath propagation are

1. Rapid changes in signal strength over a small travel distance or time interval.
2. Random frequency modulation due to varying Doppler shifts on different multipath signals.
3. Time dispersion (echoes) caused by multipath propagation delays.

24. What is Doppler shift?

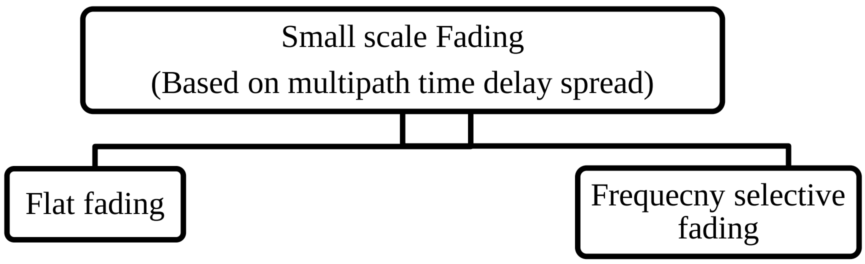
Doppler shift:

If the receiver is moving towards the source, then the zero crossings of the signal appear faster and the received frequency is higher. The opposite effect occurs if the receiver is moving away from the source. The resulting chance in frequency is known as the Doppler shift (f_D).

25. Differentiate the propagation effects with mobile radio. (or) Compare fast and slow fading. [April/May 2018]

Slow Fading	Fast Fading
Slow variations in the signal strength	Rapid variations in the signal strength.
Mobile station (MS) moves slowly	Local objects reflect the signal causes fast fading.
It occurs when the large reflectors and diffracting objects along the transmission paths are distant from the terminal.	It occurs when the user terminal (MS) move for short distances.

26. What are the different fading effects due multipath time delay spread?



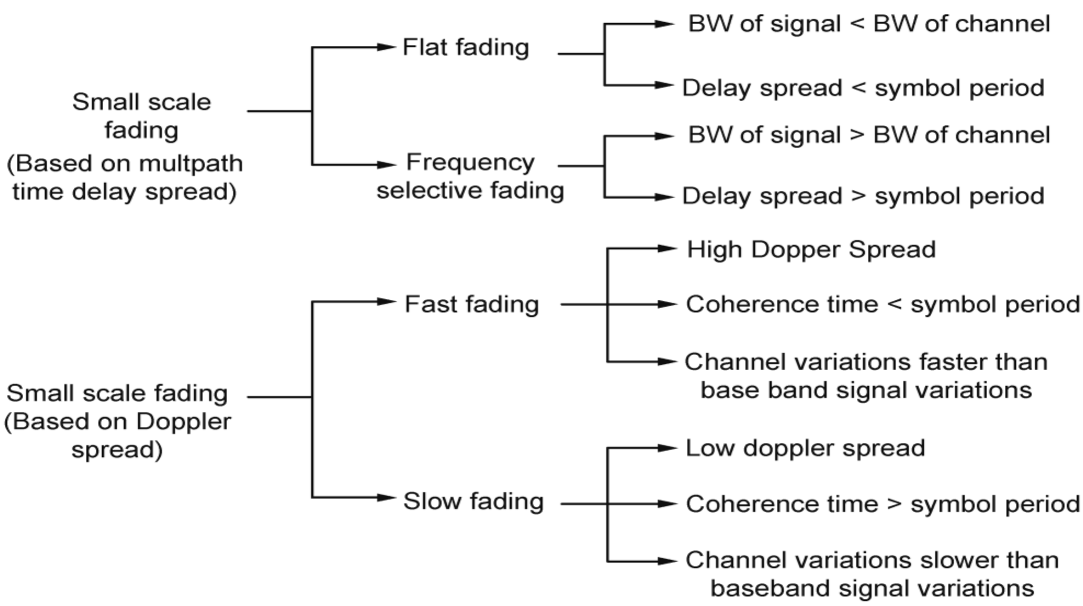
Flat fading:

1. Bandwidth of signal < Bandwidth of channel
2. Delay spread < Symbol period

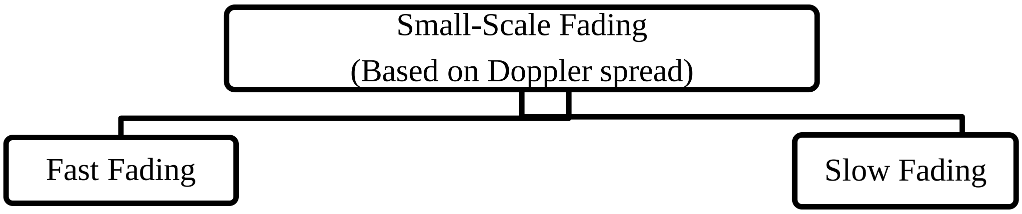
Frequency selective fading:

1. Bandwidth of signal > Bandwidth of channel
2. Delay spread > Symbol period

27. What are the types of small scale fading? [May 2013]



28. What are the different fading effects due to Doppler spread? [Nov 2014]



Fast Fading:
1. High Doppler spread
2. Coherence time < Symbol period
3. Channel variations faster than baseband signal variations

Slow Fading:
1. Low Doppler spread
2. Coherence time > Symbol period
3. Channel variations slower than baseband signal variations

29. Define coherence time and coherence bandwidth. [May 2016, Nov 2015, Nov 2016]

Coherence time is the maximum duration for which the channel can be assumed to be approximately constant. It is the time separation over which two received signals have strong potential for amplitude correlation.

Coherence bandwidth is the maximum frequency difference for which signals are strongly correlated in amplitude.

30. Give the Friis free space equation.[April/May 2023]

The ***Friis free space equation*** is given by

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

where,
$P_r(d)$ → Received power
P_t → Transmitted power
G_t → Transmitter antenna gain
G_r → Receiver antenna gain
d → T-R separation distance in meters
λ → Wavelength in meters
L → System loss factor

31. Define EIRP.

EIRP:

EIRP (Equivalent Isotropic Radiated Power) of a transmitting system in a given direction is defined as the transmitter power that would be needed, with an isotropic radiator, to produce the same power density in the given direction.

$$EIRP = P_t . G_t$$

where P_t - transmitted power in W, G_t – transmitting antenna gain

32. Give the formula to calculate Fraunhofer distance.

Fraunhofer distance is given by

$$d_f = \frac{2D^2}{\lambda}$$

where, D → Largest physical linear dimension of the antenna.

D_f → Far-field distance

λ → Wavelength in meters

33. When miscellaneous loss occurs?

The miscellaneous losses L are usually due to

- ✓ Transmission line attenuation
- ✓ Filter losses
- ✓ Antenna losses in the communication system.

34. Define path loss.

Path loss:

The path loss is defined as the difference (in Db) between the effective transmitted power and the received power. Path loss may or may not include the effect of the antenna gains.

35. Give the path loss for the free space model.

The path loss for the free space model when antenna gains are included is given by

$$PL(dB) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right]$$

The path loss for the free space model when antenna gains are excluded is given by

$$PL(dB) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right]$$

36. Give the path loss for the 2-ray model.

The path loss for the 2-ray model (with antenna gains) can be expressed in Db as

$$PL(dB) = 40\log d - (10\log G_t + 10\log G_r + 20\log h_t + 20\log h_r)$$

where,

h_t → Height of the transmitter

h_r → Height of the receiver.

d → T-R separation distance in meters

G_t → Transmitter antenna gain

G_r → Receiver antenna gain

37. What is the necessity of link budget?

The necessities of link budget are:

i. A link budget is the clearest way of computing the required transmitter power. It tabulates all equations that connect the Transmitter to the received SNR.

ii. It is reliable for communications.
iii. It is used to ensure the sufficient receiver power is available.
iv. To meet the SNR requirement link budget is calculated.

38. Express Log-distance Path Loss Model mathematically.

Average received signal power decreases logarithmically with distance.

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n$$

$$\overline{PL}(dB) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right)$$

where,

$\overline{PL}(d)$ → Average large-scale path loss
d → T-R separation
d_0 → Close-in reference distance
n → Path loss exponent

39. Differentiate ISI, fading, attenuation, shadowing and small scale, large scale fading? [Nov/dec 2012]

What are the two factors that contribute to the rapid fluctuations of the signal amplitude? [April/May 2019]

ISI: Signal dispersion leads to Inter Symbol Interference (ISI) at the Receiver.

Fading: Variations in signal strength are known as fading. It describes how the received signal amplitude changes with time.

Small Scale Fading is used to describe the rapid fluctuations of the amplitudes, phases or multipath delays of a radio signal over a short period of time. Wavelength $\lambda \simeq 1\ m$

Attenuation: It is the drop in the signal power when transmitting from one point to another.

Shadowing of the signal can occur whenever there is an obstruction between the transmitter and receiver.

Eg., buildings and hills

Large-scale fading causes signal power attenuation due to motion over large area.

Eg., large terrain (ex. Hills, forest, billboard…) between the transmitter and the receiver

40. Define shadowing. [Nov 2012]

Shadowing of the signal can occur whenever there is an obstruction between the transmitter and receiver.

41. Give various small scale fading parameters of Mobile Multipath Channels? [Dec 2012]

Small scale fading parameters of Mobile Multipath Channels

(i) Mean excess delays
(ii) RMS delay spread
(iii) Excess delay spread

42. Express Log-normal shadowing mathematically.

The path loss PL(d) at a particular location is random and distributed log-normally (normal in Db) about the mean distance dependent value .That is

$$PL(d)[dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

$$P_r(d)[dBm] = P_t[dBm] - PL(d)[dB]$$

where X_σ → Zero-mean Gaussian distributed random variable (in Db)

σ → Standard deviation (in Db)

43. What is flat fading? [Nov 2012, Nov /Dec 2017]

If the mobile radio channel has a constant gain & linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal, then the received signal will undergo flat fading.

44. What is frequency selective fading? How to avoid fading problem? [May 2012]

If the channel has a constant gain & linear phase response over a bandwidth that is smaller than the bandwidth of the transmitted signal, then the channel creates frequency selective fading on the received signal.

45. What are the factors influencing small scale fading?

- ✓ The factors influencing small scale fading are multipath propagation, speed of the mobile, speed of surrounding objects and the transmission bandwidth of the signal.
- ✓ Narrow band signal with bandwidth B > B_C, then the channel behaves like frequency selective fading.
- ✓ It occurs when

$$T_s \approx \frac{1}{B} \ll \frac{1}{B_c} \approx \sigma T_m \quad \text{causes performance degradation}$$

Where,

σTm → rms delay spread

Ts → Symbol duration

B → Bandwidth

Bc → Coherence bandwidth

46. Define mean excess delay and rms delay spread. [Nov 2015]

- ✓ The mean excess delay is the first moment of the power delay profile and is defined to be

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

- ✓ The rms delay spread is the square root of the second central moment of the power delay profile and is defined to be

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

$$\text{where,} \quad \overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)}$$

47. When a signal undergoes flat fading? (or) **State the condition for the occurrence of Flat Fading. [April/May 2021]**

A signal undergoes flat fading if

$$B_S << B_c$$

$$T_S >> \sigma_\tau$$

where Bs → Signal Bandwidth.
Bc → Coherence bandwidth
Ts → Reciprocal bandwidth
στ → rms delay spread

48. When a signal will undergoes frequency selective fading? (or)
State the condition for the occurrence of Frequency Selective Fading. [April/May 2021]

A signal undergoes frequency selective fading if

$$B_S > B_c$$

$$T_S < \sigma_\tau$$

where B_s → Signal Bandwidth.
B_c → Coherence bandwidth
T_s → Reciprocal bandwidth
σ_τ → *rms* delay spread

49. When a signal undergoes fast fading?

A signal undergoes fast fading if

$$T_S > T_c$$

$$B_S < B_D$$

where B_S → Bandwidth of the transmitted modulation

T_S → Reciprocal bandwidth of the transmitted modulation

50. When a signal will undergo slow fading?

A signal undergoes fast fading if

$$T_S << T_c$$

$$B_S >> B_D$$

where B_S → Bandwidth of the transmitted modulation

T_S → Reciprocal bandwidth of the transmitted modulation

51. State the difference between small-scale and large-scale propagation.

LARGE-SCALE PROPAGATION	SMALL-SCALE PROPAGATION
Predicts the mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance are useful in estimating the radio coverage area of a transmitter is called large-scale propagation	Rapid fluctuations of the received signal strength over very short travel distance/short duration are called Small-scale propagation.
As the mobile moves away from transmitter over large distances, the local average received signal will gradually decrease	As the mobile moves away from transmitter over small distances, , the received signal may fluctuate, giving rise to small scale fading

52. What is fading and Doppler spread? [Nov 2013, Nov 2016]

- ✓ **Fading:** The term small-scale fading or simply ***fading***, means rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short period of time or short travel distance, so that the large scale path loss effects may be ignored
- ✓ **Doppler spread:** Doppler spread B_D is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel.

53. What is Doppler spread? [May 2016]

- ✓ Doppler spread B_D is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel.
- ✓ Doppler spread B_D is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero.

54. Distinguish between Narrowband and Wideband systems. [DEC 2012, DEC 2013]

Sl. No.	Narrow band system	Wide band system
1.	In narrow band system, the available radio spectrum is divided into a large number of narrowband channels.	In wideband systems, the transmission bandwidth of a single channel is much larger than the coherence bandwidth of the channel.
2.	Small delay spread	Large delay spread
3.	High coherence bandwidth	Small coherence bandwidth

55. What is coherence bandwidth? [April/May 2021]

- ✓ Coherence bandwidth is defined as the bandwidth over which the frequency correlation function is above 0.9

$$B_C = \frac{1}{50\,\sigma_\tau}$$

If the frequency correlation function is above 0.5, then

$$B_C = \frac{1}{5\,\sigma_\tau}$$

$$\sigma_\tau \rightarrow \textit{rms} \text{ delay spread}$$

What is meant by Doppler spread?

- ✓ Doppler Spread is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero.

$F_c \rightarrow$ Pure sinusoidal tone of frequency

$f_d \rightarrow$ Doppler shift

- ✓ If f_c is transmitted then received Doppler spectrum will have components

spectrum=$f_c + f_d$ and $f_c - f_d$

56. Define coherence time. In what way does this parameter decide the behavior of wireless channel? [April 2017, Dec 2015, April/May 2021]

- ✓ Coherence time is the time over which two signals are having strong potential for amplitude correlation.
- ✓ The Doppler spread and coherence time are inversely proportional to one another.

$$\textit{Cohrence Time} = \frac{1}{\textit{Doppler Spread}}$$

57. Define mean excess delay. [Dec 2015]

Mean excess delay

- ✓ The mean excess delay is the first moment of the power delay profile (PDP).
- ✓ It is expressed as

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

58. Define RMS delay spread. [Dec 2015]

RMS delay spread

- ✓ The *rms* delay spread is the square root of the second central moment of the power delay profile.

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)}$$

where,

σ_τ → *rms* delay spread

a_k → Amplitude

$P(\tau_k)$ → Relative power levels of the individual multipath components

τ_k → Excess delay

59. **Define maximum excess delay. [Dec 2015]**

Maximum excess delay

- ✓ The maximum excess delay (X Db) of the power delay profile is defined to be the time delay during which multipath energy falls to X Db below the maximum.
- ✓ The maximum excess delay is defined $\tau_x - \tau_0$ as

  Where, τ_0 → First arriving signal

  τ_x → Maximum delay at which a multipath component is within X Db of the strongest multipath signal
- ✓ Maximum excess delay is sometimes called the ***excess delay spread***.

59. Give the difference between frequency flat and frequency selective fading. [April/May 2018][April/May 2022]

Sl. No.	Flat fading	Frequency selective fading
1.	Bandwidth of signal < Bandwidth of channel	Bandwidth of signal > Bandwidth of channel
2.	Delay spread < Symbol period	Delay spread > Symbol period

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QUESTION BANK
UNIT-II
MOBILE RADIO PROPAGATION

PART – A

1. What is meant by multipath propagation?
2. Define large scale propagation.
3. Define path loss.
4. What is free space propagation model? Write the expression for free space path loss.
5. List the different types of propagation mechanisms.
6. Which factors does diffraction depend on at high frequencies?
7. State the difference between small-scale fading and large-scale fading.
8. State the propagation Effects in mobile radio.
9. Compare fast and slow fading.
10. What are the types of small scale fading?
11. Define coherence time and coherence bandwidth.
12. Differentiate ISI, fading, attenuation, shadowing and small scale, large scale fading?
13. Give various small scale fading parameters of Mobile Multipath Channels?
14. What is flat fading?
15. What is fading and Doppler spread?
16. What is coherence bandwidth?
17. Distinguish between Narrowband and Wideband systems.
18. Define coherence time. In what way does this parameter decide the behavior of wireless channel?
19. Define maximum excess delay.
20. Give the difference between frequency flat and frequency selective fading.

PART – B

1. Describe briefly about free space propagation model. [May 2014, Nov 2012, May 2012, May 2019, May 2021, May 2023]
2. Explain the different types of multipath propagation in wireless communication. [May 2016, May 2015, Nov 2013, Nov 2012, Nov 2014]
3. Discuss the impact of time dispersion parameter, Coherence Bandwidth, Doppler Spread and Coherence time on small scale fading. [May 2021]
4. Show that a flat fading channel occurs when $T_s >= 100\sigma_\tau$. [April/May 2018]
5. Derive the path loss for large scale propagation in a multipath wireless environment.–What is Doppler spread? [April 2010]
6. Explain in detail about types of Small Scale Fading. [May 2010, May 2019, May 2023, Dec 2019]
7. Examine the effectiveness of flat fading and frequency selective fading. [May 2019, Dec 2019]

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UNIT- III

MODULATION TECHNIQUES AND EQUALIZATION AND DIVERSITY

Digital Modulation – **An Overview**: Factors That Influence The Choice Of Digital Modulation, **Linear Modulation Techniques:** Minimum Shift Keying (MSK), Gaussian Minimum Shift Keying(GMSK), **Spread Spectrum Modulation Techniques:** Pseudo- Noise (PN) Sequences, Direct Sequence Spread Spectrum (DS-SS)- Modulation Performance In Fading And Multipath Channels- **Equalization, Diversity And Channel Coding:** Introduction-Fundamentals Of Equalization- **Diversity Techniques:** Practical Space Diversity Considerations, Polarization Diversity, Frequency Diversity, Time Diversity.

3.1 Digital Modulation – An Overview

3.1.1 Factors That Influence The Choice Of Digital Modulation

3.2 Linear Modulation Techniques

3.2.1 Binary Phase Shift Keying (BPSK)

3.2.2 Differential Phase Shift Keying (DPSK)

3.2.3 Quadrature Phase Shift Keying (QPSK)

3.2.4 QPSK Transmission and Detection Techniques

3.2.5 Offset QPSK

3.2.6 $\pi/4$ QPSK

3.2.7 $\pi/4$ QPSK Transmission Techniques

3.2.8 $\pi/4$ QPSK Detection Techniques

3.3 Minimum Shift Keying (MSK)

3.4 Gaussian Minimum Shift Keying (GMSK)

3.5 Spread Spectrum Modulation Techniques

3.5.1 Pseudo- Noise (PN) Sequences

3.5.2 Direct Sequence Spread Spectrum (DS-SS)

3.6 Modulation Performance In Fading And Multipath Channels

3.7 Equalization, Diversity and Channel Coding

3.7.1 Introduction

3.7.2 Fundamentals Of Equalization

3.8 Diversity Techniques

3.8.1 Practical Space Diversity Considerations

3.8.1.1 Selection Diversity

3.8.1.2 Feedback or Scanning Diversity

3.8.1.3 Maximal Ratio Combining

3.8.1.4 Equal Gain Combining

3.8.2 Polarization Diversity

3.8.3 Frequency Diversity

3.8.4 Time Diversity

3.1 Digital Modulation – An Overview

- Modern mobile communication systems use digital modulation techniques.
- Digital modulation more cost effective than analog transmission systems.
- Some advantages are
  - greater noise immunity and robustness to channel impairments
  - easier multiplexing of various forms of information (e.g., voice, data, and video), and
  - greater security.
- Digital transmissions accommodate
  - ***digital error-control codes*** which detect and or correct transmission errors, and
  - support complex signal conditioning and processing techniques (source coding, encryption, and quantization).
- The modulating signal (e.g., the message) may be represented as a ***time sequence of symbols or pulses***.
- Each symbol represents n bits of information, where $n = log_2 m$, bits/symbol.

3.1.1 Factors that influence the choice of Digital Modulation:

Explain the factors that influence the choice of Digital Modulation.

- Several factors influence the choice of a digital modulation scheme.
- Some modulation schemes are better in terms of the bit error rate performance, while others are better in terms of bandwidth efficiency.
- The performance of a modulation scheme is often measured in terms of its power efficiency and bandwidth efficiency.
- ***Power efficiency*** describes the ability of a modulation technique to preserve the fidelity of the digital message at low power levels.
- The ***power efficiency***, η_p (sometimes called energy efficiency) of a digital modulation scheme is a measure of how favorably this tradeoff between fidelity and signal power is made.
- It is expressed as the ratio of the ***signal energy per bit*** *to* ***noise power spectral density*** (E_b/N_0) required at the receiver input.

  If R is the data rate in bits per second, and B is the bandwidth occupied by the modulated 1W signal, then bandwidth efficiency η_B is expressed as

$$\eta_B = \frac{R}{B} \; bps/Hz$$

- The ***system capacity*** of a digital mobile communication system is directly related to the bandwidth efficiency of the modulation scheme.
- By Shannon's channel coding theorem, the ***channel capacity*** formula.

$$\eta_{B\max} = \frac{C}{B} = \log_2\left(1 + \frac{S}{N}\right)$$

where *C* is the channel capacity (in bps), *B* is the RF bandwidth, and *S/N* is the signal-to-noise ratio.

- In the design of a digital communication system, very often there is a ***tradeoff between bandwidth efficiency*** and ***power efficiency***.

- Sensitivity to detection of timing jitter, caused by time-varying channels, is also an important consideration in choosing a particular modulation scheme.

3.2 Linear Modulation Techniques

- Digital modulation techniques may be broadly classified as linear and non-linear.
- In linear modulation techniques, the amplitude of the transmitted signal, *s(t)*, varies linearly with the modula6ng digital signal, m(t).
- Linear modulation techniques are bandwidth efficient.

- In a linear modulation scheme, the transmitted signal s(t) can be expressed as

$$s(t) = \text{Re}[A\, m(t)\ \exp(j2\pi f_c t)]$$
$$= A\,[m_R(t)\ \cos(2\pi f_c t) - m_I(t)\ \sin(2\pi f_c t)]$$

where *A* is the amplitude, f_c is the carrier frequency, and $m(t) = m_R(t) + jm_I(t)$ is a complex envelope representation of the modulated signal.

3.2.1 Binary Phase Shift Keying (BPSK)

Explain in detail about Binary Phase Shift Keying (BPSK).

- In binary phase shift keying (BPSK),
  - the phase of a constant amplitude carrier signal is switched between two values according to the two possible signals m_1 and m_2, corresponding to binary 1 and 0, respectively.
- Normally, the two phases are separated by 180^o.
- If the sinusoidal carrier has an amplitude A_c and energy per bit $E_b = \frac{1}{2} A_c^2 T_b$, then the transmitted BPSK signal is either

$$S_{BPSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \theta_c) \qquad 0 \le t \le T_b\ \ (binary\ 1)$$

Or

$$S_{BPSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \pi + \theta_c)$$

$$= -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \theta_c) \qquad 0 \le t \le T_b \ (binary\ 0)$$

- It is often convenient to generalize m_1 and m_2 as a binary data signal *m(t)*, which takes on one of two possible pulse shapes.
- Then the transmitted signal may be represented as

$$S_{BPSK}(t) = m(t)\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \theta_c)$$

- The BPSK signal is equivalent to a double sideband suppressed carrier amplitude modulated waveform, where $\cos(2\pi f_c t)$ is applied as the carrier, and the data signal *m(t)* is applied as the modulating waveform.
- Hence a BPSK signal can be generated using a balanced modulator.

Spectrum and Bandwidth of BPSK

- The BPSK signal using a polar baseband data waveform *m(t)* can be expressed in complex envelope form as

$$S_{BPSK} = \mathrm{Re}\{g_{BPSK}(t)\ \exp(j2\pi f_c t)\}$$

where $g_{BPSK}(t)$ is the complex envelope of the signal given by

$$g_{BPSK}(t) = \sqrt{\frac{2E_b}{T_b}}m(t)e^{j\theta_c}$$

- The power spectral density (PSD) of the complex envelope can be shown to be

$$P_{g_{BPSK}}(f) = 2E_b\left(\frac{\sin \pi f T_b}{\pi f T_b}\right)^2$$

- The PSD of a BPSK signal at 1W is given by

$$P_{BPSK} = \frac{E_b}{2}\left[\left(\frac{\sin \pi(f - f_c)T_b}{\pi(f - f_c)T_b}\right)^2 + \left(\frac{\sin \pi(-f - f_c)T_b}{\pi(-f - f_c)T_b}\right)^2\right]$$

- The PSD of the BPSK signal for both rectangular and raised cosine rolloff pulse shapes is plotted in Figure.

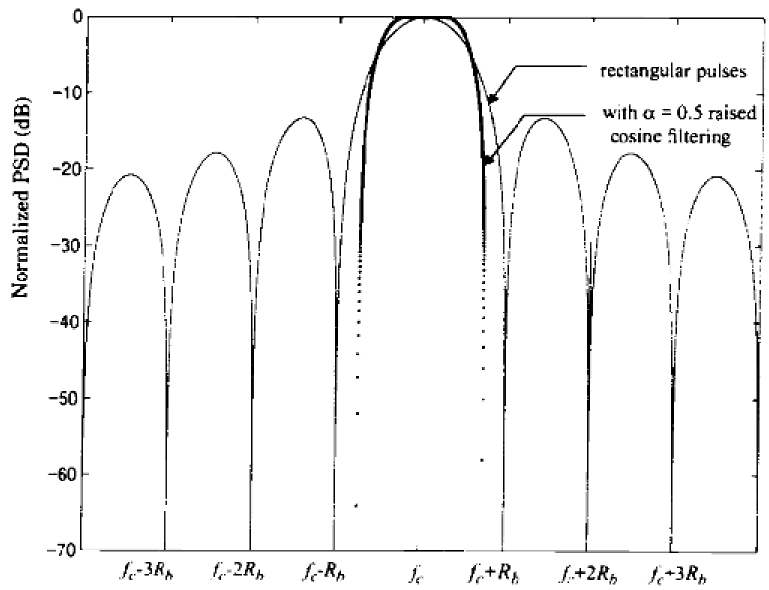

Figure. Power Spectral Density (PSD) of a BPSK signal.

BPSK Receiver

- If no multipath impairments are induced by the channel, the received BPSK signal can be expressed as

$$S_{BPSK}(t) = m(t)\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \theta_c + \theta_{ch})$$

$$= m(t)\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \theta)$$

where θ_{ch} is the phase shift corresponding to the time delay in the channel.

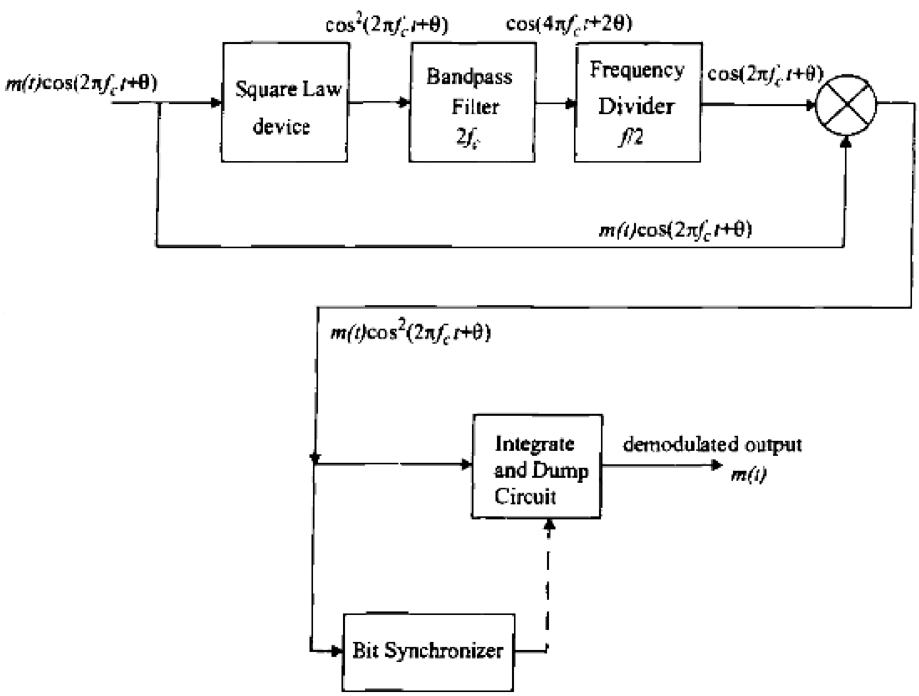

Figure: BPSK receiver with carrier recovery circuits.

- The received signal $\cos(2\pi f_c t+\theta)$ is squared to generate a dc signal and an amplitude varying sinusoid at twice the carrier frequency.
- The dc signal is filtered out using a bandpass filter with center frequency tuned to $2f_c$.
- A frequency divider is then used to recreate the waveform $\cos(2\pi f_c t+\theta)$.
- The output of the multiplier after the frequency divider is given by

$$m(t)\sqrt{\frac{2E_b}{T_b}}\cos^2(2\pi f_c t+\theta)=m(t)\sqrt{\frac{2E_b}{T_b}}\left[\frac{1}{2}+\frac{1}{2}\cos 2(2\pi f_c t+\theta)\right]$$

- This signal is applied to an ***integrate and dump circuit*** which forms the low pass filter segment of a BPSK detector.
- A ***bit synchronizer*** is used to facilitate sampling of the integrator output precisely at the end of each bit period.

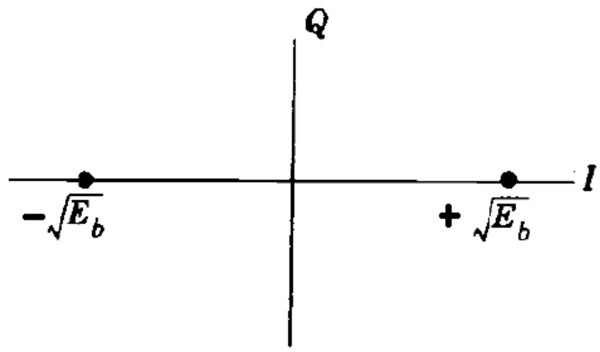

Figure: BPSK constellation diagram.

- The probability of bit error is obtained as

$$P_{e,BPSK}=Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

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3.2.2 Differential Phase Shift Keying (DPSK)

Explain in detail about Differential Phase Shift Keying (DPSK).

- Differential PSK is a noncoherent form of phase shift keying.
- It avoids the need for a coherent reference signal at the receiver.
- Noncoherent receivers are easy and cheap to build, and hence are widely used.
- In DPSK systems, the ***input binary sequence*** is first ***differentially encoded*** and then ***modulated using a BPSK modulator***.

- The ***differentially encoded sequence*** $\{d_k\}$ is generated from the ***input binary sequence*** $\{m_k\}$ ***complementing the modulo-2 sum*** of m_k and d_{k-1}.
- The effect is to leave the symbol d_k unchanged from the previous symbol if the incoming binary symbol to toggle d_k if m_k is 0.
- Table illustrates the generation of a DPSK signal for a sample sequence m_k which follows the relationship $d_k = m_k \oplus d_{k-1}$.

Table. Illustration of the Differential Encoding Process

$\{m_k\}$		1	0	0	1	0	1	1	0
$\{d_{k-1}\}$		1	1	0	1	1	0	0	0
$\{d_k\}$	1	1	0	1	1	0	0	0	1

- A block diagram of a DPSK transmitter is shown in Figure 5.24.
- It consists of ***a one bit delay element*** and ***a logic circuit*** interconnected to ***generate the differentially encoded sequence*** from the input binary sequence.

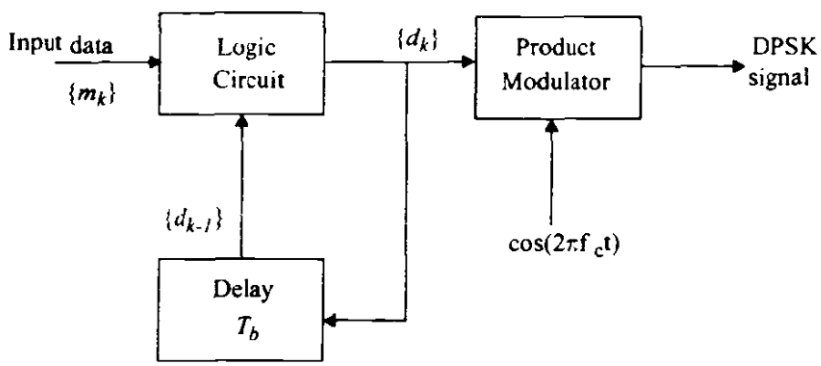

Figure. Block diagram of a DPSK transmitter.

- The output is passed through a product modulator to obtain the DPSK signal.
- At the receiver, the original sequence is recovered from the demodulated differentially encoded signal through a complementary process, as shown in Figure.

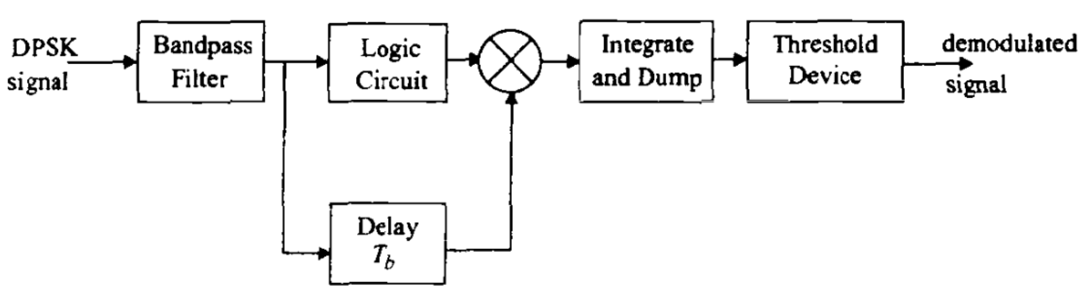

Figure. Block diagram of DPSK receiver.

- While DPSK signaling has the advantage of reduced receiver complexity, its energy efficiency is inferior to that of coherent PSK by about 3 dB.
- The average probability of error for DPSK in additive white Gaussian noise is given by

$$P_{e,DPSK} = \frac{1}{2}\exp\left(\frac{E_b}{N_0}\right)$$

****

3.2.3 Quadrature Phase Shift Keying (QPSK)

Explain in detail about Quadrature Phase Shift Keying (QPSK).

- Quadrature phase shift keying (QPSK) has twice the bandwidth efficiency of BPSK, since ***two bits are transmitted*** in ***a single modulation symbol***.
- The phase of the carrier takes on 1 of 4 equally spaced values, such as $0, \pi/2$, π, and $3\pi/2$, where ***each value of phase*** corresponds to ***a unique pair of message bits***.
- The QPSK signal for this set of symbol states may be defined as

$$S_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}}\cos\left[2\pi f_c t + (i-1)\frac{\pi}{2}\right] \qquad 0 \le t \le T_s \qquad i = 1,2,3,4.$$

where T_s is the symbol duration and is equal to twice the bit period.

- Using trigonometric identities, the above equations can be rewritten for the interval $0 \le t \le T_s$ as,

$$S_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}}\cos\left[(i-1)\frac{\pi}{2}\right]\cos(2\pi f_c t)$$
$$-\sqrt{\frac{2E_s}{T_s}}\sin\left[(i-1)\frac{\pi}{2}\right]\sin(2\pi f_c t)$$

- If basis functions $\phi_1(t) = \sqrt{\frac{2}{T_s}}\cos(2\pi f_c t)$, $\phi_2(t) = \sqrt{\frac{2}{T_s}}\sin(2\pi f_c t)$ are defined over the interval $0 \le t \le T_s$ for the QPSK signal set, then the 4 signals in the set can be expressed in terms of the basis signals as

$$S_{QPSK}(t) = \left\{\sqrt{E_s}\cos\left[(i-1)\frac{\pi}{2}\right]\phi_1(t) - \sqrt{E_s}\sin\left[(i-1)\frac{\pi}{2}\right]\phi_2(t)\right\}, \qquad i = 1,2,3,4.$$

- Based on this representation, a QPSK signal can be depicted using a two-dimensional constellation diagram with four points as shown in Figure.

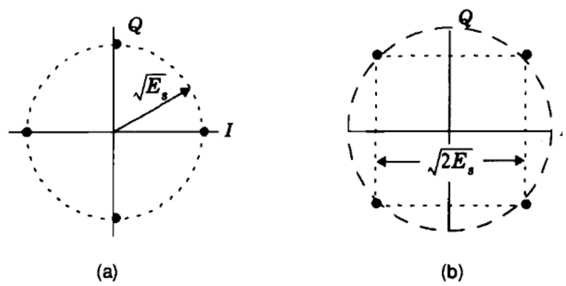

Figure:

(a) QPSK constellation where the carrier phases are 0, $\pi/2$, π, $3\pi/2$.

(b) QPSK constellation where the carrier phases are $\pi/4$, $3\pi/4$, $5\pi/4$, $7\pi/4$.

- It should be noted that different QPSK signal sets can be derived by simply rotating the constellation.
- As an example, Figure (b) shows another QPSK signal set where the phase values are $\pi/4$, $3\pi/4$, $3\pi/4$ and $7\pi/4$.
- From the constellation diagram of a QPSK signal, it can be seen that the distance between adjacent points in the constellation is $\sqrt{2E_s}$.
- Since each symbol corresponds to two bits, then $E_s = 2E_b$, thus the distance between two neighboring points in the QPSK constellation is equal to $2E_b$.
- The average probability of bit error in the additive white Gaussian noise (AWGN) channel is obtained as $P_{e,QPSK} = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$.

Spectrum and Bandwidth of QPSK Signals

Explain in detail about Spectrum and Bandwidth of QPSK Signals.

- The power spectral density of a QPSK signal can be obtained as similar to BPSK, with the bit periods T_b replaced by symbol periods T_s.
- Hence, the PSD of a QPSK signal using rectangular pulses can be expressed as

$$P_{QPSK} = \frac{E_s}{2}\left[\left(\frac{\sin \pi(f - f_c)T_s}{\pi(f - f_c)T_s}\right)^2 + \left(\frac{\sin \pi(-f - f_c)T_s}{\pi(-f - f_c)T_s}\right)^2\right]$$

$$= E_b\left[\left(\frac{\sin 2\pi(f - f_c)T_b}{2\pi(f - f_c)T_b}\right)^2 + \left(\frac{\sin 2\pi(-f - f_c)T_b}{\pi(-f - f_c)T_b}\right)^2\right]$$

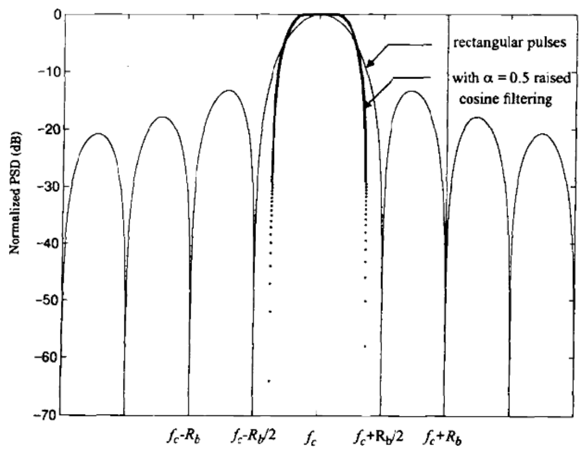

Figure. Power spectral density of a QPSK signal.

- The PSD of a QPSK signal for rectangular and raised cosine filtered pulses is plotted in Figure.
- The null-to-nul RF bandwidth is equal to the bit rate R_b, which is half that of a BPSK signal.

3.2.4 QPSK Transmission and Detection Techniques:

Explain in detail about QPSK Transmission and Detection Techniques.

QPSK transmitter

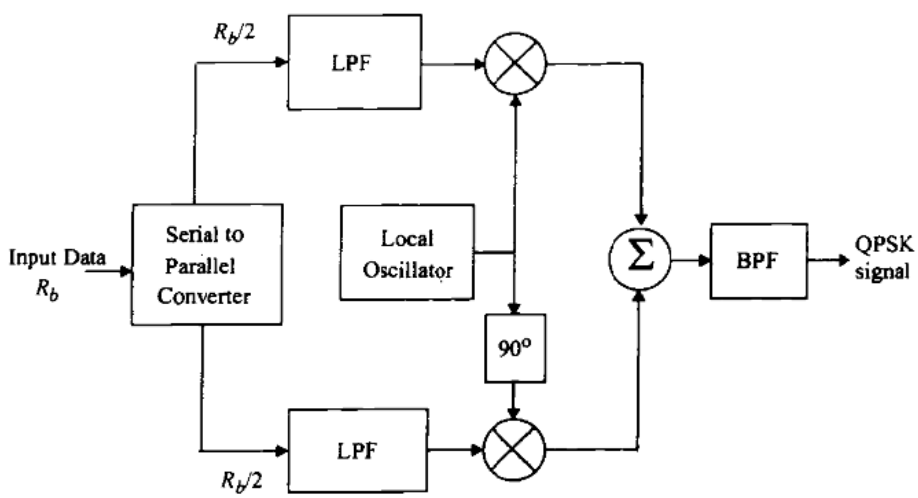

Figure. Block diagram of a QPSK transmitter.

- Figure 5.28 shows a block diagram of a typical QPSK transmitter.
- The ***unipolar binary message stream*** has bit rate R_b .
- This is first converted into a ***bipolar non-return-to-zero (NRZ) sequence*** using a unipolar to bipolar convener.
- The bit stream $m(t)$ is then split into two bit streams $m_I(t)$ and $m_Q(t)$ (in-phase and quadrature streams), each having a bit rate of $R_s = R_b/2$.
- The bit stream $m_I(t)$ is called the "even" stream and $m_Q(t)$ is called the "odd" stream.

- The ***two binary sequences*** are ***separately modulated by two carriers*** $\phi_1(t)$ and $\phi_2(t)$ which are in quadrature.
- The ***two modulated signals***, each of which can be considered to be a BPSK signal, ***are summed to produce a QPSK signal***.
- The ***filter at the output of the modulator*** confines the ***power spectrum of the QPSK signal*** within the ***allocated band***.
- This prevents spill-over of signal energy into adjacent channels.
- ***Pulse shaping*** is done at baseband ***to provide proper RF filtering*** at the transmitter output.

QPSK receiver

- Figure shows a block diagram of a ***coherent QPSK receiver***.
- The frontend bandpass filter removes the out-of-band noise and adjacent channel interference.
- The filtered output is split into two parts, and each part is coherently demodulated using the in-phase and quadrature carriers.
- The coherent carriers used for demodulation are recovered from the received signal using carrier recovery circuits.

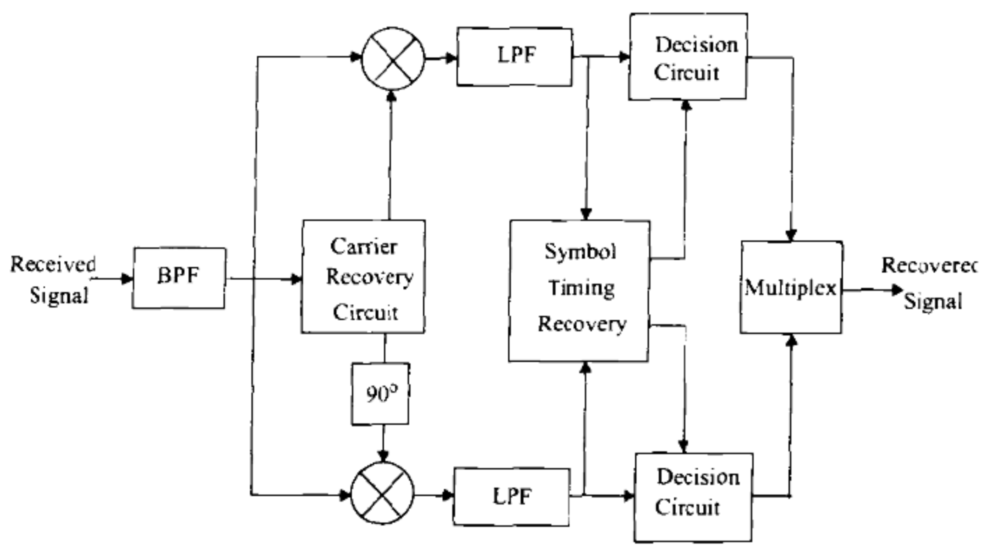

Figure. Block diagram of a QPSK receiver.

- The outputs of the demodulators are passed through decision circuits which generate the in-phase and quadrature binary streams.
- The two components are then multiplexed to reproduce the original binary sequence.

3.2.5 Offset QPSK

1. **Describe with neat diagram, the modulation technique of OQPSK and its advantage? [May 2017, Dec 2017]**
2. **Explain in detail Offset QPSK linear digital modulation techniques employed in wireless**

communication. [May 2012, May 2016]

- ✓ The amplitude of a QPSK signal is ideally constant.
- ✓ When QPSK signal is pulse shaped, they lose the constant envelope property.
- ✓ Any nonlinear amplification of the zero-crossings brings back the filtered sidelobes.
- ✓ To prevent the generation of side lobes and spectral widening offset QPSK was introduced.
- ✓ The QPSK signals are amplified only using linear amplifiers, which are less efficient.
- ✓ A modified form of QPSK, called ***offset QPSK (OQPSK)*** or ***staggered QPSK*** is less susceptible.

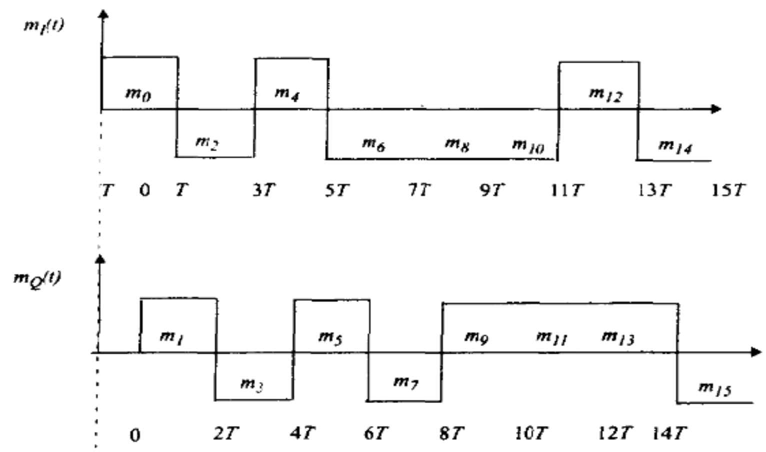

Figure: The time offset waveforms that are applied to the in-phase and quadrature arms of an OQPSK modulator. Notice that a half-symbol offset is used

- ✓ Due to the time alignment of $m_I(t)$ and $m_Q(t)$ in standard QPSK, phase transitions occur only once every $T_s = 2T_b s$, and will be a maximum of 180^0 if there is a change in the value of both $m_I(t)$ and $m_Q(t)$
- ✓ However, in OQPSK signaling, bit transitions occur every $T_b s$.
- ✓ Since the transitions instants of $m_I(t)$ and $m_Q(t)$ are offset, at any given time only one of the two bit streams can change values.
- ✓ This implies that the maximum phase shift of the transmitted signal at any given time is limited to $\pm 90^o$.
- ✓ By switching phases more frequently (i.e., every $T_b\ s$ instead of $2T_b\ s$) OQPSK signaling eliminates 180° phase transitions.
- ✓ Nonlinear amplification of OQPSK signals does not regenerate the high frequency sidelobes as much as in QPSK.
- ✓ Thus, spectral occupancy is significantly reduced, while permitting more efficient RF amplification.

- ✓ The spectrum of an OQPSK signal is identical to that of a QPSK signal; hence both signals occupy the same bandwidth.
- ✓ OQPSK retains its bandlimited nature even after nonlinear amplification.
  - Therefore this is very attractive for mobile communication systems where bandwidth efficiency and efficient nonlinear amplifiers are critical for 1.0W power drain.
- ✓ OQPSK signals also appear to perform better than QPSK in the presence of phase jitter due to noisy reference signals at the receiver.

Difference between OQPSK and QPSK

OQPSK	QPSK
In OQPSK signaling, the even and odd bit streams, $m_I(t)$ and $m_Q(t)$ are offset in their relative alignment by one bit period	In QPSK signaling, the bit transitions of the even and odd bit streams occur at the same time instants.
OQPSK signals does not regenerate the high frequency side lobes	QPSK signals regenerate the high frequency side lobes.

Similarities of OQPSK and QPSK

- ✓ The signals are identical and hence both signals occupy the same bandwidth.
- ✓ The staggered alignment of even and odd bits does not change the nature of the alignment.

Advantages of OQPSK

The advantages of offset-QPSK includes

- ✓ Lower amplitude fluctuations.
- ✓ Suppress out-of-band interference.
- ✓ Limits the phase-shift to maximum of 90° at a time.
- ✓ Spectral occupancy is significantly reduced.
- ✓ More efficient RF amplification.
- ✓ Better performance in the presence of phase jitter due to noisy reference signals at the receiver

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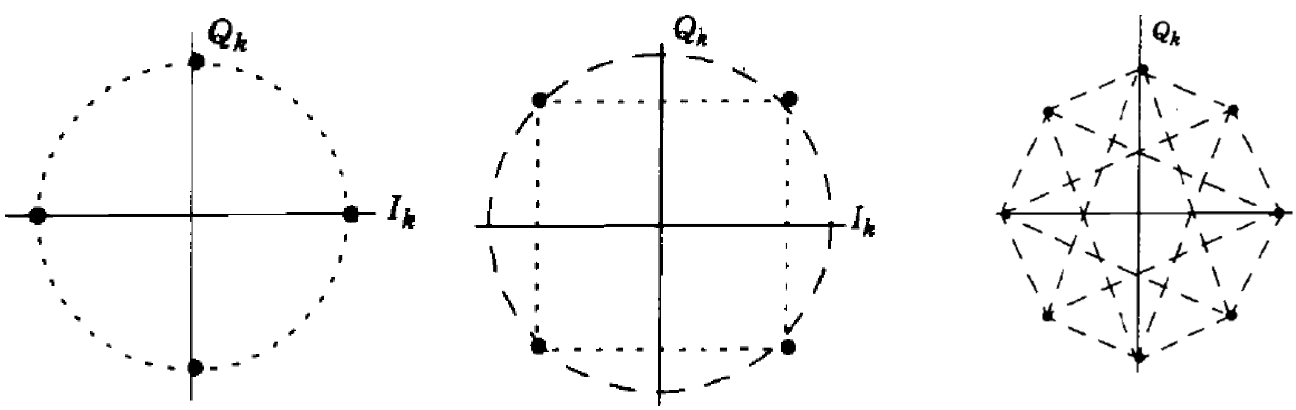
3.2.6 $\pi/4$ QPSK

1. **Explain in detail π / 4 DQPSK linear digital modulation techniques employed in wireless communication. (8m) [May 2016]**
2. **Describe with a block diagram π/4 quadrature phase shift keying and its advantages. (8m) [Nov 2014]**
3. **Explain the principle of π/4 Differential quadrature phase shift keying from a signal space diagram. (8m) [May 2013]**
4. **Draw the constellation of QPSK. (4m) [April 2010]**

5. With neat diagram, explain the modulation and demodulation of π / 4 DQPSK modulation techniques. [May 2018, May 2019, Dec 2019]

Description of $\frac{\pi}{4}$ - DQPSK

- ✓ The **π/4** shifted QPSK modulation is a quadrature phase shift keying technique.
- ✓ It offers a compromise between OQPSK and QPSK in terms of the allowed ***maximum phase transitions***.
- ✓ It may be demodulated in a coherent or noncoherent fashion.
- ✓ The ***maximum phase change*** is limited to $\pm 135^o$ as compared to 180^o for QPSK and 90^o for ***Offset QPSK***.
- ✓ Hence, the band limited ***π / 4QPSK*** signal preserves the constant envelope property better than bandlimited QPSK.
- ✓ But ***π/4QPSK*** is more susceptible to envelope variations than OQPSK.
- ✓ ***Attractive feature of π/4QPSK:*** This can be non-coherently detected fashion, which greatly simplifies the receiver design.
- ✓ In the presence of multipath spread and fading, $\pi/4$ QPSK is found to perform better.
- ✓ Very often, ***π/4QPSK*** signals are differentially encoded to offer easier differential detection or coherent demodulation.
- ✓ When differentially encoded *π/4QPSK* is called differential QPSK (DQPSK).



(a) Possible States for θ_k when $\theta_{k-1} = \frac{n\pi}{4}$

(b) Possible States for θ_k when $\theta_{k-1} = \frac{n\pi}{2}$

(c) All Possible States

Figure: Constellation diagram of a $\frac{\pi}{4}$ QPSK signal

3.2.7 $\pi/4$ QPSK Transmission Techniques

- ✓ A block diagram of a generic $\pi/4$ QPSK transmitter is shown in Figure.

- ✓ The input bit stream is partitioned by a serial-to-parallel (S/P) converter into two parallel data streams $m_{I,k}$ and $m_{Q,k}$ each with a symbol rate equal to half that of the incoming bit rate.
- ✓ The k^{th} in-phase and quadrature pulses, I_k and Q_k are produced at the output of the signal mapping circuit over time $kT \le t \le (k+1)T$ and are determined by their previous values, I_{k-1} and Q_{k-1} and as well as θ_k which itself is a function of ϕ_k which is a function of the current input symbols m_{Ik} and m_{Qk}.

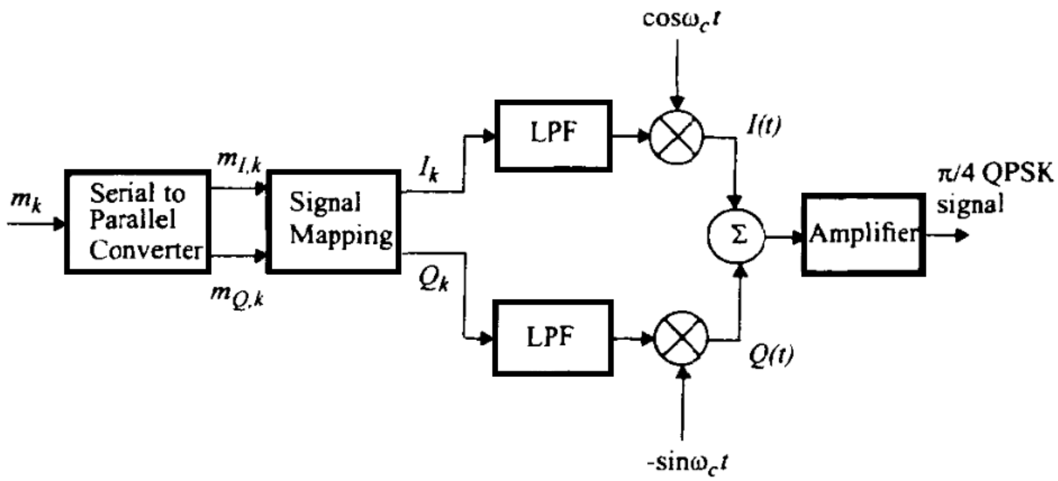


Figure: Generic $\frac{\pi}{4}$ QPSK transmitter

- ✓ I_k and Q_k represent rectangular pulses over one symbol duration having amplitudes given by

$$I_k = \cos\theta_k = I_{k-1}\cos\phi_k - Q_{k-1}\sin\phi_k$$

$$Q_k = \sin\theta_k = I_{k-1}\sin\phi_k - Q_{k-1}\cos\phi_k$$

where $$\theta_k = \theta_{k-1} + \phi_k$$

and θ_k and θ_{k-1} are phases of the k^{th} and *k-1*[st] symbols.

- ✓ The phase shift ϕ_k is related to the input symbols m_{Ik} and m_{Qk} according to Table.

Table: Carrier phase shifts corresponding to various input bit pairs

Information bits m_{Ik}, m_{Qk}	**Phase shift** ϕ_k
11	$\pi/4$
01	$3\pi/4$
00	$-3\pi/4$
10	$-\pi/4$

- ✓ As in a QPSK modulator, the in-phase and quadrature bit streams I_k and Q_k are then separately modulated by two carriers which are in quadrature with one another, to produce the $\pi/4$ QPSK waveform given by

$$S_{\pi/4QPSK}(t) = I(t)\cos\omega_c t - Q(t)\sin\omega_c t$$

3.2.8 $\pi/4$ QPSK Detection Techniques

- ✓ Due to ease of hardware implementation, differential detection is employed to demodulate $\pi/4$ QPSK signals.
- ✓ In an AWGN channel, the BER performance of
- ➢ Differentially detected $\pi/4$ QPSK is about 3 dB inferior to QPSK,
- ➢ Coherently detected $\pi/4$ QPSK has the same error performance as QPSK.
- ✓ In low bit rate, fast Rayleigh fading channels, differential detection offers a ***lower error floor*** since it does not depends on phase synchronization.
- ✓ There are various types of detection techniques that are used for the detection of $\pi/4$ QPSK signals that includes
  - ***Baseband differential detection*** determines the cosine and sine functions of the phase difference, and then decides on the phase difference
  - ***IF differential detection*** determines the cosine and sine functions of the phase difference, and then decides on the phase difference
  - ***FM discriminator detection*** detects the phase difference directly in a noncoherent manner.

<u>Baseband Differential Detection</u>

- ✓ Figure shows a block diagram of a baseband differential detector.
- ✓ The incoming $\pi/4$ QPSK signal is quadrature demodulated using two local oscillator signals that have the same frequency as the unmodulated carrier at the transmitter, but not necessarily the same phase.
- ✓ If $\phi_k = \tan^{-1}\left(Q_k / I_k\right)$ is the phase of the carrier due to the k^{th} data bit, the output and w_k and z_k from the two low pass filters in the in-phase and quadrature arms of the demodulator can be expressed as

$$w_k = \cos\left(\phi_k - \gamma\right)$$

$$z_k = \sin\left(\phi_k - \gamma\right)$$

where, γ is a phase shift due to noise, propagation, and interference.

- ✓

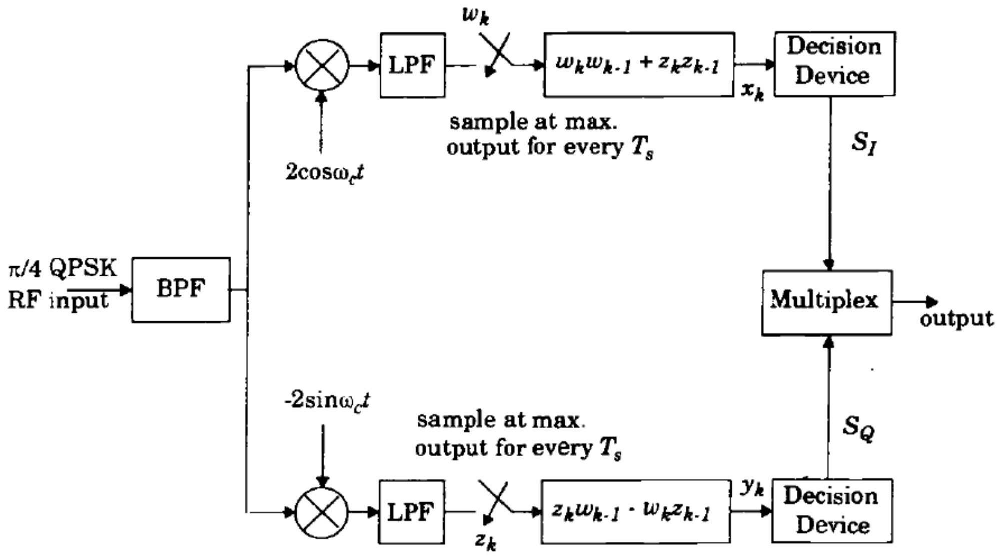


Figure: Block diagram of a baseband differential detector

- The phase γ is assumed to change much slower than ϕ_k so it is essentially a constant.

Table: Carrier phase shifts corresponding to various input bit pairs

Information bits m_{Ik}, m_{Qk}	**Phase shift** ϕ_k
11	$\pi/4$
01	$3\pi/4$
00	$-3\pi/4$
10	$-\pi/4$

- ✓ The output of the differential decoder is applied to the decision circuit, which uses the above table to determine, $S_I = 1$, if $x_k > 0$ or $S_I = 0$, if $x_k < 0$

  $S_Q = 1$, if $y_k > 0$ or $S_Q = 0$, if $y_k < 0$

  where S_I and S_Q are the detected bits in the in-phase and quadrature arms, respectively.
- ✓ It is important to ensure that the local receiver oscillator frequency is the same as the transmitter carrier frequency, and that it does not drift.
- ✓ Any drift in the carrier frequency will cause a drift in the output phase which will lead to BER degradation.

IF Differential Detector

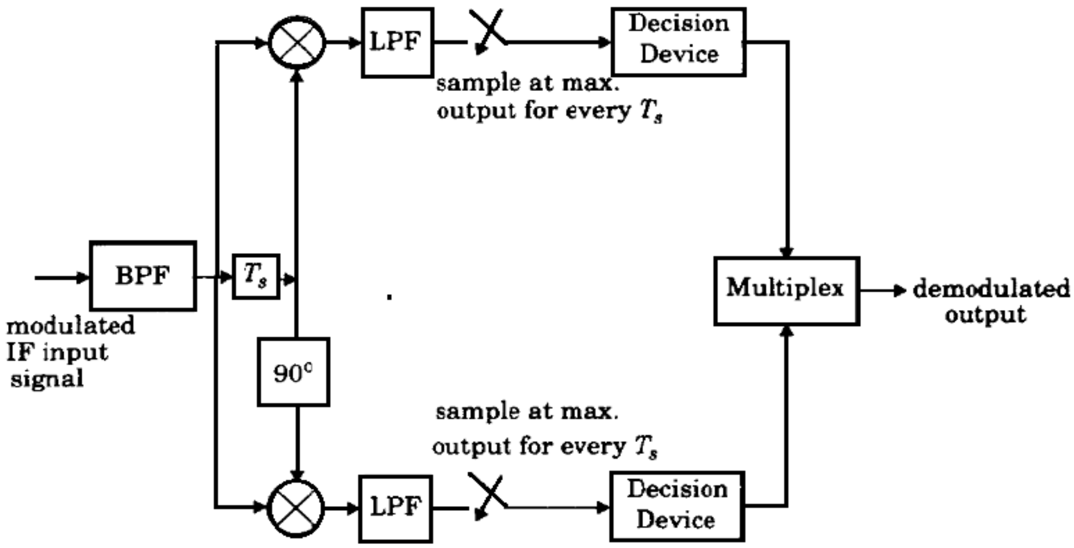


Figure: Block diagram of an IF differential detector for $\frac{\pi}{4}$ QPSK

- ✓ The IF differential detector avoids the need for a local oscillator by using a delay line and two phase detectors is shown in Figure.
- ✓ The received signal is converted to IF and is bandpass filtered.

FM Discriminator

- ✓ A block diagram of an FM discriminator detector for $\frac{\pi}{4}$ QPSK is shown in figure.
- ✓ The input signal is first filtered using a bandpass filter that is matched to the transmitted signal.
- ✓ The filtered signal is then hardlimited to remove any envelope fluctuations.

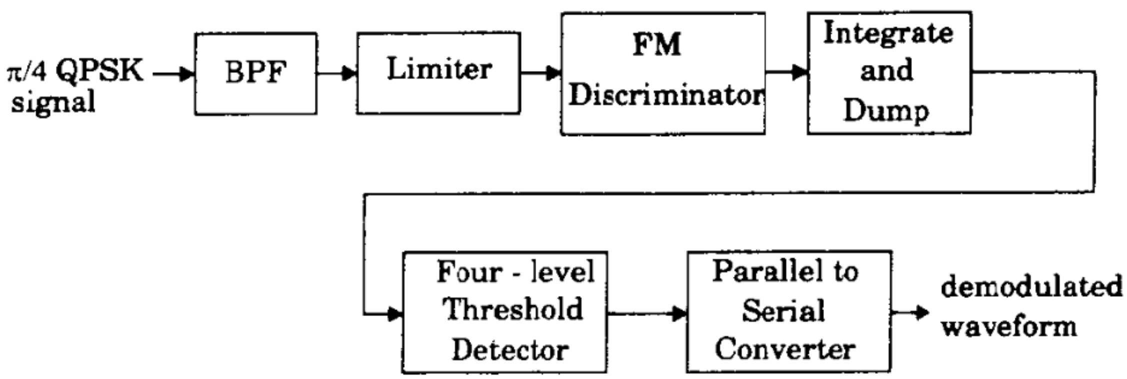


Figure: FM discriminator detector for $\frac{\pi}{4}$ QPSK demodulation

- ✓ Hard limiting preserves the phase changes in the input signal and hence no information is lost.
- ✓ The FM discriminator extracts the instantaneous frequency deviation of the received signal which, when integrated over each symbol period gives the phase difference between two sampling instants.

- ✓ The phase difference is then detected by a four level threshold comparator to obtain the original signal.
- ✓ The phase difference can also be detected using a modulo-2π phase detector.
- ✓ The modulo-2π phase detector improves the BER performance and reduces the effect of click noise.

******

3.3 Minimum Shift Keying (MSK)

1. **What is MSK? Also derive the expression of MSK signal as a special type of FSK signal and explain its spectral density. (16m) [Nov 2016]**
2. **Derive the expression for MSK as a special type of FSK signal. (16m) [Nov 2015]**
3. **Discuss in detail the demodulation techniques for Minimum shift keying. (8m) [May 2015]**
4. **Explain the principle of Minimum shift keying (MSK) modulation and derive the expression for power spectral density. (8m) [May 2013, Dec 2017]**
5. **Discuss in detail any two demodulation techniques of minimum shift keying method. (8m) [Nov 2011]**
6. **(i) Explain the working mechanism of transmitter and receiver block of MSK modulation technique (10)**
   (ii) State the salient features observed in the power spectral density of MSK when compared with QPSK and OQPSK (03). [May 2021, May 2023]

Concept of MSK:

- ✓ Minimum shift keying (MSK) is a special type of continuous phase frequency shift keying (CPFSK).
- ✓ In MSK, the peak frequency deviation is equals to 1/4 the bit rate.
- ✓ MSK is called as fast FSK since the frequency spacing used is only half as much as that used in conventional non-coherent FSK.
- ✓ MSK is a spectrally efficient modulation scheme.
- ✓ It possesses properties such as
  - Constant envelope
  - Spectral efficiency
  - Good BER performance
  - Self-synchronizing capability
- ✓ An MSK signal is a special form of OQPSK where the baseband rectangular pulses are replaced with half-sinusoidal pulses.
- ✓ If half-sinusoidal pulses are used instead of rectangular pulses in OQPSK signal, the modified signal is defined as MSK

  where Φ_k is 0 or 1 depending on whether $m_I(t)$ is 1 or -1.
- ✓ MSK has constant amplitude.
  - ✓ Phase continuity at the bit transition periods is ensured by choosing the carrier frequency to be an integral multiple of one fourth the bitrate, 1/4T.
  - ✓ MSK signal is an FSK signal with binary signaling frequencies of $f_c + 1/4T$ and $f_c - 1/4T$.
  - ✓ Phase of the MSK signal varies linearly during each bit period.

MSK Power Spectrum

- ✓ TheRFpowerspectrumisobtainedbyfrequencyshiftingthemagnitudesquaredoftheFouriertransform ofthebaseband***pulse shaping*** function.

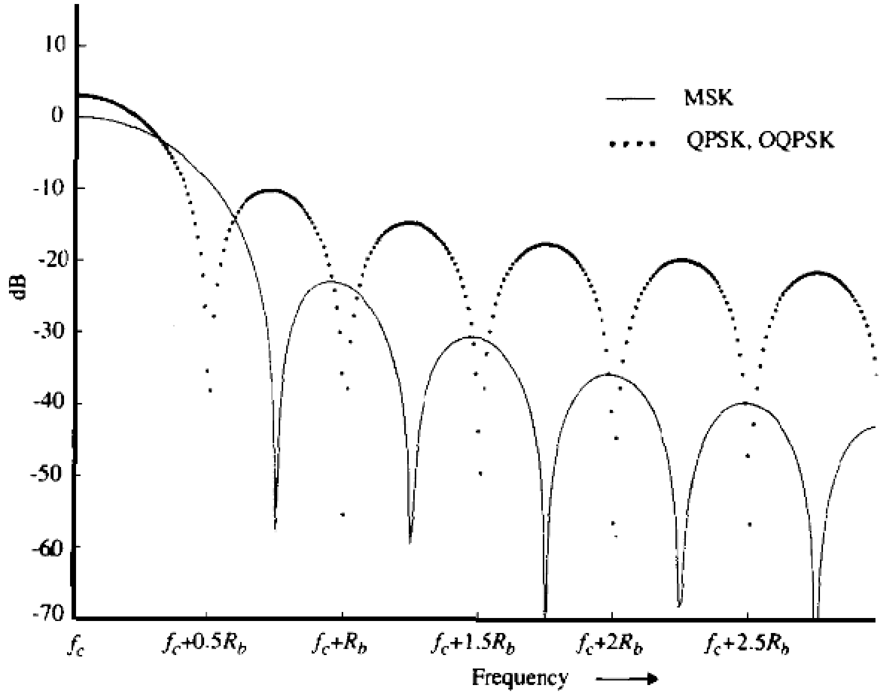


Figure: Power spectral density of MSK signals

- ✓ 99%oftheMSKpower is contained with in a bandwidth $B = 1.2/T$.
- ✓ The faster rolloff of the MSK spectrum is due to the fact that smoother pulse functions are used.
- ✓ MSK spectrum has lower sidelobes than QPSK and OQPSK.
- ✓ The mainlobe of MSK is wider than that of QPSK and OQPSK.
- ✓ In terms of null bandwidth, MSK is less spectrally efficient than the PSK techniques.
- ✓ Since there is no abrupt change in phase at bit transition periods, band limiting the MSK signal to meet required out-of-band specifications does not cause the envelope to go through zero.
- ✓ The envelope is kept more or less constant even after band limiting.
- ✓ Any small variations in the envelope level can be removed by bandlimiting at the receiver without raising the out-of-band radiation levels. Since the amplitude is kept constant.
- ✓ MSK signals can be amplified using efficient nonlinear amplifiers.
- ✓ The continuous phase property makes it highly desirable for highly reactive loads.
- ✓ MSK has simple demodulation and synchronization Circuits.

MSK Transmitter

- ✓ A typical MSK modulator is shown.

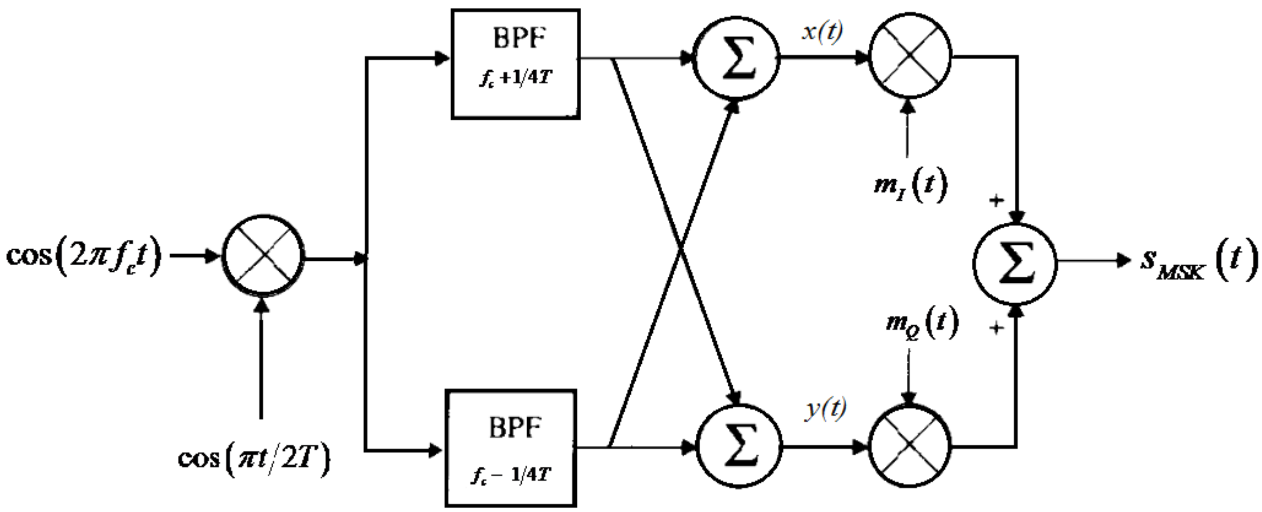


Figure: Block diagram of an MSK transmitter

- ✓ Multiplying a carrier signal with $\cos(\pi t/2T)$ produces two phase-coherent signals at $f_c + 1/4T$ and $f_c - 1/4T$.
- ✓ The two FSK signals are separated using two narrow bandpass filters and appropriately combined to form the in-phase and quadrature carrier components *x(t)* and *y(t)*, respectively.
- ✓ Carriers are multiplied with the odd and even bit streams, $m_I(t)$ and $m_Q(t)$, to produce the MSK modulated signal $s_{MSK}(t)$.

MSK Receiver

- ✓ The block diagram of an MSK receiver is shown in Figure.

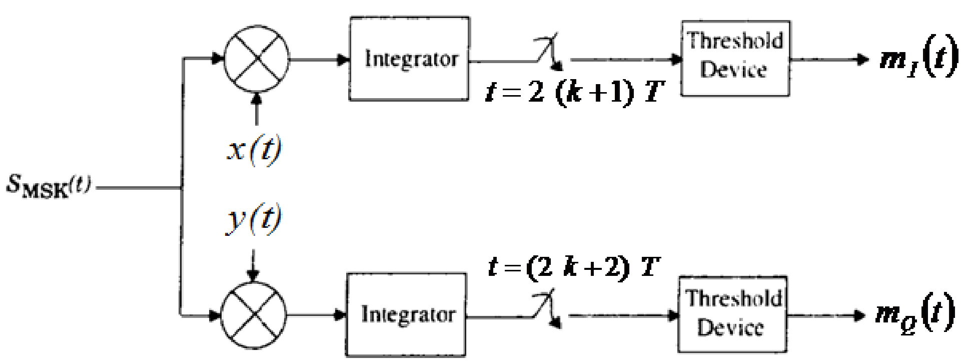


Figure: Block diagram of an MSK receiver

- ✓ The received signal $s_{MSK}(t)$ is multiplied by the respective in-phase and quadrature carriers *x(t)* and *y(t)*.

- ✓ The output of the multipliers are integrated over two bit periods and dumped to a decision circuit at the end of each two bit periods.
- ✓ Based on the level of the signal at the output of the integrator, the threshold detector decides whether the signal is a *0* or a *1*.
- ✓ The output datastreams correspond to $m_I(t)$ and $m_Q(t)$, which are offset combined to obtain the demodulated signal.

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3.4 Gaussian Minimum Shift Keying (GMSK)

1. **Explain in detail Gaussian Minimum shift Keying (GMSK) transmission and reception with necessary diagrams. (16M-May 2016) (10M-Nov 2015)**
2. **Explain with neat diagram, the principle of Gaussian Minimum shift Keying (GMSK) receiver and mention how it is different from MSK. (16M-May 2014)**
3. **Mention the advantages of GMSK and mention its advantages. (8M-May 2012)**
4. **Explain the concept of minimum shift keying and Gaussian MSK. (16m-April 2010]**
5. **With block diagram, explain the MSK transmitter and receiver. Derive an expression for MSK and its power spectrum.(Nov /Dec 2012)[April/May 2023]**

<u>Concept of Gaussian Minimum Shift Keying</u>

- ✓ GMSK is a simple binary modulation scheme.
- ✓ GMSK is a derivative of MSK.
- ✓ The sidelobe levels of the spectrum are further reduced by passing the modulating NRZ data waveform through a premodulation Gaussian pulse-shaping filter.
- ✓ GMSK detection can be coherent (like MSK) or noncoherent (like FSK)
- ✓ Premodulation pulse shaping filter used to filter NRZ data
  - converts full response message signal into partial response scheme

    Full response→ baseband symbols occupy T_b

    Partial response→transmitted symbols span several T_b
  - Pulse shaping doesn't cause pattern's averaged phasetrajectoryto deviate from simple MSK trajectory

<u>Power spectral density of GMSK Signals</u>

- ✓ GMSK filter is defined from baseband bandwidth, B and the baseband symbol duration, T.
- ✓ Increasing BT_b

- reduces signal spectrum
- results in temporal spreading and distortion

✓ Figure shows the simulated RF power spectrum of the GMSK signal for various values of BT.

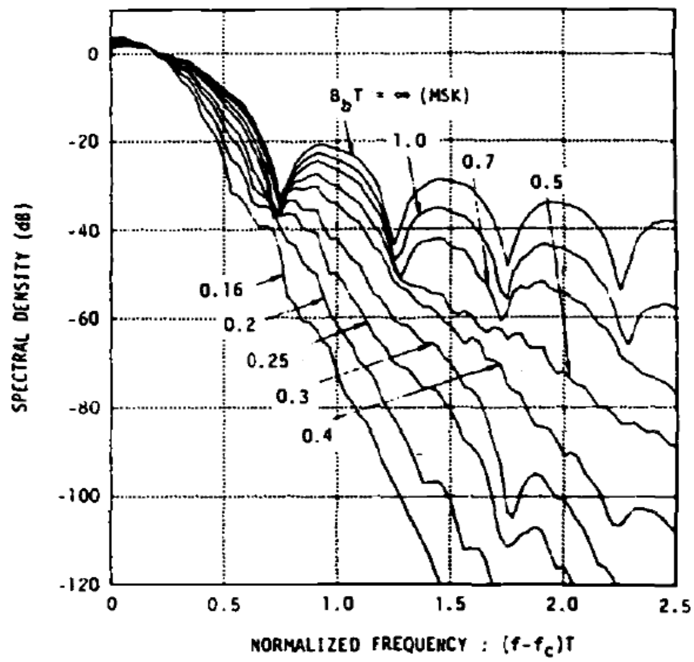


Figure: Power spectral density of a GMSK signal

Impact of $B_{3dB}{\cdot}T_b$

✓ $B_{3dB}{\cdot}T_b$ product decreases, spectrum becomes more compact (spectral efficiency)

- causes sidelobes of GMSK to fall off rapidly

$B_{3dB}{\cdot}T_b = 0.5$ → GMSK → 2nd lobe peak is 30dB below main lobe

MSK → 2nd peak lobe is 20dB below main lobe

- MSK ≈ GMSK with $B_{3dB}{\cdot}T_b = \infty$

✓ Reducing $B_{3dB}{\cdot}T_b$, increases irreducible error rate (IER)due to ISI

- ISI degradation caused by pulse shaping increases
- Mobile channels induce IER due to mobile's velocity
- If GMSK IER< mobile channel IER →no penalty for using GMSK

✓ Table shows occupied bandwidth containing a given percentage of power in a GMSK signal as a function of the BT product.

BT	90%	99%	99.9%	99.99%
0.2 GMSK	0.52	0.79	0.99	1.22

0.25 GMSK	0.57	0.86	1.09	1.37
0.5 GMSK	0.69	1.04	1.33	2.08
MSK	0.78	1.20	2.76	6.00

Occupied RF Bandwidth containing a Given Percentage of Power

- ✓ e.g. for BT = 0.2 → 99% of the power is in the bandwidth of $1.22R_b$
- ✓ While the GMSK spectrum becomes more and more compact with decreasing BT value, the degradation due to ISI increases.
- ✓ BER degradation due to ISI caused by filtering is minimum for a BT value of 0.5887, where the degradation in the required E_b/N_0 is only 0.14dB from the case of no ISI.

Advantages of GMSK

- ✓ GMSKs main advantages are
  - Power efficiency - from constant envelope (non-linear amplifiers)
  - Excellent spectral efficiency

Advantages of GMSK over MSK:

- ✓ GMSK is a derivative of MSK where the bandwidth required is further reduced by passing the modulating waveform through a Gaussian filter.
- ✓ The Gaussian filter minimizes the instantaneous frequency variations over time.
- ✓ GMSK is a spectrally efficient modulation scheme and it's particularly useful in mobile radio systems.
- ✓ It has a constant envelop spectrally efficient, good BER performance and self-synchronizing Baseband

GMSK Bit Error Rate (BER) for AWGN channel

- ✓ GMSK performs within 1dB of optimal MSK with $B_{3dB}T_b = 0.25$
- ✓ The pulse shaping impacts ISI.
- ✓ The bit error probability, P_e is a function of $B_{3dB}T_b$.

$$P_e = Q\left(\sqrt{\frac{2\lambda E_b}{N_0}}\right)$$

Where P_e → Bit error probability

λ → Constant related to $B_{3dB}T_b$

GMSK Transmitter

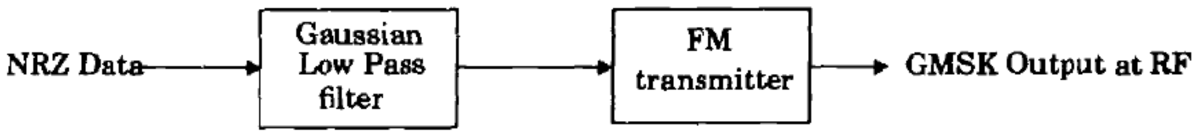


Figure: Block diagram of a GMSK transmitter using direct FM generation

- ✓ The simplest way to generate a GMSK signal is to pass a NRZ message bitstream through a Gaussian baseband filter followed by an FM modulator.

GMSK Receiver

- ✓ GMSK signals can be detected using orthogonal coherent detectors as shown in Figure, or with simple non coherent detectors such as standard FM discriminators.

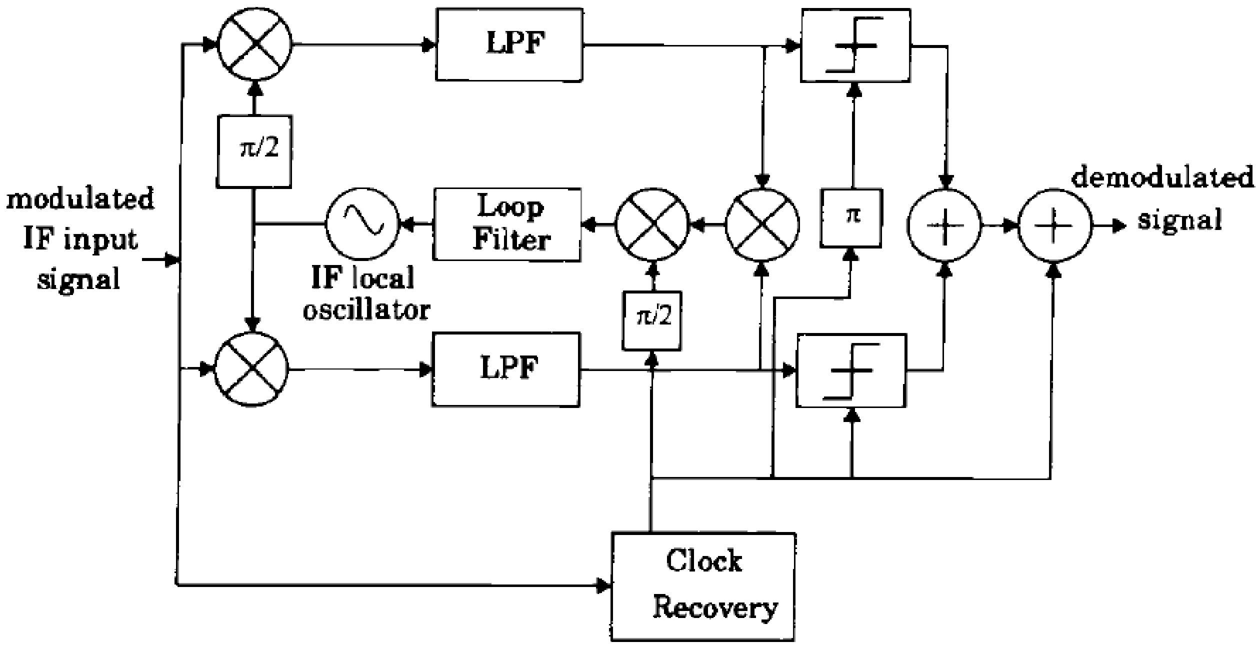


Figure: Block diagram of a GMSK receiver

- ✓ Carrier recovery is sometimes performed using a method where the sum of the two discrete frequency components contained at the output of frequency doublers is divided by four.
- ✓ De Buda's method receiver can be easily implemented using digital logic as shown in Figure.

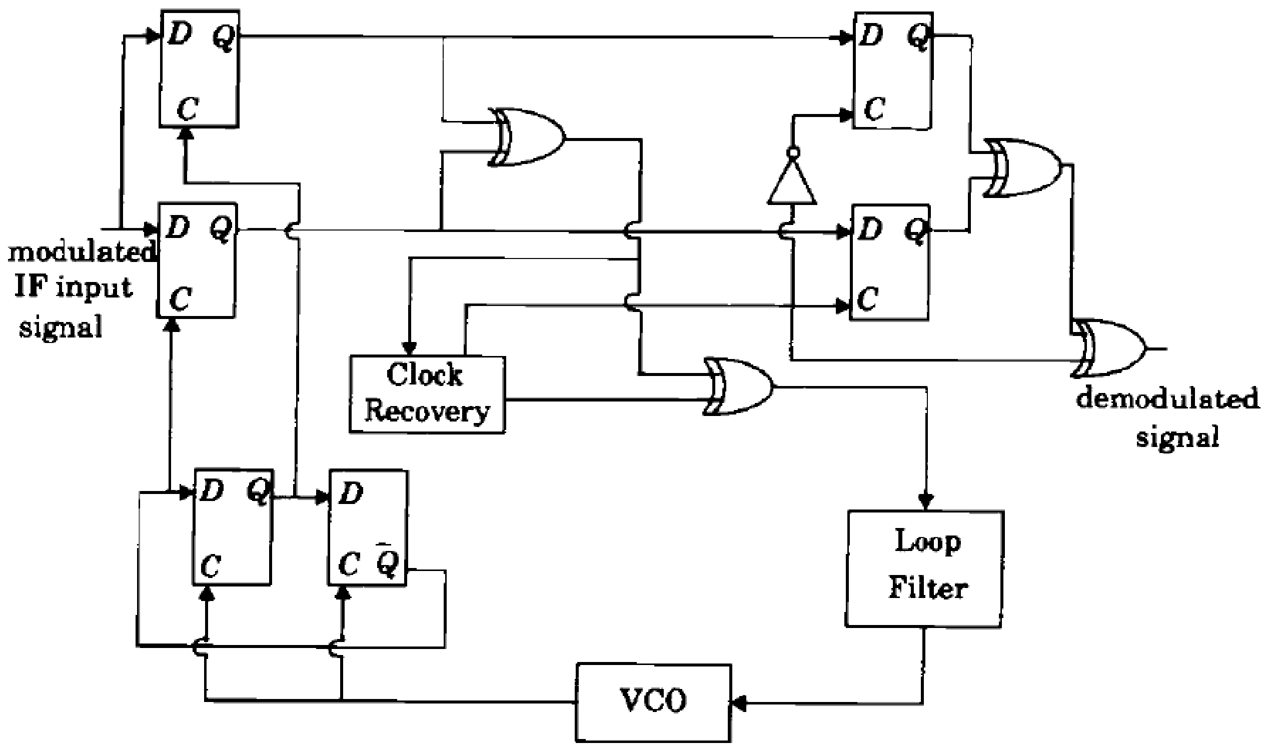


Figure: Digital logic circuit for GMSK demodulation

- ✓ 2 D flip flops (DFF) act as quadrature product demodulator
- ✓ XORs act as based band multipliers
- ✓ mutually orthogonal reference carriers are generated using two D flip-flops
- ✓ VCO center frequency is set to $4 \times f_c$ (f_c = carrier center frequency)
- ✓ Detecting GMSK signal by sampling output of FM demodulator is a non-optimal, effective method.

GMSK

- ✓ Improved spectral efficiency when compared to other phase shift keyed modes.
- ✓ Amplified by a non-linear amplifier and remain undistorted.
- ✓ Immune to amplitude variations
- ✓ More resilient to noise.
- ✓ Excellent power efficiency

MSK

- ✓ MSK has constant envelope.
- ✓ Relatively narrow bandwidth.
- ✓ Coherent detection suitable for satellite communications.
- ✓ Side lobes are zero outside the frequency band.
- ✓ Resist to co channel interference.

3.5 Spread Spectrum Modulation Techniques

Explain about Spread Spectrum Modulation Techniques.

- All of the modulation and demodulation techniques described so far try to achieve greater power and/or bandwidth efficiency in a stationary AWGN channel.
- Since bandwidth is a limited resource, the primary design objective of all the modulation schemes is to ***minimize the required transmission bandwidth***.
- In a ***multiple-user, multiple access interference (MAI)*** environment, spread spectrum systems become very bandwidth efficient.

- The spreading waveform is controlled by a pseudo-noise (PN) sequence or pseudo-noise code.
- PN sequence is a random binary sequence but can be reproduced by receivers.
- Spread spectrum signals are demodulated at the receiver through cross-correlation with a locally generated version of the pseudorandom carrier.
- Cross-correlation with the correct PM sequence ***despreads the spread spectrum signal*** and ***restores the modulated message*** as the original data.

- Spread spectrum modulation's properties make it well-suited for use in the mobile radio environment.
- The most important advantage is its ***inherent interference rejection capability***.
- Since ***each user is assigned a unique PN code***, the receiver can separate each user based on their codes.
- So, up to a certain number of users, interference between spread spectrum signals using the same frequency is negligible.

3.5.1 Pseudo- Noise (PN) Sequences

- A pseudo-noise (PN) or pseudorandom sequence is a binary sequence with an autocorrelation that resembles, over a period, the autocorrelation of a random binary sequence.
- Its autocorrelation also roughly resembles the autocorrelation of band-limited white noise.
- Although it is deterministic, a pseudonoise sequence has many characteristics that are similar to those of random binary sequences, such as having a nearly equal number of 0s and 1s, very low correlation between shifted versions of the sequence, very low crosscorrelation between any two sequences, etc.
- The PN sequence is usually generated using sequential logic circuits.
- A feedback shift register, which is diagrammed in Figure 5.48, consists of consecutive stages of two state memory devices and feedback logic.
- Binary sequences are shifted through the shift registers in response to clock pulses, and the output of the various stages are logically combined and fed back as the input to the first stage.

- When the feedback logic consists of exclusive-OR gates, which is usually the case, the shift register is called a linear PN sequence generator.

- The initial contents of the memory stages and the feedback logic circuit determine the successive contents of the memory.
- If a linear shift register reaches zero state at some time, it would always remain in the zero state, and the output would subsequently be all 0's.
- Since there are exactly 2^m-1 nonzero states for an *m*-stage feedback shift register, the period of a *PN* sequence produced by a linear *m*-stage shift register cannot exceed 2^m-1 symbols. A sequence of period 2^m-1 generated by a linear feedback register is called a maximal length (ML) sequence.

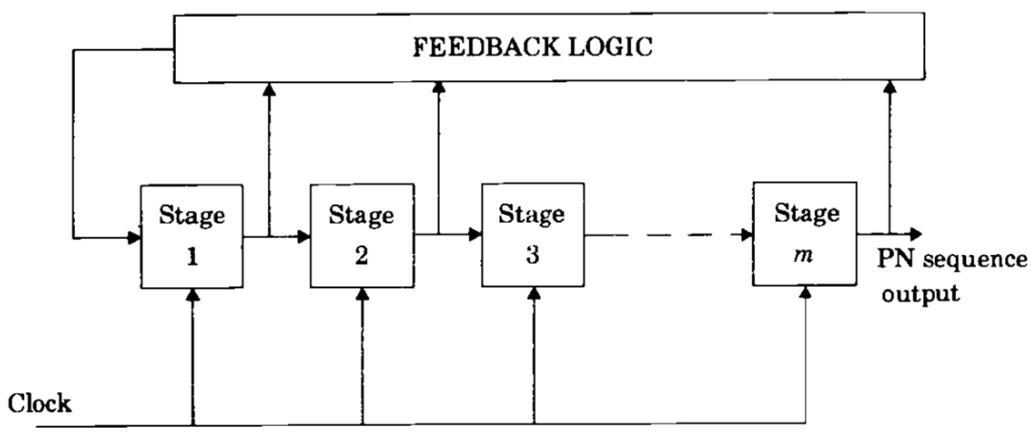


Figure 5.48 Block diagram of a generalized feedback shift register with in stages.

3.5.2 Direct Sequence Spread Spectrum (DSSS)

- A direct sequence spread spectrum (DSSS) system ***spreads the baseband data*** by ***directly multiplying the baseband data pulses*** *with a* ***pseudo-noise sequence***.
- The pseudo-noise sequence that is produced by a ***pseudo-noise code generator***.
- A ***single pulse*** or ***symbol*** of the PN waveform is called a ***chip***.

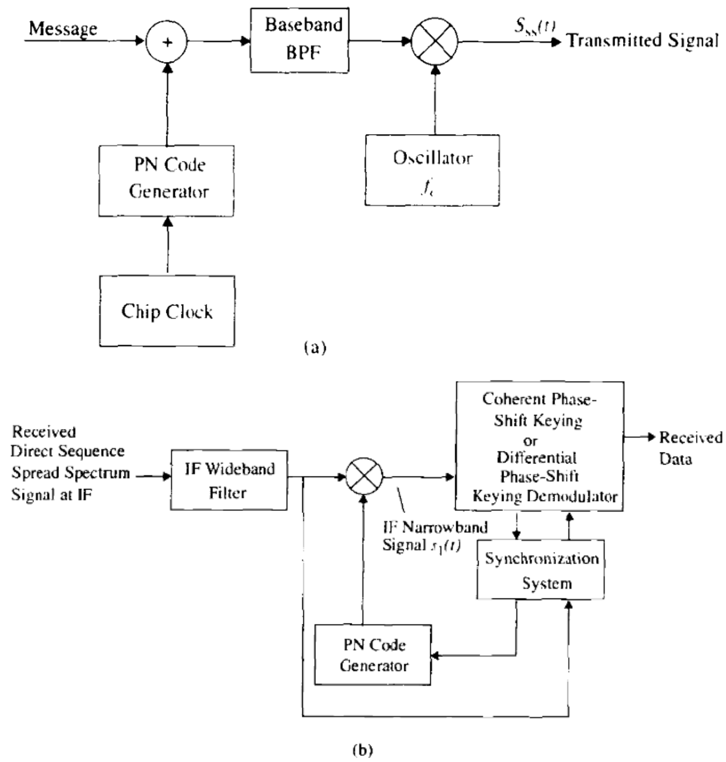


Figure. Block diagram of a DS-SS system with binary phase modulation: (a) transmitter and (b) receiver.

- Figure shows a functional block diagram of a DS system with binary phase modulation.
- ***Synchronized data symbols*** i.e., ***information bits*** or binary channel code symbols, are ***added in modulo-2 fashion*** to the chips before being phase modulated.
- A coherent or differentially coherent phase-shift keying (PSK) demodulation may be used in the receiver.

- The received spread spectrum signal for a single user can be represented as

$$S_{ss}(t) = \sqrt{\frac{2E_s}{T_s}}\ m(t)\ \ p(t)\ \ \cos(2\pi f_c t + \theta)$$

  where *m(t)* is the data sequence, *p(t)* is the PN spreading sequence, f_c is the carrier frequency, and B is the carrier phase angle at $t = 0$.
- The data waveform is a time sequence of nonoverlapping rectangular pulses, each of which has an amplitude equal to +1 or -1.
- Each symbol in *m(t)* represents a data symbol and has duration T_s.
- Each pulse in *p(t)* represents a chip, is usually rectangular with an amplitude equal to +1 or -1, and has a duration of T_c.
- The transitions of the data symbols and chips coincide such that the ratio T_s to T_c is an integer.
- If W_{ss} is the bandwidth of S_{ss}(t) and B is the bandwidth of $m(t)\ \cos(2\pi f_c t)$, the spreading due to *p(t)* gives W_{ss} >>B.

- Figure 5.49(b) illustrates a DS receiver. Assuming that code synchronization has been achieved at the receiver, the received signal passes through the wideband filter and is multiplied by a local replica of the PN code sequence p(t).
- If $p(t) = \pm 1$, then $p^2(t) = 1$, and this multiplication yields the despread signal s(t) given by

$$S_1(t) = \sqrt{\frac{2E_s}{T_s}}\ m(t)\ \cos(2\pi f_c t + \theta)$$

- at the input of the demodulator. Because $s_1(t)$ has the form of a BPSK signal, the corresponding demodulation extracts *m(t)*.

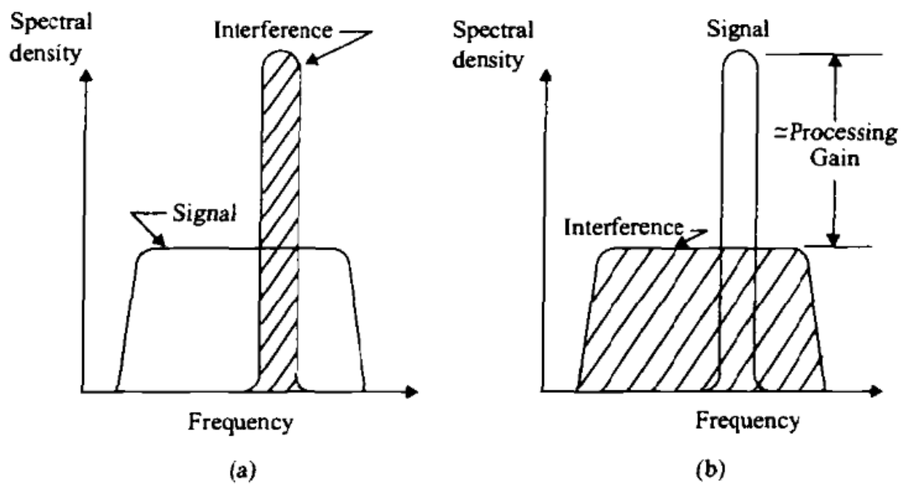


Figure. Spectra of desired received signal with interference:

(a) wideband filter output and (b) correlator output after despreading.

- Figure shows the ***received spectra of the desired signal*** and the ***interference at the output of the receiver wideband filter***.
- Multiplication by the spreading waveform produces the spectra of Figure (b) at the demodulator input.
- The signal bandwidth is reduced to B, while the ***interference energy*** is spread over a bandwidth exceeding W_{ss}.
- The ***filtering action*** of the demodulator ***removes the interference spectrum.***
- Thus, most of the original interference energy is eliminated and does not affect the receiver performance.
- An approximate measure of the interference rejection capability is given by the ratio W^{SS}/B, which is equal to the processing gain defined as

$$PG = \frac{T_s}{T_c} = \frac{R_c}{R_s} = \frac{W_{ss}}{2R_s}$$

- The greater the processing gain of the system, the greater will be its ability to suppress in-band interference.

3.6 Modulation Performance in Fading And Multipath Channels

- In order to study the effectiveness of any modulation scheme in a mobile radio environment, it is required ***to evaluate the performance of the modulation scheme*** .
- Although ***bit error rate (BER)*** evaluation gives a good indication of the performance of a particular modulation scheme.
- But, it does not provide information about the type of errors.
- For example, it does not give incidents of bursty errors.
- In a fading mobile radio channel, it is likely that a transmitted signal will suffer deep fades which can lead to outage or a complete loss of the signal.

- Evaluating the probability of outage is also to judge the effectiveness of the signaling scheme in a mobile radio channel.
- An outage event is specified by a specific number of bit errors occurring in a given transmission.
- ***Bit error rates*** and ***probability of outage*** for various modulation schemes under various types of channel impairments can be evaluated either through analytical techniques or through simulations.

3.7 Equalization, Diversity and Channel Coding:

Discuss in detail about Equalization, Diversity and Channel Coding.

- Mobile communication systems require signal processing techniques that improve the link performance in hostile mobile radio environments.
- The mobile radio channel is particularly dynamic due to multipath fading and Doppler spread.
- Mobile radio channel impairments cause the signal distortion or fading at the receiver.

3.7.1 Introduction

- Equalization, diversity, and channel coding are three techniques which can be used independently or in tandem to improve received signal quality.
- Equalization compensates for intersymbol interference (ISI) created by multipath within time dispersive channels.
- Equalizers must be adaptive since the channel is generally unknown and time varying.

- Diversity is another technique used to compensate for fading channel impairments, and is usually implemented by using two or more receiving antennas.

- Diversity is usually employed to reduce the depth and duration of the fades experienced by a receiver in a flat fading (narrowband) channel.
- Diversity techniques can be employed at both base station and mobile receivers.
- The most common diversity technique is called spatial diversity, whereby multiple antennas are strategically spaced and connected to a common receiving system.

- Channel coding improves mobile communication link performance by adding redundant data bits in the transmitted message.
- At the baseband portion of the transmitter, a channel coder maps a digital message sequence into another specific code sequence containing a greater number of bits than originally contained in the message.
- The coded message is then modulated for transmission in the wireless channel.

- Channel coding is used by the receiver to detect or correct some (or all) of the errors introduced by the channel in a particular sequence of message bits.
- Because decoding is performed after the demodulation portion of the receiver, coding can be considered to be a post detection technique.
- The added coding bits lowers the raw data transmission rate through the channel (expands the occupied bandwidth for a particular message data rate).
- There are two general types of channel codes: block codes and convolutional codes.

- The three techniques of equalization, diversity, and channel coding are used to improve radio link performance (i.e. to minimize the instantaneous bit error rate).

3.7.2 Fundamentals of Equalization

Q. Explain about equalization

- ✓ A filter which equalizes the dispersive effect of a channel is referred to as an equalizer.
- ✓ Equalization can be used to ***compensate the inter symbol interference*** (ISI) created by multipath within time dispersion channel.

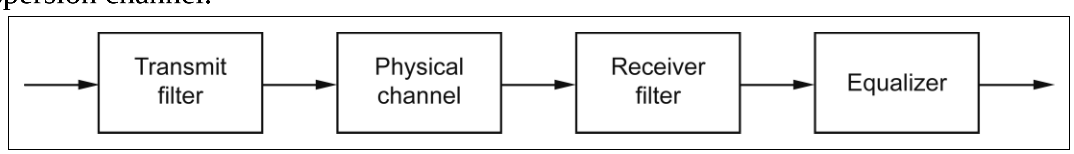


Fig. 4.1. The equalized system

- ✓ Inter Symbol Interference (ISI) caused by multipath in band limited time dispersive channels.
- ✓ It distorts the transmitted signal, causing bit errors at the receiver.
- ✓ The device which equalizes the dispersive effects of a channel is referred to as an ***equalizer.***
- ✓ In a broad sense, the term equalization can be used to describe any signal processing operation that minimizes ISI.

- ✓ In radio channels, a variety of adaptive equalizers can be used to cancel interference while providing diversity.
- ✓ Since the mobile fading channel is (*i*) random, (*ii*) time varying.
- ✓ Equalizers must track the time varying characteristics of the mobile channel and these are called adaptive equalizers.

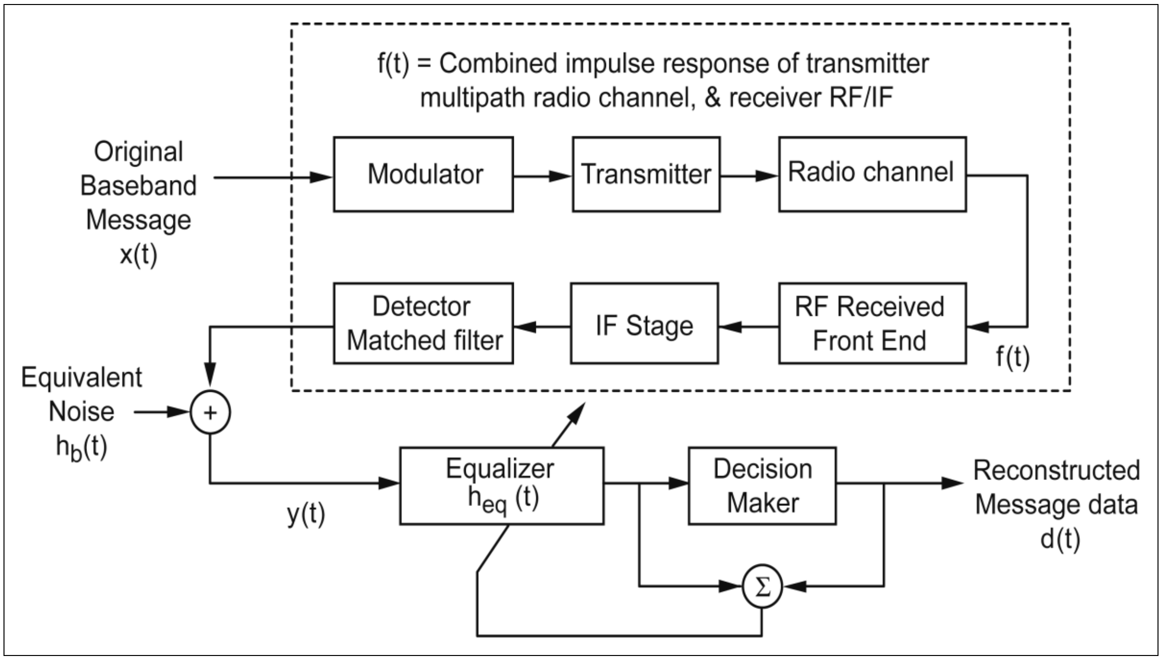


Fig. 4.2. General Block diagram of a communications system using an adaptive equalizer at the receiver

- ✓ The above Fig.4.2 shows a block diagram of a communication system with an adaptive equalizer in the receiver.
- ✓ If $x(t)$ is the original information signal and $f(t)$ is the combined complex baseband impulse response of the transmitter, channel and the RF/IF sections of the receiver, the signal received by the equalizer may be expressed as

$$y(t) = x(t) \otimes f^*(t) + n_b(t) \qquad \dots (4.1)$$

where

$f^*(t)$ → the complex conjugate of $f(t)$,

$n_b(t)$ → the baseband noise at the input of the equalizer

$\otimes$ → the convolution operation.

- ✓ If the impulse response of the equalizer is $h_{eq}(t)$, then the output of the equalizer is

$$d(t) = x(t) \otimes f^*(t) \otimes h_{eq}(t) + n_b(t) \otimes h_{eq}(t)$$

$$= x(t) \otimes g(t) + n_b(t) \otimes h_{eq}(t) \qquad \dots (4.2)$$

- ✓ Where $g(t)$ is the combined impulse response of the transmitter, channel, RF/IF sections of the receiver, and the equalizer at the receiver.

- ✓ The complex baseband impulse response of the transversal filter equalizer is given by

$$h_{eq}(t) = \sum_n C_n \delta(t - nT) \qquad \dots (4.3)$$

where c_n are the complex filter coefficients of the equalizers. The descried output of the equalizers is $x(t)$, the original source data.

- ✓ Assume that $n_b(t) = 0$. Then in order to force $\hat{d}(t) = x(t)$ in equation (4.2), $g(t)$ must be equal to

$$g(t) = f*(t) \otimes h_{eq}(t) = \delta(t) \qquad \ldots (4.4)$$

- ✓ The goal of equalization is to satisfy the equation (4.4) so that the combination of the transmitter, channel and receiver appear to be an all-pass channel. In the frequency domain equation (4.4) can be expressed as

$$H_{eq}(f)\, F*(-f) = 1 \qquad \ldots (4.5)$$

where $H_{eq}(f) \leftarrow F(f)$ are Fourier transforms of $h_{eq}(t) \leftarrow f(t)$ respectively.

- ✓ Training sequence is transmitted before the information data sequence to compute the initial optimum tap coefficients of the adaptive equalizer.

ADAPTIVE EQUALIZATION

1. **How does a generic adaptive equalizer work during training? [Dec 2012]**
2. **Explain about adaptive equalizers. [Dec 2017]**
3. **Draw and explain a simplified communication system using an adaptive equalizer at the receiver. [May 2019, 2021]**
4. **Explain the working mechanism of Equalizers with a simplified communication system that uses adaptive equalizer at the receiver. [Dec 2021, May 2023]**

- ✓ An adaptive equalizer is a time-varying filter which must constantly be returned.
- ✓ The basic structure of an adaptive equalizer is shown in Figure.
- ✓ The subscript k is used to denote a discrete time index.
- ✓ There is a single input y_k at any time instant.
- ✓ The value of y_k depends upon the instantaneous state of the radio channel and the y_k is a random process.

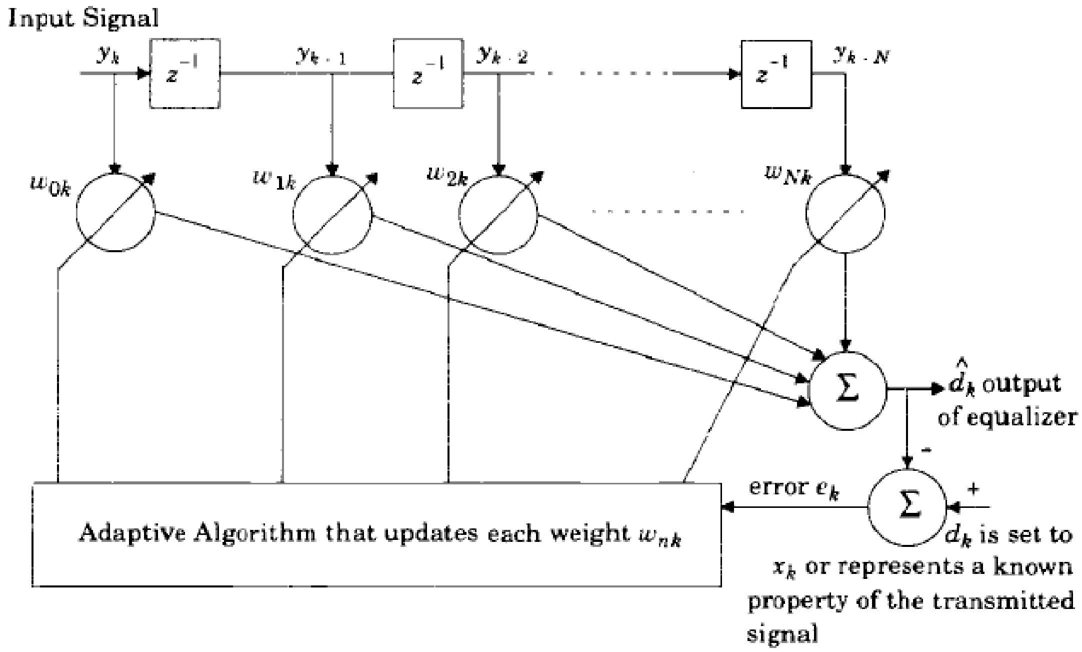


Figure 4.2: A basic adaptive equalizer during training.

- ✓ The adaptive equalizer structure shown above is called a transversal filter.
- ✓ In this case it has *N* delay elements, *N +1* taps, and *N + 1* tunable complex multiplier, called weights.
- ✓ The weights of the filter are described by their physical location in the delay line structure, and have a second subscript, *k*, to show they vary with time.
- ✓ These ***weights are updated continuously by the adaptive algorithm***, either on a sample by sample basis (i.e., whenever *k* is incremented by 1) or on a block by block basis (i.e., whenever a specified number of samples have been clocked into the equalizer).
- ✓ The adaptive algorithm is controlled by the error signal e_k.
- ✓ This ***error signal*** is derived by comparing the output of the equalizer, d_k with some signal *(which is either an exact scaled replica of the transmitted signal* x_k *).*
- ✓ The adaptive algorithm uses C_k to minimize a cost function and updates the equalizer weights in a manner that iteratively reduces the cost function.

$$New\ weights = Previous\ weights\ +\ (constant)\ \times\ (Previous\ error)\ \times\ (Current\ input\ vector)$$

where,

$$Previous\ error = Previous\ desired\ output\ -\ Previous\ actual\ output$$

- ✓ The *constant* may be adjusted by the algorithm ***to control the variation between filter weights on successive iterations***.
- ✓ This process is repeated rapidly in a programming loop while the equalizer attempts to converge.
- ✓ The most common cost function is the ***mean square error (MSE)*** between the desired signal and the output of the equalizer.
- ✓ The MSE is denoted by $E[e(k)e^*(k)]$.
- ✓ A known training sequence must be periodically transmitted signal and do not required when a replica of the transmitted signal is required at the output of the equalizer.
- ✓ By detecting the training sequence, the adaptive algorithm in the receiver is able to compute and minimize the cost function by driving the tap weights until the next training sequence is sent.
- ✓ More recent adaptive algorithms are able to exploit the characteristics of the transmitted signal and do not require training sequences.
- ✓ These modern algorithms acquire equalization through property restoral techniques of the transmitted signal, which are called as *blind algorithms*.
- ✓ These techniques include algorithms such as Constant Modulus Algorithm (CMA) and the Spectral Coherence Restoral Algorithm (SCORE).
- ✓ Constant Modulus Algorithm (CMA) is used for *constant envelope modulation*.

Algorithm:

- ✓ To study the adaptive equalizer, it is helpful to use vector and matrix algebra.
- ✓ Define the input signal to the equalizer as a vector Y_k where

$$y_k = \begin{bmatrix} y_k & y_{k-1} & y_{k-2} & \cdots & y_{k-N} \end{bmatrix}^T$$

- ✓ It should be clear that the output of the adaptive equalizer is a scalar given by

$$\hat{d}_k = \sum_{n=0}^{N} w_{nk} y_{k-n}$$

a *weight vecto*r can be written as

$$w_k = \begin{bmatrix} w_{0k} & w_{1k} & w_{2k} & \cdots & w_{Nk} \end{bmatrix}^T$$

- ✓ It may be written in vector notation as

$$\hat{d}_k = y_k^T w_k = w_k^T y_k$$

- ✓ It follows that when the desired equalizer output is known (i.e., $d_k = x_k$), the error signal e_k is given by

$$e_k = d_k - \hat{d}_k = x_k - \hat{d}_k$$

$$e_k = x_k - y_k^T w_k = x_k - w_k^T y_k$$

- ✓ The matrix *R* is sometimes called the input covariance matrix.
- ✓ The major diagonal of *R* contains the mean square values of each input sample, and the cross terms specify the autocorrelation terms resulting from delayed samples of the input signal.
- ✓ If x_k and y_k are stationary, then the elements in *R* and *p* are second order statistics which do not vary with time.
- ✓ Mean Square Error, $\xi = E\left[x_k^2\right] + w^T R w - 2 p^T w$

<u>Equalizers in a Communications Receiver:</u>

- ✓ Adaptive equalizers are implemented using digital logic.
- ✓ It is most convenient to represent all time signals in discrete form.
- ✓ Let T represent some increment of time between successive observations of signal states.
- ✓ Let $t = t_n$ where *n* is an integer that represents *time = nT*, time waveforms may be equivalently expressed as a sequence on *n* in the discrete domain.
- ✓ Then the output of the equalizer may be expressed as,

✓ $$\hat{d}(n) = x(n) \otimes g(n) + n_b(n) \otimes h_{eq}(n)$$

- ✓ The prediction error is

$$e(n) = d(n) - \hat{d}(n) = d(n) - \left[x(n) \otimes g(n) + n_b(n) \otimes h_{eq}(n)\right]$$

- ✓ The mean squared error $E\left[\,|e_n|^2\right]$ is one of the most important measures of how well an equalizer works.

- ✓ $E\left[|e_n|^2 \right]$ is the expected value *(ensemble average)* of the squared prediction error $|e_n|^2$, but time averaging can be used if $e(n)$ is ergodic.
- ✓ Minimizing the mean square error tends to reduce the bite rate.

<u>Equalization Techniques</u>

Q. Draw the chart showing the classification of equalizers. [April/May 2019]

- ➢ The major classification of equalization techniques is linear and nonlinear equalization.

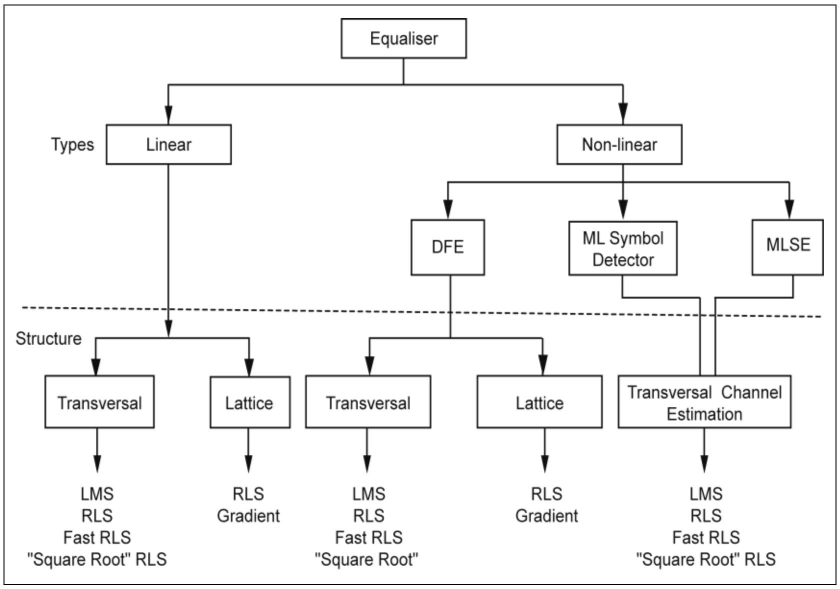


Figure 4.3: Classification of equalizers.

3.8 Diversity Techniques

1. Write short notes on spatial, temporal, polarization and Macro diversity. (Apr/May 2015)
2. Explain in detail about space diversity with necessary diagrams. (Nov/Dec 2016, Nov/Dec 2015)
3. Describe the role played by equalization and diversity as multipath mitigation technique. Compare and contrast these two techniques. (Apr/May 2017)
4. Analyze various diversity techniques used in wireless communications. (Nov/Dec 2017, Nov/Dec 2012)

Introduction of diversity

- ✓ Diversity is a powerful communication receiver technique that provides wireless link improvement at relatively low cost.
- ✓ The ***principle of diversity*** is that the RX has multiple copies of the transmit signal, where each of the copies goes through a statistically independent channel.
- ✓ Unlike equalization, diversity requires no training overhead since a training sequence is not required by the transmitter.
- ✓ Diversity implementations provides significant link improvement with little added cost.
- ✓ In all applications, diversity decisions are made by the receiver, and the decisions are unknown to the transmitter.

Diversity concept

- ✓ Signal is transmitted by more than one antenna via channel.

- ✓ If one radio path undergoes a deep fade, another independent path may have a strong signal.
- ✓ So the receiver has multiple copies of the transmit signal.

Uses of Diversity Technique

1. It is a technique used to compensate for fading channel impairments.
2. It improves the quality of a wireless communication link without increasing the transmitting power and bandwidth.

MICRO DIVERSITY

1. **Analyze various diversity techniques used in wireless communication. (Nov/Dec 2017, Nov/Dec 2014)**
2. **Write short notes on: (i) Spatial Diversity (May 2016) (ii)Frequency Diversity (May 2016) (iii) Polarization Diversity (May 2016) (iv) Time Diversity (May 2016, Nov 2013, May 2013, May 2012, May 2010)**
3. **What is the need for diversity? List different types of diversity. (May/June 2014) [April/May 2019]**
4. **Discuss about any two receiver diversity technique. [April/May 2021]**

- ✓ For reducing small scale fading, micro diversity is used.
- ✓ Types of micro diversity are,

1. Spatial diversity → Several antenna elements separated in space.
2. Temporal diversity → Repetition of the transmit signal at different times.
3. Frequency diversity → Transmission of the signal on different frequencies.
4. Angular diversity → Multiple antennas (with or without spatial separation) with different antenna patterns.
5. Polarization → Multiple antennas receiving different polarizations (e.g., vertical and horizontal).

1. SPATIAL DIVERSITY

Q. Write short notes on space diversity. [Nov/Dec 2021]

- ✓ Spatial diversity is the oldest and simplest form of diversity.
- ✓ It is the most widely used technique.
- ✓ ***Principle:*** The transmit signal is received at several antenna elements, and the signals from these antennas are then further processed.
- ✓ But, irrespective of the processing method, performance is influenced by ***correlation of the signals between the antenna elements***.
- ✓ A large correlation between signals at antenna elements is undesirable, as it decreases the effectiveness of diversity.
- ✓ A first important step in designing diversity antennas is to establish a relationship between ***antenna spacing and the correlation coefficient***.
- ✓ This relationship is different for BS antennas and MS antennas, and thus will be treated separately.

2. TEMPORAL DIVERSITY

Principle:

- ✓ As the wireless propagation channel is time variant, signals that are received at different times are uncorrelated.

- ✓ For sufficient decorrelation, the temporal distance must be at least $\frac{1}{(2\,\mathrm{n}_{\mathrm{max}})}$, where □ $_{max}$ is the maximum Doppler frequency.

- ✓ Temporal diversity can be realized in different ways.
  - (*i*) Repetition coding
  - (*ii*) Automatic repeat request
  - (*iii*) Combination of interleaving and coding

(i) Repetition coding

- ✓ This is the simplest form of linear block codes.
- ✓ The signal is repeated several times, where the repetition intervals are long enough to achieve decorrelation.
- ✓ This achieves diversity, but is also highly bandwidth inefficient.
- ✓ Spectral efficiency decreases by a factor that is equal to the number of repetitions.

(ii) Automatic Repeat Request (ARQ)

- ✓ The RX sends a message to the transmitter to indicate whether it received the data with sufficient quality. If this is not the case, then the transmission is repeated.
- ✓ The spectral efficiency of ARQ is better than that of repetition coding, since it requires multiple transmissions only when the first transmission occurs in a bad fading state, while for repetition coding, retransmission occur always.
- ✓ On the downside, ARQ requires a feedback channel.

(iii) Combination of Interleaving and Coding

- ✓ A more advanced version of repetition coding is forward error correction coding with interleaving.
- ✓ The different symbols of a codeword are transmitted at different times, which increase the probability that at least some of them arrive with a good SNR.
- ✓ When only the MS is moving, while the interacting objects (IOs) and the BS are fixed, temporal correlation can be converted into spatial correlation the correlation coefficient is $\rho = 1$ for all time intervals, and temporal diversity is useless.

3. FREQUENCY DIVERSITY

Q. Write short notes on frequency diversity. [Nov/Dec 2021]

- ✓ ***Principle:*** In frequency diversity, the same signal is transmitted at two (or more) different frequencies.
- ✓ Frequency diversity is implemented by transmitting information on more than one carrier frequency.
- ✓ If these frequencies separated by more than the coherence bandwidth of the channel, then their fading is approximately independent, and the probability is low that the signal is in a deep fade at both frequencies simultaneously.
- ✓ The correlation between two frequencies can be from the following equation by setting the numerator to unity as the signals at the two frequencies occur at the same time.

$$\rho_{xy} = \frac{J_0^2(k_0 \mathrm{v}\tau)}{1 + (2\pi)^2 S_\tau^2 (f_2 - f_1)^2}$$

Thus,

$$\rho = \frac{1}{1 + (2\pi)^2 S_\tau^2 (f_2 - f_1)^2}$$

✓ Figure shows ρ as a function of the spacing between the two frequencies.

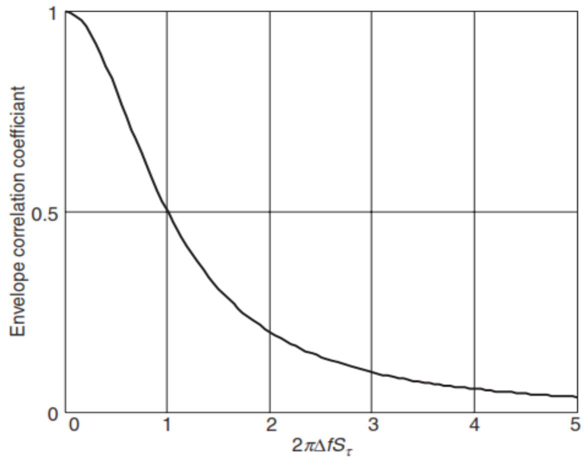


Fig. 4.13. Correlation coefficient of the envelope as a function of normalized frequency spacing.

This spreading can be done by different methods.

(i) Compressing the information in time that is, sending short burst that each occupy a large bandwidth - *e.g.* TDMA

(ii) Code Division Multiple Access – CDMA.

(iii) Multi carrier CDMA and coded orthogonal frequency division multiplexing.

(iv) Frequency hopping in conjunction with coding.

Advantages of frequency diversity

(*i*) By using redundant signal transmission, this diversity improves link transmission quality.

(*ii*) New OFDM modulation uses frequency diversity.

Disadvantages

(*i*) It requires large bandwidth.

(*ii*) More number of receivers are required.

(*iii*) High cost.

4. ANGULAR DIVERSITY

Principle: Two co-located antennas with different patterns "see" differently weighted MPCs (Multi Path Components), so that the MPCs interfere differently for the two antennas. This is the principle of angle diversity (also known as ***pattern diversity***).

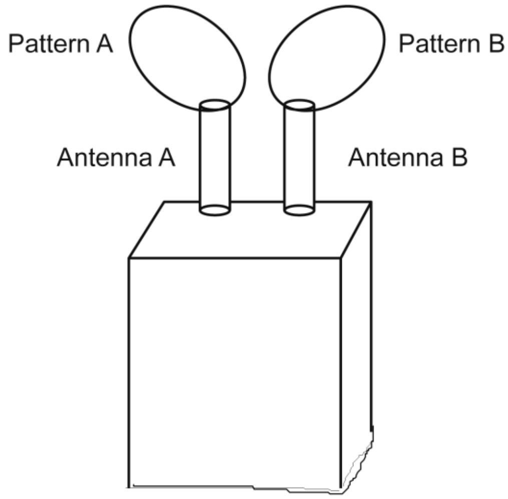


Figure 4.34. Angle diversity for closely spaced antennas

- ✓ Angular diversity is usually used in conjunction with spatial diversity.
- ✓ It enhances the decorrelation of signals at closely spaced antennas.
- ✓ Different antenna patterns can be achieved very easily.
- ✓ But even identical antennas can have different patterns when mounted close to each other.
- ✓ This effect is due to mutual coupling: antenna B acts as a reflector for antenna A, whose pattern is therefore skewed to the left.

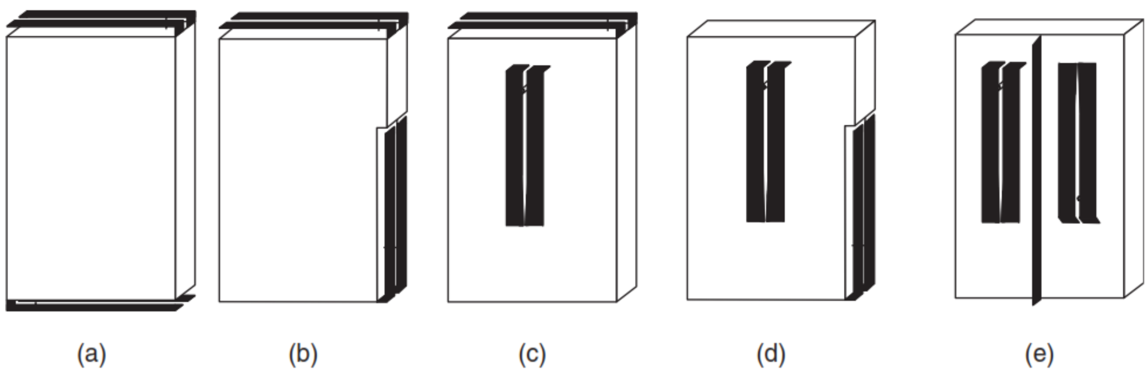


Figure 4.15. Configurations of diversity antennas at a mobile station.

5. POLARIZATION DIVERSITY

- ✓ In Transmitter side, two diversity branches are used.
- ✓ Signals are passed through two orthogonally polarized propagation path.
- ✓ In Receiver side, antenna with two elements receives the vertical or horizontally polarized signal.
- ✓ Measured horizontal and vertical polarization paths between a mobile and a base station are reported to be uncorrelated.
- ✓ The decorrelation for the signals in each polarization is caused by multiple reflections in the channel between the mobile and base stations antennas.
- ✓ The reflection coefficient for each polarization is different which results in different amplitudes and phases for each or at least some of the reflection.
- ✓ After sufficient random reflections, the polarization state of the signal will be independent of the transmitted polarization.
- ✓ Circular and linear polarized antennas have been used to characterize multipath inside buildings.

Theoretical model for polarization diversity

- ✓ It is assumed that the signal is transmitted from a mobile with vertical polarization.
- ✓ It is received at the base station by a polarization diversity antenna with 2 branches.
- ✓ Figure shows the theoretical model and the system coordinates.
- ✓ As seen in the figure, a polarization diversity antenna is composed of two antenna elements V_1 and V_2, which make $\pm\alpha$ angle (polarization angle) with the Y axis.
- ✓ A mobile station is located in the direction of offset angle β from the main beam direction of the diversity antenna as seen in Figure 4.16 (b).

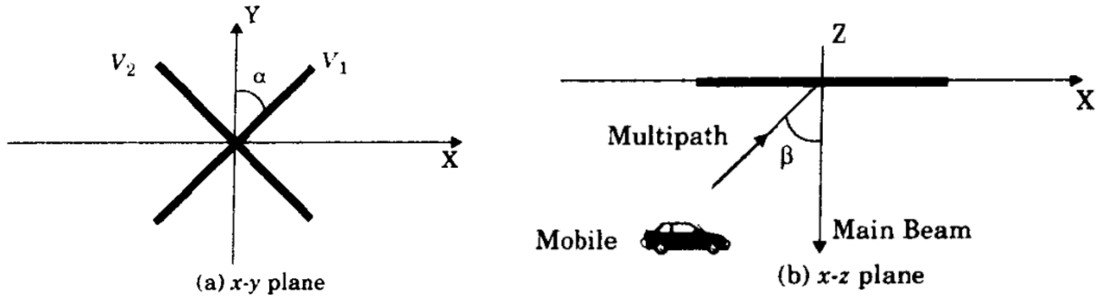


Figure 4.16. Theoretical model for base station polarization diversity

- ✓ Some of the vertically polarized signals transmitted are converted to the horizontal polarized signal because of multipath propagation.
- ✓ The signal arriving at the base station can be expressed as

$$x = r_1 \cos(□t + \phi_1)$$
$$y = r_2 \cos(□t + \phi_1)$$

where x and y are signal levels which are received when $\beta = 0$.

- ✓ Assume r_1 and r_2 have independent Rayleigh distributions and ϕ_1 and ϕ_2 have uniform distributions. The received signal values at V_1 and V_2 are

$$V_1 = (a\, r_1 \cos\phi_1 + r_2\, b \cos\phi_2) \cos □t - (a\, r_1 \sin\phi_1 + r_2 \sin\phi_2) \sin □t$$
$$V_2 = (-a\, r_1 \cos\phi_1 + r_2\, b \cos\phi_2) \cos □t - (-a\, r_1 \sin\phi_1 + r_2\, b \sin\phi_2) \sin □t$$

where, $a = \sin\alpha \cos\beta$

$b = \cos\alpha$

- ✓ Correlation coefficient $□ = \left(\dfrac{\tan^2(\alpha)\cos^2(\beta) - \Gamma}{\tan^2(\alpha)\cos^2(\beta) + \Gamma}\right)^2$

where

$$\Gamma = \frac{\langle R_2^2 \rangle}{\langle R_1^2 \rangle}$$

where,

$$R_1 = \sqrt{r_1^2 a^2 + r_2^2 b^2 + 2 r_1 r_2 ab \cos(\phi_1 + \phi_2)}$$
$$R_2 = \sqrt{r_1^2 a^2 + r_2^2 b^2 - 2 r_1 r_2 ab \cos(\phi_1 + \phi_2)}$$

Here, Γ - the cross polarization discrimination of the propagation path between a mobile and a base station.

□ is determined by three factors.

(*i*) Polarization angle

(*ii*) Offset angle from the main beam direction of the diversity antenna.
(*iii*) The cross polarization discrimination (Γ).

- ✓ When polarization angle α increases becomes lower, then horizontal polarization component increases.
- ✓ Signal loss $L = \frac{a^2}{\Gamma + b^2}$ relative to vertical polarization.

Advantage

Multipath delay spread is reduced.

MACRO DIVERSITY

- ✓ For reducing large scale fading, macro diversity is used.
- ✓ In macro diversity, a large distance between BS_1 and BS_2 is maintained.
- ✓ ***On-frequency repeaters*** that receive a signal and retransmit an amplified version of it is used.
- ✓ The same signal is transmitted simultaneously from different BSs called ***simulcast.***
- ✓ Two BSs should be synchronized in cellular applications. *e.g.* digital TV.

Advantage

1. To compensate for large scale fading effects macro diversity technique is used.
2. Distance between each BS is increased.
3. On-frequency repeaters (or) simulcast methods are used.

Drawbacks

1. Simulcast requires large amount of signaling information that has to be carried on landlines, so it requires large bandwidth.
2. On-frequency repeater causes delay dispersion.

3.8.1 Practical Space Diversity Considerations

Explain in detail about Practical Space Diversity Considerations.

- ➢ Space diversity, also known as antenna diversity, is the most popular form of diversity used in wireless systems.
- ➢ Conventional cellular radio systems consist of an ***elevated base station antenna*** and a ***mobile antenna close to the ground***.
- ➢ The existence of a direct path between the transmitter and the receiver is not guaranteed and the possibility of a number of scatterers in the vicinity of the mobile suggests a Rayleigh fading signal.

- ➢ The concept of antenna space diversity is also used in base station design.
- ➢ At each cell site, multiple base station receiving antennas are used to provide diversity reception.
- ➢ However, since the important scatterers are generally on the ground in the vicinity of the mobile, the base station antennas must be spaced considerably far apart to achieve decorrelation.
- ➢ Separations on the order of several tens of wavelengths are required at the base station.
- ➢ Space diversity can thus be used at either the mobile or base station, or both.
- ➢ Figure shows a general block diagram of a space diversity scheme [Cox83a].

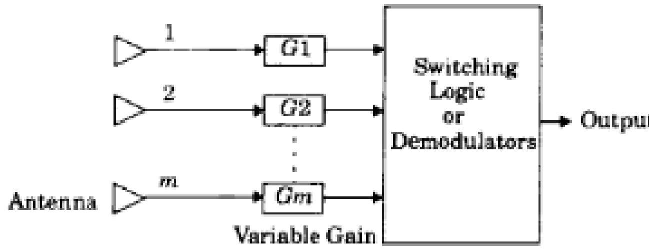


Figure. Generalized block diagram for space diversity.

Space diversity reception methods can be classified into four categories:

1. Selection diversity
2. Feedback diversity
3. Maximal ratio combining
4. Equal gain diversity

<u>DIVERSITY COMBINING TECHNIQUES (or) COMBINATION OF SIGNALS</u>

> 1. **Explain with the block diagram, maximal ratio combiner. (Nov/Dec 2014)**
> 2. **Explain with diagram, the different techniques available for signal combining. (May/June 2014)[April/May 2023]**

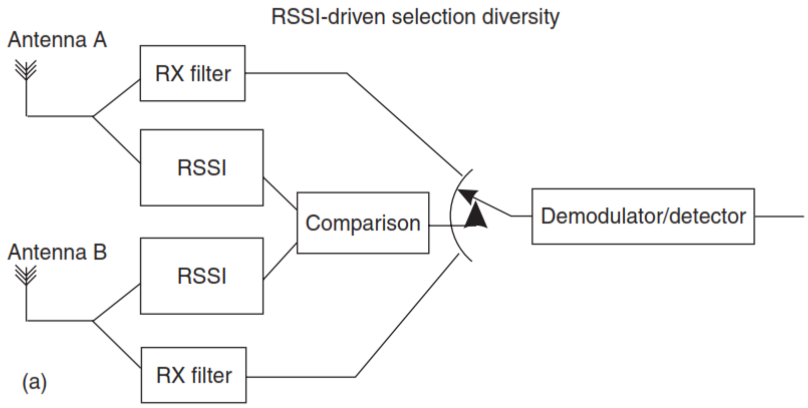
- ✓ By combining signals from different antenna at the RX, the total quality of the signal is improved.
- ✓ Signals selected from the multiple diversity branches by
  - ***1) Selection diversity:*** The "best" signal copy is selected and processed (demodulated and decoded) while all other copies are discarded.
  - ***2) Combining diversity:*** All copies of the signal are combined before or after the demodulation and the combined signals are decoded.

3.8.1.1 Selection Diversity

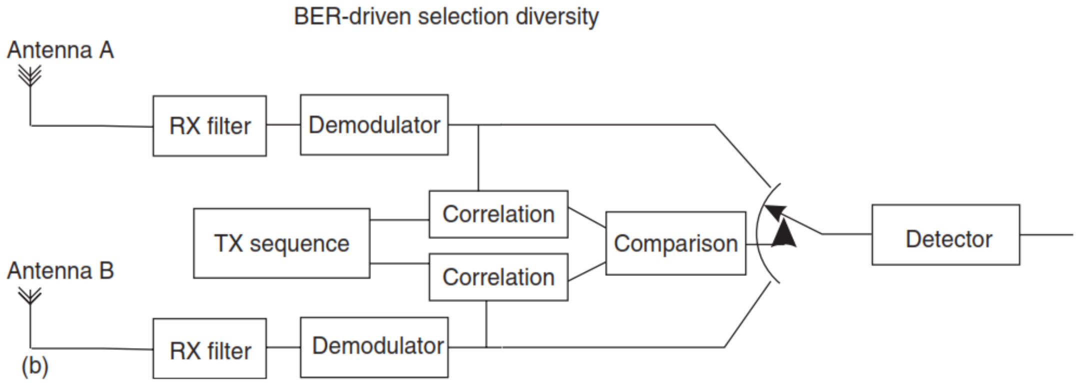
<u>Q. Explain selection combining technique in detail [Nov/Dec 2019]</u>

(i) Received – signal – strength – indication – driven diversity

- ✓***Principle:*** The RX selects the signal with the largest instantaneous power or RSSI – Received Signal Strength Indication.
- ✓ The required components are
  - ❖ N_r antenna elements
  - ❖ N_r RSSI sensors and
  - ❖ N_r to 1 multiplexer
  - ❖ only one RF chain are used.



(a) Receiver – signal – strength – indication controlled diversity



(b) Bit error rate controlled diversity

Fig. 4.37. Selection diversity principle

- ✓ If the BER is determined by noise, then RSSI – driven diversity is the best of all the diversity methods.
- ✓ Maximization of RSSI also maximizes the SNR.
- ✓ If BER is determined by co-channel interference, then RSSI is no longer a good criterion.
- ✓ SNR of the n^{th} diversity branch γ_n is

$$\mathrm{pdf}_{\gamma_n}(\gamma_n) = \frac{1}{\overline{\gamma}} \exp\left(-\frac{\gamma_n}{\overline{\gamma}}\right)$$

where $\bar{g}$ is the mean branch SNR.

The cumulative distribution function (cdf) is

$$\mathrm{cdf}_{\gamma_n}(\gamma_n) = 1 - \exp\left(-\frac{\gamma_n}{\overline{\gamma}}\right)$$

RX selects the branch with the largest SNR.
The *cdf* of the selected signal is the product of the *cdf*s of each branch.

$$\mathrm{cdf}_{\gamma}(\gamma) = \left[1 - \exp\left(-\frac{\gamma}{\overline{\gamma}}\right)\right]^{N_r}$$

Advantages

1. Only one RF chain is required.
2. It is processed with only a single received signal at a time.
3. Easy to implement.

Drawbacks

1. It wastes signal energy by discarding (N_r – 1) copies of received signal.
2. It is not an optimum method.

(ii) Bit-error-rate driven diversity

- ✓ For BER-driven diversity, at first a training sequence is transmitted *i.e.* a bit sequence that is known at the RX.
- ✓ The RX demodulates the signal from each receive antenna elements and compares it with the transmit signal.
- ✓ The signal with the smallest BER is judged to be the "best" signal and used for the subsequent reception of data signals.
- ✓ If the channel is time-variant, the training sequence has to be repeated at regular intervals and selection of the best antenna has to be done now.

Drawbacks of BER driven diversity

- ✓ More number of RXs are needed, which makes the RX more complex.
- ✓ The training sequence has to be repeated N_r times, which decreases spectral efficiency.
- ✓ If the channel changes quickly, more than one demodulators are required.
- ✓ Duration of training sequence increases, BER decreases. So, tradeoff between duration of training sequence and BER is maintained.
- ✓ Diversity branches are monitored all the times, so hardware effort increases, spectral efficiency is reduced.

3.8.1.2 Feedback or Scanning Diversity

- ✓ ***Feedback diversity*** is also called scanning diversity.
- ✓ It is very similar to selection diversity except that instead of always using the best of M signals, the M signals are scanned in a fixed sequence until one is found to be above a ***predetermined threshold***.
- ✓ This signal is then received until it falls below a threshold and the scanning process is again initiated.

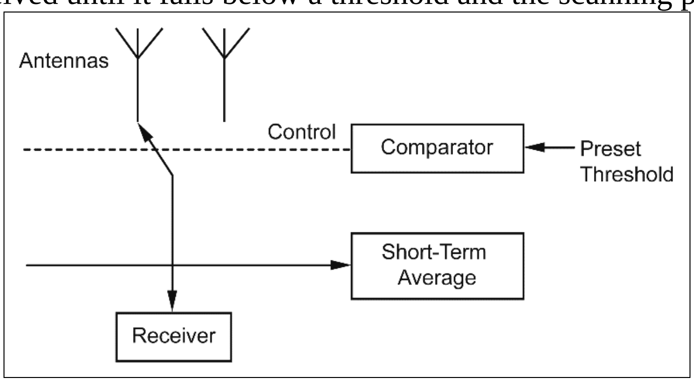


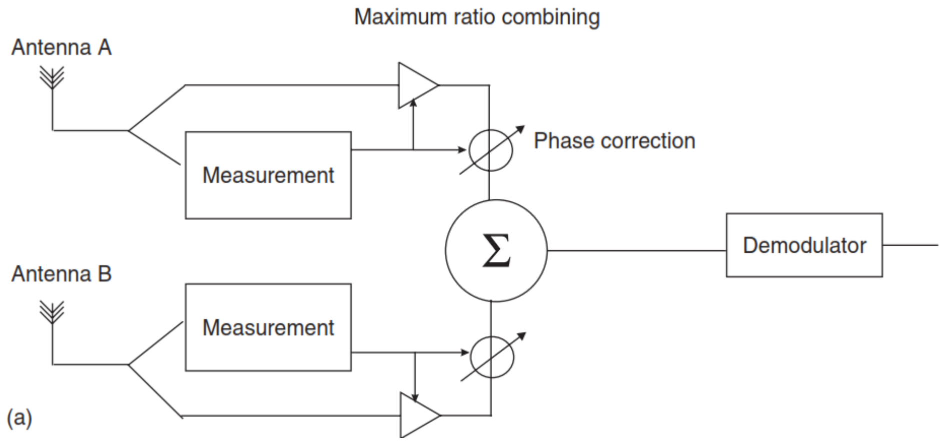
Fig. 4.48. Block diagram of feedback diversity

Advantages

(i) It is very simple to implement
(ii) Only one receiver is required.
(iii) Low cost.

Drawback: The resulting fading statistics are somewhat inferior to those obtained by other methods.

3.8.1.3 Maximal Ratio Combining



(a) Maximum ratio combining

Figure 4.19 Combining diversity principle

- ✓ MRC compensates for the phases, and weights of the signals from the different antenna branches according to their SNR.
- ✓ It is an optimum method.
- ✓ Channel is assumed as slow fading and fast fading.
- ✓ The channel is realized as a time-invariant filter with impulse response

$$h_n(\tau) = \alpha_n \delta(\tau)$$

Where, $\alpha_n \rightarrow$ attenuation diversity

$n \rightarrow$ branch

Antenna weight $= W_{MRC} = \alpha_n^*$

- ✓ The signals are phase-corrected and weighted by the amplitude.
- ✓ Output SNR of diversity combiner =Sum of the branch SNRs

$$\gamma_{MRC} = \sum_{n=1}^{N_r} \gamma_n$$

- ✓ If the branches are statistically independent, the SNR distribution in each branch is exponential.

$$pdf_\gamma(\gamma) = \frac{1}{(N_r - 1)!} \frac{\gamma^{N_r - 1}}{\bar{\gamma}^{N_r}} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right)$$

$$\bar{\gamma}_{MRC} = N_r \bar{\gamma}$$

For $N_r = 1$ there is no diversity. For $N_r = 3$, diversity is applied.

Advantages

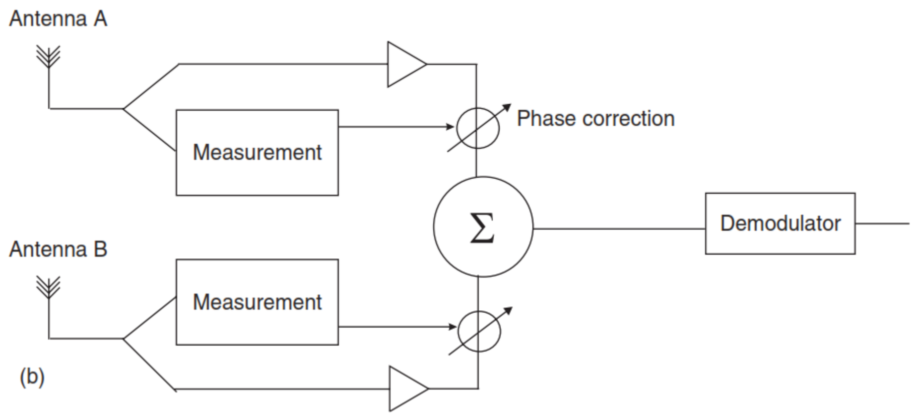
- ✓ Output is produced with an acceptable SNR even when none of the individual signals are themselves acceptable.
- ✓ This technique gives the best statistical reduction of fading of any known linear diversity combiner.

Drawbacks

1. It requires individual receiver and phasing circuits for each antenna elements.
2. High cost.

******

3.8.1.4 Equal Gain Combining



(b) Equal gain combining

Figure 4.59. Combining diversity principle

- ✓ It is similar to maximal ratio combining except that the weighting circuits are omitted.
- ✓ The branch weights are all set of unity but the signals from each branch are co-phased to provide equal gain combining diversity.
- ✓ This allows the receiver to exploit the signals that are simultaneously received on each branch.

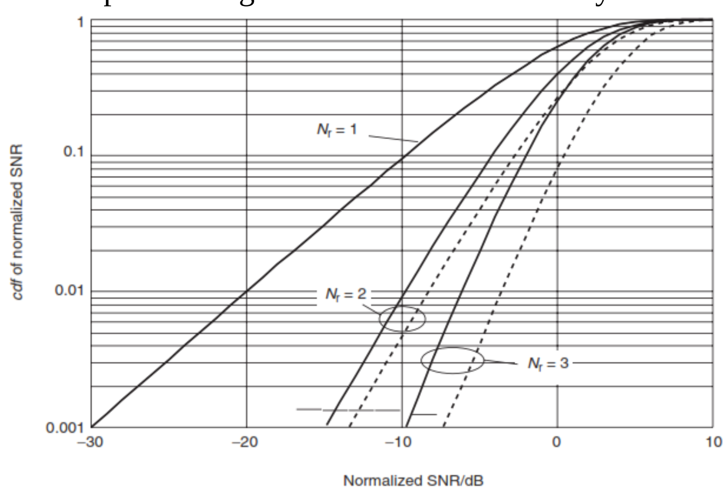


Figure 4.20. *Cumulative distribution function of the normalized instantaneous signal-to-noise ratio* $\gamma / \bar{\gamma}$ *for received-signal-strength-indication-driven selection diversity (solid), and maximum ratio combining (dashed) for Nr = 1, 2, 3. Note that for Nr =1, there is no difference between diversity types.*

✓For EGC, the SNR of the combiner output is

$$\gamma_{\mathrm{ECG}} = \frac{\left(\sum_{n=1}^{N_r} \sqrt{\gamma_n}\right)^2}{N_r}$$

✓ The mean SNR is

$$\bar{\gamma}_{\mathrm{EGC}} = \bar{\gamma}\left[1 + (N_r - 1)\frac{\pi}{4}\right]$$

for all branches suffer from ***Rayleigh fading***.

✓ For $N_r = 1$, EGC performance = MRC performance.

✓ For $N_r = 2, 3$ MRC is better than EGC.

Advantage

Equal gain combiner is superior to selection diversity.

Drawbacks

1. EGC is inferior to that of maximal ratio combiner, since interference and noise corrupted signals may be combined with high quality signals.
2. EGC performs worse than MRC by only a factor $\frac{\pi}{4}$.

3.8.2 Polarization Diversity

- ✓ In Transmitter side, two diversity branches are used.
- ✓ Signals are passed through two orthogonally polarized propagation path.
- ✓ In Receiver side, antenna with two elements receives the vertical or horizontally polarized signal.
- ✓ Measured horizontal and vertical polarization paths between a mobile and a base station are reported to be uncorrelated.
- ✓ The decorrelation for the signals in each polarization is caused by multiple reflections in the channel between the mobile and base stations antennas.
- ✓ The reflection coefficient for each polarization is different which results in different amplitudes and phases for each or at least some of the reflection.
- ✓ After sufficient random reflections, the polarization state of the signal will be independent of the transmitted polarization.
- ✓ Circular and linear polarized antennas have been used to characterize multipath inside buildings.

Theoretical model for polarization diversity

- ✓ It is assumed that the signal is transmitted from a mobile with vertical polarization.
- ✓ It is received at the base station by a polarization diversity antenna with 2 branches.
- ✓ Figure shows the theoretical model and the system coordinates.
- ✓ As seen in the figure, a polarization diversity antenna is composed of two antenna elements V_1 and V_2, which make $\pm\alpha$ angle (polarization angle) with the Y axis.
- ✓ A mobile station is located in the direction of offset angle β from the main beam direction of the diversity antenna as seen in Figure 4.16 (b).

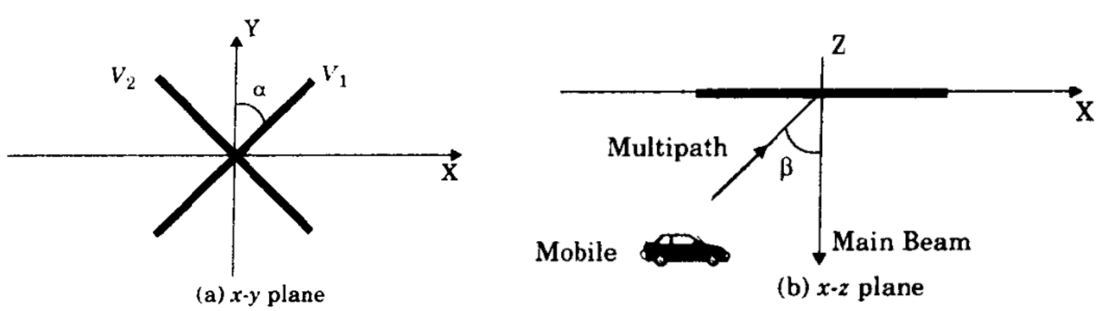


Figure 4.16. Theoretical model for base station polarization diversity

- ✓ Some of the vertically polarized signals transmitted are converted to the horizontal polarized signal because of multipath propagation.
- ✓ The signal arriving at the base station can be expressed as

$$x = r_1 \cos(\omega t + \phi_1)$$

$$y = r_2 \cos(\omega t + \phi_1)$$

Where x and y are signal levels which are received when β = 0.

- ✓ Assume r_1 and r_2 have independent Rayleigh distributions and ϕ_1 and ϕ_2 have uniform distributions. The received signal values at V_1 and V_2 are

$V_1 = (a\, r_1 \cos \phi_1 + r_2\, b \cos \phi_2) \cos \square t - (a\, r_1 \sin \phi_1 + r_2 \sin \phi_2) \sin \square t$

$V_2 = (-a\, r_1 \cos \phi_1 + r_2\, b \cos \phi_2) \cos \square t - (-a\, r_1 \sin \phi_1 + r_2\, b \sin \phi_2) \sin \square t$

where, $a = \sin \alpha \cos \beta$

$b = \cos \alpha$

- ✓ Correlation coefficient $\square = \left(\dfrac{\tan^2(\alpha)\cos^2(\beta) - \Gamma}{\tan^2(\alpha)\cos^2(\beta) + \Gamma} \right)^2$

where

$$\Gamma = \frac{\langle R_2^2 \rangle}{\langle R_1^2 \rangle}$$

where,

$$R_1 = \sqrt{r_1^2 a^2 + r_2^2 b^2 + 2 r_1 r_2 ab \cos(\phi_1 + \phi_2)}$$

$$R_2 = \sqrt{r_1^2 a^2 + r_2^2 b^2 - 2 r_1 r_2 ab \cos(\phi_1 + \phi_2)}$$

Here, Γ - the cross polarization discrimination of the propagation path between a mobile and a base station.

$\square$ is determined by three factors.

(*i*) Polarization angle

(*ii*) Offset angle from the main beam direction of the diversity antenna.

(*iii*) The cross polarization discrimination (Γ).

- ✓ When polarization angle α increases $\square$ becomes lower, then horizontal polarization component increases.
- ✓ Signal loss $L = \dfrac{a^2}{\Gamma + b^2}$ relative to vertical polarization.

Advantage

- ➢ Multipath delay spread is reduced.

3.8.3 Frequency Diversity

Q. Write short notes on frequency diversity. [Nov/Dec 2021]

- ✓ ***Principle:*** In frequency diversity, the same signal is transmitted at two (or more) different frequencies.
- ✓ Frequency diversity is implemented by transmitting information on more than one carrier frequency.
- ✓ If these frequencies separated by more than the coherence bandwidth of the channel, then their fading is approximately independent, and the probability is low that the signal is in a deep fade at both frequencies simultaneously.
- ✓ The correlation between two frequencies can be from the following equation by setting the numerator to unity as the signals at the two frequencies occur at the same time.

$$\rho_{xy} = \frac{J_0^2(k_0 v \tau)}{1 + (2\pi)^2 S_\tau^2 (f_2 - f_1)^2}$$

Thus,

$$\rho = \frac{1}{1 + (2\pi)^2 S_\tau^2 (f_2 - f_1)^2}$$

✓ Figure shows ρ as a function of the spacing between the two frequencies.

This spreading can be done by different methods.

(i) Compressing the information in time that is, sending short burst that each occupy a large bandwidth - *e.g.* TDMA

(ii) Code Division Multiple Access – CDMA.

(iii) Multi carrier CDMA and coded orthogonal frequency division multiplexing.

(iv) Frequency hopping in conjunction with coding.

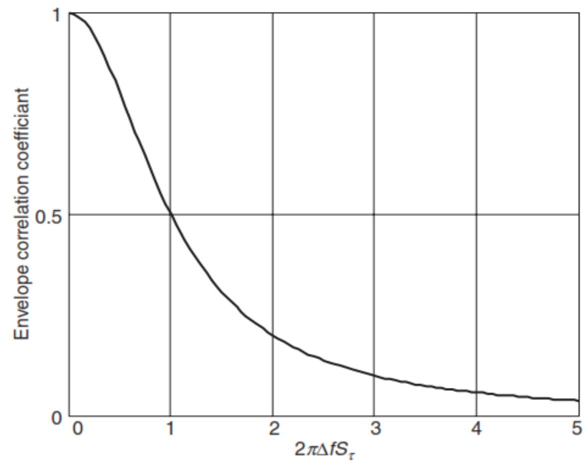


Fig. 4.13. Correlation coefficient of the envelope as a function of normalized frequency spacing.

Advantages of frequency diversity

(*i*) By using redundant signal transmission, this diversity improves link transmission quality.

(*ii*) New OFDM modulation uses frequency diversity.

Disadvantages

(*i*) It requires large bandwidth.

(*ii*) More number of receivers are required.

(*iii*) High cost.

3.8.4 Time Diversity

- Time diversity repeatedly transmits information at time spacings that exceed the coherence time of the channel.
- So that multiple repetitions of the signal will be received with independent fading conditions, thereby providing for diversity.
- One modem implementation of time diversity involves the use of the RAKE receiver for spread spectrum CDMA, where the multipath channel provides redundancy in the transmitted message.

****

UNIT- III
MODULATION TECHNIQUES AND EQUALIZATION AND DIVERSITY
TWO MARKS

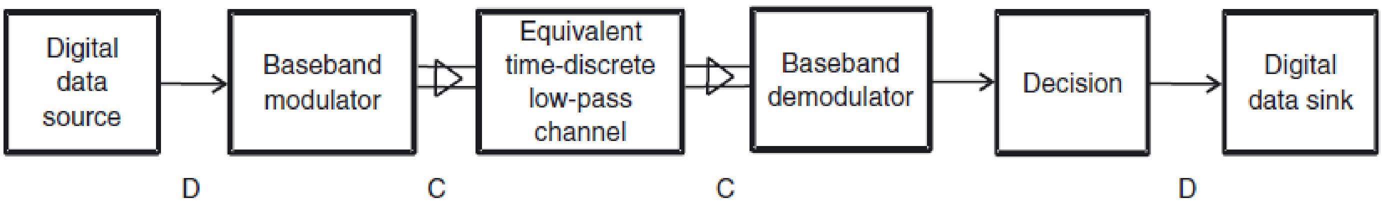
1. What are the steps involved in the wireless communication link?

The steps involved in the wireless communication link are

- ✓ Source coding
- ✓ Channel coding
- ✓ Modulation
- ✓ Multiple accessing
- ✓ Transmission through radio channel

2. Draw the mathematical link for analysis of modulation scheme. (Nov 2011)

The mathematical link for analysis of modulation scheme is given below



3. What is linear modulation?

- ✓ In linear modulation technique, the amplitude of the transmitted signal varies linearly with the modulating digital signal.
- ✓ Linear modulation does not have a constant envelope.
- ✓ Ex. Pulse shaped QPSK, OQPSK, π/4QPSK

4. List the advantages of digital modulation techniques. (May 2015)

The advantages of digital modulation techniques includes

- ✓ Greater noise immunity
- ✓ Robustness to channel impairments
- ✓ Easier multiplexing of various forms of information.
- ✓ Greater security

5. Mention any two criteria for choosing a modulation technique for a specific wireless application. (May 2013)

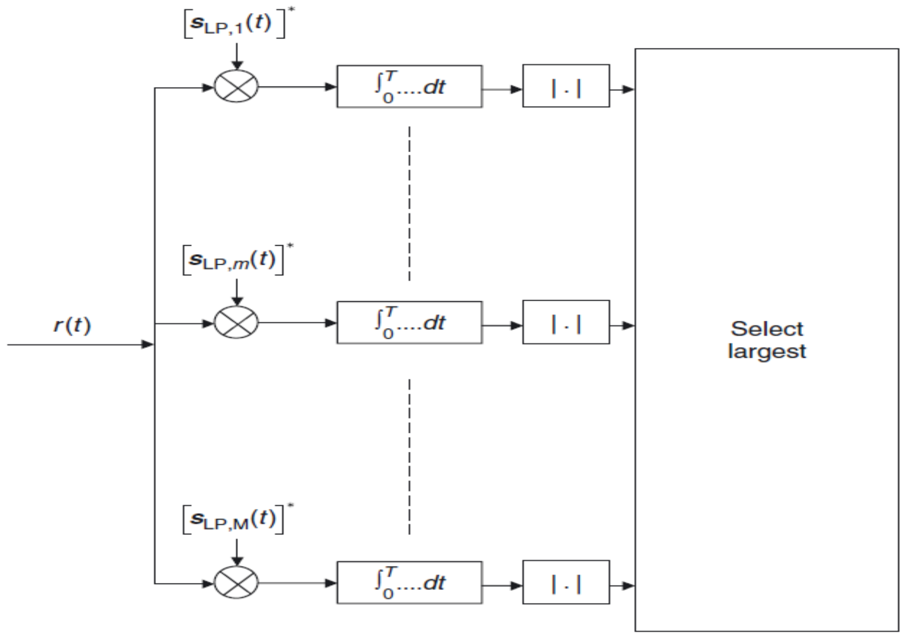
Criteria for choosing a modulation technique for a specific wireless application are

- ✓ Low BER at low received SNR.
  - i.e Bit-error rate performance
- ✓ Minimum bandwidth requirement.
  - i.e.Bandwidth efficiency
- ✓ Power efficiency
  - Adjacent channel interference must be small

  - Power spectrum of the signal should show a strong roll-off outside the desired band.
- ✓ Spectral efficiency to be high.
- ✓ Better performance in multipath and fading conditions.
- ✓ Transmission of many data bits with each symbol
- ✓ Ease of implementation and low cost.

6. Draw the structure of generic optimum receiver. (May 2013)

The structure of generic optimum receiver is given below



7. What is OQPSK? (Nov 2011)

- ✓ To prevent the regeneration of sidelobes and spectral widening, it is imperative that QPSK signals be amplified only using linear amplifiers, which are less efficient.
- ✓ A modified form of QPSK, called offset QPSK (OQPSK) or staggered QPSK is less susceptible to these deleterious effects arid supports more efficient amplification.
- ✓ OQPSK signaling is represented by equation,

$$S_{OQPSK}(t) = \sqrt{\frac{2E_S}{T_S}} \cos\left[(i-1)\frac{\pi}{2}\right]\cos(2\pi f_c t) - \sqrt{\frac{2E_S}{T_S}} \sin\left[(i-1)\frac{\pi}{2}\right]\sin(2\pi f_c t)$$

8. Differentiate between OQPSK and QPSK.[April/May 2023]

OQPSK	QPSK
In OQPSK signaling, the even and odd bit streams, $m_I(t)$ and $m_Q(t)$ are offset in their relative alignment by one bit period	In QPSK signaling, the bit transitions of the even and odd bit streams occur at the same time instants.
OQPSK signals does not regenerate the high frequency side lobes	QPSK signals regenerate the high frequency side lobes.

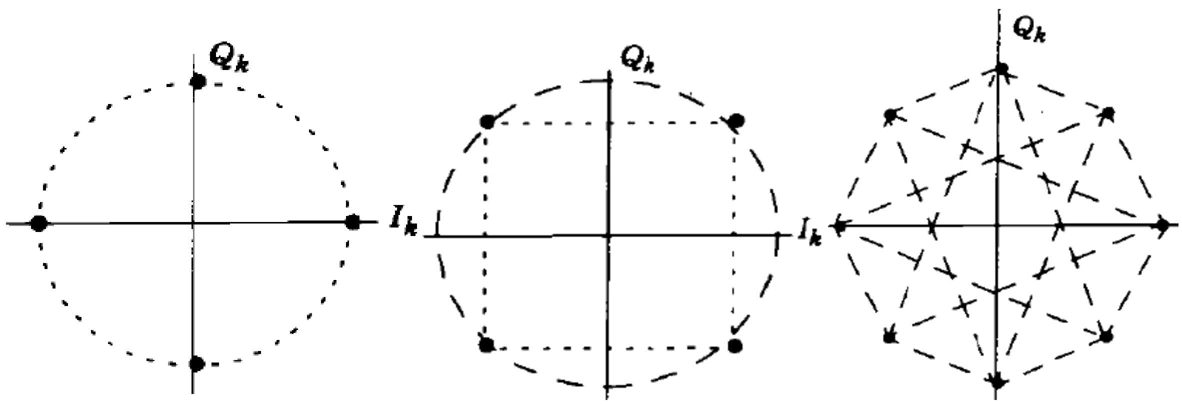
9. State the advantages of offset-QPSK. (Nov 2014)

List the features of offset- QPSK. [April/May 2019][Nov/Dec 2019]

The advantages of offset-QPSK includes

- ✓ Lower amplitude fluctuations.
- ✓ Suppress out-of-band interference.
- ✓ Limits the phase-shift to maximum of 90° at a time.
- ✓ Spectral occupancy is significantly reduced.
- ✓ More efficient RF amplification.
- ✓ Better performance in the presence of phase jitter due to noisy reference signals at the receiver

10. Draw the signal constellation and phase transition of $\pi/4$ QPSK signal.



(a) (b) (c)

(a) Possible States for θ_k when $\theta_{k-1} = \frac{n\pi}{4}$

(b) Possible States for θ_k when $\theta_{k-1} = \frac{n\pi}{2}$

(c) All Possible States

Figure: Constellation diagram of a $\frac{\pi}{4}$ QPSK signal

11. Differentiate offset QPSK and π/4 differential QPSK.

Offset QPSK	$\pi/4$ **DQPSK**
The amplitude of data pulses are kept constant. The time alignment of the even and odd bit streams are offset by one bit period in offset QPSK.	Signaling points of the modulated signal are selected from two QPSK constellations which are shifted by π/4 with respect to each other. It is differentially encoded and detected so called π/4 differential QPSK.

12. Define offset QPSK and π/4 differential QPSK. [Nov/Dec 2017]

The amplitude of data pulses are kept constant. The time alignment of the even and odd bit streams are offset by one bit period in offset QPSK.

Signaling points of the modulated signal are selected from two QPSK constellations which are shifted by π/4 with respect to each other. It is differentially encoded and detected so called π/4 differential QPSK.

13. What is meant by MSK?[Nov/Dec 2019]

- ✓ A continuous phase FSK signal with a deviation ratio of one half is referred to as MSK.
- ✓ MSK is a spectrally efficient modulation scheme.

14. Why is MSK referred to as fast FSK? (May 2016)

MSK is called as fast FSK since the frequency spacing used is only half as much as that used in convention al non-coherent FSK.

15. Mention the advantages of MSK over QPSK.

The advantages of MSK over QPSK are

- ✓ Output waveform is continuous in phase
- ✓ No abrupt changes in amplitude.
- ✓ Bandwidth requirement is less

16. Give the function of Gaussian filter in GMSK. (Nov 2016)

Comment on the necessity of a Gaussian filter in GMSK. (May 2015)

- ✓ Gaussian filters are used before the modulator to reduce the transmitted bandwidth of the signal.
- ✓ Gaussian filters use less bandwidth than conventional FSK.
- ✓ Gaussian filtering converts the full response message signal into a partial response scheme where each transmitted symbols pans several bit periods.

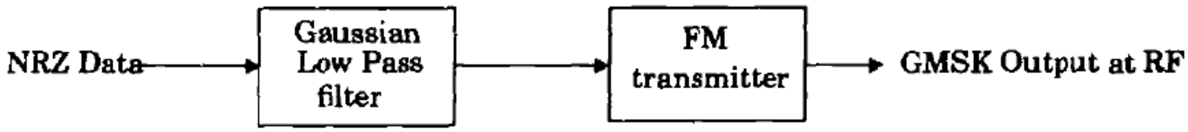
17. List the advantages of GMSK.

The advantages of GMSK are

- ✓ Improved spectral efficiency when compared to other phase shift keyed modes.
- ✓ Amplified by a non-linear amplifier and remain undistorted.
- ✓ Immune to amplitude variations
- ✓ More resilient to noise.
- ✓ Excellent power efficiency

18. How is GMSK generated?

ThesimplestwaytogenerateaGMSKsignalistopassaNRZmessagebitstreamthroughaGaussianbaseband filterfollowedbyanFMmodulator.



19. What do you mean by Non-Coherent detection? (Nov 2015)

When no phase information is required for detection, the type of detection is called non coherent detection.

20. How can we improve link performance?

Name the three techniques used to improve the received signal quality. [April/May 2019]

1. Diversity, 2. Equalization, 3. Channel coding

21. What is diversity, equalization technique?

- ✓ To reduce ISI, equalization technique is used.
- ✓ To reduce fading effects, diversity technique is used.

22. What is equalization, an equalizer? (Nov 2013)

What is the use of equalization technique? [Nov/Dec 2019][April/May 2023]

- ✓ The process of extracting the symbols from the received signal is called equalization.
- ✓ The goal of equalization is the combination of the transmitter; channel and receiver appear to be an all-pass channel. In the frequency domain equation

$$H_{eq}(f)\,F*(-f) = 1$$

Where $H_{eq}(f) \leftarrow F(f)$ are Fourier transforms of $h_{eq}(t) \leftarrow f(t)$ respectively.

$$\text{Equalizer transfer function} \propto \frac{1}{\text{Channel transfer function}}$$

Equalizer is a linear pulse shaping filter, used to reduce the dispersive effects of a channel like ISI- inter symbol interference is referred to as an ***equalizer***.

23. Write the major classifications of equalizers. State the significance of each. (May 2012, May 2013)[Nov /Dec 2019]

The major classification of equalization techniques is linear and nonlinear equalization.

Linear equalizer:

1. In linear equalizer, the current and past values of the received signal are linearly weighted by the filter coefficients and summed to produce the output. No feedback path is used.
2. Simple, easy to implement.
3. Not suitable for severely distorted channel, noise power signal is enhanced.

Non-linear equalizer:

1. If the past decisions are correct, then the ISI contributed by present symbol can be cancelled exactly, feedback path is used.
2. Suitable for severely distorted channel, also noise power is not enhanced.
3. Complex in structure, channels with low SNR, the DFE suffers from error propagation.

24. What are the types of non-linear equalizer?

It has three types

1. Decision feed back
2. Maximum likelihood symbol detector
3. Maximum likelihood sequence estimator

25. Write the advantages of lattice equalizer.

i. It is simplest and easily available.
ii. Numerical stability.
iii. Faster convergence.
iv. When the channel becomes more time dispersive, the length of the equalizer can be increased by the algorithm without stopping the operation.
v. Unique structure of the lattice filter allows the dynamic assignment.

26. Define adaptive equalization. Write the significance of it. (May 2016)

Adaptive equalizers assume channel is time varying channel and try to design equalizer filter whose filter coefficients are varying in time according to the change of channel, and try to eliminate ISI and additive noise at each time.

27. What are the applications of non linear equalizer? (May/June 2014)

Non linear equalizer is used for

- Microwave communications
- Satellite communications
- Mobile communications

28. Why is an adaptive equalizer required? (APRIL/MAY 2017)

In practice, the channel response is unknown.
Hence the optimum matched filter must be adaptively estimated to reduce error.

29. What are the applications of non linear equalizer? (May/June 2014)

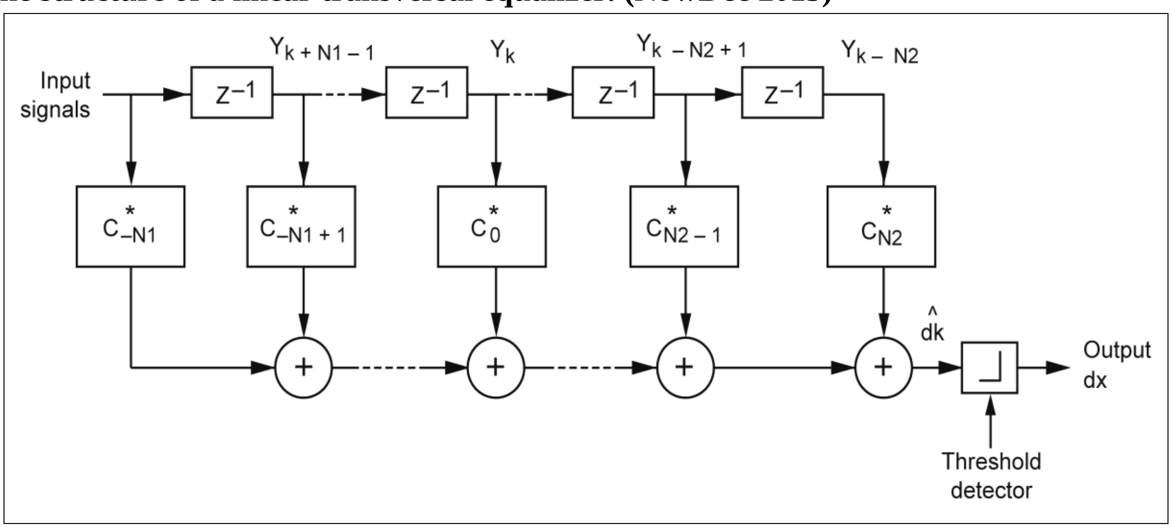
Non linear equalizer is used for i) Microwave communications ii) Satellite iii) Mobile communications.

30. What are the types of non-linear equalizer?

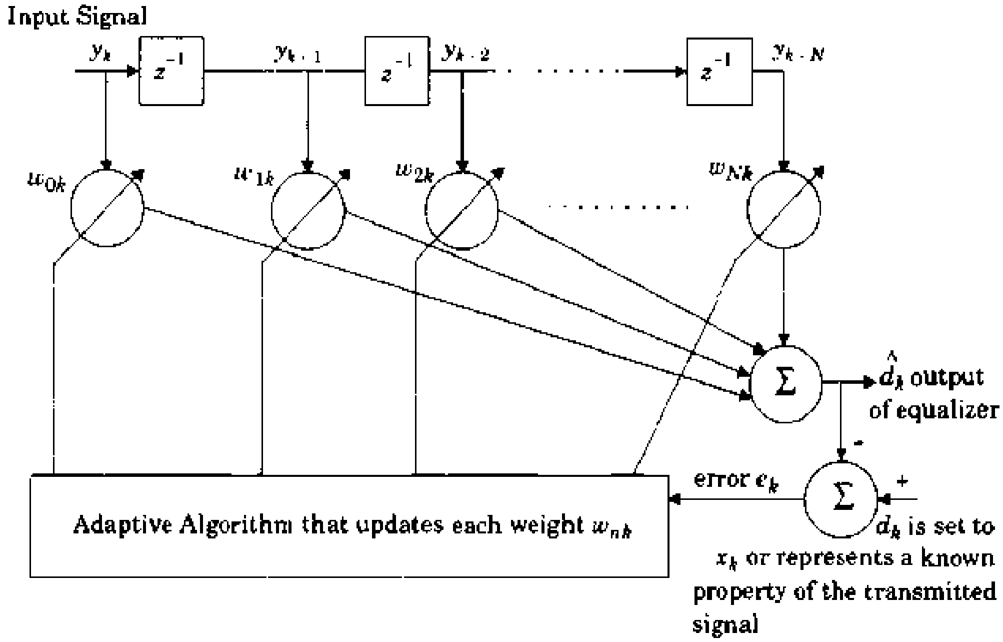
It has three types

1. Decision feed back
2. Maximum likelihood symbol detector
3. Maximum likelihood sequence estimator

31. Draw the structure of a linear transversal equalizer. (Nov/Dec 2015)



32. Draw the structure of generic optimum receiver. (May/June 2013)



33. Write about MLSE decision feedback equalizer. (May 2015)

- ✓ The MLSE is optimal in the sense that it minimizes the probability of a sequence error.
- ✓ The MLSE requires knowledge of the channel characteristics, noise in order to compute the metrics for making decisions.
- ✓ An MLSE usually has a large computational requirement, especially when the delay spread of the channel is large.

34. Write the advantages of MMSE equalizer.

Advantages of MMSE are

- ✓ The noise power of an MMSE equalizer is smaller than that of a ZF equalizer.
- ✓ Suitable for wireless link.

35. List the advantages and disadvantages of DFE equalizer.

Advantages of DFE are

- ✓ FBF can be realized as a lattice structure.
- ✓ RLS lattice algorithm can be used to yield fast convergence.
- ✓ DFE has a smaller error probability than a linear equalizer.

36. What are the factors used in adaptive algorithms?

i. Rate of convergence
ii. Misadjustment
iii. Computational complexity
iv. Numerical properties.

37. Write the basic algorithms used for adaptive equalizations.

(i) Zero forcing (ZF) algorithm.
(ii) Least mean squares (LMS) algorithm.
(iii) Recursive least square (RLS) algorithm.

38. Write the advantages drawbacks of RLS algorithm.

(i) Fast convergence

(ii) Good tracking ability. If smaller value of weighting coefficient L, the Equalizer has better tracking ability.

39. What are the differences between zero-forcing and mean squared error equalizer?[April/May 2019]

Zero Forcing Equalizer (ZF)	Mean Squared Error Equalizer (MSE)
1. Simple filters easy to implement as a transversal structure.	1. Optimum filter, implemented as a lattice structure.
2. It performs well for static channels with low SNR.	2. Suitable for static channels with high SNR.
3. Noise enhancement makes ZF equalizer not suitable for wireless link.	3. suitable for wireless link.

40. What is the principle of diversity technique? (May/June 2013, Nov/Dec 2013, Apr/May 2017)

- ✓ Signal is transmitted by more than one antenna via channel.
- ✓ It ensures that the same information reaches the receiver on statistically independent channels.

41. Why diversity technique is needed? Why it is employed? (Apr/May2017, Nov/Dec 2010)

In AWGN – channel, BER decreases exponentially as the SNR increases.

In Rayleigh fading channel – BER decreases linearly with SNR.

So, to achieve 10^{-4} BER, diversity is used.

42. Define SNR.

SNR = average received signal energy per (complex) symbol time/ noise energy per (complex) symbol time

43. What is small scale fading, large scale fading?

Small scale fading	Large scale fading
• Due to multiple reflections from the surroundings, small scale fading occur over a short period of time or travel distance. • It causes deep and rapid amplitude fluctuations in the signal.	• Due to shadowing of large terrain profile large scale fading occurs. • It causes variations in the signal strength.

44. Define 5 common methods of micro diversity. (Nov 2011)[Nov/Dec 2017]

The five most common methods are

1. Spatial diversity → several antenna elements separated in space.
2. Temporal diversity → Repetition of the transmit signal at different times.
3. Frequency diversity → Transmission of the signal on different frequencies.
4. Angular diversity → Multiple antennas with different antenna patterns.
5. Polarization → Multiple antennas receiving different polarizations

45. Define space diversity/ antenna diversity and its types. (May 2010, Nov/Dec 2015)

Space diversity is also known as antenna diversity. The concept is at each cell site, multiple base station receiving antennas are used to provide diversity reception.

Space diversity reception methods can be classified into two categories

1. Selection diversity---- a) switched diversity b) Feedback diversity
2. Combining diversity ----a) Maximal ratio combining b) Equal gain diversity

46. Differentiate selection and combining diversity.

S.No.	Selection diversity	Combining diversity
1.	The "best signal" copy is selected and processed while all other copies are discarded. *e.g.* large RSSI – received signal strength indication is selected.	Combining diversity:- All copies of the signal are combined before (demodulation) processing and the combined signals are decoded.
2.	Simple circuits are needed.	Individual receiver phasing circuits are needed.
3.	None of the signal is not in acceptable SNR means, it is degraded.	It works better than selection diversity.

47. Write the classification in signal combining techniques.

1. Selection diversity---- Fading path with highest gain used to select best signal
   - a) switched diversity----active branch is monitored continuously
   - b) Feedback diversity ---- scanned in a fixed sequence
2. Combining diversity ---- All copies of the signal are combined before processing
   - a) Maximal ratio combining --- The signals from all of the M branches are weighted according to their SNR and then summed
   - b) Equal gain combining ------ The branch weights are all set to unity but the signals from each are co-phased to provide equal gain combining diversity

48. Compare MRC and EGC techniques.

MRC- Maximal ratio combining	EGC- Equal gain combining
The signals from all of the M branches are weighted according to their SNR and then summed.	The branch weights are all set to unity but the signals from each are co-phased to provide equal gain combining diversity.

49. Define Polarization diversity.

In TX side, two diversity branches are used. Signals are transmitted through two orthogonally polarized propagation path.

In RX side, antennas with two elements receive the vertical or horizontally polarized signal.

In the channel, if the signal is obstructed, polarization diversity will reduce the multipath spread without decreasing the receiver power.

50. Differentiate between Micro, Macro diversity. (May 2014, Nov 2014) [Nov/Dec 2019]
What do you mean by micro and macro diversity? [April/May 2019]

S.No.	Micro diversity	Macro diversity
1.	Used to reduce small scale fading effects.	Used to reduce large scale fading effects.
2.	Multiple reflections cause deep fading. This effect is reduced.	Deep shadow causes fading. This effect is reduced.
3.	BS – MS are separated by a small distance.	BS – MS are separated by a large distance.

51. What is transmit diversity? (Nov/Dec 2017, Apr/May 2015, Nov/Dec 2015)

Diversity effect is achieved by transmitting signals from several transmit antenna is known as transmit diversity.

52. What is receiving diversity (or) diversity reception technique? (Nov/Dec 2017, Apr/May 2015, Nov/Dec 2015, Nov/Dec 2012)

Diversity effect is achieved by receiving signals from several receive antenna is known as receive diversity.

53. What is the basic idea of Rake receiver. (Nov 2012)

- ✓ It consists of a bank of correlators; each sampled at a different time with delay τ and thus collects energy from the MPC.
- ✓ The sample values from the correlators are then weighted and combined to achieve improved communications reliability and performance.
- ✓ The tap delays as well as the tap weights are adjustable and matched to the channel.

54. What are the benefits of RAKE receiver? (May 2016)

The main advantage of Rake Receiver is that it improves the SNR (or) E_b / N_o. Naturally, this improvement is observed in larger environments with many multipaths than in environments without obstruction.

55. What do you mean by coding gain? (Nov/Dec 16)

Coding gain is what allows a channel error rate of 10^{-2} to support decoded data rates which are 10^{-5} or better.

56. Distinguish between Diversity gain and array/ Beam forming gain.[April/May 2018]

Diversity gain reflects the fact that it is improbable that several antenna elements are in a fading dip simultaneously. Thus probability of error is very low.

Beam forming gain reflects the fact that the combiner performs an averaging over the noise at different antennas.

Thus, even if the signal levels at all antenna elements are identical, the combined output SNR is larger than the SNR at a single antenna element.

57. List out the factors that influence the performance of adaptive equalization algorithms. [April/May 2021]

- ➢ **Rate of convergence**This is defined as the number of iterations required for the algorithm, in response to stationary inputs, to converge close enough to the optimum solution.A fast rate of convergence allows the algorithm to adapt rapidly to a stationary environment of unknown statistics.
- ➢ **Misadjustment:** This parameter provides a quantitative measure of the amount by which the final value of the mean square error, averaged over an ensemble of adaptive filters, deviates from the optimal minimum mean square error.
- ➢ **Computational complexity:**This is the number of operations required to make one complete iteration of the algorithm

- **Numerical properties:**When an algorithm is implemented numerically, inaccuracies are produced due to round-oft' noise and representation errors in the computer.These kinds of errors influence the stability of the algorithm.

58. Assume 5 branch diversity is used, where each branch receives an independent Rayleigh fading signal . If the average SNR is 20 dB, determine the probability that the SNR will drop below 10 dB. [April/May 2021]

For this example the specified threshold $\gamma = 10$ dB, $\Gamma = 20$ dB, and there are four branches. Thus $\gamma / \Gamma = 0.1$ and using equation (6.58),

$$P_4(10 \text{ dB}) = (1 - e^{-0.1})^4 = 0.000082$$

When diversity is not used, equation (6.58) may be evaluated using $M = 1$.

$$P_1(10 \text{ dB}) = (1 - e^{-0.1})^1 = 0.095$$

Notice that without diversity the *SNR* drops below the specified threshold with a probability that is three orders of magnitude greater than if four branch diversity is used!

59. How equalization is achieved through zero forcing algorithm? [Nov/Dec 2021]

The zero forcing equalizer applies the inverse of the channel frequency to the received signal, to restore the signal after the channel. The name zero forcing corresponds to bringing down the intersymbol interference to zero in a noise free case.

60. How error probability is computed for fading channel in SISO system? [Nov/Dec 2021]

Fading can cause poor performance in a communication system because it can result in a loss of signal power without reducing the power of the noise. This signal loss can be over some or all of the signal bandwidth.

61. What is the error performance degradation in communication system? [April/May 2023]

The main causes of error performance degradation are interference electrical noise effect of filtering and due to the surroundings. The motion of thermal electrons causes degradation causes thermal noise, which cannot be eliminated, in system.

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UNIT – III

MODULATION TECHNIQUES AND EQUALIZATION AND DIVERSITY

QUESTION BANK

PART – A

1. What are the steps involved in the wireless communication link?
2. Draw the mathematical link for analysis of modulation scheme.
3. Mention any two criteria for choosing a modulation technique for a specific wireless application.
4. Draw the structure of generic optimum receiver.
5. Differentiate between OQPSK and QPSK.
6. State the advantages of offset-QPSK.
7. Draw the signal constellation and phase transition of $\pi/4$ QPSK signal.
8. Define offset QPSK and $\pi/4$ differential QPSK.
9. Why is MSK referred to as fast FSK?
10. Give the function of Gaussian filter in GMSK.
11. What is equalization, an equalizer?
12. Write the major classifications of equalizers. State the significance of each.
13. Why is an adaptive equalizer required?
14. What are the types of non-linear equalizer?
15. Draw the structure of a linear transversal equalizer.

PART – B & C

1. Explain the factors that influence the choice of Digital Modulation.
2. Explain in detail about Binary Phase Shift Keying (BPSK).
3. Explain in detail about Differential Phase Shift Keying (DPSK).
4. Explain in detail about Quadrature Phase Shift Keying (QPSK).
5. Explain in detail Offset QPSK linear digital modulation techniques employed in wireless communication.
6. With neat diagram, explain the modulation and demodulation of $\pi / 4$ DQPSK modulation techniques.
7. What is MSK? Also derive the expression of MSK signal as a special type of FSK signal and explain its spectral density.
8. Explain in detail Gaussian Minimum shift Keying (GMSK) transmission and reception with necessary diagrams.
9. Explain about Spread Spectrum Modulation Techniques.
10. Explain about equalization and Draw and explain a simplified communication system using an adaptive equalizer at the receiver.
11. Analyze various diversity techniques used in wireless communication.
12. Explain in detail about Practical Space Diversity Considerations.
13. Explain with diagram, the different techniques available for signal combining.

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UNIT- IV

MULTIPLE ACCESS TECHNIQUES

Introduction: Introduction To Multiple Access- Frequency Division Multiple Access (FDMA)- Time Division Multiple Access(TDMA)- Spread Spectrum Multiple Access-Code Division Multiple Access(CDMA)- Space Division Multiple Access(SDMA)- Capacity Of Cellular Systems: Capacity Of Cellular CDMA, Capacity Of CDMA With Multiple Cells.

4.1 Introduction To Multiple Access

4.2 Frequency Division Multiple Access (FDMA)

4.3 Time Division Multiple Access (TDMA)

4.4 Spread Spectrum Multiple Access

4.4.1 Frequency Hopped Multiple Access (FHMA)

4.4.2 Code Division Multiple Access (CDMA)

4.5 Space Division Multiple Access (SDMA)

4.6 Capacity Of Cellular Systems:

4.6.1 Capacity Of Cellular CDMA

4.6.2 Capacity Of CDMA With Multiple Cells

4.1 INTRODUCTION TO MULTIPLE ACCESS

1. Summarize the features of various multiple access techniques used in wireless mobile communication. State the advantages and disadvantages of each technique. (16m-May 2016)[April/May 2023]

- ✓ **Multiple access techniques** are used to allow a more number of mobile users to share the allocated spectrum in the most efficient manner.
- ✓ As the spectrum is limited, the sharing is required to increase the capacity of cell or over a geographical area.It done by allowing the available bandwidth to be used at the same time by different users.
- ✓ **Multiple access or channel access** method is based on a multiplexing method.
- ✓ It allows several data streams or signals to share the same communication channel or physical medium.

Applications of multiple access techniques:

- ✓ The first generation wireless systems used FDMA
- ✓ In second generation TDMA and CDMA are used.
- ✓ CDMA is the targeted multiple access technology for the third generation wireless communication systems.
- ✓ This Multiple access technique can be grouped as narrowband and wideband systems, depending upon how the available bandwidth is allotted to the user.

<u>Types of multiple access techniques</u>:

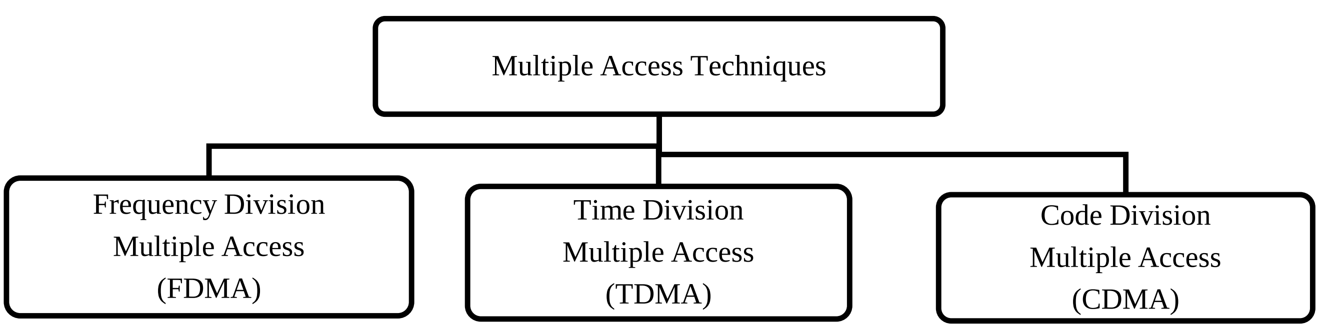

Figure: Types of multiple access techniques

4.2 FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

1. Explain any one type of multiple access schemes. (6M-May 2012)

FDMA (Frequency division multiple access): The total bandwidth is divided into non-overlapping frequency sub bands.

- ✓ It is a basic technology in the Analog Mobile Phone Service (AMPS).
- ✓ It assigns individual channels to individual users.
- ✓ Each user is allocated a unique frequency band or channel.
- ✓ These channels are assigned on demand to users who request service.
- ✓ During the period of the call, no other user can share the same frequency band.
- ✓ FDM (frequency division multiplexing) is the division of frequency band allocated for the wireless telephone communication.

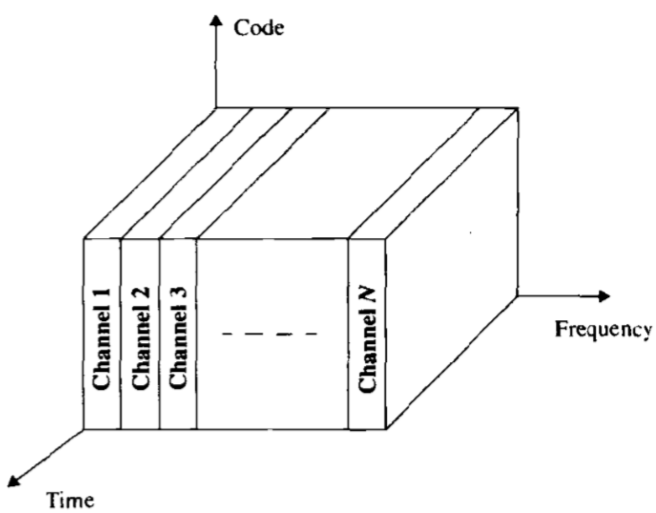

Figure:FDMA where different channels are assigned different frequency bands.

<u>Features of FDMA</u>

(Advantages)

- ✓ The FDMA channel carries ***only one phone circuit at a time***.
- ✓ 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), because each channel supports only ***one circuit per carrier***. That is, FDMA is usually ***implemented in narrowband systems***.

- ✓ The complexity of FDMA mobile systems is lower when compared to TDMA systems.
- ✓ FDMA is a ***continuous transmission scheme***, so, fewer bits are ***needed for overhead purposes*** (such as synchronization and framing bits) as compared to TDMA.
- ✓ ***Inter-symbol interference is low*** and no equalization is required.

(Disadvantages)

- ✓ 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***.
- ✓ FDMA need to use ***costly bandpass filters*** to eliminate spurious radiation at the base station.
- ✓ FDMA systems have higher cell site ***system costs as compared to TDMA systems***, because of the single channel per carrier design.
- ✓ The FDMA mobile unit uses duplexers. This increases in the cost of FDMA.

Nonlinear Effects in FDMA

- ✓ In FDMA system, many channels share same antenna at the base station.
- ✓ The power amplifiers or the power combiners, when operated at or near saturation for maximum power efficiency, are non- linear.
- ✓ The nonlinearities 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.
- ✓ To minimize inter modulation distortion, RF filters are used.

Number of channels

- ✓ 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 - Total spectrum allocation (or) Bandwidth

B_{guard} - Guard band allocated at the edge of the allocated spectrum

B_C - Channel bandwidth

4.3 TIME DIVISION MULTIPLE ACCESS (TDMA)

1. **Brief about the principle of time division multiple access (TDMA). (6M-May 2013)**
2. **Explain TDMA and discuss the time division multiple access frame structure.**
3. **Identify the channel capacity of TDMA in cell system. [Nov/Dec 2017]**

4. (i). Discuss your understanding on various multiple access techniques namely FDMA, TDMA and CDMA [April/May 2021]

(ii) Highlight their advantage, disadvantage and uses in cellular communication [April/May 2021]

TDMA (Time division multiple access): The total bandwidth is divided into time slots;different timeslot is assigned to different users.

- ✓ Each user occupies a cyclically repeating time slot.
- ✓ TDMA systems transmit data in a buffer-and-burst method, thus the transmission for any user is non continuous.
- ✓ Digital data and digital modulation must be used with TDMA.

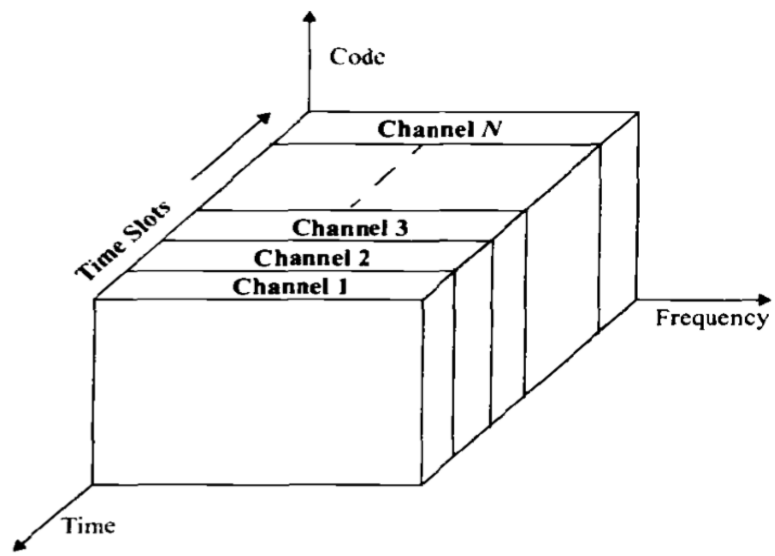

Figure:TDMA scheme where each channel occupies a cyclically repeating time slot.

Frame structure

- ✓ The transmission from various users is interlaced into a repeating frame structure as shown in Figure.
- ✓ Frame consists of a number of slots.
- ✓ Each frame is made up of a preamble, an information message, and tail bits.
- ✓ Preamble contains the address and synchronization information that both the base station and the subscribers use to identify each other.
- ✓ Guard times allow synchronization of the receivers between different slots and frames.

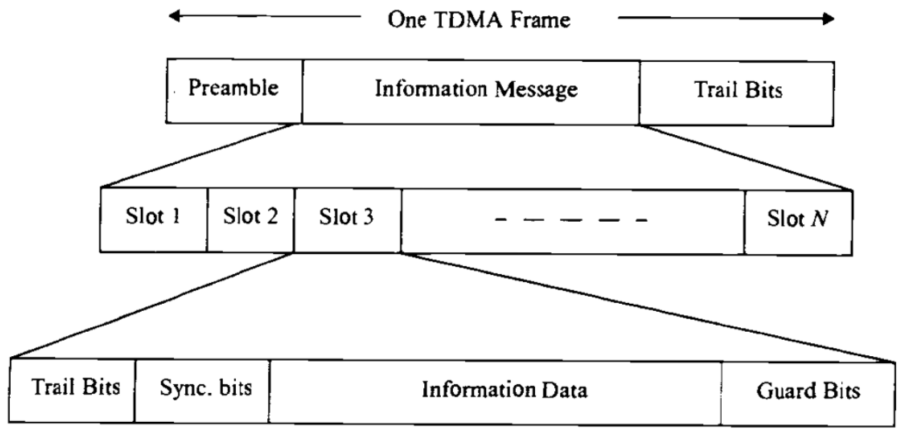

Figure: TDMA frame structure. The frame is cyclically repeated over time

Features of TDMA

Advantages:

- ✓ TDMA shares a single carrier frequency with several users, where each user makes use of non-overlapping time slots.
- ✓ Data transmission for users of a TDMA system is not continuous. This results in low battery consumption, since the subscriber transmitter can be turned off when not in use.
- ✓ Because of discontinuous transmissions in TDMA, the handoff process is much simpler for a subscriber unit.
- ✓ TDMA uses different time slots for transmission and reception, thus duplexers are not required.
- ✓ Adaptive equalization is necessary in TDMA systems.
- ✓ It is possible to allocate different numbers of time slots per frame to different users.

Disadvantages:

- ✓ High synchronization overhead is required in TDMA systems.
- ✓ In TDMA, the guard time should be minimized.

Efficiency of TDMA

- ✓ The efficiency of a TDMA system is a measure of the percentage of transmitted data that contains information as opposed to providing overhead for the access scheme.
- ✓ The frame efficiency is the percentage of bits per frame which contain transmitted data.
- ✓ The number of overhead bits per frame is

$$b_{OH} = N_r b_r + N_t b_p + N_t b_g + N_r b_g$$

where, N_r → Number of reference bursts per frame

N_t → Number of traffic bursts per frame

b_r → Number of overhead bits per reference burst,

b_p → Number of overhead bits per preamble in each slot, and

b_g → Number of equivalent bits in each guard time interval.

- ✓ The total number of bits per frameis

$$b_T = T_f R$$

where, T_f → Frame duration,

R → Channel bit rate.

- ✓ The frame efficiency is

$$\eta_f = \left(1 - \frac{b_{OH}}{b_T}\right) \times 100\ \%$$

Number of channels

- ✓ The number of channel in TDMA is given by

$$N = \frac{m\left(B_{tot} - 2B_{guard}\right)}{B_C}$$

where, m → Maximum number of TDMA users supported on each radio channel.

4.4 SPREAD SPECTRUM MULTIPLE ACCESS

Explain in detail about spread spectrum multiple access.

- ✓ Spread spectrum multiple access (SSMA) uses signals which have a transmission bandwidth that is several orders of magnitude greater than the minimum required RF bandwidth.
- ✓ A pseudo-noise (PN) sequence converts a narrowband signal to a wideband noise-like signal before transmission.

- ✓ SSMA also provides immunity to multipath interference and robust multiple access capability.
- ✓ SSMA is not very bandwidth efficient when used by a single user.
- ✓ Many users can share the same spread spectrum bandwidth without interfering with one another.
- ✓ So, spread spectrum systems become bandwidth efficient in a multiple user environment.

- ✓ It is exactly this situation that is of interest to wireless system designers.
- ✓ There are two main types of spread spectrum multiple access techniques; frequency hopped multiple access (FH) and direct sequence multiple access (DS).
- ✓ Direct sequence multiple access is also called code division multiple access (CDMA).

4.4.1 Frequency Flopped Multiple Access (FHMA)

Explain in detail about Frequency Flopped Multiple Access (FHMA).

- ✓ Frequency hopped multiple access (FHMA) is a digital multiple access system.
- ✓ Here, the ***carrier frequencies of the individual users are varied*** in a ***pseudorandom fashion*** within a wideband channel.
- ✓ The ***digital data is broken into uniform sized bursts*** which are ***transmitted on different carrier frequencies***.
- ✓ The instantaneous bandwidth of any one transmission burst is much smaller than the total spread bandwidth.
- ✓ The pseudorandom change of the carrier frequencies of the user randomizes the occupancy of a specific channel at any given time, thereby allowing for multiple access over a wide range of frequencies.

- ✓ In the FR receiver, a locally generated PN code is used to synchronize the receiver's instantaneous frequency with that of the transmitter.
- ✓ At any given point in time, a frequency hopped signal only occupies a single, relatively narrow channel since narrowband FM or FSK is used.
- ✓ The difference between FHMA and a traditional FDMA system is that the frequency hopped signal changes channels at rapid intervals.
- ✓ If the rate of change of the carrier frequency is greater than the symbol rate then the system is referred to as a fast frequency hopping system.
- ✓ If the channel changes at a rate less than or equal to the symbol rate, it is called slow frequency hopping.
- ✓ A fast frequency hopper may thus be thought of as an FDMA system which employs frequency diversity.
- ✓ FHMA systems often employ energy efficient constant envelope modulation.
- ✓ Inexpensive receivers may be built to provide noncoherent detection of FHMA.
- ✓ This implies that linearity is not an issue, and the power of multiple users at the receiver does not degrade FHMA performance.

- ✓ A frequency hopped system provides a level of security.
- ✓ Especially when large number of channels are used, since an unintended (or an intercepting) receiver that does not know the pseudorandom sequence of frequency slots must retune rapidly to search for the signal it wishes to intercept.
- ✓ In addition, the FR signal is immune to fading, since error control coding and interleaving can be used to protect the frequency hopped signal against deep fades.
- ✓ Error control coding and interleaving can also be combined to guard against Erasures.
- ✓ Erasures can occur when two or more users transmit on the same channel at the same time.

4.4.2 CODE DIVISION MULTIPLE ACCESS (CDMA)

1. **With neat illustration, explain CDMA. (6M-Nov 2014)**
2. **Describe the principle of CDMA. [April/May 2019]**

CDMA (Code division multiple access): Many users share the same frequency with same time using different coding.

- ✓ In code division multiple access (CDMA) systems, the narrowband message signal is multiplied by a very large bandwidth signal called the spreading signal.
- ✓ The spreading signal is a pseudo-noise code sequence that has a chip rate which is orders of magnitudes greater than the data rate of the message.
- ✓ Each user has its own pseudorandom codeword which is approximately orthogonal to all other codewords.
- ✓ The receiver performs a time correlation operation to detect only the specific desired codeword.
- ✓ All other codewords appear as noise due to decorrelation.
- ✓ For detection of the message signal, the receiver needs to know the codeword used by the transmitter.
- ✓ Each user operates independently with knowledge of the other users.
- ✓ In CDMA, the power of multiple users at a receiver determines the noise floor after decorrelation.
- ✓ The symbol duration is very short and usually much less than the channel delay spread.
- ✓ A RAKE receiver can be used to improve reception by collecting time delayed versions of the required signal.

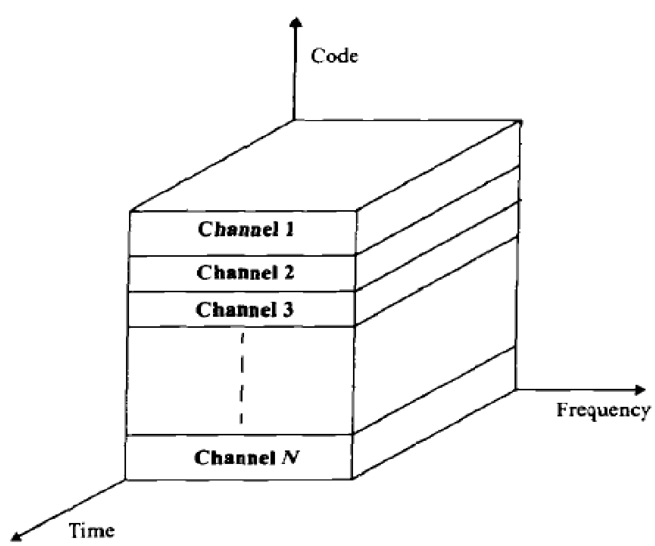

Figure: CDMA -Each channel is assigned a unique PN code

<u>Advantages</u>

- ✓ Frequency reuse
  - ➢ All users in a CDMA system use the same carrier frequency and may transmit simultaneously.
- ✓ Soft capacity
  - ➢ During peak hours, if the user can tolerate a lower QoS to a certain stage, the stem can accommodate more user to satisfy the high service demands in that period.
- ✓ Reduction in multipath fading
  - ➢ Multipath fading may be reduced because the signal is spread over the large spectrum.
- ✓ Data rates
  - ➢ Channel data rates are very high in CDMA systems.
- ✓ Handoff performance
  - ➢ When mobile user is in the cell boundary, it can establish a connection with the new base station before terminating the connection with old base station. This will improve handoff performance.
- ✓ Flexibility
  - ➢ CDMA are more flexiblethan TDMA systems in supporting multimedia services.

<u>Disadvantages</u>

- ✓ Near-far problem
  - ➢ Some of the mobile units are close to the base station while others are far from it.
  - ➢ A strong signal received at the base from a near –in mobile unit and the weak signal from a far –end mobile unit. This phenomenon is called the near-far problem.
- ✓ Self-jamming
  - ➢ Self-jamming arises by the spreading sequences of different users are not exactly orthogonal.
  - ➢ In the despreading of a particular PN code, non-zero contributions to the receiver decision statistic for a desired user arise from the transmissions of other users in the system.

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COMPARISON OF TDMA, FDMA AND CDMA

1. What are the major difference between TDMA, FDMA and CDMA? Explain in detail about each multiple access. (16m-May 2014)

Sl. No.	FDMA	TDMA	CDMA
1	The total bandwidth is divided into on-overlapping frequency sub bands.	The total bandwidth is divided into time slots; different timeslot is assigned to different users.	Many users share the same frequency with same time using different coding.
2	FDMA uses Narrow band Systems.	TDMA uses Narrow band Systems or wide band Systems	CDMA uses Wide band Systems.
3	FDMA is First generation wireless standard (1G).	TDMA is Second generation wireless standard (2G).	CDMA is third generation wireless standard (3G).
4	FDMA is use for the voice and data transmission	TDMA is used for data and digital voice signals	CDMA is use for digital voice signals and multimedia services.
5	Due to non-linearity of power amplifiers, inter-modulation products are generated due to interference between adjacent channels.	Due to incorrect synchronization there can be interference between the adjacent time slots.	Both type of interference will be present.
6	Synchronization is not necessary	Synchronization is necessary	Synchronization is not necessary
7	Code word is not required	Code word is not required	Code words are required
8	Guard bands between adjacent channels are necessary.	Guard times between adjacent time slots are necessary.	Guard bands and guard times are necessary.

4.5 SPACE DIVISION MULTIPLE ACCESS (SDMA)

Explain in detail about space division multiple access (SDMA).

- Space division multiple access (SDMA) controls the radiated energy for each user in space.
- It can be seen from Figure 8.8 that SDMA serves different users by using spot beam antennas.
- These different areas covered by the antenna beam may be served by the same frequency (in a TDMA or CDMA system) or different frequencies (in an FDMA system).

- Sectorized antennas may be thought of as a primitive application of SDMA.
- In the future, adaptive antennas will likely be used to simultaneously steer energy in the direction of many users at once and appear to be best suited for TDMA and CDMA base station architectures.

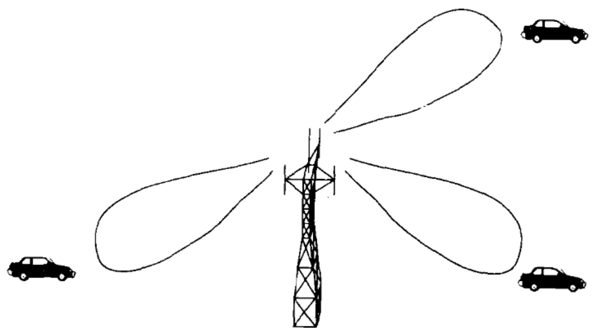

Figure 8.8 A spatially filtered base station antenna serving different users by using spot beams.

- The reverse link presents the most difficulty in cellular systems for several reasons.
- First, the base station has complete control over the power of all the transmitted signals on the forward link.
- However, because of different radio propagation paths between each user and the base station, the transmitted power from each subscriber unit must be dynamically controlled to prevent any single user from driving up the interference level for all other users.
- Second, transmit power is limited by battery consumption at the subscriber unit, therefore there are limits on the degree to which power may be controlled on the reverse link.
- If the base station antenna is made to spatially filter each desired user so that more energy is detected from each subscriber, then the reverse link for each user is improved and less power is required.

- Adaptive antennas used at the base station (and eventually at the subscriber units) promise to mitigate some of the problems on the reverse link.
- In the limiting case of infinitesimal beamwidth and infinitely fast tracking ability, adaptive antennas implement optimal SDMA, thereby providing a unique channel that is free from the interference of all other users in the cell.
- With SDMA, all users within the system would be able to communicate at the same time using the same channel.
- In addition, a perfect adaptive antenna system would be able to track individual multipath components for each user and combine them in an optimal manner to collect all of the available signal energy from each user.
- The perfect adaptive antenna system is not feasible since it requires infinitely large antennas.

4.6 Capacity Of Cellular Systems:

Explain in detail about Capacity of Cellular Systems.

- Channel capacity for a radio system can be defined as the maximum number of channels or users that can be provided in a fixed frequency band.
- Radio capacity is a parameter which measures spectrum efficiency of a wireless system.
- This parameter is determined by the required carrier-to-interference ratio (C/I) and the channel bandwidth B_c.

- In a cellular system the interference at a base station receiver will come from the subscriber units in the surrounding cells.
- This is called reverse channel interference.
- For a particular subscriber unit, the desired base station will provide the desired forward channel while the surrounding co-channel base stations will provide the forward channel interference.
- Considering the forward channel interference problem, let D be the distance between two co-channel cells and R be the cell radius.
- Then the minimum ratio of D7R that is required to provide a tolerable level of co-channel interference is called the co-channel reuse ratio and is given by,

$$Q = \frac{D}{R} \qquad (1)$$

- The radio propagation characteristics determine the *carrier-to-interference* ratio *(C/I)* at a given location, and models presented in Chapter 3 and Appendix B are used to find sensible *C/I* values.

- As shown in Figure, the *M* closest co-channel cells may be considered as first order interference in which case *C/I* is given by

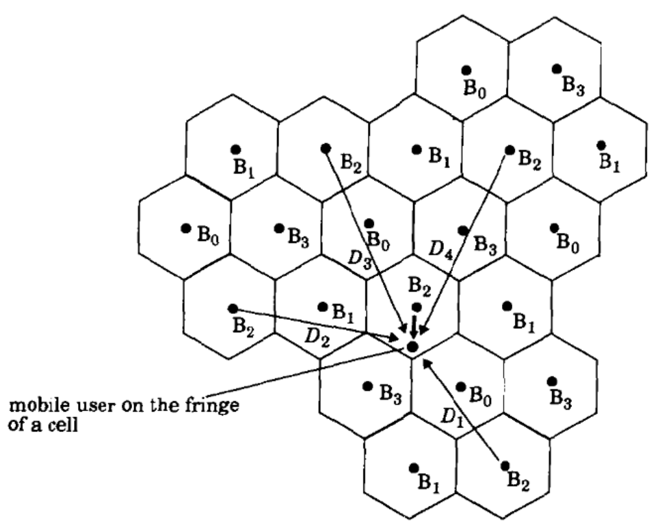

Figure. Illustration of forward channel interference for a cluster size of N = 4. Shown here are four co-channel base stations which interfere with the serving base station. The distance from the serving base station to the user is D_0, and interferers are a distance D_k from the user.

$$\frac{C}{I} = \frac{D_0^{-n_0}}{\sum_{k=1}^{M} D_0^{-n_k}} \qquad (2)$$

where,

n_0 - the path loss exponent in the desired cell

D_0 - the distance from the desired base station to the mobile

D_k - the distance of the k^{th} cell from the mobile, and

n_k - the path loss exponent to the k^{th} interfering base station.

- If only the six closest interfering cells are considered,
  and all are approximately at the same distance D
  and have similar path loss exponents equal to that in the desired cell,
  then C/I is given by

$$\frac{C}{I} = \frac{D_0^{-n}}{6\ D_0^{-n}} \qquad (3)$$

- Now, if it is assumed that maximum interference occurs when the mobile is at the cell edge $D_0 = R$, and if the C/I for each user is required to be greater than some minimum $(C/I)_{min}$ which is the minimum carrier-to-interference
- ratio that still provides acceptable signal quality at the receiver, then the following equation must hold for acceptable performance:

$$\frac{1}{6}\left(\frac{R}{D}\right)^{-n} \geq \left(\frac{C}{I}\right)_{\min} \qquad (4)$$

- Thus, from Equation (1), the co-channel reuse factor is

$$Q = \left(6\left(\frac{C}{I}\right)_{\min}\right)^{1/n} \qquad (5)$$

- The radio capacity of a cellular system is defined as

$$m = \frac{B_t}{B_c N} \ \ radio\ channels/cell \qquad (6)$$

where,

m is the radio capacity metric,

B_t is the total allocated spectrum for the system,

B_c is the channel bandwidth, and

N is the number of cells in a frequency reuse pattern.

- N is related to the co-channel reuse factor Q by

$$Q = \sqrt{3N} \tag{7}$$

- From Equations (5), (6), and (7), the radio capacity is given as

$$m = \frac{B_t}{B_c \dfrac{Q^2}{3}} = \frac{B_t}{B_c \left(\dfrac{6}{3^{n/2}} \left(\dfrac{C}{I} \right)_{\min} \right)^{2/n}} \tag{8}$$

- When n = 4, the radio capacity is given by

$$m = \frac{B_t}{B_c \sqrt{\dfrac{2}{3} \left(\dfrac{C}{I} \right)_{\min}}} \quad radio\ channels/cell \tag{9}$$

- In order to provide the same voice quality, $(C/I)_{min}$ may be lower in a digital systems when compared to an analog system.
- Typically, the minimum required C/I is about 12 dB for narrowband digital systems and 18 dB for narrowband analog FM systems, although exact values are determined by subjective listening tests in real-world propagation conditions.
- Each digital wireless standard has a different $(C/I)_{min}$ and in order to compare different systems, an equivalent C/I must be used.
- If B_t and m are kept constant in Equation (2), then it is clear that B_c and $(C/I)_{min}$ are related by

$$\left(\frac{C}{I} \right)_{eq} = \left(\frac{C}{I} \right)_{\min} \left(\frac{B_c}{B_c'} \right)^2 \tag{10}$$

where,

B_c is the bandwidth of a particular system,

$(C/I)_{min}$ value for the same system,

B_c' is the channel bandwidth for a different system, and

$(C/I)_{eq}$ is the tolerable is the minimum C/I value for the different system when compared to the $(C/I)_{min}$ for a particular system.

- Notice that for a constant number of users per radio channel, the same voice quality will be maintained in a different
  system if $(C/I)_{min}$ increases by a factor of four when the bandwidth is halved.

- Equation (9) indicates that maximum radio capacity occurs when $(C/I)_{min}$ and B_c are minimized.
- Equation (10) shows that $(C/I)_{min}$ and B_c are inversely related.
- In a digital cellular system, C/I can be expressed as

$$\frac{C}{I} = \frac{E_b R_b}{I} = \frac{E_c R_c}{I} \qquad (11)$$

- Where R_b is channel bit rate, E_b is the energy per bit, is the rate of the channel code and E_c is the energy per code symbol.
- From equations (10) and (11), the ratio of C/I to $(C/I)_{eq}$ is given as

$$\frac{\left(\frac{C}{I}\right)}{\left(\frac{C}{I}\right)_{eq}} = \frac{\frac{E_c R_c}{I}}{\frac{E_c^{'} R_c^{'}}{I}} = \left(\frac{B_c^{'}}{B_c}\right)^2 \qquad (12)$$

- The relationship between R_C and B_c is always linear, and if the interference level I is the same in the mobile environment for two different digital systems, then equation (8.25) can be rewritten as

$$\left(\frac{E_c}{E_c^{'}}\right) = \left(\frac{B_c^{'}}{B_c}\right)^3 \qquad (13)$$

- Equation (12) shows that if B_c is reduced by half, then the energy code symbol increases eight times.
- This gives the relationship between E_b/N_o and B_C in a digital cellular system.

- A comparison can now be made between the spectrum efficiency for FDMA and TDMA.
- In FDMA, is divided into M channels, each with bandwidth B_C.
- Therefore, the radio capacity for FDMA is given by

$$m = \frac{B_t}{\frac{B_t}{M}\sqrt{\frac{2}{3}\left(\frac{C}{I}\right)}} \qquad (14)$$

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4.6.1 Capacity Of Cellular CDMA

Explain the capacity of cellular CDMA.

- The capacity of CDMA systems is interference limited, while it is bandwidth limited in FDMA and TDMA.
- Therefore, any reduction in the interference will cause a linear increase in the capacity of CDMA.
- Put another way, in a CDMA system, the link performance for each user increases as the number of users decreases.
- A straightforward way to reduce interference is to use multisectorized antennas, which results in spatial isolation of users.
- The directional antennas receive signals from only a fraction of the current users, thus leading to the reduction of interference.
- Another way of increasing CDMA capacity is to operate in a discontinuous transmission mode (DTX), where advantage is taken of the intermittent nature of speech.
- In DTX, the transmitter is turned off during the periods of silence in speech.
- It has been observed that voice signals have a duty factor of about 3/8 in landline networks, and 1/2 for mobile systems, where background noise and vibration can trigger voice activity detectors.
- Thus, the average capacity of a CDMA system can be increased by a factor inversely proportional to the duty factor.
- While TDMA and FDMA reuse frequencies depending on the isolation between cells provided by the path loss in terrestrial radio propagation, CDMA can reuse the entire spectrum for all cells, and this results in an increase of capacity by a large percentage over the normal frequency reuse factor.

- For evaluating the capacity of CDMA system, first consider a single cell system.
- The cellular network consists of a large number of mobile users communicating with a base station (In a multiple cell system, all the base stations are interconnected by the mobile switching center).
- The cell-site transmitter consists of a linear combiner which adds the spread signals of the individual users and also uses a weighting factor for each signal for forward link power control purposes.
- For a single cell system under consideration, these weighting factors can be assumed to be equal.
- A pilot signal is also included in the cell-site transmitter and is used by each mobile to set its own power control for the reverse link.
- For a single-cell system with power control, all the signals on the reverse channel are received at the same power level at the base station.

- Let the number of users be N.

- Then, each demodulator at the cell site receives a composite waveform containing the desired signal of power S and (N-1) interfering users, each of which has power, S.
- Thus, the signal-to-noise ratio is,

$$SNR = \frac{S}{(N-1)S} = \frac{1}{N-1} \qquad (1)$$

- In addition to *SNR*, bit energy-to-noise ratio is an important parameter in communication systems.
- It is obtained by dividing the signal power by the base-band information bit rate, *R*, and the interference power by the total RF bandwidth, *W*.
- The SNR at the base station receiver can be represented in terms of E_b/N_0 given by

$$\frac{E_b}{N_0} = \frac{S/R}{(N-1)(S/W)} = \frac{W/R}{N-1} \qquad (2)$$

- Equation (8.29) does not take into account the background thermal noise, η in the spread bandwidth.
- To take this noise into consideration, E_b/N_0 can be represented as

$$\frac{E_b}{N_0} = \frac{W/R}{(N-1)+(\eta/S)} \qquad (3)$$

- The number of users that can access the system is thus given as

$$N = 1 + \frac{W/R}{(E_b/N_0)} - (\eta/S)$$

  where *W/R* is called the processing gain.
- The background noise determines the cell radius for a given transmitter power.
- In order to achieve an increase in capacity, the interference due to other users should be reduced.

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4.6.2 Capacity Of CDMA With Multiple Cells

Explain about Capacity Of CDMA With Multiple Cells.

- ✓ In actual COMA cellular systems that employ separate forward and reverse links, neighboring cells share the same frequency, and each base station controls the transmit power of each of its own in-cell users.
- ✓ However, a particular base station is unable to control the power of users in neighboring cells, and these users add to the noise floor and decrease capacity on the reverse link of the particular cell of interest.
- ✓ Figure 8.12 illustrates an example of how users in adjacent cells may be distributed over the coverage area.
- ✓ The transmit powers of each out-of-cell user will add to the in-cell interference (where users are under power control) at the base station receiver.
- ✓ The amount of out-of-cell interference determines the frequency reuse factor, f, of a CDMA cellular system.
- ✓ Ideally, each cell shares the same frequency and the maximum possible value of *f* (*f =1*) is achieved.

- ✓ In practice, however, the out-of-cell interference reduces *f* significantly.
- ✓ In contrast to CDMA systems which use the same frequency for each cell, narrowband FDMAJFDD systems typically reuse channels every seven cells, in which case *f* is simply 1/7.

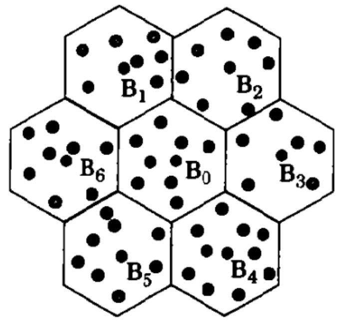

Figure 8.12 Illustration of users within a CDMA cellular radio system. Each base station reuses the same frequency. The gray dots represent users within the system, which have their transmit power controlled by their own base station.

- ✓ The frequency reuse factor for a CDMA system on the reverse link can be defined as [Rap92b]

$$f = \frac{N_0}{N_0 + \sum_i U_i N_{ai}}$$

and the frequency reuse efficiency, *F*, is defined as

$$F = f \times 100\%$$

where,

N_0 is the total interference power received from the *N-1* in-cell users,

U_i is the number of users in the i^{th} adjacent cell, and

N_{ai} is the average interference power for a user located in the i^{th} adjacent cell.

- ✓ Within the cell of interest, the desired user will have the same received power as the *N-1* undesired in-cell users when power control is employed, and the average received power from users in an adjacent cell can be found by

$$N_{ai} = \sum_j N_{ij} / U_i$$

Where,

N_{ij} is the power received at the base station of interest from the j^{th} user in the i^{th} cell.

- ✓ Each adjacent cell may have a different number of users, and each out-of-cell user will offer a different level of interference depending on its exact transmitted power and location relative to the base station of interest.
- ✓ The variance of N_{ai} can be computed using standard statistical techniques for a particular cell.

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UNIT- IV

MULTIPLE ACCESS TECHNIQUES

TWO MARKS

1. **What is multiple access technique? [May 2016, Nov 2013, May2023]**

   Multiple access or channel access method is based on a multiplexing method that allows several data streams or signals to share the same communication channel or physical medium.

2. **Write the applications of multiple access methods.**
   - The multiple access methods are used in
     - ✓ Satellite networks
     - ✓ Cellular and mobile communication networks
     - ✓ Military communication and
     - ✓ Underwater acoustic networks.

3. **What are the different types of multiple access schemes? [May 2012]**

   The different types of multiple access schemes are
   - Frequency Division Multiple Access (FDMA)
   - Time Division Multiple Access (TDMA)
   - Code Division Multiple Access (CDMA)

4. **State the difference between Narrowband and wideband systems. [Nov 2013, Nov 2012]**

NARROWBAND SYSTEMS	WIDEBAND SYSTEMS
In a narrowband system, the available radio spectrum is divided into a large number of narrowband channels.	In wideband system, a large number of transmitters are allowed to transmit on the same channels.

5. **Define FDMA.**

   In FDMA, the total bandwidth is divided into non-overlapping frequency sub bands. Each user is allocated a unique frequency sub band (channels) for the duration of the connection, whether the connection is in an active or idle state.

6. **What is the need of guard bands in FDMA?**

   The adjacent frequency bands in the FDMA spectrum are likely to interference with each other. Therefore it is necessary to include the guard bands between the adjacent frequency bands.

7. **Mention some features of FDMA.[Nov/Dec 2019]**
   - ✓ FDMA is relatively simple to implement.
   - ✓ To provide interference-free transmissions between the uplink and the downlink channels, the frequency allocations have to be separated by a sufficient amount (guard bands).

8. **Write the nonlinear effects in FDMA.**
   - ✓ In FDMA system, many channels share same antenna at the base station. The power amplifiers and the power combiners used are nonlinear, and tend to generate inter modulation frequencies resulting in inter modulation distortion.

9. **Write the expression for number of channels used in FDMA system.**
   - ✓ The number of channels that can be simultaneously supported in a FDMA system is given by

$$N_S = \frac{B_s - 2B_g}{B_c}$$

Where, $\boldsymbol{B_s}$-Total spectrum allocation (or) system bandwidth

$\boldsymbol{B_g}$-Guard band allocated at the edge of the allocated spectrum band and

$\boldsymbol{B_g}$-Channel bandwidth

10. Write the formula for spectral efficiency of FDMA.

- ✓ The spectral efficiency of FDMA is given by

$$\eta_{FDMA} = \frac{bandwidthavailablefordatatransmission}{systembandwidth}$$

$$\eta_{FDMA} = \frac{N_{data}B_c}{B_s} < 1$$

Where $\boldsymbol{N_{data}}$=Number of data channels in the system.

$\boldsymbol{N_{data} = N_S\text{-}N_{ctl}}$

$\boldsymbol{N_{ctl}}$ = Number of allocated control channels

11. Mention the disadvantages of FDMA.

- ✓ This type of multiple access support is narrow band, and is not suitable for multimedia communications with various transmission rates.
- ✓ If a FDMA channel is not in use, then it is idle and cannot be used by other users to increase or share capacity. It is essentially a wasted resource.
- ✓ FDMA is an old and is used for the analog signal.

12. Define TDMA.

- ✓ Time Division Multiple Access (TDMA) systems divide the ratio spectrum into time slots, and in each slot only one user is allowed to either transmit or receive.

13. What is W- TDMA?

- ✓ In wideband TDMA, transmission in each slot uses the entire frequency band.

14. Define N- TDMA.

- ✓ In narrow band TDMA, the whole frequency band is divided into sub band, transmission in each slot only uses the frequency width of one sub band.

15. Write the features of TDMA.

- ✓ TDMA shares a single carrier frequency with several users, where each user makes use of non-overlapping time slots.
- ✓ Data transmission for users of a TDMA system is not continuous, but occurs in bursts. This results in low battery consumption, since the subscriber transmitter can be turned off when not in use.
- ✓ Because of discontinues transmissions in TDMA, the handoff process is much simpler for a subscriber unit, since it is able to listen for other base stations during idle time slots.

16. What is frame efficiency in TDMA?

- ✓ The frame efficiency is the ***percentage***of bits per frame which contain transmitted data.

  The frame efficiency is given by

$$\eta_f = \left(1 - \frac{b_{OH}}{b_T}\right) \times 100\%$$

b_{OH} = Number of overhead bits per frame and

b_T = Number of total bits per frame

17. What are the disadvantages of TDMA?[Nov/Dec 2019]

- ✓ High synchronization overhead is required in TDMA systems because of burst transmissions.
- ✓ In TDMA, the guard time should be minimized.

18. How does near/far problem influence TDMA systems? [Nov 2015]

The near-far problem is one of detecting or filtering out a weaker signal amongst stronger signals. The near-far problem is particularly difficult in CDMA systems where transmitters share transmission frequencies and transmission time. In contrast, FDMA and TDMA systems are less vulnerable

19. State advantages of CDMA over FDMA. [Nov 2014]

CDMA sends digital signals spread out over a larger bandwidth constantly with each signal having a unique sequence code so that each call can be separated at the receiver. In theory, CDMA can carry 8-10 times the number of calls as FDMA, although probably not nearly that many times in the real world.

20. Define near-far problem in CDMA.

- ✓ Some of the mobile units are close to the base station while others are far from it. A strong signal received at the base from a near –in mobile unit and the weak signal from a far –end mobile unit. This phenomenon is called the near-far problem.

21. Write some features of CDMA.

- ✓ Many user of CDMA system share the same frequency.
- ✓ Channel data rates are very high in CDMA system.
- ✓ CDMA has more flexibility than TDMA in supporting multimedia service.

22. How FDMA handles near-far problem?[April/May 2019]

The near-far problem is one of detecting or filtering out a weaker signal amongst stronger signals. The near-far problem is particularly difficult in FDMA systems where transmitters share transmission frequencies and transmission time.

23. Differentiate between FDMA, TDMA and CDMA technologies.[April/May 2018]

S.N	FDMA	TDMA	CDMA
1	Channel bandwidth is subdivided into number of sub channels	The radio spectrum is divided into time slots and each slot is allotted for only one user who can either transmit or receive.	Sharing of bandwidth and time takes place.
2	FDMA uses Narrow band Systems.	TDMA uses Narrow band Systems or wide band Systems	CDMA uses Wide band Systems.
3	FDMA is First generation wireless standard (1G).	TDMA is Second generation wireless standard (2G).	CDMA is third generation wireless standard (3G).
4	FDMA is use for the voice and data transmission	TDMA is used for data and digital voice signals	CDMA is use for digital voice signals and multimedia services.
5	Due to non-linearity of power amplifiers, inter-modulation products are generated due to interference between adjacent channels.	Due to incorrect synchronization there can be interference between the adjacent time slots.	Both type of interference will be present.
6	Synchronization is not necessary	Synchronization is necessary	Synchronization is not necessary
7	Code word is not required	Code word is not required	Code words are required
8	Guard bands between adjacent channels are necessary.	Guard times between adjacent time slots are necessary.	Guard bands and guard times are necessary.

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UNIT- IV

MULTIPLE ACCESS TECHNIQUES

QUESTION BANK

PART – A

1. What is multiple access technique?
2. What are the different types of multiple access schemes?
3. State the difference between Narrowband and wideband systems.
4. Mention some features of FDMA.
5. Define FDMA.
6. What is the need of guard bands in FDMA?
7. Mention some features of FDMA.
8. Write the nonlinear effects in FDMA.
9. Write the expression for number of channels used in FDMA system.
10. Write the formula for spectral efficiency of FDMA.
11. Mention the disadvantages of FDMA.
12. Define TDMA.
13. Write the features of TDMA.
14. What are the disadvantages of TDMA?
15. How does near/far problem influence TDMA systems?
16. State advantages of CDMA over FDMA.
17. How FDMA handles near-far problem?
18. Differentiate between FDMA, TDMA and CDMA technologies.

PART – B & C

1. Summarize the features of various multiple access techniques used in wireless mobile communication. State the advantages and disadvantages of each technique.
2. Explain any one type of multiple access schemes.
3. Explain TDMA and discuss the time division multiple access frame structure.
4. Explain in detail about spread spectrum multiple access.
5. What are the major difference between TDMA, FDMA and CDMA? Explain in detail about each multiple access.
6. Explain in detail about space division multiple access (SDMA).
7. Explain in detail about Capacity of Cellular Systems.
8. Explain the capacity of cellular CDMA.
9. Explain about Capacity Of CDMA With Multiple Cells.

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UNIT- V
WIRELESS NETWORKING

Introduction: Difference Between Wireless And Fixed Telephone Networks, The Public Switched Telephone Network (PSTN), Development Of Wireless Networks: First Generation Wireless Networks, Second Generation Wireless Networks, Third Generation Wireless Networks, Fixed Network Transmission Hierarchy, Traffic Routing In Wireless Networks: Circuit Switching, Packet Switching- Personal Communication Services / Networks (PCS/PCNs): Packet Vs Circuit Switching For PCN, Cellular Packet-Switched Architecture - Packet Reservation Multiple Access (PRMA) - Network Databases: Distributed Database For Mobility Management - Universal Mobile Telecommunication Systems (UMTS).

5.1 Introduction to Wireless Networks
5.2 Difference Between Wireless And Fixed Telephone Networks
5.2.1 The Public Switched Telephone Network (PSTN)
5.3 Development Of Wireless Networks
5.3.1 First Generation Wireless Networks
5.3.2 Second Generation Wireless Networks
5.3.3 Third Generation Wireless Networks
5.4 Fixed Network Transmission Hierarchy
5.5 Traffic Routing In Wireless Networks
5.5.1 Circuit Switching
5.5.2 Packet Switching
5.6 Personal Communication Services / Networks (PCS/PCNs)
5.6.1 Packet Vs Circuit Switching For PCN
5.6.2 Cellular Packet - Switched Architecture
5.6.2.1 Network Functionality In Cellular Packet-Switched Architecture
5.7 Packet Reservation Multiple Access (PRMA)
5.8 Network Databases
5.8.1 Distributed Database For Mobility Management
5.9 Universal Mobile Telecommunication Systems (UMTS)

Wireless Networking: A mobile network (also wireless network) route's communications in the form of radio waves to and from users. It is composed of base stations that each cover a delimited area or "cell." When joined together these cells provide radio coverage over a wide geographic area.

5.1 Introduction to Wireless Networks

1. Give a brief discussion on wireless networks.

- The demand for universal personal communications is driving the development of new networking techniques.
- This accommodates mobile voice and data users who move throughout buildings, cities, or countries.
- Consider the cellular telephone system shown in Figure 5.1.
- The cellular telephone system is responsible for providing coverage throughout a particular territory, called a ***coverage region***.
- The interconnection of many such systems defines a wireless network.
- Wireless network is capable of providing service to mobile users throughout a country or continent.

- To provide wireless communications within a particular geographic region (i.e., a city),
  - ✓ an integrated network of ***base stations*** must be deployed
    - to provide ***sufficient radio coverage*** to all mobile users.

- The *base stations must be connected to* ***a central hub*** called the ***Mobile Switching Center (MSC)***.
- The MSC *provides connectivity between* the ***public switched telephone network (PSTN)*** and the ***numerous base stations***, and ***between all of the wireless subscribers*** in a system.
- The **PSTN** forms the ***global telecommunications grid***.
- ***PSTN connects*** conventional *(landline)* telephone switching centers ***(central offices)*** with ***MSCs throughout the world***.

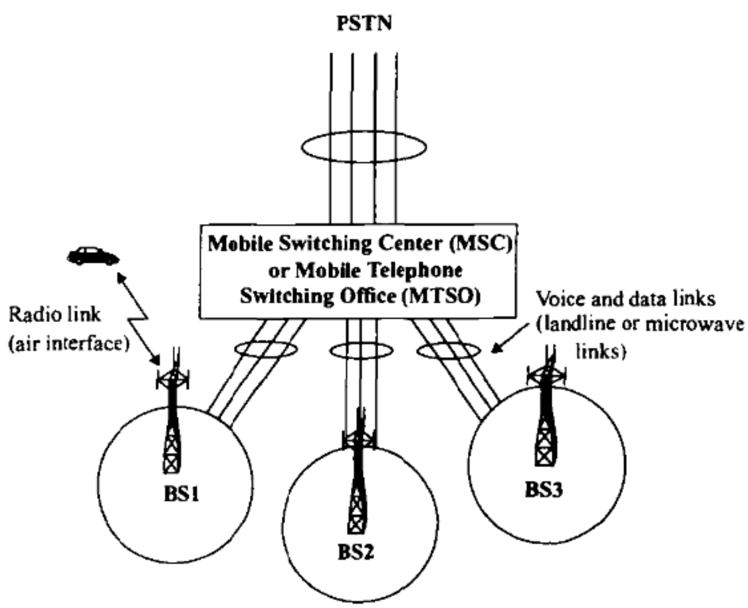

Figure 5.1 Block diagram of a cellular system.

- Figure 5.1 illustrates a typical cellular system of the early 1990s.
- Fiber optic transport architectures are also being used to connect radio ports, base stations, and MSCs.

- To connect mobile subscribers to the base stations, ***radio links*** are established using ***communication protocol*** called ***common air interface (CAI)***.
- It is a precisely defined ***handshake communication protocol***.

- The *common air interface* specifies how ***mobile subscribers and base stations communicate*** over radio frequencies.
- CAI also defines the ***control channel signaling methods***.
- The CAI must provide ***channel reliability*** to ensure that data is properly sent and received between the mobile and the base station.

- Each base station may handle on the order of 50 simultaneous calls.
- A typical MSC is responsible for connecting as many as 100 base stations to the PSTN (as many as 5,000 calls at one time).
- So, the connection between the MSC and the PSTN requires large capacity at any instant of time.

- The term ***network*** is used to describe a wide range of voice or data connections
  - ✓ from the case of a single mobile user to the base station,
  - ✓ to the connection of a large MSC to the PSTN.

5.2 Difference Between Wireless And Fixed Telephone Networks

2. Discuss the differences Between Wireless And Fixed Telephone Networks.

- ***Transfer of information in*** the public switched telephone network (***PSTN***) takes place ***over landline trunked lines*** (called trunks).
- The ***trunks*** comprised of *fiber optic cables, copper cables, microwave links, and satellite links*.

- In PSTN, the ***network configurations*** are ***virtually static***.
- The network ***connections may be changed*** when a ***subscriber changes residence***.
- It *requires* ***reprogramming at the local Central Office*** (CO) of the subscriber.
- Fixed networks are *difficult to change*.

- Wireless networks are ***highly dynamic***.
- The ***network configuration*** is being ***rearranged every time a subscriber moves*** into the coverage region of a different base station.
- Wireless networks must ***reconfigure themselves*** for users, within seconds to provide roaming and invisible handoffs between calls.

- In fixed networks, the available channel bandwidth can be increased by installing high capacity cables (fiber optic or coaxial cable).
- But, wireless networks are constrained by the very small ***RF cellular bandwidth***, provided for each user.

5.2.1 The Public Switched Telephone Network (PSTN)

3. Illustrate the Public Switched Telephone Network with relevant architectural diagrams.

- The PSTN is a ***highly integrated communications network*** that connects over 70% of the world's inhabitants.
- Each country is responsible for the regulation of the PSTN within its borders.
- In the PSTN, each city (i.e., geographic grouping of towns) is called a ***Local Access and Transport Area*** (LATA).
- Surrounding LATAs are connected by a company called a ***local exchange carrier (LEC).***
- A LEC is a company that provides ***intraLATA telephone service***, and may be a local telephone company that is regional in scope.

  Note: intraLATA - A telephone call within the same LATA (same region).

- A *long distance telephone company* ***collects toll fees*** to provide connections between different LATAs (interLATA) over its long distance network.
- These companies are referred to as ***interexchange carriers (IXC)***.
- IXCs ***own and operate*** large *fiber optic and microwave radio networks*.
- IXCs are connected to LECs (***local exchange carriers***) throughout a country or continent.

Figure 5.2 Service areas of U.S. regional Bell Operating Companies.

- Figure 5.2 shows Service areas of U.S. regional Bell Operating Companies.

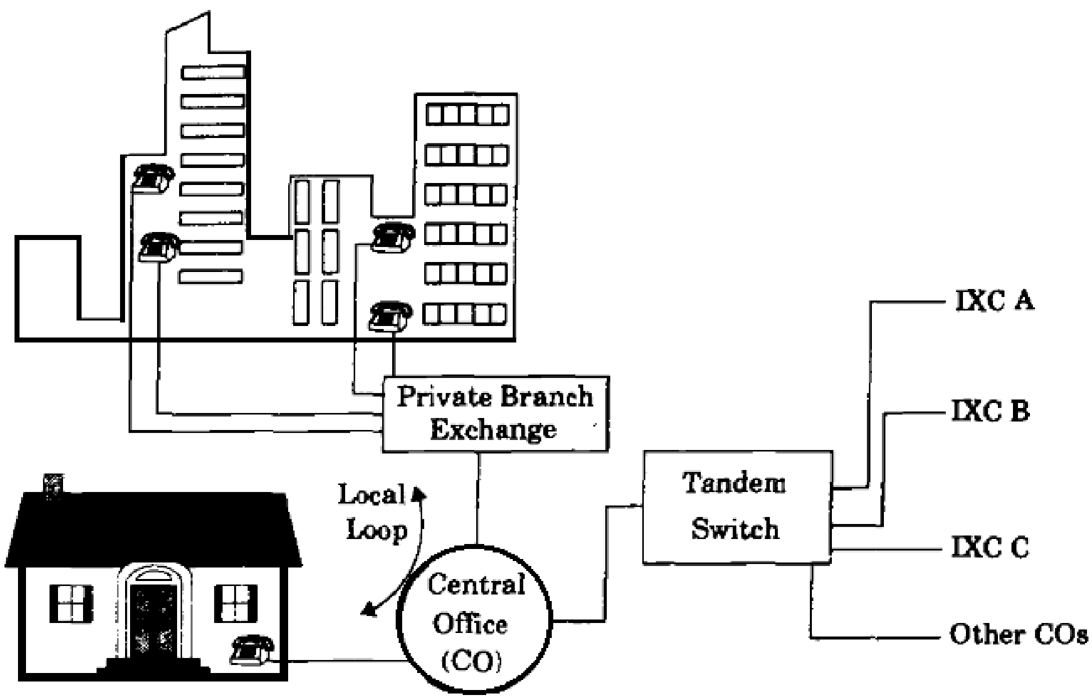

Figure 5.3 Local landline telephone network.

- Figure 5.3 is a simplified illustration of a ***local telephone network***, called a ***local exchange***.

- Each local exchange consists of a
  - central office (CO) which provides PSTN connection to the ***customer premises equipment (CPE)*** *(CPE - individual phone at a residence)*
  - a private branch exchange (PBX) at a place of business.
- The CO may handle as many as a million telephone connections.
- The CO is connected to a ***tandem switch*** which in turn ***connects the local exchange to the PSTN***.
- The tandem switch physically connects the local telephone network to the point of presence (POP) of trunked long distance lines provided by one or more IXCs.
- Sometimes IXCs connect directly to the CO switch to avoid local transport charges charged by the LEC.

- Figure 5.3 also shows how a PBX may be used to provide telephone connections throughout a building or campus.
- A PBX allows
  - an organization to provide internal calling and other in-building services (which do not involve the LEC)
  - conventional local and long distance services which pass through the CO.
  - a private networking between other organizational sites (through leased lines from LEC and IXC providers)
- Telephone ***connections within a PBX*** are maintained by ***the private owner***.
- ***Connection of the PBX to the CO*** is provided and maintained by ***the LEC***.

5.3 Development Of Wireless Networks

4. Explain the development of wireless networks through the first, second and third generations.

5.3.1 First Generation Wireless Networks

5. Discuss in detail about First Generation Wireless Networks.

- First generation cellular and cordless telephone networks are based on analog technology.
- All first generation cellular systems use FM modulation.
- The cordless telephones use a single base station to communicate with a single portable terminal.
- A typical example of a first generation cellular telephone system is the ***Advanced Mobile Phone Services (AMPS) system*** used in the United States.
- Basically, all first generation systems use the transport architecture shown in Figure 5.4.

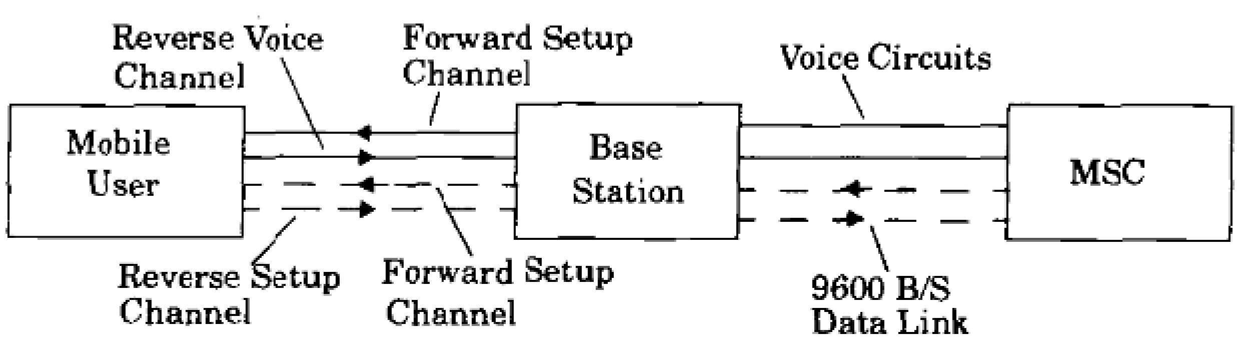

Figure 5.4 Communication signaling between mobile, base station, and MSC in first generation wireless networks.

- Figure 5.5 shows a diagram of a first generation cellular radio network.
- It includes the mobile terminals, the base stations, and MSCs.
- In first generation cellular networks, the system control for each market resides in the MSC.
- The MSC maintains all mobile related information and controls each mobile hand-off.
- The ***MSC*** also ***performs all of the network management functions***, such as call handling and processing, billing, and fraud detection within the market.
- The ***MSC is interconnected with the PSTN*** *via landline trunked lines* (trunks) and a tandem switch.
- MSCs also are connected with other MSCs via dedicated signaling channels (see Figure 5.6) for exchange of location, validation, and call signaling information.

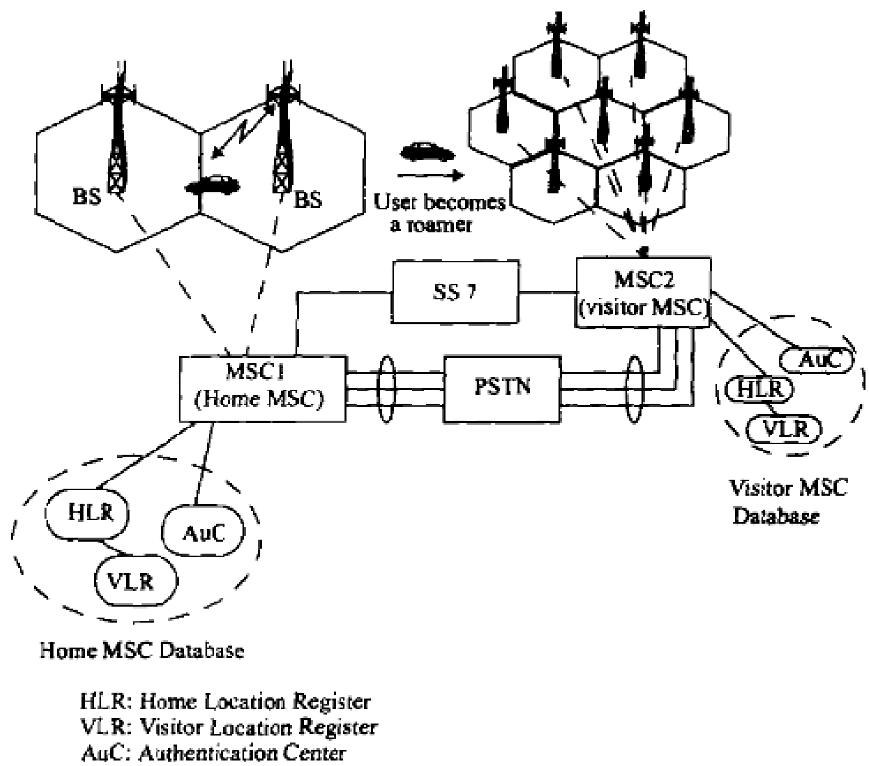

Figure 5.5 Block diagram of a cellular radio network.

- Notice that in Figure 5.6, the PSTN is a separate network from the SS7 signaling network.
- In modern cellular telephone systems, long distance voice traffic is carried on the PSTN.
- But the signaling information used to provide call set-up and to inform MSCs about a particular user is carried on the SS7 network.

- First generation wireless systems provide analog speech and inefficient, low-rate, data transmission between the base station and the mobile user.
- However, the speech signals are usually digitized using a standard, time division multiplex format for transmission between the base station and the MSC.
- Speech signals are always digitized for distribution from the MSC to the PSTN.

- The global cellular network is required to keep track of all mobile users that are registered in all markets throughout the network.
- So that it is possible to forward incoming calls to roaming users at any location throughout the world.

- When a mobile user's phone is activated but is not involved in a call, it monitors the strongest control channel in the vicinity (neighborhood).
- When the user roams into a new market covered by a different service provider,
  - ✓ the wireless network must register the user in the new area and cancel its registration with the previous service provider
  - ✓ So that, calls may be routed to the roamer as it moves through the coverage areas of different MSCs.

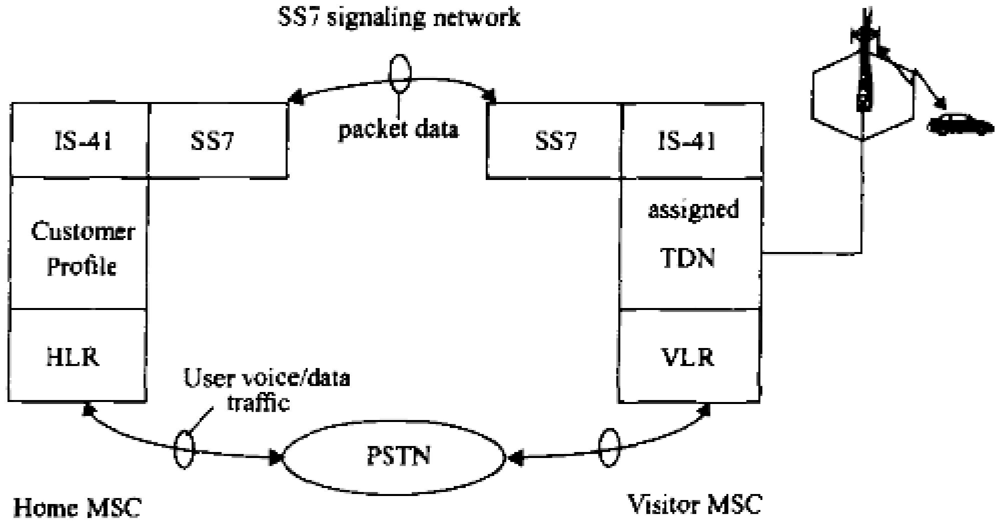

Figure 5.6 The North American Cellular Network architecture used to provide user traffic and signaling traffic between MSCs.

- Until the early 1990s, U.S. cellular customers that roamed between different cellular systems had to register manually each time they entered a new market during long distance travel.
- This required the ***user to call an operator to request registration***.

- In the early 1990s, U.S. cellular carriers implemented the network protocol standard IS-41 to allow different cellular systems to automatically accommodate subscribers who roam into their coverage region. This is called ***interoperator roaming***.

- IS-41 relies on a feature of AMPS called ***autonomous registration***.
- ***Autonomous registration*** is a process by which a mobile notifies a serving MSC of its presence and location.
- The mobile accomplishes this by periodically keying up and transmitting its identity information, which allows the MSC to constantly update its customer list.

- The ***registration command*** is sent in the overhead message of each control channel at five or ten minute intervals.

- Each mobile reports its ***MIN Mobile Identification Number)*** and ***ESN (Electronic Serial Number)*** during the brief registration transmission so that the MSC can validate and update the customer list within the market.
- The MSC is able to distinguish home users from roaming users based on the MIN of each active user.
- It maintains a real-time user list in the ***home location register (HLR)*** and ***visitor location register (VLR)*** as shown in Figure 5.5.
- IS-41 allows the MSCs of neighboring systems to ***automatically handle*** the ***registration and location validation of roamers*** so that ***users no longer need to manually register as they travel***.
- The visited system creates a VLR record for each new roamer and notifies the home system via IS-41 so it can update its own HLR.

5.3.2 Second Generation Wireless Networks

6. Discuss in detail about Second Generation Wireless Networks.

- Second generation wireless systems employ ***digital modulation and advanced call processing capabilities***.

- Examples of second generation wireless systems include
  - ✓ the *Global System for Mobile (GSM)*,
  - ✓ the *TDMA and CDMA U.S. digital standards* (IS-54 and IS-95 standards),
  - ✓ Second Generation *Cordless Telephone (CT2)*,
  - ✓ the British standard for cordless telephony,
  - ✓ the *Personal Access Communications System (PACS) local loop standard*, and
  - ✓ Digital European Cordless Telephone (DECT).

- Second generation wireless networks consists *new network architectures* that have ***reduced the computational burden*** of the MSC.
- GSM has introduced the concept of a base station controller (BSC) which is inserted between several base stations and the MSC.
- In PACS / WACS *(Personal Access Communications System / Wireless Access Communication Systems)*, the ***BSC (Base Station Controller)*** is called a ***radio port control unit***.

- All second generation systems use digital voice coding and digital modulation.
- The systems employ dedicated control channels (common channel signaling) for simultaneously ***exchanging voice and control information*** between *the subscriber, the base station, and the MSC* while a call is in progress.
- Second generation systems also ***provide dedicated voice and signaling trunks between MSCs***, and between each MSC and the PSTN.

- First generation systems, designed primarily for voice.
- Second generation wireless networks have been specifically designed to ***provide paging, and other data services such as facsimile and high-data rate network access***.

- The network controlling structure is more distributed in second generation wireless systems.
- In second generation wireless networks, the ***handoff process is mobile-controlled and is known as mobile assisted handoff (MAHO)***.

- The mobile units in these networks perform several other functions over first generation subscriber units.
- The other functions are - received power reporting, adjacent basestation scanning, data encoding, and encryption.

- DECT is an example of a second generation cordless telephone standard.
- It allows each cordless phone to communicate with any of a number of base stations, by automatically selecting the base station with the greatest signal level.

- In DECT, the base stations have greater control in terms of switching, signaling, and controlling handoffs.

5.3.3 Third Generation Wireless Networks

7. Discuss in detail about third Generation Wireless Networks.

- Third generation wireless systems will evolve from mature second generation systems.
- The aim of third generation wireless networks is
  - ✓ to provide a single set of standards that can meet a wide range of wireless applications, and
  - ✓ to provide universal access throughout the world.

- In third generation wireless systems, ***universal personal communicator*** *(a personal handset)* will ***provide access*** to ***a variety of voice, data, and video communication services***.

- Third generation systems will use the ***Broadband Integrated Services Digital Network (B-ISDN)*** to provide access to ***information networks*** (Internet and other public and private databases).

- ***Third generation networks*** will carry many types of information (voice, data, and video).
- These networks operate in varied regions (dense or sparsely populated regions)
- These networks will serve both stationary users and vehicular users traveling at high speeds.

- The terms ***Personal Communication System (PCS)*** and ***Personal Communication Network (PCN)*** are used to involve emerging third generation wireless systems for hand-held devices.
- Other names for PCS include
  - ✓ ***Future Public Land Mobile Telecommunication Systems (FPLMTS)*** for worldwide use.
  - ✓ ***Universal Mobile Telecommunication System (UMTS)*** for mobile personal services in Europe.

5.4 Fixed Network Transmission Hierarchy

8. Explain in detail about Fixed Network Transmission Hierarchy.

- Wireless networks depend heavily on landline connections.
- For example, the MSC connects to the PSTN and SS7 networks using fiber optic or copper cable or microwave links.
- Base stations within a cellular system are connected to the MSC using line-of-sight (LOS) microwave links, or copper or fiber optic cables.
- These connections require high data rate serial transmission schemes in order to reduce the number of physical circuits between two points of connection.

- Several standard ***digital signaling (DS) formats*** form a transmission hierarchy that allows high data rate digital networks which carry a large number of voice channels.
- These DS formats use time division multiplexing (TDM).

DS format in the U.S.

- **DS-0**: It represents ***one duplex voice channel*** which is ***digitized into a 64 kbps binary PCM format***.
- **DS-1**: It represents ***twenty four full duplex DS-0 voice channels*** that are ***time division multiplexed into a 1.544 Mbps data stream*** (8 kbps is used for control purposes).

- The ***T(N) designation***, which is used to denote ***transmission line compatibility*** for a particular DS format.
- DS-1 signaling is used for a T1 trunk, which is a popular point-to-point network signaling format used to connect base stations to the MSC.
- T1 trunks digitize and distribute the twenty four voice channels onto a simple four-wire full duplex circuit.

- In Europe, CEPT (Confe'rence Europe'ene Postes des et Te'le'communication) has defined a similar digital hierarchy.
- Level 0 represents a duplex 64 kbps voice channel
- Level 1 concentrates thirty channels into a 2.048 Mbps TDM data stream.
- Table 5.1 illustrates the digital hierarchy for North America and Europe.

Table 5.1 Digital Transmission Hierarchy

Signal Level	Digital Bit Rate	Equivalent Voice Circuits	Carrier System
North America and Japan			
DS-0	64.0 kbps	1	
DS-1	1.544 Mbps	24	T-1
DS-1C	3.152 Mbps	48	T-1C
DS-2	6.312 Mbps	96	T-2
DS-3	44.736 Mbps	672	T-3
DS-4	274.176 Mbps	4032	T-4
CEPT (Europe and most other PTTs)			
0	64.0 kbps	1	
1	2.048 Mbps	30	E-1
2	8.448 Mbps	120	E-1C
3	34.368 Mbps	480	E-2
4	139.264 Mbps	1920	E-3
5	565.148 Mbps	7680	E-4

- Typically, coaxial or fiber optic cable or wideband microwave links are used to transmit data rates in excess of 10 Mbps.
- Inexpensive wire (twisted pair) or coaxial cable may be used for slower data transfer.

- DS-3 and higher rate circuits are used to connect MSCs and COs to the PSTN.

5.5 Traffic Routing In Wireless Networks

9. Explain the mechanism of traffic routing in wireless networks with routing services.

- The amount of ***traffic capacity required in a wireless network*** is highly ***dependent upon the type of traffic*** carried.
- For example,
  - ✓ a subscriber's ***telephone call*** (voice traffic) requires ***dedicated network access*** to provide real-time communications.
  - ✓ the ***control and signaling traffic*** may ***share network resources with other bursty users***.
- The type of traffic carried by a network determines the routing services, protocols, and call handling techniques which must be employed.

- Two general ***routing services*** are provided by networks.
- These are
  - ✓ ***connection-oriented services*** (virtual circuit routing), and
  - ✓ ***connectionless services*** (datagram services).

- In connection-oriented routing,
  - ✓ the communications ***path*** between the message source and destination ***is fixed*** for the entire duration of the message, and
  - ✓ a call set-up procedure is required to dedicate network resources to both the called and calling parties.
- The network path is fixed, so ***the traffic*** in connection-oriented routing arrives ***at the receiver in the exact order*** it was transmitted.
- If the network connection becomes noisy, the connection-oriented service depends on ***error control coding*** to provide data protection.
- If coding is not sufficient to protect the traffic, the call is broken, and the ***entire message must be retransmitted from the beginning***.

- In Connectionless routing,
  - ✓ it ***does not establish a firm (fixed) connection*** for the traffic.
  - ✓ it relies on packet-based transmissions.
- Several ***packets form a message***, and each ***individual packet is routed separately***.
- Successive ***packets within the same message*** might ***travel completely different routes*** and ***encounter widely varying delays*** throughout the network.
- Packets sent using connectionless routing do not necessarily arrive in the order of transmission.
- These packets must to be reordered at the receiver.
- Because packets take different routes in a connectionless service, some packets may be lost due to network or link failure.
- However other packets may reach with ***sufficient redundancy to enable the entire message recreation*** at the receiver.
- The ***Packet overhead*** *information* includes
  - ✓ the packet source address,
  - ✓ the destination address,
  - ✓ the routing information, and
  - ✓ information needed to properly order packets at the receiver.
- In a connectionless service, a ***call set-up procedure is not required*** at the beginning of a call.

5.5.1 Circuit Switching

10. Explain the concepts of circuit switching in Traffic Routing In Wireless Networks.

- First generation cellular systems provide ***connection-oriented services*** for each voice user.
- Voice channels are dedicated for users at a serving base station.
- Network resources are dedicated to the voice traffic upon initiation of a call.
- That is, the ***MSC dedicates a voice channel connection*** between the ***base station and the PSTN*** for the duration of a cellular telephone call.

- Furthermore, a ***call initiation sequence*** is required to connect the called and calling parties on a cellular system.
- When used in conjunction with radio channels, connection-oriented services are provided by a technique called ***circuit switching***,
  - ✓ since a ***physical radio channel*** is dedicated ("switched in to use") for ***two-way traffic between the mobile user and the MSC***, and
  - ✓ the ***PSTN dedicates a voice circuit*** between ***the MSC and the end-user***.
- As calls are initiated and completed, different radio circuits and dedicated ***PSTN voice circuits are switched in and out to handle the traffic***.

- ***Circuit switching*** establishes a dedicated connection *(a radio channel between the base and mobile, and a dedicated phone line between the MSC and the PSTN)* for the entire duration of a call.

- Circuit switching is ***best suited*** for ***dedicated voice-only traffic***, or for instances where data is continuously sent over long periods of time

- Wireless data networks are not well supported by circuit switching, ***due to their short, bursty transmissions***.
- Often, the time required to establish a circuit exceeds the duration of the data transmission.

5.5.2 Packet Switching

11. Explain the concepts of packet switching in Traffic Routing In Wireless Networks.

- ***Connectionless services*** exploit the fact that dedicated resources are not required for message transmission.
- Packet switching (or ***virtual switching***) is the most common technique used to implement connectionless services.
- It allows a large number of data users to remain virtually connected to the same physical channel in the network.
- Since all users may access the network randomly, the call set-up procedures are not needed (to dedicate specific circuits when a particular user needs to send data).
- X.25 is a widely used packet radio protocol that defines a data interface for packet switching.

- **Packet switching** breaks ***each message into smaller units*** for transmission and recovery.
- When a message is broken into packets, a ***certain amount of control information is added*** to each packet.
  - ✓ This provides ***source and destination identification*** and ***error recovery provisions***.

Figure 5.7 Packet data format.

- Figure 5.7 illustrates the sequential format of a packet transmission.
- The packet consists of ***header information***, the ***user data***, and a ***trailer***.
  - **Header**:
    - It specifies the ***beginning of a new packet***.
    - It contains the *source address, destination address, packet sequence number, and other routing and billing information*.
  - **User data**:
    - It contains ***information***.
    - It is generally protected with error control coding.
  - **Trailer**:
    - It contains a ***cyclic redundancy checksum*** which is used for ***error detection*** at the receiver.

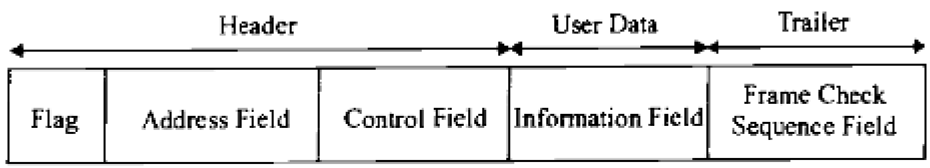

Figure 5.8 Fields in a typical packet of data.

- Figure 5.8 shows the structure of a transmitted packet.
- The transmitted packet typically consists of five fields:
  - the flag bits,
  - the address field,
  - the control field,
  - the information field, and
  - the frame check sequence field.

- **Flag bits** are specific (or reserved) bit sequences that indicate ***the beginning and end of each packet***.
- **Address field** contains the ***source and the destination address*** for transmitting messages and for receiving acknowledgments.
- **Control field** defines functions such as ***transfer of acknowledgments***, ***automatic repeat requests (ARQ)***, and ***packet sequencing***.
- **Information field** contains the ***user data*** and may have ***variable length***.
- **Frame check sequence field** or the CRC (Cyclic Redundancy Check) that is used for error detection.

Advantages:

- Packet switching (or 'packet radio' in wireless link) provides ***excellent channel efficiency*** for bursty data transmissions of short length.
- The channel is utilized only when sending or receiving ***bursts of information***.
  - This benefit is valuable in *mobile services where the available band width is limited*.
- It can provide highly reliable transfer in degraded channel conditions.

5.6 Personal Communication Services / Networks (PCS/PCNs):

12. Explain the Personal Communication Services / Networks.

- The objective of personal communication systems (PCS) or personal communication networks (PCNs) is to
  - ✓ provide ubiquitous *(Universal)* wireless communications coverage,
  - ✓ enabling users to access the telephone network for different types of communication needs (regardless of the location of the user or the location of the information being accessed).
- The concept of PCS/PCN is based on an ***advanced intelligent network (AIN)***.
- The mobile and fixed networks will be integrated to provide universal access to the network and its databases.
- AIN will also allow its users to have a single telephone number to be used for both wireless and wireline services.
- An architecture suggested by Ashity, Sheikh, and Murthy consists of three levels: ***the intelligent level, the transport level and the access level***.
  - ✓ **Intelligent level** contains
    - o databases for the storage of information about the network users,
  - ✓ **Transport level**
    - o handles the transmission of information.
  - ✓ **Access level**
    - o It provides ubiquitous access to every user in the network
    - o Also, contains databases that update the location of each user in the network.

Characteristics of Personal communication system:

- It is characterized by ***high user densities*** that requires ***enhanced network requirements***.
- A ***large amount of signaling*** will be required.
- ***Common channel signaling*** and *efficient signaling protocols* will play an important role in PCS/PCN.
- The intelligent networks that will be put to use for PCN will ***employ SS7 signaling***.
- The following table gives the data requirements that PCS/PCN networks will be expected to carry.

Table. Potential Data Loads for Wireless Networks

Application	Avg. data rates (kbps)	Peak data rate (kbps)	Maximum delay (sec)	Maximum packet loss rate
e-mail, paging	0.01 - 0.1	1 - 10	< 10 - 100	$< 10^{-9}$
computer data	0.1 - 1	10 - 100	< 1 - 10	$< 10^{-9}$
telephony	10 - 100	10 - 100	< 0.1 - 1	$< 10^{-4}$
digital audio	100 - 1000	100 - 1000	< 0.01 - 0.1	$< 10^{-5}$
video-conference	100 - 1000	1000 - 10000	0.001 - 0.01	$< 10^{-5}$

5.6.1 Packet vs. Circuit Switching For PCN

- ***Packet switching technology will have more advantages for PCS/PCN*** than circuit switching.
- The factors that influence the use of packet switching include the following:
  - ✓ PCN will be required to ***serve a wide range of services*** including voice, data, e-mail and digital video.
  - ✓ PCN will ***support large populations of infrequent users***, also effectively share the bandwidth and infrastructural equipment.
  - ✓ The relatively unreliable channel is more suited for packet switching than for circuit switching.
    - ▪ In addition, packet switching does not need a dedicated link at very low bit error rates.
    - ▪ Packet switching has the ability to compensate for lost or corrupt data through ARQ based transmission strategies.
  - ✓ PCN will ***require a high-capacity switching infrastructure*** for routing of traffic between cells.

Note: ***Unreliable protocols*** make no effort to set up a connection, they don't check to see if the data was received and usually don't make any provisions for recovering from errors or lost data. Unreliable protocols work best over physical medium with low loss and low error rates.

5.6.2 Cellular Packet - Switched Architecture

13. With neat diagram explain Cellular Packet - Switched Architecture.

- The cellular packet-switched architecture ***distributes network control*** among interface units.
- Thus, it provides the capability to support highly dense user environments.

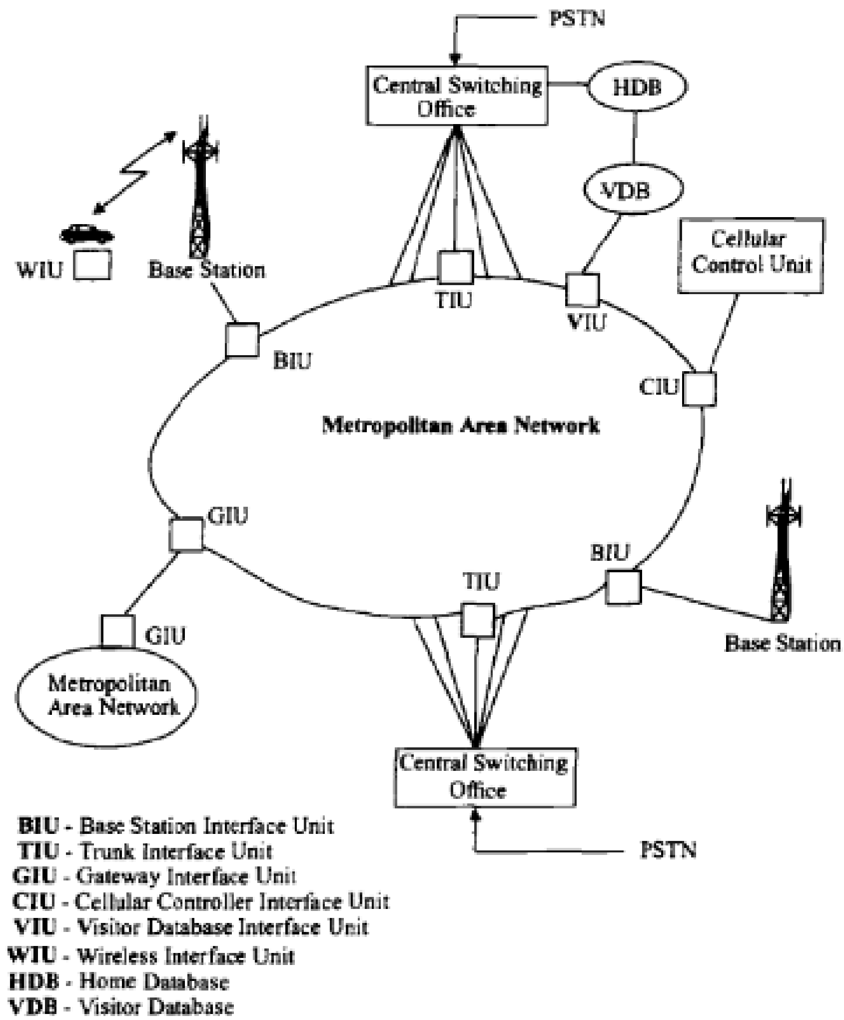

Figure 5.16 Cellular packet switched architecture for a Metropolitan Area Network.

- Figure 5.16 indicates the conceptual block diagram of such an architecture for a metropolitan area network.
- Information travels at several gigabits per second over the ***MAN (Metropolitan Area Network)***.
- It is constructed of fiber optic cable and serves as the backbone for the entire wireless network.

- Data enters and leaves the various MAN interface units.
- The MAN interface units are connected to base stations and the public network switches (including ISDN switches).

- Key elements in the network that facilitate transfer of information are
  - ✓ base station interface unit (BIU),

- ✓ cellular controller interface unit (CIU),
- ✓ trunk interface unit (TIU), and
- ✓ each subscriber's wireless interface unit (WIU).

- The BIUs are connected to the TIUs which are connected to the PSTN.
- The CIU connects to the cellular control unit.
- Different MANs are interconnected via ***gateway interface units (GIU)***.
- ***Visitor interface units (VIU)*** access the ***visitor database (VDB)*** and the ***home databases (HDB)*** for registration and location updates.

- ***Packet switching techniques*** are ***used for transmission of packets*** in the cellular-switched architecture.

The Trunk Interface Unit (TIUs)

- The function of the TIU is to accept information from the PSTN.

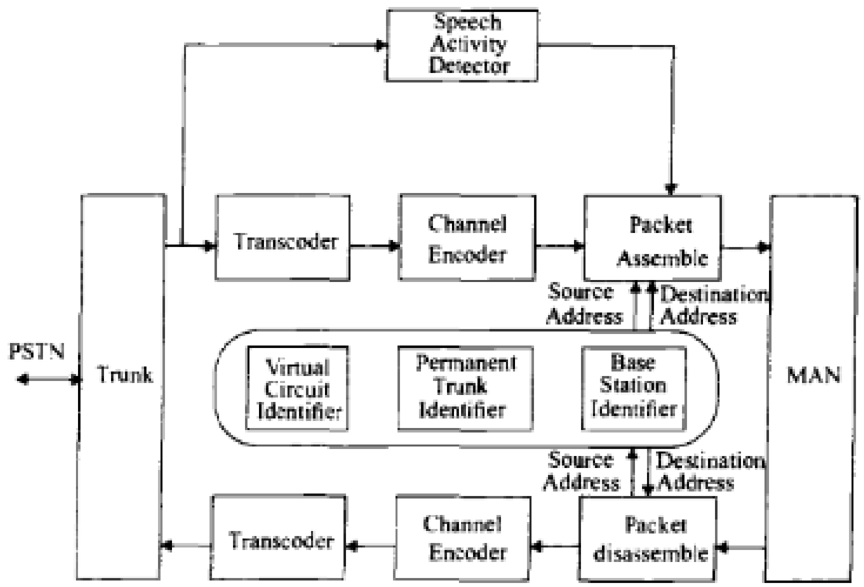

Figure 5.17 Cellular trunk interface unit.

- Figure 5.17 shows TIU, acting as the physical layer, transforms the standard format of the PSTN into the wireless access physical layer.
- TIUs use ***transcoders and channel encoders*** to ***convert the format of the packets*** transmitted across the interface to the fixed network or the wireless access format.
- TIUs also contain a ***Packet Assembler and Disassembler (PAD)*** that ***combines user information with a packet header***.

- *Information available in the packet header* contains ***flags, error checksums, packet control information, and address fields***.
- The ***TIU address*** is added to all the packets that are transmitted through this unit.

- The address can be a ***Permanent Terminal Identifier (PTI)*** or ***Virtual Circuit Identifier (VCI)***.
- The **PTI** is the ***address of the TIU*** *from where the call has originated*.
- The **VCI** is the ***information contained in the packet header*** *identifying the route* through which the transmission will take place.

- The packet generation by the PAD is controlled by a ***speech activity detector*** so that resources are not wasted in idle time.
- Packets from the TIU are routed to a base station over the MAN by ***looking up the address*** from the ***TIU routing tables***.
- The PAD ***reads the destination address*** of *all packets arriving at the MAN*, ***and matches it to the PTI*** (during call set-up) ***and the VCI*** (during a call).
- If a ***match is found, the PAD processes the packets*** or else the packet is ignored.
- Addresses of base stations engaged in traffic are maintained in the ***base station identification register*** for appropriate routing of the information.

The Wireless Terminal Interface Unit (WIU)

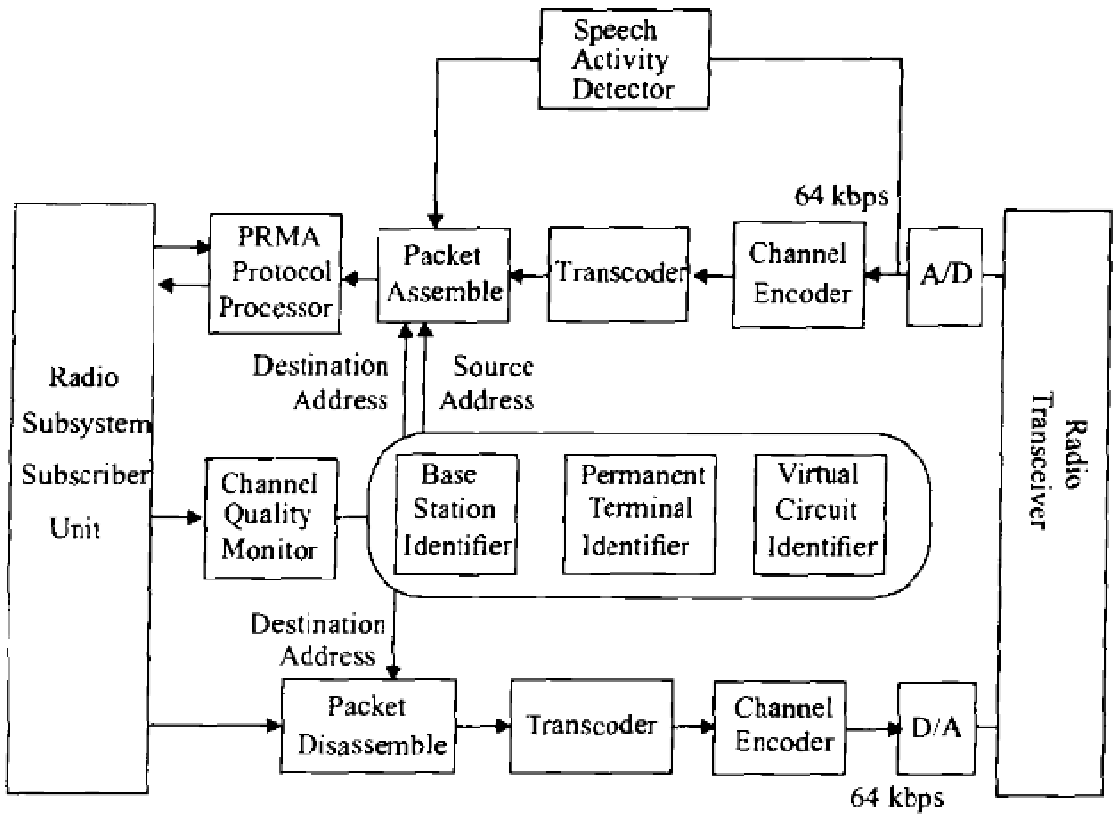

Figure 5.18 Cellular wireless interface unit.

- The WIU is directly connected to the source of the information, as is seen in Figure 5.18.
- It differs from the TIU in the sense that it ***does not interface to the PSTN or the ISDN***.
- The ***addressing process remains the same*** for WIU as in the TIU.
- The PAD ***removes signaling overhead*** from all incoming data packets and provides the information stream (64 kbps) to the terminal.
- A ***channel quality monitor*** is accessed by the WIU for ***determining handoff conditions***.
- The WIU reads the base station identifier, arid a ***handoff takes place*** whenever there is a ***base station available with a higher signal level*** or smaller error performance.

Base Station Interface Unit (BIU)

- The BIU ***provides information exchange*** between the TIUs and the WIUs.
- The BIU also ***broadcasts packets*** for providing feedback to the PRMA protocol.
- The BIU is ***addressed by its permanent address*** in the packet header.
- The major function of the BIU is ***to relay packets to either the WIU or the TIU*** using the ***virtual circuit identifiers*** of the incoming packets.

Cellular Controller Interface Unit (CIU)

- The function of the cellular controller is ***to receive, process, and generate information packets*** for network control.

5.6.2.1 Network Functionality in Cellular Packet-Switched Architecture

14. Discuss about Network Functionality in Cellular Packet-Switched Architecture.

- The control functions of a wireless network can be divided into three categories: call processing, mobility management, and radio resource management [Mei92].
- Call processing is a function of the central switching office, while mobility management and radio resource management are functions of the metropolitan area network.
- The three operations of call set-up (initiated by the mobile), speech transmission, and handoff serve to illustrate the functionality of the system.

- Before a call is set up, the subscriber terminals and the trunks are addressed by their permanent addresses, but during call set up for speech, a virtual circuit is set up.
- The corresponding virtual addresses are updated in the TIU and the WIU.
- However, the base stations and the controller retain the permanent addresses.

- **Transmission of speech**
  - ✓ ***Packets move*** between the subscriber terminal, the base station, and the central switching office in both directions over the MAN.
  - ✓ Packets are ***sent on a first-in/first-out (FIFO)*** basis, *since speech is involved and reordering of the packets is not allowed*.
  - ✓ A ***virtual circuit is assigned at the beginning of the call*** for transmission of speech in packets.
  - ✓ Packets may be lost in the conversation, but this does not significantly affect speech quality (as long as not too many packets are lost).

- **Handoff:**
  - ✓ The **cellular** ***packet switched handoff algorithms*** distributes the processing among different interface units.
  - ✓ The WIU determines the channel quality.
    - ▪ when it becomes obvious that a call can be better handled by another base station, the call handoff procedure is initiated.
  - ✓ A new base station is identified on the basis of the ***base station identifier*** read from the ***channel quality monitor***, and the ***call is rerouted to the new base station***.

- ✓ The TIU is informed of the handoff, and the routing table in the TIU is updated to reflect this information.
- ✓ The cellular controller is transparent to the handoff process.

- ✓ The WIU keeps the TIU informed of the location of the mobile when there are gaps in speech.
- ✓ As a result of the handoff, ***no packets are lost***, and any packets sent during the duration of the handoff process can be retransmitted to the new base station from the TIU.

5.7 Packet Reservation Multiple Access (PRMA)

15. Explain in detail about Packet Reservation Multiple Access (PRMA).

- ***Packet reservation multiple access (PRMA)*** is a transmission protocol proposed by Goodman, et.al., for ***packet voice terminals*** in a cellular system.
- PRMA is a ***time division multiplex (TDM) based multiple access protocol***
- Once the ***radio resource has been acquired***, it is up to the ***transmitter to release the reservation***.

- PRMA is a derivative of reservation ALOHA,
  - which is a combination of TDMA and slotted ALOHA.
- A ***reservation protocol*** like PRMA has an advantage in that *it can utilize the discontinuous nature of speech* with the help of a voice activity detector (VAD)
  - to increase capacity of the radio channel.

- The input to a voice terminal follows a pattern of ***talk spurt and silent gaps***.
- The terminals begin contending and transmitting speech packets as soon as the first packet is generated.
- Both digital packet data and speech data are simultaneously supported with PRMA.

- The ***raw channel bit stream is divided into time slots*** with ***each slot designed for a single packet of information***.
- The ***time slots are grouped as frames***, which are repeated cyclically over the channel.
- In a frame, the individual slots are accessed by the mobile for communication with the base.

- A successful call setup ensures that the particular ***mobile is given a reservation in a slot*** which is at the same position in succeeding frames.

- Selection of the ***frame duration*** is based on the fact that ***a speech terminal can generate exactly one packet per frame***.
- The ***allotted time slot is fixed within the frame*** until the conversation is over.

- When the speech terminal has completed its communications it halts transmission,
  - the base station receives a null packet, and
    - the time slot in the frame is unreserved once again, and
      - becomes available for use by other mobiles.

- The availability of time slots depends on the usage of the network.
- If there are too many users, call set-up will be prolonged.

- If ***congestion at a base station is encountered*** from many mobile users,
    - data packets are dropped, and
        - speech packets are given priority,
            - since speech requires that the packets be delivered in order.
- A ***feedback signal from the base station*** to the mobiles relating to the previous transmitted packet is multiplexed along the stream of data from the base station.
- Based on ***ARQ error correction***, the packets are retransmitted if a mobile receives a negative acknowledgment.

5.8 Network Databases

16. Write short notes on network databases with Distributed Database for Mobility Management.

- In first generation wireless networks, the network control was limited to the MSC.
- The MSCs of neighboring systems were not able to communicate easily with each other.
- This made graceful intersystem roaming impossible.

- Second and third generation wireless networks, distribute network control among several processors.
- For example, second generation networks ***access several databases*** for authentication of mobiles, location updates, billing, etc.
- The visitor location database, home location database, and the authentication center are the major databases that are accessed by various processing elements in the network.
- A distributed database has been proposed for interconnection of MSCs throughout a wireless network.

5.8.1 Distributed Database for Mobility Management

- The distributed hierarchical database architecture facilitates ***the tracking and location update of the mobile subscriber***.

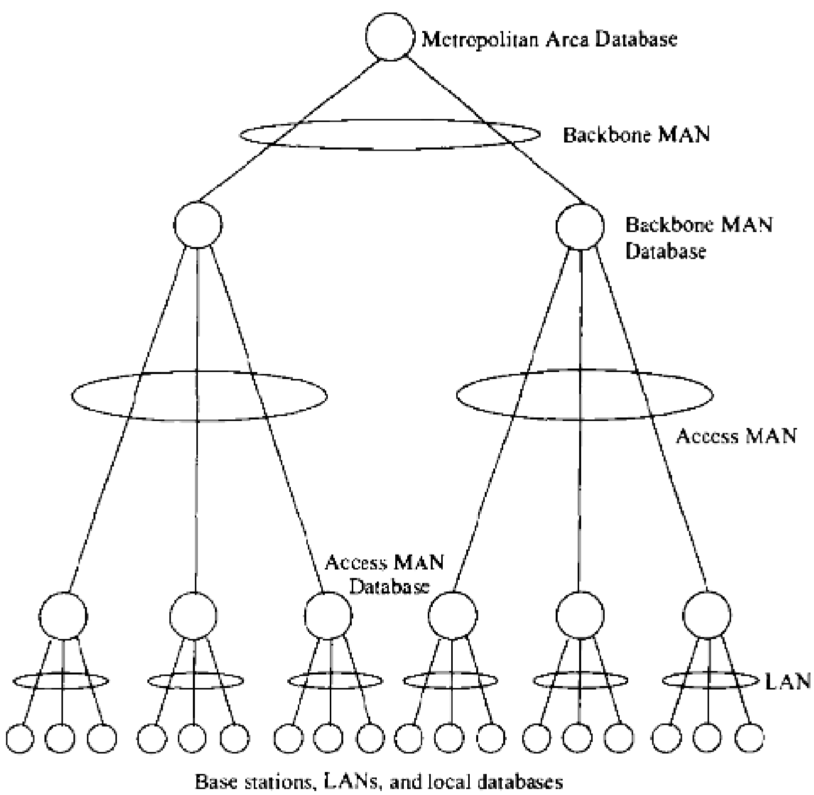

Figure 5.19 Illustration of a hierarchical distributed database.

- Figure 5.19 shows the interconnections in a distributed hierarchical database.
- The ***database partition*** at each access MAN node lists subscribers in the associated BSC control area.
- Each of the ***BSCs is able to receive the MAN broadcast*** and ***updates its database if the mobile is in its region***.

- Higher level databases at the ***backbone MAN*** level enable subscriber tracking within these areas.
- The ***access MAN databases*** indicate the mobile's BSC area location.
- The ***backbone MAN databases*** indicate the MAN access location.
- In a similar hierarchical manner, a mobile in a region can be ***tracked, and its location can be updated***.

- The method of ***partitioning*** is an efficient technique for it reduces the time required to locate any mobile.
- This ***minimizes the traffic congestion*** resulting from heavy broadcast traffic required to locate a roaming mobile.

- Each subscriber to the cellular service has an associated ***home access MAN, backbone MAN, and a MAN database***.
- ***Home and visitor databases*** are logically distinctive, but physically integrated, in a single database.
- A mobile subscriber is enlisted in a ***visitor data-base*** when it ***enters a foreign area*** and *remains in the new database until it leaves that area*.

- Whenever ***a subscriber leaves its home area***, the ***databases are updated*** so that the ***home access MAN database*** will contain ***the new location of the roaming subscriber***.

- The CCITT recommendations E.164 suggest ***a network address*** that is based on a hierarchical distribution, such that the *address indicates the access MAN node, backbone MAN,* and *MAN associated with a BSC.*
- Based on this type of format a roaming subscriber can be identified with its home base, so that the new BSC can update its database for the visiting subscriber.

5.9 Universal Mobile Telecommunication Systems (UMTS)

17. Draw and explain the Network architecture Universal Mobile Telecommunication Systems (UMTS).

- The ***Universal Mobile Telecommunication System (UMTS)*** is a system that is capable of ***providing a variety of mobile services*** to a wide range of global mobile communication standards.

- UMTS is being developed by RACE (R&D in advanced communications technologies in Europe) as the third generation wireless system.

- To handle a mixed range of traffic, ***a mixed cell layout*** (Figure 5.20),
  - ✓ that would consist of ***macrocells overlaid on micro and picocells*** is *one of the* ***architecture plans*** being considered.

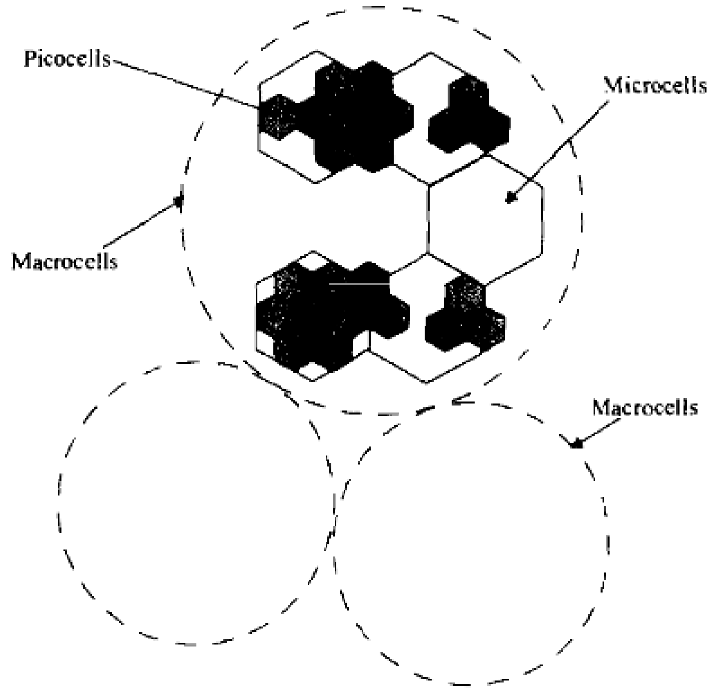

Figure 5.20 Network architecture for UMTS.

- This type of network distributes the traffic with
  - ✓ the local traffic operating on the micro and pico cells,
  - ✓ while the highly mobile traffic is operated on the macrocells,

  thus reducing the number of handoffs required for the fast moving traffic.
- It is easily observed from Figure 5.20 that the ***macrocells cover the spots not covered by other cells*** and also ***provide redundancy in certain areas***.
- Thus, ***macrocells*** will also be able to avoid the failures of the overlapped cells.

- The ***UMTS architecture*** will provide ***radio coverage with a network of base stations***, *interconnected to each other* and *to a fixed network exchange*.
- A ***metropolitan area network (MAN)*** is one of the possible choices for the network interconnection.

- ***Network Reachability:***
  - ✓ The network maintains a constant location information on each of the terminals.
  - ✓ The location will be updated by a terminal whenever it changes a location area.
  - ✓ The network will also take advantage of a distributed network database, for routing of calls once the exact location of the mobile has been accessed.

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UNIT- V
WIRELESS NETWORKING
TWO MARKS

1. **What is meant by wireless networking?**

   Wireless Networking: A mobile network (also wireless network) route's communications in the form of radio waves to and from users. It is composed of base stations that each cover a delimited area or "cell." When joined together these cells provide radio coverage over a wide geographic area.

2. **Write about mobile switching center.**

   The *base stations must be connected to* ***a central hub*** called the ***Mobile Switching Center (MSC)***. The MSC *provides connectivity between* the ***public switched telephone network (PSTN)*** and the ***numerous base stations***, and ***between all of the wireless subscribers*** in a system.

3. **What are the functions of common air interface (CAI)**.
   - To connect mobile subscribers to the base stations, ***radio links*** are established using ***communication protocol*** called ***common air interface (CAI)***.
   - It is a precisely defined ***handshake communication protocol***.
   - The *common air interface* specifies how ***mobile subscribers and base stations communicate*** over radio frequencies.
   - CAI also defines the ***control channel signaling methods***.

4. **Differentiate Wireless And Fixed Telephone Networks.**

Sl. No.	Fixed Telephone Network	Wireless Telephone Network
1.	The transmitter and receiver is fixed at one place. Information is carried over cables(fiber optic/copper) and fixed links(microwave/satellite)	The transmitter and receiver communicate via EM radio waves. They are not always fixed at one place but can move also.
2.	A telephone Central office takes care of millions of landline telephone connections.	MSCs take care of cellular telephone connections based on air traffic capacity.
3.	Less overhead data needed.	More overhead data needed as geographical location keeps changing.

5. **Write about as interexchange carriers.**
   - A *long distance telephone company* ***collects toll fees*** to provide connections between different LATAs (interLATA) over its long distance network.
   - These companies are referred to as ***interexchange carriers (IXC)***.
   - IXCs ***own and operate*** large *fiber optic and microwave radio networks*.
   - IXCs are connected to LECs (***local exchange carriers***) throughout a country or continent.

6. **Write the functions of MSCs in first generation wireless networks.**
   - T In first generation cellular networks, the system control for each market resides in the MSC.
   - The MSC maintains all mobile related information and controls each mobile hand-off.
   - The ***MSC*** also ***performs all of the network management functions***, such as call handling and processing, billing, and fraud detection within the market.

7. What is interoperator roaming?

Until the early 1990s, U.S. cellular customers that roamed between different cellular systems had to register manually each time they entered a new market during long distance travel. This required the ***user to call an operator to request registration***.

8. Give some examples of second generation wireless systems?

Examples of second generation wireless systems include

a. the *Global System for Mobile (GSM)*,
b. the *TDMA and CDMA U.S. digital standards* (IS-54 and IS-95 standards),
c. Second Generation *Cordless Telephone (CT2)*,
d. the British standard for cordless telephony,
e. the *Personal Access Communications System (PACS) local loop standard*, and
f. Digital European Cordless Telephone (DECT).

9. What are the functions handled by second generation wireless systems?

Second generation wireless networks have been specifically designed to ***provide paging, and other data services such as facsimile and high-data rate network access***.

10. What are the aims of third generation wireless networks?

The aim of third generation wireless networks is

a. to provide a single set of standards that can meet a wide range of wireless applications, and
b. to provide universal access throughout the world.

11. Write about third generation wireless networks.

The third generation wireless systems, ***universal personal communicator*** *(a personal handset)* will ***provide access*** to ***a variety of voice, data, and video communication services***.

12. Write about DS formats used in US.

DS format in the U.S.

- **DS-0**: It represents ***one duplex voice channel*** which is ***digitized into a 64 kbps binary PCM format***.
- **DS-1**: It represents ***twenty four full duplex DS-0 voice channels*** that are ***time division multiplexed into a 1.544 Mbps data stream*** (8 kbps is used for control purposes).

13. What are the routing services provided by networks?

- Two general ***routing services*** are provided by networks.
- These are

a. ***connection-oriented services*** (virtual circuit routing), and
b. ***connectionless services*** (datagram services).

14. What is connection oriented routing?

In connection-oriented routing,

a. the communications ***path*** between the message source and destination ***is fixed*** for the entire duration of the message, and
b. a call set-up procedure is required to dedicate network resources to both the called and calling parties.

15. What is connectionless routing?

In Connectionless routing,

- it ***does not establish a firm (fixed) connection*** for the traffic.
- it relies on packet-based transmissions.
- Several ***packets form a message***, and each ***individual packet is routed separately***.

16. Write about packet information overhead.

The ***Packet overhead*** *information* includes

a. the packet source address,
b. the destination address,
c. the routing information, and
d. information needed to properly order packets at the receiver.

17. What is meant circuit switching?

Circuit switching is a type of network configuration in which a physical path is obtained and dedicated to a single connection between two endpoints in the network for the duration of a dedicated connection.

18. What is meant packet switching?

- **Packet Switching** transmits data across digital networks by breaking it down into blocks or packets for more efficient transfer using various network devices.
- Each time one device sends a file to another, it breaks the file down into packets so that it can determine the most efficient route for sending the data across the network at that time.
- The network devices can then route the packets to the destination where the receiving device reassembles them for use.

19. Differentiate circuit switching and packet switching.

Sl. No.	Circuit Switching	Packet switching
1.	In circuit switching has there are 3 phases: i) Connection Establishment. ii) Data Transfer. iii) Connection Released.	In Packet switching directly data transfer takes place.
2.	In-circuit switching, each data unit knows the entire path address which is provided by the source.	In Packet switching, each data unit just knows the final destination address intermediate path is decided by the routers.
3.	In-Circuit switching, data is processed at the source system only	In Packet switching, data is processed at all intermediate nodes including the source system.
4.	The delay between data units in circuit switching is uniform.	The delay between data units in packet switching is not uniform.
5.	Resource reservation is the feature of circuit switching because the path is fixed for data transmission.	There is no resource reservation because bandwidth is shared among users.

20. What are the five fields of transmitted packet in packet switching?

The transmitted packet typically consists of five fields:

- ✓ the flag bits,
- ✓ the address field,
- ✓ the control field,
- ✓ the information field, and
- ✓ the frame check sequence field.

21. What are the advantages of packet switching?

Advantages:

- ✓ Packet switching (or 'packet radio' in wireless link) provides ***excellent channel efficiency*** for bursty data transmissions of short length.
- ✓ The channel is utilized only when sending or receiving ***bursts of information***.
    - ▪ This benefit is valuable in *mobile services where the available band width is limited*.
- ✓ It can provide highly reliable transfer in degraded channel conditions.

22. What are the aims of personal communication systems (PCS)?

The objective of personal communication systems (PCS) or personal communication networks (PCNs) is to

- ✓ provide ubiquitous *(Universal)* wireless communications coverage,
- ✓ enabling users to access the telephone network for different types of communication needs (regardless of the location of the user or the location of the information being accessed).

23. What are the architectural levels of Personal Communication Services?

- ➢ **Intelligent level** contains
    - i. databases for the storage of information about the network users,
- ➢ **Transport level**
    - i. handles the transmission of information.
- ➢ **Access level**
    - i. It provides ubiquitous access to every user in the network
    - ii. Also, contains databases that update the location of each user in the network.

24. What are the key elements of Cellular Packet Switched architecture?

Key elements in the network that facilitate transfer of information are

a. base station interface unit (BIU),
b. cellular controller interface unit (CIU),
c. trunk interface unit (TIU), and
d. each subscriber's wireless interface unit (WIU).

25. What is base station interface unit?

- ➢ The BIU ***provides information exchange*** between the TIUs and the WIUs.
- ➢ The BIU also ***broadcasts packets*** for providing feedback to the PRMA protocol.
- ➢ The BIU is ***addressed by its permanent address*** in the packet header.
- o The major function of the BIU is ***to relay packets to either the WIU or the TIU*** using the ***virtual circuit identifiers*** of the incoming packets

26. What is Packet Reservation Multiple Access (PRMA)?

- PRMA is a derivative of reservation ALOHA, which is a combination of TDMA and slotted ALOHA.
- A ***reservation protocol*** like PRMA has an advantage in that *it can utilize the discontinuous nature of speech* with the help of a voice activity detector (VAD) to increase capacity of the radio channel.

27. What is UMTS?

Universal Mobile Telecommunications Service (UMTS) refers to a group of radio technologies associated with the third generation of cellular networks (3G). Compared to its predecessors, UMTS made it possible to deploy a wider range of data-intensive IoT applications.

28. What is network reliability in UMTS?

\Network Reachability:

a. The network maintains a constant location information on each of the terminals.
b. The location will be updated by a terminal whenever it changes a location area.
c. The network will also take advantage of a distributed network database, for routing of calls once the exact location of the mobile has been accessed.

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UNIT- V
WIRELESS NETWORKING

QUESTION BANK

PART – A

1. Write about mobile switching center.
2. Differentiate Wireless And Fixed Telephone Networks.
3. Write about as interexchange carriers.
4. Write the functions of MSCs in first generation wireless networks.
5. What is interoperator roaming?
6. Give some examples of second generation wireless systems?
7. What are the functions handled by second generation wireless systems?
8. What are the aims of third generation wireless networks?
9. Write about third generation wireless networks.
10. What are the routing services provided by networks? What is connection oriented routing?
11. What is meant packet switching?
12. Differentiate circuit switching and packet switching.
13. What are the five fields of transmitted packet in packet switching? What are the advantages of packet switching?
14. What is Packet Reservation Multiple Access (PRMA)?
15. What is UMTS?

PART – B & C

1. Give a brief discussion on wireless networks.
2. Discuss the differences Between Wireless and Fixed Telephone Networks.
3. **Illustrate the Public Switched Telephone Network with relevant architectural diagrams.**
4. **Explain the development of wireless networks through the first, second and third generations.**
5. Explain in detail about Fixed Network Transmission Hierarchy.
6. Explain the mechanism of traffic routing in wireless networks with routing services.
7. **Explain the concepts of circuit and packet switching in Traffic Routing In Wireless Networks.**
8. Explain the Personal Communication Services / Networks.
9. **With neat diagram explain Cellular Packet - Switched Architecture.**
10. Discuss about Network Functionality in Cellular Packet-Switched Architecture.
11. Explain in detail about Packet Reservation Multiple Access (PRMA).
12. Write short notes on network databases with Distributed Database for Mobility Management.
13. **Draw and explain the Network architecture Universal Mobile Telecommunication Systems (UMTS).**

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