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Reduction of co-channel interference in cellular systems

L Rangaiah
Professor, Dept of ECE,
TRR College of Engg.,
Hyde**rabad, rleburu@gmail.com**

Dr. K. Srinivasa Rao
Pprofessor & Principal
TRR College of Engg

V. Thrimurthulu
Assoc. professor
Dept of ECE
Chilkur Balaji Institute of Tech, Hyd

Abstract

The frequency reuse method is useful for increasing the efficiency of spectrum usage but results in co-channel interference because the same frequency channel is used repeatedly in different co-channel cells. In most mobile radio environments, use of a seven cell reuse pattern is not sufficient to avoid co-channel interference. Increasing the K value (K>7) would reduce the number of channels per cell, and that would also reduce the spectrum efficiency. Therefore it might be advisable to retain the same number of radios as the seven cell system but to sector the cell radially. In this paper, a method to reduce the co-channel interference in cellular systems employing Directional Antennas with 120^0, 60^0 sectors developed by the authors has been presented.

Keywords:
D =Frequency reuse distance
q = Co-Channel interference reduction factor
C/N=Carrier to Noise Ratio
R = Coverage Radius
K = Frequency reuse pattern
C / I = Carrier to Interference Ratio

1. Introduction: While the frequency reuse method enhances the spectrum utility, it obviously results in co-channel interference since the same frequency band is used repeatedly in different channel cells by different users. In most mobile radio environments, use of a seven cell reuse pattern is not sufficient to avoid co-channel interference. Increasing frequency-reuse pattern ie., making K > 7 would reduce the number of channels per cell and spectrum efficiency. Therefore, it might be advisable to retain the same number of radios as in the seven cell system but to sector the cell radially. This technique [2] would reduce the interference, resulting in the use of channel sharing and channel borrowing schemes to increase the spectrum efficiency.

2. Determination of Co-Channel Interference Area

Two tests are available for this purpose.

2.1 Test 1 : From a Mobile Receiver :

When Co-channel interference occurs in one channel, it will equally occur in all other channels. The co-channel interference can be measured by selecting any one channel and transmitting on that channel, at all co-channel sites, at night while the mobile receiver is traveling in one of the co-channel cells. While performing this test, .any change detected by a field strength recorder in the mobile unit and comparing the data with the condition of no channel sites being

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transmitted. This test has to be repeated as the mobile unit travels in every co-channel cell. To facilitate this test, install a channel scanning receiver in moving vehicle. One channel (f_1) records the signal level (no co-channel condition), second channel (f_2) records the interference level (six channel condition is the maximum), third channel receives f_3, recorded only in f_3, which is not in use. Therefore, the noise level is recorded only in f_3. The carrier to interference ratio C / I can be obtained by subtracting the result obtained from f_2 and the result obtained from f_1 (Carrier minus Interference C – I). Carrier to Noise ratio C / N can be obtained by subtracting the result obtained from f_3 from the result obtained from f_2 (Carrier minus Noise C – N).

Four conditions are used to compare these results.

I. If C / I is greater than 18 dB throughout most of the cells, the system is properly designed.

II. If C / I is less than 18 dB and C / N is greater than 18 dB in some areas, there is co-channel interference.

III. If both C / N and C / I are less than 18 dB and C / N ≈ C / I in a specific area, there is a coverage problem.

IV. If both C / N and C / I are less than 18 dB and C / N > C / I in a specific area, there is a coverage problem and co-channel interference.

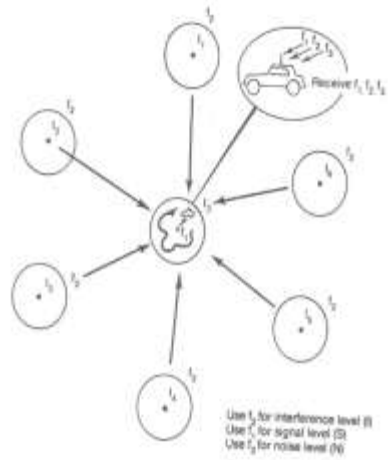

Fig1 Test 1: Co-Channel Interference at the Mobile Unit

2.2 Test 2 : From a Cell Site :

The areas in an interfering cell in which the top 10 per cent level of the signal transmitted from the mobile unit in those areas is received at the desired site. This top 10 per cent level can be distributed in different areas in a cell. The average value of the top 10 per cent level signal strength is used as the interference level from that particular interfering cell. The mobile unit also travels in different interfering cells. Up to six interference levels are obtained from a mobile unit running in six interfering cells. Then calculate the average of the bottom 10 per cent level of the signal strength which is transmitted from a mobile unit in the desired j_{th} cell and received at the desired cell site as a carrier reception level[3]. The carrier to interference ratio received in the j_{th} cell site will be as follows.

$$\mathbf{C_j / I = C_j / \sum_{i=I,\, i \neq j}^{6} I_i} \qquad \text{----------------(1)}$$

The number of co-channel cells in the system can be less than six. Therefore a translation from decibels to linear is needed before summing all the interfering sources. The test can be carried out repeatedly for any specified cell. Compare Cj / I and Cj / Nj and determined the co-channel interference condition. N_j is the noise level in the J_{th} cell assuming that no interference exists.

3. Design of a Directional Antenna System

When the call traffic begins to increase, use the frequency spectrum efficiently to avoid increasing the number of cells K in a seven cell frequency-reuse pattern. When K increases the number of frequency channels assigned in a cell may become less and the efficiency of the frequency-reuse scheme decreases.

Instead of increasing the number K in a set of cells, Directional antenna arrangement is K = 7 is choosen[5]. The co-channel interference can be reduced by using directional antennas. This means that, each cell is divided into three or six sectors and use three or six directional antennas at a base station. Each sector is assigned a set of frequencies.

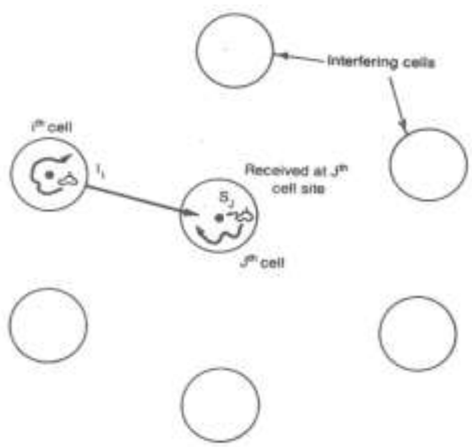

Fig2 Test 2: Co-Channel Interference at the Cell Site

3.1 Directional Antenna in K = 7 Cell Pattern

Three Sector Case : To illustrate the worst case situation, two channel cell scheme shown in Fig(3.a). The mobile unit at position E will experience greater interference in the lower shaded cell sector than upper shaded cell-sector site. This is because the mobile receiver receives the weakest signal from its own cell but fairly strong interference from the interfering cell. In a three-sector case, the interference has affected in only one direction because the front to back ratio at a cell site directional antenna is at least 10dB or more in a mobile radio environment. Because of the use of directional antennas, the number of principal interferences is reduced from six to two. The worst case of C / I occurs when the mobile unit is at position E, at which point the distance between the mobile unit and the two interfering antennas is roughly (D+R/2). However, C / I can be calculated more precisely as follows:

$$(C / I)_{\text{worst case}} = R^{-4} / [(D+0.7R)^{-4}+D^{-4}]$$
$$= 1 / [(q+0.7R)^{-4}+q^{-4}] \qquad \text{-------- (2)}$$

q=4.6, then Eq(2) becomes

$$(C/I)_{\text{worstcase}}=285=24.5\text{dB} \qquad \text{------------ (3)}$$

The C / I received by a mobile unit from the 120^o directional antenna sector system expressed in Eq.(3) highly exceeds 18 dB in the worst case. Eq.(3) shows that using directional antenna[5] sectors can improve the Signal to Interference ratio, i.e., the co-channel interference gets reduced. In reality the C / I could be 6 dB weaker than Eq.(3). In heavy traffic area, as a result of irregular terrain and imperfect site locations. The remaining 18.5 dB of C / I is adequate.

Six Sector Case :

The cell can be divided into six sectors by using six 60^o beam directional antennas shown in Fig(3.b). In this case only one instance of the interference can occur in each sector. The C / I is **(C/I)=R**$^-$

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$^{4}/(D+0.7R)^{-4}=(q+0.7)^{4}$ -------------(4)

For q=4.6, the above equation becomes C / I = 29 dB, results in a further reduction of co-channel interference. When heavy traffic occurs, the 60^{0} sector configuration[3] can be used to reduce co-channel interference.

3.2 Directional Antenna in K = 4 Cell Pattern

Three Sector Case : To obtain the C / I as in Sec 3.1. The 120^{o} directional antennas used in the sectors reduce the interferers to 2 as in the K=7 system.

$(C/I)_{worstcase}= R^{-4}/[(q+0.7)^{-4}+q^{-4}]=20dB$ ----- (5)

If 6 dB is subtracted from the result, the remaining 14 dB is unacceptable.

Six Sector Case : There is only one interferer at a distance D+R shown in Fig(3.b) with q = 3.46

$(C / I)_{worst\ case} = R^{-4} / (D+R)^{-4} = 1 / (q+1)^{-4}$ ----(6)

If 6 dB is subtracted from the result, the remaining 21dB becomes inadequate. Under heavy traffic conditions, there is still a great deal of concern over using a K = 4 cell pattern in 60^{o} sector.

4. Comparing K = 7 and K = 4

A K = 7 [1]cell pattern system is a logical way to begin the design of an omni-cell system. The co-channel reuse distance is more or less adequate, according to the designed criterion. When the traffic increase a three sector system should be implemented, i.e. with three 120^{o} directional antennas in place. In certain hot spots 60^{o} sectors can be used locally to increase the channel utilization. If a given area is covered by both K=7 and K=4 cell patterns and both patterns have a six sector configuration, then the K=7 system has a total of 42 sectors, but K = 4 system has a total of 26 sectors. One advantage of 60^{o} sectors with K=4 is that they require fewer cell sites than 120^{o} Sectors with K = 7. Two disadvantages of 60^{0}.

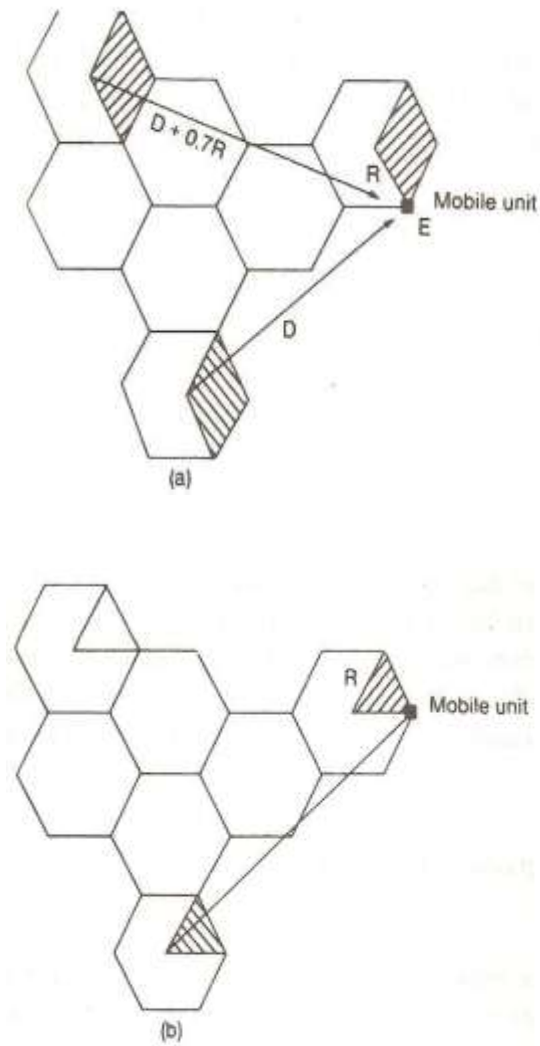

Fig 3 Determination of C / I in a directional antenna system (a) Worst case in a 120^{0} directional antenna system (N = 7), (b) Worst case in a 60^{0} directional antenna system (N = 7)

(1) They require more antennas to be mounted on the antenna mast. (2) They often require more frequent handoffs because of the increased chance of that the mobile units will travel across the six sectors of the cell.

Conclusion:

In mobile environment, use of a seven cell

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reuse pattern is not sufficient to reduce co-channel interference. Increasing frequency-reuse pattern with K > 7 would reduce the number of channels per cell and spectrum utility. Therefore, it might be advisable to retain the same number of radios as in the seven cell system but to sector the cell radially. This technique would reduce the interference optimally. The co- channel interference can be reduced by using directional antennas. This means, division of each cell into three or six sectors and the use of three or six directional antennas at a base station.

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