Interference Self-Cancellation Schemes for Space Time Frequency Block Codes MIMO-OFDM system

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Summary
This paper highlights the Space Time Frequency Block Codes (STFBC) that exploit both spatial, time and frequency diversity can be designed using orthogonal frequency division multiplexing (OFDM). Intercarrier interference (ICI) self-cancellation schemes were often employed in many OFDM systems as a simple and effective approach to suppress ICI caused by carrier frequency error (CFO). In this paper, we propose a space time frequency block coding technique MIMO-OFDM system with ICI self-cancellation of data conjugate method, which is capable of both error correction and ICI reduction produced by frequency offset (FO). Then, the system performance of the data-conjugate method with diversity techniques is compared with those of the data-conversion method. As results, it can be shown that the STFB codes MIMO-OFDM system with FO, the data-conjugate method can make remarkable improvement of the BER performance and is better than the data-conversion method and the conventional OFDM system.
Key words:
Orthogonal Frequency Division Multiplexing (OFDM), Multiple Input Multiple Output (MIMO), intercarrier interference self cancellation, Space Time Frequency Block Codes (STFBC).

1. Introduction

The next generation wireless communication systems will provide mobile stationery user with high-speed internet access, high quality multimedia streams, and mobile computing as well as data transmissions at higher data rates than ever before. The rapidly expanding demands for services with high data rates, high quality, and high mobility, are driving recent developments in communication technologies for broadband wireless communications.

Currently, MIMO-OFDM is a technology that provides spectral efficiency of OFDM and throughput/diversity gains of MIMO systems to achieve a high performance, spectral efficient broadband communication system [1],[2]. The use of MIMO technology in combination with OFDM [1],[2],[3], therefore, become an attractive solution for future broadband wireless systems.

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A multi-antenna OFDM system is very sensitive to CFO, which introduces ICI. One of the most challenging problems of OFDM modulation in MIMO system is ICI [4]. In MIMO-OFDM system, individual subcarriers in a time invariant multipath model can be made to be orthogonal by the use of guard interval. However this orthogonality is destroyed when channel is time variant. The loss of orthogonality reduces the useful signal in each subcarrier, and introduces ICI amongst subcarriers. The occurrence of ICI leads to an irreducible error floor in conventional OFDM receivers, hence degrading the MIMO-OFDM system performance.

Consequently, one of the principal shortcoming of OFDM system is its high sensitivity to timing errors and CFO [5],[6]. MIMO-OFDM receiver in the presence of CFO with even a small fraction of subcarrier spacing will degrade the performance of MIMO-OFDM receiver greatly [7]. CFO not only causes the amplitude degradation of the desired signal, but also introduces ICI.

Several methods have been proposed to reduce the effect of the ICI. Currently, five different approaches for reducing ICI have been developed including: ICI self-cancellation [8],[9],[10], frequency-domain equalization [11], time domain windowing scheme [12], frequency offset estimation and compensation techniques [13], and Doppler diversity.

In despite of a loss of bandwidth, the ICI self-cancellation scheme is a very simple way for suppressing ICI in OFDM system. Its main idea is to modulate one data symbol onto a group of subcarriers with predefined weighting coefficients. By doing so, the ICI components generated within a group can be "self cancelled" each other.

To further improve the performance, one may consider STF coding across multiple OFDM blocks to exploit all the available diversities in the spatial, temporal, and frequency domains. The STF coding strategy was first proposed in [14] for two transmit antennas and further developed in [15],[16], and [17] for multiple transmit antennas. In [15], the performance criteria for STF codes were derived, and an upper bound on the maximum achievable diversity order was established. The result from [18], shown that the upper bound proposed STF codes were guarantee to achieve the full spatial, temporal, and, frequency diversities.

So far there is no literature on the performance evaluation of the ICI-SC techniques and space time frequency block coding technique for MIMO OFDM. Therefore, in this paper, we propose a STFBC method of MIMO-OFDM employing Alamouti's scheme, [19] with low complexity to minimize ICI generated by FO. We then analyze and compare the effect of ICI-SC scheme with other conventional methods. Due to the similar natural of ICI caused by FO, phase noise, and time varying channels, we present the simulation results for FO only.

The contributions of this paper can be summarized as follows :

1) The performance of STFB codes with FO is analyzed using ICI-SC and different methods of ICI-SC .
2) A new class of STFBC MIMO-OFDM codes is proposed, which is capable of both error correction and ICI reduction produced by FO for quasi static Rayleigh fading channels.

The rest of the paper is organized as follows. Sections 2, presents the model of MIMO-OFDM systems with FO. We derive the STFB code performance criteria with FO using ICI-SC schemes and describe briefly on different ICI-SC schemes in OFDM system in section 3. In section 4, simulation frameworks are given and section 5 includes the simulation results and analysis. The results of the paper are concluded in section 6.

2. Model of MIMO OFDM with Frequency Offset (FO)

We consider an STFB-coded MIMO-OFDM system with M transmit antennas, and N receive antennas, and K subcarriers, as shown in Fig. 1. Suppose that frequency selective fading channels between each pair of transmit and receive antennas have L_p independent delay paths and the same power delay profile. The MIMO channel is assumed to be constant over each OFDM block period, but it may vary from one OFDM block to another.

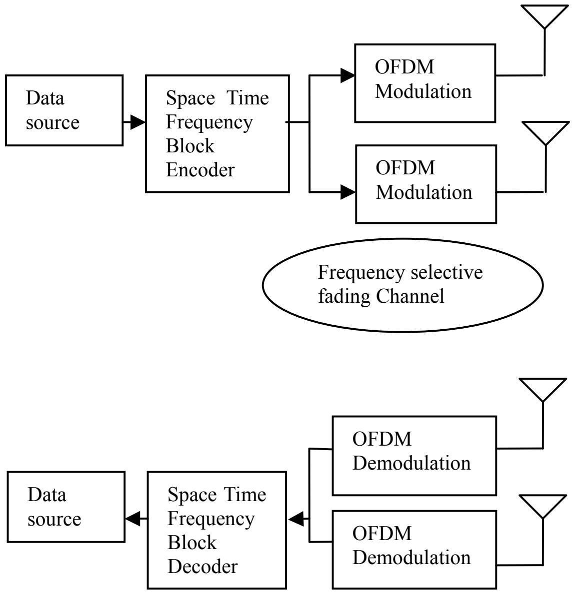

Figure 1.0: Block diagram of a MIMO-OFDM with ICI self-cancellation

In the MIMO systems, the received k[th] subcarrier is expressed as follows:

$$y_n(k) = \sum_{m=1}^{M} C_m(k) H_{m,n}(k) S_{m,n}(0) + I_n(k) + \omega_n(k) \tag{2.1}$$

There is always a frequency offset δf at the sampling points of received signal in frequency domain [13],[20]. In the MIMO-OFDM systems, let the normalized frequency offset of the transmission link from transmit antenna m and receive antenna n be $\varepsilon_{m,n}$. For MIMO systems, the inter carrier interference term $I_n(k)$ at subcarrier k of each receive antenna n is the superposition of M intercarrier interference terms $I_{m,n}(k)$ caused by transmitted signals from transmit antennas m as

$$I_n(k) = \sum_{m=1}^{M} I_{m,n}(k) \tag{2.2}$$

where

$$I_{m,n}(k) = \sum_{p=0}^{K-1} \sum_{p \neq k} C_m(p) H_{m,n}(p) S_{m,n}(p-k) \tag{2.3}$$

and coefficients

$$S_{m,n}(k) = \frac{\sin(\pi(k+\varepsilon_{m,n}))}{K\sin\left(\frac{\pi}{K}(k+\varepsilon_{m,n})\right)}.\exp\left(j\pi\left(1-\frac{1}{K}\right)(k+\varepsilon_{m,n})\right) \tag{2.4}$$

Note that coefficients $S_{m,n}(0)$ is a constant with respect to subcarrier index k=0.

$$S_{m,n}(0) = \frac{\sin(\pi\varepsilon_{m,n})}{K\sin\left(\frac{\pi}{K}\varepsilon_{m,n}\right)}.\exp\left(j\pi\left(1-\frac{1}{K}\right)\varepsilon_{m,n}\right) \tag{2.5}$$

If the value of normalized frequency offset (ε) becomes larger, the desired part $|S_{m,n}(0)|$ decreases and the undesired part $|S_{m,n}(k)|$ increases [4].

The equivalent form of

$$H_{m,n}(k) = \sum_{l=0}^{Lp-1} \alpha_{m,n}(l)e^{-j2\pi k\Delta f\tau 1}, \text{ j}=\sqrt{-1} \tag{2.6}$$

where $\Delta f = 1/T_s$ is the subcarrier spacing and T_s is the OFDM symbol duration. We assume that the channel state information $H_{m,n}(k)$ is known at the receiver, but not at the transmitter and the channel vector H is of size $KMN \times 1$ is given by

$$H = \left[H_{1,1}{}^T \ldots H_{M,1}{}^T H_{1,2}{}^T \ldots H_{M,2}{}^T \ldots H_{1,N}{}^T \ldots H_{M,N}{}^T\right]^T \tag{2.7}$$

Hence, in (2.1) we can group $H_{m,n}(k)$ and $S_{m,n}(0)$ as:

$$\overline{H}_{m,n}(k) = S_{m,n}(0)H_{m,n}(k) \tag{2.8}$$

Matrices $\overline{H}_{m,n}(k)$ are arranged into the matrix $\overline{H}$, which accounts for the presence of frequency offset.

$$\overline{H}_{m,n}(k) = \left[\overline{H}_{m,n}(0)\overline{H}_{m,n}(1)\ldots\overline{H}_{m,n}(K-1)\right]^T \tag{2.9}$$

The equivalent noise at each received subcarrier is a sum of the ICI noise and complex Gaussian thermal noise terms as

$$\overline{Z}_n(k) = I_n(k) + \omega_n(k) \tag{2.10}$$

The MIMO-OFDM model with FO is now written as

$$Y = D\overline{H} + \overline{Z} \tag{2.11}$$

where Y is the received vector and the matrix D consists of transmitted symbols and the data matrix D size $KM \times KMN$ matrix constructed from the STFB codeword that can be expressed as $K \times M$

$$C_m = \begin{bmatrix} c_1(0) & c_2(0) & c_M(0) \\ c_1(0) & c_2(0) & c_M(0) \\ . \; . \; . & . \; . \; . & . \; . \; . \\ c_1(K-1) & c_2(K-1) & c_M(K-1) \\ c_1(K-1) & c_2(K-1) & c_M(K-1) \end{bmatrix} \tag{2.12}$$

where

$$D_m = diag\left[c_m(0), c_m(1), \ldots, c_m(K-1)\right] \tag{2.13}$$

The matrix representation in (2.11) is suitable for deriving the PEP performance of STFB codes.

3. Design criteria

In this section, we derive the performance criteria for STFB coded MIMO-OFDM system with FO using ICI-SC schemes.

3.1 Space Time Frequency Block Coding Schemes

Space Time Frequency Block (STFB) coding schemes are used to enhanced the system performance and reliability by taking advantage of diversity of space, time and frequency inherent in MIMO-OFDM system. The coding distributes symbols along transmit antennas, time slots and OFDM sub channels. A STFB codeword may occupy several OFDM symbols which can increase the diversity order [17],[21].

Assume that the overall coded symbol sequence D is transmitted. The pairwise error probability of deciding erroneously in favor of the coded sequence $\overline{D}$, conditioned on the channel realization $\overline{H}$ over two OFDM blocks, is given by (3.1). Suppose that D and $\overline{D}$ are two different matrices related to two different STFB which are the pairwise error probability (PEP) between D and $\overline{D}$ can be upper bounded as [22].

$$P(D \to \overline{D}) \leq \begin{pmatrix} 2\Gamma N - 1 \\ \Gamma N \end{pmatrix} \left(\prod_{i=1}^{\Gamma} \lambda_i \right)^{-N} \rho^{-\Gamma N} \tag{3.1}$$

Where

$$\Gamma = \text{rank}(\left(\Delta D.R\right) = \text{rank}\,\Delta\left(\left\{\Delta D_{m,n} R_{m,n}\right\}\right) \tag{3.2}$$

$$\Delta D = (D - \overline{D})(D - \overline{D})^H , \tag{3.3}$$

We can also define the frequency correlation matrix, R_F, as

$$R_F == \left\{E\left\{H_{mn} H_{mn}{}^H\right\}\right\} = w \Lambda w^H \tag{3.4}$$

where

$$H_{m,n} = (I_K \otimes w) A_{m,n} \tag{3.5}$$

Where $\otimes$ denotes the tensor product, I_K is the identity matrix of size K, and using the notation $w = \exp(-j2\pi\Delta f)$, we have

$$w = \begin{bmatrix} 1 & 1 & 1 \\ w^{\tau 0} & w^{\tau 1} & w^{\tau L-1} \\ w^{(N-1)\tau 0} & w^{(N-1)\tau 1} & w^{(N-1)\tau L-1} \end{bmatrix} \tag{3.6}$$

and

$$A_{mn} = \left[\alpha_{mn}{}^1(0)\alpha_{mn}{}^1(1).\alpha_{mn}{}^1(L-1)..\alpha_{mn}{}^K(0)\alpha_{mn}{}^K(1).\alpha_{mn}{}^K(L-1)\right]^T \tag{3.7}$$

Substituting (3.4) into (3.5), $R_{m,n}$ can be calculated as follows:

$$\begin{aligned} R_{m,n} &= E\left\{(I_K \otimes w) A_{m,n} A_{m,n}{}^H (I_K \otimes w)^H\right\} \\ &= (I_K \otimes w) E\left\{A_{m,n} A_{m,n}{}^H\right\}(I_K \otimes w^H) \end{aligned} \tag{3.8}$$

Thus, the correlation matrix $E\left\{A_{m,n} A_{m,n}{}^H\right\}$ can be expressed as

$$E\left\{A_{m,n} A_{m,n}{}^H\right\} = R_T \otimes \Lambda \tag{3.9}$$

where $\Lambda = diag\left\{\delta_0{}^2, \delta_1{}^2, ..., \delta_{L-1}{}^2\right\}$, and R_T is the temporal correlation matrix of size $K \times K$, whose entry in the p-th row and the q-th column is given by $r_T(q-p)$ for $1 \leq p, q \leq K.$

Therefore,

$$R_{m,n} = R_T \otimes (w \Lambda w^H) = (R_T \otimes R_F) \tag{3.10}$$

and λ_i $(i = 1,......., \Gamma)$ are the non-zero/positive eigenvalues of $\left(\Delta D.R\right)$.

The superscript H stands for the complex conjugate and transpose of a matrix and ρ is the average signal-to-noise ratio (SNR).

We need to minimize the upper bound of the PEP for better performance. Consequently, we can formulate the performance criteria for STFB codes as follows:

- Diversity (rank) criterion : the minimum rank of $\left(\Delta D.R\right)$ over all pairs of different codewords D and $\overline{D}$ should be as large as possible.
- Product criterion: the minimum value of the product $\prod \lambda_i$, over all pairs of distinct D and $\overline{D}$ should also be maximized.

However, we can find the maximum achievable diversity. Since the rank of $\left(\Delta D\right)$ is at most M, the rank of R is at most L_p, and that of $\left(\Delta D.R\right)$ is at most K. In addition, according to the rank inequalities on Hadamard products and tensor products, we have

$$rank\left(\Delta D.R\right) \leq rank\left(\Delta D\right) rank\left(r\right) \leq L_p M \tag{3.11}$$

Thus,

$$rank\left(\Delta D.R\right) \leq \min\left\{L_p, K\right\} \tag{3.12}$$

From the above discussion, we know the maximum achievable diversity is at most *min (L_pMN, KN)* , which is in agreement with the results of [23], [24], and [25] and the diversity order of STFB codes is ΓN [13].

3.2 Space Time Frequency Block Coding schemes with FO

These analysis are focusing with the two assumption below:-

(1) The path gain $\alpha_{m,n}{}^{k}(l)$ are independent for different paths and different pairs of transmit and receives antennas and the time correlation is the same for all transmit and receive antenna pairs and all paths for the second order statistics.

(2) The value of NFOs $\varepsilon_{m,n}$ are independent of the channel coefficients. During the process of transmission, data over multiple antennas have correlation among the transmitted data streams and therefore, the ICI noise terms, $I_{m,n}(k)$ are also correlated with respect to the subscript m. The value of ICI in equations 2.2 and 2.3 are independent, and all the receive antennas will have the same variance and zero mean.

Using the MIMO-OFDM model developed in Section 2, we derive PEP performance given in (3.14) with FO in the following.

Let $p(\varepsilon)$ be the probability density function (pdf) of $\varepsilon_{m,n}$. In the case of constant FO, $p(\varepsilon)$=1, S_o can be evaluated as

$$S_o = \left(\frac{\sin(\pi\varepsilon_0)}{\pi\varepsilon_0} \right)^2 = [\sin c(\varepsilon_0)]^2 \tag{3.13}$$

and the ICI noise of MIMO-OFDM $\overline{Z}_n(k)$ given in (2.10) is zero mean complex with variance

$$\sigma_z{}^2 = M(1 - S_o + 1/\rho) \tag{3.14}$$

whereas, the values of $\sigma_z{}^2$ are identical for all receive antennas.

From 2.1, the received signal power is multiplied by S_o, therefore the equivalent SNR at each antenna with FO is

$$\widetilde{\rho} = \frac{MS_o}{\sigma_z{}^2} = \left(\frac{S_0}{(1 - S_0)\rho + 1} \right)\rho \tag{3.15}$$

The correlation matrix defined in (3.10) for equivalent channel matrix $\overline{H}_{m,n}$ given in (2.9) has a new form

$$\begin{aligned} R_{m,n} &= S_o(R_T + R_F) \\ &= S_o R_{m,n} \end{aligned} \tag{3.16}$$

Hence, the matrix $\Delta D.R$ in (3.2) becomes matrix $\Delta D.\widetilde{R}$

$$\Delta D.\widetilde{R} = \text{So}\,(\Delta D.R) \tag{3.17}$$

Where the value of $\Delta D.\widetilde{R}$ and $\Delta D.R$ have the same rank Γ and substitute $\widetilde{\lambda} = So\lambda i$ and $\widetilde{\rho}$ into (3.1) , re-arrange the terms, the PEP expression with frequency offset is

$$P(D \to \overline{D}) \le L_o \begin{pmatrix} 2\Gamma N - 1 \\ \Gamma N \end{pmatrix} \left(\prod_{i=1}^{\Gamma} \lambda_i \right)^{-N} \rho^{-\Gamma N} \tag{3.18}$$

where

$$L_o = \left(\frac{S_o{}^2}{\rho(1 - S_o) + 1} \right)^{-\Gamma N} \tag{3.19}$$

Comparing (3.1) and (3.18), we discern that L_o represents the PEP performance loss due to FO. From (3.13), (3.18), and (3.19), we can conclude the theoretical as follows:

1) STFB codes without FO still valid in the case of FO for the design criteria. The diversity order and coding gain for code design should maximize.

2) If FO is nonzero, the BER curves will shift to the right. However, with the same NFO, the shift of BER curves of lower diversity order systems is larger than the shift of BER curves of the system with higher diversity order. This is due to the fact that given the same loss factor L_o; the SNR compensation for this loss is smaller for the codes with higher diversity order from equation (3.17). Thus, the higher diversity order systems are more robust to the effects of FO.

3) At the same transmit power, if the NFO increase then the BER performance loss also be increase. Therefore, at the same BER, the higher the NFO, the further the BER curved shifted to the right.

These analytical results can be preferred since the ICI term is considered as an additional Gaussian noise. When FO is small, the ICI power is smaller than the power of the thermal noise; thus its impact on the performance of STFB codes is negligible. However, when the FO is large, the ICI noise dominates thermal noise. Therefore, the ICI power increases with desired signal power.

3.3 ICI Self Cancellation Schemes

In [4], the effect of the ICI coefficient with respect to FO was identified where it showed that the ICI coefficient gradually changes with respect to the position of the subcarriers. The closer the subcarriers with respect to the desired subcarrier, the more interference occurred especially at the adjacent positions.

Due to very small ICI coefficients difference between majorities of subcarrier adjacent pairs, ICI self-cancellation scheme was inherent. The scheme by [4] is a form of redundancy coding where it maps the data to be transmitted onto adjacent papers rather than onto single subcarriers before performing IFFT on the OFDM block.

A space time frequency codeword has the form (3.1). Applying the interference cancellation modulation scheme, for r=2, this scheme is actually a repetation scheme but the repeated symbols are sign-reversed and conjugate sign reversed. Let the number of OFDM subcarriers K=2 $\hat{K}$. Suppose that the length of an STFB codeword equals the number of subcarriers K. If the STFB codeword length is smaller than K, a zero-padding matrix can be used for the remaining subcarriers. In the case of MIMO-OFDM, the repeated rows are sign-reversed (3.20) and conjugate sign-reversed (3.21) to form new ISC-STFB codewords as

$$C_{m1} = \begin{bmatrix} c_1(0) & c_2(0) & c_M(0) \\ -c_1(0) & -c_2(0) & -c_M(0) \\ . \; . \; . \; . & . \; . \; . \; . & . \; . \; . \; . \\ c_1(K-1) & c_2(K-1) & c_M(K-1) \\ -c_1(K-1) & -c_2(K-1) & -c_M(K-1) \end{bmatrix} \tag{3.20}$$

$C_m(k) = x(k)$
$C_m(k+1) = -x(k)$ (data conversion method)

$$C_{m2} = \begin{bmatrix} c_1(0) & c_2(0) & c_M(0) \\ -c_1(0)* & -c_2(0)* & -c_M(0)* \\ . \; . \; . \; . & . \; . \; . \; . & . \; . \; . \; . \\ c_1(K-1) & c_2(K-1) & c_M(K-1) \\ -c_1(K-1)* & -c_2(K-1)* & -c_M(K-1)* \end{bmatrix} \tag{3.21}$$

$C_m(k) = x(k)$
$C_m(k+1) = -x(k)*$ (data conjugate method)

The combination of ICI cancellation modulation (ICM) and ICI cancellation demodulation (ICD) is called ICI self-cancellation [26]. ICM is a process where one data symbol is sent over two subcarriers as illustrated in Figure 3.1.

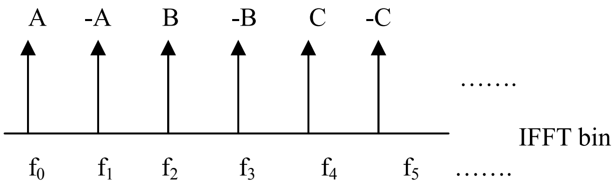

Figure 3.1: ICM process

The signal redundancy makes it possible to improve the system performance at the receiver side. In considering a further reduction of ICI, ICI cancelling demodulation (ICD) scheme is analyzed here. ICD is a process in which the received signals create a new signal for detection. If the received signals are $y(k)$ and $y(k+1)$, by using addition or subtraction at the receiver, the new signal created will be [21]

$$y'(k) = y(k) - y(k+1) \tag{3.22}$$

This process is named ICD. It is worth mentioning that the proposed ICD also improves the signal system signal-to-noise ratio. Repetation the STFB codewords more than twice in combination with polynomial cancellation coding will gain additional diversity order and inter-carrier interference mitigation. Thus, ISC-STFB codes with capability of canceling inter carrier interference should perform well compared with space time frequency without this features for the case of frequency offset.

4. Simulation Framework

From figure 4.1, initialization sets startup parameters, such as the number of loops and the file name used to store data. The important work of the initialization is to provide the simulation with the system settings, including the channel profile, IFFT/FFT size, ICI-SC, SNR, sampling time, and Doppler Frequency.

In the loop, the symbols are randomly created by using the MATLAB programming. We should map the data integers and then the modulation function will map these data integers into the desired gray coded constellation points. After symbols are demodulated at the receiver, the reverse de-mapping process is used to recover the estimates of the original data integers.

After the QAM modulation, symbols are fed into a STFB coding and mapping module. These symbols are reshape into a matrix with dimension $K \times J$ where K is the number of OFDM subchannels (we assume we use all subchannels to transmit data), and J is the number of OFDM blocks, which depends on the preset number of symbols to be processed in one rotation. Then the OFDM module at each transmit antenna applies the IFFT operation on the symbol matrix along the columns and is ready to be sent to the channel module as time signals from the transmit antenna.

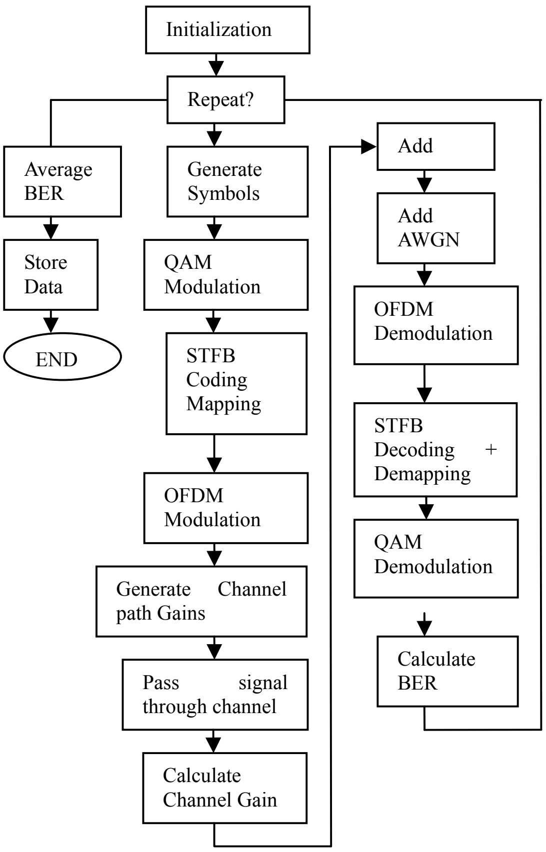

Figure: 4.1 Simulation process diagram

The channel module generates path gains for each transmit-receive antenna pair and add FO to each path. These path gains are obtained by passing Additive White Gaussian Noise (AWGN) sequence through a Jakes filter, and then are scaled to the designated powers. The faded signals from all transmit antennas are added up to form the mixed time signals received at the receive antenna and takes the FFT on the resulting signals.

The STFB decoding and de-mapping module perform the designed algorithm corresponding to the coding scheme implemented at the receiver. The resulting symbols estimates are demodulated into the received data (integers) using QAM modulation techniques.

Finally, BER is calculated using the functions biterr() which compare the received data with the original transmitted data.

5. Performance Evaluation

We simulated the proposed STFB codes design methods for ICI-SC and different ICI-SC schemes for quasi static Rayleigh fading channel in MIMO-OFDM system and compared their performance. The system to be examined have 64 subcarriers, 2 transmit and 2 receive antennas (MIMO), 32-QAM modulation technique, maximum doppler frequency (f_d = 50 Hz) and sampling time (T_s = $4x10^{-8}$s).We used different channel conditions for quasi static Rayleigh fading channels, which have three independent paths, path delays = (0, $8x10^{-8}$, $2.4x10^{-7}$] seconds, average path gains = [0, -5.3, -16] dB and the simulation result present BER curves as functions of SNR.

5.1 Channel with STFB codes with and without ICI-SC for different frequency offsets

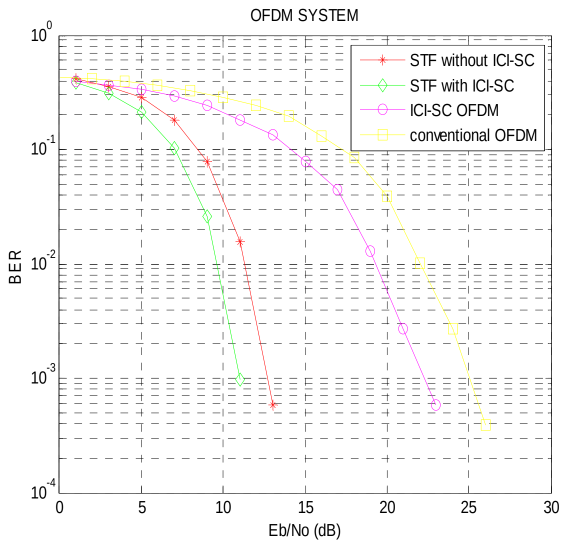

Figure 5.1: BER performance of ICI self-cancellation schemes using 3 path quasi-static Rayleigh fading channel

By examining figure 5.1, the BER curves for STFB codes with ICI-SC of all systems with f_o = 0.05 are shifted to the left and more steeper than the curves of STF codes without ICI-SC, whereas the loss is about 2 dB. The performance of BER for ICI-SC OFDM is better than conventional OFDM, which is at BER=$10^{-3.5}$ the performance loss is about 2.5 dB, whereas for STFB codes with ICI-SC the performance lost is about 10 dB.

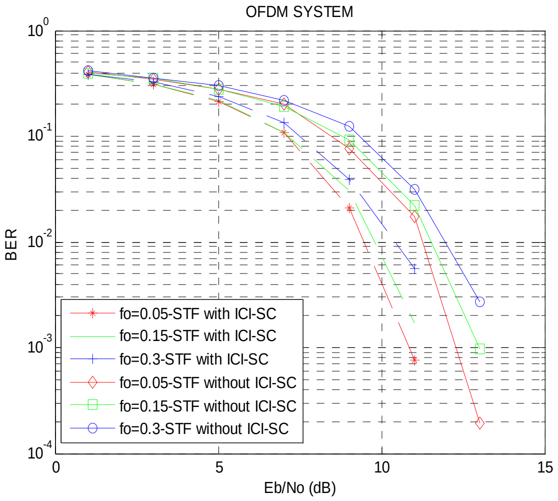

Figure 5.2: Performance of STF codes with and without ICI-SC using three path quasi-static Rayleigh fading channel

From the simulation, the BER investigations are conducted in the presence of 0.05, 0.15, and 0.3 FO in the transmission channel for STFB codes with and without ICI-SC. Figure 5.2 illustrate the performance gain obtained by coding across OFDM blocks decrease as the correlation factor f_o increases. The BER curves for STFB codes without ICI-SC are shifted to the right and less steeper than the curves of STF codes with ICI-SC. For example in figure 4.2 at BER= 10^{-2} and fo=0.15, the performance loss of STFB codes with and without ICI-SC is about 2.2 dB and the performance loss of STFB codes with ICI-SC for fo=0.05 and fo=0.15 is about 0.3 dB.

5.2 Comparison with ICI-SC schemes

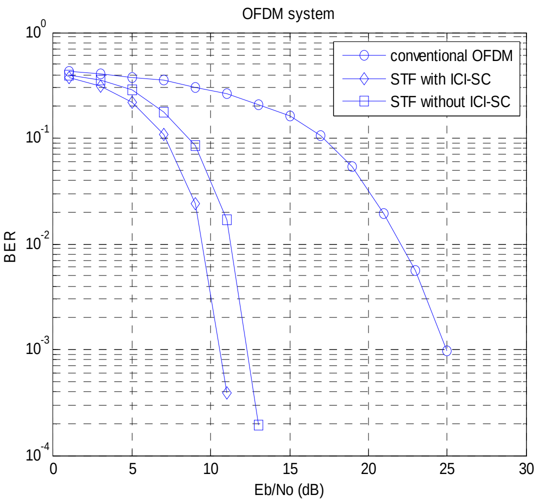

Figure 5.3: BER performance of STFB codes with and without ICI self-cancellation schemes

Here, we present our simulation results for the performance of ICI-SC STFB codes for MIMO-OFDM. By examining figure 5.3, the BER curves for STFB codes with ICI-SC of all systems with f_o = 0.05 are shifted to the left and more steeper than the curves of STF codes without ICI-SC, whereas the loss is about 2 dB for STFB codes without ICI-SC and 12.5 dB for conventional OFDM at BER=10^{-2}.

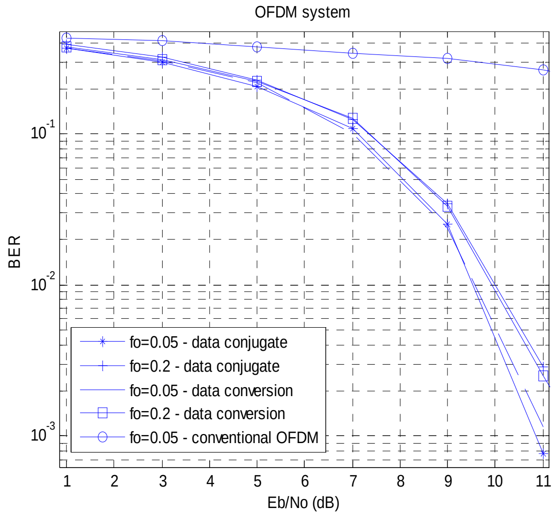

Figure 5.4: Performance of STFB codes with ICI self-cancellation schemes using different ICI-SC method with different f_o

From the simulation, the BER investigations are conducted in the presence of 0.05, and 0.2 frequency offsets in the transmission channel for STFB codes with ICI-SC for different methods. Figure 5.4 illustrate the performance gain obtained by coding across OFDM blocks decrease as the correlation factor f_o increases. The BER curves of conjugate method are shifted to the left and less steeper than the curves of conversion method. For example in figure 4.4 at BER= $10^{-2.8}$ and f_o=0.05, the performance loss of STFB codes with different methods is about 0.25 dB and the performance loss for f_o=0.2 is about 0.3 dB. In addition, conventional OFDM lowers the error floor level notably when the system produces diversity techniques with ICI-SC.

The simulation result showed that the STFB coding across OFDM block for MIMO system using ICI-SC schemes for conjugate method can produce the error correction coding and reduce ICI effectively with the present of FO compared to conversion method.

5. Conclusion

We proposed a general framework for the performance analysis of STFB coded MIMO-OFDM systems with frequency offset. We analyze the BER performance of STFB codes with ICI-SC based on different FO for two different methods. This method provides an excellent BER performance for small frequency offset over a MIMO-OFDM system using STFB coding techniques in AWGN channel and 3-ray quasi static Rayleigh fading channels. The proposed system using the ICI-SC scheme performs much better than conventional OFDM systems and also it easy to implement without increasing system complexity. The result also suggest the system with diversity using conjugate method not only improves the performance of OFDM system especially for error correction in the quasi static Rayleigh fading channel, but also makes the system robust to ICI.

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