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BER Performance Analysis of DS-CDMA over AWGN Channel

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Abstract-In this paper, we present a bit error rate (BER) performance of DS-CDMA over AWGN channel with perfect power control. The standard Gaussian approximation (SGA), Simplified Improved Gaussian Approximation (SIGA), Reverse Channel and performance with adaptive antennas at the base stations and Modified SIGA are used to evaluate the BER performance for the DS-CDMA. Power control is the important system requirement for CDMA. For CDMA system to function properly, we need to control the power; if power control is not implemented many problems arises such as the near-far problem will start to dominate and consequently will lower the capacity of the CDMA system. However, when the power control in CDMA systems is employed, it allows users to share resources of the system equally between themselves, leading to increased capacity. Power control is an important method to reduce co-channel interference and it can improve the system capacity.

Index Terms- AWGN, BER, DS-CDMA, Power Control.

I. INTRODUCTION

In cellular communication systems, the mobile transmission powers must be controlled to reduce interference in the base stations. In cellular systems where individual users are identified by a particular frequency carrier such as Frequency Division Multiple Access (FDMA), effective power control methods have been applied to minimize co-channel interference and maximize frequency reuse. As a result, the quality of communication links can be improved and the system capacity can be increased. In Code Division Multiple Access (CDMA) systems, all users employ the same wideband signal and multiple access is achieved through the use of a user-specific spreading code.

As a consequence, the received signal of a given user at the base station views all other arriving intracell or intercell signals as interference or noise because they both degrade the decoding process of extracting the real user's signal. Thus, power control is crucial to guarantee each user transmits at a level which insures adequate Signal-to-Interference Ratio (SIR) at the base station. The Bit Error Ratio (BER) is one of the important performances metric in communication systems and hence it has been extensively studied in various contexts. In Direct Sequence Code Division Multiple Access (DS-CDMA) systems various versions of the so-called Gaussian approximation are widely used for modelling the distribution of the Multiple Access Interference (MAI). A few examples are the Standard Gaussian Approximation (SGA) [1], [2], the Improved Gaussian Approximation (IGA), the Simplified IGA (SIGA) and the Improved Holtzman Gaussian Approximation (IHGA). However, the accuracy of the various Gaussian approximation techniques depends on the specific configuration of the system.

It is well known that the Gaussian approximation techniques become less accurate, when a low number of users is supported or when there is a dominant interferer.

The BER performance of DS-CDMA systems communicating over Additive White Gaussian Noise (AWGN) channels has been extensively examined and there are numerous studies also for transmission over both Rayleigh [3], [4] and Nakagami *m* channels. Geraniotis and Pursley were the first authors, who investigated the accurate BER calculation of asynchronous DS-CDMA systems over AWGN channels. Then Cheng and Beaulieu extended the results to both Rayleigh and Nakagami-*m* channels.

BER indicates the quality of service QoS. Section II deals with different base station antenna configurations. Section III and IV deal with Standard Gaussian Approximation SGA and Simplified Improved Gaussian Approximation SIGA. In Section V and VI we discussed a new approximation method which is computationally simple and yet provides the closer results to SIGA for different antennas.

II. DIRECTIVE ANTENNA

This section illustrates how directive antenna can improve the reverse link in a single-cell CDMA system. Fig. 1 shows three different base station antenna configurations. The omni-directional antenna will detect signal from all users in the system and thus will receive the greatest amount of noise. The sectored antenna will divide the received noise in to smaller values and will increase the number of users in CDMA system.

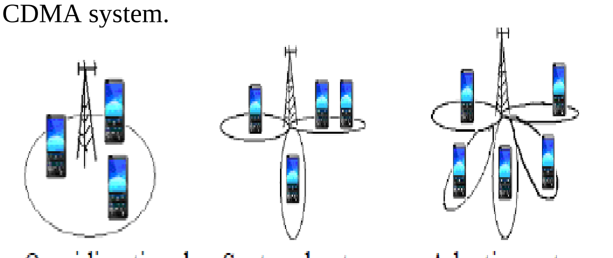

Fig. 1: Base Station Antenna Configurations.

Adaptive antenna provides a spot beam for each user and base station tracks each user in the cell as it moves. Assume beam pattern G(φ) is formed such that the pattern has maximum gain in the direction of desired user. It can be seen that the probability of bit error is depend on the beam pattern of a receiver, and there is considerable improvement that is achieved using high gain adaptive antennas at the base station.

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In cellular installations, D ranges between 3dB to10 dB. As the antenna beam pattern is made narrower, D increases, and the received interference decreases proportionally.

III. POWER CONTROL METHODS

A. Standard Gaussian Approximation

For interference limited asynchronous reverse channel CDMA over an additive white Gaussian noise (AWGN) channel, operating with perfect power control with no interference from adjacent cells and with Omni directional antennas used at the base station, the Standard Gaussian Approximation(SGA) bit error rate (BER), P_b (SGA), is approximated by [5]

$$P_b(SGA) \approx Q\left(\sqrt{\frac{3N}{K-1}}\right) \quad (1)$$

Where K is the number of users in a cell and N is the spreading factor, $Q(Y)$ is the standard Q-function, Equation (1) assumes that the signature sequences are random and that K is sufficiently large to allow the Gaussian approximation described in [5] to be applied.

In order to develop simple bit error rate expressions for simultaneous asynchronous interference limited CDMA users when directive antennas are used, we assume that the BER expression of equation (1) can be expressed as

$$P_b \approx Q\left(\sqrt{3N \times CIR}\right) \quad (2)$$

Where N is the spreading factor and CIR (Carrier Interference Ratio) is the ratio of the power of the desired signal to the total interference. This assumption is known to be inaccurate when the powers of users are widely different and when the number of users is small [7], however, it provides a approximation for the case of a large number of users (K).

Let us assume that the base station is able to form a directional beam with power pattern G(φ), whose two–dimensional directivity is defined as:

$$D = \frac{2\pi}{\int_0^{2\pi} G(\varphi)d\varphi} \quad (3)$$

We assume that the beam is steered such that, in the direction of the desired user, $G(\varphi_0) = 1$. If we assume that K users are uniformly distributed throughout a cell with radius R, the expected value of interference received at the base station on the reverse link is given by,

$$I = (K-1)\int_0^R \int_0^{2\pi} \frac{rP_r}{\pi R^2} G(\varphi)drd\varphi = \frac{(K-1)P_r}{D} \quad (4)$$

Using the fact that the desired signal power, weighted by the antenna pattern, is simply P_r, and substituting Equation (4) in to (2) we obtain,

$$P_b(SGA) = Q\left(\sqrt{\frac{3DN}{K-1}}\right) \quad (5)$$

B. Simplified Improved Gaussian Approximation (Siga), Reverse Channel And Performance With Adaptive Antennas At The Base Stations

The Equation (5) is valid only when a single cell is considered. To consider the effective adaptive antenna when the CDMA users are simultaneously active in several adjacent cells, we must first define the geometry of the cell region. For simplicity, we consider the geometry proposed in [6] with the single layer of surrounding cells as illustrated in the Fig. 2.

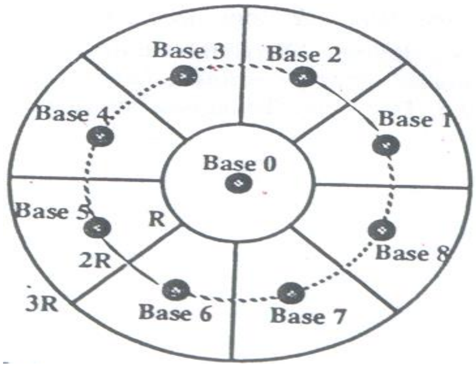

Fig. 2: Nine cell wedge geometry proposed in [6].

β is related to the reuse factor, f, which is defined in [6], as the ratio of interference, received at the central base station, from users within the cell to total interference. When perfect power control is applied, then the reuse factor, f, may be expressed as:

$$f = \frac{(K-1)P_r}{(K-1)P_r + 8K\beta P_r} \approx \frac{1}{1+8\beta} \quad (6)$$

Where we assumed that there are K users in each of the nine cells, f provides a measure of the impact of adjacent cell interference. Note that, when omni-directional antennas are used at the both the base station and the portable unit, the value of the reuse factor, f is determined by the cell geometry, power control scheme, and the path loss exponent. Let us assume that the mth user in the central cell, an antenna beam from the base station, with pattern $G(\varphi)$, may be formed by the base station with maximum gain in the direction of user m. It can be shown that the carrier to interference ratio is approximated by,

$$CIR = \frac{D}{K(1+8\beta)} \quad (7)$$

Using equation (2), the average bit error rate is approximately given by,

$$P_b(SGA) \approx Q\left(\sqrt{\frac{3ND}{K(1+8\beta)}}\right) \quad (8)$$

Equation (8) relates the probability of error to the number of users per cell, the directivity of the base station antenna, and the propagation path loss component through the value of β. SIGA requires the evaluation of mean μ and variance σ^2 the approximation BER becomes

$$P_e(SIGA) = \frac{2}{3}a + \frac{1}{6}b + \frac{1}{6}c \quad (9)$$

Where $a = Q\left[\sqrt{\frac{N^2}{\mu}}\right]$, $b = Q\left[\sqrt{\frac{N^2}{\mu + \sqrt{3}\sigma}}\right]$

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And

$$c = Q\left[\sqrt{\frac{N^2}{\mu - \sqrt{3}\sigma}}\right]$$

The value of μ and σ^2 are given by

$$\mu = (K-1)\frac{N}{3}$$

And

$$\sigma^2 = (K-1)\left[N^2\frac{23}{360} + N\left(\frac{1}{2}+\frac{K-2}{30}\right) - \frac{1}{20} - \frac{K-2}{36}\right] \qquad (10)$$

Since μ is proportional to K and σ is proportional to $\sqrt{K}$, The SIGA converges to SGA as K increases [8].

C. Modified Siga

From equation (9) it can be noticed that $\sqrt{3}\,\sigma$ can be greater than μ for smaller values of K. This results in imaginary argument to Q-function and hence c cannot be determined. Under such conditions c can be neglected without the loss accuracy. If the quantity B is set to a value $\frac{(N-1)}{2}$, without significant loss in accuracy, σ^2 can be evaluated as

$$\sigma^2 \approx (K-1)\left[\frac{23N^2}{360}\right] \qquad (11)$$

D. Simulation Of Adaptive Antennas At The Base Station For Reverse Channel

To explore the utility of equation 4.3 and to verify its accuracy, we considered five base station antenna patterns which are illustrated in Fig. 3. These antenna patterns are assumed to be directed such that the maximum gain is in the direction of the desired mobile user. The first base station antenna pattern similar to that used in traditional cellular systems. The second pattern, illustrated in Fig. 3 (b), used 120^0 sectorization at the base station. The third simulated base station pattern shown in Fig. 3 (c) was a "flat-topped" pattern. The main beam was 30^0 wide with uniform gain in the main lobe. The uniform side lobe level, which was 6dB below the main beam gain, was assumed.

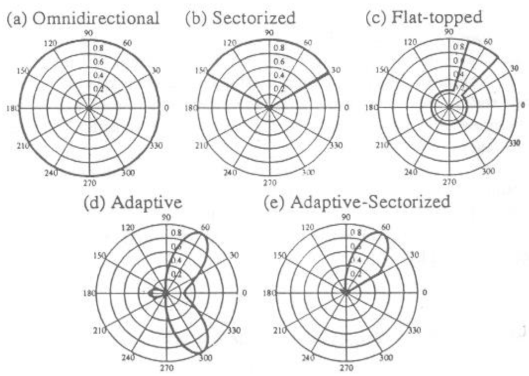

Fig. 3: The five base antenna patterns used for the study (a) the omni-directional pattern, (b) the 120^0 sectorized pattern, (c) the flat-topped pattern, (d) the three element binomial phased array and (e) the binomial phased array pattern overlaid with a 120^0 sectorization pattern.

The fourth pattern, which used simple three linear arrays, is illustrated in Fig. 3 (d). This is the beam pattern formed by a binomial phased array with elements spaced a half wavelength apart. While the three dimensional gain a binomial phased array is constant at 4.3 dB regardless of scan angle, the two dimensional directivity defined by Equation (3), varies between 2.6 and 6.0 dB, depending on the scan angle.

IV. SIMULATION RESULTS

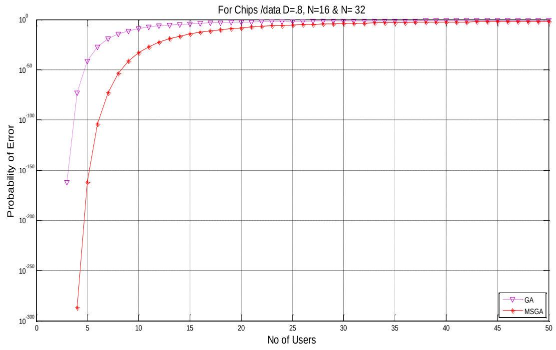

Fig. 4: BER Performance of SGA and Modified SGA

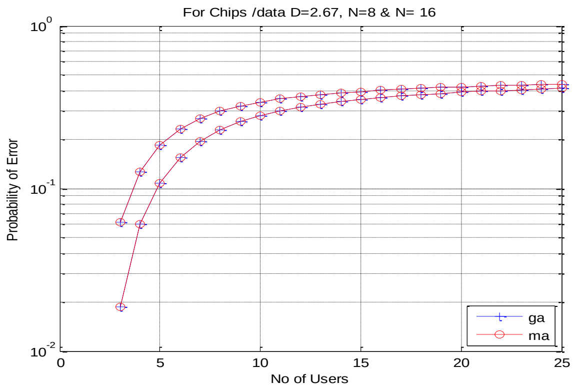

Fig. 5: BER performance using Gaussian approximation and modified Gaussian approximation.

V. CONCLUSION

In this paper, the reverse link (mobile to base station) performance of DS-CDMA cellular system over a AWGN channel is evaluated. The standard Gaussian approximation (SGA), Simplified Improved Gaussian Approximation (SIGA), Reverse Channel and performance with adaptive antennas at the base stations and Modified SIGA in case of perfect power control has been used to evaluate the BER performance for the DS-CDMA system. From the simulation results we conclude that the BER performance is affected by the number of components, the value of spreading factor and the number of interfering cells. It is observed that adaptive antennas, with relatively modest beam width requirements, and no interference nulling capability, both at the base station and at the portable, can provide large improvements in BER, as compared to omni-directional systems. Further it is observed that the number of chips/data increases the BER decreases.

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