Linear Processing for Two-Way Relay Systems with 2x2 STBC

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Jingon Joung
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Communication Scenario

- **Two-way relay system**

  ![Two-Way communications diagram](image)

  - Two source nodes (sensors) want to exchange their own data
  - **1st step**: two source nodes transmit to relay node
  - **2nd step**: relay node retransmission
    - Amplification and forward (AF)
    - Decode and forward (DF)
    - Etc.
  - **3rd step**: two source nodes receive the retransmitted signal

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Motivation

- For the AF relay
  - Simple linear processing can improve system performance
  - For two source nodes employing STBC
System and Signal Model

● System model

Source Node 1 (SN1)

\[ S_1 = \begin{bmatrix} x_1 & x_2^* \\ x_2 & -x_1^* \end{bmatrix} \]

Source Node 2 (SN2)

\[ S_2 = \begin{bmatrix} x_3 & x_4^* \\ x_4 & -x_3^* \end{bmatrix} \]

Time slot 2t

Processing with \( W \)

Time slot 2t+1

● Signal model

■ Channel matrices

\[ H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \quad G = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \]

■ Transmitted STBC signal

\[ S_1 = \begin{bmatrix} x_1 & x_2^* \\ x_2 & -x_1^* \end{bmatrix} \quad S_2 = \begin{bmatrix} x_3 & x_4^* \\ x_4 & -x_3^* \end{bmatrix} \]
Relaying And Detection

- **Received signal at the RN**
  \[
  Y_R = HS_1 + G^T S_2 + N_R \quad \text{Linear Processing with } W \quad \rightarrow \quad WY_R
  \]

- **Received signal at the SNs**
  - **At SN1**
    \[
    Y_1 = H^T W^T Y_R + R_1
    = H^T W^T (HS_1 + G^T S_2 + N_R) + N_1
    \]
  - **At SN2**
    \[
    Y_2 = GW (HS_1 + G^T S_2 + N_R) + N_2
    \]

- **SNs can cancel self-interference**
  \[
  \bar{Y}_1 = H^T W^T G^T S_2 + H^T W^T N_R + N_1
  \]
  \[
  \bar{Y}_2 = GW HS_1 + GWN_R + N_2
  \]
Proposed Preprocessing $W$

- Signal model rewritten
  - Received signal model
    \[ \bar{Y}_1 = F^T S_2 + Z_1, \quad \bar{Y}_2 = FS_1 + Z_2 \]
  - Effective channel matrix $F = GWH$
  - Colored noise plus AWGN $Z_1 = H^T W^T N_R + N_1$, $Z_2 = GWN_R + N_2$

- Designing of $W$
  - To avoid noise enhancement $WW^H = I_2$
  - Maximize the received SNR
    - For the SN1 and the SN2
      \[ W_1 = \max_{w_1} \left( \frac{E\left[ \|F^T S_1\|_F^2 \right]}{E\left[ \|Z_1\|_1^2 \right]} \right) \]
      \[ W_2 = \max_{w_2} \left( \frac{E\left[ \|FS_2\|_F^2 \right]}{E\left[ \|Z_2\|_1^2 \right]} \right) \]
      \[ E\left[ \|F^T S_1\|_F^2 \right] = E\left[ \|FS_2\|_F^2 \right] \]
      Independent on $W$ (see the Appendix in paper)
Optimization Problems

- **Cost function**
  \[ \|F\|_F^2 = tr \left( F^H F \right) = tr \left( H^H W^H G^H G W H \right) \]
  - Convex with respect to \( W \)

- **Optimal linear processing**
  \[ W = \max_W \left( \|F\|_F^2 \right) \]
  - Returns only one out of possible many global maximizers
  - Just rewritten as follows:
  \[ W = \max_{W \in \Upsilon} \left( \|F\|_F^2 \right) \]
  - \( \Upsilon \) is a unitary matrix set
Simulation Environments

- **Assumption**
  - Channel state information is perfect at each node

- **BER simulation environment**
  - 2x2 STBC used
  - SNRs of SN and RN are termed $\text{SNR}_{SN}$ and $\text{SNR}_{RN}$, respectively
  - Relay processing unitary matrices

\[
\mathcal{Y}_2 = \left\{ \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \right\},
\]

\[
\mathcal{Y}_4 = \left\{ \mathcal{Y}_2, \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}, \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \right\},
\]

\[
\mathcal{Y}_8 = \left\{ \mathcal{Y}_4, \begin{bmatrix} 1 & 0 \\ 0 & j \end{bmatrix}, \begin{bmatrix} -1 & 0 \\ 0 & j \end{bmatrix}, \begin{bmatrix} 0 & 1 \\ j & 0 \end{bmatrix}, \begin{bmatrix} 0 & -1 \\ j & 0 \end{bmatrix} \right\}.
\]
Simulation Results (1/2)

- BER comparison w/o processing and w/ processing in $\Upsilon_4$

![Graphs showing BER comparison with and without processing for different SNR values.](image-url)
Simulation Results (2/2)

- BER comparison with respect to the preprocessing

![Graph](image)

- $SNR_{SN} = 3$ dB, $SNR_{RN} = 6$ dB
- $SNR_{SN} = 6$ dB, $SNR_{RN} = 9$ dB
- $SNR_{SN} = 9$ dB, $SNR_{RN} = 12$ dB
Conclusion & Further Work

**Conclusion**
- Linear processing at the RN
- Under the perfect CSI the proposed system achieve better BER performance

**Further work**
- Channel estimation
- Find an unique or optimal set of linear processing matrix