Performance Analysis of SFBC-OFDM System with Frequency Domain Equalization

Mohammad Aftab Alam Khan, Mehwash Farooqui, Ishan Budhiraja

Abstract - In modern wireless communication systems, Multiple Input Multiple Output (MIMO)-Orthogonal Frequency Division Multiplexing (OFDM) techniques have become popular. This system has potential to meet high data rate requirements and high performance over various challenging channels that may be time selective and frequency selective. MIMO-OFDM system exploits the space and frequency diversity simultaneously to improve the performance of system. The popular approach to combine the space time codes and OFDM system is SFBC-OFDM. In this paper, Space-Frequency block coding for MIMO-OFDM along with different equalizers is investigated. Bit Error Rate (BER) performance analysis is presented using different equalizers and then optimum equalization method is suggested.

Index Terms - MIMO-OFDM system, Space-Frequency Block Coding, (SFBC), BER.

1 Introduction

THE rapidly expanding demand of multimedia services and growth of internet related contents require high data rate transmission and better quality of service. To achieve high data rate, the system has to overcome problems such as multipath fading and interference [1]. Multiple input multiple output (MIMO) system can mitigate the multipath fading, increases the system capacity, improves the interference performance and transmission reliability [2]. The key advantage of employing multiple antennas is to get reliable performance through diversity and the achievable higher data rate through spatial multiplexing.

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.

On combining the advantages of space-time coding and OFDM is attractive in wireless system designs [3, 4]. This involves coding across space and frequency, which is often referred to as space-frequency coding (SFC). A way to do space-frequency coding is to take the space-time codes (e.g., Alamouti code [5]), and apply them in the frequency dimension instead of time dimension [6]. That is, instead of mounting the space-time coded symbols on multiple time slots, they are mounted on multiple OFDM subcarriers. SFBC provides high order diversity gain, which helps to enhance the transmission data rate without requiring the bandwidth expansion. A space-frequency block coded (SFBC) OFDM scheme which uses Alamouti code in the frequency dimension is defined in [7] for high mobility broadband wireless access.

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2 System Model

In Space frequency (SF) scheme, the coding is performed across the antennas and OFDM sub-channels. SF coding can be realized by applying the Alamouti code over two adjacent sub-channels in one OFDM block as shown in Table-1.

TABLE-1

SF Coding for Two Transmit Antenna

	OFDM Sub-Channel	
	K	**L**
Tx-1	S_0	$-S_1^*$
Tx-2	S_1	S_0^*

Two symbols S_0 and $-S_1^*$are sent from sub-channels K and L of the same OFDM block through transmitting antenna 1. Similarly symbols S_1 and S_0^* are sent from sub-channels K and L of the same OFDM block but through transmitting antenna 2. The block diagrams of SFBC-OFDM system with M_T transmit and M_R receiver antenna is shown in Fig.1.

Let Ns be the number of sub-bands chosen to be Ns = N/q, where q is the symbol period of the SFBC system and N is the number of sub-channels. Then, all sub-bands are modulated using MQAM or MPSK where M is determined by the number of allocated bits. Let Consider an SFBC-OFDM system with two transmit antennas (M_T = 2), therefore, a signal vector S = {s[0], s[1], ⋯,s[N−1]} is provided as the input to the SFBC encoder.

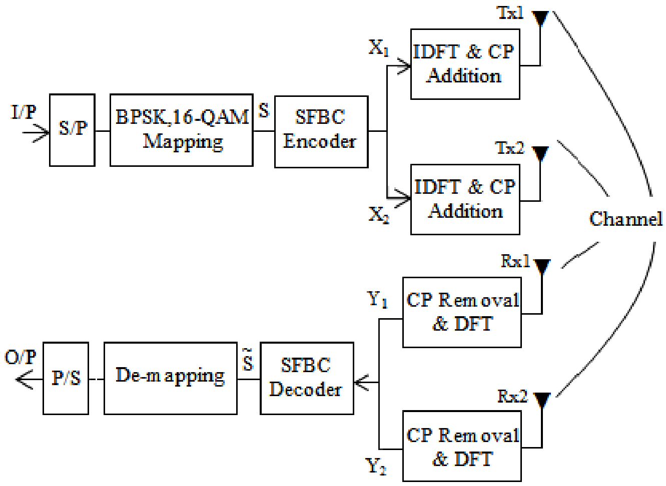

Fig.1 Block diagram of SFBC coded MIMO-OFDM system

Let us define sub-blocks $S_1[k]$ = {s[2k] -s*[2k+1]} and $S_2[k]$ = {s[2k+1] s*[2k]}. Now the orthogonal block code for two transmit antennas can be given in equation (2.1).

$$G_2 = \left[\left(s_1[k]\right)^T \quad \left(s_2[k]\right)^T \right] \quad k=0,......,\frac{N}{2}-1 \quad .....(2.1)$$

SFBC provides two blocks S_1 and S_2, each of the length N, for OFDM at the transmitter. In order to utilize the space-frequency diversity, the input blocks are encoded as per the Table-1. OFDM modulators generate blocks X_1 and X_2, corresponding to S_1 and S_2, which are transmitted by the first and second transmit antenna respectively. Then given that the channel is assumed static during an OFDM block, after removing the cyclic prefix at the receiver side, the DFT output as the demodulated received signal at the j - th receive antenna can be expressed as:

$$r_j = H_{j,1}S_1 + H_{j,2}S_2 + W_j \quad .....(2.2)$$

Where Wj denotes the AWGN and Hj,i is an N × N diagonal matrix with elements corresponding to the DFT of the channel response between the i-th transmit and j-th receive antennas and are given as:

$$W_j = \left(W_j[0],.....W_j[N-1]\right)^T \quad .....(2.3)$$

$$H_{j,i} = diag\left(H_{j,i}[k]\right)_{k=0}^{N-1} \quad .....(2.4)$$

Finally, under channel state information (CSI) at the receiver, Maximum Likelihood detection can be used for the SFBC decoding of the received signal. Detection scheme is written as:

$$\tilde{S}[k] = \sum_{j=1}^{N_r}\left(h_{j,1}^*[2n]r_j[2n] + h_{j,2}[2n]r_j^*[2n+1]\right) \quad .....(2.5)$$

$$\tilde{S}[2k+1] = \sum_{j=1}^{N_r}\left(h_{j,2}^*[2n+1]r_j[2n] - h_{j,1}[2n+1]r_j^*[2n+1]\right) \quad .....(2.6)$$

Then combined signal is equalized by applying different equalizers like Zero Forcing detection, Decision Feedback Equalization and Maximum Likelihood detection.

3 Equalization

In MIMO system Inter Symbol Interference (ISI) occurs due to multipath, which distorted the transmitted signal, which in turn causes bit error at the receiver. Equalizer is used to minimize the error between actual output and desired output by continuous updating its filter coefficients. Equalization can be done in both time and frequency domain but frequency domain is simpler to use as compared to time domain. Different equalizer methods are implemented in this paper in frequency domain and their performance evaluation is done in terms of BER.

3.1 Zero-Forcing (ZF) Equalization

In zero-forcing equalization [8] the coefficients are chosen to force the samples of the combined channel and equalizer impulse response to zero. The combined response of the channel with the equalizer is given by:

$$H_{ch}(f)H_{eq}(f) = 1 \quad .....(3.1)$$

Where $H_{ch}(f)$ is folded frequency response of the MIMO-channel and Heq(f) is frequency response of equalizer. Equations (2.5) and (2.6) show the combined MIMO-OFDM symbols at receiver 1 and 2. ZF equalizer can be realized by multiplying the (2.5) and (2.6) by vector 1/H(k). Where H(k) is the normalized MIMO-channel vector which can be formed as:

$$H = H_{11}.*H_{12}^* + H_{21}.*H_{22}^* \quad .....(3.2)$$

In this case, the equalizer filter compensates for the channel-induced ISI as well as the ISI brought about by the transmitter and receiver filters. Zero-Forcing filter designed using the equation above does not eliminate all ISI because the filter is of finite length.

3.2 Decision Feedback (DF) Equalization

In DFE [9] once an input symbol has been detected, the ISI that it induces on future symbols is estimated and subtracted out before detection of subsequent symbols. DFE is realized in direct transversal form which consists of feed forward filter (FFF) and a feedback filter (FBF) as shown in Fig. 2.

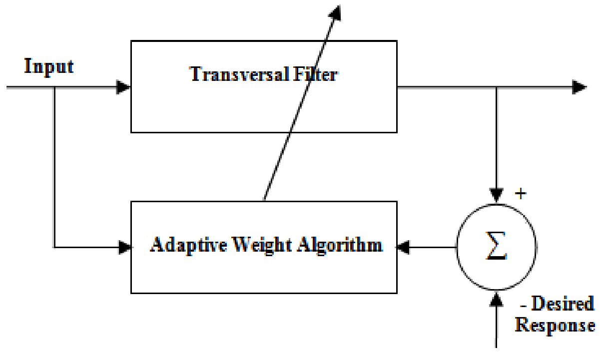

Fig.2: Schematic of DF equalizer

The FBF is driven by decision on the output of the detector, and its coefficients are adjusted to cancel out the ISI on the current symbol from past detected symbols. RLS (recursive least squares) algorithm is used for determining the coefficient of an adaptive filter [10]. RLS (recursive least squares) algorithm is used for determining the coefficient of an adaptive filter [10]. RLS algorithm uses information from all past input samples to estimate the autocorrelation matrix of the input vector. To decrease the influence of input samples, a weighting factor for the influence of each sample is used. First process is the filtering in which RLS computes the output of a linear filter in response to an input signal and generates an estimation error. Second is the adjustment of parameters of the filter in accordance with the estimation error. Equation (3.3) describes the filtering portion of the algorithm.

$$r(n) = wH(n)C(n) \qquad .....(3.3)$$

Where w is the weight vector. Transversal filter is excited to compute error estimates given by 3.4. All subscripts are omitted for simplification

$$e(n) = d(n) - r(n) \qquad .....(3.4)$$

Where d(n) is the desired response and is given by (3.5). Equation (3.6) describes the adaptive operation in which the tap-weight vector is updated by incrementing its old value by an amount equal to the complex conjugate of the estimation error.

$$d(n) = wr(n) \qquad .....(3.5)$$

$$w(nr+1) = w(nr) + \mu C(n) e^{*}(n) \qquad .....(3.6)$$

Where nr is number of iterations and μ is step size, which controls the convergence and stability of algorithm.

3.3 Maximum Likelihood (ML) Detection

The ML [11] detection is used in more practical situations, which tests all possible data sequences and chooses the data sequence with the maximum probability as the output. It requires knowledge of channel characteristics in order to compute the metrics for making decisions. It also requires knowledge of statistical distribution of the noise, which determines the form of metric for optimum demodulation of the received signal. Assuming that perfect CSI is available, the receiver chooses S= (s1, s2 ,…….., sN) from the transmission constellation C that minimize the following decision metric given by (3.7)

$$\|r - Hs\|^2 = \sum_{m=1}^{N_r} \sum_{t=1}^{L} d^2\left(r_{t,m}, \sum_{n=1}^{N_t} h_{n,m} s_{n,t} \right) \qquad .....(3.7)$$

The minimization of (2.5, 2.6) results in a ML decoding, which can alternatively be represented by:

$$\hat{s} = \arg\min_{S \in C} \|r - Hs\|^2 \qquad .....(3.8)$$

Where ‖A‖ denotes the Euclidean norm of matrix A defined by $\|A\|^2 = tr(A^H A),\ tr(A)$ and A^H, respectively, denotes the trace and Hermitian transpose of matrix *A*, and $d^2(a,b)$ is the squared Euclidean distance between signals and b calculated by:

$$d^2(a,b) = |a-b|^2 = (a-b)(a^* - b^*) \qquad .....(3.9)$$

Above equations holds good for all data sequences. Decoding complexity increases exponentially by increasing number of transmitting and receiver antennas in such cases joint detection will be used like sphere decoding.

4 Simulated Results

Simulation is carried out in two phases, in first phase two transmit and one receiving antenna is considered and in second phase two transmit and two receiving antenna is considered. The channel experienced by each transmitting antenna is considered to be independent of each other. It is also assumed that transmitting power of each transmitting antenna is same. Further, we assume that the receiver has perfect knowledge of the channel. Fig.4.1 shows the BER performance for BPSK using 2x1 MIMO-OFDM systems. When frequency diversity is not considered then BER reduced to 0.0040 at SNR of about 18 dB and around 10^{-3} at SNR of 17, 16 and 15 dB in subsequent sub-plots using ZF, DFE and ML equalizer. Result shows that ML equalizer performs well out other equalizers.

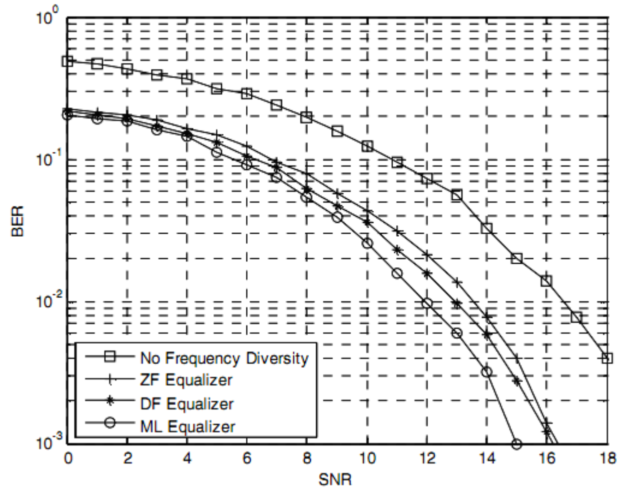

Fig.4.1 BER for BPSK using 2x1 MIMO-OFDM system

BER performance of two transmits and two receiving antennas using BPSK and 16-QAM are shown in Fig.4.2 and Fig.4.3 respectively.

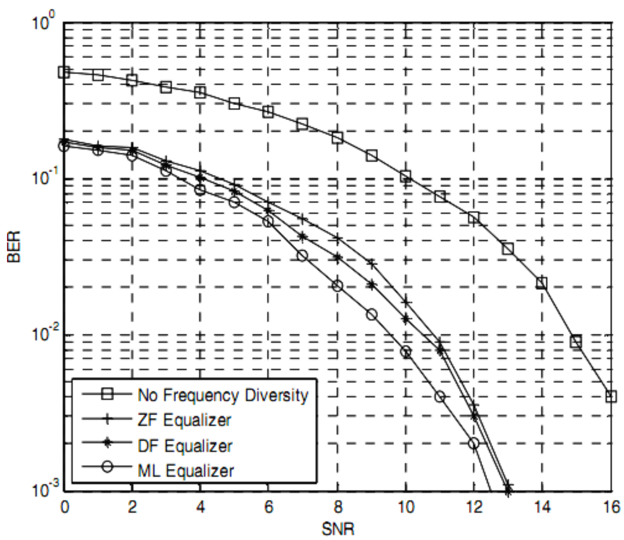

Fig.4.2 BER for BPSK using 2x2 MIMO-OFDM system

Fig.4.2, BER get reduced to 0.0040 at SNR of 18 dB, when no frequency diversity is considered and around 10^{-3} at SNR of 13 and 12 in subsequent sub-plots. In Fig.4.3, BER get reduced to 10^{-3} at SNR of around 25 when no diversity is considered and around 20 dB in other sub-plots. Thus BER performance of BPSK is comparatively better than 16-QAM. So it can be clearly observed that employing two receivers greatly enhance the system performance.

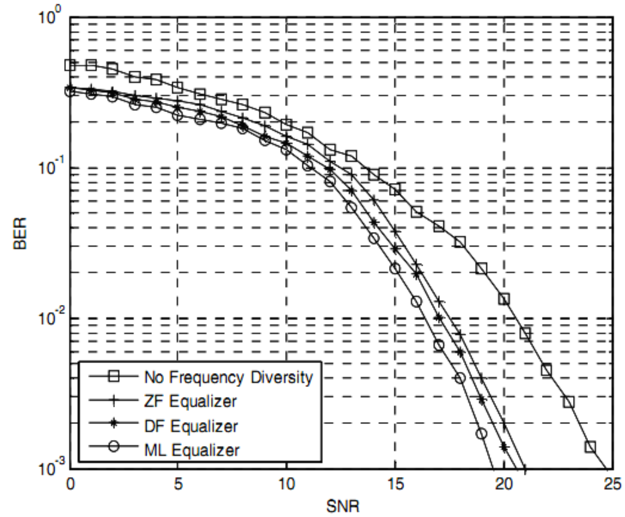

Fig.4.3 BER for 16-QAM using 2x2 MIMO-OFDM system

5 Conclusion

The performance of 2x1 and 2x2 MIMO-OFDM system under mobile radio channel using SF coding is studied in this paper. Further, the system performance is compared with different equalizers in frequency domain. A significant performance gain is observed by employing equalizers along with Alamouti scheme. Mentioned system does not showing full-diversity so research is going for full-diversity rate 1 codes. Rate can be further enhanced by employing algebraic SF codes. System performance can further be improved by extending coding in three dimension i.e. space, time and frequency such codes are called STF codes. STF codes further increase the complexity of the system.

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