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

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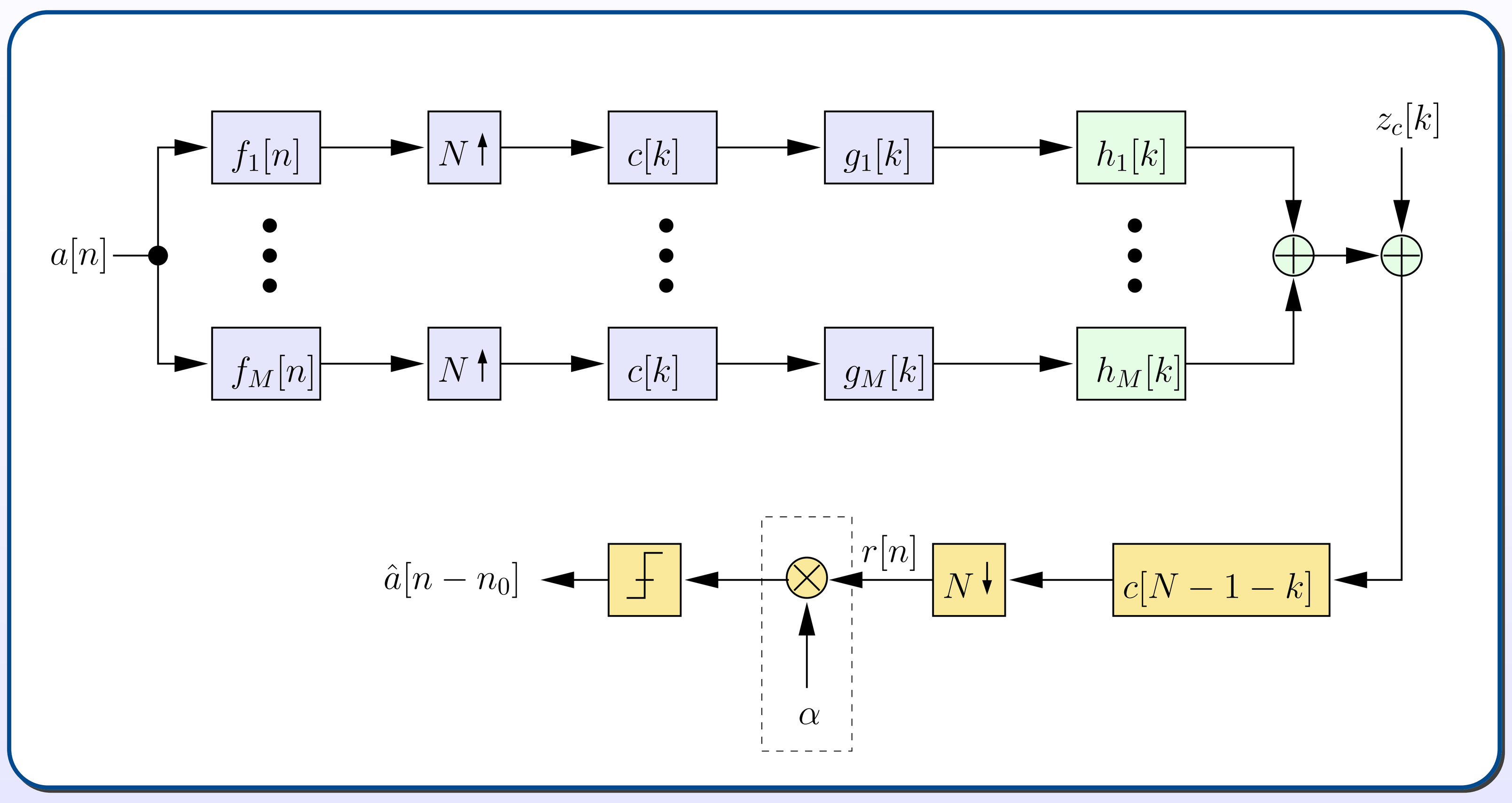
Introduction and Motivation

- **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



M:	number of transmit antennas
n:	discrete-time index at symbol rate
k:	discrete-time index at chip rate
$a[n]$:	i.i.d. data symbols $\in \{\pm 1\}$
$f_m[n]$:	PEF of length L_f (symbol rate), $m=1,\dots,M$
$c[\cdot]$:	spreading/ de-spreading (spreading length N)
$g_m[k]$:	pre-Rake combining (chip rate), $m=1,\dots,M$
$h_m[k]$:	discrete-time baseband CIR of length L_h, $m=1,\dots,M$
$z_c[k]$:	chip-level AWGN, variance σ_c^2

Moreover: $\tilde{g}_m[k] \triangleq c[k] * g_m[k]$ $\quad \tilde{h}_m[k] \triangleq h_m[k] * c[N-1-k]$

$\Rightarrow$ $q_m[k] \triangleq \tilde{g}_m[k] * \tilde{h}_m[k]$ overall CIR

PEF Optimization

- **MMSE criterion:** Minimize error variance

$$\sigma_e^2 \triangleq \mathcal{E}\{|\, a[n-n_0] - \alpha\, r[n]\,|^2\},$$

while limiting transmitted signal power over one symbol interval

⇒ **Convex** optimization problem (here for FIR case):

$$\text{minimize} \quad \sigma_e^2 = 1 + |\alpha|^2\sigma_c^2 - \alpha \boldsymbol{f}^H\boldsymbol{q} - \alpha^*\boldsymbol{q}^H\boldsymbol{f} + |\alpha|^2\boldsymbol{f}^H\boldsymbol{Q}^H\boldsymbol{Q}\boldsymbol{f}$$
$$\text{subject to} \quad P = \boldsymbol{f}^H\boldsymbol{\Phi}\boldsymbol{f} = 1,$$

where $\boldsymbol{f} \triangleq [\boldsymbol{f}_1^T \dots \boldsymbol{f}_M^T]^T$, $\quad \boldsymbol{f}_m \triangleq [\,f_m[0], \dots, f_m[L_f-1]\,]^H$

$\boldsymbol{q}$,$\boldsymbol{Q}$: vector/ matrix based on overall CIR $q_m[k]$

$\boldsymbol{\Phi}$: correlation matrix based on $\varphi_m[k] \triangleq \tilde{g}_m[k] * \tilde{g}_m^*[-k]$

- **Optimum solution:**

$$\boldsymbol{f}_{\text{opt}} = \frac{\boldsymbol{V}^{-1}\boldsymbol{q}}{\alpha_{\text{opt}}^*} = \frac{\boldsymbol{V}^{-1}\boldsymbol{q}}{\sqrt{\boldsymbol{q}^H\boldsymbol{V}^{-1}\boldsymbol{\Phi}\boldsymbol{V}^{-1}\boldsymbol{q}}}, \qquad \boldsymbol{V} \triangleq \left(\boldsymbol{Q}^H\boldsymbol{Q} + \sigma_c^2\boldsymbol{\Phi}\right)$$

Minimum error variance: $\quad \sigma_{e,\min}^2 = 1 - \boldsymbol{q}^H\boldsymbol{V}^{-1}\boldsymbol{q}$

- Solution sufficiently general to include also **complexity-reduced** versions of pre-Rake combining ($S < L_h$ Rake fingers)
- **Simplified PEF (S-PEF) scheme:** $\boldsymbol{f}_1 \triangleq \dots \triangleq \boldsymbol{f}_M$
  - 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

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 with 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 ($\boldsymbol{V}$: $ML_f \times ML_f$)

⇒ **S-PEF scheme** suffers from performance degradation for short PEFs, but offers near-optimum performance for sufficiently long PEFs