Combined Efficient Precoding Technique for Multi-User MIMO

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ABSTRACT

Recently, a multiuser MIMO system has attracted much attention because of an important area of focus for next generation wireless system because of their potential for higher capacity, increased diversity and interference suppression with leading higher data rate support. In Multiuser MIMO (MU-MIMO) systems, precoding is essential to eliminate or minimize the multiuser interference (MUI) as in the downlink of the multiuser MIMO system where the base station simultaneously transmits signals to terminals. However, the design of a suitable precoding algorithm with good performance and low computational complexity at the same time is quite challenging, especially with the increase of system dimensions which increases with number of antennas. In this thesis, we mainly focus on MU-MIMO broadcast channel, consider the case where the multiple transmit antennas are used to deliver independent data streams to multiple users and compare the performance for linear and non linear precoding techniques in terms of BER, SNR and complexity point with increase in the number of users and the number of transmit antennas. We propose a new practical scheme leads with low computation complexity and better BER performance with better system utilization.

Index Terms— About Downlink Precoding Techniques, Zero Forcing (ZF), Minimum mean-square-error (MMSE), Block Diagonalization (BD), Tomlinson-Harashima Precoding (THP), Dirty Paper Coding (DPC) ZF-THP scheme, MMSE-THP scheme.

I. INTRODUCTION

In recent years, there has been a considerable interest in wireless multiple-input, multiple output (MIMO) communication systems because of their promising improvement in terms of performance and bandwidth efficiency. An important research topic is the study of multi-user (MU) MIMO systems. Such systems have the potential to combine the high throughput achievable with MIMO processing with the benefits of space division multiple access (SDMA). In the downlink scenario, a base station (BS) is equipped with multiple antennas and it is antennas are associated with different users that are typically unable to coordinate with each other. The BS exploits the channel state information (CSI) available at the transmitter to allow these users to share the same channel and mitigate or ideally completely eliminate multi-user interference (MUI) by beam forming (linear pre-coding) or by the use of “dirty-paper” codes. It is essential to have CSI at the base station since it allows joint processing of all users’ signals which results in a significant performance improvement and increased data rates.

All pre-coding techniques can be classified considering whether they allow MUI (as zero or non-zero MUI techniques) and by their linearity (as linear and non-linear techniques). Linear precoding techniques require no overhead to provide the mobile with the demodulation information and are less computationally expensive than their non-linear counterparts.

II. BASIC PRECODING TECHNIQUES

A. Zero Forcing Filter (ZF)

Submit Since the base station has no influence on the noise at the user terminals, the most intuitive approach for pre-coding is a zero forcing filter (ZF) which eliminates all interference at the user terminals. Assuming single antenna terminals, the decoding matrix becomes

\[
G = I_K \text{ and } M_R = K .
\]

Let us define the precoding matrix \( F \) as

\[
F = \beta F_a .
\]

The precoding matrix \( F_a \) and the scaling factor \( \beta \) result from the following optimization

\[
F_a = \arg \min E[|HF_a x - x|]^2
\]

Such that

\[
HF_a = I_K - \text{--------}(1)
\]

In the same as the decoding ZF filter, the transmit ZF filter also suffers from the noise enhancement problem and required increase in transmit power. It is suboptimal and results in significant performance degradation.

B. Minimum mean-square-error (MMSE)

This pre-coding improves the system performance by allowing a certain amount of interference especially for users equipped with a single antenna. However, it suffers a performance loss when it attempts to mitigate the interference between two closely spaced antennas, situation always occurring when the user terminal is equipped with more than one receive antenna. The ZF pre-coder completely eliminates the multiuser interference at the cost of noise enhancement. The minimum mean square error (MMSE) pre-coder balances the multiuser interference.
mitigation with noise enhancement and minimizes the total error so compare to ZF pre-coder, the MMSE pre-coder cannot design in a straightforward way.

The ZF pre-coder completely eliminates the multiuser interface at the cost of noise enhancement. The minimum mean square error (MMSE) pre-coder balances the multiuser interface mitigation with noise enhancement and minimizes the total error so compare to ZF pre-coder, the MMSE precoder cannot design in a straightforward way. A key to design the MMSE precoder is to scale the transmit vector such that the total transmit power has the predefined level i.e

\[ F_a = \arg \min_{F_a} E\{ \| \beta^{-1} y - x \|^2 \} \]

Such that

\[ \beta^2 \| F_a x \|^2 \leq P_T \quad \text{(2)} \]

The MMSE precoder is defined as

\[ F_a = (H^H H + \alpha I_{MT})^{-1} H^H \quad \text{(3)} \]

Where parameters \( \alpha \) and \( \beta \) are equal to

\[ \alpha = \frac{\sigma_n^2}{P_T}, \quad \beta = \sqrt{\frac{P_T}{\alpha \sigma_n^2}} \quad \text{(4)} \]

The MMSE precoder, in the same way received signal MMSE filter, approximates a match filter at low SNRs and is near optimal. At high SNRs the MMSE precoder converges to a ZF pre-coder.

### C. Tomlinson-Harashima Precoding (THP)

It is a non-linear pre-coding developed for single-input .single-output(SISO) multipath channels. THP can be interpreted as moving the feedback part of the DFE to the transmitter. Recently it has been also applied for the pre-equalization of MUI in MIMO systems, where it performs spatial pre-equalization instead of temporal pre-equalization for ISI channels. There by, no error propagation occurs. Hence the pre-coding can be performed for the interference free channel.

MMSE pre-coding in combination with THP is proposed in MMSE balances the MUI in order to reduce the performance loss that occurs with zero interference techniques while THP is used to reduce the MUI and to improve the diversity.

So THP proposed in combines SO and THP in order to reduce the capacity loss due to the cancellation of overlapping subspaces of different user sand to eliminate the MUI. After the pre-coding, the resulting equivalent combined channel matrix of all users is a gain block diagonal. This also facilitates the definition of a new ordering algorithm. This technique allows more than one antenna at the mobile terminal sand has no performance loss due to the cancellation of interference e between the signals transmitted to two closely spaced antennas at the same terminal.

### D. Block diagonalization precoding

Block diagonalization was proposed to solve either the problem of maximizing the total system throughput under a transmit power constrain or to minimize the total transmit power for a predefined QoS level. It is restricted to channel where the number of transmit antennas \( M_T \) Another difference is that BD, unlike ZF and MMSE precoders, allows also the option that user terminals can be equipped with more than one antenna. A similar method can be applicable to multiple users, each with multiple antennas. Since the inter antenna interference in its own signal as well as other user interference are canceled or mitigated, noise enhancement becomes more severe from the perspective of the target user. In this situation, a block diagonalization (BD) method is more suitable. In the BD method, unlike in the ZF and MMSE methods, only the interference from other user signals is canceled in the process of precoding. Then, the inter-antenna interference for each user can be canceled by various signal detection methods.

E. MMSE THP precoding

THP precoding is performed at the transmitter, whereas receiver still performs the linear filtering. In both feed forward and feedback filter are developed at the transmitter which results in noteworthy reduction in computational load at the receiver side. The MMSE THP precoder is derived from the linear transmitter MMSE precoding optimization by neglecting the contribution of the elements of the lower triangular part of \( H F_a \) to the overall.

\[ F_a = \arg \min_{F_a} E\{ \| \beta^{-1} y - x \|^2 \} \]

Such that

\[ \beta^2 \| F_a x \|^2 \leq P_T, \quad [H F_a]_{ij} = 0, i > j, \forall i, j \quad \text{(5)} \]

Where \([H F_a]_{ij}\) denotes the elements of ith row and jth column of the matrix \( H F_a \). The interference remaining after the precoding using \( F_a \) from these lower triangular matrix is eliminated using THP. First a precoding matrix \( F_a \) is defined column by column starting from user K. The column corresponding to the ith user is obtained as the ith column of the matrix \( HF_a \) calculated using the first I rows of the network channel matrix \( H \). Let us introduce the matrix

\[ \bar{H}_i = \begin{bmatrix} H_1 \\ \vdots \\ H_{i-1} \\ H_i \end{bmatrix} \quad \text{(6)} \]

Which contains the first I rows of the channel matrix \( H \). Then the ith column of the precoding matrix \( F_a \) is given by

\[ [F_a]_{(i,j)} = \left( \bar{H}_i^H \bar{H}_i + \alpha I_{MT} \right)^{-1} \bar{H}_i^H \quad \text{(7)} \]

After this, the users are encoded in the reverse order from the one in which precoding matrices are generated. i.e starting from the first user, then the second, etc. Using THP we eliminate the multiuser interference to the ith user originating from previous i-1 users

## III. SIMULATION RESULTS

**MMSE-THP:**

MMSE THP is applied only on the combined network channel corresponding to these single antenna users. The data transmitted to the multiple antenna users is also precoded using THP in order to eliminate the MUI which in this case only originates from the single antenna users.
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<th>SNR in Db</th>
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<th>(1,1)x2 BER</th>
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Table 3.1 BER performance of MMSE-THP

<table>
<thead>
<tr>
<th>SNR in Db</th>
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<th>(2,2)x2 BER</th>
<th>(1,1)x2 BER</th>
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</table>

Table 3.2 BER performance of BD

IV. CONCLUSION

By using BD only for multiple antenna users we effectively eliminate the interference that these users generate to single antenna users. Then by using MMSE THP only for the single antenna users we improve their and the overall system performance. And finally BD MMSE-THP will provide better communication when user equipped with single as well as multiple antenna in MU-MIMO.

REFERENCES