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PROJECT: T1E1.4 Standards Project: HDSL Study Project

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TITLE: Proposal for HDSL2 Transmission: Spectra, Line Code & Coding

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ABSTRACT:

This contribution proposes a Trellis-Coded Staggered FDM (TCSFDM) system as the line code for the single-loop HDSL (HDSL2) project. Shaping is included in the TCSFDM system as an option, which can provide more performance margin as needed. A non-shaping TCSFDM line code consists of: 1) 64QAM modulation (5 bits/symbol), 2) rate-2/3 long constraint trellis code, 3) Tomlinson precoding in the transmitter path, 4) partially overlapped transmit and receive spectrum. A TCSFDM system with shaping shall include shaping encoder and apply flexible precoding, instead of Tomlinson precoding, in the transmitter path. The TCSFDM system with transmit power control shall provide the best performance margin, minimize the overall interference level, and achieve spectrum compatibility with all other existing DSL services.

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NOTICE:

1. Introduction

This contribution is intended to propose aspects of the transmit spectra, line coding and error correction coding for HDSL2 applications. Focus is on the single pair T1 rate with intention to enumerate other rates at later dates. Other performance issues or operational options (e.g. shaping and power control) are addressed here, and will also be elaborated in subsequent contributions.

As discussed in [1], the staggered FDM system allows performance in different NEXT environment to be balanced with a partial overlap between up and down stream channels. The results indicated that the best staggered FDM system with 5 bits/symbol can achieve more than 1 dB uncoded optimal DFE margins over a symmetric echo-canceled system. A 64QAM signal constellation in conjunction with trellis coding shall provide an improved performance margin without any power and bandwidth expansion. As also suggested in [2], trellis code, as proposed to be part of the standard in this contribution, with sequential decoding technique has several advantages for HDSL2 applications.

For a non-shaping TCSFDM system, Tomlinson precoding technique shall be able to eliminate the error propagation issues in a DFE type system. When shaping is included as an option for a TCSFDM system, flexible precoding shall be used in the transmitter in order to combine shaping, trellis coding, and precoding to prevent any loss of the shaping gain.

This contribution is organized as follows. Section 2 gives a brief overview of a trellis-coded staggered FDM system. A detailed description of the transmitter portion of the system is given in Section 3. The performance and spectrum compatibility issues of the TCSFDM system are addressed in Section 4. Finally, the conclusions of this contribution are given in Section 5.

2. Trellis-Coded Staggered FDM System (TCSFDM) Overview

The high level system block diagram of the TCSFDM system is shown in Figure 1. As indicated in the system block diagram, the shaping technique, which can provides extra 0.5 to 1 dB shaping gain, is intended to be as an option for the current design; but will be elaborated in later contributions.

In the transmitter end, the SHDSL framer converts from the 1.544 Mbps T1 format to the 1.552 Mbps HDSL2 data bit sequence format. For a non-shaping system, after scrambler operation, the information bit are processed by a trellis encoder. The bit-to-symbol mapper maps the 6 bits output from the trellis encoder to one of the 64 QAM signal constellation point. The output symbol sequence is then passed through a Tomlinson precoder to mitigate the effect of the time-dispersive nature of the loop.

For a shaping system, after scrambler, the information bits are first processed by a shaping encoder. The output bits are then mapped into symbol of a signal constellation with a larger alphabet, e.g. 96 or 128. The output symbol are processed by a flexible precoding technique[3], which includes both trellis coding and precoding functions.

In the receiver end, the FFE filter compensates part of the intersymbol interference, as introduced by the loop, and also whitens the noise. For a non-shaping system, the sequential decoder may be used to recover the transmit information bit sequence with demonstrated coding gains exceeding 5 dB[4], and possible up to 6 dB[5]. For a shaping system, a flexible decoding technique[3] in conjunction with shaping decoder shall be used to recover the transmit information bit sequence.

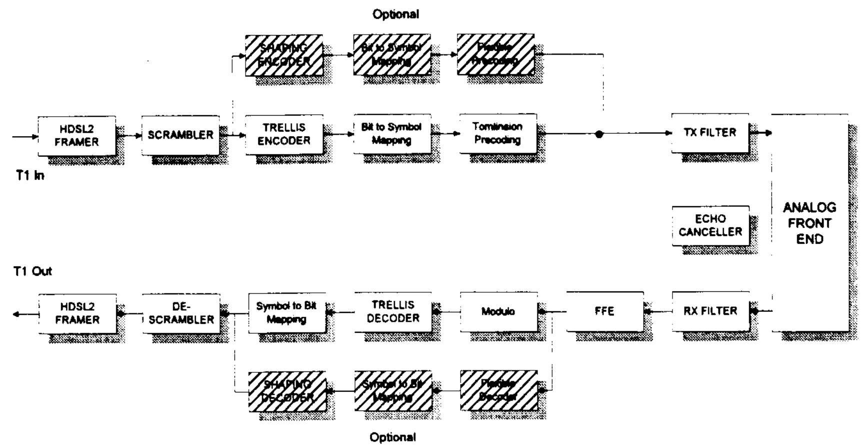

Figure 1. High Level TCSFDM System Block Diagram

3. Transmitter

3.1 Frequency Spectral Placement

The total transmit power shall be 16.8 dBm. The starting, ending, and center frequencies, for both downstream and upstream signal, are listed in Table 1.

Service Direction	Starting Frequency	Ending Frequency	Center Frequency
Up stream	0 Hz	356.96 kHz	178.5 kHz
Down stream	131.52 kHz	441.92 kHz	310.0 kHz

Table 1 TCSFDM spectral placement

3.1.1 Downstream Transmit Spectrum Mask

The downstream signal transmit spectrum is shown in Figure 2. The downstream transceiver shall use a nominal square root raised cosine spectrum with 15% excess bandwidth. At the first null of the square root raised cosine, the attenuation flattens at 35 dB down, on the lower band edge. On the upper frequency band, there is a 3rd order lowpass filter. The rolloff frequency shall start at 511 kHz.

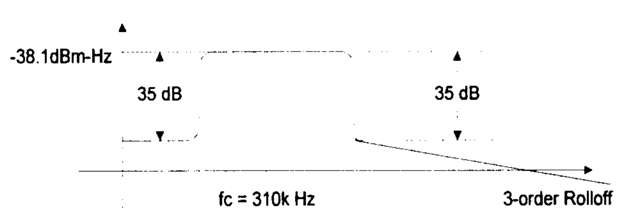

Figure 2: The downstream transmit spectrum mask

3.1.2 Upstream Transmit Spectrum Mask

The upstream signal transmit spectrum is shown in Figure 3. The upstream transceiver shall use a nominal square root raised cosine spectrum with 15% excess bandwidth. Here the attenuation following the first null is masked at 40 dB down. On the upper frequency band, there is, same as in the downstream case, a 3rd order lowpass filter with a rolloff frequency starting at 389.6 kHz.

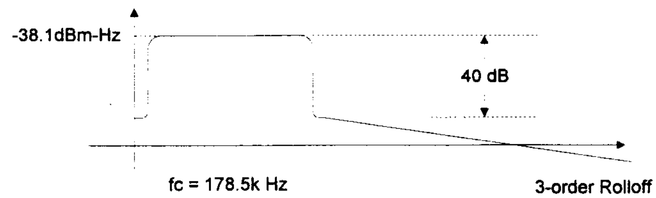

Figure 3: The upstream transmit spectrum mask

3.2 Signal Constellation

3.2.1 Non-shaping System Signal Constellation

The signal constellation for a non-shaping TCSFDM system is shown in Figure 4.

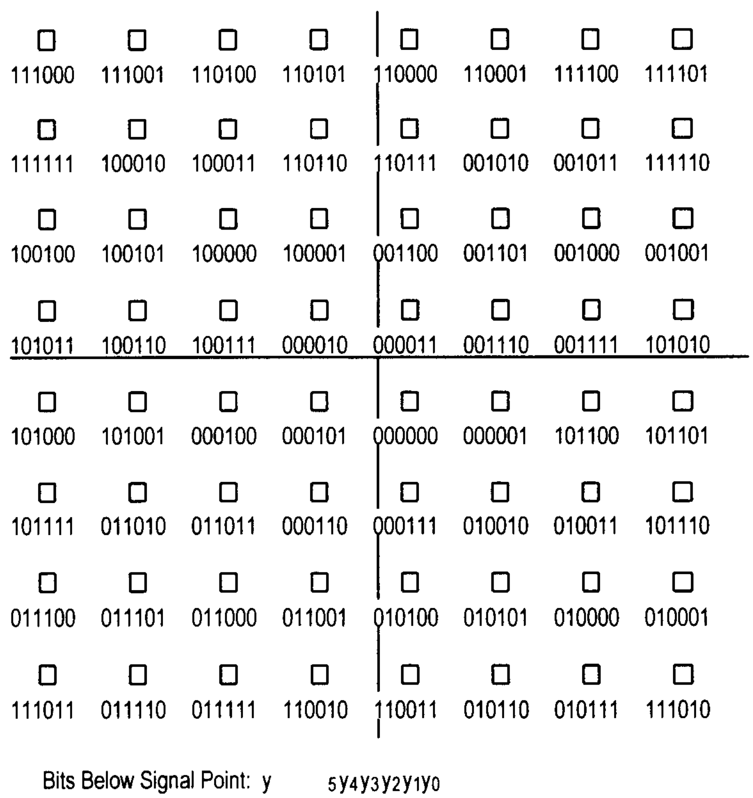

Figure 4: 64 QAM Constellation for a Rate 2/3 trellis code without shaping

3.2.2 Shaping System Signal Constellation

TBD

3.3 Precoder

3.3.1 Non-Shaping System: Tomlinson Precoder

Tomlinson precoder is the same as the one proposed in an Adtran contribution[6]. The system block of the Tomlinson precoder can be found in Figure 4 in [6]. Noted that the modulo function shall perform for the 64QAM constellation, in TCSFDM system, instead of PAM constellation as used in the Adtran contribution.

3.3.2 Shaping System: Flexible Precoder (Optional)

The block diagram for the flexible precoder is shown in Figure 5. It consists of a stable feedback filter H(z), a trellis encoder, a 90° symbol phase rotator, and a Q function. The Q function perform a generalized modulo operation, which generates d_k, the quantization error, q_k, the quantized value, and W_k, a control signal. A detailed description of the functions performed by each block can be found in [3].

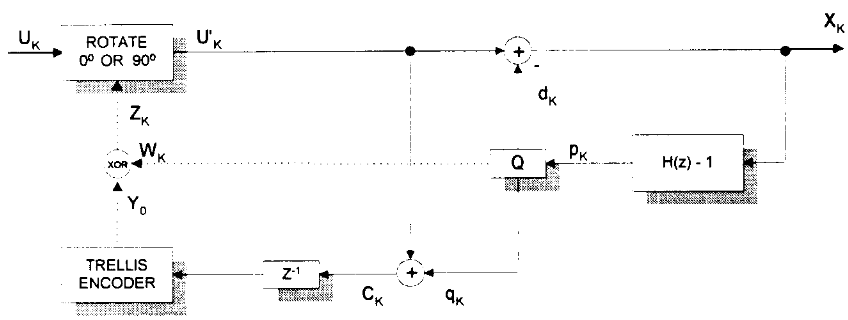

Figure 5: System block diagram for the flexible precoding technique

3.4 Forward Error Correction Coding

3.4.1 Bit-to-Symbol Mapping

The mapping from the encoded bit to a constellation point is shown in the Figure 4. The bits below each signal point in the constellation is read as (y5y4y3y2y0) as generated by the trellis encoder.

3.4.1 Trellis Code

The trellis encoder is shown in Figure 6. It is a rate 2/3 systematic trellis code with constraint length 13. Coding gain up to 6dB are achievable with this code[5]. However, the analysis with current complexity from multiple vendors suggests that a budge of 5.1 coding gain in initial system is prudent. [4]

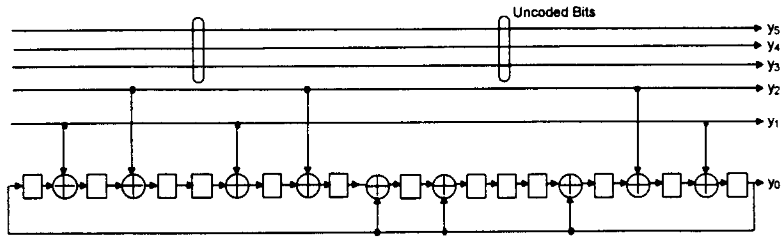

Figure 6: System block diagram for a rate-2/3 constraint length 13 trellis code

3.5 Scrambler

The scrambler/descrambler shall be different in the two directions of the transmission. The generating polynomials shall be as follows:

Upstream transceiver: $g(x) = 1 + x^{-18} + x^{-23}$
Downstream transceiver: $g(x) = 1 + x^{-5} + x^{-23}$

where "+" is the modulo 2 operation.

At the transmitter side, the scrambler shall divide the transmit bit sequence by the generating polynomial. At the receiver side, the received bit sequence shall be multiplied, as performed by the descrambler, by the generating polynomial to recover the original transmit bit stream.

3.6 Transmit Power Control

The transmit power for each HDSL2 module will be increased or decreased as needed in order to minimize the overall interference level. A detailed description of the power control mechanism will be provided in later contributions. A similar power control mechanisms has been previously described in a Level One contribution.

4. Spectrum Compatibility Issues and Performance Analysis

4.1 Spectrum Compatibility

Spectral compatibility with HDSL, ADSL services has already been addressed in [1]. Initial results for T1 service have indicated that spectral compatibility may be achieved with proper transmit power control[1]. However, future contributions will detail spectral compatibility of this proposed transmission scheme with T1 service. Note this scheme, TCSFDM system, differs from analysis performed by Level One in that it includes a 3rd lowpass rolloff on the upper band of the transmit spectrum.

4.2 Performance Estimate

Uncoded optimal DFE margin for this system are:[1]

Interference Model	DFE SNR Margin
49 ADSL	-0.507 dB
25 T1	1.22 dB
39 SNEXT/SFEXT	-0.384 dB

With 5.1 dB coding, minimum performance margin is expected to be 4.6 dB. The ultimate 6.4 dB performance margin can be achieved with 0.9 dB gain from error correction coding gain improvement and 0.9 dB gain from optional shaping operation. The implementation loss will be estimated in the future contributions.

5. Conclusions

This contribution proposes a Trellis-Coded Staggered FDM (TCSFDM) system as the line code for the single-loop HDSL (HDSL2) project. Shaping is included in the TCSFDM system as an option, which can provide more performance margin as needed.

The TCSFDM system with transmit power control shall provide the best performance margin, minimize the overall interference level, and achieve spectrum compatibility with all other existing DSL services.

Reference

[1] G. Zimmerman, "*A Modulation Strategy for HDSL,*" PairGain Contribution T1E1.4/96-340 Nov. 1996

[2] G. Ziemmerman, "Advantages of Sequential Decoding for HDSL2," PairGain Contribution T1E1.4/97-054 Feb. 1997

[3] Rajiv Laroia, "*Coding for Intersymbol Interference Channels - Combined Coding and Precoding,*" IEEE Trans. on Information Theory, VOL. 42, NO. 4, July 1996

[4] R. Goodson, "Simulation Results for Sequential Decoding of 2D Codes," ADTRAN contribution T1E1.4/96-319

[5] B. Grayson, "*Further Results on Sequential Decoding of TCM: The Performance of Coded 64-QAM with HDSL Delay Restrictions,*" PairGain contribution T1E1.4/96-255 September 1996

[6] R. Goodson, K. Schneider, and J. Moore, "Proposal for Single-Loop HDSL Using Simple Coded PAM," ADTRAN contribution T1E1.4/96-037