Improving spatial reuse of wireless channel

Tra Huong Thi Le, Duc Ngoc Minh Dang and Choong Seon Hong
Department of Computer Engineering, Kyung Hee University
huong_tra25@khu.ac.kr, dnmduc@khu.ac.kr, cshong@khu.ac.kr

Abstract

In cellular systems, hot-spot which is the region with traffic load substantially larger than design load, creates large blocking probability. To handle this problem, cell sectoring using directional array antenna is especially interested. In this paper, we use switched beam antennas to cover a cell to get blocking probability below 1%. Firstly, we consider the relationship between antenna parameters and blocking probability of multibeam CDMA based system under the presence of hotbeam. We find out sidelobe levels are required to be over 8.6 dB and over 9 dB for beamwidth of 45^0 and 30^0, respectively, in order to guarantee blocking probability below 1%. After that, we apply two methods of windowing technique and Generalized Sidelobe Canceller (GSC) structure to cancel sidelobes, which helps to improve the network performance.

1. Introduction

During operation of a cellular system, unexpected growth of traffic may develop in various regions, create traffic congestion. To deal with this problem, several approaches can be taken such as: cell splitting, channel borrowing, and cell overlaying, channel sharing, cell sectoring [1], adaptive sectorization [2], and antenna tilt [3]....Another method is cell sectoring using directional antennas, which has advantages of interference avoidance and increasing in frequency reusing.

There are three kinds of beamforming schemes for array antenna systems: switched, steerable single beam and adaptive beamforming. Switched beam systems consist of multiple beams, i.e. multibeam, having fixed beamwidth and point of directions. Steerable single beam can adjust the radiation pattern toward the users and set the directions toward the interference sources to the null. In adaptive beamforming, the radiation pattern can be adjusted to receive multipath signals by using space diversity algorithms and techniques, set the interference directions to the null and dynamically form beam patterns..... Compared to conventional single antenna, switched beamforming systems achieve performance improvement because of the higher directivity. Switched beamforming is also easier to implement in existing cell structures than the more sophisticated steerable single beam and adaptive beamforming. These are the reasons we consider switched beamforming in this article.

In this paper, based on investigating the relationship between antenna parameters and blocking probabilities, we set a design goal in beamwidth and sidelobe levels aiming to guarantee below 1% of blocking probability. This is described in Section 2. In Section 3, we consider suppressing sidelobe using windowing the array element and GSC structure. Section 4 presents some numerical results in linear arrays deployment. Conclusions are given in Section 5.

2. Relationship between antenna parameters and blocking probability

We consider the uplink of power controlled CDMA system with array antennas at the base station. Each cell is divided into non-overlapping M beams which have equal main beamwidth of α. In each cell, there are one hot beam and $M-1$ light beams. The traffic load offered for hot beam and light beam are χ_H and χ_L, respectively. In the brick-wall antenna model [4] then antenna beam pattern has main beamwidth of α and side lobe attenuation of D as depicted in Fig. 1 [4].

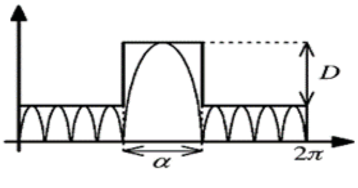

Fig. 1. Brick-wall antenna pattern [4].

We inherit Eqs (10), (11), (12) from [4] to calculate admissible probabilities P_α^H and P_α^L for the hot beam and light beam, respectively. These admissible probabilities are calculated by

$$P_\alpha^H = \sum_{k=0}^{N_{\max}^{\alpha}} P(N^\alpha = k, \chi_H) \sum_{l-0}^{N_{\max}^{\bar{\alpha}}(N^\alpha = k)} P(N^{\bar{\alpha}} = l, \chi_L) \qquad (1)$$

$$P_\alpha^L = \sum_{k=0}^{N_{\max}^{\alpha}} P(N^\alpha = k, \chi_L) \tag{2}$$
$$\sum_{l=0}^{N_{\max}^{\bar{\alpha}}(N^\alpha=k)} \sum_{i=0}^{l} P(N^{(M-2)\alpha} = l, \chi_L) P(N^\alpha = l-i, \chi_H)$$

Where $N_{\max}^{\alpha}$ is the maximum number of users in sector α and $N_{\max}^{\bar{\alpha}}$ is the maximum number of users outside sector α.

The blocking probability is the probability that a new user cannot be admitted. Let P_b^H and P_b^L be the blocking probabilities for hot beam and light beam, respectively. These blocking probabilities are

$$P_b^H = 1 - P_\alpha^H \tag{3}$$

$$P_b^L = 1 - P_\alpha^L \tag{4}$$

Therefore the total blocking probability is

$$P_b^{total} = \frac{(M-1)P_b^L + \xi P_b^H}{M-1+\xi} \tag{5}$$

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

In Fig. 2, we describe the sidelobe attenuation versus the blocking probability in 2 cases. The first case is when the offered load of the light beam is 3.09 Erlangs, traffic load ratio is 1.90 and α= 45^0. The second case is when the offered load of the light beam is 2.85 Erlangs, traffic load ratio is 1.90 and α= 30^0. As the sidelobe level increases, the total blocking probability decreases. When the sidelobe attenuation is larger than 8.60dB and 9.00 dB for beamwidth of 45^0 and 30^0, respectively, the blocking probability is below 1%.

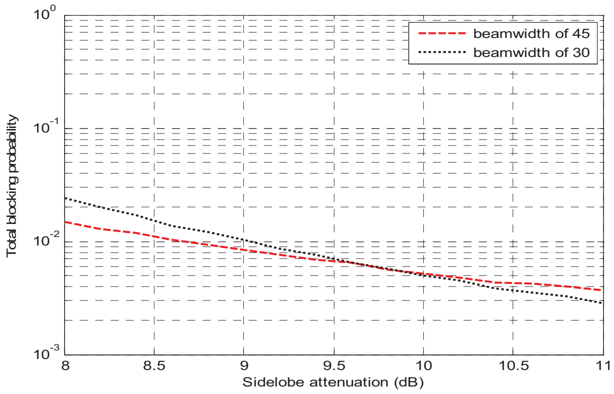

Fig. 2. Blocking probability versus sidelobe antennuation

3. Sidelobe Canceller

The presence of sidelobe means that the arrays are radiating energy in undirected directions. It affects the Quality of Service cellular systems. The sidelobe can be suppressed by using windowing technique or GSC structure.

1. Windowing technique

There are a vast number of possible windows: Binomial, Hamming, Blackman, Kaiser- Bessel...We apply them to steer the beam toward the desired direction and shape the sidelobes.

2. General Sidelobe Canceller (GSC)

Let B be the constraint matrix, and g be gain vector. The overall weight vector of the beamformer is defined by:

$$B^H w = g \tag{6}$$

Eq. 4 is called multiple linear constraints. GSC is applied here to find weights in order to place nulls in the direction of interference and adjust beam width and sidelobe peaks as expected.

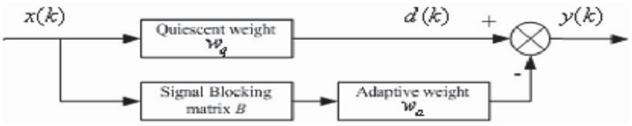

Fig. 3. General Sidelobe Canceller [5].

The structure of GSC is illustrated in Fig. 3. The upper path includes the matched filter for quiescent signal with weight w_q, expressed as

$$w_q = B(B^H B)^{-1} g \tag{7}$$

The lower path includes the blocking matrix B and the interference cancelling filter with weight w_a. GSC converts the linearly constrained optimization problem into a standard optimum filtering problem [5]. Then we can find the optimum weight as

$$w_{a,opt} = (B^H R_x B)^{-1} B^H R_x w_q \tag{8}$$

The overall weight vector of the beamformer as

$$w = w_q - B w_a \tag{9}$$

With the input of GSC is $x(k)$, the output $y(k)$ of GSC expressed as

$$y(k) = (w_q - B w_a)^H x(k) \tag{10}$$

4. Simulation Results

In this section, we present some simulation results of using windowing technique and GSC structure. As mention in section 1, each cell has a switched beam antenna with 12 beams (beam width of 30^0), we need maximum sidelobe level being less than -9 dB to get blocking probability under 1%.

We sectorize the cell into 3 equal sectors and we consider a sector from -60^0 to 60^0. The center of each beam is defined by 45^0, 15^0, -45^0, -15^0. Fig. 4 depicts the array factor of 5 element linear array using window Kaiser- Bessel. Fig. 5 shows the array factor of 6 elements linear array using GSC. As we can see from Figs. 4, 5, we obtain the design goal in main beamwidth and sidelobe peaks.

In case of using Kaiser- Bessel window, when the desired direction is 15^0, the array factor at interference direction of 45^0 and -15^0 are both -12 dB. This happens similarly when the desired direction are 45^0, -15^0, -45^0. However, GSC structure places nulls at the directions of interference. The price paid for that is increasing in the number of elements in array antenna and computation complexity, compared with using windowing technique

5. Conclusions

In this paper we studied the relationship between blocking probability and antenna parameters in multibeam CDMA based system using switched array antennas. In addition, we compare windowing technique and GSC structure to obtain the design goal in mainbeam width and maximum sidelobe.

6. Acknowledgement

This research was supported by the MSIP(Ministry of Science, ICT&Future Planning), Korea, under the ITRC(Information Technology Research Center) support program supervised by the NIPA(National IT Industry Promotion Agency)" (NIPA-2014-(H0301-14-1003). Dr. CS Hong is the corresponding author

7. Reference

[1] T.P. Yum and W. Wong, " Hot-Spot Traffic Relief in cellular systems" ,IEEE Journal on selected areas in communications, Vol. 11, No.6, pp. 934-941, August , 1993.

[2] J. Wu, J. Chung, and C. Wen. "Hot-Spot Traffic Relief with a Tilted Antenna in CDMA Cellular Networks", IEEE Trans. on Veh. Tech. Vol. 47, No. 1, pp. 1–9, February, 1998.

[3] C.U. Saraydar and A. Yener, "Adaptive Cell Sectorization for CDMA Systems", IEEE JSAC, Vol. 19, No. 6, pp. 1041–1051, June, 2001.

[4] Hyunduk Kang, Seokjin Sung, Insoo Koo and Kiseon Kim, " On Blocking Probability of Multi-Beam CDMA Systems Using SBF Array Antennas", In Proceedings of the IEEE Vehicular Technology Conference (VTC), Vol. 1, pp. 72–76, September, 2002.

[5] S. Haykin, "Adaptive filter theory", Prentice-Hall, Inc., 1996.

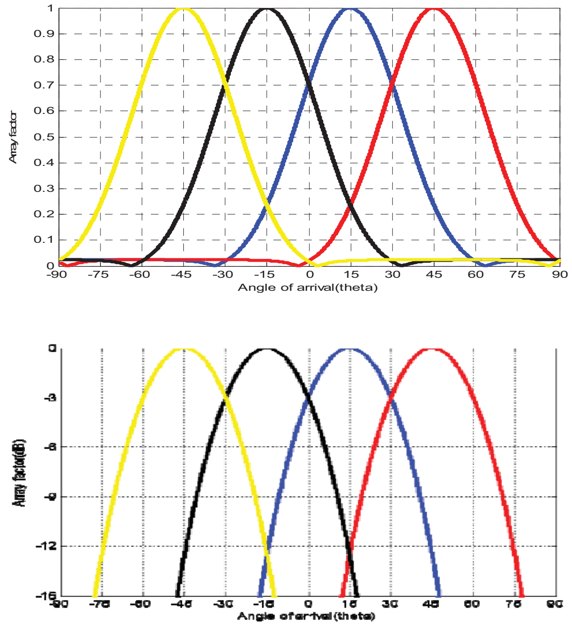

Fig. 4. Array factor (using Kaiser- Bessel window)

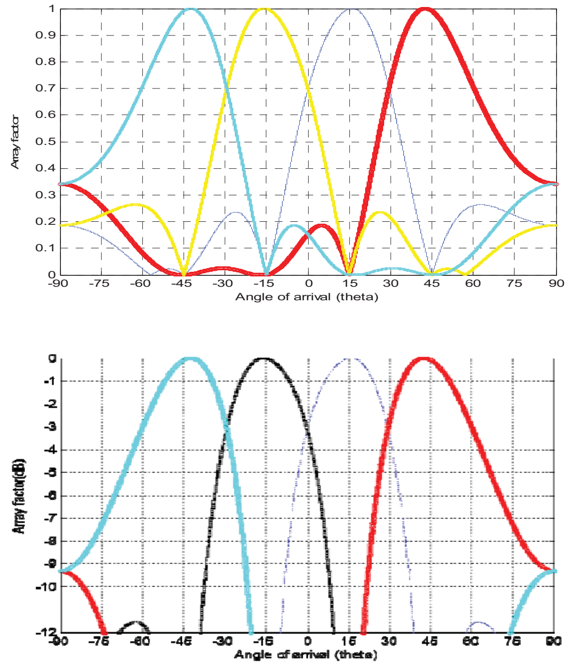

Fig. 5. Array factor (using GSC)