Design of Co-phasing Allpass Filters for Full-Duplex OFDM Relays

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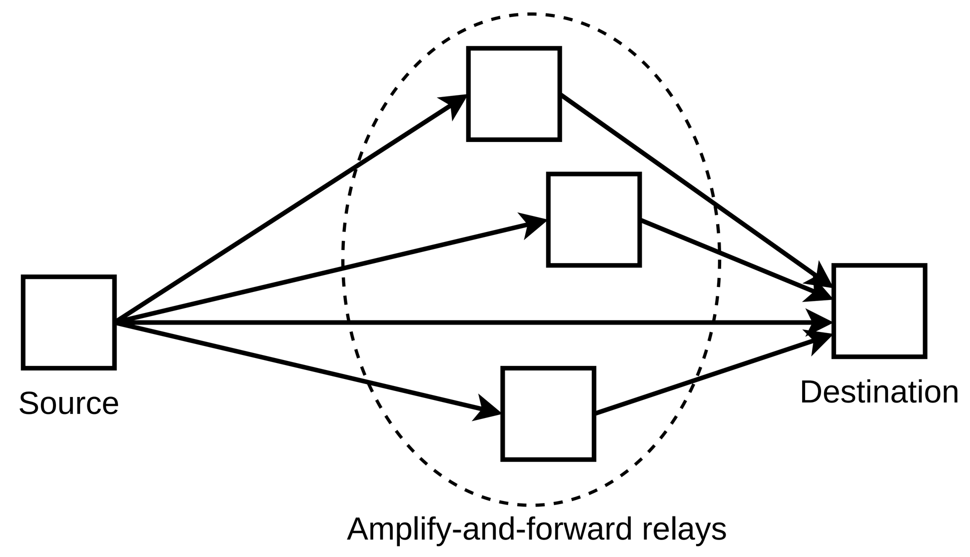
Introduction

- M parallel amplify-and-forward relays:
  - Frequency-selective multipath channels
  - OFDM signal, all multipaths within the cyclic prefix



- Benefits from spatial diversity by coherent combining, i.e., by inducing appropriate phase shifts in the relays
  - Previously considered with the **half-duplex** mode
    - * Symbol-by-symbol forwarding
    - * Co-phasing is trivial in the frequency domain

      → Suitable for mobile relays, user cooperation
  - The **full-duplex** mode is more spectrally efficient
    - * Sample-by-sample forwarding within the cyclic prefix
    - * Requires countermeasures against loop interference

      → Suitable for fixed, infrastructure-based relays
    - * Frequency domain processing is not possible
  - Can co-phasing be implemented also in full-duplex relays?

System model

- Amplification with linear filters $B_m(\omega)$ in the relays:

$$R_m(\omega) = H_{\mathrm{S}m}(\omega)X(\omega) + N_m(\omega)$$
$$T_m(\omega) = B_m(\omega)R_m(\omega)$$

- The destination receives a superposition of signals:

$$Y(\omega) = \underbrace{\left[H_{\mathrm{SD}}(\omega) + \sum_{m=1}^{M} H_{m\mathrm{D}}(\omega)B_m(\omega)H_{\mathrm{S}m}(\omega)\right]}_{=H(\omega)} X(\omega) + \sum_{m=1}^{M} H_{m\mathrm{D}}(\omega)B_m(\omega)N_m(\omega) + N_{\mathrm{D}}(\omega)$$

- Incoherent relaying with $B_m(\omega) = 1$
- Diversity gain by designing each $B_m(\omega)$ such that

$$|H(\omega)| \approx |H_{\mathrm{SD}}(\omega)| + \sum_{m=1}^{M} |H_{\mathrm{S}m}(\omega)|\,|H_{m\mathrm{D}}(\omega)|$$

  - Desired phase response at the kth subcarrier ($1 \leq k \leq K$):

$$\Theta_m(\omega_k) = \angle H_{\mathrm{SD}}(\omega_k) - \angle H_{\mathrm{S}m}(\omega_k)H_{m\mathrm{D}}(\omega_k)$$

  - Power allocation between the subcarriers is not considered

    ⇒ Uniform gain for the subcarriers is preferred

Filter design

- We need to design

$$B_m(\omega) = \underbrace{\left[1, e^{-j\omega}, \ldots, e^{-jN\omega}\right]}_{=\mathbf{c}^T(\omega)} \underbrace{\left[b_m[0], b_m[1], \ldots, b_m[N]\right]^T}_{=\mathbf{b}_m}$$

  that approximates the response $D_m(\omega_k) = e^{j\Theta_m(\omega_k)}$

  → Allpass filters: controllable phase and uniform gain
- FIR approximation of the ideal IIR allpass structure
  - Fixed-length impulse response, stability
  - No strict requirements for phase response or flat magnitude

  → We can apply the design method of complex FIR eigenfilters
- The error function by modifying the LS criterion:

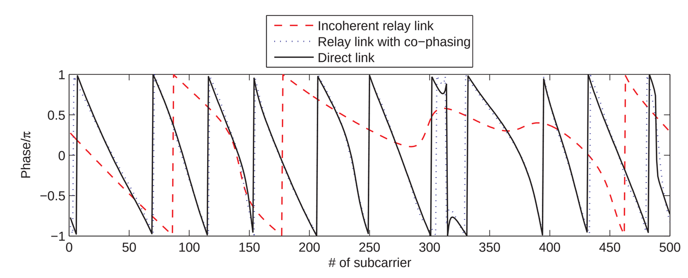
$$E_m = \sum_{k=1}^{K} \left| \frac{D_m(\omega_k)}{D_m(\omega_0)} B_m(\omega_0) - B_m(\omega_k) \right|^2 = \mathbf{b}_m^H \mathbf{Q}_m \mathbf{b}_m$$

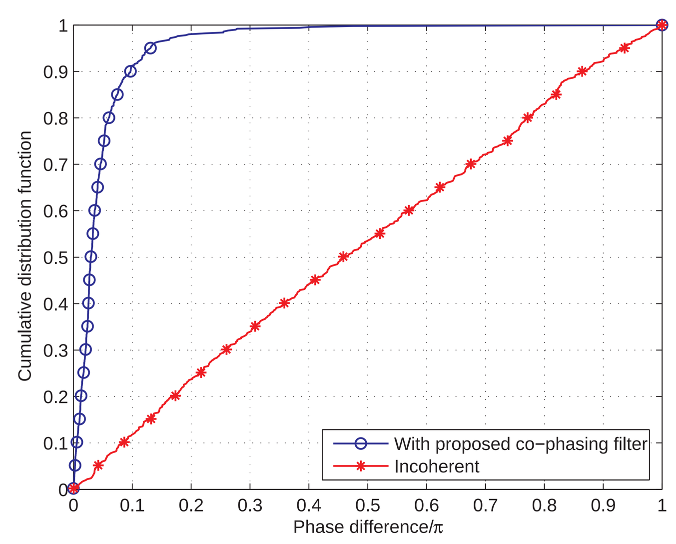
  is quadratic with

$$\mathbf{Q}_m = \sum_{k=1}^{K} \left[\frac{D_m(\omega_k)}{D_m(\omega_0)}\mathbf{c}(\omega_0) - \mathbf{c}(\omega_k)\right]^* \left[\frac{D_m(\omega_k)}{D_m(\omega_0)}\mathbf{c}(\omega_0) - \mathbf{c}(\omega_k)\right]^T$$

  ⇒ **Rayleigh's principle:** E_m is minimized by selecting $\mathbf{b}_m$ as the eigenvector corresponding to the smallest eigenvalue of $\mathbf{Q}_m$

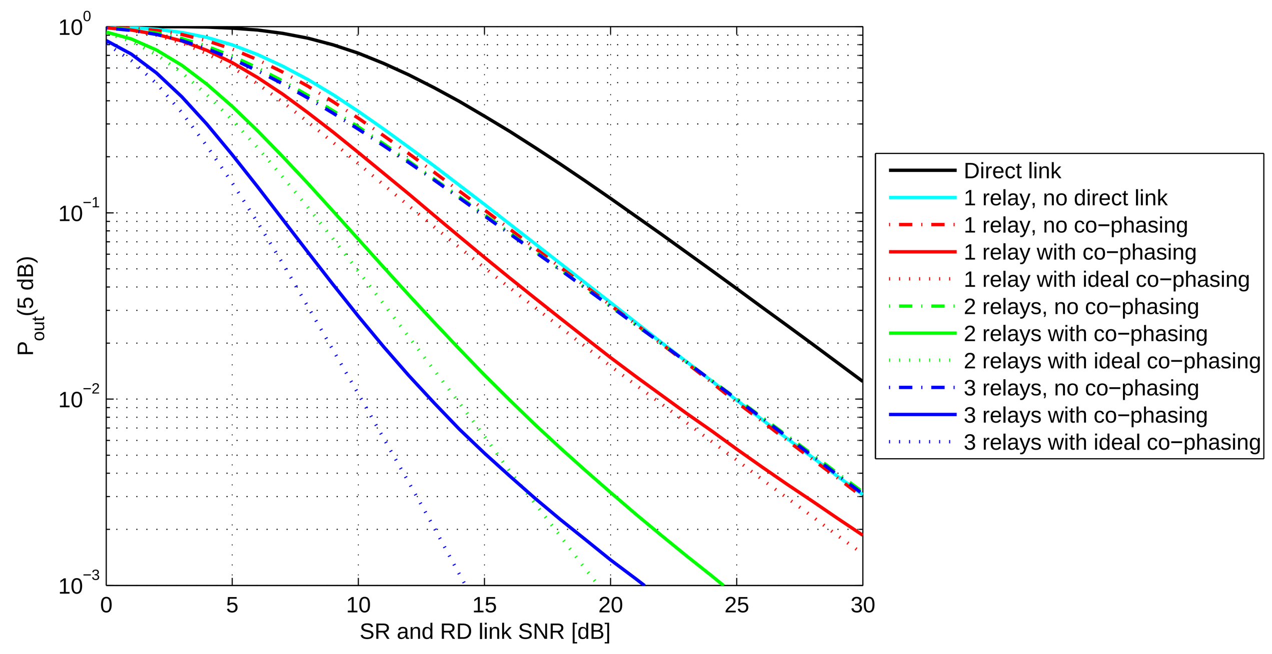
  - Example: Combining coherently transmission of a single relay with the direct transmission





Simulation results

- Outage probability simulations
  - SR and RD channels: 4 uniform Rayleigh-fading taps
  - SD channel: 15 uniform Rayleigh-fading taps, SNR is 6 dB below SR and RD link SNRs
  - $K = 500$, $N = 30$



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