Wireless mobile communication
UNIT- 2

Module 2(9hours)

Cellular Concept. Cell area, Signal strength, Cell parameter, Capacity of Cell, Co channel interference, Frequency reuse, , Cell splitting
Cell sectoring, Multiple Radio access protocols Frequencydivision Multiple Access, , Time division Multiple Access
Fixed ALOHA , Slotted ALOHA, Multiple Access with Collision Avoidance, Space division Multiple Access Code division Multiple Access, Spread ALOHA multiple Access

Cellular Concept & Frequency Reuse

The design objective of early mobile radio systems was to achieve a large coverage area

by using a single, high powered transmitter with an antenna mounted on a tall tower.

While this approach achieved very good coverage, it also meant that it was impossible to reuse those same frequencies throughout the system, since any attempts to achieve frequency reuse would result in interference.

For example, the Bell mobile system in New York City in the 1970s could only support a maximum of twelve simultaneous calls over a thousand square miles. Faced with the fact that government regulatory agencies could not make spectrum allocations in proportion to the increasing demand for mobile services, it became imperative to restructure the radio telephone system to achieve high capacity with limited radio spectrum while at the same time covering very large areas.

The cellular concept was a major breakthrough in solving the **problem of spectral congestion and user capacity.**

It offered very high capacity in a limited spectrum allocation without any major technological changes.

The cellular concept is a system-level idea which calls for replacing a single, high power transmitter (large cell) with many low power transmitters (small cells), each providing coverage to only a small portion of the service area.

Each base station is allocated a portion of the total number of channels available to the entire system, and nearby base stations are assigned different groups of channels so that all the available channels are assigned to a relatively small number of neighboring base stations.

Neighboring base stations are assigned different groups of channels so that the interference between base stations (and the mobile users under their control) is minimized.

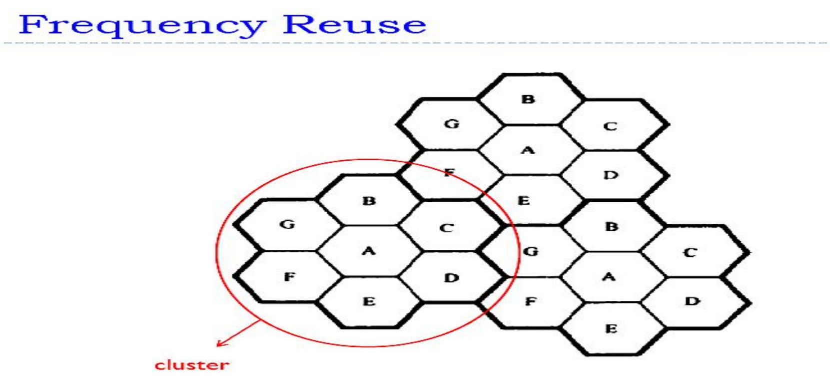
By systematically spacing base stations and their channel groups throughout a market, the available channels are distributed throughout the geographic region and may be reused as many times as necessary so long as the interference between cochannel stations is kept below acceptable levels.

As the demand for service increases (i.e., as more channels are needed within a particular market), the number of base stations may be increased (along with a corresponding decrease in transmitter power to avoid added interference), thereby providing additional radio capacity with no additional increase in radio spectrum.

This fundamental principle is the foundation for all modern wireless communication systems, since it enables a fixed number of channels to serve an arbitrarily large number of subscribers by reusing the channels throughout the coverage region.

Furthermore, the cellular concept allows every piece of subscriber equipment within a country or continent to be manufactured with the same set of channels so that any mobile may be used

Frequency Reuse



Frequency reuse, or, frequency planning, is a technique of reusing frequencies and channels within a communication system to improve capacity and spectral efficiency.

Frequency reuse is one of the fundamental concepts on which commercial wireless systems
The increased capacity in a commercial wireless network, compared with a network with a single transmitter, comes from the fact that the same radio frequency can be reused in a different area for a completely different transmission.

Frequency reuse in mobile cellular systems means that frequencies allocated to the service are reused in a regular pattern of cells, each covered by one base station.

Each cellular base station is allocated a group of radio channels to be used within a small geographic area called a *cell*.

Group Of Cell is Called as Clustures

The actual radio coverage of a cell is known as the *footprint*

· 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*

Figure illustrates the concept of cellular frequency reuse, where cells labeled with the same letter use the sa me group of channels. The frequency reuse plan is overlaid upon a map to indicate where different frequency channels are used.

When considering ge ometric shapes which cover an entire region without overlap and with equal area, there are **three sensible choices— a square, an equilateral triangle, and a hexagon** it might seem natural to choose **a circle to** represent the coverage area of a base station, adjace nt circles cannot be overlaid upon a map w ithout leaving gaps or creating overlapping r egions.

- The hexagonal cell s hape is a simplistic model of the radio c overage for each base station, but it has been universally adopted since the hexagon permits easy and manageable analysis of a cellular system. by using the hexagon geometry, the fewest

number of cells can cover a geographic region, and the hexagon

closely approximates a circular radiation pattern which would occur for an omnidirectional base station antenna and free space propagation. Of course, the actual cellular footprint is determined by the contour in which a given transmitter serves the mobiles successfully.

When using hexagons to model coverage areas, base station transmitters are depicted as either being in the center of the cell (center-excited cells) or on three of the six cell vertices (edge-excited cells).

Normally, omnidirecional antennas are used in center-excited cells and sectored directional antennas are used in corner-excited cells.

- Due to the fact that the hexagonal geometry of has exactly six equi distant neighbors

and that the lines joining the centers of any cell and each of its neighbors are separated by multiples of 60 degrees,

In order to connect without gaps between adjacent cells— $N=i^2+ij+j^2$ where i and j are non- negative integers.

To find the nearest co-channel neighbors of a particular cell, one must do the following:

move i cells along any chain of hexagons and then

Turn 60 degrees counter-clockwise and move j cells.

To understand the frequency reuse concept, consider a cellular system which has a total of S duplex channels available for use.

If each cell is allocated a group of k channels ($k < S$), and

if the S channels are divided among N cells into unique and disjoint channel groups which each have the same number of channels, the total number of available radio channels can be expressed as

- ***S=kN***

The N cells which collectively use the complete set of available frequencies is called a *cluster*. If a **cluster is replicated *M* times within the system**, the total number of duplex channels,

C, can be used as a measure of capacity and is given by

C=MkN=MS

The factor N is called the *cluster size* and is typically equal to 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 (a larger value of C) is achieved. A large cluster size indicates that the ratio between the cell radius and the distance between co-channel cells is small.

The *frequency reuse factor* of a cellular system is given by $1/N$, since each cell within a cluster is only assigned $1/N$ of the total available channels in the system.

PROBLEM

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) four-cell reuse, (b) seven-cell reuse, and (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.

Solution

Given:

Total bandwidth = 33 MHz

Channel bandwidth = 25 kHz × 2 simplex channels = 5 0 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.

If 1 MHz is used for control channels, it means that there are 1000/50 = 20 control channels out of 660 channels

In other words, it has 640 voice channels

For N = 4, we have 640/4 = 160 voice channels and 20/4 = 5 control channels per cell
For N = 7, we have 640/7 = 92 voice channels and 20/7 = 3 control channels per cell

For N = 12, we have 640/12 = 54 voice channels and 20/12 = 1.5 control channels per cell
In practice, each cell only need 1 control channel and equitable distribution should apply

Channel Assignment Strategies

For efficient utilization of the radio spectrum, a frequency reuse scheme that is consistent with the objectives of increasing capacity and minimizing interference is required.

A variety of channel assignment strategies have been developed to achieve these objectives.

Channel assignment strategies can be classified as either ***fixed*** ***or dynamic***.

The choice of channel assignment strategy impacts the performance of the system, particularly as to how calls are managed when a mobile user is handed off from one cell to another.

Fixed Channel Assignment Strategies

In a fixed channel assignment strategy, 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.

Several variations of the fixed assignment strategy exist. In one approach, called the ***borrowing strategy,*** a cell is allowed to borrow channels from a neighboring cell if all of its own channels are already occupied.

· The mobile switching center (MSC) supervises such borrowing procedures and ensures that the borrowing of a channel does not disrupt or interfere with any of the calls in progress in the donor cell.

Dynamic Channel Assignment Strategies

In a dynamic channel assignment strategy, voice channels are not allocated to different cells permanently.

Instead, each time a call request is made, the serving base station requests a channel from the MSC.

The switch then allocates a channel to the requested cell following an algorithm that takes into account the

Likelihood of future blocking within the cell,

The frequency of use of the candidate channel,

The reuse distance of the channel, and

Other cost functions

Accordingly, the MSC only allocates a given frequency if that frequency is not presently in use in the cell or any other cell which falls within the minimum restricted distance of frequency reuse to avoid co-channel interference.

Dynamic channel assignment reduces the likelihood of blocking, which increases the trunking capacity of the system, since all the available channels in a market are accessible to all of the cells.

Dynamic channel assignment strategies require the MSC to collect real-time data on channel occupancy, traffic distribution, and *radio signal strength indications* (RSSI) of all channels on a continuous basis.

This increases the storage and computational load on the system but provides the advantage of increased channel utilization and decreased probability of a blocked call.

HANDOFF & its STRATEGIES

When a mobile moves 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.

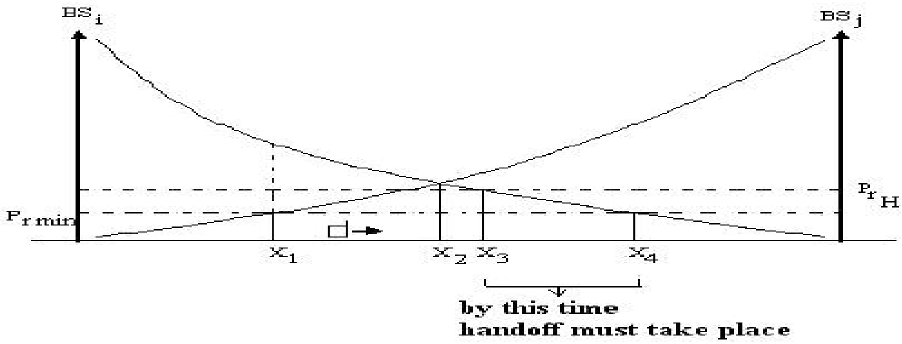
This handoff operation not only involves identifying a new base station, but also requires that the voice and control signals be allocated to channels associated with the new base station.

Processing handoffs is an important task in any cellular radio system.

Handoffs must be performed successfully and as infrequently as possible, and be imperceptible to the users.

In order to meet these requirements, system designers must specify an optimum signal level at which to initiate a handoff.

Once a particular signal level is specified as the minimum usablee signal for acceptable voice quality at the ba se station receiver (normally taken as between –90 dBm and –100 dBm), a slightly stron ger signal level is used as a threshold at which a handoff is made.



BS_i = Base station of i th cell
BS_j = Base station of any adjacent j th cell

- This margin, given **by** ***= Pr handoff – Pr minimum usable***, cannot be too large or

too small.
If $\wedge$ is too large, unne cessary handoffs which burden the MSC may occur, and

If $\triangle$ is too small, there may be insufficient time to complete a h andoff before a call is lost due to weak signal conditions.
Therefore $\triangle$ is chosen carefully to meet these conflicting requiremeents

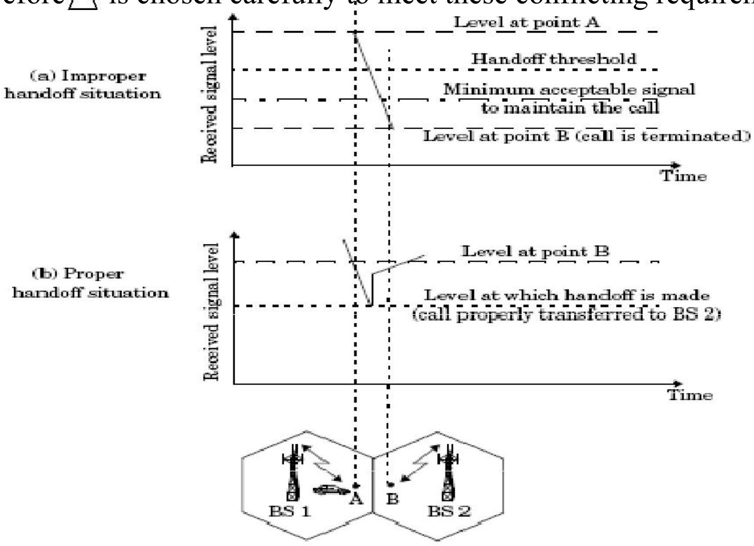


Figure demonstrates the case where a handoff is not made and the signal drops below the minimum acceptable level to keep the channel active.

This dropped call event can happen when there is an excessive delay by the MSC in

assigning a handoff or when the threshold $\triangle$ is set too small for the handoff time in the system.

Excessive delays may occur during high traffic conditions due to computational loading at the MSC or due to the fact that no channels are available on any of the nearby base stations (thus forcing the MSC to wait until a channel in a nearby cell becomes free).

In deciding when to handoff, it is important to ensure that the drop in the measured signal level is not due to momentary fading and that the mobile is actually moving away from the serving base station.

In order to ensure this, the base station monitors the signal level for a certain period of time before a handoff is initiated.

This running average measurement of signal strength should be optimized so that unnecessary handoffs are avoided, while ensuring that necessary handoffs are completed before a call is terminated due to poor signal level.

The length of time needed to decide if a handoff is necessary depends on the speed at which the vehicle is moving.

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

The dwell time of a particular user is governed by a number of factors, including propagation, interference, distance between the subscriber and the base station, and other

time varying effects

- In **first generation analog cellular systems**,

    * Signal strength measurements are made by the base station and supervised by the MSC.

    * Additionally, a spare receiver in each base station, called the location receiver, is used to determine signal strengths of mobile users which are in neighboring cells (and appear to be in need of handoff.)

In **today's second generation systems, handoff decisions are** ***mobile assisted.*** ***handoff*** **(MAHO)**, handoff decisions are mobile assisted (MAHO).

* Mobile units measure the received power from surrounding base stations and report the results to the serving base station.

* A handoff is initiated when the power received from the neighboring cell begins to exceed the power received from the current base station by a certain level or for a certain period of time.

* The MAHO performs at a much faster rate, and is particularly suited for micro cellular environments. ***Intersystem handoff***

* Moves from one cellular system to a different cellular system controlled by a different MSC.

* It may become a long-distance call and a roamer.

* Compatibility between the two MSCs need to be determined.

Different Types Of Handoff

NO HANDOFF: New Call is made once mobile moves out of range.

Hard handoff : Mobile Unit needs to break its connection with BS before connecting to another. Not too Reliable. Results in noticeable break in conversation especially when Mobile unit moving fast between small cells

Soft handoff : Ability to select between the instantaneous received signals from

different base Station is called Soft handoff. A new link is set up to BS before old one is dropped,

Reliable

Intercell handoff ; Mobile Unit moving from current cell to its adjacent cell using same channel

Intracell handoff : Mobile Unit is in the same cell and channel is changed during handoff.ie the hand off in which cell is not changed and channel is changed.

Prioritizing Handoffs

One method for giving priority to handoffs is called the ***guard channel concept***, whereby 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.

This method has the disadvantage of reducing the total carried traffic, as fewer channels are allocated to originating calls.

Guard channels, however, offer efficient spectrum utilization when dynamic channel assignment strategies, which minimize the number of required guard channels by efficient demand-based allocation, are used.

Queuing of handoff requests is another method to decrease the probability of forced termination of a call due to lack of available channels.

There is a tradeoff between the decrease in probability of forced termination and total carried traffic.

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

It should be noted that queuing does not guarantee a zero probability of forced termination, since large delays will cause the received signal level to drop below the minimum required level to maintain communication and hence lead to forced termination

Practical Handoff Considerations

In practical cellular systems, several problems arise when attempting to design for a wide range of mobile velocities.

High speed vehicles pass through the coverage region of a cell within a matter of seconds, whereas pedestrian users may never need a handoff during a call.

Particularly with the addition of microcells to provide capacity, the MSC can quickly become burdened if high speed users are constantly being passed between very small cells.

Another practical limitation is the ability to obtain new cell sites.

Although the cellular concept clearly provides additional capacity through the addition of cell sites, in practice it is difficult for cellular service providers to obtain new physical cell site locations in urban areas.

By using different antenna heights (often on the 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 and is used to provide large area coverage to high speed users while providing small area coverage to users traveling at low speeds.

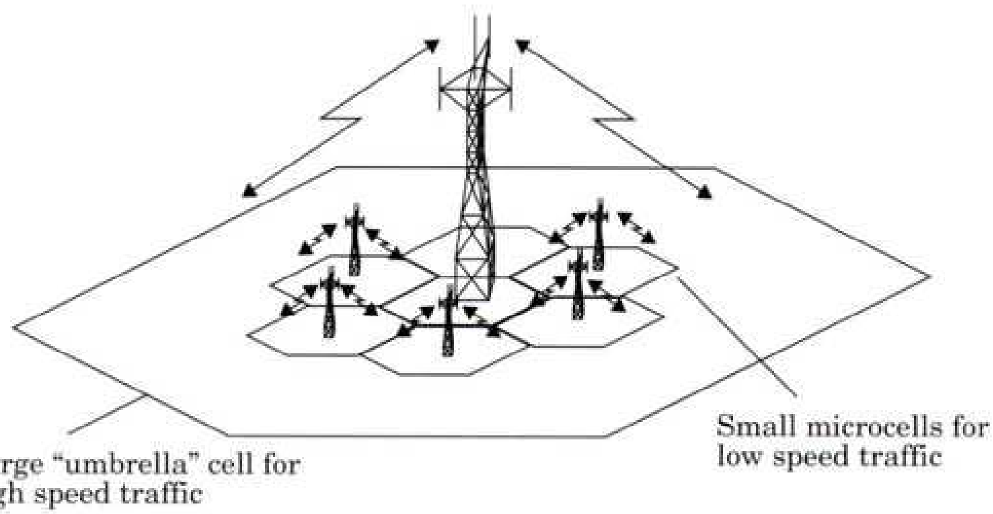


Figure The umbrella cell approach.

Figure illustrates an umbrella cell which is collocated 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.

If a high speed user in the large umbrella cell is approaching the base station, and its velocity is rapidly decreasing, the base station may decide to hand the user into the co-located microcell, without MSC intervention.

Another practical handoff problem in microcell systems is known as *cell dragging*.

Cell dragging results from pedestrian 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.

This creates a potential interference and traffic management problem, since the user has meanwhile traveled deep within a neighboring cell.

· To solve the cell dragging problem, handoff thresholds and radio coverage parameters must be adjusted carefully.

·

· Interference and System Capacity

Interference is the major limiting factor in the performance of cellular radio systems.

Sources of interference

Another mobile in the same cell

A cell in progress in a neighboring cell

Other base stations operating in the same frequency band.

Any noncellular system which inadvertently leaks energy into the cellular frequency band..

Interference on voice channels causes cross talk, where the subscriber hears interference in the background due to an undesired transmission.

On control channels, interference leads to missed and blocked calls due to errors in the digital signaling.

· Interference is more severe in urban areas, due to the greater RF noise floor and the large number of base stations and mobiles.

Interference has been recognized as a major bottleneck in increasing capacity and is often responsible for dropped calls.

The two major types of system-generated cellular interference are ***co-channel interference*** **and** ***adjacent channel interference*.**

Even though interfering signals are often generated within the cellular system, they are difficult to control in practice.

Co-channel Interference and System Capacity

Frequency reuse implies that in a given coverage area there are several cells that use the same set of frequencies.

These cells are called *co-channel cells*, and the interference between signals from these cells is called *co-channel interference*.

Unlike thermal noise which can be overcome by increasing the signal-to-noise ratio (SNR), co-channel interference cannot be combated by simply increasing the carrier power of a transmitter.

This is because an increase in carrier transmit power increases the interference to neighboring co-channel cells.

To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.

When the size of each cell is approximately the same and the base stations transmit the same power, the co-channel interference ratio is independent of the transmitted power and becomes a function of the radius of the cell (R) and the distance between centers of the nearest co-channel cells (D).

By increasing the ratio of D/R, the spatial separation between co-channel cells relative to the coverage distance of a cell is increased.

The parameter Q, called the *co-channel reuse ratio*, is related to the cluster size For a hexagonal Geometry

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

- N small, Q small, larger capacity

N large, Q large, better transmission quality due to a small level of co-channel interference.

Signal-to-interference ratio for a mobile receiver which monitors a forward channel:

- The average received power at a distance d from the transmitting antenna is approx. by

where P_0 is the power received at a close-in reference point in the far field region of the antenna at a small distance d_0 from the transmitting antenna, and n is the path loss exponent (is the reduction of power density of electromagnetic wave propogates through space)

- When the transmit power of each base station is equal and the path loss exponent is the same throughout the coverage area, S/I for a mobile can be approx. as

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

- For simplification, assume all interferers have equidistance,

$$\frac{S}{I} = \frac{(D/R)^n}{i_0} = \frac{(\sqrt{3N})^n}{i_0}$$

which relates S/I to the cluster size, and in turn determines the overall capacity of the system

PROBLEM

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) n = 3? Assume that there are six cochannel cells in the first tier, and all of them are at the same distance from the mobile. Use suitable approximations.

Design Parameters

Desired signal-to-interference ratio = 15 db

<u>A) Path Loss exponent ,n=4</u>

N = 4,7, 12 is used

Reuse Factor = ?
When we Choose N=4

D / R =√3N =√3* 4 = 3.46

$$S / I = \frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}} = (1/6) / (3.46)^{-4} = 24.0$$

Converting signal in db 10 log (24) = 13.80 db

Since this is less than the desired 15 db it cannot be used
So we have to choose N =7

D/R = √3N =√3*7 = 4.58

-4

Converting signal in db 10 log (75.3) = 18.76 db

Since this is greater than required 15db N= 7 can be used.

The required Re-use Factor is 1 / N = 1 / 7

<u>B) Path loss exponent n= 3</u>

N= 4, 7 .12 can be used

D / R = √3N = √3 * 7 = = 4.58

$S / I = (1/6) / (4.58)^{-3} = 16.04$

Converting signal in db 10 log (16.04) = 12.05 db

Since this is less than the desired 15 db it cannot be used . have to use a larger N
N=12

D / R = √3N = 6.0

$S / I = (1/6) / (6)^{3} = 36 =$ 10 log (36) =15.56db

This is greater than minimum required signal N=12 can be used and Reuse factor 1 /N = 1 / 12

<u>Adjacent Channel Interference</u>

- Results from imperfect receiver filters which allow nearby frequencies to leak into the pass band.

- ***<u>Near-far effect</u>*** (the adjacent channel interference is particularly serious.)

  * An adjacent channel user is transmitting in very close range to subscriber's receiver, while the receiver attempts to receive a base station on the desired channel.

It also occurs when a mobile close to a base station transmits on a channel close to one being used by a weak mobile.

The base station may use by a weak mobile. The base station may have difficulty in discriminating the desired mobile user from the "bl eed over" caused by the close adjacent channel mobile

Adjacent channel interference can be minimized through careful filtering and channel assignments.

Since each cell is given only a fraction of the available channels, a cell need not be Assigned channels which are all adjacent in frequency.

By keeping the frequency separation between each channel in a given cell as large as possible, the adjacent channel interference may be reduced considerably.

Channel allocation schemes also prevent a secondary source of adjacent channel interference by avoiding the use of adjacent channels in neighboring cell sites.

If the frequency reuse factor is large (e.g., small *N*), the separation between adjacent channels at the base station may not be sufficient to keep the adjacent channel interference level within tolerable limits.

If the subscriber is at the distance d1 and interferer is at d2 then Signal To Interference

  ◦ $S/I = (d1/d2)^n$

where n is path loss exponent

<u>Power Control for Reducing Interferences</u>

- In practical cellular radio and personal communication systems, the power levels transmitted by every mobile unit are under constant control by the serving base stations.

- This is done to ensure that each mobile transmits the smallest power necessary on the reverse channel.

- Power control not only helps prolong battery life, also reduces the interference on the reverse channel.

- It is especially important for CDMA systems, because every user in every cell share the same radio channel. (to reduce the co-channel interference.

<u>Improving Coverage and Capacity in Cellular Systems</u>

As the demand for wireless service increases, the number of channels assigned to a cell eventually becomes insufficient to support the required number of users.

At this point, cellular design techniques are needed to provide more channels per unit coverage area.

Techniques such as *cell splitting*, *sectoring*, and *coverage zone approaches* are used in practice to expand the capacity of cellular systems.

Cell splitting allows an orderly growth of the cellular system.

Sectoring uses directional antennas to further control the interference and frequency reuse of channels.

The *zone microcell* concept distributes the coverage of a cell and extends the cell boundary to hard to-reach places.

While cell splitting increases the number of base stations in order to increase capacity, sectoring and zone microcells rely on base station antenna placements to improve capacity by reducing co-channel interference.

These three popular capacity improvement techniques will be explained in detail.

Cell Splitting

First technique to increase the capacity.

Cell splitting is the process of subdividing a congested cell into smaller cells,
each with its own base station and

a corresponding reduction in antenna height and
a corresponding reduction in transmitter power.

Increase the number of base Station deployed and allows an orderly growth of cellular system

Cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused.

· 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.
The increased number of cells would increase the number of clusters over the coverage region, which in turn would increase the number of channels, and thus capacity, in the coverage area.

Cell splitting allows a system to grow by replacing large cells with smaller cells, while not upsetting the channel allocation scheme required to maintain the minimum co-channel reuse ratio between co-channel cells.

Cells are splits with no additional bandwidth or new spectrum usage

Depending on traffic pattern smaller cells may be activated / deactivated inorder to efficiently use the cell resource

New cell radious is half the original cell

Required Transmit power for new cell

$P_{T2} = P_{T1}/ 2^n$

P_{T1} Power in original Cell

P_{T2} Power in new Cell

n Pathloss component

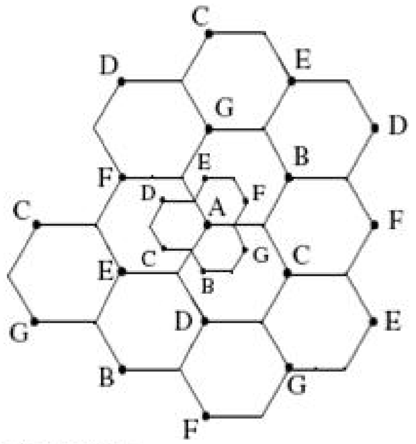


Illustration of cell splitting.

An example of cell splitting is shown the base stations are placed at corners of the cells, and the area served by base station *A* is assumed to be saturated with traffic (i.e., the blocking of base station *A* exceeds acceptable rates).

New base stations are therefore needed in the region to increase the number of channels in the area and to reduce the area served by the single base station. , the smaller cells were added in such a way as to preserve the frequency reuse plan of the system.

Cell Sectoring

Cell splitting achieves capacity improvement by essentially rescaling the system.

By decreasing the cell radius *R* and keeping the co-channel reuse ratio *D*/*R* unchanged,

cell splitting increases the number of channels per unit area.

However, another way to increase capacity is to keep the cell radius unchanged and seek methods to decrease the *D*/*R* ratio. As we now show, *sectoring* increases SIR so that the cluster size may be reduced.

In this approach, first the SIR is improved using directional antennas, then capacity improvement is achieved by reducing the number of cells in a cluster, thus increasing the frequency reuse.

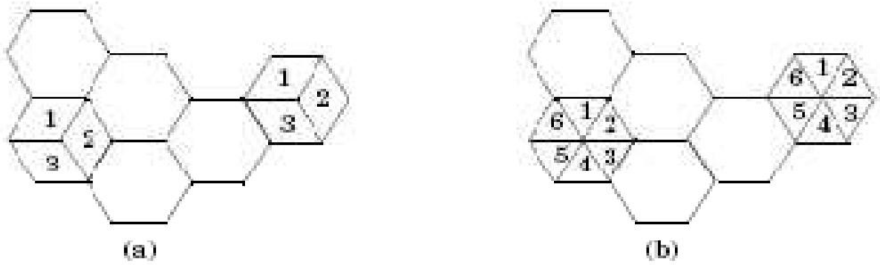
However, in order to do this successfully, it is necessary to reduce the relative interference without decreasing the transmit power.

The co-channel interference in a cellular system may be decreased by replacing a single omnidirectional antenna at the base station by several directional antennas, each radiating within a specified sector.

By using directional antennas, a given cell will receive interference and transmit with only a fraction of the available co-channel cells. The technique for decreasing co-channel interference and thus increasing system performance by using directional antennas is called *sectoring*

The factor by which the co-channel interference is reduced depends on the amount of sectoring used.

A cell is normally partitioned into three 120° sec tors or six 60° sectors or four 90^0 sectors



(a) 120° sectoring; (b) 60° sectoring.

Below 60^0 is not preferred because too many sectors required too many handoffs and too many antennas.

When sectoring is employed, the channels used in a particular cell are broken down into sectored groups and are used only within a particular sector,

The base station feeds three 120o directional antennas, each of which radiates into one of the three sectors. The channel set serving this cell has also been divided, so that each sector is assigned one-third of the available number cell of channels.

This technique for reducing co-channel interference wherein by using suitable directional antennas, a given cell would receive interference and transmit with a fraction of available co-channel cells is called 'sectoring'.

Base station in the center cell will receive co-channel interference from mobile units in only two of the co-channel cells. Hence the signal to interference ratio is now modified to

$$\frac{S}{I} = \frac{(\sqrt{3N})^n}{2}$$

where the denominator has been reduced from 6 to 2 to account for the reduced number of interfering sources.

Problems in sectoring

Reduction in Trunking efficiency,

Dividing a cell into sectors requires that a call in progress will have to be handed off

This increases the complexity of the system and also the load on the mobile switching center/base station.

Repeaters for Range Extension

Often a wireless operator needs to provide dedicated coverage for hard-to-reach areas, such as within buildings, or in valleys or tunnels.

Radio retransmitters, known as *repeaters*, are often used to provide such range extension capabilities.

Repeaters are bidirectional in nature, and simultaneously send signals to and receive signals from a serving base station.

Repeaters work using over-the-air signals, so they may be installed anywhere and are capable of repeating an entire cellular or PCS band.

Upon receiving signals from a base station forward link, the repeater amplifies and reradiates the base station signals to the specific coverage region.

Unfortunately, the received noise and interference is also reradiated by the repeater on both the forward and reverse link, so care must be taken to properly place the repeaters, and to adjust the various forward and reverse link amplifier levels and antenna patterns.

In practice, directional antennas or *distributed antenna systems (DAS)* are connected to the inputs or outputs of repeaters for localized spot coverage, particularly in tunnels or

Microcell Zone Concept

The increased number of handoffs required when sectoring is employed results in an increased load on the switching and control link elements of the mobile system. To overcome this problem, a new microcell zone concept has been proposed.

This scheme has a cell divided into three microcell zones, with each of the three zone sites connected to the base station and sharing the same radio equipment.
It is necessary to note that all the microcell zones, within a cell, use the same frequency used by that cell; that is no handovers occur between microcells. Thus when a mobile user moves between two microcell zones of the cell, the BS simply switches the channel to a different zone site and no physical re-allotment of channel takes place.

Locating the mobile unit within the cell: An active mobile unit sends a signal to all zone sites, which in turn send a signal to the BS. A zone selector at the BS uses that signal to select a suitable zone to serve the mobile unit - choosing the zone with the strongest signal.

The zone site receives the cellular signal from the base station and transmits that signal to the mobile phone after amplification.

Co-channel interference is reduced between the zones and the capacity of system is increased.

Benefits of the micro-cell zone concept:

1) Interference is reduced in this case as compared to the scheme in which the cell size is reduced.
2) Handoffs are reduced (also compared to decreasing the cell size) since the microcells within the cell operate at the same frequency; no handover occurs when the mobile unit moves between the microcells.
3) Size of the zone apparatus is small. The zone site equipment being small can be mounted on the side of a building or on poles.
4) System capacity is increased. The new microcell knows where to locate the mobile unit in a particular zone of the cell and deliver the power to that zone.
5) The signal power is reduced, the microcells can be closer and result in an increased system capacity.

However, in a microcellular system, the transmitted power to a mobile phone within a microcell has to be precise; too much power results interference between microcells, while with too little power the signal might not reach the mobile phone. This is a drawback of microcellular systems, since a change in the surrounding (a new building, say, within a microcell) will require a change of the transmission power.

Trunking and Grade of Service

Cellular radio systems rely on trunking to accommodate a large nu mber of users in a limited radio spectrum

In a trunked radio system, each user is allocated a channel on a per call basis and upon termination of the call , the previously occupied channel is immediately returned to the pool of available channels

The fundamentals of t runking theory were developed by Erlang

One Erlang represents the amount of traffic intensity carried by a c hannel that is completely occupied (i.e. one call-hour per hour or one call-minute per minute)

The GOS is a measure of the ability of a user to access a trunked sy stem during the busiesthour

GOS is typically given as the likelihood that a call is blocked or the likelihood of a call experiencing a delay g reater than a certain queuing timeSome definitions:

Set-up Time: The time required to allocate a trunked radio channel to a requesting user.
Blocked Call: Call which cannot be completed at time of request, due to congestion. Also referred to as a *lost call*.
Holding Time: Average duration of a typical call. Denoted by H (in seconds).
Traffic Intensity: Measure of channel time utilization, which is the average channel occupancy measured in Erlangs. This is a dimensionless quantity and may be used to measure the time utilization of single or multiple channels. Denoted by A.
Load: Traffic intensity across the entire trunked radio system, measured in Erlangs.
Grade of Service (GOS): A measure of congestion which is specified as the probability of a call being blocked (for Erlang B), or the probability of a call being delayed beyond a certain amount of time (for Erlang C).
Request Rate: The average number of call requests per unit time. Denoted by λ seconds^{-1}.

The traffic intensity offered by each user is equal to the call request rate multiplied by the holding time

- Each user generates a traffic intensity of *Au* Erlangs given by

$$A_u = \lambda H$$

For a system containing *U* user and an unspecified number of channels, the total offered traffic intensity is

In a *C* channel trunked system, if the traffic is equally distributed among the channels, then the traffic intensity per channel is
The offered traffic is not necessarily the traffic which is carried by the trunked system, only that which is offered to the trunked system
When the offered traffic exceeds the maximum capacity of the system, the carried traffic becomes limited due to the limited capacity
For example, the AMPS cellular system is designed for a GOS of 2% blocking
That implies that 2 out of 100 calls will be blocked due to channel occupancy during the busiest hour. There are two types of trunked systems: blocked calls cleared and b locked calls delayed
In blocked calls cleared: for every user who requests service, it is assumed there is no setup time and the user is given immediate access to a channel if on e is available
If no channels are avai lable, the requesting user is blocked without access and is free to try again later
This scenario uses Erl ang B formula

$$\Pr\left[blocking\right] = \frac{\dfrac{A^C}{C!}}{\displaystyle\sum_{k=0}^{C} \frac{A^k}{k!}} = GOS$$

In block calls delayed, if a channel is not available immediately, th e call request may be delayed until a channel becomes available
The likelihood of a cal l not having immediate access to a channel i s formulated by Erlang
C

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

The GOS of a trunked system where blocked calls are delayed is

$$\Pr[delay > t] = \Pr[delay > 0]\Pr[delay > t \mid delay > 0]$$
$$= \Pr[delay > 0]\exp(-(C-A)t/H)$$

The average delay for all calls in a queued system is given by

$$D = \Pr[delay > 0]\frac{H}{C-A}$$

Multiple access techniques; FDMA, TDMA and CDMA. Spread spectrum-cellular CDMA.

Principles-Power control- WCDMA-multiuser detection in CDMA.

Introduction To Spread Spectrum Modulation

All *of* the modulation and demodulation techniques described so far strive to achieve greater power and/or bandwidth efficiency in a stationary additive white Gaussian noise channel.

Since bandwidth is a limited resource, one of the primary design objectives of all the modulation schemes detailed thus far is to minimize the required transmission bandwidth.

Spread spectrum techniques, on the other hand, employ a transmission bandwidth that is several orders of magnitude greater than the minimum required signal bandwidth.

While this system is very bandwidth inefficient for a single user, the

advantage of spread spectrum is that many users can simultaneously use the same bandwidth without significantly interfering with one another.

In a multiple-user, multiple access interfer-ence (MAl) environment,

spread spectrum systems become very bandwidth efficient.

spread spectrum signals are pseudorandom and have noise-like

properties when compared with the digital information data.

The spreading waveform is controlled by a pseudo-noise (PNJ sequence or pseudo-noise code, which is a binary sequence that appears random but can be reproduced in a deterministic manner by intended receivers.

Spread spectrum signals are demodulated at the receiver through crosscorrelation with a locally-generated version of the pseudorandom carrier.

Crosscorrelation with the correct PN sequence despreads the spread spectrum signal and restores the modulated message in the same narrow band as the original data.

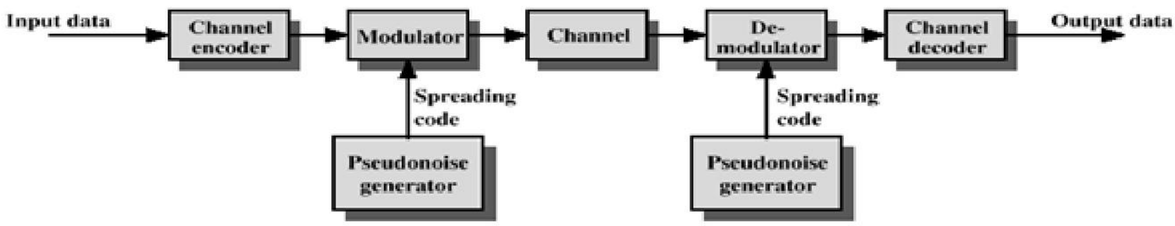
Spread spectrum modulation has many properties that make it particularly well-suited for use in the mobile radio environment. The most important advantage is its inherent interference rejection capability.

Narrowband interference effects only a small portion of the spread spectrum signal, it can easily be removed through notch filtering without much loss of information.

· Since all users are able to share the same spectrum, spreadspectrum may eliminate frequency planning, since all cells can use the same channels.

Resistance to multipath fading is another fundamental reason for

considering spread spectrum systems for wireless communications.



General Model of Spread Spectrum Digital Communication System

Input is fed into a channel encoder

- o Produces analog signal with narrow bandwidth

Signal is further modulated using sequence of digits

- o Spreading code or spreading sequence
- o Generated by pseudonoise, or pseudo-random number generator

Effect of modulation is to increase bandwidth of signal to be transmitted

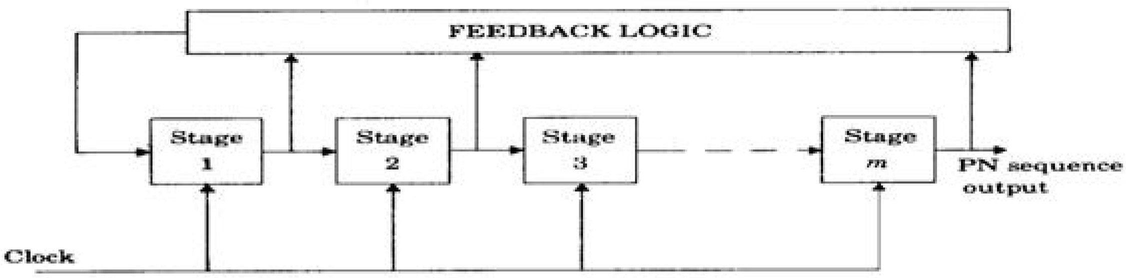
On receiving end, digit sequence is used to demodulate the spread spectrum signal

Signal is fed into a channel decoder to recover data

Pseudo-random (PN) Sequences

A *pseudo-noise (PN) sequence* is a periodic binary sequence with a noise like waveform that is usually generated by a means of a *feed back shift register*.

It consists of a *shift register* made up of *m flip-flops* and a *logic circuit* to form a multiloop *feedback* circuit.



- An *m*-bit codeword produces a sequence of length 2^m-1
- The peak values are 2^m-1The autocorrelation function is equal to –1 other t han at the peaks.
- The O/P sequence contains 2^{m-1} ones & 2^{m-1} -1 Zeros.
- Their power density spectrum is uniform so they may used as white noise sources.
- A typical matched filter implements convolution using FIR filter whose coefficients are the time inverse of the expected PN sequence to decode the transmitted data.

- If the receiver is not synchronized, then the received signal will propagate through the matched filter, which outputs the complete correlation function.

The output of the FIR filter is the decod**ed data.**

Properties needed for signal to spectrum modulated PN Sequence Properties

Randomness

Unpredictability

Two criteria used to validate a PN Sequence

Uniform Distribution
Independence

Uniform distribution

Distribution of numbers in the sequence should be uniform

Frequence of occurance of each of numbers should be approximately same.

For a stream of binary digits two properties are desired

Balance property : in long sequence the number of binary ones always one more than the number of 0's.

Run property: run is defined as a sequence of all 1-s or a sequence of all 0-s.Among the runs of 1's and 0's in each period of sequence one half the runs of each kind are of length one,one fourth of length two,one eigth of length three and so on as long as these fractions represent meaningful number of runs.

Auto Correlation Property : Autocorrelation function of a maximal length sequence is periodic and binary valued. The periodic autocorrelation of a

±1 m-sequence is

Correlation Property : . the cross-correlation of two *m*-sequences tends to be large. If the codes which are used are not completely orthogonal, the cross-correlation factor is unequal to zero. In this situation the different users are interferers to each other, hence the near-far problem appears

good auto-and cross-correlation properties
Independence

no one value in sequence can be inferred from the others
Unpredictability

Direct Sequence Spread Spectrum (DS-SS)

A direct sequence spread spectrum (DS-SS) system spreads the baseband

data by directly multiplying the baseband data pulses with a 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.*

A functional block diagram of a DS system with binary phase modulation.

This system is one of the most widely used direct sequence implementations.

Synchronized data symbols, which may be 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 se quence,

p(t) is the PN spreading sequence,

fc is the carrier frequency, and

a is the carrier phase angle at *t* = 0.

- The data waveform is a time sequence of nonoverlapping rectangu lar pulses,
each of which has an am plitude equal to +1 or -1. Each symb ol in *m(t)*
represents a data symbol and has duration *Tc.*

Each pulse in p(t) represen ts a chip, is usually rectangular with an amplitude equal to +1 or -1, and has a du ration of *Tc.* The transitions of the data symbols and

chips coincide such that the rati o *T,* to *Tc* is an integer. If *Wss* is the b andwidth of S.,(t) and *B* is the bandwidth of m(t)cos(2pifct) , the spreading d ue to *p(t)* gives *W ss* » *B.*

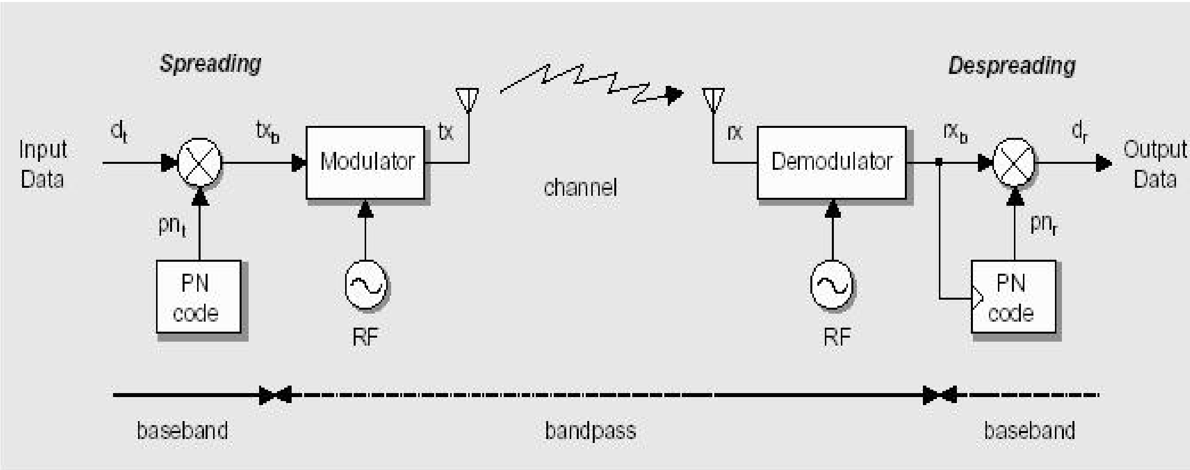
Figure 5.49(b) illustrate s a DS receiver. Assuming that code synchronization

rece iver,
has been achieved at the the received signal passes throug h the wideband filte is multiplied by a loc al
r and replica of the PN code sequence *p(tj.* If *p(t)* = ±l,

then $p^2(t) = 1$, and this mu ltiplication 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 demodul ato-r. Because s 1 (t) has the form of a BPSK signal, the corresponding demodulation extracts $m(t)$.



Below figur shows the received spectra of the desired signal and the interference at the output of the receiver wideband filter. Multiplication by the ratio Wss/B, which is equal to the processing gain defined as

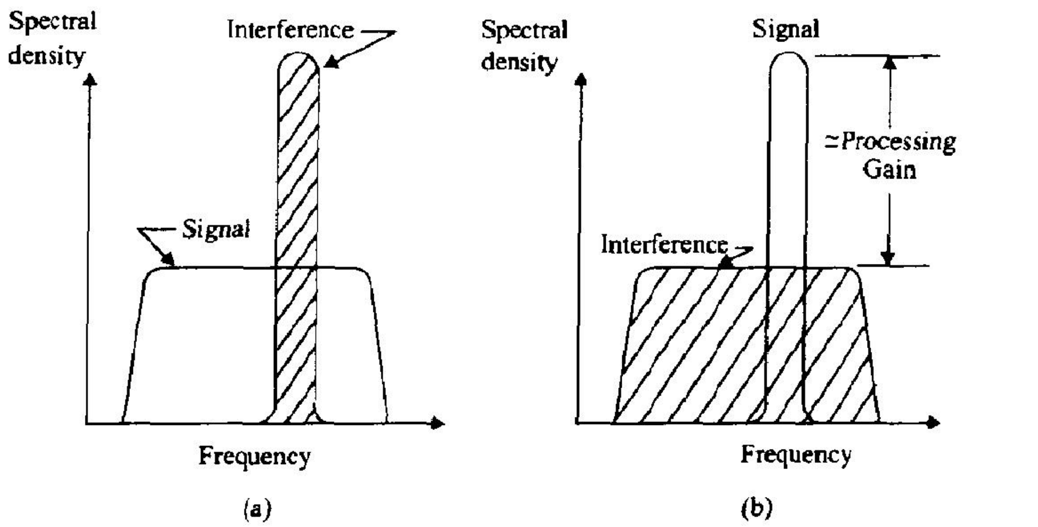


Figure 5.50
Spectra of desired received signal with interference: (a) wideband filter output and (b) correlator output after despreading.

T_s R_c W_{ss}

The greater the processing gain of the system, the greater will be its ability to suppress in-band interference.

- Consider a direct sequence spread spectrum system with K multiple access users. Assume each user has a PN sequence with N chips per message symbol period T such that $NTc = T$.

The transmitted signal of the k th user can be expressed as

[redacted]

where $Pk(t)$ is the PN code sequence of the kth user, and $mk(t)$ is The data sequence of the k th user. The received signal Will consist of the sum of K Different transmitted signals (one desired user and K- I Undesired users).

The despreader at the receiver multiplies $s_r(t)$ by *c(t), for jamming*

Which is simply a BPSK modulation of the carrier tone

the carrier power S_j is spread over a bandwidth of approximately $2/T_c$
Using Bandpass filter with BW 2/T, most of the jamming power is filtered
as an approximation, we can say that the jamming power passed by the filter is

The jamming is reduced by (T_c/T)
The inverse of this factor is the gain in SNR

$$G_P = \frac{T}{T_c} = \frac{R_c}{R} \approx \frac{W_s}{W_d}$$

Frequency Hopped Spread Spectrum (FH-SS)

Frequency hopping involves a periodic change of transmission frequency.

A frequency hopping signal may be regarded as a sequence of modulated data bursts with time-varying, pseudorandom carrier frequencies.

- The set of possible carrier frequencies is called the hopset.
- Hopping occurs over a frequency band that includes a number of

channels.

Each channel is defined as a spectral region with a central frequency in the hopset and a bandwidth large enough to include most of the power in a narrowband modulation burst (usually FSK) having the corresponding carrier frequency.

The bandwidth of a channel used in the hopset is called the instantaneous bandwidth.

- The bandwidth of the spectrum over which the hopping occurs is called the total hopping bandwidth. Data is sent by hopping The transmitter carrier to seemingly random channels which Are known only to the desired receiver.
- On each channel, smallbursts of data are sent Using

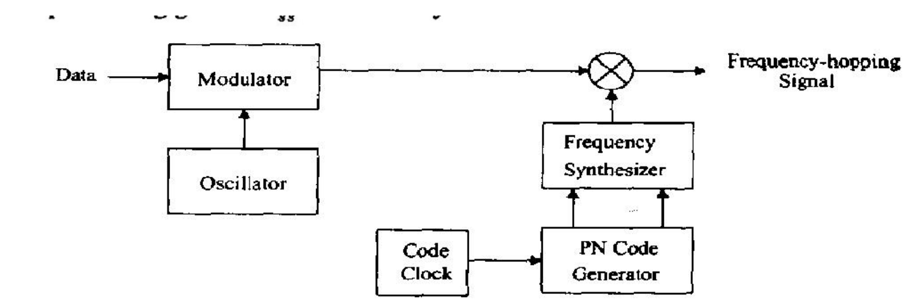
conventional narrowband modulation before the transmitter hops again.

If only a single carrier frequency (single channel) is used on each hop, digital data modulation is called single channel modulation

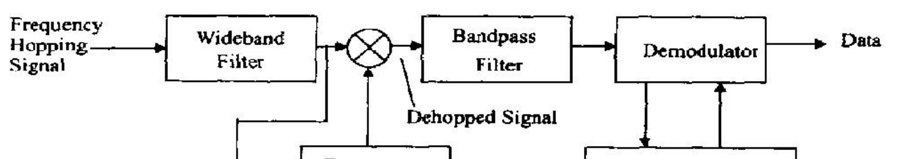
. Figure a single channel FH-SS system. The time duration bet-

ween hops is called the *lwp duration* or the *hopping period* and is denoted by *Th.*

The total hopping bandwidth and the instantaneous bandwidth are denoted by W s s and *B,* respectively.



(a) Transmitter



The processing gain = **Wss / B** for FH systems.

After frequency hopping has been removed from the received signal, the

resulting signal is said to be dehopped.

If the frequency pattern produced by receiver synthesizer in Figure5.51(b) is synchronized with frequency pattern of the received

signal, then the mixer output is a dehopped signal at a fixed difference frequency.

Before demodulation, the dehopped signal is applied to a conventional receiver.

In FH, whenever an undesired signal occupies a particular hopping channel,the noise and interference in that channel are translated in

frequency so that they enter the demodulator.

Thus it is possible to have collissions in a FH system where an undesired user transmits in the same channel at the same time as the desired user.

Frequency hopping may be classified as fast or slow. \

Fast frequency hopping occurs if there is more than one frequency hop during each transmitted symbol. Thus, fast frequency hopping implies that the hopping rate equals or exceeds the information symbol rate.

Slow frequency hopping occurs if one or more symbols

are transmitted in the time interval between frequency hops.

If binary frequency-shift keying (FSK}is used, the pair of possible instanta-neous frequencies changes With each hop.

The frequency channel occupied by a transmitted symbol is called the transmission channel.

The channel that would be occupied if the altemative symbol were transmitted is called the complementary channel.

The frequency hop rate of a FH-SSsystem is determined

by the frequency agility of receiver synthesizers, the type of information being transmitted, the amount of redundancy used to code against collisions, and the distance to the nearest potential interferer.

In FH-SS systems, several users independently hop their carrier frequencies

While using BFSK modulation. If two users not simultaneously utilizing the same frequency band, the probability of error for BFSK can be given by

$$P_e = \frac{1}{2}\exp\left(-\frac{E_b}{2N_0}\right)$$

However, if two users transmit simultaneously in the same frequency band,

a collision, or "hit", occurs. In this case it is reasonable to assume that the probability of error is 0.5. Thus the overall probability of bit error can be modeled as

$$P_e = \frac{1}{2}\exp\left(-\frac{E_b}{2N_0}\right)(1-p_h) + \frac{1}{2}p_h$$

where *ph* is the probability of hit, which must be determined. If there are *M* possible hopping channels (called slots), there is a I*IM* probability that a given

interferer will be present in the desired user's slot.

<u>FH-SS has an advantage over DS-SS i</u>n that it is not as susceptible to the near-far problem. Because signals are generally not utilizing the same frequency simultaneously, the relative power levels of signals are not as critical as in DS-SS. The near-far problem is not totally avoided, however, since there will be some interference caused by stronger signals bleeding into weaker signals due to imperfect filtering of adjacent channels.

To combat the occasional hits, error-cor- rection coding is required

on all transmissions. By applying strong Reed- Solomon or other burst error correcting codes, performance can be increased dra-matically, even with an occassional collision.

Performance of FHSS

Performance analysis

Major issue: Tx and Rx may use difference frequency slots

channel mismatch

SNR for coherent demodulation is

- $$\boxed{\gamma_{\text{coherent}} = \frac{\hat{M}^2 \sigma_s^2}{M \sigma_v^2}}$$

where $\hat{M} = \sum_{m=0}^{M-1} I_{j_1 = j_2}$ is the number of matched frequency slot selections among M selections.

Performance is limited by the correctness of frequency-selection

Assume mismatch probability p_d be the probability that there is mismatch in the first j channels

With our simple channel selection rule $P_j \leq 1 - (1 - p_d)^j$

Average channel mismatch probability $\bar{P}_J \leq \frac{1}{J} \sum_{j=0}^{J-1} 1 - (1 - p_d)^j$.

For every M transmissions, number of correct matches is

$$\hat{M} = M(1 - P_J) \geq M\left(1 - \frac{1}{J}\sum_{j=0}^{J-1} 1 - (1 - p_d)^j\right)$$

Hybrid Spread Spectrum Techniques

In addition to the frequency hopped and direct sequence, spread spectrum multiple access techniques, there are certain other hybrid combinations that pro vide certain advantages. These hybrid techniques are described below

<u>Hybrid FDMA/CDMA (FCDMA)</u>

This technique can be used as an alternative to the DS-CDMA technique

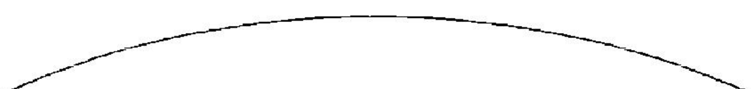
- Figure shows the spectrum of this hybrid scheme.

The available wideband spectrum is divided into a number of subspectras with smaller bandwidths.

Each of these smaller sub channels becomes a narrowband CDMA system having processing gain lower than the original CDMA system.

This hybrid system has an advantage in that the required bandwidth need not be contiguous and different users can be allot ted different subspectrum bandwidths depending on their requirements.

The capacity of this FDMA/CDMA technique is calculated as the sum of the capacities of a sysm operating in the subspectra

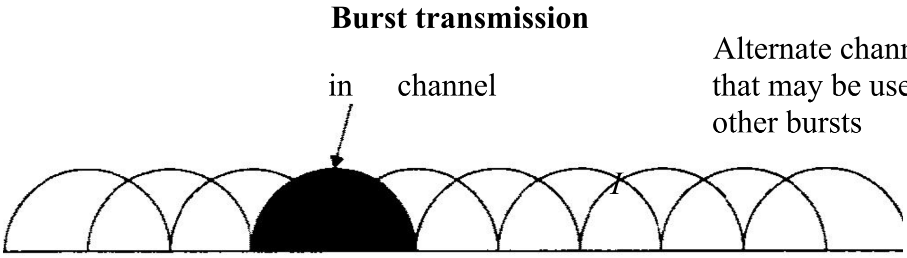


Hybrid Direct Sequence/Frequency Hopped Multiple Access (DS/ FHMA)

- This technique consists of a direct sequence modulated signal whose center frequency is made to hop periodically in a pseudorandom fashion

F i g u r e shows the frequency spectrum of such a signal [Dix94). Direct sequence, frequency hopped systems have an advantage in that they avoid the near far effect

However, frequency hopped CDMA systems are not adaptable to the soft handoff process since it is difficult to synchronize the frequency hopped base station receiver to the multiple hopped signals.



Frequency spectrum of a hybrid FHIDS system

Time Division CDMA (TCDMA)

In a TCDMA (also called TDMA/ CDMA) system, different spreading codes are assigned to different cells.

Within each cell, only one user per cell is allotted a particular time slot.

- Thus at any time, only one CDMA user is transmitting in each cell

When a handoff takes place, the spreading code of the user is changed to that of the new cell.

Using TCDMA has an advantage in that it avoids the near-far effect since only one user transmits at a time within a cell

Time Division Frequency Hopping (TDFH)

This multiple access technique hasan advantage insevere multipath or when severe co-channel interference occurs

· . The subscriber can hop to a new frequency at the start of a new TDMA frame, thus avoiding a severe fade or erasure event on a particular channel.

This technique has been adopted for the GSM standard, where the hop ping sequence is predefined and the subscriber is allowed to hop only on certain frequencies which are assigned to a cell.

This scheme also avoids co-channel interference problems between neighboring cells if two interfering base station transmitters are made to transmit on different frequencies at different times.

The use of TDFH can increase the capacity of GSM by several fold.

MUTIPLE ACCESS TECHNIQUES

Multiple access schemes are used to allow many mobile users to share simultaneously a finite amount of radio spectrum.

The sharing of spectrum is required to achieve high capacity by simultaneously allocating the available bandwidth (or the available amount of channels) to mul- tiple users.

For high quality communications, this must be done without severe degradation in the performance of the system.

Frequency division multiple access (FDMA), *time division multiple access* (TDMA), and *code division multiple access* (CDMA) are the three major access techniques used to share the available bandwidth in a wireless communication system.

These techniques can be grouped as *narrowband* and *wideband* systems,

depending upon how the available bandwidth is allocated to the users.

Narrowband Systems - The. term *narrowband* is used to relate the bandwidth of a single channel to the expected coherence bandwidth of the channel.

- In a narrowband multiple access system, the available radio spectrum is divided into a large number of narrowband channels

The channels are usually operated using FDD.

- To minimize interference between forward and reverse links on each channel, the frequency split is made as great as possible within the frequency spectrum, while still allowing inexpensive duplexers and a common transceiver antenna to be used in each subscriber unit

In narrowband FDMA, a user is assigned a particular channel which is not shared by other users , and if FDD is used {that is, each channel has a

forward and reverse link), then the system is called FDMAIFDD.

Narrowband TDMA, on the other hand, allows users to share the same channel but allocates a unique time slot to each user in a cyclical fashion on the channel, thus separating a small number of users in time on a single channel.

For narrowband TDMA, there generally are a large number of channels allocated using either FDD or TDD, and each channel is shared using TDMA Such systems are called TDMAIFDD or TDMA!l'DD access systems.

Wideband systems -In wideband systems, the transmission bandwidth

of a single channel is much larger than the coherence bandwidth of the channel.

Thus, multipath fading does not greatly affect the received signal within a wide band channel, and frequency selective fades occur in only a small fraction of the signal bandwidth.

wideband multiple access systems, the users are allowed to transmit in a large part of the spectrum. \

A large number of transmitters are also allowed to transmit on the same channel.

TDMA allocates time slots to the many transmitters on the same channel and allows only one transmitter to access the channel at any instant oftime, whereas spread spectrum CDMA allows all of the transmitters to access the channel at the same time.

TDMA and CDMA systems may use either FDD or TDD multiplexing techniques.

Frequency Division Multiple Access (FDMA)

- Frequency division multiple access (FDMA) 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 samefrequency band.

- In FDD systems, the users are assigned a channel as a pair of frequencies; one frequency is used for the forward channel, while the other frequency is used for the reverse channel.

The features of FDMA are as fol lows;

- The FDMA channel carries only one phone circuit at a time.

  If an FDMA channel is not in use, then it sits idle and cannot be used by

  other users to increase or share capacity. It is essentially a wasted resource.

- After the assignment of a voice channel, the base station and the mobile transmit simultaneously and continuously.

- The bandwidths of FDMA channels are relatively narrow (30 kHz) as each channl supports only one circuit per carrier. That is, FDMA is usually implemnted in narrowband systems.

- The symbol time is large as compared to the average delay spread. This implies.that the amount of intersymbol interference is low and, thus, little or no equalization is required in FDMA narrowband systems.

- The complexity of FDMA mobile systems is lower when compared to TDMA systems, though this is changing as digital signal processing methods improve for TDMA.

- Since FDMA is a continuous transmission scheme, fewer bits are needed for overhead purposes (such as synchronization and framing bits) as compared to TDMA.

- FDMA systems have higher cell site system costs as compared to TDMA sys tems,

  because of the single channel per carrier design, and the need to use costly bandpass filters to eliminate spurious radiation at the base station.

- The FDMA mobile unit uses duplexers since both the transmitter and receiver operate at the same time. This results in an increase in the cost of FDMA subscriber units and base stations.

- FDMA requires tight RF filtering to minimize adjacent channel interference.

Nonlinear Effects in FDMA-

- In a FDMA system, many channels share the same antenna at the base station.
  The power amplifiers or the power combiners, when operated at or near saturation for maximum power efficiency, are 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. Spreading of the spectrum results in adjacent-channel interference

Intermodulation is the generation of undesirable harmonics. Harmonics generated outside the mobile radio band cause interference to adjacent services, while those present inside the band cause interference to other users in the mobile system

The first U.S. analog cellular system, the *Advanced Mobile Phone System* {AMPS), is based on FDMAIFDD.

A single user occupies a single channel while the call is in progress, and the single channel is actually two simplex channels which are frequency duplexed with a 45 MHz split.

- When a call is completed, or when a handoff occurs, the channel is vacated so that another mobile subscriber may use it.

Multiple or simultaneous users are accommodated in AMPS by giv ing each user a unique channel. Voice signals are sent on the forward channel

from the base station to mobile unit, and on the reverse channel from the mobile unit to the base station.

In AMPS, analog narrowband frequency modulation (NBFM} is used to modulate the carrier. \

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

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

where B_t is the total spectrum allocation,

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

Time Division Multiple Access (TDMA)

Time division multiple access (TDMA) systems divide the radio spectrum into time

slots, and in each slot only one user is allowed to either transmit or receive.

TDMA systems transmit data in a buffer-and-burst method, thus the transmission for any user is non continuous.

This implies that, unlike in FDMA systems which accommodate analog FM, digital data and digital modulation must be used with TDMA.

The transmission from various users is interlaced into a repeating frame structure as shown in Figure. It can be seen that a frame consists of a number of slots.

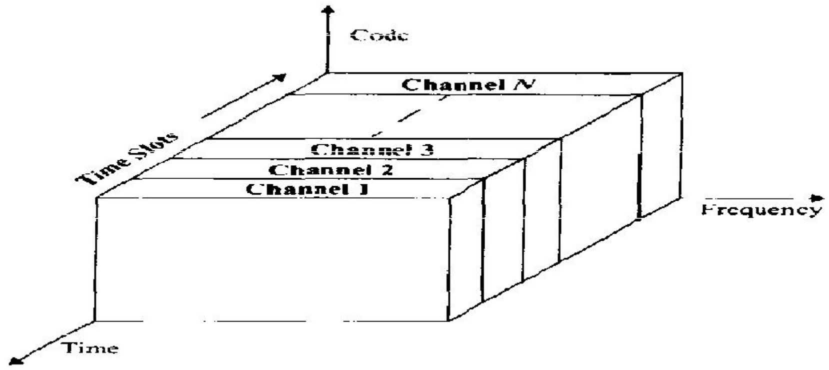
Each frame is made up of a preamble, an information message, and tail bits.

- In TDMA!I'DD, half of the time slots in the frame information message would be used for the forward link channels and half would be used for reverse link channels.

In TDMNFDD systems, an identical or similar frame structure would be used solely

for either forward or reverse transmission, but the carrier frequencies would be different for the forward and reverse links.

In general, TDMNFDD systems intentionally induce several time slots of delay between the forward and reverse time slots of a particular user, so that duplexers are not required in the subscriber unit.



In a TDMA frame, the preamble contains the address and synchronization information that both the base station and the subscribers use to identify each other.

· Guard times are utilized to allow synchronization of the receivers between different slots and frames. Different TDMA wireless standards have different TDMA frame structures

· **The features of TDMA include the following:**

TDMA shares a single carrier frequency with several users, where each user makes use of non overlapping time slots. The number of time slots per frame depends on several factors, such as modulation technique, available band- width, etc.

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 (which is most of the time)

Because of discontinuous 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.

An enhanced link control, such as that pro- vided by *mobile assisted handoff(MAR.O)* can be carried out by a subscriber by listening on an idle slot in the TDMA frame.

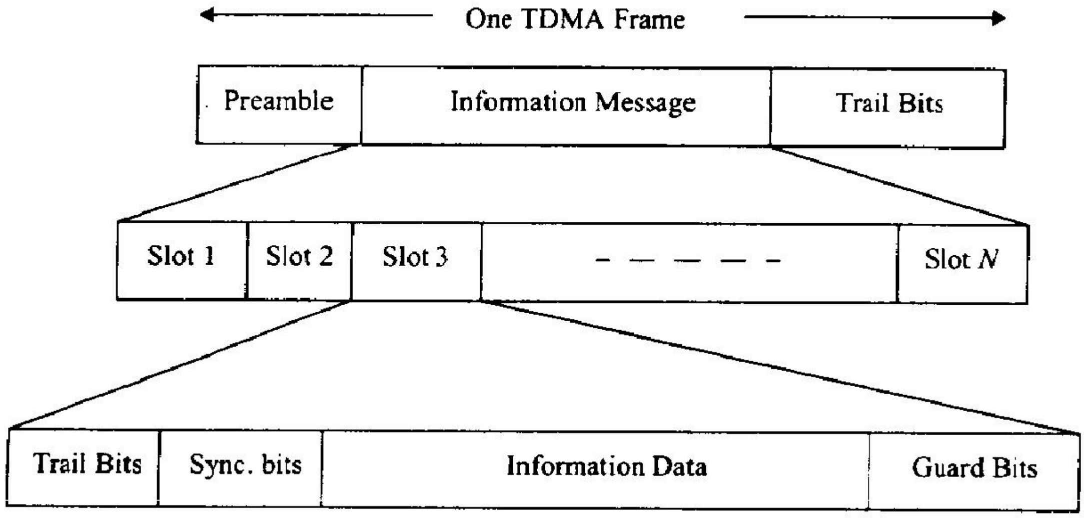
TDMA uses different time slots for transmission and reception, thus duplexers are not required.

- Even if FDD is used, a switch rather than a duplexer inside the subscriber unit is all that is required to switch between transmitter and receiver using TDMA.

- Adaptive equalization is usually necessary in TDMA systems, since transmission the rates are generally very high as compared to FDMA channels.

In TDMA, the guard time should be minimized. If the transmitted signal at the edges of a time slot are suppressed sharply in order to shorten the guard time, the transmitted spectrum will expand and cause interference to adjacent channels.

High synchronization overhead is required in TDMA systems because of burst transmissions. TDMA transmissions are slotted, and this requires the receivers to be synchronized for each data burst. In addition, guard slots are necessary to separate users, and this results in the TDMA systems having larger overheads as compared to FDMA.



TDMA has an advantage in that it is possible to allocate different numbers

of time slots per frame to different users. Thus bandwidth can be supplied on demand to different users by concatenating or reassigning time slots based on priority.

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, *'fir•* is the percentage of bits per frame which contain transmitted data. Note that the transmitted data may include source and channel coding bits, so the raw end-user efficiency of a system is generally less than *'fir.*

The frame efficiency can be found as follows.

The number of overhead bits per frame is [Zie921],

$$b_{OH} = N_r b_r + N_t b_p + N_t b_g + N_r b_g$$

where, *Nr* is the number of reference bursts per frame, *N,* is the number of traffic bursts per frame,

br is the number of overhead bits per reference burst, *bP* is the number of overhead bits per preamble in each slot, and *bg* is the number of equivalent bits in each guard time interval.

The total number of bits per frame, *br,* is

$$b_T = T_f R$$

where *Tr* is the frame duration, *R* is the channel bit rate.

The frame efficiency is thus given as

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

Number of channels in TDMA system

The number of TDMA channel slots that can be provided in a TDMA system

is found by multiplying the number of TDMA slots per channel by the number of channels available and is given by

$$N = \frac{m\,(B_{tot} - 2B_{guard})}{B_c}$$

where *m* is the maximum number of TDMA users supported on each radio channel. Note that two guard bands, one at the low end of the allocated frequency band and one at the high end, are required to ensure that users at

the edge of the band do not "bleed over" into an adjacent radio service.

Code Division Multiple Access (CDMA)

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.

· All users in a CDMA system, as seen from Figure, use the same carrier frequency and may transmit simultaneously.

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 codewords. 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 no knowledge of the other users.

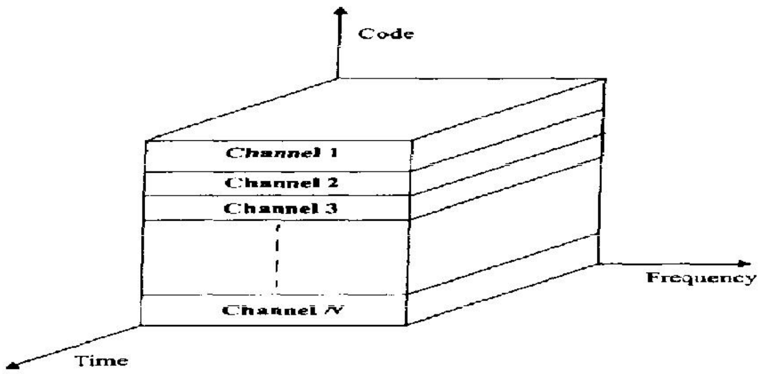
In CDMA, the power of multiple users at a receiver determines the noise floor after decorrelation.

If the power of each user within a cell is not controlled such that they do not appear equal at the base station receiver, then the *near-far problem* occurs.

The near-far problem occurs when many mobile users share the same channel. In general, the strongest received mobile signal will *capture* the demodulator at a base station.

In CDMA, stronger received signal levels raise the noise floor at the base station demodulators for the weaker signals, thereby decreasing the probability that weaker signals will be received.

To combat the near-far problem, *power control* is used in most CDMA implementations.



Power control is provided by each base station in a cellular system and assures that each mobile within the base station coverage area provides the same signal level to the base station receiver.

This solves the problem of a nearby subscriber overpowering the base station receiver and drowning out the signals of far away subscribers.

· Power control is implemented at the base station by rapidly sampling the radiosignal strength indicator (RSSI) levels of each mobile and then sending a power change command over the forward radio link.

Despite the use of power control within each cell, out-of-cell mobiles provide interference which is not under the control of the receiving base station.

The features of CDMA including the following:

Many users of a CDMA system share the same frequency. Either TDD or FDD may be used.

• Unlike TDMA or FDMA, CDMA has a soft capacity limit.

Increasing the number of users in a CDMA system raises the noise floor in a linear manner.

Thus, there is no absolute limit *on* the number of users in CDMA. Rather, the system performance gradually degrades for all users as the number of users is increased, and improves as the number of users is decreased.

Multipath fading may be substantially reduced because the signal is spread over a large spectrum.

If the spread spectrum bandwidth is greater than the coherence bandwidth of the channel, the inherent frequency diversity will mitigate the effects of small-scale fading.

Channel data rates are very high in CDMA systems. Consequently, the symbol (chip) duration is very short and usually much less than the channel delay spread.

Since PN sequences have low autocorrelation, multi path which is delayed by more than a chip will appear as noise. A RAKE receiver can be used

to improve reception by collecting time delayed versions of the required signal.

Since CDMA uses co-channel cells, it can use macroscopic spatial diversity to provide soft handoff. Soft handoff is performed by the MSC, which can simultaneously monitor a particular user from two or more base stations. The MSC may chose the best version of the signal at any time without switching frequencies.

Self-jamming is a problem in CDMA system.

· Self-jamming arises from the fact that the spreading sequences of different users are not exactly orthogonal, hence 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.

The near-far problem occurs at a CDMA receiver if an undesired user

has a high detected power as compared to the desired user.

<u>Capacity of CDMA</u>

In CDMA users are separated by different codes but not by frequencies or time slots as in TDMA and FDMA. In CDMA many users can share the same frequency band and communicate at the same time.

A channel in TDMA or FDMA is a frequency and a time slot. There is only a limited number of channels, which restrict the number of simultaneous users. In CDMA a channel is a code. There is an almost unlimited number of codes, and thus channels, but it doesn’t mean an unlimited capacity.

Each user is a source of noise to the receivers of other users (recall the discussion we had on DSSS) or to the receiver in the base station. This will limit the number of users.

The number of user per cell (the capacity) is determined by the signal to noise ratio. If there are too many users, the noise will be high, the S/N (signal to noise) ratio will be low and reception quality will be poor.

This is different from TDMA/FDMA, where the capacity is determined by the number of available channels

n: number of users

W: total bandwidth

R: data rate

S_r: signal to noise ratio

$$n = \frac{W}{R \times S_r}$$

Cellular CDMA

When analyzing the multi access (FDMA,TDMA,CDMA) capability of a system,it prevents us from serving infinite number of users.

· In TDMA or FDMA, it has infinite number of available time or the frequency slot without interfere from each other.
In cellular CDMA, mechanism is different:

First we analyze the uplink where the spreading codes and power control are imperfect due to scattering, multipath fading, Doppler fading.

The different users are distinguish by different spreading codes.

The users separation is non perfect hence causing interference to other users.

As the number users increases, interference increases & cause decrease in the transmission quality.

The CDMA puts a soft limit on no: of users, that is the no: of users depends on signal to interference noise ratio required by the receiver.

The no: of users depends on increase or decrease in signal to interference noise ratio at receiver and it effect the capacity.

Two types of interference in cellular CDMA:

1. Intercell interference
2. Intracell interference

INTRACELL	INTERCELL
• Interference cause in same cell Behaves as an Gaussian noise & effect is similar to thermal noise	from the neighbouring cell

It is described by noise rise

Noise rise is the sum of noise & inter-

ference compare to the noise alone,

$$= \frac{N+I}{N}$$

Amount of interference is determined by the code used in different cell.

A key property of CDMA system is,it uses the universal frequency reuse concept.

The same frequency band is used in all the cell & the users are distinguished in different cell by different codes.

ADVANTAGE:

In uplink, the interference behaves like noise like structure & it is because of no: of users in each cell is large & the signal arriving in base station have the same strength.

In downlink, spreading codes are orthogonal and different users can be separated completely.

The no: of users is limited by WALSH HADAMARD codes.

The interference is improved by multiplying by WALSH HADAMARD code by a spreading code or scrambling code.

POWER CONTROL:

In uplink, they are classified into two types :

1) Closed loop 2) Open loop

<u>CLOSED LOOP</u>

The mobile station first send certain power to the base station & base station will tell whether the power is too high or too low and the mobile station adjust its power accordingly.

The bandwidth is chosen inorder to compensate the small scale fading.

Due to noise in the channel there is variation in power arriving at the base station which causes reduction.

<u>OPEN LOOP</u>

Using conjection with closed loop.

Compensate for large scale fading.

In downlink,

The power control is not necessary for CDMA because all the signal from the base station arrives at the mobile station with same power.

The goal is to minimize the total transmission power by keeping the bit error rate and signal to interference noise ratio above the threshold.

It decrease the intercell interferences and improves the capacity.

The power cntrl is necessary for CDMA and is optional for FDMA & TDMA .

ADVANTAGES OF CELLULAR CDMA:

Soft handoff

Soft capacity

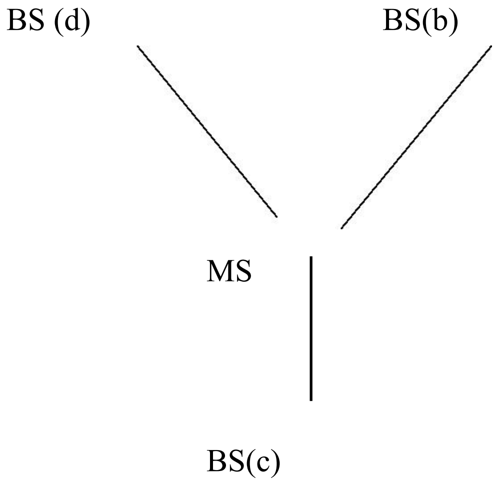
No need of frequency planning

Multipath tolerance

SOFT HANDOVER:

~~If a mobile station close the cell boundary , receiving the signal from two or more base station~~ and also to all the base station

And the signal coming from different mobile station must have different delay & is compensated by rake receiver.



PROBLEM IN CELLULAR CDMA:

Cell interference.

Dispersion causes shifted version of codes,it leads to signal to interference noise ratio.ULTI

3G W-CDMA (UMTS)

The Universal Mobile Telecommunications System (UMTS) is a visionary sir interface standard that has enveloped since late 1996 under the auspices of the European Telecommunications Standards Institute (ETSI).

UMTS was submitted by ETSI to ITU's IMT-2000 body in 1998 for consideration as a world standard.

At that time, UMTS was known as Terrestrial Radio Access (UTRA) and was designed to provide a high capacity upgrade path for GSM.

Around the turn of the century, several other competing wideband CDMA (W-CDMA) proposals agreed to merge into a single W-CDMA standard, and this resulting W-CDMA standard is now called UMTS.

UMTS, or W-CDMA, assures backward compatibility with the second generation GSM, IS-136, and PDC TDMA technologies, as well as all 2.5G TDMA technologies.

The network structure and bit level packaging of GSM data is retained by W-CDMA, with additional capacity and bandwidth provided by a new CDMA air interface.

TDMA technologies will involve into a unified W-CDMA standard.
W-CDMA is the primary focus of the 3GPP world standard body.

This 3GPP standards body is developing W-CDMA for both wide area mobile cellular coverage (using FDD) as well as indoor cordless type applications (using TDD).

The 3G W-CDMA air interface standard had been designed for "always-on" packet based wireless service, so that computers, entertainment devices, and telephones may all share the same wireless network and be connected to the internet, anytime, anywhere.

W-CDMA will support packet data rates up to 2.048 Mbps per user (if the user is stationary), thereby allowing high quality data, multimedia, streaming audio, streaming video and broadcast-type services to consumers.

Future versions of W-CDMA will support stationary user data rates in excess of 8 Mbps.

W-CDMA provides public and private network features, as well as videoconferencing and *virtual home entertainment* (VHE).

W-CDMA designers compensate that broadcasting, mobile commerce (m-commerce), games, interactive video, and virtual private networking will be possible throughout the world, all from a small portable wireless device.

W-CDMA requires a minimum spectrum allocation of 5 MHz, which is an important distinction from the other 3G standards.

W-CDMA is designed to provide backward compatibility and interoperability for all GSM, IS-136/PDC, GPRS, and EDGE.

With this, data rates from as low as 8 kbps to as high as 2Mbps will be carried simultaneously on a single W-CDMA 5MHz radio channel, and each channel will be able to support between 100 and 350 simultaneous voice calls at once, depending on antenna sectoring, propagation conditions, user velocity, and antenna polarizations.

W-CDMA employs variable/selectable direct sequence spread spectrum chip rates that can exceed 16 Mega chips per second per user.

A common rule of thumb is that W-CDMA will provide at least a six times increase in spectral efficiency over GSM.

Because W-CDMA will require expensive new base station equipment, the installation of W-CDMA will likely be slow and gradual throughout the world.

The evolutionary path to 3G will require dual mode or tri-mode cell phones that can automatically switch between the incumbent 2G TDMA technology, EDGE, or W-CDMA service where its available.

Multiuser Detection in CDMA

Idea is proposed in 1980

Primary Idea of Multiuser detection techniques is to cancel the interference and noise caused by other users

Total Interference (Includes interference due to other cells also)

Near Far Problem in CDMA

- Difficulty to implement more sophisticated algorithm at receiver because of limitations of size, cost, weight of handset.
- Solutions to all such problems is Multi-user detection

It is done by exploiting information of interfering user rather than ignoring the presence of other user like in single user detection technique and help to overcome near far problem

Features

Reduced interference leads to capacity
increase Alleviates the near/far problem

Capability to reject interference created by narrow band
MUD can be implemented in the BS or mobile, or both
In a cellular system, base station (BS) has knowledge of all the chip
sequences Capability to achieve diversity in frequency

Reduces Complexity and increase in spectral efficiency
Robustness to multipath fading

Effects of ISI and delay spread is mitigateLinear detectors apply linear transformations to matched filter outputs to minimize MAI. Simple to implement but can get complex.

- Non-Linear detectors are more complex calculation wise than linear detectors due to nonlinearity, however they perform better under severe conditions

Optimum Multiuser Detector

- Jointly detect all users data bits
- Optimum Multiuser Detector

Maximum Likelihood Sequence Detector

- Selects the mostly likely sequences of data bits given the observations
- Needs knowledge of side information such as

- ○ received powers of all users

  relative delays of all users

  spreading sequences of all user

  Thus Optimum Multiuser Detector is highly complex
  complexity grows exponentially with number of users

  Impractical even for moderate number of users

- Need to know the received signal energies of all the users

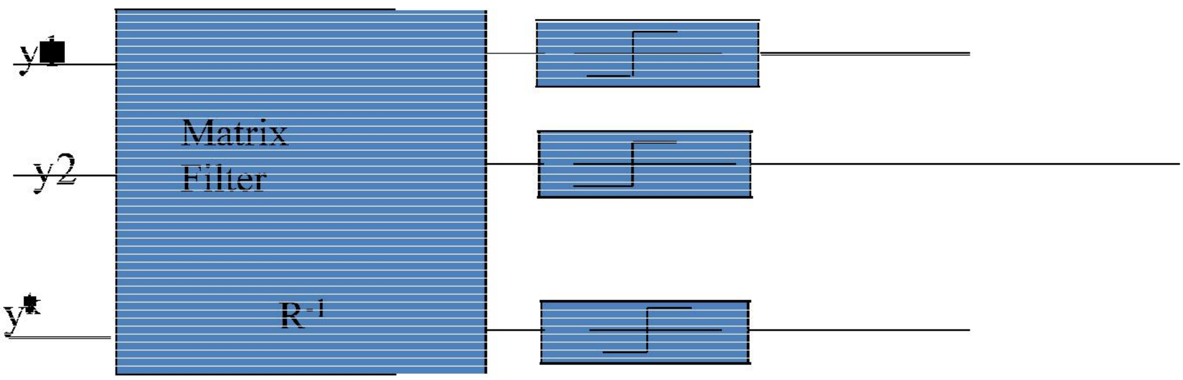
Linear Algorithms

- Linear mapping algorithms are applied to the outputs of the matched filters
- Less complexity than optimal ML receiver
- Practical Linear Algorithms:
  - **<u>Decorrelating Detector</u>**

  Minimum-mean squared error (MMSE)

  Blind (adaptive non-adaptive) te chniques

- **<u>Decorrelating Detector</u>**



– w[redacted]re y=[redacted]$y_1,y_2,\ldots,y_K]^T$, R and W are KxK ma[redacted]ces

– Compo[redacted]s of R are given by cross-corr[redacted]s between signature waveforms $s_i(t)$

- The matrix representation method is analogous to zero-forcing (ZF) equalizers for ISI channels
- Advantages:

– Does not require knowledge of users' powers

- Disadvantages:

– Noise enhancement

MMSE

Optimum multi-user detection applies maximum-likelihood principle:

The ML principle

- ○ has the optimum performance provided transmitted symbols equal alike
- ○ has large computational complexity - In exhaustive search 2^{NK} vectors to be considered! (*K* users, *N* bits)
- ○ requires estimation of received amplitudes and phases that takes still more computational power
- ○ can be implemented by using Viterbi-decoder that is 'practically optimum' ML-detection scheme to reduce computational complexity by surviving path selections

Suboptimum Detectors

DetectorPrefer

– Better near-far resistance than Matched Filter Detector

– Lesser complexity (linear complexity) than Optimum Detector

Non-Linear Algorithms

- **Non-Linear Algorithms:**

- ○ **Estimate the interference caused by each _received signal. This is done through multitude of stages.**
- ○ **Practical Non-Linear Detectors:**

Multistage Detector

Decision Feedback Detector

Successive Interference Cancellation (SIC)
Parallel Interference Cancellation (PIC)

Decisions produced by 1st stage are $\hat{x}_1(1), \hat{x}_2(1)$

2nd stage: $\hat{x}_1(2), \hat{x}_2(2)$

Decision-Feedback Detectors

Characterized by two matrix transformation: forward filter and feedback filter Whitening filter yields a lower triangular MAI matrix Performance similar to that of the decorrelator

DECISION FEEDBACK

Pretty much same performance as the Decorrelator detector

– **Successive Interference Cancellers**

– Better near-far resistance than Matched Filter Detector

– Lesser complexity (linear complexity) than Optimum Detector

– **The main advantages are**:

– 1) The weakest user will see a tremendous signal gain from the MAI reduction since all of the interfering channel will add up as signals to the weakest user. Hence every user is on a win-win situation.

– 2) For severe conditions if we remove the strongest user the rest of weaker users will benefit hence the signal can be recovered

– 3) Can recover from near-far effects**The main disadvantages are:**

- 1) If the strongest estimate is not highly reliable it results on performance degradation

  2) As the power profile changes the signals must be reordered

  3) Every stage introduces a delay

Parallel Interference Cancellation

Parallely cancels the estimates of the multi access interfaces from output of matched filters

1) Because of the parallel nature no delays/stage required!

2) Simpler than other linear detectors

Disadvantages

1) **More vulnerable to near-far issues**

2) **Complicated circuitry**

Issues in practical implementation
Processing complexity
Processing delay

Sensitivity and robustness

Limitations of MUD

Capacity improvements only on the uplink would only be partly used anyway in determining overall system capacity

Cost of doing MUD must be as low as possible so that there is a performance/cost tradeoff advantage