Performance Evaluation of CDMA Mobile Cellular System Using Smart Antenna

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Abstract

In the last few years, the demand for mobile communication services has been increased tremendously. However, there is no proportionate increase in the allocated spectrum. As a result, there is an urgent need for new techniques to improve system spectral efficiency. The use of smart antenna at the base station divides the space into spatial dimension using Space Division Multiple Access (SDMA) technique, which results in maximizing the capacity of cellular system and improving system performance. In this paper, the Bit Error Rate (BER) performance of asynchronous reverse link Code Division Multiple Access (CDMA) mobile cellular system is simulated, taking into account Rayleigh fading channel, convolutional encoder, Viterbi decoder, and Rake Receiver. Also, smart antenna is simulated using Linearly Constrained Minimum Variance (LCMV) beamforming algorithm. The results show that using smart antenna at the base station of mobile system has a significant improvement on CDMA system performance and capacity.

Keywords: CDMA; convolutional encoder; Viterbi decoder; Rake receiver; SDMA; smart antenna; LCMV and directivity.

Received: 28/3/2020 Accepted: 13/12/2020

تقييم أداء نظام الهاتف الخلوي نوع CDMA باستخدام الهوائي الذكي

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المستخلص

ازداد الطلب في السنوات القليلة الماضية على خدمات الاتصالات المتنقلة بشكل كبير على الرغم من عدم وجود زيادة متناسبة في تخصيص الترددات اللازمة لها ونتيجة لذلك ظهرت حاجة ملحة لتقنيات جديدة لتحسين كفاءة النظام الطيفية ان استخدام الهوائيات الذكية في المحطة الأساسية يعمل على تقسيم الفضاء في البعد المكاني باستخدام تقنية الوصول المتعدد بتقسيم الفضاء (SDMA) والذي ينتج عنه تعظيم في قدرة الهاتف الخلوي وتحسين أداء وسعة النظام. في هذا البحث تمت محاكاة اداء معدل نسبة الخطأ لنظام الوصول المتعدد بتقسيم الشفرة غير المتزامنة (CDMA) للنظام الخلوي النقال مع الاخذ بنظر الاعتبار قناة الخفوت نوع رايلي ومشفر الالتفاف وفاك الشفرة نوع فايتربي ومستقبلة ريك. كما وتمت محاكاة الهوائي الذكي باستخدام خوارزمية تكوين الشعاع (LCMV). أظهرت النتائج أن استخدام الهوائيات الذكية في المحطة الأساسية في النظام الخلوي يعمل على تحسين وبشكل كبير من أداء النظام وسعته.

الكلمات المفتاحية: CDMA، الضرب الآلتوائي، مشفر فيتربي، المستقبل الشوكي، SDMA، الهوائي الذكي، LCMV والأتجاهيه.

I. Introduction

CDMA is a “spread spectrum” technology, which spreads the information over a much greater bandwidth than the original signal. This is achieved by multiplying the signal with a very large bandwidth signal called the spreading signal. Each user has its own pseudorandom code word which is approximately orthogonal to all other code words [1].

The capacity of CDMA system is interference limited, this means that as the number of users in the CDMA system increase, the noise floor increase which decreases the system performance. SDMA is recognized as one of the most useful techniques for enhancing the performance and increase capacity by allowing different users to share the same available resources at the same time and are distinguished only in the spatial dimension. In particular, the radiation pattern of the base station, both in transmission and receptions is adapted to each user using adaptive beamforming so as to obtain the highest gain in the direction of the mobile user [2].

This subject has been investigated by many researchers, for example: R. Lamare and R. Sampaio examine blind adaptive and iterative decision feedback (DF) receivers for Direct Sequence Code Division Multiple Access (DS-CDMA) systems in frequency selective channels, and the proposed DF structure has achieved the best performance amongst all analyzed receivers [3]. B. Salem, S. Tiong, S. Koh and S. Darzi present Minimum Variance Distortion less Response (MVDR) algorithm and Linear Constraint Minimum Variance (LCMV) algorithm, which gave a high output power, required the direction of all incoming sources and avoid the self-nulling even if the user is very closed to the interference [4]. Particle swarm optimization (PSO) technique was used by K. Budhwar and A. Sharma to find out the best connection as a particular connection combination affects the error correcting capability of convolution code [5].

In this paper, MATLAB simulation is performed for asynchronous reverse link of CDMA taking into consideration convolutional encoder at the transmitter and Rake receiver with Viterbi decoder at the receiver. That's to evaluate system performance represented by the BER metrics and the capacity presented by number of users (k) with the beamforming simulation for smart antenna. In addition, SDMA-CDMA System performance and capacity are evaluated.

II. The mathematical model of asynchronous (reverse link) SDMA- CDMA

The SDMA-CDMA asynchronous reverse link (from mobile station to base station) system model is shown in Fig. (1).

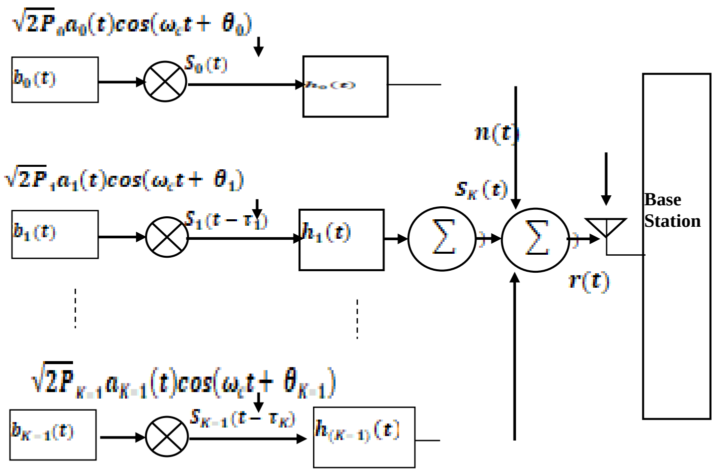

Figure (1)

Asynchronous SDMA-CDMA Link Model

Considering k active users transmitting signals in asynchronous SDMA-CDMA system, each of them transmits a signal which can be described as [6].

$$S_k(t-\tau_k) = \sqrt{2P_k}\,b_k(t-\tau_k)c_k(t-\tau_k)\cos(\omega_c t+\theta_k) \quad (1)$$

where $b_k(t)$ is binary data sequence, $c_k(t)$ is a spreading sequence, P_k is the power of the transmitted signal, ω_c is the carrier angular frequency, τ_k is the time delay of user k relative to some reference user 0 that accounts for the lack of synchronism among the transmitters, and θ_k is the carrier phase angle of user k relative to a reference user 0. Since τ_k and θ_k are relative terms, we can define $\tau_0=0$ and $\theta_0=0$

Assuming that the channel $h_k(t)$ is multipath Rayleigh frequency selective fading channel. The delay difference between any two different paths is larger than the chip duration (T_c) of the spreading sequence. The complex low pass equivalent impulse response of the channel is given by:

$$h_k(t) = \sum_{l_k=1}^{L_k} \alpha_{k,l_k} e^{j\Phi_{1,l_k}} \delta(t-\tau_{k,l_k}) \quad (2)$$

where Φ_{k,l_k} is the phase of the multipath component, τ_{k,l_k} is the path delay, L_k is the number of multipath components and α_{k,l_k} is magnitude of the l^{th} multipath with Rayleigh distribution.

A correlated receiver is typically used to filter the desired user from all other users which share the same channel, therefore the received signal at the input of the receiver is given by:

$$r(t) = h_k(t) \times S_k(t) + n(t) \quad (3)$$

where n(t) is Additive White Gaussian Noise (AWGN) and $\times$ is the convolutional product.

III.Convolutional Encoder

A. Design of convolutional encoder:

A convolutional code is a type of error-correcting code. It introduces redundant bits into information data sequence (k-bit sequence) by passing it through a linear shift register to be transmitted into an n-bit sequence, where k/n is the code rate (r) and (n $\geq$ k) [7].

The number of shifts required for a message bit to enter the shift register and finally come out is called the Constraint Length of the code (CL). In this paper, CL is set to 3 and the code rate (r) is equal to 1/4 as shown is Fig. (2).

The Polynomial Generator in Fig. 2 shows the hardware connection of the shift register taps to the modulo-2 adders. In this paper the Polynomial Generator (G) for the encoder is $[7\ 7\ 5\ 5]_8$ where G1= $[111]_2$, G2= $[111]_2$, G3= $[101]_2$, G4= $[101]_2$ and v1, v2, v3, v4 are the corresponding output terminals.

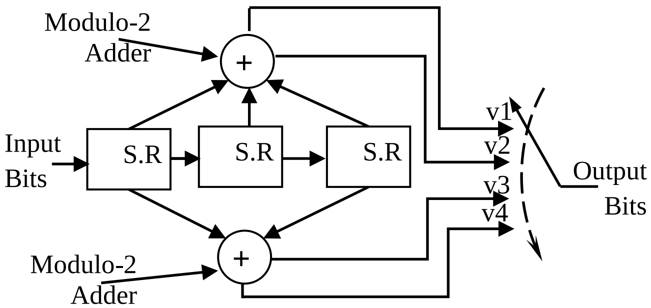

Figure (2)

Block Diagram of Polynomial Generator as Convolutional Encoder

B. State diagram

Since the output of the encoder is determined by the input and the current state of the encoder, a state diagram (signal flow graph) can be used to represent the encoding process as shown in Fig. (3).

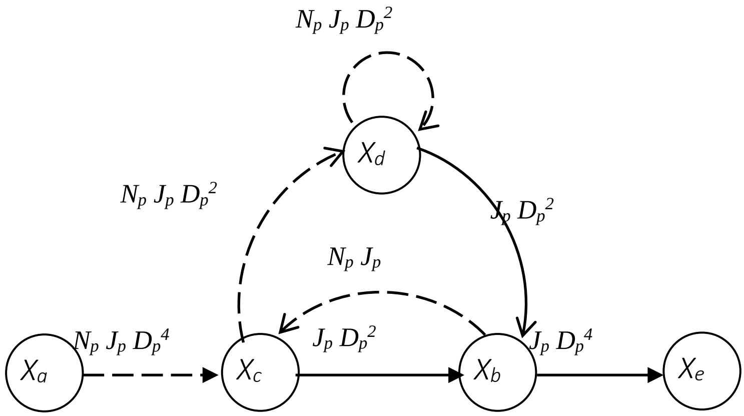

Figure (3)

State Diagrams for convolutional encoder

Here dotted lines indicate that the input bit is 1 and solid lines indicate that the input bit is 0. The corresponding output is given on the corresponding line. The exponent of D_p on a branch denotes the number of 1's in the output sequence for that path. The exponent of J_p is always equal to 1, since the length of each branch is one. The exponent of N_p denotes the input (i.e., for input 0, exponent of N is 0 and for input 1, it is equal to 1). The transfer function (TF) of the convolutional encoder with r=1/4 is calculated by:

$$T(D_p, N_p) = \frac{N_p D_p^{10}}{(1 - 2N_p D_p^{2})} \qquad (4)$$

IV. Rake Receiver

Due to reflection from obstacles, a wideband radio channel can consist of many copies (multipaths) of originally transmitted signals having different amplitude, phase, and delays. If the signal components arrive in more than duration of one chip apart from each other, a Rake receiver can be used to resolve multipath component by providing separate correlator for each one of them, and combine them to achieve improved communication reliability and performance. Fig. 4 shows the block diagram of Rake Receiver, where the outputs of the M correlators are denoted as Z_0, Z_1, ... and Z_{M-1} and they are weighted by α_0, α_1, ... α_{M-1}, respectively [8].

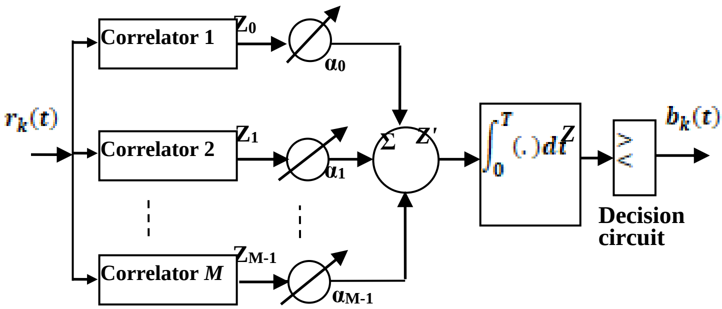

Figure (4)

Block diagram of Rake Receiver

V. SMART ANTENNA

Smart Antenna consists of array antenna and beamforming processor.

UCCA (Uniform Concentric Circular Array) antenna [9] is adopted in this paper since it has the capability to perform the scan in all directions without a considerable change in the beam pattern or directivity value and provide 360° azimuth plane and 180° in elevation plane.

In UCAA, the elements are arranged in such a way that all array elements are positioned in multiple concentric circular rings, which vary in radii and in number of elements. Fig. (5) shows the general configuration of UCAA with M concentric circular rings, where the m^{th} ($m = 1, 2, \ldots, M$) ring has a radius r_m and the corresponding number of elements is N.

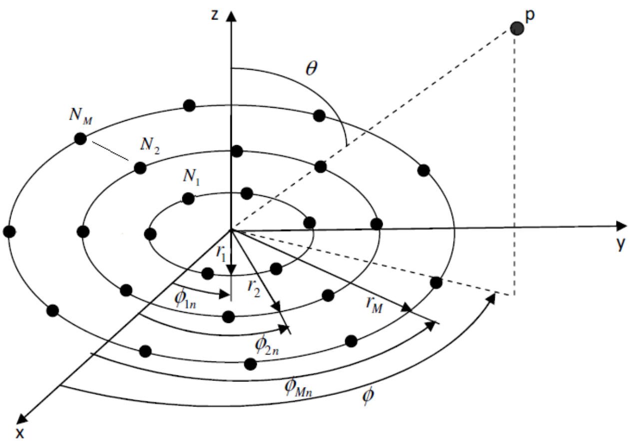

Figure (5)

Uniform Concentric Circular Array Geometry

Assuming that all the elements are isotopic sources, then the radiation pattern of this array can be written in terms of its array factor only. The array factor (AF) is given by [9]:

$$AF(\theta, \Phi) = \sum_{m=1}^{M} \sum_{n=1}^{N} I_{mn} e^{i\{\beta r_m\{\sin\theta \cos(\Phi - \Phi_{mn}) + \alpha_{mn}\}\}} \quad (5)$$

where, β is the wave number = $2\pi/\lambda$, λ is the signal wavelength, r_m is the radius of the m^{th} ring N d/2π, d is inter element arc spacing of the m^{th} ring, Φ_{mn} is the angular position of the n^{th} element of the m^{th} ring = $2\pi(n-1)/N$, I_{mn} is the current excitation of the nth element of the m^{th} ring , θ and Φ are the angle Azimuth and elevation angle respectively, α_{mn} is the residual phase = $-\beta r_m \cos(\Phi_0 - \Phi_{mn})$, Φ_0 is the value of Φ where main beam is to be directed.

Antenna Directivity (D), which is a measure of how 'directional' an antenna's radiation pattern is, can be given by [10]:

$$\mathrm{D} = \frac{4\pi \; |AF(\theta,\Phi)|^2}{\int_o^{2\pi} \int_o^{\pi} |AF(\theta,\Phi)|^2 sin\theta d\theta d\Phi} \qquad (6)$$

A Digital Signal Processor (DSP) located at the base station works in conjunction with the antenna array and is responsible for computing the Direction-Of-Arrival (DOA) of the Signal-Of-Interest (SOI). The DSP adjusts the excitations (Amplitudes and phases of the elements) to produce a radiation pattern in an adaptive manner that focuses on the SOI while tuning out any interferers or Signals-Not-Of-Interest (SNOI). Fig. (6) illustrates the general idea of an adaptive antenna system [11].

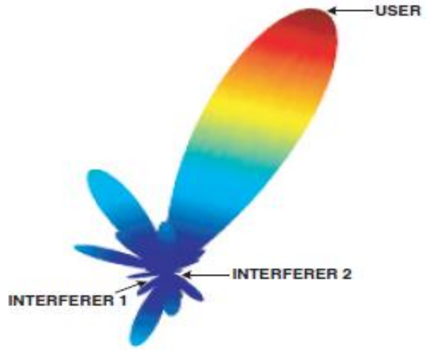

Figure (6)

Adaptive Array Coverage

Based on the received signal, the signal-processing unit calculates the complex weights $w_0, w_1, \ldots, w_N$, these weights will determine the antenna pattern in the uplink direction. Fig. (7) shows the block diagram of the digital signal processing part of an adaptive array antenna system used in CDMA system [12].

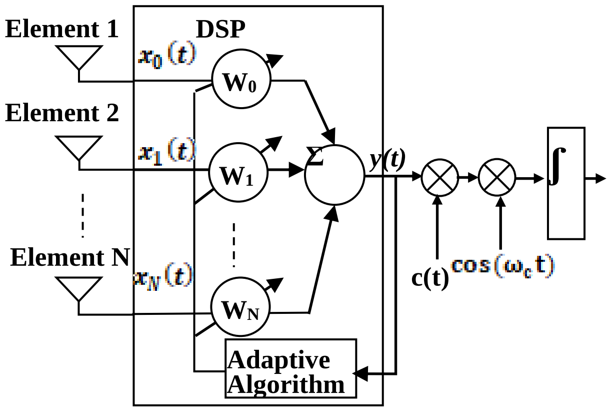

Figure (7)

Block Diagram of An Adaptive Array Used In CDMA System

The array output in Fig. 7 is given by:

$$y(t) = w^{T}x(t) \qquad (7)$$

where W^{T} denotes the complex conjugate transpose of the weight vector w.

The received signal x(t) contains the desired signal $S_d(t)$ with the interference signals $S_i(t)$ and can be given by:

$$x(t) = S_d(t)V_d(\theta) + S_i(t)V_i(\theta) + n(t) \qquad (8)$$

where n(t) denotes the noise, $V_d(\theta)$ denotes the steering vector of the desired signal and $V_i(\theta)$ denotes the steering vector of the interference signal and for UCCA is given by:

$$V(\theta) = \begin{bmatrix} e^{-j2\pi\frac{R}{\lambda}\sin\phi\cos\theta} \\ e^{-j2\pi\frac{R}{\lambda}\sin\phi\cos\left(\theta-\frac{2\pi}{N}\right)} \\ \cdot \\ \cdot \\ e^{-j2\pi\frac{R}{\lambda}\sin\phi\cos\left(\theta-\frac{2\pi(m-1)}{N}\right)} \end{bmatrix} \qquad (9)$$

VI. LCMV (Linearly Constrained Minimum Variance)

In this paper LCMV beamforming algorithm is adopted to compute the optimum weights. LCMV constraints the beamforming where the array elements choose their weights so as to minimize the filter's output variance or power subject to constraints to ensure signal preservation at the location of interest while minimizing the variance effects of signals originating from other locations.

In LCMV, the optimum weights are given by [13]:

$$w_{opt} = \frac{\gamma\, R_{xx}^{-1} V(\theta_0)}{V(\theta_0)^H R_{xx}^{-1}\, V(\theta_0)} \qquad (10)$$

where γ denotes Lagrange multiplier, $V(\theta_0)$ denotes the steering vector towards the desired signal (θ_0) and R_{xx} denotes the covariance matrix of x(t) which given by:

$$R_{xx} = x(t)x(t)^T \qquad (11)$$

VII. BER Evaluation

In this section, we consider the Standard Gaussian Approximation (SGA) of the noise and interference on the receiver output to evaluate the bit error rate (BER) performance for an asynchronous CDMA system with spreading factor (Nc) and perfect power control over a frequency selective multipath Rayleigh fading channel (L) with BPSK, adjacent cells interference (Mc), Rake receiver with Maximal Ratio Combiner having (M) number of fingers, convolutional code with code rate (r), Viterbi decoder and UCCA smart antenna with directivity (D) to perform SDMA. Considering perfect channel estimation then the BEP (Bit Error Probability) for SDMA /CDMA system is given by [2]:

$$BEP = \left(\frac{1-\mu_1}{2}\right)^M \sum_{j=0}^{M-1} \binom{M-1+j}{j} \left(\frac{1+\mu_1}{2}\right)^j \qquad (12)$$

where,

$$\mu_1 = \sqrt{\frac{1}{1 + \frac{N_0}{2rE_b} + \frac{2}{3DN_c}\left[\left(1 + \frac{M_c}{5}\right)LK - 1\right]}} \qquad (13)$$

Using Viterbi decoder, BER is given by:

$$BER \le \frac{d}{dN_p} T(D_p, N_p)\Big|_{N_p=1,\ D_p=2\sqrt{BEP(1-BEP)}} \qquad (14)$$

VIII. Simulation

In order to evaluate system performance and capacity, MATLAB 7.13 program is used to offer a near scenario for asynchronous reverse link CDMA system with beamforming. The parameters used in the simulation are shown in Table (I).

TABLE (1)
SIMULATION PARAMETERS

Simulation Parameters	Value
Number of users (k)	15
Bit duration (T_b)	1 ms
Code rate (r)	1/4
Carrier frequency (F_c)	1900 MHz
Gold code polynomials	[5 4 3 2 0], [5 2 0]
Chip duration (T_c)	31.25 µs
Spreading factor (N_c)	32
SNR	5 dB
Multipath (L)	3
Rake fingers (M)	3
Adjacent interfering cells(M_c)	1
No. of rings	5
No. of array elements in each ring	[8, 14, 20, 26, 32]
Distance between the elements (d)	0.5 λ
SOI (θ_0, Φ_0)	(30^o, 0^o)
SNOI (θ_i, Φ_i)	(-90^o, 0^o), (60^o,0^o), (0^o, 30^o)

IX. Simulation and theoretical results

A. The effect of channel coding and Rake receiver

Fig. (8) and Fig. (9) shows the effect of using Rake receiver and adding channel coding to the system. From Fig. (8) at BER=10^{-1}, the CDMA system without Rake receiver can support 5 users only. While it can support 35 users with Rake receiver and 45 users using Rake receiver and convolutional encoder with code rate r=1/4 and Viterbi decoder. From Fig. (9) at E_b/N_0=5 dB, the BER≈2*10^{-1} without using Rake receiver while BER≈4*10^{-2} using Rake receiver only and BER≈10^{-3} using Rake receiver and convolutional encoder with code rate r=1/4 and Viterbi decoder. This means that using Rake receiver and adding channel coding to the system improves the system capacity and performance.

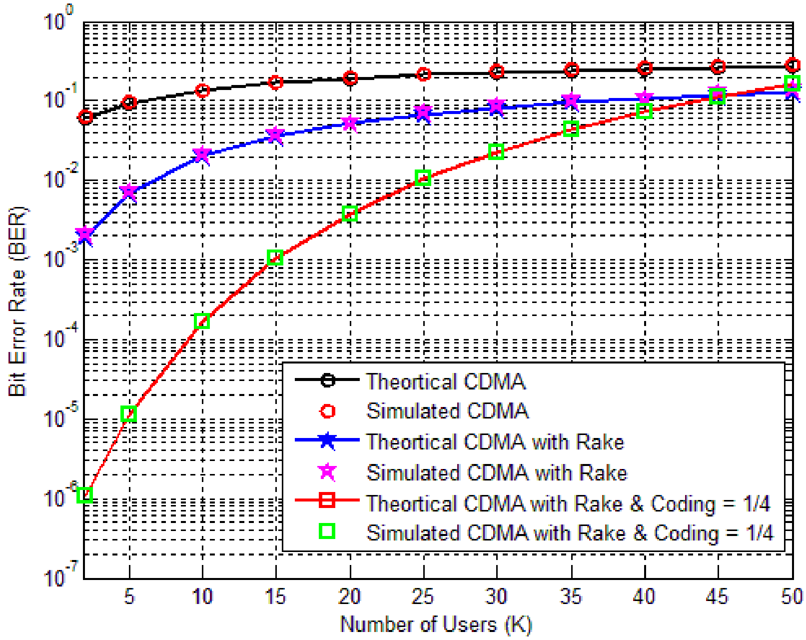

Figure (8)

Capacity with and without Rake receiver and coding

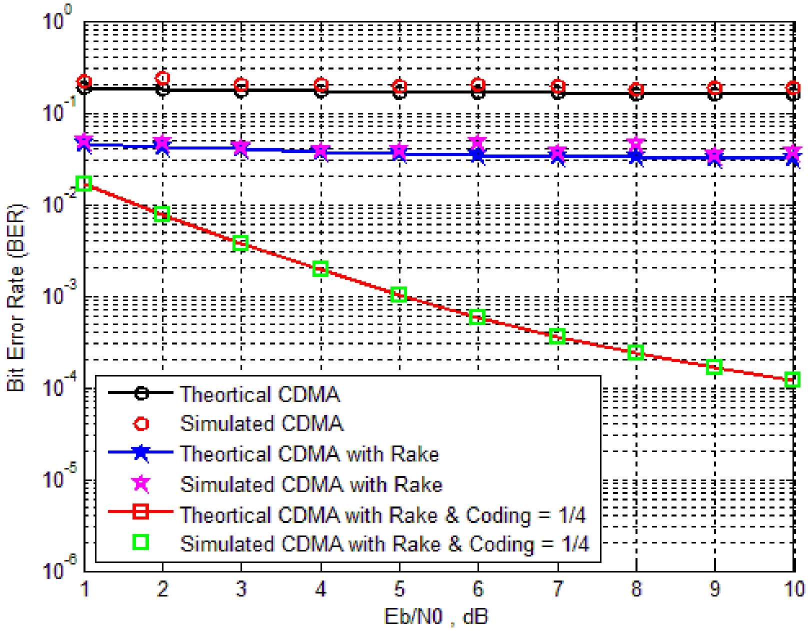

Figure (9)

BER performance with and without Rake receiver and coding

B. **Beamforming**

Fig. (10) shows the radiation pattern of UCCA smart antenna with directivity D=21.458 dB before and after LCMV beamforming, assuming that the DOA of the desired user is (30°, 0°) and (-90°, 0°), (60°, 0°), (0°, 30°) for the interferences.

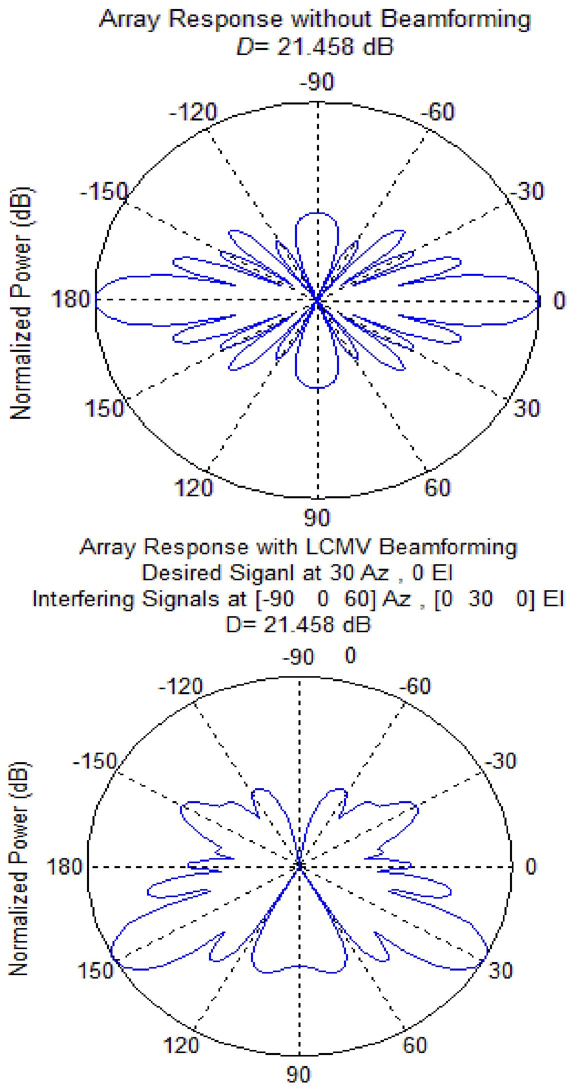

Figure (10)

LCMV beamforming

C. The effect of using SDMA-CDMA

In Fig. (11) at BER= $2*10^{-9}$, using Rake receiver and channel coding, CDMA system can support only one user while SDMA-CDMA system can support 95 users. Fig. (12) shows that at E_b/N_0=6dB, the BER decreases from ≈ 10^{-5} to ≈ 10^{-10} using SDMA technique. This means SDMA technique can improve the CDMA system capacity and performance using UCCA smart antenna at the mobile system base station.

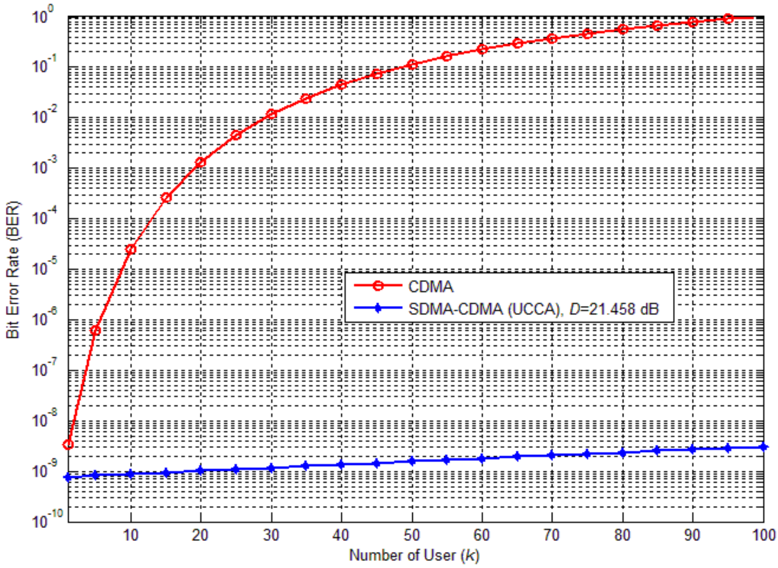

Figure (11)

Comparing capacity between CDMA and SDMA

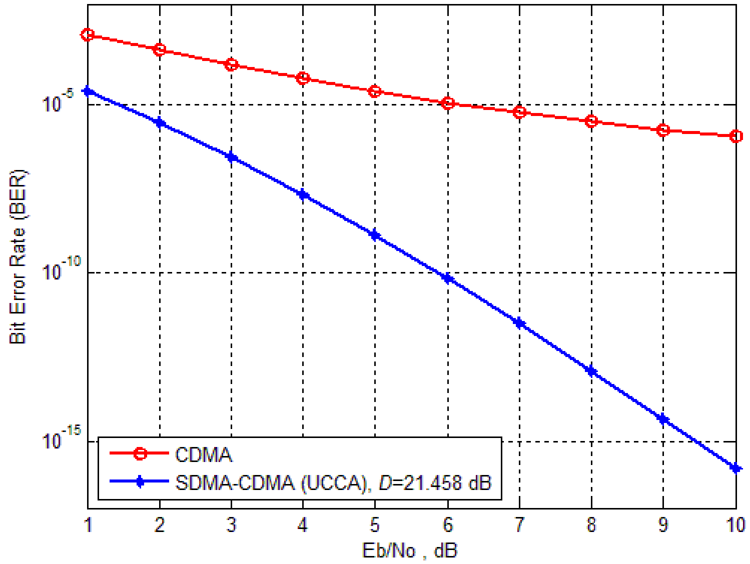

Figure (12)

Comparing performance between CDMA and SDMA

D. The effect of smart antenna directivity (D)

From Fig. (13) at BER=10^{-8}, increasing the directivity of the base station antenna from 3, 5 to 15 dB leads to increase in system capacity from 2, 5 to 45 users respectively. From Fig. (14) and at E_b/N_0=5 dB the system performance increases from BER≈$2*10^{-6}$, ≈10^{-7} to ≈10^{-9} respectively for the same directivity increments. This shows that introducing SDMA using directive smart antenna at the base station has a significant effect on system performance and capacity.

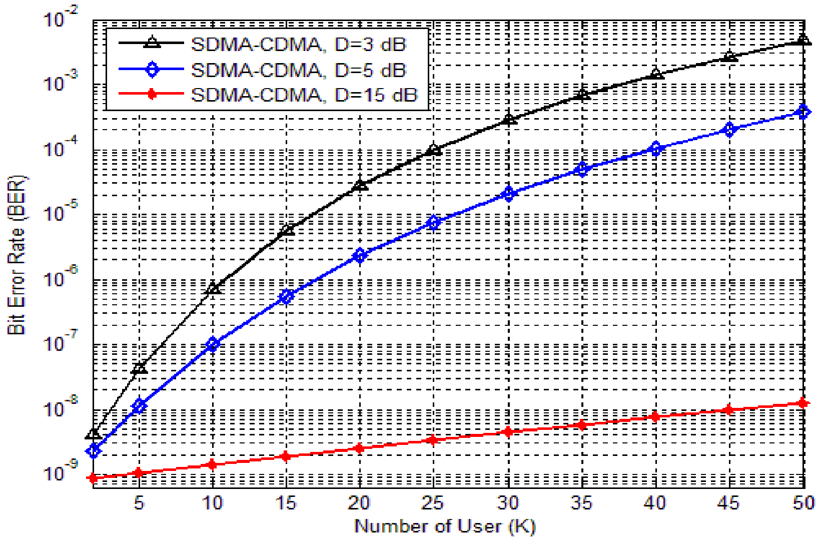

Figure (13)

Capacity as a function of Directivity (D)

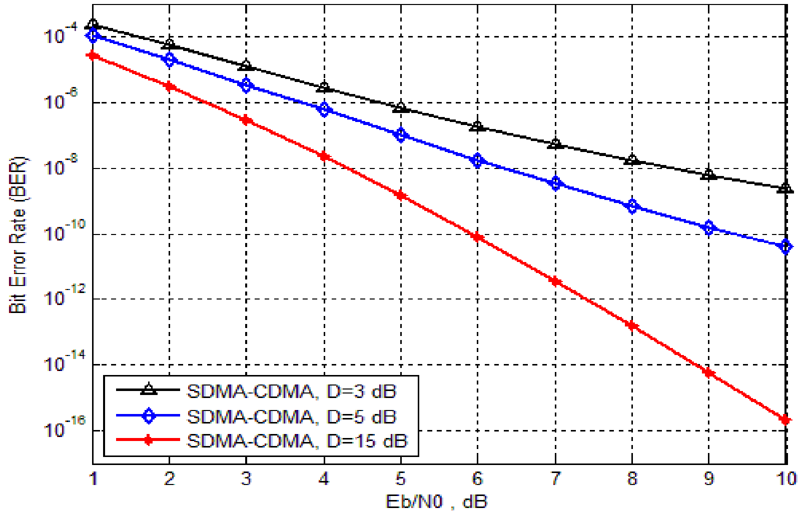

Figure (14)

BER performance as a function of Directivity (D)

X. Conclosion

Simulation supported by theoretical formulas has been used in this paper to evaluate capacity and performance of reverse link CDMA and SDMA-CDMA systems using smart antenna. The results show that at BER=10^{-1}, using Rake receiver increases system capacity from 5 to 35 users, and adding channel coding increases capacity to 45 users, also increases system performance at E_b/N_0=5 dB from BER≈$2*10^{-1}$ to ≈$4*10^{-2}$ using Rake receiver and to BER≈10^{-3} using channel coding. SDMA using smart antenna with LCMV beamforming algorithm can steer the radiation pattern of UCCA antenna towards the desired user and nulls towards the inferences which improves CDMA system capacity from 1 to 95 users at BER=$2*10^{-9}$, and improves performance from BER ≈10^{-5} to ≈10^{-10} at E_b/N_0=6 dB. At BER= 10^{-8}, increasing the directivity of the Base station antenna from 3 to 15 dB, leads to increase system capacity from 2 to 45 users and increase performance from BER≈$2*10^{-6}$ to ≈10^{-9} at E_b/N_0=5 dB. This improvement in system capacity and performance makes the system more complex and required more power.

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