Department of Electrical and Electronic Engineering (EEE)

Faculty of Engineering (FE)

American International University- Bangladesh (AIUB)

Laboratory Report

TELECOMMUNICATIONS ENGINEERING

Section: B Semester: Spring 2020-21

Course Instructor: **SHUVRA SAHA**

Experiment No: 07
Experiment Title: Cellular Mobile System Design
Date of Experiment:

Group-06

Name:	Student ID	Department
Das, Sourav	18-37400-1	EEE
Shanto, Md. Shahadot Hossain	18-37397-1	EEE
Purnendu, Prodip Kumar Saha	18-37389-1	EEE
Hasan Ekramul	18-37424-1	EEE
Shimanto, Khaled Mahmud	18-37452-1	EEE

Submitted by:

Name	Student ID	Department
Khaled Mahmud Shimanto	**18-37452-1**	**EEE**

For faculty use only:

Total Marks:	Marks Obtained:
Faculty Comments:	

Title: Cellular Mobile System Design

Introduction: The system design objective of early mobile radio systems was to achieve a large coverage area by using a single, high powered transmitter with an antenna mounted on a tall tower. However, with this approach, it was impossible to reuse the same frequencies throughout the system because of frequency reuse results in interference. A good example is the Bell mobile system in New York City (in the 1970s) that could only support a maximum of twelve simultaneous calls over a thousand square miles.

In addition, government regulatory agencies could not make spectrum allocations in proportion to the increasing demand for mobile services. Considering these constraints, it became essential to restructure the radio telephone system to achieve high capacity with limited radio spectrum that covers very large areas as well. And the cellular concept was applied in restructuring the early radio telephone system.

Objective: The objective of this experiment is to understand the concept of cells, frequency reuse, cluster, cluster size, co-channel and adjacent channel interference, cell splitting, and cell sectoring associated to cellular system design.

Theory and Methodology:

The cellular concept is a system level idea where.

- A single, high power transmitter (large cell) is replaced with many low power transmitters (small cells) and each small cell provides coverage to only a small portion of the service area.
- Each base station is allocated a portion of the total number of channels available to the entire system.

- And nearby base stations is assigned different groups of channels so that all the available channels are assigned to a relatively small number of neighboring base stations, and the interference between base stations (and the mobile users under their control) is minimized.

- Base stations and their channel groups are systematically spaced throughout a market so that the available channels are distributed throughout the geographic region and may be reused as many times as necessary so long as the interference between co-channel stations is kept below acceptable levels.

- With the demand for service increases, i.e. as more channels are needed within a particular market), the number of base stations may be increased along with a corresponding decrease in transmitter power to avoid added interference.
- Thereby, it provides additional radio capacity with no additional increase in radio spectrum – the fundamental principle, which is the foundation for all modem wireless communication systems.

Hence, the cellular concept enables a fixed number of channels to serve an arbitrarily large number of subscribers by reusing the channels throughout the coverage region. Furthermore, the cellular concept allows every piece of subscriber equipment within a country or continent to be manufactured with the same set of channels, so that any mobile may be used anywhere within the region.

A. Cellular Frequency Reuse Concept

- In cellular system, each cellular base station is allocated a group of radio channels to be used within a small geographic area called a cell.

- Base stations in adjacent cells are assigned channel groups which contain completely different channels than neighboring cells. The base station antennas are designed to achieve the desired coverage within the particular cell.

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

- The design process of selecting and allocating channel groups for all of the cellular base stations within a system is called frequency reuse or frequency planning. Figure 6.1 illustrates the concept of cellular frequency reuse, where cells labeled with the same letter use the same group of channels.

Note that the hexagonal cell shape shown in figure 5.1 is conceptual and is a simplistic model of the radio coverage for each base station. However, it has been universally adopted since the hexagon permits easy and manageable analysis of a cellular system.

The actual radio coverage of a cell is known as the footprint and is determined from field measurements or propagation prediction models. Although the real footprint is amorphous in nature, a regular cell shape is needed for systematic system design and adaptation for future growth. While it might seem natural to choose a circle to represent the coverage area of a base station, adjacent circles cannot be overlaid upon a map without leaving gaps or creating overlapping regions.

Thus, when considering geometric shapes which cover an entire region without overlap and with equal area, there are three sensible choices: a square; an equilateral triangle; and a hexagon. However, for a given distance between the center of a polygon and its farthest perimeter points, the hexagon has the largest area of the three. Thus, by using the hexagon geometric, the fewest number of cells can cover a geographic region, and the hexagon closely approximates a circular radiation pattern which would occur for an omnidirectional base station antenna and free space propagation. Note of course that the actual cellular footprint is determined by the contour in which a given transmitter serves the mobiles successfully.

When using hexagons to model coverage areas, base station transmitters are depicted as either being in the center of the cell, center-excited cells or on three of the six cell vertices, edge-excited cells. Normally, omnidirectional antennas are used in center-excited cells, and sectored directional antennas are used in corner-excited cells.

Practical considerations usually do not allow base stations to be placed exactly as they appear in the hexagonal layout. Most system designs permit a base station to be positioned up to one-fourth the cell radius away from the ideal location.

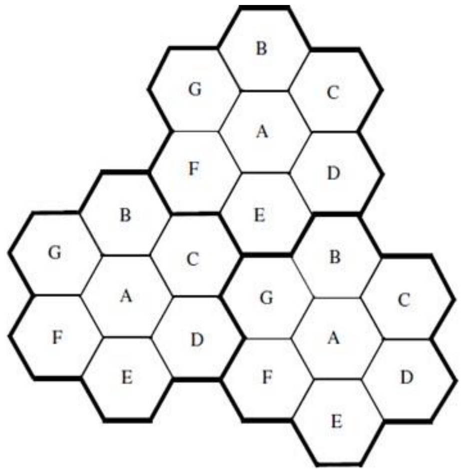


Figure 4.1: Illustration of the cellular frequency reuse concept. Cells with the same letter use the same set of frequencies. A cell cluster is outlined in bold and replicated over the coverage area. In this example, the cluster size N is equal to seven, and the frequency reuse factor is 1/7.

Consider a cellular system with the followings.

- S duplex channels available for use
- Each cell is allocated a group of k channels (k < S) and
- 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

$$S = k.N \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.1)$$

The N cells 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 be used as a measure of capacity and is given by

$$C = M.k.N = M.S \ldots\ldots\ldots\ldots (4.2)$$

Note from equation (4.2) that 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 is typically equal to 4, 7, or 12. The value of N plays an important role in system design and performance. If the cluster size N is reduced while the cell size is kept constant, more clusters are required to cover a given area. And hence, more capacity (a larger value of C) is achieved. In addition, the value for N is a function of how much interference a mobile or base station can tolerate while maintaining a sufficient quality of communications.

Note that a large cluster size indicates that the ratio between the cell radius (R) and the distance between co-channel cells (D) is large. Conversely, a small cluster size indicates that co-channel cells are located much closer together.

From a design viewpoint, the smallest possible value of N is desirable in order to maximize capacity over a given coverage area, i.e. to maximize C. 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 design network without gaps between adjacent cells, the geometry of hexagons is such that the number of cells per cluster N can only have values which satisfy equation (4.3).

$$N = i^2 + ij + j^2 \text{.................. (4.3)}$$

where i and j are non-negative integers, and i $\geq$ j are called shift parameters.

Note that in order to find the nearest co-channel neighbors of a particular cell, the followings steps should consider.

Step 1 move i cells along any chain of hexagons, then
Step 2 turn 60 degrees counter-clockwise, and finally
Step 3 move j cells; the j^{th} cell is the co-channel cell.

or

Step 1 move j cells along any chain of hexagons, then

Step 2 turn 60 degrees clockwise, and finally

Step 3 move i cells; the i^{th} cell is the co-channel cell.

This is illustrated in figure 4.2 for i = 3 and j = 2, hence N = 19; an example illustration.

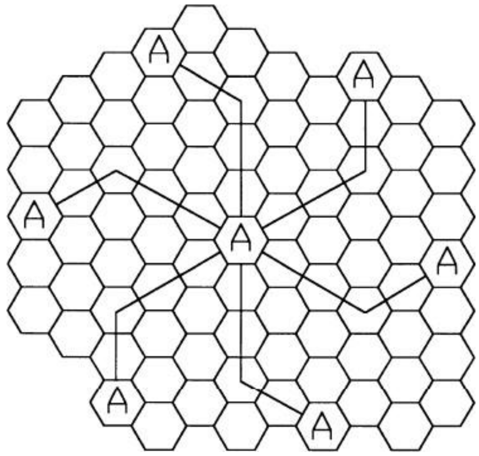


Figure 4.2: Method of locating co-channel cell in a cellular system (for i = 3 and j = 2, hence N= 19).

(I) Channel Assignment Strategies

A variety of channel assignment strategies have been developed to achieve the objectives: increasing capacity and minimizing interference for efficient utilization of the radio spectrum. Channel assignment strategies can be classified as either fixed or dynamic. Channel assignment strategy impacts the performance of the system, particularly during handing off a mobile phone from one cell to another.

In a fixed channel assignment strategy,

- Each cell is allocated a predetermined set of voice channels.
- Any call attempt within the cell can only be served by the unused channels in that particular cell.
- If all the channels in that cell are occupied, the call is blocked and the subscriber does not receive service.

Note that several variations of the fixed assignment strategy exist such as borrowing strategy where a cell is allowed to borrow channels from a neighboring cell if all of its own channels are already occupied. The mobile switching center (MSC) supervises such borrowing procedures and ensures that the borrowing of a channel does not disrupt or interfere with any of the calls in progress in the donor cell.

In a dynamic channel assignment strategy,

- Voice channels are not allocated to different cells permanently. Instead, each time a call request is made, the serving base station requests a channel from the MSC.
- The switch then allocates a channel to the requested cell following an algorithm that takes into account the likelihood of future blocking within the cell, the frequency of use of the candidate channel, the reuse distance of the channel, and other cost functions.
- Accordingly, the MSC only allocates a given frequency if that frequency is not presently in use in the cell or any other cell which falls within the minimum restricted distance of frequency reuse to avoid co-channel interference.

Dynamic channel assignment reduces the likelihood of blocking which increases the trunking capacity of the system since all the available channels in a market are accessible to all of the cells. However, dynamic channel assignment strategies require the MSC to collect real-time data on channel occupancy, traffic distribution, and radio signal strength indications (RSSI) of all channels on a continuous basis. This increases the storage and computational load on the system.

The following table shows the assignment of traffic channels for the first half (Block A) of the 666 channel AMPS system (where 42 channels are reserved as control channels) for the frequency reuse factor K = 7 and 3 sectors per cell. It can be easily seen that in any group the minimum frequency separation between channels is 21.

Table 4.1: Assignment of traffic channels.

Group Number	Channel Assignment														
1A	1	22	43	64	85	106	127	148	169	190	211	232	253	274	295
2A	2	23	44	65	86	107	128	149	170	191	212	233	254	275	296
3A	3	24	45	66	87	108	129	150	171	192	213	234	255	276	297
4A	4	25	46	67	88	109	130	151	172	193	214	235	256	277	298
5A	5	26	47	68	89	110	131	152	173	194	215	236	257	278	299
6A	6	27	48	69	90	111	132	153	174	195	216	237	258	279	300
7A	7	28	49	70	91	112	133	154	175	196	217	238	259	280	301
1B	8	29	50	71	92	113	134	155	176	197	218	239	260	281	302
2B	9	30	51	72	93	114	135	156	177	198	219	240	261	282	303
3B	10	31	52	73	94	115	136	157	178	199	220	241	262	283	304
4B	11	32	53	74	95	116	137	158	179	200	221	242	263	284	305
5B	12	33	54	75	96	117	138	159	180	201	222	243	264	285	306
6B	13	34	55	76	97	118	139	160	181	202	223	244	265	286	307
7B	14	35	56	77	98	119	140	161	182	203	224	245	266	287	308
1C	15	36	57	78	99	120	141	162	183	204	225	246	267	288	309
2C	16	37	58	79	100	121	142	163	184	205	226	247	268	289	310
3C	17	38	59	80	101	122	143	164	185	206	227	248	269	290	311
4C	18	39	60	81	102	123	144	165	186	207	228	249	270	291	312
5C	19	40	61	82	103	124	145	166	187	208	229	250	271	292	–
6C	20	41	62	83	104	125	146	167	188	209	230	251	272	293	–
7C	21	42	63	84	105	126	147	168	189	210	231	252	273	294	–

The following figure 4.3 shows a channel assignment corresponding to the table, when each 2π/3 sector antenna is located in the corner of hexagonal cell.

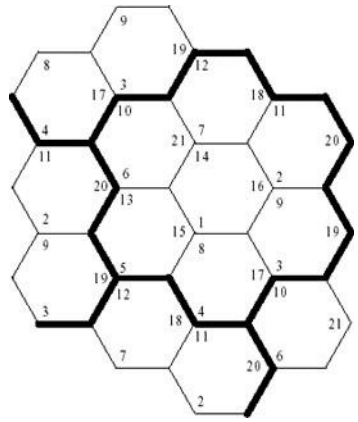


Figure 4.3 shows a channel assignment corresponding to the table.

(II) Interference in Cellular Systems

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

- Interference on voice channels causes cross talk, where the subscriber hears interference in the background due to an undesired transmission. On control channels, interference leads to missed and blocked calls due to errors in the digital signaling.
- Interference is more severe in urban areas, due to the greater high frequency (HF) noise floor and the large number of base stations and mobiles.
- Interference has been recognized as a major bottleneck in increasing capacity and is often responsible for dropped calls.
- The two major types of system-generated cellular interference are co-channel interference and adjacent channel interference.

- They are difficult to control in practice due to random propagation effects and more so is the interference due to out-of-band users, which arises without warning due to front end overload of subscriber equipment or intermittent inter-modulation products. In practice, the transmitters from competing cellular carriers are often a significant source of out-of-band interference, since competitors often locate their base stations in close proximity to one another in order to provide comparable coverage to customers.

(III) Co-channel Interference

Frequency reuse implies that in a given coverage area, there are several cells that use the same set of frequencies. These cells are called co-channel cells, and the interference between signals from these cells is called co-channel interference. Note that unlike thermal noise which can be overcome by increasing the signal-to-noise ratio (SNR), co-channel interference cannot be combated by simply increasing the carrier power of a transmitter. This is because an increase in carrier transmit power increases the interference to neighboring co-channel cells. To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.

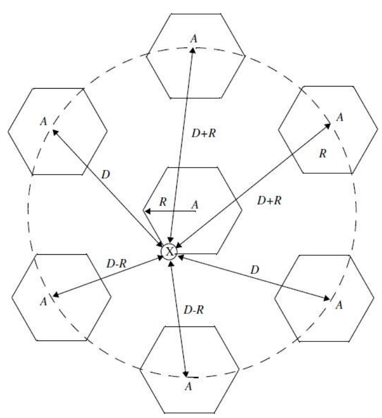


Figure 4.4: Illustration of the first tier of co-channel cells for a cluster size of N=7.

When the mobile is at the cell boundary (point A), it experiences worst case co-channel interference on the forward channel. The marked distances between the mobile and different co-channel cells are based on approximations made for easy analysis

(IV) Adjacent Channel Interference

Interference resulting from signals which are adjacent in frequency to the desired signal is called adjacent channel interference. Adjacent channel interference results from imperfect receiver filters which allow nearby frequencies to leak into the passband.

The problem can be particularly serious if an adjacent channel user is transmitting in very close range to a subscriber's receiver, while the receiver attempts to receive a base station on the desired channel. This is referred to as the near-far effect, where a nearby transmitter (which may or may not be of the same type as that used by the cellular system) captures the receiver of the subscriber. Alternatively, the near-far effect occurs when a mobile close to a base station transmits on a channel close to one being used by a weak mobile. The base station may have difficulty in discriminating the desired mobile user from the bleedover caused by the close adjacent channel mobile.

- Adjacent channel interference can be minimized through careful filtering and channel assignments. Since each cell is given only a fraction of the available channels, a cell need not be assigned channels which are all adjacent in frequency.

- By keeping the frequency separation between each channel in a given cell as large as possible, the adjacent channel interference may be reduced considerably.

- Thus instead of assigning channels which form a contiguous band of frequencies within a particular cell, channels are allocated such that the frequency separation between channels in a given cell is maximized.

- By sequentially assigning successive channels in the frequency band to different cells, many channel allocation schemes are able to separate adjacent channels in a cell by as many as N channel bandwidths, where N is the cluster size.

- Some channel allocation schemes also prevent a secondary source of adjacent channel interference by avoiding the use of adjacent channels in neighboring cell sites.

(V) Improving Capacity in Cellular Systems

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.

While cell splitting increases the number of base stations in order to increase capacity, sectoring and zone microcells rely on base station antenna placements to improve capacity by reducing co-channel interference. Cell splitting and zone microcell techniques do not suffer the trunking inefficiencies experienced by sectored cells, and enable the base station to oversee all handoff chores related to the microcells and thus reducing the computational load at the MSC. In this lab we consider investigating Cell splitting and sectorization.

(VI) 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 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 between the existing cells, capacity increases due to the additional number of channels per unit area.

An example of cell splitting is shown in figure 4.5. In figure 4.5, the base stations are placed at corners of the cells, and the area served by base station A is assumed to be saturated with traffic (i.e., the blocking of base station A exceeds acceptable rates). New base stations are therefore needed in the region to increase the number of channels in the area and to reduce the area served by the single base station.

Note in the figure that the original base station A has been surrounded by six new microcell base stations. In the example shown in figure 4.5, the smaller cells were added in such a way as to preserve the frequency reuse plan of the system. For example, the new cell base station labeled G was placed half-way between two larger stations utilizing the same channel set G. This is also the case for the other new cells in the figure. As can be seen from figure 4.5, cell splitting merely scales the geometry of the cluster. In this case, the radius of each new microcell is half that of the original cell.

For the new cells to be smaller in size, the transmit power of these cells must be reduced. The transmit power of the new cells with radius half that of the original cells can be found by examining the received power at the new and old cell boundaries and setting them equal to each other. This is necessary to ensure that the frequency reuse plan for the new microcells behaves exactly as for the original cells. For figure 4.5,

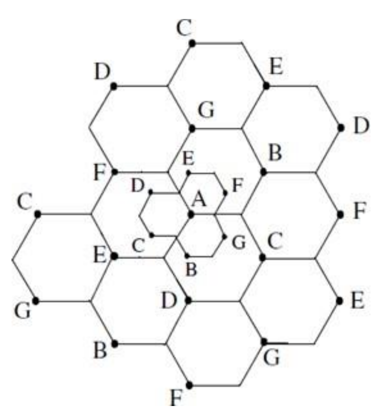


Figure 4.5: Illustration of cell splitting

where Pt1 and Pt2 are the transmit powers of the larger and smaller cell base stations, respectively, and n is the path loss exponent. If we take n = 4 and set the received powers equal to each other, then

$$P_{t2} = \frac{P_{t1}}{16} \quad \text{..........................4.6}$$

In other words, the transmit power must be reduced by 12 dB (-4*10log10 (1/2) dB) in order to fill in the original coverage area with microcells, while maintaining the S/I requirement.

In practice, not all cells are split at the same time. It is often difficult for service providers to find real estate that is perfectly situated for cell splitting. Therefore, different cell sizes will exist simultaneously. In such situations, special care needs to be taken to keep the distance between co-channel cells at the required minimum, and hence channel assignments become more complicated.

When there are two cell sizes in the same region as shown in figure 4.5, one cannot simply use the original transmit power for all new cells or the new transmit power for all the original cells. If the larger transmit power is used for all cells, some channels used by the smaller cells would not be sufficiently separated from co-channel cells. On the other hand, if the smaller transmit power is used for all the cells, there would be parts of the larger cells left unserved.

For this reason, channels in the old cell must be broken down into two channel groups, one that corresponds to the smaller cell reuse requirements and the other that corresponds to the larger cell reuse requirements. The larger cell is usually dedicated to high speed traffic so that handoffs occur less frequently.

At the beginning of the cell splitting process, there will be fewer channels in the small power groups.

However, as demand grows, more channels will be required, and thus the smaller groups will require more channels. This splitting process continues until all the channels in an area are used in the lower power group, at which point cell splitting is complete within the region, and the entire system is rescaled to have a smaller radius per cell.

Antenna down tilting (oriented), which deliberately focuses radiated energy from the base station towards the ground rather than towards the horizon (sphere), is often used to limit the radio coverage of newly formed microcells.

(VII) Sectoring

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.

However, another way to increase capacity is to keep the cell radius unchanged and seek methods to decrease the D/R ratio. In this approach, capacity improvement is achieved by reducing the number of cells in a cluster and thus increasing the frequency reuse. However, in order to do this, it is necessary to reduce the relative interference without decreasing the transmit power.

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. By using directional antennas, a given cell will receive interference and transmit with only a fraction of the available co-channel cells.

The technique for decreasing co-channel interference and thus increasing system capacity by using directional antennas is called sectoring. The factor by which the co-channel

interference is reduced depends on the amount of sectoring used. A cell is normally partitioned into three 1200 sectors or six 600 sectors as shown in figure 4.6 (a) and (b).

When sectoring is employed, the channels used in a particular cell are broken down into sectored groups and are used only within a particular sector, as illustrated in figure 4.6 (a) and (b). Assuming 7-cell reuse, for the case of 120° sectors, the number of interferers in the first tier is reduced from 6 to 2. This is because only 2 of the 6 co-channel cells receive interference with a particular sectored channel group.

Referring to figure 4.7, consider the interference experienced by a mobile located in the right-most sector in the center cell labeled “5”. There are 3 co-channel cell sectors labeled "5" to the right of the center cell, and 3 to the left of the center cell. Out of these 6 co- channel cells, only 2 cells have sectors with antenna patterns which radiate into the center cell, and hence a mobile in the center cell will experience interference on the forward link from only these two sectors. The resulting S/I for this case can be found to be 24.2 dB, which is a significant improvement over the omni-directional case in, where the worst case S/I was 17 dB.

In practical systems, further Improvement in S/I is achieved by downtilting the sector antennas such that the radiation pattern in the vertical (elevation) plane has a notch at the nearest co-channel cell distance. Thus, sectoring reduces interference, which amounts to an increase in capacity by a factor of 12/7 or 1.714. In practice, the reduction in interference offered by sectoring enable planners to reduce the cluster size N and provides an additional degree of freedom in assigning channels.

The penalty for improved S/I and the resulting capacity improvement is an increased number of antennas at each base station, and a decrease in trunking efficiency due to channel sectoring at the base station. Since sectoring reduces the coverage area of a particular group of channels, the number of handoffs increases, as well.

Fortunately, many modern base stations support sectorization and allow mobiles to be handed off from sector to sector within the same cell without intervention from the MSC, so the handoff problem is often not a major concern.

It is the loss of traffic due to decreased trunking efficiency that causes some operators to shy away from the sectoring approach, particularly in dense urban areas where the directional antenna patterns are somewhat ineffective in controlling radio propagation. Because sectoring uses more than one antenna per base station, the available channels in the cell must be subdivided and dedicated to a specific antenna. This breaks up the available trunked channel pool into several smaller pools, and decreases trunking efficiency.

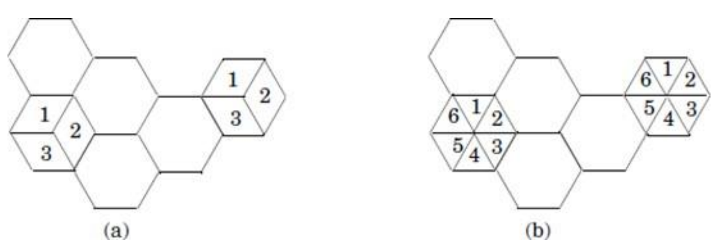


Figure 4.6: Sectorization of cells: (a) 1200 sectoring (b) 600 sectoring.

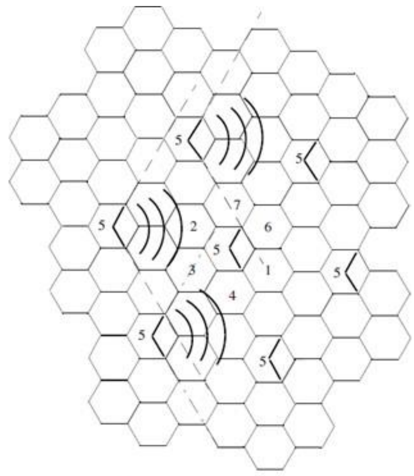


Figure 4.7: Illustration of how 1200 sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only 2 of them interfere with the center cell. If omni-directional antennas were used at each base station, all 6 co- channel cells would interfere with the center cell.

(VIII) System Modeling

Frequency Modeling

- The frequency reuse is one of the most important design challenges in cellular networks.
- The base stations (BSs) of the cellular network should be located as near to each other as possible to maximize the number of simultaneous users, but should not be so close that the cochannel interference results in unacceptable speech quality.
- The reuse distance, i.e. distance between co-channel cells D is an important parameter that determines the reuse pattern within the cellular network.

Specifically, we assume that

- all co-channel base stations have same transmitter power,
- the path loss is proportional to d-4,
- noise level is negligible when compared to interference level
- there are 6 equidistant interferers at the channel, and the interference from interferers, that are further away, can be neglected,
- cell radius is R, and
- the distance between co-channel cells is D.

We can approximately analyze the co-channel interference on basis of the following figure

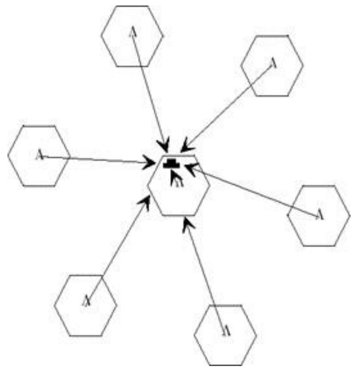


Figure 4.8: co-channel interference from first tier.

Hence, the *signal to co-channel interference ratio* is given as

$$\frac{C}{I} = \frac{C}{\sum_{i=1}^{6} Ii} =$$

$$= \frac{R^{4}}{6D^{4}}$$

So that

$$D = R\sqrt[4]{6\frac{C}{I}} \quad \text{............................}4.7$$

The ratio of co-channel cell site distance to the cell radius R is given by

$$\frac{D}{R} = \sqrt{3K} \quad \text{............................} \quad 4.8$$

For K=7 and i=2 and j=1, the desired carrier-to-interference ratio at the cell site is given by

$$C \qquad C \qquad c$$

$$\frac{C}{I_T} = \frac{C}{\sum_{i=1}^{6} Ii} = \frac{C}{6I}$$

$$= \frac{1}{6}\,\frac{R^{-n}}{(D-R)^{-n}}$$

$$= \frac{1}{6}\left(\frac{D-R}{R}\right)^{n}$$

We can then express frequency reuse factor K as,

$$K = \frac{1}{3}\left[\left(\frac{6C}{I_T}\right)^{\frac{1}{n}} + 1\right]^{2} \text{ ....4.9}$$

Note that “for low value of CIR, K is reduced. Hence, larger number of channels per cell and a large traffic capacity”.

For n=4, and CIR=18 dB, K≈10, Neglecting 1, for a higher CIR and n=4,

$$K = \frac{2}{3}\sqrt{\left(\frac{C}{I_T}\right)}$$

Hence if CIR increases that results in decrease in co-channel interference and so results higher value of K.

If N_f is the number of channels per cell, then

$$N_f = \frac{B_a}{KB_c}$$

$$= \frac{B_a}{B_c\sqrt{\frac{2}{3}\left(\frac{C}{I}\right)_T}}$$

(IX). Cell Splitting

Typically the area of a cell is split into 4 new cells, which means that the radius of each new cell is one half of the radius of the original cell.

Assume 40 dB/decade pathloss so that the power can be reduced by 12 dB. Thus, after n splitting, the new traffic capacity within the original area will be

$$T_n = 4^n T_0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.10$$

and the new power of the transmitters will be

$$P_n(dB) = P_0 - 12n \ldots\ldots\ldots\ldots\ldots 4.11$$

The spectral efficiency of cellular systems (FDMA and TDMA) can be expressed in terms of number of channels per cell as follows.

$$N_f = \frac{\left(\frac{B_{tot}}{B_c}\right)}{K_C}$$

$$= \frac{\left(\frac{B_{tot}}{B_c}\right)}{\sqrt{\frac{2}{3}\left(\frac{C}{I}\right)_{min}}}$$

where

Btot is the total bandwidth of the system

Bc is the (equivalent) bandwidth of a single channel

(C/I)min is the minimum acceptable signal-to-interference ration K is the reuse factor

Hence it is shown that we can increase the spectral efficiency by either decreasing the channel bandwidth Bc or decreasing the C/I requirement.

(x) Bit Transfer Capacity

We can calculate the bit transfer capacity: number of bits transmitted within one second in bandwidth of one Hertz in a single cell of the network.

$$c = \frac{R^t}{B_c K} \qquad \text{..............................4.12}$$

(XI) System capacity

For an allocation of N frequency channels for a coverage area A, the capacity of the system can be assessed in terms of number of simultaneous calls, which can be calculated as

$$c = \frac{A}{ABS}\left(\frac{N}{K}\right) \qquad \text{..............................4.13}$$

where A_{BS} is the area of a single base station. For hexagonal cells, this area can be calculated from the cell radius as

$$ABS = \frac{2}{3}\sqrt{3}R2$$

$$\approx 2.6R^2$$

The number of cells is

$$N_{BS} = \frac{A}{ABS} \qquad \text{......................} \quad 4.14$$

The *number of simultaneous calls* in the system is

$$n = \frac{N}{N_{BS}\,K} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4.15$$

(XII) Adjacent Channel Interference and Traffic Channel Assignment

Note that what follows is all about describing fixed channel assignment, where each cell is permanently allocated a preselected set of frequency channels. Adjacent channel interference occurs when signal energy spills over from one channel into another channel that is adjacent to it in the frequency spectrum. The most important adjacent channel interference is caused by the immediately preceding and following channels.

In principle it is possible to control adjacent channel interference completely through filtering at the transmitter and the receiver. However, tight filtering makes mobile units more expensive and introduces ISI in the received signal.

Assume a relatively simple receiving filter with 6 dB/oct low-pass equivalent attenuation characteristics, we can calculate for a 30 kHz channel the attenuation from the edge of the band at f1 = 15 kHz to frequency offset f2 as

$$A(dB) = \frac{6}{\log(2)} \log\left(\frac{f2}{f1}\right) \quad \ldots\ldots\ldots\ldots \quad 4.16$$

For f2 = 120 kHz and (f2/f1) = 8, i.e. 4 channels away, we get the attenuation of 18 dB.

Thus, if we require C/I ratio of 18 dB as for cochannel interference, the three adjacent channels to any channel in use cannot be used for traffic. Adjacent channel interference can be reduced by maintaining maximum frequency separation between channels in any given cell. For maximum frequency separation between channels, the frequencies k, k+K, k+2K ... should be assigned to the kth cell, when the frequency reuse factor K is used.

The following table shows the procedure of the frequency allocation used for the AMPS system for the frequency reuse factor K = 7.The letters A, B and C refer to 3 sectors of directional antennas that are used in each BS.

Table 4.3: Procedure of the frequency allocation used for the AMPS system for the frequency reuse factor K = 7.

Group Number	Channel Assignment														
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	
1	1	8	15	22	29	36	43	50	57	64	71	78	85	92	…
2	2	9	16	23	30	37	44	51	58	65	72	79	86	93	…
3	3	10	17	24	31	38	45	52	59	66	73	80	87	94	…
4	4	11	18	25	32	39	46	53	60	67	74	81	88	95	…
5	5	12	19	26	33	40	47	54	61	68	75	82	89	96	…
6	6	13	20	27	34	41	48	55	62	69	76	83	90	97	…
7	7	14	21	28	35	42	49	56	63	70	77	84	91	98	…

- Since the adjacent group numbers contain adjacent frequency channels, they should not be assigned to neighboring sectors in cells.
- It should be noted that for small reuse factors (e.g. K = 4), it is impossible (especially, without sectoring) to avoid using immediately adjacent frequency channels in some of the neighboring six cells.
- Already, for K = 7, it is very difficult without sectoring to find a channel assignment in which the use of immediately adjacent frequency channels could be avoided.
- However, for K = 9, we can find a channel assignment (see following Figure) in which immediately adjacent frequency channels are never used in neighboring cells.

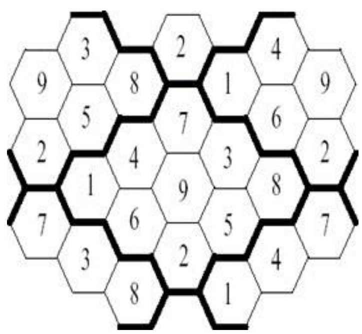


Figure 4.9: Channel assignment for K=9.

An example of adjacent Channel frequency separation for two channels which are used in a 12-cell cluster is shown below. Here K=12, Ch. 1, 13, 25, 30 kHz is channel bandwidth center to center is 360 kHz Edge to edge is 330 kHz.

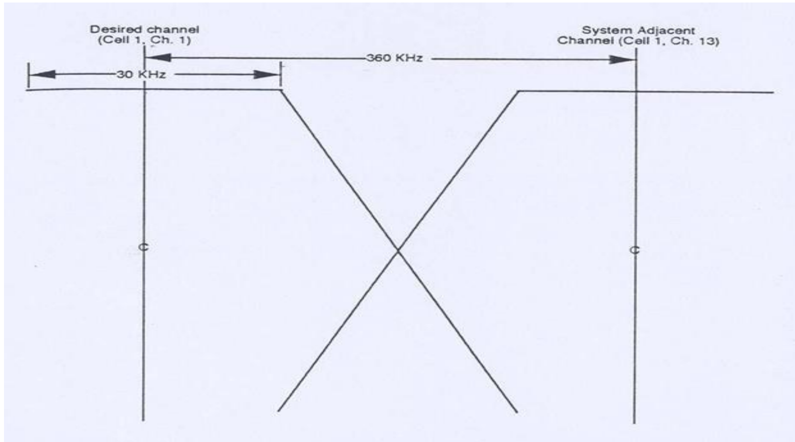


Figure 4.10: Frequency separation between desired and system-adjacent channel.

(XIII) Near-End-to-Far-End Ratio

When the mobile units are moving within a cell, we often encounter a situation, where two MSs are transmitting simultaneously to the BS at different channels. And one of the MSs is much nearer to the BS than the other.

Assuming that the mobile transmits the same power, the signal received at the cell site is proportional to the geographical distance between the cell site and the MS. When the separation from two MS operating on adjacent channels is widely different, a situation can arise when the power received at the cell site from a nearby MS is far higher than that of from another MS farther away.

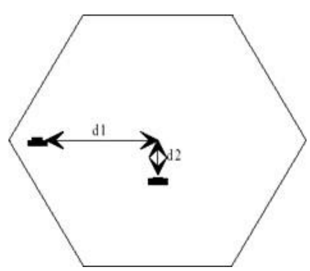


Figure 4.11: Near-far effects.

These unbalanced received powers are due to different path losses and known as near-end (NE) to far-end (FE) ratio interference (NE / FE) = (path loss due to path d1) / (path loss due to path d2), where nearby distance d1 is from interfering MS and farther distance d2 is from the desired MS. If n=4, then

$$\frac{NE}{FE} = \left(\frac{d_1}{d_2}\right)^{-4} \quad \text{.........................} \quad 4.17$$

This large imbalance in the received levels makes the problem of adjacent channel interference even more severe, and as a consequence it also increases the required frequency separation between channels.

For example, in a case the distances of MSs from the BS are 0.5 and 10 km and assuming 40 dB/dec pathloss, the ratio of received powers at the BS is 52 dB. This ratio of received powers due to different locations of two transmitters is called near-end-to-far-end ratio. If we still require C/I ratio of 18 dB, the required attenuation of the lowpass-equivalent receiving filter for the lower-level channel is 52 + 18 = 70 dB. Even if we assume a slightly better receiving filter with 12 dB/oct attenuation characteristics, the required frequency ratio f2/f1 is 58.

Matlab code:

```
close all;
clc;

% Name:Khaled Mahmud Shimanto; Id:18-37452-1

% Denote variables
%-----------------------------------------------------------------
-----------
c_i=18; % Carrier-to-interference ratio at the receiver (dB)
c_i_abs=10^1.8; % in absolute value
sys_bw=25*10^6; % System bandwidth in Hz
ch_bw=200*10^3; % Channel bandwidth in Hz
p_loss_exp=4; % Pathloss exponent equals to 4
area_covered=(2.6*9)*10^6; % Area to be covered is 23.4 km2
cell_radius=1*10^3; % Cell radious is 1 km (consider hexagonal
cell)
```

```
call_rate=1;% call arrival rate is 1 persecond
hold_time=0.5; % call holding time is 0.5 seconds
rec_filter_ch=6;
% receiver filter characteristics 6 dB per octave
pt_old=46; % transmit power 46 dBm
split=1; % number of splitting the original cell
bit_rate=1000;% bit rate 1 kbps system level
%-----------------------------------------------------------------
-----------
% part 01 cell layout and c0-channel interference
%-----------------------------------------------------------------
-----------

% 01 minimum co-channel cell reuse ratio
D_R=(6*c_i_abs)^(1/p_loss_exp); % consider only first-tier
interferer
% 02 frequency reuse factor
K=1/3*(D_R+1)^2;
% 03 Area of a hexagonal cell
area_cell=2.6*cell_radius^2;
% 04 number of cells required to cover the given area
cell_no=area_covered/area_cell;
% 05 number of channels per cell
channel_no_cell=sys_bw/(ch_bw*K);
% 05 maximum number of channels in the system (no of users)
% or system capacity
channel_no_sys=sys_bw/ch_bw;
% system capacity
sys_capa_old=channel_no_sys;
%-----------------------------------------------------------------
-----------
% Part 02 Cell splitting
% consider each cell is splitted into 4 new cells
%-----------------------------------------------------------------
-----------
% 06 new system capacity after cell splitting
sys_capa_new=4^split*sys_capa_old;
% 07 new system transmit power requirement after cell splitting
pt_new=pt_old-12*split;
%-----------------------------------------------------------------
-----------
% Part 03 Bit transfer capacity per cell
%-----------------------------------------------------------------
-----------
% 08 Bit transfer capacity per Hz per cell
bit_trans_capa_cell=bit_rate/(ch_bw*K); %bps/hz/cell
```

```
%-----------------------------------------------------------------
-----------
% Part 04 receiver filter attenuatuation characteristics for no
adjacent channel
% interference
%-----------------------------------------------------------------
-----------
f1=15;
f2=120;
f2_f1=f2/f1; % difference between channels (frequencies) apart
% 09 receiver filter attenuation characteristics
filter_atten_cha=c_i*(log10(2)/log10(f2_f1)); % in dB/octave
%-----------------------------------------------------------------
-----------
% Part 05 Channel assignment strategy in cells
%-----------------------------------------------------------------
-----------

%10 Fixed channel assignment strategy
channel_no_sys=125;
K=7;
i=1; % for no sectorrization
% i=3; % for 3-sector
% i=6; % for 6-sector
cha_cell=round(channel_no_sys/(K*i));
cha_cell_ind_sec01=zeros(K,cha_cell);
chanl=1:1:channel_no_sys;
chanl_no=zeros(K,channel_no_sys);
%--------------------------------------------------
for k1=1:1:K
 for j=k1:i*K:channel_no_sys
 chanl_no(k1,j)=j;
 end
end
for i2=1:K
 s=0;
 for j2=1:channel_no_sys
 xx=chanl_no(i2,j2);
 if xx>0
 s=s+1;
 cha_cell_ind_sec01(i2,s)=xx;
 end
 end
end
%--------------------------------------------------
% note that for sectorization, for example 3-sector, the output
gives only
```

```
% for one sector. For other sectors, readers are advised to try
on their
% own. set i=1 for no sectorization.
%-----------------------------------------------------------
% output
%-----------------------------------------------------------
disp('01 minimum co-channel cell reuse ratio = ')
disp(D_R)

disp('02 frequency reuse factor = ')
disp(K)
disp('03 Area of a hexagonal cell in m2= ')
disp(area_cell)
disp('04 number of cells required to cover the given area = ')
disp(cell_no)
disp('05 system capacity in maximum number of users = ')
disp(sys_capa_old)
disp('06 new system capacity after cell splitting in maximum
number of users = ')
disp(sys_capa_new)
disp('07 new system transmit power requirement after cell
splitting in dB = ')
disp(pt_new)
disp('08 Bit transfer capacity in bps/Hz/cell = ')
disp(bit_trans_capa_cell)
disp('09 receiver filter attenuation characteristics in
dB/octave = ')
disp(filter_atten_cha)
disp('10 Fixed channel assignment strategy = ')
disp(cha_cell_ind_sec01)
%------------------------------------------------------------
```

Output:

01. minimum co-channel cell reuse ratio =

4.4110

02. frequency reuse factor =

7

03. Area of a hexagonal cell in m2=

2600000

04. number of cells required to cover the given area =

9.0000

05. system capacity in maximum number of users =

125

06. new system capacity after cell splitting in maximum number of users =

500

07. new system transmit power requirement after cell splitting in dB =

34

08. Bit transfer capacity in bps/Hz/cell =

5.1231e-04

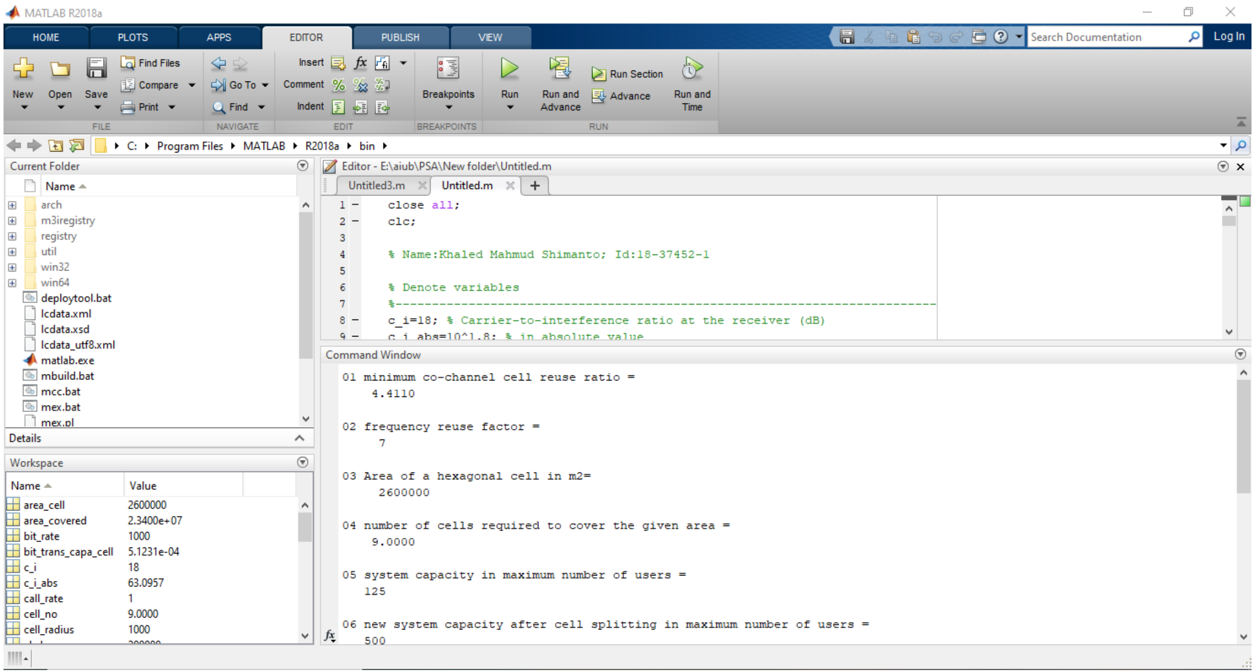
09. receiver filter attenuation characteristics in dB/octave =

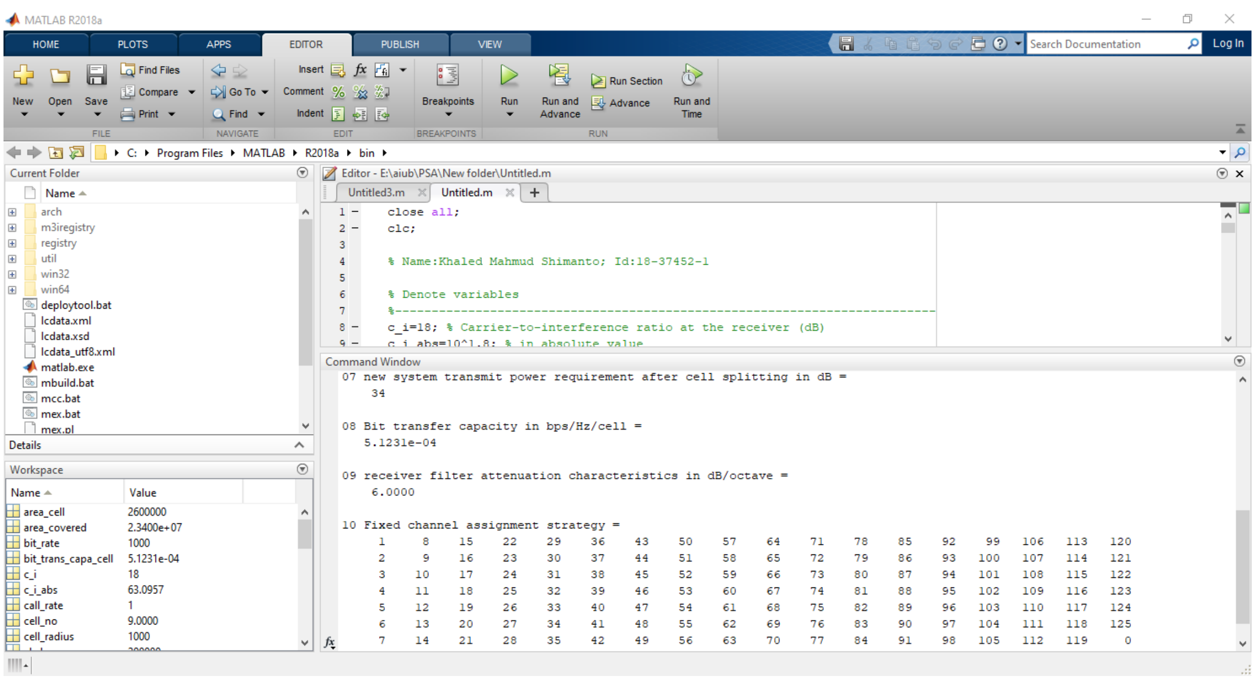
6.0000

10. Fixed channel assignment strategy =

1	8	15	22	29	36	43	50	57	64	71	78	85	92	99	106	113	120
2	9	16	23	30	37	44	51	58	65	72	79	86	93	100	107	114	121
3	10	17	24	31	38	45	52	59	66	73	80	87	94	101	108	115	122
4	11	18	25	32	39	46	53	60	67	74	81	88	95	102	109	116	123
5	12	19	26	33	40	47	54	61	68	75	82	89	96	103	110	117	124
6	13	20	27	34	41	48	55	62	69	76	83	90	97	104	111	118	125

7 14 21 28 35 42 49 56 63 70 77 84 91 98 105 112 119 0

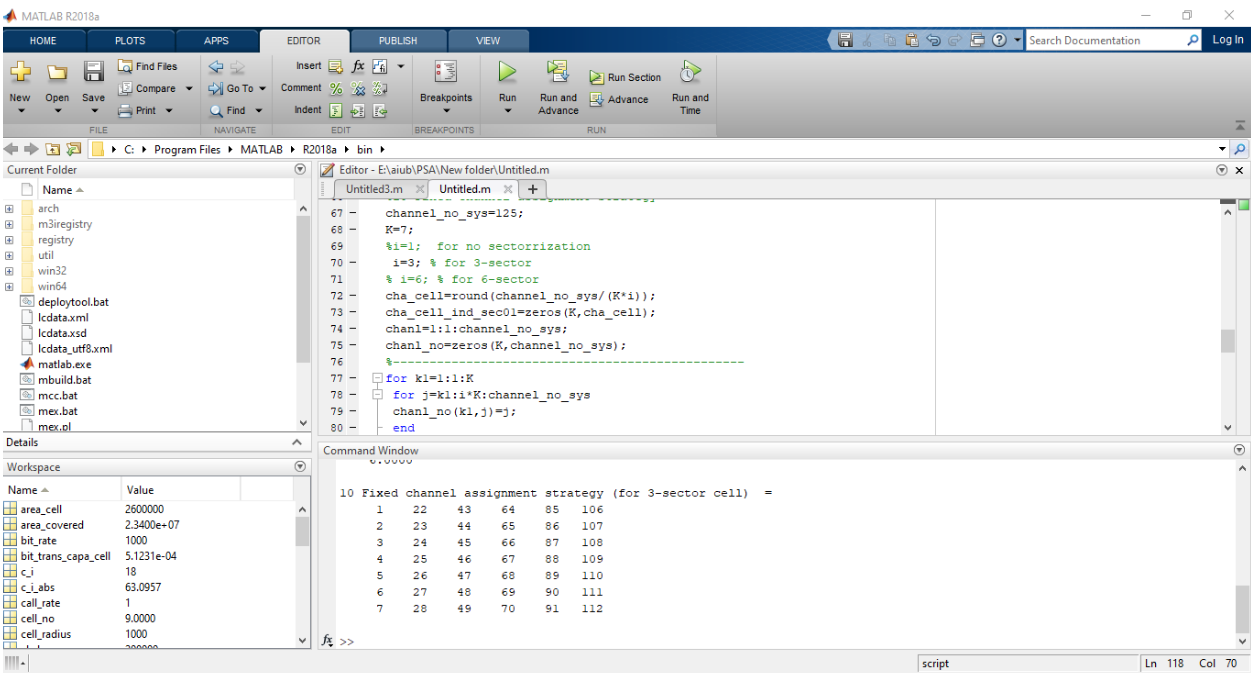




for 3-sector cell:

10. Fixed channel assignment strategy (for 3-sector cell) =

1	22	43	64	85	106
2	23	44	65	86	107
3	24	45	66	87	108
4	25	46	67	88	109
5	26	47	68	89	110
6	27	48	69	90	111
7	28	49	70	91	112

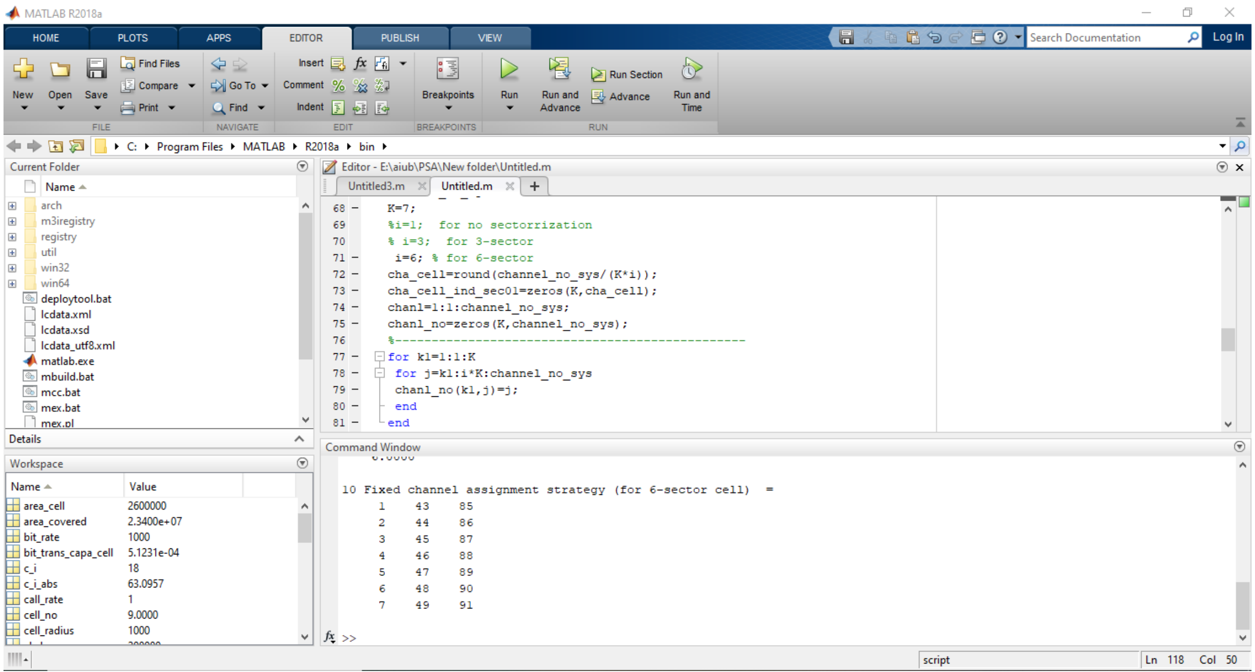


for 6-sector cell:

10. Fixed channel assignment strategy (for 6-sector cell) =

1	43	85
2	44	86
3	45	87
4	46	88
5	47	89
6	48	90

7   49   91



Discussion:

Discussion: In this experiment cellular communication technology was introduced. Before starting the experiment, our honorable course teacher explain the theory behind the experiment. Also he made us understand how to do this exp. The experiment was done by using MATLAB simulation ~~for~~ software. Here Min Co-channel cell reuse ratio, frequency reuse factor, area of a hexagonal cell, number of cells required to cover the given area, system capacity, new system transmit power requirement after cell splitting, bit transfer capacity, receiver filter attenuation characteristics all the parameter was determined in matlab. The experiment was successfully completed with the help of an instructor.

Reference(s):

[1] K. M. Ahmed, “Cellular Mobile Systems” Lecture notes: AT77.07, Asian Institute of Technology, Thailand, January 2010.

[2] R. K. Saha & A B M Siddique Hossain, “Student Handout: Cellular Mobile Communications Technologies, Standards, and Systems”, edi 01, v 02, May 2011.