PERFORMANCE ANALYSIS OF MC-DS-CDMA WIRELESS COMMUNICATIONS OVER RAYLEIGH FADING USING MAXIMAL RATIO COMBINING DIVERSITY TECHNIQUE

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Abstract

Multi carrier direct sequence code division multiple access (MC-DS-CDMA) becomes a promising technique to support multiple users with secured high speed wireless communications as it capable to improve the system performance by mitigating inter-symbol interference (ISI). In this paper, MC-DS-CDMA with binary phase shift modulation (BPSK) scheme over Rayleigh and AWGN fading channel has been studied. An analytical approach is developed to find out the expressions of signal to interference plus noise ratio (SINR) as well as BER with maximal ratio combining (MRC) in the presence of multi-access interference (MAI). The system performance are evaluated in terms of SINR and BER by varying number of multiple users, fading parameter, number of subcarriers using MATLAB simulation. It is found that, the system performance highly deteriorated due to multipath fading. Optimum value of system parameters and receiver diversity technique improves the system performance significantly.

Keywords: BPSK, SINR, Multi Access Interference, Bit Error Rate, MRC

Introduction

Multi carrier direct sequence CDMA is an attractive candidate for next generation high speed wireless communications, which have to be highly spectral efficient in order to support multi user access and meet the ever increasing demands, such as, high voice quality and bit rate, coverage, bandwidth and power efficiency, less effect of channel impairments, ability to be deployed in diverse environments, and so on. Multi access interference (MAI) and multipath fading severely affect the performance and degrade the quality of received signal. (Smida *et.al, 2007;* Elnoubi and Hashem, 2008;

Alamouti, 1998; Smida *et.al, 2010;* Sinha *et.al.*, 2010) MC-DS-CDMA is suitable for high data rate applications over frequency selective fading channel. The transmitted signal experiences both small-scale and large scale fading. Rayleigh fading can be considered as small scale fading since there are so many multiple reflective paths in environment and there is no line of sight between transmitter and receiver. (Sklar,1997) In the context of broadband wireless communication it has been reported that MC CDMA uses frequency domain and DS-CDMA uses time domain. But MC-DS-CDMA uses both time domain and frequency domain spreading codes that leads to several advantages over DS-CDMA. (Yang and Hanzo, 2003). The most important advantages of this technology is its robustness in case of multipath propagation, immunity to the dispersive channel, less peak-to-average power ratio (PAPR) and cancellation of interference effect efficiently. Because by introducing Orthogonal frequency division multiplexing (OFDM) technique with CDMA makes the system robust to frequency selectivity, helps the system utilizing the advantage of frequency diversity by spreading the signal across multiple subcarriers as well as increasing data transmission rate and achieving higher bandwidth efficiency. (Hanzo *et. al.*; 2004, Prasad, 2004; Chen *et. al.*, 1995; Faisal *et. al.*, 2012)

In (Yee *et. al.*, 1993), MC-CDMA has been proposed to combat severe indoor multipath effect. The more effective technique is MC-DS-CDMA over MC-CDMA has been proposed by Kondo and Milstein to suppress the partial band interference. (Kondo and Milstein, 1996) In (Simon and Alouini, 1999; Sundro and Konalavasa, 2012; Hashem *et. al.*, 2007), the MC-DS-CDMA system performance, in conjunction with MRC has been studied over Nakagami-m fading channel. Paul *et. al.* (2012) discussed the bit error rate analysis of MC DS CDMA wireless communication system with Rake receiver over Rayleigh fading channel considering Equal Gain Combining (EGC) diversity technique. Jayaraman and Pushpam (2013) analyzed the performance of this system considering both Rayleigh and Rician fading over AWGN channel using Alamoutis' Space Time Block Code (STBC) scheme. Several studies have been carried out on MC-DS-CDMA over Rayleigh fading channel with MRC receiver diversity considering Rake receiver (Smida *et. al.*, 2007; Gupta and Tiwari, 2011; Taher *et. al.*, 2013; Xu, and Milstein, 2001). The results showed that employing Rake structure at the receiving end dramatically improves the performance of MC system. MC-DS-CDMA has the capability of exploiting frequency diversity and mitigating the frequency-selective fading effect without the use of Rake receivers.

Accordingly, in this paper, an analytical approach has been carried out to determine the expression of SINR and BER in the presence of MAI and AWGN noises with MRC diversity. Moreover, BER performance of

MC-DS-CDMA wireless system is investigated over Rayleigh fading environment using multiple receiving antennas to determine optimum system parameters without Rake structure.

The rest of the paper is organized as follows. In section II, the system model is presented including transmitter model, channel model, and receiver model. An analytical expression of SINR, conditional BER and unconditional BER are presented in section III. In section IV, we present the explanations and results of the system performance and finally we conclude the work in section V.

System Model

A. Transmitter Model

Figure 1. Block Diagram of MC-DS-CDMA Transmitter

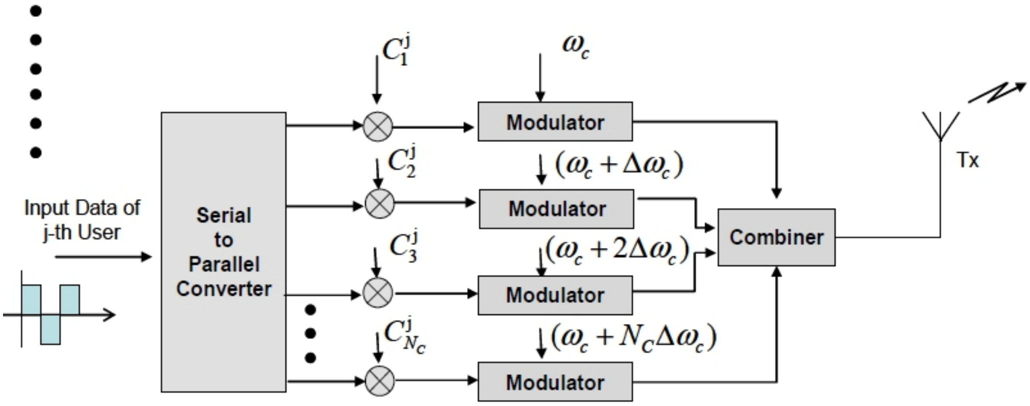

Figure 1 shows the transmitter block diagram of a MC-DS-CDMA system. In this model, input data stream of j-th user is converted into N_c parallel data path using serial to parallel (S-P) converter. The function of S-P converter is to reduce the subcarrier data rate by mapping the serial data to a number of reduced rate parallel streams. Due to S-P conversion, symbol duration at subcarrier level is N_c times of the bit duration. The data symbols at each parallel sequences are coded by a particular PN code with a chip duration of T_c. Then the coded data streams are modulated by N_c subcarriers. The bandwidth per subcarrier is $2/T_c$. Finally the modulated data streams are combined and transmitted through the transmitting antenna. In MC-DS-CDMA systems DS-based T-domain subcarrier spreading is invoked to increase the achievable processing gain associated with each subcarrier signal,while F-domain spreading across several subcarriers are employed to further increase the total attainable processing gain. The total processing gain is usually determined by the product of theT-domain and F-domain spreading factors (Yang and Hanzo, 2003).

For j-th user, the general expressions of BPSK modulated transmitted signal is given by:

$$S_T(t) = \sum_{k=1}^{N_c}\{\sqrt{2p}\,b_{n,k}^{j}(\sum_{x=1}^{N} C_{x,k}^{j})\cos(\omega_c t + k\Delta\omega + \phi_k)\} \quad (1)$$

Where, $b_{n,k}^{j}$=n-th bit of the j-th user which is being modulated by the k-th channel

$C_{x,k}^{j}$=x-th chip of the k-th section of the j-th users code.

P= Chip power of the user, N_c= Number of subcarrier channels, N=Number of chips of the code for each subcarrier channel, C^j= Code of the j-th user, $b_{n,k}^{j}$=n-th bit $m_j(t)$, $m_j(t)=\sum_{n=-\infty}^{\infty} b_n^j$, and b= ±1

B. Channel Model

The wireless communication channel is severely corrupted by multipath fading and unwanted signal namely Additive White Gaussian Noise (AWGN). Multipath propagation occurs when two or more radio signals follows different path and causes multipath fading. Diffraction, reflection and scattering add the additional phase shifts of the transmitted signal between the transmitter and receiver which results constructive and destructive interference. When there is no LOS (Line of Sight) between the transmitter and receiver, the Rayleigh fading channel is commonly applied. When AWGN noise is associated along the wireless channel the received signal cab expressed as follows;

$$y = \alpha x + n$$

Where n is AWGN with zero mean and unit variance, α is a Rayleigh fading parameter and x is the transmitted signal.

To modeling wireless channel impulse response can be written as

$$C^j(t) = \sum_{l=0}^{L-1} C_l^j P(t - lTc)$$

Where P is transmitted power per symbol, T_c is the chip duration of pseudo random noise (PN) code; C_l^j represents the$l$-th chip of the j-th code word.

C. Receiver Model

The receiver block diagram of j-th receiver MC DS CDMA system is shown in figure 2. The receiver is equipped with demodulator, parallel to serial converter for doing the reverse operation of the transmitter. In this model, we assume several antennas are employed at the receiver and finally all the outputs of the antennas are combined using maximal ratio combining.

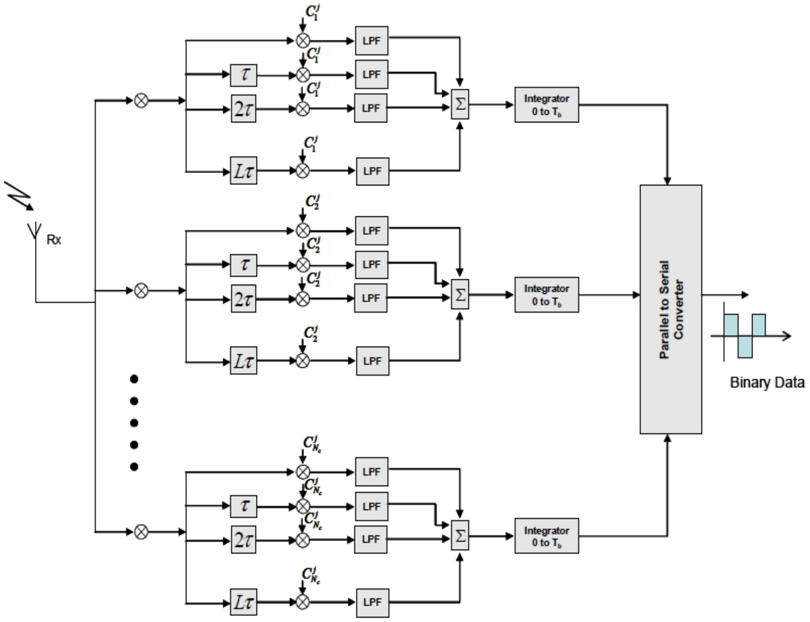

Figure 2. Block Diagram of MC DS-CDMA Receiver

The general expression of received signal for j-th user is as follows:

$r(t) = \sum_{m=1}^{J}[\sqrt{2P}\sum_{k=1}^{N_c} \{ b_{n,k}^{j} \ (\sum_{x=1}^{N} C_{x,k}^{j}) \ \cos(\omega_c t + k\Delta\omega + \phi_k)\} + n(t)]$ (2)

n(t)= Additive White Gaussian Noise (AWGN) noise signal

Theoretical Analysis

We assume N number of users in the system and perfect power control are employed. After necessary assumptions; the general expression of the received signal for j-th users takes the following form (Mallick and Majumder, 2008; Mark and Zhuang, 2003).

$$y(t) = \frac{Na\sqrt{2p}}{2T_b}\sum_{k=1}^{N_c} b_{n,k}^{j}\cos(\phi_k + \theta)\int_0^{T_b} dt + \sum_{m=1}^{j-1}[\frac{a\mu N\sqrt{2p}}{2T_b}\sum_{k=1}^{N_c}\{ b_{n,k}^{m}\cos(\phi_k + \theta) + \frac{1}{T_b}\int_0^{T_b}\sum_{k=1}^{N_c}\eta(t)\sum_{x=1}^{N} C_{x,k}^{j}\cos(\omega_c t + k\Delta\omega)\, dt \qquad (3)$$

or we get, $y(t)= y_j(t)+y_{MAI}(t)+ n(t)$ (4)

Where, $y_j(t)$ is the desired signal term, $y_{MAI}(t)$ is the multiple access interference term and $n(t)$ is a AWGN noise part.

The desired signal of the j-th user is $y_j(t)$ which is given as follows:

$$y_j(t)= Na\sqrt{P/2}\sum_{k=1}^{Nc} b_{n,k}^{j}\cos(\phi_k + \theta) \qquad (5)$$

Since, $b_{n,k}^{j} = \pm 1,\ \sum_{k=1}^{Nc} b_{n,k}^{j} = N_C$

Thus, the above term becomes, y_j(t)= $NN_c a\sqrt{P/2}\sum_{k=1}^{Nc} b_{n,k}^{j}\cos(\phi_k+\theta)$ (6)

So, for the j-th user, the desired signal power, P_s is given as

$$P_s = \frac{1}{2}a^2(\left(NN_c\sqrt{P/2})^2\right) = \frac{1}{4}(a^2N^2N_c^2P) \qquad (7)$$

Now, the MAI term can be written as

$$y_{MAI}(t) = \sum_{m=1}^{j-1}[\frac{aN\mu\sqrt{2P}}{2}\sum_{k=1}^{Nc} b_{n,k}^{m}\cos(\phi_k+\theta)] \qquad (8)$$

The interference power is given as follows

$$P_{MAI}(t) = \sum_{m=0}^{j-1}[\frac{1}{2}\alpha^2\mu^2N^2N_c^2\frac{P}{2}) = \sum_{m=0}^{j-1}[\frac{1}{4}\alpha^2\mu^2N^2N_c^2P)$$

$$= \frac{1}{4}\alpha^2\mu^2N^2N_c^2P(j\text{-}1) \qquad (9)$$

Now the AWGN noise part can be expressed as follows

$$n(t) = \frac{1}{T_b}\int_0^{T_b} w(t)\sum_{x=1}^{N} C_{x,k}^{j}\cos(\omega_c t + k\Delta\omega_c)\,dt \qquad (10)$$

Now, it can be evaluated that, the noise power is: $\sigma_n^2 = \frac{N_0}{4T_b}$, where $N_0 = KTR_b$ (11)

By using the equations of (7), (9), and (11),Signal to Interference and Noise Ratio(SINR) can be define as:

$$\text{SINR} = \frac{P_s}{P_{MAI}+\sigma_n^2}$$

$$= \frac{\frac{1}{4}a^2N^2N_c^2P}{\frac{1}{4}a^2\mu^2N^2N_c^2P(j-1)+\frac{N_0}{4T_b}} = \frac{a^2N^2N_c^2PT_b}{a^2\mu^2N^2N_c^2P(j-1)+N_0} \qquad (12)$$

Here, α is equal to 1 which means no fading & μ is varied.

Instantaneous (Conditional) Bit Error Rate (BER)= $\frac{1}{2}erfc[\frac{SINR}{\sqrt{2}}]$ (13)

Now, the average bit error rate of the system without rake can be obtained as follows:

$$P_b = \int_0^{\infty} P_b(\alpha)\times f(\alpha)d\alpha \qquad (14)$$

Here, $P_b(\alpha)$= Instantaneous BER

f(α) =Probability distribution function (*pdf*) of amplitude distortion co-efficient for Rayleigh fading

$$f_\alpha(x) = \frac{x}{\sigma_\alpha^2}exp^{(-x^2/2\sigma_\alpha^2)}$$

Here, σ_α^2 is amplitude variance.

The probability density function for Rayleigh fading is, $f_\gamma(x) = \frac{x^{L-1}exp(-x/\Gamma_c)}{(L-1)\Gamma_c^L}$, x≥0, The average SINR after combing each diversity channel is, $\Gamma_b = E[\gamma_k = L\Gamma_c$

Where $\Gamma_c = 2\sigma_\alpha^2$ E_b/N_0 is the average SINR per bit in each diversity channel. E_b is the energy per bit and L is the number of receiving antenna. γ_k follows a chi-square distribution with 2L degrees of freedom.

The further extension of Eq. (14) can be considered as an unconditional BER

$$P_b = \int_0^\infty P_{e|\,\gamma}(x) f_\gamma(x)dx \tag{15}$$

$$= [0.5(1-\mu)^L]\sum_{l=0}^{L-1}\binom{L-1+l}{l}[0.5(1+\mu)^l]$$

Here, $\mu = \sqrt{\frac{\Gamma_c}{1+\Gamma_c}}$,$P_{e|\,\gamma}(x) = Q(\sqrt{2x})$

Results and Discussions

According to the theoretical approach presented in section III, we investigate SINR and BER performance of MC DS CDMA wireless system by varying different system parameters. Results have evaluated numerically and compared to standard accepted BER 10^{-6}.

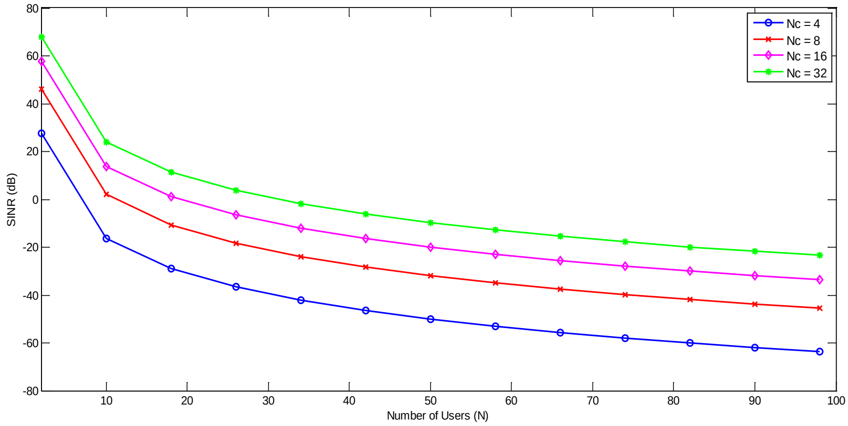

Figure 3. SINR (dB) vs number of users (N) varying number of sub-carriers (Nc)

The Figure 3 presents the SINR versus number of users varying number of subcarriers considering fading coefficient α = 1. The graph shows that with the increasing number of users SINR decreases. Besides, as the number of subcarriers increases the SINR performance is significantly improved.

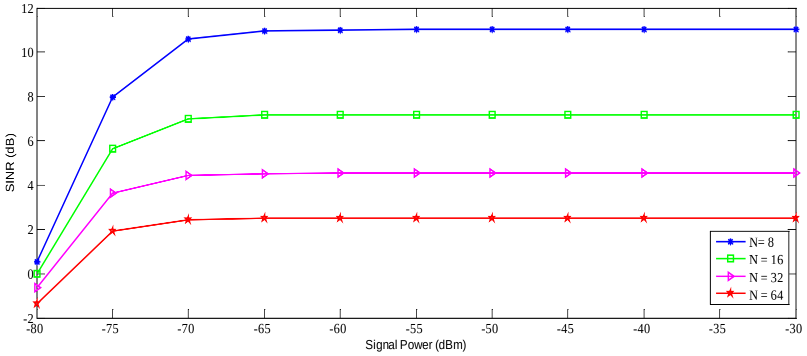

Figure 4. SINR vs signal power (dBm) varying number of users (N)

The plot of SINR vs. signal power by varying number of users with a fixed value of bandwidth = 10MHz, number of subcarriers = 20, fading parameter α = 0.8 are shown in figure 4. It is observed that there is an increment of SINR with the decreasing number of users for a given value of input power. The value of SINR is also almost constant when signal power increases above -70dBm.

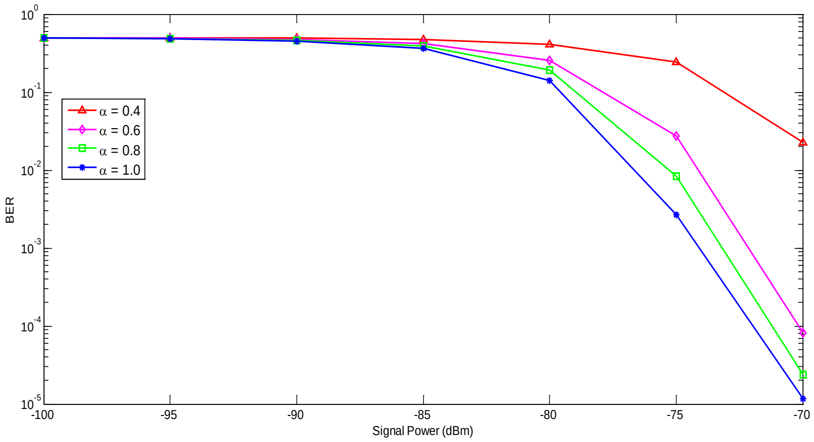

Figure 5. BER vs. signal power (dBm) varying fading parameter (α)

Figure 5 demonstrates the BER vs. signal power by varying fading parameter (α) for a fixed value of bandwidth 10 MHz, number of users, N= 16, number of subcarriers,N_c = 20. The figure depicts that BER performance is getting improved with the decrement of fading parameter and above -85dBm signal power, BER reduces drastically.

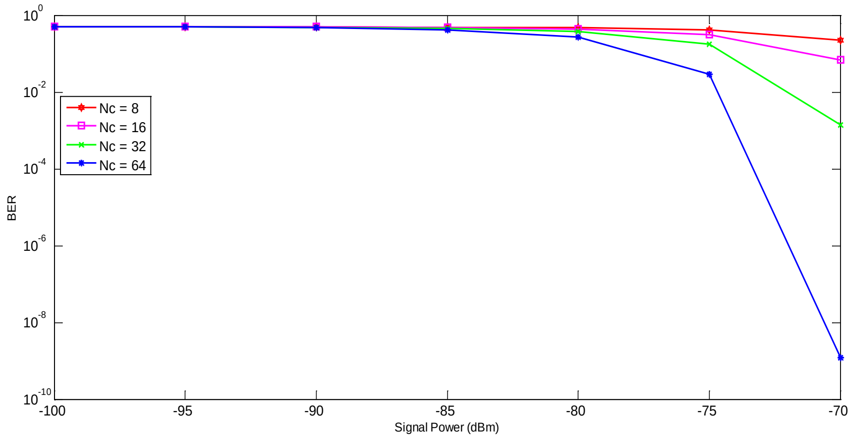

Figure 6. BER vs. signal power (dBm) varying number of subcarriers (Nc)

In figure 6, we present a graphical representation of BER vs. signal power by varying number of subcarriers. The plot shows that the desired BER is obtained when number of subcarriers is highest(i.e. N_c =64). Also the BER is significantly reduced as the input power increases sufficiently. So the BER is decreased with the increasing value of subcarriers.

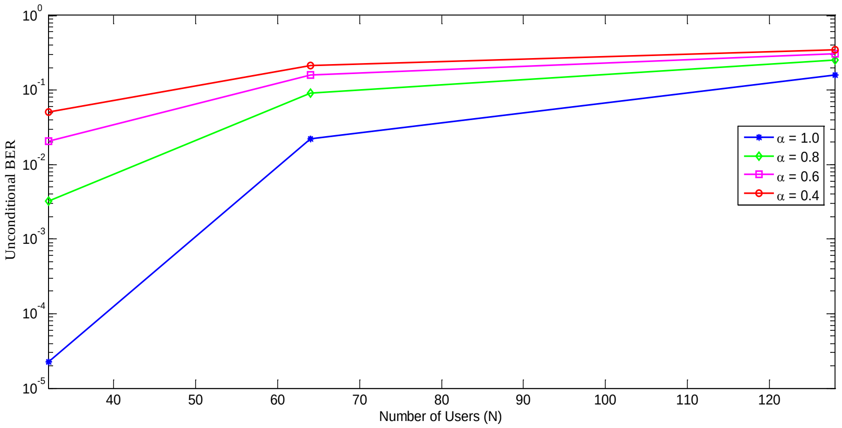

Figure 7. BER vs. number of users (N) varying fading parameter (α)

In figure 7, unconditional BER is plotted against number of users (N) by varying α for a fixed value of bandwidth 10MHz and 70 mW input power. It is found that, BER increases with the increment of both number of subscribers and fading coefficient. Therefore, a lower fading effect provides better system performance.

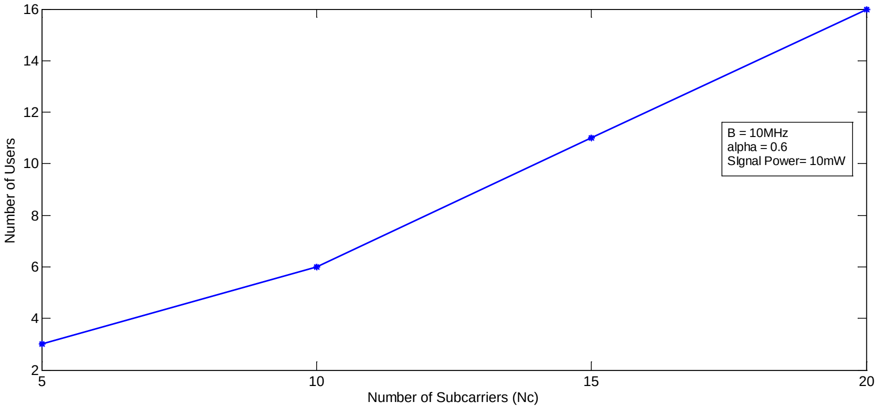

Figure 8. Number of users (N) vs. number of subcarriers (Nc) for a fixed BER=10^{-5}

In figure 8, the number of subscribers is plotted against the number of subcarriers. This graph is derived from the plot of unconditional BER vs. number of users varying number of subcarriers. The graph shows that a large number of subcarriers can support a large number of users.

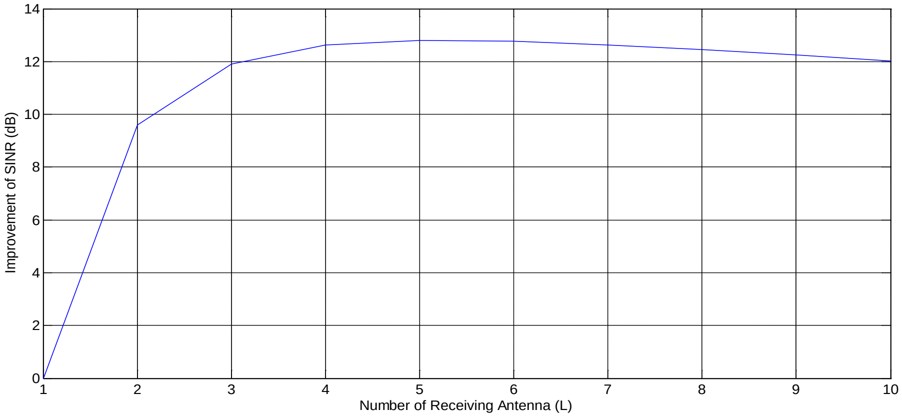

Figure 9. Improvement of SINR vs. number of receiving antennas (L)

Figure 9 demonstrates the improvement of receiver sensitivity by varying number of receiving antenna with maximal ratio combining diversity. The figure implies that receiver sensitivity can be substantially improved up to L=4. But this SINR improvement is almost unchanged as the number of receiving antenna is further increased. Thus optimum number of antennas should be used at the receiver to get better result and minimize the cost also.

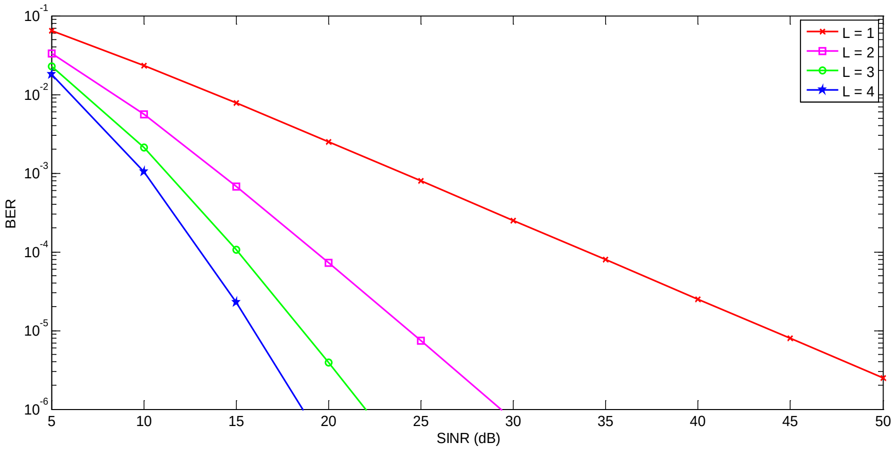

Figure 10. Unconditional BER vs. average SINR varying number of receiving antenna

In figure 10, unconditional BER is demonstrated against average SINR by varying the number of receiving antenna (L) for a fixed number of users (N) 128. The graph shows that BER performance is remarkably improved with the increased number of receiving antennas. This technique is analogous to single input multiple output (SIMO) and provides dramatically better performance than a single input single output (SISO) system. So it can be concluded that BER performance improvement can be achieved by using receive diversity with Maximal Ratio Combining (MRC) technique.

Conclusion

In this article, a general approach has been taken to evaluate the performance of MC-DS-CDMA system over Rayleigh fading with BPSK modulation scheme considering maximal ratio combining technique. We have investigated the results in terms of BER and SINR by varying different system parameters like number of users, number of subcarriers, fading coefficient and number of receiving antennas. Outcome of our investigation implies that the system performance can be severely suffered, when the number of users and fading effect is increased. It is also found that performance degradation of the system substantially improved by using higher number of subcarriers and optimum number of antennas at the receiver. In future we expect to extend our analysis with multiple input multiple output (MIMO) as a receive diversity and space time block code (STBC) as a transmit diversity incorporate with MC-DS-CDMA system with different fading models.

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