Performance of Linear Maximum Likelihood Alamouti Decoder with Diversity Techniques

Azlina Idris, Kaharudin Dimyati, and Sharifah K. Syed Yusof

***Abstract*—Multiple input multiple output (MIMO) communication systems with orthogonal frequency division multiplexing (OFDM) modulation have a great potential to play an important part in the design of the next generation broadband wireless communication system. In this paper, the bit error rate (BER) performance using linear maximum likelihood alamouti combiner (LMLAC) decoding technique for space time frequency block codes (STFBC) MIMO-OFDM system with frequency offset (FO) is being evaluated to provide the system with low complexity and maximum diversity. As will be shown, the performance of diversity system depends on maximum diversity combiner decoder technique with low complexity and achieves maximum diversity order compare to the maximum likelihood (ML) and other LMLAC decoder techniques.**

***Index Terms*—space time frequency block codes, multiple input multiple output orthogonal frequency division multiplexing, linear maximum likelihood alamouti combiner, frequency offset**

I. INTRODUCTION

Multiple antenna systems have shown significant improvement in communication over the wireless channel compared to the traditional single antenna systems [1]. By employing multiple transmit and receive antennas, the adverse effects of the wireless propagation environment can be significantly reduced [2]. In case of broadband wireless communications, where the fading channel is frequency selective, OFDM modulation can be used to transform the frequency-selective channel into a set parallel frequency flat channels [2]. OFDM is a popular modulation technique that can be utilized for high data rate wireless transmission to combat multipath fading.

For this case, MIMO-OFDM was introduced, where resulting major channel coding approach, which is space time frequency (STF) coding [2]. STFBC is a simple yet ingenious transmit diversity technique in MIMO technology, and have rapidly become one of the most active research areas in wireless communications.

The first space time codes proposed by TarokhV, Jafarkhani H, and Calderbank A.R. [3] for coherent systems over MIMO quasi static flat fading channels, by introduced their space time trellis coding technique and Alamouti introduced his STFBC techniques to improve link-level performance based on diversity [4]. The concept of STFBC is to enable maximum diversity order against Rayleigh fading channel [5]. A STF coding scheme for OFDM based broadband wireless systems is proposed to efficiently achieve the full diversity resources that can improve the signal quality and also use to increase spectral efficiency of OFDM. Recently, in designing the MIMO-OFDM, was focused on the decoder complexity instead of the main criteria of code rate, diversity order and coding gain [6], which in this paper the LMLAC decoding techniques is introduced in STFBC whereby to achieve low-complexity.

From the [7], LMLAC decoding of orthogonal space time block codes brings the complexity involved in the application of such codes to implementable levels (even with higher order modulation schemes). Purposely, this paper is focuses on the study of identifying the performance and development of STFBC MIMO-OFDM by introducing the LMLAC decoder to enable maximum diversity order against Rayleigh fading channel, to obtain highest E_b/N_o, lowest noise based on BER.

This paper is organized as follows: In section II, STFBC in MIMO-OFDM system with FO is discussed and have derived a different LMLAC decoding. In section III, simulation results will be analyzed in terms of BER and E_b/N_o performance. Finally, some concluding remarks are delivered in section IV.

II. METHODOLOGY

A. *Space Time Frequency diversity*

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;

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

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.

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 [2] as shown in Fig. 1

Manuscript received March 5, 2011; revised April 8, 2011.

Azlina Idris is with the Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia. She is currently pursuing PhD with the Department of Electrical Engineering, Universiti Malaya, Malaysia. (Phone: +6193883443; fax: 6355435077; e-mail: azlina_idr@yahoo.com).

Kaharudin Dimyati is with the Faculty of Engineering, National Defence University of Malaysia (e-mail: kaharudindimyati @yahoo.co.uk).

Sharifah K. Syed Yusof is with the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, (e-mail: kamilah @fke.utm.my).

where *Ti* (time slots), *f* (frequencies) and *Ant* (Antennas).

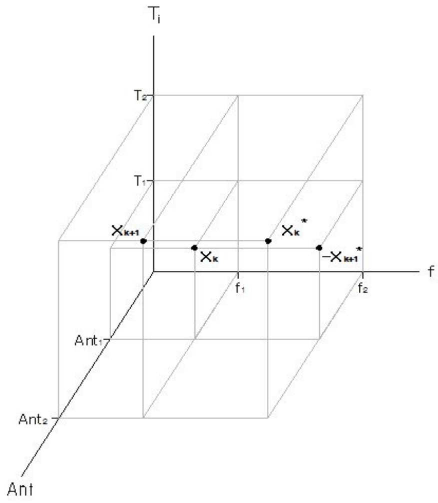

Fig. 1. Coding in STFBC method

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. In the MIMO-OFDM systems, with subcarrier, the coefficients from [8] is a constant with respect to subcarrier index *k=0*, where is the normalized frequency offset (NFO).

$$S_{m,n}(0) = \frac{\sin(\pi\varepsilon_{m,n})}{K\sin\left(\frac{\pi}{K}\varepsilon_{m,n}\right)}.\exp\left(j\pi\left(1-\frac{1}{K}\right)\varepsilon_{m,n}\right) \tag{3}$$

B. Linear Maximum Likelihood Alamouti Combiner decoder

The performance of a detector or receiver is highly depending on the characteristic of the decoder. For this purpose, three LMLAC decoding techniques have been applied namely the conventional combiner, maximum diversity combiner and orthogonal combiner. It must be noted that different LMLAC decoding techniques have different pairs to the received signals. The different between the averages of E_b/N_o with combination of space time and space frequency is also being considered.

3.1 Conventional combiner

In conventional MLD, the received signals at *k* and *k+1* for STFBC can be written as follows

$$\begin{aligned} Y_T(k) &= H_{1,1}(1)S_1 + H_{1,2}(1)S_2 \\ Y_T(k+1) &= H_{2,1}(2)S_1 - H_{2,2}(2)S_2 \\ Y_F(k) &= H_{1,1}(1)S_1 + H_{2,1}(1)S_2 \\ Y_F(k+1) &= H_{2,2}(1)S_1 - H_{1,2}(1)S_2 \end{aligned} \tag{4}$$

by which the maximum likelihood equations, S_1 and S_2 are given as

$$S_1 = \begin{aligned} &(X_1(k)\left[H_{1,1}(k)S(0)+H_{2,1}(k)^*S(0)^*\right] \\ &-X_2(k)^*\left[H_{1,2}(k)S(1)+H_{2,2}(k)^*S(-1)^*\right] \\ &+(1/4\sum_{l=0}^{N-1} \begin{aligned} &X_1(l)H_{1,1}(k)S(l-k)+ \\ &X_2(l)^*H_{2,2}(l)^*S(l-k-1))+N_k) \end{aligned} \end{aligned} \tag{5}$$

$$S_2 = \begin{aligned} &(X_2(k)\left[H_{2,1}(k)S(0)-H_{1,2}(k)^*S(0)^*\right] \\ &+X_1(k)^*\left[H_{2,2}(k)S(1)+H_{1,1}(k)^*S(-1)^*\right] \\ &+(1/4\sum_{l=0}^{N-1} \begin{aligned} &X_2(l)H_{2,1}(k)S(l-k)- \\ &X_1(l)^*H_{1,2}(l)^*S(l-k-1))+(N_k+1)) \end{aligned} \end{aligned} \tag{6}$$

Then, the pairs $(H^*_{1,1}(1), H_{2,1}(1))$, $(H^*_{2,1}(1), -H_{1,1}(1))$ and $(H^*_{1,1}(2), H_{2,1}(2))$, $(H^*_{2,1}(2), -H_{1,1}(2))$ that are used to combine the received signals Y_1 and Y_2 at times t and $t+1$ (time domain) become;

$$\begin{aligned} Y_1(k) &= H_{1,1}(1)^*Y_T(k) + H_{2,1}(1)Y_T(k+1)^* \\ Y_2(k) &= H_{1,1}(2)^*Y_T(k) + H_{2,1}(2)Y_T(k+1)^* \\ Y_1(k+1) &= H_{2,1}(1)^*Y_T(k) - H_{1,1}(1)Y_T(k+1)^* \\ Y_2(k+1) &= H_{2,1}(2)^*Y_T(k) - H_{1,1}(2)Y_T(k+1)^* \end{aligned} \tag{7}$$

Next, the frequency domain that are being used to combine the received signal become; $(H^*_{1,2}(1), H_{2,2}(1))$, $(H^*_{2,1}(1), -H_{1,2}(1))$ for the received signals Y_1 and $(H^*_{1,1}(2), H_{2,1}(2))$, $(H^*_{2,1}(2), -H_{1,1}(2))$ for the received signals Y_2. The received signal (frequency domain) becomes;

$$\begin{aligned} \overline{Y}_1(k) &= H_{1,2}(1)^*Y_F(k) + H_{2,2}(1)Y_F(k+1)^* \\ \overline{Y}_2(k) &= H_{1,1}(2)^*Y_F(k) + H_{2,1}(2)Y_F(k+1)^* \\ \overline{Y}_1(k+1) &= H_{2,2}(1)^*Y_F(k) - H_{1,2}(1)Y_F(k+1)^* \\ \overline{Y}_2(k+1) &= H_{2,1}(2)^*Y_F(k) - H_{1,1}(2)Y_F(k+1)^* \end{aligned} \tag{8}$$

The transmit symbols, S_1 and S_2, can be obtained by combining equations (7) and (8)

$$\hat{S}_1 = Y_1(k) + Y_2(k) + \overline{Y}_1(k) + \overline{Y}_2(k) \tag{9}$$

and equations (11) and (12)

$$\hat{S}_2 = Y_1(k+1) + Y_2(k+1) + \overline{Y}_1(k+1) + \overline{Y}_2(k+1) \tag{10}$$

By referring to [7], the equation of E_b/N_o via the combination of space time and space frequency is;

$$\xi = \frac{(1+\alpha_{ij})\sigma_H^2\sigma_S^2}{2\sigma_w^2 + (\rho_{ij})\Gamma\left(3/2\right)\sigma_H^2\sigma_S^2} \tag{11}$$

by which σ_S^2 is the average energy of the transmit symbols, σ_H^2 is the average power of the channel gain, σ_w^2 is the average noise, α_{ij} is the complex gain, and ρ_{ij} is the normalized interference coefficient transmit symbols.

3.2 Maximum diversity combiner

In the next step, another technique to achieve performance of low complexity, with maximum diversity order is being performed. 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 procedure as in equations (9) and (10) on different pairs, the value of $\hat{S}_1$ and $\hat{S}_2$ are obtained. From [7], the resulting average E_b/N_o for space time and space frequency is;

$$\xi = \frac{2\sigma_H^2 \sigma_S^2}{2\sigma_w^2 + \left(\rho_{ij}\right)\sigma_H^2 \sigma_S^2} \tag{12}$$

3.3 Orthogonal combiner

Similar to the previous two sections, another technique known as orthogonal combiner is proposed. Then, we 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 ($Y_1 = \left(H_{1,2}^{*}(1), H_{2,1}(1)\right), \left(H_{2,2}^{*}(1), -H_{1,1}(1)\right)$)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 can obtain $\hat{S}_1$ from equation (9) and $\hat{S}_2$ from equation (10) respectively. The average E_b/N_o with the combination of space time and space frequency is as obtained below [7];

$$\xi = \frac{2\left(\alpha_{ij}\right)\sigma_H^2 \sigma_S^2}{2\sigma_w^2} \tag{13}$$

III. RESULT AND DISCUSSION

In this section, the STFBC MIMO-OFDM design methods using LMLAC decoding technique are simulated and the BER performance is then being investigated. The six-path COST 207 (Jakes model) TU channel model which is a more realistic model for quasi static Rayleigh fading channel MIMO-OFDM system [9] is being used. The simulation parameters are as shown in **Table 1**.

The performance of STFBC for MIMO-OFDM with insertion ML and LMLAC decoding process is simulated. In this system, few techniques that have been proposed in LMLAC decoding with an ordinary system technique ML, by insertion the conventional linear combiner from equation (11), maximum diversity linear combiner from equation (12) and orthogonal combiner from equation (13) are being compared. As illustrated in Fig. 2, it shows that the BER curves of STFBC MIMO-OFDM with NFO=0% for maximum diversity combiner is increasing comparing with other techniques in LMLAC. It is noticeable that the ML decoding performs worse than other techniques in LMLAC.

TABLE 1
SIMULATION PARAMETERS FOR THE 3RD GENERATION PARTNERSHIP PROJECT LONG TERM EVOLUTION (3GPP-LTE) SYSTEM [10].

Parameters	Value
Bandwidth (BW)	1.25MHz
Sampling frequency	1.92MHz
Sampling time	5.208x10^{-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, 0.2x10^{-6}, 0.5x10^{-6}, 1.6x10^{-6}, 2.3x10^{-6}, 5.0x10^{-6})seconds Average path gains = [0.5011, 1.122, 0.6309, 0.251, 0.158, 0.1] dB
Decoding method	Maximum Likelihood Decoding

The simulation results are presented in terms of BER curves as functions of E_b/N_o.

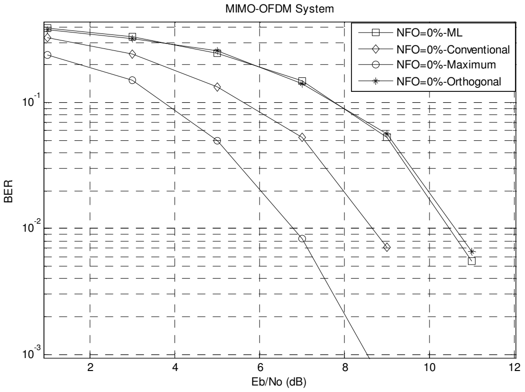

Fig. 2. Performance of BER for STFBC systems with NFO=0% using different decoding technique.

Fig. 2 illustrates the method of ML decoding for the STFBC scheme is used as a reference in our comparisons. It also shows that, when BER=10^{-2} the performance between maximum diversity combiner and conventional combiner, orthogonal combiner and ML is about 2 dB, 4 dB and 3.7 dB. In the case of symbol-by-symbol ML decoding, the maximum diversity combiner yield the best performance than other LMLAC techniques. It has also achieved low complexity decoding technique with high E_b/N_o in the system as demonstrated in equation (12).

Next, the STFBC systems are being simulated using different NFO, whereby the NFO = 0%, 5%, 10% and 20% are being evaluated using the maximum diversity combiner decoding technique. As illustrate in Fig. 3, BER performance of STFBC MIMO-OFDM with NFO=0% is decreasing comparing to the system with NFO=5% and NFO=15%. The system with lower value of FO performs better as shown in Fig.3; when BER =10^{-2} the BER performance for STFBC MIMO-OFDM system between NFO=0% and 5% is about 0.6 dB and for 15% is about 2.2 dB.

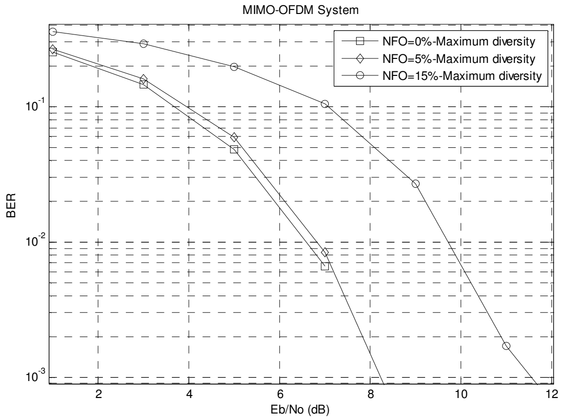

Fig. 3. Performance of BER for STFBC MIMO-OFDM systems using maximum diversity combiner decoding technique with different NFO.

The above simulation shows that the lower the NFO the better the performance of the system; which can increase the E_b/N_o in equation (12) and decrease the BER. If the NFO decreased, the BER curves with lower diversity order are shift smaller than the BER curves with higher diversity order. Therefore, for the same transmit power, higher diversity order systems are more robust to the effect of NFO in STFBC MIMO-OFDM system.

IV. CONCLUSION

The proposed of LMLAC decoder in the system is to get the performance with low complexity. The simulation results shows that LMLAC which perform maximum diversity combiner technique with low NFO yields the best performance of BER compare to other techniques in the system. With combining the space time and space frequency in the system, it will enable to achieve of high E_b/N_o with low decoding complexity and maximum diversity order in MIMO-OFDM system.

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