A Novel Design for Hybrid Space-Time Block Codes and Spatial Multiplexing Scheme

Seung-Jun Yu, Jang-Kyun Ahn, Eui-Young Lee and Hyoung-Kyu Song,

Abstract—Space-time block codes (STBC) and spatial multiplexing (SM) are promising techniques that effectively exploit multiple-input multiple-output (MIMO) transmission to achieve more reliable communication and a higher multiplexing rate, respectively. In this paper, we study a practical design for hybrid scheme with multi-input multi-output orthogonal frequency division multiplexing (MIMO-OFDM) systems to flexibly maximize the tradeoff between diversity and multiplexing gains. Unlike the existing STBC and SM designs which are suitable for the integer multiplexing rate, the proposed design can achieve arbitrary number of multiplexing rate.

Keywords—Space-Time Block Codes, Spatial Multiplexing, MIMO-OFDM.

I. INTRODUCTION

FOR next generation wireless systems offering high quality multimedia services, an wireless communication system which combats impairments in the severe wireless environment is required to achieve better service quality and higher data rate. Recent research has shown that multi-input multi-output (MIMO) systems increase the data rate without requiring neither power nor bandwidth resources. A MIMO system uses multiple transmit and receive antennas to achieve high spectral efficiency for increased throughput using the same bandwidth, adding an extra degree of freedom in the design of wireless communication systems. Two general transmission techniques have been devised to take advantage of MIMO systems: Diversity Transmission and Spatial Multiplexing. The first technique has the goal of increasing diversity gain; this was achieved by Space-Time Block Codes (STBC). Implementing STBC decoders is a tractable problem, but they have the disadvantage that their spectral efficiency is low. A popular scheme that reaches full-diversity and full-rate was proposed by Alamouti [1]. The second technique aims to increase the number of available transmit channels; one of its main proponents are Vertical Layered Space-Time Codes, also known as V-BLAST (Bell-Labs Architecture for Space-Time), which were first introduced in [3]. Its most interesting attributes are a very high spectral efficiency, ease of code design and comparatively simple receiver architectures; their performance is highly dependent on the channel statistics such as the spatial correlation between antennas at the receiver and transmitter ends. In [4], Zheng and Tes investigated the theoretical tradeoff between diversity and multiplexing. It studied diversity and multiplexing from the viewpoint of Information Theory, using

an approach based on outage probability formulation. Then, in [5], an approach that all the transmit antennas switch to either diversity or multiplexing with the lower conditional error rate for an instantaneous channel realization is proposed. But it wastes spatial efficiency when switching to diversity. Some schemes called hybrid MIMO schemes consisting of STBC and spatial multiplexing schemes combine transmit diversity and spatial multiplexing, achieving the diversity gain and multiplexing gain at the same time [6]-[11]. The work in [7] proposed a hybrid MIMO system with four transmit antennas, where the Alamouti scheme is applied separately to two pairs of transmit antennas. This means that two data streams are spatially multiplexed on two different pairs of antennas. The work in [8] and [9] proposed a hybrid MIMO system that the first two transmit antennas transmitted Alamouti STBC and the others transmitted spatial multiplexing data streams. Since this scheme fixed the allocation of transmit antennas for Alamouti STBC and spatial multiplexing data streams without considering the instantaneous channel state, the spatial multiplexing data streams are more susceptible to the fading effect when the subchannel condition is poor.

In this paper, A hybrid scheme is proposed for MIMO-OFDM systems to flexibly maximize the tradeoff between diversity and multiplexing gains to match the user's requirements. A hybrid scheme combines STBC and SM in different OFDM subcarriers to achieve variable rates. By choosing different parameter settings for the design of hybrid scheme, it is possible to adjust the rate of the code, without changing the receiver implementation. This paper is organized as follows. In section II, system model is defined. A hybrid scheme for MIMO-OFDM systems is presented in section III. Simulation result is given in section IV, and finally conclusion is made in section V.

II. SYSTEM MODEL

In this paper, we consider a MIMO-OFDM system with N_C subcarriers, M_T transmit antennas and N_R receive antennas. M_T transmit antennas share the same frequency band and transmit M_T synchronous data streams. The Channel State Information (CSI) of the MIMO Channel, where is assumed to be frequency-flat Rayleigh fading, is known at the receiver and to be perfectly synchronized. The MIMO-OFDM system model is defined by

$$\mathbf{R}(k) = \mathbf{H}(k)\mathbf{X}_k + \mathbf{N}(k), \qquad (1)$$

where $\mathbf{R}(k)$ is the received signal from N_R receive antennas corresponding to k-th subcarrier, $k = 1,\dots,N_C$ and $\mathbf{H}(k)$

Seung-Jun Yu Jang-Kyun Ahn Eui-Young Lee and Hyoung-Kyu Song(Corresponding Author) are with uT Communication Research Institute, Sejong University, Seoul, Korea e-mail: for1stlove@gmail.com, songhk@sejong.ac.kr.

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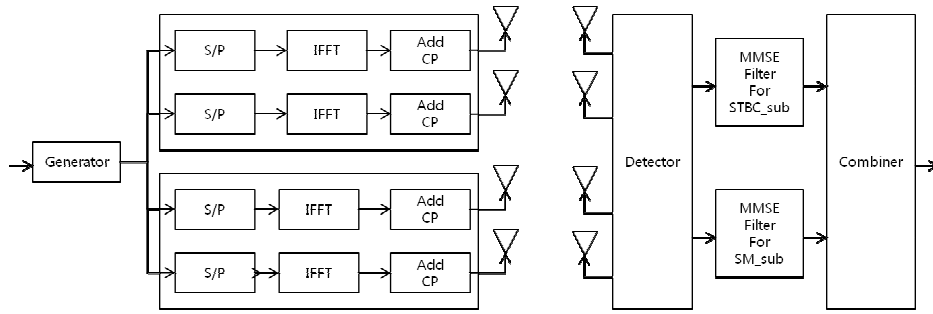

Fig. 1. A Hybrid Scheme for MIMO-OFDM systems.

$= [H_{nm}(k)]$, $m = 1,\ldots,M_T$, $n = 1,\ldots,N_R$, $k = 1,\ldots,N_C$. $H_{nm}(k)$ is the channel frequency response at k-th subcarrier from m-th transmit antenna to n-th receive antenna. It is assumed that $H_{nm}(k)$ are independently Rayleigh distributed. X_k corresponds to k-th column of matrix X, which is the transmit matrix of size $M_T \times N_C$. $\mathbf{N}(k)$ is the additive white Gaussian noise (AWGN) vector of size $N_R \times 1$ and $\mathbf{N}(k) \sim CN(\mathbf{0}, N_0\mathbf{I})$. This MIMO-OFDM system model is defined in the frequency domain and applied to STBC, SM and a hybrid scheme, being different only in the design of transmit matrix X. The transmit matrix X is defined by

$$\mathbf{X} = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N_C}^1 \\ x_1^2 & x_2^2 & \cdots & x_{N_C}^2 \\ \vdots & \vdots & & \vdots \\ x_1^{M_T} & x_2^{M_T} & \cdots & x_{N_C}^{M_T} \end{bmatrix}, \quad (2)$$

where x_k^m is quadrature amplitude modulation (QAM)-modulated symbols alloted to k-th subcarrier in m-th transmit antenna.

We neoterically define the rate of code, where is the number of symbols tansmitted in one OFDM symbol divided by the number of subcarriers, Unlike the existing rate of code. It is easy to observe that the rate obtained from matrix $\mathbf{X}$ in (2) is defined by

$$r = \frac{N_S}{N_C}, \quad (3)$$

where N_S is the number of symbols transmitted in one OFDM symbol.

III. A HYBRID SCHEME

A. SM and STBC

We consider a system with $M_T = 2$, $N_R = 2$ and $N_C = 6$. In SM, matrix $\mathbf{X}$ will be organized as

$$\mathbf{X} = \begin{bmatrix} x_1^1 & x_2^1 & x_3^1 & x_4^1 & x_5^1 & x_6^1 \\ x_1^2 & x_2^2 & x_3^2 & x_4^2 & x_5^2 & x_6^2 \end{bmatrix}. \quad (4)$$

The rate of this code is 2. In STBC, matrix $\mathbf{X}^T$ will be organized as

$$\mathbf{X^1} = \begin{bmatrix} x_1^1 & x_2^1 & x_3^1 & x_4^1 & x_5^1 & x_6^1 \\ x_1^2 & x_2^2 & x_3^2 & x_4^2 & x_5^2 & x_6^2 \end{bmatrix}, \quad (5)$$

$$\mathbf{X^2} = \begin{bmatrix} -x_1^{2*} & -x_2^{2*} & -x_3^{2*} & -x_4^{2*} & -x_5^{2*} & -x_6^{2*} \\ x_1^{1*} & x_2^{1*} & x_3^{1*} & x_4^{1*} & x_5^{1*} & x_6^{1*} \end{bmatrix}, \quad (6)$$

where $\mathbf{X}^T$ is transmit matrix at t-th time slot. The rate of this code is

$$r = \frac{N_S/T}{N_C} = \frac{12/2}{6} = 1, \quad (7)$$

where T is total time slots.

B. Design of a Hybrid Scheme

In Hybrd, the design of matrix X is different. If we want to get a higher rate of code, we can transform matrix X as this example

$$\mathbf{X^1} = \begin{bmatrix} x_1^1 & x_2^1 & x_3^1 & x_4^1 & x_5^1 & x_6^1 \\ x_1^2 & x_2^2 & x_3^2 & x_4^2 & x_5^2 & x_6^2 \end{bmatrix}, \quad (8)$$

$$\mathbf{X^2} = \begin{bmatrix} -x_1^{2*} & -x_2^{2*} & -x_3^{2*} & -x_4^{2*} & x_7^1 & x_8^1 \\ x_1^{1*} & x_2^{1*} & x_3^{1*} & x_4^{1*} & x_7^2 & x_8^2 \end{bmatrix}. \quad (9)$$

We have introduced new symbols x_7^1, x_8^1, x_7^2 and x_8^2 in matrix X without changing the system model. As we transmit more symbols, the rate of the code increases. This is clear since in (8),(9) we send 16 symbols in 6 subcarriers during 2 time slots. The rate of this new code is

$$r = \frac{N_S^{STBC}/T + N_S^{SM}}{N_C} = \frac{8/2 + 8}{6} = 1.666, \quad (10)$$

which is higher than rate 1 code obtained with STBC in (5),(6). As we observe, symbols x_5^1, x_6^1, x_5^2, x_6^2 and x_7^1, x_8^1, x_7^2, x_8^2 are not repeated and not used for STBC, and it is expected that the diversity performance of this new code is lower than obtained in STBC. Increasing multiplexing gain results in reduced diversity gain in the system since there is always a tradeoff. In the same way, it is possible to add more symbols and obtain higher rate codes with different compositions. As a great advantage of hybrid scheme , the rate of this code is very flexible to adjust according to requirements in the system.

A OFDM system usually has a large number of subcarriers. For Design of a hybrid scheme , it is necessary to define a method to form matrix X. Matrix X is divided into submatrix to help for the design of a hybrid scheme. These submatrices

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are concatenated sequentially to form the marix X^T and is defined by

$$\mathbf{X}^T = [X_1, X_2, \cdots, X_S], \qquad (11)$$

where X_s, $s = 1,...,$S is the s-th submatrix. The submatrix has a size of $M_T \times V$ where $V = N_C/S$ is the size of the submatrix.

C. Decoding a Hybrid Scheme

Unlike SM, A hybrid scheme uses two MMSE receivers to decode data streams. one MMSE receiver decodes the subcarriers where STBC is applied and the other MMSE receiver decodes the subcarriers where SM is applied. To be able to use two MMSE receivers in a hybrid scheme, it is necessary to define two system models. First system model is defined by

$$\mathbf{R}(k) = \widehat{\mathbf{H}}(k) \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \mathbf{N}(k), \qquad (12)$$

where

$$\widehat{\mathbf{H}}(k) = \begin{bmatrix} h_{11}(k) & h_{12}(k) \\ h_{21}(k) & h_{22}(k) \\ h_{12}^*(k) & -h_{11}^*(k) \\ h_{22}^*(k) & -h_{21}^*(k) \end{bmatrix}. \qquad (13)$$

This channel model is used only for subcarriers where STBC is applied. Second system model is defined by

$$\mathbf{R}(k) = \breve{\mathbf{H}}(k) \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \mathbf{N}(k), \qquad (14)$$

where

$$\breve{\mathbf{H}}(k) = \begin{bmatrix} h_{11}(k) & h_{12}(k) \\ h_{21}(k) & h_{22}(k) \end{bmatrix}. \qquad (15)$$

This channel model is used only for subcarriers where SM is applied.

We define two MMSE receivers: First MMSE receiver uses system model (12) and is applied to STBC subcarries, defined by

$$W_{STBC,MMSE} = (\widehat{\mathbf{H}}(k)^H \widehat{\mathbf{H}}(k) + \sigma_n^2 \mathbf{I_{2T}})^{-1} \widehat{\mathbf{H}}(k)^H, \quad (16)$$

where $W_{STBC,MMSE}$ is of size $2T \times N_R$.

$$\mathbf{R}(k) = \widehat{\mathbf{H}}(k) \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \mathbf{N}(k). \qquad (17)$$

Second MMSE receiver is applied to the MIMO channel to decode each stream from each transmit antenna and is used for SM subcarriers, defined by

$$W_{SM,MMSE} = (\breve{\mathbf{H}}(k)^H \breve{\mathbf{H}}(k) + \sigma_n^2 \mathbf{I}_{M_T})^{-1} \breve{\mathbf{H}}(k)^H, \quad (18)$$

where $W_{SM,MMSE}$ is of size $M_T \times N_R$.

As an example, in submatrix (8),(9) we apply STBC-MMSE receiver for the first 4 subcarriers and apply SM-MMSE receiver for the next 2 subcarriers to decode symbols. We
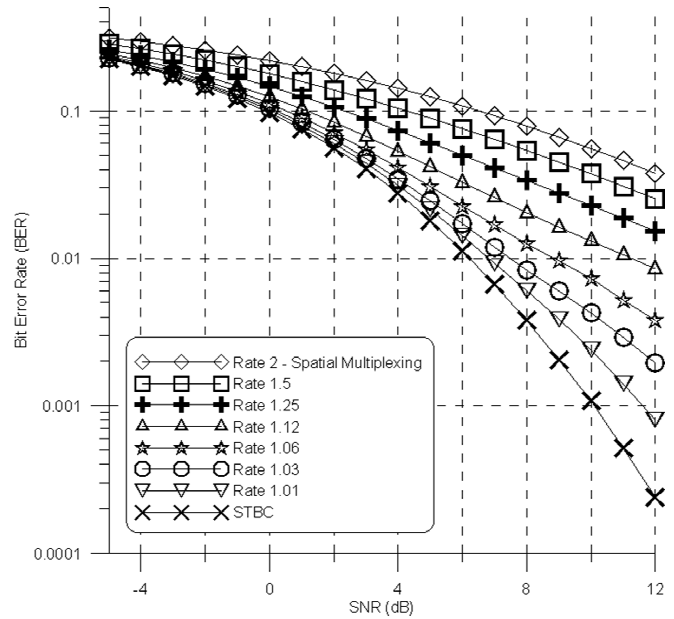

Fig. 2. BER performance of a hybrid scheme for 2x2 MIMO-OFDM system with QPSK modulation.

realize the same operation across all submatrices in the OFDM symbol. As a general form:

$$\begin{bmatrix} \widehat{x}_k^1 \\ \widehat{x}_k^2 \end{bmatrix} = W_{STBC,MMSE} \mathbf{R}(k), \qquad (19)$$

where k is the set of STBC subcarriers is applied and

$$\begin{bmatrix} \widehat{x}_k^1 \\ \widehat{x}_k^2 \end{bmatrix} = W_{SM,MMSE} \mathbf{R}(k), \qquad (20)$$

where k is the set of SM subcarriers is applied. After Two MMSE receivers, a hybrid combiner is in charge of arranging the order of the symbols as shown in Fig.1.

IV. SIMULATION RESULT

In our simulation, the MIMO-OFDM system with $N_C = 128$, Fig. 2 shows results for different rates in a flat fading channel. We evaluate for rates 1.5, 1.25, 1.12, 1.06, 1.03 and 1.01, and compare them with the Rate 1 - STBC system and Rate 2 SM system. In Fig. 2, we observe how the diversity gain is decreasing when the rate of the system is higher. This is clear because a hybrid scheme at higher rates uses more subcarriers for spatial multiplexing and less of them for diversity gain.

V. CONCLUSION

We have shown that the proposed hybrid scheme can be a flexible space-time code in terms of adjustable rate. With a hybrid scheme, it is possible to reach non-integer values for its rate an therefore obtain an optimized tradeoff between diversity and multiplexing gain according to system requirements.

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Seung-Jun Yu was born in GyeongSang-Namdo, Korea in 1984. He received the B.S. degree in Information & Communication Engineering, Sejong University, Seoul, Korea, in 2011. He is working toward to M.S. degree in the Department of information and communications engineering, Sejong University, Seoul, Korea. His research interests are in the areas of wireless communication system design, data communications, cooperative communication.

Jang-Kyun Ahn was born in ChungCheong-Namdo, Korea in 1985. He received the B.S. degree in Information & Communication Engineering, Sejong University, Seoul, Korea, in 2011. He is working toward to M.S. degree in the Department of information and communications engineering, Sejong University, Seoul, Korea. His research interests are in the areas of wireless communication system design, data communications, MIMO signal processing.

Eui-Young Lee was born in KangWon-do, Korea in 1989. She received the B.S. degree in Information & Communication Engineering, Sejong University,Seoul,Korea,in 2011. She is working toward to M.S. degree in the Department of Information and Communication Engineering, Sejong University, Seoul,Korea. Her research interests are in the areas of wireless communication system design, data communications, MIMO signal processing.

Hyoung-Kyu Song was born in ChungCheong-Bukdo, Korea in 1967. He received B.S., M.S., and Ph.D. degrees in electronic engineering from Yonsei University, Seoul, Korea, in 1990, 1992, and 1996, respectively. From 1996 to 2000 he had been managerial engineer in Korea Electronics Technology Institute (KETI), Korea. Since 2000, he has been a professor of the Department of information and communications engineering, Sejong University, Seoul, Korea. His research interests include digital and data communications, information theory and their applications with an emphasis on mobile communications.