Echo Cancellation for Discrete Multitone Frame-Asynchronous ADSL Transceivers

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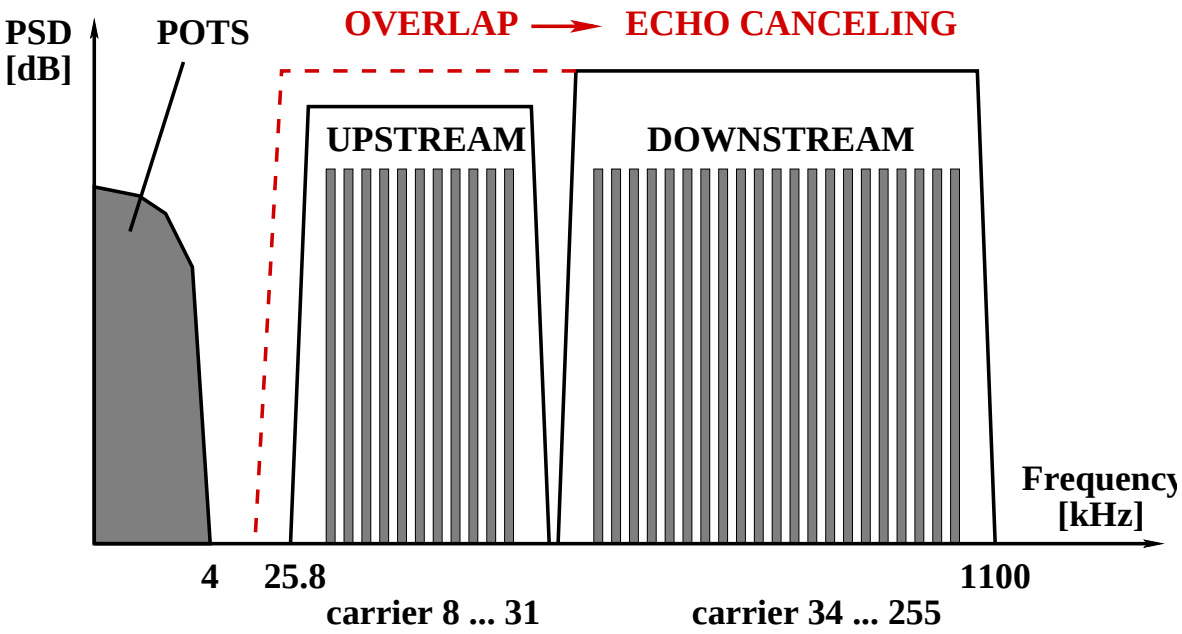


Overview

- Introduction
  - FDD vs. Echo Canceling in ADSL
- Frame-Asynchronous Echo Cancellation:
  A. Symmetric Setup
  - Time Domain Echo Canceling+Misalignment
  - Mixed Time/Freq. Domain Echo Canceling
  - Proposed Algorithm
- Frame-Asynchronous Echo Cancellation:
  B. Multi Rate Structures
  - Remote Terminal (RT)
  - Central Offcice (CO)
- Complexity
- Simulation Results
- Conclusions

Introduction

- ADSL employs discrete multitone modulation (DMT)
- ADSL standard → two duplexing schemes:
  - Frequency Division Duplexing (FDD)
  - Echo Canceling (EC)

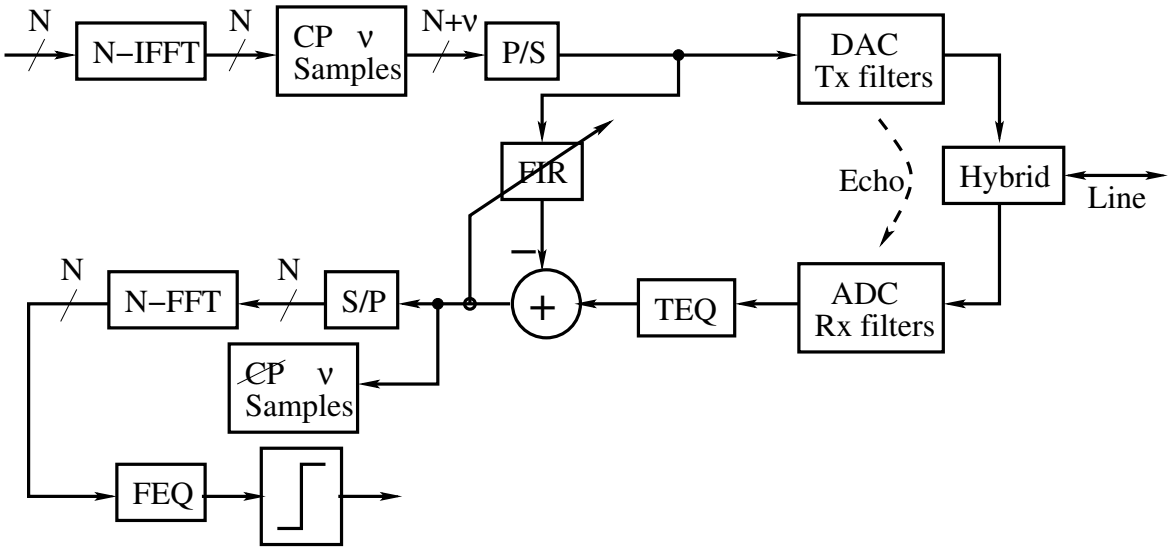


- Advantages and drawbacks

	FDD	EC
⊕	- easy to implement - robust	- increased reach, bit rate or noise margin - cheap front end filters - equalization is easier
⊖	- complex front end filters - difficult equalization	- extra DSP cost - more sensitive to NEXT

Frame-Asynchronous Echo Cancellation: A. Symmetric Setup (1)

- Time domain EC



- Received echo:

$$\mathbf{y}^k = \mathbf{U}^{k-1,k,k+1}\mathbf{h}_E + \mathbf{n}^k$$

  - $\mathbf{n}^k$: AWGN+far end signal
  - $\mathbf{h}_E$: echo channel (length $M \leq N$+zero padded to N)
  - $\mathbf{U}^{k-1,k,k+1}$: echo reference symbols are misaligned by Δ compared to received symbols $\longrightarrow$ 3 echo reference symbols

- Echo emulation:

$$\hat{\mathbf{y}}^k = \mathbf{U}^{k-1,k,k+1}\mathbf{w}_E$$

- Echo canceling in time domain:

$$\mathbf{e}^k = \mathbf{y}^k - \hat{\mathbf{y}}^k$$

Frame-Asynchronous Echo Cancellation: A. Symmetric Setup (2)

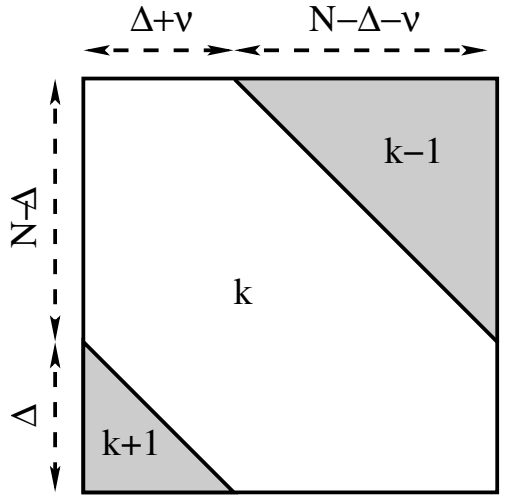
- Mixed time/frequency domain EC (MTF EC) [Ho '96]:

$$\mathbf{U}^{k-1,k,k+1} = \underbrace{\mathbf{C}^k}_{\text{circulant}} + \underbrace{\chi^{k-1,k,k+1}}_{\text{sparse}}$$

- 'Circular echo synthesis (CES)' in time domain+efficient cancellation in frequency domain

$$\begin{aligned} E^k &= \mathcal{F}_N \mathbf{e}^k \\ &= \mathcal{F}_N \underbrace{(\mathbf{y}^k - \chi^{k-1,k,k+1}\mathbf{w}_E^k)}_{\text{CES}} \underbrace{-(U^k \odot \mathbf{p} \odot W_E^k)}_{\text{Freq. Domain EC}} \end{aligned}$$

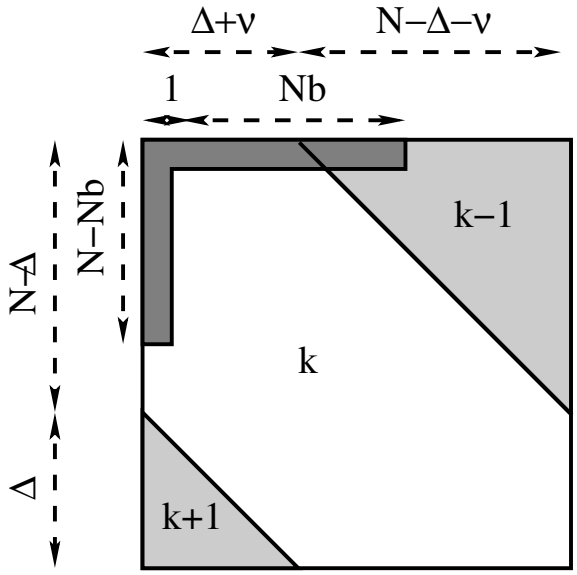
  - $\mathbf{p}$: phase rotation due to Δ
  - U^k: transmitted echo freq. dom. symbol at time k
  - W_E^k: echo channel in freq. dom.
- CES determines overall complexity $\longrightarrow$ sparsity of $\chi^{k-1,k,k+1}$!!



Frame-Asynchronous Echo Cancellation: A. Symmetric Setup (3)

- minimize CES complexity by choosing specific alignment [Jones '95]
  - ⊕ low complexity
  - ⊖ choice of alignment only feasible at 1 side
  - ⊖ other side: 2 extra FFT's (at RX) for low CES complexity
- Solution: minimize CES complexity independent of alignment
  → define different split of $\mathbf{U}^{k-1,k,k+1}$

$$\mathbf{U}^{k-1,k,k+1} = \underbrace{\tilde{\mathbf{C}}}_{\text{circulant}} + \underbrace{\tilde{\chi}^{k-1,k,k+1}}_{\text{sparse}}$$



- Similar cancellation in time/freq. dom.

$$E^k = \mathcal{F}_N \underbrace{(\mathbf{y}^k - \tilde{\chi}^{k-1,k,k+1}\mathbf{w}_E^k)}_{\text{CES}} \underbrace{-(\tilde{U}^k \odot W_E^k)}_{\text{Freq. Domain EC}}$$

  - $\ominus$ Extra FFT required: $\tilde{U}^k = \mathcal{F}_N \mathbf{C}_1$, but now at TX side !
  - $\oplus$ $N_b = \frac{M}{2}$ minimizes CES complexity
  - $\oplus$ FFT at RX side: shared between EC and far end demodulator $\longrightarrow$ cheap double talk cancellation [Evans '02], [Ysebaert '02]
- Similar update in freq. dom. as MTF EC

$$W_E^{k+1} \leftarrow W_E^k + \mu(\tilde{U}^{k^*} \odot E^k)$$

- Efficient double talk cancellation only possible when RX FFT is shared:

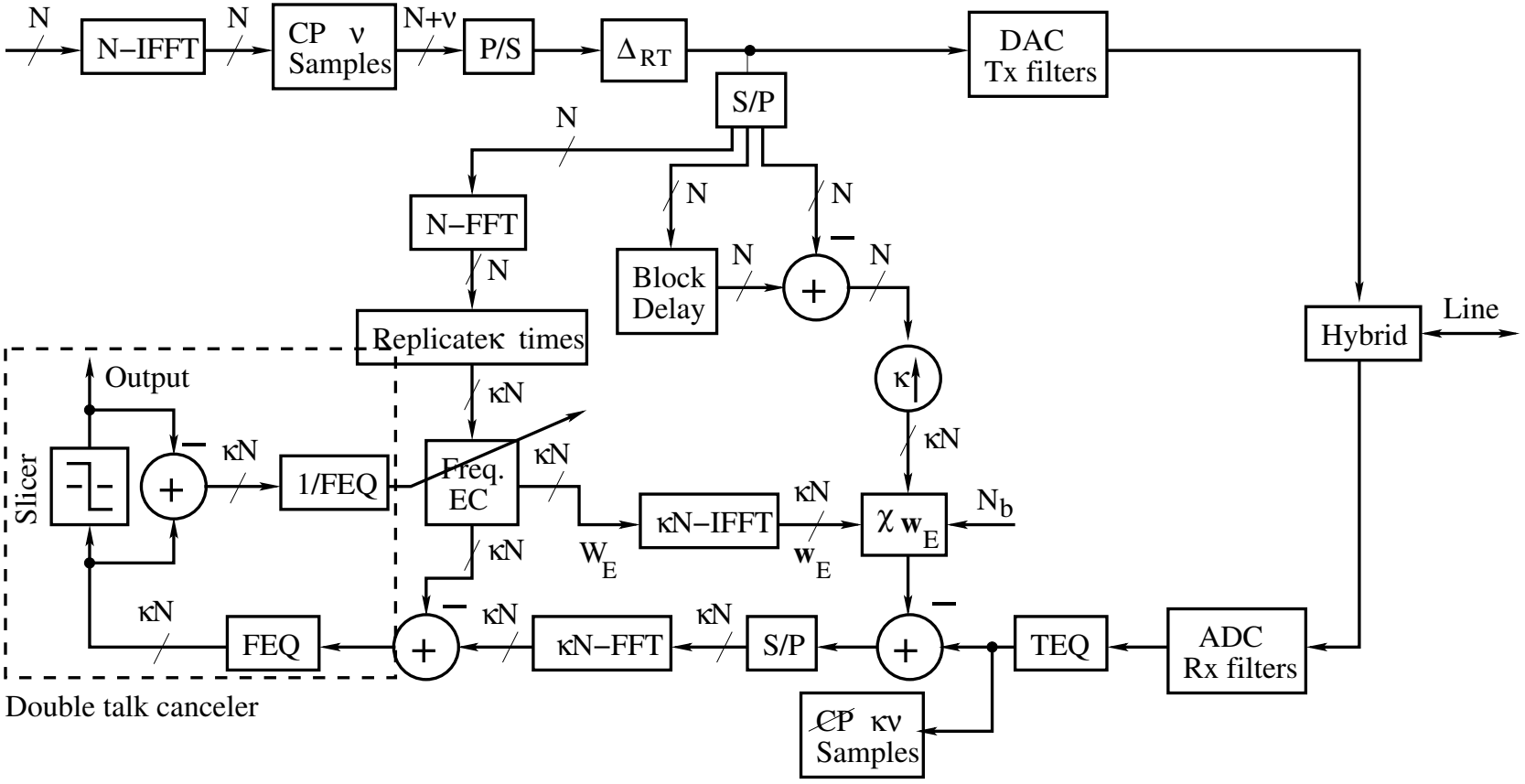
$$E^k \leftarrow (FEQ^k)^{-1} \odot (FEQ^k \odot E^k - X^k)$$

- Time domain coefficients:

$$\mathbf{w}_E^{k+1} = \mathcal{I}_N W_E^{k+1}$$

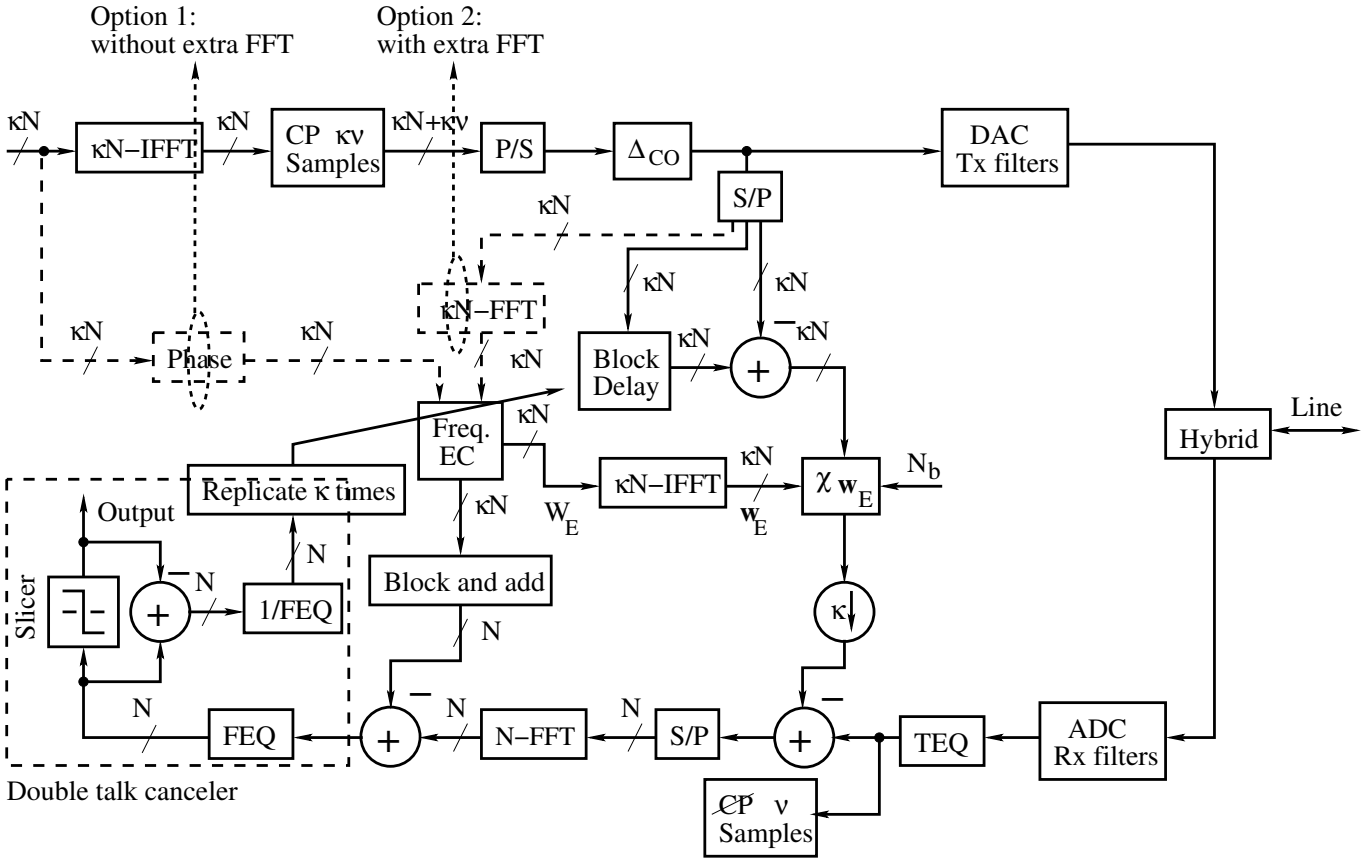
Frame-Asynchronous Echo Cancellation: B. Multi Rate Structures (1)

- Different TX and RX bandwidth (factor κ): e.g. ADSL RT: N_{TX}=64, N_{RX}=512



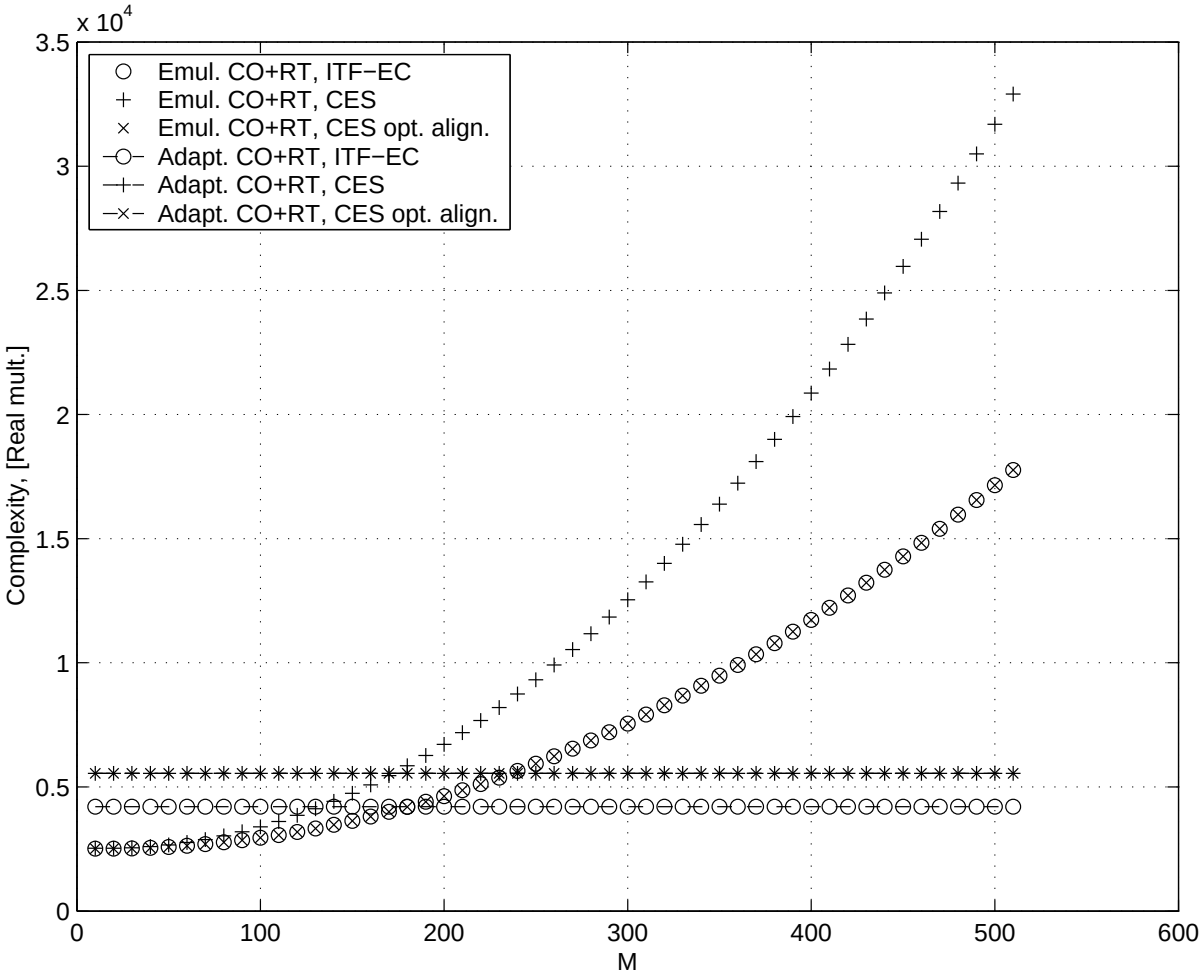
Frame-Asynchronous Echo Cancellation: B. Multi Rate Structures (2)

- Different TX and RX bandwidth (factor κ): e.g. ADSL CO: N_{TX}=512, N_{RX}=64



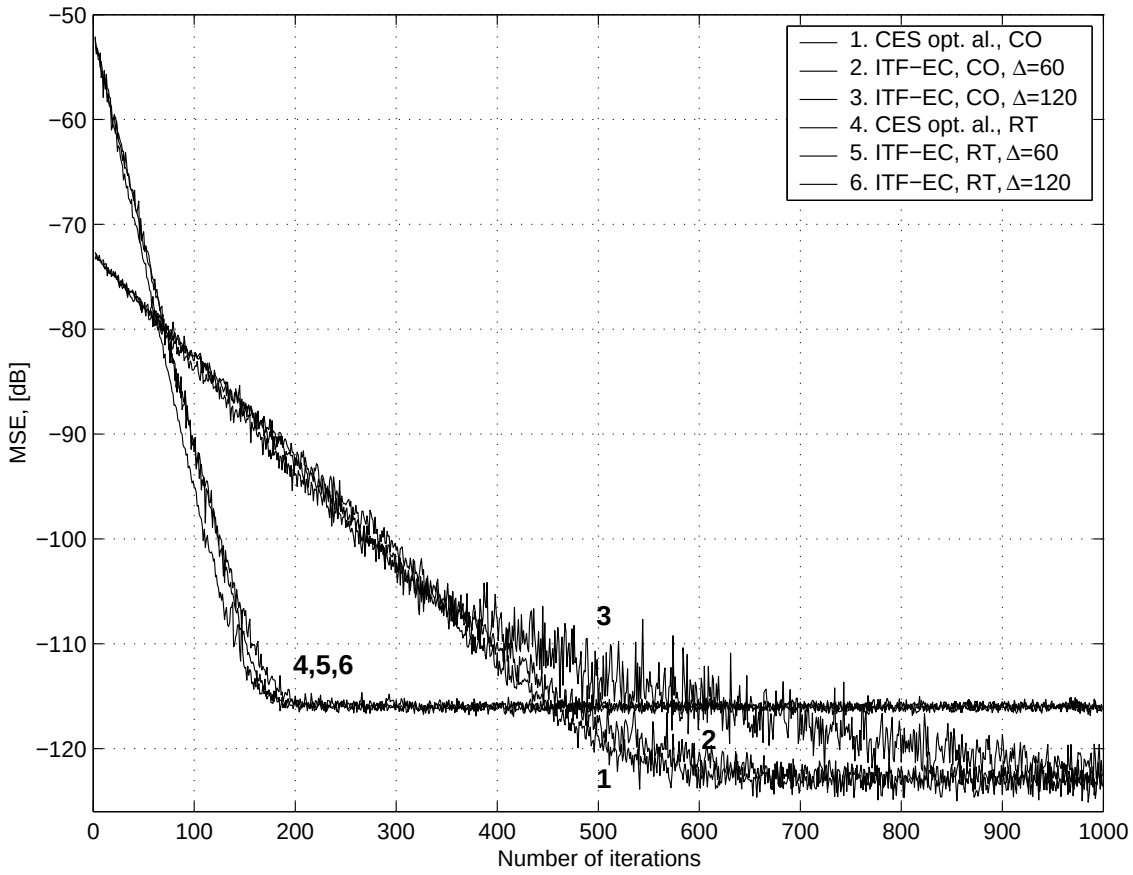
Complexity

- Complexity in real multiplications at symbol rate
- Emulation vs. adaptation
- 3 scenarios for RT and CO:
  - MTF EC [Ho '96]+double talk cancellation
  - MTF EC [Jones '95] with optimal alignment+double talk cancellation
  - proposed algorithm



Simulations

- Simulation parameters:
  - 3 km 26 AWG channel
  - $N = 64$, $\kappa = 8$
  - upstream tones 7-31, downstream tones 33-255
    $\longrightarrow$ echo due to DFT leakage
  - transmit power -40 dBm/Hz (CO), -38 dBm/Hz (RT), 20 dB lower power on unused tones, AWGN of -140 dBm/Hz
  - $M = 220$, $N_b = 110$, normalized LMS update
- Learning curves: proposed algorithm has similar convergence as existing algorithms



Conclusions

- modification of existing time/freq. domain EC
- CES complexity is minimized, independent of the alignment
- similar learning curves as existing algorithms
- extra FFT required but at TX side $\rightarrow$ RX FFT is shared between EC and far end demodulation
- efficient double talk cancellation: coefficient update independent of far end
- overall complexity = low