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Double Talk Cancellation in Echo Cancelled DMT-Systems [1]

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[1]This report is available by anonymous ftp from *ftp.esat.kuleuven.ac.be* in the directory *pub/sista/ysebaert/reports/01_131b.pdf*

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Abstract

The existing ADSL standard allows for two possible transmission systems: frequency division duplexing (FDD) and echo cancelling (EC). Echo cancelling is particularly attractive for its ability to achieve higher data rates compared with FDD schemes. A disadvantage of EC is that adaptive schemes exhibit slow tracking properties in the presence of a far end signal or double talker. This paper presents an efficient method for updating echo canceller taps in ADSL transceivers in the presence of a far end signal, by effectively cancelling most of the received far end energy. The presented scheme extends existing multicarrier echo cancelling schemes with a feedback of decisions on the far end signal. As a result the convergence is much faster and hence fast tracking properties are possible at a low computational complexity.

Double Talk Cancellation in Echo Cancelled DMT-Systems

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Abstract

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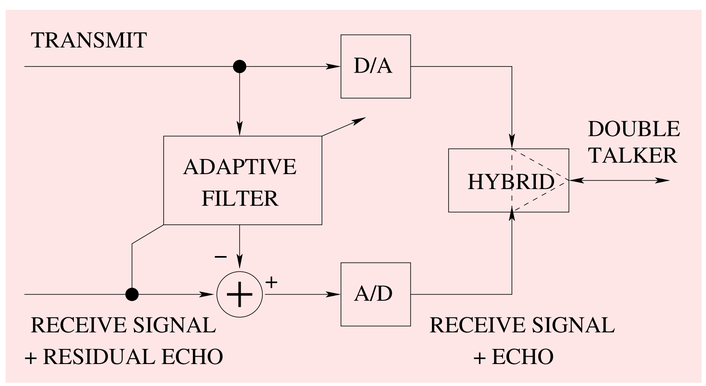
1 Introduction+Definitions

FDD and EC

Two different options allowed in ADSL: frequency division duplexing (FDD) and echo cancelling (EC).

Echo

Transmitter and receiver at one end are coupled to the line by a *hybrid*. Due to large variations in the subscriber loops, a fixed hybrid can not be exactly balanced for all loops and hence leakage occurs.



Double talk problem

When the far end signal is not silenced, the adaptive scheme exhibits a large excess mean square error (MSE). Although far end signal and echo reference signal are uncorrelated, the far end signal will cause a large excess MSE in the adaptation process.

$\Longrightarrow$ the signal to noise ratio (SNR) of the far end signal at the receiver degrades

$\Longrightarrow$ reduced bitrate.

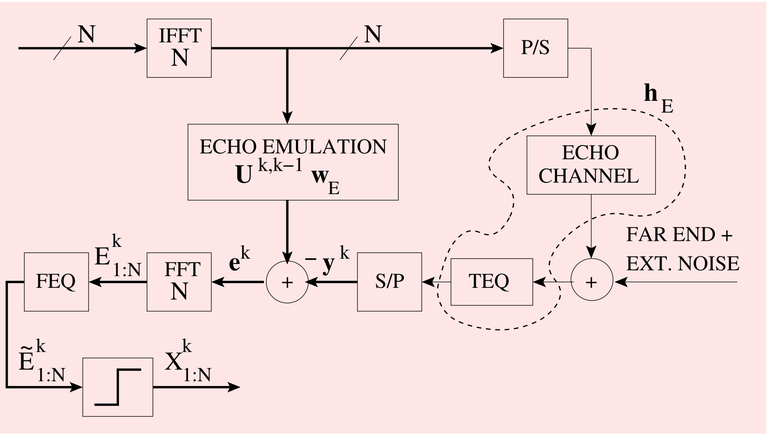
2 Data Model

Received DMT symbol:

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

Echo cancelled symbol:

$$\mathbf{e}^k = \mathbf{y}^k - \mathbf{U}^{k,k-1}\mathbf{w}_E \tag{2}$$



with

- $\mathbf{w}_E$: echo canceller taps of size M
- N: (I)FFT size
- $\mathbf{U}^{k,k-1}$: Toeplitz matrix with echo reference signal
- $\mathbf{n}^k$: external noise+far end signal
- $E^k_{1:N} = \mathcal{F}_N\mathbf{e}^k$: FFT output
- $\tilde{E}^k_{1:N}$: FEQ output
- $B_{1:N}$: 1-tap FEQs

3 Signal-Driven Echo Canceller

Optimal MMSE echo canceller can be found as

$$\min_{\mathbf{w}_E} \mathcal{E}\{(e^k)^2\} \approx \min_{\mathbf{w}_E} \|E^k_{1:N}\|_2^2 = \min_{\mathbf{w}_E} \sum_{i=1}^{N} |E_i^k|^2, \tag{3}$$

Include FEQs in the cost function:

$$\begin{aligned}\min_{\mathbf{w}_E} \sum_{i=1}^{N} \frac{|B_i \cdot E_i^k|^2}{|B_i|^2} &= \min_{\mathbf{w}_E} \sum_{i=1}^{N} \frac{|\tilde{E}_i^k|^2}{|B_i|^2} \\ &= \min_{\mathbf{w}_E} \sum_{i=1}^{N} \frac{\left|B_i \cdot \mathcal{F}_N(i,:)(\mathbf{y}^k - \mathbf{U}^{k,k-1}\mathbf{w}_E)\right|^2}{|B_i|^2}\end{aligned} \tag{4}$$

Remove far end contribution, using decision X_i^k on FEQ output (= cancel double talker):

$$\min_{\mathbf{w}_E} \sum_{i=1}^{N} \frac{\left|B_i \cdot \mathcal{F}_N(i,:)(\mathbf{y}^k - \mathbf{U}^{k,k-1}\mathbf{w}_E) - X_i^k\right|^2}{|B_i|^2}, \tag{5}$$

Numerator now contains: ext. noise+ISI/ICI+residual echo. The LMS updating formulas for **time domain echo cancelling** can be obtained by calculating the gradient with respect to $\mathbf{w}_E$:

$$\begin{aligned}\mathbf{w}_E^{k+1} \leftarrow \mathbf{w}_E^k + \mu(\mathrm{diag}\{B_{1:N}\}^{-1}\mathrm{diag}\{B_{1:N}\}\mathcal{F}_N\mathbf{U}^{k,k-1})^{\mathrm{H}} \cdot \\ \mathrm{diag}\{B_{1:N}\}^{-1}(\mathrm{diag}\{B_{1:N}\}\mathcal{F}_N(\mathbf{y}^k - \mathbf{U}^{k,k-1}\mathbf{w}_E^k) - X_{1:N}^k)\end{aligned} \tag{6}$$

$$\boxed{\mathbf{w}_E^{k+1} \leftarrow \mathbf{w}_E^k + \mu\mathbf{U}^{k,k-1^{\mathrm{T}}}\mathcal{I}_N\mathrm{diag}\{B_{1:N}\}^{-1}(\tilde{E}_{1:N}^k - X_{1:N}^k)}$$

4 Data-Driven Echo Canceller

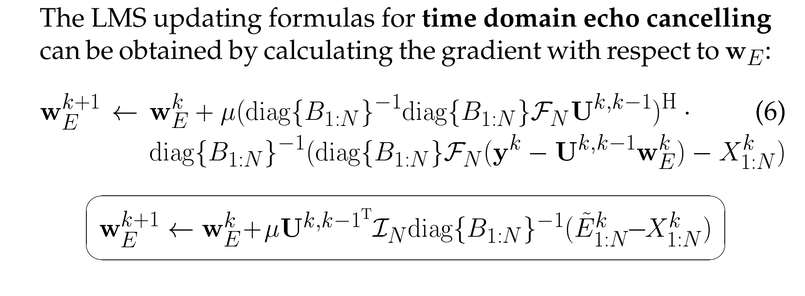
Cioffi *et al.* developed a cheaper echo canceller:
updating part in frequency domain, filtering part in time domain.
$\hookrightarrow$ LMS updating without double talk canceller:

$$W_{E,1:N}^{k+1} \leftarrow W_{E,1:N}^k + \mu\mathrm{diag}\{U_{1:N}^{k^*}\}\mathcal{F}_N(\mathbf{y}^k - \mathbf{U}^{k,k-1}\mathbf{w}_E^k) \tag{7}$$

$\hookrightarrow$ LMS updating with double talk canceller:

$$\begin{aligned}W_{E,1:N}^{k+1} \leftarrow W_{E,1:N}^k + \mu\mathrm{diag}\{U_{1:N}^{k^*}\}\mathrm{diag}\{B_{1:N}\}^{-1} \cdot \\ (\mathrm{diag}\{B_{1:N}\}\mathcal{F}_N(\mathbf{y}^k - \mathbf{U}^{k,k-1}\mathbf{w}_E^k) - X_{1:N}^k)\end{aligned} \tag{8}$$

$$\boxed{W_{E,1:N}^{k+1} \leftarrow W_{E,1:N}^k + \mathrm{diag}\{\mu_{1:N}\}\mathrm{diag}\{U_{1:N}^{k^*}\}(\tilde{E}_{1:N}^k - X_{1:N}^k)}$$



Design criterion:

make residual echo much lower than external noise+ISI/ICI

$\Longrightarrow$ residual echo will not be the dominant noise source. Residual echo at the receiver can be expressed as the excess MSE of the echo cancelling scheme. Excess MSE per tone i [Cioffi *et al.*]:

$$\xi_{\mathrm{excess},i} = \frac{\mu\sqrt{\frac{M}{N}}}{2}\frac{1}{1-\gamma_i}\sigma_{u,i}^2\sigma_{n,i}^2 \tag{9}$$

5 Complexity

signal-driven echo canceller

- difference complex input and output of decision device: $2\frac{N}{2}$ add./symbol
- complex multiplication with inverse FEQ: $4\frac{N}{2} + 2\frac{N}{2}$ mult./symbol, $2\frac{N}{2} + \frac{N}{2}$ add./symbol, $2\frac{N}{2}$ div./symbol
- transformation of frequency error to time domain with complex to real ifft: $N\log\frac{N}{2}$ mult./symbol and $N\log\frac{N}{2}$ add./symbol

data-driven echo canceller

- difference complex input and output of decision device: $2\frac{N}{2}$ add./symbol
- computation[1] $\mu_{1:N}$: $4\frac{N}{2} + 2\frac{N}{2}$ mult./symbol, $2\frac{N}{2} + \frac{N}{2}$ add./symbol, $2\frac{N}{2}$ div./symbol

$\Longrightarrow$ Complexity double talk canceller is small compared to the complexity of the echo canceller itself (typically $2-4\%$)

6 Simulation Results

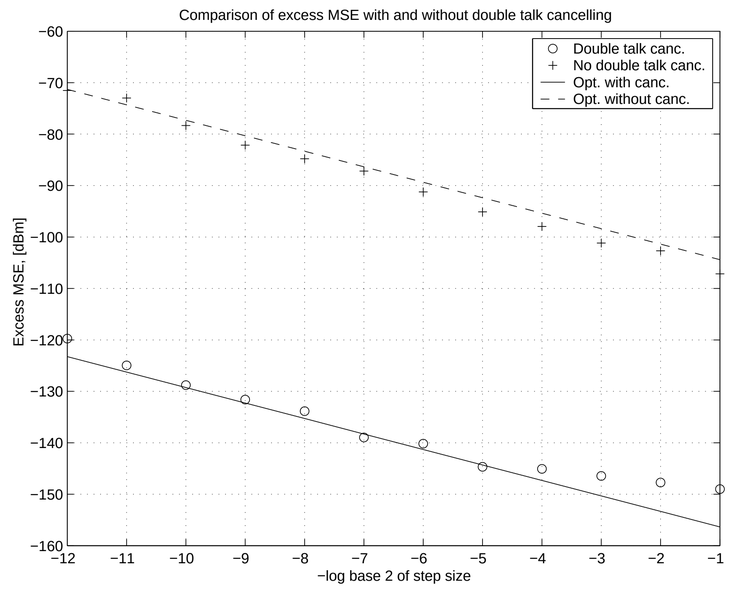
Performance measure:

excess mean square error summed over all tones

$$\hat{\xi}_{\mathrm{excess}} = \sum_{i=1}^{N/2+1} |\mathcal{F}_N(i,:)(\mathbf{U}^{k,k-1}\mathbf{h}_E - \mathbf{U}^{k,k-1}\mathbf{w}_E)|^2 \tag{10}$$

Simulation scenario:

- ADSL 26awg line of 3000 m at central office
- far end: upstream tones $8-32$,
- echo: downstream tones $34-256$
- AWGN+ISI/ICI summed over all tones= -118dBm
- $N = 512$, $M = 300$
- excess MSE as a function of stepsize with double-talker present



Conclusion:

if residual echo 10 dB below noise floor,

- stepsize $< 2^{10}$ *with* double talk canceller
- stepsize $\ll 2^1$ *without* double talk canceller.

7 Conclusions

We presented a low complexity solution for double talk cancellation in ADSL echo cancelled systems. The proposed method allows to use a larger stepsize in the adaptation process resulting in fast tracking and/or convergence in the presence of a far end signal, and hence, increased robustness against, e.g., temperature changes in the echo-path.

[1]It is assumed that the FEQ is also adaptive, such that $\mu_{1:N}$ is recomputed in every iteration.