Impact Analysis of effective PSD shaping in VDSL2 systems

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Abstract

This paper analyses the need for shaping the downstream PSD of VDSL2 systems, so that it can coexist with legacy systems (like ADSL2+) in the same cable. It shows how PSD shaping can be applied in practice, what the penalty will be on the performance of VDSL2 itself, and how effective it can protect legacy systems. These studies are based on a mix of simulations and measurements which are relevant for any operator interested in rolling out VDSL2 systems. As an accurate evaluation of the insertion loss is not always possible, a sensitivity analysis for ADSL2+ is performed evaluating the impact of "wrong" shape configurations*.

Introduction

There are different ways to deliver broadband services to end users. When counting the volumes, the use of ADSL-based technologies via ordinary telephony wiring is often a preferred solution, followed by the use of cable modems via coaxial CATV networks when those networks are available. Fiber-based solutions are sometimes offered as well, but they are a minority compared to ADSL-based deployments in many areas.

The demand for delivering bitrates (to be able to deliver triple-play services) that are higher than ADSL can offer is increasing, and the use of Fiber-to-the-Home is a strong candidate for a next step. However the huge investments for digging fiber in the ground to connect all customer locations, is a significant barrier. This makes the use of VDSL2-based solutions attractive as alternative that is more cost-effective: extending fiber to street cabinets and use existing telephony copper wiring only for the last few hundred meters. With such a solution, bitrates in the order of 20-30 Mb/s can be offered to most customers, and occasionally even much higher rates following several techniques (e.g. vectored-DSM) [8],[9],[10],[11],[12].

However, another barrier has to be resolved first, before VDSL2 can be deployed. VDSL2 has to operate in an unbundled environment, meaning that it has to share the cable with systems from other (competitive) DSL-operators. Without special measures, VDSL2 (deployed from cabinets) and ADSL (deployed from a local exchange) cannot coexist in the same cable: VDSL2 can easily cause a significant performance drop of ADSL due to crosstalk between different wire pairs in the same telephony cable.

If a system of one DSL operators impairs the systems of its competitors in a disproportional manner, national regulations will force him to stop immediately.

Technical solutions to enable VDSL2 to protect ADSL do exist, the concept of "PSD Shaping" have been standardized, but since that associated settings are network specific (different for each country) all details on the settings are left for the DSL operator. Practice has shown that this issue of not harming ADSL is so delicate in many countries, that DSL operators aiming at VDSL2 are first to provide proof that their settings for PSD shaping are adequate before they may start deploying VDSL2.

The PSD shaping mechanism we follow in this work is based on the insertion loss (attenuation of the cable) between the central office (exchange) and the cabinet.

An accurate evaluation of the insertion loss is not always possible in practice. For this purpose, we provide, in section V, a sensitivity analysis which quantifies the impact of "wrong" shaping.

In this contribution, we make use of a specific methodology for shaping VDSL2 systems [1,2]. In section II, we discuss the impact in legacy systems if PSD Shaping were not applied. Section III discusses PSD Shaping. Then, in section IV we evaluate by simulation [7] the penalty in VDSL2 systems when PSD shaping is applied between the CO and the CAB. The effectiveness of PSD Shaping is demonstrated by means of an experiment in section V. Finally a sensitivity analysis of shaping, using simulations, is derived in section VI and section VII concludes the paper.

Impact on legacy systems without PSD Shaping

Figure 1 illustrates how easy signals injected from the cabinet (CAB) can impair signals injected from the central office (CO) when they are overlapping in frequency and injected at equal level. The level injected at the cabinet is significantly higher than the attenuated level from the central office (in another wire pair) at the same location.

In order to have an idea of the impact in terms of performance, Figure 2 illustrates how much ADSL2+ will deteriorate from cabinet deployed VDSL2, in case no measures are taken. The simulated curves show the

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ADSL2+ bitrate for different loop lengths, for the cases that several ADSL2+ systems are replaced by an equal number of VDSL2 systems from the cabinet. The curves are evaluated for different locations of these cabinets (1km, 1.5km and 2 km from central office). They show that a single VDSL2 system can halve the bitrate of ADSL2+ when deployed from a cabinet at 2 km in a loop of 2.5 km. Multiple VDSL2 systems can easily do even worse.

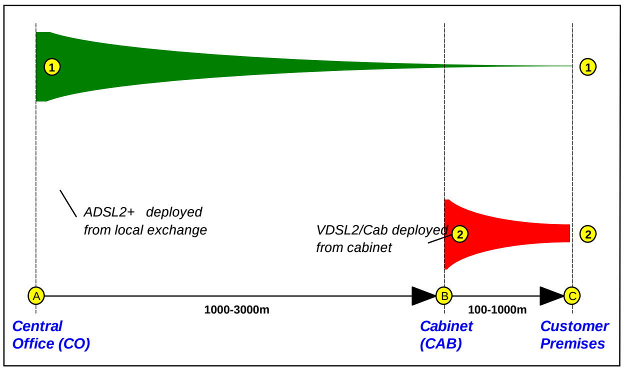

Figure 1: ADSL2+ and VDSL2 signals from the CO and CAB.

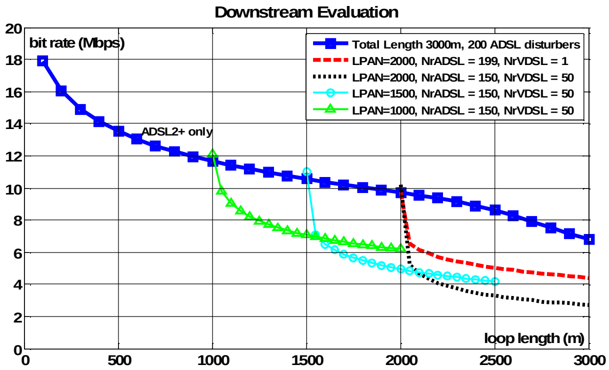

Figure 2: Simulated performance degradation of ADSL2+ systems when VDSL2 disturbers are present. L_{PAN} represents the distance between the CO and the CAB. NrADSL and NrVDSL account for the number of ADSL2+ and VDSL2 disturbers, respectively, summing up in all scenarios to 200 disturbers, as in the case where only ADSL2+ disturbers are present (blue square line).

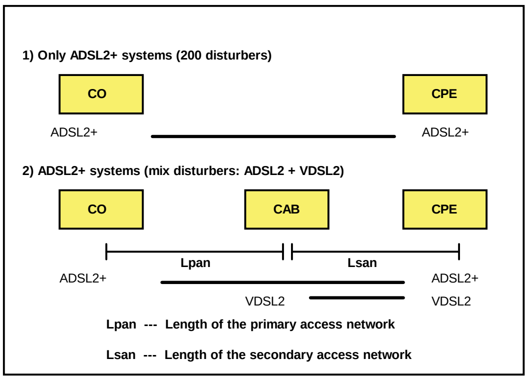

Figure 3: Topology corresponding to performance obtained in Figure 2. Blue square line in figure 2 corresponds to the first scenario in Figure 3. The other curves correspond to scenario 2, varying the number of disturbers between ADSL2+ and VDSL2 and varying the distance between the CO and CAB.

PSD Shaping, as principle solution

It may be clear that when VDSL2 in the sub loop is to coexist with legacy systems in the local loop of the same cable (like ADSL2+ from the local exchange), a solution is needed to protect the local loop systems. An effective solution is the use of "PSD shaping" for the VDSL2 spectrum (also known as downstream power back-off, DPBO).

Roughly speaking, PSD Shaping consists of reducing the downstream VDSL2 signal to a level similar to the attenuated ADSL2+ signals near the cabinet. This is only required up to some maximum usable frequency in a particular loop (e.g. for ADSL2+, 2.2MHz). In practice, the shape is a few dB different, and is considered as optimal when the FEXT received at the customer premises, from downstream VDSL2 and from downstream ADSL2+, are equal. Thus, our approach makes use of an equal-FEXT criterion.

PSD shaping can be specified in a technology-independent way, by defining upper signal limits within a given resolution bandwidth (PSD-masks). The specification in [1,2] illustrates how this can be done in practice. It specifies a set of different PSD masks for different values of the insertion loss (IL) of the loop between central office and cabinet. In total 46 shaped masks for each dB insertion loss, measured at 300 kHz, up to 45 dB, have been defined.

The design is based on a "TP150†" cable [3], which is a Dutch 0.5mm cable, also known as "KPN_L1".

Figure 4 shows the PSD template of signals compliant with the specification in [1,2], for IL values 0, 10 and 25 dB (roughly equivalent to loops of 0, 1 and 2.5 km in TP150 cable). The changes up to 2.2 MHz are due to the required shaping. Above 2.2 MHz nothing is changed by the shaping.

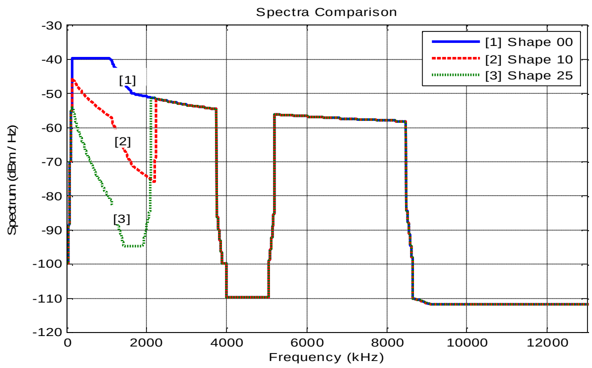

Figure 4: Simulated PSD templates when VDSL2 is shaped as shape-10, shape-25 or as shape-0.

The precise shapes of the PSD masks in [1,2] were designed by simulation [17], according to the above

† TP150 cable has an attenuation of roughly 10dB/km. For example, 45dB corresponds to roughly 4.5km.

mentioned optimization criteria, and are fully tailored to the TP150 cable. These limiting masks are mandatory for the Netherlands and have been proposed for inclusion in the ETSI Spectral Management standard [5]. The shapes may be somewhat different for other type of cables, but the principle remains the same.

Shaping VDSL2 spectra in this way will be fair to legacy deployments (like ADSL2+ from the local exchange) but it may be obvious that it has a penalty for VDSL2. The forced reduction in power up to 2.2 MHz will translate into some degradation in its performance, in a typical noise environment. We will show the impact of shaping in the sequel.

The concept of PSD shaping is not always restrictive for the transmit power of VDSL2. Many practical implementations lack the power to fill up the full spectrum as granted by the limits specified in [1, 2] when the loop between local exchange and cabinet is short. Therefore the penalty in performance is not always significant.

Penalty when Shaping VDSL2 Spectra

The use of PSD shaping for VDSL2 can preserve the performance of local loop systems like ADSL2+ but it may have a penalty in the performance of VDSL2. This penalty may be lower than expected, since shaping will not only reduce signal power in the victim, but also crosstalk noise power from neighbouring VDSL2 systems.

To quantify this penalty, we studied the change in (predicted) downstream VDSL2 performance, between two equivalent (noise) scenarios. Equivalence means in this context that the number of disturbers is kept the same, but the type of disturbers (shaped or non-shaped) changes.

All scenarios being studied within this context assume a disturber mix of 40 broadband systems, as summarized in table 1, a topology shown in figure 5, performance predictions at 6 dB noise margins and worst case values of FEXT and NEXT for the Netherlands. In addition, cable model TP150 [3] was used to evaluate the signal loss, and the crosstalk noise level was 6dB below the 99% near worst-case‡ limits (the limits that will not be exceeded in 99% of the cases for the Netherlands) to avoid overly pessimistic performance predictions.

‡ The near worst case for the Netherlands is higher than the commonly used values of EL-FEXT= -45 dB and NEXT=-50 dB

Table 1: Noise Scenario used for evaluating VDSL2 performance by simulation.

Type of Disturbers	Number of disturbers
VDSL2 (B8-4, 12a)	20
ADSL (POTS)	8
ADSL (ISDN)	1
ADSL2+ (POTS)	8
ADSL2+ (ISDN)	2
SDSL	1
Total Broadband disturbers	*40*
Total Narrowband-ISDN	*14*
Total	**54**

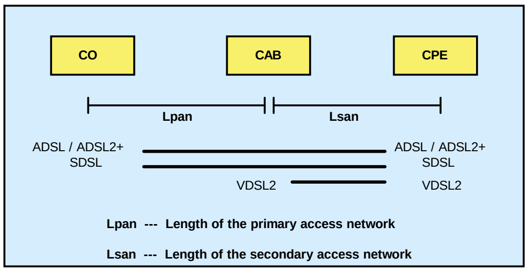

Figure 5: Topology being used in the simulations.

Additionally, the receiver performance model assumed 25% line rate overhead to be used by the INP§ (Reed-Solomon) mechanism.

Figure 6 shows the change in performance predicted for VDSL2 modems when their transmit spectra can equal those in figure 4. This means that they have sufficient power to fill-up the full spectrum being granted. The curve associated with shape-0 represents the case that VDSL2 could inject the same power in the loop from cabinets at 25 dB "distance" as ADSL2+ is granted from the exchange. As expected, the VDSL2 performance under shape-25 conditions is significantly lower then the "maximum" performance under shape-0 conditions. It is observed that Shape-10 follows slightly lower performance than shape-0

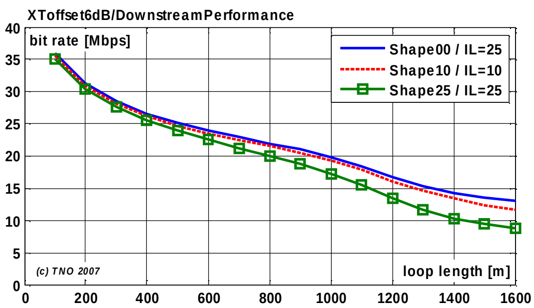

Figure 6: Performance drop when shaping prevents VDSL2 to operate at ADSL2+ levels.

Similar results have been observed if the power limitations of today's equipment are taken into account in our simulations (compliant with ITU band plan 998, using a boosted mask B8-4 and profile 12a, [4]).

§ Though important, impulse noise was not considered in this study.

We have also validated the penalty of shaping by measurements, using state-of-the-art VDSL2 equipment under conditions that are similar as above. Only the cable characteristics of the test loop were a slightly different, but the "distance" in terms of insertion loss was kept the same. The results were consistent to our theoretical analysis (by simulation) with minor differences.

In conclusion, PSD shaping causes VDSL2 to reduce in performance. This reduction will depend on the type of cable and the distance between CO and CAB.

Effectiveness of PSD Shaping applied to ADSL2+

Now it will be demonstrated how effective PSD shaping can protect the deployment of ADSL2+ from the local exchange, when it complies with [1,2]. This can be verified by simulations, but also by means of a simple lab experiment as it will be presented here.

A. Experimental verification at a specific cabinet location

Four experiments have been elaborated to illustrate that PSD shaping according to [1,2] is effective for protecting legacy ADSL2+ services. In all these experiments the same cable is used with four twisted wire pairs, each with 0.5mm wire gauge (NKF N92 cable**). The cable is shielded over its full length to prevent ingress and egress.

Figure 7 shows how the modems were connected to the cable for each experiment, and table 2 summarizes the associated bitrate reported as attainable by the (disturbed) ADSL2+ modem.

The results in table 2 clearly demonstrate that the impact from VDSL2 on ADSL2+ becomes significant if no shaping is applied (a performance drop of about 45% from the original bitrate). This performance drop is prevented by PSD shaping (even a minor performance gain in this experiment). Due to the fact that coupling between twisted wire pairs is never homogeneously over the full cable length, the difference in observed bitrate between experiment #1 and #4 is of no concern.

** A typical cable used in the Dutch access network

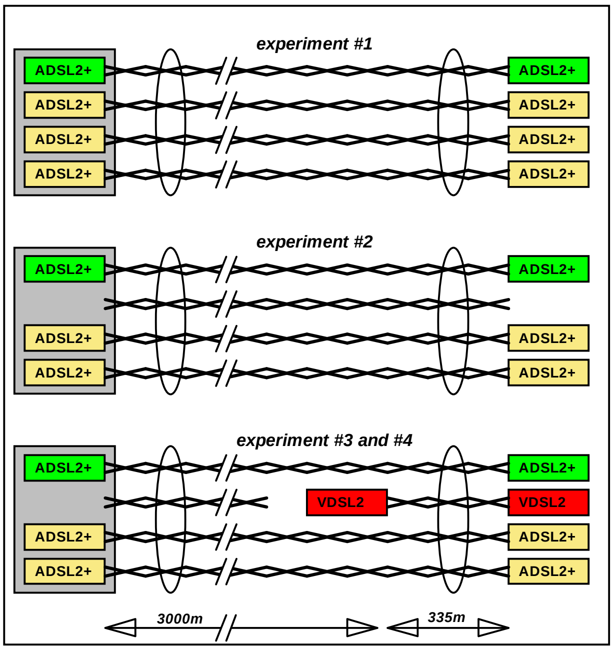

Figure 7: Scenarios being used to verify the effectiveness of PSD Shaping

Table 2: ADSL2+ performance for different number and type of disturbers.

	Scenario: **an (ADSL2+) modem disturbed by:**	**Bit rate [Mbps]**
#1	3×(ADSL2+)	14,8
#2	2×(ADSL2+)	15,6
#3	2×(ADSL2+) and 1×(VDSL2,unshaped)	9,9
#4	2×(ADSL2+) and 1×(VDSL2,shaped)	15,5

B. Experimental verification at multiple cabinet locations

The previous experiments have been repeated for a range of "PAN lengths" (copper length between exchange and cabinet) and "SAN length" (copper length between cabinet and customer premises).

Figure 8 illustrates the change in bitrate, reported by one victim ADSL2+ modem as attainable, for customers at different SAN-lengths, served from a cabinet at 1 km from the exchange. The same applies in figure 9 and 10 for cabinets located more remotely. The PSD shape being applied was different for each cabinet location, to comply with the requirements defined in [1,2].

The curves clearly demonstrate that when PSD shaping is applied to downstream VDSL2, as specified in [1,2], an ADSL2+ victim modem does not observe the difference of being disturbed by shaped VDSL2 or by ADSL2+. In other words, adequate shaping causes that VDSL2 has no other impact than legacy disturbers. This demonstrates how effective PSD shaping can be.

On the other hand, when no shaping is applied, VDSL2 has a negative impact on ADSL2+. Therefore, the drop in ADSL2+ performance increases with the distance of the cabinet as it becomes more difficult for ADSL2+ to make itself heard through the noise.

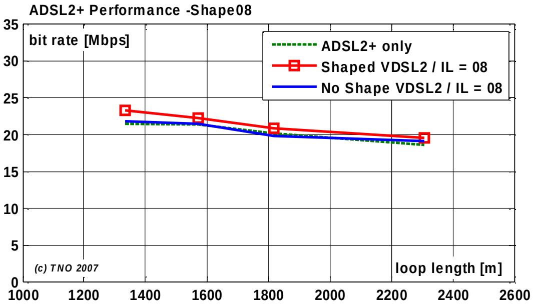

Figure 8: ADSL2+ performance under different disturber conditions for cabinets at 8 dB "distance"

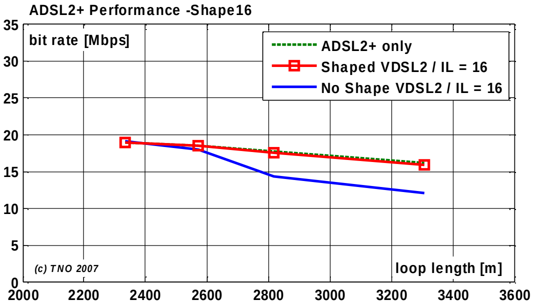

Figure 9: ADSL2+ performance under different disturber conditions for cabinets at 16 dB "distance"

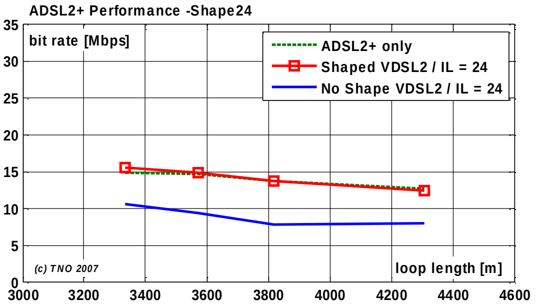

Figure 10: ADSL2+ performance under different disturber conditions for cabinets at 24 dB "distance"

Sensitivity to badly shaped VDSL2 spectra

PSD shaping has been introduced to protect legacy local loop systems (from the local exchange), and therefore its use is a mandatory requirement in the Netherlands for deploying sub loop systems (from the cabinet). This is why the signal limits in [1,2] are so tightly specified.

However the shapes change with the insertion loss of the loop between exchange and cabinet, so a value should be allocated to each involved cabinet. Preferably this value is estimated from length information in a cable database (easy to do for "ten thousands" cabinets) but even when it is measured on a per-cabinet basis it will not be obvious what "the" insertion loss value should be. Typical distribution cables in the Netherlands contain 900 concentric layered wire pairs, therefore, a few percent variation in length (or dB in loss) between wire pairs is common, so what value to choose?

To identify how critical an accurate value for "the" insertion loss should be, we analyzed for a typical Dutch scenario how much the ADSL2+ performance changes when the actual insertion loss differs from the allocated value being used for selecting the shape.

In this study, we assume that the distribution cable (between CO and CAB) will split-up at the cabinet into smaller cables with a split ratio of 1:9. This means that the 20 local loop systems beyond the cabinet (non VDSL2) share the distribution cable with 9×20=180 local loop systems.
To enable a fair analysis, the disturber mix should be equivalent with the mix in table 1. This means using a mix consisting of 180 non-VDSL2 systems (over the local loop) plus the same 20 VDSL2 systems (in the sub loop).
Figure 11 shows a simulation with such a scenario of the ADSL2+ performance. The study shows for a fixed cabinet location what the attainable ADSL2+ bitrate would be in case (a) VDSL2 is correctly-shaped (assumed loss equal to the actual loss), (b) in case it is over-shaped (assumed loss 5dB above actual loss) and (c) when it is under-shaped (assumed loss 5dB under actual loss). Figure 12 and 13 do the same for other locations.

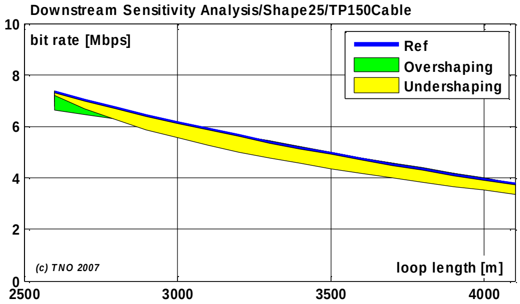

Figure 11: Sensitivity Analysis of the impact to ADSL2+ when VDSL2 is under/over shaped in 25 dB loops.

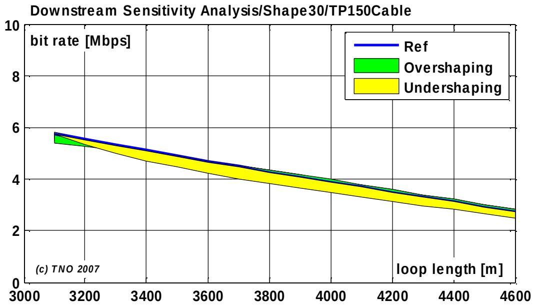

Figure 12: Sensitivity Analysis of the impact to ADSL2+ when VDSL2 is under/over shaped in 30 dB loops.

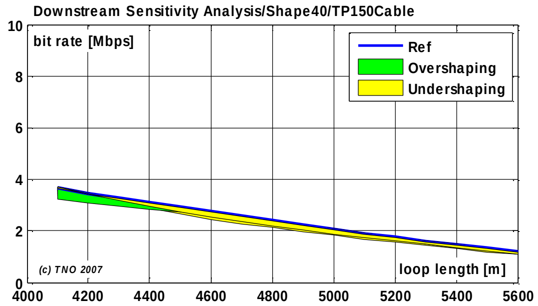

Figure 13: Sensitivity Analysis of the impact to ADSL2+ when VDSL2 is under/over shaped in 40 dB loops.

All these figures illustrate that under-shaping deteriorates the attainable ADSL2+ and should be avoided in operational networks. In the case of overshaping, the performance deteriorates for some ADSL customers on the line while some other ADSL customers get a slightly better performance. Additionally, we observed in our studies that overshaping reduces VDSL2 performance in most cases, so overshaping should be avoided as well. This motivates why estimating the insertion loss between the CO and the CAB is not recommended; it is better to measure it for each cabinet being prepared for VDSL2. However the impact to ADSL2+ of over-shaping is significantly lower compared to under-shaping. This means that when some wire pairs are longer than others in the same cable, it is better to choose the longest one for measuring “the” insertion loss value.

Conclusions

When VDSL2 is deployed in the sub loop (from a street cabinet) it will often share the cable with legacy systems like ADSL2+ in the local loop (from the local Exchange). To let VDSL2 coexist with ADSL2+ in the same cable, it is equipped with the capability to modify the downstream PSD.

This paper illustrates how severe ADSL2+ will deteriorate in performance if VDSL2 is deployed without the use of any PSD shaping.

We verified experimentally that PSD shaping of VDSL2 is very effective in protecting legacy systems from the exchange, like ADSL2+. Shaping has as consequence a negative impact on the VDSL2 performance that cannot be neglected.

In addition, we demonstrated that the selection of an adequate shape from a list with many shapes, requires a proper selection of “the” insertion loss value of the loop between exchange and cabinet should. We advised against a pure estimation of this loss, and showed why it is recommended to measure the loss of the longest wire pairs.

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