1 - Motivation & Contribution

- In cellular systems, intercell interference is present between close base stations.
- For spreading-based NOMA or OMA, intercell interference causes full collision of the spreading sequences in the code-domain.
- We propose to reduce intercell interference by employing jointly designed codebooks.
- The criterion for the design is to minimize the maximum cross-correlation between the codebooks.

2 - System Model

- For a NOMA system with spreading length \( N \), number of users \( M \), the received signal at the base station is
  \[ y = \sum_{m=1}^{M} h_m \sqrt{P_m} s_m + n , \]
  (1)
  where
  \( \quad h_m \in \mathbb{C} \ldots \) transmit symbol,
  \( \quad s_m \in \mathbb{C}^{N \times 1} \ldots \) unit-norm signature,
  \( \quad \sqrt{P_m} \in \mathbb{R}^+ \ldots \) transmit power,
  \( \quad h_m \in \mathbb{C} \ldots \) fading coefficient,
  \( \quad n \in \mathbb{C}^{N \times 1} \ldots \) noise.

- Intercell interference adds extra terms to (1) from the other cells.
- The base stations are unaware of the transmit powers of the interfering users from the interfering cells.
- From the code-domain perspective, the performance depends on the codebook of signatures defined as
  \[ S \in \mathbb{C}^{N \times M} = [s_1 \ s_2 \ldots \ s_M] . \]
  (2)

3 - Codebook Design Problem

- Instead of reusing the codebook in each cell, we assign different codebooks that are jointly designed.
- To keep the intracell interference unaffected, the codebooks need to have identical Gramians, i.e.,
  \[ S_i^H S_i - S_j^H S_j - \ldots - S_K^H S_K . \]
  (3)
- We attempt to get close to orthogonality according to some metric \( ||S_i^H S_j|| \).
- Consider the element-wise maximum norm
  \[ ||A||_{max} = \max_{i,j} ||A_{i,j}|. \]
  (4)

Applying it to our problem, we obtain
  \[ ||S_i^H S_j||_{max} = \max_{i,j} ||S_i^H S_j||_{i,j} = \max_{i,j} ||S_i^H S_j||_{i,j} \]
  (5)

This is a robust approach that minimizes the maximum cross-correlation between the codebooks.

4 - Alternating Projection

- Find codebooks \( S_1, S_2, \ldots, S_K \) such that
  \[ S_i^H S_i - S_j^H S_j \quad \text{for every } i, \]
  \[ ||S_i^H S_i||_{max} \leq \mu, \quad \text{for every } i \neq j . \]
  (6)
- Let \( \Sigma = [S_1 \ S_2 \ldots \ S_K] \). The Gramian of the codebooks is given by
  \[ G = \Sigma^H \Sigma = \begin{bmatrix} S_1^H S_1 & S_1^H S_2 & \ldots & S_1^H S_K \\ S_2^H S_1 & S_2^H S_2 & \ldots & S_2^H S_K \\ \vdots & \vdots & \ddots & \vdots \\ S_K^H S_1 & S_K^H S_2 & \ldots & S_K^H S_K \end{bmatrix} . \]
  (7)
- The properties of the Gramian matrix \( G \) from (6) can be divided into a structural constraints set
  \[ \mathcal{H} = \{ H \in \mathbb{C}^{MK \times MK} : H - H^H, \]
  \[ H_{i,i} - S_i^H S_i, \quad ||H_{i,j}||_{max} \leq \mu, \quad \text{for } i \neq j \}, \]
  (8)

and a spectral constraints set
  \[ \mathcal{G} = \{ G \in \mathbb{C}^{MK \times MK} : \text{rank}(G) = N, \]
  \[ \text{trace}(G) = MK \} \].
  (9)

We use the alternating projection algorithm to find a matrix \( G \) satisfying both constraint sets.
- The algorithm operates by iteratively solving a nearest matrix problem to each constraint set.

5 - Simulation Scenario

- Two cells with spreading length \( N = 8 \), for both NOMA and OMA systems.
- For the NOMA system, a base \( 8 \times 24 \) codebook is used. The lowest \( \mu \) found was 0.52.
- For the OMA system, a base \( 8 \times 8 \) unitary codebook is used. The lowest \( \mu \) found was 0.3536.
- The SNR of the users in the primary cell is uniformly distributed in \( [4, 20] \) dB.
- The SNR of the cell-edge user is fixed to 4 dB.
- The SNR of the users from the interfering cell at the primary base station is uniformly distributed in \( [-12, 4] \) dB.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spreading length</td>
<td>8</td>
</tr>
<tr>
<td>Number of users for NOMA</td>
<td>8, 16, 24</td>
</tr>
<tr>
<td>Number of users for OMA</td>
<td>8</td>
</tr>
<tr>
<td>Modulation</td>
<td>4-QAM</td>
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<td>Channel coding</td>
<td>Turbo, code rate 1/3</td>
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<td>Channel model</td>
<td>Flat fading</td>
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<tr>
<td>Channel estimation</td>
<td>Ideal</td>
</tr>
<tr>
<td>Multiuser Detector</td>
<td>CWL-MMSE-SIC</td>
</tr>
</tbody>
</table>

6 - Cell-Edge Performance

- The figures below show the performance of the cell-edge user for two strategies:
  - Reuse; in which the base codebook is reused in each cell.
  - Joint; in which joint codebooks are used.
- \( A_P \) and \( A_I \) are the number of active users in the primary cell and interfering cell, respectively.

\[ \text{Performance of the OMA cell-edge user for } A_P = 8 \quad (100\%), \quad \text{and } A_I = 8 \quad (100\%) . \]

\[ \text{Performance of the NOMA cell-edge user for } A_P = 24 \quad (300\%), \quad \text{and } A_I = 8, 16, 24, 100, 200, 300\% . \]

Summary

- We propose a method for reducing intercell interference in NOMA and OMA systems by using jointly designed codebooks.
- The criterion for the codebook design is to minimize the maximum cross-correlation between the codebooks.
- The performance of the cell-edge user is evaluated, in which a considerable gain is obtained.

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