Adaptive Self-interference Cancellation in Wideband Full-Duplex Decode-and-Forward MIMO Relays

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SYSTEM MODEL

- System model consists of a **source** ($\mathcal{S}$), a **relay** ($\mathcal{R}$) and a **destination** ($\mathcal{D}$).
  - $\mathcal{S}$ transmits M_s streams using M_t antennas.
  - $\mathcal{R}$ has N_r receive and M_r transmit antennas.
  - The decoder, $f_r(\cdot)$, retrieves M_s the streams.
  - $\mathbf{G}_s(z)$ and $\mathbf{G}_r(z)$ are linear precoding matrices.

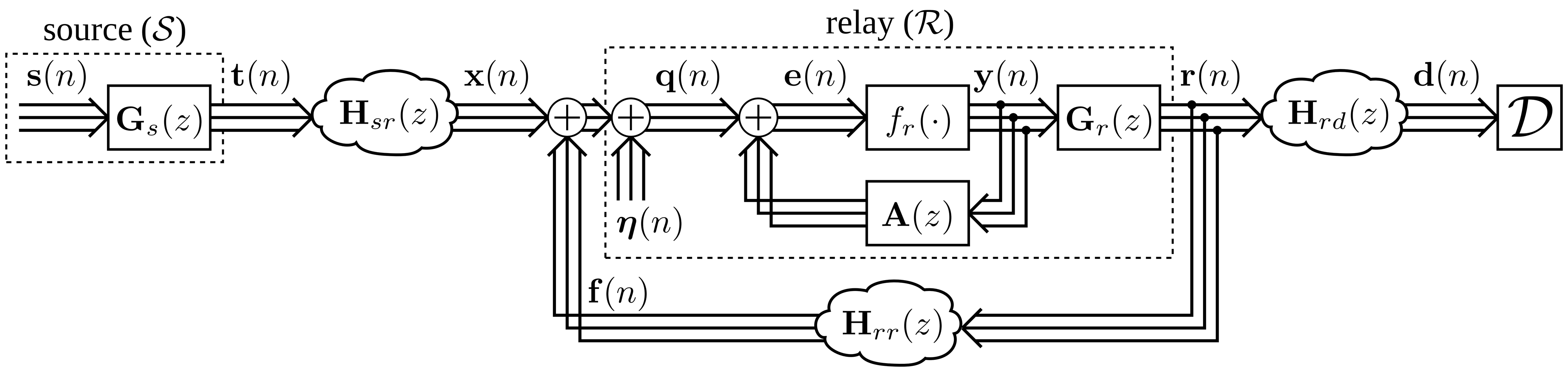


Figure : System model of a full-duplex decode-and-forward relay with self-interference mitigation.

INTRODUCTION

- **Full-duplex relays** are used to extend network **coverage** and increase network **performance**.
  - Higher **spectral efficiency** than half-duplex relays.
  - **Self-interference** due to simultaneous reception and transmission.
- Self-interference can **degrade** the relay performance. We propose a **mitigation method** that
  - introduces **no** extra **delay** in the relay.
  - works **independently** of the **relay protocol**.
  - is **adaptive**, so it can continuously update and refine the estimation.

PROBLEM SETTING AND MITIGATION METHOD

- The signal $\mathbf{y}(n)$ couples back into the relay through $\mathbf{H}_{rr}(z)\mathbf{G}_r(z)$ and interferes with $\mathbf{x}(n)$.
- Signal-to-interference ratio, SIR, can be very low.

Self-interference must be mitigated

- We assume a decoding delay such that $\mathbb{E}\{\mathbf{t}(n)\mathbf{y}^H(n-k)\} \approx \mathbf{0}$, for any $k > 0$.
- We propose an adaptive filter, $\mathbf{A}(z)$, for self-interference mitigation.
- Cancellation filter $\mathbf{A}(z)$ should identify $\mathbf{H}_{rr}(z)\mathbf{G}_r(z)$.
- The proposed adaptation rule for $\mathbf{A}(z)$ is

$$\mathbf{A}[k](n+1) = \mathbf{A}[k](n) + \mu_a(\mathbf{R}_\star[k] - \mathbf{e}(n)\mathbf{y}^H(n-k))$$

for $k = 0, \ldots, L_a$, with L_a being the order of $\mathbf{A}(z)$, and $\mu_a > 0$ being the step-size. Matrix $\mathbf{R}_\star[k]$ is a predefined bias term.

ALGORITHM ANALYSIS

- Upon convergence, any stationary point satisfies

$$\mathbf{A}_\star\mathbf{R}_Y^{(L_a,L_a)} + \mathbf{H}\mathbf{R}_Y^{(L_{eq},L_a)} = \mathbf{R}_\star$$

where $\mathbf{A}_\star = [\mathbf{A}_\star[0] \cdots \mathbf{A}_\star[L_a]]$. $\mathbf{H}$ and $\mathbf{R}$ are analogous defined. Matrix $\mathbf{H}(z) = \mathbf{H}_{rr}(z)\mathbf{G}_r(z)$ is of order L_{eq}. Additionally,

$$\mathbf{R}_Y^{(\alpha,\beta)} = \begin{pmatrix} \mathbf{R}_{yy}[0] & \cdots & \mathbf{R}_{yy}[\beta] \\ \vdots & \ddots & \vdots \\ \mathbf{R}_{yy}[-\alpha] & \cdots & \mathbf{R}_{yy}[\beta-\alpha] \end{pmatrix}$$

with $\mathbf{R}_{yy}[k]$ is the autocorrelation of $\mathbf{y}(n)$ at lag k.

- We can distinguish the following cases:
  - *Undermodeled case* ($L_a < L_{eq}$): algorithm converges to a biased solution.

$$\mathbf{A}_\star = -\mathbf{H}_L + (\mathbf{R} - \mathbf{H}_U\mathbf{D}_Y^{(L_{eq},L_a)})(\mathbf{R}_Y^{(L_a,L_a)})^{-1}$$

  - *Sufficient order case* ($L_a \geq L_{eq}$): algorithm converges to $\mathbf{A}_\star = \mathbf{H}$ by using $\mathbf{R}[k] = \mathbf{0}$. It is equivalent to a gradient descent.

ALGORITHM ANALYSIS (continued)

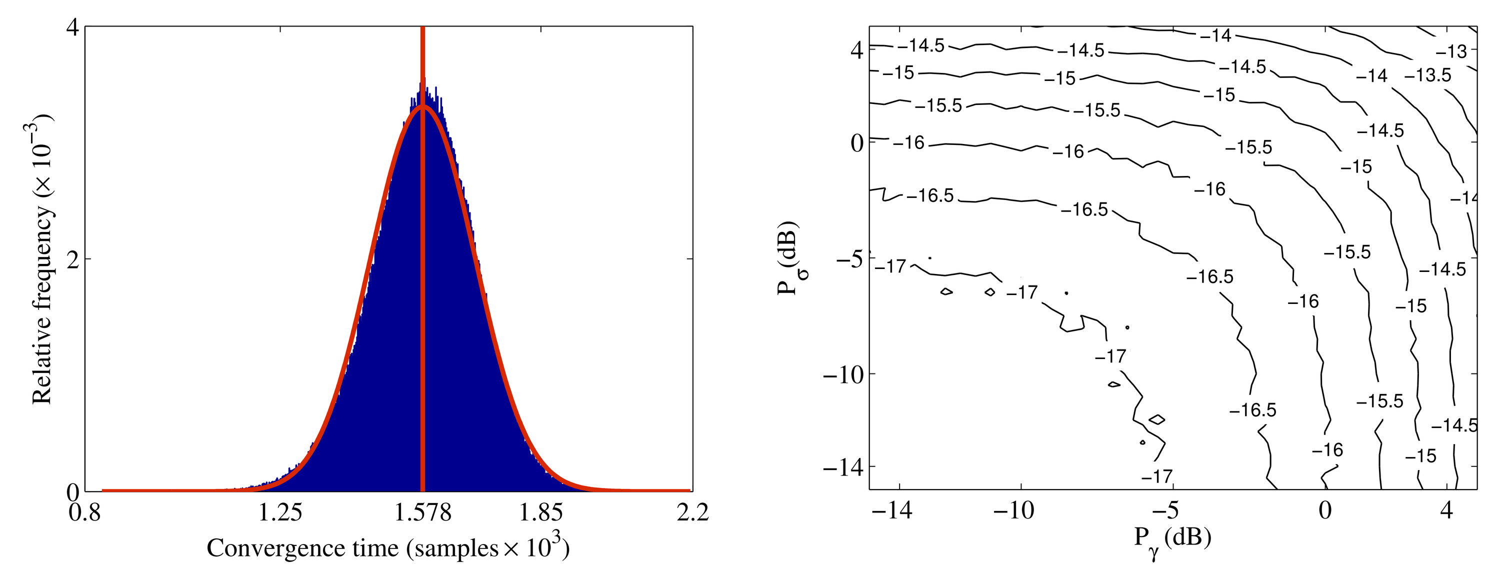
  - *Singular case* ($\mathbf{R}_Y^{(L_a,L_a)}$ rank-deficient): multiple solutions. The bias can be reduced by selecting $\mathbf{R}_\star[k](n) = \sum_{i=0}^{L_a}\mathbf{A}[i](n)\boldsymbol{\Theta}_{ik}$ as the solution of

$$\underset{\boldsymbol{\Theta}}{\text{minimize}} \;\; \text{tr}\{\mathbf{H}_{res}\mathbf{R}_Y^{(L_a,L_a)}\mathbf{H}_{res}^H\}$$
$$\text{subject to} \;\; \text{rank}\{\mathbf{R}_Y^{(L_a,L_a)} - \boldsymbol{\Theta}\} = M_s(L_a+1)$$

- In all the above cases, the algorithm is **globally convergent** regardless of the initialization and $\mathbf{R}[k]$.

SIMULATION RESULTS

- $M_s = 2$ OFDM independent streams with $N_{sub} = 8192$ subcarriers and cyclic prefix length $1/4N_{sub}$.
- $N_r = 4$, $M_r = 3$, $P_x = 0$ dB and $\mu_a = 10^{-3}$.
- Sufficient order case, $L_a = 2$.



(a) Convergence time distribution (in samples).

(b) residual self-interference after mitigation.

- Figure (a) shows the samples needed from initialization $\mathbf{A}(0) = \mathbf{0}$ to $||\mathbf{A}(\tau) + \mathbf{H}||_F/||\mathbf{H}||_F < -25$ dB. $\text{SIR}_{pre} = -20$ dB and SNR $= 3.8$ dB.
  - **Convergence time** lies within the **cyclic prefix**.
- Figure (b) shows the **residual self-interference** power after mitigation. $\text{SIR}_{pre} = -20$ dB and SNR is variable.
  - More than **30 dB** of **mitigation** is attained with a single OFDM symbol and more than **46 dB** with 15 symbols. Residual self-interference is **below noise** level.

CONCLUSIONS

- **No** extra **delay** is introduced into the system, which is critical for network **latency**.
- The relay decoder is **decoupled** from the mitigation method, which **eases** the relay **design**.
- Algorithm convergence is **fast** enough to suit a wideband **OFDM** system. Algorithm converges within duration of cyclic prefix . **Global convergence** is **ensured** regardless of the initialization.
- Mitigation level attained within one OFDM symbol is **sufficient** for a typical scenario. Additional symbols **increase** the mitigation. Self-interference can be mitigated **below noise** level.

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