SINR Optimization in Wideband Full-Duplex MIMO Relays under Limited Dynamic Range

Aalto University
School of Electrical Engineering

Emilio Antonio-Rodríguez[†⋆], **Roberto López-Valcarce**[†]
Taneli Riihonen[⋆], **Stefan Werner**[⋆] and **Risto Wichman**[⋆]

[†]Department of Signal Theory and Communications, University of Vigo, Vigo, Spain
[⋆]Department of Signal Processing and Acoustics, Aalto University, Helsinki, Finland

Universidade de Vigo

INTRODUCTION

- We consider a full-duplex MIMO decode-and-forward relay with:
  - **limited dynamic range** at receive and transmit side.
  - **self-interference** due to simultaneous reception and transmission.
- We propose a cancellation-suppression design that aims to:
  - maximize the **signal-to-interference-plus-noise** ratio at the relay.
  - control the **distortion** in the **relay-destination** link.

SYSTEM MODEL

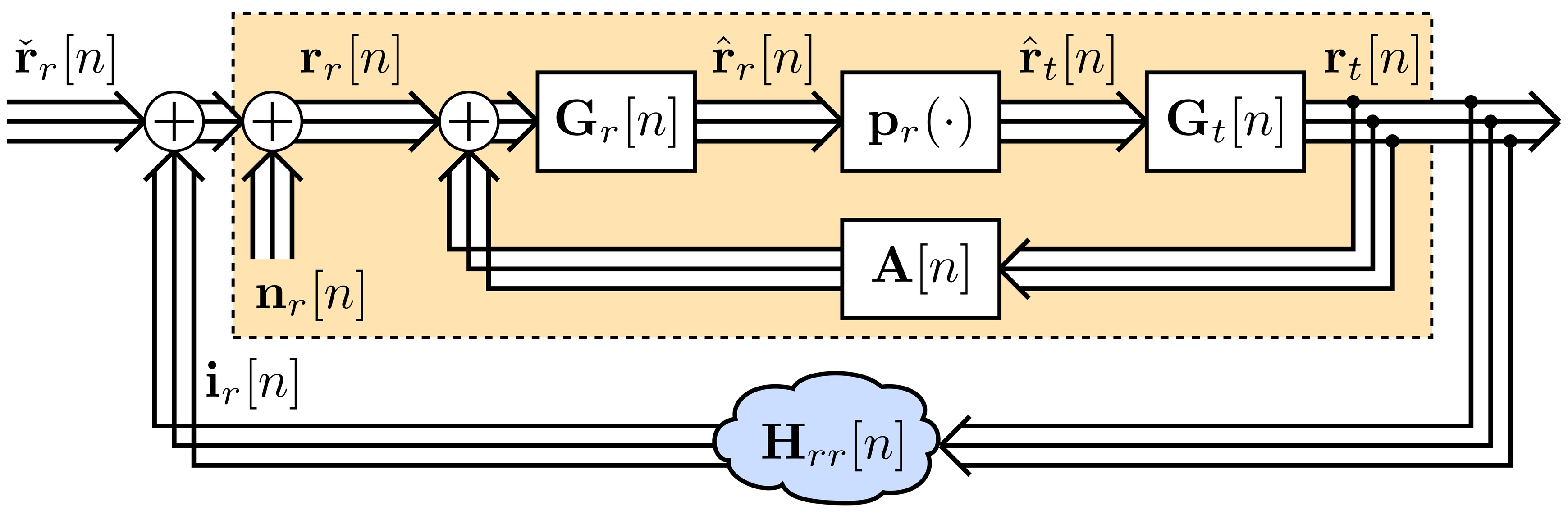

Figure: System model of a relay incorporating the cancellation-suppression architecture.

- The link consists of a source node ($\mathcal{S}$), a relay node ($\mathcal{R}$), and a destination node ($\mathcal{D}$) with the following characteristics:
  - $\mathcal{S}$ has M_t transmit antennas and transmits $\mathbf{s}_t[n]$.
  - $\mathcal{D}$ has M_r receive antennas and receives $\mathbf{d}_r[n]$.
  - $\mathcal{R}$ has N_r receive antennas and N_t transmit antennas, and transmits $\mathbf{r}_t[n]$ while receiving $\mathbf{r}_r[n]$.
- The received signal at $\mathcal{R}$ consists of the the information signal $\check{\mathbf{r}}_r[n] = \mathbf{H}_{sr}[n] \star \mathbf{s}_t[n]$, the self-interference $\mathbf{i}_r[n] = \mathbf{H}_{rr}[n] \star \mathbf{r}_t[n]$ and the noise $\mathbf{n}_r[n]$:

$$\mathbf{n}_r[n] = \mathbf{n}_i[n] + \mathbf{v}_r[n] + \mathbf{H}_{rr}[n] \star \mathbf{v}_t[n] \tag{1}$$

where $\mathbf{n}_i[n] \sim \mathcal{CN}(\mathbf{0}, \sigma^2\mathbf{I})$ is the receiver input noise, $\mathbf{v}_t[n] \sim \mathcal{CN}(\mathbf{0}, \delta \operatorname{diag} \mathbb{E}\{\mathbf{r}_t[n]\mathbf{r}_t^H[n]\})$ models transmitter imperfections, and $\mathbf{v}_r[n] \sim \mathcal{CN}(\mathbf{0}, \gamma \operatorname{diag} \mathbb{E}\{\mathbf{r}_c[n]\mathbf{r}_c^H[n]\})$, with $\mathbf{r}_c[n] = \mathbf{r}_r[n] - \mathbf{v}_r[n]$, models receiver dynamic range.

PROBLEM SETTING AND DESIGN

- The cancellation-suppression architecture consists of the L_a-th order cancellation filter $\mathbf{A}[n]$, the L_r-th order filter $\mathbf{G}_r[n]$ and the L_t-th order filter $\mathbf{G}_t[n]$.
- The signal-to-interference-plus-noise ratio after processing is defined as

$$\mathrm{SINR}_{\mathcal{R}} = \frac{\mathbb{E}\{\|\mathbf{G}_r[n] \star \check{\mathbf{r}}_r[n]\|^2\}}{\mathbb{E}\{\|\mathbf{G}_r[n] \star \mathbf{n}_r[n] + \mathbf{G}_r[n] \star (\mathbf{A}[n] + \mathbf{H}_{rr}[n]) \star \mathbf{G}_t[n] \star \hat{\mathbf{r}}_t[n]\|^2\}}$$

- Filters $\mathbf{A}[n]$, $\mathbf{G}_r[n]$ and $\mathbf{G}_t[n]$ are designed as the solution to the problem:

$$\begin{aligned} \underset{\mathbf{A}[n],\mathbf{G}_t[n],\mathbf{G}_r[n]}{\text{maximize}} \quad & \mathrm{SINR}_{\mathcal{R}} \\ \text{subject to} \quad & \mathbb{E}\{\|\mathbf{r}_t[n]\|^2\} \leq P_{max} \end{aligned} \tag{2}$$

- The solution for $\mathbf{A}[n]$ is $\mathbf{A}[n] = -\mathbf{H}_{rr}[n]$.
- We decouple $\mathbf{G}_t[n]$ and $\mathbf{G}_r[n]$ by designing $\mathbf{G}_t[n]$ as the solution to

$$\begin{aligned} \underset{\mathbf{G}_t[n]}{\text{minimize}} \quad & \mathbb{E}\{\|\mathbf{i}_r[n]\|^2\} + \mathbb{E}\{\|\mathbf{H}_{rr}[n] \star \mathbf{v}_t[n]\|^2\} \\ \text{subject to} \quad & \mathbf{H}_{rd}[n] \star \mathbf{G}_t[n] = \mathbf{H}_{rd}^{(eq)}[n] \\ & \mathbb{E}\{\|\mathbf{r}_t[n]\|^2\} \leq P_{max} \end{aligned} \tag{3}$$

- Linear constraints preclude trivial solutions and control the distortion in the relay-destination link.

DESIGN

- Problem (3) is equivalent to

$$\begin{aligned} \underset{\mathbf{g}_t}{\text{minimize}} \quad & \mathbf{g}_t^H(\mathbf{P}_i + \mathbf{R}_i)\mathbf{g}_t \\ \text{subject to} \quad & \mathbf{H}_{rd}\mathbf{g}_t = \mathbf{h}_{rd}^{(eq)} \\ & \mathbf{g}_t^H \mathbf{R} \mathbf{g}_t \leq P_{max} \end{aligned} \tag{4}$$

- After some calculations, problem (4) can be expressed as a standard linear least squares with inequality constraints. For a feasible solution we require that $N_t > M_r$ and $L_t > (M_r L_{rd}/(N_t - M_r)) - 1$.
- Finally, $\mathbf{G}_r[n]$ is designed as the solution to

$$\underset{\mathbf{g}_r}{\text{maximize}} \quad \frac{\mathbf{g}_r^H \mathbf{P}_r \mathbf{g}_r}{\mathbf{g}_r^H \mathbf{P}_n \mathbf{g}_r} \tag{5}$$

- Problem (5) is recognized as a generalized eigenvalue problem.

SIMULATIONS AND RESULTS

- The simulations have the following parameters:
  - $m_s = m_r = M_r = M_t = 2$.
  - 64-QAM OFDM with 8192 subcarriers, a cyclic prefix length of $1/4$ and an oversampling factor of 2.
  - $\mathbf{H}_{sr}[n]$, $\mathbf{H}_{rd}[n]$ and $\mathbf{H}_{rr}[n]$ have orders $L_{sr} = L_{rd} = L_{rr} = 2$ and gains of 0, 0 and 30 dB, respectively. Additionally, $L_a = L_{rr} = L_t = L_r = 2$ and $P_{max} = 20$ dB.
  - $$\mathbf{H}_{rd}^{(eq)}[n] = \begin{cases} \mathbf{I}, & n = 0 \\ \mathbf{0}, & n \neq 0 \end{cases}$$

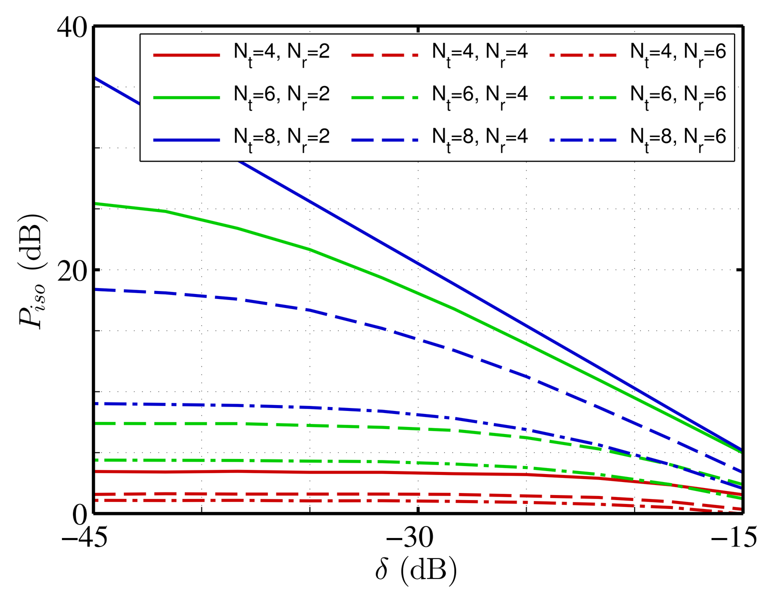

Figure: Self-interference power isolation in terms of the noise level at the transmitter.

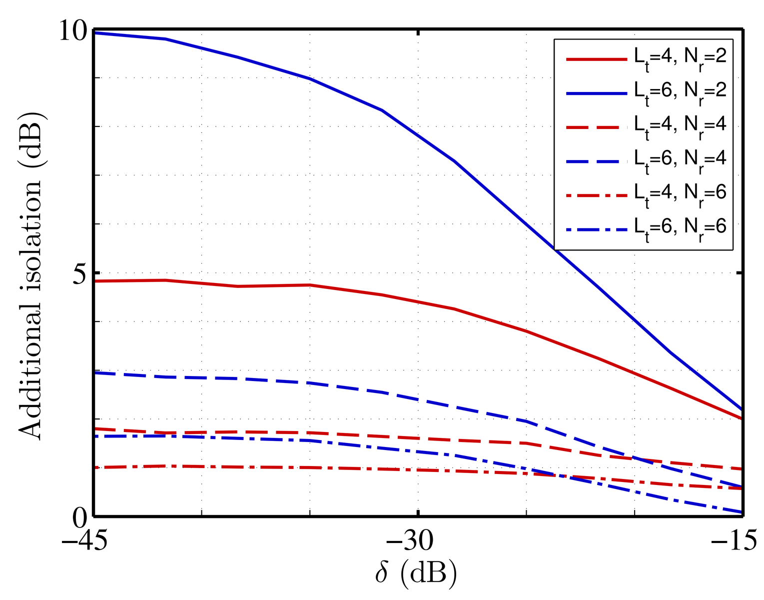

Figure: Additional isolation in terms of the noise level at the transmitter for different orders of $\mathbf{G}_r[n]$.

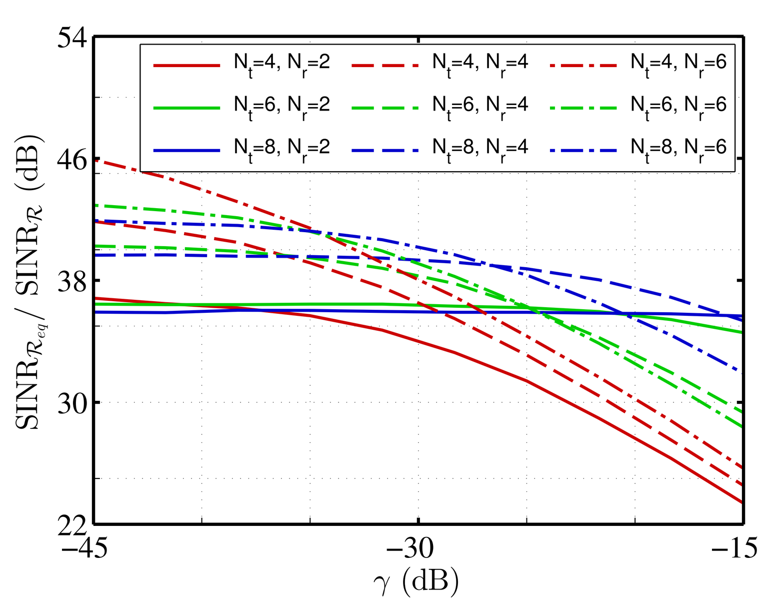

Figure: SINR improvement in terms of the dynamic range of the receiver.

Contact: emilio.antoniorodriguez@aalto.fi, valcarce@gts.uvigo.es, risto.wichman@aalto.fi