Aalto University
School of Electrical Engineering

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

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

- **Motivation:** To take advantage of the full-duplex operation, self-interference must be mitigated.
- **Problem:** Limited dynamic range at reception and transmission impairments complicate the design.
- The self-interference mitigation method should not impact the relay normal operation.
- **Solution:** We propose a self-interference mitigation method, based on linear filtering, for full-duplex relays under limited dynamic range:
  - Our method maximizes the **signal-to-interference-plus-noise** ratio by using combined spatial and time filtering.
  - Our method causes no impact on the system operation by imposing constraints into the design.

SYSTEM MODEL

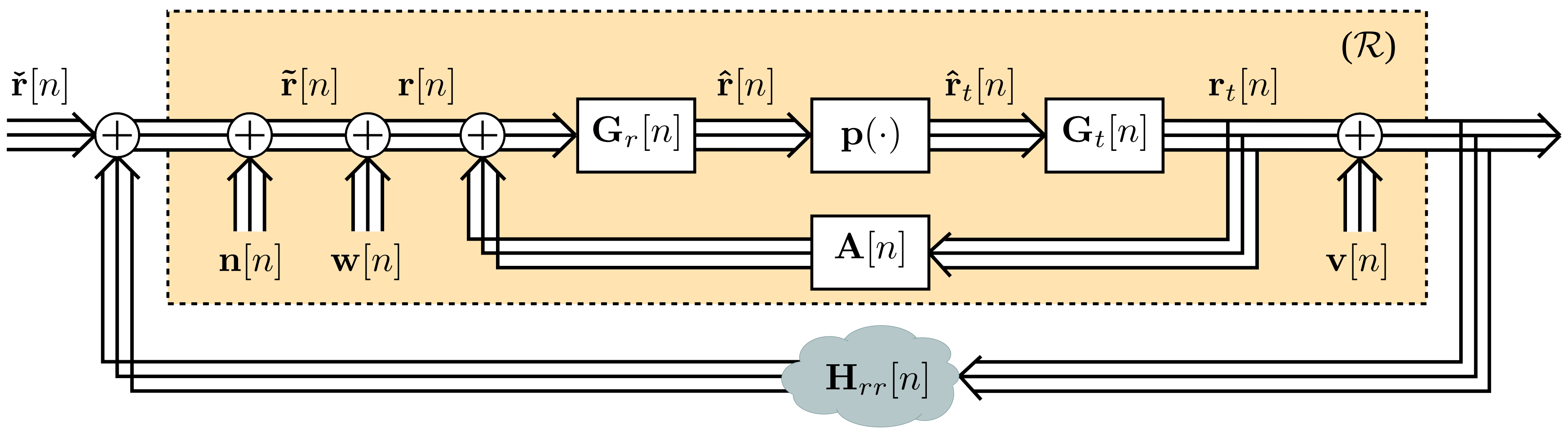

Figure 1: Full-duplex relay with self-interference mitigation.

- The link consists of source ($\mathcal{S}$), relay ($\mathcal{R}$) and destination ($\mathcal{D}$) nodes:
  - $\mathcal{R}$ has N_r receive antennas and N_t transmit antennas. $\mathcal{S}$ has M_t antennas while $\mathcal{D}$ has M_r antennas.
  - $\check{\mathbf{r}}[n]$ is the received signal at $\mathcal{R}$ from $\mathcal{S}$ and $\mathbf{r}_t[n]$ is the transmitted signal.
  - $\mathbf{r}[n]$ is the signal after digital conversion.
- The received signal at $\mathcal{R}$ consists of the the information signal $\check{\mathbf{r}}[n] = \mathbf{H}_{sr}[n] \star \mathbf{s}[n]$, the self-interference $\mathbf{i}[n] = \mathbf{H}_{rr}[n] \star \mathbf{r}_t[n]$ and the noise $\mathbf{n}_r[n]$:

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

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

PROBLEM SETTING AND DESIGN

- The mitigation 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

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

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

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

- The solution for $\mathbf{A}[n]$ is $\mathbf{A}[n] = -\mathbf{H}_{rr}[n]$. Filters $\mathbf{G}_r[n]$ and $\mathbf{G}_t[n]$ are obtained using an **alternating optimization technique**.
- For a fixed $\mathbf{G}_t[n]$, $\mathbf{G}_r[n]$ is designed as the solution to the following generalized eigenvalue problem

$$\underset{\mathbf{g}_r}{\text{maximize}} \ \frac{\mathbf{g}_r^H \mathbf{P}_r \mathbf{g}_r}{\mathbf{g}_r^H \mathbf{P}_n \mathbf{g}_r} \tag{3}$$

- Design of $\mathbf{G}_t[n]$ should avoid the trivial solution $\mathbf{G}_t[n] = \mathbf{0}$ while controlling the distortion over the $\mathcal{R}$-$\mathcal{D}$ channel.

DESIGN

- We impose the following constraints on $\mathbf{G}_t[n]$:
  - Channel shortening constraints.
  - Power delivered at $\mathcal{D}$.
- Channel shortening constraints are expressed as $\mathbf{H}_{rd}(\tau)\mathbf{g}_t = \mathbf{0}$, where τ denotes the order of $\mathbf{H}_{rd}[n] \star \mathbf{G}_t[n]$ and $N_t(L_t+1) > M_r(L_{eq} - \tau)$.
- Additionally, $\mathbf{G}_t[n]$ ensures that the power delivered at $\mathcal{D}$ is a fraction α of the maximum deliverable power. The design problem of $\mathbf{G}_t[n]$ transforms into

$$\begin{aligned} &\underset{\mathbf{q}}{\text{minimize}} \ \mathbf{q}^H \mathbf{P}_{eq} \mathbf{q} \\ &\text{subject to} \ \|\mathbf{q}\|^2 = p_{max} \end{aligned} \tag{4}$$

- Vector $\mathbf{q}$ is related to $\mathbf{g}_t$ through a projection into the constraints subspace, and p_{max} ensures that the relay transmits at full power.

SIMULATIONS AND RESULTS

- The simulations have the following parameters:
  - $M_r = M_t = 2$, $N_t = 4$ and $N_r = 2$.
  - 64-QAM OFDM with 8192 subcarriers, a cyclic prefix length of $1/4$ symbol and an oversampling factor of 2. Transmit noise $\delta = -30$ dB.
  - $\mathbf{H}_{sr}[n]$, $\mathbf{H}_{rd}[n]$ and $\mathbf{H}_{rr}[n]$ have order $L_{sr} = L_{rd} = L_{rr} = 2$ and gain of 0, 0 and 30 dB, while $L_a = L_{rr} = L_t = L_r = 2$ and $P_{max} = 20$ dB.
  - We compare performance with our previous method in [1].

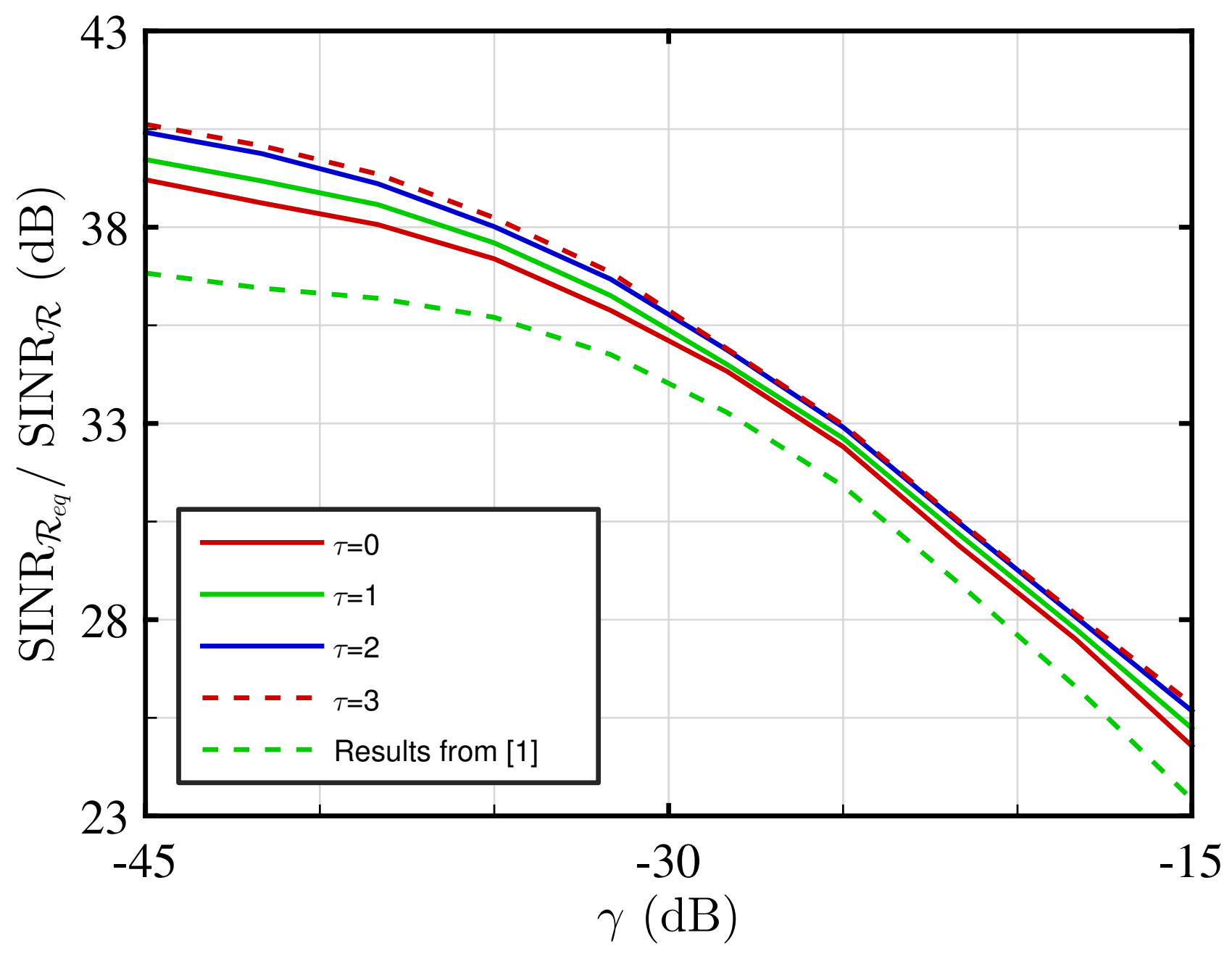

Figure 2: SNR improvement in terms of the dynamic range and the $\mathcal{R}$-$\mathcal{D}$ channel memory.

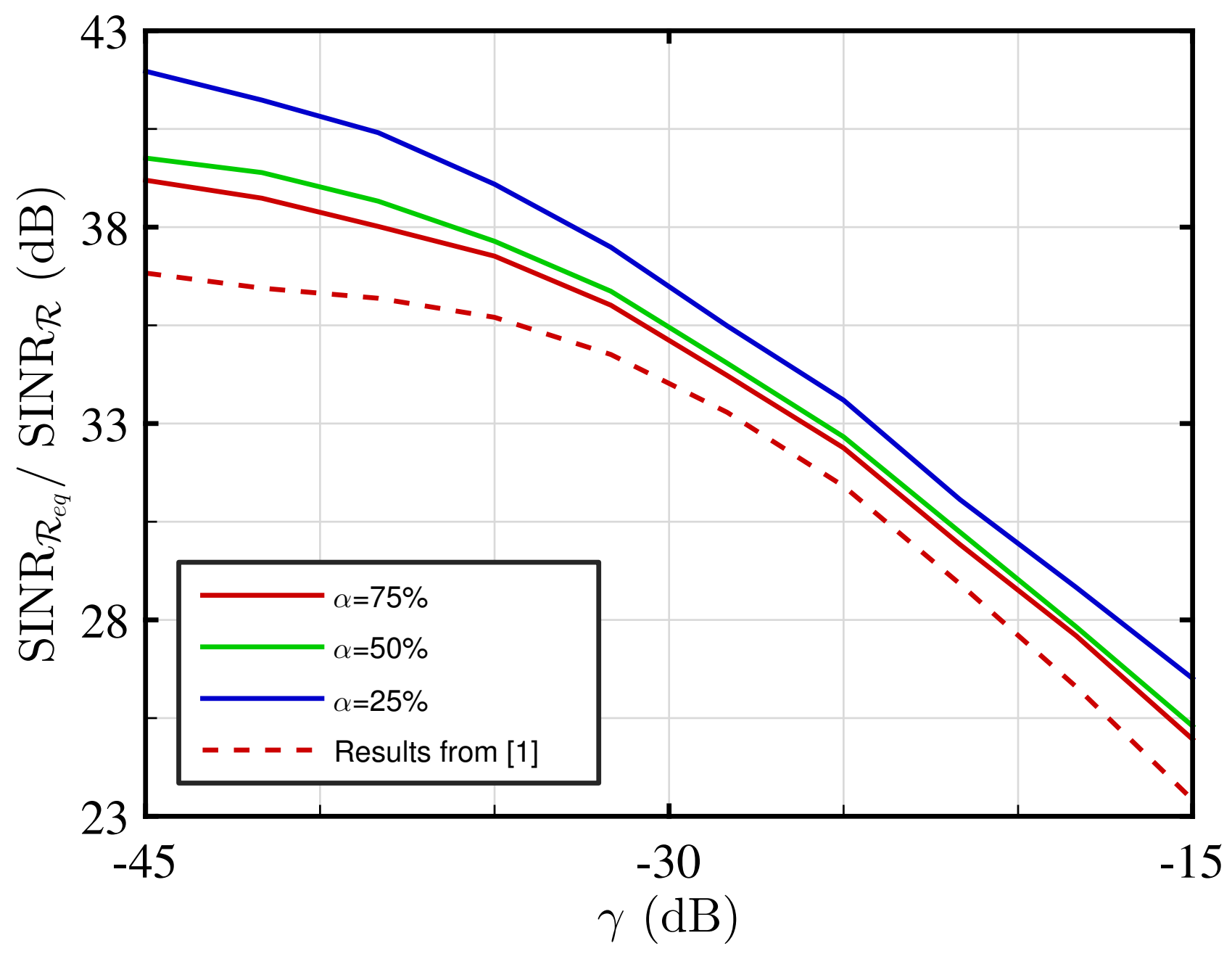

Figure 3: SNR improvement in terms of the dynamic range and the delivered power at $\mathcal{D}$.

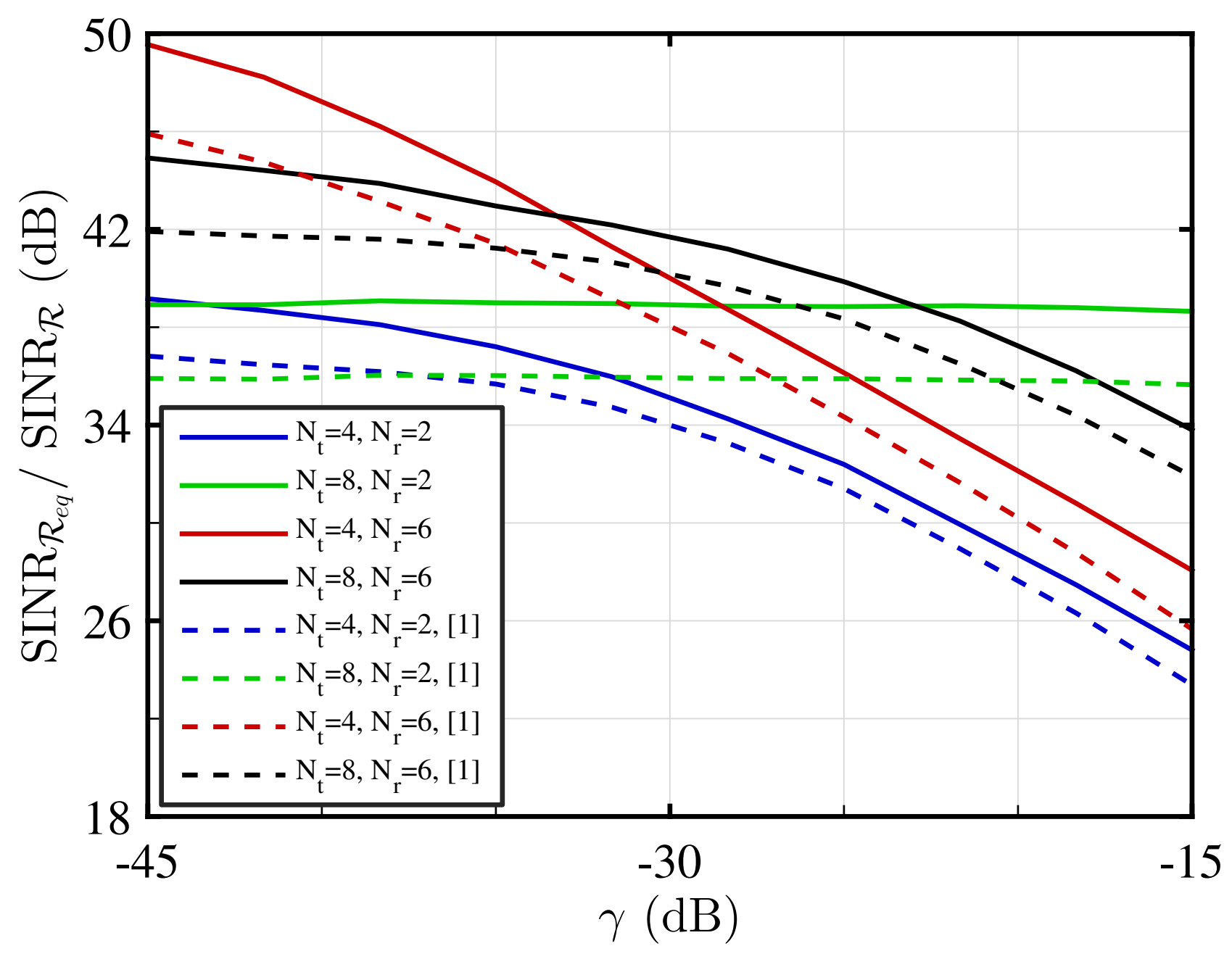

Figure 4: SINR improvement in terms of the dynamic range and the antennas of $\mathcal{R}$.

- [1]. E. Antonio-Rodríguez, R. López-Valcarce, T. Riihonen, S. Werner, and R. Wichman, *SINR optimization in wideband full-duplex MIMO relays under limited dynamic range*, Proc. IEEE Sensor Array and Multichannel Signal Process. Workshop (SAM), Jun. 2014.