Performance Analysis of Interference Alignment (IA) Scheme with the Presence of Frequency Offset

Nor Azlizan Hussien, Azlina Idris, Norsuzila Ya'acob
Faculty of Electrical Engineering, Universiti Teknologi Mara, Shah Alam, Selangor.
iazlizan90@gmail.com

***Abstract*—MIMO OFDMA system known as a good choice for high data rate wireless applications, but the factors such as carrier frequency offset (CFO) from frequency mismatching, time variations due to Doppler shift or phase noise has extensively destroys the orthogonality of the subcarriers which leads to inter-carrier interference (ICI) which severely degrades the performance of the system significantly. Hence, in this paper, the Space Time Frequency Block Codes (STFBC) technique and Interference Alignment (IA) scheme is applied to achieve the diversity and as an alternative approach to mitigate the ICI respectively. Through simulations, it is shown that the proposed scheme is able to improve the system performance in term of Bit Error Rate (BER).**

***Index Terms*—Interference Alignment; Space Time Frequency Block Codes; Carrier Frequency Offset; Inter-carrier Interference; Bit Error Rate.**

I. Introduction

The mobile stationery user demanding for high quality multimedia streams and mobile computing, as well as high speed data internet access for the future generation wireless communication systems. This issue has driving recent developments in communication technologies especially for broadband wireless communications. Therefore, OFDM is introduced as the preferred modulation scheme in modern high data rate wireless communication systems. And combination of MIMO and OFDM offer the system with the simplicity and high performance [1].

Furthermore, there is currently strong interest in extending the OFDM concept to multiuser communication scenarios known as Orthogonal Frequency Division Multiple Access (OFDMA) technology.

An OFDMA system is defined as one in which each terminal occupies a subset of subcarriers (termed an OFDMA traffic channel), and each traffic channel is assigned exclusively to one user at any time [2]. In OFDMA, users are not overlapped in frequency domain at any given time [3]. However, the frequency bands assigned to a particular user may change over the time. However, this OFDMA inherit the infirmity of OFDM which is very sensitive to carrier frequency offsets (CFO) which may violate the orthogonality among subcarriers which reduce the useful signal in each subcarrier and increase the noise level, hence induce to the presence of the inter-carrier interference (ICI) among subcarriers [4]. CFO not only introduces the ICI but also causes the amplitude degradation of the desired signal.

Moreover, STFBC technique is also proposed to achieve full diversity, to maximize spectral efficiency and also upgrade the signal quality [5]. It is because this technique is able to exploit space, time, and frequency domains; hence the data rates in frequency selective fading channels can be increased and can achieve high spectral efficiency in the system.

Several methods have been proposed to reduce the effect of the ICI including ICI self-cancellation [6],[7],[8] time domain windowing scheme [9] frequency offset estimation and compensation techniques [10].

Recently, they have been proposed a technique called interference alignment (IA) scheme which refers to the idea that system can be designed to remove overlapping interference and distinguishable the desired signals at the receiver [11]. Even though they are not mentioned about the specific interference that can be overcome, but it is believed that this technique can also be used to reduce the effect of ICI in the system.

There are several researchers who have proposed IA scheme in their project. Researcher [12] introduce iterative algorithm used the local side information available which also provide numerical insights into the feasibility of IA. An algorithm for interference alignment with random number of users, antennas or spatial streams and assume for the usage of frequency flat channel (for simplicity) was presented in [13]. In [14], the researcher applied interference alignment algorithm over the flat slow fading channel but limited to cellular system only. All these research are basically studying on how to increase the degree of freedom (DOF) in their system and not to reduce the effect of ICI.

So far, there is no literature on the performance evaluation of the IA scheme with the presence of CFO in the MIMO-OFDMA system. Therefore, in this paper, we propose the IA scheme of STFBC MIMO-OFDMA to minimize ICI generated by FO.

II. Simulation Process

From the simulation process diagram as shown in figure 1, initialization sets start up to provide the system settings, including the channel profile, IFFT/FFT size, and number of subcarrier, SNR, sampling time, sampling frequency, bandwidth and Doppler Frequency to the simulation.

In the loop of simulation, the symbols are randomly created. The entry of the data integers is then being processed with the modulation function, and then being mapped into the 64-QAM modulation technique.

After the 64-QAM modulation process, After the QAM modulation, symbols are fed into a STFB coding and mapping module.

These symbols are reshaped into a matrix with dimension NxK where N is the number of OFDM subchannels (assuming all subchannels to transmit data are used), and K is the number of OFDM blocks, which depends on the preset number of symbols to be processed in one rotation.

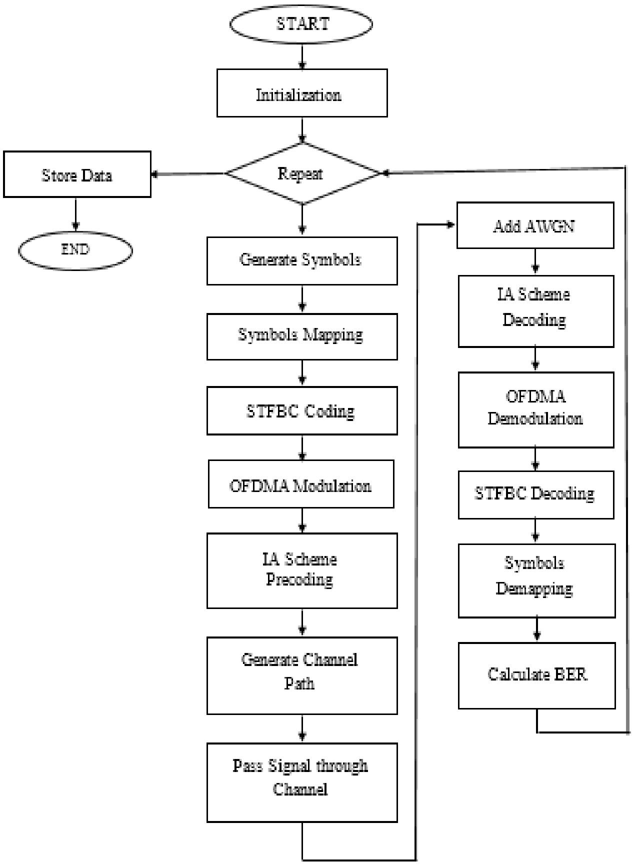

Figure 1: Simulation Process Diagram

The IA scheme linear precoding process take place to define the dimensions of vector matrix for each of the symbol before the symbol is assigned to time signal to be transmitted. At this stage, 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.

The channel module generates path gains for each transmits-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. The faded signals from all transmit antennas are then added up to form the mixed time signals received at the receive antenna. After that, the IA scheme decoding is performed to decode the receive signal into their respective signal dimensions and takes the FFT function 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 bitter () which compare the received data with the original transmitted data.

A. *ICI Analysis in OFDMA System*

This part will discuss the general of input output equation for ICI analysis in the system. The transmitted time signal $x_{u,n}$ of a user u can be expressed as [15].

$$x_{u,n} = \frac{1}{N}\sum_{k=0}^{N-1} X_{u,k} e^{i2\pi\frac{kn}{N}} \qquad (1)$$

where $X_{u,k}$ is the complex valued modulation symbol for user u on subcarrier k, while k is the subcarrier index on the transmitter (MT) side. In order to model the multiple access procedure in the system, the modulation symbols $X_{u,k}$ of a user u need to show non-zero values on the allocated subcarriers and zero values elsewhere. Moreover, the transmitted time signal $x_{u,n}$ of every MT will pass through each of multipath radio channels and will induce individual Carrier Frequency Offset (CFO). Then, all user signals will combine and superimpose at the BS to an overall receive signal y_n, stated as:

$$y_n = \frac{1}{N}\sum_{k=0}^{N-1}\sum_{u=0}^{N_{u-1}} X_{u,k} Z_{u,k}(n) e^{j2\pi\frac{kn}{N}} + \eta_n^{AWG} \qquad (2)$$

where η_n^{AWG} is the additive white Gaussian noise component at the receiver and $Z_{u,k}(n)$ is the combined channel fading and CFO influence to the signal of user u.

III. METHODOLOGY

In this section, we derive the performance criteria for MIMO-OFDMA system with FO using STFBC technique and IA schemes.

A. *Interference Alignment Scheme*

Basically, in the MIMO channel the input output equation is given by:

$$Y^{[1]} = H^{[11]}V^{[11]}X^{[11]} + H^{[11]}V^{[21]}X^{[21]} + H^{[12]}V^{[12]}X^{[12]} + H^{[12]}V^{[22]}X^{[22]} + N^{[1]} \qquad (3)$$

$$Y^{[2]} = H^{[21]}V^{[11]}X^{[11]} + H^{[21]}V^{[21]}X^{[21]} + H^{[22]}V^{[12]}X^{[12]} + H^{[22]}V^{[22]}X^{[22]} + N^{[2]} \qquad (4)$$

where $Y^{[1]}$ is the N1 x 1 output vector at receiver 1, $Y^{[2]}$ is the N2 x 1 output vector at receiver 2, $N^{[1]}$ is the N1 x 1 additive white Gaussian noise (AWGN) vector at receiver 1, $N^{[2]}$ is the N2 x 1 AWGN vector at receiver 2. $X^{[1]}$ is the M1 x 1 input vector at transmitter 1, $X^{[2]}$ is the M2 x 1 input vector at transmitter 2, $H^{[11]}$ is the N1 x M1 channel matrix between transmitter 1 and receiver 1, $H^{[22]}$ is the N1 x M1 channel matrix between transmitter 2 and receiver 1, and $H^{[21]}$ is the N2 x M1 channel matrix between transmitter 1and receiver 2.

Hence, interference alignment refers to the careful choice of the vector directions in order to separate the desired signals at their respective receivers but the interference is aligned. For example, based on Equation (3) for the receiver 1, the $H^{[11]}V^{[11]}X^{[11]}$ and$H^{[12]}V^{[12]}X^{[12]}$ occupy the same spatial dimension while the interference vectors $H^{[11]}V^{[21]}X^{[21]}$ and $H^{[12]}V^{[22]}X^{[22]}$ will share the same signal space.

B. *Space Time Frequency Block Codes*

In the proposed system model, the Space Time Frequency Block (STFB) coding technique are used as it takes an advantage of diversity of space, time and frequency and hence can help to enhance the reliability and system performance. The coding distributes symbols along transmit antennas, time slot and OFDM sub channels. A STF codeword may occupy several OFDM symbols which can increase the diversity order [16][17]. The coding of this technique is shown in Table 1.

Table 1
Space Time Frequency Block Codes

Antenna time slot Frequency	Ant1 (T1)	Ant 2 (T2)
f1	Xk	Xk+1
f2	-Xk+1*	Xk*

The proposed technique is implemented by applying the interference alignment scheme in a state of that the transmit symbol (independent codeword) is send by using the space time frequency block codes technique referring to table 1 above. In other word, sending the independent codeword at different time and frequency by using multiple antennas, so that, the system can exploit the space, time and frequency domains. It is happened since the STFB codeword may occupy several OFDM symbols and hence the diversity order can be increased. For example, based on table 1, the *Xk* is represented the first codeword that carries the first message of input vector that will be transmitted by transmit antenna 1 during the time slot 1 and frequency slot 1 followed by the second symbol *Xk+1* and so on.

IV. Result and Discussion

Figure 2 shows the simulation results of BER performance STFBC MIMO-OFDMA with FO = (5%, 10%, 15%, 20%). Roughly, from the graph pattern, we can see that the BER performance is improved as the FO value is decreased. For example, we take the reading at constant value of Eb/No= 10 dB, the BER performance is at 1.0x10-2 at FO=5%, 5x10-2 at FO=10%, 1.5x10-1 at FO=15% and 3.0x10-1 at FO=20% respectively. This is because, the FO itself represent the disturbances that will induce the ICI interference in the system, so that if the interference is increased, the system as well as the BER performance is decreased. The simulation results above prove that the lower the FO the better the performance of the system; which can then increase the Eb/No and decrease the BER. If the FO increased, the shift of BER curves with lower diversity order is larger than the shift of BER curves with higher diversity order. Therefore, higher diversity order systems are more robust to the effect of FO.

From the simulation, the BER investigations are conducted in the presence of FO=0% and 5% in the transmission channel for STFBC with and without IA scheme. Figure 3 illustrates that the BER performance obtained by coding across OFDM blocks decrease as the frequency offset (FO) increases. The BER performance decreases for the STFBC MIMO-OFDMA system without the IA scheme as compared to the system with IA scheme. This is due to the fact that the STFBC system without IA scheme consists of higher ICI than the system with IA scheme. For example, in figure 3 at BER = 10-2and FO=5%, the different of BER performance for STFBC with and without IA scheme is about 0.5 dB and the BER performance of STFBC with IA scheme for NFO=0% and NFO=5% is about 0.3 dB.

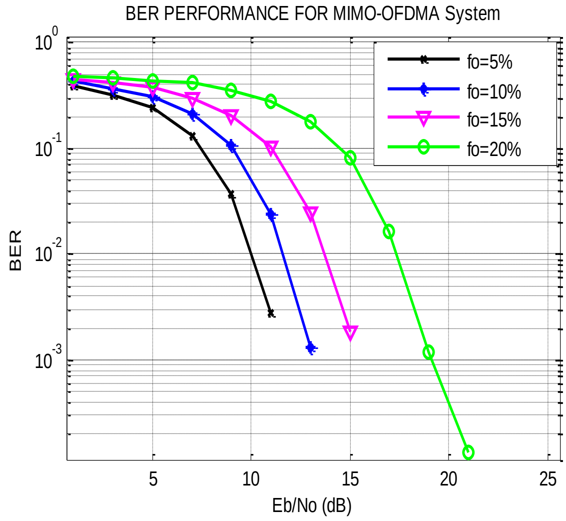

Figure 2: BER performance for different value of frequency offset

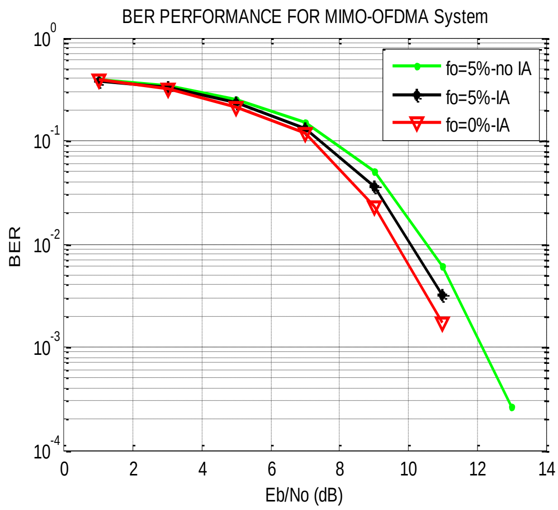

Figure 3: BER performances for STFBC MIMO-OFDMA system with and without IA scheme using different FO

V. Conclusion

The general framework for the performance analysis of MIMO-OFDMA systems with frequency offset has been proposed. The BER performance of STFB codes with IA scheme based on different FO is also being analysed. This system provides a good BER performance for small frequency offset in AWGN channel and Rayleigh fading channels. The results also suggest that the system with IA scheme not only improves the performance of OFDMA system, but also makes the system robust to ICI.

Acknowledgment

This work was supported in part by Ministry of Education (MOE) under Exploratory Research Grant Scheme (ERGS) number 600-RMI/ERGS 5/3 (34/2012).

References

[1] XuJ., KimJ., PaikW., and SeoJ., "Adaptive Resource Allocation Algorithm with Fairness for MIMO-OFDMA System," *IEEE Transactions on Wireless Communications*, pp. 0–4, 2006.

[2] ManL. A. N., CommitteeS., Computer I., TheoryM., and SocietyT., "IEEE Standard for Local and Metropolitan Area Net-works Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access

Systems," *Amendment 3: Management Plane Procedures and Services*, December 2007.

[3] Hui L. and Guoqing L., "OFDM-Based Broadband Wireless Networks Design and Optimization," *CANADA: JOHN WILEY AND SONS*, 2005.

[4] AzizB., FijalkowI., and AriaudoM., "Intercarrier interference in uplink OFDMA systems with carrier frequency offset," *21st Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 746–751, Sep. 2010.

[5] SuW., SafarZ., OlfatM., MemberS., and LiuK. J. R., "Obtaining Full-Diversity Space-Frequency Codes From Space-Time Codes via Mapping," *IEEE Transactions on Signal Processing*, vol. 51, no. 11, pp. 2905–2916, 2003.

[6] Li C., Hu W., and Wang T., "Frequency Offset Estimation for OFDM Systems Using ICI Self," *Cancellation Schemes*, pp. 2305–2309, 2007.

[7] Zhao Y.and HäggmanS., "Intercarrier interference self-cancellation scheme for OFDM mobile communication systems," *IEEE Transactions on Communications*, vol. 49, no. 7, pp.1185–1191, 2001.

[8] YehH., "A Conjugate Operation for Mitigating Intercarrier Interference of OFDM Systems," pp. 3965–3969, 2004.

[9] MuschallikC., "Improving an OFDM Reception Using an Adaptive Nyquist Windowing," 1996.

[10] MooseP. H., "A Technique for Orthogonal Frequency Division Multiplexing Frequency Offset Correction," *IEEE Transactions on Communications*, pp. 2908–2914, 1994.

[11] CadambeV., JafarS. a., and ShamaiS., "Interference alignment on the deterministic channel and application to fully connected AWGN interference networks," *IEEE Information Theory Workshop*, pp. 41–45. May 2008.

[12] Gomadam, K. "Approaching the capacity of wireless networks through distributed interference alignment," IEEE Conference, pp. 1–6, 2008.

[13] Peters S.and HeathR., "Interference alignment via alternating minimization," *Acoustics, Speech and Signal*, pp. 2445–2448, 2009.

[14] J.-C. G. and Yong FengJ. L., "A New Interference Alignment Algorithm in the MIMO-OFDM System," *information technology journal*, pp. 12, 2013.

[15] Stemick M.and RohlingH., "Effect of Carrier Frequency Offset on the Channel Capacity in Multiuser OFDM-FDMA Systems," *Wireless Personal Communications*, vol. 47, no. 1, pp. 5–14. Oct 2007.

[16] LiuZ., XinY., Member S., and GiannakisG. B., "Space-Time-Frequency Coded OFDM Over Frequency-Selective Fading Channels," *IEEE Transactions on Signal Processing*, vol. 50, no. 10, pp. 2465–2476, 2002.

[17] Fitz M. P.and GrimmJ., "A new view of performance analysis techniques in correlated Rayleigh fading. Conference," *WCNC*. pp. 139–144,1999.