Estimation Algorithm for Large MIMO System

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Abstract. In multiuser Large MIMO communication systems, signal recovery is a relevant factor for ensuring a safe and reliable communication, especially when the users are intercorrelated. Solutions for interference minimization include analysis regarding source coding/decoding techniques, channel coding/decoding methods and multiuser detection algorithms. This paper illustrates the performance improvement brought by convex optimization technique in Large MIMO systems when the channel is affected by AWGN and Rice fading. The performance is evaluated for different sets of spreading sequences (Walsh-Hadamard and PN) and based on the simulation results several conclusions are highlighted and further improvement will be proposed for fading effects reduction and interference minimization.

Keywords: Large MIMO · Convex optimization · POCS algorithm
Multiuser MIMO · Rice fading

1 Introduction

In the last decades many studies have been made regarding the Multiple-Input Multiple-Output (MIMO) technology because of its advantages including superior data rates, range and reliability without requiring additional bandwidth or transmit power. If initially the research has been focused on point-to-point MIMO links [1], recently the multi-user MIMO system brings more benefits due to spatial multiplexing. Thus, MU-MIMO is used in modern wireless standards, including in IEEE 802.11n, 3GPP LTE/LTE Advanced, and mobile WiMAX systems [2].

In order to be able to achieve better performance in terms of throughput and energy efficiency, Massive MIMO system, also known as Large-Scale Antenna System or Large MIMO, has been proposed [3]. The transmitter/receiver is equipped with a very large number of service antennas (e.g. hundreds) which are working fully coherent and adaptive. This approach considerably eliminates the effects of noise fading and other interferences, allowing thus to improve the spectral efficiency and robustness of the system [4].

Although Massive MIMO system has many advantages, there are still many challenges to be studied. In [1] it is presented the importance of user scheduling, which in conventional MIMO implementation can be avoided using more complex signal

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processing to separate spatially correlated users. Other issue represents the channel state information (CSI), which has to be known by the multi-user Massive MIMO system in order to advance the capacity gain offered by it [4, 5]. Thus [6] shows that the use of TDD (time-division duplexing) allows the system to "learn" the channel, for both uplink and downlink. However, as the number of antennas increases this becomes a difficult task. Other challenge caused by the high number of antennas is the implementation of coders and detectors with reasonable complexity.

The scope of this paper is to analyse the effects of the correlated users on the performance of an uplink Large MIMO system, when Rice fading occurs on the communication channel. At the base station an algorithm based on projection onto convex sets is proposed to eliminate the interference between the users.

The remainder of this article is organized as follows. The benefits of using convex optimization are discussed in Sect. 2. Section 3 presents the proposed algorithm and the results obtained. Finally, conclusions are drawn in Sect. 4.

2 Convex Optimization

The optimization methods are very useful in addressing challenges in many domains. Numerous communication issues can be cast as or can be transposed into convex optimization problems, which facilitate their analytic and numerical solutions [7]. The convex optimization has been successfully applied in several domains in wireless communications and signal processing. The success of this class of optimization techniques is due to their features. During the years, a lot of efficient and fast algorithms for resolving convex optimization problems have been developed and implemented, and a part of them have a significant impact in area of MIMO, OFDM and 3G/4G wireless systems, which makes convex optimization a good candidate for wireless communications [8].

The convex optimization is used in Massive MIMO as well. In [9] the authors propose signal detection schemes for massive overloaded MIMO. The signal detection is formulated as a convex optimization problem, which can be solved via a fast algorithm based on Douglas-Rachford splitting. In [10], an energy efficient antenna selection algorithm based on convex optimization for Massive MIMO system has been proposed.

In mathematics, convex optimization refers to the minimization of a convex objective function subject to convex constraints. In this paper, we are interested in projections onto convex sets (POCS), which is a method to find a point in the intersection of two closed convex sets or to find the minimum distance between these sets.

3 System Model and Parameters

In the following an uplink transmission of a Massive MIMO system is considered. First the system is considered an ideal one, in which the users are totally uncorrelated one another, and then the real situation is analysed, in which, because of fading or other impairments, the users are getting correlated one another. A general block diagram of the system is presented in Fig. 1.

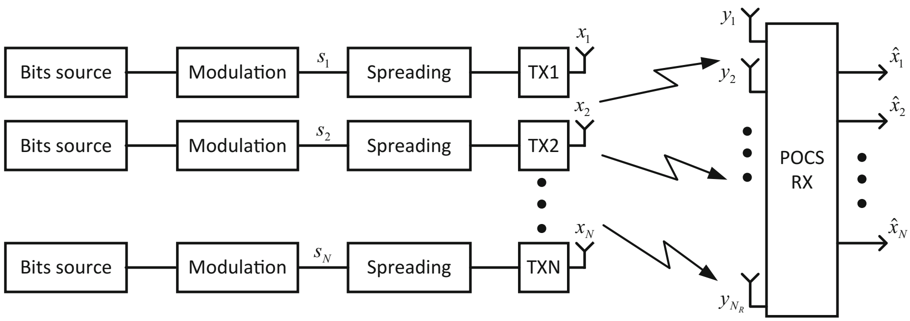

Fig. 1. System model

The base station (BS), represented in our scheme by the POCS RX block, is equipped with N_R receive antennas and N_T transmission antennas, one for each user. It was assumed perfect CSI at the transmitter and at the BS. In the case of multiuser MIMO system, the signal from a user, after dispreading and demodulation, may be considered as interference for the others, so the number of users is limited by multiuser interference, noise and fading. The $N_R \times 1$ received signal vector at BS can be written as the combination of all signals transmitted from all users:

$$\mathbf{y} = \sqrt{p}\sum_{k=1}^{N}\mathbf{h}_k\mathbf{x}_k + \mathbf{n} = \sqrt{p}\mathbf{H}\mathbf{x} + \mathbf{n}, \tag{1}$$

where p is the average signal to noise ratio, $\mathbf{n} \in \mathbb{C}^{N_R \times 1}$ is white Gaussian noise vector with mean equal to zero and variance one, $\mathbf{x} = [x_1, x_2, \ldots, x_N]^T$ is the matrix of the transmitted signal from all users and $\mathbf{H} \in \mathbb{C}^{N_t \times N}$ is the channel matrix between the N users and the BS, where $\mathbf{h}_k$ is a $N_R \times 1$ vector which represents the channel vector between the k$^{\text{th}}$ user and the BS.

The scope of the following proposed algorithm is to detect signals transmitted by the users from the received BS signal. In the uplink, multiuser detection can be used. The problem can be formulated as:

$$\hat{\mathbf{x}} = \arg\min_{x \in S^N} \left\|\mathbf{y} - \sqrt{p}\mathbf{H}\mathbf{x}\right\|^2, \tag{2}$$

where S is the finite alphabet of $x_k,\ k = 1, 2, \ldots, N$. The problem (2) is a least square problem with a finite-alphabet constraint. It is well known that linear least squares problems are convex optimization problems, thus the POCS algorithm can be applied.

A $N_R \times N$ linear detection matrix which contains the correlation coefficients between the users, r_k, denoted by $\mathbf{R}$, it is introduced in (1) as follows:

$$\mathbf{y} = \sqrt{p}\mathbf{R}\mathbf{H}\mathbf{x} + \mathbf{n}. \tag{3}$$

In this way, the information sent by the users is decoded independently. From (3), the k[th] stream of $\mathbf{y}$ which is used to decode x_k is given by:

$$\mathbf{y}_k = \underbrace{\sqrt{p}\mathbf{r}_k\mathbf{h}_k\mathbf{x}_k}_{desired\ signal} + \underbrace{\sqrt{p}\sum_{p \neq k}^{N} \mathbf{r}_k\mathbf{h}_p\mathbf{x}_p}_{\text{int}eruser\ \text{int}erference} + \underbrace{\mathbf{n}}_{noise}. \quad (4)$$

Considering the initial estimate of the problem (2), the least square solution:

$$\hat{\mathbf{x}}_{LS} = \left(\mathbf{R}^H\mathbf{R}\right)^{-1}\mathbf{R}^H\hat{\mathbf{x}}_{MF}, \quad (5)$$

where $\hat{\mathbf{x}}_{MF}$ is the output of the matched filter. Further, at stage $k+1$ the POCS estimation can be written as:

$$\hat{\mathbf{x}}_{POCS}^{(k+1)} = \hat{\mathbf{x}}_{POCS}^{(k)} + \left(\sigma^2\mathbf{I} + \mathbf{R}^H\mathbf{R}\right)^{-1}\mathbf{R}^H\left(\hat{\mathbf{x}}_{MF} - R\hat{\mathbf{x}}_{POCS}^{(k)}\right), \quad (6)$$

where σ^2 is the noise estimated variance and $\mathbf{I}$ is the identity matrix.

For the evaluation of our algorithm we consider that four baseband users are sending binary data streams towards the same BS. We analysed the performance when data is transmitted using different modulation schemes and the users are separated by Walsh-Hadamard and PN signature sequences. The communication channel is affected by AWGN and Rice fading, we study the situation of a rural area when the users have line of sight with the BS.

First, we would like to study the differences between our algorithm and the MMSE one, which is already used on Massive MIMO for the same purpose. If perfectly orthogonal Walsh codes of length 32 are used to separate the users, there is no difference between the performance obtained. However, if PN codes of length 31 are used as signature sequences, there is a small correlation between the user that cannot be eliminated and the POCS algorithm reduce its effects, as can be shown in Figs. 2 and 3. For this case 5 antennas at the BS and QPSK modulation have been used.

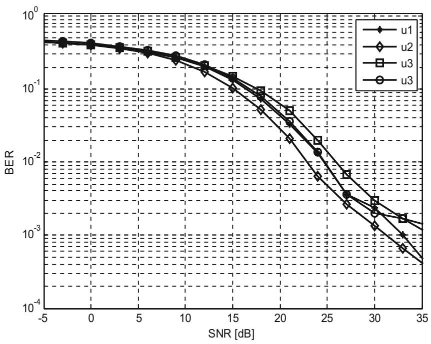

Fig. 2. MMSE algorithm, PN codes, 1 × 5 MIMO

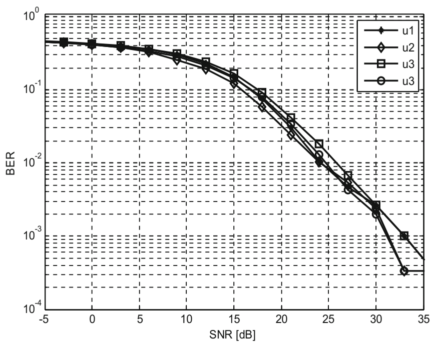

Fig. 3. POCS algorithm, PN codes, 1 × 5 MIMO

Figure 2 presents the results obtained by MMSE algorithm when PN codes of length 31 are used, and it can be easily observed that, because of inter-correlation between the users the performance is limited to a BER = 10^{-3} for SNR = 35 dB. When the POCS algorithm is used, Fig. 3, the performance archived by each user is slightly improved, but this improvement is very small.

Further are presented the results obtained in the same scenario and with the optimization algorithm for different types of modulation. Figure 4 shows the performance achieved when the BS is equipped with 2 receive antennas and PN codes are used. It can be noted that, even for the lowest order modulation, the signal cannot be recovered even at high SNR, since the BER is very high. Increasing the number of antennas might bring an improvement of the results as has been previously shown.

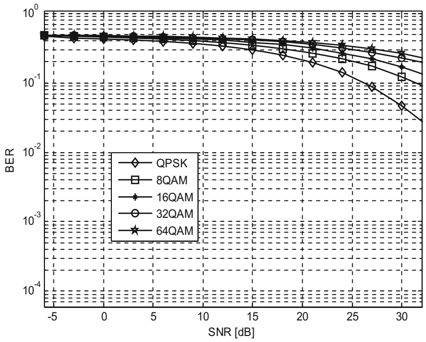

Fig. 4. POCS algorithm, PN codes, 1 × 2 MIMO

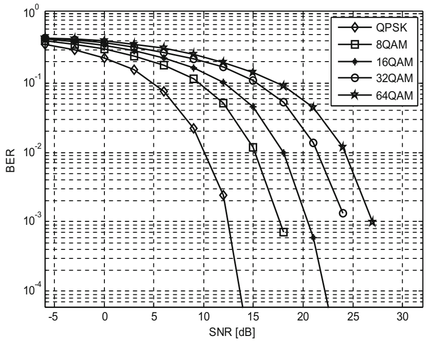

Fig. 5. POCS algorithm, Walsh codes, 1 × 10 MIMO

Thus, we increase the numbers of antennas at the BS from 5 to 10 to see how much the performance of the system is increased. In Fig. 5 are presented the results for Walsh and it is obvious that the performance is significantly improved even for high order modulation, reaching a BER around 10^{-3} for a signal to noise ratio less than 27 dB.

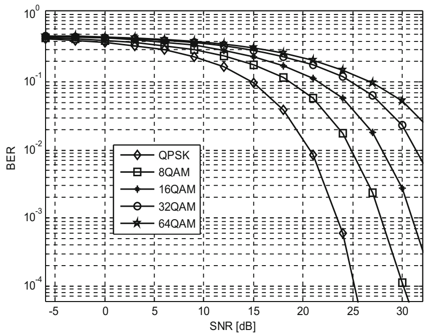

Fig. 6. POCS algorithm, PN codes, 1 × 10 MIMO

When the Walsh codes are replaced with PN codes the results get worse (see Fig. 6) in comparison with those from Fig. 5, but better from those from Fig. 4 when BS has only 2 antennas. Also, if we compare the results for the QPSK modulation, we can see that increasing the BS' antennas from 5 (Fig. 3) to 10 (Fig. 6) we have a gain of almost 9 dB for a bit error rate of 10^{-3}.

4 Conclusion and Future Work

The present paper illustrates the behaviour of an estimation algorithm, based on convex optimization, for Large MIMO systems. The presented algorithm can reduce the undesired effects of non-orthogonality of spreading sequences and fading. Furthermore, when Walsh codes are used the algorithm achieves good results, also as the number of BS' antennas increase.

Future work implies to change the random data sent on the communication channel to one that contains visual information (images or video streaming). The quality of the recovered data can be analysed using different quality metrics and the effect of the algorithm in data estimation will also be analysed (Video Quality Metric, Structural Similarity Index etc.). Also different types of channel coding, like Turbo and LDPC, which are suitable for 5G technologies, will be tested together with the algorithm.

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