CIR Performance of One-third ICI-SC Subcarrier Mapping Technique with STFBC in MIMO-OFDMA System

Hanis Adiba Mohamad, Azlina Idris, Kaharudin Dimyati
Wireless Communication Technology Group (WiCoT),
Advanced Computing and Communication Communities of Research,
Faculty of Electrical Engineering,
Universiti Teknologi MARA (UiTM),
40450 Shah Alam, Malaysia.
adibahanis@yahoo.com

***Abstract*—In multiple input multiple output (MIMO) with orthogonal frequency division multiple access (OFDMA) system, intercarrier interference (ICI) is one of the major drawback in the system. This is due to the orthogonality of the subcarrier which has been destroyed by frequency offset (FO) and thus degrades the system performance. In order to overcome this problem, one-third intercarrier interference self-cancellation (ICI-SC) subcarrier mapping method with space time frequency block codes (STFBC) is proposed. Average power desired (APD) signal, ICI and carrier to interference ratio (CIR) are derived theoretically and the proposed signal is analyzed with other previous methods. As a result, it is proven that by choosing the suitable subcarrier mapping with ICI-SC method, MIMO-OFDMA system performance which affected by FO can be improved with maximum diversity order.**

***Index Terms*—Carrier to Interference Ratio; Intercarrier Interference Self-Cancellation; Space Time Frequency Block codes; Mapping Technique.**

I. INTRODUCTION

In mobile communications systems, high bit rates is vital for video, high quality audio, mobile integrated service digital network and other services. This situation causes rapid development on researches to improve wireless communication systems [1] and one prominent example of this trend is Orthogonal Frequency Division Multiple Access (OFDMA) [2].

Combination of OFDMA and multiple antennas at both end of wireless link (MIMO technology) can promote the benefits of simplicity, high performance system [3], and exploitation of the multipath diversity which increases data rates and link reliability [4].

Basically, there are two basic diversity orders in OFDMA, which are Space-Time Block Codes (STBC) [5] and Space-Frequency Block Codes (SFBC) [6] while combination of both is Space-Time-Frequency Block Codes (STFBC) [7]. In MIMO channels, the coding distributes symbols in different time slots and frequencies which can increase diversity order of the system [8].

OFDMA systems have efficient spectrum utilization due to the overlapping spectra of subcarrier signals. However, this is only true when the orthogonality among subcarriers is preserved. If this is not the case, may be caused by Doppler shift in the channel or difference of local oscillator frequencies between the transmitter and receiver, system performance will be degraded by intercarrier interference (ICI). Various researches have been done to combat ICI, and some of the methods are frequency domain equalization [9], time-domain windowing [10], self-cancellation(SC) scheme [7], pulse shaping, maximum likelihood (ML) etc.

This paper will focus on SC technique as it is a simple and easy way to suppress ICI. The main idea is to modulate one data symbol onto a group of subcarriers with predefined weighting coefficients. As a result, the ICI components generated within a group can be “self-cancelled each other.

Based on the previous researches [11], ICI-SC technique combined with STFBC can greatly improve system performance in terms of CIR with maximum diversity order. As the frequency diversity gain is difficult to obtain because the gap between subcarriers and repeated subcarriers is far away or near, one-third subcarrier mapping is proposed to improve MIMO-OFDMA system performance. The result of CIR performance in presence of FO using one-third subcarrier mapping will be analyzed to determine whether this method would promote ideal solution to mitigate ICI compared to other subcarrier mapping method.

II. SYSTEM MODEL OF STFBC FOR MIMO_OFDMA

The transmitter and receiver architecture is constructed according to one-third ICI-SC subcarrier mapping scheme is shown in Figure 1. The MIMO-OFDMA system is using m transmit antennas and n receive antennas. Six paths COST207 (Jakes Model) of the L-path quasi static Rayleigh fading channel model is applied between each pair of transmit and receive antennas. K is the number of subcarriers in the OFDM modulators. 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.

The system is simulated in MATLAB software using MATLAB command language. Mobile WiMAX wireless communication standards is chosen because OFDMA technology is used for uplink and downlink transmission. The data input produced at the transmitter side are random

Table 1
Mobile WiMAX System Parameter

System Bandwidth (MHz)	Sampling Frequency (MHz)	FFT size	Subcarrier Spacing (kHz)	OFDM Symbol Duration (µs)	Useful symbol time (µs)	Cyclic Prefix (µs)
1.25	1.40	128	10.94	102.86	91.43	11.43
2.50	2.80	256				
5.00	5.60	512				
10.00	11.20	1024				
20.00	22.40	2048				

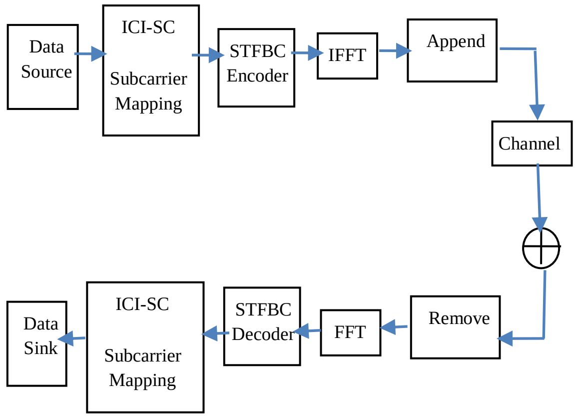

Figure 1: Block diagram of MIMO-OFDMA with ICI self-cancellation mapping scheme

data and the system parameters used are shown in Table 1.

At the receiver, the k_{th} subcarriers are divided into segments respectively in MIMO-OFDMA and the received signal vector can be shown in Equation (1):

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

$Y_n(k)$ = received signal at the receiver
$X_m(k)$ = the transmitted signal
$H_{m,n}(k)$ = channel impulse response
$S_{m,n}(0)$ = desired k_{th} carrier component
$z_n(k)$ = complex Gaussian thermal noise

where basic mapping codeword of STFBC can be expressed as follows:

$$X_m=\begin{bmatrix} X_1(0)\cdots\cdots\cdots X_2(0) \\ X_1(0)\cdots\cdots\cdots -X_2(0) \\ \cdots \qquad\qquad \cdots \\ X_1(N-1)\cdots X_2(N-1) \\ X_1(N-1)\cdots X_2(N-1) \end{bmatrix} \tag{2}$$

A. ICI Self-Cancellation Scheme

ICI-SC technique was applied to STFBC using the subcarrier mapping technique suggested by [12] with a repeating scheme where $r = 2$, indicates that the symbols are being repeated twice but the repeated symbols are signed-reversed. The main idea is to modulate the input data symbol onto a group of subcarriers with predefined coefficients such that the generated ICI signals within that group cancel each other (self-cancellation). In 2000, a few authors introduced adjacent mapping [13] followed by authors who introduced symmetric mapping in 2003 [14]. Nevertheless, in this paper, the CIR estimation of MIMO-OFDMA is done by using one-third subcarrier mapping technique. The STFBC codeword has the form of:-

$$\begin{bmatrix} x_1(0) & \cdots & \cdots & x_2(0) \\ -x_1(\frac{N}{6}) & \cdots & \cdots & -x_2(\frac{N}{6}) \\ x_1(\frac{N}{36}) & \cdots & \cdots & x_2(\frac{N}{36}) \\ -x_1(\frac{N}{6}-1) & \cdots & \cdots & -x_2(\frac{N}{6}-1) \\ \cdots & \cdots & \cdots & \cdots \\ x_1(\frac{N}{6}+1) & \cdots & \cdots & x_2(\frac{N}{6}+1) \\ -x_1(\frac{N}{3}) & \cdots & \cdots & -x_2(\frac{N}{3}) \\ \vdots & \cdots & \cdots & \vdots \\ x_1(\frac{N}{3}+1) & \cdots & \cdots & x_2(\frac{N}{3}+1) \\ -x_1(\frac{N}{2}) & \cdots & \cdots & -x_2(\frac{N}{2}) \\ x_1(\frac{N}{2}) & \cdots & \cdots & x_2(\frac{N}{2}) \\ -x_1(\frac{N}{3}+1) & & & -x_2(\frac{N}{3}+1) \end{bmatrix} \tag{3}$$

ICI-SC technique proposed by [14] is exerted into the system whereby interference cancellation modulation (ICM) is applied to STFBC encoder. In this paper, one-third method will be evaluated using CIR performance.
The ICI coefficient is:

$$S_{m,n}(k)=\frac{\sin\left(\pi\left(k+\varepsilon_{m,n}\right)\right)}{K\sin\left(\frac{\pi}{K}\left(k+\varepsilon_{m,n}\right)\right)}\exp\left[j\pi\left(1-\frac{1}{K}\right)\left(k+\varepsilon_{m,n}\right)\right] \tag{4}$$

Note that $S_{m,n}$ is constant with respect to subcarrier index k=0, where $\varepsilon_{m,n}$ is normalized frequency offset (NFO) from transmitter antenna, m and receiver antenna.

$$S_{m,n}(0)=\frac{\sin\left(\pi\varepsilon_{m,n}\right)}{K\sin\left(\frac{\pi}{K}\varepsilon_{m,n}\right)}.\exp(j\pi\left(1-\frac{1}{K}\right)\varepsilon_{m,n}) \tag{5}$$

In order to get better system performance, it is crucial to get higher CIR value for lower noise and interference. As the value of $\varepsilon_{m,n}$ in equation (4) increases, ICI will also increase. As a result, ICI causes increasing in CIR and decreasing of SNR performance.

B. Design Criteria of Carrier to Interference Ratio (CIR)

In this section, different ICI-SC subcarrier mapping scheme techniques were used to derive STFBC MIMO-OFDMA system with FO. Suppose channels have similar flat frequency response in two paths, where $H_l^1=H_l^2$ and the performance of CIR is defined as follows:

$$CIR = \frac{E[|C_k|^2\ ]}{E[|ICI_k|^2\ ]} \tag{6}$$

C_k = the desired kth carrier component
IC_{Ik} = ICI component of kth carrier

C. Adjacent Data Conversion Method

For adjacent data conversion method, the subcarrier signals are remapped as the form of $X'_{2k} = X_k$, $X'_{2k+1} = -X_k$ where:

X_k = information data in kth carrier before adjacent data
X'_{2k} = information data in $2k2k_{th}$ carrier after adjacent data

The desired signal is:

$$Z'_k = \frac{Y_{2k} - Y_{2k+1}}{4} \tag{7}$$

The APD component is:

$$APD = X_k[-S_{-1}+2(S_0-1)-S_1] \tag{8}$$

and ICI component of k_{th} subcarrier is:

$$ICI = \sum_{\substack{l=0\\ l\neq k}}^{\frac{N}{2}-1} X_k[-S_{2l-2k-1}+2\left(S_{2l-2k}\right)-S_{2l-2k+1}] \tag{9}$$

So CIR is expressed as follows:

$$CIR = \frac{|-S_{-1}+2S_0-S_1|^2}{\sum_{l=1}^{\frac{N}{2}-1}|-S_{2l-1}+2S_{2l}-S_{2l+1}|^2} \tag{10}$$

D. Symmetric Data Conversion Method

For symmetric data conversion method, the subcarrier signals are remapped as the form of $X'_k = X_k$, $X'_{N-1-k} = X_k$. The desired signal is:

$$Z'_k = \frac{Y_k - Y_{N-1-k}}{4} \tag{11}$$

The APD component is:

$$APD = X_k[-S_{N-2k-1}+2(S_0-1)-S_{2k-N+1}] \tag{12}$$

and ICI component of k_{th} subcarrier is:

$$ICI = \sum_{\substack{l=0\\ l\neq k}}^{\frac{N}{2}-1} X_l[-S_{l-N+1+k}+S_{l-k}+S_{k-l}-S_{2N-1-l-k}]+N'_k \tag{13}$$

So CIR is expressed as follows:

$$CIR = \frac{|-S_{N-1}+2S_0-S_{1-N}|^2}{\sum_{l=1}^{\frac{N}{2}-1}|-S_{l-N+1}+S_l-S_{-l}-S_{N-1-l}|^2} \tag{14}$$

E. Median Data Conversion Method

Median data subcarrier method is remapped in the form of $X_k = X_k,\ X_{N-\left(\frac{N}{2}+1\right)-k} = -X_k$ for $k=0,\ldots..,\left(\frac{N}{2}-1\right)$ and $X_k = X_k,\ X_{N-\left(\frac{N}{2}+1\right)-k} = -X_k$ for $k=\frac{N}{2},\ldots..,(N-1).k = \frac{N}{2},\ldots..,(N-1).$

The desired signal is:

$$Z'_k = \frac{R_{X_{(k)}} - R_{X_{(N-\left(\frac{N}{2}+1\right)-k)}} + R_{X_{(N-\left(\frac{N}{2}+1\right)-k)}}}{4} \tag{15}$$

The APD component is:

$$APD = \frac{1}{4}\left\{X_{(k)}\left[3\left(\begin{matrix}S(0)-S(N-2k-1)-S\left(2k+N-\frac{N}{2}+1\right)\\ -S\left(2k+N+\left(\frac{N}{2}+1\right)\right)\end{matrix}\right)\right]\right\} \tag{16}$$

and ICI component of k_{th} subcarrier is:

$$ICI = \frac{1}{4}\left\{\begin{matrix}\sum_{\substack{l=0\\ l\neq k}}^{\frac{N}{2}-1} X_k(l)\left[S(l-k)-2S(k-l)\right]-X_{N-1-k}\left[S(l-N+1+k)\right]\\ +X_{\left(N-\left(\frac{N}{2}+1\right)-k\right)}\left[S\left(N-\left(\frac{N}{2}+1\right)-l-k\right)\right]-\\ X_{\left(N+\left(\frac{N}{2}-1\right)-k\right)}\left[S\left(N+\left(\frac{N}{2}-1\right)-l-k\right)\right]\end{matrix}\right\} \tag{17}$$

So CIR is expressed as follows,

$$CIR = \frac{\left|\begin{matrix}2S(0)-\left(\left(S_{(-N-1)}+S_{\left(\frac{-N}{2}\right)}\right)-S_{\left(\frac{-N}{2}-1\right)}\right)\\ -\left(\left(S_{(N-1)}+S_{\left(\frac{N}{2}\right)}\right)-S_{\left(\frac{N}{2}-1\right)}\right)\end{matrix}\right|}{\sum_{l=1}^{\frac{N}{2}-1}\left|\begin{matrix}S_{(l)}+S_{(-l)}-\left(\left(S_{(-N-1)-l}+S_{\left(\frac{N}{2}\right)}\right)-S_{\left(\frac{N}{2}-1\right)}\right)\\ -\left(\left(S_{(l-N-1)}+S_{\left(\frac{-N}{2}\right)}\right)-S_{\left(\frac{-N}{2}-1\right)}\right)\end{matrix}\right|} \tag{18}$$

F. Quarter Data Conversion Method

Quarter data subcarrier method is remapped in the form of $X_k = X_k,\ X_{N-\left(\frac{N}{4}+1\right)-k} = -X_k$ for $k = 0,\ldots..,\left(\frac{N}{4}-1\right)$ and $X_k = X_k,\ X_{N-\left(\frac{N}{4}+1\right)-k} = -X_k$ for $k = \frac{N}{4},\ldots..,(N-1)$. The desired signal is:

$$Z'_k = \frac{R_{X_{(k)}} - R_{X_{\left(N-\left(\frac{N}{4}+1\right)-k\right)}} + R_{X_{\left(N-\left(\frac{N}{4}+1\right)-k\right)}}}{4} \tag{19}$$

The APD component is:

$$APD = \frac{1}{4}\left\{X_{(k)}\left[3\left(\begin{array}{l} S(0)-S(N-2k-1) \\ -S\left(2k+N-\frac{N}{4}+1\right) \\ -S\left(2k+N+\left(\frac{N}{4}+1\right)\right)\end{array}\right)\right]\right\} \tag{20}$$

and ICI component of kth subcarrier is:

$$ICI = \frac{1}{4}\left\{\begin{array}{l} \sum\limits_{\substack{l=0 \\ l\neq k}}^{\frac{N}{4}-1} X_k(l)\left[S(l-k)-2S(k-l)\right] \\ -X_{N-1-k}\left[S(l-N+1+k)\right] \\ +X_{\left(N-\left(\frac{N}{4}+1\right)-k\right)}\left[S\left(N-\left(\frac{N}{4}+1\right)-l-k\right)\right] \\ -X_{\left(N+\left(\frac{N}{4}-1\right)-k\right)}\left[S\left(N+\left(\frac{N}{4}-1\right)-l-k\right)\right]\end{array}\right\} \tag{21}$$

So CIR is expressed as follows:

$$CIR = \frac{\left|\begin{array}{c} 2S(0)-\left(\left(S_{(-N-1)}+S_{\left(\frac{-N}{4}\right)}\right)-S_{\left(\frac{-N}{4}-1\right)}\right) \\ -\left(\left(S_{(N-1)}+S_{\left(\frac{N}{4}\right)}\right)-S_{\left(\frac{N}{4}-1\right)}\right)\end{array}\right|}{\sum_{l=1}^{\frac{N}{3}-1}\left|\begin{array}{c} S_{(l)}+S_{(-l)}-\left(\left(S_{(-N-1)-l}+S_{\left(\frac{N}{4}\right)}\right)-S_{\left(\frac{N}{4}-1\right)}\right) \\ -\left(\left(S_{(l-N-1)}+S_{\left(\frac{-N}{4}\right)}\right)-S_{\left(\frac{-N}{4}-1\right)}\right)\end{array}\right|} \tag{22}$$

G. One-Third Data Conversion Method

One-third data subcarrier method is remapped in the form of $X_k = X_k,\ X_{N-\left(\frac{N}{3}+1\right)-k} = -X_k$ for $k = 0,\ldots..,\left(\frac{N}{3}-1\right)$ and $X_k = X_k,\ X_{N-\left(\frac{N}{3}+1\right)-k} = -X_k$ for $k = \frac{N}{3},\ldots..,(N-1)$. The desired signal is:

$$Z'_k = \frac{R_{X_{(k)}} - R_{X_{\left(N-\left(\frac{N}{3}+1\right)-k\right)}} + R_{X_{\left(N-\left(\frac{N}{3}+1\right)-k\right)}}}{4} \tag{23}$$

The APD component is:

$$APD = \frac{1}{4}\left\{X_{(k)}\left[3\left(\begin{array}{l} S(0)-S(N-2k-1) \\ -S\left(2k+N-\frac{N}{3}+1\right) \\ -S\left(2k+N+\left(\frac{N}{3}+1\right)\right)\end{array}\right)\right]\right\} \tag{24}$$

And ICI component of kth subcarrier is:

$$ICI = \frac{1}{4}\left\{\begin{array}{l} \sum\limits_{\substack{l=0 \\ l\neq k}}^{\frac{N}{3}-1} X_k(l)\left[S(l-k)-2S(k-l)\right] \\ -X_{N-1-k}\left[S(l-N+1+k)\right]+ \\ X_{\left(N-\left(\frac{N}{3}+1\right)-k\right)}\left[S\left(N-\left(\frac{N}{3}+1\right)-l-k\right)\right] \\ -X_{\left(N+\left(\frac{N}{3}-1\right)-k\right)}\left[S\left(N+\left(\frac{N}{3}-1\right)-l-k\right)\right]\end{array}\right\} \tag{25}$$

So CIR is expressed as follows:

$$CIR = \frac{\left|\begin{array}{c} 2S(0)-\left(\left(S_{(-N-1)}+S_{\left(\frac{-N}{3}\right)}\right)-S_{\left(\frac{-N}{3}-1\right)}\right) \\ -\left(\left(S_{(N-1)}+S_{\left(\frac{N}{3}\right)}\right)-S_{\left(\frac{N}{3}-1\right)}\right)\end{array}\right|}{\sum_{l=1}^{\frac{N}{3}-1}\left|\begin{array}{c} S_{(l)}+S_{(-l)}-\left(\left(S_{(-N-1)-l}+S_{\left(\frac{N}{3}\right)}\right)-S_{\left(\frac{N}{3}-1\right)}\right) \\ -\left(\left(S_{(l-N-1)}+S_{\left(\frac{-N}{3}\right)}\right)-S_{\left(\frac{-N}{3}-1\right)}\right)\end{array}\right|} \tag{26}$$

H. Space Time Frequency Block Coding Schemes

A space time frequency is a combination of ST and SF code in order to get the spatial, frequency and time diversity. STF diversity is beneficial since it can allow many similar symbols to be transmitted through multiple antennas at different time and frequency. Therefore, a maximum diversity order can be seized by using this spatial multiplexing and diversity technique. Below is the example of coding in STFBC method as suggested in [14].

Table 2
Coding in STFBC Method

Antenna and time slot frequency	Ant 1 (T1)	Ant 2 (T2)
f1	X_k	X_{k+1}
f2	$-X_{k+1}$	$X_k{}'$

III. SIMULATION RESULTS AND DISCUSSION

The proposed STFBC design methods were simulated using MATLAB programming with system parameter in Table 3. The system uses 72 subcarriers for STFB codes design methods with different subcarrier mapping scheme such as adjacent, symmetric, median, quarter and one-third. The results are compared to analyze the best performance.

Table 3
Simulation Parameters

Parameters	Values
IFFT size	128
Mapping scheme	64-QAM
No of OFDMA symbols	100
Bits per OFDMA symbols	N*log2(M)
Number of carriers	72
Channel	Multipath Rayleigh Fading
Frequency offset	0-0.5

Figure 2 shows CIR performance of different ICI-SC subcarrier mapping techniques according to FO. From the graph, one-third method has significantly larger CIRs compared to other methods where the average value is 233.3dB respectively. The average CIR value for quarter method is 163.3dB, median method is 140dB, symmetry method is 19.7dB and adjacent method is 24dB. Overall results prove that one-third ICI-SC subcarrier signal remapping with STFBC MIMO-OFDMA system have an outstanding performance of CIR compared to four other methods with average 209.3 dB of improvement.

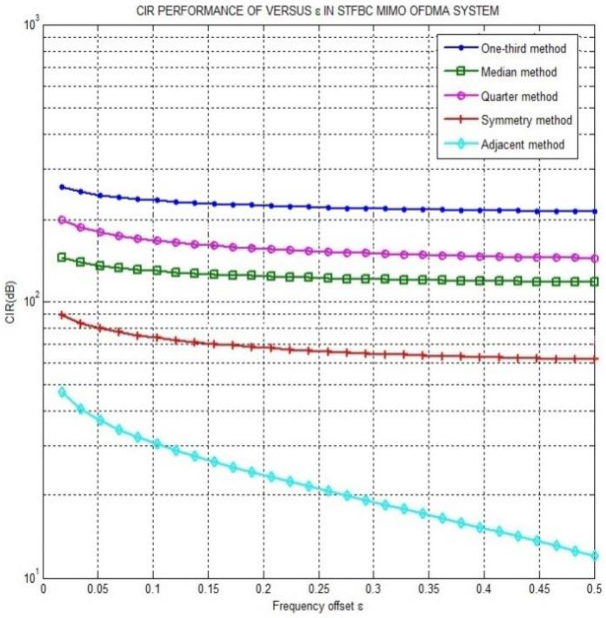

Figure 2: CIR performance of different subcarrier mapping scheme with 5% frequency offsets

Table 4
CIR (dB) Performance for Different Methods with FO = (0.05, 0.25, 0.5)

Method	FO		
	0.05	0.25	0.50
Adjacent	37dB	21dB	14dB
Symmetry	80dB	67dB	62dB
Median	150dB	140dB	130dB
Quarter	180dB	160dB	150dB
One-third	250dB	230dB	220dB

IV. CONCLUSION

In conclusion, ICI reduction for MIMO-OFDMA system model with FO has been proposed and studied. Performance degradations caused by FO were discussed and the ICI reduction has been compared for different subcarrier mapping methods using CIR performance. It can be observed that one-third ICI-SC subcarrier mapping method using with STFBC can achieve maximum diversity order and promising technique for MIMO-OFDMA system. Last but not least, by choosing suitable ICI-SC subcarrier mapping technique, the effect of FO can be reduced and performance of MIMO-OFDMA system can be achieved.

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