LETTER

Improved Transmit and Detection Scheme for Hybrid STBC in MIMO-OFDM Systems*

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SUMMARY The conventional hybrid STBC schemes can achieve less BER performance for STBC detection schemes than conventional STBC schemes since SM symbols interfere with STBC symbols. Therefore, this letter proposes the improved scheme for hybrid STBC systems. STBC and SM schemes are combined for the hybrid space-time block code system. Our approach effectively obtains both diversity gain and spectral efficiency gain. The proposed scheme offers improved BER performance since it uses iterative detection. Moreover, it increases the data rate effectively with a little performance loss.

key words: spatial multiplexing, hybrid STBC, diversity, MIMO, OFDM

1. Introduction

Nowadays, the increasing demands being placed on multiple-input multiple-out (MIMO) communication systems have led to present MIMO systems based on orthogonal frequency division multiplexing (OFDM). MIMO-OFDM systems are very useful to obtain high data rates, capacity efficiency and spectral efficiency. The time, space and frequency domains are employed simultaneously to obtain these efficiencies.

MIMO-OFDM systems provide a spectral efficiency gain and an antenna diversity gain. Spatial division multiplexing (SDM) improves the spectral efficiency gain while space time coding (STC) improves the antenna diversity gain. Most systems satisfy either spectral gain or diversity gain but hybrid STBC system can satisfy both gains. The representative hybrid STBC system is a combination of space-time block code (STBC) and spatial multiplexing (SM) schemes. STBC schemes attain diversity gain but SM schemes attain spectral efficiency gain.

STBC schemes transmit data during two time slots. Therefore, STBC schemes have low throughput. However, SM schemes have worse bit error rate (BER) than STBC schemes since SM schemes obtain multiplexing gain. Hybrid STBC systems optimize both schemes. Therefore, hybrid STBC systems achieve better BER performance than

SM schemes and achieve higher throughput than STBC schemes.

In a hybrid STBC system, STBC symbols are detected at first since they have an advantage of transmit diversity. Next, detected symbols are removed from received signals and SM symbols are detected. General MIMO detection schemes are applied when SM symbols are detected. However, BER performance of the hybrid STBC system is close to that of decision feedback equalization (DFE) schemes. Therefore, hybrid systems that offer improved performance or improved throughput are required.

In this letter, an iterative detection scheme is proposed to improve performance and efficient schemes are proposed for higher throughput with a little performance loss. These efficient schemes are applied to MIMO-OFDM systems with hybrid STBC symbols.

2. Hybrid STBC System

A 4×3 hybrid STBC system is considered. The M denotes the number of transmit antennas and the N denotes the number of receive antennas. Three parallel data streams are shown in Fig. 1. The x^* denotes complex conjugate of the symbols. STBC symbols x_1 and x_2 are transmitted by the first and second antenna. SM symbols x_3 , x_4 , x_5 and x_6 are transmitted by the third and fourth antenna for 2 time slots as shown in Fig. 1.

The first incoming data stream goes into the space time encoder. The output is Alamouti STBC to achieve diversity gain. The second and third incoming data stream are transmitted at once to achieve multiplexing gain. Accordingly, antennas transmit six symbols for two consecutive time periods. Each data stream goes into OFDM sequences. An inverse fast Fourier transform (IFFT) process transforms each OFDM sequence of constellation symbol and each an-

Fig. 1 Conventional hybrid system with STBC and SM symbols.

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tenna transmit signals for their relevant stream simultaneously. Then, the received signals undergo the process of fast Fourier transform (FFT) at each antenna. Received signals are written over two symbol periods as follows

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \end{bmatrix} \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \\ x_3 & x_5 \\ x_4 & x_6 \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \quad (1)$$

where y_k is a 3×1 received signal vector, x_i is a 4×1 transmitted signal vector, h_{mn} is random complex vector of multipath channel of transmit antenna m to receive antenna n , w_k is a 3×1 noise vector and it is assumed that the noise is zero mean and Gaussian distributed white noise.

3. The Proposed Scheme for Hybrid STBC

3.1 Conventional Detection Schemes for STBC and SM Symbols

In this section, conventional detection schemes are introduced. STBC symbols and SM symbols use different detection schemes respectively.

To detect STBC symbol, the 4×4 detection scheme [3] is used. To estimate SM symbols, the detected symbols x_1 and x_2 are canceled from the received signal y_1 and y_2 . After that, the conventional DFE detection scheme [4], [5] is used to detect SM symbols and V-algorithm [6], [7] is applied to improve better performance.

3.2 Proposed Scheme for STBC and SM Symbols

In this section, the efficient schemes are described which provide two kinds of improvement in hybrid STBC systems. The process of proposed schemes is shown in Fig. 2.

First, a bit modulation type of x_1 - x_4 symbols is modified to increase data rate at transmitter [8]. STBC symbols are composed of x_1 - x_4 data. Transmitter transmits two different bit data symbols simultaneously and controls data rate flexibly. x_1 and x_2 are bound and it denotes S_1 as shown in Fig. 2. x_3 and x_4 are bound and it denotes S_2 as shown in Fig. 2. S_1 and S_2 are modulated by higher modulation type than the type of x_1 in Fig. 1. Modulated S_1 and S_2 act as modulated x_1 and x_2 in Fig. 1. Therefore, x_7 and x_8 can be

Fig. 2 Proposed scheme for modulation.

transmitted additionally. Received signals are rewritten as follows

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \end{bmatrix} \begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \\ x_5 & x_7 \\ x_6 & x_8 \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \quad (2)$$

This proposed scheme can transmit more bits than the conventional scheme. It is efficient to attain higher data rate than the conventional scheme.

Second, STBC symbols are detected. To detect STBC symbols [3], the 4×3 channel matrix is decomposed into the four 2×2 matrixes as follows

$$A = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \quad B = \begin{bmatrix} h_{13} & h_{14} \\ h_{23} & h_{24} \end{bmatrix} \quad (3)$$

$$C = \begin{bmatrix} h_{21} & h_{22} \\ h_{31} & h_{32} \end{bmatrix} \quad D = \begin{bmatrix} h_{23} & h_{24} \\ h_{33} & h_{34} \end{bmatrix} \quad (4)$$

The transmitted signals in two consecutive symbol periods and the corresponding received signals are

$$S_{12} = \begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \end{bmatrix} \quad x_{56} = \begin{bmatrix} x_5 & x_7 \\ x_6 & x_8 \end{bmatrix} \quad (5)$$

$$Y_1 = \begin{bmatrix} y_1 & y_4 \\ y_2 & y_5 \end{bmatrix} \quad Y_2 = \begin{bmatrix} y_2 & y_5 \\ y_3 & y_6 \end{bmatrix} \quad (6)$$

Then,

$$\begin{aligned} Y_1 &= AS_{12} + Bx_{56} + w_1 \\ Y_2 &= CS_{12} + Dx_{56} + w_2 \end{aligned} \quad (7)$$

where w_1 and w_2 are noise matrix added to Y_1 and Y_2 respectively. To detect S_{12} in the 2×2 matrix, the term containing only S_{12} is required. Matrix is transformed as

$$\begin{aligned} Z &= B^{-1}Y_1 - D^{-1}Y_2 \\ &= (B^{-1}A - D^{-1}C)S_{12} + B^{-1}w_1 - D^{-1}w_2. \end{aligned} \quad (8)$$

It is expressed as

$$Z = \tilde{H}S_{12} + \tilde{w} \quad (9)$$

where

$$Z = \begin{bmatrix} z_1 & z_3 \\ z_2 & z_4 \end{bmatrix} \quad (10)$$

$$\tilde{H} = B^{-1}A - D^{-1}C \quad (11)$$

$$\tilde{w} = B^{-1}w_1 - D^{-1}w_2. \quad (12)$$

To estimate S_1 and S_2 , z_1 , z_2 , z_3 and z_4 are combined as follows

$$\begin{aligned} \tilde{S}_1 &= \tilde{h}_{11}^* z_1 + \tilde{h}_{21}^* z_2 + \tilde{h}_{12}^* z_3 + \tilde{h}_{22}^* z_4 \\ &= (|\tilde{h}_{11}|^2 + |\tilde{h}_{12}|^2 + |\tilde{h}_{21}|^2 + |\tilde{h}_{22}|^2)S_1 + W_1 \end{aligned} \quad (13)$$

$$\begin{aligned}\tilde{S}_2 &= \tilde{h}_{12}^* z_1 + \tilde{h}_{22}^* z_2 - \tilde{h}_{11} z_3^* - \tilde{h}_{21} z_4^* \\ &= (|\tilde{h}_{11}|^2 + |\tilde{h}_{12}|^2 + |\tilde{h}_{21}|^2 + |\tilde{h}_{22}|^2) S_2 + W_2\end{aligned}\quad (14)$$

and then are quantized as follows

$$S_1 = Q(\tilde{S}_1 \times 1/(|\tilde{h}_{11}|^2 + |\tilde{h}_{12}|^2 + |\tilde{h}_{21}|^2 + |\tilde{h}_{22}|^2)) \quad (15)$$

$$S_2 = Q(\tilde{S}_2 \times 1/(|\tilde{h}_{11}|^2 + |\tilde{h}_{12}|^2 + |\tilde{h}_{21}|^2 + |\tilde{h}_{22}|^2)). \quad (16)$$

STBC symbols are removed from the received signal as follows

$$\begin{bmatrix} \tilde{Y}_1 \\ \tilde{Y}_2 \end{bmatrix} = \begin{bmatrix} y_1 & y_4 \\ y_2 & y_5 \\ y_3 & y_6 \end{bmatrix} - \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \\ h_{31} & h_{32} \end{bmatrix} \begin{bmatrix} S_1 & -S_2^* \\ S_2 & S_1^* \end{bmatrix}. \quad (17)$$

After that, SM symbols are detected by the proposed scheme in [4], [5].

Third, V-algorithm [6], [7] ($V = 4$) is applied in order to detect SM symbols accurately when SM symbols are estimated.

Fourth, the estimated SM symbols are removed from the received signals, STBC symbols are re-estimated [9] to detect STBC symbols accurately and then the re-estimated symbols are compared with the first estimated symbols. If they are same, the estimation is stopped and then transmitted symbols are decided. Otherwise, the first estimated symbols are replaced with the re-estimated symbols, go back to the second step and re-estimate. This process lasts until the compared result is same. The process of re-estimation is required to attain accuracy of detection. However, the constant K is set for the limit of repetition. If K is large number, the detection process is complex.

4. Simulation Results

In this section, improved performance of the proposed schemes is presented in Fig. 3 and Fig. 4. A 4×3 MIMO-OFDM system with a QPSK modulation is considered and sets the number of subcarriers to 64. Occasionally, a 16QAM modulation is considered when STBC symbols are modulated. At transmitter, power allocation of each antenna is $1/N_t$. N_t is the number of transmit antennas. Therefore, the power is overall 1 and the power allocation of STBC symbols with QPSK modulation, STBC symbols with 16QAM modulation and SM symbols is same each other. V-algorithm ($V = 4$) is used when SM symbols are estimated. The channel is a Rayleigh frequency flat fading during two OFDM symbol periods, the number of paths is 7, the noise is additive white Gaussian noise. It is supposed that receiver knows channel state information (CSI) perfectly.

Figure 3 shows BER performance of the conventional hybrid scheme, iterative hybrid scheme and the proposed hybrid scheme. The STBC BER performance of the iterative hybrid STBC scheme has better about 1.5 dB at $\text{BER} = 10^{-4}$ than the conventional scheme and proposed increased data rate scheme has less BER performance than

Fig. 3 BER performance of STBC symbols.

Fig. 4 BER performance of total symbols.

iterative scheme [9]. The proposed scheme transmits more bit data efficiently without BER performance loss compared with the conventional scheme and conventional scheme has lower performance compared with the iterative scheme as shown in Fig. 3. STBC symbols of the proposed scheme are detected by efficient iterative detection scheme and iterative scheme also uses efficient iterative detection scheme. However, conventional scheme doesn't use iterative scheme. Therefore, conventional scheme has the worst BER performance of STBC symbol and proposed scheme transmits data of STBC symbol two times more than conventional and iterative scheme as shown in Table 1. As a result, the proposed scheme has worse BER performance of STBC symbol than iterative scheme.

Conventional scheme has the worst total BER performance as shown in Fig. 4 since STBC symbols of the proposed scheme and iterative scheme are detected efficiently by iterative detection scheme. Iteration for detection affects accurate detection of STBC symbol and accurate de-

Table 1 Comparison of the number of bit per 2 time slots.

	conventional scheme and iterative scheme	proposed scheme
STBC	4	8
SM	8	8
Total	12	16

Fig. 5 The number of iteration times at each SNR.

tection of STBC symbol also affects when SM symbols are estimated accurately. Therefore, conventional scheme has the worst total BER performance since it doesn't use iterative scheme. Figure 4 shows that the total BER performance of the proposed scheme has still better performance than the conventional scheme even though a little performance of STBC symbols is lost as shown in Fig. 3. Performance of STBC symbols of the proposed scheme is lost as shown in Fig. 3 since the data rate of STBC symbols is increased. However, STBC symbols are detected by iterative detection scheme and detection process of the SM symbols doesn't change compared with iterative scheme. Moreover, the number of iteration times in the proposed scheme is increased to detect more accurate symbols as shown in Fig. 5. Therefore, effect of BER performance of STBC symbol is insignificant in Fig. 4. A little total BER performance is lost as shown in Fig. 4 since total BER performance is influenced by STBC symbol and SM symbol. Table 1 shows that proposed scheme transmits more data than conventional and iterative hybrid STBC scheme. Proposed scheme transmits data of total symbol 1.3 times more than conventional and iterative scheme.

The proposed scheme is the most effective when it is performed at low signal-to-noise ratio (SNR) condition due to iteration process. Figure 5 shows that how many times estimations are iterated averagely at each SNR. The number

of iteration times in the iterative scheme is nearly 1.4 times, the proposed scheme is 1.9 times at very low SNR and the proposed scheme always iterates more than iterative scheme at each SNR. However, the number of iteration times is very small number. It indicates that the number of iteration times is insignificant in order to attain high data rate as shown in Table 1 with better performance. In other words, iteration is effective in the iterative detection and estimation of accurate symbols for the proposed scheme. Iteration is operated more efficiently in case of the proposed scheme than the iterative scheme at all SNR as shown in Fig. 5. Consequently, the proposed scheme attains better performance gain with higher data rate than the conventional scheme.

5. Conclusion

In this letter, improved schemes for hybrid STBC system are proposed. The conventional scheme is enhanced by the addition of iterative detection and an increased data rate scheme to improved the performance. Simulation results show that better BER performance and increased data rate are obtained by iterative detection scheme and proposed scheme.

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