Erasure Marking in DSL Systems Based on the Common-Mode

Oana Graur and Werner Henkel
Jacobs University Bremen, Transmission Systems Group (TrSys)
E-mail {o.graur, w.henkel}@jacobs-university.de

***Abstract*—We propose a scheme which makes use of the strong correlation present between differential-mode (DM) and common-mode (CM) in the case of a few strong impulsive interferers, in order to improve the BER in a DMT system. This is achieved by flagging the bits on the carriers corrupted by impulse noise as erasures before decoding, thus allowing the Reed Solomon (RS) decoder to correct twice as many erasures than errors.**

***Index Terms*—erasure, common-mode, impulse noise, DSL system, Reed Solomon code**

I. Introduction

The conventional approach of using differential signaling (DM) to convey information over copper cables is extended to incorporate the common-mode (CM) signal. Since there is a high correlation between CM and DM, the CM signal can be used as side information at the receiver side in order to estimate erasure positions introduced by disturbances such as impulse noise, RFI and crosstalk. Although the current paper focuses on erasure marking when impulse noise is present in the system, the proposed scheme is applicable to any disturbance type which shows a high correlation between CM and DM. Previous work in the area of joint DM-CM processing can be found in [1], [2].

In Section II, a review of the CM vs. DM signals is provided with the purpose of outlining the practical benefits of making use of their correlation in wireline transmission systems. Statistical properties of impulse noise along with some modeling parameters are discussed in Section III. The idea of erasure marking along with a description of conventional RS (Reed-Solomon) codes can be observed in Section IV. A description of the erasure marking scheme proposed in this paper can be found in Section V. In Section VI it is shown through simulation results that the proposed method provides a considerable performance improvement for DMT (Discrete Multitone) systems, similar to the impulse noise cancellation results attained in [3]. Concluding remarks are presented in Section VII.

II. Differential and Common-Mode Signaling

Before the proposed method is described, an introduction to DM (differential-mode) and CM (common-mode) signals is necessary. Differential Mode (DM) signals are complementary signals sent on two separate wires. The receiver measures the voltage difference between the two balanced lines. The reason why differential signaling has been chosen as the conventional approach in wireline transmissions is that it is resilient to electromagnetic interference. This fact is illustrated in Fig. 1 a). Assuming $180°$ out of phase square waves of $1V$ sent on the two lines, the receiver would measure a 2 V peak-to-peak square wave. In the case of Common-Mode signaling, which is defined as the arithmetic mean of the signals received on the two wires, measured with respect to ground, the measured output would be 0 V. When interference is introduced additively to the system, Fig. 1 b) illustrates the CM and DM outputs. This would be the ideal case when external interference couples identically on both wires. In practical situations, this is not entirely valid and although differential signaling on balanced lines is, by design, less prone to ingress than other signaling methods, the residual interference that makes it to the receiver side can be critical enough to originate in transmission errors. For a mathematical description of signals received in DM and CM in a multi-pair DSL system, which takes into account an arbitrary number of near- and far-end crosstalk disturbances, the reader is referred to [3].

III. Impulse Noise

Given its non-stationary nature, impulse noise represents a major impairment in wireline systems. It can arise from a variety of sources, such as industrial appliances, electrical discharges, switching events,

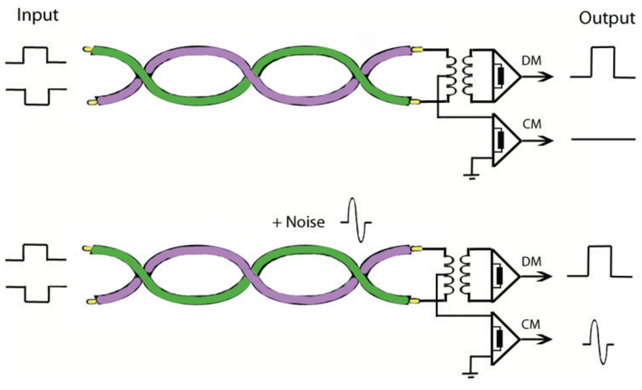

Fig. 1. DM vs. CM signaling. Here, square pulses have been used for illustrative purposes, which is not the case in practical situations. The simulation results described in Section VI have been obtained by employing an ADSL transmission system as described in [4].

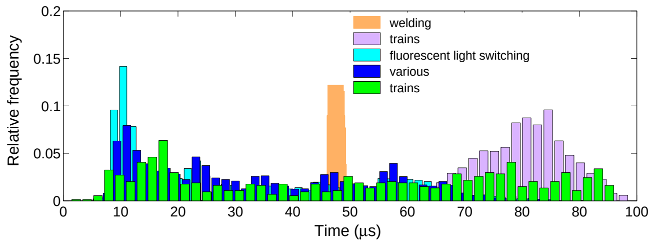

Fig. 2. Normalized histograms of impulse duration. The sets of impulses were measured in different locations in Bremen, Germany, and were caused by various sources, e.g., welding, fluorescent light switching, etc.

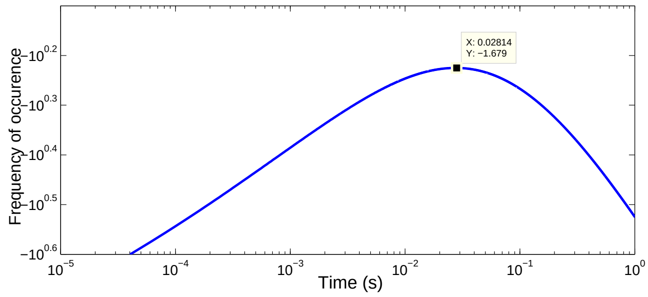

Fig. 3. Logarithmic plot of impulse inter-arrival time approximated by a generalized Poisson distribution with parameters detailed in Table I.

TABLE I
INTER-ARRIVAL DISTRIBUTION PARAMETERS [a]

a_1	a_2	a_3	a_4	x
-7.54	1.88	5.44	1.52	t/100 ns

[a] Obtained from a set of measurements at customer premises (CP) in Arheiligen, Germany. First coefficient is computed such that the area under the curve integrates to 1.

etc.. Sets of impulses were measured at phone outlets in different locations in Germany, being caused by different sources, e.g., furnace ignition, trains, trams, fluorescent light switching, welding etc. and their normalized histograms of impulse durations are shown in Fig. III.

The impulse inter-arrival times used for the simulations in Section VI obey the generalized Poisson distribution given in (1), with the parameters specified in Table I. An extensive description of the PDF of inter-arrival times, along with other parameters for impulse noise modeling such as amplitude and duration, is found in [5]–[8]. Figure 3 is a logarithmic plot of the distribution in (1).

$$f_d(x) = \frac{10^{a_1}}{\ln(10)} x^{a_4-1} 10^{-\frac{a_4}{\ln(a_2)} a_2^{\log_{10}(x)-a_3}} \quad (1)$$

IV. Error and Erasure Coding in DMT Systems

Wireline systems are prone to transmission errors caused by ingress. These errors can occur at random locations or in isolated finite-length sequences, in the case of impulse noise and RFI, known as bursts. Prior to transmission, in the case of block coding, the information is split into blocks of equal length and redundancy symbols are added to each individual block in order to facilitate the correct recovery of the information symbols by the decoder at the receiver side.

Many codes can successfully correct for the errors originating in AWGN environments but are unsuccessful in the case of error bursts typically caused by impulse noise. More burst errors present in a codeword can cause the decoder to fail retrieving the correct information. Reed-Solomon codes have been chosen for ADSL transmission due to their multiple-burst error correction capability and analytical performance computation. Defined as versatile algebraic codes on Galois fields, Reed-Solomon codes are able to correct up to $(n-k)/2$ erroneous symbols if the error locations are not known in advance, where $(n-k)$ represents the number of redundant bits in a block (n: length of codewords, k: number of information symbols).

If side information is present at the demodulator 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

$$s + 2(e - v) \leq 2t = n - k \quad (2)$$

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.

The performance of RS codes in bursty environments can be further enhanced when used in conjunction with interleaving. If the number of erroneous symbols b in a codeword is smaller than the error correcting capability of the code, namely t, then the codeword will be successfully decoded, otherwise spreading the error burst to multiple codewords is necessary. Interleaving ensures a higher probability that the number of erroneous symbols in each codeword would be less than t. Thus, by using an interleaver with interleaving depth d, symbol i is delayed by $(d-1)i$ symbol periods. Interleaving will, thus, increase the burst-error correction capability by the interleaving depth as a factor.

V. ERASURE MARKING APPROACH

Given the fact that the CM signal is readily available on the receiver side, with limited extra costs, and there is a strong correlation between DM and CM, it can be used as a reference to flag erasure positions for Reed Solomon (RS) decoding. At the receiver, both the DM signal and the impulse noise estimate signal obtained from CM are processed in parallel. [9] specifies a convolutional interleaver for ADSL systems. Although a convolutional interleaver reduces the end-to-end latency incurred in the case of burst-error correction to half the latency of a block interleaver [10], since the matter of latency was not under analysis here, a block interleaver was used for convenience. Algorithm 1 presents the main implementation steps of the proposed scheme.

Algorithm 1 Proposed scheme

```
Let λ1, λ2 be two different thresholds whose choice is discussed in Section V.
Initialize DMT system.
Estimate TCTL function.
Get DM and CM signals.
if CM ≥ λ1 then
  activate erasure marking
else
  set deinterleaver erasure matrix to zero
  proceed without using the CM signal
end if
while erasure marking activated do
  obtain impulse noise estimate
  for both DM and estimate do
    pass through TEQ
    remove guard interval
    perform FFT
    perform frequency domain equalization
  end for
  pass DM to demapper
  if estimate^1 ≥ λ2 then
    get vector u of corrupted carrier indices
    for every position in u do
      determine corrupted bits given bit allocation table
      mark possibly corrupted bits as erasures
    end for
    build deinterleaver erasure matrix
  end if
  build deinterleaver error matrix
end while
perform RS decoding^2
```

A. Impulse noise estimation

Given an impulse measured in CM, and knowing the Common Mode Conversion Transfer Loss (TCTL) beforehand, an estimate of the DM impulse can be obtained. The transfer characteristic between common and differential mode was practically obtained from the average cross-PSD between CM and DM and the average[3] PSD of the CM, as follows:

$$T_{TCTL} = \frac{P_{CM-DM}}{P_{CM-CM}} \tag{3}$$

B. Carrier marking

Once the estimate is available, 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 λ_2. The choice of this threshold is critical, since it determines the number of erasures in a DMT symbol. A larger value of the threshold would yield a smaller number of erasures, while a smaller value would increase the number of erasures.

[3]deliberately assuming stationarity. This is a reasonable assumption for wireline systems. The average was performed, however, on a set of 10.000 measurements.

[1]Since FFT has already been performed, thresholding this estimate gives the positions of the carriers affected by impulse noise.

[2]For simulation purposes, no actual implementation of a RS decoder and encoder is necessary. Error statistics can be obtained by incrementing the error count variable in the deinterleaving matrix whenever equation (2) is not satisfied.

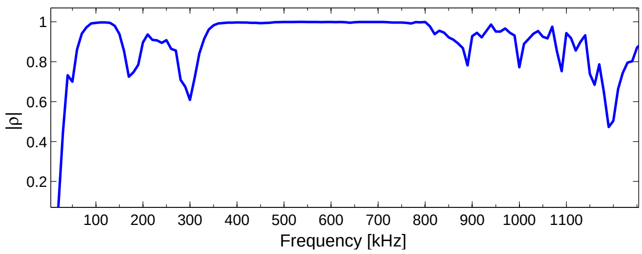

Fig. 4. Frequency dependent correlation coefficient between DM and CM for the ADSL spectral range.

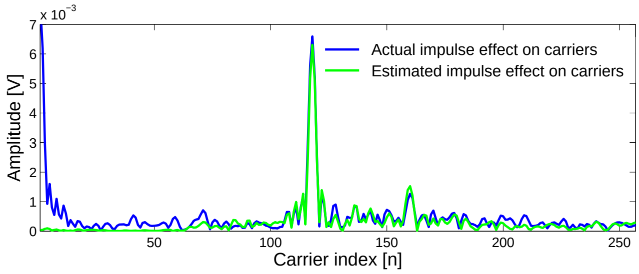

Fig. 5. Carriers corrupted by impulse noise obtained from measurements and estimated impulse noise. For this plot, one measured impulse originating from fluorescent light switching was used.

λ_1 is chosen such that an impulse can be accurately detected in CM.

The DMT carriers affected by impulse noise and estimated impulse noise are shown in Fig. 5. It can be observed that for the middle-range carriers, a more accurate estimation is obtained. This is explained by the fact that there is a higher correlation between CM and DM for that range of frequencies, as depicted in Fig. 4. For a frequency dependent correlation coefficient, above the ADSL spectral range, the reader is referred to [3].

VI. Simulation Results

For the simulation results depicted in the current section, an ADSL DMT system was implemented, with a hard-decision RS code with 12 parity symbols and 134 information symbols.

For a DMT system with parameters summarized in Table II, given a redundancy overhead $n - k$ of 12 bytes for 134 bytes of information data and an uncoded transmission rate of 2048 kbps = 256 kB/s, the coded transmission rate can be computed to be 278.92 kB/s, where 22.92 kB/s represent coding overhead. Knowing the codeword duration to be 500 μs, the DMT symbol duration is 250 μs, since 2 DMT symbols are grouped in one codeword. Considering an average impulse duration of 80 μs as provided by the ”trains” data set shown in Figure III, and assuming the worst case scenario when all the bytes hit result in an error, it can be concluded that if a codeword is hit by an impulse, then 23.36 bytes will be corrupted. When no interleaving is used, the RS decoding will fail, since the error-correcting capability of the code is exceeded. For an interleaving depth $d = 32$, the error-correcting capability is recomputed as $t \cdot d = 192$. It can be easily extrapolated, after consulting Fig. 3, that for a likely inter-arrival time of approximately 30 ms, mostly no second impulse hits any of the other 31 codewords with which the current one has been interleaved, since the duration of the 32 interleaved codewords is computed to be 16 ms.

So far, the above calculations do not take into account the effect of AWGN or the crosstalk introduced in the system. Multiple NEXT disturbers can severely degrade the overall performance of the DMT system, especially in the case of upper carriers and long subscriber loops. FEXT is insignificant for ADSL cable loops longer than 2 km.

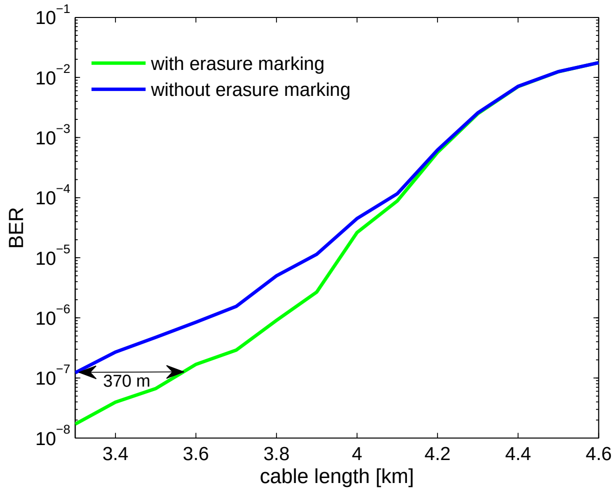

Fig. 6. BER after RS decoding when erasure marking is employed.

For the simulations described in Section VI, perfect echo cancellation is assumed to be employed in order to distinguish between the upstream and downstream signals.

A gain similar to that obtained in the impulse cancellation case in [3] can be observed in Fig. VI for DSL-specific BER of 10^{-7}. The proposed erasure scheme is not limited to impulse noise, it can be extended to RFI and crosstalk as long as there is

TABLE II
ADSL SIMULATION PARAMETERS

Reed Solomon (RS) Code Parameters	
Interleaver depth d	32
DMT symbols in RS codeword s	2
Information symbols k in RS codeword	134
Error correcting capability t	6
RS symbol size	8 bits
DMT Downstream [a] Parameters	
AWGN	-120 dBm/Hz
Number of carriers	254
Downstream net rate	2.048 Mbit/s
Reserved carriers	0–5, 96
Carrier spacing	4.3125 kHz
Cable diameter	4 mm
Transmit power	20 dBm
Sampling rate	2.208 MHz
Loop range	2.6 - 4.6 km
Cyclic prefix	32 samples
Number of NEXT disturbers [b]	4 AslMx

[a] Simulations were performed for downstream only.
[b] FEXT effect is considered negligible.

a small number of disturbers and there is a high correlation between the interference present in CM and DM.

VII. SUMMARY AND CONCLUSION

In the previous section, simulation results have shown that in the case of DMT (Discrete Multitone) transmissions, when the correlation between CM and DM is exploited in order to provide error positions for a RS decoder with interleaving, a gain of 370 m for 0.4 mm diameter cable is attained for a required BER of 10^{-7}. An almost standard-compliant ADSL system has been implemented in order to evaluate the performance of the proposed scheme.

ACKNOWLEDGMENT

This work is supported by the German National Science Foundation (Deutsche Forschungsgemeinschaft – DGF).

REFERENCES

[1] T. Magesacher, P. Ödling, and P. O. Börjesson, "Analysis of Adaptive Interference Cancellation Using Common-Mode Information in Wireline Communications," *EURASIP J. Adv. Signal Process*, vol. 2007, pp. 9–9, June 2007.

[2] T. Magesacher, P. Ödling, P. O. Börjesson, and T. Nordström, "Exploiting the Common-Mode Signal in xDSL," *European Signal Processing Conference*, 2004.

[3] O. Graur and W. Henkel, "Impulse-Noise Cancellation Utilizing the Common-Mode Signal to Improve the Bit-Error Ratio in DSL Systems," in *15th International OFDM-Workshop 2010*, Hamburg, Germany, September 2010.

[4] "Test Procedures for Digital Subscriber Line (DSL) Transceivers," International Telecommunication Union, Draft ITU-T Recommendation G.996.1, February 2001.

[5] W. Henkel, T. Kessler, H. Chung, and H. Y. Chung, "A Wide-Band Impulse-Noise Survey On Subscriber Lines And Inter-Office Trunks - Modeling And Simulation," in *Lines and Inter-Office Trunks - Modeling and Simulation, Globecom/CTMC '95*, 1995, pp. 13–17.

[6] I. Mann, S. McLaughlin, W. Henkel, R. Kirkby, and T. Kessler, "Impulse Generation with Appropriate Amplitude, Length, Inter-arrival, and Spectral Characteristics," *IEEE Journal on Selected Areas in Communications*, vol. 20, no. 5, pp. 901–912, June 2002.

[7] W. Henkel, T. Kessler, and H. Chung, "Coded 64-CAP ADSL in an Impulse-Noise Environment - Modeling of Impulse Noise and First Simulation Results," *IEEE Journal on Selected Areas in Communications*, vol. 13, no. 9, pp. 1611–1621, December 1995.

[8] W. Henkel and T. Kessler, "A Wideband Impulsive Noise Survey in the German Telephone Network: Statistical Description and Modeling," *AEÜ*, vol. 48, no. 6, pp. 277–288, Nov.-Dec. 1994.

[9] "Asymmetric Digital Subscriber Line (ADSL) Transceivers," International Telecommunication Union, ITU-T Recommendation G.992.1, June 1999.

[10] T. Starr, P. Silverman, and S. Thomas, *DSL Advances*. Pearson Education, 2002.