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Study on Improving Coverage Area by Cell Splitting and Cell Sectoring Method in Cellular System

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Abstract— In GSM system the main problem is coverage area because of GSM user increases, day by day. The traffic on a network system also increases, which causes congestion of allocated spectrum as well as the problem of inefficient coverage area. Hence, for enhancement of efficient coverage we can use Cell Splitting and Cell Sectoring technique. This report presents a comparative study on Cell splitting and Sectoring, so we can find an efficient method for improved channel capacity.

Keywords— cell splitting, D/R ratio, Frequency Reuse, Handoff

I. INTRODUCTION

This GSM (Global System for Mobile Communications), is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for second generation (2G) digital cellular networks used by mobile phones.

GSM is a cellular network, which means that cell phones connect to it by searching for cells in the immediate vicinity. The cellular concept is a system-level idea which calls for replacing a single, high power transmitter (large cell) with many low power transmitter (small cells) each providing a coverage to only a small portion of the service area.

A cell is nothing but a basic geographical unit of cellular system. Cells are base stations transmitting over small geographic areas that are represented as hexagons. Each cell size varies depending on the landscape. Because of constraints imposed by natural terrain and man-made structures, the true shape of cells is not a perfect hexagon [1] [15].

For an example, let us assume any antenna is placed as a transmitter then its coverage area be represented by a cell as shown below in figure.

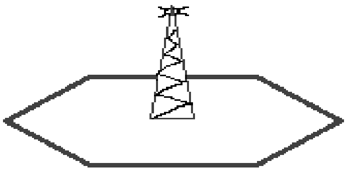


Figure 1.1:- Representation of a transmitter's Cell

II. DIFFERENT TYPES OF CELL

An There are five different cell sizes in a cellular network- Macro, Micro, Pico, Femto and Umbrella cells. The Coverage area of each cell varies according to the implementation environment [3] [14].

Macro Cells: Macro cells can be regarded as cells where the base station antenna is installed on a mast or a building above average rooftop level.

Micro Cells : Micro cells are cells whose antenna height is under average rooftop level; they are typically used in urban areas.

Pico Cells : Pico cells are small cells whose coverage diameter is a few dozen meters; they are mainly used indoors

Femto Cells : Femto cells are cells designed for use in residential or small business environments and connect to the service provider's network via a broadband internet connection.

Umbrella Cells : Umbrella cells are used to cover shadowed regions of smaller cells and fill in gaps in coverage between those cells.

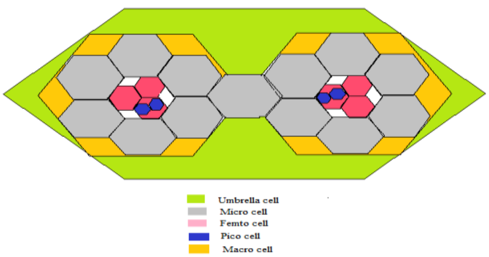


Figure 1.2: Representation of cells according to their size

III. CELLULAR NETWORK

The term cellular comes from the honeycomb shape of areas into which a coverage region is divided. A basic cellular system is represented in following figure, in which the tower represents base stations which provide radio access between mobile users and the Mobile Switching Center (MSC).

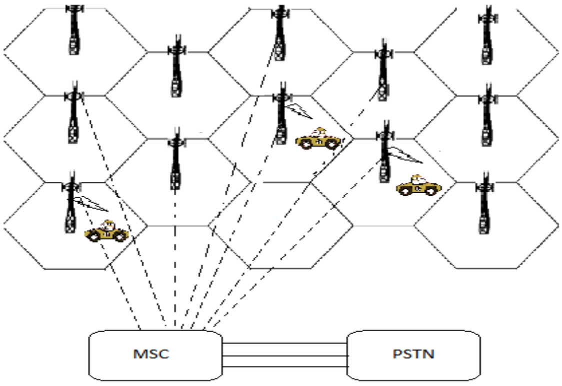


Figure 1.3: Representation of basic Cellular system [14]

We use hexagonal geometry to represent a cell because by using hexagonal geometry, the fewest number of cells can cover a geographic region, and hexagon closely approximates a circular radiation pattern which would occur for an omni-directionl antenna and free space propagation.

A. *Cellular frequency choice in mobile phone networks*

The effect of frequency on cell coverage means that different frequencies serve better for different uses. Low frequencies, such as 450 MHz NMT, serve very well for countryside coverage. GSM 900 (900 MHz) is a suitable solution for light urban coverage. GSM 1800 (1.8 GHz) starts to be limited by structural walls. UMTS, at 2.1 GHz is quite similar in coverage to GSM 1800. There are fourteen bands defined in 3GPP TS 45.005, which succeeded 3GPP TS 05.05:

Table 1.1: GSM bands defined in 3GPP TS 45.005 [14] [15]

System	Band	Uplink (MHz)	Downlink (MHz)	Channel number
T-GSM-380	380	380.2-389.8	390.2-399.8	Dynamic
T-GSM-410	410	410.2-419.8	420.2-429.8	Dynamic
GSM-450	450	450.6-457.6	460.6-467.6	259-293
GSM-480	480	479.0-486.0	489.0-496.0	306-340
GSM-710	710	698.2-716.2	728.2-746.2	Dynamic
GSM-750	750	747.2-762.2	777.2-792.2	438-511
T-GSM-810	810	806.2-821.2	851.2-866.2	Dynamic
GSM-850	850	824.2-849.2	869.2-894.2	128-251
P-GSM-900	900	890.0-915.0	935.0-960.0	1-124
E-GSM-900	900	880.0-915.0	925.0-960.0	975-1023, 0-124
R-GSM-900	900	876.0-915.0	921.0-960.0	955-1023, 0-124
T-GSM-900	900	870.4-876.0	915.4-921.0	Dynamic
DCS-1800	1800	1710.2-1784.8	1805.2-1879.8	512-885
PCS-1900	1900	1850.2-1909.8	1930.2-1989.8	512-810

- entire P-GSM, Standard or Primary GSM-900 Band
- E-GSM, Extended GSM-900 Band (includes Standard GSM-900 band)
- R-GSM, Railways GSM-900 Band (includes Standard and Extended GSM-900 band)
- T-GSM, Trunking -GSM

In most parts of the world, GSM-900 and GSM-1800 are used

B. *GSM – 900*

Title GSM -900 uses 890–915 MHz to send information from the mobile station to the base station (uplink) and 935–960 MHz for the other direction (downlink), providing 124 RF channels (channel numbers 1 to 124) spaced at 200 KHz. Duplex spacing of 45 MHz is used. Guard bands 100 KHz wide are placed at either end of the range of frequencies.

C. GSM-1800

GSM-1800 uses 1,710–1,785 MHz to send information from the mobile station to the base transceiver station (uplink) and 1,805–1,880 MHz for the other direction (downlink), providing 374 channels (channel numbers 512 to 885). Duplex spacing is 95 MHz. GSM-1800 is also called DCS (Digital Cellular Service) in the United Kingdom, while being called PCS in Hong Kong[3] – to avoid confusion with GSM-1900 which is commonly called PCS in the rest of the world. Mobile Communication Services on Aircraft (MCA) uses GSM1800.

D. Coverage comparison of different frequencies: -

The following table shows the dependency of the coverage area of one cell on the frequency of a CDMA2000 network

Table 1.2: Coverage area of a cell depending upon frequency [5] [14]

Frequency (MHz)	Cell radius (km)	Cell area (km^2)	Relative cell count
450	48.9	7521	1
950	26.9	2269	3.3
1800	14.0	618	12.2
2100	12.0	449	16.2

IV. CELL SPLITTING

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.

Cell splitting is done by defining and installing new cells which have a smaller radius than the original cells (microcells). Cell splitting increases the capacity of a cellular system since it increases the number of times that channels are reused. By defining new cells which have a smaller radius than the original cells and by installing these smaller cells (called microcells) between the existing cells, capacity increases due to the additional number of channels per unit area [8]. The consequence of the cell splitting is that the frequency assignment has to be done again, which affects the neighboring cells. It also increases the handoff rate because the cells are now smaller and a mobile is likely to cross cell boundaries more often compared with the case when the cells are big. Because of altered this also affects the traffic in control channels [9]. Cell splitting preserves the geometry of the architecture and therefore simply scales the geometry of the architecture. The increased number of cells would increase the number of clusters which in turn would increase the number of channels reused, and capacity [8] [14] [15].

A typical example of cell splitting is shown in Figure 1.4. Here, it is assumed that the cell cluster is congested and as a result, the call blocking probability has risen above an acceptable level. Imagine if every cell in the cluster was reduced in such a way that the radius, R of every cell was cut in half, (R/2). In order to cover the entire service area with smaller cells, approximately four times as many cells would be required. The increased number of cells would increase the number of clusters over the coverage region, which in turn would increase the number of channels, and thus capacity, in the coverage area. In the example shown in Figure 2.1, the smaller cells were added in such a way as to preserve the frequency reuse plan of the system. In this case, the radius of each new microcell is half that of the original cell.

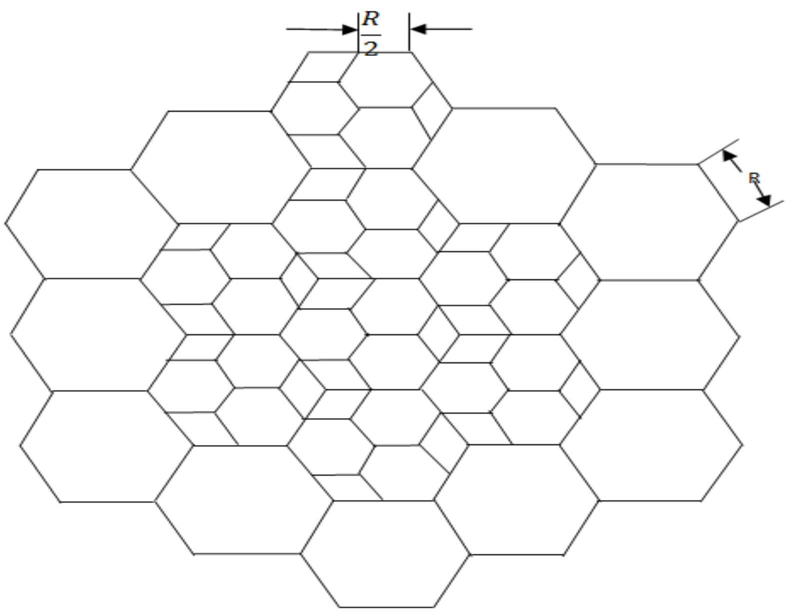
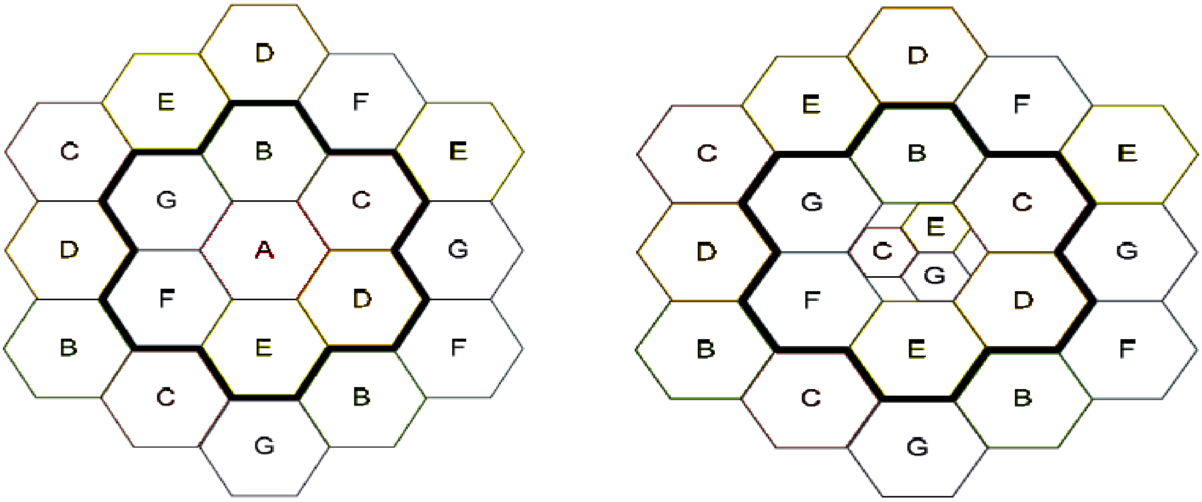


Figure 1.4: Each cell in a cluster is split into approximately four smaller cells by reducing R by half.

An example of cell splitting is given below from which we can go through the sectoring mechanism.



(a) Original cell distribution (b) After splitting cell A

Figure 1.5: Example of cell splitting

By following cell splitting, the new small cells are reassigned new frequencies that do not cause co-channel interference with adjacent cells as shown in the above figure. In addition, the power transmitted in the small cells is reduced compared to the power transmitted in the large cells as it would require much less power to cover the cell compared to the large cells. In fact the power has to be reduced by a factor of [9] [14]

$$\frac{P_{transmitted\ in\ Small\ cell}}{P_{transmitted\ in\ large\ cell}} = \left(\frac{R_{Small\ cell}}{R_{Large\ cell}}\right)^n$$

For example, if the cell radius of the small cells is half the radius of the large cell and the path loss exponent $n = 4$, the power transmitted by the tower of the small cell is only 1/16 that of the power transmitted by the tower of the large cell. In addition to the advantage of having a higher network capacity due to cell splitting, the reduced transmitted power, especially by the mobile phone, is another major advantage because it increases the battery life of these mobile phones. The main disadvantage of cell splitting is that it requires the construction of new towers, which is very costly.

E. Frequency Reuse

The concept of frequency reuse is based on assigning to each cell a group of radio channels used within a small geographic area called cell. Cells are assigned a group of radio channels that is completely different from neighboring cells. The coverage area of cell is called the footprint. This footprint is limited by a boundary so that the same group of channels can be used in different cells that are far enough away from each other so that their frequencies do not interfere [8] [10].

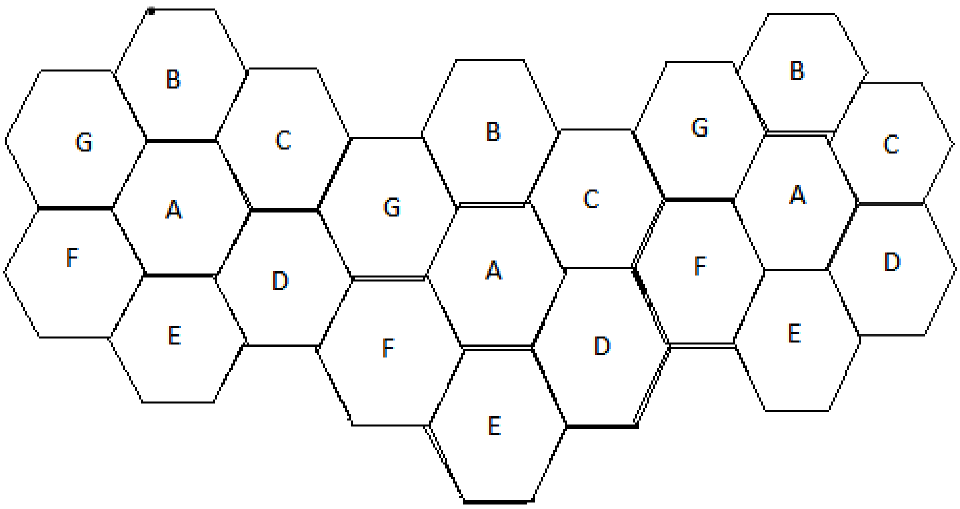


Figure 1.6: Representation of Frequency reuse concept

Cell with the same letter uses same set of frequencies. Here, the cluster size, N, is equal to 7, and the frequency reuse factor is 1/7 since each cell contains the one-seventh of the total number of available channels.

To understand the frequency reuse concept, we consider a cellular system which has a total of S duplex channels available for use. If each channel is allocated a group of m channels (m < S), and if S channels are divided among N cells into unique and disjoint channel groups which each have the same number of channels, the total number of available radio channels can be expressed as

$$S = m\,N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1.1)$$

The cells N which collectively use the complete set of available frequencies is called a cluster. If a cluster is replicated M times within the system, the total number of duplex channels, C, can e used as measure of capacity and is given as

$$C = M\,k\,N = MS \ldots\ldots\ldots\ldots \quad (1.2)$$

As seen from above equation, the capacity of a cellular system is directly proportional to the number of times a cluster is replicated in a fixed service area. The factor N is called the cluster size and typically equal to 4, 7, or 12. From a design viewpoint, the smallest possible value of N is desirable in order to maximize capacity over a given coverage area.

The frequency reuse factor of a cellular system is given by 1/N, since each cell within a cluster is only assigned 1/N of the total available channels in the system. To connect each cell in the manner that no gaps are present in adjacent cells, the geometry of hexagons is such that the number of cells per cluster (N) can only have values which satisfy the following equation

$$N = i^2 + ij + j^2 \ldots\ldots\ldots\ldots\ldots\ldots \quad (1.3)$$

Where i and j are non negative integers. To find the nearest co-channel neighbors of a particular cell, one must do the following [14] [15]

(a) Move i cells along any chain of hexagons and then
(b) Turn 60° counter clockwise and move j cells.

This is illustrated in following figure in which i = 3 and j = 2 (N = 19).

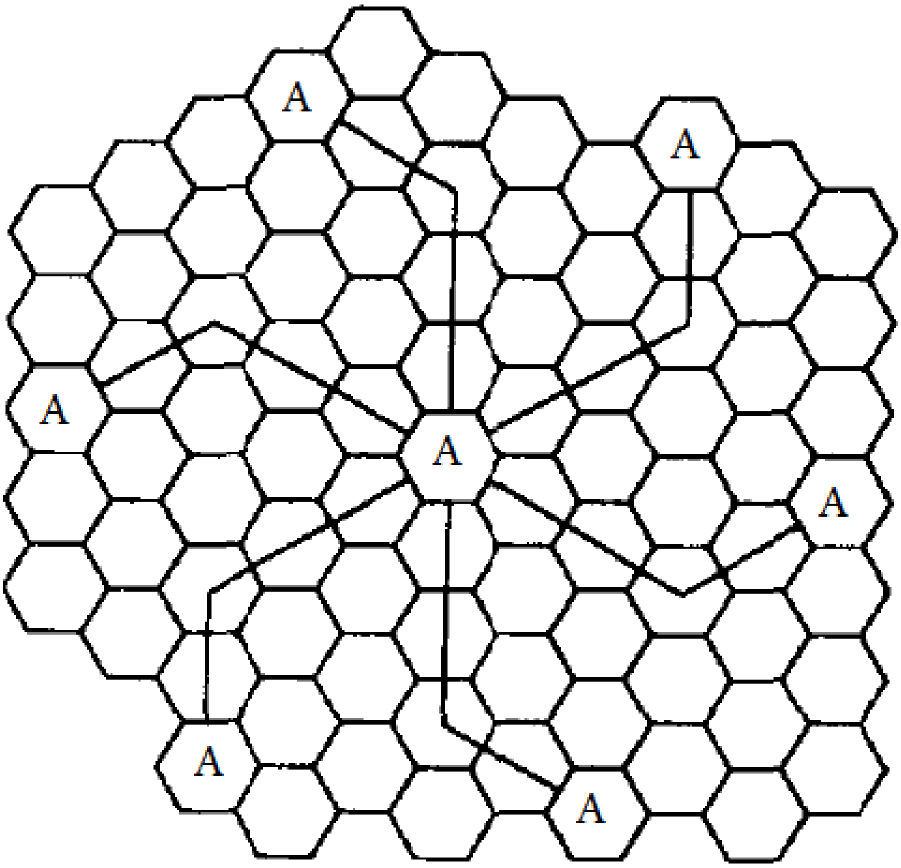
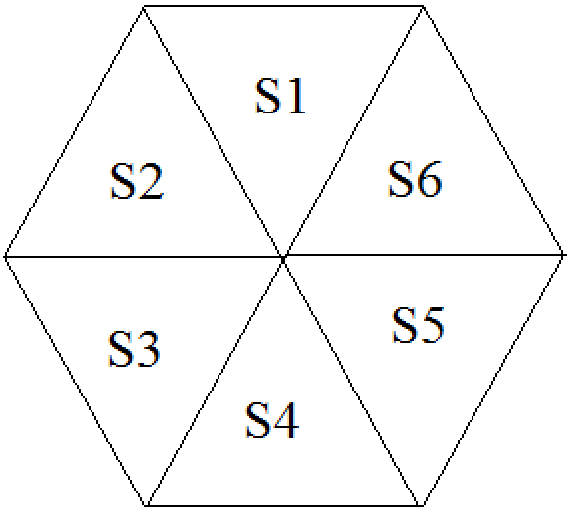


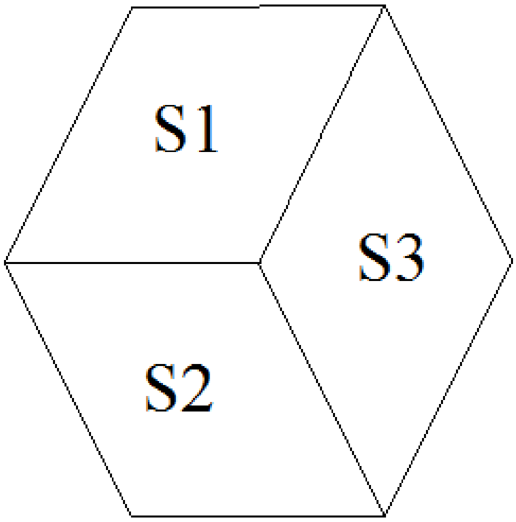
Figure 1.8: An example of frequency reuse with N = 19 [14]

V. CELL SECTORING

Cell sectoring technique increases the capacity via a different strategy. In this method, a cell has the same coverage space but instead of using a single Omni-directional antenna that transmits in all directions, either 3 or 6 directional antennas are used such that each of these antennas provides coverage to a sector of the hexagon. When 3 directional antennas are used, 120° sectoring is achieved (each antenna covers 120°), and when 6 directional antennas are used, 60° sectoring is achieved (each antenna covers 60°).



a) 60° Cell Sectoring



b) 120° Cell Sectoring

Figure 1.9: Cell Sectoring

Dividing the cells into sectors actually reduces the network capacity because the channels allocated to a cell are now divided among the different sectors [3] [6].

In fact, handoff takes place when a cell phone moves from one sector to another in the same cell. The gain in network capacity is achieved by reducing the number of interfering co-channel cells. If sectoring is done in a way that channels assigned to a particular sector are always at the same direction in the different cells (i.e., group A of channels is assigned to the sector to the left of the tower in all cells, and group B of channels is assigned to the sector at the top of all cells, and so on), each sector causes interference to the cells that are in its transmission angle only. Unlike the case of no sectoring where 6 interfering co-channel cells from the first-tier co-channels cells cause interference, with 120° sectoring, 2 or 3 co-channel cells cause interference and with 60° sectoring, 1 or 2 co-channel cells cause interference. The number of co-channel interfering cells depends on the cluster shape and size. By having less than 6 interfering first-tier co-channel cells causing interference, the SIR is increased for the same cluster size.

This allows us to reduce the cluster size and achieve the same original SIR, which directly increases the network capacity.

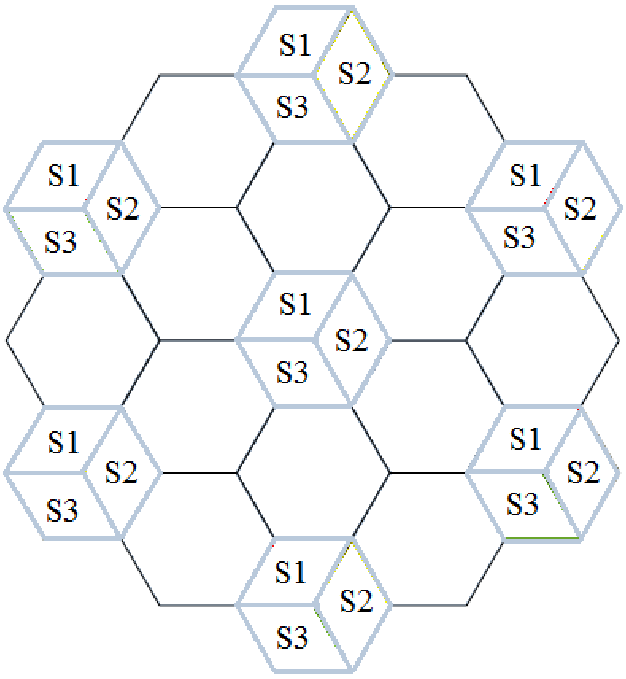


Figure 2.0: Handoff take place

As seen in the figures below, for the case of cluster size of $N = 4$, only 2 of the 6 co-channel cells cause interference to the middle cell for the sector labeled S2 in the case of 120° cell sectoring . The other 4 cells, although they are radiating at the same frequencies cause no interference because the middle cell is not in their radiation angles. For the case of 60° cell sectoring only one cell causes interference [8] [15].

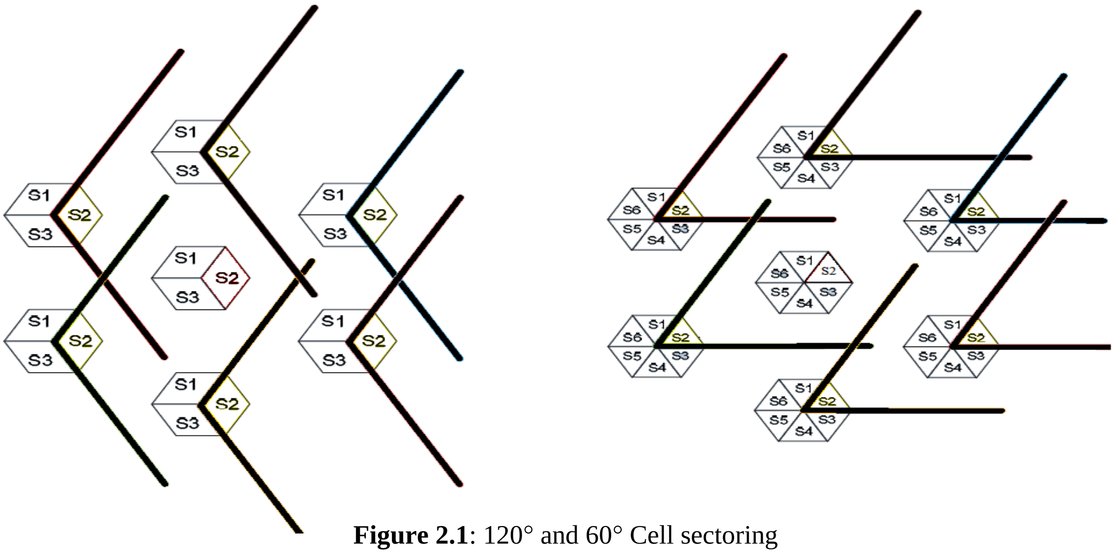


Figure 2.1: 120° and 60° Cell sectoring

In addition to the reduced number of interfering towers that sectoring produces, the SIR is reduced due to another reason. Since interfering tower always fall behind the tower (i.e., if a sector is radiating to the Right, for example, the interfering cells must be to its Left). Therefore, the worst case SIR occurs when the mobile phone being served by that sector is located at a relatively far corner with respect to the interfering cells. This means that among the 6 interfering co-channel cells in a non-sectored system, the sectored system gets rid of some of the worst interfering cells (the cells closest to the corner at which the mobile phone is located).

The SIR can be calculated by the following formula [3] [14] :

$$\frac{S}{I} = \frac{R^{-n}}{\sum_{i=1}^{i_0} (D_i)^{-n}} \qquad \text{......................... (1.4)}$$

Where, D is the distance between nearest co-channel cells center,

R is radius of the cell,

I_0 is the number of co channel interfering cells.

When sectoring is employed, the problem of increased number of handoffs required. As the solution of this problem we use novel microcell zone concept proposed by Lee.

F. ***Novel Microcell Zone Concept:***

In this scheme, each of the 3 (or more) zone sites (represented as Tx/Rx in Figure 4.4.) are connected to a single base station and share the same radio equipment.

• The zones are connected by coaxial cable, fiber optic cable (Radio over fiber), **or** microwave link to the base station. Multiple zones and a single base station make up a cell.

• As a mobile travels within the cell, it is served by the zone with the strongest signal.

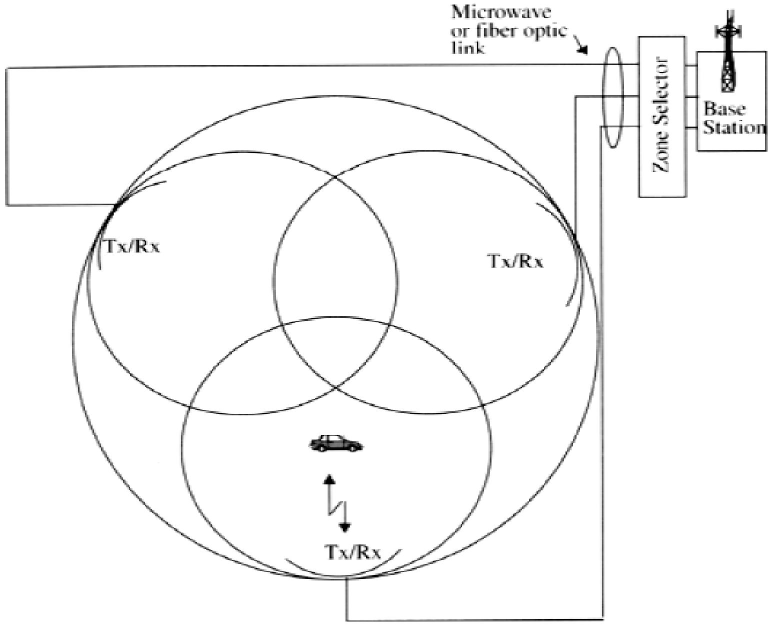


Figure 2.3: Microcell zone concept[14]

This approach is superior to sectoring since antennas are placed at the outer edges of the cell, and any base station channel may be assigned to any zone by the base station.

As a mobile travels from one zone to another within the cell, it retains the **s**ame channel. The base station simply switches the channel to a different zone site. (Thus, unlike in sectoring, a handoff is not required at the MSC when the mobile travels between zones within the cell.)

• The base station radiation is localized and interference is reduced. The channels are distributed in time and space by all three zones and are also reused in co-channel cells in the normal fashion.

• This technique is particularly useful for urban traffic

• Decreased co-channel interference improves the signal quality and also leads to an increase in capacity, without the degradation in trunking efficiency caused by sectoring.

VI. CONCLUSION

In this article, have studied to enhancement of channel capacity by the cell splitting and cell sectoring method. Each of those has some pros and cons, which decides different area for using these techniques. The capacity of a cellular communication system can be increased using cell splitting and by the sectoring method. The extent to which the capacity increment can be achieved is dependent on signal-to-interference ratio. The results show that when properly and orderly carried out, the cell splitting technique has the capability of increasing the capacity of a congested cellular system. Cell splitting achieves capacity improvement by essentially rescaling the system. By decreasing the cell radius R and keeping the co-channel reuse ratio D/R unchanged, cell splitting increases the number of channels per unit area. But cost factor will increase. In cell sectoring the main demerit is increase handoff condition. Sectoring decreases the trunking efficiency while improving the S/I for each user in the system. So the Mircocell zone concept to avoid the handoff , less interference and better reception and transmission.

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