Wireless & Mobile Communication (EEC-801)
UNIT-III

Cellular concepts, Frequency reuse, channel assignment strategies, handoff strategies, interference and system capacity, improving coverage and capacity in cellular systems.

INTRODUCTION

We have seen that the technique of substituting a single high powertransmitter by several low power transmitters to support many users is the backbone of the cellular concept. In practice, the following four parameters are most important while considering the cellular issues: system capacity, quality of service, spectrum efficiency and power management. Starting from the basic notion of a cell, we would deal with these parameters in the context of cellular engineering in this chapter.

WHAT IS A CELL?

The power of the radio signals transmitted by the BS decay as the signals travelaway from it. A minimum amount of signal strength (let us say, x dB) is needed in order to be detected by the MS or mobile sets which may the hand-held personal units or those installed in the vehicles. The region over which the signal strength lies above this threshold value x dB is known as the coverage area of a BS and it must be a circular region, considering the BS to be isotropic radiator. Such a circle, which gives this actual radio coverage, is called the foot print of a cell (in reality, it is amorphous). It might so happen that either there may be an overlapbetween any two such side by side circles or there might be a gap between the
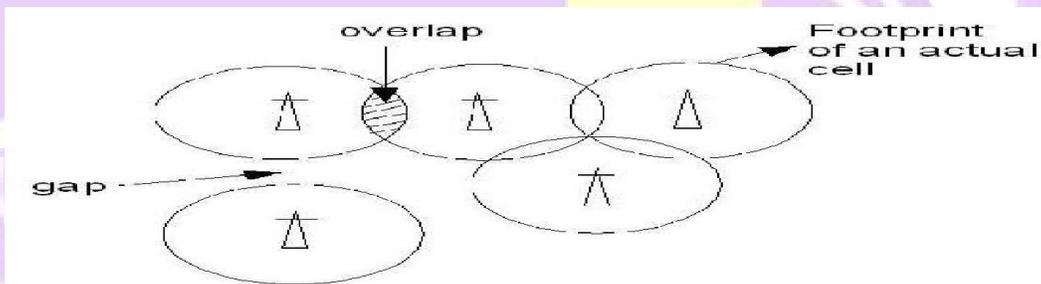

Figure: Footprint of cells showing the overlaps and gaps.

coverage areas of two adjacent circles. This is shown in Figure. Such a circular geometry, therefore, cannot serve as a regular shape to describe cells. We need a regular shape for cellular design over a territory which can be served by 3 regular polygons, namely, equilateral triangle, square and regular hexagon, which can cover the entire area without any overlap and gaps. Along with its regularity, a cell must be designed such that it is most reliable too, i.e., it supports even the weakest mobile with occurs at the edges of the cell. For any distance between the center and the farthest point in the cell from it, a regular hexagon covers the maxi-mum area. Hence regular hexagonal geometry is used as the cells in mobile communication.

FREQUENCY REUSE:

Frequency reuse, or, frequency planning, is a technique of reusing frequencies andchannels within a communication system to improve capacity and spectral efficiency. Frequency reuse is one of the fundamental concepts on which commercial wireless systems are based that involve the partitioning of an RF radiating area into cells. 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.
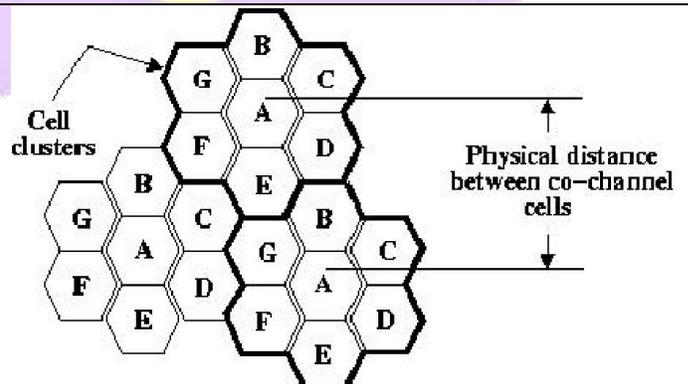
The repeating regular pattern of cells is called cluster. Since each cell is designed to use radio frequencies only within its boundaries, the same frequencies can be reused in other cells not far away without interference, in another cluster. Such cells are called `co-channel' cells. The reuse of frequencies enables a cellular system to handle a huge number of calls with a limited number of channels. Figure shows a frequency planning with cluster size of 7, showing the co-channels cells in different clusters by the same letter. The closest distance between the co-channel cells (in different clusters) is determined by the choice of the cluster size and the layout of the cell cluster. Consider a cellular system with S duplex channels available for use and let N be the number of cells in a cluster. If each cell is allotted K duplex channels with all being allotted unique and disjoint channel groups we have S = KN under normal circumstances. Now, if the cluster are repeated M times within the total area, the total number of duplex channels, or, the total number of users in the system would be T = MS = KMN. Clearly, if K and N remain constant, then

$$T \propto M \quad \ldots\ldots\ldots(1)$$

And, if T and K remain constant, then $\quad N \propto 1/M \quad \ldots\ldots\ldots(2)$

Hence the capacity gain achieved is directly proportional to the number of times
a cluster is repeated, as shown in, as well as, for a fixed cell size, small N decreases the size of the cluster with in turn results in the increase of the number of clusters and hence the capacity. However for small N, co-channel cells are located much closer and hence more interference. The value of N is determined by calculating the amount of interference that can be tolerated for a sufficient quality communication. Hence the smallest N having interference below the tolerated limit is used. However, the cluster size N cannot take on any value and is given only by the following equation

$$N = i^2 + i\,j + j^2; \quad i \geq 0; j \geq 0; \quad \ldots\ldots(3)$$

Where i and j are integer numbers.

CHANNEL ASSIGNMENT STRATEGIES:

With the rapid increase in number of mobile users, the mobile service providers had to follow strategies which ensure the effective utilization of the limited radio spectrum. With increased capacity and low interference being the prime objectives, a frequency reuse scheme was helpful in achieving this objective. A variety of channel assignment strategies have been followed to aid these objectives. Channel assignment strategies are classified into two types: fixed and dynamic, as discussed below.

| Fixed Channel Assignment (FCA)	Dynamic Channel Assignment (DCA)
In fixed channel assignment strategy each cell is allocated a fixed number of voice channels. Any communication within the cell can only be made with the designated unused channels of that particular cell. Suppose if all the channels are occupied, then the call is blocked and subscriber has to wait. This is simplest of the channelassignment strategies as it requires very simple circuitry but provides worst channel utilization. Later there was another approach in which the channels were borrowed from adjacent cell if all of its own designated channels were occupied. This was named as borrowing strategy. In such cases the MSC supervises the borrowing process and ensures that none of the calls in progress are interrupted.	In dynamic channel assignment strategy channels are temporarily assigned for use in cells for the duration of the call. Each time a call attempt is made from a cell the corresponding BS requests a channel from MSC. The MSC then allocates a channel to the requesting the BS. After the call is over the channel is returned and kept in a central pool. To avoid co-channel interference any channel that in use in one cell can only be reassigned simultaneously to another cell in the system if the distance between the two cells is larger than minimum reuse distance. When compared to the FCA, DCA has reduced the likelihood of blocking and even increased the trunking capacity of the network as all of the channels are available to all cells, i.e., good quality of service. But this type of assignment strategy results in heavy load on switching center at heavy traffic condition.

HANDOFF PROCESS

When a user moves from one cell to the other, to keep the communication
between the user pair, the user channel has to be shifted from one BS to the other without interrupting the call, i.e., when a MS moves into another cell, while the conversation is still in progress, the MSC automatically transfers the call to a new FDD channel without disturbing the conversation. This process is called as handoff. A schematic diagram of handoff is given in Figure.

Processing of handoff is an important task in any cellular system. Handoffs must be performed successfully and be imperceptible to the users. Once a signal level is set as the minimum acceptable for good voice quality (Pr_{min}), then a slightly stronger level is chosen as the threshold (PrH)at which handoff has to be made, as shown in Figure.

A parameter, called power margin, defined

Δ = PrH - Prmin

is quite an important parameter during the handoff process since this margin Δcan neither be too large nor too small. If Δ is too small, then there may not be enough time to complete the handoff and the call might be lost even if the user crosses the cell boundary.

If Δ is too high o the other hand, then MSC has to be burdened with unnecessary handoffs. This is because MS may not intend to enter the other cell. Therefore Δ should be judiciously chosen to ensure imperceptible handoffs and to meet other objectives.
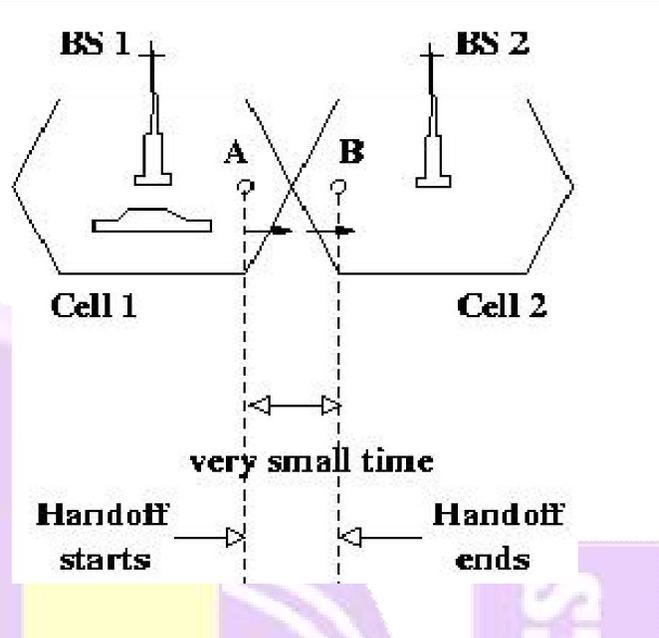
Factors Influencing Handoffs

The following factors influence the entire handoff process:

(a) Transmitted power: as we know that the transmission power is different for different cells, the handoff threshold or the power margin varies from cell to cell.

(b) Received power: the received power mostly depends on the Line of Sight (LoS) path between the user and the BS. Especially when the user is on the boundary ofthe two cells, the LoS path plays a critical role in handoffs and therefore the power margin Δdepends on the minimum received power value from cell to cell.
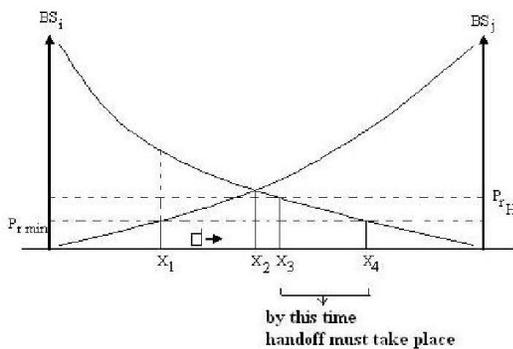
BS_i = Base station of ith cell
BS_j = Base station of any adjacent j^{th} cell

(c) Area and shape of the cell: Apart from the power levels, the cell structure also a plays an important role in the handoff process.

(d) Mobility of users: The number of mobile users entering or going out of a particular cell, also Fixes the handoff strategy of a cell.

Figure: Hando_ process associated with power levels, when the user is goingfrom i-th cell to j-th cell.

HANDOFF PRIORITY

While assigning channels using either FCA or DCA strategy, a guard channel concept must be followed to facilitate the handoffs. This means, a fraction of total available channels must be kept for handoff requests. But this would reduce the carried traffic and only fewer channels can be assigned for the residual users of a cell. A good solution to avoid such a dead-lock is to use DCA with handoff priority (demand based allocation).

A Few Practical Problems in Handoff Scenario

(a) *Different speed of mobile users*: With the increase of mobile users in urban areas, microcells are introduced in the cells to increase the capacity (this will be discussed later in this chapter). The users with high speed frequently crossing the micro-cells become burdened to MSC as it has to take care of handoffs. Several schemes thus have been designed to handle the simultaneous traffic of high speed and low speed users while minimizing the handoff intervention from the MSC, one of them being the `Umbrella Cell' approach.

This technique provides large area coverage to high speed users while providing small area coverage to users traveling at low speed. By using different antenna heights and different power levels, it is possible to provide larger and smaller cells at a same location. As illustrated in the Figure umbrella cell is co-located with few other microcells. The BS can measure the speed of the user by its short term average signal strength over the RVC and decides which cell to handle that call. If the speed is less, then the corresponding microcell handles the call so that there is good corner coverage. This approach assures that handoffs are minimized for high speed users and provides additional microcell channels forpedestrian users.

(b) *Cell dragging problem*: this is another practical problem in the urban area with additional microcells. For example, consider there is a LOS path between the MS and BS1 while the user is in the cell covered by BS2. Since there is a LOS with the BS1, the signal strength received from BS1 would be greater than that received from BS2. However, since the user is in cell covered by BS2, handoff cannot take place and as a result, it experiences a lot of interferences. This problem can be solved by judiciously choosing the handoff threshold along with adjusting the coverage area.

(c) *Inter-system handoff:* if one user is leaving the coverage area of one MSC and is Entering the area of another MSC, then the call might be lost if there is no handoff in this case too. Such a handoff is called inter-system handoff and in order to facilitate this, mobiles usually have roaming facility.

INTERFERENCE & SYSTEM CAPACITY

Susceptibility and interference problems associated with mobile communicationsEquipment are because of the problem of time congestion within the electromagnetic spectrum. It is the limiting factor in the performance of cellular systems. This interference can occur from clash with another mobile in the same cell or because of a call in the adjacent cell.

There can be interference between the base stations operating at same frequency band or any other non-cellular system's energy leaking inadvertently into the frequency band of the cellular system. If there is an interference in the voice channels, cross talk is heard will appear as noise between the users. The interference in the control channels leads to missed and error calls because of digital signaling. Interference is more severe in urban areas because of the greater RF noise and greater density of mobiles and base stations. The interference can be divided into 2 parts:

Co-channel interference and
Adjacent channel interference.

➢ **Co-channel interference (CCI):** For the efficient use of available spectrum, it is Necessaryto
reuse frequency bandwidth over relatively small geographical areas. However, increasing frequency reuse also increases interference, which decreases system capacity and service quality. The cells where the same set of frequencies is used are call co-channel cells. Co-channel interference is the cross talk between two different radio transmitters using the same radio frequency as is the case with the co-channel cells. The reasons of CCI can be because of either adverse weather conditions or poor frequency planning or overly crowded radio spectrum. If the cell size and the power transmitted at the base stations are same then CCI will become independent of the transmitted power and will depend on radius of the cell (R) and the distance between the interfering co-channel cells (D). If D/R ratio is increased, then the effective distance between the coco-channel cells will increase and interference will decrease. The parameter Q is called the frequency reuse ratio and is related to the cluster size. For hexagonal geometry

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

From the above equation, small of `Q' means small value of cluster size `N' and increase in cellular capacity. But large `Q' leads to decrease in system capacity but increase in transmission quality. Choosing the options is very careful for the selection of `N', the proof of which is given in the first section. The worst case is when the mobile is at the corner of the cell i.e., on a vertex as shown in the Figure Therefore N = 12 cluster size should be used.

But this reduces the capacity by 7/12 times. Therefore, co-channel interference controls link performance, which in a way controls frequency reuse plan and the overall capacity of the cellular system. The effect of co-channel interference can be minimized by optimizing the frequency assignments of the basestations and their transmit powers. Tilting the base-station antenna to limit the spread of the signals in the system can also be done.
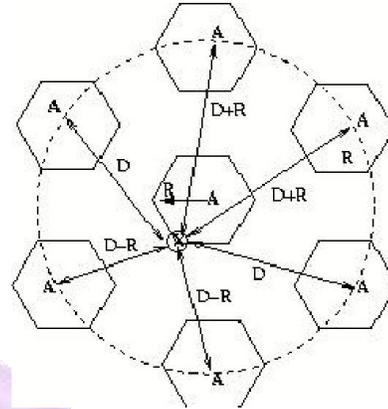

Figure: First tier of co-channel interfering cells

Adjacent Channel Interference (ACI)

Adjacent channel interference occurs more frequently in small cell clusters and heavily used cells. If the frequency separation between the channels is kept large this interference can be reduced to some extent. Thus assignment of channels is given such that they do not form a contiguous band of frequencies within a particular cell and frequency separation is maximized. Efficient assignment strategies are very much important in making the interference as less as possible. If the frequency factor is small then distance between the adjacent channels cannot put the interference level within tolerance limits. If a mobile is 10 times close to the base station than other mobile and has energy spill out of its passband, then SIR for weak mobile is approximately

$$S/ I = 10^{-n}$$

This can be easily found from the earlier SIR expressions. If n = 4, then SIR is -52 dB. Perfect base station filters are needed when close-in and distant users share the same cell. Practically, each base station receiver is preceded by a high Q cavity filter in order to remove adjacent channel interference. Power control is also very much important for the prolonging of the battery life for the subscriber unit but also reduces reverse channel SIR in the system. Power control is done such that each mobile transmits the lowest power required to maintain a good quality link on the reverse channel.

Enhancing Capacity And Cell Coverage:
The cell radius governs both the geographical area covered by a cell and also the number of subscribers who can be serviced, given the subscriber density. It is easy to see that the cell radius must be as large as possible. This is because, every cell requires an investment in a tower, land on which the tower is placed, and radio transmission equipment and so a large cell size minimizes the cost per subscriber.

The basic idea of adopting the cellular approach is to allow space for the growth of mobile users. When a new system is deployed, the demand for it is fairly low and users are assumed to be uniformly distributed over the service area. However, as new users subscribe to the cellular service, the demand for channels may begin to exceed the capacity of some base stations once a system has been initially deployed, a system-wide reduction in cluster size may not be necessary since user density does not grow uniformly in all parts of the geographical area. It might be that an increase in channel density is required only in specific parts of the system to support an increased demand in those areas. Cell-splitting is a technique whichhas the capability to add new smaller cells in specific areas of the system.

CELL-SPLITTING

Cell Splitting is based on the cell radius reduction and minimizes the need to modify the existing cell parameters. Cell splitting involves the process of sub-dividing acongested cell into smaller cells, each with its own base station and a corresponding reduction in antenna size and transmitting power. This increases the capacity of a cellular system since it increases the number of times that channels are reused. Since the new cells have smaller radii than the existing cells, inserting these smaller cells, known as microcells, between the already existing cells results in an increase of capacity due to the additional number of channels per unit area.

There are few challenges in increasing the capacity by reducing the cell radius. Clearly, if cells are small, there would have to be more of them and so additional base stations will be needed in the system. The challenge in this case is to

introduce the new base stations without the need to move the already existing base station towers. The other challenge is to meet the generally increasing demand that may vary quite rapidly between geographical areas of the system. For instance, a city may have highly populated areas and so the demand must be supported by cells with the smallest radius. The radius of cells will generally increase as we move from urban to sub urban areas, because the user density decreases on moving towards sub-urban areas. The key factor is to add as minimum number of smaller cells as possible
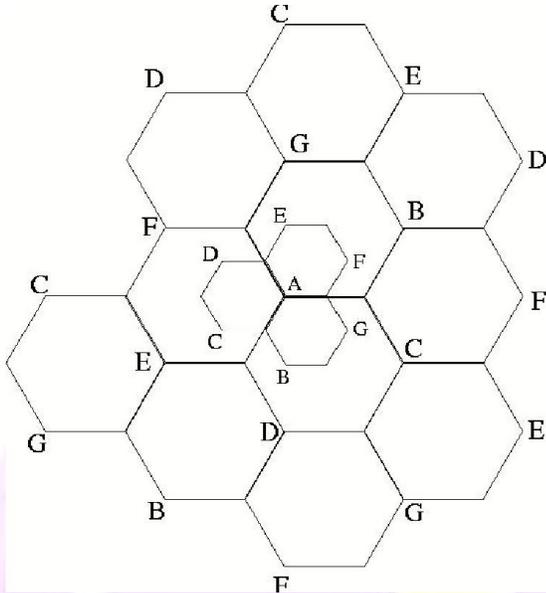
Fig: Splitting of congested seven-cell clusters

Wherever an increase in demand occurs. The gradual addition of the smaller cells implies that, at least for a time, the cellular system operates with cells of more than one size. Figure shows a cellular layout with seven-cell clusters. Consider that the cells in the center of the diagram are becoming congested, and cell A in the center has reached its maximum capacity. Figure also shows how the smaller cells are being superimposed on the original layout. The new smaller cells have half the cell radius of the original cells. At half the radius, the new cells will have one-fourth of the area and will consequently need to support one-fourth the number of subscribers. Notice that one of the new smaller cells lies in the center of each of the larger cells. If we assume that base stations are located in the cell centers, this allows the original base stations to be maintained even in the new system layout.

However, new base stations will have to be added for new cells that do not lie in the center of the larger cells. The organization of cells into clusters is independent of the cell radius, so that the cluster size can be the same in the small-cell layout as it was in the large-cell layout. Also the signal-to-interference ratio is determined by cluster size and not by cell radius. Consequently, if the cluster size is maintained, the signal-to-interference ratio will be the same after cell splitting as it was before.

SECTORING

Sectoring is basically a technique which can increase the SIR without Necessitating an Increase in the cluster size. Till now, it has been assumed that the base station is located in the center of a cell and radiates uniformly in all the directions behaving as an Omni-directional antenna. However it has been found that the co-channel interference in a cellular system may be decreased by replacing a single Omni-directional antenna at the base station by several directional antennas, each radiating within a specified sector. In the Figure, a cell is shown which has been split into three 120° sectors. 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'. In a seven-cell-cluster layout with 120o sectored cells, it can be easily understood that the mobile units in a particular sector of the center cell will receive co-channel interference from only two of the first-tier co-channel base stations, rather than from all six.
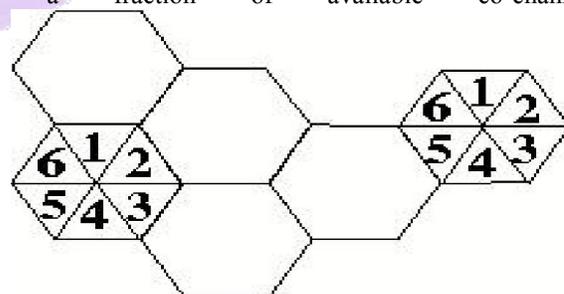
Fig: a seven cell cluster with 60^0 sectors

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. As shown in Figure 3.10, 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.

Base Station Signals:

When a call is made to a cellular phone, the system already knows the cell location of that phone. The base station of that cell knows in whichzone, within that cell, the cellular phone is located. Therefore when it receives the signal, the base station transmits it to the suitable zone site. The zone site receives the cellular signal from the base station and transmits that signal to the mobile phone after amplification. By confining the power transmitted to the mobile phone, 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. Since 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 in 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.
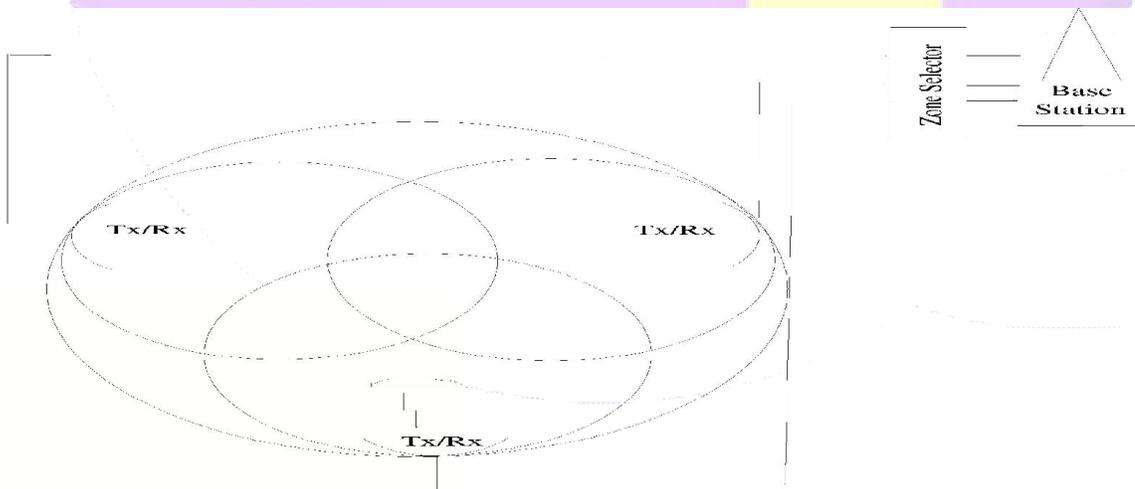

Fig. The micro-cell zone concept.