

Precoding Decision for Full-Duplex X-Relay Channel with Decode-and-Forward

Themistoklis Charalambous*, Ioannis Krikidis[‡], and Mikael Johansson*

*Department of Automatic Control, Royal Institute of Technology (KTH)

[‡]Department of Electrical and Computer Engineering, University of Cyprus



International Wireless Communications and Mobile Computing Conference (IWCMC '14)
Nicosia, Cyprus, 4-8 August 2014

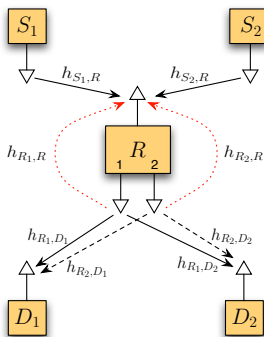
- 1 Motivation - Introduction
- 2 System model
- 3 Precoding matrix design
- 4 Main results: Precoding decision
- 5 Illustrative example
- 6 Concluding remarks and future directions

- Full-duplex (FD) relaying resolves the problem of bandwidth loss associated with half-duplex (HD)
- FD suffers from the interference caused from the relay output to the relay input
- Most of work done on FD relaying deals with the mitigation of the Loop Interference (LI)
- Interference Cancellation (IC) techniques do not completely remove LI → residual LI components remain
- To further mitigate the effects of LI, signal processing techniques, such as precoding design, have been investigated

- X-relay channel: a basic network structure extensively studied when the relay is HD
- We study the precoding problem for an X-relay configuration with a FD relay
- Limited spatial degrees at the relay node and partial instantaneous channel state information (CSI)
- Relay node *cannot* perform real-time switchings of the precoding matrix (forced by strict hardware/complexity constraints)
- Design constraints \rightarrow static precoding decision with only statistical knowledge of the channel conditions

System Model

- simple X-relay configuration: 2 sources, 2 destinations, and a relay
- a direct link from the sources to the destinations is not available
- relay node operates in a FD mode and employs a DF strategy
- sources access channel simultaneously and transmit with r_0 BPCU
- multi-packet reception channel (probabilistic receptions of simultaneously transmitted packets)



- LI is generated at R input and a MUI is generated at D_1 and D_2

- interferences affect the decoding performance of the system
- goal is to design a precoding matrix $\mathbf{T} \in \mathbb{C}^{2 \times 2}$

$$\mathbf{T} = \begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix}$$

that eliminate either the LI or the MUI

- Loop Interference Cancellation (LIC):

$$(h_{R_1,R} \quad h_{R_2,R}) \begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix} = (0 \quad 0) \Rightarrow \mathbf{T} = \begin{pmatrix} \alpha_1 & \alpha_1 \\ \alpha_2 & \alpha_2 \end{pmatrix}$$

where $\alpha_i, i = \{1, 2\}$ are constants

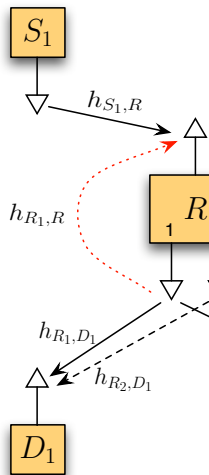
- Multi-User Interference Cancellation (MUIC):

$$\underbrace{\begin{pmatrix} h_{R_1,D_1} & h_{R_2,D_1} \\ h_{R_1,D_2} & h_{R_2,D_2} \end{pmatrix}}_{\mathbf{H}} \begin{pmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{pmatrix} = \begin{pmatrix} \beta_1 & 0 \\ 0 & \beta_2 \end{pmatrix} \Rightarrow \mathbf{T} = \underbrace{\mathbf{H}^H (\mathbf{H}\mathbf{H}^H)^{-1}}_{\text{zero-forcing precoder}}$$

where $\beta_i, i = \{1, 2\}$ are constants

Markov chain representation

Definition of events



$$A_1 \triangleq \{R \text{ decodes } x_1[n], x_2[n] \text{ with LI}\}$$

$$A_2 \triangleq \{R \text{ decodes } x_1[n], x_2[n] \text{ without LI}\}$$

$$B_1 \triangleq \{D_1 \text{ decodes } x_1[n] \text{ with MUI}\}$$

$$B_2 \triangleq \{D_1 \text{ decodes } x_1[n] \text{ without MUI}\}$$

$$V_1 \triangleq \{\text{precoding matrix } \mathbf{T} \text{ suppresses LI}\}$$

$$V_2 \triangleq \{\text{precoding matrix } \mathbf{T} \text{ suppresses MUI}\}$$

$$Y \triangleq \{R \text{ decodes } x_1[n-1], x_2[n-1]\}$$

$$B \triangleq \{D_1 \text{ decodes } x_1[n-1]\}$$

Markov chain representation

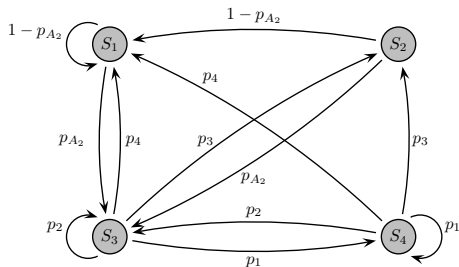
Definition of events

$S_1 = \{00\}$ neither the relay nor the destinations have decoded a signal

$S_2 = \{01\}$ the relay didn't decode the received signal but the destinations did

$S_3 = \{10\}$ the relay only decodes a signal

$S_4 = \{11\}$ both the relay and the destinations decode the received signals



$$\mathbf{M} = \begin{pmatrix} 1 - p_{A_2} & 1 - p_{A_2} & p_4 & p_4 \\ 0 & 0 & p_3 & p_3 \\ p_{A_2} & p_{A_2} & p_2 & p_2 \\ 0 & 0 & p_1 & p_1 \end{pmatrix}$$

$$\mathbb{P}(Y \cap B|Y) \triangleq p_1, \mathbb{P}(Y \cap \bar{B}|Y) \triangleq p_2, \mathbb{P}(\bar{Y} \cap B|Y) \triangleq p_3 \text{ and } \mathbb{P}(\bar{Y} \cap \bar{B}|Y) \triangleq p_4$$

Proposition

The Markov chain \mathbf{M} is Stochastic, Indecomposable and Aperiodic (SIA).

Markov chain representation

Outage probability

- Probabilities p_1 , p_2 , p_3 and p_4

$$p_1 = (1 - v)p_{A_2}p_{B_1} + vp_{A_1}p_{B_2}$$

$$p_2 = (1 - v)p_{A_2}(1 - p_{B_1}) + vp_{A_1}(1 - p_{B_2})$$

$$p_3 = (1 - v)(1 - p_{A_2})p_{B_1} + v(1 - p_{A_1})p_{B_2}$$

$$p_4 = 1 - (p_1 + p_2 + p_3)$$

where v is the probability that the precoding matrix \mathbf{T} suppresses MUI

- The event of outage is given by

$$E = (\bar{Y} \cap \bar{A}_2) \cup Y \cap \left[\left[v_1 \cap (\bar{A}_2 \cup (A_2 \cap \bar{B}_1)) \right] \cup \left[v_2 \cap (\bar{A}_1 \cup (A_1 \cap \bar{B}_2)) \right] \right]$$

- The outage probability is given by

$$\mathbb{P}(E) = 1 - p_{A_2} + p_{A_2} \frac{p_{A_2}(1 - p_{B_1}) + v(p_{A_2}p_{B_1} - p_{A_1}p_{B_2})}{1 + v(p_{A_2} - p_{A_1})}$$

Precoding decision

The decision is the result of the following minimization problem

$$\min_{v \in [0,1]} \mathbb{P}(E) \equiv \min_{v \in [0,1]} \frac{\rho_{A_2}(1 - \rho_{B_1}) + v(\rho_{A_2}\rho_{B_1} - \rho_{A_1}\rho_{B_2})}{1 + v(\rho_{A_2} - \rho_{A_1})}$$

Main Theorem

Given the probabilities ρ_{A_1} , ρ_{A_2} , ρ_{B_1} and ρ_{B_2} , the outage probability of the system $\mathbb{P}(E)$ is minimized if for

- 1 $\rho_{A_2}\rho_{B_1} - \rho_{A_1}\rho_{B_2} > \rho_{A_2}(1 - \rho_{B_1})(\rho_{A_2} - \rho_{A_1})$
the precoding matrix suppresses the loop interference
- 2 $\rho_{A_2}\rho_{B_1} - \rho_{A_1}\rho_{B_2} < \rho_{A_2}(1 - \rho_{B_1})(\rho_{A_2} - \rho_{A_1})$
the precoding matrix suppresses the multi-user interference

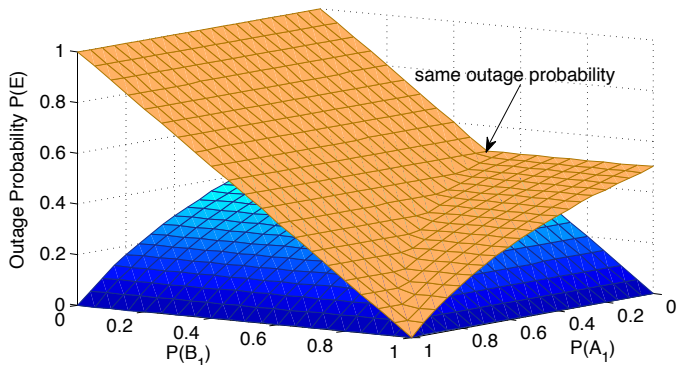
When $\rho_{A_2}\rho_{B_1} - \rho_{A_1}\rho_{B_2} = \rho_{A_2}(1 - \rho_{B_1})(\rho_{A_2} - \rho_{A_1})$ any choice of precoding matrix yields the same results.

Remark:

The theorem provides *easily verifiable conditions* that do not require complex calculations and full knowledge of the channel states

Illustrative example

- $p_{A_2} = p_{B_2} = 1$
- $p(A_1)$ and $p(B_1)$ vary



- when $p_{A_2}p_{B_1} - p_{A_1}p_{B_2} = p_{A_2}(1 - p_{B_1})(p_{A_2} - p_{A_1})$ choice of precoding does not matter

Conclusions:

- simple X-relay configuration was studied:
 - shared relay operates in FD mode
 - not able to handle both the LI and the MUI due to critical energy/complexity/bandwidth constraints
- system formulated as a Markov chain:
 - outage probability was derived in close form
 - precoding decision as an *optimization parameter*
- precoding decision is made based only on statistical knowledge of the channel conditions

Future work:

- 1 study the achievable rates of this setup, which is essentially limited by the bottleneck link
- 2 investigate the case in which the relay can dynamically choose to cancel either the LI or the MUI



Questions?

For more information:

themisc@kth.se

krikidis@ucy.ac.cy

mikaelj@kth.se