# EVALUATING A NEW SUBCARRIER MAPPING ICI-SC SCHEME USING LINEAR MAXIMUM LIKELIHOOD ALAMOUTI COMBINER (LMLAC) DECODING TECHNIQUE

AZLINA IDRIS[1,2,*], KAHARUDIN DIMYATI[3], SHARIFAH K. SYED YUSOF[4]

[1]Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia
[2]Department of Electrical Engineering, Universiti Malaya, Malaysia
[3]Faculty of Engineering, National Defence University of Malaysia, Malaysia
[4]Faculty of Electrical Engineering, Universiti Teknologi Malaysia
*Corresponding Author: azlina_idr@yahoo.com

## Abstract

This paper presents a new subcarrier mapping scheme ICI-SC technique that use Linear Maximum Likelihood Alamouti Combiner (LMLAC) as a decoding technique to mitigate intercarrier interference (ICI) problem with low complexity decoding system for space time frequency block codes (STFBC) orthogonal frequency division multiplexing (OFDM) in the frequency selective environments. We provide details of the mathematical models of the proposed scheme and simulate its error performance caused by frequency offset (FO). We also analyze the impact of the STFBC of the system. The simulation results showed that the scheme has the ability to reduce ICI effectively with a low decoding complexity and maximum diversity in terms of bandwidth efficiency and also in the bit error rate (BER) performance especially at high signal to noise ratio.

Keywords: Intercarrier interference self cancellation, Space time frequency block code, Linear maximum likelihood Alamouti combiner, Signal to noise ratio, Frequency offset.

## 1. Introduction

Orthogonal frequency division multiplexing OFDM is an effective technique to mitigate inter-symbol interference that multipath delay may cause in a frequency selective environment [1, 2]. This phenomenon brings about a frequency of selective fading due to the different echoes of transmitted symbols overlapping at the receiving end. This factor can lead to the BER degradation [3, 4]. To effectively

## Nomenclatures

| | |
|---|---|
| $E_b/N_o$ | Signal to noise ratio |
| $H_{m,n}(k)$ | Channel coefficient |
| $K$ | Number of subcarriers |
| $L$ | Path gain |
| $M$ | Transmit antennas |
| $N$ | Receive antennas |
| $R$ | Repeated data |
| $S_1$ | Transmit symbol 1 using maximum likelihood |
| $\hat{S}_1$ | Transmit symbol 1 using linear combiner |
| $S_2$ | Transmit symbol 2 using maximum likelihood |
| $\hat{S}_2$ | Transmit symbol 2 using linear combiner |
| $X_m$ | Codeword |
| $Y_1(k)$ | Received signal $Y_1$ at time $k$ using linear combiner |
| $\bar{Y}_1(k)$ | Received signal $Y_1$ at frequency $k$ using linear combiner |
| $Y_1(k+1)$ | Received signal $Y_1$ at time $k+1$ using linear combiner |
| $\bar{Y}_1(k+1)$ | Received signal $Y_1$ at frequency $k+1$ using linear combiner |
| $Y_2(k)$ | Received signal $Y_2$ at time $k$ using linear combiner |
| $\bar{Y}_2(k)$ | Received signal $Y_2$ at frequency $k$ using linear combiner |
| $Y_2(k+1)$ | Received signal $Y_2$ at time $k+1$ using linear combiner |
| $\bar{Y}_2(k+1)$ | Received signal $Y_2$ at frequency $k+1$ using linear combiner |
| $Y_F(k)$ | Received signal at frequency $k$ |
| $Y_F(k+1)$ | Received signal at frequency $k+1$ |
| $Y_T(k)$ | Received signal at time $k$ |
| $Y_T(k+1)$ | Received signal at time $k+1$ |

*Greek Symbols*

| | |
|---|---|
| $\alpha_{ij}$ | Complex gain |
| $\rho_{ij}$ | Normalized interference coefficient transmit symbols |
| $\sigma_H^2$ | Average power of the channel gain |
| $\sigma_S^2$ | Average energy of the transmit symbols |
| $\sigma_w^2$ | Average noise |
| $\xi$ | Average signal to noise ratio |

## Abbreviations

| | |
|---|---|
| BER | Bit error rate |
| FO | Frequency offset |
| ICI | Intercarrier interferencece |
| ICI-SC | Intercarrier interference self cancellation |
| LMLAC | Linear maximum likelihood Alamouti combiner |
| MIMO | Multiple-input and multiple-output |
| ML | Maximum likelihood |
| OFDM | Orthogonal frequency division multiplexing |
| STFBC | Space time frequency block codes |

mitigate the impairments of a multipath fading channel, yet still maintaining high-data rates in a limited bandwidth, the OFDM can be used [5, 6]. Multiple antennas can be combined with OFDM to increase diversity gain and to improve spectral efficiency through spatial multiplexing [7, 8].

It is also evident that the combination of MIMO and OFDM produces a powerful technique for providing high data rates over frequency-selective fading channels. It is now a leading application for future fourth generation (4G) wireless communication systems [9, 10].

This paper addresses two related problems in realizing practical mobile communication system with MIMO and OFDM technologies. First and foremost, it is concerned about ICI in the system. In the case of SISO OFDM, the authors in [11-13] proposed ICI-SC coding or polynomial cancellation coding to mitigate ICI caused by FO effectively. However, this scheme inherently reduces throughput and bandwidth efficiency by a factor of 2 (repeated symbols) [13]. Nevertheless, this problem can be improved or compensated by using the higher order modulation scheme with a high transmission rate [14, 15].

OFDM has become more complex and time consuming in MIMO system utilizing maximum likelihood (ML) decoding, mainly due to the large size of the system constellation and the codeword structure and it become the second problems addressed in this paper. To overcome these problems, the LMLAC decoding techniques can be introduced as they can provide a satisfactory decoding performance in most cases and a simple method [16].

This paper is organized as follows: In Section 2, a simulation model of STFBC in OFDM system with FO using a new subcarrier mapping scheme ICI-SC technique will be derived and discussed. We have derived a different LMLAC decoding algorithm and briefly described the derivation of proposed equation in MIMO-OFDM system in Section 3. In Section 4, simulation results will be analyzed in terms of BER and $E_b/N_o$ performance. Finally, some concluding remarks were given in Section 5.

## 2. System Model

As illustrated in Fig. 1, we focused on MIMO-OFDM system with $M=2$ Transmit and $N=2$ Receive antennas. Let the number of subcarriers in the OFDM modulators as $K$. Using typical urban (TU) channel, the $L$-path quasi static Rayleigh fading channel model between each pair of transmit and receive antennas used in this system is six paths COST207.

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 a new data conversion subcarrier mapping scheme ICI-SC technique codeword as follows:
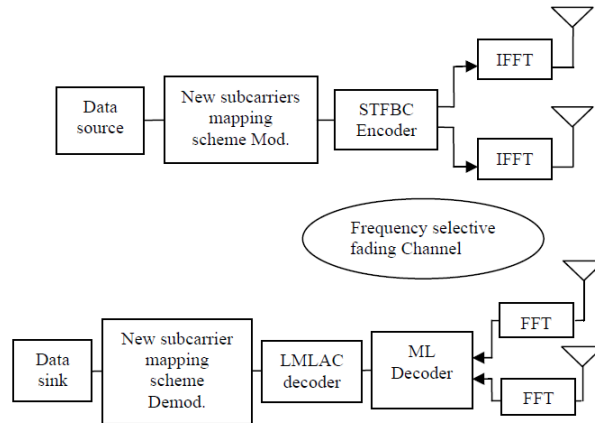
**Fig. 1. Block Diagram for STFBC with New Subcarrier Mapping
Scheme ICI-SC Technique using a MIMO-OFDM System.**

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

(1)

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

$$
X_m = \begin{bmatrix}
X_1(0) & \dots & X_2(0) & \dots & X_M(0) \\
-X_1(\frac{N}{2}-1)* & \dots & -X_2(\frac{N}{2}-1)* & \dots & -X_M(\frac{N}{2}-1)* \\
. & & . & & . \\
X_1(\frac{N}{2}-1) & \dots & X_2(\frac{N}{2}-1) & \dots & X_M(\frac{N}{2}-1) \\
-X_1(\frac{N}{2}-1)* & \dots & -X_2(\frac{N}{2}-1)* & \dots & -X_M(\frac{N}{2}-1)* \\
X_1(\frac{N}{2}) & \dots & X_2(\frac{N}{2}) & \dots & X_M(\frac{N}{2}) \\
-X_1((N-1)+\frac{N}{2})*\dots & -X_2((N-1)+\frac{N}{2})*\dots & -X_M((N-1)+\frac{N}{2})* \\
. & & . & & . \\
X_1(N-1) & \dots & X_2(N-1) & \dots & X_M(N-1) \\
-X_1((N-1)+\frac{N}{2})*\dots & -X_2((N-1)+\frac{N}{2})*\dots & -X_M((N-1)+\frac{N}{2})*
\end{bmatrix}
$$

(2)

By allocating a pair of complex signals, the phase different between two adjacent subcarriers varies with respect to the signal itself [17]. This method is called new data conjugate subcarrier mapping scheme ICI-SC technique.

## 3. Linear Maximum Likelihood Decoding of STFBC

Three LMLAC decoding techniques are considered, namely the conventional combiner, maximum diversity combiner and orthogonal combiner. Different LMLAC decoding techniques have different pairs to combine the received signals and the average $E_b/N_o$ with combination space time and space frequency is also different.

### 3.1. Conventional combiner

In conventional ML decoder, the received signals at times ($T$) and frequencies ($F$) $k$ and $k+1$ for STFBC can be written as follows:-

$$Y_T(k) = H_{1,1}(1)S_1 + H_{1,2}(1)S_2 \tag{3}$$

$$Y_T(k+1) = H_{2,1}(2)S_1 - H_{2,2}(2)S_2 \tag{4}$$

$$Y_F(k) = H_{1,1}(1)S_1 + H_{2,1}(1)S_2 \tag{5}$$

$$Y_F(k+1) = H_{2,2}(1)S_1 - H_{1,2}(1)S_2 \tag{6}$$

by which the transmit symbol using maximum likelihood equations, $S_1$ and $S_2$ are given as

$$S_1 = (X_1(k)\left[H_{1,1}(k)S(0) + H_{2,1}(k)^* S(0)^*\right] - X_2(k)^*\left[H_{1,2}(k)S(1) + H_{2,2}(k)^* S(-1)^*\right]$$
$$+ (1/4\sum\nolimits_{l=0}^{N-1} \begin{matrix} X_1(l)H_{1,1}(k)S(l-k) + \\ X_2(l)^* H_{2,2}(l)^* S(l-k-1)) + N_k) \end{matrix} \tag{7}$$

$$S_2 = (X_2(k)\left[H_{2,1}(k)S(0) - H_{1,2}(k)^* S(0)^*\right] + X_1(k)^*\left[H_{2,2}(k)S(1) + H_{1,1}(k)^* S(-1)^*\right]$$
$$+ (1/4\sum\nolimits_{l=0}^{N-1} \begin{matrix} X_2(l)H_{2,1}(k)S(l-k) - \\ X_1(l)^* H_{1,2}(l)^* S(l-k-1)) + (N_k+1)) \end{matrix} \tag{8}$$

The channel coefficient is $H_{m,n}(k)$ whereas the value of $m$, $n$ and $k$ are indexes of transmitting antennas, subcarriers and time. Then, the pairs $\left(H_{1,1}^*(1), H_{2,1}(1)\right), \left(H_{2,1}^*(1), -H_{1,1}(1)\right)$ and $\left(H_{1,1}^*(2), H_{2,1}(2)\right), \left(H_{2,1}^*(2), -H_{1,1}(2)\right)$ that are used to combine the received signals $Y_1$ and $Y_2$ at $k$ and $k+1$ for time domain become:

$$Y_1(k) = H_{1,1}(1)^* Y_T(k) + H_{2,1}(1)Y_T(k+1)^* \tag{9}$$

$$Y_2(k) = H_{1,1}(2)^* Y_T(k) + H_{2,1}(2)Y_T(k+1)^* \tag{10}$$

$$Y_1(k+1) = H_{2,1}(1)^* Y_T(k) - H_{1,1}(1)Y_T(k+1)^* \tag{11}$$

$$Y_2(k+1) = H_{2,1}(2)^* Y_T(k) - H_{1,1}(2)Y_T(k+1)^* \tag{12}$$

Consequently, the frequency domain that are being used to combine the received signal are; $\left(H_{1,2}^*(1), H_{2,2}(1)\right), \left(H_{2,1}^*(1), -H_{1,2}(1)\right)$ for the received signals $Y_1$ and $\left(H_{1,1}^*(2), H_{2,1}(2)\right), \left(H_{2,1}^*(2), -H_{1,1}(2)\right)$ for the received signals $Y_2$. The received signal for frequency domain becomes:

$$\overline{Y}_1(k) = H_{1,2}(1)^* Y_F(k) + H_{2,2}(1) Y_F(k+1)^* \tag{13}$$

$$\overline{Y}_2(k) = H_{1,1}(2)^* Y_F(k) + H_{2,1}(2) Y_F(k+1)^* \tag{14}$$

$$\overline{Y}_1(k+1) = H_{2,2}(1)^* Y_F(k) - H_{1,2}(1) Y_F(k+1)^* \tag{15}$$

$$\overline{Y}_2(k+1) = H_{2,1}(2)^* Y_F(k) - H_{1,1}(2) Y_F(k+1)^* \tag{16}$$

Substituting Eqs. (9), (10), (13) and (14) into Eq. (17), then the transmit symbols resulted using conventional combiner is:-

$$\hat{S}_1 = Y_1(k) + Y_2(k) + \overline{Y}_1(k) + \overline{Y}_2(k) \tag{17}$$

and substituting Eqs. (11), (12), (15) and (16) into Eq. (18)

$$\hat{S}_2 = Y_1(k+1) + Y_2(k+1) + \overline{Y}_1(k+1) + \overline{Y}_2(k+1) \tag{18}$$

By referring to [16], the equation of average $E_b/N_o$ via the combination of space time and space frequency it becomes:

$$\xi = \frac{(1+\alpha_{ij})\sigma_H^2 \sigma_S^2}{2\sigma_w^2 + (\rho_{ij})\Gamma\left(\frac{3}{2}\right)\sigma_H^2 \sigma_S^2} \tag{19}$$

by which $\sigma_S^2$ is the average energy of the transmit symbols, $\sigma_H^2$ is the average power of the channel gain, $\sigma_w^2$ is the average noise, $\alpha_{ij}$ is the complex gain at the value of $i$ (time) and $j$ (frequency), and $\rho_{ij}$ is the normalized interference coefficient transmit symbols at $i$ and $j$.

### 3.2. Maximum diversity combiner

We now propose a second technique to achieve performance of low complexity, with maximum diversity order. By using the same mapping method, the received signal for time domain pair are $\left(H_{1,2}^*(1), H_{2,2}(2)\right)$, $\left(H_{2,2}^*(2), -H_{1,2}(2)\right)$ and $\left(H_{1,1}^*(1), H_{2,1}(2)\right)$, $\left(H_{2,1}^*(1), -H_{1,1}(2)\right)$, and for frequency domain pair are $\left(H_{1,1}^*(1), H_{2,2}(1)\right)$, $\left(H_{2,1}^*(1), -H_{1,2}(1)\right)$ and $\left(H_{1,1}^*(2), H_{2,2}(2)\right), \left(H_{2,1}^*(2), -H_{1,2}(2)\right)$.

By employing the same method as in Eqs. (17) and (18) on different pairs, we obtained the equations $\hat{S}_1$ and $\hat{S}_2$. From [16], the resulting average $E_b/N_o$ for space time and space frequency is:

$$\xi = \frac{2\sigma_H^2 \sigma_S^2}{2\sigma_w^2 + (\rho_{ij})\sigma_H^2 \sigma_S^2} \tag{20}$$

### 3.3. Orthogonal combiner

Next, we propose another technique known as orthogonal combiner. Let's substitute Eqs. (9) to (16) into the equations for $\hat{S}_1$ and $\hat{S}_2$, then, combine different pairs in the time domain $Y_1 = \left(H_{1,1}^*(2), H_{2,1}(1)\right)$, $\left(H_{2,1}^*(2), -H_{1,1}(1)\right)$ and

$Y_2 = \left(H_{1,2}^*(2), H_{2,2}(1)\right)$ , $\left(H_{2,2}^*(2), -H_{1,2}(1)\right)$ and apply the frequency domain $Y_1 = \left(H_{1,2}^*(1), H_{1,1}(1)\right), \left(H_{2,2}^*(1), -H_{1,1}(1)\right)$ and $Y_2 = \left(H_{1,2}^*(2), H_{2,1}(2)\right), \left(H_{2,2}^*(2), -H_{1,1}(2)\right)$.

From the above pairs, the received signals for orthogonal combiner can obtain $\hat{S}_1$ and $\hat{S}_2$ respectively. The average $E_b/N_o$ with the combination of space time and space frequency is as obtained below [16]:

$$\xi = \frac{2(\alpha_{ij})\sigma_H^2 \sigma_S^2}{2\sigma_w^2} \tag{21}$$

At this stage, we can conclude that, in STFBC MIMO-OFDM, as the average $E_b/N_o$ becomes higher, the noise in system become lower.

## 4. Simulation Results and Discussion

This section shows the simulation of the proposed STFBC design methods with the insertion of LMLAC Decoding. For this system, we use the six-path COST 207 (Jakes model) typical urban (TU) channel model [18] over a more realistic model. By using OFDM base, the simulation parameters are shown in Table 1.

**Table 1. Simulation Parameters for the System [19].**

| Parameters | Value |
|---|---|
| **Bandwidth (BW)** | 1.25MHz |
| **Sampling frequency** | 1.92MHz |
| **Sampling time** | $5.208 \times 10^{-7}$ 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, $L_p = (0, 0.2 \times 10^{-6}, 0.5 \times 10^{-6}, 1.6 \times 10^{-6}, 2.3 \times 10^{-6}, 5.0 \times 10^{-6})$ seconds Average path gains = [0.5011, 1.122, 0.6309, 0.251, 0.158, 0.1] dB |

The simulation results presented BER curves as functions of $E_b/N_o$ as shown in Fig. 2. Figure 2, depicts the BER performance of STFBC with new data conjugate and data conversion subcarrier mapping scheme ICI-SC technique by using four types of subcarrier mapping compared at NFO=5%. BER for data conjugate improves at high $E_b/N_o$ than conversion method for all decoding methods using new subcarrier mapping scheme. The data conjugate with maximum diversity combiner has the best BER performance compared to the other three decoding techniques because the system has a low decoding complexity system with optimal distance that can achieve maximum frequency diversity and less interference. For instance, at BER=$2 \times 10^{-2}$, the $E_b/N_o$ value for maximum diversity combiner with data conjugate is 4.4 dB. The performance loss of data conjugate between maximum diversity combiner with conventional combiner, orthogonal combiner and ML decoding are about 2.1 dB, 4

dB and 4.5 dB respectively. It is noticeable that the ML decoding performed worse than other techniques in linear combiner and performs the lowest value of $E_b/N_o$. It is also shown that maximum diversity combined with new data conjugate subcarrier mapping scheme ICI-SC technique from Eq. (2) yields the best performance with low complexity and less time consumption compared with other linear combiner techniques, and produces the highest $E_b/N_o$ values from Eq. (20). In overall, linear combiner performs at better BER performance with higher $E_b/N_o$ from Eqs. (19), (20) and (21) than the ML decoding with a NFO=5%.
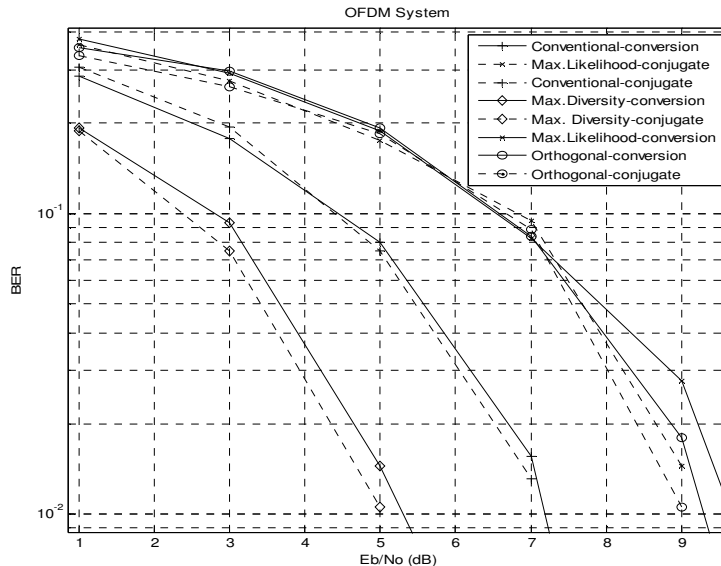


**Fig. 2. STFBC Systems for $f_o$ = 0.05 with New Data Conjugate and Data Conversion Subcarrier Mapping Scheme ICI-SC Technique Using Different Decoding Techniques.**

Figure 3 depicts the simulation results of BER performance of STFBC with new data conjugate subcarrier mapping schemes ICI-SC technique with NFO = (0%, 5%, 15%, 20%) using maximum diversity combiner decoding technique. Figure 3 shows that when the NFO is 0% at BER=$3\times10^{-2}$, the performance loss is about 0.9 dB for NFO=5%, 2.2 dB for NFO=15% and 6 dB for NFO=20% respectively. The value of $E_b/N_o$ needs to be compensated for the effect of FO increases. The new data conjugate subcarrier mapping scheme from Eq. (2) at NFO=0% produces the best BER performance for all NFO in the system. It is proven that there is a significant improvement when the value of FO decreases in the system. The above simulation shows that the lower the FO the better performance of the system, which can increase the $E_b/N_o$ and decrease the BER. If the FO decreases, the shift of BER curves with higher diversity order is larger than the shift of BER curves with lower diversity order. Therefore, the higher diversity order systems are more robust to the effect of FO. From the above simulation, the result confirm that the BER performance for a new subcarrier mapping scheme ICI-SC technique using maximum diversity combiner method produces ICI reduction in the system with low complexity decoding technique and can achieve maximum diversity order.
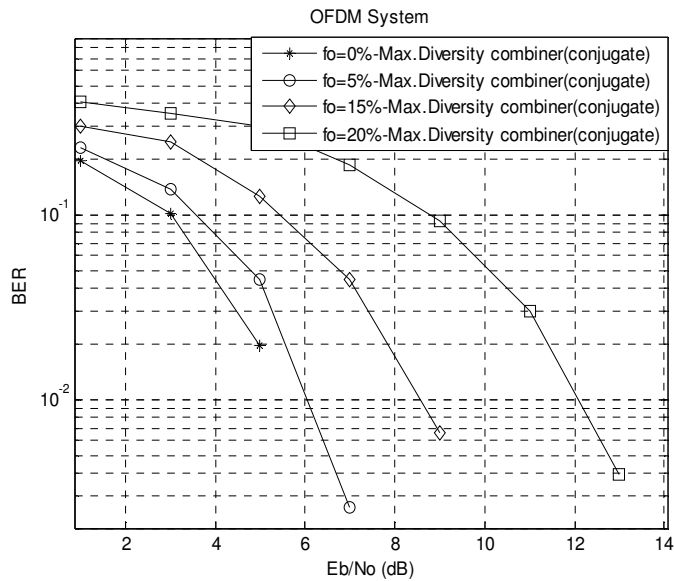
**Fig. 3. STFBC Systems for Different $f_o$ with New Data
Conjugate Subcarrier Mapping Scheme ICI-SC Technique
Using Maximum Diversity Combiner Decoding Techniques.**

## 5. Conclusions

In this paper, a new subcarrier mapping technique that is combined with LMLAC decoding techniques is proposed using STFBC MIMO-OFDM system. The simulation results have shown that the performance improvement of BER can achieve the objectives of this paper to study for ICI reduction methods with low decoder complexity and maximum diversity order system. These has proven that the proposed subcarrier mapping ICI-SC technique combined with maximum diversity combiner technique using STFBC can be considered as a promising candidate in the MIMO OFDM-based system.

## References

1. Falconer, D.; Ariyavisitakul, S.L.; Benyamin-Seeyar, A.; and Eidson, B. (2002). Frequency domain equalization for single-carrier broadband wireless systems. *IEEE Communication Magazine*, 40(4), 58-66.

2. Omar, M.H.; Hassan, S.; and Shabli, A.H.M. (2009). COGRADNET: Ubiquitous heterogeneous wireless networks. *Journal of Engineering Science & Technology* (*JESTEC*), 4(2), 184-195.

3. Weifeng, S.; Safar, Z.; and Liu K.J.R. (2005). Towards maximum achievable diversity in space, time, and frequency: Performance analysis and code design. IEEE Transactions on Wireless Communications, 4(4), 1847-1857.

4. Prianka, F.; Matin, M.A.; Saleh, A.Z.; and Ali, M.A.M. (2010). BER analysis of OFDM with improved ICI self-cancellation scheme. *International Conference on Material and Manufacturing Technology (ICMMT)*.

5.  Weifeng, S.; Safar, Z.; Olfat, M., and Liu, K.J.R. (2003). Obtaining full-diversity space-frequency codes from space-time codes via mapping. *IEEE Transactions on Signal Processing*, 51(11), 2905-2916.

6.  Hwang, T.; Yang, C.; Wu, G.; Li, S.; and Ye Li, G. (2009). OFDM and its wireless applications: A survey. *IEEE Transactions on Vehicular Technology*, 58(4), 1673-1649.

7.  Stuber, G.L.; Barry, J.R.; Mclaughlin, S.W.; Li, Y.; Ingram, M.A.; and Pratt, T.G. (2004). Broadband MIMO-OFDM wireless communications. *Proceedings of the IEEE*, 92(2), 271-294.

8.  Hwang, T.; Yang, C.; Wu, G.; Li, S.; and Ye Li, G. (2009). OFDM and its wireless applications: A survey. *IEEE Transactions on Vehicular Technology*, 58(4), 1673-1649.

9.  Russel, M.; and Stuber, G.L. (1995). Interchannel interference analysis of OFDM in a mobile environment. *IEEE 45'th Vehicular Technology Conference*, 2, 820-824.

10. Bera, R.N.; Sinha, N.B.; Kandar, D.; Bera, R.; and Sarkar, S.K. (2008). Experimental studies and simulations Based prediction of a better MIMO-OFDM combined system for broadband wireless mobile communication. *Progress in Electromagnetics Research C*, 2, 47–64.

11. Muschallik, C. (1996). Improving an OFDM reception using an adaptive Nyquist windowing. *IEEE Transactions on Consumer Electronics*, 42(3), 259-269.

12. Moose, P.H. (1994). A technique for orthogonal frequency division multiplexing frequency offset correction. *IEEE Transactions on Communication*, 42(10), 2908-2914.

13. Chung Y.H. (2008). Inter-carrier interference self-cancellation scheme with Improved bandwidth efficiency for OFDM transmission systems. *International Conference on Convergence and Hybrid Information Technology*, 95-99.

14. Zhao, Li; and Zhang, P. (2006). A new ICI self-cancellation scheme based on repeated symbol in OFDM system. *International Conference on Communications, Circuites, and Systems Proceedings*, 2, 1216-1220.

15. Qiang Shi; Yong Fang; and  Min Wang. (2009). A new ICI self-cancellation scheme for OFDM systems. *5th International Conference on Wireless communications, networking and mobile computing*, 1-4.

16. de Abreu, G.T.F.; Ochiai, H.; and Kohno, R.. (2004). Linear maximum likelihood decoding of space-time block coded OFDM systems for mobile communications. *IEE Proceedings-Communications*, 151(5),447-459.

17. Dũng Ngoc Đào; and Tellambura, C. (2005). Intercarrier interference self-cancellation space-frequency codes for MIMO-OFDM. *IEEE Transactions on Vehicular Technology*, 54(5), 1729-1738.

18. Jeruchim, M.C; Balaban, P.; Shanmugan, K.S. (2000). *Simulation of communication systems: Modeling, methodology, and techniques.* (2nd Ed.) Springer.

19. Chiueh, T.D.; and Tsai, P.Y. (2007). *OFDM baseband receiver design for wireless communications*. John Wiley and Sons (Asia) Pte Ltd, Singapore.