**Wireless Communication:** Transmitting/receiving voice and data using electromagnetic waves in open space.

- The information from sender to receiver is carried over a well-defined frequency band.
- Each channel has a fixed frequency bandwidth and Capacity (bit-rate)
- Different channels can be used to transmit information in parallel and independently.

**Types of Wireless Communication**

- Mobile (moving at high speed e.g. in a car)
  - Cellular Phones (GSM / cdma2000)
- Portable (Laptop connected to Wireless LAN)
  - IEEE 802.11b (WiFi)
  - IEEE 802.15.3 (UWB)
- Fixed
  - IEEE 802.16 (Wireless MAN)

**Terminology**

- **Mobile Station (MS):** A mobile station or simply mobile is a radio terminal that may be attached to a high speed mobile platform (e.g. a cell phone in a fast moving vehicle).
- **Portable:** It is a radio terminal that can be hand held and can be used by someone at walking speed (e.g. a cordless phone).
- **Subscriber:** A mobile or a portable user
- **Base Station (BS):** Base stations are fixed antenna units with which the subscribers communicate. Base stations are connected to a commercial power source and a backbone network.
- **Cell:** The area of coverage is divided into cells. Each cell has a base station usually located at its centre or at the edge.
- **Control Channel:** Radio channels used for transmission of call setup, call request and call initiation.
- **Forward Channel (downlink):** Radio channel used for transmission of information from the base station to the mobile.
- **Reverse Channel (uplink):** Radio channel used for transmission of information from the mobile to the base station.
- **Full Duplex System:** A full duplex system is one in which simultaneously two way communications can take place. The transmission and reception takes place on two different channels.
- **Half Duplex System:** Two way communication done by using same radio channel for both transmission and reception. At any given time the user can either transmit or receive.
- **Handoff:** The process of transferring the mobile station from one channel or base station to another.
- **Page**: Page is a brief message that is broadcast over the entire service area by many base stations at the same time primarily to locate where the mobile station is.

- **Mobile Switching Centre (MSC)**: Mobile switching centre plays central role in the cellular switching network. All of the base stations are connected to mobile switching centre and MSC itself is connected to the public switched telephone network (PSTN).

- **Transceiver**: A device capable of transmitting and receiving radio signals.

- **Forward Voice Channel (FVC)**: Used for voice transmission from BS to MS.

- **Reverse Voice Channel (RVC)**: Used for voice transmission from MS to BS.

- **Forward Control Channel (FCC)**: Used for initiating a call from BS to MS.

- **Reverse Control Channel (FCC)**: Used for initiating a call from MS to BS.

**Basic Concepts: Multiple Access**

- Multiple Access schemes are used to allow many mobile users to share a finite amount of radio spectrum

**Frequency Division Multiple Access (FDMA)**

- In FDMA available spectrum is divided into smaller frequency bands called channels. Different users are given different channels

- Guard bands are provided between adjacent channels

**Time Division Multiplexing**

- In TDMA whole available spectrum is used by any user
• The time is divided into slots and each time slot constitutes a channel. Different users are allocated different time slots
• Time guard band is provided between adjacent time slots
• TDMA can be used only in digital systems
• Synchronization is very important in TDMA otherwise one user may listen in some other time slot

**Code Division Multiple Access (CDMA)**

![CDMA Diagram]

• User may use whole available spectrum and may transmit all the time
• The users use different codes

**Full Duplex Systems**

Full duplex is provided either by FDD or the frequency division duplex or TDD the time division duplex. Here full duplex refers to the communication between the mobile and the base station. It is for single user. So a mobile system may use a combination of a multiple access scheme and a duplex system. For example we can have an FDMA/FDD or a TDMA/ FDD and CDMA/FDD.

**FDD**

In FDD one frequency band is used for communication from base station to mobile and another frequency band is used for communication from mobile to base station.

**TDD**

In TDD one time slot is used for communication from base station to mobile and another time slot is used for communication from mobile to base station.

**Cellular Networks Evolution**

• First Generation
- Launched in mid-1980s
- Analog Systems
- Analog modulation, mostly FM
- Supported voice traffic only
- Multiple access technique used was FDMA/FDD
- Confined to national boundaries
- Example: AMPS (Advanced Mobile Phone Services)

**Second Generation (2G)**
- Developed for voice communication
- Digital system, digital modulation (e.g. GMSK in GSM)
- TDMA/FDD and CDMA/FDD multiple access
- Even though they were designed for voice they had provision for data rates of the order of ~9.6 kbps
- After some time need of data traffic was felt but a lot of GSM phone had been sold by that time (66% of the mobile phones in 2002 were GSM phones). So it was not possible to change the standard immediately. So 2.5G was developed

**Examples of 2G Systems**
- Global System for Mobile Communication (GSM) (uses TDMA/FDD)
- Personal Digital Communication (Popular in Japan)
  - IS-95 (CDMA, US/South Korea)

**Limitation of 2G Systems**
- Developed for voice communication (not suitable for data traffic)
- Average data rate of the order of tens of kbps
- Not suitable for Internet (packet switched network)
- Multiple standards (no true global coverage)

**Cellular Networks Evolution**

**2.5 G**
- The efforts to remove the limitations of 2G resulted in 2.5G
- Digital System
- Voice + low-data rate
- Internet access through GPRS (General Packet Radio Service, provides data-rates of the order of 50 kbps)
- Enhanced Data Rate Through Global Evolution (EDGE): provided better data rates through the use of better modulation. Data-rate of the order of 200kbps.

**Cellular Networks Evolution**

**3 G**
- Digital modulation
- Simultaneous voice + high-data rate
- Multi-megabit Internet access
- Voice-activated calls
- Multimedia transmission
- 3G puts constraints on how fast you go and how fast you can download the traffic.
- 3G is truly a world standard
- Examples are W-CDMA which is the wide band CDMA and the other is a CDMA 2000 standard (data-rate 384 kbps), improved version HSPA: provides data rate of the order of 5-30 Mbps,

**Cellular Networks Evolution**

- **4 G**
  - Based on an all-IP packet switched network
  - The ability to offer high quality of service for next generation multimedia support.
  - Use multiple antenna system and MIMO to provide high spectral efficiency
  - Use Orthogonal Frequency Division Multiplexing (OFDM)
  - WiMAX and LTE provide data rates in the range 100-200 Mbps

**Detail of a Cellular Call**

- A cell phone, when turned on, (though not engaged in call) scans the group of FCC to determine the one with the strongest signal.
- The MS monitors that channel until it drops below a usable threshold. It then scans for another channel which is the strongest.
- MS is continuously monitoring signal strength and the base station it is associated with (cell standby power consumption). At any time it knows at least one base station with which it can communicate.
- Control channels are defined and standardized over the entire area of service. Typically the control channel use up 5% of total number of channels.

**A call to a Mobile User**

- The MSC dispatches the request to all base stations. The Mobile Identification Number (MIN) is broadcast as a paging message over all FCC throughout the service area.
- The MS receives the paging message from the BS it is monitoring. It responds by identifying itself over the RCC.
The BS conveys the handshake to the MSC. The MSC instructs the BS to move to an unused voice channel. If voice channel is not available no call initiation will take place.

The BS signals the MS to change over to an unused FVC and RVC.

A data message (called alert) is transmitted over the FVC to instruct the mobile to ring.

All of this sequence of events occurs in just a few seconds, are not noticeable to the user.

While the call is in progress, the MSC adjusts the transmitted power in order to maintain the call quality.

Modern base stations perform some activities (e.g. power control) of MSC since MSC cannot handle such a huge traffic.

The mobile phones which have powerful processors also perform power calculations.

A Call from a Mobile User

A call initiation request is sent to the RCC.

Along with this, MS transmits its MIN, Electronic Serial Number (ESN) and the phone number of the called party.

The MS also transmits the Station Class Mark (SCM) which indicates the maximum transmitter power level for the particular user.

The BS forwards the data to the MSC, which validates the data and makes connection to the called party through PSTN.

Cellular Mobile System Concept

1. The early mobile radio systems achieved a large coverage area by using a single, high powered transmitter with an antenna mounted on a tall tower.
2. This approach achieved very good coverage, but it to reuse was impossible the frequencies.
3. The cellular concept offered very high capacity in a limited spectrum by reusing frequencies.
4. In cellular system the coverage area is divided into (conceptually hexagonal) cells. A low power transmitter provides coverage to a cell. The actual radio coverage of a cell is known as the footprint and is amorphous in nature.

5. Each base station is allocated a portion of the total number of channels available to the entire system. Nearby base stations are assigned different groups of channels to reduce interference. All the available channels are assigned to a small number (called cluster size) of neighbouring base stations.

6. The channel groups may be reused as many times as necessary, as long as the interference between co-channel stations is kept below acceptable levels.

7. 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 without additional radio spectrum.

**Frequency Reuse**

1. In cellular system by limiting the coverage area to within the boundaries of a cell, the same group of channels may be used to cover different cells that are separated from one another by large enough distances to keep interference levels within tolerable limits.

2. 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.*

3. Figure 1 illustrates the concept of cellular frequency reuse, where cells labelled with the same letter use the same group of channels. They are called co-channel cells.

4. 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, the total number of available radio channels can be expressed as
\[ S = kN \]  

9. The N cells which collectively use the complete set of available frequencies is called a cluster and N is called cluster size. 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

\[ C = MkN = MS \]  

10. The capacity of a cellular system is directly proportional to the number of times a cluster is replicated in the service area.

11. If the cluster size N is reduced while keeping the cell size constant, more clusters are required to cover a given area and hence more capacity (a larger value of C) is achieved. But a small cluster size indicates that co-channel cells are located closer which means larger co-channel interference.

12. If the cluster size N is increased while keeping the cell size constant, lesser number of clusters is required to cover a given area and hence less capacity (a smaller value of C) is achieved. But a larger cluster size indicates that co-channel cells are located at larger distance which means smaller co-channel interference.

13. Hence the value for N is a function of how much interference a mobile or base station can tolerate while maintaining a sufficient quality of communications.

14. The frequency reuse factor of a cellular system is given by \( \frac{1}{N} \), since each cell within a cluster is only assigned \( \frac{1}{N} \) of the total available channels in the system.

15. In hexagonal geometry, there are only certain cluster sizes and cell layouts which are possible. N can only have values which satisfy

\[ N = i^2 + ij + j^2 \]  

where i and j are non-negative integers.

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

   (1) move i cells along any chain of hexagons and then
   (2) turn 60 degrees counter-clockwise and move j cells.

This is illustrated in Figure 2 for \( i = 3 \) and \( j = 2 \) (N = 19).
Example: If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels, compute the number of channels available per cell if a system uses (a) 4-cell reuse, (b) 7-cell reuse (c) 12-cell reuse. If 1 MHz of the allocated spectrum is dedicated to control channels, determine an equitable distribution of control channels and voice channels in each cell for each of the three systems.

Channel Assignment Strategies

1. Channel assignment strategies can be either fixed or dynamic. The choice of channel assignment strategy affects the performance of the system, when a mobile user is handed off from one cell to another.
2. In a fixed channel assignment strategy; each cell is allocated a predetermined set of voice channels. If all the channels in that cell are occupied, the call is blocked and the subscriber does not receive service.
3. 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.
4. 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.
5. 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 the cells.
6. 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 Strategies
1. 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 process called handoff requires that the voice and control signals be allocated to channels associated with the new base station.

2. Processing handoffs is an important task in any cellular radio system. Many handoff strategies prioritize handoff requests over call initiation requests when allocating unused channels in a cell site.

3. The system designers must specify an optimum signal level at which to initiate a handoff. A slightly stronger signal level is used as a threshold at which a handoff is made. This margin, given by $\Delta = P_{\text{rhandoff}} - P_{\text{rminimumusable}}$ should not be too large or too small.

4. If $\Delta$ is too large, unnecessary handoffs will occur and will burden the MSC. If $\Delta$ is too small, there may be insufficient time to complete a handoff before a call is lost due to weak signal conditions.

5. 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. To ensure this the base station monitors the signal level for a certain period of time before a handoff is initiated.

6. The length of time needed to decide if a handoff is necessary depends on the speed at which the vehicle is moving. If the slope of the short-term average received signal level in a given time interval is steep, the handoff should be made quickly.

7. In first generation analog cellular systems, signal strength measurements are made by the base stations and supervised by the MSC. Each base station constantly monitors the signal strengths of all of its reverse voice channels to determine the relative location of each mobile user with respect to the base station tower.

8. In second generation systems that use digital TDMA technology, handoff decisions are mobile assisted. In mobile assisted handoff (MAHO), every mobile station measures the received power from surrounding base stations and continually reports the results of these measurements to the serving base station. A handoff is initiated when the power received from the base station of a neighboring cell begins to exceed the power received from the current base station by a certain level or for a certain period of time.

9. The MAHO method enables the call to be handed over between base stations at a much faster rate.

10. During the course of a call, if a mobile moves from one cellular system to a different cellular system controlled by a different MSC, an intersystem handoff becomes necessary. An MSC engages in an intersystem handoff when a mobile signal becomes weak in a given cell and the MSC cannot find another cell within its system to which it can transfer the call in progress.
**Practical Handoff Considerations**

1. In practical cellular systems, several problems arise when designing 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.

2. Several schemes have been devised to handle the simultaneous traffic of high speed and low speed users while minimizing the handoff intervention from the MSC.

3. Another practical limitation is the ability to obtain new cell sites. Often it is more convenient to install additional channels and base stations at the same physical location of an existing cell, rather than find new site locations.

4. 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.

5. The umbrella cell approach ensures that the number of handoffs is minimized for high speed users and provides additional microcell channels for pedestrian users.

6. 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.

7. Another practical handoff problem in microcell systems is known as cell dragging. Cell dragging occurs when there is a line-of-sight (LOS) radio path between the subscriber and the base station. The user enters the neighboring cell without handoff. This creates a potential interference and traffic management problem.

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

9. The IS-95 code division multiple access (CDMA) spread spectrum cellular system the mobiles share the same channel in every cell. Thus handoff does not mean a physical change in the assigned channel, but rather that a different base station handles the radio communication task.
10. By simultaneously evaluating the received signals from a single subscriber at several neighboring base stations, the MSC may actually decide which version of the user's signal is best at any moment in time.

11. The ability to select between the instantaneous received signals from a variety of base stations is called soft handoff.

**Interference**

1. Interference is the major limiting factor in the performance of cellular radio systems. Sources of interference include another mobile in the same cell, a call in progress in a neighboring cell, other base stations operating in the same frequency band, or any non-cellular system which leaks energy into the cellular frequency band.

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

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

4. Interference is more severe in urban areas.

5. Interference is a major bottleneck in increasing capacity and is often responsible for dropped calls.

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

7. Even though interfering signals are often generated within the cellular system, they are difficult to control in practice (due to random propagation effects).

**Co-channel Interference and System Capacity**

1. Due to frequency reuse 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.

2. Co-channel interference cannot be reduced by simply increasing power of a transmitter. An increase in transmit power also increases the interference to neighboring co-channel cells.

3. To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance.

4. When the size of each cell is same and the base stations transmit the same power, the co-channel interference 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).

5. By increasing the ratio of D/R, interference is reduced from the co-channel cell. The parameter $Q = D / R$, is called co-channel reuse ratio. For hexagonal geometry

\[ Q = \frac{D}{R} = \sqrt{3N} \]  

A small value of $Q$ provides larger capacity since the cluster size $N$ is small, whereas a large value of $Q$ improves the transmission quality, due to a smaller co-channel interference. A trade-off must be made between these two objectives in cellular design.

6. Let $i_0$ be the number of co-channel interfering cells. Then, the signal-to-interference ratio (S/I or SIR) for a mobile receiver which monitors a forward channel can be expressed as
\[
\frac{S}{I} = \frac{S}{\sum_{i=1}^{N} I_i}
\]  

where S is the desired signal power from the desired base station and \(I_i\) is the interference power caused by the \(i^{th}\) interfering co-channel cell base station.

7. In a mobile radio channel, the average received power \(P\) at a distance \(d\) from the transmitting antenna is approximated by

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

or

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

where \(P_0\) is the power received at a close reference point at a small distance \(d_0\) from the transmitting antenna, and \(n\) is called path loss exponent.

8. Now consider the forward link where the desired signal is the serving base station and interference is due to co-channel base stations. If \(D_i\) is the distance of the \(i^{th}\) interferer from the mobile, the received power at a given mobile due to the \(i^{th}\) interfering cell will be proportional to \((D_i)^n\)

9. 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 approximated as

\[
\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{N} (D_i)^{-n}}
\]

10. Considering only the first layer of interfering cells, if all the interfering base stations are equidistant from the desired base station and if this distance is equal to the distance \(D\) between cell centers, then equation (5) simplifies to

\[
\frac{S}{I} = \frac{(D/R)^n}{i_0} = \left(\frac{\sqrt{3N}}{i_0}\right)^n
\]

11. The co-channel interference determines link performance, which in turn dictates the frequency reuse plan and the overall capacity of cellular systems.

**Example**

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 6 co-channels cells in the first tier, and all of them are at the same distance from the mobile. Use suitable approximations.

**Solution**

\(n = 4\), First, let us consider a 7-cell reuse pattern. The co-channel reuse ratio \(D/R = 4.583\). The signal-to-noise interference ratio is given by \(S/I = (1/6) \times (4.583)^4 = 75.3 = 18.66\) dB. Since this is greater than the minimum required \(S/I\), \(N = 7\) can be used.
First, let us consider a 7-cell reuse pattern. The signal-to-interference ratio is given by \[ S/I = \left(\frac{1}{6}\right) \times (4.583)^3 = 16.04 = 12.05 \text{ dB}. \]

Since this is less than the minimum required \( S/I \), we need to use a larger \( N \). For \( N=12 \), the corresponding co-channel ratio is given by equation (2.4) \( D/R = 6.0 \). The signal-to-interference ratio is given by \( S/I = \left(\frac{1}{6}\right) \times 6^3 = 36 = 15.56 \text{ dB}. \) Since this is greater than the minimum required \( S/I \), \( N = 12 \) can be used.

**Adjacent Channel Interference**

1. Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference. Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the passband.
2. The problem is serious if an adjacent channel user is transmitting in very close range to a subscriber's receiver, while the receiver attempts to receive a base station on the desired channel. This is referred to as the near-far effect in which nearby transmitter captures the receiver of the subscriber. The near-far effect also occurs when a mobile close to a base station transmits on a channel close to one being used by a weak mobile.
3. Adjacent channel interference can be minimized by careful filtering and channel assignments.
4. By sequentially assigning successive channels in the frequency band to different cells we can separate adjacent channels in a cell by \( N \) channel bandwidths, where \( N \) is the cluster size.
5. Large enough channel separation is needed to bring the adjacent channel interference to an acceptable level, or tighter base station filters are needed. In practice, each base station receiver is preceded by a high Q cavity filter to reject adjacent channel interference.

**Power Control for Reducing Interference**

1. In cellular systems the power levels transmitted by every subscriber unit are under constant control by the serving base stations. This is done to ensure that each mobile transmits the smallest power necessary to maintain a good quality link on the reverse channel.
2. Power control not only increases battery life for subscriber unit, but also significantly reduces the interference on reverse channel in the system.
3. Power control is especially important for CDMA spread spectrum systems that allow every user in every cell to share the same radio channel.

**Improving Capacity in Cellular Systems**

As the demand for wireless service increases, the number of channels assigned to a cell 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. Following techniques are used for increasing capacity

a. Cell splitting
b. Sectoring
c. Coverage zone approach

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. 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. Cell splitting and zone microcell techniques do not suffer the trunking inefficiencies experienced by sectored cells, and enable the base station do all handoff chores related to the microcells, reducing the computational load at the MSC.

**Cell Splitting**

1. 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 transmitter power. Capacity increases due to the additional number of channels per unit area.
2. Assume that the radius of every cell is reduced to half. To cover the service area with smaller cells, approximately four times as many cells (and clusters) would be required. That would increase the number of channels, and thus capacity, in the coverage area.
3. Cell splitting is done without affecting the channel allocation scheme required to maintain the minimum co-channel reuse ratio \( Q \) between co-channel cells.
4. For the new cells to be smaller in size, the transmit power of these cells must be reduced. The transmit power of the new cells will be \( 1/16 \) of larger call (assuming \( n=4 \)). This is necessary to ensure that the frequency reuse plan for the new microcells behaves exactly as for the original cell.
5. In practice, not all cells are split at the same time. Therefore, different cell sizes will exist simultaneously. In such situations, special care should to be taken to keep the distance between co-channel cells at the required minimum, and hence channel assignments become more complicated.
6. Also, handoff issues must be addressed so that high speed and low speed traffic can be simultaneously accommodated (the umbrella cell approach is commonly used).
7. One can not simply use the original transmit power for all new cells or the new transmit power for all the original cells. If the larger transmit power is used for all cells, some channels used by the smaller cells would not be sufficiently separated from co-channel cells. On the other hand, if the smaller transmit power is used for all the cells, there would be parts of the larger cells left unserved. For this reason, channels in the old cell must be broken down into two channel groups, one that corresponds to the smaller cell reuse requirements and the other that corresponds to the larger cell reuse requirements.
8. Antenna down-tilting, which focuses radiated energy from the base station towards the ground (rather than towards the horizon), is often used to limit the radio coverage of newly formed microcells.