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Performance Analysis of MIMO SFBC CI-COFDM System against the Nonlinear Distortion and Narrowband Interference

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Abstract – Carrier Interferometry Coded Orthogonal Frequency Division Multiplexing (CI-COFDM) system has been widely studied in multi-carrier communication system. The CI-COFDM system spreads each coded information symbol across all N sub-carriers using orthogonal CI spreading codes. The CI-COFDM system shows the advantages of Peak to Average Power Ratio (PAPR) reduction, frequency diversity and coding gain without any loss of communication throughput. On the other side, a great attention has been devoted to Multi Input Multi Output (MIMO) antenna systems and space-time-frequency processing. In this paper, we focus on two Transmit (Tx)/one Receive (Rx) antennas configuration and evaluate the performance of MIMO OFDM, MIMO CI-OFDM and MIMO CI-COFDM systems. Space Frequency Block Coding (SFBC) is applied to MIMO OFDM, MIMO CI-ODFM and MIMO CI-COFDM systems. For CI-COFDM realization, digital implemented CI-COFDM is used in which information conventional is encoded, CI code spreading operation and carrier allocation are processed by IFFT type operation. From simulation results, it is shown that MIMO SFBC CI-COFDM reduces PAPR significantly as compared with that of MIMO SFBC CI-OFDM and MIMO SFBC OFDM systems. In Narrow Band Interference (NBI) channel MIMO SFBC CI-COFDM systems achieve considerable Bit Error Rate (BER) improvement compared with MMO SFBC CI-OFDM and MIMO SFBC OFDM system.

Keywords- COFDM, CI, PAPR, MIMO, SFBC.

I.INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) technique has been adopted as the standards in the several high data rate applications, for example, European DAB/DVB (Digital Audio and Video Broadcasting) system and high-rate WLAN (Wireless Local Area Networks) such as IEEE802.11x and HIPERLAN II. OFDM system transmits information data by many sub-carriers, where sub-carriers are orthogonal to each other and sub-channels are overlapped so that the spectrum efficiency may be enhanced. OFDM can easily be implemented by the Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform(FFT) process in digital domain, and has the property of high-speed broadband transmission and robustness to multi-path interference, frequency selective fading. However, OFDM signal has high PAPR because of the superimposition of multi- carrier signals with large number of sub-carriers. The high PAPR makes the signal more sensitive to the nonlinearities of the HPA and result in signal distortion when the peak power exceeds the dynamic range of the amplifier. To transmit the high PAPR signal without distortion requires more expensive.

Recently, a new kind of technique called CI-COFDM has been widely studied [1-4, 9]. In the CI-COFDM technique, each coded information symbol is sent simultaneously over all carriers and the each carrier for the symbol is assigned a corresponding orthogonal CI spreading code. This CI/COFDM system not only can reduce PAPR significantly problem but also achieve coding gain and frequency diversity gains without any loss in throughput.

Besides, a great deal attention has been devoted to MIMO antenna array systems and space-time-frequency processing [5-7]. MIMO diversity technique which exists diversity gain and coding gain can resolve the high link budget problem in the high data rate transmission, especially in the multi-path fading channel Besides, the space-time-frequency processing, especially Alamouti's diversity technique offers significant increase in performance at a low decoding complexity. Alamouti's Space-Time Block Coding (STBC) method is very efficient when delay spread is big or channel's time variation is very small during the coded continuous OFDM symbols and OFDM sub carrier number is small. On the other hand, when Doppler spread is big or channel's time variation is large and channel is non frequency selective, the inter-sub carrier's channel frequency response is nearly constant in the OFDM system with many sub carriers, the SFBC method is more efficient for the high quality transmission.

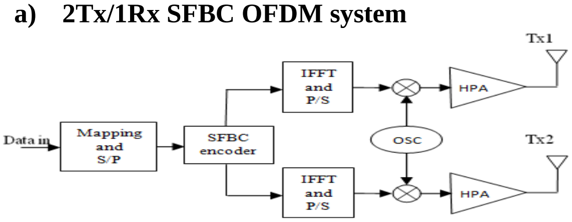
In recent times, some studies in the area of CI-OFDM system with MIMO have been performed [8-10]. There, STBC method is applied in some algorithms, and, MIMO CI-COFDM system is utilized to compensate the BER penalty caused by Doppler frequency or frequency selective fading.

In this paper, we focus on two Tx / one Rx antenna and two Tx/ two Rx antenna configurations, we evaluate the performance of MIMO OFDM, MIMO CI-OFDM and MIMO CI-COFDM system on the basis of MIMO technique theoretical analysis when HPA nonlinearity or NBI are included. SFBC coding is applied in MIMO OFDM, MIMO CI-OFDM and MIMO CI-COFDM systems. For CI-COFDM realization, digital implemented CI-COFDM is used in which information is coded by conventional encoder and CI code spreading operation and carrier allocation are separately processed by simple IFFT type operation [11]. As a result, MIMO CI-COFDM system outperforms MIMO SFBC OFDM and MIMO SFBC CI-COFDM systems significantly in the existence of both HPA nonlinearity and NBI.

II.SYSTEM DESCRIPTION

In this paper, SFBC transmit diversity technique is applied into the OFDM system. Simply, the 2Tx/1Rx and 2Tx/2Rx antenna configuration are considered to compare the system performance of the MIMO OFDM and MIMO CI-COFDM system. First, we discuss the traditional MIMO SFBC OFDM structure with 2Tx/1Rx and 2Tx/2Rx antenna.

a) 2Tx/1Rx SFBC OFDM system



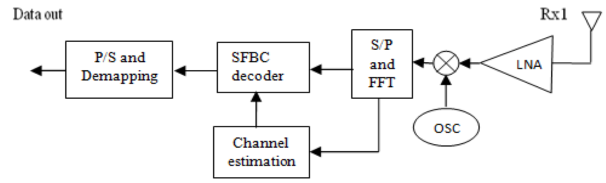


Fig.1. MIMO SFBC OFDM transceiver diagram with 2x1 diversity.

When 2 Tx antennas and 1 Rx antenna are considered, assuming the system transmits data symbols $X_0, X_1,\ldots,X_k,X_{k+1},\ldots,X_{N-1}$ on carriers $0,1,\ldots,k,k+1,\ldots,N-1$, respectively, the encoding algorithm is

$$\begin{array}{c} \\ f_k \\ f_{k+1} \end{array} \begin{array}{c} Tx1 \quad\quad Tx2 \\ \begin{bmatrix} X_k & X_{k+1} \\ -X_{k+1}^* & X_k^* \end{bmatrix} \end{array}$$

Channel coefficients between the Tx1, Tx2 antenna and Rx1 antenna is H^1, H^2 respectively

Received signals at the Rx1antenna is R_k ,R_{k+1} for k^{th}, $(k+1)^{th}$ carriers respectively.

So, received signal in frequency domain is as follows

$$R=\begin{bmatrix} R_k \\ R_{k+1}^* \end{bmatrix}=HX+N=\begin{bmatrix} H_k^1 & H_k^2 \\ H_{k+1}^{2\ *} & -H_{k+1}^{1\ *} \end{bmatrix}\begin{bmatrix} X_k \\ X_{k+1} \end{bmatrix}+\begin{bmatrix} N_k \\ N_{k+1}^* \end{bmatrix}$$

(1)

Let's assume that adjacent two carriers have same channel characteristic, such as

$$H_k^1 = H_{k+1}^1 = H^1, H_k^2 = H_{k+1}^2 = H^2.$$

Then, decoding algorithm is as follows

$$\hat{R} = \begin{bmatrix} \hat{R}_k \\ \hat{R}_{k+1} \end{bmatrix} = H^H R = \begin{bmatrix} H^{1^*} & H^2 \\ H^{2^*} & -H^1 \end{bmatrix}\begin{bmatrix} R_k \\ R_{k+1}^* \end{bmatrix}$$

$$= \left(\left|H^1\right|^2 + \left|H^2\right|^2\right).\begin{bmatrix} X_k \\ X_{k+1} \end{bmatrix} + \begin{bmatrix} \tilde{N}_k \\ \tilde{N}_{k+1} \end{bmatrix} \quad (2)$$

where H^H means the conjugate transpose of H ,and

$$\begin{bmatrix} \tilde{N}_k \\ \tilde{N}_{k+1} \end{bmatrix} = \begin{bmatrix} H^{1^*} & H^2 \\ H^{2^*} & -H^1 \end{bmatrix} \begin{bmatrix} N_k \\ N^*_{k+1} \end{bmatrix} \qquad (3)$$

b) 2Tx/2Rx SFBC OFDM system

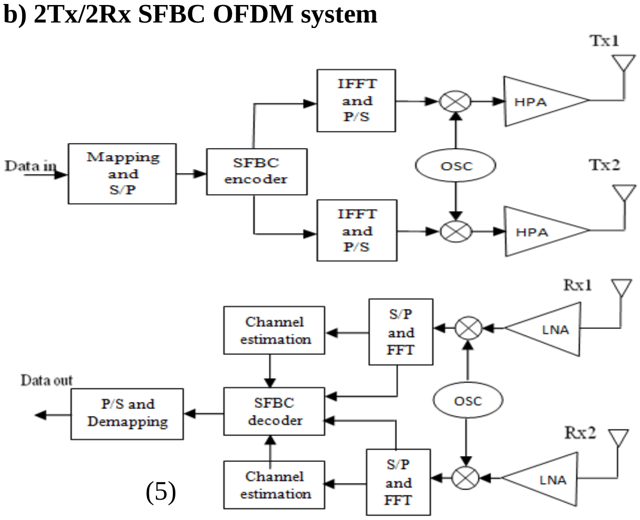


Fig.2. MIMO SFBC OFDM transceiver diagram with 2x2 diversity.

Channel coefficients between the Tx1, Tx2 antenna and Rx1 antenna is H^{11}, H^{21} respectively, and Tx1, Tx2 antenna and Rx2 antenna is H^{12}, H^{22} respectively.

Received signals at the two Rx antennas are defined as

	Rx antenna1	Rx antenna2
k^{th} carrier	R_k^1	R_k^2
$k+1^{th}$ carrier	R_{k+1}^1	R_{k+1}^2

So, received signals in frequency domain are expressed as follows.

$$R = \begin{bmatrix} R_k^1 \\ R^{1^*}_{k+1} \\ R_k^2 \\ R^{2^*}_{k+1} \end{bmatrix} = HX + N = \begin{bmatrix} H_k^{11} & H_k^{21} \\ H_{k+1}^{21\,*} & -H_{k+1}^{11\,*} \\ H_k^{12} & H_k^{22} \\ H_{k+1}^{22\,*} & -H_{k+1}^{12\,*} \end{bmatrix} \begin{bmatrix} X_k \\ X_{k+1} \end{bmatrix} + \begin{bmatrix} N_k^1 \\ N_{k+1}^{1\,*} \\ N_{k+1}^2 \\ N_{k+1}^{2\,*} \end{bmatrix}$$

(4)

Let's assume that adjacent two carriers have same channel characteristic, such as

$$H_k^{11} = H_{k+1}^{11} = H^{11}, H_k^{12} = H_{k+1}^{12} = H^{12},$$

$$H_k^{22} = H_{k+1}^{22} = H^{22}, H_k^{21} = H_{k+1}^{21} = H^{21}.$$

Then decoding algorithm is as follows

$$\hat{R} = \begin{bmatrix} \hat{R}_k \\ \hat{R}_{k+1} \end{bmatrix} = H^H R = \begin{bmatrix} H^{11^*} & H^{21} & H^{12^*} & H^{22} \\ H^{21^*} & -H^{11} & H^{22^*} & -H^{12} \end{bmatrix} \begin{bmatrix} R_k^1 \\ R^{1^*}_{k+1} \\ R_k^2 \\ R^{2^*}_{k+1} \end{bmatrix}$$

$$= (\left|H^{11}\right|^2 + \left|H^{22}\right|^2 + \left|H^{12}\right|^2 + \left|H^{21}\right|^2) \begin{bmatrix} X_k \\ X_{k+1} \end{bmatrix} + \begin{bmatrix} \tilde{N}_k \\ \tilde{N}_{k+1} \end{bmatrix}$$

(5)

where

$$\begin{bmatrix} \tilde{N}_k \\ \tilde{N}_{k+1} \end{bmatrix} = \begin{bmatrix} H^{11^*} & H^{21} & H^{12^*} & H^{22} \\ H^{21^*} & -H^{11} & H^{22^*} & -H^{12} \end{bmatrix} \begin{bmatrix} N_k^1 \\ N^{1^*}_{k+1} \\ N_k^2 \\ N^{2^*}_{k+1} \end{bmatrix}$$

(6)

III.MIMO SFBC CI-COFDM

In MIMO SFBC CI-COFDM system, at the transmitter the incoming bits are channel coded with interleaver and mapped into transmitted data symbols corresponding to arbitrary modulation such as 16QAM. In the CI spreading process can be expressed as follows

$$C_i(t) = \sum_{k=0}^{N-1} e^{j2\pi k\Delta f t} . e^{jk\Delta\theta_i}$$

$$\Delta\theta_i = \frac{2\pi}{N} i, \qquad i = 0,1,....N-1. \qquad (7)$$

where N is the total number of subcarriers Δf means the carrier spacing and $\Delta\theta_i$ is the assigned base spreading phase offset for the i th parallel data. Here, for general expression, we define CI spreading sequence series for the i th parallel data as

$$[c_i] = \{c_i^0, c_i^1, ..., c_i^{N-1}\} = \left\{e^{j\frac{2\pi}{N}i.0}, e^{j\frac{2\pi}{N}i.1}, ..., e^{j\frac{2\pi}{N}i.(N-1)}\right\}$$
(8)

Before passing through nonlinear HPA, the l^{th} Tx antenna signal for one entire MIMO SFBC CI-COFDM symbol is as:

$$S^l(t) = \sum_{k=0}^{N-1}\sum_{i=0}^{N-1} x_k^l . e^{j2\pi k\Delta f t} . e^{jk\Delta\theta_i} . e^{j2\pi f_c t} . p(t)$$
$$= e^{j2\pi f_c t} . \sum_{k=0}^{N-1} s_k^l e^{j2\pi k\Delta f t}$$
(9)

where, x_k^l is time domain SFBC coded data on the k^{th} carrier and l^{th} Tx antenna, f_c is the center frequency and $p(t)$ is the pulse shaping for the bit duration T_b. We define $\sum_{i=0}^{N-1} x_i^l . e^{jk\Delta\theta_i}$ as s_k^l

In the MIMO SFBC CI-COFDM receiver side, the r^{th} Rx received signal can be expressed as:

$$R^r(t) = e^{j2\pi f_c t} \cdot \sum_{l=1}^{L}\sum_{k=0}^{N-1} h_k^{lr} . s_k^l . e^{j2\pi k\Delta f t} + n^{lr}(t)$$
$$= e^{j2\pi f_c t} \cdot \sum_{l=1}^{L}\sum_{k=0}^{N-1} \alpha_k^{lr} . s_k^l . e^{j2\pi k\Delta f t} . e^{j\phi_k^{lr}} + n^{lr}(t)$$
$$= \sum_{l=1}^{L}\sum_{k=0}^{N-1}\sum_{i=0}^{N-1} \alpha_k^{lr} x_k^l . e^{j2\pi k\Delta f t} e^{jk\Delta\theta_i} . e^{j2\pi f_c t} e^{j\phi_k^{lr}} . + n^{lr}(t)$$
(10)

where L indicates number of transmit antennas and here we consider L=2. $R^r(t)$ is the r^{th} Rx antenna received signal, h_k^{lr} is the time domain response of the k^{th} carrier from l^{th} Tx antenna to r^{th} Rx antenna when channel is frequency selective fading channel, α_k^{lr} and ϕ_k^{lr} are the fade parameter and phase offset of h_k^{lr} respectively, and $n^{lr}(t)$ is the Additive White Gaussian Noise (AWGN) with power spectral density $N_0/2$ from l^{th} Tx antenna r^{th} Rx antenna.

The above received signal is separated into its N orthogonal sub-carriers through FFT process. After channel state estimation assuming the channel responses are known or can be estimated accurately at the receiver, each symbol stream's phase offset due to spreading is removed from each carrier by CI codes despreading. The obtained vectors from each carrier are then combined by certain combining strategy. The combining strategy is employed to help restore orthogonality between symbol streams, minimizing interference and maximizing frequency diversity benefits. In the fading channel, Minimum Mean-Square Error Combining (MMSEC) can be used to minimize inter-symbol- interference from other spreading codes and noise [1, 8].Finally, the received data samples are deinterleaved and are given to the decision device which uses hard decision Viterbi Algorithm (VA).

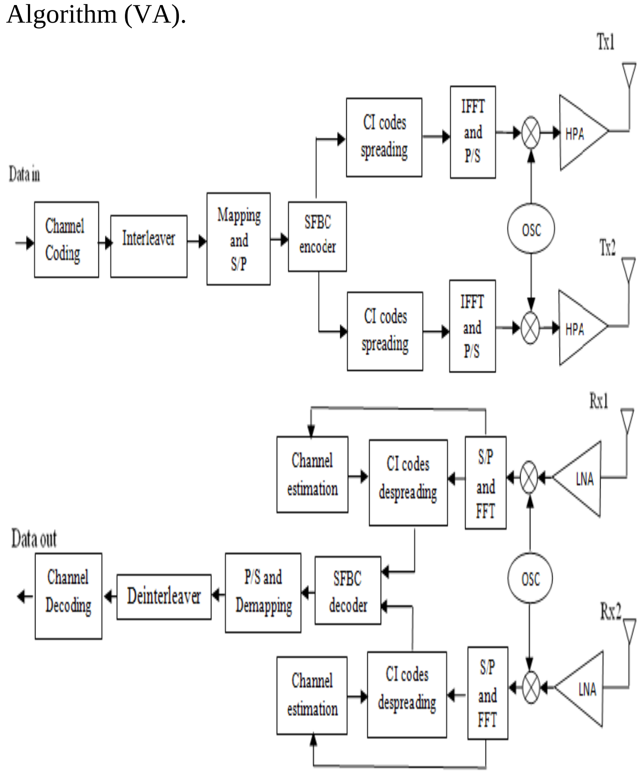


Fig.3. MIMO SFBC CI-COFDM transceiver diagram with 2x2 diversity

IV.PEAK to AVERAGE POWER RATIO

In the case of two transmit antennas, each of N dimensional OFDM symbol is transmitted from Tx1 and Tx2 antenna respectively. Generally, PAPR of the transmitted OFDM signal is defined as

$$PAPR^{l} \equiv \frac{\max_{0 \le t < T} \left| S^{l}(t) \right|^{2}}{E\left[\left| S^{l}(t) \right|^{2} \right]}$$

(11) $E[\bullet]$

where l means the transmit antenna number and means expectation operation.

To show statistical characteristics of PAPR, we use Complementary Cumulative Distribution Function (CCDF), which is the probability that PAPR of OFDM signal exceeds a certain threshold $PAPR_0$. The CCDF is defined as

$$\begin{aligned} CCDF &= \Pr(PAPR^{l} > PAPR_{0}) \\ &= 1 - \Pr(PAPR^{l} \le PAPR_{0}) \\ &= 1 - \prod_{n=1}^{N} \left[1 - \exp\left(-PAPR_{0} \times \frac{P_{avg}^{l}}{P_{n}^{l}} \right) \right] \end{aligned}$$

(12)

where P_n^l is the average sample power of l^{th} transmit antenna signal, $P_{avg}^{l} = (1/T)\int_{0}^{T} \left| S^{l}(t) \right|^{2} dt$ is the average power of l^{th} transmit antenna signal. We define the observed CCDF of MIMO transmitter as

$$CCDF = \max_{0 < l \le L} \left(CCDF^{l} \right) \qquad (13)$$

Table 1: Simulation Parameters

Modulation/Detection	16QAM/Coherent detection
FFT size(N)	1024
Number of sub carriers	1024
Guard intervals	256
Forward error correction	Convolution coding and viterbi decoding
Coding rate(R)	1/2
Constraint length(K)	7

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V. PERFORMANCE ANALISES and DISCUSSION

In order to compare the transmission performance in the MIMO SFBC OFDM, MIMO SFBC CI-OFDM and MIMO SFBC CI-COFDM system, we evaluate the PAPR and BER of MIMO SFBC OFDM, MIMO SFBC CI-OFDM and MIMO SFBC CI-COFDM when Solid State Power Amplifier (SSPA) is used as each transmitter's HPA or NBI is inserted to the data carriers. In the present work, 2Tx-1Rx and 2Tx-2Rx MIMO schemes are considered. HPA with certain backoff such as 2, 3 and 6. Total number of sub-carrier interrupted by NBI is defined as p and p=8, besides, JSR of NBI is 0dB or 1dB considered. The whole evaluation consider with single path between the each Tx and Rx antenna and simulation parameters are given in Table 1.

Fig.4 compare the CCDF of the PAPR for MIMO SFBC OFDM, MIMO SFBC CI-OFDM and MIMO SFBC CI-COFDM.As shown in Fig.4 MIMO SFBC CI-COFDM system 0.5dB and 1.5dB PAPR gains at 10^{-1} over MIMO SFBC CI-OFDM and MIMO SFBC OFDM when total subcarriers number is 1024 and modulation of 16QAM

Fig.5 shows BER performances of MIMO SFBC based OFDM, CI-OFDM and CI-COFDM when SSPA with backoff 2 is considered as the transmitter HPA. As seen in Fig.5, 12.5dB and 8dB SNR are required at 10^{-4} of BER in the 2Tx-1Rx SFBC CI-COFDM and 2Tx-2Rx SFBC CI-COFDM system respectively, but 10^{-4} of BER are achieved at SNR of 16.5dB in 2Tx-1Rx SFBC CI-OFDM and 13dB in 2Tx-2Rx SFBC CI-OFDM, but in both MIMO SFBC OFDM even if SNR of 30dB error floors occurs with BER of 10^{-2}

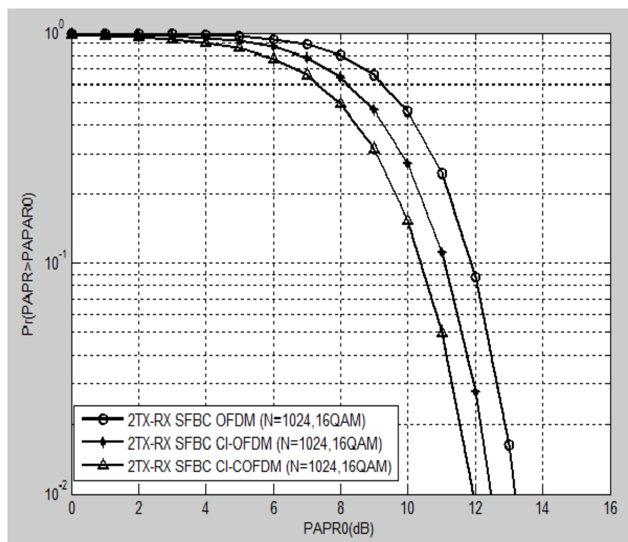

Fig.4. PAPR in MIMO SFBC OFDM, MIMO SFBC CI-OFDM and MIMO SFBC CI-COFDM (N=1024, 16QAM).

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Fig.6 is shows the BER vs Eb/N0 plot for MIMO

SFBC based OFDM, CI-OFDM and CI-COFDM when SSPA with certain backoff is considered as transmitter HPA. As seen in Fig.6 when backoff 6 and 3 are supposed respectively in 2Tx-1Rx SFBC CI-COFDM and 2Tx-2Rx SFBC CI-COFDM system, SSPA nonlinearity is almost compensated completely. In 2Tx-1Rx SFBC CI-COFDM outperforms a 2Tx-1Rx SFBC CI-OFDM and 2Tx-1Rx SFBC OFDM system by 5dB and 5.5dB respectively at BER of 10^{-4}, and in 2Tx-2Rx SFBC CI-COFDM system gains 7dB compare with 2Tx-2Rx SFBC CI-OFDM system, but in 2Tx-2Rx SFBC OFDM system even if SNR of 30dB error floors occurs with BER of 10^{-2}.

Fig.7 is shows the BER vs Eb/N0 plot for MIMO SFBC based OFDM, CI-OFDM and CI-COFDM when NBI is inserted to data carriers. As seen in Fig.7 MIMO SFBC CI-COFDM system compensates all the NBI affect when p is equal to 8 and JSR is 0 or 1 respectively. In SFBC based 2Tx-1Rx CI-COFDM gains 2.5dB over 2Tx-1Rx CI-OFDM at BER of 10^{-4}. In 2Tx-2Rx CI-COFDM gains 2.5dB over 2Tx-2Rx CI-OFDM at BER of 10^{-4}, but in both MIMO SFBC OFDM systems even if SNR of 30dB error floors occurs with BER of 10^{-3}

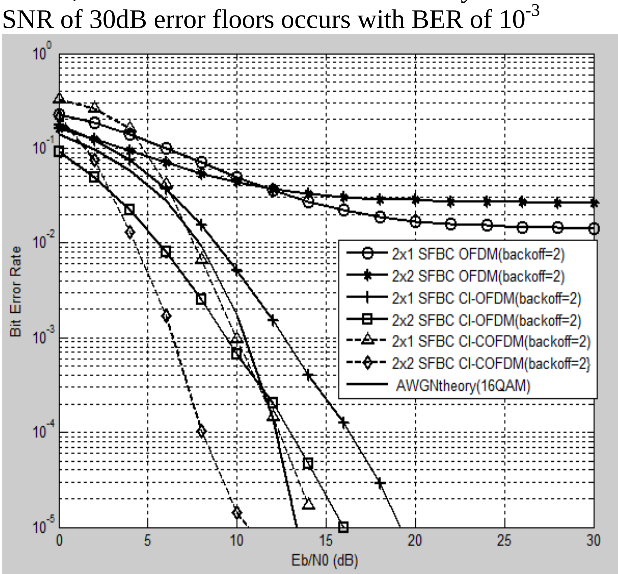

Fig.5. BER performance of MIMO SFBC OFDM, MIMO SFBC CI-OFDM and MIMO SFBC CI-COFDM with SSPA (N=1024, 16QAM).

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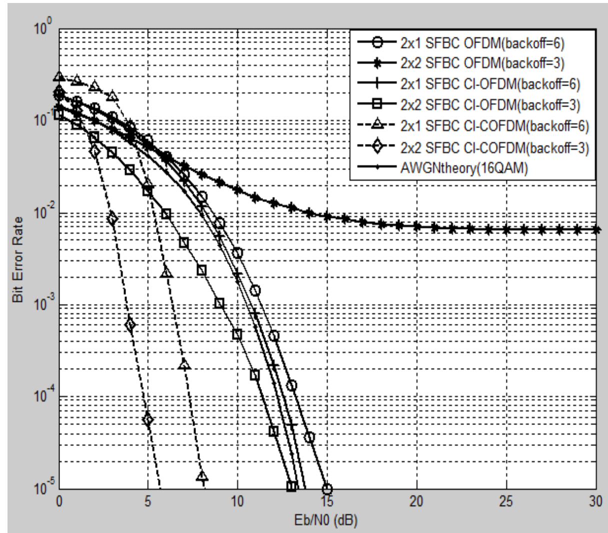

Fig.6. BER performance of MIMO SFBC OFDM, MIMO SFBC CI-OFDM and MIMO SFBC CI-COFDM when SSPA back-off=6 or 3 (N=1024, 16QAM).

Fig.8 is shows the BER vs Eb/N0 plot for MIMO SFBC based OFDM, CI-OFDM and CI-COFDM when SSPA with backoff 2 is considered as the transmitter HPA and also NBI is inserted to data carriers. As seen in Fig.8 in SFBC based 2Tx-1Rx CI-COFDM and 2Tx-2Rx CI-COFDM required 8.5dB and 5.5dB respectively at BER of 10^{-4}, but in 2Tx-1Rx SFBC CI-OFDM and 2Tx-2Rx SFBC CI-OFDM even if SNR of 30dB error floors occurs with BER of 10^{-4}, and in both MIMO SFBC OFDM systems even if SNR of 30dB error floors occurs with BER of 10^{-2}.

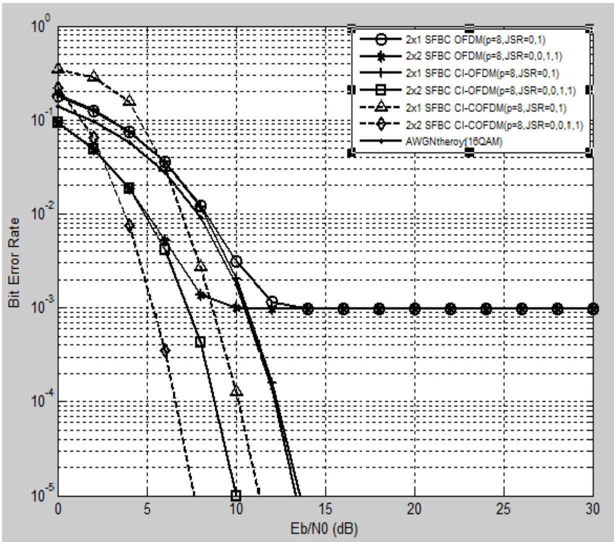

Fig.7. BER performance MIMO SFBC OFDM, MIMO SFBC CI-OFDM and MIMO SFBC CI-OFDM with NBI (N=1024, 16QAM).

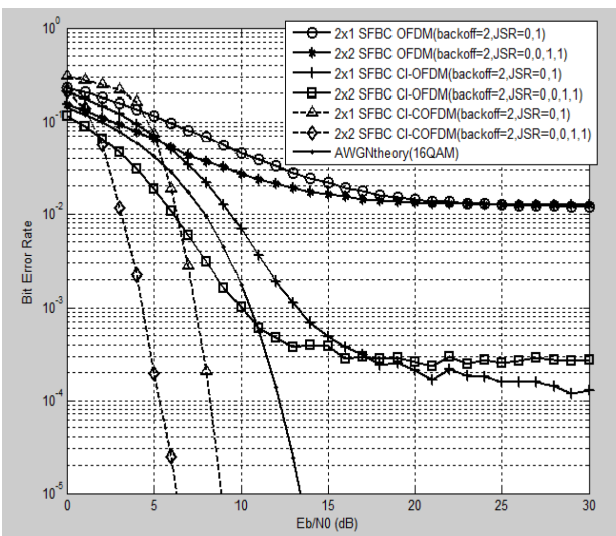

Fig.8. BER performance of MIMO SFBC OFDM, MIMO SFBC CI-OFDM and MIMO SFBC CI-COFDM with SSPA and NBI (p=8, N=1024, 16QAM).

VI. CONCLUSION

In this paper, we focused on the two Tx / one Rx antenna and two Tx / two Rx antenna configurations, we evaluate the performance of MIMO SFBC OFDM, MIMO SFBC CI-OFDM and MIMO SFBC CI-COFDM systems when HPA nonlinearity or NBI are existed. From the simulation result MIMO SFBC CI-COFDM system outperforms MIMO SFBC CI-OFDM and MIMO SFBC OFDM significantly when systems interrupted by the HPA nonlinearity or NBI. Therefore, the MIMO SFBC CI-COFDM method can be further applicable to the any kinds of MIMO type multi-carrier communication systems with many sub carriers.

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