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Full Length Research Paper

Diversity technique for multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system using a new subcarrier mapping scheme

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The objective of this research is to propose a new subcarrier mapping scheme intercarrier interference self cancellation intercarrier interference self cancellation (ICI-SC) technique using data allocation in space time frequency block codes (STFBC) multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system. It aims to achieve maximum diversity order and to compensate integrated effect of frequency offset (FO) for intercarrier interference (ICI) reduction in the system. Using theoretical derivation of the pairwise error probability (PEP), a simulation model is then being used to compare with adjacent and symmetric subcarrier mapping scheme with FO. The results show that the ICI contained in the received signals can be effectively reduced using a new subcarrier mapping scheme. Thus, the proposed method is using STFBC outperforms existing subcarrier mapping schemes by approximately reducing the ICI with maximum diversity order in MIMO-OFDM system.

Key words: Intercarrier interference self cancellation (ICI-SC), multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM), frequency offset (FO), space time frequency block codes (STFBC).

INTRODUCTION

Multiple input multiple output orthogonal frequency division multiplexing (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 domains (Muthanna and Michael, 2010; Abdul Wahab and Ain, 2010; Su et al., 2005). Hence, space time frequency block codes (STFBC) was applied into MIMO-OFDM system to efficiently achieve full diversity that can improve the signal quality and also increase spectral efficiency (Yang et al., 2009; Su et al., 2006; Majid et al., 2005). STFBC is a simple yet ingenious transmit diversity technique in MIMO technology, and has rapidly become one of the most active research areas in wireless communications. A combination of MIMO systems with OFDM modulation using STFBC, and taking advantage of the spatial, temporal, and frequency diversities available in frequency selective MIMO channels (Zhang et al., 2007) have produced very high advantage in communications system and give great benefit to the wireless communications system. This paper addresses a related problem in realizing practical mobile communication system with MIMO and OFDM technologies. It is concerned about the MIMO-OFDM system. 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 Ben Slimane et al. (2000) and Đào and Tellambura (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 intercarrier interference self cancellation (ICI-SC) technique using STFBC is proposed to achieve the improved frequency diversity with optimal distance between subcarriers and repeated subcarriers that can reduce

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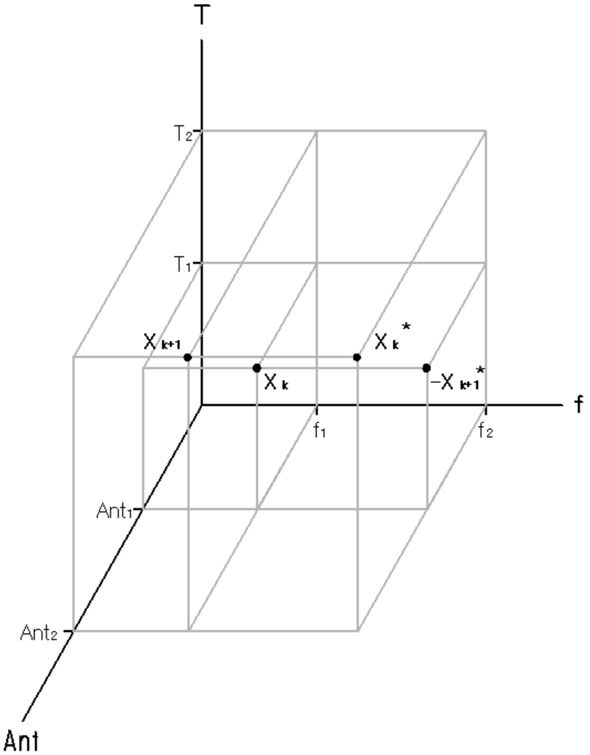


Figure 1. Coding in STFBC method.

intercarrier interference (ICI) with maximum diversity order system. However, this scheme inherently reduces throughput and bandwidth efficiency by a factor of 2 (repeated symbols) (Chung, 2008). Nevertheless, this problem can be improved or compensated by using the higher order modulation scheme with a high transmission rate (Qiang et al., 2009; Zhao and Zhang, 2006).

In this paper, a new subcarrier mapping scheme ICI-SC technique using STFBC is proposed to compensate integrated effect of FO in MIMO-OFDM system and then compare existing subcarriers mapping scheme introduced by Ben Slimane et al. (2000) and Đào and Tellambura (2005). Theoretically, pairwise error probability (PEP) equation has also been derived especially considering time and frequency correlation with multiple antennas. The derivations are then being simulated to verify the achievement of maximum diversity order and minimum ICI generated by FO with the bandwidth efficient in the system.

STFBC MIMO-OFDM SYSTEM

Now, let the MIMO channel is assumed to be constant over each OFDM block period, but vary from one OFDM block to another (Taewon et al., 2009). 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;

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

where $X_m(k)$, $H_{m,n}(k)$, $S_{m,n}(0)$, $z_n(k)$ are transmitted signal, channel impulse response, desired k^{th} carrier component and complex Gaussian thermal noise, respectively.Space, time, and frequency are performed using space time (ST) code and space frequency (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 Su et al. (2005) as shown in Figure 1 where Ti (time slots), f (frequencies) and Ant (Antennas).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 intercarrier interference self cancellation (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 (Đào and Tellambura, 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:

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

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 system with k^{th} subcarrier, the coefficients $S_{m,n}(0)$ from Zhao and Haggman (2001) is a constant with respect to subcarrier index *k = 0*, where $\varepsilon_{m,n}$ is the normalized frequency offset (NFO).

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

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

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

DESIGN CRITERIA OF PEP WITH FO

STF coding strategy was introduced in Liu et al. (2002) for two transmit antennas and subsequently further developed in Zhang et al. (2007), for multiple transmit antennas. In Su et al. (2003), the performance criteria for STF codes were derived and an upper bound on the maximum achievable diversity order was established. The result 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 Su et al. (2003) is adopted for the PEP with FO which can be formulated as follows:

$$P(D \to \overline{D}) \le \ell \binom{2\Gamma N - 1}{\Gamma N} \left(\prod_{i=1}^{\Gamma} \lambda_i \right)^{-N} \xi^{-\Gamma N} \quad (8)$$

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

From Equation (8), the following equation will be recognized:

$$\Gamma = rank(\Delta D \cdot R) \tag{9}$$

where $\Delta D = (D - \overline{D})(D - \overline{D})^H$. *D* is the transmitted codeword, and $\overline{D}$ 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 *Hm,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

$$R_F = \{E\{H_{m,n} \quad H_{m,n}\}\} = w\Lambda w^H \tag{10}$$

where $H_{m,n} = (I_k \otimes w)A_{m,n}$. The I_k in this case is identify matrix of size *k* and $w = \exp(-j2\pi\Delta f)$ and $A_{m,n} = \lfloor \alpha_{m,n}{}'(0)..\alpha_{m,n}{}'(L-1)..\alpha_{m,n}{}^k(0)..\alpha_{m,n}{}^k(L-1) \rfloor$

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

$$R_T \otimes \Lambda = \{E\{A_{m,n} \quad A_{m,n}{}^H\}\} \tag{11}$$

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

They are modeled as zero-mean complex Gaussian random variable (GRVs) with variance. Combining (10) and (11), $R_{m,n}$ can be calculated as follows

$$R_{m,n} = R_T \otimes (w\Lambda w^H) = R_T \otimes R_F \tag{12}$$

Thus,

$$R = I_{m,n} \otimes (R_T \otimes R_F) \tag{13}$$

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 (Zhao and Zhang, 2006) is,

$$\sigma^2_{I_{m,n}} = E\left[\left|I_m(k)\right|^2\right]$$

$$= \left[\sum_{p=0}^{K-1} E\left[\left|X_m(p)\right|^2\right] E\left[\left|H_{m,n}(p)\right|^2\right] E\left[\left|S_{m,n}(p-k)\right|^2\right]\right] - E\left[\left|X_{m,}(k)\right|^2\right] E\left[\left|H_{m,n}(k)\right|^2\right] E\left[\left|S_{m,n}(0)\right|^2\right] \tag{14}$$

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 (Liu et al., 2002), the sum $\sum_{p-0}^{K-1} E\left[\left|S_{m,n}(p-k)\right|^2\right] = 1$. Then, Equation (15) becomes:

$$\sigma^2_{I_{m,n}} = 1 - S_0 \tag{15}$$

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 SNR (signal to noise ratio). Therefore, the equivalent SNR (E_b/N_o) at the receive antenna with the FO is given as (Ðào and Tellambura, 2005):

$$\tilde{\xi} = \left(\frac{S_0}{(1-S_0)\xi + 1}\right)\xi \tag{16}$$

and the performance loss due to FO is given by (Ðào and Tellambura, 2005):

$$\ell = \left(\frac{S_0{}^2}{\xi(1-S_0)+1}\right)^{-\Gamma N} \tag{17}$$

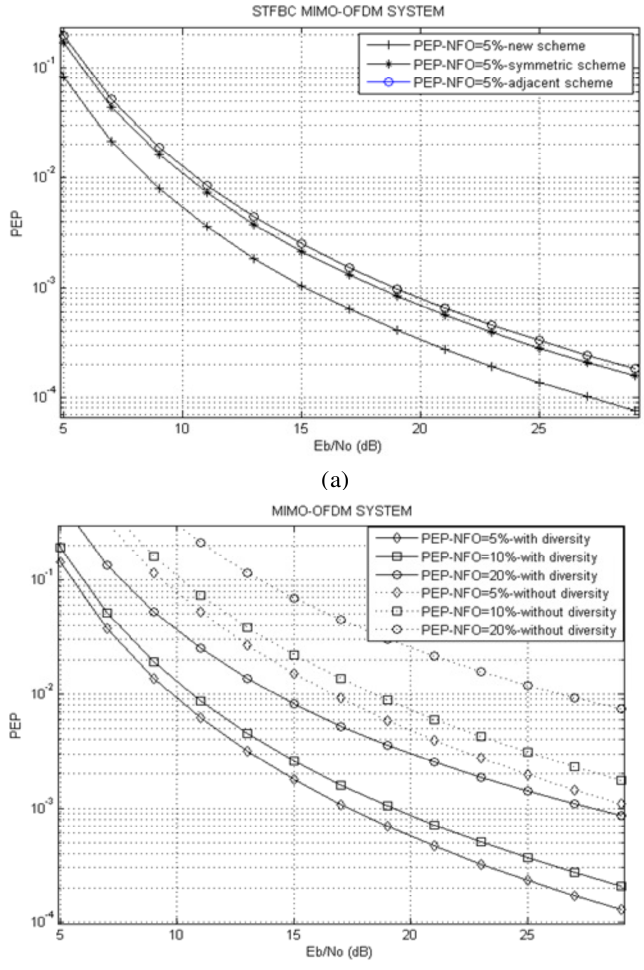
SIMULATION RESULTS AND PERFORMANCE EVALUATION

The results for the performance of the new subcarrier

Table 1. Performance analysis parameter (Chiueh et al., 2007).

Parameter	Value
Bandwidth (BW)	1.25 MHz
Sampling frequency	1.92 MHz
Sampling time	5.208×10-7 s
No. of subcarriers	128 subcarriers
Modulation technique	64-QAM
Maximum doppler frequency	100 Hz
IFFT size	128
Channel model	COST207 typical urban (TU) channel path delays, L_p = (0, 0.2×10^{-6}, 0.5×10^{-6}, 1.6×10^{-6}, 2.3×10^{-6}, 5.0×10^{-6}) s; Average path gains = [0.5011, 1.122, 0.6309, 0.251, 0.158, 0.1] dB

mapping schemes ICI-SC technique using STFBC for Multipath Rayleigh fading channel in MIMO-OFDM system are presented in Table 1.The simulation results present PEP curves as functions of SNR and NFO. Figure 2a shows that the new data conjugate subcarrier mapping scheme ICI-SC technique from Equation (4) has the best PEP performance as compared to data conjugate symmetric and adjacent scheme which indicates that this method produce lower noise and interference with FO. For example, at PEP = 10^{-3}, the SNR value for new data conjugate subcarrier mapping scheme is 15 dB. The PEP performance for new data conjugate subcarrier mapping between symmetric and adjacent scheme are about 3 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 for example the codeword of subcarrier $(-X(0))$ becomes $(-X(N-1))$. This 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 Equations (14) and (15), 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 data conjugate 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.



(a)

(b)

Figure 2. (a) PEP performance of STFBC MIMO-OFDM for NFO = 5% with different subcarrier mapping scheme (ICI-SC technique) using ML decoding technique (b) PEP performance for MIMO-OFDM system with and without diversity at different NFO using ML decoding technique.

The PEP performance of STFBC coding schemes with and without diversity techniques is illustrated in Figure 2b. In this system, the STFBC system with and without diversity technique for NFO 5, 10 and 20% is simulated. If the value of S_o from Equations (14) and (15) is decreased, the equivalent SNR at the receive antenna with NFO from Equation (17) will be increased. As a result, the PEP performance of the system will be increased as expressed from Equation (8). Figure 2b illustrates the PEP performance for the systems with diversity technique are increased as compared to the system without diversity technique. As shown Figure 2b, the performance of PEP will be decreased when the NFO is nonzero. In this system, the performance of MIMO-OFDM system at NFO = 5, 10 and 20% with and without diversity technique are being compared. At PEP = 10^{-2} and NFO = 5%, the PEP performance for the system with and without diversity technique is about 7.5 dB and at NFO = 10% for the system with and without diversity the PEP performance is 8.2 dB and for NFO 20%, the PEP performance between this two techniques is 13 dB. It shows that for the system with diversity technique, the PEP is much better than without diversity technique.

Conclusion

In this paper, a new data conjugate subcarrier mapping scheme ICI-SC technique is proposed using STFBC in MIMO-OFDM system. Performance degradations caused by FO are also discussed in term of PEP. By choosing appropriate subcarrier mapping scheme combining with STFBC, the diversity order can be maximized and hence minimize the ICI. The results have confirmed that the proposed subcarrier mapping scheme ICI-SC technique using STFBC can be considered as a promising candidate in the MIMO-OFDM based system. For this research, it is assumed that the channel state information (CSI) is known to the receiver. One direction for the future work is to develop channel estimation algorithms applicable to fast fading channels to investigate the performance signals by using the channel estimation, such as mean square error (MSE), least square estimation (LSE) and recursive square error estimation (RSEE).

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