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Designing Antenna Parameters for Reduction of Co-Channel Interference in Cellular Mobile Communication by Mechanical Antenna Downtilt

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Abstract

The problem of co-channel interference in GSM cellular mobile communication is studied. One effective method of reducing co-channel interference, namely 'Mechanical antenna downtilt' is investigated. Suitable values of base station antenna parameters is calculated using MATLAB to find for reducing co-channel interference through this method. The simulation result provided suitable values for antenna height and vertical beamwidth angle to maintain the downtilt angle within optimum range for standard coverage area. These values can be used to design a real site to achieve reduced co-channel interference so as to improve the performance of cellular network.

Keywords

Cellular Mobile, Co-Channel Interference, Antenna, Mechanical Downtilt, Beam Width

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1. Introduction

Cellular radio systems rely on an intelligent allocation and reuse of channels throughout a coverage region**.** Each cellular base station is allocated a group of radio channels to be used within a small geographic area, known as cell that comprises a base station having either one omni directional antenna or more than one directional antenna. Frequency reuse is the core concept of the cellular mobile radio system, where users in different geographic locations (different cells) may simultaneously use the same frequency channel. Hence, in a given coverage areas there are several cells that use the same set of frequencies. These cells are called co-channel cells (Fig. 1), and the interference between signals from these cells is called co-channel interference [1].

Co-channel interference is one of the major limiting factors in the performance of cellular radio system and a bottleneck in increasing its capacity [2-4]. Interference causes cross talk on voice channels and leads to missed and blocked calls on control channels due to errors in the digital signalling. Interference is more severe in urban areas, due to the large number of base stations and mobiles. Unfortunately, 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 neighbouring co-channel cells. Co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation so as to keep interference levels within tolerable limits [2-4].

In a cellular network, each set of cells with unique frequencies is known as cluster (bold boundary line in Fig. 1) and the network can be thought as repetition of clusters. For a hexagonal geometry with cell radius R and distance between

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the centres of the nearest co-channel cells D, the parameter Q, called the co-channel reuse ratio, is related to the cluster size N through [5],

$$Q = \frac{D}{R} = \sqrt{3N} \quad (1)$$

A large cluster size indicates that the ratio between the cell radius and the distance between co-channel cells is small. Conversely, a small cluster size indicates that co-channel cells are located much closer together. Thus, the cluster size is a function of how much interference a mobile or base station can tolerate while maintaining the quality of service.

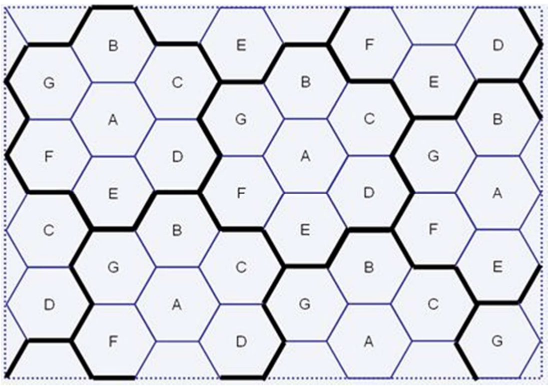

Fig. 1. Schematic of a cellular system with hexa-gonal cells. Cells marked with same letter are co-channel cells.

If i_0 be the number of co-channel interfering cells. then, the signal-to-interference ratio (*S/I* or *SIR*) for a mobile receiver which monitors a forward channel can be expressed as [5],

$$\frac{S}{I} = \frac{S}{\sum_{i=1}^{i_o} I_i} \quad (2)$$

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. If the signal levels of co-channel cells are known, then the S/I ratio for the forward link can be found.

It has been shown that, to meet an *S/I* requirement of 18 dB (which ensures sufficient voice quality in some cellular systems), minimum required cluster size is seven [5-7]. Equation (2) is based on the hexagonal cell geometry where all the interfering cells are equidistant from the base station receiver, and hence provides an optimistic result in many cases as in practice cells are not always purely hexagonal due to some constrains.

Reduction of co-channel interference in cellular mobile system is always a challenging problem. A number of methods can be considered, such as increasing the separation between two co-channel cells, lowering the antenna height at base station or using directional antennas at the base stations [2-6]. First method is not advisable because when the frequency reuse cells increases, the system efficiency decreases, as it is directly proportional to the number of channels per cell [2]. Second Method is not recommended because such an arrangement also weakens the reception level at the mobile unit [2]. However, third method is a good approach, especially when the number of frequency reuse cells is fixed [6-14].

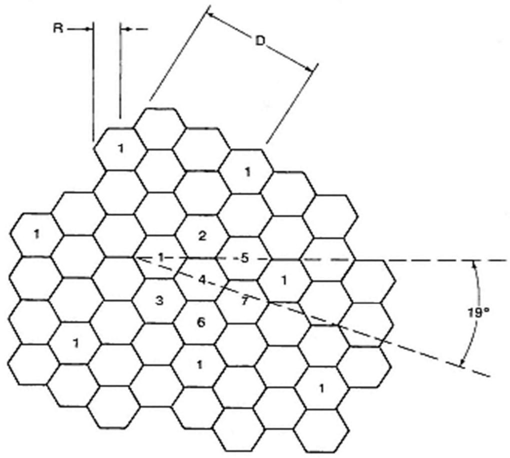

Fig. 2. A seven cell cellular configuration [7].

The objective of this work is to design and obtain necessary parameters for the directional antenna of a cell site using mechanical downtilt of base station antenna through MATLAB simulation in order to reduce the co-channel interference.

2. Method

At normal condition, radiation from a co-channel serving site can easily interfere with another co-channel cell as shown in Fig. 2. Using a 120º directional antenna can reduces the interference in a system by eliminating the radiation in rest of its 240º sector. But co-channel interference can exist as the serving site can interfere with the co-channel cell that directly ahead [7]. Assuming a seven cell cellular system, the co-channel interference reduction factor Q becomes [5],

$$Q = \sqrt{3N} = 4.6$$

If the cell radius is R, then the co-channel cell separation D is found from Eq. 1 as,

$$D = QR = 4.6R$$

It is already well studied that, with a separation of 4.6R, the area of interference at the interference receiving cell is illuminated by the central 19º sector of the entire 120º transmitting antenna pattern at the serving cell as shown in

Fig. 2. Thus, if three 120º antennas are implemented in every cell, then every sector receives interference in the central 19º sector of the every 120º sectors [7].

To achieve a significant gain of Signal to interference (S/I) in the interference receiving cell, using a notch in the centre of the antenna pattern at the interfering cell is considered by some authors [6-11]. An antenna pattern with a notch in the centre can be obtained in a number of ways. A relatively simple way is to tilt the high gain directional antenna mechanically down word [7]. The mechanical down tilting means tilting the antenna physically.

Mechanical downtilting is widely used [6-14] in TDMA/FDMA based GSM networks as well as in CDMA networks [9-11] to decrease the co-channel interference in order to achieve smaller frequency reuse factor, and hence to increase the capacity. However, improvement in the radio network quality due to tilting have traditionally not directly been taken into account in capacity or frequency planning but have used as an extra margin to avoid serious interference area [6-14].

Mechanical antenna downtilt reduce co-channel interference by confining the signal to its own dominance area [6, 7]. Earlier works showed this for 3-sectored sites in uplink and downtilt directions [8]. However, the downtilting can also produce a reduction in the sectorization efficiency in the uplink [9]. Thus, the effect of antenna downtilt ought to be studied more carefully in highly sectorised sites, especially, in a case of a mechanical antenna downtilt in downlink direction [8, 9, 13]. Downlink is also more attractive since capacity of a GSM network is typically downlink limited [10, 11].

It is reported in that, when a high gain directional antenna is physically tilted by an angle in the x-y plane, the centre beam is also tilted downward by the same angle, but the off-centre beam is tilted downward by a much lesser angle [7]. It is also shown there that the physically tilted angle and the off-center beam angle are not linearly related. That work [7] also suggested keeping antenna tilting angle between 22 to 24° in order to increase the signal-to-interference ratio *S/I* by an additional 7 to 8 dB in the interfering cell. So, co-channel interference can be reduced by an additional 7 to 8 dB because of the notch in the mechanically tilted-antenna pattern. This can be achieved by suitably adjusting rest other antenna parameters to achieve the required downtilt angle.

The selection of antenna downtilt angle depends on the site and antenna configuration, and hence it has to be set site-by-site basis in practice. The parameters needed to achieve required downtilting angle are geometrical factor and antenna vertical beamwidth factor which are further linked with heights of the base station antenna and mobile station antenna as well as the size of the dominance area. To adjust the mechanical downtilting of antenna at optimum level, all these parameters need to be designed properly. Here, we will design and obtain these parameters of a cell site to keep the tilting angle between 22º and 24º so as to reduce the co-channel interference.

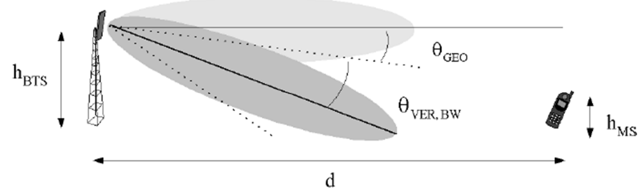

Fig. 3. Schematic of Mechanical Downtilting of Base station antenna [10].

Mechanical antenna downtilt scheme is illustrated in Fig. 3. In GSM, an optimum downtilt angle is obviously a trade-off between other-cell interference mitigation and coverage thresholds. The optimum downtilt angle is achieved if other-cell interference is reduced to the minimum achievable level while still providing the target coverage. Mechanical downtilt is achieved by directing the antenna element towards the ground. Clearly, optimum downtilt angle depends at least on two factors: geometrical factor (θ_{GEO}) and antenna vertical beamwidth factor ($\theta_{VER,BW}$), as shown in Fig. 3. The geometrical factor takes into account the height of the base station antenna (h_{BTS}) and mobile station antenna (h_{MS}) as well as the size of the dominance area (d). The geometrical factor is not enough to describe the optimum downtilt angle, since certainly antenna vertical beamwidth affects the optimum downtilt angle. Eventually, antenna vertical beamwidth is expected to have a great impact on the downtilt angle. Hence, the optimum mechanical downtilt angle v_m is assumed [10] to be a function of the vertical beamwidth factor and geometrical factor.

$$\nu_m = f(\theta_{GEO}, \theta_{VER,BW})$$

The geometrical factor can be calculated using the relation of the height difference between the base station antenna and mobile station antenna, and sector dominance area size [10, 11],

$$\theta_{GEO} = \tan^{-1}\left\{\frac{h_{BTS} - h_{MS}}{d}\right\} \quad (3)$$

Intuitively, an increase of the antenna height should also increase the required downtilt angle and vice versa. Correspondingly, a cell with a small dominance area should require a larger downtilt angle. However, the geometrical factor as such is not enough to define the required downtilt angle, as it does not take into account any information about antenna vertical beamwidth. The antenna beam-width factor could be easily selected as an angle between upper -3dB position in the antenna radiation pattern and zero direction. This is, in most of the cases, the same as a half of the antenna vertical radiation pattern. The angle between base station mechanical antenna downtilt and the effective downtilt angle is the same in the horizontal plane only in the main lobe direction. The effective downtilt angle decreases as a function of horizontal angle in such a manner that the antenna radiation pattern is not downtilted from the side lobe direction of an antenna [10, 11].

3. Results

Based on above arguments, the antenna beamwidth factor is selected here as half of the antenna half-power (-3dB) vertical beamwidth (θ_{-3dB}), and the geometrical downtilt angle (V_{geo}) is selected as [11],

$$v_{GEO} = \theta_{GEO} + \frac{\theta_{-3dB}}{2} \tag{4}$$

Using these valid assumptions and mutual relations between the parameters, suitable values of h_{BTS}, θ_{GEO} and $\theta_{-3\ dB}$ can be obtained from MATLAB simulation for a standard coverage area (2 km and 3 km here) with 1.5 meter height of the mobile station (average height of a man on ground). Table 1 shows chosen data from our MATLAB simulation to keep tilting angle V_{GEO}in between 22° and 24°.

From Table-1, it can be observed that, to obtain desired tilting angle between 22° and 24° so as to reduce co-channel interference (as suggested by earlier works), following parameters of cell site antenna can be adjusted:

For d = 3km and h_{MS}=1.5 m, by increasing the base station antenna height h_{BTS} from 15 m to 55 m and the vertical beam width angle, $\theta_{-3\ dB}$ from 28° to 52°. We can achieve the desired tilting angle from $\theta_{-3\ dB}$=44°, h_{BTS} =15 m to $\theta_{-3\ dB}$=48°, h_{BTS} =15 m.

For d = 2 km and h_{MS}=1.5 m, by increasing both the base station antenna height h_{BTS} from 15 m to 55 m and the vertical beam width angle$\theta_{-3\ dB}$ from 28° to 52°. We can achieve the desired tilting angle from $\theta_{-3\ dB}$=44°, h_{BTS}=15 m to $\theta_{-3\ dB}$ =44°, h_{BTS}=55 m.

For any fixed d, if we increase the antenna height then, vertical beam width angle is reduced and vice versa. That means, we can keep downtilting angle within desired range either by reducing antenna height with increased vertical beam width angle or we may increase antenna height with a reduced vertical beam width angle. From simulation, it was found that, to obtain required antenna downtilt, vertical beam width angle need to be adjusted between 44° to 48° with antenna height 15 m to 55 m. This was found to be true for both d = 2 km and d=3 km, and this essentially means that d has comparatively lesser effect on required downtilting which is not completely unexpected.

Table 1. MATLAB Results.

hBTS (meter)	θ-3 dB (degree)	Vgeo (degree)	$\frac{Vgeo}{\theta_{-3\ dB}} x100$ %
With Size of Dominance area, d= 3 km,			
MS Antenna height,hMS= 1.5 m			
15	44	22.26	50.58 %
25	44	22.45	51.02 %
35	44	22.64	51.45 %
45	44	22.83	51.88 %
55	44	23.02	52.32 %
15	48	24.26	50.54 %
55	48	25.02	52.13 %
15	52	26.26	50.49 %
55	52	27.02	51.96 %
With Size of Dominance area, d= 2 km,			
MS Antenna height,hMS= 1.5 m			
15	36	18.39	51.07 %
55	36	19.53	54.26 %
15	44	22.39	50.88 %
25	44	22.67	51.53 %
35	44	22.96	52.18 %
45	44	23.25	52.83 %
55	44	23.53	53.48 %
15	48	24.39	50.80 %
55	48	25.53	53.19 %
15	52	26.39	50.74 %
55	52	27.53	52.95 %

4. Conclusions

The problem of 'co-channel interference' in GSM cellular mobile communication is studied. The importance of reducing co-channel interference to improve the quality of service is discussed. One effective method to reducing co-channel interference namely 'Mechanical downtilt of base station antenna' is analyzed. Suitable set of antenna parameters is calculated using MATLAB to find for reducing 'co-channel interference' through this method. The simulation result provided a set of values for relevant antenna parameters like antenna height, vertical beamwidth angle and maximum coverage area. it was found that, to obtain required antenna downtilt, vertical beam width angle need to be adjusted between 44° to 48° with antenna height 15 m to 55 m for a coverage area of 2 km to 3 km. These values can be used to design a real site for achieving reduced co-channel interference so as to improve the performance of cellular network.

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