Error Localization in DSL Systems Using the Common-Mode Signals

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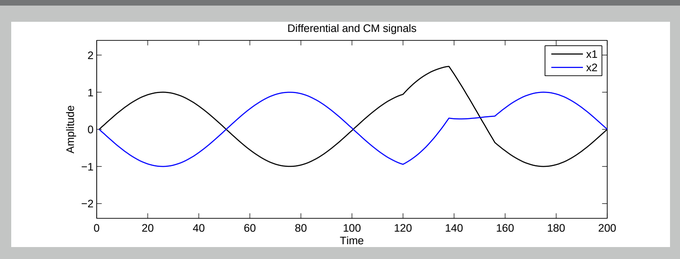
Introduction

- Transmission quality is often degraded by bursts of high amplitude referred to as impulse noise.
  - visible artefacts in images, breaks in audio content
- The conventional approach of transmission over copper cables is carried out using Differential-Mode (DM) signals.
  - Common-Mode (CM) signals are more vulnerable to unwanted interference such as impulse noise and RFI.
  - Common Mode (CM) and Differential Mode (DM) show significant correlations for a few strong interferers.
  - The CM provides a perfect reference to cancel impulse noise in the DM.

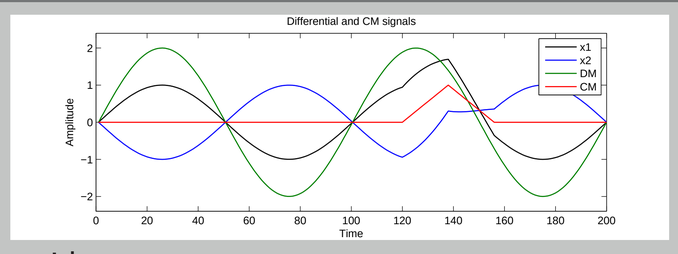
Differential Mode Signals

- sent on two wires, opposite polarity with respect to GND
- voltage difference on the twisted pair is measured
- high immunity against interference



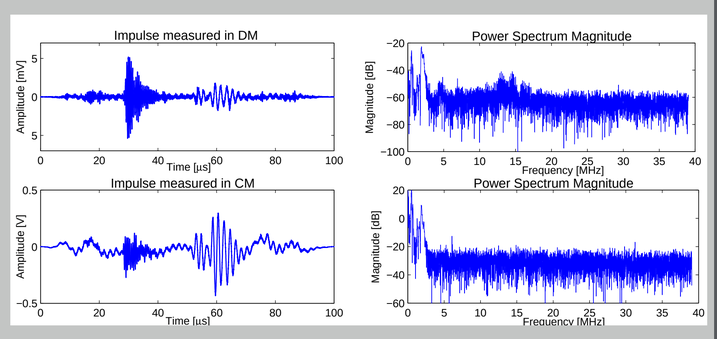
Common-Mode (CM) Signals

- arithmetic mean of two signals measured with respect to GND
- used as reference signal for interference
- freely available on the receiver side
- measured at the center tap of a balun



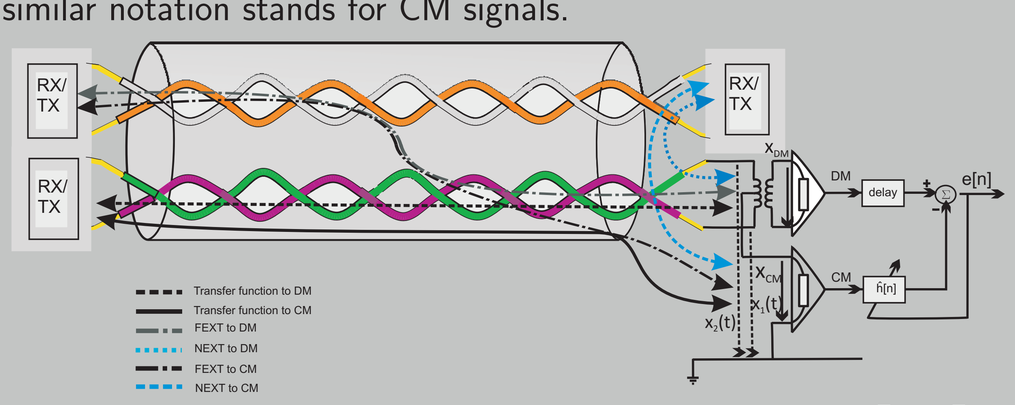
Impulse Noise

- significantly higher amplitudes in CM
- energy concentrated at lower frequencies
- measurements of impulse noise have been taken at inhouse phone outlets, both in DM and CM
- interarrival distribution detailed in [Henkel,2001]



System Model

On the transmitter side, a differential-mode signal $\mathbf{s_j}$ is transmitted on pair j. At the receiver side, two signals $\mathbf{y_j^{DM}}$ and $\mathbf{y_j^{CM}}$ are measured, where $\mathbf{H_{j,j}^{DM}}$ denotes the $N \times N$ convolution matrix describing the DM to DM path on the jth pair. $\mathbf{w^{DM}}$ denotes uncorrelated AWGN in DM referred to as background noise, and $\mathbf{i^{DM}}$ represents the DM coupled impulse noise signal. A similar notation stands for CM signals.



$$\begin{bmatrix} \mathbf{y_j^{DM}} \\ \mathbf{y_j^{CM}} \end{bmatrix} = \begin{bmatrix} \mathbf{H_{j,j}^{DM}} \\ \mathbf{H_{j,j}^{CM}} \end{bmatrix} [\mathbf{s_j}] + \underbrace{\begin{bmatrix} \mathbf{H_{j,1}^{DM}} \cdots \mathbf{H_{j,j-1}^{DM}} \, \mathbf{H_{j,j+1}^{DM}} \cdots \mathbf{H_{j,L}^{DM}} \\ \mathbf{H_{j,1}^{CM}} \cdots \mathbf{H_{j,j-1}^{CM}} \, \mathbf{H_{j,j+1}^{CM}} \cdots \mathbf{H_{j,L}^{CM}} \end{bmatrix}}_{\text{FEXT}} \begin{bmatrix} \mathbf{s_1} \\ \vdots \\ \mathbf{s_{j-1}} \\ \mathbf{s_{j+1}} \\ \vdots \\ \mathbf{s_L} \end{bmatrix} + \underbrace{\begin{bmatrix} \mathbf{H_{j,L+1}^{DM}} \cdots \mathbf{H_{j,L+K}^{DM}} \\ \mathbf{H_{j,L+1}^{CM}} \cdots \mathbf{H_{j,L+K}^{CM}} \end{bmatrix}}_{\text{NEXT}} \begin{bmatrix} \mathbf{v_1} \\ \vdots \\ \mathbf{v_K} \end{bmatrix} + \underbrace{\begin{bmatrix} \mathbf{w^{DM}} \\ \mathbf{w^{CM}} \end{bmatrix}}_{\text{AWGN}} + \underbrace{\begin{bmatrix} \mathbf{i^{DM}} \\ \mathbf{i^{CM}} \end{bmatrix}}_{\text{impulse noise}} \quad (1)$$

Coding and Block Interleaving

- channel errors can occur at randomly isolated locations or in finite length sequences (burst errors)
- robust mechanism for checking and correcting errors needed
- Reed Solomon (RS) codes chosen for ADSL transmission due to burst-error correction capability
  - take a block of **k** symbols, add **n-k** redundant symbols
  - an RS code is able to correct up to $\mathbf{(n-k)/2}$ erroneous symbols if the error locations are not known
  - if side information is present on the demodulator side and erasure marking is possible, a Reed-Solomon code is able to decode twice as many erasures than errors, or any combination of errors and erasures as long as the relation $\mathbf{s + 2(e - v) \leq 2t = n - k}$ holds, where **s** is the number of erasures, **e** is the number of errors, **v** are the common ones and **t** is the error correcting capability of the code
- a burst of symbol errors is distributed among multiple received words and fewer errors occur in each received codeword
- interleaving will increase the burst-error correction capability by the interleaving depth as a factor

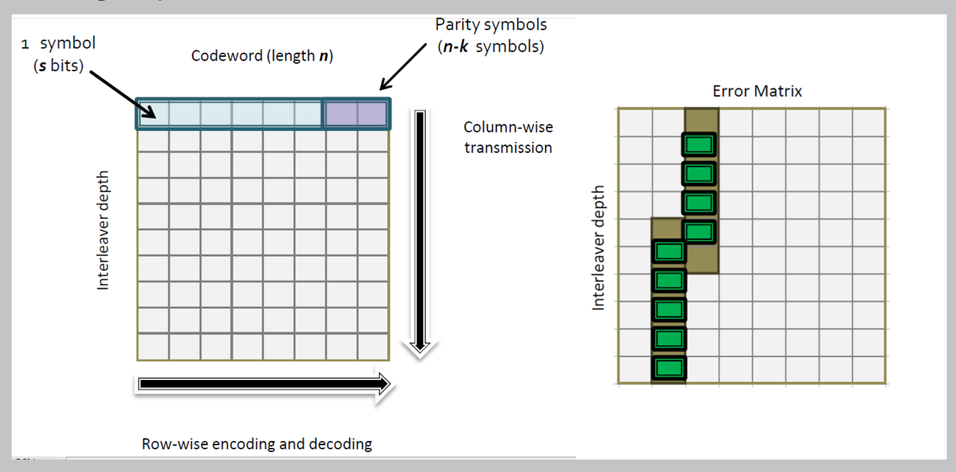


Figure: Error and erasure matrices, block interleaving

Error Location Estimation

- given the Transverse Conversion Transfer Loss (TCTL) and an impulse measured in CM, an estimate of the DM impulse can be obtained
- the TCTL can be practically obtained from the cross-PSD between CM and DM and the PSD of CM

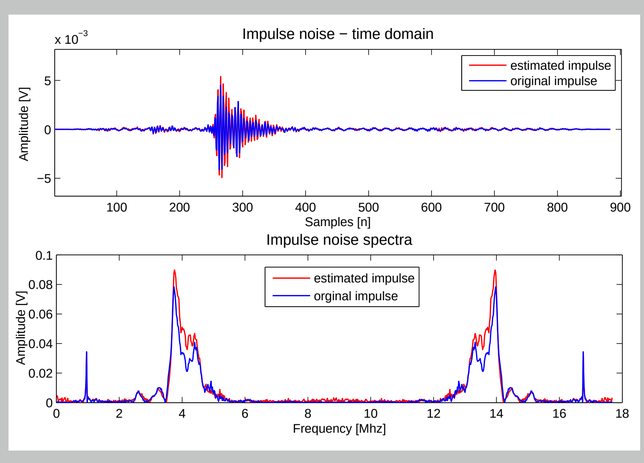


Figure: Original vs. estimated impulse noise

- once the estimate is obtained, the bits present on the carriers affected by impulse noise are flagged as erasures when the estimate of the impulse noise exceeds a certain level

Results

- for an ADSL specific BER of $\mathbf{10^{-7}}$ a gain of 370m is observed

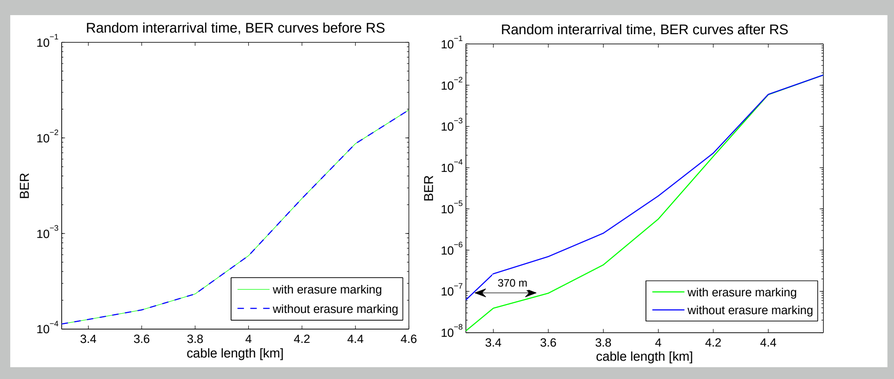


Figure: Erasure marking results, random interarrival time, before and after RS decoding

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