The art of Spectral Management Downstream power back-off for VDSL2

Whitepaper on DSL – Rob F.M. van den Brink, TNO, The Netherlands, Oct 2009

Abstract[1]*: Spectral Management (SpM) involves managing an access network such that different systems can co-exist with each other. In relation to DSL systems, spectral management ensures that they can co-exist within the same cable. The use of spectral signal limits (specified via mandatory access rules) is necessary for all DSL deployments, and serves a common interest of all involved DSL operators.*

VDSL2 is a new technology, and can be deployed from remote locations such as street cabinets to shorten the loop to the home and thus increase the achievable bitrate. However, remote deployments can easily disturb legacy deployments (e.g. ADSL) from the central office if the transmit power is not reduced properly. This is called downstream power back-off (DPBO).

Such reductions can only be effective if they are tailored to underlying business needs, installed base of legacy equipment selected degree of protection, and loop characteristics. These are all country or region specific, and cannot be copied blindly from neighbouring countries. This paper explains the need for DPBO, and shows that an effective amount of DPBO can protect legacy deployments at the cost of only a small penalty for the VDSL2 performance itself.

1. INTRODUCTION

VDSL2 is a new DSL modem technology to deliver third generation broadband services (3GBB) via existing telephony wiring. Unlike ADSL2 or ADSL2plus, VDSL2 can deliver data rates of tens of Mb/s or higher, which makes it appropriate for offering multiple video services simultaneously. To enable these higher bitrates, VDSL2 has to be deployed via loops that are relatively short, preferably no longer than about 1 km. When the loop is too long a shorter loop can be achieved by deploying VDSL2 in the subloop from remote locations (like street cabinets being fed via fiber).

Since VDSL2 has to share the cables with legacy systems such as ADSL, SDSL and HDSL (deployed via other wire pairs), it can easily disturb legacy deployments when VDSL2 is deployed from remote locations. Spectral management is required [7] to prevent this undesired behaviour.

One such measure is a significant (frequency dependent) suppression of the downstream transmit signal, before it is injected in the loop from remote locations. This measure is called *downstream power back-off* (DPBO), also known as *PSD shaping*. Such reductions should be tailored to underlying business needs, the required degree of protection of legacy deployments and loop characteristics. Additionally, they are all country or region specific. This paper explains the need for DPBO, how effective it can be, and the penalty for VDSL2 when it is applied.

2. DEPLOYING VDSL2 WITHOUT DPBO

Introducing VDSL2 from street cabinets (VDSL2/Cab for short) may have a negative impact on systems such as ADSL2plus deployed from central offices (ADSL2plus/CO for short). Since the addition of any system will diminish the performance of other systems, it makes no sense to study what happens if we ***add*** VDSL2/Cab one by one. However if we ***replace*** a number of existing modem pairs (e.g. ADSL2plus/CO) by an equal number of VDSL2/Cab, then we can identify whether VDSL2/Cab creates less, equal or more disturbance than ADSL2plus/CO. This keeps the scenarios under study *equivalent*, a necessity for meaningful impact analyses.

The goal is to study the change in performance of a legacy system, when its noise environment changes from one to another (equivalent) scenario. If the maximum achievable bitrates of deployed DSL systems are the same under both scenarios (where the legacy system, ADSL2plus, is replaced by an equal amount of VDSL2/Cab) then we call it *zero impact*. If the maximum achievable bitrate of ADSL2plus increases we call it *positive impact* (due to less disturbance from VDSL2) or if it decreases (due to more disturbance from VDSL2), we call it *negative impact.*

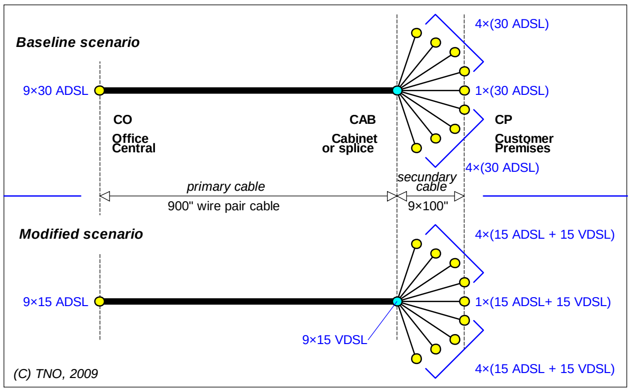

Figure 1*: Two possible scenarios for studying the impact of VDSL2 on deployed ADSL systems when swapping from the baseline scenario to an equivalent modified scenario.*

Figure 1 shows two equivalent distribution scenarios for studying the impact. A primary (distribution) cable connects the central office (CO) with a street cabinet (CAB), and from thereon the wire pairs fan out via several secondary cables to customer premises (CP). The baseline as well as the modified scenario provide broadband to 270 customers.

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However, the modified scenario serves half of the users via VDSL2 from the cabinet.

To study the impact of introducing VDSL2 we need a baseline performance first. Figure 2 shows typical values for the ADSL2plus performance within this baseline scenario. It has been evaluated for a 0.5mm cable having crosstalk coupling values that are somewhat optimistic.

- Curve 1 shows the result of a classic bitrate prediction where all assumptions are kept very simple. It assumed that all customer premises are virtually co-located so that the branching beyond street cabinets can be ignored.
- Curve 2-5 shows a more realistic bitrate prediction by accounting for the fact that the topology is branched. Customers are served in smaller groups beyond a street cabinet, and this refinement is essential to keep it consistent with the modified scenario. It has been evaluated for street cabinets at 500, 1500, 2500 and 3500m from the local exchange.

It may be obvious that the inclusion of branching in the topology results in bitrates that are higher than those used in classic performance calculations (without any branching from a street cabinet). The crosstalk in the secondary cable originates from fewer systems and is therefore lower.

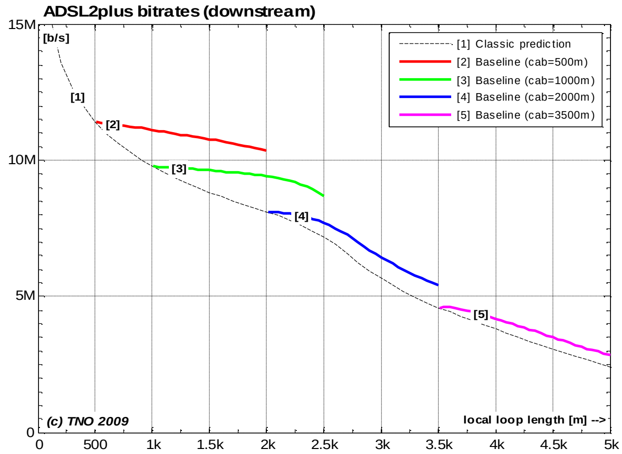


Figure 2: Baseline performance of ADSL2plus, for different locations of street cabinets.

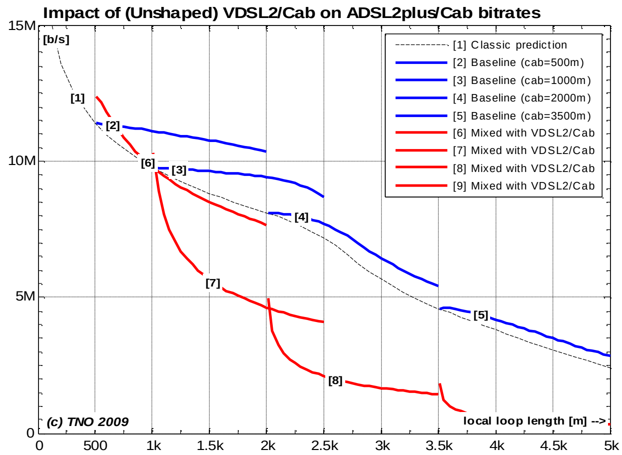


Figure 3: Negative impact of VDSL2 on baseline performance of ADSL2plus, when power back-off has not been applied to downstream signals. It has been evaluated for different locations of street cabinets.

Figure 3 shows how much the baseline performance (shown in Figure 2) drops if the deployment scenario migrates from "baseline" to "modified" for introducing VDSL2. It relies on the same assumptions as those used in Figure 2 and assumes that VDSL2 is deployed from cabinets without any downstream power back-off. A significant deterioration of the ADSL2plus bitrates under these conditions is observed. It may be obvious that such a negative impact is totally unacceptable from a business point of view for those deploying ADSL2plus.

3. PROTECTING LEGACY VIA DPBO

Negative impacts of VDSL2 on legacy deployments such as ADSL2plus can be prevented by a significant reduction of transmit power. The transmit power reducations are applied to downstream VDSL2 signals, before they are injected in the subloop. This mechanism is called downstream power back-off (DPBO) and is also known as PSD shaping.

The aim of DPBO is to reduce the transmit power of VDSL2 modems in remote locations so that they do not disturb more than legacy systems do. This is only needed for the frequency bands used by these legacy modems, and the amount of required DPBO is even frequency dependent.

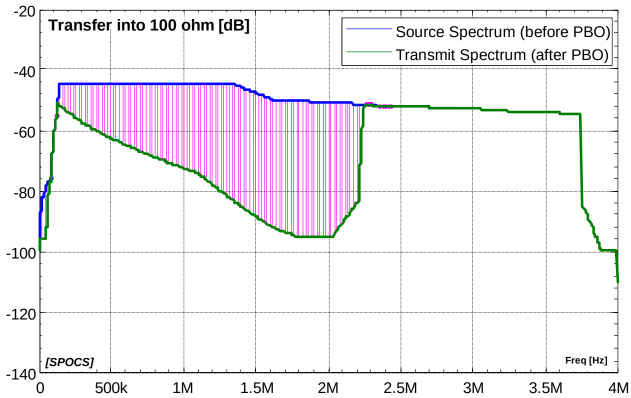


Figure 4: A typical amount of spectral power reduction of VDSL2 downstream signals, to enable coexistence with other DSL systems when deploying VDSL2 from street cabinets. It has been evaluated for a street cabinet at 2km copper distance from the central office.

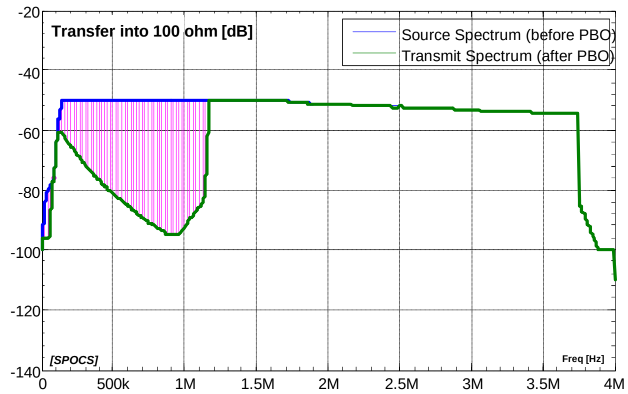


Figure 5: Similar to Figure 4 but for street cabinets at 4 km copper distance from the central office.

Figure 4 gives an example of one such PSD shape, evaluated for a cabinet located at a loop distance of 2km from the central office. The reduced spectrum of VDSL2 follows (roughly) the spectrum of ADSL2plus after it has been attenuated by the primary loop between the central office and the cabinet.

If a cabinet has another primary loop length, then it needs a different amount of DPBO as well. Figure 5 illustrates this for a cabinet at 4 km. Shaping is not only deeper but also restricted to a narrower frequency band. Therefore, each cabinet location requires its own PSD shape.

The methodology for designing an effective set of PSD shapes is beyond the scope of this paper. However, such a set can be analysed for its effectiveness.

Figure 6 shows the results of a similar impact analysis as that presented in Figure 3, with the assumption that DPBO has been applied. The PSD values are taken from the Dutch access rules, as summarized in [1]. The figure illustrates that when half of the ADSL2plus systems are replaced by VDSL2 systems with this particular amount of DPBO, the performance of all remaining ADSL2plus modems improves.

In this example, the amount of DPBO was deliberately more than required ("over shaping") to make PSD shaping robust enough to handle a variety of scenarios. The consequence is that there is a positive impact of VDSL2 in many scenarios, which is better than required.

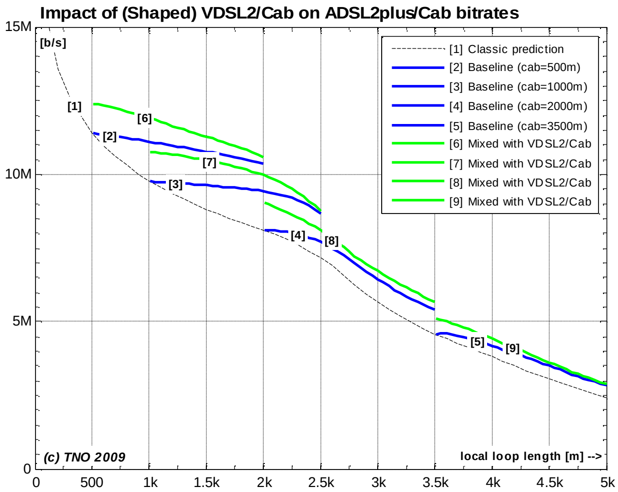


Figure 6: Positive impact of VDSL2 on baseline performance of ADSL2plus, when an adequate amount of power back-off has been applied to downstream signals.

4. PERFORMANCE PENALTY FOR VDSL2

Protecting legacy deployments from the central office by shaping the PSD of VDSL2/Cab has its penalty: it decreases the downstream performance of VDSL2/Cab as well. Fortunately, this decrease is relatively small compared to what can be gained for protecting legacy systems like ADSL2plus/CO.

The result of such a performance analysis according to [2,4] is shown in Figure 7, according to the modified scenario shown in Figure 1. The figure shows the downstream performance of VDSL2/Cab from 4 different cabinet locations, with and without applying DPBO. Since the topology is branched, it is only disturbed in the subloop by 14 other VDSL2 systems and 15 ADSL2plus/CO systems (attenuated by the primary loop). The remaining 8×30 systems have their signals passing via other branches and do not disturb the VDSL2/Cab system under study.

The penalty varies not only with the position of the street cabinet, but also with the copper distance between street cabinet and customer premises. Its maximum is for street cabinets at about 2.5 km copper distance from the central office. The highest penalties are for customers served via the longest subloops.

It may be surprising, but reduction in the ("average") VDSL2/Cab performance due to DPBO is rather limited; in many cases, this figure is less than 10%. This is because when the transmit power of VDSL2 is reduced, the transmit power for all other systems (i.e. those systems that are interfering) is reduced as well. The signal to noise ratio will therefore hardly change, and the same applies for the maximum bitrate. This motivates the use of a sufficient "safety" margin during the design of PSD shapes.

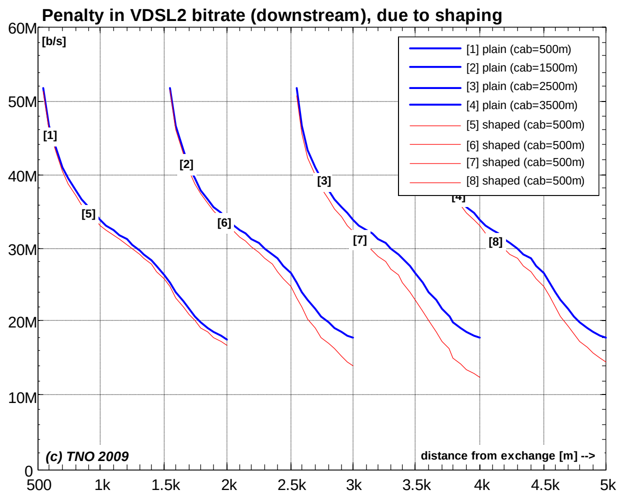


Figure 7: Penalty for VDSL2 bitrates, when it has to operate under a typical upstream power back-off regime. The achievable bitrate reduces due to DPBO, but not dramatic.

The performance penalty has been evaluated only for "regular" stationary crosstalk noise, caused by DSL systems in other wire pairs. In practice however, VDSL2 will also receive impulse noise from sources outside the cable. Since the transmit signal has been weakened significantly by DPBO, the sensitivity of VDSL2 to impulse noise becomes more pronounced. Therefore the penalty is in practice higher than that predicted by Figure 7 .

5. SPECIFYING DPBO VIA ACCESS RULES

Protecting legacy equipment is only feasible if a sufficient amount of DPBO is applied to *all* involved VDSL2 modems. Since this has to be mandatory for all involved DSL operators, it needs to be well-specified by means of an access rule [1]. However, it is not obvious how to do such a specification.

Mandatory rules should be unambiguous to enable an indisputable verification whether a modem complies with such rules, and should not discriminate between DSL products from different vendors. This can only be facilitated

when rules are defined without any assumption about the implementation details of equipment, i.e. a black-box approach. Therefore this cannot be fulfilled by simply "specifying" it as: "DPBO shall be compliant with ITU *product* standard G.993.2 [3], and here are the associated parameter settings".
The same applies for rules to grant access to the subloop. If these rules are specified as spectral limits to the generated signals, instead of specifying modem settings, then compliance can be verified in an indisputable manner: simply check the levels of the signals injected in the loop. If another kind of modem can comply with the rules (for instance deploying ADSL2plus from cabinets to enable customers to keep their legacy modems) then it does not disturb others in a disproportional manner, and should therefore not be forbidden (from a pure spectral management point of view) by implementation-specific rules tailored to G.993.2 [3].

This can be explained via implementation details of VDSL2. The VDSL2 product standard [3] defines a set of capabilities to enable DPBO. The VDSL2 management system controls DPBO by means of 9 parameters plus a (tabular) definition of the legacy spectrum to be protected (ADSL2plus). The modem evaluates how much DPBO should be applied as a function of the frequency via a complex expression, as specified in the standard [3]. Figure 8 provides an overview of the involved parameter names as they can be found in the ITU product standard.
One may still consider specifying access rules for the subloop by providing the required modem settings for DPBO. If all values for these settings are specified and programmed into a VDSL2 modem, then the desired DPBO *should* be achieved. This is because the current ITU standard gives no accuracy requirements for these settings. However, *should* is not enough for a mandatory rule. Moreover, how can disputes be handled? Should a loop provider be allowed to check the management system of a DSL operator to verify if the DSL operator complies with the rules?

Parameter	Description
DPBOEPSD	The exchange side maximum PSD mask
DPBOPSDMASKds	The overall maximum PSD mask limit when DPBO is applied
DPBOESEL	The electrical length of exchange to cabinet cable
DPBOFMIN	The lower bound on the DPBO frequency span
DPBOFMAX	The upper bound on the DPBO frequency span
DPBOESCMA	E-side cable model parameter A
DPBOESCMB	E-side cable model parameter B
DPBOESCMC	E-side cable model parameter C
DPBOMUS	Assumed minimum usable PSD mask of exchange signals at remote site
DPBOLFO	The low frequency PSD mask override

Figure 8: Summary of modem parameters to force VDSL2 to back-off its downstream transmit power.

This is analogous to speed limits in ordinary traffic rules to prevent road accidents. Traffic rules specify speed limits in a neutral manner (km/hour) so that they can be verified *from the outside of the vehicle*. This enables an indisputable verification of whether the vehicle is exceeding the speed limits. Traffic rules do not specify the measurement of speed in an implementation-specific manner (e.g. what the speedometer of the vehicle indicates) because this would be susceptible to argument.
For this reason, the Dutch and British access rules have been specified [1] in a black-box manner, by means of spectral limits and not by means of modem settings. It is essentially a set of spectral limits, one for each cabinet location. It is up to the involved DSL operator (and its VDSL2 vendor) to ensure that their modems do not exceed these limits; how they achieve that is irrelevant from a spectral management point of view.

6. SUMMARY

VDSL2 is a new DSL modem technology to deliver third generation broadband services (3GBB) via existing telephony wiring. To ensure that VDSL2 can coexist with legacy DSL systems from the central office, it is essential that the downstream transmit powers of VDSL2 systems deployed from remote locations are reduced properly. This is called downstream power back-off (DPBO).
Deploying VDSL2 from cabinets without DPBO can easily cause a significant drop in the performance of ADSL2plus deployments. Fortunately, an adequate amount of DPBO can fully prevent this at the cost of only a small ("average") penalty for the VDSL2 performance itself. However, DPBO makes VDSL2 more sensitive to impulse noise.
The required amount of power back-off depends on many factors, including underlying business needs, selected degree of protection of legacy deployments, the loop characteristics, the copper distance between the cabinet and central office, and the spectra of the modems to be protected. These aspects are all country or region specific, and this illustrates why different countries may need different DPBO regimes to serve local needs. A DSL performance simulator (such as [4]) is required to find the most appropriate DPBO regimes and to show that DPBO limits are effective.
The preferred method for specifying a DPBO regime in access rules is via spectral limits at the output of the modems. This enables an indisputable verification if modems comply with these rules, and is technology-independent as well. This cannot be facilitated if access rules "specify" DPBO via parameter values to instruct the VDSL2 management system.

7. REFERENCES

[1] ETSI TR 101 830-1, "Spectral Management, part 1: Definitions and signal library", 2008.

[2] ETSI TR 101 830-2, "Spectral Management, part 2: Technical methods for performance evaluations", 2008.

[3] ITU-T, Recommendation G993.2 "Very high speed Digital Subscriber Line Transceivers 2 (VDSL2)" (including all corrigenda).

[4] SPOCS, a simulation tool compliant with ETSI TR 101 830-2, www.tno.nl/spocs

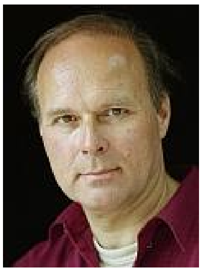
[5] Rob F.M. van den Brink, "*Cable reference models for simulating metallic access networks*", ETSI/STC TM6 permanent document, June 1998.

Other whitepapers in this series:

[6] Rob F.M. van den Brink, "*The art of deploying DSL; Broadband via noisy telephony wiring*", TNO 35090, White paper on DSL, Oct 2009 (revision from June 2008)

[7] Rob F.M. van den Brink, "*The art of Spectral Management; Access rules for VDSL2*"; TNO 35091, white paper on DSL, Oct 2009.
[8] Rob F.M. van den Brink, "*The art of Spectral Management; Frequency allocations for VDSL2*"; TNO 35092, White paper on DSL, Oct 2009.
[9] Rob F.M. van den Brink, "*The art of Spectral Management; Downstream power back-off for VDSL*2"; TNO 35093, White paper on DSL, Oct 2009.
[10] Rob F.M. van den Brink, "*The art of Spectral Management; Upstream power back-off for VDSL2*"; TNO 35094, White paper on DSL, Oct 2009.

Rob F.M. van den Brink graduated in Electronics from Delft University in 1984, and received his PhD in 1994. He works as a senior scientist within TNO on broadband access networks.
Since 1996, he has played a very prominent role in DSL standardisation in Europe (ETSI, FSAN), written more than 100 technical contributions to



ETSI, and took the lead within ETSI-TM6 in identifying / defining cable models, test loops, noise models, performance tests, and spectral management. He is the editor of an ETSI-TM6 reference document on European cables, and led the creation of the MUSE Test Suite, a comprehensive document for analyzing access networks as a whole. He also designed solutions for Spectral Management policies in the Netherlands, and created various DSL tools for performance simulation (SPOCS, www.spocs.nl/en) and testing that are currently in the market.
He has also been Rapporteur/Editor for ETSI since 1999 (on Spectral Management: TR 101 830), Board Member of the MUSE consortium (2004-2008, www.ist-muse.org) and Work Package leader within the Celtic 4GBB Consortium (2009-2011, www.4gbb.eu).