

A SIMPLE POLYNOMIAL METHOD FOR OPTIMIZING UPSTREAM PERFORMANCE IN MULTIUSER VDSL2 LINES

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Abstract: In telecommunications, much efforts are spent nowadays to make ICT more Green. Rising energy costs, an economic slowdown and environmental awareness have introduced serious strategic challenges to enterprises worldwide. There are a variety of new and existing technologies available that aid in green IT, such as more efficient hardware that demand less power. In access networks, often the copper telephony network ensuring POTS is used to offer Digital Subscriber Line services to industry and private customers; e.g. to offer high bandwidth Internet access. The reduction of the electrical power in the modems (both in the Central Office and at the premises of the customers) for the transmission of the digital data is a key issue in making xDSL a more green ICT service. In this paper attention is paid to optimize Power Back off methods in upstream VDSL2. We study the excess of power that is required and the performance degradation that occurs when no power control measures are taken at the upstream of a Very high-speed Digital Subscriber Line (VDSL2). We propose a two-step approach: first, to perform an off-line exhaustive search algorithm that can find the optimal upstream power back-off (UPBO) parameters for almost every constraint within a cable bundle, following the current spectrum management specifications and regulations. As any exhaustive search approach, finding the parameters becomes typically very time-consuming, thus, secondly, we propose a simplified polynomial method based on the initial results such that the time to find the optimal parameters is significantly reduced. The algorithm turns out to be a pragmatic approach for current operators and performs well in practice though it does not exploit dynamic spectrum management (DSM) capabilities (being considered a Level-1 DSM-sort of algorithm) and relies on accurate insertion loss calculations for the different users distributed along the cable. However, in practice, given specific conditions per country, higher levels of DSM coordination might not be feasible; thus the motivation of our proposal. Simulation results show very similar results between these steps but at a reduced complexity for the polynomial approach, making the second method attractive for practical VDSL2 lines. We do not maximize the minimum capacity of the system; as it is common practice for operators to try to maximize the performance up to certain distance, we pursue this approach, instead. Finally, we show how our proposed method could be adopted in a specific region/country via a spectrum

management policy such that it can be enforced by the regulatory local entities ensuring that all operators properly follow it. We also demonstrate the severe impact when the policy is not properly applied by all DSL operators..

Keywords: VDSL2, power back-off, near-far problem, spectrum management, green ICT.

1. INTRODUCTION

Ideally, Optical Fiber should be the technology to be deployed to reaching the end-users. However, the investment and maintenance costs are still prohibitive for some countries. Digital subscriber line (DSL) technology is currently the most widely deployed broadband access technology, however, and will continue to play an important role during the coming years. Nevertheless, to cope with the bandwidth-intensive and a mixed set of quality-of-service (QoS) and quality-of-experience (QoE) requirements of the many emerging broadband applications and services (i.e. VoIP, triple-play services including HDTV, IPTV, video-conferences, etc), it is essential to further improve DSL technology.

Thus, the demand for higher bit rates has forced the emerging of new technologies like VDSL2. In order to achieve this purpose, VDSL2 makes use of more bandwidth (up to 30 MHz), enabling higher bit rates, as shown in [1].

It is a common practice in performance studies to assume that all systems deployed from the central office are also co-located at the customer premises side. If this approximation would have been applied to VDSL2 then we get a first estimation on the performance of VDSL2 in both directions. However, such an approximation may be valid for many ADSL deployments, but is inadequate for most VDSL2 deployments (due to relatively short loops). In those cases, the CPE-modems are distributed along the cable, as illustrated in Fig 1.

When all upstream modems transmit in such a distributed topology at full power, those modems connected via longer loops are in a disadvantage, compared to the co-located case. The crosstalk from upstream modems connected via shorter loops will then dominate, causing the performance of modems connected via longer loops to be lower than would have been achieved if all loops were equally long. This effect is typically called the near-far

problem [2, 3], and can be alleviated by means of adequate measures (i.e. upstream power back off – UPBO).

UPBO tries to alleviate the performance loss, for instance, by reducing the transmit PSD level of the shorter nodes (thus, reducing the FEXT crosstalk noise induced in the farther nodes) and therefore allowing longer nodes to achieve a better upstream performance. Fig 2 shows that there is no performance left (without enabling US0) after 600m when no UPBO measures are taken (in a distributed topology).

For a distributed topology, there is a trade-off in the upstream: for shorter distances, there is a loss in performance but for farther distances there is a gain in performance. This trade-off brings the motivation of finding the right balance (and defining the criteria) for getting the “optimal” UPBO parameters for a specific situation (constraints).

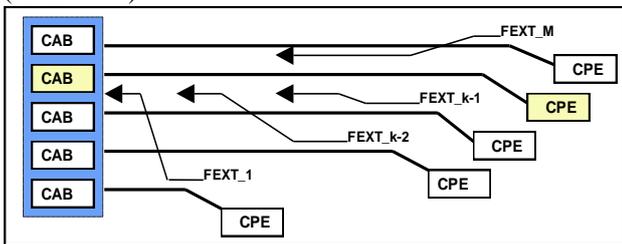


Fig. 1: A typical topology for VDSL2 deployment with a DSLAM located at the cabinet and the users placed at different distances from that cabinet.

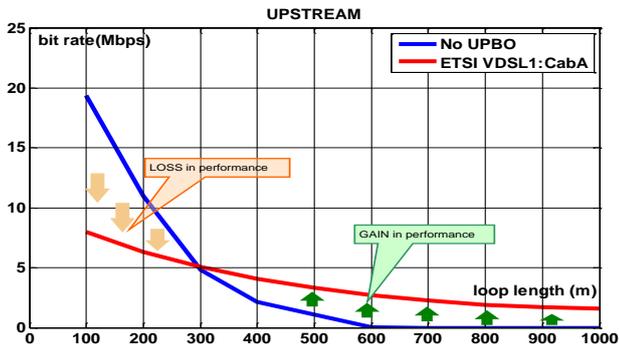


Fig. 2: UPBO trade-off demonstration. US0 is not taken into account to stress the effect of no applying UPBO.

Different methods have been proposed, [3, 5, 6, 7, 9, 10]. Nevertheless, the only one that has been considered into the standard [4] is the reference power spectral density (reference) length method where different reference PSDs have been defined for each upstream sub-band. The actual parameters used for the reference PBO in the current VDSL standards were established in [6] and in [7]. They both used a kind of exhaustive search to find optimized UPBO parameters, which is time consuming. To circumvent this problem, a method to calculate the UPBO parameters by using the Nelder-Mead simplex algorithm has been proposed in [8]. The concept of user-unique PBO (UUPBO) was introduced in [9], where the UPBO parameters are optimized for each line, separately. In [10], the concept of cable-bundle PBO (CBPBO) was introduced, where the UPBO parameters are optimized per cable.

In this paper, we follow the same principle of optimizing the UPBO parameters per cable (CBPBO) but at some

specific length, say L_R . So, we do not maximize the minimum data rate of user i as in [10] but, instead, it maximizes the data rate of user i at some specific length, L_R . In practice, it is very common to find this approach pursued by DSL operators: maximize the capacity of the system up to some specific distance, for instance, to deliver and guarantee a specific class of service. This study is a continuation of the work started in [11] where preliminary results were reported.

Section 2 describes the system model and problem statement; the proposed solution is explained in Section 3; simulations results follow in section 4 and conclusions are drawn in section 5.

2. SYSTEM MODEL AND PROBLEM STATEMENT

A. Overview of UPBO in the VDSL2 Standard [4]

The UPBO mask is calculated in the standard [4] as follows:

$$UPBO_{mask}(kl_o, f) = UPBO_{PSD}(f) + LOSS(kl_o, f) + 3.5 [dBm/Hz] \quad (1)$$

Where

$$UPBO_{PSD}(f) = -\alpha - \beta\sqrt{f} \quad (2)$$

$$LOSS(kl_o, f) = kl_o\sqrt{f} [dB] \quad (3)$$

$$kl_o = \min \left\{ \frac{LOSS(f)}{\sqrt{f}} \right\} \quad (4)$$

The $UPBO_{PSD}$, depends on two parameters: α and β . These are the parameters that have to be configured to obtain the adequate PSD level.

In expression (4), $LOSS(f)$ is the insertion loss in dB of the loop at frequency f . If the loss of the cable cannot be “fit” as \sqrt{f} using kl_o as in (4), it might lead to incorrect estimations of the attenuation (and therefore, of the $LOSS(kl_o, f)$). This term, $LOSS(kl_o, f)$ should be evaluated by the CPE modem (thus, becoming manufacturer-dependent).

We illustrate the variation of the (upstream) spectra for different length values in the sub-loop (see Fig. 3). Using the UPBO settings established in the ETSI VDSL1 standard [12] (CabA), we can show (illustrated in Fig. 3) that the US2 has a reference length equal to $\sim 950m$ (using cable TP150, also known as “KPN_L1” [13]). A similar analysis allows us finding the corresponding reference length for US1, which is equal to $\sim 1300m$ (using the same cable, TP150).

We can also notice from Fig. 3 that there are 3 sub-bands that compose the overall upstream signal (though we will not focus in the sub-band US0). Unlike ADSL2/ADSL2+ systems, VDSL2 is composed of several sub-bands in both upstream and downstream, as shown in [1] where the performance for a specific mask was calculated using different sub-bands.

B. System Model and Data Rate Calculation

A multiuser (MU) DMT channel environment of M users with a maximum number of N tones is represented by:

$$y_i^n = h_i^n \cdot x^n + z_i^n; \quad n \in \mathcal{N}, i \in \mathcal{M} \quad (5)$$

Where H_{ii}^n is the diagonal representing the main channel transfer function of user i at tone n ; H_{ij}^n ($i \neq j$) corresponds to the off-diagonal elements, representing the crosstalk transfer function from user j to user i at tone n ; Z_i^n represents the additive white Gaussian noise (AWGN) of user i at tone n whose power is given by $\sigma_{i,n}^2$. Expression (5) states that the QAM symbol x^n at the input of the DMT transmitter's IFFT is transmitted over tone h^n without any interference from the other symbols x^m for $m \neq n$ and with a noise component corresponding to the receive noise on tone n . So, DMT transmission achieves a full decoupling over tones which is a very important property of this technology.

The general expression for bit loading in a multiuser environment, assuming that each modem treats interference from other modems as noise (so, leading to a Gaussian distribution) is given by:

$$b_i^n = \log_2 \left(1 + \frac{S_i^n |H_{ii}^n|^2}{\Gamma(N_i^n)} \right) \quad (6)$$

Where the total noise power is given by:

$$N_i^n = \sigma_{i,n}^2 + \sum_{j \neq i} S_j^n |H_{ij}^n|^2 \quad (7)$$

And Γ depends on the bit-error rate, coding gain and noise margin. The aggregate data rate in a multiuser environment is thus given by:

$$R_{total} = \sum_{i=1}^M R_i = f_{sym} \cdot \sum_{i=1}^M \sum_{n=1}^N b_i^n \quad (8)$$

Where f_{sym} is the symbol rate (a typical value for DMT systems is 4000 symbols/s).

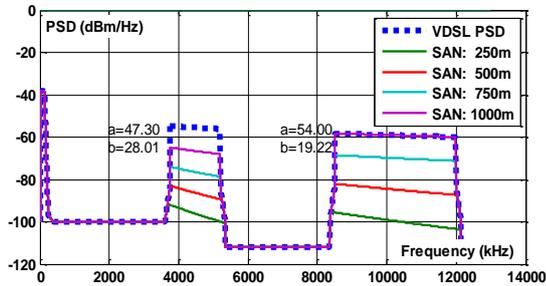


Fig. 1: Upstream Spectra for different (secondary access network) SAN lengths

C. Problem Statement

In this specific study, we will focus on the following optimization problem: to find $\{\alpha, \beta\}$, values per upstream sub-band (not taking into account US0) such that the upstream performance is maximized at some specific reference length¹, L_R . Mathematically expressed as:

$$\max (R_{user_at_L_R}) \quad (9)$$

Subject to

$$UPBO(kl_o, f) \leq UPBO_{mask} \quad (9.1)$$

$$40 \leq \alpha \leq 80, 1 \leq \beta \leq 40 \quad (9.2)$$

$$P_i \leq P_{total}, \forall i, i = 1, \dots, M \quad (9.3)$$

¹ Other criteria can be used, for instance, the maximization of the product bit rate times market share or the performance left at some specific distance, etc.

This optimization problem results in optimizing the performance of all the users located up to L_R of distance from the cabinet. Those users located after L_R will get a performance based on best effort and its performance is expected to decrease rapidly. Constraint (9.1) ensures that there is no any violation according to the levels specified in [4]. Constraint (9.2) indicates the search space boundaries for the pair $\{\alpha, \beta\}$ per upstream sub-band, as indicated in [4]. Constraint (9.3) enforces the power per line to be equal or less than the minimum between the maximum possible power limited by the equipment (CPE modem) and the specification in [4].

3. PROPOSED SOLUTION

A. First Step: Exhaustive Search

We will hereby make use of an off-line exhaustive search to find the optimal parameters under the constraints (9.1 to 9.3) and under specific criterion (Criteria I, II and III which are described later in this section). We will use a typical Dutch cable for this study though it is straightforward to extend it to other cables.

The exhaustive search (ES) algorithm consists of evaluating the bit-rate performance for all possible values of α and β (as described in [4]) in steps of 0.5 dB. We have limited the range of this study up to 1000m.

The generic off-line exhaustive search algorithm is time-consuming but provides with all the details to find the best possible UPBO parameters depending on your specific criteria. Its implementation and explanation is straightforward.

The exhaustive search needs, in principle, to be run for every cable loop in order to be able to get the optimal UPBO parameters. However, implementing the optimal UPBO parameters found in one specific cable into another might be a good starting point for a practical deployment though the penalty in terms of performance can be non-negligible (up to 4Mbps and depending on the cable). Hence, final evaluation of accepting this penalty needs to be decided (by operators) against the complexity of managing several UPBO parameters per cable.

We defined three criteria to be considered in our analysis though the main focus of this paper is on criteria I. The other criteria are included to show the flexibility and robustness of the proposed algorithm and should be used when you have conflicting constraints, i.e. maximizing a weighted sum rate instead of maximizing the data rate at L_R .

Algorithm 1a: Generic Off-line Exhaustive Search

```

for all upstream sub-bands  $\{US_1, \dots, US_{max\_us}\}$ 
  (where  $max\_us$  corresponds to the maximum number of
  upstream sub-bands to be considered in the study)
  for all possible values of  $\alpha$ 
    for all possible values of  $\beta$ 
      for all nodes in the study
        Get  $UPBO_{PSD}$ , according to (2)
        Calculate data rate of  $R_i$  (for
         $i = 1, \dots, M$ ), according to (8)

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Store Results in  $\pi$  where  $\pi$  is the set of
([USUSnr] { $\alpha$ ,  $\beta$ }, Ri) that has been
stored.
    end
end
end
end

```

Criterion I is built upon the information gathered by the Exhaustive Search algorithm. Thus, it retrieves the information from it and finds the user(s) at the selected reference length, L_R , where the (upstream) performance is maximum. Such UPBO parameters ($\{\alpha, \beta\}$ per upstream sub-band) are stored and applied to all the modems in the system.

Criterion I: Algorithm for finding the Maximum Upstream Performance at some specific (reference) length, L_R

1. Find one user, φ , at L_R , that is, the user at node μ where μ represents the different nodes of the distributed topology ($\mu \leq M$).
2. Search within π the values of $\{\alpha, \beta\}$ for this user φ that maximize the performance at L_R .
3. Get UPBO_{PSD} for all i^{th} users, $= 1, \dots, M$, according to (2).
4. Calculate data rate of R_i (for $i= 1, \dots, M$), according to (8).

Criterion II is a relaxation of Criterion I. Instead of searching for the optimal point at a specific reference length, L_R , it introduces a parameter ξ that can be interpreted as the distance of how close the selected set of points is from the optimal point (a tolerance). In case of other conflicting constraints, this criterion can be very useful to find a sub-optimal trade-off between the maximum data rate at L_R and the specific constraint.

Criterion II: Quasi-Optimum aggregate weighted data rate in a subset of the (relaxed-maximum) performance at some specific (reference) length, L_R .

1. Find one user, φ , at L_R , that is, the user at node μ where μ represents the different nodes of the distributed topology ($\mu \leq M$).
2. Search within π the values of $\{\alpha, \beta\}$ for this user φ that are ξ close to the maximum performance at L_R where ξ is a value between 0 and 1.
3. Create a new set \emptyset where all new elements of this set are created based on point 2.
4. Within this set \emptyset , search for the values of $\{\alpha, \beta\}$ that maximize the aggregate weighted data rate.
5. Get UPBO_{PSD} for all i^{th} users, $= 1, \dots, M$, according to (2).
6. Calculate data rate of R_i (for $i= 1, \dots, M$), according to (8).

Criterion III focus on maximizing the aggregate (weighted) data rate up to some specific reference length, L_R . For this purpose, Algorithm 1 has to be slightly modified to also store the aggregate data rate. Note that in this case, specific weights need to be given to each of the users up to the specific reference length, L_R such that the $R_{w,aggregate}$ is calculated as:

$$R_{w,aggregate} = \sum_{\mu \in U} w_{\mu} R_{\mu} \quad (10)$$

Algorithm 1b: Generic Off-line Exhaustive Search, storing also the aggregated data rate

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for all upstream sub-bands {US1, ..., USmax_us}
  (where max_us corresponds to the maximum number of
  upstream sub-bands to be considered in the study)
  for all possible values of  $\alpha$ 
    for all possible values of  $\beta$ 
      for all nodes in the study
        Get UPBOPSD, according to (2)
        Calculate data rate of Ri (for
        i= 1, ..., M), according to (8)
        Calculate aggregate weighted data rate,
        according to (10).
        Store Results in  $\pi$  where  $\pi$  is the set of
        ([USUSnr] { $\alpha$ ,  $\beta$ }, Ri, Rw,aggregate,) that
        has been stored.
      end
    end
  end
end
end

```

Criterion III: Maximum aggregate weighted data rate – small variant of Algorithm 1

1. Find one user, φ , at L_R , that is, the user at node μ where μ represents the different nodes of the distributed topology ($\mu \leq M$).
2. Search within π the values of $\{\alpha, \beta\}$ for this user φ that maximize the $R_{w,aggregate}$ at L_R .
3. Get UPBO_{PSD} for all i^{th} users, $= 1, \dots, M$, according to (2).
4. Calculate data rate of R_i (for $i= 1, \dots, M$), according to (8).
5. Calculate the aggregate weighted data rate, $R_{w,aggregate}$, according to (10).

B. Second Step: Simplification and Parameterization

Though our exhaustive search algorithm provides the possibility to practically meet any criteria, it is time-consuming and might be difficult to implement in practice, at least in very dynamic environments. Thus, having run the simulations for different scenarios, cables and crosstalk noise levels, it was possible to explore a practical yet pragmatic approach to simplify the selection of the UPBO parameters (tailored to typical Dutch cables).

Figures 4 and 5 show the polynomial fitting (for upstream sub-band 1, that is, US1 and up to $L_R = 500m$) of the results obtained by the exhaustive search algorithm. Clearly, this motivates the linear simplification of the

selection of the UPBO parameters. Annex C presents a similar analysis for US2.

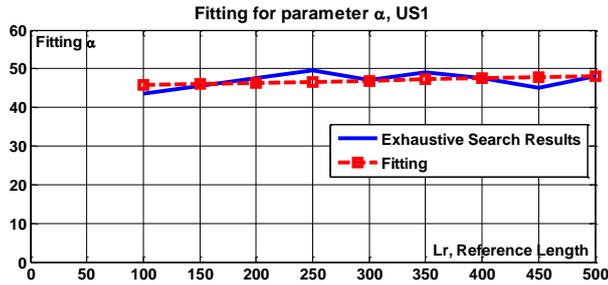


Fig. 2: α Fitting for US1

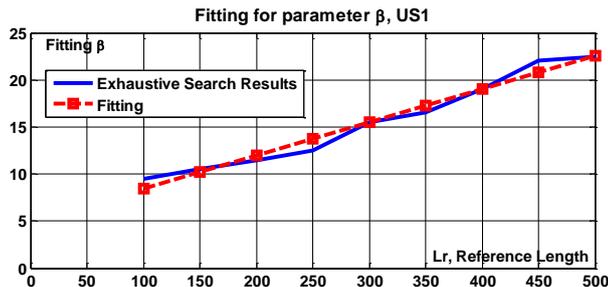


Fig. 3: β fitting for US1.

The set depicted in Table 1 is derived from averaging different results, with an estimated error of approximately $\pm 2.25\%$, leading to the following look-up table:

Table 1: UPBO parameters model as result of Best fitting

UPBO parameters	US1	US2
α	46.3	49.3
β	$4.5 + 18.8L_R^2$	$3.3 + 18.8L_R$

These results have been further validated in the lab tailored to typical Dutch noise scenarios, reaching similar results to the exhaustive search method. The results from the measurements are omitted in this study.

This approach substantially simplifies the calculation; therefore, the problem is reduced to indicate up to which specific reference length, an operator would like to maximize the performance. Furthermore, the adoption of the algorithm has no impact at the CPE-side (user side).

4. SIMULATION RESULTS

The topology to be used consists of several disturbers in a distributed topology as depicted in Fig. 6. The distribution of the customers follows the national average (more than 80% of the users are located up to 1000m) for the Netherlands though the results are practically topology independent.

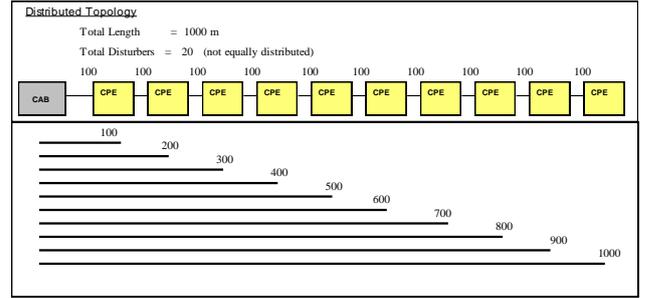


Fig. 4: Distributed Topology for scenario under study

The concept of crosstalk (X-talk) offset level is re-used as proposed in [1], which basically consists of lowering the overall crosstalk noise by some determined offset value, following the results from a statistical analysis of the crosstalk over the cable loops (coming from measurements in the field).

Table 2: Overview of the Parameters used in the Simulation

Description	VDSL 2 Configuration
VDSL Type	B8-4 / A
Profile	12a (using US1 and US2 only) \equiv to profile 12b
Cable Type	TP 150 (0.5mm)
Noise Margin	6 dB
Disturbers Type	20 x VDSL B8-4 / A (self-talk only)
Xtalk-Offset level	- 12 dB
INP	2 symbols
Delay	8 ms
$SNR_{gap, \Gamma}$	12,75 dB [9.75 + 6dB noise margin - 3dB coding gain]
f_{sym}	4000 [symbols/s]
BER	10^{-7}
Crosstalk summation method	FSAN
α, β range	$40 \leq \alpha \leq 80,$ $1 \leq \beta \leq 40$

A. Initial results from the Exhaustive Search

Initial results depicted in Fig 7 and 8 (from the proposed exhaustive search algorithm) indicate that it is possible to reach a global maximum in both upstream sub-bands at some specific L_R (figures are shown for $L_R = 800m$). However, we can fairly conclude that there is some freedom to select values of α and therefore, the main challenge remains in finding the optimal β . Furthermore, additional constraints can (should) be added to enhance the overall optimization problem due to the fact that there are several points close to the maximum optimal; so there is not too much gain in really finding the optimal but instead in achieving other constraints (e.g. maximize aggregate data rate, minimize power, maximize class average rates, etc). A contour view is presented in Annex A.

² L_{ref} is given in km

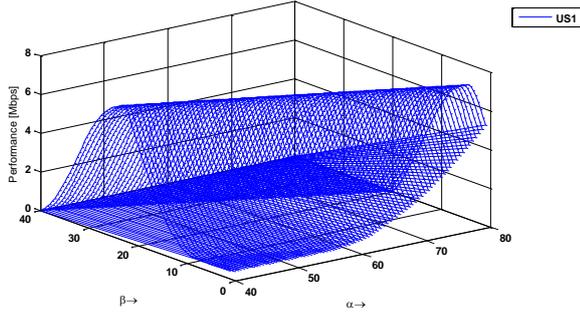


Fig. 5: Overview of upstream US1 performance for different values of $\{\alpha, \beta\}$, $L_R = 800\text{m}$

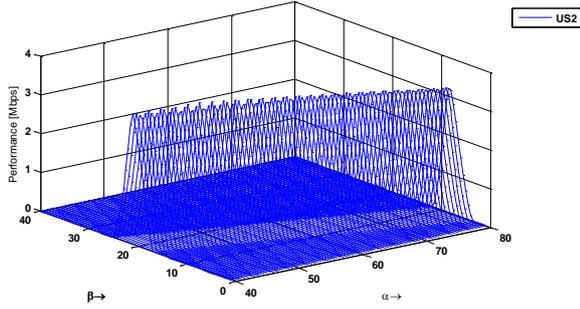


Fig. 6: Overview of upstream US2 performance for different values of $\{\alpha, \beta\}$, $L_R = 800\text{m}$

Similar results have been found for other values of L_R ; for instance, simulation results for $L_R = 500\text{m}$ can be inspected in Annex B.

B. Evaluating performance at different values of L_R .

Selecting the adequate reference length L_R is crucial in our proposed algorithm. Therefore, we provide an overview of the potential performance gain/loss for different values of L_R . In practice, the value of L_R is expected to be chosen by the operator, according to some criterion, e.g. the distribution of the customers.

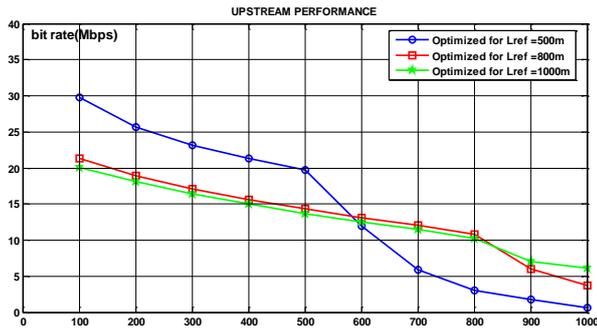


Fig. 7: Optimized Performance at different reference lengths.

C. Distinguishing between cabinets

The operator has the possibility to distinguish between cabinets, e.g., understanding what the user distribution is and defining more than one (reference) length L_R to be optimized. This will bring performance benefits in terms of clustering the different users per cabinet and setting different optimal UPBO parameters per cabinet (per cable).

Fig. 10 shows the resulting gain when distinguishing among cabinets. We can observe that a gain up to 7.5Mbps can be obtained in this particular case.

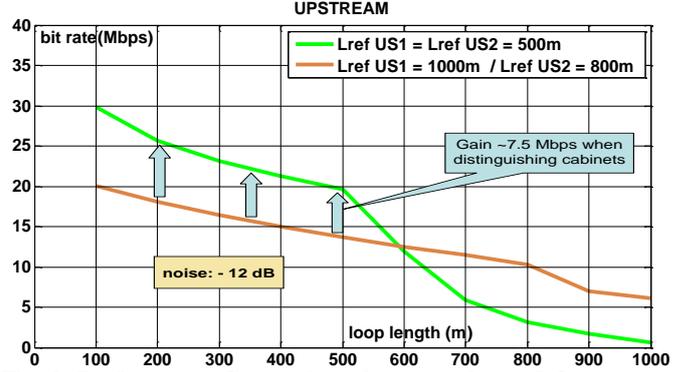


Fig. 8: Performance Comparison for two values of L_R .

D. Evaluating other criterion

Observing the results from section 4.a, we concluded that further constraints might be added to the optimization problem as described in (9), and hence, the other criteria (II and III) were defined.

Figures 11 and 12 show the performance comparison using all criteria defined in section III. We can notice that the difference among these optimization problems is minor. Furthermore, we can notice in Fig. 12 that maximizing the aggregate weighted data rate lead to better performance at distances greater than the selected value of L_R (500m).

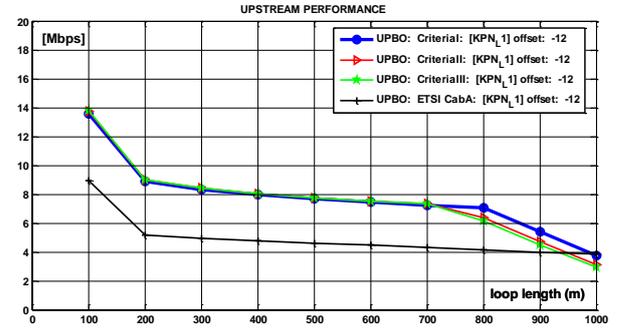


Fig. 9: Performance Comparison using other optimization criteria, at $L_R = 800\text{m}$

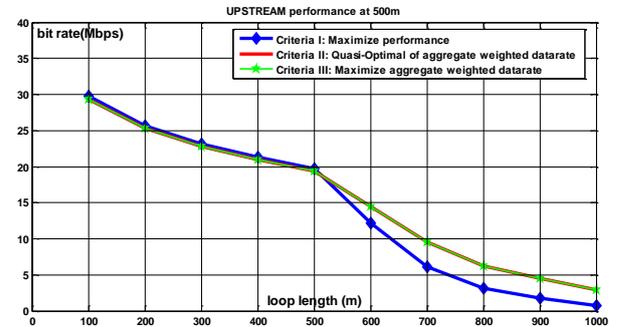


Fig. 10: Performance Comparison using other optimization criteria, at $L_R = 500\text{m}$

Figure 13 shows an interesting result: for distances up to $\sim 700\text{m}$, criteria II (and therefore criteria I as well) and criteria III lead to similar results, so maximizing the rate up

to a specific L_R leads to almost similar results than maximizing the aggregate data rate at that specific L_R (up to 700m, using this particular cable). Notice that the x axis represents the different values of L_R and not the loop length.

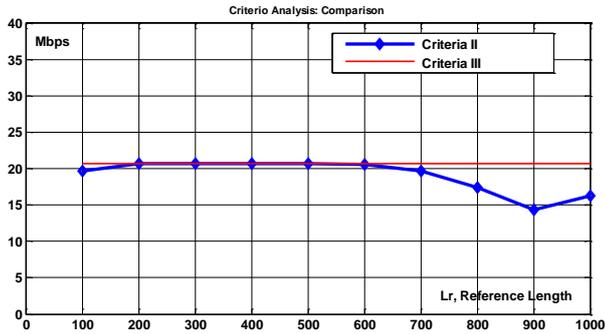


Fig. 11: Performance Comparison between Criteria II and III

E. Ambiguity when evaluating kl_o

There is some uncertainty on how kl_o is evaluated for each (CPE-modem) manufacturer. Evaluating kl_o at different frequencies will translate in an error. We investigate here this effect by evaluating kl_o at 1 MHz and 3.75 MHz using cable TP150.

We observed that the difference in terms of performance (for this specific cable, TP150) is translated into ~ 1 to 3Mbps, depending (now more heavily) on the crosstalk environment.

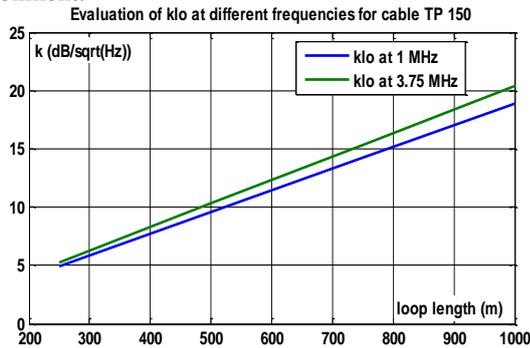


Fig. 12: Attenuation when kl_o is evaluated at different frequencies

5. HOW TO DEPLOY THIS METHOD AND IMPLICATIONS IN THE POLICY ADOPTION

Our work is further motivated by the fact that current operators need to deal with local and international (standards) regulations. However, the management of the spectrum is typically managed per country and thus local policies can always be deployed.

In this section, we demonstrate that the gain in performance when applying effective UPBO measures is jeopardized when only one single node (composed by one or more users) does not apply the (optimal) UPBO settings. Thus, a single failure degrades the performance. Therefore, the proposed solution works well only when is used by all modems (from all different operators). Hence, a local rule needs to in place to safeguard the performance of the whole system.

Figure 15 shows the performance degradation when one node fails at applying the (*agreed*) UPBO parameters. Curve 1 in the plots correspond to a UPBO at $L_R = 1000m$. Certainly the (negative) effect is more severe for nodes (so, users) located closer to the cabinet.

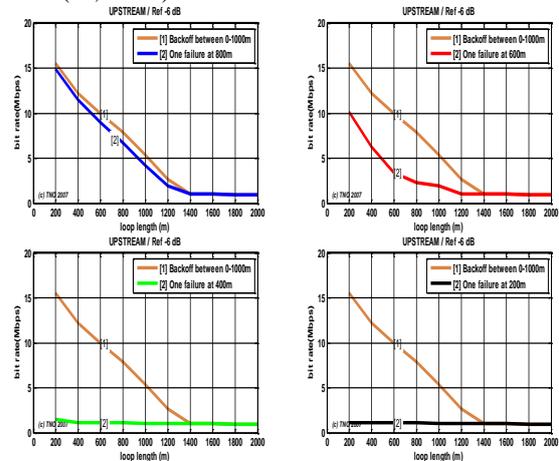


Fig. 13: The performance loss is shown when a failure occurs at different distances (between 200m and 800m). Ref-6dB means a crosstalk offset level of -6dB, as explained in [1].

Therefore it is clear that measures need to be taken. However, the next question is: how to define UPBO in a rule?

A classic (very common) approach is to apply spectra policing only at the transmitter side. However, UPBO should pursue a different approach: applying spectra policing at both sides.

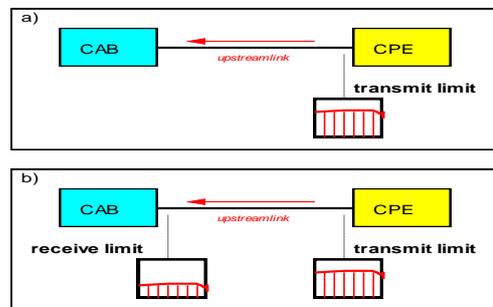


Fig. 14: a) Classic approach; policing only at the transmitter b) Proposed UPBO approach, policing at both sides

Several ways to establish the received spectra can be pursued, depending on the number of UPBO parameters that are going to be accepted per region or country. But, it is advisable to start with one single set of UPBO parameters that cover more than 80% of the users-distribution (when feasible). Then, other settings (i.e. following our cabinet classification concept) might be added as required. One example of pursuing a nationwide transmit and receive PSD limits is depicted in Fig. 17, for $L_R = 1000m$. When available (and feasible), a Spectrum Management Center (SMC) could further help to improve the spectrum and signal coordination at the receiver side and/or send some information via message-passing (depending on the algorithm) to all (or certain number of) modems.

Furthermore, applying and/or enforcing this policy has no impact at the CPE-side (the user side) due to all operators need to apply the policy at the cabinet (DSLAM's) equipment.

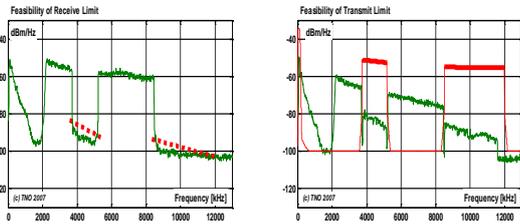


Fig. 15: a) Feasibility of Receive Limit b) Feasibility of Transmit Limit

6. CONCLUSIONS

We described the near-far problem in Multiuser VDSL2 systems. We started proposing an off-line exhaustive search algorithm to find the optimal UPBO parameters for different criterions, within a cable-bundle. By inspecting the results under different scenarios, we could perform a polynomial fitting, leading to a very simple formula that provides the optimal UPBO parameters that maximize the data rate up to the (given) specific reference length at negligible performance loss (less than 2%). We further investigate how to deploy the proposed method over practical VDSL2 lines from an operator perspective. We demonstrate that a national policy is needed among all DSL operators in order to successfully benefit from the implementation of UPBO.

Our algorithm has no impact at the user-side due to neither any special information is needed nor message-passing is required. However, we also demonstrate that there might be a non-negligible difference (in the order of up to 3Mbps for the cable under test, TP150) when calculating the insertion loss at the CPE-side due to a manufacturer-dependent way of evaluation.

7. ACKNOWLEDGMENTS

Authors acknowledge TNO for partially funding this project and for facilitating the realization of measurements to validate the results herein presented.

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9. ANNEX A: CONTOUR VIEW OF UPSTREAM PERFORMANCE OPTIMIZATION

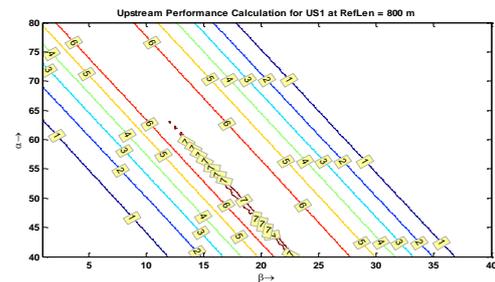


Fig. 16: Contour overview of upstream US1 performance for different values of $\{\alpha, \beta\}$, $L_R = 800m$

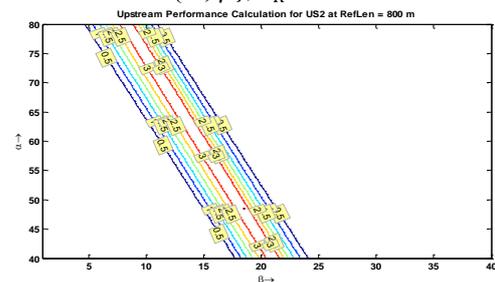


Fig. 17: Contour overview of upstream US2 performance for different values of $\{\alpha, \beta\}$, $L_R = 800m$

10. ANNEX B: EXHAUSTIVE SEARCH ALGORITHM RESULTS FOR $L_R = 500m$

11. ANNEX C: POLYNOMIAL FITTING FOR US2

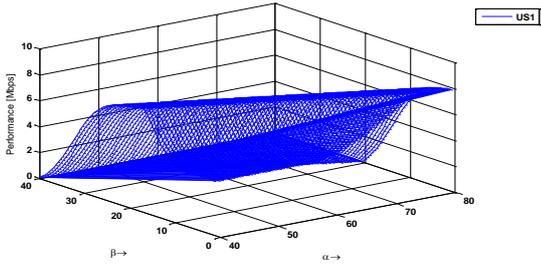


Fig. 18: Overview of upstream US1 performance for different values of $\{\alpha, \beta\}$, $L_R = 500m$

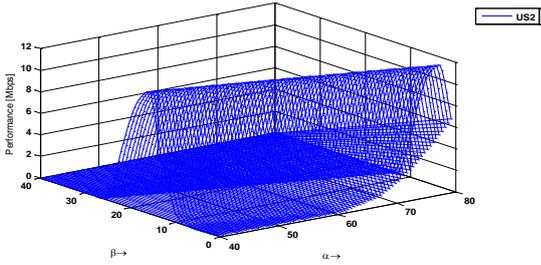


Fig. 19: Overview of upstream US2 performance for different values of $\{\alpha, \beta\}$, $L_R = 500m$

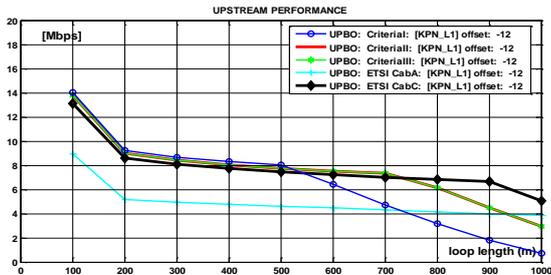


Fig. 20: Performance Comparison using other optimization criteria, at $L_R = 500m$

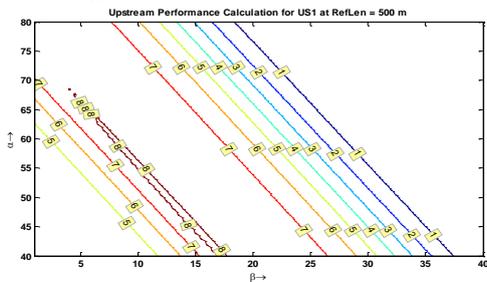


Fig. 21: Contour overview of upstream US1 performance for different values of $\{\alpha, \beta\}$, $L_R = 500m$

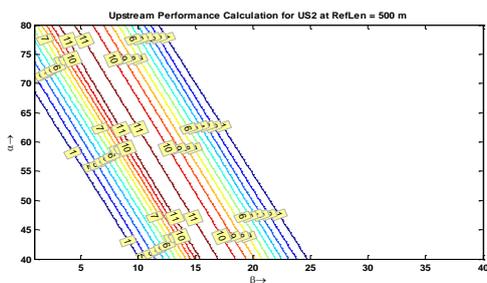


Fig. 22: Contour overview of upstream US2 performance for different values of $\{\alpha, \beta\}$, $L_R = 500m$

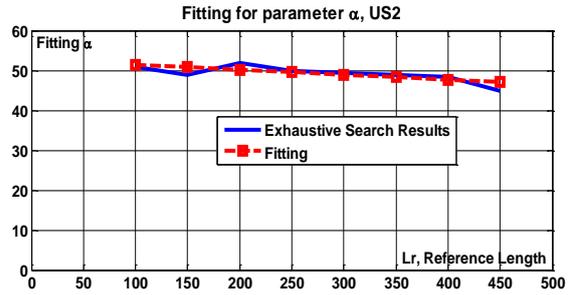


Fig. 23: Contour overview of upstream US2 performance for different values of $\{\alpha, \beta\}$, $L_R = 500m$

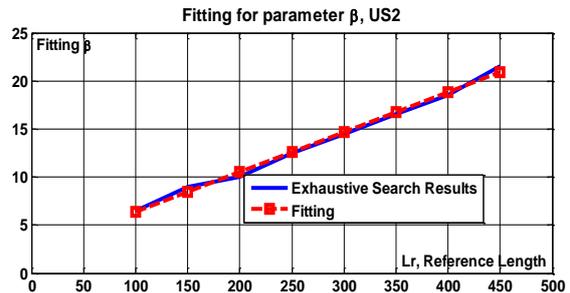


Fig. 24: Contour overview of upstream US2 performance for different values of $\{\alpha, \beta\}$, $L_R = 500m$