Project:	T1E1.4: HDSL2 Standard
Title:	**Transmit Spectra Adaptive to Noise and Interference at Activation for HDSL2**
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Abstract

We present several methods for implementing optimal HDSL2 transmit spectra that, at activation, adapt to the surrounding interference and noise. The methods are based around either a set of fixed transmit filters or a single adaptive transmit filter that uses the optimal transmit spectrum. Designing optimal spectra with minimum required power can further increase the spectral compatibility of the system. Transmit spectrum can be adapted on-line to changes in interference characteristics either by reshaping the spectrum optimally or by adjusting the power in step increments until the desired margin is reached (power control). Adaptation of transmit spectra to interference and noise could be made an option in the HDSL2 standard.

1 Introduction

The T1E1.4 committee seeks to define transmit spectra for HDSL2 that achieve high performance margins and are simultaneously spectrally compatible with existing services.

In our earlier contributions [1,2] we outlined the concept of *optimal transmit spectra* that adapt to the surrounding noise and interference combination under an average power constraint [1] and under an average plus peak frequency-domain power constraint [2]. Adaptation to surrounding interferers provides substantial performance margin and spectral compatibility margin gains as compared to using one fixed transmit spectrum (from 4 to 15 dB in many cases). This contribution addresses some of the practical aspects of implementing such adaptive transmit spectra.

We will discuss several possible implementations of adaptive spectra:

1. Design of a fixed set of N transmit spectra, one of which is chosen at activation depending on the noise and interference combination.
2. Design of optimal transmit spectra that adapt to the noise and interference combination at activation.
3. Design of minimum-power optimal transmit spectra. These spectra utilize the minimum power required to meet a specific performance margin. Minimum-power optimal transmit spectra are related to the power control ideas of [3]. However, they differ from power control in that they employ spectral shaping depending on the surrounding interference. Adaptive minimum-power optimal transmit spectra give optimal spectral compatibility — even better than systems utilizing power control.
4. On-line adaptation when new interferers power-up.

Adaptive transmit spectra can also be designed under a fixed static mask if desired — see [2].

Adaptation of transmit spectra could be made optional in the HDSL2 standard.

2 Adaptation to Noise and Interference at Activation

We can adapt the transmit spectra in the activation phase by performing the following steps:

1. At startup, measure/estimate the total interference from neighboring interferers plus noise.
2. Compute adaptive transmit spectra for this interference plus noise distribution as per [1] or [2]. This requires knowledge of the contribution of self-interference to the total measured interference plus noise. We suggest two simple ways of estimating this self-interference by determining the number of HDSL2 interferers:
   - Tap into a central office database for information on currently active HDSL2 lines within the binder.
   - Use energy-based detection techniques for HDSL2 service to estimate the number of interfering HDSL2 lines.

> Armed with an estimate of the number of HDSL2 interferers, we can estimate the total self-interference from the number of HDSL2 lines using the worst-case self-NEXT and self-FEXT characteristics. Subtracting this self-interference from the total measured interference plus noise, we can treat the residual as additive Gaussian noise (AGN). Using water-filling techniques [5, 6] and joint signaling strategies as suggested in [7], we obtain a transmit spectrum using EQPSD (EQual PSD) signaling and FDS (Frequency Division Signaling).

Minimum-power optimal transmit spectra can be incorporated into this scheme, but we should maintain enough performance margin so that the HDSL2 service can tolerate the startup of any new neighboring interferers without degradation in performance.

Optimal transmit spectra can either be chosen from a pre-determined fixed set of transmit spectra or can be evaluated at run-time during activation.

2.1 Fixed set of Transmit Spectra

For a varied set of noise and interference combinations, we can determine the optimal transmit spectra and use them to fix the transmit filters. At activation, we use one of these fixed transmit masks (filters) — the closest in terms of some metric of the interference.

2.2 Optimal Transmit Spectra

If possible we should optimally adapt to the total noise and interference combination each time at activation and use this to adjust the transmit filter taps. This scheme would lead to increased complexity of the system, but would result in even better spectral compatibility and performance margins (for fixed average input power) than one fixed spectrum such as OPTIS [4] or a fixed set of transmit spectra (refer to Section 2.1).

2.3 Minimum-power Optimal Transmit Spectra

Significant gains in spectral compatibility margins can be achieved if we use minimum-power optimal transmit spectra, that is, fix the required performance margin and use the minimum required power to design optimal transmit spectra. To make these transmit spectra robust, we must reserve enough performance margin to allow the startup of neighboring interferers.

3 On-line adaptation

In addition to adaptation at activation, it is desirable to have some on-line (or run-time) adaptation as new interferers power-up or existing interferers power-down or change characteristics.

After activation, if an interferer powers-up we can perform a slow adaptation to the new interference; the presence of sufficient performance margin ensures that the existing HDSL2 service will not break down. We avoid race conditions, because we jointly optimize the performance of all the currently active HDSL2 lines. We can adapt on-line in several ways:

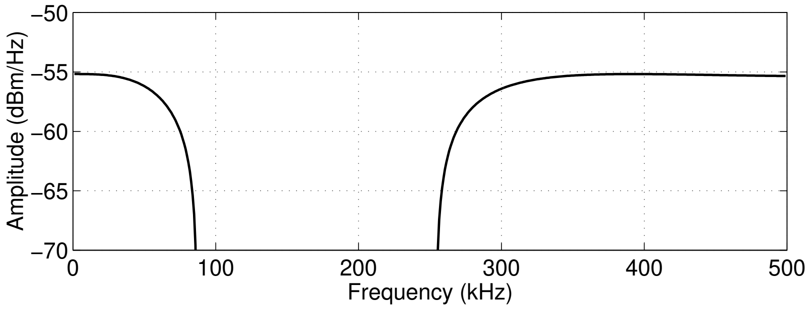

Figure 1: *Minimum-power optimal upstream/downstream transmit spectrum for HDSL2 on CSA loop* 6 *with* 49 *HDSL NEXT interferers and AGN of* −140 *dBm/Hz. The input power was determined for a fixed uncoded performance margin of* 1 *dB.*

1. Consider the input of the new interference to the total noise and interference, and recompute the choice of a transmit spectrum from the set of fixed transmit spectral masks.
2. Recompute the optimal transmit spectrum, that is, reshape the spectrum by measuring or estimating the additional interference.
3. Recompute the minimum-power optimal transmit spectrum, that is, reshape the spectrum by measuring or estimating the additional interference using minimum required power.
4. Increase the power in discrete step increments without spectral shaping (power control idea — see [3]) until the desired performance margin is again achieved.

The above steps can also be carried out in the case of channel variations or if an existing interferer powers-down.

4 Examples

In this section we illustrate minimum-power optimal transmit spectra. For optimal transmit spectra that utilize the maximum allowable input power, please refer to [1,2].

Simulation Details: For the results presented here, we fixed the uncoded performance margin at 1 dB and found the minimum input power required to achieve the DS1 rate of 1.552 Mbps and the corresponding optimal transmit spectra. We assume a 5 dB coding gain that gives us a total coded performance margin of 6 dB. Please refer to [1] for the complete simulation details.

Minimum-power Optimal Transmit Spectra: Figures 1–3 illustrate the minimum-power optimal transmit spectra for HDSL2 on CSA loop 6 with 49 HDSL NEXT, 10 HDSL NEXT plus 10 T1 NEXT, and 39 HDSL2 self-NEXT + self-FEXT plus 10 HDSL NEXT, respectively. We see that in the case of self-interference we separate the upstream and downstream spectra in frequency (FDS). In the absence of self-interference we use the same transmit spectrum for both upstream and downstream directions (EQPSD signaling).

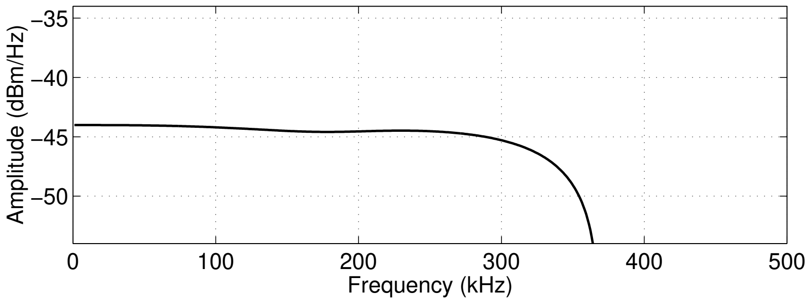

Figure 2: *Minimum-power optimal upstream/downstream transmit spectrum for HDSL2 on CSA loop* 6 *with* 10 *HDSL NEXT interferers,* 10 *T1 NEXT interferers, and AGN of* −140 *dBm/Hz. The input power was determined for a fixed uncoded performance margin of* 1 *dB.*

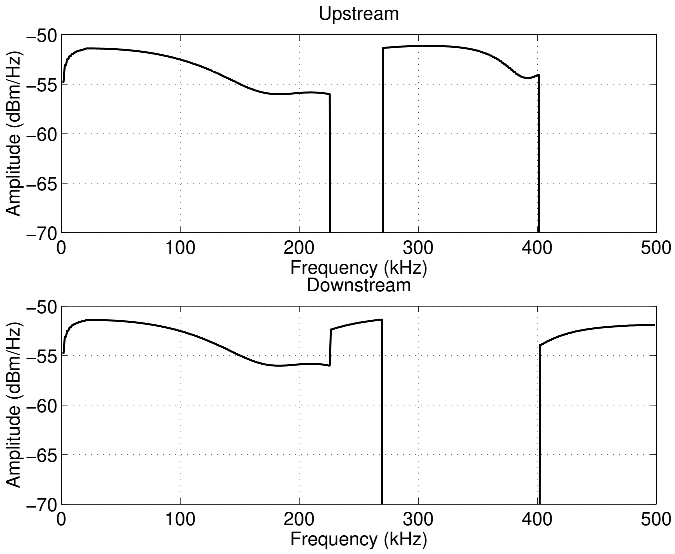

Figure 3: *Minimum-power optimal upstream and downstream transmit spectra for HDSL2 on CSA loop* 6 *with* 39 *self-NEXT + self-FEXT interferers,* 10 *T1 NEXT interferers, and AGN of* −140 *dBm/Hz. The input power was determined for a fixed uncoded performance margin of* 1 *dB.*

Input Powers: Table 1 lists the average input powers required to achieve the uncoded performance margin of 1 dB. The required input powers are significantly lower than the upper limit of 16.78 dBm suggested by OPTIS [4].

5 Conclusions and Key Contributions

- Adaptive transmit spectra can be implemented in a variety of ways. Some knowledge/estimation of at least the number of self-interfering lines in a binder is required.
- Adaptive transmit spectra (fixed set and optimal) yield large performance margins.
- Adaptive transmit spectra have good spectral compatibility with minimum-power optimal transmit spectra having the best.

Table 1: *Average input powers (one-sided, in dBm) for CSA loop 6 using optimal transmit spectra.*

Crosstalk Src	xDSL service	Input Power (dBm)
49 HDSL NEXT	HDSL2	-0.75
25 T1 NEXT	HDSL2	10.87
39 HDSL2 NEXT/FEXT + 10 HDSL NEXT	HDSL2	2.88

6 Recommendations

- Include adaptive transmit spectra at activation and at run-time.
- If required adapt under a static mask that limits the peak power in the frequency domain (OPTIS PSD masks, for example).
- Adaptation could be made optional. We will provide further details in a future contribution.

References

[1] R. Gaikwad and R. Baraniuk, "Optimal Transmit Spectra for HDSL2," *T1E1.4/98-162R1.*

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[4] J. Girardeau, M. Rude, H. Takatori and G. Zimmerman, "Updated OPTIS PSD Mask and Power Specification for HDSL2," *T1E1.4/97-435.*

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[6] J.T. Aslanis and J.M. Cioffi, "Achievable Information Rates on Digital Subscriber Loops: Limiting Information Rates with Crosstalk Noise," *IEEE Trans. Commun., vol. 40, no. 2, Feb. 1992.*

[7] R. Gaikwad and R. Baraniuk, "Optimal Signaling Schemes in the Presence of Cross-talk Interference," Technical report # 9806, Department of Electrical and Computer Engineering, Rice University, July 1998. On Web: `www.dsp.rice.edu/~rohitg/pubs.html`