

Low-complexity Detector for MIMO-OFDM Coded System

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Abstract—This paper proposes an adaptive joint combination of the maximum likelihood detection (MLD) and MMSE detection with successive interference cancellation (MMSE-SIC) for MIMO-OFDM coded system. The coded system employs the linear convolutional code as the channel encoder, in order to deal with the severe fading. The cyclic redundancy check (CRC) is attached in the tail of the channel coder to detect whether there exists error in the detected information bits. To utilize the CRC function sufficiently, this paper proposes an adaptive joint combination of MLD and MMSE-SIC for the coded systems. The number of data streams to be detected by MLD is adaptively increased if the CRC finds some error in the detected information bits. This procedure ends when there is no error in the detected bits or the number of streams to be detected by MLD exceeds a predetermined threshold. Computer Simulation results show that the proposed scheme can achieve near-MLD performance with very low detection complexity.

Index Terms—MIMO-OFDM, CRC, low-complexity detector, MLD

I. INTRODUCTION

The multi-input multi-output (MIMO) orthogonal frequency division multiplexing (OFDM) is one of the most promising techniques for high bit-rate mobile communications because it can utilize the spectrum efficiently and improve the system capacity [1-3]. To deal with the severe frequency-selective fading, the channel coder such as the linear convolutional code is applied. In the receiver side, the optimal signal detection is the maximum likelihood detection (MLD), followed by a channel decoder, such as the Viterbi algorithm. Although MLD can achieve the minimum packet-error-rate (PER), it has a severe problem: MLD requires a prohibitively large amount of computational complexity, which exponentially increases with both the number of transmit antennas and the modulation size. Therefore, suboptimal detection algorithms that can reduce the complexity are required.

As a suboptimal algorithm, the linear detection including the zero-forcing (ZF) and the minimum mean square error (MMSE) needs a very small amount of complexity, but exhibits poor BER performance due to the noise enhancement [4, 5]. To cope with the noise enhancement, a combination of MMSE and successive interference cancellation (SIC) has been proposed, termed MMSE-SIC [6, 7]. For further improvement, a combination of MLD and MMSE-SIC has been proposed, which can achieve a good trade-off between the

performance and complexity [8]. In this combination scheme (CS), one data stream is detected by MLD, while the others are detected by MMSE-SIC [8]. However, this scheme fails to work properly when the number of negligible singular values of the channel matrix is more than one.

To design a near-optimal low-complexity detector for the coded MIMO-OFDM system, this paper proposes an adaptive CS algorithm. The proposed scheme controls the number of data streams to be detected by MLD, by checking whether there exists error in the detected bits, implemented by the cyclic redundancy check (CRC). In this way, the proposed scheme can both achieve the near-MLD performance and very low detection complexity. Computer simulations under IEEE 802.11a standard demonstrate the validity of the proposed scheme.

II. SYSTEM MODEL

A. MIMO-OFDM transmitter and receiver

Fig. 1 shows a block diagram of a MIMO-OFDM transmitter. An information bit sequence is divided into L_T parallel streams. Then each stream is fed into a channel encoder including the cyclic redundancy check (CRC). The resultant coded bit sequence is passed into an interleaver and an OFDM modulator to generate OFDM signals that have N subcarriers with the guard interval (GI). After pulse shaping, the OFDM signals are up-converted into RF signals and transmitted.

In the receiver side, we first remove the GI component from the received signal at each receiver antennas, and then we use the FFT operation to extract N subcarrier signals for the L_R receiver antennas. After this, the subcarrier signals of the same frequency subcarrier are passed into some kind of signal detector, followed by the channel decoder using Viterbi decoding algorithm to recover the transmitted information bits.

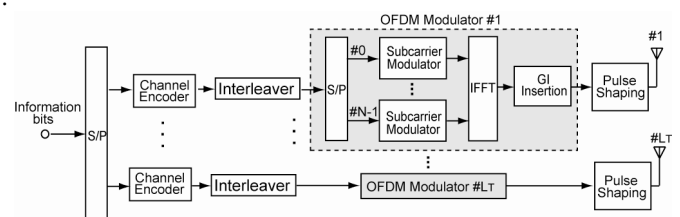


Figure 1. MIMO-OFDM transmitter

B. Signal model

The MIMO signal model at the n th subcarrier of the i th symbol can be expressed as

$$\mathbf{y}(i, n) = \mathbf{H}(n)\mathbf{b}(i, n) + \mathbf{n}(i, n)$$

where the L_R -by-1 vector $\mathbf{y}(i, n)$, L_R -by- L_T matrix $\mathbf{H}(n)$, L_T -by-1 vector $\mathbf{b}(i, n)$ denote the received signal vector, the channel frequency response matrix, the transmitted signal vector, respectively. $\mathbf{n}(i, n)$ is the L_R -by-1 additive white Gaussian noise vector with its average being the null vector and its covariance matrix being $\sigma_n^2 \mathbf{I}_{L_R}$.

The MLD algorithm is given by

$$\hat{\mathbf{b}}(i, n) = \arg \min_{\mathbf{b}^c(i, n) \in \Omega} \|\mathbf{y}(i, n) - \mathbf{H}(n)\mathbf{b}^c(i, n)\|^2$$

Where Ω denotes the set of the transmitted signal vector. $\mathbf{b}^c(i, n)$ represents one candidate from Ω . The ZF and MMSE detection results are given by

$$\mathbf{b}_{ZF}^{\square}(i, n) = [\mathbf{H}^H(n)\mathbf{H}(n)]^{-1}\mathbf{H}^H(n)\mathbf{y}(i, n)$$

$$\mathbf{b}_{MMSE}^{\square}(i, n) = [\mathbf{H}^H(n)\mathbf{H}(n) + \sigma_n^2 \mathbf{I}_{L_R}]^{-1}\mathbf{H}^H(n)\mathbf{y}(i, n)$$

III. PROPOSED SCHEME

In this section, we first extend the conventional CS scheme into a general case, and then propose our detection scheme.

a) Extension of the conventional CS

The conventional CS assumes that only one data stream is detected by MLD, while the others are detected by MMSE-SIC. Here we extend the conventional CS and assume that l data streams can be detected by MLD, termed l -CS, where $1 \leq l \leq L_T$. First, we decompose the transmitted signal vector $\mathbf{b}(i, n)$ and the channel matrix $\mathbf{H}(n)$ into two blocks as

$$\mathbf{b}(i, n) = \begin{bmatrix} \mathbf{b}^s(i, n) \\ \mathbf{b}^w(i, n) \end{bmatrix}, \quad \mathbf{H}(n) = [\mathbf{H}^s(n), \mathbf{H}^w(n)]$$

where the $(L_T - l)$ -by-1 vector $\mathbf{b}^s(i, n)$ and the l -by-1 vector $\mathbf{b}^w(i, n)$ represent signals to be detected by MMSE-SIC and MLD, respectively. The L_R -by- $(L_T - l)$ matrix $\mathbf{H}^s(n)$ and the L_R -by- l matrix $\mathbf{H}^w(n)$ represent channel matrices of the former and latter signals, respectively.

L_R -by-1 vector $\mathbf{y}^s(i, n)$ and $\mathbf{y}^w(i, n)$ correspond to $\mathbf{b}^s(i, n)$ and $\mathbf{b}^w(i, n)$, respectively, and are defined as

$$\mathbf{y}^s(i, n) = \mathbf{y}(i, n) - \mathbf{H}^w(n)\mathbf{b}^w(i, n)$$

$$= \mathbf{H}^s(n)\mathbf{b}^s(i, n) + \mathbf{n}(i, n)$$

$$\mathbf{y}^w(i, n) = \mathbf{y}(i, n) - \mathbf{H}^s(n)\mathbf{b}^s(i, n)$$

$$= \mathbf{H}^w(n)\mathbf{b}^w(i, n) + \mathbf{n}(i, n)$$

$\mathbf{b}^w(i, n)$ is detected by MLD using $\mathbf{y}^w(i, n)$ and $\mathbf{H}^w(n)$, jointly with $\mathbf{b}^s(i, n)$ detected by MMSE-SIC by using $\mathbf{y}^s(i, n)$ and $\mathbf{H}^s(n)$.

b) Proposed scheme

Based on the extended CS scheme, this paper proposes an adaptive detection algorithm for the coded system, shown in Fig. 2. Firstly, l is set to zero for the purpose of reducing the complexity. Then l data streams with the l smallest SINR are detected by MLD, jointly with the residual $(L_T - l)$ data streams detected by MMSE-SIC. After the detection, we employ the Viterbi decoding algorithm to recover the transmitted information bits. If the CRC finds some error in the detected bits, the reliability of the signal detection is considered to be insufficient. Hence, l increases by one and the above procedure continues. This procedure stops when there is no error in the detected bits or l exceeds a predetermine threshold l_{\max} . In this way, the proposed scheme can achieve a near-optimal PER performance at the cost of low computational complexity.

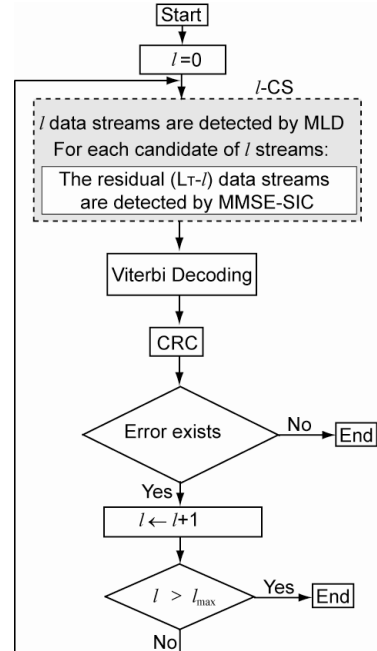


Figure 2. Procedure of the proposed scheme

IV. SIMULATION RESULTS

In order to demonstrate the performance of the proposed scheme, simulations were conducted in a fading channel under the IEEE 802.11a standard. Here we employ the 4×4 MIMO-OFDM system consisting of 64 subcarriers. The transmitted packet consists of 4 preamble symbols, followed by 10 data symbols. There are 17 Rayleigh fading paths, whose amplitude powers are subject to the exponential decay. The modulation scheme is 16QAM (16 quadrature amplitude modulation). The predetermined threshold I_{\max} is set to 2.

Fig. 3 shows the packet-error-rate (PER) performance of the referred schemes versus the average Eb/No. It can be seen that the proposed scheme can achieve nearly the optimal performance, while the conventional ones, such as MMSE-SIC or CS, fail to achieve optimal performance.

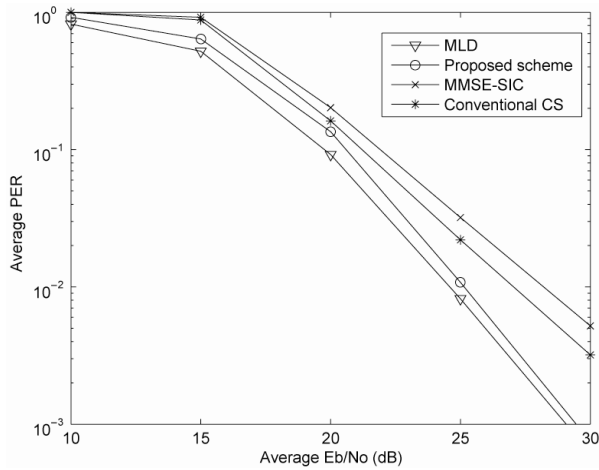


Figure 3. PER performance versus average Eb/No

TABLE I
SIMULATION CONDITIONS

Scheme	Number of multiplications
0-CS(MMSE-SIC)	$2L^2 + L$
1-CS	$2N_s L^2$
2-CS	$(N_s)^2 (L^2 - L)$
MLD	$(N_s)^L (L^2 + L)$

Table I lists the computational complexity, measured by the number of multiplications for several schemes, where $L_T = L_R = L$, and N_s

stands for the constellation size. The complexity of the proposed scheme is expressed by

$$C(\text{Proposed scheme}) = C(0\text{-CS}) + \text{PER}(0\text{-CS}) \times C(1\text{-CS}) + \text{PER}(1\text{-CS}) \times C(2\text{-CS})$$

where $C()$ denotes the computational complexity. After some calculation, we can see that in the case of Eb/No=25dB, the number of multiplications for MMSE-SIC, the conventional CS, the proposed scheme, MLD are 36, 512, 120, 1310720. The complexity of the proposed scheme is much smaller than that of the conventional one, and it only has about 0.0092% of the MLD complexity when Eb/No=25dB, which demonstrates the validity of the proposed scheme.

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