MSE based Precoding Schemes for Partially Correlated Transmissions in Interference Channels
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Introduction

A wireless sensor network (WSN) in presence of interferes experiences MSE degradation at the fusion center. 

Modeling as an interference channel (IC) with known CSI, MSE based interference alignment (IA) methods [1] can be used to design precoding methods.

Since the sensors transmit correlated observations [2], we present two iterative precoding methods based on MSE that achieve global convergence.

The first method normalizes the precoder for the power constraint. However, only one of the correlated transmitters fulfill the constraint. Therefore, the second method jointly considers the MSE optimization problem subject to the constraint.

System Model

In IA-feasible MIMO IC (\(M \times N \times d\) \(, d\)), correlated transmitted signal of two or more users (\(S = \{1, 2\}\)) is given as

\[
x_{i} = \frac{1}{\sqrt{\sigma^{2} + \sigma_{i}^{2}}} \left( x_{i}^{0} + w_{i}^{n} \right), \quad i \in S
\]

where \(w_{i} \sim CN(0, I_{d})\).

For example, in a WSN with amplify and forward (AF) sensors, observations \(x_i - \sigma w_i\), \(w_i \sim CN(0, \sigma I)\) are scaled to satisfy unity transmit power constraint, i.e., with \(\sigma_i^2 = \frac{\sigma^2}{\sigma^2 + \sigma_i^2}\).

The received signal is given as 

\[
\mathbf{y} = \mathbf{H} \mathbf{x} + \mathbf{w}
\]

where \(\mathbf{H} \in K \times K\) and \(\mathbf{w} \sim CN(0, \sigma I)\). The simplification \(\sqrt{1 - \sigma^2} \mathbf{V}_{k} \mathbf{x} + \sqrt{\sigma^2} \mathbf{V}_{k} \mathbf{x} - \mathbf{H}_{k} \mathbf{V}_{k} \mathbf{x}\) is used.

Global convergence conditions

The equations for avoiding under-determined MSE optimization is expressed as

\[
\mathbf{U}_{k} \mathbf{H}_{k} \mathbf{V}_{k} = 0 \quad \forall (k, k') \in D.
\]

where \(D = \left\{ (k, k') | k \in K, k' \in K, \mathbf{x} = \mathbf{k}, k' \notin S \right\}\) and \(z = K \times K \setminus D\).

The above equations result in the modified necessary conditions as

\[
M + N = K + (|S| - 1) (1 + \mathbf{M}'\mathbf{D})
\]

MSE based Transmit Precoder (Method-I)

The precoder expressions to minimize the sum MSE is obtained as

\[
\mathbf{V}_{i} = \left( A_{i} + D \left( \mathbf{w}_{i}, l \in S \right) \right)^{-1} \mathbf{H}_{i} \mathbf{x}
\]

\[
\mathbf{V}_{i} = \beta_{i} \mathbf{V}_{i}
\]

\[
\mathbf{V}_{i} = A_{i}^{-1} \mathbf{H}_{i} \mathbf{V}_{i} + J_{i} \mathbf{V}_{i}
\]

where \(A_{i} = \sum_{j=1}^{K} \mathbf{H}_{j} \mathbf{U}_{j} \mathbf{H}_{j}\) and \(\beta_{i} = \frac{1}{\mathbf{M}'\mathbf{D}}\) stands for the normalization to satisfy the power constraint.

MSE based Transmit Precoder (Method-II)

To minimize the sum MSE subject to individual transmit power constraint can be written as

\[
\mathbf{V}_{i} = \arg \min \{ |\mathbf{V}_{i}| \} \quad \forall l \in S
\]

and for \(j \in K \setminus S\)

\[
\mathbf{V}_{i} = \arg \min \{ |\mathbf{V}_{i}| \} \quad \forall l \in S
\]

Simulation Results

MSE receiver, Rate, and Loss of DoFs

The decoder expression to minimize the kth receiver's MSE \(E_{k}\) is given as

\[
\mathbf{U}_{k} = \arg \min \mathbb{E} \left\{ |\mathbf{U}_{k} \mathbf{x}_{k} - \mathbf{x}_{k}|^{2} \right\} \mathbf{B}_{k} \mathbf{H}_{k} \mathbf{V}_{k}
\]

where \(\mathbf{B}_{k} = \sum_{j=1}^{K} \mathbf{H}_{j} \mathbf{V}_{j} \mathbf{H}_{j}^{*} + \mathbf{S} \mathbf{C}_{k}\).

Information rate expression for \(k\)th user can be obtained as

\[
R_{k} = \log \left| \mathbf{U}_{k} \mathbf{B}_{k} \mathbf{U}_{k} \right| \mathbf{U}_{k} \mathbf{B}_{k} \mathbf{U}_{k} - \mathbf{H}_{k} \mathbf{V}_{k} \mathbf{H}_{k} \mathbf{V}_{k}
\]

\[
R_{k} = \log \left| \mathbf{U}_{k} \mathbf{B}_{k} \mathbf{U}_{k} \right| \mathbf{U}_{k} \mathbf{B}_{k} \mathbf{U}_{k} - \mathbf{H}_{k} \mathbf{V}_{k} \mathbf{H}_{k} \mathbf{V}_{k}
\]

which yields that the higher \(\mathbf{U}_{k}\) is, the lower \(R_{k}\) will be. For \(k \in S\), \(\lim_{P \to \infty} R_{k} = \log \mathbf{U}_{k}\) show the loss of DoF lost these users.

Conclusion

When transmissions from two (or more users) are partially correlated, two MSE based precoding methods are derived exploiting the correlation.

In particular, first method is based on joint precoding computation, while the other computes individual user’s precoder.

With an iterative convergent procedure similar to a typical IA algorithm, simulation results verify the sum rate global convergence and the improved sum rate performance of method-II over the method-I and typical IA applied to this system.

References
