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A CDD Based MIMO-HARQ Transmission Scheme

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Abstract — **This paper proposes a CDD based HARQ scheme for MIMO-OFDM systems, i.e. a signed operation is conjoint with CDD-HARQ to exploit both spatial and time diversity gains from symbol retransmission. Theoretical analysis and simulations verify its performance improvement over conventional Chase Combing HARQ in MIMO-OFDM systems. Another advantage of this operation is that since only a sign multiplying operation is added, the increase in complexity is minimal.**

Keywords — **CDD, MIMO-OFDM, HARQ, Chase Combine, MMSE**

I. Introduction

Cyclic delay diversity (CDD) is a simple transmit diversity technique for coded MIMO-OFDM systems [1]. The increased frequency-selectivity due to CDD can be picked up by a forward error control (FEC) decoder, thus neither an extended guard interval nor any modifications to the standard OFDM receiver are required.

Hybrid automatic repeat request (HARQ) is an effective error-control technique as it uses the combination of automatic repeat request (ARQ) and forward error correction (FEC). One effective and practical HARQ scheme exploiting retransmit time diversity is the Chase Combining scheme [2], which combines copies of one codeword received at different times by weighting them with their corresponding instantaneous channel gains. When the channel conditions for different transmitted copies vary significantly, time diversity can be achieved at the receiver.

CDD in conjunction with HARQ can exploit both spatial diversity and time diversity for a more robust system performance, such as a lower BLER (Block Error Rate), etc. However, in case of slow fading channels, the required interval for HARQ schemes to achieve time diversity could be too large to tolerate. This problem has been noted in [3].

In this paper, a signed operation that can help to solve this problem and obtain extra time diversity gain from retransmission is proposed. This paper is organized as follows: the CDD principle is explained in Section II, combined CDD and HARQ with a sign operation scheme based on an MMSE (Minimum Mean Square Error) receiver format is discussed in Section III, simulation verification is given in Section IV, and finally we conclude this paper in Section V.

II. Principle of CDD in MIMO-OFDM Systems

Fig. 1 shows the principle of the CDD scheme, which can also be applied in frequency domain for OFDM systems by shifting phase to frequency domain symbols. The equivalence between this phase shift and cyclic delay can be seen from the length N-points IDFT definition as shown in (1):

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S(k) \cdot e^{j\frac{2\pi}{N}kt}$$

$$\underbrace{s((t-\Delta) \bmod N)}_{\text{CDD signal}} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \underbrace{e^{-j\frac{2\pi}{N}k\Delta} \cdot S(k)}_{\text{phase shift signal}} \cdot e^{j\frac{2\pi}{N}kt} \tag{1}$$

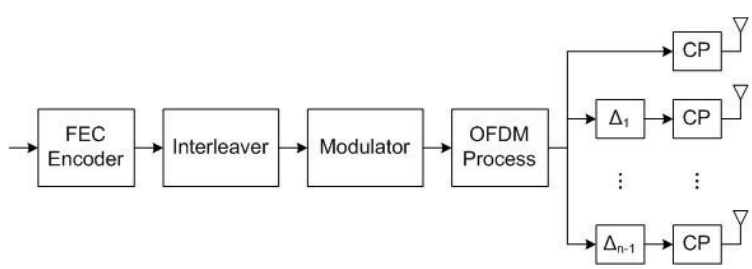

Figure 1. CDD MIMO-OFDM Transmission Scheme.

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where t, k, $s(t)$ and $S(k)$ denote the discrete time, frequency and the complex-valued signals in time and frequency domains respectively, with $t, k = 1 \ldots N-1$, and Δ is cyclic delay parameter.

Phase shift factor in (1) is $e^{-j\frac{2\pi}{N}k\Delta}$, and can be rewritten as $e^{-j\phi(k)}$, where $\phi(k)$ is an arbitrary function of the discrete frequency k.

III. Signed Operation for CDD HARQ scheme

A. Scheme description

For CDD based HARQ (CDD MIMO-HARQ) with Chase Combining at receiver side, the transmission and retransmission signal processing at the kth sub-carrier can be expressed by (2) and (3) respectively.

$$r^{(1)}(k) = H^{(1)}(k) \cdot D(k) \cdot S^{(1)} \cdot s(k) + n^{(1)}(k) \tag{2}$$

$$r^{(2)}(k) = H^{(2)}(k) \cdot D(k) \cdot S^{(2)} \cdot s(k) + n^{(2)}(k) \tag{3}$$

Here, we assume that there are two transmit antennas and one receive antenna, so $H^{(1)}(k)$ and $H^{(2)}(k)$ denote the frequency domain impulse response of spatial channel for the 1st and 2nd transmission respectively, as is described in (4) and (5) in more detail. Furthermore, we let $D(k)$ be the CDD phase shift matrix for the kth sub-carrier (refer to (6)), where Δf is the sub-carrier spacing and the optimal phase shift parameter $\Delta_n = \frac{n}{2}$ $(n = 0, 1)$ [4], $S^{(t)}$ is the signed operation for the tth slot transmission, and $s(k)$, $r^{(t)}(k)$, and $n^{(t)}(k)$ is the transmit symbol, receive symbol and additive noise respectively.

$$H^{(1)}(k) = \begin{bmatrix} h_{11}^{(1)}(k) & h_{12}^{(1)}(k) \end{bmatrix} \tag{4}$$

$$H^{(2)}(k) = \begin{bmatrix} h_{11}^{(2)}(k) & h_{12}^{(2)}(k) \end{bmatrix} \tag{5}$$

$$D(k) = \begin{bmatrix} 1 & 0 \\ 0 & e^{-j2\pi k \cdot \Delta f \cdot \Delta_1} \end{bmatrix} \tag{6}$$

Consequently, for the conventional CDD-HARQ without signed operation, $S^{(1)} = S^{(2)} = [1 \quad 1]^T$ in (2) and (3).

Alternatively, we propose a sign operation to explore performance improvement for CDD MIMO-HARQ, as shown in Fig. 2. Accordingly, the transmission pattern of CDD-HARQ with signed operation is as shown in Table 1, where $S^{(1)} = [1 \quad -1]^T$ and $S^{(2)} = [-1 \quad 1]^T$, if we use simple bit scrambling for this signed operation.

TABLE 1
SIGNED CDD-HARQ TRANSMISSION PATTERN

	Tx 1	Tx 2
1st transmission	s_1	$-s_1(t-\Delta_1)$
2nd transmission	$-s_1$	$s_1(t-\Delta_1)$

B. Theoretical analysis for receiving performance

Without losing generality, let's compare receiving performance in an MMSE receiver manner.

For Non-signed CDD-HARQ, the combination and the detected $\tilde{s}(k)$ for the two transmissions is given in (7):

$$\tilde{s}(k) = (H^H(k)H(k) + N_0 I)^{-1} H^H(k) r(k) \tag{7}$$

where

$$H(k) = \begin{bmatrix} H^{(1)}(k) \cdot D(k) \cdot S^{(1)} \\ H^{(2)}(k) \cdot D(k) \cdot S^{(2)} \end{bmatrix} = \begin{bmatrix} h_{11}^{(1)}(k) + h_{12}^{(1)}(k) \cdot e^{j2\pi k \cdot \Delta f \cdot \Delta_1} \\ h_{11}^{(2)}(k) + h_{12}^{(2)}(k) \cdot e^{j2\pi k \cdot \Delta f \cdot \Delta_1} \end{bmatrix}, \tag{8}$$

$r(k) = \begin{bmatrix} r^{(1)}(k) \\ r^{(2)}(k) \end{bmatrix}$, N_0 is the symbol to noise power ratio, and ^{H} represents a Hermitian transpose operation.

If the channels of two transmissions are assumed to be identical so that $H^{(1)}(k) = H^{(2)}(k)$ (e.g., assuming a low-mobility scenario or low retransmission delay case), the operation in (7) is the same as the detection of one transmission. So there will be no time-diversity gain for this scenario.

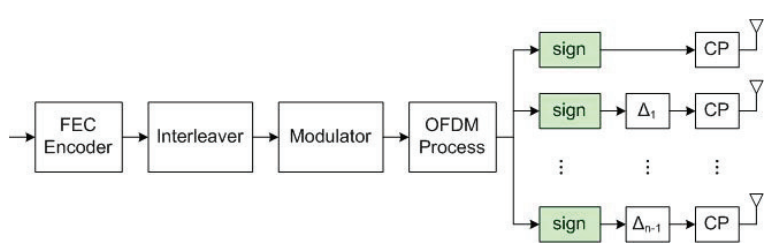

Figure 2. CDD MIMO-OFDM Transmission Scheme with Signed Operation.

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However, although the combination and the detection of the two transmissions for the signed CDD-HARQ scheme is the same as in (7), the combined channel $H(k)$ will be different as shown in (9).

$$H(k)=\begin{bmatrix} H^{(1)}(k)\cdot D(k)\cdot S^{(1)} \\ H^{(2)}(k)\cdot D(k)\cdot S^{(2)} \end{bmatrix} = \begin{bmatrix} h_{11}^{(1)}(k)-h_{12}^{(1)}(k)\cdot e^{j2\pi k\cdot\Delta f\cdot\Delta_1} \\ -h_{11}^{(2)}(k)+h_{12}^{(2)}(k)\cdot e^{j2\pi k\cdot\Delta f\cdot\Delta_1} \end{bmatrix} \quad (9)$$

Therefore, in case that the channels for the two transmissions are similar (i.e., in low mobility or less re-transmission delay case), the signed operation can help to alter the channel status so as to reinforce the time diversity gain, together with channel coding and interleaving operations.

IV. Simulation Verification

Table 2 lists the main parameters for the verification by means of simulation [5], and the results are shown in Fig. 3 and Fig. 4.

TABLE 2
MAIN SIMULATION PARAMETERS

Bandwidth	5 MHz
OFDM FFT Size	512
Sampling Frequency	7.68 MHz
Number of OFDM Symbols Per Sub-frame	7
Tx Antenna Number	2
Rx Antenna Number	1
Transmit Antenna Spacing	10
Modulation	QPSK
FEC Coding	Turbo Code
Coding Rate	1/2
Channel Mode	SCM [6] urban-macro
Velocity	3 km/h or 120km/h
Receiver algorithm	MMSE
Maximum transmission times (including initial transmission)	2
Retransmission Delay	3 ms
Transmission power in each antenna	Normalized as 1/2

As shown in Fig. 3, the Signed CDD-HARQ scheme outperforms the Non-Signed CDD-HARQ scheme by about 1.5dB in terms of BLER performance. In the case of high mobility where the re-transmission delay has a small value, as shown in Fig. 4, the signed operation will still work, though the performance gain is reduced a little.

It is further noted that compared to the Non-Signed CDD-HARQ scheme, the Signed CDD-HARQ transmitter only requires additional sign multiplication processing while the receiver structure remains the same. Therefore, the performance gain brought about by the proposed scheme is promising, especially considering the benefits during practical implementation.

V. Conclusion

This paper illustrates that the signed operation can help obtain time diversity gain for Chase-Combining based CDD-HARQ and that signed CDD-HARQ is a "practical" Chase Combing HARQ scheme for MIMO-OFDM systems considering its minimal increase in complexity.

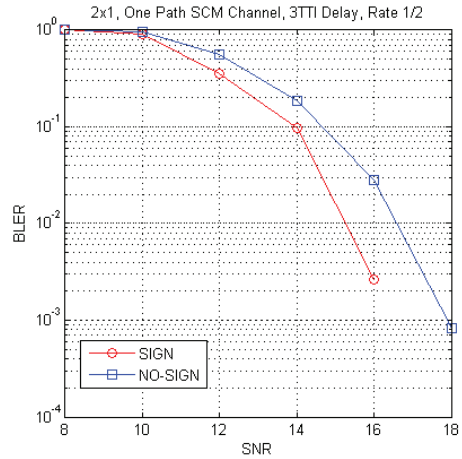

Figure 3. BLER performances of Signed and Non-Signed CDD-HARQ in a Single path channel at 3km/h.

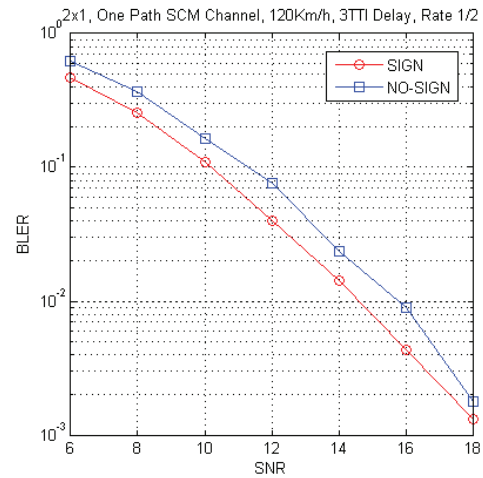

Figure 4. BLER performances of Signed and Non-Signed CDD-HARQ in a Single path channel at 120km/h.

References

[1] A. Dammann, S. Kaiser, "Standard conformable antenna diversity techniques for OFDM and its application to the DVB-T system," in Proc. IEEE Globalcom, vol.5, pp.3100-3105, 2001.

[2] D. Chase, "Code combining - a maximum-likelihood decoding approach for combining an arbitrary number of noisy packets," IEEE Trans. Communication, vol.33, no.5, pp.385-393, May 1985.

[3] M. Gidlund, P. Ahag, "Enhanced HARQ scheme based on rearrangement of signal constellations and frequency diversity for OFDM systems," in Proc. IEEE VTC, vol.1, pp.500-504, May 2004.

[4] G. Bauch, J.S. Malik, "Parameter optimization, interleaving and multiple access in OFDM with cyclic delay diversity," in Proc. IEEE VTC, vol.1, pp.505-509, May 2004.

[5] 3GPP TR 25.814, "Physical Layer Aspects for Evolved UTRA," V7.1.0 (2007-3)

[6] 3GPP TR 25.996, "Spatial channel model for Multiple Input Multiple Output (MIMO) simulations," V6.1.0 (2003-9)

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