

# Switched Beam Smart Antenna BER Performance analysis for 3G CDMA Cellular Communication

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## Abstract

The technology of smart antenna for mobile communications has received enormous interest worldwide in recent decade. A smart antenna forms a pattern that adapts to the current radio conditions improving the communication link. The principal reason for applying smart antennas is the possibility for a large increase in capacity and to introduce new services. The purpose of this paper is to give a performance analysis of Switch Beam Smart Antenna (SBSA) and its comparison with conventional CDMA systems.

## 1. Introduction

Recently, an enormous increase of traffic in 3<sup>rd</sup> generation (3G) mobile communication systems has been experienced [Rappaport02], [Stuber96]. This is due both to an increased number of users as well as new high bit rate data services being introduced. This increase in traffic will put a demand to provide enough *capacity* in the networks. One of the most promising techniques for increasing the capacity in cellular systems is *smart antenna*. The technology of smart antennas is based on array antennas where the radiation pattern is altered by adjusting the amplitude and relative phase on the different array elements. It is feasible to use these techniques in 3G cellular systems in the frequency range 1-2 GHz.

The signals from users communicating via the same base station traditionally are separated by frequency (FDMA), by time (TDMA), or by code (CDMA). Smart antennas add a new possibility of user separation, by space, through SDMA (Space Division Multiple Access), which means that users in the same cell can use the same communication channel that is defined as a combination of carrier frequency, time slot and spreading code. In addition, the SDMA principles are valid for both TDMA systems (e.g., GSM) and CDMA systems (e.g., IS-95 and UMTS) [Liberti99].

The convenient base station antenna is 120° sectored. For this reason most of electromagnetic pollution power is radiated in other directions than toward the desirable user. Furthermore,

the power radiated in other directions is experienced as interference by other users. The smart antenna uses the base station antenna patterns directing a beam toward the user of interest only. Consequently, smart antenna will lead to a much more efficient use of the power and spectrum, increasing the useful received power as well as reducing interference. The reason for smart antenna being widely applied during the past years is that the new technologies of digital communications now are available. It means, powerful digital signal processors (DSP), more capacity and spectrum efficiency, and new CDMA systems (e.g., IS-95 and UMTS) etc. In addition to increased capacity, smart antennas also introduce a number of new advantages to wireless networks, including *increased range*, *a higher level of security*, and *the possibility for new services*.

The technology of direct-sequence CDMA (DS-SS) has been chosen for the 3G because of numerous advantages. A major advantage of the DS-SS is to provide a better capacity compared to the other possible technologies of multiple access. Interference suppression techniques with smart antenna to apply them in DS-SS have wide interest for investigation [Godara97], [Liberti99].

This paper presents the Switch Beam Smart Antenna (SBSA) version of smart antenna. It starts with an explanation of the basic principles of SBSA. The windowed SBSA is constructed and its performance analysis is carried out.

## 3. Switched-Beam Antenna and Signal Model

### 3.1 Switched beam antenna concept

SBSA creates a group of overlapping beams that together result in omnidirectional coverage. The overlapping beam patterns pointing in slightly different directions are presented in Figure 1. The SBSA creates a number of two-way spatial channels on a single conventional channel in frequency, time, or code. Each of these spatial channels has the interference rejection capabilities of the array, depending on side lobe level ( $\gamma$ ).

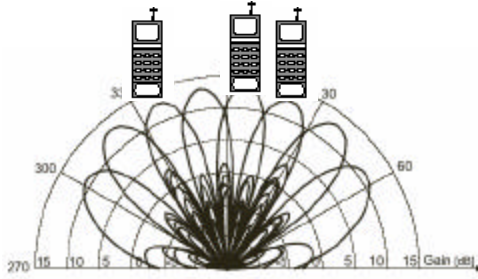


Figure.1. Switched beam array pattern

As the mobile moves, beam-switching algorithms for each call determine when a particular beam should be selected to maintain the highest quality signal and the system continuously updates beam selection, ensuring that user gets optimal quality for their call. The system scans the outputs of each beam and selects the beam with the largest output power as well as suppresses interference arriving from directions away from the active beam's center.

### 3.2 Signal model and decision rule of SBSA

The input signal of  $N$  antenna elements from  $N$  spatial channels is given by

$$U = |U_1, U_2, \dots, U_i, \dots, U_N|, \quad (1)$$

where  $U_i(t) = \sqrt{\rho_i} |1, e^{-j\psi_i}, e^{-j2\psi_i}, \dots, e^{-j(N-1)\psi_i}|^T$  is  $i$ -th user signal,  $\mathbf{j}_i = 2\mathbf{p}(d/I) \sin \mathbf{f}_i$ ,  $\mathbf{f}_i$  is  $i$ -th user angle of arrival signal,  $\tilde{\mathbf{A}}_i$  is power of  $i$ -th user signal and,  $\tilde{\mathbf{A}}_i = 0$  if  $i > K$ , where  $K$  is a number of active, resolved in space users.

The steering matrix for  $N$  spatial channels has a form

$$\Phi = |a_1, a_2, \dots, a_i, \dots, a_N|, \quad (2)$$

where  $a_i = |1, e^{-j\Psi_i}, e^{-j2\Psi_i}, \dots, e^{-j(N-1)\Psi_i}|^T$  is the steering vector,  $\Psi_i = 2\mathbf{p}(d/I) \sin \mathbf{q}_i$ ,  $\mathbf{q}_i$  is  $i$ -th reference angle.

The matrix  $\Phi$  forms the spatial filters (see Figure 2) with orthogonal properties  $a_i^H a_k = N$ ,  $i = k$ , and  $a_i^H a_k = 0$ ,  $i \neq k$ .

Taking into account eq. (1) and eq. (2), the output of switch beam antenna is

$$S = \Phi^H U = |S_1, S_2, \dots, S_i, \dots, S_N| \quad (3)$$

If all users are located exactly in directions of reference angles  $\mathbf{f}_i = \mathbf{q}_i$ , the vector  $S_i = |0, 0, \dots, \sqrt{\rho_i}, \dots, 0|^T$ . But if  $\mathbf{f}_i \neq \mathbf{q}_i$  we need to evaluate the maximum element of each vector to detect active users. Really, in practice, the signals  $S_1, S_2, \dots, S_i, \dots, S_N$  are not available separately and the output of the antenna is

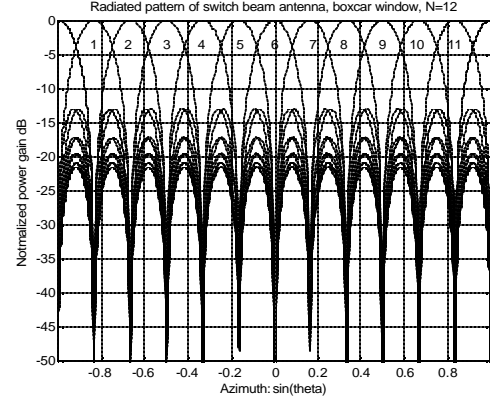


Figure 2. The spatial switched pattern for number of antenna elements  $N=12$

$$X = \sum_{i=1}^N S_i + n(t), \quad (4)$$

where  $n(t)$  is zero-mean thermal noise that is presented at the input of the receiver.

The next decision rule is applied: if  $|x_i| \geq \mathbf{a}$ , there is an active user in  $i$ -th channel where  $i=1, 2, \dots, N$ ,  $\mathbf{a}$  is threshold and  $x_i$  is  $i$ -th element of vector  $X$ .

### 4. Windowed beamformer

The simplest way to beamform in order to maximize the signal to interference ratio of SBSA is to use non-adaptive windowed beamformers [Harris78]. By carefully controlling the sidelobes in non-adaptive windowed arrays most interference can be reduced to insignificant power.

Windowed non-adaptive beamforming has the following advantages and disadvantages. The advantages are:

- Cheaper to implement than adaptive beamformers,
- No main-lobe distortions due to interference (unlike adaptive beamformers),
- Almost any level of side lobe ( $\gamma$ ) suppression can be achieved with the correct choice of windows
- No limit to the number of interference sources that can be suppressed.

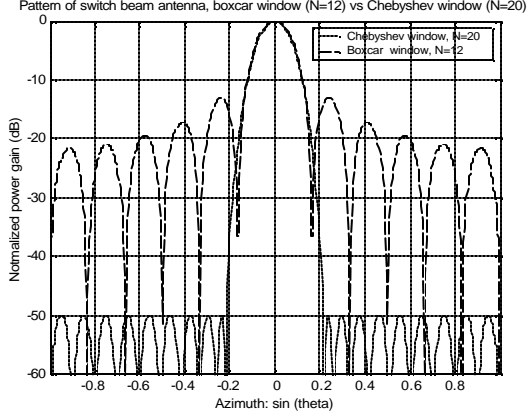
Their disadvantages include:

- The optimum window function (in terms of SIR) will depend on the distribution of interference sources and their power relative to uncorrelated noise, and
- Side lobe suppression is achieved at the expense of main beam width ( $\Delta$ ).

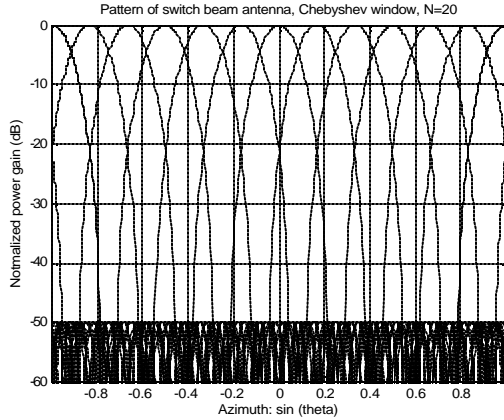
The parameters of windowed beams for various windows was calculated and presented in Table 1. The comparison of beam width for boxcar window (e.g. no windowed antenna) and Chebyshev window with parameters  $N=20$ ,  $\gamma=-50$ dB is presented in Figure 3.

**Table 1.** Main parameters of windowed beams

Window	$N$	$\Delta$	$\gamma$ (db)
Boxcar	12	1	-13
Hamming	18	1.5	-40
Triangular	17	1.42	-26
Blackman	23	1.92	-58
Gauss (a=3.0)	22	1.83	-56
Chebyshev	20	1.58	-50



**Figure 3.** Comparison of spatial beam width for rectangular ( $N=12$ ) and Chebyshev ( $N=20$ ,  $\gamma=-50$ dB) windows



**Figure 4.** The spatial switched pattern with Chebyshev ( $N=20$ ,  $\gamma=-50$ dB) windowing

As can be seen, the same beam width is achieved with 12 and 20 elements respectively. The switch beamformer with Chebyshev window and the number of spatial channel is 12 (the same as for rectangular window in the Figure 2), is presented in Figure 4.

## 5. Performance Analysis and Simulation Result

We consider the DS/CDMA system model presented in [Simon94]. The  $k$ -th user's received signal is given by

$$s_k(t - \mathbf{t}_k) = \sqrt{2P} b_k(t - \mathbf{t}_k) a_k(t - \mathbf{t}_k) \cos(\mathbf{w}_c t + \mathbf{q}_k) \quad (5)$$

where  $b_k(t)$  and  $a_k(t)$  are the data and pseudo noise (PN) code rectangular signals respectively,  $P$  is the received power, and  $\omega_c$  is the carrier frequency;  $\mathbf{t}_k$  and  $\mathbf{q}_k$  are the time delays and phase shifts of the signal propagation.

The received signal,  $r(t)$  is given by

$$r(t) = \sum_{k=1}^K s_k(t - \mathbf{t}_k) + n(t) \quad (6)$$

where  $K$  is the total number of simultaneous active users and  $n(t)$  is the thermal noise, which we neglect in this paper.

If the received signal  $r(t)$  is the input to a correlation receiver matched to  $s_l(t)$ , the output is

$$y(t) = \int_0^{T_b} r(t) a_l(t - \mathbf{t}_1) \cos(\mathbf{w}_c t + \hat{\mathbf{q}}_1) dt \quad (7)$$

where  $T_b$  is the data bit period,  $\mathbf{t}_1$  and  $\hat{\mathbf{q}}_1$  are the estimates of time delay and phase shift of the desired signal.

As shown in [Simon94], [Rappaport02] the Bit Error Rate (BER) for DS-CDMA system is given by

$$P_e = Q \left\{ \sqrt{\left( \sum_{k=2}^K \frac{E_b^{(k)}}{3E_b^{(1)}} \frac{1}{N_0} + \frac{1}{2E_b^{(1)}} \frac{1}{N_0} \right)^{-1}} \right\} \quad (8)$$

where  $E_b^{(1)}/N_0$  is relation of signal energy to noise power spectral density for user of interest (#1),  $E_b^{(k)}/N_0$  is the same for interfering users,  $M$  is PN-code length,  $Q(y)$  is the tabulated function [Rappaport02].

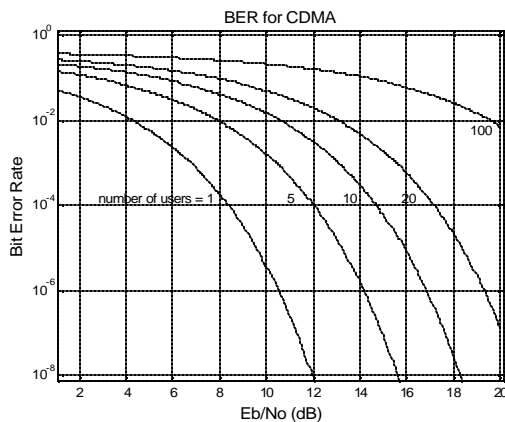
We extended eq.(8) to switch beam antenna

$$P_e = Q \left\{ \sqrt{\left( \sum_{k=2}^{K_1} \frac{E_b^{(k)} \mathbf{g}}{3E_b^{(1)}} \frac{1}{N_0} + \sum_{k=2}^{K_2} \frac{E_b^{(k)}}{3E_b^{(1)}} \frac{1}{N_0} + \sum_{k=2}^{K_3} \frac{E_b^{(k)} \mathbf{g}}{3E_b^{(1)}} \frac{1}{N_0} + \frac{1}{2E_b^{(1)}} \frac{1}{N_0} \right)^{-1}} \right\} \quad (9)$$

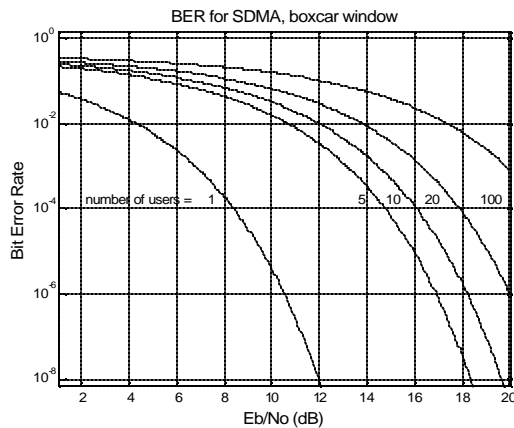
where  $K_1$  is the number of interfering users with the same PN-code like user #1, affected side lobes;  $K_2$  is the number of interfering users with the different PN-codes affected main lobe;  $K_3$  is like  $K_2$  but affected side lobes.

We assume that the data is modulated using binary phase shift keying (BPSK) format. The pulse and PN-code amplitudes are all independently and identically distributed random variables. The probability of being either positive or negative amplitude is 0.5. All odd channels, as well as even ones (see Figure 3) have the same PN-codes length  $M=128$ . We assume that the power of each mobile station (MS) is perfectly controlled by the same BS, and, the received power

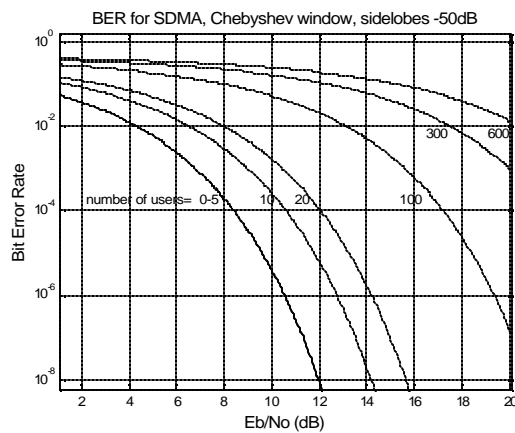
of each mobile is 15 dB. MSs of a cell are uniformly distributed. The decision statistic was evaluated for desired receiver 1, and given  $K - 1$  interfering transmitters.



**Figure 5.** The BER performance of DS-CDMA system and  $120^\circ$  sectored antenna



**Figure 6.** The BER performance of DS-CDMA/SDMA switched beam no windowed antenna



**Figure 7.** The BER performance for DS-CDMA/SDMA and switched beams Chebyshev ( $N=20, \gamma=-50\text{dB}$ ) windowed antenna

The simulation results are presented in Figure 5, 6 and 7, where BER as a function of  $E_b/N_0$  and number of active users in the service area is plotted. Figure 5 presents DS-CDMA system with conventional  $120^\circ$  antenna, Figures 6 presents no windowed SBSA ( $N=12$ ) system and, Figures 7 presents Chebyshev windowed SBSA ( $N=20, \gamma=-50\text{dB}$ ). As follows from Figures 5, 6, and 7, for the fixing level of BER, (for example for 3G communication acceptable BER is  $P_e=10^{-4}$ ) the application of SBSA can increase the number of active users up to 1.5 times for no windowed antenna and up to 8 times for Chebyshev windowed antenna without losing of performance quality.

## 6. Conclusions

In this paper the performance analysis of Switch Beam Smart Antenna (SBSA) was investigated. The relation of Bit Error Rate (BER) for DS/CDMA system was extended in the case of application of SBSA in base station. As result shows, the number of active users for any desirable BER can be increased depending of the windowed function applied to antenna aperture. For example, for  $P_e = 10^{-4}$  and application of SBSA the number of active users in conventional CDMA systems can be increased up to 1.5 times for no windowed antenna and up to 8 times for Chebyshev windowed antenna. But the Chebyshev windowed antenna requires 20 radiated elements for this particular case as opposed of 12 for no-windowed antenna. In spite of increasing of number of the radiated elements to achieve a desirable bandwidth of main beam, the switch beam antenna is still an attractive solution to increase the capacity of existing 3G wireless communication systems.

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