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

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Outline

Motivation / Objectives

Interference alignment (IA) in two-way relaying networks

Introduction of a partially connected network

Proposed algorithm

Simulation results

Summary

Motivation / Objectives

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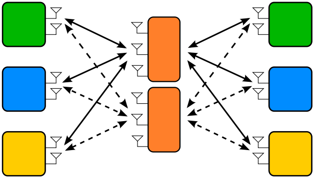
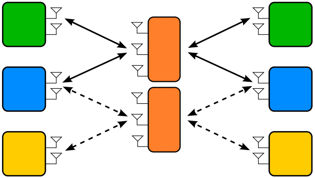
- Bidirectional communication via intermediate half-duplex relays
- Direct links between the nodes not utilized



Full connected network

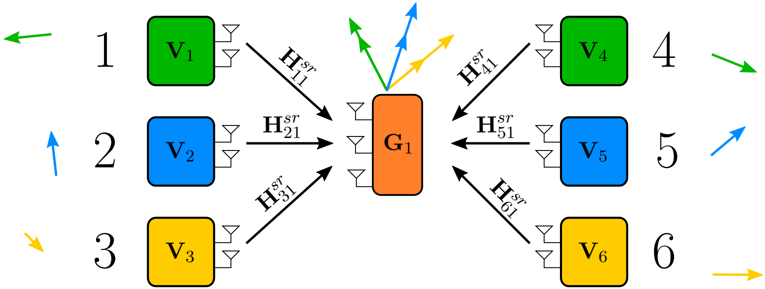
- All relays are connected to all nodes
- All relays can help to perform IA in the whole network
- Requires global CSI



Partially connected network

- Not all nodes are connected to all relays $\Rightarrow$ 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

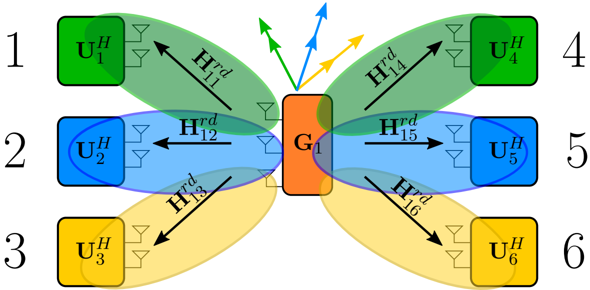


- **Signal alignment:** The communication partners transmit their signal to the relay such that the signals of each communication pair are aligned.

$$\text{span}\left(\mathbf{H}_{j1}^{sr}\mathbf{V}_j\right) = \text{span}\left(\mathbf{H}_{k1}^{sr}\mathbf{V}_k\right)$$

- **Assumption:** Self interference can be canceled

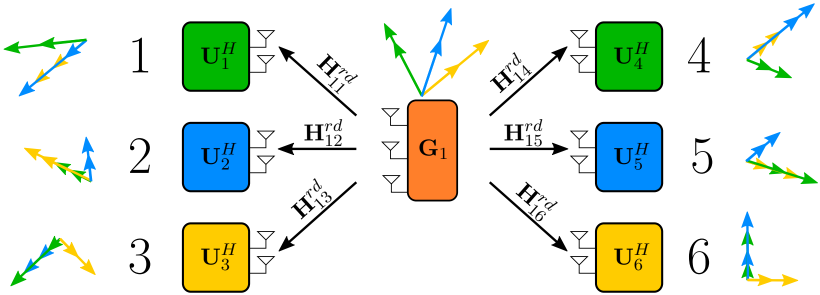
IA in two-way relaying networks
Concept of channel alignment



- **Channel alignment:** Each communication pair designs its receive filters such that the effective channels span the same subspace.

$$\text{span}\left(\mathbf{H}_{j1}^{\text{rdH}}\mathbf{U}_j\right) = \text{span}\left(\mathbf{H}_{k1}^{\text{rdH}}\mathbf{U}_k\right)$$

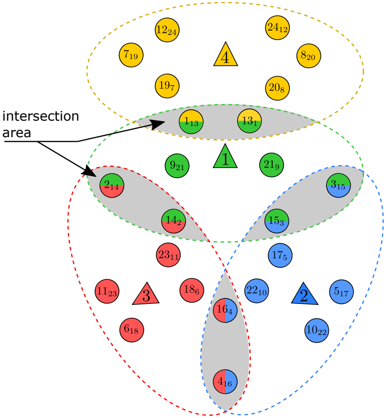
IA in two-way relaying networks
Transceive zero forcing



- **Transceive zero forcing:** The relay filter is designed such that all aligned links are orthogonal.

$$\mathbf{I} = \mathbf{H}_{\text{eff}q}^{\text{BC}} \cdot \mathbf{G}_q \cdot \mathbf{H}_{\text{eff}q}^{\text{MAC}}$$

System model
Partially connected network



j_k : j is the node-number and k its communication partner

q : q is the relay-number

- 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

Proposed algorithm
One possible solution

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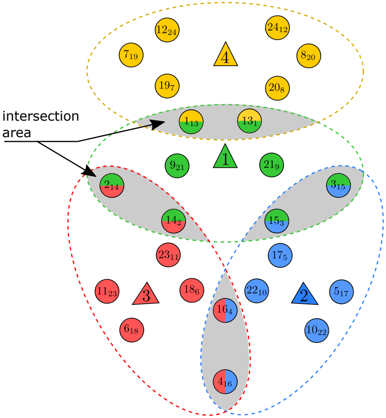

j_k : j is the node-number and k its communication partner

q : q is the relay-number

- 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

Proposed algorithm
Simultaneous Signal Alignment (SSA)

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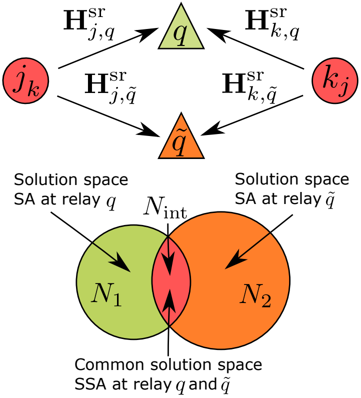

Performed in the multiple access (MAC) phase

- Signal alignment at relay q:
  $\mathrm{span}\left(\mathbf{H}^{\mathrm{sr}}_{j,q}\mathbf{V}_{j,q}\right) = \mathrm{span}\left(\mathbf{H}^{\mathrm{sr}}_{k,q}\mathbf{V}_{k,q}\right)$
- Results in solution space N_1

- Signal alignment at relay $\tilde{q}$:
  $\mathrm{span}\left(\mathbf{H}^{\mathrm{sr}}_{j,\tilde{q}}\mathbf{V}_{j,\tilde{q}}\right) = \mathrm{span}\left(\mathbf{H}^{\mathrm{sr}}_{k,\tilde{q}}\mathbf{V}_{k,\tilde{q}}\right)$
- Results in solution space N_2

- Solutions selected form N_{int} results in SSA at both relays simultaneously
  $N_{\mathrm{int}} = N_1 \cap N_2$
- Transmit spaces have to be large enough

Proposed algorithm
Simultaneous Channel Alignment (SCA)

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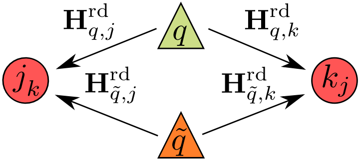
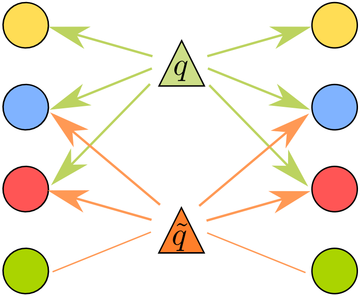


Performed in the broadcast (BC) phase

- 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
  $\mathbf{G}_q^{\mathrm{RX\,H}} = \left(\mathbf{H}_{\mathrm{eff}q}^{\mathrm{MAC}}\right)^{-1}$
  - Square matrix
  - Non-singular
- Transmit zero forcing matrix
  $\mathbf{G}_q^{\mathrm{TX}} = \left(\mathbf{H}_{\mathrm{eff}q}^{\mathrm{BC}}\right)^{-1}$
  - Square matrix
  - Non-singular
- Relay processing matrix
  $\mathbf{G}_q = \mathbf{G}_q^{\mathrm{TX}} \cdot \mathbf{G}_q^{\mathrm{RX\,H}} = \left(\mathbf{H}_{\mathrm{eff}q}^{\mathrm{MAC}} \cdot \mathbf{H}_{\mathrm{eff}q}^{\mathrm{BC}}\right)^{-1}$

Proposed algorithm
Counting the required dimensions of signal space (CDSS)

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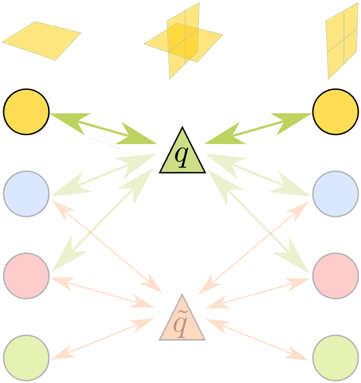

d: Data streams
$|\mathcal{K}(q)|$: Nodes connected to relay q
R_q: Antennas at each relay
N_k: Antennas at each node

- 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

Required CSI

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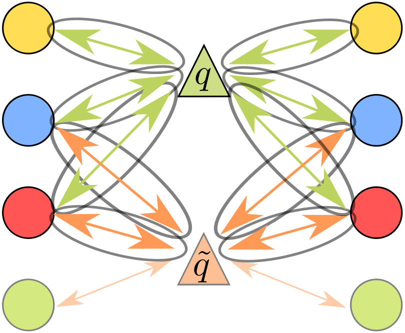
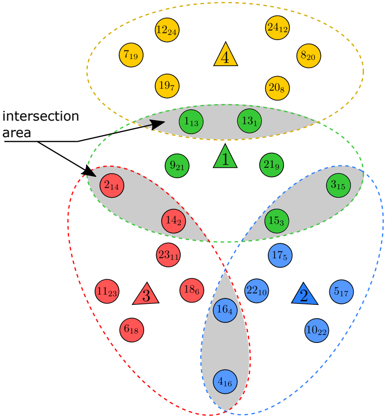


- Required CSI at the nodes:
  - Determined by SSA and SCA
  - Channels to all connected relays
  - **local CSI at the nodes**, to achieve IA
- Required CSI at the relays:
  - Determined by TRxZF
  - Effective channels of all nodes which are connected to a certain relay
  - **local CSI at the relays**, to achieve IA

Simulation results
Reference method



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

(q) : q is the relay-number

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

Simulation results

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

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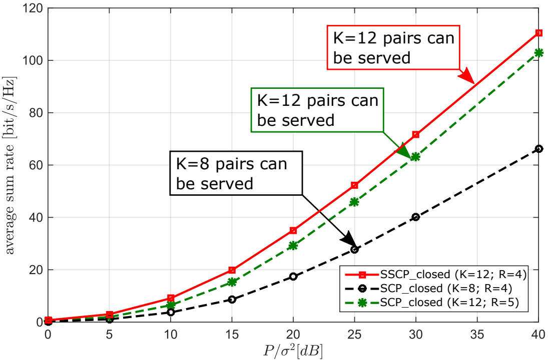

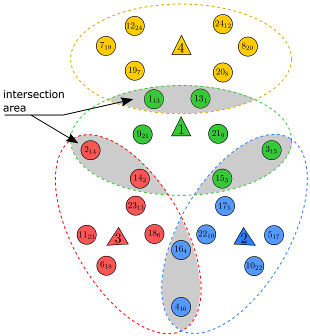

j_k : j is the node-number and k its communication partner

q : q is the relay-number

Summary

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- 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!