Comparison of BER Performance of SISO, MISO and MIMO Systems Based on OSTBC and EO-STBC Techniques

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ABSTRACT

Comparison of bit error rate (BER) performance of single input single output (SISO), multiple input single output (MISO), and multiple input multiple output (MIMO) systems based on orthogonal space time block coding (OSTBC) and extended orthogonal space time block coding (EO-STBC) techniques, over flat fading channel, is addressed. The antenna configurations of MIMO system used in LTE and WiMAX, supports up to four antennas at either the transmitter, receiver, or both. Therefore, the comparison of BER performance of SISO, MISO and MIMO systems are a subject of this paper. The implementation of open loop SIMO and MIMO are based on OSTBC technique. Whereas, the implementation of closed loop SIMO and MIMO are based on EO-STBC technique. Losing the orthogonality decreasing the spatial diversity order. To achieve full spatial diversity order, closed loop (feedback) is used. The MATLAB simulation results confirm that, when the transmitted signals are fully orthogonal as in the system based on OSTBC (Alamouti) scheme, the system achieves full spatial diversity order which means that the best BER performance is reached. In contrast, when the transmitted signals are not fully orthogonal as in the system based on open loop EO-STBC scheme, the system can not reach full spatial diversity order which means that the worst BER performance is recorded. In the former system, feedback is exploited to achieve full spatial diversity order.

Keywords: SISO; MISO; MIMO; OSTBC; open and closed loop EO-STBC; diversity order; flat fading channel.

1 Introduction

The use of multiple antennas allows independent channels to be created in space which called diversity and is one of the most interesting and promising areas of recent innovation in wireless communications. Rayleigh fading wireless channels make a very large power penalty on the BER performance of the conventional single input single output (SISO) wireless system. To mitigate the effects of Rayleigh fading due to wireless channels, is to use diversity techniques. There are many types of achieving diversity in a wireless system. First method of achieving diversity is by using either two transmit antennas or two receive antennas with different polarization. Second method is frequency diversity, where it achieved by transmitting the same narrowband signal at different carrier frequencies, this technique requires additional transmit power to send the signal over multiple frequency bands. Third method, time diversity is achieved by transmitting the same signal at different times, the time difference should be greater than the channel coherence time. Time diversity does not require increased transmit power, but it does decrease the data rate. Fourth method is space diversity, this type uses multiple transmit antennas, receive antennas, or transmit and receive antennas at both sides [1], [2]. In practical, the Long-Term Evolution (LTE), LTE-Advanced and Worldwide Interoperability for Microwave Access (WiMAX) based approaches utilize OFDM modulation and employ multiple input multiple output (MIMO) antenna technology. The antenna configurations of MIMO system used in LTE and WiMAX, supports up to four antennas at either the transmitter, receiver, or both [3]. Therefore, performance of MIMO system is a subject of this paper. Space diversity can be classified into three types. Firstly, receive diversity, which is implemented by single input multiple output (SIMO) system and based on maximum ratio combining (MRC) technique. Secondly, transmit diversity, which is implemented by multiple input single output (MISO) system and based on OSTBC (Alamouti) and open and closed EO-STBC schemes. Finally, transmit and receive diversity, which is implemented by MIMO system and also based on MRC, OSTBC (Alamouti) and open and closed EO-STBC schemes [1]. EO-STBC scheme consists of operating two OSTBC (two Alamouti code) schemes in parallel.

There are two common metrics that are used to characterize the amount of spatial diversity in a conventional SISO, SIMO, MISO and MIMO systems. These two common metrics are: spatial diversity order and spatial diversity gain [2]. Spatial diversity gain and spatial diversity order may appear fundamentally different; however, spatial diversity gain refers to the number of orthogonal signal replicas being combined which is equal to $M_T \times M_R$. Whereas, the spatial diversity order mentions to the slope of the BER versus average signal-to-noise ratio (SNR) curve. In another wards, increasing the diversity order means increasing the number of orthogonal independent copies at high diversity order, the probability that at least one of the copies is not experiencing a deep fade is increases. As a result, improving the quality and reliability of received signal. For example, a MIMO system with M_T transmit antennas and M_R receive antennas theoretically offers $M_T \times M_R$ diversity gain, and hence a spatial diversity order is the slope of the BER versus SNR curve. Spatial diversity order is equal to diversity gain ($M_T \times M_R$) or less. However, the correlation between the individual M_T and M_R channel gains depends on the orthogonality of the transmitted signal and antenna spacing at the transmitter and the receiver. If the channel coefficients are fully correlated, then, the spatial diversity order of the channel is one. Likewise, if the transmitted signal is not fully orthogonal, then, the spatial diversity order is also not full. To achieve full diversity order, feedback is needed [4], [5], [6].

The Focus of This Paper

Comparing BER performance of conventional SISO, open MISO (2×1), open MISO (4×1), closed MISO (4×1), open MIMO (2×2), open MIMO (4×2), and closed MIMO (4×2) systems. All systems are exploiting QPSK modulation scheme and experiencing flat fading channels. Providing system and mathematical models for each system. Moreover, from each BER performance curve measuring the diversity order and comparing it for all proposed systems.

The Organization of the Rest of This Paper

The rest of this paper is organized as follows. In Section **2**, the SISO wireless system over flat fading channel, including system and mathematical models, are presented. In Section **3**, the MISO wireless system over flat fading channel, including system and mathematical models of open (2x1), open (4x1), and closed (4x1) are studied. In Section **4**, the MIMO wireless system over flat fading channel, including system and mathematical models of open (2x2), open (4x2), and closed (4x2) are explained. In Section **5**, diversity order and diversity gain are drawn, Finally, simulation results and conclusions are given in Section **6** and Section **7,** respectively.

Next, system model of SISO wireless system over flat fading channel will be presented.

2 SISO Wireless System over Flat Fading Channel

2.1 System model of SISO (1×1) system

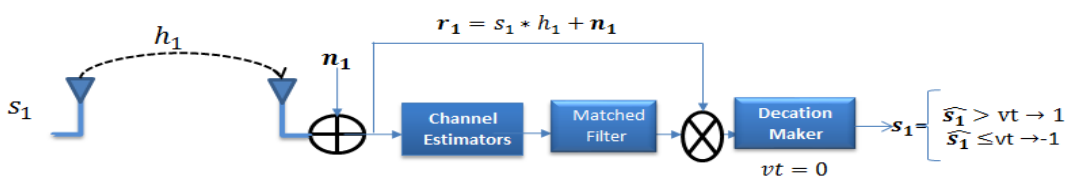

Fig. 1. Schematic system model of open loop SISO system (1Tx, 1Rx) over flat fading channel.

2.2 Mathematical model of SISO (1×1) system

The received signal can be represented as

$$r = Sh + n \tag{1}$$

Where s is the transmitted signal, n is the additive white Gaussian noise and h is the channel coefficient $h = \alpha . e^{j\theta}$, then the channel state information is assumed to be known perfectly at the receiver. Then, the estimated received signal $(\tilde{r})$ before decision maker can be written as

$$\tilde{S} = H^H r \tag{2}$$

Then the estimated received signal $\hat{S}$ after decision maker

$$\hat{S} = \begin{cases} \check{S} > V_t \rightarrow \hat{S} = \ \ 1 \\ \check{S} \leq V_t \rightarrow \hat{S} = -1 \end{cases} \tag{3}$$

System model of MISO wireless system over flat fading channel will be presented next.

3 MISO Wireless System over Flat Fading Channel

3.1 System model of open loop MISO (2×1) system based on OSTBC scheme

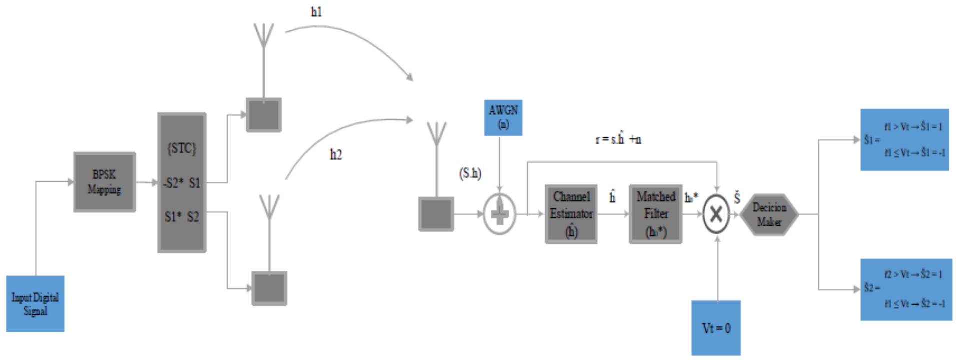

Fig. 2. Schematic system model of open loop MISO system (2Tx, 1Rx) based on OSTBC over flat fading channel.

3.2 Mathematical model of open loop MISO (2×1) system based on OSTBC scheme

In open loop MISO (2×1) system, the transmission based on OSTBC (Alamouti), which is done in two time slots, then, the received signal can be represented as:

-Time slot 1:

$$r_1 = S_1 h_1 + S_2 h_2 + n_1 \tag{4}$$

-Time slot 2:

$$r_2^* = S_1 h_2^* - S_2 h_1^* + n_2^* \tag{5}$$

The received signals in matrix form can be represented as:

$$\begin{bmatrix} r_1 \\ r_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \tag{6}$$

Then, H Hermitian transpose operation can be written as:

$$\mathrm{H^H H} = \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} = \begin{bmatrix} \alpha & 0 \\ 0 & \alpha \end{bmatrix} \tag{7}$$

Then, the estimated received signal can be written in matrix form as follows:

$$\begin{bmatrix} \check{S}_1 \\ \check{S}_2 \end{bmatrix} = \begin{bmatrix} \alpha & 0 \\ 0 & \alpha \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \tag{8}$$

The estimated received signals $\check{S}_1, \check{S}_2$represented before decision maker as

$$\check{S}_1 = \alpha S_1 + h_1^* n_1 + h_2 n_2^* \tag{9}$$

$$\check{S}_2 = \alpha S_2 + h_2^* n_1 - h_1 n_2^* \tag{10}$$

Then the estimated received signal $\hat{S}_1, \hat{S}_2$ after decision maker

$$\hat{S}_1 = \begin{cases} \check{S}_1 > V_t \rightarrow \hat{S}_1 = \ \ 1 \\ \check{S}_1 \leq V_t \rightarrow \hat{S}_1 = -1 \end{cases} \quad \text{and} \quad \hat{S}_2 = \begin{cases} \check{S}_2 > V_t \rightarrow \hat{S}_2 = \ \ 1 \\ \check{S}_2 \leq V_t \rightarrow \hat{S}_2 = -1 \end{cases} \tag{11}$$

3.3 System model of open loop MISO (4×1) system based on EO-STBC scheme

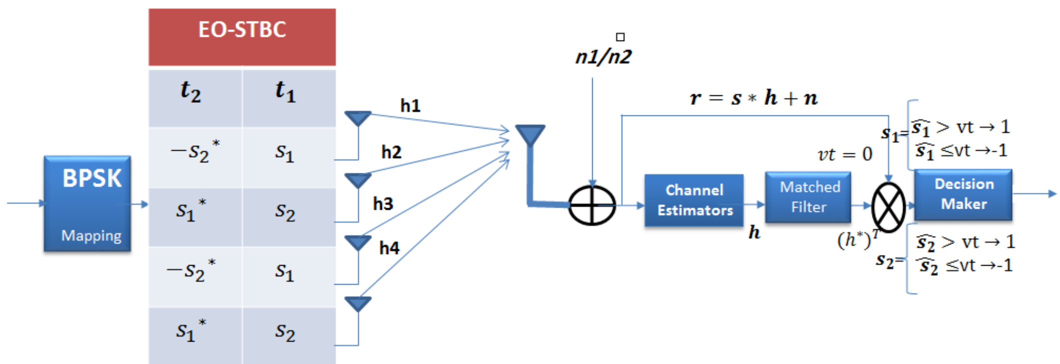

Fig. 3. Schematic system model of open loop MISO system (4Tx, 1Rx) based on EO-STBC over flat fading channel.

3.4 Mathematical model of open loop MISO (4×1) system based on EO-STBC scheme

In open loop MISO (4×1) system, the transmission based on the EO-STBC, which is done in two time slots, then, the received signal can be represented as:

-Time slot 1:

$$r_1 = S_1 h_1 + S_1 h_2 + S_2 h_3 + S_2 h_4 + n_1 \tag{12}$$

-Time slot 2:

$$r_2^* = S_1 h_3^* + S_1 h_4^* - S_2 h_1^* - S_2 h_2^* + n_2^* \tag{13}$$

The received signals r_1, r_2 at time slots 1and 2, respectively can be represented as:

$$\mathrm{H^H H} = \begin{bmatrix} h_1^* + h_2^* & h_3 + h_4 \\ h_3^* + h_4^* & -h_1 - h_2 \end{bmatrix} \begin{bmatrix} h_1 + h_2 & h_3 + h_4 \\ h_3^* + h_4^* & -h_1^* - h_2^* \end{bmatrix} = \begin{bmatrix} \alpha + \beta & 0 \\ 0 & \alpha + \beta \end{bmatrix} \tag{14}$$

Then, the estimated received signal before decision maker can be written in matrix form as follows:

$$\begin{bmatrix} \check{S}_1 \\ \check{S}_2 \end{bmatrix} = \begin{bmatrix} \alpha + \beta & 0 \\ 0 & \alpha + \beta \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} h_1^* + h_2^* & h_3 + h_4 \\ h_3^* + h_4^* & -h_1 - h_2 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \tag{15}$$

The estimated received signals represented before decision maker as

$$\check{S}_1 = (\alpha + \beta) S_1 + (h_1^* + h_2^*) n_1 + (h_3 + h_4) n_2^* \tag{16}$$

$$\check{S}_2 = (\alpha + \beta) S_2 + (h_3^* + h_4^*) n_1 - (h_1 + h_2) n_2^* \tag{17}$$

Where:

$$\alpha = h_1 . h_1^* + h_2 . h_2^* + h_3 . h_3^* + h_4 . h_4^* \tag{18}$$

$$\beta = (h_1 . h_2^* + h_2 . h_1^* + h_3 . h_4^* + h_4 . h_3^*) \tag{19}$$

Then the estimated received signal $\hat{S}_1, \hat{S}_2$ after decision maker

$$\hat{S}_1 = \begin{cases} \check{S}_1 > V_t \rightarrow \hat{S}_1 = \ \ 1 \\ \check{S}_1 \leq V_t \rightarrow \hat{S}_1 = -1 \end{cases} \quad \text{and} \quad \hat{S}_2 = \begin{cases} \check{S}_2 > V_t \rightarrow \hat{S}_2 = \ \ 1 \\ \check{S}_2 \leq V_t \rightarrow \hat{S}_2 = -1 \end{cases} \tag{20}$$

3.5 System model of closed loop MISO (4×1) system based on EO-STBC scheme

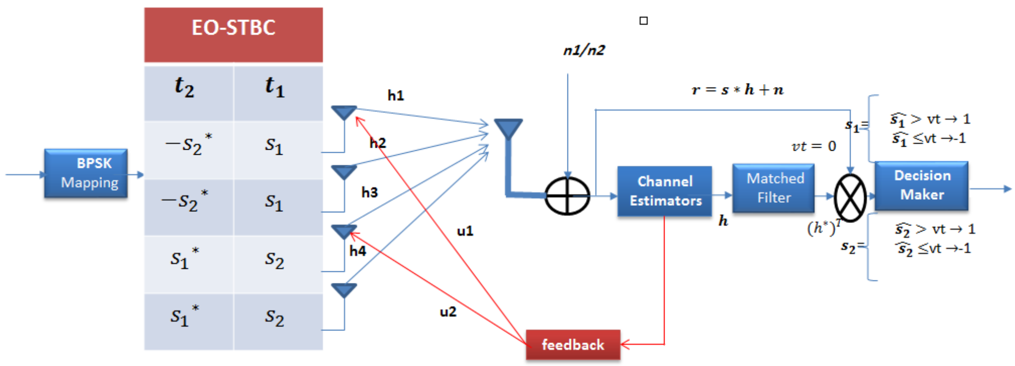

Fig. 4. Schematic system model of closed loop MISO system (4Tx, 1Rx) based on EO-STBC over flat fading channel.

3.6 Mathematical model of closed loop MISO (4×1) system based on EO-STBC scheme

In closed loop MISO (4×1) system, the transmission based on the EO-STBC, which is done in two time slots, then, the received signal can be represented as:

-Time slot 1:

$$r_1 = S_1 h_1 + S_1 h_2 + S_2 h_3 + S_2 h_4 + n_1 \tag{21}$$

-Time slot 2:

$$r_2^* = S_1 h_3^* + S_1 h_4^* - S_2 h_1^* - S_2 h_2^* + n_2^* \tag{22}$$

Then, the estimated received signals $\check{S}_1, \check{S}_2$ before decision maker in matrix form as follows:

$$\begin{bmatrix} \check{S}_1 \\ \check{S}_2 \end{bmatrix} = \begin{bmatrix} \alpha + \beta e^{j\theta} & 0 \\ 0 & \alpha + \beta e^{j\theta} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} h_1^* + h_2^* & h_3 + h_4 \\ h_3^* + h_4^* & -h_1 - h_2 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \tag{23}$$

The estimated received signals represented before decision maker as

$$\check{S}_1 = \left(\alpha + \beta e^{j\theta}\right) S_1 + (h_1^* + h_2^*) n_1 + (h_3 + h_4) n_2^* \tag{24}$$

$$\check{S}_2 = \left(\alpha + \beta e^{j\theta}\right) S_2 + (h_3^* + h_4^*) n_1 - (h_1 + h_2) n_2^* \tag{25}$$

Where:

$$\alpha = h_1.h_1^* + h_2.h_2^* + h_3.h_3^* + h_4.h_4^* \tag{26}$$

$$\beta = (h_1.h_2^* + h_2.h_1^* + h_3.h_4^* + h_4.h_3^*) \tag{27}$$

$$\theta = -\text{angle}(h_1.h_2^* + h_3.h_4^*) \tag{28}$$

As in [7], common phasor $e^{j\theta}$ is used to rotate the transmitted symbols from the first and third antennas and the rotation angle is existing in a range between 0 and 2π. It is apparent that this does not change the transmitted power. Since the phase rotation on the transmitted symbols is effectively equivalent to rotating the phases of the corresponding channel coefficients. Then, the estimated received signal $\hat{S}_1, \hat{S}_2$ after decision maker

$$\hat{S}_1 = \begin{cases} \breve{S}_1 > V_t \rightarrow \hat{S}_1 = 1 \\ \breve{S}_1 \leq V_t \rightarrow \hat{S}_1 = -1 \end{cases} \quad \text{and} \quad \hat{S}_2 = \begin{cases} \breve{S}_2 > V_t \rightarrow \hat{S}_2 = 1 \\ \breve{S}_2 \leq V_t \rightarrow \hat{S}_2 = -1 \end{cases}. \tag{29}$$

Next, system model of MIMO wireless system over flat fading channel will be studied.

3.7 System model of open loop MIMO (2×2) system based on OSTBC scheme

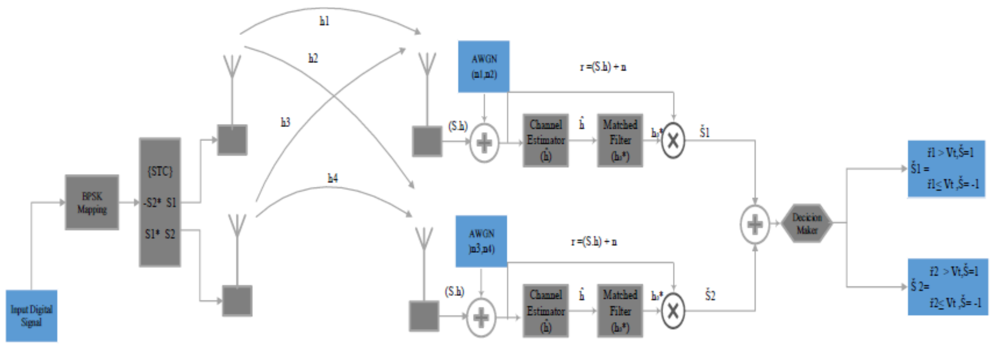

Fig. 5. Schematic system model of open loop MIMO system (2Tx, 2Rx) based on OSTBC over flat fading channel.

3.8 Mathematical model of open loop MIMO (2×2) system based on OSTBC scheme

In open loop MIMO (2×2) system, the transmission based on the OSTBC (Alamouti), which is done in two time slots, then, the received signal can be represented as:

-Time slot 1:

$$r_1 = S_1 h_1 + S_2 h_2 + n_1 \tag{30}$$

$$r_2^* = S_1 h_2^* - S_2 h_1^* + n_2^* \tag{31}$$

-Time slot 2:

$$r_3 = S_1 h_3 + S_2 h_4 + n_3 \tag{32}$$

$$r_4^* = S_1 h_4^* - S_2 h_3^* + n_4^* \tag{33}$$

The received signals in matrix form can be expressed as follows

$$\begin{bmatrix} r_1 \\ r_2^* \\ r_3 \\ r_4^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \\ h_3 & h_4 \\ h_4^* & -h_3^* \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \\ n_3 \\ n_2^* \end{bmatrix} \tag{34}$$

The part $H^H.H$ yields to the following form of OSTBC, were α is the gain.

$$\mathrm{H^H H} = \begin{bmatrix} h_1^* & h_2 & h_3^* & h_4 \\ h_2^* & -h_1 & h_4^* & -h_3 \end{bmatrix} \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \\ h_3 & h_4 \\ h_4^* & -h_3^* \end{bmatrix} = \begin{bmatrix} \alpha & 0 \\ 0 & \alpha \end{bmatrix} \tag{35}$$

The estimated received signals $\breve{S}_1, \breve{S}_2$before decision maker

$$\begin{bmatrix} \breve{S}_1 \\ \breve{S}_2 \end{bmatrix} = \begin{bmatrix} \alpha & 0 \\ 0 & \alpha \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} h_1^* & h_2 & h_3^* & h_4 \\ h_2^* & -h_1 & h_4^* & -h_3 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2^* \\ n_3 \\ n_4^* \end{bmatrix} \tag{36}$$

Then,

$$\breve{S}_1 = \alpha S_1 + h_1^* n_1 + h_2 n_2^* + h_3^* n_3 + h_4 n_4^* \tag{37}$$

$$\breve{S}_2 = \alpha S_2 + h_2^* n_1 - h_1 n_2^* + h_4^* n_3 - h_3 n_4^* \tag{38}$$

Then the estimated received signal $\hat{S}_1$, $\hat{S}_2$ after decision maker

$$\hat{S}_1 = \begin{cases} \breve{S}_1 > V_t \rightarrow \hat{S}_1 = 1 \\ \breve{S}_1 \leq V_t \rightarrow \hat{S}_1 = -1 \end{cases} \quad \text{and} \quad \hat{S}_2 = \begin{cases} \breve{S}_2 > V_t \rightarrow \hat{S}_2 = 1 \\ \breve{S}_2 \leq V_t \rightarrow \hat{S}_2 = -1 \end{cases}. \tag{39}$$

3.9 System model of open loop MIMO (4×2) system based on EO-STBC scheme

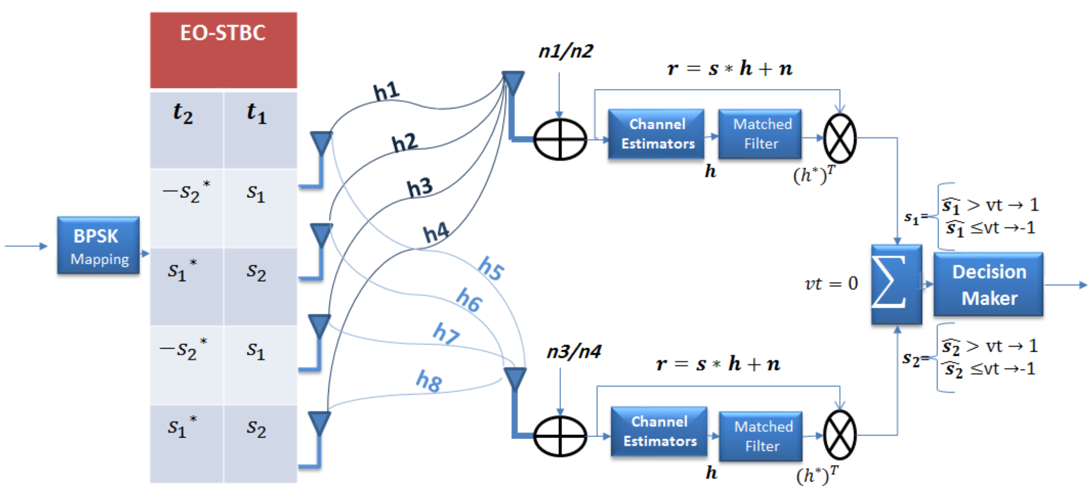

Fig. 6. Schematic system model of open loop MIMO system (4Tx, 2Rx) based on EO-STBC over flat fading channel.

3.10 Mathematical model of open loop MIMO (4×2) system based on EO-STBC scheme

In open loop MIMO (4×2) system, the transmission based on the EO-STBC, which is done in two time slots, then, the received signal can be represented as:

-Time slot 1:

$$r_1 = S_1h_1 + S_1h_2 + S_2h_3 + S_2h_4 + n_1 \tag{40}$$

$$r_2^* = S_1h_3^* + S_1h_4^* - S_2h_1^* - S_2h_2^* + n_2^* \tag{41}$$

-Time slot 2:

$$r_3 = S_1h_5 + S_1h_6 + S_2h_7 + S_2h_8 + n_3 \tag{42}$$

$$r_4^* = S_1h_7^* + S_1h_8^* - S_2h_5^* - S_2h_6^* + n_4^* \tag{43}$$

The received signals r_1, r_2, r_3, r_4 at time slots 1 and 2, respectively can be represented as

$$\begin{bmatrix} r_1 \\ r_2^* \\ r_3 \\ r_4^* \end{bmatrix} = \begin{bmatrix} h_1 + h_2 & h_3 + h_4 \\ h_3^* + h_4^* & -h_1^* - h_2^* \\ h_5 + h_6 & h_7 + h_8 \\ h_7^* + h_8^* & -h_5^* - h_6^* \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \\ n_3 \\ n_4^* \end{bmatrix}. \tag{44}$$

Then, H Hermitian transpose operation can be written as:

$$\mathrm{H^H.H} = \begin{bmatrix} h_1^* + h_2^* & h_3 + h_4 & h_5^* + h_6^* & h_7 + h_8 \\ h_3^* + h_4^* & -h_1 - h_2 & h_7^* + h_8^* & -h_5 - h_6 \end{bmatrix} \begin{bmatrix} h_1 + h_2 & h_3 + h_4 \\ h_3^* + h_4^* & -h_1^* - h_2^* \\ h_5 + h_6 & h_7 + h_8 \\ h_7^* + h_8^* & -h_5^* - h_6^* \end{bmatrix} = \begin{bmatrix} \alpha + \beta & 0 \\ 0 & \alpha + \beta \end{bmatrix} \tag{45}$$

where α is the gain and β is the interference

$$\alpha = h_1.h_1^* + h_2.h_2^* + h_3.h_3^* + h_4.h_4^* + h_5.h_5^* + h_6.h_6^* + h_7.h_7^* + h_8.h_8^* \tag{46 }$$

$$\beta = 2real(h_1.h_2^* + h_3.h_4^* + h_5.h_6^* + h_7.h_8^*) \tag{47 }$$

The estimated received signals $\breve{S}_1, \breve{S}_2$ represented before decision maker as

$$\begin{bmatrix} \breve{S}_1 \\ \breve{S}_2 \end{bmatrix} = \begin{bmatrix} \alpha + \beta & 0 \\ 0 & \alpha + \beta \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} h_1^* + h_2^* & h_3 + h_4 & h_5^* + h_6^* & h_7 + h_8 \\ h_3^* + h_4^* & -h_1 - h_2 & h_7^* + h_8^* & -h_5 - h_6 \end{bmatrix} \begin{bmatrix} n_1 \\ n_2^* \\ n_3 \\ n_4^* \end{bmatrix} \tag{48}$$

$$\breve{S}_1 = (\alpha + \beta)S_1 + (h_1^* + h_2^*)n_1 + (h_3 + h_4)n_2^* + (h_5^* + h_6^*)n_3 + (h_7 + h_8)n_4^* \tag{49}$$

$$\breve{S}_2 = (\alpha + \beta)S_2 + (h_3^* + h_4^*)n_1 - (h_1 + h_2)n_2^* + (h_7^* + h_8^*)n_3 - (h_5 + h_6)n_4^* \tag{50}$$

Then, the estimated received signal $\hat{S}_1, \hat{S}_2$, after decision maker

$$\hat{S}_1 = \begin{cases} \breve{S}_1 > V_t \rightarrow \hat{S}_1 = 1 \\ \breve{S}_1 \leq V_t \rightarrow \hat{S}_1 = -1 \end{cases} \quad \text{and} \quad \hat{S}_2 = \begin{cases} \breve{S}_2 > V_t \rightarrow \hat{S}_2 = 1 \\ \breve{S}_2 \leq V_t \rightarrow \hat{S}_2 = -1 \end{cases}. \tag{51}$$

3.11 System model of closed loop MIMO (4×2) system based on EO-STBC scheme

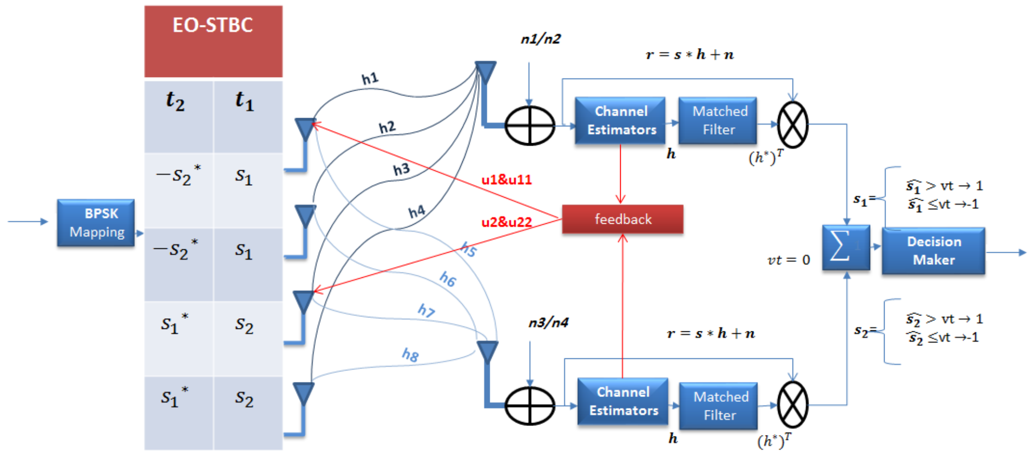

Fig. 7. Schematic system model of closed loop MIMO system (4Tx, 2Rx) based on EO-STBC over flat fading channel.

3.12 Mathematical model of closed loop MIMO (4×2) system based on EO-STBC scheme

In closed loop MIMO (4×2) system, the transmission based on the EO-STBC, which is done in two time slots, then, the received signal can be represented as:

-Time slot 1:

$$r_1 = S_1 h_1 + S_1 h_2 + S_2 h_3 + S_2 h_4 + n_1 \tag{52}$$

$$r_2^* = S_1 h_3^* + S_1 h_4^* - S_2 h_1^* - S_2 h_2^* + n_2^* \tag{53}$$

-Time slot 2:

$$r_3 = S_1 h_5 + S_1 h_6 + S_2 h_7 + S_2 h_8 + n_3 \tag{54}$$

$$r_4^* = S_1 h_7^* + S_1 h_8^* - S_2 h_5^* - S_2 h_6^* + n_4^* \tag{55}$$

The received signals r_1, r_2, r_3, r_4 at time slots 1 and 2, respectively can be represented as

$$\begin{bmatrix} r_1 \\ r_2^* \\ r_3 \\ r_4^* \end{bmatrix} = \begin{bmatrix} h_1 + h_2 & h_3 + h_4 \\ h_3^* + h_4^* & -h_1^* - h_2^* \\ h_5 + h_6 & h_7 + h_8 \\ h_7^* + h_8^* & -h_5^* - h_6^* \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \\ n_3 \\ n_4^* \end{bmatrix}. \tag{56}$$

Then, H Hermitian transpose operation can be written as:

$$\mathrm{H^H.H} = \begin{bmatrix} h_1^* + h_2^* & h_3 + h_4 & h_5^* + h_6^* & h_7 + h_8 \\ h_3^* + h_4^* & -h_1 - h_2 & h_7^* + h_8^* & -h_5 - h_6 \end{bmatrix} \begin{bmatrix} h_1 + h_2 & h_3 + h_4 \\ h_3^* + h_4^* & -h_1^* - h_2^* \\ h_5 + h_6 & h_7 + h_8 \\ h_7^* + h_8^* & -h_5^* - h_6^* \end{bmatrix} \begin{bmatrix} \alpha + \beta & 0 \\ 0 & \alpha + \beta \end{bmatrix} \tag{57}$$

Where, α is the gain and β is the interference.

$$\alpha = h_1.h_1^* + h_2.h_2^* + h_3.h_3^* + h_4.h_4^* + h_5.h_5^* + h_6.h_6^* + h_7.h_7^* + h_8.h_8^* \tag{58}$$

$$\beta = 2real(h_1.h_2^* + h_3.h_4^* + h_5.h_6^* + h_7.h_8^*) \tag{59}$$

The phasor $e^{j\theta}$ is used to rotate the transmitted symbols from the first and third antennas. The rotation angle is existing in a range between 0 and 2π. Then, the estimated received signals $\breve{S}_1, \breve{S}_2$ represented before decision maker as

$$\begin{bmatrix}\breve{S}_1\\ \breve{S}_2\end{bmatrix}=\begin{bmatrix}\alpha+\beta e^{j\theta} & 0\\ 0 & \alpha+\beta e^{j\theta}\end{bmatrix}\begin{bmatrix}S_1\\ S_2\end{bmatrix}+\begin{bmatrix}h_1^*+h_2^* & h_3+h_4 & h_5^*+h_6^* & h_7+h_8\\ h_3^*+h_4^* & -h_1-h_2 & h_7^*+h_8^* & -h_5-h_6\end{bmatrix}\begin{bmatrix}n_1\\ n_2^*\\ n_3\\ n_4^*\end{bmatrix} \tag{60}$$

$$\breve{S}_1=(\alpha+\beta e^{j\theta})S_1+(h_1^*+h_2^*)n_1+(h_3+h_4)n_2^*+(h_5^*+h_6^*)n_3+(h_7+h_8)n_4^* \tag{61}$$

$$\breve{S}_2=(\alpha+\beta e^{j\theta})S_2+(h_3^*+h_4^*)n_1-(h_1+h_2)n_2^*+(h_7^*+h_8^*)n_3-(h_5+h_6)n_4^* \tag{62}$$

Then, the estimated received signal $\hat{S}_1$, $\hat{S}_2$, after decision maker

$$\hat{S}_1=\begin{cases}\breve{S}_1>V_t\rightarrow\hat{S}_1=\ \ 1\\ \breve{S}_1\le V_t\rightarrow\hat{S}_1=-1\end{cases}\quad\text{and}\quad\hat{S}_2=\begin{cases}\breve{S}_2>V_t\rightarrow\hat{S}_2=\ \ 1\\ \breve{S}_2\le V_t\rightarrow\hat{S}_2=-1\end{cases}. \tag{63}$$

Diversity order and diversity gain will be explained next.

4 Diversity Order and Diversity Gain

Diversity is important matric in random fading environments and it is a key factor influencing the relationship between the link quality such as average BER, and system performance such as throughput. The slope of the SNR versus BER, in the region of small BER, is often used to characterize the diversity order [8]. To quantifying the benefits of diversity is to use the slope of the curve obtained by plotting BER on a logarithmic scale versus average SNR in dB, when SNR gets large the curve is becoming linear. The resulting slope is defined as the real diversity gain of the system, which it denoted by Gd. the theoretical BER can express as in [4]:

$$P_b=\zeta[G_c(\overline{SNR})]^{-G_d}, \tag{64}$$

where ζ is a constant depends on the type of modulation scheme, $\boldsymbol{G_C}$ is a coding gain constant of the system, and the bar over SNR denotes the mean.

$$P_{b1}-P_{b2}=-G_d(\rho_1-\rho_2), \tag{65}$$

where ϱ_i represents SNRs and P_{bi} represents bit error probability.
Simulation results will be presented in next section.

5 Simulation Results of SISO, MISO, and MIMO Wireless Systems

5.1 Comparison the simulation results between SISO (1×1), open MISO (2×1), open MISO (4×1), closed MISO (4×1), open MIMO (2×2), open MIMO (4×2), and closed MIMO (4×2) systems

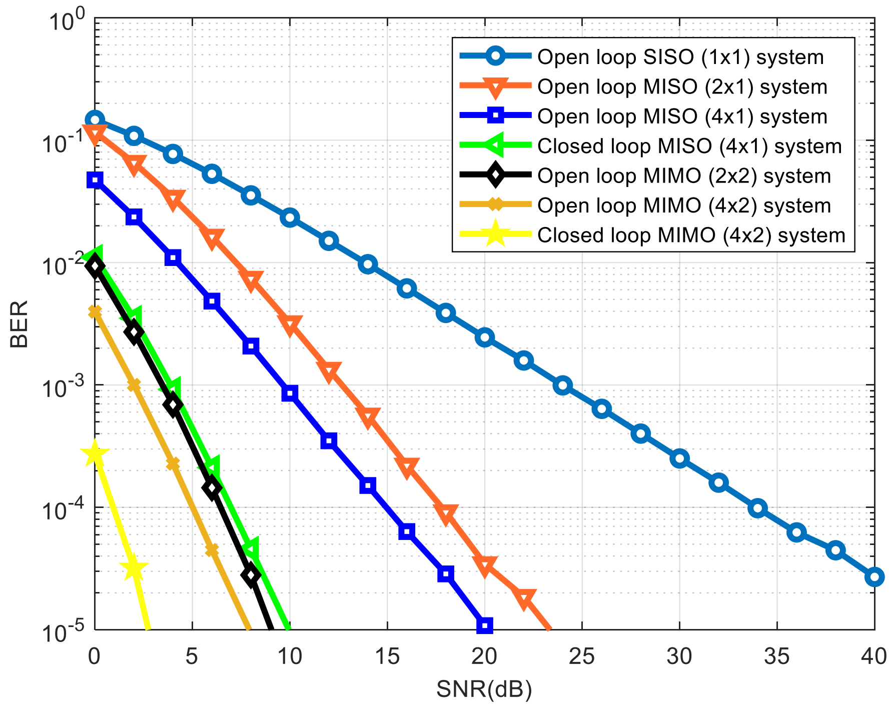

Fig. 8. Comparison the Simulation results between SISO (1×1) system, open loop MISO (2×1), open loop MISO (4×1), closed loop MISO (4×1) systems, MIMO (2×2), open loop MIMO (4×2), closed loop MIMO (4×2) systems with QPSK modulation scheme, over flat fading channel.

Figure 8 illustrate comparison of the simulation results between conventional SISO (1×1) system, open loop MISO (2×1), open loop MISO (4×1), closed loop MISO (4×1) systems, MIMO (2×2), open loop MIMO (4×2), closed loop MIMO (4×2) systems. All systems are experience flat fading channel and exploit QPSK modulation scheme. From the graph, it is clear that the conventional SISO (1×1) system has the worst BER performance because, according the equation (65), has the diversity order is equal just one. Whereas, closed loop MIMO (4×2) system has the best BER performance. Also, according equation (106), the diversity order equal to diversity gain which is equal eight. Moreover, open loop MISO (2×1) system based on OSTBC (Alamouti) scheme and open loop MISO (4×1) based on EO-STBC scheme achieve the same diversity order which is equal two, but with a 3 dB penalty in performance of MISO (4×1) system. Whereas, closed loop MISO (4×1) based on EO-STBC scheme has the same diversity order as open loop MIMO (2×2) without penalty which means the both curves are almost identical, the diversity order of both is equal four. In addition, open loop MISO (2×2) system based on OSTBC (Alamouti) scheme, closed loop MISO (4×1) based on EO-STBC scheme and open loop MIMO (4×2) based on EO-STBC scheme achieve the same diversity order which is equal four, but with improving by about 3 dB in performance of open loop MIMO (4×2) system. To conclude, MISO and MIMO systems based on OSTBC (Alamouti) have full diversity order and full rate. In contrast, open loop MISO and open loop MIMO systems based on EO-STBC scheme have approximately half diversity order and half rate. Feedback has been used to improve just only spatial diversity gain. Therefore, closed loop MISO and closed loop MIMO systems based on EO-STBC scheme have full diversity gain and half rate.

6 Conclusions

In this paper, we have studied the comparison of the simulation results between conventional SISO (1×1) system, open loop MISO (2×1), open loop MISO (4×1), closed loop MISO (4×1) systems, open loop MIMO (2×2), open loop MIMO (4×2), closed loop MIMO (4×2) systems. The maximal diversity gain achievable is the diversity order of the channel $M_T \times M_R$. All systems are experience flat fading channel and they exploit QPSK modulation scheme. Conventional SISO (1×1) system had the worst BER performance with diversity order equal just one. Whereas, MISO and MIMO systems based on OSTBC (Alamouti) have had full diversity gain and full rate. Although system with feedback had overhead drawback, feedback had improved MISO and MIMO systems based on EO-STBC scheme to achieve full diversity gain. Cooperative MIMO system based on OSTBC (Alamouti), open and closed loop EO-STBC schemes, decode-and-forward (DF) and amplify-and-forward (AF) relaying protocols, is a subject of our ongoing study.

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