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Space-time Block Coding Techniques for Minimizing BER for MIMO 2×2 System in Rayleigh Fading Channel

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Abstract: This paper proposes new Space-time block coding techniques for MIMO 2×2 system (STBC-MIMO 2×2) in order to minimize the bit error rate (BER), without the need to exploit the spatial diversity by using a larger number of antennas, with reduced decoding complexity using zero forcing (ZF) or Minimum mean square error (MMSE) linear detection techniques in Rayleigh fading channels. Similarly, the proposed STBC code aims to ensure the same spectral efficiency of which it is given by the Alamouti code with its unitary rate. The main objective is therefore to contribute in the improvement of the quality of service (QoS) for wireless communication systems and the optimization of the use of the number of antennas in terminals and base stations. In the proposed space-time block code (STBC) we exploit the technique of spectrum spreading by direct sequences (DSSS) using the orthogonal codes of Walsh-Hadamard in order to ensure the orthogonality between all the symbol vectors to be transmitted and to create an orthogonal and real full-rate STBC code. All computer simulations were done in MATLAB to evaluate the BER performance versus signal to noise ratio per bit of the proposed STBC code and Alamouti code in MIMO 2×2 system with 16QAM modulation and using the Rayleigh channel model in both cases of detection ZF and MMSE. The obtained results demonstrate that the proposed real STBC code provides much better BER performance compared to Alamouti code in both cases of detection ZF and MMSE.

Keywords: MIMO, Space-time block codes, Bit error rate, Rayleigh fading channel.

1 Introduction

The prime requirement of wireless communication systems is to provide high-data-rate wireless access and high quality of service (QoS), under the constraints of limited spectrum resource and hostile propagation conditions. This requires increased spectral efficiency and improvement in the bit error rate at reception of the link [1].

Multiple Input Multiple Output (MIMO) technology using multiple antennas at the transmitter and the receiver has attracted attention in wireless communications and becomes a key and basic element of the majority of modern wireless communications systems, because it offers significant increases in data throughput and link range without additional bandwidth or transmit power [2-3]. MIMO achieves this by higher spectral efficiency and link reliability or diversity. MIMO system takes advantage of the multi-path environment that characterizes mobile radio channel by using the various propagation channels created by reflection and/or by diffraction of the waves to increase the transmission capacity

[4]. Because of these properties, MIMO is an important part of MIMO system takes advantage modern wireless communication standards such as IEEE 802.16e (WiMAX), IEEE 802.11n (Wi-Fi), LTE and LTE Advanced mobile phone, and 5G future networks over Massive MIMO technology [5].

Space-time block codes (STBC) were designed to achieve the maximum diversity order for the given number of transmit and receive antennas by using a simple linear decoding algorithm at reception [6]. Due to this diversity approach, the space time block coding makes it possible to improve the quality of the link by avoiding channel fading and to ensure safer communications (improved BER performance) [7-8]. This has made space-time block codes a very popular and widely used [9]. The STBC Alamouti code using two transmit antennas discovered by S. Alamouti in 1998 is the only complex orthogonal code of a unitary rate, i.e., yield of one [10-11], and is the basic schema of the higher-order STBCs. Therefore, Alamouti code is an early space time code and one of the most commonly adopted.

The wireless communication standard WiMAX (IEEE 802.16e) for example which is used today as a transmission and high-speed internet access system covering a large geographical area is based on the use of MIMO technology [12]. This standard adopts extensively Alamouti space-time block coding technique using two transmit antennas and two receive antennas (MIMO 2×2 system) with MMSE receiver [12]. This specification allows a robust signal at the reception and acceptable BER performance [12]. Increasing the number of both transmit and receive antenna improves system performance and reduces the bit error rate [13-14]. Due to this method, WiMAX in one of its modes also supports the use of four transmit antennas to avoid sudden increases in error rates or minimize them in the severe multipath channels, i.e., in the presence of multiple interferers [14-15]. However, this WiMAX mode does not change the data rate [14].

This paper proposes a new full-rate space-time code, for a MIMO 2×2 system in Rayleigh fading channels, which aims to improve the BER performance under the signal-to-noise ratio (SNR) constraint (especially in low signal-to-noise ratios) with low complexity decoding. The main objective is therefore to contribute in the improvement of the quality of service for wireless communication systems and optimization of the use of the number of antennas in terminals and base stations. The paper is organized as follows: in Section 2, important general background information on MIMO system is provided. Next, the STBC coding and Alamouti code are discussed in Section 3. Then, the proposed STBC code is described in Section 4. In Section 5, the simulation methodology is discussed, then, results and analysis are presented. Finally, Section 6 concludes this paper and presents the future scope.

2 Multiple Input Multiple Output (MIMO)

2.1 Basic Principle

MIMO systems use multiple transmit antennas and multiple receive antennas. Both transmit and receive diversity schemes are applied to reduce fading resulting from signal variations by wireless channel. It depends on the degree at which the multiple data replicas are faded independently; the system provides diversity gains which represent the difference in SNR at the output of the diversity combiner as compared to that of single branch diversity at certain probability level [16]. A MIMO system with N_t transmit antennas and N_r receive antennas has potentially full diversity gain equal to N_tN_r [17].

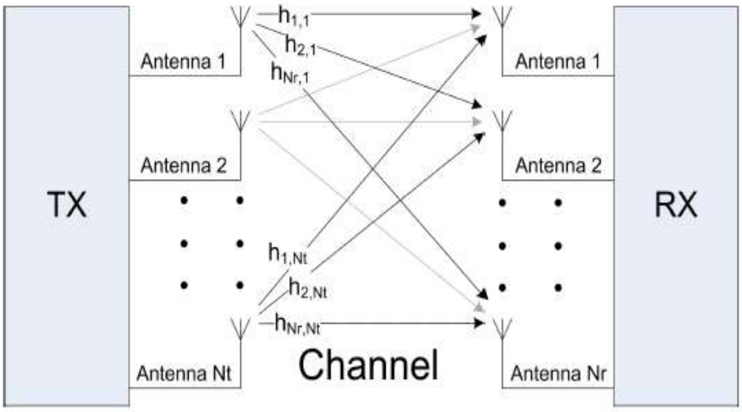

Figure. 1. Multiple-Input Multiple-Output system block diagram

The MIMO system theoretically allows increasing the capacity of wireless communication links in comparison with systems composed of a single antenna for transmission and reception. Assuming that the paths between each transmit antenna and reception are independent, Foshini and Telatar showed that the theoretical capacity of the MIMO channel with N_t transmit antennas and N_r receive antennas increases linearly with the min (N_t,N_r) [3, 18].

The basic principle of MIMO systems is therefore to combine the signals appropriately as on transmission and reception to exploit spatial diversity and thus reduce the effects of fading or increase the transmission rate [18].

2.2 System Model

For a MIMO system with N_t transmit antennas and N_r receive antennas, the received signal y_j at each moment on the j^{th} receive antenna is the sum of the symbols derived from the N_t transmitted signals:

$$y_j = \sum_{i=1}^{N_t} h_{j,i} c_i + n_j \qquad (1)$$

Where $h_{j,i}$ is the attenuation and phase shift (transfer function) of the non-selective frequency channel between the j^{th} transmit antenna and i^{th} receive antenna, and n_j is the additive noise. The complex matrix H of the channel can then be written as follows:

$$H = \begin{bmatrix} h_{1,1} & . & .. & h_{1,N_t} \\ . & h_{2,2} & .. & . \\ : & : & : & : \\ h_{N_r,1} & h_{N_r,2} & .. & h_{N_r,N_t} \end{bmatrix} \qquad (2)$$

The MIMO signal model is described as:

$$y = H.c + n \qquad (3)$$

Where y and n are respectively receive and noise vectors of size $N_r \times 1$, H is the channel matrix of size $N_r \times N_t$, and c is the transmitted vector of size $N_t \times 1$.

The transmitted signals are mixed in the channel since they use the same carrier frequency [17]. The receiver can solve the transmitted signals by treating the system of linear equations (3). If the channel H is correlated, the system of linear equations will have more unknowns than equations [17].

One reason of the correlation between signals can be due to the spacing between antennas. To avoid the correlation which is due to the spacing factor, they are typically spaced at least $\lambda_c/2$ where λ_c is the wavelength of the carrier frequency [17, 19]. The second reason of correlation can occur as a result of multipath components. It is for this reason that rich multipath is desirable in MIMO systems. The multipath effect can be interpreted by each receive antenna being in a different channel. For this reason, the rank of a MIMO channel is defined as the number of independent equations offered [20].

$$rank(H) \le \min(N_r, N_t) \tag{4}$$

The maximum number of streams that a MIMO system can support is upper-bounded by min (N_t,N_r).

3 Space-Time Block Coding

3.1 Basic Principle

One of the methodologies for exploiting the capacity in MIMO system consists of using the additional diversity of MIMO systems, namely spatial diversity, to combat channel fading. This can be achieved by transmitting several replicas of the same information through each antenna. By doing this, the probability of losing the information decreases exponentially. The diversity order or diversity gain of a MIMO system is defined as the number of independent receptions of the same signal [4]. The different replicas sent for exploiting diversity are generated by a space-time encoder which encodes a single stream through space using all the transmit antennas and through time by sending each symbol at different times. This form of coding is called Space-Time Coding (STC) [18].

The space-time block coding (STBC) is the most dominant form of space-time codes [21]. The STBC codes are a generalized version of Alamouti scheme, but have the same key features [6]. Due to their orthogonality these codes can achieve full transmit diversity specified by the number of transmit antennas [9]. The data are constructed as a matrix which has its rows equal to the number of the transmit antennas and its columns equal to the number of the time slots required to transmit the data. Space-time block codes were designed to achieve the maximum diversity order for the given number of transmit and receive antennas subject to the constraint of having a simple linear decoding algorithm. This method is very attractive because it does not require knowledge of the channel state [6]. The resulting diversity gain improves the reliability of the faded wireless links and improves the quality of the transmission [21-22].

3.2 Alamouti STBC Code

Alamouti proposed an orthogonal complex block code of *code rate* of 1 (i.e., $R_{STBC} = Q/T$, where Q is the number of symbols transmitted per code, and T is the number of time slots required) using two transmit antennas. This code provides full diversity and very low complexity decoding [23]. Every two time slots, two symbols are transmitted simultaneously over two antennas. At first time t, the symbol s_1 and symbol s_2 are transmitted from antenna 1 and antenna 2 respectively. Assuming that each symbol has duration T, then at second time t + T, the symbols $-s_2^*$ and s_1^*, where $(.)^*$ denotes the complex conjugate, are transmitted from antenna 1 and antenna 2 respectively, as shown in Table 1. The Figure below (Fig. 2) presents the general block diagram of the STBC-MIMO 2 × 2 system.

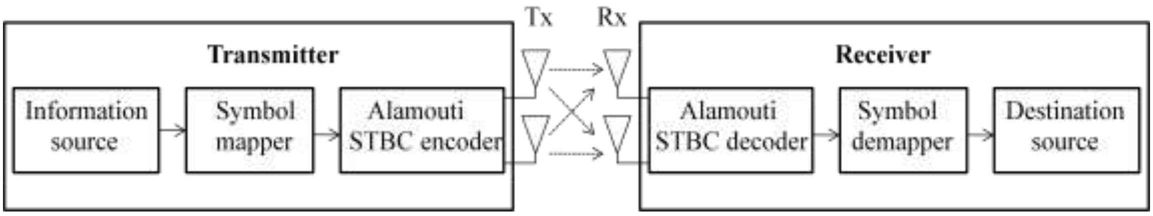

Figure. 2. Block diagram of the Alamouti STBC-MIMO 2×2 system

Table 1. Space-time Alamouti coding

	Antenna 1	Antenna 2
Time t	s_1	s_2
Time t+T	$-s_2^*$	s_1^*

Thus in matrix form we have:

$$C_{STBC,2} = \begin{pmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{pmatrix} \qquad (5)$$

The code has the property of being orthogonal because we have:

$$C_{STBC,2}.C_{STBC,2}^H = (|s_1|^2 + |s_2|^2) I_2 \qquad (6)$$

The reception and decoding of the signal depends on the number of receive antennas available [17]. The Alamouti code is no longer optimal in the case of two receive antennas [18].

4 Proposed STBC Code

4.1 Principle of the contribution and Properties

The principle of the MIMO 2×2 coding proposed in this research aims to exploit the technique of spectrum spreading by direct sequences (DSSS) using the orthogonal codes of Walsh-Hadamard in order to ensure orthogonality between all the symbol vectors to be transmitted and create an orthogonal and real STBC code at a rate of 1.

Spread spectrum is a mean of transmission in which signal occupies a bandwidth in excess of the minimum necessary to send the information. This operation in the proposed method is performed by the multiplication in the time domain of the useful symbol to be transmitted by its own Walsh-Hadamard code. The resulted signal occupies a frequency spectrum similar to the spectrum of the Walsh-Hadamard code (due to the fact that $T_{W\text{-}H} < T_s$, where $T_{W\text{-}H}$ and T_s represent the duration of one bit in the Walsh-Hadamard code and one symbol of the data signal, respectively).

Walsh-Hadamard codes are not very length or PN type codes for a significant spread spectrum. The Walsh-Hadamard codes are adopted in our designed MIMO-STBC system for their property of being orthogonal and their ease of implementation. Walsh-Hadamard codes have a significant role in code division multiple access (CDMA) communication [24]. Thus, these codes make it possible to obtain optimal performance in the presence of a synchronous communication on a non-selective AWGN channel (Downlink, MC-CDMA systems...) [25].

Figure 3 presents a block diagram of the proposed STBC-MIMO 2×2 system in transmission. It can be seen from this Figure that the proposed scheme of STBC-MIMO 2×2 system in transmission consists of four main sub-systems: modulator, serial to parallel converter, Walsh-Hadamard coder and STBC encoder. After mapping operation, the data to be transmitted are converted from serial to parallel with two symbols at the output. Then these both symbols are correlated (multiplication in the time domain) by both their own different Walsh-Hadamard codes of the same length (Fig. 4). Finally, the reconverted symbols from parallel to serial forms attack the STBC coder for space-time encoding according to the coding matrix adopted by Alamouti code, as shown in Table 2.

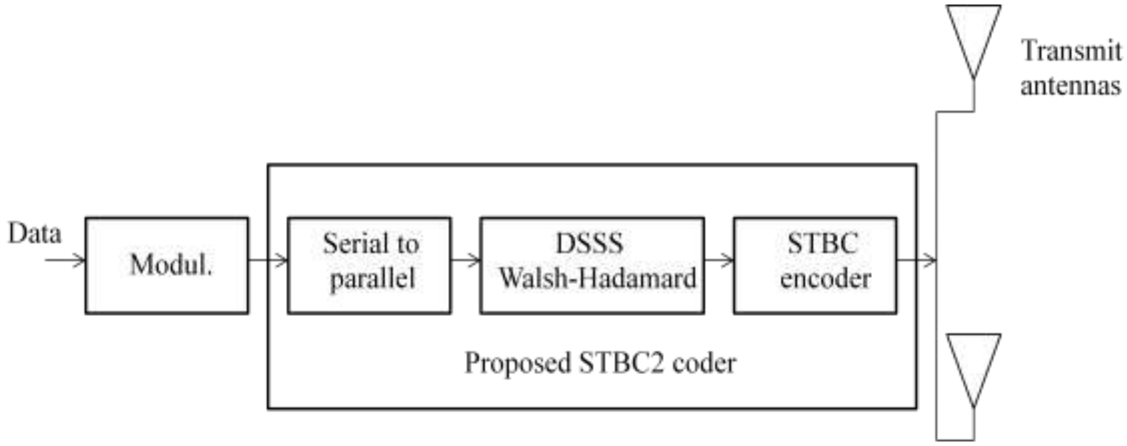

Figure. 3. Block diagram of the proposed STBC-MIMO 2×2 system in transmission

The transmitted proposed real STBC2 code using two transmit antennas is presented as:

$$C_{STBC,2} = \begin{pmatrix} s_{1,1} & s_{2,2} \\ s_{2,2} & s_{1,1} \end{pmatrix} \quad (7)$$

Table 2. Proposed space-time coding

	Antenna 1	Antenna 2
Time t	$s_{1,1}$	$s_{2,2}$
Time t+T	$s_{2,2}$	$s_{1,1}$

$s_{i,j}$ denotes a symbol to be transmitted where the first index number i indicates the useful symbol to transmit, and the second index j indicates the own Walsh-Hadamard code of this symbol. The code rate presented by this code STBC2 is $R_{STBC2} = 1$.

Each symbol $s_{i,j}$ of the proposed STBC code is a correlation product of the useful symbol with its own Walsh-Hadamard code. The two signals obtained from the both correlation products are also orthogonal. The proposed STBC coding scheme is shown in Figure 4.

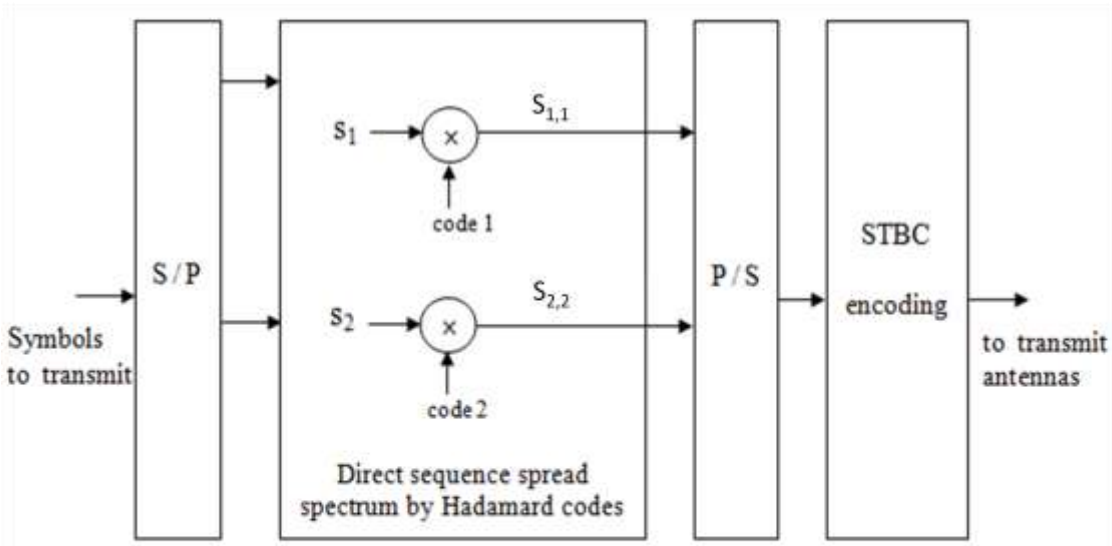

Figure. 4. Principle of the proposed STBC2 coding

The Walsh-Hadamard codes of length n are constructed from a Hadamard matrix of order n. An example of the 8-bit Hadamard codes adopted in this study is shown in Figure 5.

$$H_8 = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{pmatrix}$$

code 1 code 2 . . . code 8

Figure. 5. 8-bit Walsh-Hadamard codes from Hadamard matrix of order 8

Due to this orthogonality property, the cross correlation between the two symbols $s_{1,1}$ and $s_{2,2}$ transmitted simultaneously every two time slots is zero due to the perfect synchronization of their transmission. Similarly, the relation obtained in (8) below shows the orthogonality of the matrix of the presented STBC2 code:

$$C_{STBC,2} * C_{STBC,2}^{H} = \begin{pmatrix} s_{1,1} & s_{2,2} \\ s_{2,2} & s_{1,1} \end{pmatrix} * \begin{pmatrix} s_{1,1} & s_{2,2} \\ s_{2,2} & s_{1,1} \end{pmatrix} = (|s_{1,1}|^2 + |s_{2,2}|^2) . \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = A.I_2 \qquad (8)$$

Where C^H denotes the transposed code matrix, A is real coefficient and I_2 is identity matrix of size 2.

The orthogonality property of the proposed STBC code allows spatial orthogonality between all the symbol vectors to be transmitted. The proposed orthogonal STBC code also provides inter-channel orthogonality between different transmit antennas. Thus, these proposed techniques can contribute to minimize the spacing between antennas and therefore enhance miniaturization.

4.2 Reception Performance

The proposed system at the reception performs the inverse operation of the transmit system, as shown in Fig. 6, with the equalization proposal either by ZF or MMSE linear detectors.

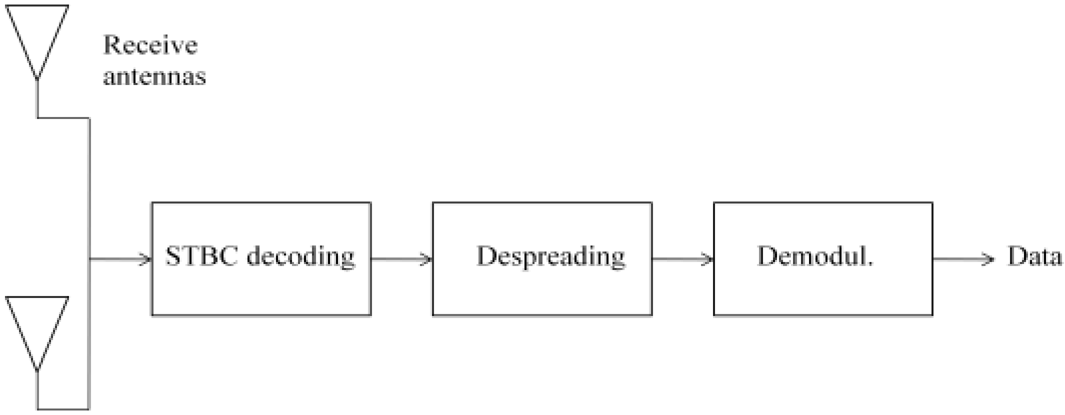

Figure. 6. Block diagram of the proposed STBC-MIMO 2×2 system in reception

The received signals in the first time slot:

$$y_{1,1} = h_{1,1}s_{1,1} + h_{1,2}s_{2,2} + n_{1,1} \quad (9)$$

$$y_{1,2} = h_{2,1}s_{1,1} + h_{2,2}s_{2,2} + n_{1,2} \quad (10)$$

The received signals in the second time slot:

$$y_{2,1} = h_{1,2}s_{1,1} + h_{1,1}s_{2,2} + n_{2,1} \quad (11)$$

$$y_{2,2} = h_{2,2}s_{1,1} + h_{2,1}s_{2,2} + n_{2,2} \quad (12)$$

The vector of the received signal can be then defined as:

$$\begin{bmatrix} y_{1,1} \\ y_{1,2} \\ y_{2,1} \\ y_{2,2} \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \\ h_{1,2} & h_{1,1} \\ h_{2,2} & h_{2,1} \end{bmatrix} . \begin{bmatrix} s_{1,1} \\ s_{2,2} \end{bmatrix} + \begin{bmatrix} n_{1,1} \\ n_{1,2} \\ n_{2,1} \\ n_{2,2} \end{bmatrix} \quad (13)$$

Where $y_{i,j}$ is the received signal at time slot i by j^{th} receive antenna, $s_{i,j}$ is the transmitted symbol, $h_{i,j}$ is the complex coefficient of sub-channel between the transmit antenna and the receive antenna respectively j and i, and $n_{i,j}$ is the noise at time slot i on j^{th} receive antenna.

The detection of the transmitted symbols from the received vector (13) can be done simply using linear detection techniques ZF or MMSE. These two techniques ZF and MMSE seek to apply to the received vector y, respectively, the following equalization matrices W_{ZF} and W_{MMSE}:

$$W_{ZF} = (H^H H)^{-1} H^H \quad (14)$$

$$W_{MMSE} = (H^H H + \sigma^2 I)^{-1} H^H \quad (15)$$

Where $(.)^H$ denotes the Hermitian transpose operation and σ^2 is the statistical information of noise. The estimate of the transmitted signal vector is given then by:

$$\hat{s}_{ZF} = W_{ZF}.y \qquad (16)$$

$$\hat{s}_{MMSE} = W_{MMSE}.y \qquad (17)$$

Thereafter, the useful symbols can be retrieved, after STBC decoding, by multiplying each by its own Walsh-Hadamard code (dispreading), as shown in Fig. 7.

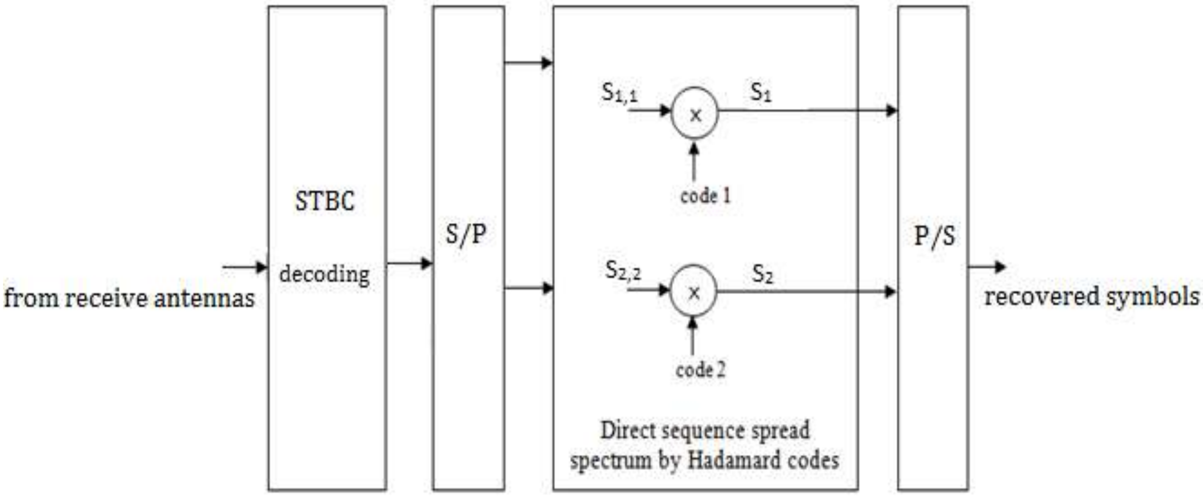

Figure. 7. Principle of the proposed STBC2 decoding

The proposed STBC2 code was simulated in MIMO 2×2 system in MATLAB using the two aforesaid equalization techniques.

5 Simulations and Results

The simulations were made in MATLAB using the Rayleigh channel model with additive white Gaussian noise. Different MIMO sub-channels are assumed correlated using random channel matrices. The proposed real STBC2 code for two transmit antennas and Alamouti code are simulated in MIMO 2×2 system using 16QAM modulation in both cases of detection ZF and MMSE.

Both Walsh-Hadamard codes used for each two symbols to transmit in the simulated proposed STBC2 code that are 8-bit length are [1 -1 -1 1 1 -1 -1 1] and [1 -1 1 -1 -1 1 -1 1], which are shown in Fig. 5. The number of useful bits to transmit in all simulated chains is 10^5 bits. Detection is in single-user mode and the channel is assumed perfectly estimated.

The same simulation conditions are applied in all the simulated transmission chains. The performance of the proposed code is evaluated by simulating the bit error rate (BER) versus signal to noise ratio per bit (Eb/No) and comparing it with that obtained by the Alamouti code in the various predefined cases.

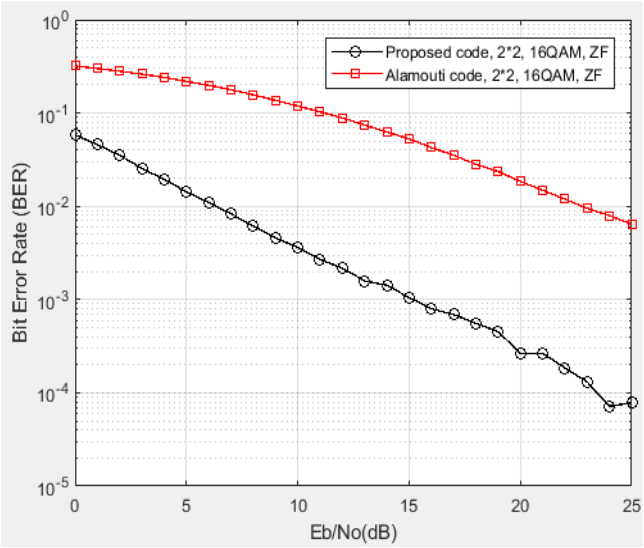

Figure. 8. BER Performance of proposed STBC and Alamouti codes with 16QAM modulation for ZF equalization

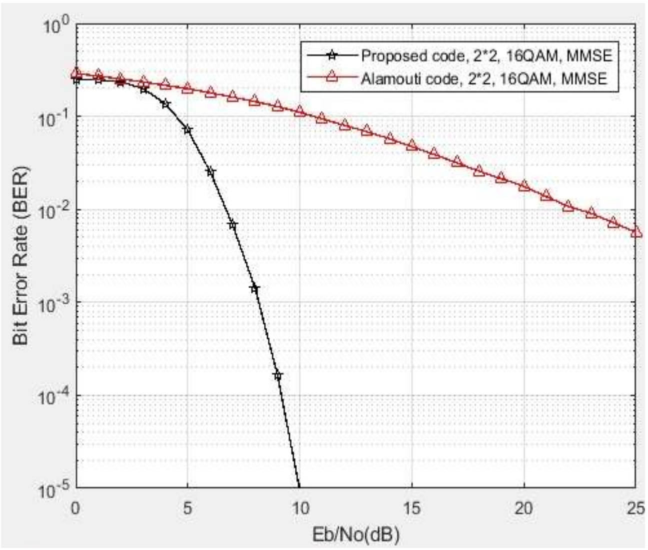

Figure. 9. BER Performance of proposed STBC and Alamouti codes with 16QAM modulation for MMSE equalization

Both figures Fig. 8 and Fig. 9 represent the obtained BER performance according to signal to noise ratio Eb/No of the proposed real STBC2 code and the Alamouti code using 16QAM modulation in cases of equalization ZF and MMSE, respectively. It can be clearly seen from these Figures that the real STBC2 code proposed in MIMO 2×2 system provides much better performance in terms of bit error rate compared to the STBC Alamouti code by using the same modulation technique 16QAM for both equalization cases ZF and MMSE.

The proposed STBC2 code in MIMO 2×2 using 16QAM modulation in case of ZF provides much better bit error rate than in the case of MMSE for small signal-to-noise ratios Eb/No below 7dB. In the case of MMSE, the BER curve of the proposed code from an Eb/No ratio of 5dB drops rapidly until it reaches an error rate of 10^{-5} just for an Eb/No ratio of 10dB, as shown in Fig. 9. While in the case of ZF, the BER curve of the proposed code always decreases regularly until it reaches an error rate of 7.10^{-5} for an Eb/No ratio of 24dB, as shown in Fig. 8.

Table 3. BER analysis of the proposed code and Alamouti code in MIMO 2×2 system in Rayleigh fading channel

	BER			
	ZF decoding		MMSE decoding	
Eb/No (dB)	Alamouti code	Proposed code	Alamouti code	Proposed code
0	2×10^{-1}	6×10^{-2}	2.8×10^{-1}	2.4×10^{-1}
3	2.8×10^{-1}	2.6×10^{-2}	2.4×10^{-1}	2×10^{-1}
5	2.1×10^{-1}	1.5×10^{-2}	2×10^{-1}	7.5×10^{-2}
10	1.1×10^{-1}	3.7×10^{-3}	1.1×10^{-1}	10^{-5}
15	5×10^{-2}	10^{-3}	5×10^{-2}	10^{-9}

The proposed STBC code using ZF detection exhibits a noticeable reduction in the error rate in low signal-to-noise ratios (Eb/No≤ 5dB) from 14% to 25.4%, and ≤ 4.9% at Eb/No> 15dB, compared to Alamouti code. For MMSE detection, the proposed STBC code offers a 4% reduction in the error rate in very low signal-to-noise ratios (0dB≤ Eb/No≤ 3dB), from 11% to 13% reduction at 3dB< Eb/No≤ 10dB and a reduction of 5% or less at Eb/No> 15dB, compared to Alamouti code.

It can be concluded that the proposed STBC code using ZF decoding makes greater contribution compared to decoding with MMSE technique in a low signal-to-noise ratio channel.

5 Conclusions & Future Scope

In this work we have proposed new STBC-MIMO 2×2 coding techniques that aim for minimizing the bit error rate with low complexity decoding using ZF or MMSE linear detection techniques in Rayleigh fading channels. The simulation results show that the proposed real STBC2 code in MIMO 2×2 system outperforms the Alamouti code by providing much better error rates with a same decoding complexity at reception using the same ZF or MMSE detection techniques. The use of the proposed code exhibits a noticeable reduction in the error rate in low signal-to-noise ratios, compared to Alamouti code, from 14% to 25,4% using ZF decoding and from 4% to 12,5% using MMSE decoding.

Similarly, the proposed STBC code ensures the same spectral efficiency as the Alamouti code thanks to his unitary rate. Therefore, this proposed method contributes in improving the quality of service of wireless communication systems, and optimizing the use of the number of antennas as in the case of a WiMAX context in the severe multipath channels.

Lastly, the present work constitutes the bases of a new concept time-space for a MIMO system. Thus, we aim to generalize, in the next work, this concept to a larger number of transmit antennas for an STBC-MIMO system by building full-rate STBC codes. We also aim to analyze the impact of antenna spacing on the performance of proposed STBC techniques.

References

[1]. Molisch. A. F, Wireless Communications, Wiley-IEEE Press, 2nd edition, 2011.

[2]. Mishra. P, Singh. G, Vij. R and Chandil. G, "BER analysis of Alamouti space-time block coded 2×2 MIMO systems using Rayleigh dent mobile radio channel". 3rd IEEE International Advance Computing Conference (IACC), 2013.

[3]. Narayana. M and Bhavana. G, "Performance analysis of MIMO system under fading channels (Rayleigh & Rician) using SVD, PCA& FSVD". Journal of Engineering Technology, ISSN: 0747-9964, 2016, Vol. 5, Issue 2, PP. 116-126.

[4]. Lee. J, Han. J.K and Zhang. J, "MIMO technologies in 3GPP LTE and LTE-advanced". EURASIP Journal on Wireless Communications and Networking, 2009.

[5]. Eldemerdash. Y. A, Dobre. O. A and Liao. B. J, "Blind identification of SM and Alamouti STBC-OFDM signals". IEEE Transactions on Wireless Communications, 2015; 14(2):972-982.

[6]. Santumon. S.D and Sujatha. B. R, "Space-time block coding (STBC) for wireless networks". International Journal of Distributed and Parallel Systems (IJDPS), 2012, Vol. 3, No. 4.

[7]. Biradar. R and Sadashivappa. G, "Study and analysis of 2×2 MIMO systems for different modulation techniques using MATLAB". International Journal of Advanced Research in Computer and Communication Engineering, 2015, Vol. 4, Issue 7.

[8]. SINHA. H, MESHRAM. M. R and SINHA. G. R, "Performance analysis of MIMO-STBC with orthogonal uncorrelated channel". I-Manager's Journal on Wireless Communications Networks, 2017, Vol. 6, No. 1, PP. 22-30.

[9]. Pathak. P and Pandey. R, "A novel Alamouti STBC technique for MIMO system using 16-QAM modulation and moving average filter". International Journal of Engineering Research and Applications, ISSN: 2248-962, 2014, Vol. 4, Issue 8 (Version 6), PP. 49-55.

[10]. Cho. Y. S, Kim. J, Yang. W. Y and Kang. C, MIMO-OFDM Wireless Communications with MATLAB, 1st ed., Wiley-IEEE Press, 2010.

[11]. Rabiei. P, Al-Dhahir. N and Calderbank. R, "New rate-2 STBC design for 2 TX with reduced-complexity maximum likelihood decoding". IEEE Trans. on Wireless Communications, 2009, Vol. 8, No. 2, PP. 1803–1813.

[12]. Wang. F, Ghosh. A, Sankaran. C and Benes. S, "WiMAX system performance with multiple transmit and multiple receive antennas". in Proc. IEEE 65th Vehicular Technology Conference (VTC2007), 2007.

[13]. Ghayoula. E and Ghayoula. R, "Bit error rate performance of MIMO systems for wireless communications". World Academy of Science, Engineering and Technology, Electrical and Computer Engineering, 2015, Vol. 2, No. 1.

[14]. Tchao. E. T, Diawuo. K, Ofosu. W. K and Affum. E, "Analysis of MIMO systems used in planning a 4G-WiMAX network in Ghana". International Journal of Advanced Computer Science and Applications (IJACSA), 2013, Vol. 4, No. 7.

[15]. Li. Q, Lin. X, Zhang. J and Roh. W, "Advancement of MIMO technology in WiMAX: from IEEE 802.16d/e/j to 802.16m". IEEE Communications Magazine, 2009; 47(6):100-107.

[16]. Kushwah. A. S, Rathore. P and Kumar. R, "Performance estimation of 2*4 MIMO-MC-CDMA using convolution code in different modulation technique using ZF detection scheme". International Journal of Engineering Trends and Technology (IJETT), 2014, Vol. 10, No. 13.

[17]. Miguel. L and Pena. C, "MIMO space-time block coding (STBC): Simulations and results" Design Project: Personal and Mobile Communications, Georgia Tech (ECE6604), 2009.

[18]. Le Ruyet. D, Systèmes MIMO et codage spatio-temporel, National Conservatory of Arts and Crafts, ELE203, Version 2.0, Paris, 2007.

[19]. Srinivasulu. O and Kumar. P. R, “BER performance analysis of MIMO-WiMAX wireless communication system for the transportation of multimedia data”. Global Journal of Computer Science and Technology: E Network, Web & Security, 2018, Vol. 18, Issue 1, Version 1.0.

[20]. Gesbert. D, Shafi. M, Shiu. D, Smith. P and Naguib. A, “From theory to practice: An overview of MIMO space-time coded wireless systems”. IEEE Journal on Selected Areas in Communications, 2003, Vol. 21, No. 3, PP. 281–302.

[21]. Gupta. V and Pipariya. J, “Performance analysis of space-time block codes achieving full diversity with linear receivers using MIMO”. International Journal of Engineering and Innovative Technology (IJEIT), ISSN: 2277-3754, 2012, Vol. 2, Issue 2.

[22]. Parveen. N and Venkateswarlu. D. S, “Implementation of space-time block coding (STBC) using 2 transmit and 2 receive antennas”. International Journal of Emerging Technology and Advanced Engineering, 2012, Vol. 2, Issue 10.

[23]. Selvaprabhu. P, Chinnadurai. S, Sarker1. MD. A. L, Chong. K. T and Lee. M. H, “Guiding blind transmitters: Relay-aided topological interference alignment for K-user downlink MIMO channel”. Journal of Engineering Technology, ISSN: 0747-9964, 2018, Vol. 6, Special issue (Emerging Trends in Engineering Technology), PP. 31-49.

[24]. Mandal. S, Samanta. S, Maity. G. K and Mukhopadhyay. S, “Walsh-hadamard code design using optical nonlinear material” in Proc. 2nd International Conf. 2017 Devices for Integrated Circuit (DevIC), Kalyani, India, March 2017.

[25]. Srivastava. D and Prasad. R. K, “Spreading codes performances for correlation function using Matlab” International Journal of Electronics, Communication & Instrumentation Engineering Research and Development, ISSN: 2249-684X, 2013, Vol. 3, Issue 2, 15-24.