Aalto University
School of Electrical Engineering

Autocorrelation-based Adaptation Rule for Feedback Equalization in Wideband Full-Duplex Amplify-and-Forward MIMO Relays

UNIVERSIDADE DE VIGO

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

SYSTEM MODEL

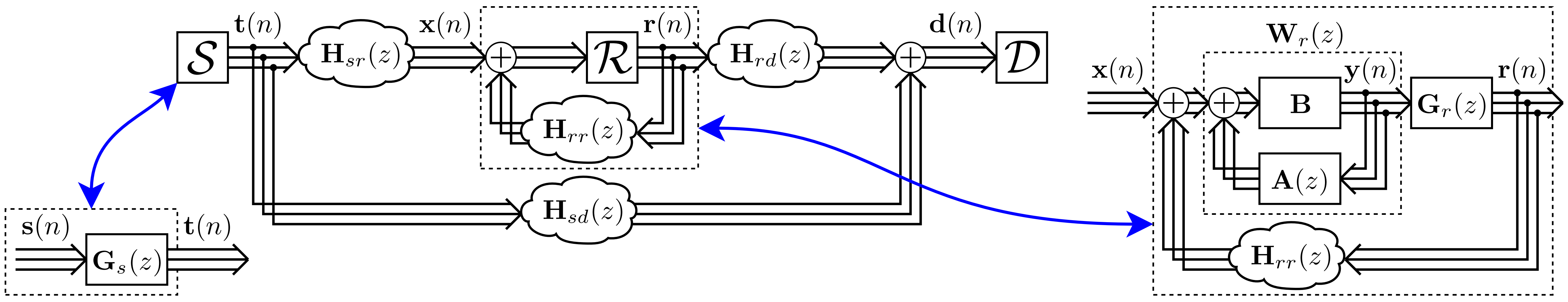


Figure: System model of a full-duplex amplify-and-forward relay with self-interference mitigation and channel equalization.

INTRODUCTION

- **Relays** allow for an extended network **coverage** and increased network **performance**, especially within single-frequency networks (SFN). Among the different relay types, **full-duplex** relays transmit and receive **simultaneously**, which translates into:
  - Higher **spectral efficiency** than half-duplex relays.
  - **Self-interference** at the relay receive side.
- Self-interference at the relay can **dramatically** reduce the relay **performance** if its power is high enough. Consequently **mitigation** of this distortion is required. We propose:
  - a self-interference mitigation **method** for full-duplex amplify-and-forward MIMO relays.
- Our method has the following characteristics:
  - it is **adaptive**, so it can keep track of environment changes.
  - it only requires **statistical** information of the source signal.
  - it introduces **no** extra **delay** in the relay processing.
  - it can **equalize** the source-relay channel.

PROBLEM SETTING AND MITIGATION METHOD

- The system model consists of a **source** ($\mathcal{S}$), a **relay** ($\mathcal{R}$) and a **destination** ($\mathcal{D}$), with the following characteristics:
  - $\mathcal{S}$ transmits M_s streams using M_t antennas.
  - $\mathcal{R}$ has M_s receive and M_r transmit antennas.
  - the proposed equalizer is $\mathbf{W}_r(z) = (\mathbf{I} - \mathbf{B}\mathbf{A}(z))^{-1}\mathbf{B}$, with $\mathbf{B}$ and $\mathbf{A}(z)$ being $M_s \times M_s$ matrices.
- The relay response from $\mathbf{x}(n)$ to $\mathbf{y}(n)$ is $\mathbf{H}_{xy}(z) = (\mathbf{I} - \mathbf{W}_r(z)\mathbf{H}_{rr}(z)\mathbf{G}_r(z))^{-1}\mathbf{W}_r(z)$. Self-interference is eliminated $\mathbf{W}_r(z) = (\mathbf{I} + \mathbf{H}_{rr}(z)\mathbf{G}_r(z))^{-1}$.
- $\mathbf{W}_r(z)$ has enough degrees of freedom to additionally equalize $\mathbf{H}_{sr}(z)\mathbf{G}_t(z)$, so we have $\mathbf{y}(n) = \mathbf{s}(n-\delta)$.
- In order to achieve such desirable equalization, we adapt $\mathbf{B}$ and $\mathbf{A}(z)$ using the following rule:

$$\boxed{\begin{aligned}\mathbf{A}[k](n+1) &= \mathbf{A}[k](n) + \mu_a(\mathbf{R}_\star[k] - \mathbf{y}(n)\mathbf{y}^H(n-k))\\ \mathbf{B}(n+1) &= \mathbf{B}(n) + \mu_b(\mathbf{R}_\star[0] - \mathbf{y}(n)\mathbf{y}^H(n))\end{aligned}}$$

for $k = 0, \ldots, L_a$, with L_a being the order of $\mathbf{W}_r(z)$ and step-sizes $\mu_a > 0$ and $\mu_b > 0$. The algorithm only makes use of the side information $\mathbf{R}_\star[k] = \mathbb{E}\{\mathbf{s}(n)\mathbf{s}^H(n-k)\}$.

CONCLUSIONS I

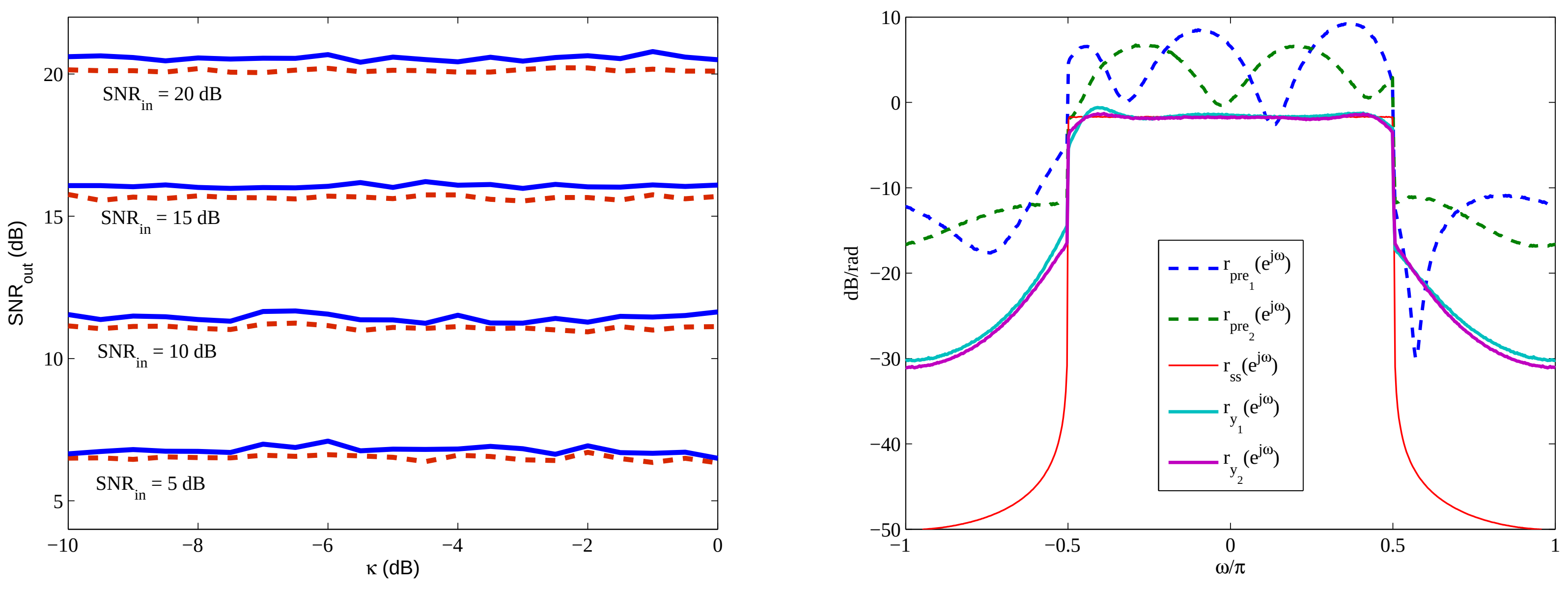
- The proposed method **solves** the problem of self-interference mitigation in amplify-and-forward MIMO full-duplex relays by using only **statistical** information of the source signal as **side information**.
- **Simulations** show that our method **improves** the output **SNR** for a wide range of self-interference power levels.

ALGORITHM ANALYSIS

- Upon convergence, and assuming sufficient order L_a, any stationary point will satisfy:
  - $\mathbf{H}_{xy}(z) = \mathbf{\Sigma}(z)\mathbf{V}\mathbf{\Gamma}^{-1}(z)$, with $\mathbf{\Sigma}(z)$ and $\mathbf{\Gamma}(z)$ being the minimum phase factors of $\mathbf{s}(n)$ and $\mathbf{x}(n)$, respectively. $\mathbf{V}$ is a unitary matrix.
  - $\mathbf{y}(n)$ can be thought of as $\mathbf{s}(n)$ being filtered by a pre-whitening filter $\mathbf{\Gamma}^{-1}(z)$, followed by a undetermined spatial rotation $\mathbf{V}$, and a conformation filter $\mathbf{\Sigma}(z)$.
  - Assuming that $\mathbf{H}_{sr}(z)\mathbf{G}_t(z)$ is minimum-phase and $\mathbf{\Sigma}(z) = \sigma\mathbf{I}$, we can explicitly state that $\mathbf{H}_{sy}(z) = \mathbf{V}$ and, consequently, the algorithm is able of self-interference **mitigation** and channel **equalization**.

SIMULATION RESULTS

- Simulation parameters:
  - We use $M_s = 2$ independent streams of an OFDM-modulated source signal with $N_{sub} = 8192$ subcarriers and $1/4N_{sub}$ cyclic prefix length. An oversampling factor of 2 is used at the input and output of $\mathbf{W}_r(z)$.
  - Sufficient-order case with $L_a = 4$, SNR$_{in}$ = 10 dB and $\kappa = -5$ dB (ratio between information signal and self-interference signal powers).



(a) SNR$_{out}$ as function of κ and SNR$_{in}$.

(b) Restoration of reference psd.

- Figure (a) shows the relation between SNR$_{in}$ and SNR$_{out}$ as a function of κ. We see that the algorithm always **improves** the signal-to-noise ratio of the system, i.e. SNR$_{out}$/SNR$_{in}$ > 1, and the **improvement** is bigger for lower SNR$_{in}$.
- Figure (b) shows the resulting spectrum after convergence of the algorithm, and how the algorithm is effectively capable of mitigating the self-interference signal and channel equalization while improving the SNR$_{in}$ (note the spectrum ripples caused by the self-interference signal and the $\mathcal{S} - \mathcal{R}$ channel).

CONCLUSIONS II

- In addition to self-interference mitigation, our method is able of **equalizing** the source-relay channel up to of a mere **spatial rotation**.
- Note that due to the structure of $\mathbf{W}_r(z)$, **no** extra **delay** is introduced into the system, and therefore **not increasing** the network **latency**.

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