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Application of Generalized Sidelobe Canceller and Sparse Array in Relieving Congestion in Multi-beam CDMA Systems

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Abstract

During operation of a cellular system, unexpected growth of traffic may develop in various regions, create traffic congestion. Among many methods to solve problem of large blocking probability, dynamic cell sectoring using smart array antenna is specially interested. In this paper, we investigate the relationship between antenna parameters (main beamwidth, sidelobe attenuation...) and blocking probability of multibeam CDMA system under the presence of hotbeam. From that, we consider deployment sectoring dynamically based on Generalized Sidelobe Canceller (GSC) structure to get blocking probability below 1%. In addition, we consider the way to decrease the complexity of array antenna using sparse array.

Keywords: *blocking probability, multibeam, SBF, GSC, sparse array*

1. Introduction

Because of mobility of mobile users, there is region that has traffic load may develop into “hot- spot”, that is region with traffic load substantially larger than design load. Hot-spot region introduces large blocking probability, which deteriorate the Quality of Service of cellular systems. To deal with this problem, several approaches can be taken such as: cell splitting, channel borrowing, cell overlaying, channel sharing, cell sectoring, adaptive sectorization, and antenna tilt [1-3]. Cell splitting is efficient when there are the large numbers of hot-spots, however, it is costly when there are a few isolated hot-spots because of additional equipment. Channel borrowing has disadvantages of interference avoidance when the channels being lent could not be used by the lending beam and the co-channel beams closest to the hot-spots. Cell overlaying may cause more hand-over. Moreover, these methods involved in the cellular system using a single antenna. Therefore, they increase in cost. Another method is cell sectoring using switched beamforming. This is an efficient method because its advantages of interference avoidance and increasing in frequency reusing.

In this paper, based on blocking probabilities of multibeam CDMA system using switched beamforming (SBF) array antennas under the presence of the hot-beam, we investigate the relationship between antenna parameters and blocking probabilities. This is described in Section 2. In Section 3, we consider deployment SBF to create multi beams to cover the cell based on GSC structure. In Section 4, we introduce sparse array to decrease the number antenna elements in array and show some numerical examples. Conclusions are given in Section 5.

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2. The Relationship between Antenna Parameters and Blocking Probability

We consider the uplink of power controlled CDMA system with array antennas at the base station. We assume that each cell can be described by an independent Poision traffic model with call rate of λ and mean holding time of μ, where inter arrival times as well as call holding times are exponentially distributed. For each cell we can obtain an offered traffic load of $\chi = \lambda / \mu$. As analysis in [4], for each beam we have $\chi_{beam} = \lambda_{beam} / \mu$ where λ_{beam} is the call rate in each beam having mainbeam width of α.

Each cell is divided into M beams with equal main beamwidth and non-overlapped each other. There is one beam having heavier traffic load than each of remaining (M-1) beams. Without loss of generality, we assign the first beam as the hot beam and the other (M-1) beams in cell as light beams. For the hotbeam, we have offered traffic load $\chi_H = \lambda_H / \mu$. Similarly, offered traffic load for light beam is $\chi_L = \lambda_L / \mu$.

The antenna beam pattern is modeled by brickwall antenna model with main beamwidth and side lobe attenuation of D as depicted in Figure 1 [4].

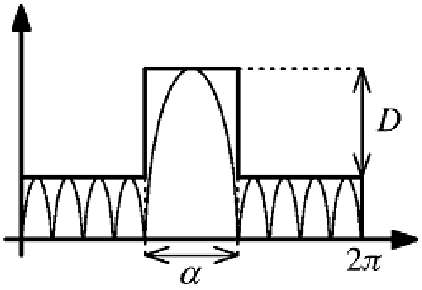

Figure 1. Brickwall Antenna Pattern [4]

By referring equation (4), (8),(9),(10),(11),(12) in [4] the probability that having k active users in each beam with an angular sector of width α is

$$P\left(N^{\alpha} = k, \chi_{beam}\right) = \frac{(\chi_{beam})^{k}}{k!} e^{-\chi_{beam}} \tag{1}$$

Using a call admission control, a new user is admitted to the system only if the system can achieve the required signal-to-interference and noise ratio $\gamma_{\min}$.

$$\frac{1}{\frac{N^{\alpha}}{s} + \frac{1}{D} \cdot \frac{N^{\bar{\alpha}}}{s} + \frac{N_I}{P}} \geq \gamma_{\min} \tag{2}$$

$N^{\alpha}, N^{\bar{\alpha}}$ is the number of active user within the main beam and outside the main beam, respectively. D is side lobe attenuation, N_I is the power of interference from the other cell plus background noise, P is set to a normalizing constant power value for each user through the perfect power control value for each user.

Therefore, the probability that a new user is admitted by a CAC, is represented by

$$P_{\alpha} = P(N^{\alpha} + \frac{1}{D} . N^{\bar{\alpha}} \leq s . C_0) \tag{3}$$

Expanded

$$\begin{aligned} P_{\alpha} &= \sum_{k=0}^{N^{\alpha}_{\max}} P\left(\bar{N}^{\alpha} \le D\left(s.C_0 - \left(N^{\alpha} = k\right) | \left(N^{\alpha} = k\right)\right) P\left(N^{\alpha} = k\right) \\ &= \sum_{k=0}^{N^{\alpha}_{\max}} P\left(N^{\alpha} = k\right) \sum_{l=0}^{\bar{N}^{\alpha}_{\max}(N^{\alpha}=k)} P\left(\bar{N}^{\alpha} = l\right) \end{aligned} \tag{4}$$

Where

$C_0 = \dfrac{1}{\gamma_{\min}} - \dfrac{N_I}{P}$

$N^{\alpha}_{\max} = s.C_0$: the maximum number of users in sector α

$\bar{N}^{\alpha}_{\max} = D(s.C_0 - N^{\alpha})$: the maximum number of users outside sector α

For the hot beam, the admissible probability is calculated by

$$P^{H}_{\alpha} = \sum_{k=0}^{N^{\alpha}_{\max}} P\left(N^{\alpha} = k, \chi_H\right) \sum_{l-0}^{\bar{N}^{\alpha}_{\max}(N^{\alpha}=k)} P\left(\bar{N}^{\alpha} = l, \chi_L\right) \tag{5}$$

For each lightly loaded beam, the admissible probability is calculated by

$$\begin{aligned} P^{L}_{\alpha} &= \sum_{k=0}^{N^{\alpha}_{\max}} P\left(N^{\alpha} = k, \chi_L\right) \\ &\sum_{l=0}^{\bar{N}^{\alpha}_{\max}(N^{\alpha}=k)} \sum_{i=0}^{l} P\left(N^{(M-2)\alpha} = l, \chi_L\right) P\left(N^{\alpha} = l - i, \chi_H\right) \end{aligned} \tag{6}$$

The blocking probability is the probability that a new user cannot be admitted, therefore the total blocking probability is

$$P_b^{total} = \frac{(M-1)\, P_b^{L} + \xi P_b^{H}}{M - 1 + \xi} \tag{7}$$

Where $\xi = \chi_H / \chi_L$ is the traffic load ratio

Next, we evaluate blocking probabilities using general parameters listed in Table 1. According to the main beamwidth, we find out the FLT, where the total blocking probabilities is below 1%, both per cell and per beam. Table 2 shows the case when the main beamwidth is as an example.

In Figure 2, we describe side lobe attenuation vs. blocking probability when the offered load of the lightly loaded beam is 3.09 Erlangs, traffic load ration is 1.79 and $\alpha = 45^0$. As the side lode level increases, the total blocking probability decreases. When the side lobe attenuation is larger than 9dB, the blocking probability is below 1%.

In Figure 3, we describes blocking probability according to main beamwidth when $\xi = 1.79$ and the offered traffic load of the lightly loaded beam is 0.8 × FLT/beam. When the main beamwidth equal 45^0, the blocking probability is 1%.

Table 1. General Parameters

Parameter	Value	Description
R_{cell}	1km	Cell radius
$\gamma_{\min}$	7dB	Minimum request SINR
α	15,30,45,60	Mainbeam width
D	8-12dB	Side lobe attenuation
P	1W	Normalized power value
	0.1 W	Interference and noise power
s	127	Spread factor

Table 2. Mainbeam vs. FLT when the Total Blocking Probability is Under 1%

Mainbeam width (degree)	Number of beam/ cell	FLT / cell	FLT / beam
15	24	59.1 Erlangs	2.4625 Erlangs
30	12	42.8 Erlangs	3.5666 Erlangs
45	8	30.9 Erlangs	3.8625 Erlangs
60	6	27.8 Erlangs	4.6333 Erlangs

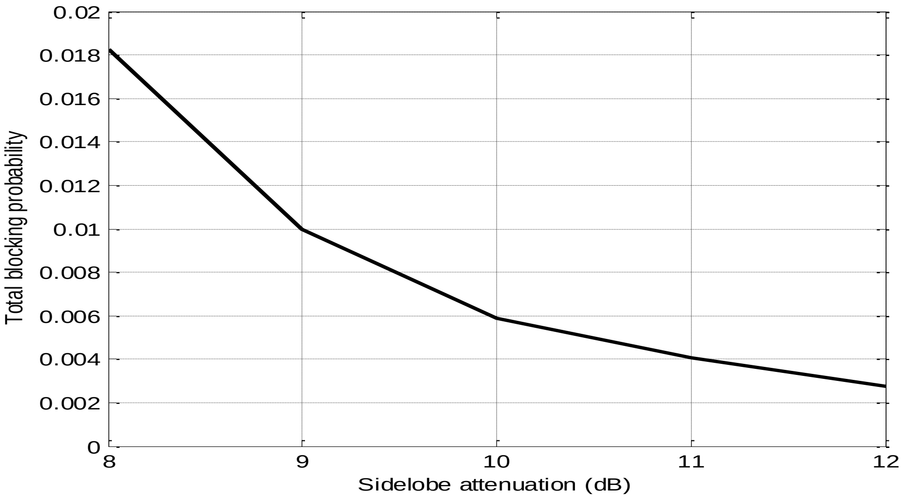

Figure 2. Blocking Probability vs. Sidelobe Antennuation

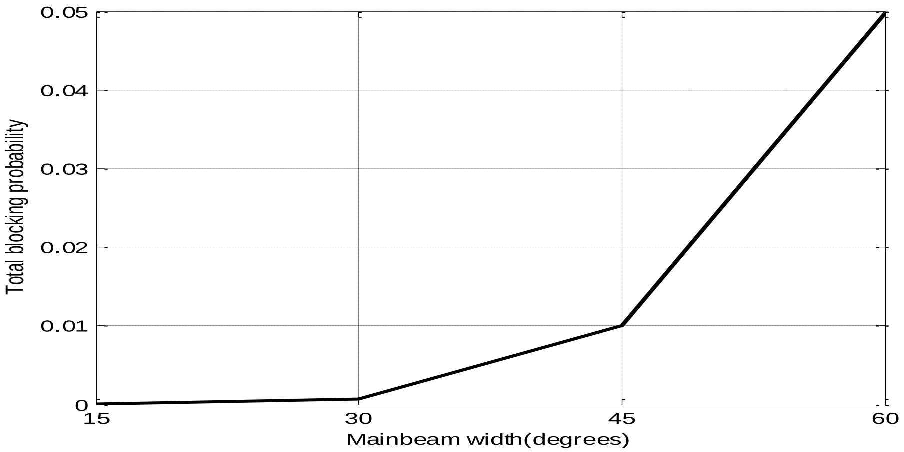

Figure 3. Blocking Probability vs. Mainbeam Width

3. Generalized Sidelobe Canceller

GSC is applied here to find weights in order to place nulls in the direction of interference and adjust multibeam width and sidelobe peaks as expected. Multiple linear constraints is defined by

$$B^H w = g \tag{8}$$

The matrix B is termed constraint matrix, and vector g is termed gain vector. Assuming there are L linear constraints, B is M by L matrix, and g is an L by 1 vector.

The structure of GSC is illustrated in Figure 5. As shown in the figure, the upper path includes the quiescent signal matched filter. w_q is selected as a fixed beam with boresight to desire signal direction and expressed as

$$w_q = B(B^H B)^{-1} g \tag{9}$$

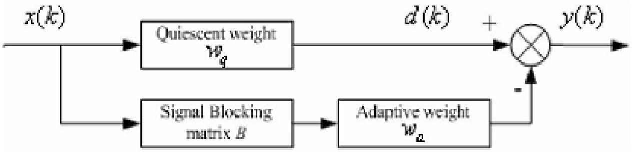

Figure 5. Generalized Sidelobe Canceller

The lower path includes the blocking matrix B and the interference cancelling filter. The operation performed by B is referred to as the signal blocking operation for removing the desired signals from the received array data.

The overall weight vector of the beamformer as

$$w = w_q - B w_a \tag{10}$$

The output of GSC expressed as

$$y(k) = (w_q - B w_a)^H x(k) \tag{11}$$

GSC converts the linearly constrained optimization problem into a standard optimum filtering problem [5]. In particular, we have an constrained optimization problem involving the adjustable portion of the weight vector, which may be formally written as

$$\min_{w_a} J = \min_{w_a} E\left\{\left|y(k)\right|^2\right\} = \min_{w_a}(w_q - Bw_a)^H R_x (w_q - Bw_a) \tag{12}$$

Where R_x is (M-L)x(M-L) autocorrelation matrix of the input signal vector x(k). Then we can find the optimum weight as

$$w_{a,opt} = (B^H R_x B)^{-1} B^H R_x w_q \tag{13}$$

4. Sparse Array

Sparse array are antenna arrays that originally were equally-spaced arrays, but where several elements have been removed. This is called thinning. The motivation for using sparse array is economy. Each of the elements needs to be connected to a transmitter and a preamplifier for reception, in addition to receive and transmit beamformers. Increase in the number of the antenna elements means increase in cost. Besides, sparse array decreases the complexity in signal processing. [7-10]

In the following, we present some simulation results. The employed pattern synthesis technique is based on iteratively aligning the sidelobe peaks and mainbeam width to prespecified levels. As mention in Section 1, if cells are sectorized into 8 beams with the mainbeam width of, we need maximum sidelobe level being less than -9dB to get blocking probability under 1%.

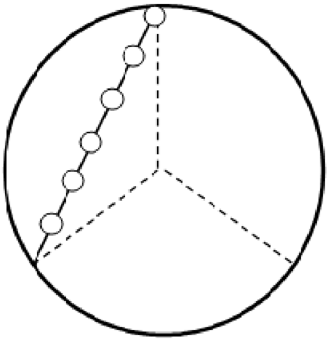

Figure 6. Using 6 Element Linear Array/ Sector

In the first case, we sectorize the cells into 3 equal width sectors and use linear array to cover each sector as figure 6. Using GSC, we can choose array weights to create 4 beams having mainbeam width of 30^0 as Figure 7a, 7b. The center of each beam is defined by $45^0, 15^0, -45^0, -15^0$. Figure 7a depicts the array factor of 6 element linear array. Figure 7b depicts the array factor of thinned array of 5 elements after removing 1 element from the full array in figure 6a. As we can see from Figure 7a, 7b, we obtain the design goal in main beamwidth and sidelobe peaks as well as economize the number of 1 antenna element in array when using thinned array covering each sector. In other words, we decrease 3 antennas to achieve the design goal.

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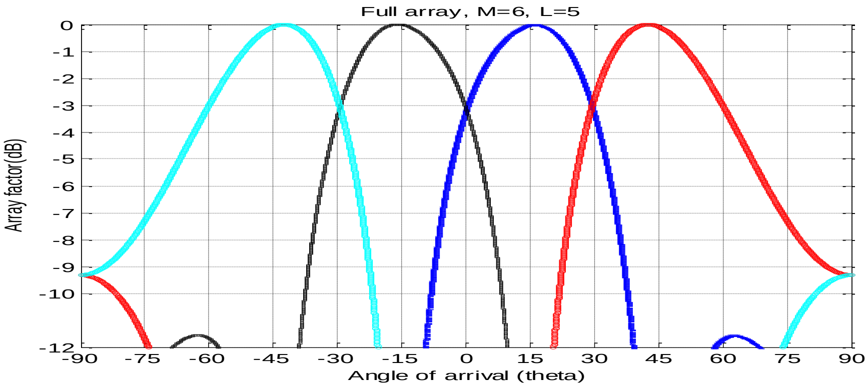

Figure 7a. Array Factor of Full Array M = 6 Antennas

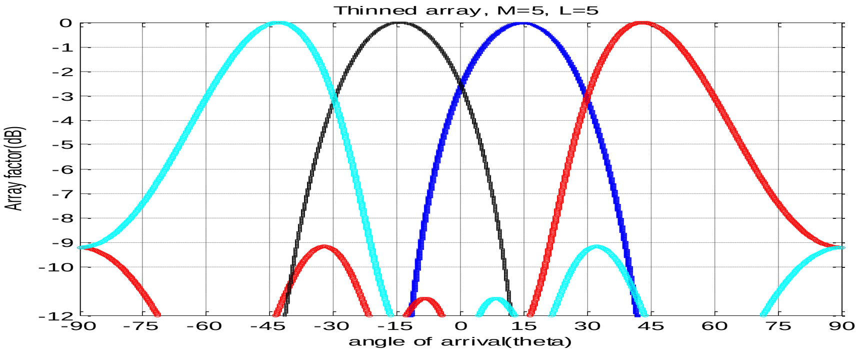

Figure 7b. Array Factor of Thinned Array M = 5 Antennas

In the second case, we use circular array to create 8 beams covering the cells as figure 8. Each beams has the mainbeam width of 45^0 and maximum sidelobe level of 9dB. The center of each beam is defined by $157.5^0, 112.5^0, 67.5^0, 22.5^0, -157.5^0, -112.5^0, -67.5^0, -22.5^0$. Figure 9a depicts the array factor of 13 element full circular array. Removing 4 elements from full array in Figure 9a, we can create array factor of 9 element array as Figure 9b. Similar to the first case, we can obtain design goals while using less antenna elements.

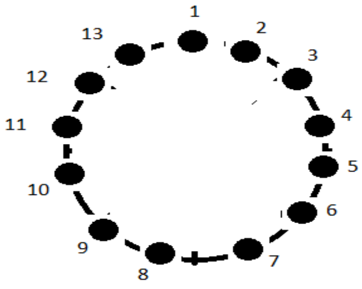

Figure 8. Using 13 Element Circular Array

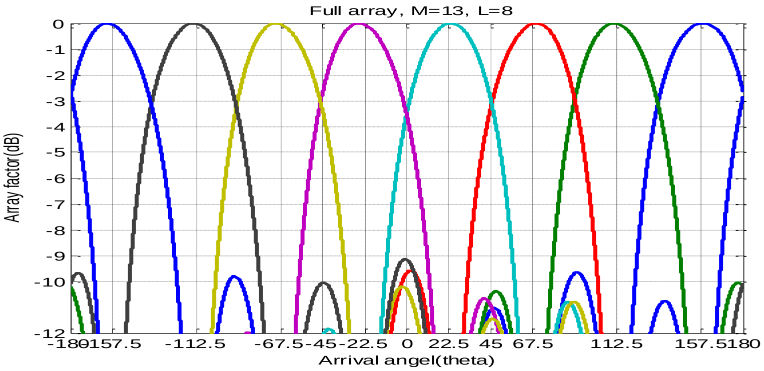

Figure 9a. Array Factor of Full Array M = 13 Antennas

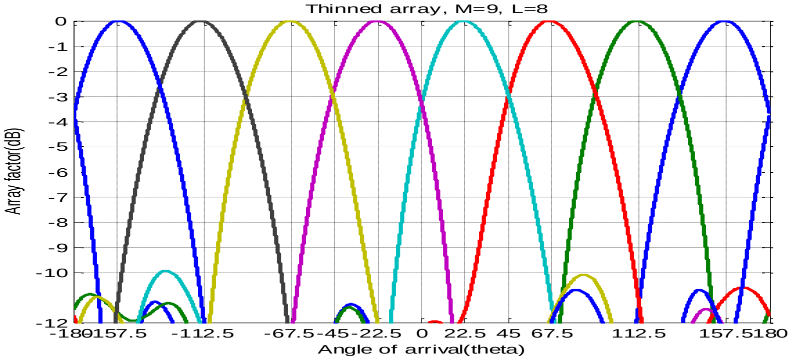

Figure 9b. Array Factor of Thinned Array M = 9 Antennas

5. Conclusions

This paper studied SDMA technique using SBF array to solve the hotbeam situation. We also investigated the relationship between blocking probability and antenna parameters before finding out design goal. We proposed GSC structure to choose the array weights such as nulls are placed in the direction of interference and we can obtain the design goal in mainbeam width and maximum sidelobe level. Furthermore, simulation results revealed that using sparse array provides a considerable reduction in the number of elements in the array while still getting beam pattern as expected.

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