Interference Alignment for High Rate Transmission in Partially Connected Multi-User Two-Way Relay Networks

Technische Universität Darmstadt, Germany
Daniel Papsdorf and Anja Klein

In cooperation with Universität Rostock, Germany
Xiang Li and Tobias Weber

ITG-Fachgruppe “Angewandte Informationstheorie“ 2015
Outline

Motivation / Objectives

Interference alignment (IA) in two-way relaying networks

Introduction of a partially connected network

Proposed algorithm

Simulation results

Summary
Motivation / Objectives

- Bidirectional communication via intermediate half-duplex relays
- Direct links between the nodes not utilized

**Full connected network**

- All relays are connected to all nodes
- All relays can help to perform IA in the whole network
- Requires global CSI

**Partially connected network**

- Not all nodes are connected to all relays ⇒ Less interference
- Not all relays can help to perform IA in the whole network
- Requires local CSI
IA in two-way relaying networks
Concept of signal alignment

▶ **Signal alignment:** The communication partners transmit their signal to the relay such that the signals of each communication pair are aligned.

\[
\text{span} \left( H_{j1}^{sr} V_j \right) = \text{span} \left( H_{k1}^{sr} V_k \right)
\]

▶ **Assumption:** Self interference can be canceled
Channel alignment: Each communication pair designs its receive filters such that the effective channels span the same subspace.

\[ \text{span} \left( \mathbf{H}_{j1}^{rdH} \mathbf{U}_j \right) = \text{span} \left( \mathbf{H}_{k1}^{rdH} \mathbf{U}_k \right) \]
Transceive zero forcing: The relay filter is designed such that all aligned links are orthogonal.

\[ I = H_{\text{eff}q}^{\text{BC}} \cdot G_q \cdot H_{\text{eff}q}^{\text{MAC}} \]
**System model**

**Partially connected network**

- Not all nodes are connected to all relays
- Some nodes are connected to multiple relays
- The network consists of partially connected subnetworks
  - Subnetwork = \{ Relay; connected node-pairs \}
- Nodes inside the intersection area belong to more than one subnetwork

\[ j_k : j \] is the node-number and \( k \) its communication partner

\[ q \] : \( q \) is the relay-number
Proposed algorithm
One possible solution

- Most challenging part is the handling of the nodes inside the intersection area
- Each relay serves all connected node pairs
- Nodes inside an intersection area will be served by two relays
- Assumption: Only pairs of nodes are connected to a relay

\( j_k : j \) is the node-number and \( k \) is its communication partner
\( q \) is the relay-number
Proposed algorithm
Simultaneous Signal Alignment (SSA)

Performed in the multiple access (MAC) phase

- Signal alignment at relay $q$:
  \[
  \text{span} \left( H_{j,q}^s r V_j, q \right) = \text{span} \left( H_{k,q}^s r V_k, q \right)
  \]

- Results in solution space $N_1$

- Signal alignment at relay $\tilde{q}$:
  \[
  \text{span} \left( H_{j,\tilde{q}}^s r V_j, \tilde{q} \right) = \text{span} \left( H_{k,\tilde{q}}^s r V_k, \tilde{q} \right)
  \]

- Results in solution space $N_2$

- Solutions selected form $N_{\text{int}}$ results in SSA at both relays simultaneously
  \[ N_{\text{int}} = N_1 \cap N_2 \]

- Transmit spaces have to be large enough
Proposed algorithm
Simultaneous Channel Alignment (SCA)

Performed in the broadcast (BC) phase

▶ Signal and channel alignment are dual problems

▶ Determination of the solution space is similar to determining the SA solution space.
Proposed algorithm
Transceive zero forcing (TRxZF)

Receive zero forcing matrix
\[ G_{q}^{RX H} = \left( H_{\text{eff}q}^{\text{MAC}} \right)^{-1} \]
- Square matrix
- Non-singular

Transmit zero forcing matrix
\[ G_{q}^{TX} = \left( H_{\text{eff}q}^{\text{BC}} \right)^{-1} \]
- Square matrix
- Non-singular

Relay processing matrix
\[ G_{q} = G_{q}^{TX} \cdot G_{q}^{RX H} = \left( H_{\text{eff}q}^{\text{MAC}} \cdot H_{\text{eff}q}^{\text{BC}} \right)^{-1} \]
Proposed algorithm
Counting the required dimensions of signal space (CDSS)

- Number of relay antennas:
  - Number of effective data streams
    \[ R_q = \frac{1}{2} |\mathcal{K}(q)| d \]

- Number of antennas at each node:
  - connected to relay \( q \):
    \[ N_k \geq \frac{R_q + d}{2} \]
  - connected to relay \( q \) and \( \tilde{q} \):
    \[ N_k \geq \frac{R_q + R_{\tilde{q}} + d}{2} \]
  - Large enough, such that a communication pair can select a common subspace at the common relay space
  - Optimization is possible, if \( N_k \) is larger than the minimum required number

\( d \): Data streams
\( |\mathcal{K}(q)| \): Nodes connected to relay \( q \)
\( R_q \): Antennas at each relay
\( N_k \): Antennas at each node
Required CSI

- Required CSI at the nodes:
  - Determined by SSA and SCA
  - Channels to all connected relays
  - local CSI at the nodes, to achieve IA

- Required CSI at the relays:
  - Determined by TRxZF
  - Effective channels of all nodes which are connected to a certain relay
  - local CSI at the relays, to achieve IA
Simulation results
Reference method

Proposed method
- Simultaneous signal and channel alignment in a partially connected network (SSCP_closed)
- Nodes inside an intersection area will be served by several relays

Reference method
- Signal and channel alignment in a partially connected network (SCP_closed)
- Nodes inside an intersection area will only be served by one relay
- The other relay treats these signals as interference and suppresses it

$j_k$ : $j$ is the node-number and $k$: its communication partner
$q$ : $q$ is the relay-number
Simulation results

Number of relays: $Q = 4$, Number of node antennas: $N = 5$,
Number of data streams per node: $d = 1$

- $K = 12$ pairs can be served
- $K = 8$ pairs can be served
- $K = 12$ pairs can be served

**SSCP\_closed** ($K=12; R=4$)

**SCP\_closed** ($K=8; R=4$)

**SCP\_closed** ($K=12; R=5$)

: $j$ is the node-number and $k$ its communication partner
: $q$ is the relay-number

average sum rate [bit/s/Hz]

$P/\sigma^2$ [dB]

29-04-2015 | Institut für Nachrichtentechnik | Communications Engineering Lab | D. Papsdorf | 15
A partially connected network was introduced

The new techniques called simultaneous signal and channel alignment were introduced to perform signal and channel alignment at multiple relays simultaneously

Closed form solution was presented
  - Requires only local CSI
  - Requires less antennas at the relays than the reference method
  - Serves more communication pairs than the reference method

Properness conditions was derived

Thank you for your attention!