Pre-Equalization for Pre-Rake MISO DS-UWB Systems

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Introduction and Motivation

- DS-UWB systems can resolve dense multipath components using Rake combining at the receiver => Mitigation of fading effects
- To move complexity to transmitter, pre-Rake combining can be used => Shortening of the effective channel impulse response (CIR)
- For UWB channels pure pre-Rake combining (with symbol-by-symbol detection at receiver) entails relatively high error floors
- Receiver-side equalization and/or post-Rake combining can remedy drawback of pure pre-Rake combining => Receiver complexity
- Alternative: Pre-equalization at the transmitter => Simple receiver structure retained

Focus: Linear pre-equalization at symbol rate instead chip rate => Relatively short pre-equalization filters (PEFs) required
Contributions: Two novel PEF schemes for MISO DS-UWB systems; derivation of optimum FIR and IIR PEFs (MMSE solution)

Transmitter Structure for the MISO Case

- Simple receiver structure
- Solution sufficiently general to include also complexity-reduced versions of pre-Rake combining (S < L_r, Rake fingers)
- Simplified PEF (S-PEF) scheme: \( f_1, \ldots, f_M \)
  - Just single PEF shared by all transmit antennas => less complex
  - Structure of solution very similar to that of original PEF scheme
  - S-PEF scheme cannot outperform original PEF scheme
  - For IIR PEFs and full-complexity pre-Rake (A-pre-Rake), S-PEF scheme achieves same performance as original PEF scheme

PEF Optimization

- MMSE criterion: Minimize error variance \( \sigma^2 = E\{ |a[n] - \alpha r[n]|^2 \} \), while limiting transmitted signal power over one symbol interval
  => Convex optimization problem (here for FIR case):
    minimize \( \sigma^2 = 1 + |\alpha|^2 q_q^2 - \alpha f^T q - \alpha^* q^T f + |\alpha|^2 f^T Q f \)
  subject to \( P = f^T \Phi f = 1 \),
  where \( f = [f_1^T \ldots f_M^T]^T \), \( f_m = [f_m[0], \ldots, f_m[L_f - 1]]^T \)
  \( q, Q \): vector/ matrix based on overall CIR \( q_m[k] \)
  \( \Phi \): correlation matrix based on \( \varphi_m[k] \equiv q_m[k] + g_m[-k] \)
- Optimum solution:
  \( f_{opt} = V^{-1}q \)
  \( V = (Q + \sigma^2 I)^{-1/2} \)
  Minimun error variance: \( \sigma^2_{min} = 1 - q^T V^{-1} q \)
  Solution sufficiently general to include also complexity-reduced versions of pre-Rake combining (S < L_r, Rake fingers)

Performance Results and Conclusions

- PEF scheme vs. S-PEF scheme vs. pure pre-Rake combining
- \( M = 2 \) transmit antennas, spreading length \( N = 6 \), A-pre-Rake filters
- UWB channel model CM4 (IEEE 802.15.3a)
  => Both PEF schemes achieve significant performance gains over pure pre-Rake combining by symbol-by-symbol detection
  => Relatively short PEFs achieve close-to-optimum performance even for long UWB CIRs
  => PEF implementation at symbol-level leads to comparatively low complexity for filter computation (\( V \cdot (M L_f \times M L_f) \))
  => S-PEF scheme suffers from performance degradation for short PEFs, but offers near-optimum performance for sufficiently long PEFs

\[ \text{BER} \quad |E_b/N_0| [\text{dB}] \]