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:
  
  $R_m(\omega) = H_{SD}(\omega)X(\omega) + N_m(\omega)$
  
  $T_m(\omega) = B_m(\omega)R_m(\omega)$

- The destination receives a superposition of signals:
  
  $Y(\omega) = \left[ H_{SD}(\omega) + \sum_{m=1}^{M} H_{mD}(\omega) B_m(\omega) H_{Sm}(\omega) \right] X(\omega)$
  
  $\Rightarrow \sum_{m=1}^{M} H_{mD}(\omega) B_m(\omega) N_m(\omega) + N_D(\omega)$

- Incoherent relaying with $B_m(\omega) = 1$

- Diversity gain by designing each $B_m(\omega)$ such that
  
  $|H(\omega)| \approx |H_{SD}(\omega)| + \sum_{m=1}^{M} |H_{Sm}(\omega)| |H_{mD}(\omega)|$

- Desired phase response at the kth subcarrier (1 ≤ k ≤ K):
  
  $\Theta_m(\omega_k) = \angle H_{SD}(\omega_k) - \angle H_{Sm}(\omega_k) H_{mD}(\omega_k)$

- Power allocation between the subcarriers is not considered

Filter design

- We need to design
  
  $B_m(\omega) = \left[ 1, e^{-j\omega}, \ldots, e^{-jN_{\omega}} \right] \left[ b_m[0], b_m[1], \ldots, b_m[N] \right]^T$

  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:
  
  $E_m = \sum_{k=1}^{K} \left| D_m(\omega_k) b_m(\omega_k) - B_m(\omega_k) \right|^2 = b_m^H Q_m b_m$

  is quadratic with

  $Q_m = \sum_{k=1}^{K} \left[ D_m(\omega_k) c(\omega_k) - c(\omega_k) \right]^* \left[ D_m(\omega_k) c(\omega_k) - c(\omega_k) \right]^T$

  $\Rightarrow$ Rayleigh’s principle: $E_m$ minimized by selecting $b_m$ as the eigenvector corresponding to the smallest eigenvalue of $Q_m$

  - 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
  - $K = 500$, $N = 30$