Australian Journal of Basic and Applied Sciences, 5(5): 273-286, 2011
ISSN 1991-8178

Pairwise Error Probability of a New Subcarrier Mapping Scheme (ICI-SC Technique) for STFBC MIMO-OFDM System

[1,2]Azlina Idris, [3]Kaharudin Dimyati and [4]Sharifah Kamilah Syed Yusof and [1,2]Darmawaty Mohd Ali

[1]Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
[2]Department of Electrical Engineering, Universiti Malaya, 50603 Kuala Lumpur, Malaysia.
[3]Faculty of Engineering,National Defence University of Malaysia, 57000 Kuala Lumpur, Malaysia.
[4]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.

Abstract: This paper analyses the Pair-wise Error Probability (PEP) performance for multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) system to reduce the problem of intercarrier interference (ICI) where coding scheme is applied over space time frequency block codes (STFBC). It is expected that by inserting new subcarrier mapping scheme (ICI-SC technique) at the transmitter, PEP can be improved, ICI can be reduced, and maximum diversity order can be achieved with the efficient bandwidth. An analytical framework for the PEP performance analysis of STFBC MIMO-OFDM system has been proposed. Then, a new subcarrier mapping scheme (ICI-SC technique) is introduced to compensate the integrated effect of frequency offset (FO) for intercarrier interference (ICI) reduction with maximum diversity order in the system. The result shows that the proposed PEP offers an improvement over STFBC MIMO-OFDM system by using a new subcarrier mapping scheme (ICI-SC technique).

Key words: PEP (Pair-wise Error Probability), ICI-SC (Inter-carrier interference self-cancellation), STFBC (space time frequency block code), FO (frequency offset), SNR (signal to noise ratio).

INTRODUCTION

MIMO is an emerging technology that has recently gained a lot of attention for its capability to achieve high capacity and link reliability within a given bandwidth at no additional transmitting power. Theoretically, capacity increases linearly with the number of antennas when the channel exhibits rich scattering and slow variations over the time (Winters, 1987; Foschini, 1998). This improvement is achieved through parallel sub channels created by the dense multipath environment, provided that the established transmission paths between the transmitter and receiver antennas are uncorrelated. Therefore, in order to design, analyze and implement such systems, realistic wireless channel models that incorporate spatial characteristics are required (Yu, 2002).

Today, orthogonal frequency division multiplexing (OFDM) is a major contender for 4G wireless applications since it is capable of dealing with higher data rates, with significant potential performance enhancements over existing wireless technology. The combination of both MIMO and OFDM (referred to as MIMO-OFDM and is being considered for a number of different standards) has become the most promising candidate for future 4G broadband wireless communication systems (Gordon, 2004; Taewon Hwang, 2009).

MIMO-OFDM systems can enhance the data rates in frequency-selective fading channels and achieve high spectral efficiency by simultaneously exploiting the space, time, and frequency (STF) domains (Weifeng Su, 2005; Weifeng Su, 2003). Hence, STF coding is applied into MIMO-OFDM system to efficiently achieve full diversity that can improve the signal quality and also increase spectral efficiency (Weifeng Su, 2005; Majid Fozunbal, 2005; Weifeng Su, 2006). Space-time-frequency block coding (STFBC) is a simple yet ingenious transmit diversity technique in MIMO technology, and had rapidly become one of the most active research areas in wireless communications.

One of the most challenging problems in OFDM modulation is inter-carrier interference (ICI) (Russel, 1995). Since ICI can severely degrade the performance of OFDM, ICI-SC scheme has been proposed as one

Corresponding Author: Azlina Idris, Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia. Department of Electrical Engineering, Universiti Malaysia, 50603, Kuala Lumpur, Malaysia.

of the suppression methods (Zhao, 2001). ICI-SC approach transmits each symbol over a pair of adjacent or non-adjacent subcarriers with a phase shift of π/2 (Zhao, 2001; Sathananthan, 1999). Self-cancellation technique used a simple conjugated data allocation of $\left(X_k, X_{k+1} = -X^*_k\right)$ (Dung Ngoc Đào, 2005) to improve the PEP performance. In this paper, the ICI-SC technique has been employed to reduce the problem of ICI, where an STFBC encoder takes place. In the case where the user transmit the data symbols to the receiver in the MIMO-OFDM system using symmetric method or adjacent method proposed by (Slimane Ben Slimane, 2000) and (Dung Ngoc Đào, 2005), it is difficult to effectively obtain frequency diversity gain because of the distance between the subcarriers and repeated subcarriers is too far or too short. A new subcarrier mapping scheme (ICI-SC technique) is then proposed to achieve the improved frequency diversity with optimal distance between subcarriers and repeated subcarriers that can reduce ICI. However, this scheme inherently reduces throughput and bandwidth efficiency by a factor of 2 (repeated symbols) (Yeon-Ho Chung, 2008). Nevertheless, this problem can be improved or compensated by using the higher order modulation scheme with a high transmission rate (Li Zhao, Ping Zhang, 2006; Qiang Shi, 2009).

The paper is organized as follows. In section 2, the system model of STFBC for MIMO-OFDM system with FO will be discussed. We derive the PEP algorithm and briefly describe the derivation of proposed equation in OFDM system in section 3. In section 4, simulation results will be analyzed in terms of PEP by comparison between the different subcarrier mapping scheme (ICI-SC technique) and the different value of FO. Finally, some concluding remarks are given in section 5.

System Model of a New Subcarrier Mapping Scheme (ICI-SC Technique) for STFBC MIMO-OFDM:

The transceiver architecture is designed according to a new subcarrier mapping scheme (ICI-SC technique) as shown in Figure 2.1. A brief description of the model is provided below. It shows the block diagram for STFBC using MIMO-OFDM system with *M* transmits antennas and *N* receives antennas. Let the number of subcarriers in the OFDM modulators is *K*, and that, between each pair of transmit and receive antennas, six paths COST207 (Jakes Model) of the *L*-path quasi static Rayleigh fading channel model are being applied.

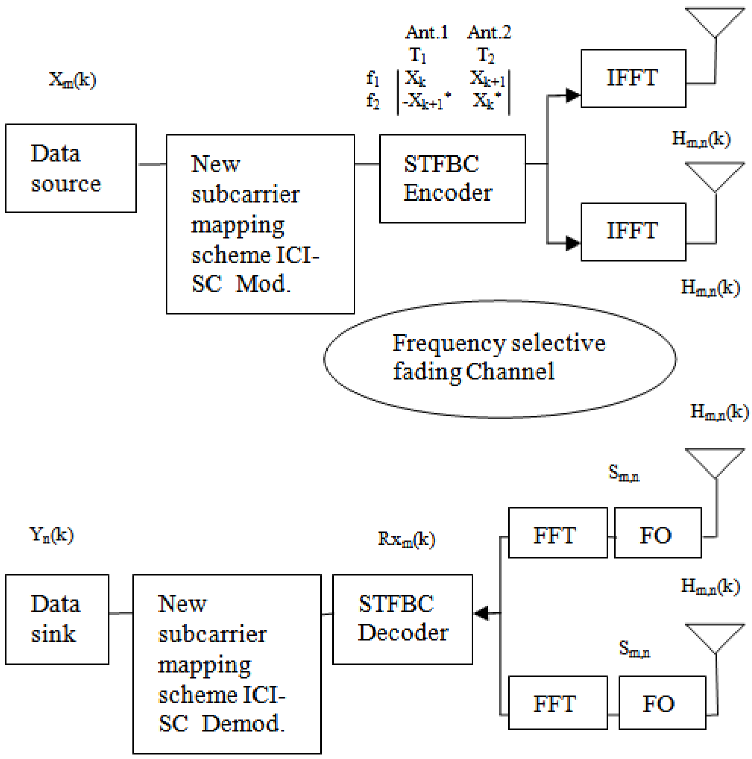

Fig. 2.1: STFBC for MIMO-OFDM with new subcarrier mapping scheme (ICI-SC technique) model.

Now, let the MIMO channel is assumed to be constant over each OFDM block period, but vary from one OFDM block to another (Hirosaki, B., 1981). In the same manner, the received k^{th} subcarriers are assumed to be perfectly sampled and the received signal at the receive antenna can be expressed as follows for the MIMO systems;

$$Y_n(k) = \sum_{m=1}^{M} X_m(k) H_{m,n}(k) S_{m,n}(0) + z_n(k) \tag{1}$$

Space, time, and frequency is performed using ST code and SF code where the same symbols are transmitted through multiple antennas at different times and frequency. The encoding of STFBC is accomplished by the following (Weifeng Su, 2005) as shown in Figure 2.2 where *Ti* (time slots), *f* (frequencies) and *Ant* (Antennas).

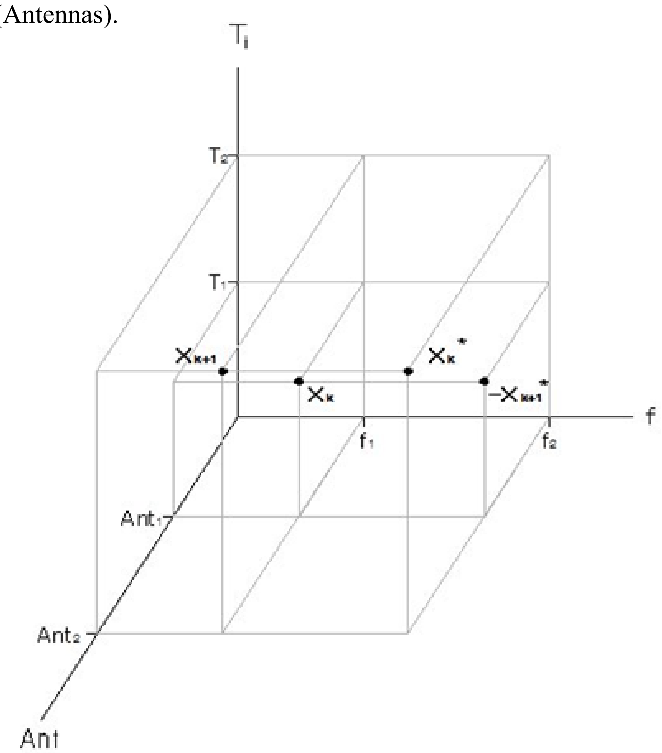

Fig. 2.2: Coding in STFBC method.

The STFBC codeword has the form of,

$$X_m = \begin{bmatrix} X_1(0) & \cdots & X_2(0) \\ X_1(0) & \cdots & -X_2(0) \\ . & & . \\ X_1(k-1) & \cdots & X_2(k-1) \\ X_1(k-1) & \cdots & X_2(k-1) \end{bmatrix} \tag{2}$$

In the case of MIMO-OFDM, the repetition is done with r=2 where r is how many times the data is repeated. The interference cancellation modulation (ICM) is then applied to STFBC using the repeating scheme but the repeated symbols are signed-reversed to form new subcarrier mapping scheme (ICI-SC technique) codeword as followed:

$$X_m = \begin{bmatrix} X_1(0) & \cdots & X_2(0) \\ -X_1(\frac{N}{2}-1) & \cdots & -X_2(\frac{N}{2}-1) \\ . & & . \\ X_1(\frac{N}{2}-1) & \cdots & X_2(\frac{N}{2}-1) \\ -X_1(\frac{N}{2}-1) & \cdots & -X_2(\frac{N}{2}-1) \\ X_1(\frac{N}{2}) & \cdots & X_2(\frac{N}{2}) \\ -X_1((N-1)+\frac{N}{2}) & \cdots & -X_2((N-1)+\frac{N}{2}) \\ . & & . \\ X_1(N-1) & \cdots & X_2(N-1) \\ -X_1((N-1)+\frac{N}{2}) & \cdots & -X_2((N-1)+\frac{N}{2}) \end{bmatrix} \quad (3)$$

Applying the conjugate interference cancellation modulation (ICM) scheme to the repeating signal to reduce ICI, the codeword becomes:

$$X_m = \begin{bmatrix} X_1(0) & \cdots & X_2(0) \\ -X_1(\frac{N}{2}-1)^* & \cdots & -X_2(\frac{N}{2}-1)^* \\ . & & . \\ X_1(\frac{N}{2}-1) & \cdots & X_2(\frac{N}{2}-1) \\ -X_1(\frac{N}{2}-1)^* & \cdots & -X_2(\frac{N}{2}-1)^* \\ X_1(\frac{N}{2}) & \cdots & X_2(\frac{N}{2}) \\ -X_1((N-1)+\frac{N}{2})^* & \cdots & -X_2((N-1)+\frac{N}{2})^* \\ . & & . \\ X_1(N-1) & \cdots & X_2(N-1) \\ -X_1((N-1)+\frac{N}{2})^* & \cdots & -X_2((N-1)+\frac{N}{2})^* \end{bmatrix} \quad (4)$$

By allocating a pair of complex signals, the phase different between two adjacent subcarriers varies with respect to the signal itself (Dung Ngoc Đào, 2005). This method is called new data conjugate subcarrier mapping scheme (ICI-SC technique).

The channel impulse response of the channels between *Tx* (transmitter) antenna *m* and *Rx* (receiver) antenna *n* at subcarrier *k* is:

$$H_{m,n}(k) = \sum_{l=0}^{Lp-1} \alpha_{m,n}(l) e^{-j2\pi k \Delta f \tau \ell} \quad , \; \mathrm{j} = \sqrt{-1} \tag{5}$$

by which $\alpha_{m,n}$ is the complex amplitude, $\Delta f = 1/T_s$ is the subcarrier spacing, T_s is the sampling time, $\tau_{(\ell)}$ is the channel delay of the ℓ th path (ℓ = 0,..., L_p -1) and L_p is the total number of propagation path. The input data symbols are divided into symbol source words and are parsed into blocks and mapped to STFBC codeword as represented in Equations (3) and (4).

In the MIMO-OFDM systems, with k^{th} subcarrier, the coefficients $S_{m,n}(0)$ from (Russel, 1995) is a constant with respect to subcarrier index $k=0$, where $\varepsilon_{m,n}$ is the normalized frequency offset (NFO).

$$S_{m,n}(0) = \frac{\sin\left(\pi \varepsilon_{m,n}\right)}{K \sin\left(\frac{\pi}{K} \varepsilon_{m,n}\right)} . \exp\left(j\pi \left(1 - \frac{1}{K}\right) \varepsilon_{m,n} \right) \tag{6}$$

The ICI coefficients are given in (Zhao, 2001).

$$S_{m,n}(k) = \frac{\sin\left(\pi \left(k + \varepsilon_{m,n}\right)\right)}{K \sin\left(\frac{\pi}{K}\left(k + \varepsilon_{m,n}\right)\right)} . \exp\left(j\pi \left(1 - \frac{1}{K}\right)\left(k + \varepsilon_{m,n}\right) \right) \tag{7}$$

The corresponding in function of noise at each received subcarrier is the sum of the ICI noise and complex Gaussian thermal noise terms as $z_n(k)$'s are indepen3dent and identically distributed noise samples that can be written as follows;

$$z_n(k) = I_n(k) + \omega_n(k) \tag{8}$$

where $I_n(k)$ is the term for (ICI), at subcarrier k of each receive antenna n. In this manner, the summation of M inter-carrier interference $I_{m,n}(k)$ caused by transmitted signals from transmit antenna m is then can be expressed as;

$$I_{m,n}(k) = \sum_{p=0}^{k-1} \sum_{p \neq k} X_m(p) H_{m,n}(p) S_{m,n} \left| p - k \right| \tag{9}$$

Thereafter, the k^{th} and $k+1^{th}$ subcarrier signal after fast fourier transform (FFT) for the proposed model from figure 2.1 at the receiver can be respectively expressed as follows:
For antenna 1 at time slot 1

$$R_{X1}(k) = X_k(k) H_k(k) S(0) - X^{*}_{k+1}(k) H_{k+1}(k) S(1)$$

$$+ \sum_{\substack{i=0 \\ l \neq k \\ k+1}}^{N-1} X_k(l) H_k(l) S(l-k) + \omega_k \ldots \tag{10}$$

$$R_{X2}(k) = X_k(k)H_k(k)S(-1) - X^*_{k+1}(k)H_{k+1}(k)S(0)$$

$$+\sum_{\substack{i=0\\ l\neq k\\ k+1}}^{N-1} X_k(l)H_k(l)S(l-k-1) + \omega_{k+1}\cdots \tag{11}$$

For antenna 2 at time slot 2.

$$R_{X2}(k) = X_{k+1}(k)H_{k+1}(k)S(0) + X^*_k(k)H_k(k)S(1)$$

$$+\sum_{\substack{i=0\\ l\neq k\\ k+1}}^{N-1} X_{k+1}(l)H_{k+1}(l)S(l-k) + \omega_k\cdots \tag{12}$$

$$R_{X2}(k+1) = X_{k+1}(k)H_{k+1}(k)S(-1) + X^*_k(k)H_k(k)S(0)$$

$$+\sum_{\substack{i=0\\ l\neq k\\ k+1}}^{N-1} X_{k+1}(l)H_{k+1}(l)S(l-k-1) + \omega_{k+1}\cdots \tag{13}$$

At the receiver, the diversity is obtained by applying maximal-ratio receiver combiner (MRRC). The scheme can be easily realised with these two transmitter and two receiver antennas. The final decision variables Y_k and Y_{k+1} of the k^{th} and $k+1^{th}$ symbols are derived from two subcarrier signal influenced by ICI. In this manner, the MRRC scheme can be expressed as follow

$$Y_k = \frac{R_{X_1}(k) + R_{X_2}(k) + R^*_{X_1}(k+1) + R^*_{X_2}(k+1)}{4} \tag{14}$$

and

$$Y_{k+1} = \frac{R_{X_1}(k) + R_{X_2}(k) - R^*_{X_1}(k+1) + R^*_{X_2}(k+1)}{4} \tag{15}$$

where

$\omega_k = \frac{1}{4}\left(\omega_k + \omega^*_{k+1}\right)$ and $\omega_{k+1} = \frac{1}{4}\left(\omega_k - \omega^*_{k+1}\right)$ correspond to the additive white gaussian noise (AWGN) of the k^{th} and $k+1^{th}$ carrier signal of the receiver.

Design Criteria of Pairwise Error Probability (PEP) with FO:

Pair-wise error probability (PEP) is an important factor for studying the reliability of a communication system. PEP is defined as the probability of detecting one symbol when another (different) symbol is transmitted. The "pair" is the transmitted symbol and the detected symbol. It is used when determining the union bound to sum the overall pairwise error probability. It must be noted that the detected symbol is also depends on the previous symbol, and possibly the following symbol. For example, given that the *D* codeword is transmitted, the PEP $P\left(D \rightarrow \bar{D}\right)$ probability that the received signal vector is closed to the erroneous codeword $\bar{D}$. At this point, the value of the PEP is distinguished, hence the bound on the error probability, depends on the decoding method is then employed. In this paper, the corresponding maximum likelihood decoder is used and an upper bound on the error probability is computed for STFBC MIMO-OFDM system. STF coding strategy was introduced in (Liu, 2002) for two transmit antennas and subsequently further developed in (Lee, 2000; Yue, 2002; Gong, 2001) for multiple transmit antennas. In (Yue, 2002), the performance criteria for STF codes were derived and an upper bound on the maximum achievable diversity order was established. The result from (Weifeng Su, 2003) shows that the upper bound proposed STF codes are assured to achieve the full spatial, temporal, and frequency diversities. In this paper, the approach in (Weifeng Su, 2003) is adopted for the PEP with FO which can be formulated as follows:

$$P\left(D \rightarrow \bar{D}\right) \leq \ell \begin{pmatrix} 2\Gamma N - 1 \\ \Gamma N \end{pmatrix} \left(\prod_{i=1}^{\Gamma} \lambda_i \right)^{-N} \xi^{-\Gamma N} \tag{16}$$

$P\left(D \rightarrow \bar{D}\right) =$ probability of wrongly decoding in favour of codeword $\bar{D}$ and the matrix D consists of transmitted symbols and the data matrix D size *KMN*×*KMN* matrix derived from the STFBC codeword that can be expressed as $K \times M\, D_M = diag\left[x_m(0), x_m(1), ..., x_m(k-1)\right]$. The value of X_m is referring to the new subcarrier mapping scheme (ICI-SC technique) from Equation (3) and (4) and λ= non-zero Eigen value of ($\Delta D.R$).

From Equation (16), the following equation will be recognized:

$$\Gamma = rank\left(\Delta D \cdot R\right) \tag{17}$$

where $\Delta D = \left(D - \bar{D}\right)\left(D - \bar{D}\right)^H$. D is the transmitted codeword, $\bar{D}$ and is the erroneously decoded codeword. Superscript H stands for the complex conjugate and transpose matrix (Hermitian matrix). R is refers to the correlation matrix of $H_{m,n}(k)$, and for the proposed system model, it consist of combination of frequency and time correlation matrix. The frequency correlation matrix, R_F is written as

$$R_F = \left\{E\left\{H_{m,n} H_{m,n}\right\}\right\} = w \Lambda w^H \tag{18}$$

where $H_{m,n} = \left(I_k \otimes w\right) A_{m,n}$. The I_k in this case is identify matrix of size k and $w = \exp\left(-j2\pi\Delta f\right)$ and

$$A_{m,n} = \left[\alpha_{m,n}'(0)...\alpha_{m,n}'(L-1)...\alpha_{m,n}{}^k(0)...\alpha_{m,n}{}^k(L-1)\right]$$

For time correlation matrix of size $K \times K$, the R_T can be expressed as

$$R_T \otimes \Lambda = \left\{E\left\{A_{m,n} A_{m,n}{}^H\right\}\right\} \tag{19}$$

where $\Lambda = diag\left\{S_0{}^2, S_1{}^2, ..., S_{k-1}{}^2\right\}$.

They are modeled as zero-mean complex Gaussian random variable (GRVs) with variance. Combining (18) and (19), $R_{m,n}$ can be calculated as follows

$$R_{m,n} = \left(I_k \otimes w\right) E\left(A_{m,n} A_{m,n}{}^{H}\right)\left(I_k \otimes w\right)^{H}$$

$$= R_T \otimes \left(w \Lambda w^{H}\right) = R_T \otimes R_F \tag{20}$$

Thus,

$$R = I_{m,n} \otimes (R_T \otimes R_F) \tag{21}$$

The $I_n(k)$ is the term for ICI at subcarrier *k* of each received antenna *n*, whereby the summation of *M* intercarrier interference $I_{m,n}(k)$ caused by transmitted signals from transmit antenna *m*. The variance $\sigma^2_{I_{m,n}}$ of $I_{m,n}(k)$ as written in (Li Zhao, Ping Zhang, 2006) is,

$$\sigma^2_{I_{m,n}} = E\left[\left|I_m(k)\right|^2\right] = \left[\sum_{p=0}^{K-1} E\left[\left|X_m(p)\right|^2\right] E\left[\left|H_{m,n}(p)\right|^2\right] E\left[\left|S_{m,n}(p-k)\right|^2\right]\right] - E\left[\left|X_{m,}(k)\right|^2\right] E\left[\left|H_{m,n}(k)\right|^2\right] E\left[\left|S_{m,n}(0)\right|^2\right] \tag{22}$$

in which the term $E\left[\left|X_m(k)\right|^2\right]$ is the signal power, which is normalized to 1 and the term $E\left[\left|H_{m,n}(k)\right|^2\right]$ is the average of the channel power, which is also normalized to 1. As suggested in (Lee, K.F. and D.B. Williams, 2000),

the sum $\sum_{p-0}^{K-1} E\left[\left|S_{m,n}(p-k)\right|^2\right] = 1$. Then, Equation (23) becomes:

$$\sigma^2_{I_{m,n}} = 1 - S_0 \tag{23}$$

It is found that $\sigma^2_{I_{m,n}}$ is independent of indices *m* and *n*, and only depends on the NFO through S_0 . It can be seen from Equation (1) that the received signal power has a factor of S_0 .

The symbol ξ is the average E_b/N_o. Therefore, the equivalent E_b/N_o at the receive antenna with the FO is given as (Dung Ngoc Đào, 2005):

$$\tilde{\xi} = \left(\frac{S_0}{\left(1 - S_0\right)\xi + 1}\right)\xi \tag{24}$$

and the performance loss due to FO is given by (Dung Ngoc Đào, 2005):

$$\ell = \left(\frac{S_0^{\ 2}}{\xi\left(1 - S_0\right) + 1} \right)^{-\Gamma N} \tag{25}$$

At this stage, we can conclude that for STFBC MIMO-OFDM, as the average (SNR) become higher, the noise in the system become lower and ICI effect in the OFDM system become lesser. A new subcarrier mapping scheme (ICI-SC technique) for STFBC MIMO-OFDM system has been developed to reduce ICI with an optimal distance at the maximum diversity frequency caused by FO. For instance, if the distance between subcarriers is too far or too short, it may not affect the system. If the value of NFO (ε) becomes larger, the desired part, $\left|S_{m,n}(0)\right|$ from Equation (6), decreases and the undesired part, $\left|S_{m,n}(k)\right|$, from Equation (7) increases (Slimane Ben Slimane, 2000). ICI causes increasing of the PEP and decreasing of the SNR performance.

Simulation Results and Discussion:

In this section, the proposed STFBC design methods with new subcarrier mapping scheme (ICI-SC technique) are simulated and the PEP performance is then be investigated. The six-path COST 207 (Jakes model) TU channel model which is a more realistic model for quasi static Rayleigh fading channel MIMO-OFDM system (Jeruchim, 2000) is being used. The simulation parameters are as shown in Table 1.

Table 1: Simulation parameters for the 3rd Generation Partnership Project Long Term Evolution (3GPP-LTE) system (Chiueh, 2007).

Parameters	Value
Bandwidth (BW)	1.25MHz
Sampling frequency	1.92MHz
Sampling time	$5.208\text{x}10^{-7}$ second
No. of subcarriers	76 subcarriers
Modulation technique	64-QAM
Maximum Doppler frequency	120Hz
IFFT size	128
Channel model	COST207 Typical Urban (TU) channel Path delays, L_p= (0, $0.2\text{x}10^{-6}$, $0.5\text{x}10^{-6}$, $1.6\text{x}10^{-6}$, $2.3\text{x}10^{-6}$, $5.0\text{x}10^{-6}$)seconds Average path gains = [0.5011, 1.122, 0.6309, 0.251, 0.158, 0.1] dB
Decoding method	Maximum Likelihood Decoding

The simulation results are presented in terms of PEP curves as functions of SNR.

Figure 4.1 shows the simulation result and theoretical result of STFBC using new subcarrier mapping scheme (ICI-SC technique) with different NFO. The result show that the new subcarrier mapping scheme (ICI-SC technique) with NFO=0% for both techniques (simulation and theoretical) has the best BER performance as compared to NFO=10% and 20% in STFBC MIMO-OFDM system. The BER performance of new subcarrier mapping scheme (ICI-SC technique) from Equation (3) and (4) produce the less interference system, as well as reducing the ICI with maximum diversity order system. The BER of new subcarrier mapping scheme from Equation (3) and (4) for theoretical is increased and the value of E_b/N_o is higher than the simulation. The subcarrier signal remapping for new subcarrier mapping scheme (ICI-SC technique) can produce the system with optimal distance and can achieve maximum frequency diversity and highest diversity order in the system when the NFO=0%. Overall result shows that the signals for both techniques (simulation and theoretical) produces almost the same result.

Figure 4.2 shows that the new subcarrier mapping scheme (ICI-SC technique) from Equation (3) and (4) has the best PEP performance as compared to symmetric and adjacent scheme which indicates that this method produce lower noise and interference with FO. For example, at PEP=10^{-6}, the SNR value for new subcarrier mapping scheme is 15dB. The PEP performance for new subcarrier mapping between symmetric and adjacent scheme are about 3 dB and 4 dB respectively. It shows that, if the distance between the subcarriers in the system is too far, the PEP performance is better and the interference is less than the shortest distance. This

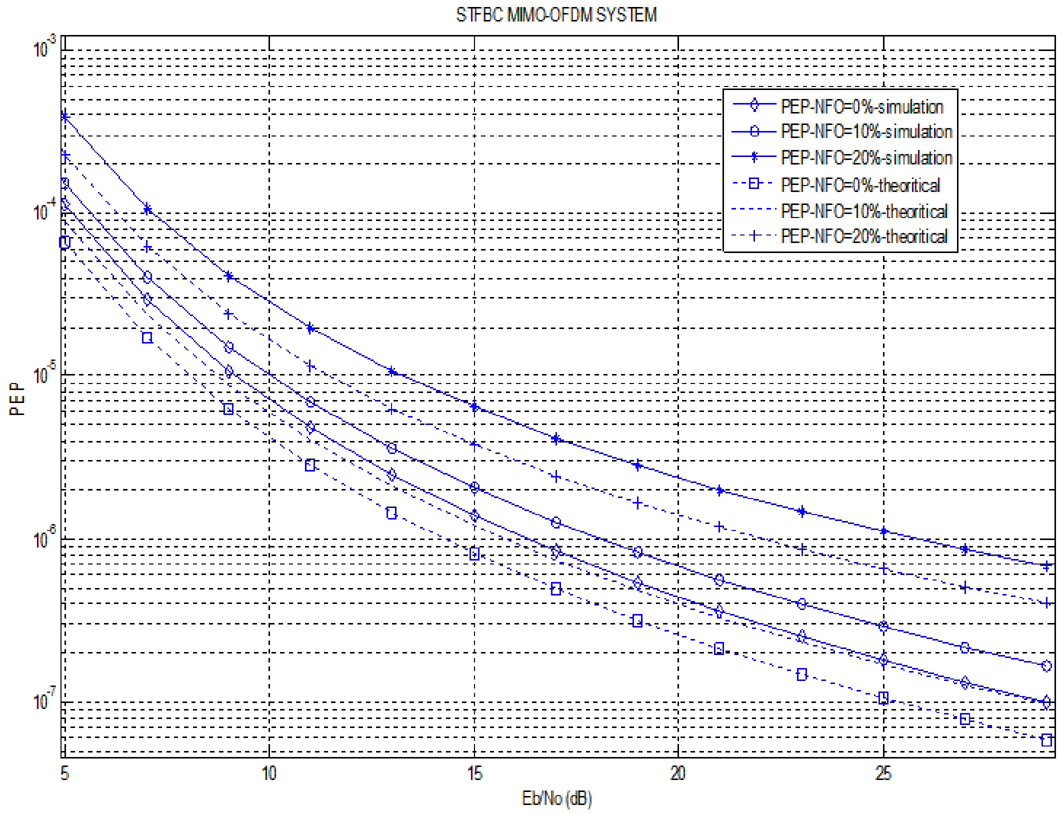

Fig. 4.1: Comparison PEP performance for STFBC MIMO-OFDM system with different NFO using new subcarrier mapping scheme (ICI-SC technique) (simulation and theoretical) for PEP versus Frequency E_b/N_o(dB).

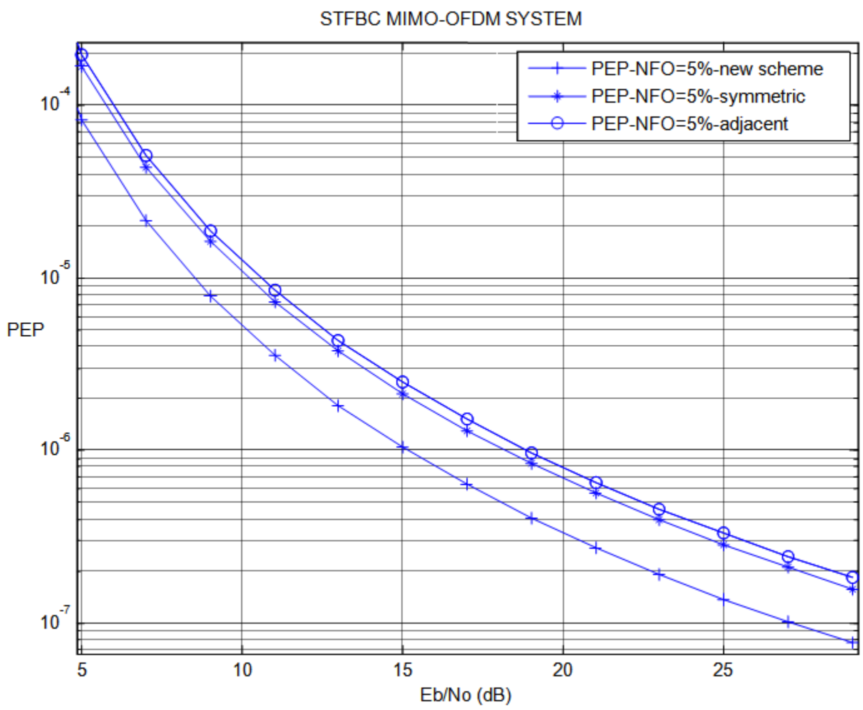

Fig. 4.2: PEP performance of STFBC MIMO-OFDM systems for NFO=5% with different subcarrier mapping scheme (ICI-SC technique).

is due to the fact that the PEP will be affected by variance $\sigma^2_{I_{m,n}}$ of $I_{m,n}(k)$, in which from Equation (22) and (23), the value of $S_0 \approx 1$. In other words, it will only produce a small value of variance. Note that the smaller variance will result in better PEP and SNR. This explains that the new subcarrier mapping scheme has the optimal distance with maximum frequency diversity and hence produces the best PEP performance as compared to the other subcarrier mapping scheme (ICI-SC technique).

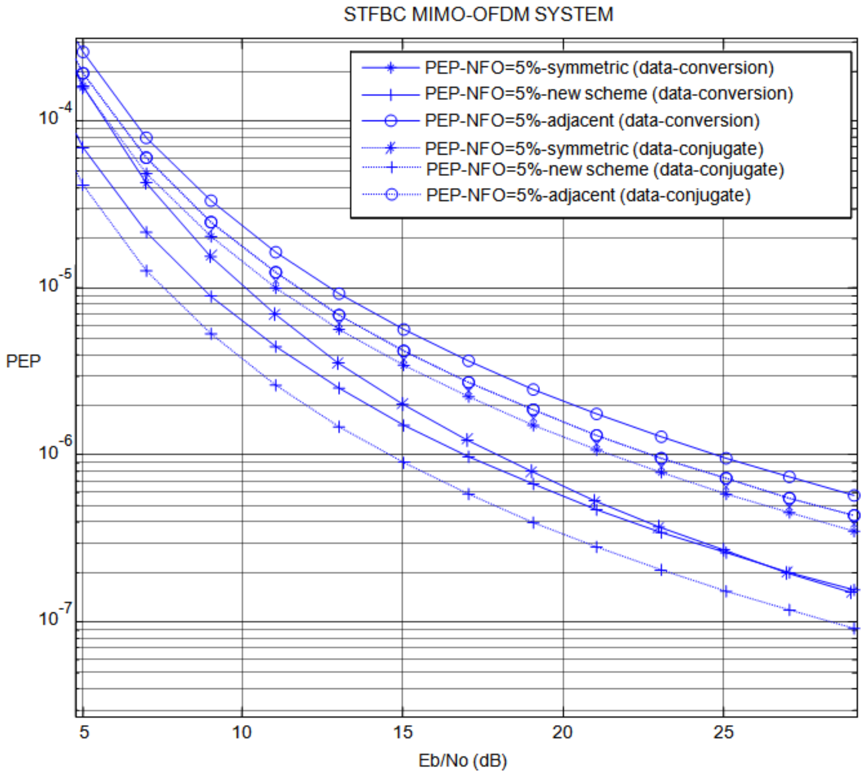

Fig. 4.3: PEP performance for STFBC MIMO-OFDM systems with NFO=5% using different data conjugate and data conversion subcarrier mapping scheme (ICI-SC technique)

Next, the PEP with data conjugate and data conversion using different subcarrier mapping scheme (ICI-SC techniques) is evaluated. In this paper, the simulation using NFO=5% is performed. From Figure 4.3, it shows that PEP for STFBC with NFO=5% with the new data conjugate subcarrier mapping scheme (ICI-SC technique) outperformed STFBC with others.

From the simulation, PEP for data conjugate type performs better than conversion method for all mapping type. The Figure 4.3 shows that, at PEP=10^{-6}, the performance loss from Equation (25) of PEP between symmetric data conjugate and adjacent data conjugate scheme is about 2.5 dB and 8 dB. It shows that the distance between subcarriers using symmetric method is too far and using adjacent method is too short. In order to produce the system with low ICI and high diversity order, the subcarrier distance must be optimum. Sometimes, these criteria of mapping will not affect the system. The new data conjugate subcarrier mapping scheme ICI-SC method have an optimal distance with maximum frequency diversity system to reduce ICI caused by FO. These results attest that new data conjugate scheme yields the best PEP performance at the highest SNR. Likewise, this method can reduce the PEP performance due to FO and produce a small value of variance from Equation (22) and (24) with the better PEP. This reaffirm that new data conjugate subcarrier mapping scheme (ICI-SC technique) performs better performance than others.

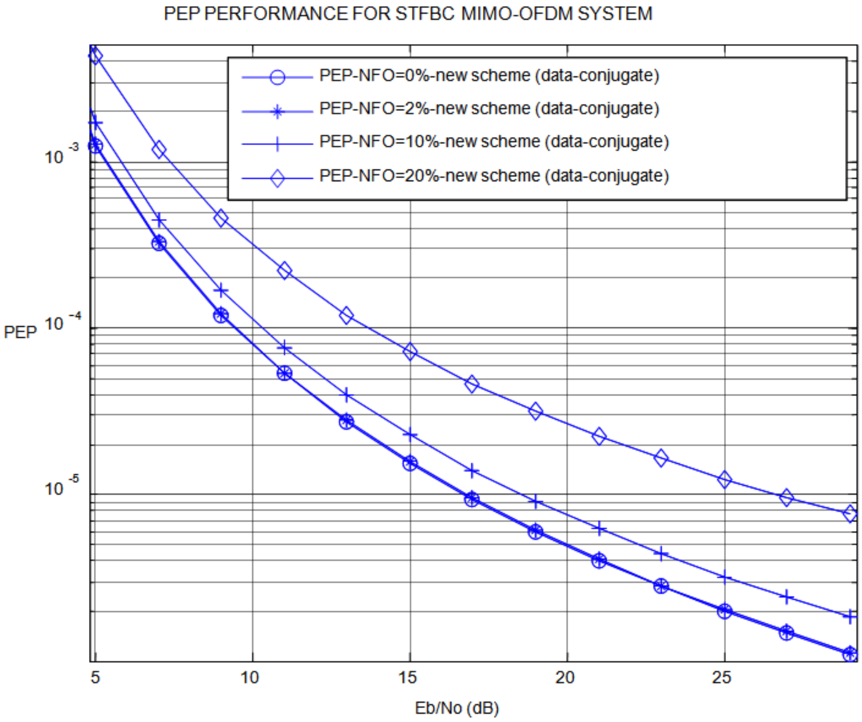

Fig. 4.4: PEP performance for STFBC MIMO-OFDM systems using new subcarrier mapping scheme (ICI-SC technique) with different NFO

Figure 4.4 illustrate the different NFO using new data conjugate subcarrier mapping scheme (ICI-SC technique) for multipath Rayleigh fading channels using 64-QAM modulation techniques. When the equivalent SNR at the receive antenna with FO $(\tilde{\xi})$ from Equation (24) is decreased then the value of So from Equation (23) will increase. This will reduce the PEP performance. Simulation results are given to verify the theoretical analysis for STFBC with different NFOs. The performance of STFBC for NFO=2%, 10%, 20% are then being compared with the system NFO (NFO =0%). By using the equation of So from Equation (23) for NFO= 2%, So=0.9987 and $\ell \approx 1$ in the SNR region of interest ($\leq 30dB$). Therefore, theoretically, the performance loss (ℓ) is not significant, and Figure 4.4 proves this conclusion.

As illustrated in the Figure 4.4, for NFO=2%, the PEP curves almost overlap the PEP curves of the systems with no FO (NFO=0%). For this case, NFO=10%, the PEP performance of all systems increases as compared to the curves of PEP with NFO=2%. At PEP $=10^{-5}$, the system with NFO=10% and NFO=20% increase the PEP performance from NFO=2% and the PEP performance is about 1.2 dB and 9.7 dB. Even though the SNR is increased from Equation (24), the PEP from Equation (16) is slightly reduced. It shows that the lower the FO the better is the performance of the system in which can increase the SNR and decrease the PEP.

From this paper, the equations of PEP of STFBC in MIMO-OFDM have been derived. For the case of performance of PEP, it will be affected by the value of SNR, where the lower value of SNR, and the better performance of PEP. Base on the system with PEP, the value of upper bound of the PEP have been minimized to get the better performance. Refer to the Equation (17), the minimum rank of $(\Delta D \cdot R)$ of all pairs of different codewords, *D*, so $\bar{D}$ should be larger as possible, as at reach the value of *M*, than we can get the maximum of diversity. Whereby the combination of frequency correlation matrix (R_F) and time correlation matrix (R_T) in the system will improve the performance. Base on the Equation of variance (22), $\partial^2_{I_{m,n}}$ of $I_{m,n}(k)$, the value of coefficient $\sum_{p=0}^{k-1}\left[\left|S_{m,n}(p-k)\right|^2\right]$ must below than 1, to achieve that, the value of $S_0 \approx 1$, so that it will produce a small value of variance. This finding confirms to the suggestion that the smaller the variance, the better the performance of PEP.

Conclusion:

In this paper, a new data conjugate and data conversion subcarrier mapping scheme (ICI-SC technique) is proposed. By analyzing the PEP performance with different subcarrier mapping scheme (ICI-SC technique) in the STFBC MIMO-OFDM system, the system with a low ICI and bandwidth efficiency at a high transmission rate and SNR can be derived. In principle, ICI is less severe for STFBC with high diversity order. The simulation results show that by using the new data conjugate subcarrier mapping scheme (ICI-SC technique) the PEP has been improved. Therefore, diversity not only improves the performance of MIMO-OFDM systems in the multipath Rayleigh channels, but also makes the system robust to intercarrier interference. As a result, the PEP for new data conjugate subcarrier mapping scheme (ICI-SC technique) for STFBC MIMO-OFDM system produces the best performance than the others.

REFERENCES

Chiueh, T.D. and P.Y. Tsai, 2007. OFDM baseband Receiver Design for Wireless Communications. John Wiley and Sons (Asia) Pte Ltd, Singapore.

Dũng Ngoc Đào and Chintha Tellambura, 2005. Intercarrier Interference Self-Cancellation Space-Frequency Codes for MIMO-OFDM. IEEE Transaction. on Vehicular Technology, 54(5): 1729-1738.

Foschini, G.J. and M.J. Gans, 1998. On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas. Wireless Personel. Communication, 6: 311-335.

Gordon L. Stuber, John R. Barry, Steve W. McLaughlin, Ye (Geoffrey) Li, Mary Ann Ingram and Thomas G. Pratt, 2004. Broadband MIMO-OFDM Wireless Communications. IEEE, 92.

Gong, Y. and K.B. Letaief, 2001. Low Rank Channel Estimation for Space Time Coded Wideband OFDM System. IEEE Vehicular Technology Conference, 2: 848-852.

Hirosaki, B., 1981. An Orthogonally Multiplexed QAM System Using the Discrete Fourier Transform. IEEE Transaction Communication, 29: 982-989.

Jeruchim, M.C., P. Balaban, *et al.*, 2000. Simulation of Communication Systems Modeling, Methodology, and Techniques. Kluwer Academic/Plenum Publishers.

Li Zhao, Ping Zhang, 2006. A New ICI Self Cancellation Scheme Based on Repeated Symbol in OFDM System, 1216-1220.

Liu, Z., X. Ma and G.B. Giannakis, 2002. Space-Time Coding And Kalman Filtering For Time-Selective Fading Channels. IEEE Transaction Communication, 50: 183-186.

Lee, K.F. and D.B. Williams, 2000. A Space-Time Coded Transmitter Diversity Technique for Frequency Selective Fading Channels. Proceeding IEEE Sensor Array and Multichannel Signal Processing Workshop, 149-152.

Majid Fozunbal, Steven W. McLaughlin and Ronald W. Schafer, 2005. On Space Time Frequency Coding over MIMO-OFDM Systems. IEEE Transactions on Wireless Communications, 4(1).

Qiang Shi, Yong Fang, Min Wang, 2009. A Novel ICI Self-Cancellation Scheme for OFDM systems. 5th International Conference on Wireless communications, networking and mobile computing, 1-4.

Russel, M. and Gl-Stuber, 1995. Interchannel Interference Analysis of OFDM in a Mobile Environment. IEEE 45th Vehicular Technology Conference.

Sathananthan, K., R.M.A.P. Rajatheva and S.B. Slimane, 1999. Cancellation Technique to Reduce Intercarrier Interference in OFDM. Electronics Letters, 36(25): 2078-2079.

Slimane Ben Slimane, K.Sathanathan, R.M.A.P. Rajatheva, 2000. Analysis of OFDM in the Presence of Frequency Offset and a Method to Reduce Performance Degradation. IEEE Transactions on Communications, 1: 72-76.

Taewon Hwang, Chenyang Yang, Gang Wu, Shaoqian Li and Geoffrey Ye Li, 2009. OFDM and Its Wireless Applications: A survey. IEEE Transactions on Vehicular Technology, 58(4): 1673-1694.

Winters, J., 1987. On the Capacity of Radio Communication System with Diversity in a Rayleigh Fading Environment. IEEE J. Select. Areas Communication, 5: 871-878.

Weifeng Su, Zoltan Safar and K.J. Ray Liu, 2005. Towards Maximum Achievable Diversity in Space, Time, and Frequency: Performance Analysis and Code Design. IEEE Transaction On Wireless Communications, 4: 1847-1857.

Weifeng Su, Zoltan Safar, and K.J. Ray Liu, 2003. Obtaining Full-Diversity Space-Frequency Codes from Space-Time Codes via Mapping. IEEE Transactions on Signal Processing, 51(11).

Weifeng Su, Zoltan Safar and K.J. Ray Liu, 2006. Diversity Analysis of Space Time Frequency Coded Broadband OFDM Systems. IEEE Transactions on Communications, 54(5): 878-888.

Yu, K. and B. Ottersten, 2002. Models For MIMO Propagation Channels: A Review. Wiley Journal on Wireless Communication. and Mobile Computer, 2: 653-666.

Yue, J. and J.D. Gibson, 2002. Performance of Space-Time Block Coded OFDM System. 36^{th} Asilamor Conference on Signals, Systems and Computers, 2: 1862-1866.

Yeon-Ho Chung, 2008. Intercarrier Interference Self-Cancellation with Improved Bandwidth Efficiency for OFDM Transmission Systems. International Conference on Convergence and Hybrid Information Technology, 95-99.

Zhao, Y. and S.G. Haggman, 2001. Intercarrier interference self-cancellation scheme for OFDM mobile communication systems. IEEE Transactions on Communications, 49: 1185-1191.