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Abstract

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ABSTRACT

The paper provides a method for linear combining HARQ along with Self-Interference Cancellation Coding (SICC), so that the reliability of spatial multiplexing MIMO transmissions can be improved. Furthermore we introduce a low-complexity decoding scheme with MMSE and linear combining. The simulation results show that significant gain is achieved over the traditional Chase Combining(CC) despite of the low-complexity decoding with small memory.

I. INTRODUCTION

In current and evolving mobile cellular communication systems, the use of MIMO transmission technology is becoming more widespread. MIMO systems increase capacity by transmitting multiple data symbols over several antennas simultaneously, in a technique usually termed Spatial Multiplexing (SM). SM is a transmission technique in MIMO to transmit different data signals, so called streams, from each of the multiple transmission antennas. A MIMO receiver can use advanced signal processing and the properties of the channel to separate out and decode the individual symbols. A technique to improve reliability is termed Space Time Block Coding (STBC), in which a MIMO system transmits copies of the data symbols from multiple antennas. The IEEE 802.16e standard [1], upon which WiMAX is based, employs both SM and STBC techniques. In addition to MIMO, these newer standards also make use of Hybrid Automatic Repeat request (HARQ). Currently, two types of HARQ are widely used: (i) repetition coding[2]; (ii) incremental redundancy coding. Both HARQ schemes have drawbacks. Incremental-redundancy methods require more complicated decoders, while repetition coding shows poor performance when applied to spatial-multiplexing systems. This is due to the self-interference between spatial streams, and the absence of diversity in time-invariant channels. In this paper, we propose an alternative that offers a simple decoding scheme as well as excellent performance in MIMO systems. Our scheme is a combination of HARQ with a sort of STBC. The retransmitted signal is a space-time encoded version of the original signal that allows elimination of self-interference through simple linear receivers and (for some of the proposed schemes) offers enhanced diversity as well. The idea of combining HARQ with space-time codes was treated for convolutional codes in [3], and Tarokh [8] introduced an HARQ scheme for 2x2 MIMO systems based on Alamouti STBC codes that gives diversity benefits as well as self-interference cancellation. This scheme was adopted on the IEEE802.16e standard [1]. In this paper, we compare the SICC-based approach to [1]; we also give generalizations to larger MIMO arrays and show how the SICC approach can be combined with STBCs. The remainder of the paper is organized as follows: Section II presents the system model. Our new scheme is described for 2x2 MIMO in Section III; we detail various encoding matrices that can be used with our scheme. Generalizations to larger MIMO systems are presented in Sec. IV, a low-complexity decoding scheme with small memory is introduced in Sec. V, followed by simulation results and conclusions.

II. MIMO WITH SPATIAL MULTIPLEXING AND HARQ

A. MIMO-OFDM with Spatial Multiplexing

Figure 1 shows a block diagram of a MIMO-OFDM transmitter with 2 transmit antennas. The exact nature of the space-time encoder determines the type of MIMO transmission. In the case of spatial multiplexing (SM), different bits are mapped onto the two transmit antennas, thus increasing the spectral efficiency. For example, in the case of vertical encoding, two consecutive symbols S_1 and S_2 are transmitted during one channel use, since S_1 is transmitted on antenna 1 and S_2 is transmitted on antenna 2. A receiver of the signal typically needs to have the same or more receive antennas to enable the separation and decoding of the symbols. Many receiver types have been developed in the literature, including the optimal Maximum Likelihood detector (MLD) as well as suboptimal receivers such as the Minimum Mean Square Error (MMSE)[5].

Let us next compute the received signal. The MIMO channel seen by each of the OFDM subcarriers is denoted as a 2x2 matrix $\mathbf{H} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix}$, where the element $h_{i,j}$ is the channel gain from the j^{th} transmit antenna to the i^{th} receive antenna as shown in Figure 2. We can write the received signal at the two antennas as $\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} +$

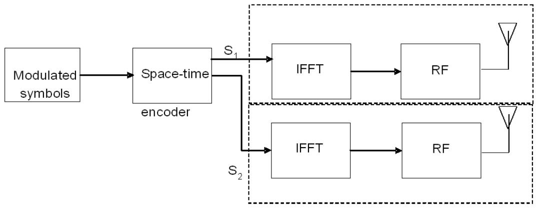

Fig. 1. General MIMO OFDM transmitter

$\begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$, which is equivalent, in matrix notation, to $\mathbf{R} = \mathbf{HS} + \mathbf{n}$, where $\mathbf{n}$ is an independent identically distributed(iid) Gaussian noise vector and $\mathbf{S}$ is the vector of transmitted signals. Under normal operation, the receiver operates on the vector $\mathbf{R}$ to estimate the transmitted vector $\mathbf{S}$. It is assumed the receiver also has knowledge of the channel matrix $\mathbf{H}$, which aides in the estimation of S and can implement decoding schemes such as MMSE. We see that the terms $h_{1,2}s_2$ and $h_{2,1}s_1$ are the interference terms at receive antenna 1 from transmit antenna 2 and receive antenna 2 from transmit antenna 1 respectively. This type of interference is typically called self-interference, since it is due to the transmission of multiple streams from multiple antennas.

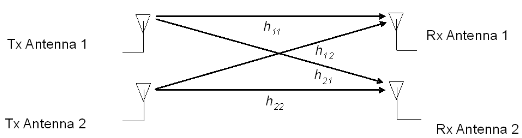

Fig. 2. General MIMO OFDM transmitter

B. Chase combining in MIMO-OFDM systems

Even with appropriate forward error correction coding and adaptive modulation, not all data packets arrive at the receiver error-free. The receiver can find out whether decoding failed, e.g., from CRC (cyclic redundancy check) bits. In any case, if the decoding fails, the receiver can initiate an HARQ procedure, in which the receiver retains a copy of $\mathbf{R}$ and sends retransmission request. In conventional CC, the transmitter then sends an exact duplicate of the vector $\mathbf{S}$. We denote the two successive transmissions as $\left[\mathbf{S}^{(1)}\ \mathbf{S}^{(2)}\right]$ where $\mathbf{S}^{(1)} = \mathbf{S}^{(2)}$ After reception of the retransmission, the receiver has two copies of the signals $\mathbf{R}^{(1)}, \mathbf{R}^{(2)}$. These can be expressed as $\begin{bmatrix} \mathbf{R}^{(1)} & \mathbf{R}^{(1)} \end{bmatrix} = \begin{bmatrix} r_1^{(1)} & r_1^{(2)} \\ r_2^{(1)} & r_2^{(2)} \end{bmatrix} = \begin{bmatrix} h_{1,1}s_1 + h_{1,2}s_2 + n_1^{(1)} & h_{1,1}s_1 + h_{1,2}s_2 + n_1^{(2)} \\ h_{2,1}s_1 + h_{2,2}s_2 + n_2^{(1)} & h_{2,1}s_1 + h_{2,2}s_2 + n_2^{(2)} \end{bmatrix}$, where the term $r_j^{(i)}$, represents the signal at the j^{th} antenna element due to the i^{th} transmission, and $n_j^{(i)}$ is the noise at the j^{th} antenna element associated with the i^{th} transmission. It should be noted that $n_j^{(i)}, \{j = 1, 2, i = 1, 2\}$ are all iid Gaussian with variance σ^2. The receiver now has two copies of the data which can be combined so as to improve the decoding probability. One common way to combine $R^{(1)}$ and $R^{(2)}$ is to simply average the two vectors to obtain $\mathbf{R}' = \left(\mathbf{R^{(1)}} + \mathbf{R^{(2)}}\right)/2$.

This operation has the effect of reducing the noise variance/power by a factor of two and will aid in decoding. However, the self-interference discussed in Sec. II.A is not improved by this procedure. An analysis of the SINR for a spatial multiplexing MIMO-OFDM system using an MMSE receiver and CC is found in [6].

III. HARQ WITH SICC FOR $2X2$ MIMO

Our proposed coding schemes that can be used to eliminate the self-interference after an HARQ transmission is one which we term Self-Interference Cancellation Coding (SICC). This is based on Hadamard matrix as one example and is simple to implement.

We again consider a 2x2 system and denote $\mathbf{S} = [S_1\ S_2]^T$ as a vector of signals transmitted from the two antennas. Once again after the reception of the signal $\mathbf{R} = \mathbf{HS} + \mathbf{n}$, and a decoding failure, the HARQ process is initiated and a request for a retransmission is sent to the transmitter. However, the retransmission occurs in a slightly different form, which enables easy cancellation of the self-interference. In the scheme discussed here, the receiver has at least 2 antennas, and often can decode the signal from the 1st transmission alone; the 2nd transmission is sent only if required.

The retransmission is of the form $\mathbf{S}^{(1)} = \begin{bmatrix} S_1 & S_2 \end{bmatrix}^T$, $\mathbf{S}^{(2)} = \begin{bmatrix} S_1 & -S_2 \end{bmatrix}^T$, where in this case the signal transmitted from the second antenna is simply sent with a negative sign. At receiver, the signals for the original transmission along with the HARQ retransmission can be expressed as $\mathbf{R}^{(1,2)} = \mathbf{H}\begin{bmatrix} \mathbf{S}^{(1)} & \mathbf{S}^{(2)} \end{bmatrix}^T + \mathbf{n}^{(1,2)} = \begin{bmatrix} h_{1,1}S_1 + h_{1,2}S_2 & h_{1,1}(S_1) - h_{1,2}(S_2) \\ h_{2,1}S_1 + h_{2,2}S_2 & h_{2,1}(S_1) - h_{2,2}(S_2) \end{bmatrix} + \mathbf{n}^{(1,2)}$.

The linear combining scheme for SICC begins with the multiplication of the received matrix $\mathbf{R}^{(1,2)}$ by a 2×2 Hadamard matrix yielding $\mathbf{R}^{(1,2)'} = \mathbf{R}^{(1,2)} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} = 2\begin{bmatrix} h_{11}S_1 & h_{12}S_2 \\ h_{21}S_1 & h_{22}S_2 \end{bmatrix} + \tilde{\mathbf{n}}$, where $\tilde{\mathbf{n}}$ is again an iid Gaussian matrix whose entries have twice the variance of the entries of $\mathbf{n}^{(1,2)}$. Thus we see that the signal component of the matrix, $\mathbf{R}^{(1,2)'}$, contains two columns were the first column depends only on the signal S_1 and the second column depends only on the signal S_2. We can combine the signals by multiplying the first column of $\mathbf{R}^{(1,2)'}$ by the vector $h^{(1)} = [h_{11}^* h_{21}^*]^T$ and the second column of $\mathbf{R}^{(1,2)'}$ by the vector $h^{(2)} = [h_{12}^* h_{22}^*]^T$. This yields

$$\begin{aligned} &2h_{1,1}S_1h_{1,1}^* + 2h_{2,1}S_1h_{2,1}^* + \mathbf{n'}_1 \\ &= 2(|h_{1,1}|^2 + |h_{2,1}|^2) \cdot S_1 + \mathbf{n'}_1 \\ &2h_{1,2}S_2h_{1,2}^* + 2h_{2,2}S_2h_{2,2}^* + \mathbf{n'}_2 \\ &= 2(|h_{1,2}|^2 + |h_{2,2}|^2) \cdot S_2 + \mathbf{n'}_2 \end{aligned} \tag{1}$$

where $\mathbf{n'}_1 = \tilde{\mathbf{n}}\mathbf{h}^{(1)}$ and $\mathbf{n'}_2 = \tilde{\mathbf{n}}\mathbf{h}^{(2)}$.

Thus we see that the SICC linear combining yields signals where the self-interference has been eliminated. This

Hadamard matrix type SICC can be applied for MIMO systems.

IV. SICC FOR GROUPING STC 2^kX2^k MIMO

By combining the SICC and Alamouti STBC schemes we can achieve new MIMO space-time codes that achieve the elimination of self-interference for larger MIMO arrays with high rate. In the following discussion we assume $2^k,\ k \in \mathcal{N}$ transmit antennas and 2^k receive antennas. We combine the 2x2 Alamouti STC coding along with the SICC coding to transmit the sequence of vectors $\mathbf{S} = \mathbf{W}_{2^k} \otimes \mathbf{A}_{2^k \times 2^k}$, where $\otimes$ denotes the Kronecker product, $\mathbf{W}_{2^k}$ is a Hadamard matrix of order 2^k such as

$$\mathbf{W}_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix},$$
$$\mathbf{W}_{2^k} = \begin{bmatrix} \mathbf{W}_{2^{k-1}} & \mathbf{W}_{2^{k-1}} \\ \mathbf{W}_{2^{k-1}} & -\mathbf{W}_{2^{k-1}} \end{bmatrix} = \mathbf{W}_2 \otimes \mathbf{W}_{2^k-1},$$

and $\mathbf{A}_{2^k \times 2^k}$ is $2^k \times 2^k$ Alamouti codes matrix such as

$$\mathbf{A}_{2^k \times 2^k} = \begin{bmatrix} A_1 & A_1 & \cdots & A_1 \\ A_2 & A_2 & \cdots & A_2 \\ \vdots & \vdots & \ddots & \vdots \\ A_{2^k} & A_{2^k} & \cdots & A_{2^k} \end{bmatrix},$$
$$A_i = \begin{bmatrix} S_{2(i-1)+1} & -S^*_{2(i-1)+2} \\ S_{2(i-1)+2} & S^*_{2(i-1)+1} \end{bmatrix}, i \in \mathcal{N}.$$

For example, for $2^k = 4$ transmit antennas, the symbols are defined as,

$$\mathbf{S} = \begin{bmatrix} S_1 & -S_2^* & S_1 & -S_2^* \\ S_2 & S_1^* & S_2 & S_1^* \\ S_3 & -S_4^* & -S_3 & S_4^* \\ S_4 & S_3^* & -S_4 & -S_3^* \end{bmatrix}. \qquad (2)$$

Here each column of $\mathbf{S}$ represents the symbols transmitted at each transmission/retransmission interval. The structure of the first 2 columns of $\mathbf{S}$ can be seen an Alamouti code on the symbols S_1 and S_2 transmitted on antennas Tx1 and Tx2, while a second Alamouti code on symbols S_3 and S_4 transmitted on antennas Tx3 and Tx4. The next two columns repeat the Alamouti code however the symbols on antennas Tx3 and Tx4 have been negated. The advantage of this scheme is that after the transmission of the symbols in (2) a simple linear combining scheme can be employed at the receiver to eliminate the self-interference. At the receiver, the signal $\mathbf{R} = \mathbf{HS} + \mathbf{n}$ where $\mathbf{R}$ is a 4x4 matrix is received.

For S_1 , the receiver could combine the symbols from each antenna as ,

$$\begin{aligned}
&\begin{bmatrix} r_{1,1} & r^*_{1,2} & r_{1,3} & r^*_{1,4} \end{bmatrix} \begin{bmatrix} h^*_{1,1} & h_{1,2} & h^*_{1,1} & h_{1,2} \end{bmatrix}^T \\
&+ \begin{bmatrix} r_{2,1} & r^*_{2,2} & r_{2,3} & r^*_{2,4} \end{bmatrix} \begin{bmatrix} h^*_{2,1} & h_{2,2} & h^*_{2,1} & h_{2,2} \end{bmatrix}^T \\
&+ \begin{bmatrix} r_{3,1} & r^*_{3,2} & r_{3,3} & r^*_{3,4} \end{bmatrix} \begin{bmatrix} h^*_{3,1} & h_{3,2} & h^*_{3,1} & h_{3,2} \end{bmatrix}^T \\
&+ \begin{bmatrix} r_{4,1} & r^*_{4,2} & r_{4,3} & r^*_{4,4} \end{bmatrix} \begin{bmatrix} h^*_{4,1} & h_{4,2} & h^*_{4,1} & h_{4,2} \end{bmatrix}^T \\
&= 2\Big(|h_{1,1}|^2 + |h_{1,2}|^2 + |h_{2,1}|^2 + |h_{2,2}|^2 \\
&+ |h_{3,1}|^2 + |h_{3,2}|^2 + |h_{4,1}|^2 + |h_{4,2}|^2\Big) S_1 + n'_1,
\end{aligned} \qquad (3)$$

similarly, for S_2, S_3 and S_4, we obtain

$$\begin{aligned}
&2\Big(|h_{1,1}|^2 + |h_{1,2}|^2 + |h_{2,1}|^2 + |h_{2,2}|^2 \\
&+ |h_{3,1}|^2 + |h_{3,2}|^2 + |h_{4,1}|^2 + |h_{4,2}|^2\Big) S_2 + n'_2, \\
&2\Big(|h_{1,3}|^2 + |h_{1,4}|^2 + |h_{2,3}|^2 + |h_{2,4}|^2 \\
&+ |h_{3,3}|^2 + |h_{3,4}|^2 + |h_{4,3}|^2 + |h_{4,4}|^2\Big) S_3 + n'_3, \\
&2\Big(|h_{1,3}|^2 + |h_{1,4}|^2 + |h_{2,3}|^2 + |h_{2,4}|^2 \\
&+ |h_{3,3}|^2 + |h_{3,4}|^2 + |h_{4,3}|^2 + |h_{4,4}|^2\Big) S_4 + n'_4.
\end{aligned} \qquad (4)$$

As we can see, the linear combining yields 4 symbols that contain no self-interference terms and thus simple detection schemes can be applied to estimate the transmitted symbols. On the other hand, the conventional STBC scheme in the IEEE 802.16e standard [1] uses the following retransmission matrix

$$\mathbf{S} = \begin{bmatrix} S_1 & -S_2^* & S_1 & -S_2^* \\ S_2 & S_1^* & S_2 & S_1^* \\ S_3 & -S_4^* & S_3 & -S_4^* \\ S_4 & S_3^* & S_4 & S_3^* \end{bmatrix}. \qquad (5)$$

If the same linear combining scheme for (5) is used as the equ.(3) and (4), the following decision statistics can be obtained:

$$\begin{aligned}
&2\Big(|h_{1,1}|^2 + |h_{1,2}|^2 + |h_{2,1}|^2 + |h_{2,2}|^2 \\
&+ |h_{3,1}|^2 + |h_{3,2}|^2 + |h_{4,1}|^2 + |h_{4,2}|^2\Big) S_1 + I_3 + I_4 + n'_1, \\
&2\Big(|h_{1,1}|^2 + |h_{1,2}|^2 + |h_{2,1}|^2 + |h_{2,2}|^2 \\
&+ |h_{3,1}|^2 + |h_{3,2}|^2 + |h_{4,1}|^2 + |h_{4,2}|^2\Big) S_2 + I_3 + I_4 + n'_2, \\
&2\Big(|h_{1,3}|^2 + |h_{1,4}|^2 + |h_{2,3}|^2 + |h_{2,4}|^2 \\
&+ |h_{3,3}|^2 + |h_{3,4}|^2 + |h_{4,3}|^2 + |h_{4,4}|^2\Big) S_3 + I_1 + I_2 + n'_3, \\
&2\Big(|h_{1,3}|^2 + |h_{1,4}|^2 + |h_{2,3}|^2 + |h_{2,4}|^2 \\
&+ |h_{3,3}|^2 + |h_{3,4}|^2 + |h_{4,3}|^2 + |h_{4,4}|^2\Big) S_4 + I_1 + I_2 + n'_4.
\end{aligned}$$

where I_i is the interference from the ith transmit antenna. Therefore, the detector based on MRC for the transmission matrix (5) cause the performance degradation due to the self-interference.

V. DECODING SCHEME WITH SMALL MEMORY

As we see the MRC decoding algorithm as eqs. (3) and (4) in the previous section, however, MRC needs large memory to store the channel matrices for all transmission/retransmission. In order to resolve such problem, we consider the MMSE + linear combining(LC) scheme. Let $\hat{\mathbf{S}}^{(l)}$ be an estimated symbol vector at l-th reception. MMSE decoder calculates the estimated symbols as

$$\begin{aligned}
\hat{\mathbf{S}}^{(l)} &= \left(\mathbf{H}^{(l)H}\mathbf{H}^{(l)} + \sigma^2 I\right)^{-1} \mathbf{H}^{(l)H} \cdot \mathbf{r}^{(l)} \\
&= \left(\mathbf{H}^{(l)H}\mathbf{H}^{(l)} + \sigma^2 I\right)^{-1} \mathbf{H}^{(l)H} \cdot \left(\mathbf{H}^{(l)} \cdot \mathbf{S}^{(l)} + \tilde{\mathbf{n}}^{(l)}\right).
\end{aligned} \qquad (6)$$

where $\mathbf{H}^{(l)}$ is channel matrix at l-th reception and $\tilde{\mathbf{n}}^{(l)}$ is the noise at the l-th transmission.

Next, after simple converting as $\hat{S}_i^{(l)*} \rightarrow \hat{S}_i^{(l)}$ or $-\hat{S}_i^{(l)*} \rightarrow \hat{S}_i^{(l)}$, the linear combining is used as $\bar{S}_i = \frac{1}{L}\sum_{l=1}^{L}\hat{S}_i^{(l)}$, where L is the number of total transmission, $\bar{S}_i$ is an estimated symbol for i-th transmit antenna after L reception and $\hat{S}_i^{(l)}$ an estimated symbol for i-th transmit antenna at l-th reception.

Individual symbol estimates can be obtained after MMSE decoding at each reception. So the linear combining could be done with less memory, because it is not necessary to store the channel matrix $\mathbf{H}^{(l)}$ after $\mathbf{S}^{(l)}$ is derived at l-th reception.

For example, for 4 transmit antennas and 4 successive transmission based eqs.(6), the estimated symbol vectors are

$$\begin{aligned}
\hat{\mathbf{S}}^{(1)} &= \left[\begin{array}{cccc} \hat{S}_1^{(1)} & \hat{S}_2^{(1)} & \hat{S}_3^{(1)} & \hat{S}_4^{(1)} \end{array}\right], \\
\hat{\mathbf{S}}^{(2)} &= \left[\begin{array}{cccc} -\hat{S}_2^{(2)*} & \hat{S}_1^{(2)*} & -\hat{S}_4^{(2)*} & \hat{S}_3^{(2)*} \end{array}\right], \\
\hat{\mathbf{S}}^{(3)} &= \left[\begin{array}{cccc} \hat{S}_1^{(3)} & \hat{S}_2^{(3)} & -\hat{S}_3^{(3)} & -\hat{S}_4^{(3)} \end{array}\right], \\
\hat{\mathbf{S}}^{(4)} &= \left[\begin{array}{cccc} -\hat{S}_2^{(4)*} & \hat{S}_1^{(4)*} & \hat{S}_4^{(4)*} & -\hat{S}_3^{(4)*} \end{array}\right].
\end{aligned}$$

The linear combining yields as

$$\begin{aligned}
\bar{S}_1 &= \left(\hat{S}_1^{(1)} + \left(\hat{S}_1^{(2)*}\right)^* + \hat{S}_1^{(3)} + \left(\hat{S}_1^{(4)*}\right)^*\right)\Big/4, \\
\bar{S}_2 &= \left(\hat{S}_2^{(1)} - \left(-\hat{S}_2^{(2)*}\right)^* + \hat{S}_2^{(3)} - \left(-\hat{S}_2^{(4)*}\right)^*\right)\Big/4, \\
\bar{S}_3 &= \left(\hat{S}_3^{(1)} + \left(\hat{S}_3^{(2)*}\right)^* - \left(-\hat{S}_3^{(3)}\right) - \left(-\hat{S}_3^{(4)*}\right)^*\right)\Big/4, \\
\bar{S}_4 &= \left(\hat{S}_4^{(1)} - \left(-\hat{S}_4^{(2)*}\right)^* - \left(-\hat{S}_4^{(3)}\right) + \left(\hat{S}_4^{(4)*}\right)^*\right)\Big/4.
\end{aligned}$$

In the case of MMSE + LC on a static channel, the self-interference can be eliminated same as MRC.

$$\begin{aligned}
&\bar{S}_1 = \left(\hat{S}_1^{(1)} + \left(\hat{S}_1^{(2)*}\right)^* + \hat{S}_1^{(3)} + \left(\hat{S}_1^{(4)*}\right)^*\right)\Big/4 \\
&= \left\{4\left(\mathbf{H}^H\mathbf{H} + \sigma^2 I\right)\right\}^{-1}\left\{2\left(|h_{1,1}|^2 + |h_{1,2}|^2 + |h_{2,1}|^2 + |h_{2,2}|^2\right.\right. \\
&\left.\left. + |h_{3,1}|^2 + |h_{3,2}|^2 + |h_{4,1}|^2 + |h_{4,2}|^2\right)S_1 + \mathbf{H}^H n_1'\right\},
\end{aligned}$$

where $\mathbf{H} = \mathbf{H}^{(l)}$ due to the static channel.
However, the conventional STBC with MMSE + LC can not eliminate the self-interference same as MRC.

VI. Simulation Results

This section evaluates the error rate performance of SICC in comparison with CC and the conventional STBC. The simulation parameters are shown in the table I, where CTC denotes Convolutional Turbo Code and SM denotes Spartial Multiplexing.

TABLE I
Simulation parameters.

Parameters	Assumption
Bandwidth	10MHz
Number of subcarrier	1024
Frame length	5ms
Channel estimation	Perfect
Channel code	CTC 1/2
Codeword length	480bits
MIMO configuration	4x4 SM
Resource allocation	Distributed resource allocation
Retransmission latency	10ms

Figure 3 and Figure 4 show the simulation results of SICC vs. CC with QPSK, MMSE + LC, the mobile velocity 0 Km/h and 120 Km/h, respectively. Figure 5 and Figure 6 show the simulation results of SICC vs. conventional STBC with QPSK, MMSE + LC, the mobile velocity 0 Km/h and 120 Km/h, respectively. Figure 7 shows the simulation results of MMSE + LC vs. MRC with QPSK, the mobile velocity 0 Km/h.

Figure 3 shows that the proposed strategy SICC has a gain over CC of about 3dB, 3dB and 2.6dB (@BLER=10-2) at the 2nd, 3rd and 4th retransmission, respectively, on the static channel as the mobile velocity 0Km/h. In Figure 4, for the high mobility as the velocity 120Km/h, the proposed strategy SICC has a gain over CC of about 0.2dB, 0.5dB and 0.4dB (@BLER=10-2) at the 2nd, 3rd and 4th retransmission, respectively. The channel coefficients are changed at each transmission due to the mobility, so the higher the mobile velocity is, the closer to the performance of CC that of SICC is, under the condition of MMSE + LC.

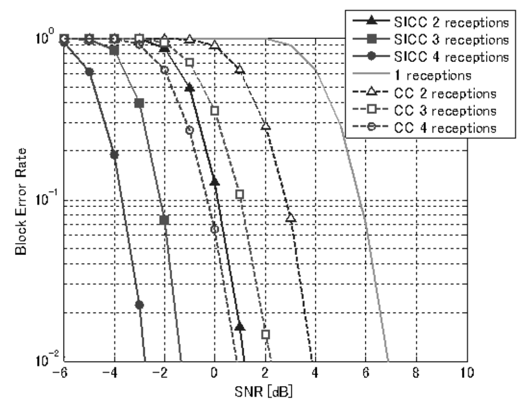

Fig. 3. Performance comparison for SICC vs. CC with QPSK, MMSE + LC, 0 Km/h.

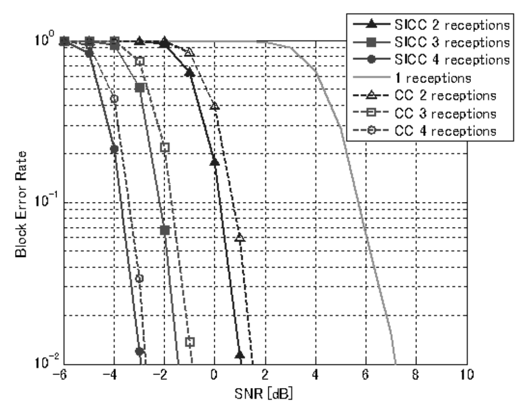

Fig. 4. Performance comparison for SICC vs. CC with QPSK, MMSE + LC, 120 Km/h.

Next, in Figure 5 and Figure 6, we compare its performance to the STBC scheme used in the IEEE 802.16e standard [1], which uses the transmission matrix (5) for 0km/h and 120km/h. As we can see in Figure 5, the both SICC and

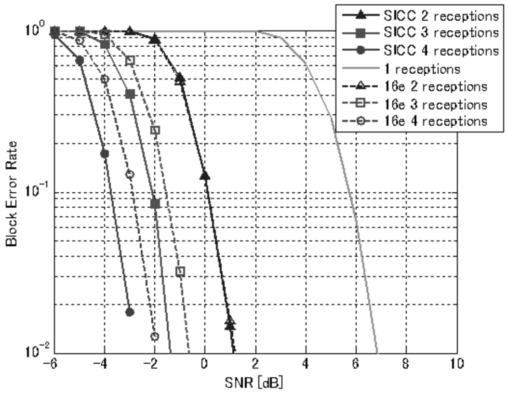

Fig. 5. Performance comparison for SICC vs. conventional STBC(16e) with QPSK, MMSE + LC, 0 Km/h.

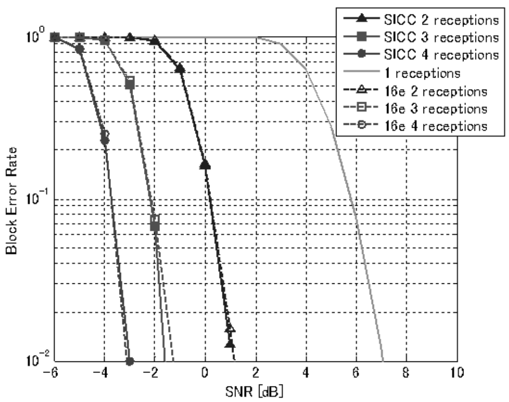

Fig. 6. Performance comparison for SICC vs. conventional STBC(16e) with QPSK, MMSE + LC, 120 Km/h.

conventional STBC performance are same at the 2nd retransmission due to the same transmitted signal vectors for the both schemes, however, the SICC scheme outperforms the conventional STBC scheme by about 0.6dB to 0.8dB at 3rd and 4th retransmission due to cancellation of self-interference for 0Km/h. However, for the velocity 120Km/h, the both SICC and conventional STBC performance are almost same at all retransmission, because the correlation between H's for each retransmission are very weak.

For MRC, as we can see in Figure 7, SICC can get the ideal performance after 4th retransmission. It should be noted that MMSE + LC can achieve the same performance to MRC after 4th retransmission. Furthermore, MMSE + LC can provide better performance than MRC at 2nd and 3rd retransmission. Therefore, we regard MMSE + LC scheme for SICC as enough feasible.

VII. CONCLUSIONS

In this paper, a new HARQ method using SICC is presented, which extends and generalizes the ingenious scheme of Tarokh [8]. When using HARQ in a MIMO system, this new method uses Hadamard matrix to generate retransmission packets and performs a combining and cancellation using all the received symbols. A combining SICC and Alamouti code scheme is

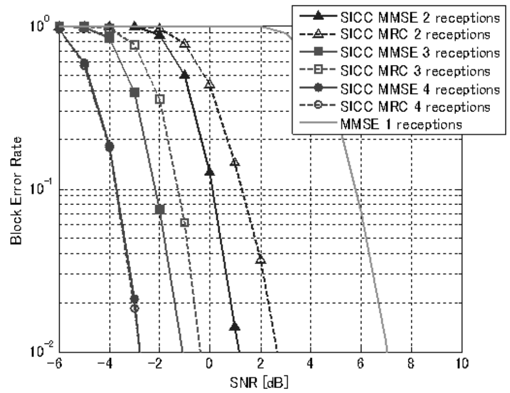

Fig. 7. Performance comparison for MMSE + LC vs. MRC with QPSK, 0 Km/h.

proposed to provide new MIMO space-time codes that achieve the elimination of self-interference for a $2^k \times 2^k$ case. The proposed method has high gains over CC HARQ schemes under static and low-mobility channel. It should be noted that SICC can provide the same performance as conventional STBC scheme even under high-mobility channel. Furthermore we introduce MMSE + LC decoding for SICC which can achieve good performance despite of small memory.

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