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***Abstract*—The paper provides a method for combining HARQ along with Self-Interference Cancellation Coding (SICC), so that the reliability of spatial multiplexing MIMO transmissions can be improved. The simulation results show that significant gain is achieved over the traditional Chase Combing.**

Keywords - MIMO, HARQ , Self Interference Cancellation

I. INTRODUCTION

In current and evolving mobile cellular communication systems, the use of MIMO transmission technology is becoming more widespread. The Worldwide Interoperability for Microwave Access (WiMAX) forum as well as 3rd Generation Partnership Project (3GPP) have released standard specifications that make use of MIMO and continue to enhance the technology to improve transmission capacity and reliability. 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 802.16 standard "*Part 16: Air interface for Broadband Wireless Access Systems*" 802.16[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). As in traditional Automatic Repeat request (ARQ), a receiver requests a retransmission of a message that failed to be decoded correctly, but with HARQ rather than discarding the original (corrupted) message, the receive retains a copy and combines the original message [2],[3]. Currently, two types of HARQ are widely used: (i) repetition coding, i.e., the transmitter repeats exactly the same signals that were previously transmitted; the receiver adds up the received signals and achieves an improvement in the signal-to-noise ratio through noise averaging; (ii) incremental redundancy encoding, where the transmitter sends different parity-check bits during each retransmission. 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 the current 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 space-time block coding. 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 simplest form of our method occurs in a 2x2 MIMO scheme: during a first transmission, we just transmit two symbols from the two TX antennas. If an HARQ transmission is necessary, we transmit the same symbol from antenna 1, but the 180 degree phase shifted symbol from antenna 2. Thus, when the receiver adds up the signals of the first and second transmission, the contribution of symbol 2 cancels out (and similarly, the contribution of symbol 1 can be eliminated by subtracting the signals). The simulation results show significant gain is achieved over the traditional Chase Combining

The idea of combining HARQ with space-time codes was treated for convolutional codes in [4], and for turbo codes in [5], though none of those papers discusses space-time block codes. Tarokh [11] 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 [11]; 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, 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 transmitter consists of a source of modulated data symbols, a space-time encoder, and two OFDM chains that consist of an OFDM modulator that performs an IFFT on the input data and then filters, amplifies and upconverts the time domain signal to the pass-band in the RF block. 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 as well as suboptimal receivers such as the Minimum Mean Square Error (MMSE) and Zero Forcing (ZF) receivers [6].

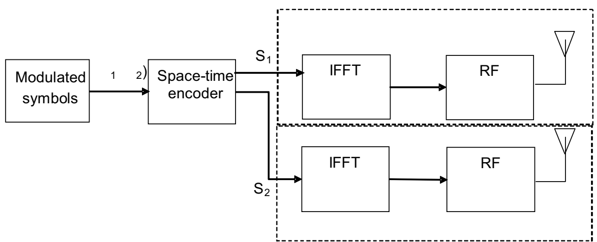

Figure1: General MIMO OFDM transmitter

Let us next compute the received signal. The MIMO channel seen by each of the OFDM subcarriers is denoted as a 2x2 matrix

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix}, \quad (1)$$

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

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

(2)

which is equivalent, in matrix notation, to **R** = **HS**+**n,** where **n** is an additive white Gaussian noise vector and **S** is the vector of transmitted signals.

Under normal operation, the receiver operates on the vector **R** to estimate the transmitted vector **S.** It is assumed the receiver also has knowledge of the channel coefficients **H**, which aides in the estimation of **S** and can implement decoding schemes such as Minimum Mean Squared Error (MMSE) or Zero Forcing (ZF) to estimate.

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.

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 coding failed, e.g., from CRC (cyclic redundancy check) bits or from the consistency messages passed in an LDPC (low-density parity check) decoder. In any case, if the decoding fails, the receiver can initiate an HARQ procedure, in which the receiver retains a copy of **R** and sends retransmission request. In conventional chase-combining, the transmitter then sends an exact duplicate of the vector **S**.

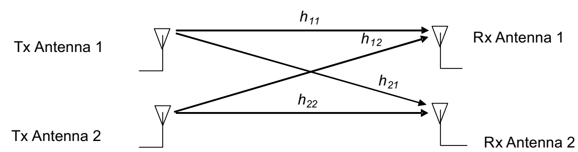

Fig 2. MIMO channel model

We denote the two successive transmissions as $[\mathbf{S}^{(1)} \ \ \mathbf{S}^{(2)}]$ 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

$$\begin{bmatrix} r_1^{(1)} & r_1^{(2)} \\ r_2^{(1)} & r_2^{(2)} \end{bmatrix} = \begin{bmatrix} h_{1,1}s_1 + h_{1,2}s_2 + n_1^{(1)} & h_{1,1}s_1 + h_{1,2}s_2 + n_1^{(2)} \\ h_{2,1}s_1 + h_{2,2}s_2 + n_2^{(1)} & h_{2,1}s_1 + h_{2,2}s_2 + n_2^{(2)} \end{bmatrix} \quad (4)$$

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 independent identically distributed 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 $\mathbf{R}^{(1)}$ and $\mathbf{R}^{(2)}$ is to simply average the two vectors to obtain

$$\mathbf{R}' = \frac{\mathbf{R}^{(1)} + \mathbf{R}^{(2)}}{2} \quad (5)$$

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 chase combining is found in [7].

III. HARQ WITH SICC FOR 2X2 MIMO

Our proposed coding scheme 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 matrices, Discrete Fourier Transform, or Alamouti coding and is simple to implement. We again consider a 2x2 system and denote $S = [S_1\ S_2]^T$ 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.

We stress that there is a key difference between the above-mentioned scheme and the conventional STBC scheme. In a conventional STC, the transmitter *always* sends the 1st and 2nd transmissions, and any receiver (single-antenna or multiple-antenna) can decode the received signal. 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.

A. Hadamard matrix type

The retransmission is of the form:

$$\mathbf{S}^{(2)} = \begin{bmatrix} S_1 \\ -S_2 \end{bmatrix}. \tag{7}$$

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

$$\begin{aligned}\mathbf{R}^{(1,2)} &= \mathbf{H}\left[\mathbf{S}^{(1)} \quad \mathbf{S}^{(2)}\right] + \mathbf{n}^{(1,2)} \\ &= \begin{bmatrix} h_{1,1}S_1 + h_{1,2}S_2 & h_{1,1}(S_1) - h_{1,2}(S_2) \\ h_{2,1}S_1 - h_{2,2}S_2 & h_{2,1}(S_1) - h_{2,2}(S_2) \end{bmatrix} + \mathbf{n}^{(1,2)}\end{aligned} \tag{9}$$

The combining scheme for SICC begins with the multiplication of the received matrix ($\mathbf{R}^{(1,2)}$) by a 2x2 Hadamard matrix yielding,

$$\mathbf{R}^{(1,2)'} = \mathbf{R}^{(1,2)}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} = 2\begin{bmatrix} h_{11}S_1 & h_{12}S_2 \\ h_{21}S_1 & h_{22}S_2 \end{bmatrix} + \tilde{\mathbf{n}} \tag{10}$$

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 $\mathbf{h}^{(1)} = [h_{11}^*\ h_{21}^*]^T$ and the second column of $\mathbf{R}^{(1,2)'}$ by the vector $\mathbf{h}^{(2)} = [h_{12}^*\ h_{22}^*]^T$. This yields

$$2h_{1,1}S_1h_{1,1}^* + 2h_{2,1}S_1h_{2,1}^* + \mathbf{n}_1' = 2(|h_{1,1}|^2 + |h_{2,1}|^2)\cdot S_1 + \mathbf{n}_1' \tag{11}$$

$$2h_{1,2}S_2h_{1,2}^* + 2h_{2,2}S_2h_{2,2}^* + \mathbf{n}_2' = 2(|h_{1,2}|^2 + |h_{2,2}|^2)\cdot S_2 + \mathbf{n}_2'$$

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 combining yields signals where the self interference has been eliminated. This Hadamard matrix type SICC can be applied for $2^m \times 2^m\ (m \in \mathbf{N})$ MIMO systems.

For the 2x2 case, if after the initial HARQ retransmission, $S^{(2)}$, the receiver still detects a decoding error on the signals S_1, and S_2 then the additional retransmission can be requested. Denoting $S^{(j)}$ as the jth HARQ transmission atthe receiver, we have

$$\mathbf{r}^{(1,2,\cdots)} = \mathbf{H}\left[\mathbf{S}^{(1)} \quad \mathbf{S}^{(2)}\,\mathbf{S}^{(3)} \quad \mathbf{S}^{(4)}\cdots\right] + \mathbf{n}^{(1,2\cdots)} \tag{12}$$

By applying the same scheme for SICC, we process the signals arriving at each antenna with a repeated Hadamard matrix

$$\mathbf{r}^{(1,2,\cdots)}\begin{bmatrix} 1 & 1\,1 & 1 & \cdots \\ 1 & -1\,1 & -1 & \end{bmatrix} \tag{13}$$

Within each Hadamard repetition, the received signals are combined according to the method described above; the results from those repeated matrices are then chase-combined. It is noteworthy that in a time-invariant channel, the repetitions of the Hadamdard matrix do not increase the diversity order, but just increase the SNR by 3 dB for each doubling of the number of repetitions.

B. Discrete Fourier Transform type

As a generalization of the SICC scheme, it is noted that we can also describe the SICC scheme using discrete Fourier transform matrices. The k-th transmission symbol at t-th transmission antenna is given by multiplying 1st transmission symbol by $e^{-j\frac{2\pi}{N_T}\cdot(t-1)\cdot(k-1)}$.

The 1st and 2nd transmissions are

$$\mathbf{S}^{(1)} = \begin{bmatrix} S_1\cdot e^{-j\frac{2\pi}{2}\cdot 0\cdot 0} \\ S_2\cdot e^{-j\frac{2\pi}{2}\cdot 1\cdot 0} \end{bmatrix} = \begin{bmatrix} S_1 \\ S_2 \end{bmatrix},\quad \mathbf{S}^{(2)} = \begin{bmatrix} S_1\cdot e^{-j\frac{2\pi}{2}\cdot 0\cdot 1} \\ S_2\cdot e^{-j\frac{2\pi}{2}\cdot 1\cdot 1} \end{bmatrix} = \begin{bmatrix} S_1 \\ -S_2 \end{bmatrix}, \tag{14}$$

and at receiver, the signals for the original transmission along with the HARQ retransmission can be expressed same as in Sec. III.A.

The combining scheme for SICC begins with the multiplication of the received matrix ($\mathbf{R}^{(1,2)}$) by a 2x2 Inverse Discrete Fourier Transform matrix such as $\frac{1}{N_T}e^{j\frac{2\pi}{N_T}\cdot a\cdot b}$ (for $a(0 \le a \le N_T)$-th row, $b(0 \le b \le N_R)$ th column)

This representation is useful for MIMO systems in which the number of transmit and receive antennas are greater than two, and it enables extensions of the SICC combining scheme to these systems. However, in order to completely remove self-interference square MIMO systems are required.

C. Alamouti coding type

We note that the SICC scheme is very similar to the Space Time Block Code (STBC) first presented by Alamouti [4]. which also completely eliminates self-inference between antennas. Essentially, if we encode the transmitted signals prior to transmission and use slightly more complex (as compared to simple chase combining) processing at the receiver, we effectively eliminate self interference and at the same time provide diversity benefits.

The 1st and 2nd transmissions are of the form:

$$\mathbf{S}^{(1)} = \begin{bmatrix} S_1 \\ S_2 \end{bmatrix}, \mathbf{S}^{(2)} = \begin{bmatrix} -(S_2)^* \\ (S_1)^* \end{bmatrix} \qquad (15)$$

The combining at the receiver is done as for standard Alamouti-decoders [8], after which the receiver then attempts to detect the transmitted signal **S.** Since the combined signal no longer contains self interference the probability of correct detection increases. This scheme was proposed by Tarokh [11] and adopted into the Wimax specifications [1].

IV. SICC for Grouping STC 4x4 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 4 transmit antennas and 4 receive antennas.

We combine the 2x2 Alamouti STC coding along with the SICC coding to transmit the following sequence of vectors

$$\mathbf{S} = \begin{bmatrix} S_1 & -S_2^* & S_1 & -S_2^* \\ S_2 & S_1^* & S_2 & S_1^* \\ S_3 & -S_4^* & -S_3 & S_4^* \\ S_4 & S_3^* & -S_4 & -S_3^* \end{bmatrix}. \qquad (15)$$

Here each column of **S** represents the symbols transmitted at each transmission/retransmission interval. The structure of the first 2 columns of **S** can be seen to be an Alamouti type code on the symbols S_1 and S_2 transmitted on antennas 1 and 2, while a second Alamouti type code on symbols S_3 and S_4 transmitted on antennas 3 and 4. The next two columns repeat the Alamouti code however the symbols on antennas 3 and 4 have been negated. The advantage of this scheme is that after the transmission of the symbols in (15) a simple linear combining scheme can be employed at the receiver to eliminate the self interference.

At the receiver, the following signal is received,

$\mathbf{r} = \mathbf{HS} + \mathbf{n}$

where **r** is a 4x4 matrix.

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

$$\begin{bmatrix} r_{1,1} & r_{1,2}^* & r_{1,3} & r_{1,4}^* \end{bmatrix} \begin{bmatrix} h_{1,1}^* \\ h_{1,2} \\ h_{1,1}^* \\ h_{1,2} \end{bmatrix} + \begin{bmatrix} r_{2,1} & r_{2,2}^* & r_{2,3} & r_{2,4}^* \end{bmatrix} \begin{bmatrix} h_{2,1}^* \\ h_{2,2} \\ h_{2,1}^* \\ h_{2,2} \end{bmatrix}$$

$$+ \begin{bmatrix} r_{3,1} & r_{3,2}^* & r_{3,3} & r_{3,4}^* \end{bmatrix} \begin{bmatrix} h_{3,1}^* \\ h_{3,2} \\ h_{3,1}^* \\ h_{3,2} \end{bmatrix} + \begin{bmatrix} r_{4,1} & r_{4,2}^* & r_{4,3} & r_{4,4}^* \end{bmatrix} \begin{bmatrix} h_{4,1}^* \\ h_{4,2} \\ h_{4,1}^* \\ h_{4,2} \end{bmatrix}$$

$$= 2\left(|h_{1,1}|^2 + |h_{1,2}|^2 + |h_{2,1}|^2 + |h_{2,2}|^2 + |h_{3,1}|^2 + |h_{3,2}|^2 + |h_{4,1}|^2 + |h_{4,2}|^2\right)S_1 + n_1' \qquad (17)$$

similarly, for S_2, S_3 and S_4 we obtain

$$2\left(|h_{1,1}|^2 + |h_{1,2}|^2 + |h_{2,1}|^2 + |h_{2,2}|^2 + |h_{3,1}|^2 + |h_{3,2}|^2 + |h_{4,1}|^2 + |h_{4,2}|^2\right)S_2 + n_2',$$

$$2\left(|h_{1,3}|^2 + |h_{1,4}|^2 + |h_{2,3}|^2 + |h_{2,4}|^2 + |h_{3,3}|^2 + |h_{3,4}|^2 + |h_{4,3}|^2 + |h_{4,4}|^2\right)S_3 + n_3',$$

$$2\left(|h_{1,3}|^2 + |h_{1,4}|^2 + |h_{2,3}|^2 + |h_{2,4}|^2 + |h_{3,3}|^2 + |h_{3,4}|^2 + |h_{4,3}|^2 + |h_{4,4}|^2\right)S_4 + n_4'. \qquad (18)$$

As we can see the combining yields 4 symbols that contain no self-interference terms and thus simple detection schemes can be applied to estimate the transmitted symbols.

V. Simulation Results

This section evaluates the error rate performance at the 2nd transmission for both retransmission methods—the proposed HARQ with Hadamard type and Alamouti coding type method vs. the Chase Combining (repetition and averaging). We consider a 2x2 MIMO system similar to WiMAX [1] in which each antenna transmits an OFDM symbol consisting of 1024 subcarriers. The system is simulated over an WINNER "Urban micro-cell"[10] channel model with a mobile velocity of 0.5m/s. Modulation is assumed to be 16QAM on each subcarrier and the WiMAX rate ½ convolutional turbo coder is used to protect data. SM may be used under a low-mobility case, so we select "Urban micro-cell" in Winner channel model [10] with a mobile velocity 0.5m/s for the simulation.

Figure 3.1 shows that the proposed strategy SICC(Hadamard type and Alamouti coding type) has a gain over Chase Combining(repeat) of about 12dB and 13.5dB (@BLER=10^{-2}), respectively, at the second retransmission.

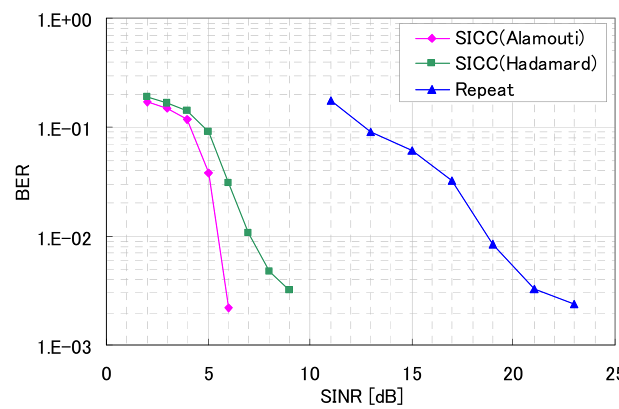

Figure 3.1 Performance comparison for the MIMO stream 1 in a 2x2 SM with "Urban micro-cell" with 0.5 m/s velocity and 16QAM at the 2nd transmission.

Next, for a 4x4 case, we simulate our HARQ scheme from Sec. IV using QPSK modulation over a Rayleigh fading channel. We compare its performance to the scheme used in the IEEE 802.16 standard [1], which uses the following retransmission matrix

$$\mathbf{S}=\begin{bmatrix} S_1 & -S_2^* & S_1 & -S_2^* \\ S_2 & S_1^* & S_2 & S_1^* \\ S_3 & -S_4^* & S_3 & -S_4^* \\ S_4 & S_3^* & S_4 & S_3^* \end{bmatrix}. \quad (19)$$

As we can see, the conventional scheme also employs Alamouti coding between antennas 1 and 2, but after that retransmits (without modifications). This is in contrast to our scheme that uses SICC for retransmissions 3 and 4, and thus is able to cancel self-interference between streams 1/2 on one hand, and streams 3/4 on the other hand.

For the simulation of the conventional STC coding scheme, it is assumed that received subpackets are chase combined and then a Zero-forcing MIMO receiver is employed after Alamouti combining. In this case, the first and third receptions are chase combined and the second and fourth receptions are chase combined. Alamouti decoding is then performed on the signals at the first and second antennas as well as on the third and fourth antennas. At this point a Zero-forcing receiver can be employed to finally recover the symbols. The bit error rates for the transmission schemes in equations (15) and (19) are shown in the Figure 4 and we see that the proposed SICC+STBC scheme outperforms the existing scheme [1] by about 2.5-3dB after 4 transmissions.

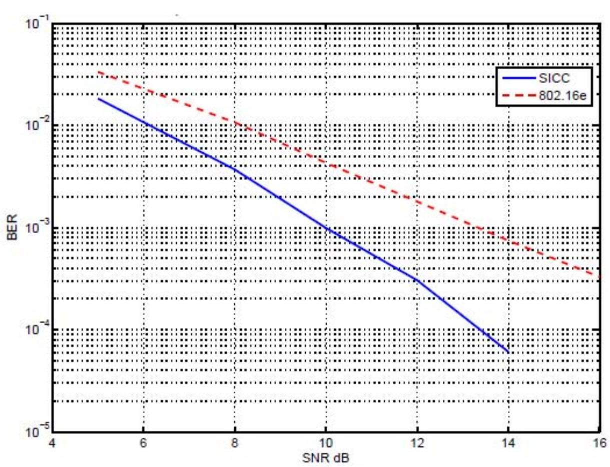

Figure 3.2 Performance comparison of 4x4 SICC+STBC scheme with 4x4 802.16e scheme.

VI. Conclusions

In this paper a new HARQ method using SICC is presented, which extends and generalizes the ingenious scheme of Tarokh [11]. When using HARQ in a MIMO system, this new method uses Hadamard matrices, Discrete Fourier Transform, and Alamouti coding to generate retransmission packets and performs a combining and cancellation using all the received symbols. The proposed method has significant gains over the conventional chase combining HARQ schemes. A tradeoff in performance and complexity of the different schemes is possible, as shown in the Table 1.

Table.1 Comparison table for HARQ schemes

	No coding	Hadamard	DFT	Alamouti
Performance (gain on Fig.3.1)	0dB (ref.)	13dB	13dB	14.5dB
Diversity order	0	2	2	4
Encoder complexity	No coding	addition of sign(+,-)	Same as Hadamard type for 2x2 MIMO.	Exchange symbols and complex conju -gation
Decoder complexity	(6)	(10)	(10) for 2x2.	see [8]
Remarks		number of antenna is power of 2.	No restriction for the number of antenna.	

Furthermore, a combining the SICC and STBC scheme is proposed to achieve new MIMO space-time codes that achieve the elimination of self interference for a 4x4 case. This proposed SICC+STBC scheme outperforms the existing scheme in section 8.4.8.6 of [1] by about 2.5-3dB over a Rayleigh fading channel.

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