Bit Error Rate Analysis of a MIMO MC-CDMA System in the presence of Carrier Frequency Jitter under Rayleigh Fading Channel

A.K.M. Toriqullah, S.P. Majumder

Abstract— **Upcoming wireless services require ultra-high-speed data transmission. Future generation wireless communication systems can meet up the high data rate transmission demand through Multi-Carrier CDMA (MC-CDMA) technology. In this paper, we proposed a system model of MIMO MC-CDMA transmitter and MIMO MC-CDMA receiver model with the help of MRC technique at receiver side. Here, we derived the expressions of Signal to Noise plus Interference Ratio (SNIR) and Bit Error Rate (BER) considering frequency jitter with diversity under Rayleigh fading channel. The theoretical analysis is presented in terms of BER and SNIR to improve the receiver sensitivity concerning multiple antennas. The analytical expression demonstrates that numerical results are closely match simulation findings, and the receiver antenna diversity considerably improves the system performance.**

Keywords*— *MIMO, OFDM, MC-CDMA, SNIR, BER, INR Frequency Jitter.

I. INTRODUCTION

High data rate demand and capacity became challenging due to increased number of mobile users. It’s very challenging to accommodate huge number of traffic in limited bandwidth. MC-CDMA is a rising technology for next generation mobile communication that can solve higher spectrum demand [1]. [2] MC-CDMA is a hybrid technology that combines Orthogonal Frequency Division Multiplexing (OFDM) with Direct Sequence CDMA (DS-CDMA), allowing all users to simultaneously access the full frequency spectrum. Multipath fading, Inter Symbol Interference (ISI) and Multi-Access Interference (MAI) all contribute to the degradation of wireless communication channel performance [3]. These effects have high negative impression on BER performance which reduces the high speed data transmission. MC-CDMA systems reduce the frequency selective fading and ISI due to orthogonal spreading code of each subcarrier [3]. Orthogonality among subcarriers and ISI generated by timing jitter diminish the MC-DS-CDMA system's performance [4]. Orthogonality among the OFDM subcarriers is very important in the performance of a MC-DS-CDMA system using OFDM multicarrier modulation. The OFDM subcarriers lose orthogonality because of frequency offset caused by fading and Doppler offset. As a result, an OFDM link's performance is highly degraded [5]. Downlink MC-CDMA systems for Rayleigh fading channel already analyzed by author [6], where output found better. This paper is the extended version of [8] where authors had evaluated BER performance with frequency jitter by varying different system parameters such as Interference Noise Ratio (INR) and processing gain for a single antenna. [9] In research, the BER performance of MC-CDMA systems was explored and compared for several fading channels including Rayleigh, Rician, and Nakagami-m fading distribution. The authors investigate how the functionality of single-input and single-output (SISO) OFDM systems is affected when the number of subcarriers is increased. MIMO-OFDM environments are used to evaluate the performance of zero-forcing (ZF) and minimal mean square error (MMSE) [10].

In this paper, we present a theoretical approach of our proposed system which is developed to derive the equation for SNIR and average BER for MIMO MC-CDMA wireless communication with frequency jitter under Rayleigh fading channel. Results are evaluated in terms of BER considering different values of receiver sensitivity, different values of variance and frequency jitter.

The remainder of the work is structured as follows: Section II illustrates the MC-CDMA system model with multiple antenna, Section III includes analysis of MIMO MC-CDMA system, Section IV gives the simulation results from MATLAB and finally this paper is concluded in Section V.

II. SYSTEM MODEL

A. MIMO MC-CDMA Transmitter

MC-CDMA transmitter model is shown in Fig. 1. The input data stream b_i^j, are assumed to be serial binary data symbol which is converted into parallel data after passing through serial to parallel converter. It is distributed to L number of channels. The parallel data symbols are encoded using a unique code sequence with chip duration T_c and processing gain N_c. Thereafter, each data symbol is spread out parallelly over different subcarriers using a given spreading code in the frequency domain. The coded symbol of each subcarrier data is modulated by the carrier frequency of the relevant channel and then broadcast by the OFDM modulator.

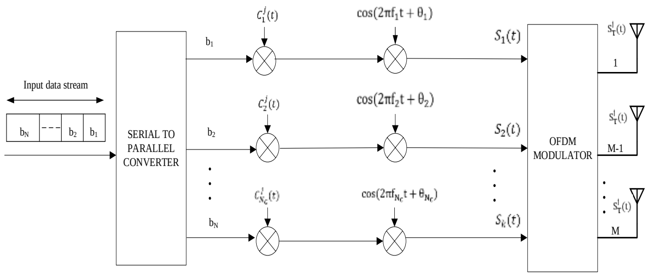

Fig. 1. Model of MIMO-MC-CDMA system

B. MIMO MC-CDMA Receiver

In Fig. 2, the MIMO-MC-CDMA receiver is shown as a block diagram. [8] where j^{th} user is shown. During data reception, the receiver of the j^{th} user receives all the signals transmitted by M number of antennas. The OFDM demodulator, integrators, and low pass filter (LPF) are the key components of the receiver block, and the output data symbol is combined using the Maximal Ratio Combining (MRC) technique.

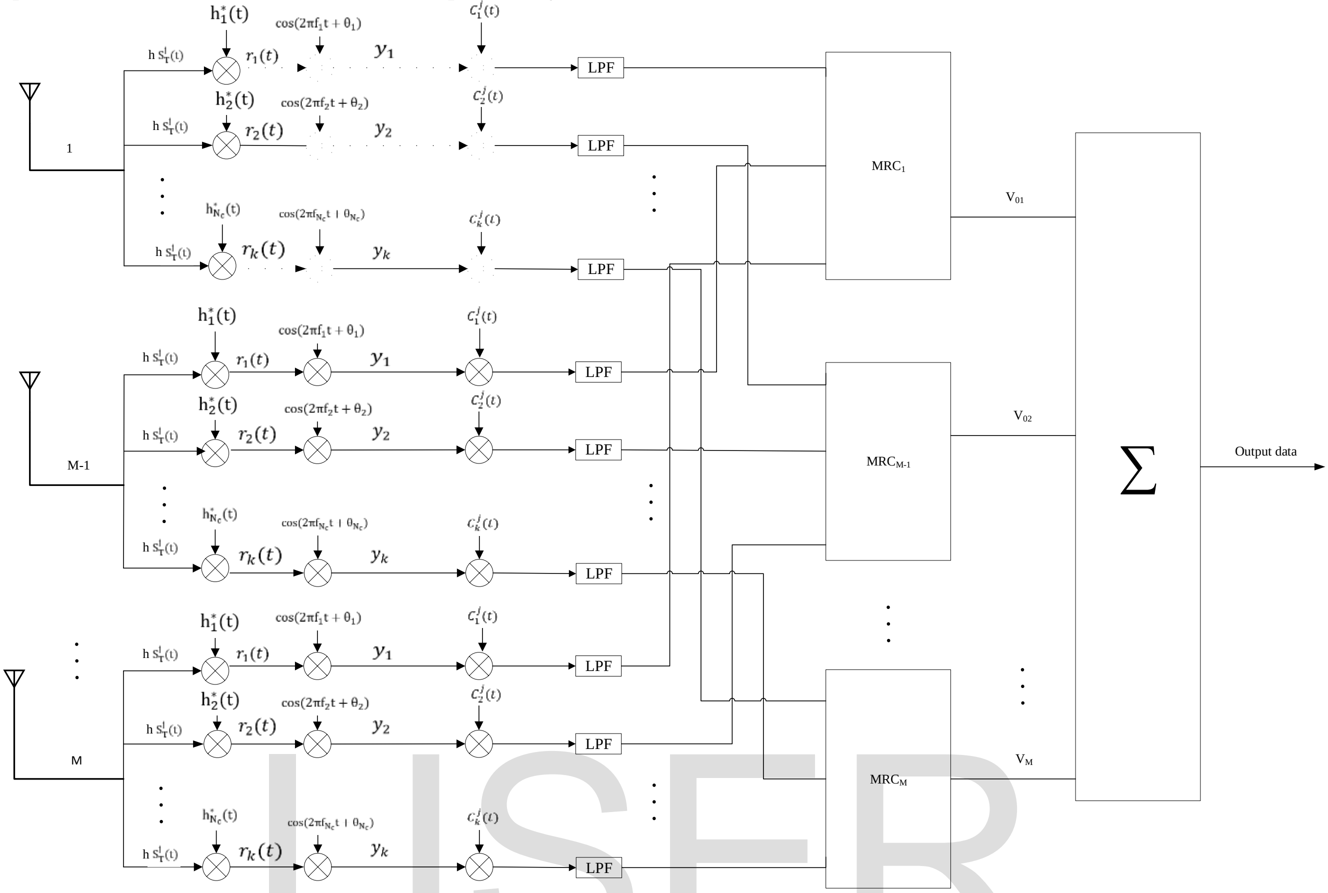

Fig. 2. System model of an MC-CDMA receiver with several receiving antennas [10].

III. ANALYSIS OF MIMO MC-CDMA SYSTEM

From Fig.1. the MC-CDMA transmitted signal can be written as after passing through OFDM modulated [7].

$$s_T^j(t) = \sum_{i=1}^{N} b_i^j c_i^j P(t - iT_s)\cos(w_i t + \theta_i) \qquad (1)$$

Where, b_i^j represents the j^{th} user's transmitted signal in the i^{th} sub channel modulated by $N = N_c$ sub-carrier, c_i^j represents the j^{th} user code, and i = [1 2... N] shows the number of sub-carriers in the system.

Receiver Analysis for MIMO MC-CDMA

A total of M antennas on the receiving side are considered in the proposed model. Each of them is equipped with a coherent receiver with N branching paths. The receiver of the j^{th} user receives all of the MC-CDMA transmitter's signals user. As a result, the equation for the received signal is:

$$r_i^j(t) = h^j s_T^j(t) + n(t) \qquad (2)$$

$$r(t) = \sum_{j=1}^{M}\sum_{i=1}^{N} h_{i,j}^*(t) b_i^j c_i^j P(t - iT_s)\cos(w_i t + \theta_i) + n_i(t) \qquad (3)$$

Where, j=1:M

Consequently, the SNIR for a multi-user MIMO MC-CDMA system may be stated as,

$$\mathrm{SNIR} = \frac{[\frac{P_r}{2} b^j \sum_{i=1}^{M} |h_i^j(t) c_i^j|^2 \times \frac{1}{2}\cos(\Delta f T)]^2}{\sigma_{MAI}^2 + \sigma_n^2} \qquad (4)$$

After simplified the equation (4)

$$\mathrm{SNIR}(\Delta f) = \frac{P_r^2}{4}\gamma(\Delta f)\cos^2(\Delta\theta) \qquad (5)$$

Where, the resultant SNIR is indicated by the symbol,

$$\gamma(\Delta f) = \sum_i^M \mathrm{SNIR}_i^j \qquad (6)$$

$$\gamma(\Delta f) = \frac{[\frac{P_r}{2} b^j \sum_{i=1}^{M} |h_i^j(t) c_i^j|^2 \times \frac{1}{4}\cos(\Delta f T)]^2}{1+\xi} \qquad (7)$$

The probability density function (pdf) for the Rayleigh fading distribution can be expressed as follows:

$$P(\gamma, \Delta f) = \frac{\gamma^{M-1} e^{-\frac{\gamma(\Delta f)}{\Gamma c}}}{(M-1)!\,\Gamma c^{M-1}} \qquad (8)$$

$$\text{Where, } \Gamma c = 2\sigma_n^2 \frac{E_b/N_0}{1+\xi} \qquad (9)$$

In the BPSK modulated system, the conditional BER is described by the formula:

$$\mathrm{BER}(\gamma, \Delta f) = 0.5\,\mathrm{erfc}\left[\frac{\sqrt{\Gamma c\,\gamma(\Delta f)}}{\sqrt{2}}\right] \times \cos(\Delta\theta) \qquad (10)$$

Either average BER or conditional BER can be written

$$\mathrm{BER}(\Delta f) = \int_0^\infty \mathrm{BER}(\gamma, \Delta f) P(\gamma, \Delta f)\,d\gamma \qquad (11)$$

$$\mathrm{BER}(\Delta f) = \int_0^\infty 0.5\,\mathrm{erfc}\left[\frac{\sqrt{\Gamma c\,\gamma(\Delta f)}}{\sqrt{2}}\right] \times \cos(\Delta\theta)\,\frac{\gamma^{M-1} e^{-\frac{\gamma(\Delta f)}{\Gamma c}}}{(M-1)!\,\Gamma c^{M-1}}\,d\gamma \tag{12}$$

IV. NUMERICAL RESULTS AND DISCUSSION

It is shown here how the suggested MIMO MC-CDMA system performs in the face of carrier frequency jitter in a theoretical study and simulation. Multiple antenna MC-CDMA transmission is used to generate the numerical results, which use BPSK modulation. Matlab is used to assess the performance of MIMO MC-CDMA under Rayleigh fading channel conditions with frequency jitter. The BER analysis and receiver sensitivity have been calculated for MIMO MC-CDMA wireless network using Rayleigh fading environment.

In Fig. 3. definite improvement of SNR while increasing number of antennas and Rx sensitivity improvement with respect to multiple antennas at 10^{-10} (BER) is observed.

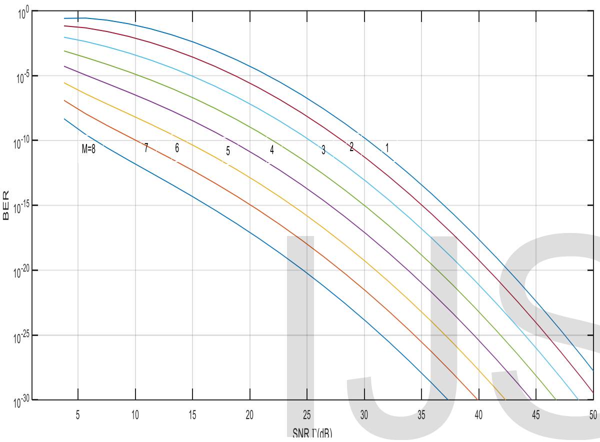

Fig. 3. BER vs Gamma, Γc (SNR) for Multiple Antennas considering Variance=1 and Δf=0.

The Fig. 4. indicates that with the increasing the value of Variance, BER decreases therefore performance of the system is improved.

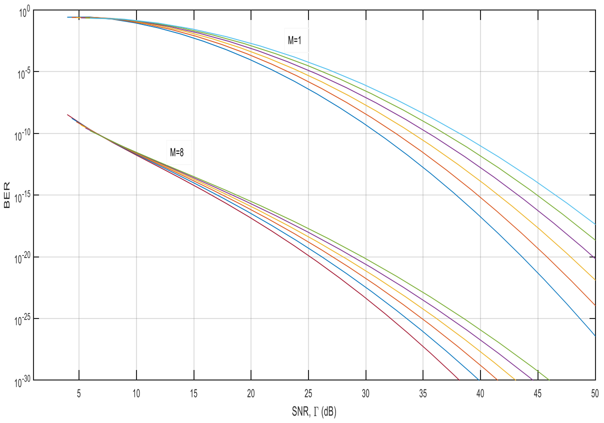

Fig. 4. BER vs Gamma, Γc (SNR) for Multiple Antennas considering different Variance.

The following Fig. 5. illustrates the BER performance against system noise where allowable user considered as Zeta, ξ = .01, .06, 0.1, 0.16, 0.5 and 1.5. In the above figure it is shown that with the increase of allowable users, noise to interference ratio decreased and finally system performance improved.

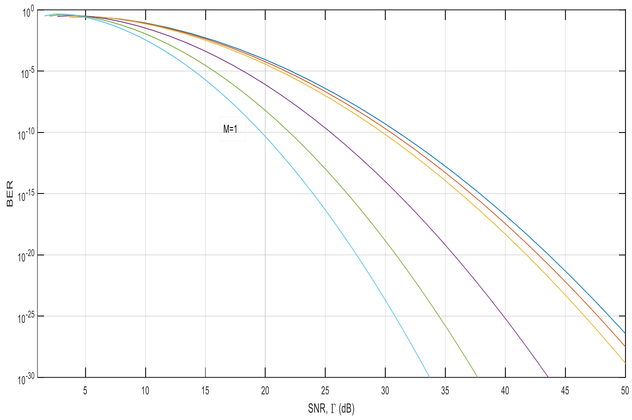

Fig. 5. BER vs Gamma, Γc (SNR) for Multiple Antennas considering different INR.

Finally, in the above figure it is indicated that due to frequency jitter Receiver Sensitivity is also changed for multi-receiver antennas.

After analyzing the above figure for multiple antenna, we determined the receiver sensitivity for our proposed system as follows:

Table I. Receiver sensitivity for different variance.

Antennas	1	2	3	4	5	6	7	8
Rx Sensitivity (dB) σ_n^2=1.0	36	33	29	25.4	21	16	10.5	6.7
Rx Sensitivity (dB) σ_n^2=1.5	31	28	26	22	18	14	10	7

It is observed from Fig. 6 the Receiver Sensitivity changed due to frequency jitter.

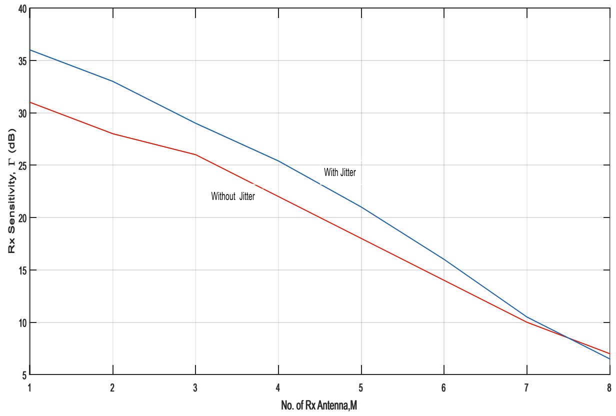

Fig. 6. Rx Sensitivity vs Number of Antennas for Multiple Antennas with and without frequency jitter.

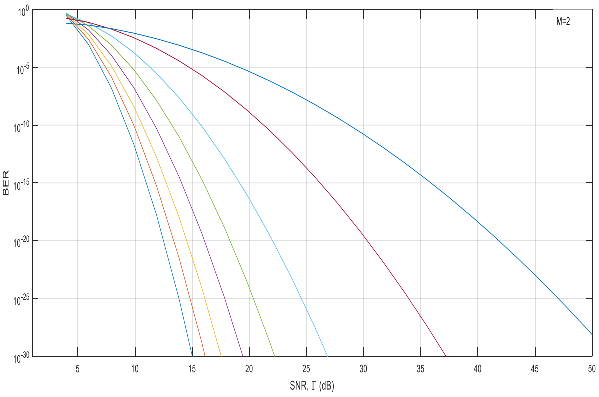

Fig. 7. BER vs Γ (SNR) two receiving Antennas considering different fading variance.

Fig. 7. shows that higher fading variance reduced the receiver noise thereby increasing system performance for eight antennas. We analyzed BER for different antennas to find the power penalty for the system performance as shown below:

Table II. Power Penalty at BER=10^{-10}

M=1	σ_n^2	0.1	0.2	0.4	0.6	0.8	1	1.2	1.4
	PP (dB)	31	22	16	14	13	12	11	9
M=2	σ_n^2	0.1	0.2	0.4	0.6	0.8	1	1.2	1.4
	PP (dB)	29	21	15	13	12	11	10	8
M=5	σ_n^2	0.1	0.2	0.4	0.6	0.8	1	1.2	1.4
	PP (dB)	19	15	13	12	10	9	8	7
M=8	σ_n^2	0.1	0.2	0.4	0.6	0.8	1	1.2	1.4
	PP (dB)	7	6.8	6.5	6	5.5	5	4.5	4

Fig. 8. illustrates the variation of Power Penalty with different fading variance.

The curves plotted for .1, .2, .4, .6, .8, 1, 1.2, and 1.4 fading variance respectively for multiple antennas. It is found that Power Penalty is 31 dB when single antenna is used. On the other hand, it became 7 dB once 8 antennas were used.

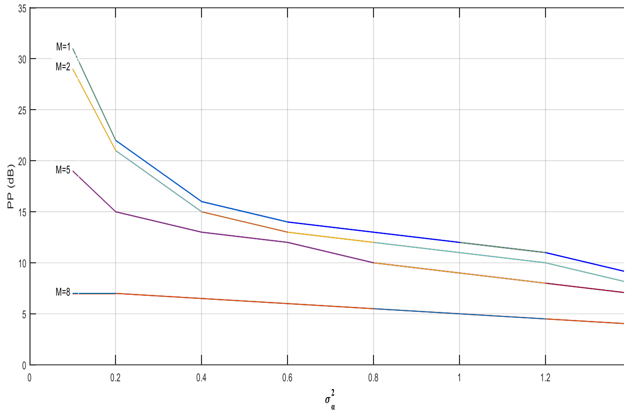

Fig. 8. PP (dB) vs σ_n^2 for BER 10^{-10} considering different fading variance.

V. CONCLUSION

The mathematical equation is deduced to find the system performance in terms of BER of MIMO MC-CDMA wireless communication considering frequency jitter. In this paper, performance of MIMO MC-CDMA communication system is analyzed using Rayleigh fading environment with diversity. The average BER findings show that a different and unique receiver design has resulted in a marked increase in BER performance. It is also observed that frequency jitter causes the variation in system SNIR and BER performance. Receiver sensitivity is also degraded due to frequency jitter. However, the introduction of multiple antennas at the receiver side improves the receiver sensitivity and optimum power penalty is also observed for multiple antennas. It is found that the theoretical analysis for the suggested system is closely matched to the simulation findings in terms of accuracy.

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