BASICS OF MOBILE CELLULAR COMMUNICATIONS

Introduction:

From the subscribers point of view, mobile systems are perhaps the most exciting telecommunications development since the invention of the telephone. The developments Of optical fiber technology sound very impressive and the statistics involved is mind boggling to the average person in the street, but that person does not usually fully appreciate how he or she benefits personally. Such developments are mainly occurring In the wings or backstage and are not really tangible service improvements to the Subscriber. In the fact, good service is expected.

The pocket telephone, on the other hand, is a revolution that is center stage and whose Benefits can be instantly appreciated by a person who decided to invest in one of these Devices. However, despite the many advantages of being in contact with business associates or friends at all hours of the day, no matter where one many happen to be Within a city, there are some sociological disadvantages to the pocket telephone. For example, the anti social aspects of receiving calls in a quiet restaurant have already Prompted some establishments to require customers to leave their pocket phones at the Reception desk.

Cellular mobile telephone systems are difficult to classify. They could be considered To be part of the local loop since they extend out to the subscriber handset. Because of the distances traveled between a fixed subscriber and the mobile subscriber (or mobile-to-mobile subscriber), they could be called long-haul circuits. The technology incorporated some of the most advanced radio transmission techniques. In addition, the call processing

Requires high-level digital switching techniques to locate the mobile subscriber and setup and to maintain calls while the mobile subscriber and setup and to maintain calls While the mobile subscriber and setup and to maintain calls while the mobile subscriber is in transit.

The portable telephone was only recently made possible by the miniaturization resulting from VLSI electronic circuitry. Even today there are still some technologies problems to solve, such as increasing the time between recharging the batteries of portable telephones. More serious is the fact that vehicular mobile telephones and portable radiotelephones have some severe technical incompatibilities. These take Two forms. First, the systems developed in different parts of the world do not yet Even have the same operating frequency,and the system designs vary quite considerably. However ,the ITU is currently coordinating Recommendations with all Major parties to enable equipment compatibility fo r the next generation of cellular mobile radio systems. Second,one can say there are three generations of cellular radio Systems: analog FM, narrowband TDMA, and wideband CDMA. The analog has been around for a number of years, narrowband TDMA is currently being put into service, And wideband CDMA is possibly on the horizon. There are significant equipment incompatibilities when moving from one system to the other or trying to incorporate two or three of these into the same network. Many of these problems stem from the difference

In power outputs. Vehicle radios transmit at relatively high power levels in the region of 1 of 10 W,whereas portable units transmit relatively low power levels of 1 to 10mW. While this is fine for the customer, it makes coexistence of the two systems a network Planners nightmare.

In summary, cellular telephony is the culmination of several technologies which have progressed in parallel over the past two decades.In fact,the progress has been so Rapid that the ITU has had a problem in organizing CCITT/CCIR meetings fast enough To determine standards that are consistent with the new technology.

INTRDUCTION

Instead of wire, we use radio equipment to transfer information between the mobile station and the GSM network.

Anyone who has traveled in a car while listening to broadcast radio may have noticed that the reception quality changes from time to time. For example, when passing through a tunnel or between hills. This particular effect is called shadowing or long-term fading and is only one of many things that must be dealt with in a wireless world.

This chapter addresses some of the major problems in the cellular radio environment plus some solutions used to resolve these problems. Additionally, it provides an overview of some of the digital communications principles.
Weak signal strength is a common problem. Often random (thermal) noise or an interfering signal can be described as any unwanted signal received on the same channel as the desired signal. It could for example; another transmitter that is too close to the one we would like to listen to and transmitting on the same frequency.

Fig

The fact that the system is cellular and that all frequencies are reused means that reception is poor due primarily to the amount of interference rather than noise. That is, a signal in most cases would be strong enough to provide good reception, were it not for interfering signals.
When planning how the frequencies are to be used, special precautions must be taken. this described in the cell planning section.

Cellular strtucture and planning:

The mobile telephony system uses a hexagonal “honeycomb” structure of cells, with a base station at the center of each cell which gives radio coverage to that cell and connects into the public telephone network, as shown in the figure. The hexagonal cell pattern arises from the best method of covering a given area, remembering that radio coverage is ideally radial in nature. The three possibilities of cell coverage is also shown in the figure.

Fig.

Cell type	Center-center Distance	Unit zone coverage	Area of coverage	Width of overlap	Min. No. of freqs.
Triangle	R	~1.3*sqr(r)	~3.7*sqr(r)	R	6
Square	R8 sqrt(2)	2*sqr(r)	~2.3*sqr(r)	0.59*r	4
Hexagon	R8 sqrt(3)	~2.6*sqr(r)	~1.1*sqr(r)	0.27*r	3

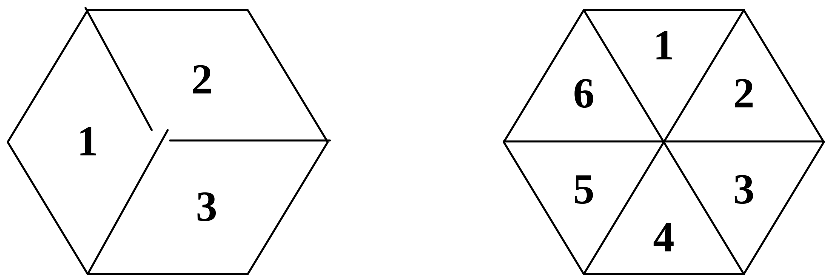
A cellular structure with smaller and smaller cells is evolving for two main reasons.

1. the increasingly limited available power which can be transmitted by the smaller and smaller mobile phones.
2. Increased capacity.

Whereas the mobile base station can have a large power output and therefore cover a radius of 50 km or more, themove to smaller, pocket sized mobile phones restruicts the return path distance only to a few hundred metres. For example, the transmitted output power of 5 mW can reliably work over a distance of about 300 metres. The smaller cell sixze of less than 1 km radius is called a microcell structure and has the major of benefit of providing orders of magnitude improvement of system capacity over the large cell size (20 km). The ijn crease in channel capacity is approximately inversely proportional to the square of the microcell radius. For example, reducing the cell radius from 8 km to 150 metres will increase the network capacity by a factor of more than 2500. In a rapidly in increasing market, keeping up witgh the ever-increaing customer demand for access to the mobile network is a major problem. It is currently believed that the microcell structure will satisfy that demand.

Capacity can be further enhanced by cell sectorisation. As cell size decreases, the distance between the base stations of identical frequency also decreases. This can be offset by careful control of th epower radiated from either the base station and/or the mobile ststion. That process is described later, but another way to reduce the cochannel interference coming from the six surrounding cells of a seven cell structure is to use several directional antennas at each base station. The various sectorisation of cells are as shown in the figure.

Fig.



Mobile Location

For a mobile subscriber to receive a call, the subscriber's precise location must obviously be known. There are several possible ways to track the movement of mobile station. A convenient method is to split up the whole cellular network into a number of location areas, each having its own ID number. Each base station with in a particular area periodically transmits its area ID number as part of its system control information. As the mobile station moves from the control of one base station to another, and the network is updated with the new area in which it can be found. This is all done during signaling information to transfer.

Frequency Allocations

As usual, in the absence of global standards, mobile radio system designs in different parts of the world have evolved using frequencies in the bands made available by their national frequency coordinators. Inevitably the frequencies chosen are different from one country to another. While this may not be a problem in a large country like the United States, it renders the mobile telephone useless to many European users who travel across the borders of several countries to conduct their normal daily business. In the 1970s Federal Communications Commission (FCC) in the United States allocated the frequencies shown in Table.

For land based mobile radiotelephones. The accompanying diagram fig. Illustrates how the allocated frequency spectrum is used.

The 800 MHz band has been allocated for the use of cellular mobile radio, and the original systems used analog modulation. In the not too distant future, this band will be probably completely digital although, at present it contains both analog and digital. Full duplex operation is made possible by using 20 MHz upstream and 20 MHz down stream carriers, separated by 45 MHz
870 to 890MHz are the base station transmit frequency band and 825 to 845 MHz is the mobile station transmit frequency band. The carrier spacing is 30 KHz.

Personal Communications Network (PCN) is a term now associated with micro cellular technology, which specifically uses portable or pocket-sized telephones. The trend for these systems is to use higher frequencies than previous mobile systems notably

The 1.7 GHz to 2.3 GHz band

Although most of this band is already allocated, the FCC is under considerable pressure to allocate exclusively or at least up to 200 to 300 MHz of this band for PCNs.
In Europe the frequencies in Table 8.2.

Have been adopted for land based mobile radiotelephones.

Initially the AM systems operated in the 935 to 960 MHz (base transmit) and 890 to 915 MHz (Mobile Transmit) bands. On introduction of the digital modulationsytems, they were allocated the upper 10 MHz of upstream and down stream bands, but eventually the analog systems will be displaced and the full 2 x 25 MHz will be for digital.

In Japan, Yet another set of frequencies has been chosen, as indicated in Table………
As in the United States, the newer digital systems operate in frequency bands that are common to the analog systems. Upstream and downstream frequencies are separated by 55 MHz.

Fig

Propagation Problems:

The following discussion is primarily related to moving vehicles but is equally applicable to portable telephone users,where the vehicle is just one of the propagation situations encountered and perhaps the most difficult to qualify. Radio propagation is one of the most Fundamental problems in mobile communication engineering. Unlike fixed point-to-point systems,there are no simple formulas that can be used to determine anticipated Path loss.By the nature of the continuosly varying environment of the mobile subscriber, There is a very complicated relationship between the mobile telephone received signal Strength and time. The situation is not so bad if the mobile unit remains stationary for The duration of the call. If a particularly poor reception point is encountered,a short move Down the road may significantly improve the reception. For a moving subscriber, as in the typical call placed from a moving car,the signal strength variation is a formidable Problem which can be approached only on a statisticals level.For land –based mobile Communication the received signal variation is primarily the result of multipath fading Caused by obstacles such as buildings or terrain irregularities.

The obstacles (clutter) cab be classified in three areas, as follows,

1. Rural area, in which there are wide-open spaces with perhaps a few scattered trees but no buildings in the propagation path.
2. Suburban area, including villages where houses and scattered trees obstruct the propagation path
3. Urban area, which are heavily built up with large buildings or multistory houses or apartment and greater numbers of trees

The terrain conditions can be categorized as follows

1. Rolling hills, which have irregular undulations but are not mountainous
2. Isolated mountains, where a single mountain or ridge is within the propagation path and nothing else interferes with the received signal
3. Slopes, where the up-or down slopes are atleast 5 km long

Antennas

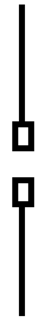
Previously described microwave antennas have all been parabolic in nature. Those were highly directional, since it was necessary to focus the energy in one directional, since it was necessary to focus the energy in one direction. Conversely, mobile station radios require antennas to be omni directional in the horizontal plane (looking from above) but to have very little upward radiation. This is because at anytime, the mobile unit could be at any point around the full 360 range of the base station antenna. Note that these are not isotropic antenna qualities, which would require equal radiation in all directions. There are several styles of antenna that can be used for this purpose. Since these antenna are generally variations on the dipole antenna, a few comments on the dipole antenna are necessary. The dipole is the simplest of all antennas as far as physical construction is concerned. But even this antenna has some rather elaborate mathematics associated with it. The radiation pattern for a short piece of metallic rod is shown in fig..

Which indicates that it is indeed nondirectional in the horizontal plane, although there is some directivity in the vertical plane. When the dipole is fed from the center of the metal rod antenna such that the total length is one half-wave length, as one would expect this is referred to as the half wave dipole antenna, as in fig……….. The gain of a half wave is about 2 dB (i.e. relative to the Isotropic antenna)

The impedance of antennas is important because the idea is to match the impedance of the transmitting device to that of free space so that 100 percent energy transfer takes place. If there is a bad mismatch reflection from the antenna back into the transmitter cause severe interference. In the analogous case of TV antenna the interference caused by mismatch is observed as ‘ ghosting’ on the picture.

Base station Antennas

There are several types of antennas frequently used for mobile base station and there are illustrated in fig…



1. **Bent or Folded dipole antenna**
   This is constructed as a bent or folded conductor whose horizontal dimension is one half wavelength.

2. **Ground plane antenna**
   The coaxially fed antenna is physically convenient for many applications. The finite ground plane tends to incline the radiation pattern maximum slightly upward instead of horizontally. This is not usually desirable and can be circumvented by several techniques for improving the ground plane.
3. **Stacked Antenna**
   A stack of several half-wave dipole antennas reduces the radiation in the vertical direction and effectively increases the omni directional horizontal gain. For e.g. a stack of four folded dipoles increases the gain to about 6 dB.

   Variations on the stacked antenna can be used if the gain in the horizontal direction needs to be asymmetrical to illuminate preferences some areas of a cell, which may have some geographical or building screening problems.

4. **Corner reflector Antenna**

For the case of cell sectorization the base station must radiate only over a specific angle (e.g.60) For this antenna a half wave dipole is placed in the corner of a V shaped wire plane reflector at 0.25 to 0.65 Y spacing from the vertex. The wires are typically spaced less than 0.1 Y apart. With an angle of 90 a typical gain of at least 8 dB relative to a half wave dipole can be achieved. As the angle is made smaller, the directivity (gain) increases.

In order to provide coverage to some difficult area, it may be necessary to use an antenna that has a high directivity or preferred orientation of radiation. A corner reflector may not have enough gain, in which case the high gain YAGI could be used.

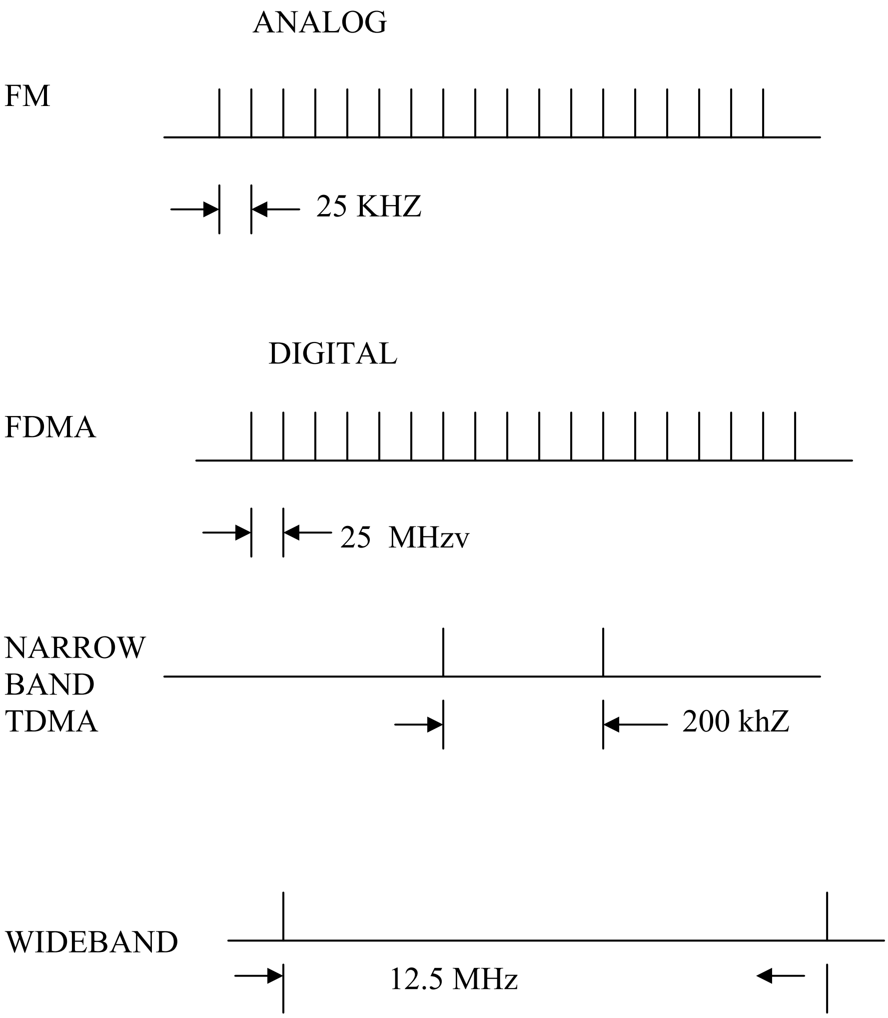
Mobile Antennas

The antennas used for car mobile radios must be omni directional and as small as possible and must not be adversely affected by the car body. The location of the antenna is usually on the roof, trunk (boot) or rear fender (bumper). The whip antenna of fig.'s one possibility. This is a $\lambda/4$ vertical conductor with the body acting as a ground plane. The compact size makes this a very popular style, the center of the best location so that the car body least affects the signal. Figure 1 is a $\lambda/2$ coaxial antenna. Figure .2 is as high gain whip antenna with a loading impedance coil used to adjust the current distribution.

Portable radio antennas are usually either short ($\lambda/4$ or less) vertical conductor whip antennas or normal-made helical designs. There are a variety of options. Some are coaxial fed and retractable for compactness, where as other are detachable. Still others are encased in a plastic or rubber materials for ruggedness. Ideally, for maximum convenience, the antenna should not even protrude from the body of the portable radio. The antenna used for portables is a difficult problem. First there is no ground plane as is the case for automobiles, s o its efficiency is reduced. Second, the user may not be pointing the antenna in the optimum direction, or, even worse, it may be held almost horizontally. In either case the antenna may not be in the best orientation for the correct polarization reception. Third, the user's head may cause disturbances by mismatching the antenna impedance. Incidentally, the long-term health effects of holding a portable telephone close to the head for extended periods of time are at present unknown.

Types of mobile systems

The different type of mobile systems, in terms of frequency spectrum usage, are summarized in fig. They differ primarily in modulation technique and carrier spacing.



FREQUENCY SPECTRUM
OCCUPIED

Analog FM.

The first generation cellular systems in operation were analog FM radio systems, which allocated a single carrier for each call. Each carrier was frequency modulated by the caller. The carriers were typically spaced at 25 kHz intervals 9i.e carrier bandwidth 0. the allocated bandwidth was relatively narrow, and only a few channels were available.

Digital FDMA

The FDMA systems resemble analog FM, with the exception that the carrier is modulated by a digitally encoded speech signal. The bandwidth of each carrier is similar to the analog FM system (i.e. 25 kHz).

Digital narrowband TDMA

The TDMA systems operates with several customers sharing one carrier. Each user is allocated a specific timeslot for transmission and reception of short bursts or packets of information.

The bandwidth of each carrier is typically 200 kHz, and the total bandwidth available is in the region of 10 to 30 Mhz, which allows a reasonably large channel capacity in the region of 500 to 1000 channels.

In the united states, for example the 823 to 849 Mhz frequency band is allocated for the one –way transmission form the base station to the user, and the 868 – to- 894 –Mhz band is allocated for transmission form the user to the base station. To enable two competitive systems to operate simultaneously, only half of each of these bands is available to each operator. Each system therefore has 12.5 Mhz available for transmission and 12.5Mhz for reception. Each of these 12.5 Mhz bands is sub dived into 30- kHz channels for voice communication. If the cellular structure chosen is that shown in fig, having a total of seven frequency bands for the hexagonal base station pattern, each base station can be allocated only 12.5 Mhz/7, or about 1.8 Mhz of bandwidth. The resulting frequency reuse enable 1.8 Mhz /30 kHz =60 channel per cell be used for voice communication, which is reduced to about 55 since some channels are necessary signaling. The final value for the number of users pr cell is 55 X 3 =165 (or 55 X12 = 660 with degradation).

Digital wideband.

One from of digital wideband operation which has good future potential is CDMA. In these is a single carrier, which is modulated by the speech signals of many users. Instead of allocating each user a different time slot, each is allocated a different modulation code. Mobile user contributes some interfering energy to the receivers of the fellow users, the magnitude of which depends on the processing gain. In addition to interference from users in adjacent cells. Because the distance between adjacent user can be approximately 50 percent. Since this is considered to be acceptable, frequency reuse is unnecessary. Consequently, each cell can use the full available bandwidth (12.5 MHz) for CDMA operation. The total number of users per cell has been estimated to be

$$M \approx 3\ N/B$$

Where N is the processing gain, and the signal power is assumed to be at least 10 db higher than the thermal noise power in the receiver.

For a 12.5 MHz available bandwidth, the spreading sequence is taken to be 12.5 Mb/s , and if the voice signals are each digitized to 8.5 kHz , N=12.5 MHz/8.5 KHz=1470 (31.7 db) M is therefore =551 (or about 1900 with 2.4 kb/s voice digitization, that is with degradation).since about 50% of the interference comes from user located in each cell is approximately M/1.5=367(or abut 1270 with degradation).

Digital cellular radio

The digital cellular radio can be divided into two categories, narrowband and wideband. The narrowband systems are often considered to the second generation of cellular radio, which is the main technology of today.

Digital narrowband TDMA

Although the digital narrow band TDMA systems in North America and Europe have developed along similar lines, there many features that are different. The digital narrow band TDMA cellular radio will be the pan-European system called GSM, to which the U.S system is called IS-54 will be compared. GSM now stands for Global System for Mobile Communications.

The radio link

To cater to both vehicle-mounted and hand-held portable mobile stations, the peak output power ranges from 20W(43 dbm) for vehicles and 2 to 5 W (33 to 37 dbm) for portables. The maximum receiver sensitivity of either vehicle or base stations is –104 dbm and it is –102 dbm for the portables giving the vehicle-mounted mobile an operational advantage of several decibles.this balanced by fact that portables are intended for use within micro cells in city centers or dense urban areas. The use of portables inside buildings, elevators, subway, and other poor radio reception location is still a problem that has not yet been fully solved.

ANALOGUE SIGNALS AND DIGITAL TRANSMISSION

Digital transmission involves sending a series of symbols, ones and zeros; from one point to another. Because speech is analogue, that is, a continuous wave form; it must me converted to the digital signals before it can be transmitted. This process is called analogue to digital conversion (A/D conversion).

Fig

The A/D conversion is performed by using a process called Pulse Code Modulation (PCM). PCM is a common method used in telecommunication systems. Involves the three main steps described below;

Sampling
Quantization
Coding

SAMPLING

Sampling involves measuring the analogue signal at specific time intervals. Each measurement is called a sample and the sampling time interval is defined as Ts [s]. The accuracy of describing the analogue signal in digital terms depends on how often the analogue signal is sampled, among other things. .This expressed as the sampling frequency fs= 1/Ts [Hz].

Fig.

According to the sampling principle

To reproduce and analogue signal without distortion, the signal must be sampled with at least twice the frequency of the highest frequency component in the analogue signal.

Normal speech mainly contains frequency components lower than the 3000Hz. higher components have quite low energy and may be omitted without affecting the speech quality very much. Applying the sampling principle when sampling analogue speech signals, the sampling frequency fs, should be at least 2 X 3 KHz = 6KHz. Telecommunication systems use a sampling frequency of 8 KHz, which is acceptable based on the sampling principle.

QUANTIZATION

In order to limit the number of values transmitted, the amplitude level is divided into a finite set of levels. Each sample within a certain interval is represented by one of these levels, figure shows the principle of quantization applied to the analogue signal – the actual sample and the quantified value the figure shows the principle of uniform quantization used in the GSM system. In uniform quantization, the distance between two levels is constant.

The public switched telephone network use A law or ------- law quantization where the distance between the levels vary, thus optimizing a constant quantization error regardless of signal amplitude.
The degree of accuracy depends on the number of levels used. Within common telephony, 256 levels are used while in GSM 8192 levels are used.

Thus, with a finite number of levels, a continuous, analogue waveform cannot be precisely represented. In most cases, there is a difference between the sampled value and the quantified value as shown in the figure., the size of the quantization error can be reduced by increasing the umber of discrete levels, but cannot be entirely removed.

CODING

Every quantified value is represented by a binary code. In order to obtain in the 256 levels, 8 bits are used. in GSM, 13 bits are used to obtain the 8192 levels.
The process of PCM, including sampling at 8khz and performing quantization and coding using 8 bits; produces a bit rate of 8000 X 8 = 64 kbit/s.
A digital link used to transmit these is called PCM link. In order to use the link more efficiently several channels are multiplexed on to the same link. The technique used is called Time division Multiple Access (TDMA) and means that several channels share the same link. Each channels uses the link during a certain amount of time called a time slot.

Figure shows how 32 channels are multiplexed onto one PCM system. The bit rate on such a link is 32 X 8 X 8000 = 2048 kbit/s.

Fig

There is also a solution where 24 channels are multiplexed onto one PCM link . the bit rate for this solution is 24 X 8 X 8000 = 1544 kbit/s.this type link preferable in the US.

Power Control and handoff

One of the most important features of any cellular radio system is handoff. In the GSM System, handoff is closely interrelated with an elaborate power control mechanism, which is designed to minimize co channel interference. The intention is to operate the mobile and base stations at the lowest possible power level, base station periodically sends a message to the mobile station to adjust its power level. By the very nature of TDMA, the mobile and base stations must transmit pulses of power that do not cause sideband generation, which would interfere with adjacent channels. The shape of pulses power control is 30 dB in steps of 2 dB. This adaptive power control during calls is estimated to improve the mean system C/I values up to 2 dB.

Frequency Hopping:

Frequency agility is an essential aspect of cellular mobile radio. The mobile station has to monitor the different frequencies of all surrounding base stations in order to facilitate the handoff process as the mobile user moves to another location which, from the system point of view, is in another cell.Frequency hopping,which was originally designed for military privacy,is nowFeatured in modern cellular radio designs to enhance performance in a multipath fadingEnvironment. Since multipath fading is a narrowband phenomenon,shifting a relatively Small amount in carrier frequency can place the radio link in a nonfading condition. GSM mobile stations use slow frequency hopping at 2000 hops per second. The frequency systhesizers that achieve this agility must settle in 100μs.

Further frequency hopping can be done by changing base station frequencies. Their Synthesizers must settle in 30μs. A minimum of five carriers are used for base station Hopping,and it is their baseband frequencies that are changed and not the transceiver RF frequencies