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Iterative Receiver Combining IB-DFE with MRC for Massive MIMO Schemes

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Abstract

Once we are moving to the 5G system it is imperative to reduce the complexity of massive MIMO (Multiple-Input, Multiple Output) receivers. This paper considers the uplink transmission using massive MIMO combined with SC-FDE (Single-Carrier with Frequency-Domain Equalization). We propose an iterative frequency-domain receiver merging IB-DFE (Iterative Block Decision-Feedback Equalizer) with MRC (Maximal Ratio Combining). We propose a novel approach to reduce the complexity of the receiver by avoiding matrix inversions while maintaining a level of performance very close to the Matched Filter Bound (MFB), which makes it an excellent option for 5G systems.

Keywords: Massive MIMO; 5G; SC-FDE; IB-DFE; MRC

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1. Introduction

The 5^{th} Generation imposes high quality of service at high bit rates. This requests can be fulfilled, in part, with MIMO. In fact, when we speak about MIMO it is well know that while the spectral efficiency of the system is improved also its complexity increases[1]. Yet, despite this, we can raise the number of antenna elements to tens or even hundreds leading to massive MIMO.

As shown in[2] massive MIMO schemes are expected to be the central elements of future 5G systems, therefore it is desirable that we use simple techniques at the receiver side.

In order to improve an efficient power amplification at the mobile terminals (MTs) we use SC-FDE for the uplink transmission once single-carrier signals have much lower envelope fluctuations than OFDM (Orthogonal Frequency Division Multiplexing) ones[3].

When we want to reach MFB the main receiver used was based on iterative frequency-domain, for instance, IB-DFE can be used to achieve MFB with just a few iterations. The IB-DFE receiver was proposed in[4] and its performance

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was studied in several articles such as[5,6]. On one hand we have the excellent performance that IB-DFE brings but on the other hand we have the complexity resulting from the matrix inversions.

As we know, in massive MIMO schemes the number of antenna elements is high leading to large matrices, consequently the matrix inversions are complex operations[7]. The MRC receiver does not require matrix inversions therefore its complexity is decreased, although the interference among different transmitted streams and the inter-symbol interference (ISI) increases.

In this paper we propose an iterative frequency-domain receiver that only demands matrix inversions in the first iteration, resulting in a low-complexity receiver with a extraordinary performance.

This paper is organized as follows: in Section II we describe the adopted system, following to Section III where we present the first iteration of the receiver design and the remaining iterations. Section IV presents a set of performance results and in section V we conclude this paper.

Through the paper we employ the following notation: vectors and matrices are denoted by upper-case, italic, bold letters, $\boldsymbol{X}^T$ and $\boldsymbol{X}^H$ denotes the Transpose and Hermitian of the matrix $\boldsymbol{X}$. The expectation of x is denoted by $\mathbb{E}[\mathrm{x}]$.

1.1. Research objectives

This work intends to develop a low complexity receiver that allows to achieve a high level of performance suitable for the 5G system. The low complexity achieved is due to the fact that matrix inversions are not used in our algorithm except at first iteration, as opposed to most common approaches.

2. System characterization

For this work we consider an uplink single-carrier massive MIMO scenario presented in Fig. 1 where T MT (Mobile Terminals) are communicating with a base station (BS). In this case a BS has R receive antennas with $R >> T$. In order to simplify the scenario we only consider a single antenna for the MT, with no loss of generality.

We use SC-DFE modulations in MT and perfect synchronization and channel estimation in the receiver are assumed. Once we use SC-FDE, in the transmission side, for each transmitted block of N data symbol a cyclic prefix longer than the maximum overall channel impulse response is appended and in the receiver side this prefix is removed.

The data block transited in the t^{th} MT is $\{x_n^{(t)}; n = 0, 1, \cdots, N-1\}$ with $x_n^{(t)}$ selected from a given constellation (in our case we consider QPSK constellation) according to the Gray mapping rule. The received block at the r^{th} BS, after we remove the prefix, is $\{y_n^{(r)}; k = 0, 1, \cdots, N-1\}$ and the corresponding frequency-domain block is $\{Y_n^{(r)}; k = 0, 1, \cdots, N-1\}$.

The block $Y_n^{(r)}$, when expressed in matrix form, is represented by:

$$\boldsymbol{Y}_k^{(r)} = [Y_k^{(1)}, \cdots, Y_k^{(R)}]^T = \boldsymbol{H}_k \boldsymbol{X}_k + \boldsymbol{N}_K \qquad (1)$$

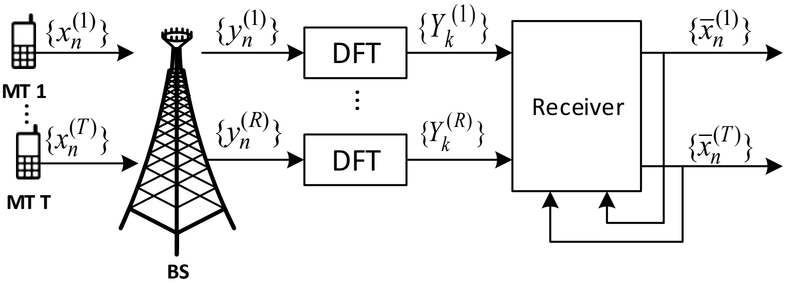

Fig. 1. System model.

where $\boldsymbol{H}_k$ is the $\mathbf{R} \times \mathbf{T}$ channel matrix for the k^{th} frequency, $\boldsymbol{X}_k = [X_k^{(1)}, \cdots, X_k^{(T)}]^T$ and $\boldsymbol{H}_k$ denotes the channel noise. It is also assumed that $\mathbb{E}[\mathbf{N}_k \mathbf{N}_k^H] = N_0 \mathbf{I}_R$.

3. Receiver Structure

In this paper we propose a low-complexity iterative frequency-domain receiver. Due to its low complexity this receiver is indicated for massive MIMO schemes. Once complexity is mainly related with the matrix inversions we will try to simplify the receiver by rendering this operation.

Therefore we propose a receiver that uses a linear decision feedback equalizer, in our case we use IB-DFE in the first iteration, and on the following iterations it uses a structure that does not involve matrix inversions, the MRC technique.

This combination was chosen because the results of the first iteration of the MRC are far from MFB. So, if we start with the IB-DFE and use the resulting values to initiate the MRC receiver in the first iteration (the second in the global) than it will be very close to the MFB.

3.1. First iteration

The conventional IB-DFE receiver is well studied in[4,5] and[8].

As we can see in the mentioned papers, the complexity of the receiver is related to the need of solving a system of R equations for every frequency of each MT. In the first iteration, if we look for the p^{th} MT, the estimated symbols $\{\tilde{x}_n^{(p)}; n = 0, 1, \cdots, N-1\}$ are the hard decisions of the time-domain detector output $\{\tilde{\mathbf{x}}_n^{(p)}; n = 0, 1, \cdots, N-1\}$ = IDFT $\{\tilde{\boldsymbol{X}}_k^{(p)}; k = 0, 1, \cdots, N-1\}$, where IDFT denotes the Inverse Discrete Fourier Transform.

The $\bar{\mathbf{X}}_k^{(p)}$ is given by:

$$\tilde{\boldsymbol{X}}_k^{(p)} = \boldsymbol{F}_k^{(p)T} \boldsymbol{Y}_k^Q - \boldsymbol{B}_k^{(p)T} \bar{\boldsymbol{X}}_k^{(p)} \tag{2}$$

where $\boldsymbol{F}_k^{(p)T} = [F_k^{(p),(1)}, \cdots, F_k^{(p),(R)}]^T$ represents the feedforward coefficients and $\boldsymbol{B}_k^{(p')T} = [B_k^{(p'),(1)}, \cdots, B_k^{(p),(P)}]^T$ denotes the feedback coefficients. $\bar{\boldsymbol{X}}_k^{(p)}$ represents the average values conditioned to the detector output calculated in[8]. At the first iteration there are no feedback coefficients so the equation 3 can be simplified to:

$$\tilde{\boldsymbol{X}}_k^{(p)} = \boldsymbol{F}_k^{(p)T} \boldsymbol{Y}_k^Q \tag{3}$$

The IB-DFE receiver for the first iteration is presented in Fig. 2.

3.2. Remaining iterations

As previously stated, the IB-DFE is very complex and the first iteration of the MRC has a poor performance, so we decided to use the output of IB-DFE (in the first iteration) to improve the performance of the MRC (Fig. 3).

Another advantage of the MRC receiver, besides its low complexity for the system, is the small correlation between channels and between different transmitters and receive antennas. In fact, the elements outside main diagonal $\boldsymbol{A}_k^H \boldsymbol{H}_k$

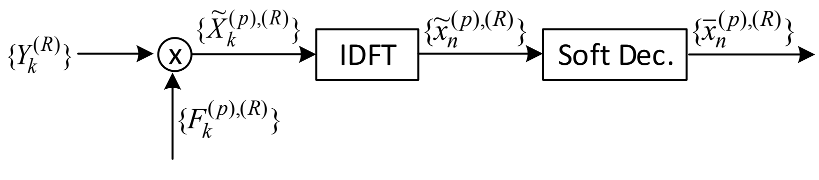

Fig. 2. IB-DFE receiver for the first iteration

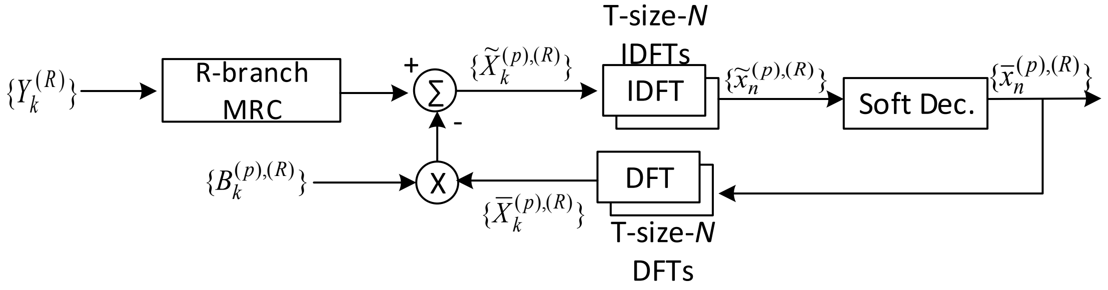

Fig. 3. Remaining iterations with MRC

are much lower than the ones at its diagonal[9]. The matrix $\boldsymbol{A}$ is given by:

$$[\boldsymbol{A}]_{i,i'} = [\boldsymbol{H}]_{i,i'} \tag{4}$$

As carefully explained in[9] to the SC-FDE, we employ a receiver based on $\boldsymbol{A}_k^H \boldsymbol{Y}_k$ but the residual interference levels are still considerable, so we propose a receiver where

$$\bar{\boldsymbol{X}}_k = \Psi \boldsymbol{A}_k^H \boldsymbol{Y}_k - \boldsymbol{B}_k \overline{\boldsymbol{X}}_k, \tag{5}$$

the diagonal matrix, whose $(t,t)^{th}$ element is given by $(\sum_{k=0}^{N-1} \sum_{r=1}^{R} |\boldsymbol{H}_k^{(r,t)}|^2)^{-1}$ is represented by Ψ. This element ensures that the overall frequency-response for each MT of the "channel plus receiver " has average 1[6].

$\boldsymbol{B}_k$ is used to remove the residual ISI and inter-user interference.

$\overline{\boldsymbol{X}}_k$ is used to canal interference and its values are conditioned with the previous iterations.

4. Results

In this section, we consider the proposed receiver and present a set of performance results. We consider a massive MIMO system with *T=4* single-antenna transmitter with R receivers. We also consider the uplink scenario with SC-FDE modulations implemented in each antenna. Each block has *N=256* data symbols, each symbol is selected from a QSPK constellation, plus an appropriate CP. Every channel has 100 slots, symbol-spaced, equal-power multipath components.

We consider an uncorrelated Ryeligh channel with different links between transmit and receive antennas. It is assumed perfect synchronization and channel estimation. In this simulations we assume a BS with *R=16* or *R=32* receive antennas and 4 iterations.

First in Fig. 4 we present the performance of the IB-DFE receiver. As we can see the performance of this receiver never matches with MFB. After the first iteration the remaining iterations have about the same performance as the first one for an error rate above 5×10^{-2} for *R=16* and 10^{-2} for *R=32*.

The performance of a receiver that does not require matrix inversions is present in Fig. 5. In this figure it is possible to see that for both *R=16* and *R=32* the first two iterations are far away from the MFB but the remaining iterations approach it.

In Fig. 6 we can see the performance of the implemented receiver. We can see in first iteration the performance of IB-DFE and in the remaining iterations the performance of the MRC. In fact, the junction of this two receivers improves the performance, after the first iteration. This receiver approaches MFB with only 2 iterations and merely needs matrix inversions in the first iteration.

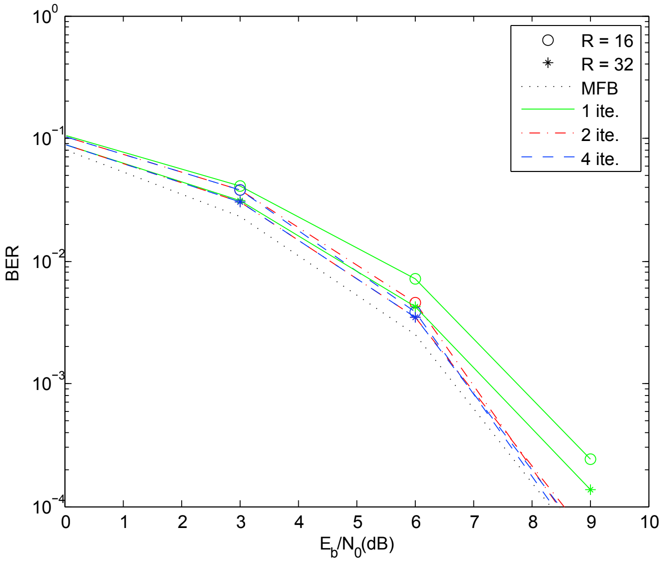

Fig. 4. BER performance for IB-DFE receiver

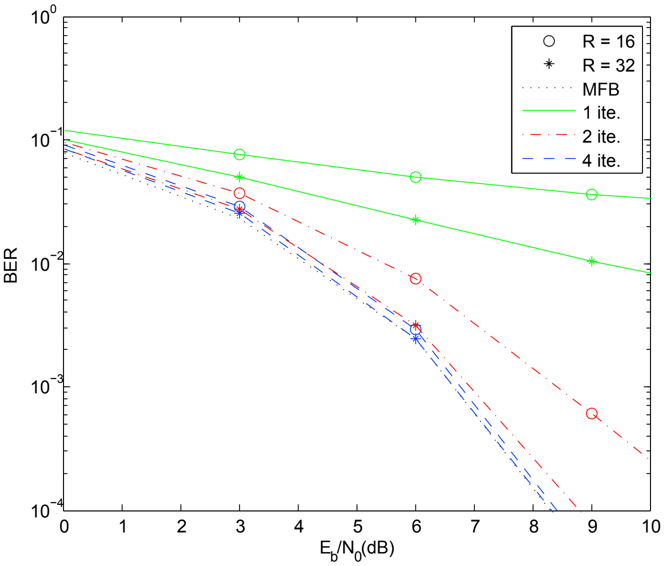

Fig. 5. BER performance for MRC receiver

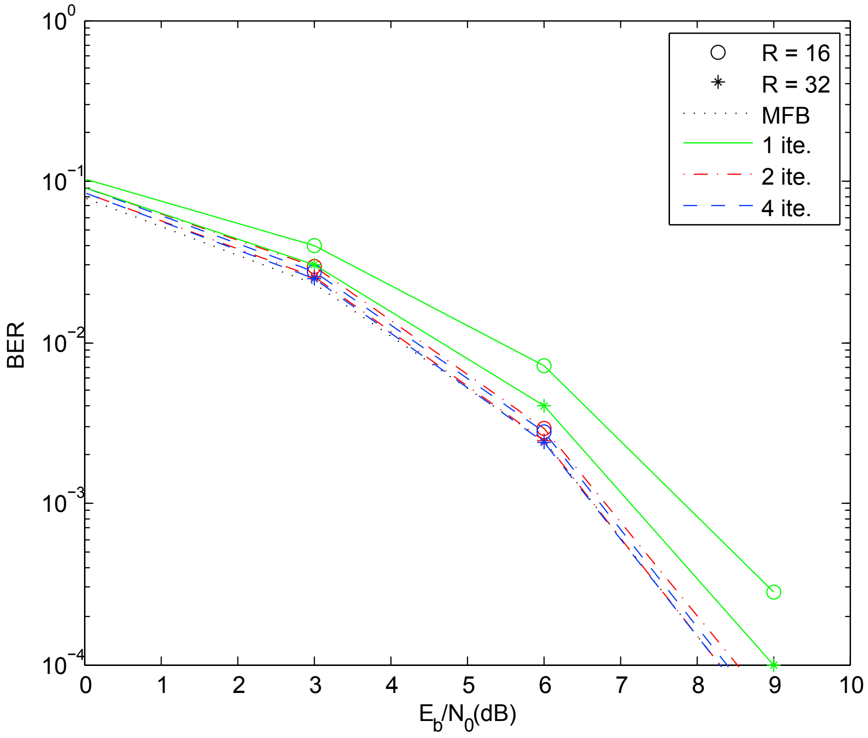

Fig. 6. BER performance for the proposed receiver

5. Conclusion

In this paper a low complexity iterative receiver was proposed. This receiver was designed for massive MIMO schemes and after the second iteration the results are already very close to the MFB. The greatest advantage of this receiver proposal is the fact that it only needs one matrix inversion and no matrix inversions are used at remaining iterations.

With this research work it can be shown that it is possible to reduce the complexity of the receiver by maintaining high performance levels. These excellent performance results are very promising for the future of 5G system, as it is expected to achieve high performance with low complexity, as proposed by our algorithm, enabling cheaper and more efficient receivers.

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