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Title:	On the Optimization of the Upstream Power Back-Off Parameters
Source:	FTW
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Abstract:	The purpose of this contribution is to describe different methods for optimizing the VDSL2 upstream power back-off parameters.
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1 Introduction

Over the last years telecom operators have shown strong interest in the updated version of very high-speed DSL (VDSL) [1, 2], known as VDSL2 [3]. VDSL2 is the DSL technology with the highest performance of all DSL systems and can utilize frequencies up to 30 MHz. Similar to ADSL, VDSL2 is based solely on discrete multi-tone modulation (DMT) and it uses frequency division duplex (FDD) in order to avoid near-end crosstalk (NEXT) noise between VDSL systems. Furthermore, by using a 'Zipper' transmission scheme [4] (also known as digital FDD), VDSL is much more flexible than other DSL systems in how the frequencies can be divided between the downstream (toward the customer) and upstream (toward the network) directions.

A determining factor for the performance of VDSL is crosstalk noise between twisted-pairs in a cable bundle. This is particularly pronounced for the so called near-far problem, as illustrated in Figure 1, where the modems in the upstream direction that are closer to the central office (CO) or cabinet disturb modems located further out in the network. The solution to this problem involves some form of length dependent power back-off (PBO) [5]. By using PBO, modems located close to the central office (CO) or cabinet reduce their transmitted power spectral densities (PSDs) in order to improve the performance of modems located further away.

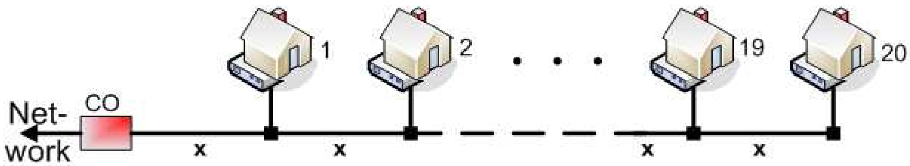

Figure 1: A DSL scenario with near-far crosstalk problems in the upstream direction.

After the identification of the problem, in a contribution from BT [6], many PBO methods were proposed for VDSL, as described by Schelstraete in [5] and the references therein. In the end, the standardization bodies have agreed to use the so-called 'reference PBO' method [5]. With this method a desired *received* PSD is defined as parameterized *reference* PSD for each upstream band. However, the VDSL standard(s) gives little or no guidance to an operator how to establish these optimized PBO parameters for its particular network and customers.

In order to help an operator, or a developer of DSL management systems, determining the optimal PBO parameters this contribution will summarize the currently best available methods for this optimization. The optimal PBO parameters will depend on the topology of the access networks, cable characteristics, mixture of DSL in the cables, and the needs of customers.

The rest of the contribution is organized as follows, first we give some basic concepts concerning PBO and PSD shaping in standardized VDSL and then describe three different *levels* of PBO parameter optimization. The description of these optimization methods are based on three recent papers [7, 8, 9] from FTW[1].

[1] These papers can be downloaded from webpage: http://xdsl.ftw.at.

2 The Reference PSD Method for PBO

The reference PSD method was developed after observing that many PBO methods could be described by a certain desired *received* PSD. This reference PSD, $\mathcal{P}_{\text{REF}}(f)$, which determines the maximum received PSD, is a parameterized function of frequency. Even if almost any shape of $\mathcal{P}_{\text{REF}}(f)$ is conceivable, for practical reasons it was decided during the standardization process [5, 10] to select a reference PSD model expressed as

$$\mathcal{P}_{\text{REF\_dBm}}(f) = \alpha + \beta\sqrt{f}, \qquad \text{[dBm/Hz]}, \tag{1}$$

where f is given in MHz, and α and β are the parameters that are free to be determined in order to meet certain objectives (the objectives depend on the selected optimization strategy as will be described below). It was also decided that independent reference PSDs (independent α's and β's) should be assigned for each upstream band.
In addition, modems need also adhere to a maximum allowed transmit PSD, $\mathcal{P}^{\max}(f)$. Hence, the transmit signal PSD of a particular user u is given by

$$\mathcal{P}_{\text{Tx},u}(f) = \min\left\{ \frac{\mathcal{P}_{\text{REF}}(f)}{|H_u(f)|^2}, \mathcal{P}^{\max}(f) \right\}, \tag{2}$$

where $|H_u(f)|^2$ denotes the insertion loss of lines of user u.

3 Levels of PBO

The traditional way to standardize and optimize parameters like the PBO parameters we study in this paper is to find a good compromise for a region like Europe or North America. For DSL the decision for the PBO parameters typically falls on the network operator(s) or telecommunication regulatory of a country. If one looks at what can influence the optimization of the PBO parameters it is clearly confined to a single cable. Thus, the next natural level of PBO optimization is to establish unique PBO parameters for each cable bundle. The ultimate level of optimization is to establish unique PBO parameters for each user or line. That is, there exist three *levels* of PBO parameter optimization:

- Regional PBO (RPBO) [7],
- Cable-bundle Unique PBO (CUPBO) [8],
- User Unique PBO (UUPBO) [9].

In the following subsections we will discuss these these levels separately and describe current state-of-the-art methods for optimizing at each of them.

3.1 Regional PBO

As the name implies, in this level the PBO parameters are optimized for a particular region. The region might be: a large region as for example Europe and North America, country as for example Austria, a part of a country, a city or even part of a city. The actual Europe and North America regional parameters proposed by the VDSL standards were established by Schelstraete [5] and Oksman [10]. They both used a kind of exhaustive search to find optimized PBO parameters, which is time consuming. In [7] we develop a faster and a more exact method to calculate the PBO parameters by using the Nelder-Mead simplex algorithm [11].

To make the calculation of PBO parameters independent of any particular network scenario, a concept of a worst-case far-end crosstalk (FEXT) noise was introduced in [5]. However, in [7] we show that this concept does not always represent the worst-case, especially for discrete multi-tone (DMT) based VDSL systems. Therefore, we have proposed a new improved way to establish the worst-case FEXT noise environment, which is based on a concept of *virtual modems* [7].

When doing optimization various objectives can be used. We have found that a robust objective is to use a min-max approach, that is, we aim to minimize the maximum difference in the loop reach achieved with collocated modems without PBO and modems using PBO that are distributed in the way to represent the worst-case noise environment. This is similar to the approach originally used by Schelstraete and Oksman [5, 10]. Mathematically the optimization can be expressed as:

$$\min \left(\max_i \left\{ l_{\text{NoPBO}}(R_i) - l_{\text{PBO}}(R_i) \right\} \right), \tag{3}$$

where R_i denote the bit rates for which the reference PSDs are optimized; $l_{\text{NoPBO}}(R_i)$ denotes the reach without PBO and collocated disturbers; and $l_{\text{PBO}}(R_i)$ denotes the reach with PBO and worst-case FEXT.

For this level of optimization the PBO parameters are calculated offline. The operators only need to select a particular cable model and the set of bit rates they want to protect. The cable model should be selected in such a way that it is a good model for the cables used in the region. Based on these parameters our proposed algorithm in [7], that we here will call Regional PBO (RPBO), establishes a set of optimized PBO parameters without any other human interaction. We denote this set by $\Phi = \{(\alpha_1, \beta_1), \ldots, (\alpha_{SB}, \beta_{SB})\}$, where the subscript SB denotes the number of upstream bands.

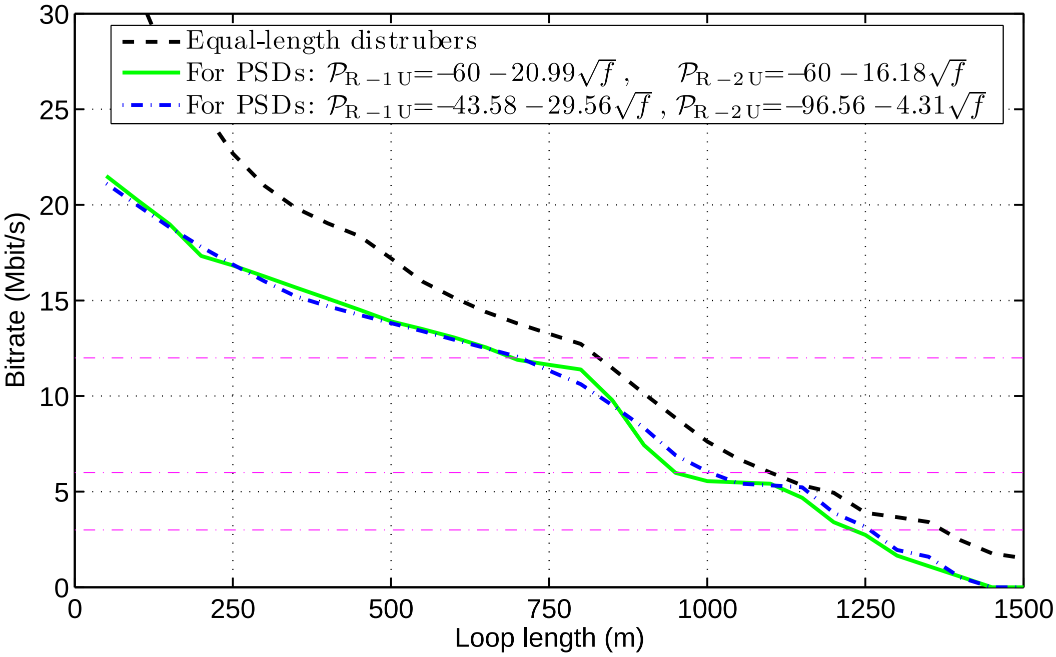

Figure 2: Upstream bit rates for noise model E for equal-length disturbers and for reference PSDs optimized to protect bit rates: 3, 6, and 12 Mbit/s.

With the RPBO algorithm we can either optimize both α's and β's together or optimize with fixed α's and only calculate optimized β's . As can be seen from the bit rate/reach plots in Figure 2, the performance for fixed and varying α's are very similar. Therefore, we mostly uses the RPBO algorithm with fixed α's and searches only for the optimized β's, since this strategy substantially reduces the number of iterations and therefore also the computation time.

3.2 Cable-bundle Unique PBO

In the cable-bundle unique PBO (CUPBO) strategy [8], the PBO parameters are optimized on the level of a cable-bundle. The CUPBO does not use the worst-case noise environment, as used by RPBO, to calculate a set of PBO parameters. Instead, it uses a concept of *normalized* FEXT couplings [8] to calculate the FEXT noise in the cable bundle, which then is used to calculate optimized PBO parameters.

In this approach, as in RPBO, we use Nelder-Mead simplex algorithm [11] to find the optimized PBO parameters; however, we deploy different optimization criteria. We have considered two optimization criteria for CUPBO: maximizing the sum of weighted bit rates and maximizing the minimum bit rate. After experimenting with various network scenarios, we have recognized that both approaches show similar performance. However, for the first approach we also have to determine the appropriate weighting values. Hence, we decided to use the maximization of the minimum bit rate as optimization criteria for CUPBO. The aim is to find a set of PBO parameters, $\Phi = \{(\alpha_1, \beta_1), \ldots, (\alpha_{SB}, \beta_{SB})\}$, which are the same for all users and unique for each cable bundle.

The CUPBO algorithm is a centralized optimization algorithm, thus a central agent that we call PBO center performs the required calculation. The PBO center, which in fact is a piece of software, can operate as a separate entity that communicates with many DSLAMs or as a

logical part implemented within the DSLAM.
The following input parameters are needed by PBO center:

- Measured insertion loss for each user line.
- Background noise level of each user including the noise from the other DSL systems (non-VDSL systems) deployed in a cable bundle.
- Total noise (sum of background noise and FEXT noise), which is used to estimate *normalized* FEXT couplings as described on [8].

All this information can easily be provided to the PBO center by the DSLAM. The background noise levels and insertion losses of the users can be easily measured on-line by the modems and/or the CO. The total noise can be computed from the signal-to-noise ratio (SNR) values that modems are estimating for the aim of bit-loading.

There is a clear benefit to optimize the PBO parameters for each cable bundle whenever the situation in the cable is far from the normal case as specified for RPBO. For illustration purposes, Figure 3 shows the bit rate gain in percentage, of maximization of minimum bit rate and virtual line optimizations[2] versus ETSI PBO parameters, for the distance between users in the range from 10 to 75 m (x-value in Figure 1) . One can see that the largest improvements are achieved for short and long cables. For the medium length cables the improvements are lower, which is due the fact that the standardized PBO parameters are optimized for medium length cables.

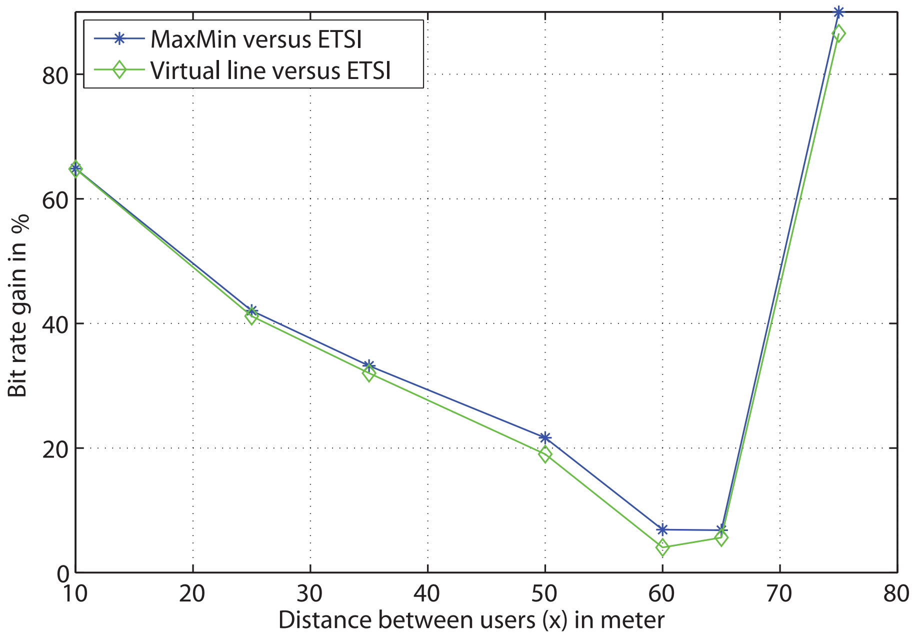

Figure 3: Rate gain in percentage of maximization of minimum bit rate and virtual line optimizations versus ETSI PBO parameters.

[2]Two different strategies that can be used in the core of CUPBO algorithm to build the network scenario to calculate optimized PBO parameters.

3.3 User Unique PBO

The goal for this level of optimization is to determine an individual set of PBO parameters for each user (line). We denote this set by $\Phi_u = \{(\alpha_{1,u}, \beta_{1,u}), \ldots, (\alpha_{SB,u}, \beta_{SB,u})\}$, where the subscript u denotes the user index.
In multi-user DSL environment increasing the bit rate of one user decreases the bit rate of the other users and vice-versa, since the channel is an interference channel. Therefore, a trade-off should be made between different users when optimizing PBO parameters for such an environment. An efficient algorithm to calculate optimized PBO parameters for multi-user DSL systems is the user-unique PBO (UUPBO) algorithm [9]. The UUPBO algorithm uses dual-decomposition optimization and it allocates cable capacity to users based on predefined bit rate shares as described in [9].
The UUPBO algorithm is also a centralized optimization algorithm, running at a PCO center. The following input parameters are needed by the PBO center:

- Desired relative or absolute bit rates which shall be provided to each user.
- Background noise level of each user including the noise from the other DSL systems (non-VDSL systems) deployed in a cable bundle.
- Measured insertion loss for each user.
- Measured far-end crosstalk (FEXT) couplings between all users in the bundle; optionally a generic FEXT model can be assumed or FEXT couplings are estimated on the basis of empirical data.

All this information can be provided to the PBO center using current technology: The network service provider knows in advance what bit rates it aims to offer to each customer. The background noise levels and insertion losses are measured as described in the CUPBO section above. If an online-measure of FEXT crosstalk couplings are not available, FEXT couplings can be estimated on the basis of empirical data constituting a generic FEXT model. All this information is made available at the PBO center without requiring changes in current VDSL standards. Based on this information the PBO center calculates an optimized set of UPBO parameters for each modem.

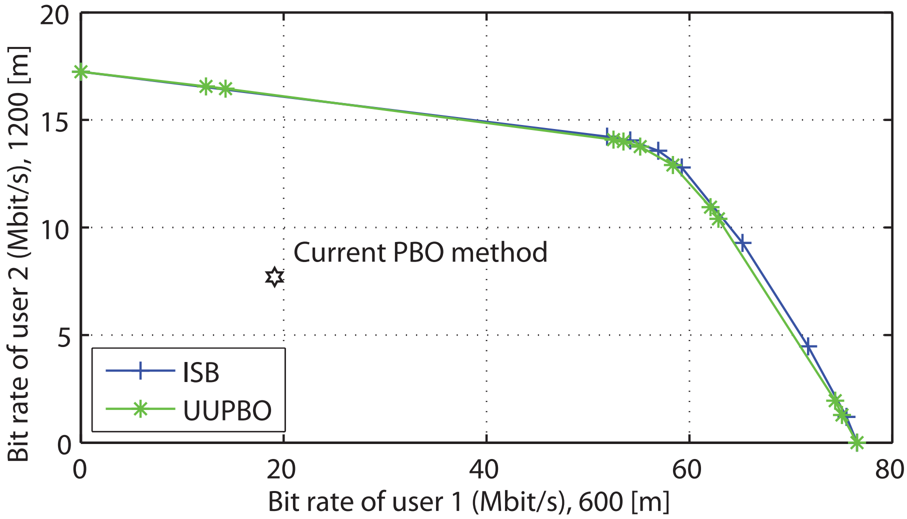

Figure 4: Comparison of the rate regions between UUPBO and ISB algorithms for two users.

With our UUPBO algorithm the performance is comparable to the performance of optimal dynamic spectrum management methods (OSB[12] and its iterative variant ISB[13]). In Figure 4 we have compared the performance of UUPBO and ISB on one of the standard scenarios used to compare DSM algorithms (one modem at 600 m and one at 1200 m). From this simulation we see that UUPBO and ISB algorithms show nearly equivalent performance.

4 Conclusions

This contribution reviews various strategies to optimize upstream power back-off (PBO) parameters for very high-speed DSL (VDSL) and VDSL2 transmission systems. Three levels of optimization have been identified: optimization for a particular region, cable-bundle and user (line), respectively. For each level we propose some highly efficient algorithms to perform this optimization: Regional PBO (RPBO) [7], Cable-bundle Unique PBO (CUPBO)[8], and User Unique PBO (UUPBO) [9].
With increasing level of optimization we find, as expected, increasing performance. We even find that the user unique power back-off (UUPBO) method shows similar performance as optimal spectrum balancing methods. And it should be noted that this is achieved with a spectrum shaping method that all VDSL modems already must implement.

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