A New Multiuser Receiver for the Application Of Space-time Coded OFDM Systems

Van-Su Pham, Minh-Tuan Le, Linh Mai, Jae-young Lee and Giwan Yoon , *Member, KIMICS*

***Abstract*—**In this work, a novel optimal multiuser detection (MUD) approach, which not only achieves the optimal maximum-likelihood (ML)-like performance but also has reasonably low computational complexity, for Space-time coded OFDM (ST-OFDM) systems is presented. In the proposed detection scheme, the signal model is firstly re-expressed into linearly equivalent one. Then, with the linearly equivalent signal model, a new jointly MUD algorithm is proposed to detect signals. The ML-like bit-error-rate (BER) performance and reasonably low complexity of the proposed detection are verified by computer simulations.

***Index Terms*—**Space Time Code, Multiple-Input Multiple-Output (MIMO) system, Multiuser Detection (MUD), OFDM system, Optimal Detection, Wireless Communication System.

I. INTRODUCTION

In recent works [1], [6],orthogonal space-time block codes (OSTBC) were introduced to obtain coded diversity for communication systems with multiple antennas. The code designs were based on orthogonal principle, thus OSTBC not only can provide significant improvement in reception quality but also allow to implement receiver more simply by linear ML decoding individual symbols. However, the OSTBC designs and performance evaluations are introduced almost under the assumption that the channel is quasi-static slow flat fading. Therefore, the performance of OSTBC will be degraded so much in selective fading channel.

It is well-known that OFDM [2], [7] is the most promising modulation technique to combat selective fading channel. By using orthogonally modulation, the bandwidth is divided into a number of sub-carriers resulting in that the channel becomes flat fading to each sub-carrier. Another advantage of OFDM is remarkable that the system implementation complexity can be reduced by applying well-known fast Fourier transform (FFT) and inverse fast Fourier transform.

The advantages of OSTBC and OFDM motivate us to exploit the combinations of OSTBC and OFDM to improve system performance and mitigate selective fading channel as well. The first combination ST-OFDM was presented by Lee et al. [8]. Then Space-frequency coded OFDM (SF-OFDM) and Space-time-frequency coded OFDM (STF-OFDM) were introduced in [9]-[10]. In [8]-[10], the performances of ST/SF/STF-OFDM were evaluated for single user (SU) scenarios. Unfortunately, in modern wireless communication system, capacity of handling multi-user (MU) simultaneously is crucial. It is obvious that optimal detection for both SU and MU scenarios is brute-force ML detection. However, the detection complexity is exponentially proportion to the number of transmit antennas and the order of the applied modulation scheme. As a result, the brute-force ML detection becomes impractical when large number of transmit antennas and/or high order modulation scheme are applied. In [3], equivalent linear MMSE MU detection was introduced. The MMSE MUD provides significantly low computational complexity at the expense of large degradation in performance. In this work, we present a novel optimal MUD ST-OFDM scheme in which the special format of upper triangular matrix resulted from QR decomposition the equivalent linear system model was exploited and our previous work [4]-[5] inspiration was employed. Consequently, the proposed optimal MUD ST-OFDM can provide performance comparable to that of brute-force ML MUD whereas result in remarkably low complexity comparable to that of MMSE MUD.

The remainder of the paper is organized as follows. In section II, we present multi-user ST-OFDM signal model. The equivalent linear signal model and proposed MUD ST-OFDM are given in section III. The computer simulation results for verifying the proposed detection

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Manuscript received , November 14, 2006.

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scheme is presented in section IV. Finally, the conclusion of our work is shown in section V.

II. SIGNAL MODEL

The diagram of multi-user ST-OFDM is depicted in Figure 1, in which the simple combination of OSTBC and OFDM to take advantage of high diversity gain of OSTBC and mitigate the contamination of selective fading channel. In the system, there are K active users and each of them is equipped M transmit antennas. The base station uses N antennas to receive signal from users.

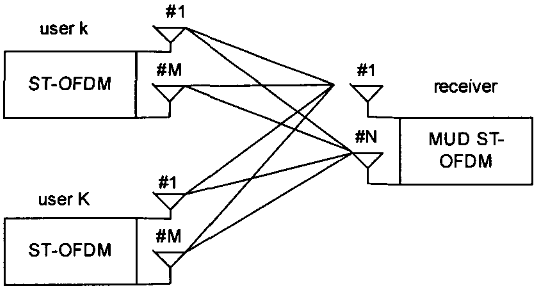

Fig. 1 Block diagram of MU ST-OFDM systems.

Without loss of generality, we assume that each user employs OSTBC [1] for space-time mapping. The equivalent OSTBC of user k^{th} is given as:

$$\mathbf{G}^{(k)}=\begin{bmatrix}\mathbf{X}_1^{(k)} & -\mathbf{X}_2^{(k)*}\\ \mathbf{X}_2^{(k)} & \mathbf{X}_1^{(k)*}\end{bmatrix} \tag{1}$$

Where $\mathbf{X}_i^{(k)}$ ($i=1,2$) is an OFDM symbol, that is

$$\mathbf{X}_i^{(k)}=\left[X_i^{(k)}(0)\quad X_i^{(k)}(1)\quad \cdots \quad X_i^{(k)}(P-1)\right]^T ;$$

P is length of fast Fourier transform (FFT); $()^*$ is conjugate version of ().

The equivalent OSTBC is then OFDM modulated to form a ST-OFDM as:

$$\mathbf{g}^{(k)}=\begin{bmatrix}\mathbf{x}_{11}^{(k)} & \mathbf{x}_{12}^{(k)}\\ \mathbf{x}_{21}^{(k)} & \mathbf{x}_{22}^{(k)}\end{bmatrix} \tag{2}$$

After being modulated, each ST-OFDM symbol $\mathbf{x}_{ij}^{(k)}$ is added cyclic prefix to avoid ISI. Now, the transmit signal matrix becomes:

$$\overline{\mathbf{g}}^{(k)}=\begin{bmatrix}\overline{\mathbf{x}}_{11}^{(k)} & \overline{\mathbf{x}}_{12}^{(k)}\\ \overline{\mathbf{x}}_{21}^{(k)} & \overline{\mathbf{x}}_{22}^{(k)}\end{bmatrix} \tag{3}$$

Then, at the first transmit duration, $\overline{\mathbf{x}}_{11}^{(k)}$ is transmitted from the first antenna and $\overline{\mathbf{x}}_{21}^{(k)}$ is transmitted from the second antennas. At the next transmit duration, $\overline{\mathbf{x}}_{12}^{(k)}$ is transmitted from the first antenna, and $\overline{\mathbf{x}}_{22}^{(k)}$ is transmitted from the second antenna.

At the receiver, the receiver first removes cyclic prefix, and then demodulates (FFT) signal to get received signal. With the assumption that the length of cyclic prefix is long enough to compensate ISI, the received signal at the m^{th} receive antenna can be written as:

$$\mathbf{Y}_m=\sum_{k=1}^{K}\mathbf{H}_m^{(k)}\mathbf{G}^{(k)}+\mathbf{W}_m \tag{4}$$

In (4), $\mathbf{Y}_m$ is an $P\times 2$ received signal matrix of m^{th} antenna at the first and second time duration. $\mathbf{H}_m^{(k)}$ is $2P\times 2P$ complex channel matrix from k^{th} user to m^{th} receive antenna. $\mathbf{W}_m$ is $P\times 2$ additive Gaussian noise matrix.

III. PROPOSED DETECTION SCHEME

From (4), let consider the received signal on the n^{th} sub-carrier, then we can rewrite (4) as follows:

$$\mathbf{Y}_m[n]=\sum_{k=1}^{K}\mathbf{H}_m^{(k)}[n]\mathbf{G}^{(k)}[n]+\mathbf{W}_m[n] \tag{5}$$

Where $\mathbf{Y}_m[n]=\left[Y_{m,1}[n]\quad Y_{m,2}[n]\right]$, $Y_{m,i}[n]$ ($i=1,2$) is the received signal at m^{th} receive antenna on n^{th} sub-carrier during i^{th} time slot. $\mathbf{H}_m^{(k)}[n]$ is 2×2 complex channel matrix from k^{th} user to m^{th} receive antenna on n^{th} sub-carrier. $\mathbf{G}^{(k)}[n]$ is 2×2 corresponding OSTBC on n^{th} sub-carrier. $\mathbf{W}_m[n]=\left[W_{m,1}[n]\quad W_{m,2}[n]\right]$, $W_{m,i}[n]$ ($i=1,2$) is the additive Gaussian noise at the m^{th} receive antenna on n^{th} sub-carrier during i^{th} time slot.

Our next step is to re-express (5) in linear system. To do so, we first introduce some definition as follows:

$$\overline{\mathbf{X}}^{(k)}[n]=\left[X_1^{(k)}[n]\quad X_2^{(k)}[n]\right]^T \tag{6a}$$

$$\overline{\mathbf{X}}[n]=\left[\overline{\mathbf{X}}^{(1)}[n]\ ;\ \cdots\ ;\ \overline{\mathbf{X}}^{(K)}[n]\right] \tag{6b}$$

$$\overline{\mathbf{Y}}_m[n]=\left[Y_{m,1}^{(k)}[n]\quad Y_{m,2}^{(k)*}[n]\right]^T \tag{6c}$$

$$\bar{\mathbf{W}}_m[n] = \left[W_{m,1}[n] \quad W^*_{m,2}[n] \right]^T \tag{6d}$$

$$\bar{\mathbf{H}}^{(k)}_m[n] = \begin{bmatrix} H^{(k)}_{m,1}[n] & H^{(k)}_{m,2}[n] \\ H^{(k)*}_{m,2}[n] & -H^{(k)*}_{m,1}[n] \end{bmatrix} \tag{6e}$$

$$\bar{\mathbf{H}}_m[n] = \left[\bar{\mathbf{H}}^{(1)}_m[n] \ ; \ \cdots \ ; \ \bar{\mathbf{H}}^{(K)}_m[n] \right] \tag{6f}$$

With the new definitions from (6a) to (6f), (5) can be re-written as:

$$\bar{\mathbf{Y}}_m[n] = \bar{\mathbf{H}}_m[n]\bar{\mathbf{X}}[n] + \bar{\mathbf{W}}_m[n] \tag{7}$$

Now, the received signal from all N receive antennas can be expressed as:

$$\bar{\mathbf{Y}}[n] = \bar{\mathbf{H}}[n]\bar{\mathbf{X}}[n] + \bar{\mathbf{W}}[n] \tag{8}$$

Where $\bar{\mathbf{Y}}[n] = \left[\bar{\mathbf{Y}}_1[n] \ ; \ \cdots \ ; \ \bar{\mathbf{Y}}_N[n] \right]$, $\bar{\mathbf{H}}[n] = \left[\bar{\mathbf{H}}_1[n] \ ; \ \cdots \ ; \ \bar{\mathbf{H}}_N[n] \right]$, and $\bar{\mathbf{W}}[n] = \left[\bar{\mathbf{W}}_1[n] \ ; \ \cdots \ ; \ \bar{\mathbf{W}}_N[n] \right]$.

It is easy to see that (8) is linear equation of transmitted signal, therefore it is worth emphasizing that any conventional MUD schemes such as linear ZF, MMSE [2],[3] can be applied here. However, with inspiration from our previous work [4]-[5], we will present our new jointly optimal MUD scheme by exploiting the special format of upper matrix resulted from the QR decomposition of $\bar{\mathbf{H}}[n]$. The summary of the algorithm is as follows:

1. (Initialization) Set $k := K$, $Th_{opt} := 0$, $CV := 0$, $UV := 0$
2. Construct (8) and take QR decomposition of $\bar{\mathbf{H}}[n]$.
3. Jointly decode signal for the user k^{th} ($k = K,\ldots,1$) by using LCMLDec1 [4].

IV. COMPUTER SIMULATION RESULTS

The improved performance of the proposed MUD approach is verified through simulations. In our simulations, the modulation scheme for baseband signal is assumed to be QPSK. The length of FFT is set to 64. The transmit power of users are assumed to be equal by using any known power control algorithm.

First, the BER performance of the proposed algorithm is compared to that of brute-force ML detection, linear ZF [2] and linear MMSE [2], [3]. The comparison is shown in Figure 2. In this simulation, we consider system with 2 active users, the base station is equipped with 2 receive antennas. As can be seen from Figure 2, the proposed MUD scheme can get BER performance which is comparable to that of brute-force ML detection. In other hands, it is obviously that the proposed MUD approach outperforms linear ZF and MMSE. The same improvement trend can be also seen from Figure 3 for system of 2 active users with 4-receive-antenna base station.

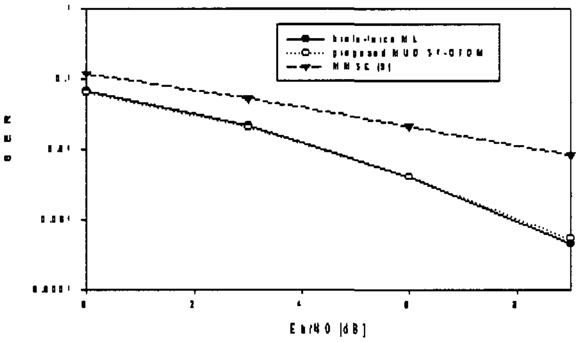

Fig. 2 BER performance comparison of the proposed MUD ST-OFDM and its counterparts under the system with 2 active users and 2-receive-antenna base station.

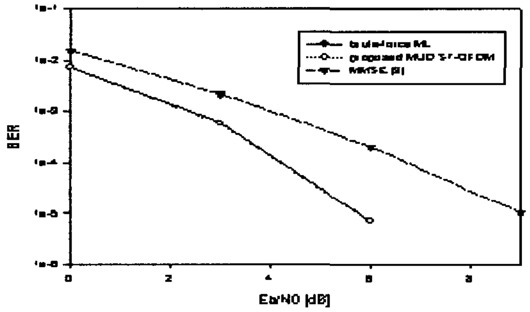

Fig. 3 BER performance comparison of the proposed MUD ST-OFDM and its counterparts under the system with 2 active user, and 4-receive-antenna base station

V. CONCLUSION

In this work, a new jointly optimal MUD ST-OFDM scheme, which is based on QR decomposition of the equivalent linear signal model, has been introduced. By wisely exploiting the special upper triangular matrix, our jointly optimal detection scheme can avoid being suffered from heavily computational complexity whereas can improve system performance significantly. Consequently, the proposed detection is promisingly applicable to combat in MU wireless applications.

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