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ICT209: MOBILE COMMUNICATION

INDICATIVE CONTENT

INTRODUCTION

In communication engineering **mobile** has been used to classify any radio terminal (a device which transmits or receives a signal) that could move during operation and therefore essentially provides a wireless connection to the other end.

Nowadays a **mobile** or **user** is being used to mean a radio terminal with ability to move very fast (like talking on a mobile phone inside a high speed car). While term **portable** describes a radio terminal used by someone only at waking speed (like a cordless telephone inside a home or a remote controller).

When any subscriber uses either a **mobile** or **portable** radio terminal for communication purposes, the mode of communication is called "**mobile communication".**

By definition, mobile radio terminal means any radio terminal that could be moved during its operation. Depending on the radio channel, there can be three different types of mobile communication.

In general, however, a Mobile Station (MS) or subscriber unit communicates to a fixed Base Station (BS) which in turn communicates to the desired user at the other end. The MS consists of transceiver, control circuitry, duplexer and an antenna while the BS consists of transceiver and channel multiplexer along with antennas mounted on the tower. The BSs are also linked to a power source for the transmission of the radio signals for communication and are connected to a fixed backbone network.

Figure 1.2 shows a basic mobile communication with low power transmitters/receivers at the BS, the MS and also the Mobile Switching Center (MSC). The MSC is sometimes also called Mobile Telephone Switching Office (MTSO).The radio signals emitted by the BS decay as the signals travel away from it. A minimum amount of signal strength is needed in order to be detected by the mobile stations or mobile sets which are the hand-held personal units (portables) or those installed in the vehicles (mobiles). The region over which the signal strength lies above such a threshold value is known as the coverage area of a BS. The fixed backbone network is a wired network that links all the base stations and also the landline and other telephone networks through wires.

Radio Transmission Techniques

There are 3 types of mobile communication techniques:

- **Simplex system:** It allows communication in only one direction. For Example a remote controller radio terminal, a signal can be sent but whether intended appliance has been controlled properly or not, it is not acknowledged.

- **Half duplex system:** A bidirectional communication is possible but only one at a time. A user can transmit or receive a signal at any given time. Ex: Walkie-talkies (The mobile radio terminal has a button with a unique feature like push to talk and release to listen).

- **Full duplex system:** It allows simultaneous signal transmission and reception between any two ends of communication system (Ex: cell phone). This can be done by providing two simultaneous but separate channels to both the users.

This is possible by one of the two following methods.

Frequency Division Duplexing (FDD): FDD supports two-way radio communication by using two distinct radio channels. One frequency channel is transmitted downstream from the BS to the MS (forward channel).
A second frequency is used in the upstream direction and supports transmission from the MS to the BS (reverse channel). Because of the pairing of frequencies, simultaneous transmission in both directions is possible. To mitigate self-interference between upstream and downstream transmissions, a minimum amount of frequency separation must be maintained between the frequency pair.

Time Division Duplexing (TDD): TDD uses a single frequency band to transmit signals in both the downstream and upstream directions. TDD operates by toggling transmission directions over a time interval. This toggling takes place very rapidly and is imperceptible to the user.
A full duplex mobile system can further be subdivided into two categories: a single MS for a dedicated BS, and many MS for a single BS.

Cordless telephone systems are full duplex communication systems that use radio to connect to a portable handset to a single dedicated BS, which is then connected to a dedicated telephone line with a special telephone number on the Public Switched Telephone Network (PSTN).
A mobile system, in general, on the other hand, is the example of the second category of a full duplex mobile system where many users connect among themselves via a single BS.

Evolution of mobile radio communications

The first wire-line telephone system was introduced in the year 1877. Mobile communication systems as early as 1934 were based on Amplitude Modulation (AM) schemes and only certain public organizations maintained such systems. With the demand for newer and better mobile radio communication systems during the World War II and the development of Frequency Modulation (FM) technique by Edwin Armstrong, the mobile radio communication systems began to witness many new changes. Mobile telephone was introduced in the year 1946.

However, during its initial three and a half decades it found very less market penetration owing to high costs and numerous technological drawbacks. But with the development of the cellular concept in the 1960s at the Bell Laboratories, mobile communications began to be a promising field of expanse which could serve wider populations.

Initially, mobile communication was restricted to certain official users and the cellular concept was never even dreamt of being made commercially available. Moreover, even the growth in the cellular networks was very slow. However, with the development of newer and better technologies starting from the 1970s and with the mobile users now connected to the Public Switched Telephone Network (PSTN), there has been an astronomical growth in the cellular radio and the personal communication systems.

Advanced Mobile Phone System (AMPS) was the first U.S. cellular telephone system and it was deployed in 1983. Wireless services have since then been experiencing a 50% per year growth rate. The number of cellular telephone users grew from 25000 in 1984 to around 3 billion in the year 2007 and the demand rate is increasing day by day.

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Present Day Mobile Communication

Since the time of wireless telegraphy, radio communication has been used extensively. Our society has been looking for acquiring mobility in communication since then. Initially the mobile communication was limited between one pair of users on single channel pair. The range of mobility was defined by the transmitter power, type of antenna used and the frequency of operation. With the increase in the number of users, accommodating them within the limited available frequency spectrum became a major problem. To resolve this problem, the concept of cellular communication was evolved.

The present day cellular communication uses a basic unit called cell. Each cell consists of small hexagonal area with a base station located at the center of the cell which communicates with the user. To accommodate multiple users Time Division multiple Access (TDMA), Code Division Multiple Access (CDMA), Frequency Division Multiple Access (FDMA) and their hybrids are used. Numerous mobile radio standards have been deployed at various places such as AMPS, PACS, GSM, NTT, PHS and IS-95, each utilizing different set of frequencies and allocating different number of users and channels.

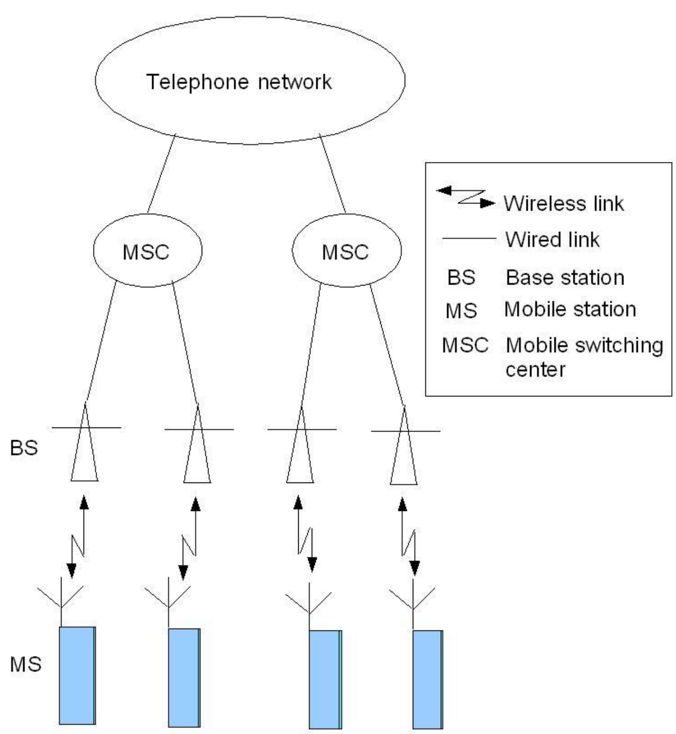

Figure 1.1: Basic mobile communication structure

Chap.I: CELLULAR MOBILE SYSTEMS

I.1. Introduction to Cellular Mobile Systems

Cellular telephone systems must accommodate a large number of users over a large geographic area with limited frequency spectrum, i.e., with limited number of channels. If a single transmitter/ receiver is used with only a single base station, then sufficient amount of power may not be present at a huge distance from the BS.

For a large geographic coverage area, a high powered transmitter therefore has to be used. But a high power radio transmitter causes harm to environment. Mobile communication thus calls for replacing the high power transmitters by low power transmitters by dividing the coverage area into small segments, called **cells**. Each cell uses a certain number of the available channels and a group of adjacent cells together use all the available channels. Such a group is called a **cluster**.

This cluster can repeat itself and hence the same set of channels can be used again and again.
Each cell has a low power transmitter with a coverage area equal to the area of the cell. This technique of substituting a single high powered transmitter by several low powered transmitters to support many users is the backbone of the cellular concept.

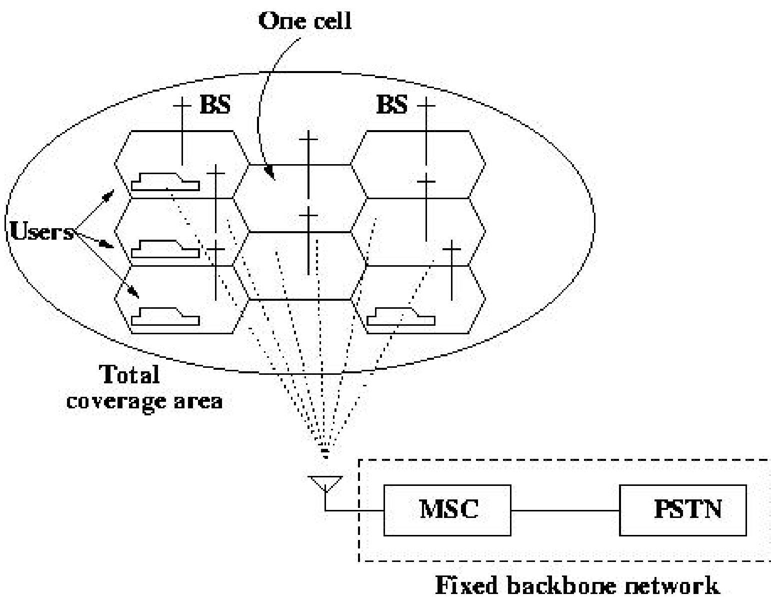

Figure 1.2: Basic Cellular Structure.

Operational Channels

In each cell, there are four types of channels that take active part during a mobile call.These are
- **Forward Voice Channel (FVC):** This channel is used for the voice transmission from the BS to the MS.
- **Reverse Voice Channel (RVC):** This is used for the voice transmission from the MS to the BS.

- **Forward Control Channel (FCC):** Control channels are generally used for controlling the activity of the call, i.e., they are used for setting up calls and to divert the call to unused voice channels. Hence these are also called setup channels. These channels transmit and receive call initiation and service request messages. The FCC is used for control signaling purpose from the BS to MS.
- **Reverse Control Channel (RCC):** This is used for the call control purpose from the MS to the BS. Control channels are usually monitored by mobiles.

Making a Call

When a mobile is idle, i.e., it is not experiencing the process of a call, then it searches all the FCCs to determine the one with the highest signal strength. The mobile then monitors this particular FCC. However, when the signal strength falls below a particular threshold that is insufficient for a call to take place, the mobile again searches all the FCCs for the one with the highest signal strength.

For a particular country or continent, the control channels will be the same. So, all mobiles in that country or continent will search among the same set of control channels. However, when mobile moves to a different country or continent, then the control channels for that particular location will be different and hence the mobile will not work.

Each mobile has a mobile identification number (MIN). When a user wants to make a call, he sends a call request to the MSC on the reverse control channel. He also sends the MIN of the person to whom the call has to be made. The MSC then sends this MIN to all the base stations. The base station transmits this MIN and all the mobiles within the coverage area of that base station receive the MIN and match it with their own. If the MIN matches with a particular MS, that mobile sends an acknowledgment to the BS. The BS then informs the MSC that the mobile is within its coverage area. The MSC then instructs the base station to access specific unused voice channel pair. The base station then sends a message to the mobile to move to the particular channels and it also sends a signal to the mobile for ringing.

In order to maintain the quality of the call, the MSC adjusts the transmitted power of the mobile which is usually expressed in dB or dBm. When a mobile moves from the coverage area of one base station to the coverage area of another base station i.e., from one cell to another cell, then the signal strength of the initial base station may not be sufficient to continue the call in progress. So the call has to be transferred to the other base station. This is called **handoff.** In such cases, in order to maintain the call, the MSC transfers the call to one of the unused voice channels of the new base station or it transfers the control of the current voice channels to the new base station.

1.2. Elements of cellular Radio System Design

Based on the concepts of efficient spectrum utilization, the cellular mobile radio system design can be broken down into many elements and each element can be analyzed and related to the others.

The major elements are:

1. The concept of frequency reuse channels
2. The co- channel interference reduction Factor
3. The desired carrier to interference ratio
4. The handoff mechanism
5. Cell splitting.

1. The concept of frequency reuse channels

A radio channel consists of a pair of frequencies one for each direction of transmission that is used for full-duplex operation. Particular radio channels, say F1, used in one geographic zone to call a cell, say C1, with a coverage radius R can be used in another cell with the same coverage radius at a distance D away.

The reuse of frequencies enables a cellular system to handle a huge number of calls with a limited number of channels. Figure 3.2 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.

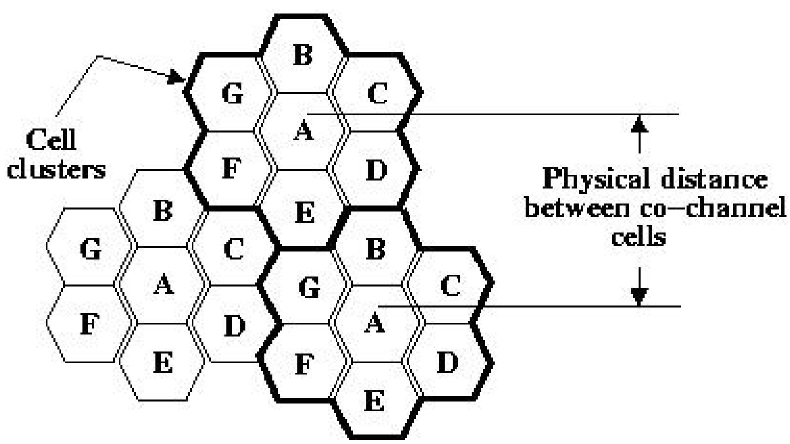

Figure 1.3: Frequency reuse technique of a cellular system.

Frequency reuse is the core concept of the cellular mobile radio system. In this frequency reuse system users in different geographic locations (different cells) may simultaneously use the same frequency channel. The frequency reuse system can drastically increase the spectrum efficiency, but if the system is not properly designed, serious interference may occur.
Interference due to the common use of the same channel is called **co-channel interference** and is our major concern in the concept of frequency reuse.

The capacity gain achieved in a cellular system with S duplex channels available for use and N number of cells in a cluster, is directly proportional to the number of times a cluster is repeated,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

$N = i^2 + ij + j^2$ Where i and j are integer numbers

Frequency reuse scheme: The frequency reuse concept can be used in the time domain and the space domain. Frequency reuse in the time domain results in the occupation of the same frequency in different time slots. It is called time division multiplexing (TDM). Frequency reuse in the space domain can be divided into two categories.

1. Same frequency assigned in two different geographic areas, such as A.M or FM radio stations using the same frequency in different cities.

2. Same frequency repeatedly used in a same general area in one system - the scheme is used in cellular systems. There are many co-channel cells in the system. The total frequency spectrum allocation is divided into K frequency reuse patterns.

Frequency reuse distance: The minimum distance which allows the same frequency to be reused will depend on many factors, such as the number of co-channel cells in the vicinity of the center cell, the type of geographical terrain contour, the antenna height and the transmitted power at each cell site. For a hexagonal geometry:

Reuse distance: $\boldsymbol{D = \sqrt{3N}\,R}$

Where: **R** is cell radius

N is the reuse pattern (the cluster size or number of cell per cluster)

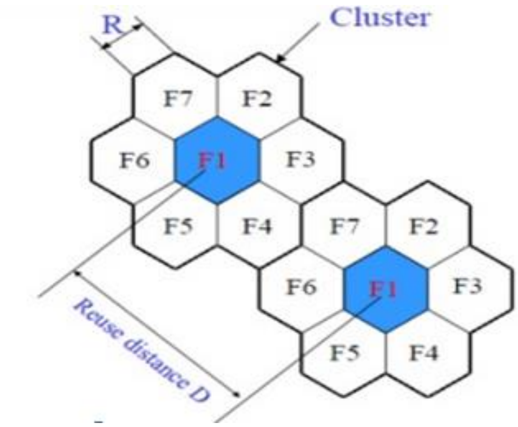

Fig.1.4. Reuse distance

2. Co-channel interference reduction factor

Reusing an identical frequency channel in different cells is limited by co-channel interference between cells, and the co-channel interference can become a major problem.

Assume that the size of all cells is roughly the same. The cell size is determined by the coverage area of the signal strength in each cell. As long as the cell size is fixed, co-channel interference is independent of the transmitted power of each cell. It means that the received threshold level at the mobile unit is adjusted to the size of the cell. Actually, co-channel interference is a function of a parameter q defined as q = D/R

The parameter q is the co-channel interference reduction factor. When the ratio q increases, co-channel interference decreases. Furthermore, the separation D is a function of K, and C/I,
D=f (K,C/I)

Where K, is the number of co-channel interfering cells in the first tier and C/I is the received carrier-to-interference ratio at the desired mobile receiver.

How to Calculate Cluster Size in Cellular Network

•Hexagonal geometry has

– Exactly six equidistance neighbors

•The number of cells per cluster, *N*, can only has values which satisfy

$$\boldsymbol{N = i^2 + ij + j^2}$$

- Co-channel neighbors of a particular cell, ex, *i=3* and *j=2*.

❖ The lines joining the centers of any cell and each of its neighbors are separated by multiples of 60 degrees. Move I cells along any chain of hexagon then

❖ Turn 60 degree counter-clockwise and move j cells.

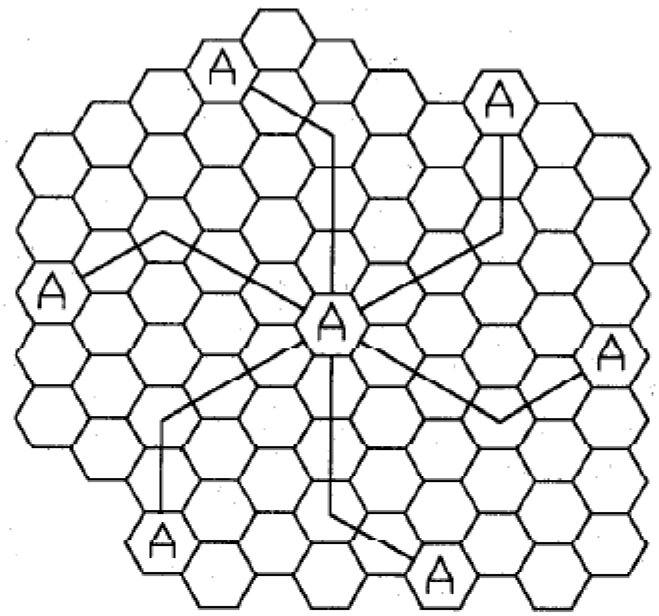

Fig.1.5. How to locate co-channel Cells

	Cluster size(N) $N = i^2 + ij + j^2$	Co-channel reuse Ratio(Q), $Q = \frac{D}{R} = \sqrt{3N}$
i=1, j=1	**3**	**3**
i=1, j=2	**7**	**4.58**
i=2, j=2	**12**	**6**
i=1, j=3	**13**	**6.24**

Table of Co-channel reuse Ratio for some values of N

3. The desired carrier to interference ratio

The carrier-to-Interference (C/I or S/I) ratio is the ratio that expressed in dB, between a desired carrier (C) and an interfering carrier (I) received by the same receiver. Let i_0 be the number of co-channel interfering cells.

Then, the signal-to-interference ratio (C/I or S/R) for a mobile receiver which monitors a forward channel can be expressed as

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

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.

Propagation measurements in a mobile radio channel show that the average received signal strength at any point decays as a power law of the distance of separation between a transmitter and receiver. The average received power P_r at a distance d from the transmitting antenna is approximated
by

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

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

Where P_0 is the power transmitted at a close-in reference point in the far field region of the antenna at a small distance $d0$ from the transmitting antenna and n is the path loss exponent.

4. The handoff mechanism

Hand-off is the process of automatically changing the frequencies. When the mobile unit moves out of the coverage areas of a particular cell site, the reception becomes weak. At this instant the present cell site requests Hand-off, then system switches the call to a new frequency channel in a new cell site without interrupting either call or user. This phenomenon is known as "hand -off' or 'handover'. Hand -off processing scheme is an important task for any successful mobile system. This concept can be applied to one dimensional as well as two dimensional cellular configurations.
By the reception of weak signals from the mobile unit by the cell site, the Hand-off is required in the following two situations:

- The level for requesting a Hand-off in a noise limited environment is at the cell boundary say-l00 dBm.
- In a particular cell site, when the mobile unit is reaching the signal strength holes (gaps).

Reasons for a Handoff to be conducted:

- To avoid call termination when the phone is moving away from the area covered by one cell and entering the area covered by another cell.
- When the capacity for connecting new calls of a given cell is used up.
- When there is interference in the channels due to the different phones using the same channel in different cells.
- When the user behaviors change

Importance of Handling Handoff:

Customer satisfaction is very important in cellular communication and handling handoff is directly related to customer satisfaction. Effective handling of handoff leads to improved reception and fewer dropped calls and results in customer satisfaction which is very important in Mobile communication.

Handoff is very common and most frequently occurred in cellular communication so it should be handled efficiently for desired performance of the cellular network.

Handoff is very important for managing the different resources in Cellular Systems. Handoffs should not lead to significant interruptions even though resource shortages after a handoff cannot be avoided completely. Thus handling handoffs is very much important for a desired interruption free cellular communication.

Handoffs are classified into two categories – *hard and soft handoffs*, which are further divided among themselves:

Hard handoff:

A hard handoff is essentially a "*break before make*" connection. Here the link to the prior base station is terminated before or as the user is transferred to the new cell's base station. This means that the mobile is linked to no more than one base station at a given time. A hard handoff occurs when users experience an interruption during the handover process caused by frequency shifting. A hard handoff is perceived by network engineers as event during the call. These are intended to be instantaneous inorder to minimize the disruption of the call. Hard handoff can be further divided as intra and inter-cell handoffs.

Soft handoff:

Soft handoff is also called as Mobile Directed Handoff as they are directed by the mobile telephones. Soft handoff is the ability to select between the instantaneous received signals from different base stations. Here the channel in the source cell is retained and used for a while in parallel with the channel in the target cell. In this the connection to the target is established before the connection to the source is broken, hence this is called *"make-before-break"*. The interval during which the two connections are used in parallel, may be brief or substantial because of this the soft handoff is perceived by the network engineers as state of the call. Soft handoffs can be classified as Multiways and softer handoffs.

5. Cell splitting

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. 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.

Cell splitting is the process of subdividing a congested (heavy traffic)) cell into smaller cells (**called microcells),** each with its own base station and a corresponding reduction in antenna height and transmitter power.

The original congested bigger cell is called **macrocells** and the smaller cells are called **microcells.**
Cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused.

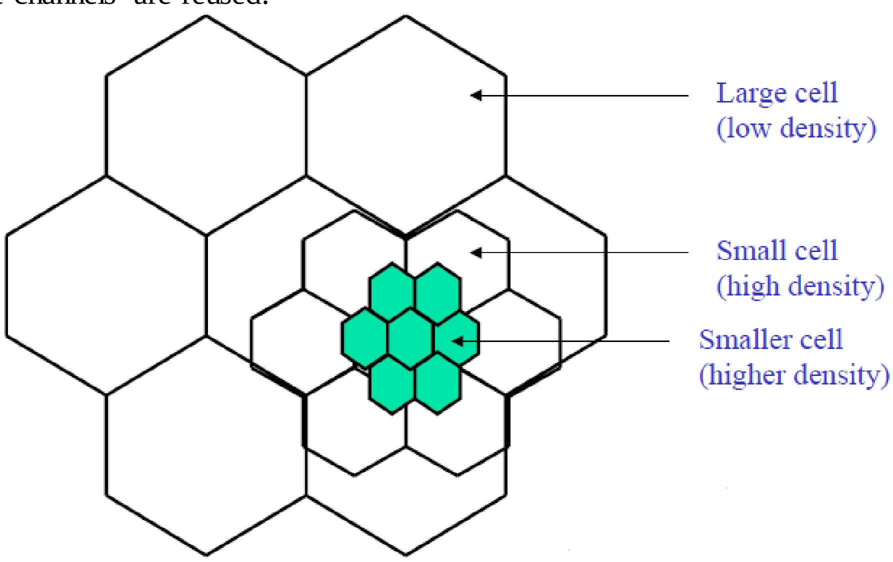

Fig.1.6. Cell splitting