Technical Sciences
Anna van Buerenplein 1
2595 DA The Hague
P.O. Box 96800
2509 JE The Hague
The Netherlands

www.tno.nl

T +31 88 866 70 00
F +31 88 866 70 57

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Impact Analysis of VDSL2 from the local exchange (EVSDL) on VDSL2 from the cabinet (CVDSL)
For the Irish access network

Date	18 March 2015
Author(s)	Jeroen Boschma, Teun van der Veen
Reviewer	Bas van den Heuvel
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Contents

Abbreviations

ADSL	Asymmetric DSL
CPE	Customer Premises Equipment
CLFMP	Copper Loop Frequency Management Plan
CVDSL	Cabinet-launched VDSL
DP	Distribution Point
DPBO	Downstream Power Back-Off
DS	Downstream
DSL	Digital Subscriber Line
DSLAM	DSL Access Multiplexer
EL-FEXT	Equal Level FEXT
EOC	Embedded Operations Channel
ES	Errored Second
EVDSL	Exchange-launched VDSL
FEXT	Far-end crosstalk
ITU	International Telecommunications Union
LEx	Local Exchange
LLU	Local Loop Unbundling
NDR	Net Data Rate
NM	Noise Margin
NEXT	Near-end crosstalk
RI	Re-Initialisation
SLU	Sub Loop Unbundling
SRA	Seamless Rate Adaptation
US	Upstream
UPBO	Upstream Power Back-Off
VDSL	Very high bit rate Digital Subscriber Line (refers to VDSL2, the ITU G993.2 standard)
xDSL	Generic DSL, used to describe any form of DSL

Management Summary

Problem
ComReg needs to make a decision on allowing the introduction of VDSL2 from the local exchange (EVDSL) in the Irish copper access network. A previous qualitative TNO study has shown that the risk of negative impact on VDSL2 from the cabinet (CVDSL) is not negligible in the so-called topology 3 (**Fig 1**)

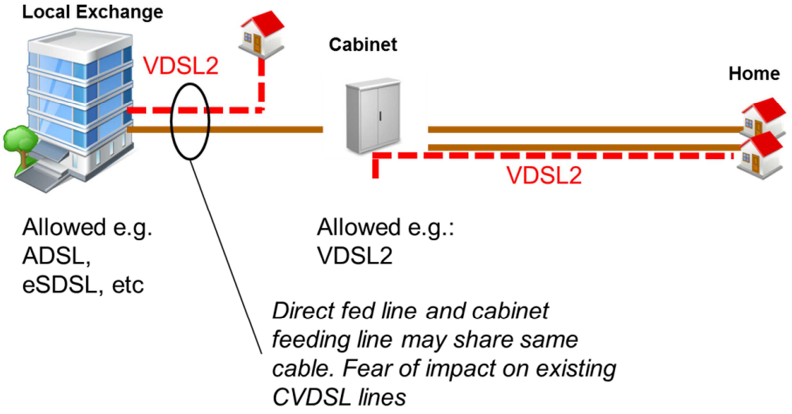

Fig 1: "Topology 3" in the Irish access network, taken from [3]

Aim
The aim of this report is to provide a quantitative impact analysis of EVSDL on CVDSL in topology 3 and making any tradeoffs visual.

Relevance
The results of this impact analysis will provide ComReg with a strong foundation for making a decision on allowing EVDSL or not.

Conclusions
Introducing EVDSL will cause near-zero impact on downstream CVDSL; However there is significant negative impact (up to 37%) on upstream CVDSL.
The negative impact will occur for certain combinations of distances ("regions") Local Exchange to Distribution point ("L1") and Distribution point to Cabinet ("L2").

Follow up
Determine what level of negative impact is acceptable by trading off performance gain of EVDSL over ADSL2+ versus negative impact on CVDSL. This may include considerations on the amount of customers and homes passed involved.
If the acceptable level of negative impact is below the maximum level found, determine the region spanned by L1 and L2 where EVDSL is not allowed.

- Define together with industry how these L1 and L2 should be determined in practice. For instance they could be measured (e.g. via loop attenuation) or extracted from a network database.
- Take into account that no matter how L1 and L2 are determined, there will be a finite accuracy. This may be dealt with by setting an extra safety margin.

With these steps, ComReg can make a balanced decision on where to allow EVDSL in topology 3 or not.

Possible additional strategies for mitigating the negative impact of EVDSL on CVDSL include the following:

1. CVDSL could benefit from optimised UPBO settings that are tailored for Vectored VDSL2.
2. The negative impact of EVDSL can be partly mitigated by "curtailing" EVDSL by limiting the upstream spectrum, reducing negative impact at the cost of upstream EVDSL bitrate.

A general recommendation for future proposed changes to the access rules is to include impact analyses based on agreed assumptions in any proposal. This may speed up the decision process.

1 Introduction: goal of the impact analysis

1.1 Current situation

The Irish copper access network is owned by eircom, and is used in an unbundled way by different DSL operators to offer services to their customers. ComReg has obliged eircom to allow these other DSL operators to use the eircom network in an unbundled way, meaning that operators have physical access to copper loops and are able to connect their DSL equipment.

To prevent that one DSL system impairs another one in a disproportional manner, access rules have been set by eircom in agreement with the industry. These rules put spectral limits on DSL technologies that are allowed for deployment and forbid the deployment of other DSL technologies. The rules are captured in the Copper Loop Frequency Management Plan (CLFMP) [2].

1.2 Problem

Eircom wishes to deploy VDSL2 from the local exchange (“EVDSL”). Currently, the Copper Loop Frequency Management Plan (CLFMP) does not allow EVDSL [2]. However, eircom has proposed an amendment to the CLFMP to allow EVDSL, arguing that this will not have a negative impact on existing services in the copper plant [1]. The copper plant is schematically drawn in **Fig 2**.

Other operators contradict eircom, and raise concerns on possible negative impact, specifically impact on VDSL2 deployed from the cabinet (“CVDSL”).

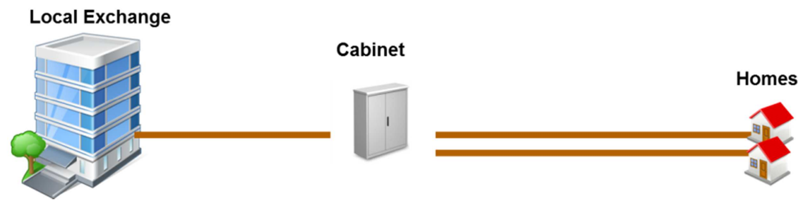

Fig 2: Schematic representation of the Irish access network, with Exchange-fed and cabinet fed xDSL lines to the homes. In the current CLFMP, VDSL2 is only allowed to be deployed from the cabinet (CVDSL).

In 2014, ComReg commissioned TNO to review the proposed CLFMP amendment and the comments from the industry on this proposal and to perform a qualitative EVDSL impact analysis. TNO distinguished three topologies in the Irish access network, and concluded that in “topology 3” there is non-negligible risk of negative impact for specific cases. These cases are determined by the different cable lengths.

Goal of the current impact analysis in this report is:

- To quantify the impact on CVDSL when EVDSL is introduced in the Irish copper access network.
- Enable a common understanding of the technical consequences of the proposed CLFMP amendment to allow EVDSL.

1.3 Applying the reference methodology and definition of impact

To be able to assess the impact of EVDSL on CVDSL, it should first be made clear what we mean with the word ‘impact‘. In this context, we define impact as the difference in potential performance of systems under study between:

- A reference scenario, and
- a modified scenario with new technology introduced in the network.

This impact can be positive, zero or negative.

In a fair evaluation, these scenarios should be equivalent, meaning that the number of broadband disturbers in both scenarios is the same.

This approach is called the reference methodology and is described in more detail in [5].

1.4 Scenarios for a qualitative analysis of the impact of EVDSL on CVDSL

For DSL impact analyses, scenarios should take into account cable topology, cable characteristics and the DSL technology mix in the cable.

For this qualitative analysis, we will focus on scenarios that include:

- Cable topology 3 from **Fig 4**.
- Technology mixes that will be described in the next chapter:
    - o The technology mix in the reference situation is called the reference mix.
    - o The technology mix in the modified situation, with the new technology introduced, is called the modified mix.

As in this case the scenarios will only differ in the technology mixes, the impact analysis boils down to comparing performance of the system under study (being CVDSL) in the two difference mixes.

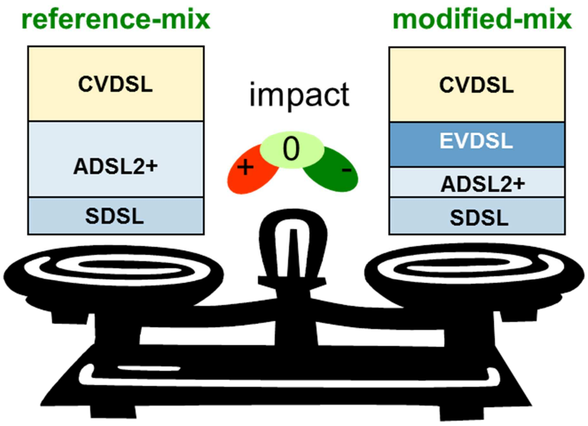

Fig 3: Illustration of the reference methodology.

The reference mix should contain:

- A substantial amount of CVDSL.
- A substantial amount of exchange launched “legacy” systems (ADSL, ADSL2+, SDSL etc.)

The modified mix should reflect the questions under study. For this specific evaluation, the central question “*Does EVDSL have a negative impact on CVDSL?*“ should be split into two evaluation points:

1) What is the impact on CVDSL when replacing ADSL2+ by EVDSL ?
2) What is the impact on CVDSL when replacing ADSL2+ by CVDSL ?

1.5 The impact analysis in this report

The calculation methods in this report comply with international standards on spectral management (ETSI [4]). The amount of detail in this report on technical assumptions is such that a third party (skilled in the art) is able of reproducing this impact analysis. It enables other parties to provide detailed (technical) information about improved assumptions (and calculation methods) in case the results of this impact analysis are subject of technical disputes.

2 Summary of technical assumptions used

2.1 Introduction

A meaningful performance study of DSL bitrates requires the definition of the scenario being used. Such a scenario is a combination of:

- *Assumed topology* (how the loop fans-out from the cabinet into smaller loops).
- *Assumed system mix* (the number and composition of DSL systems).
- *Assumed cable characteristics* (insertion loss, crosstalk coupling of involved wire pairs).
- *Assumed transmitter models* (spectral powers of involved DSL equipment).
- *Assumed receiver models* (sensitivity of involved DSL equipment to recover data from a received signal).
- *Used calculation method*.

A meaningful impact analysis of one DSL technology to another requires the definition of at least two scenarios: a "*reference*" one (acting as baseline without the newly proposed technology) and a "*modified*" one (including the new technology). Both scenarios have to be equivalent, meaning that in both cases the same number of customers is being served via DSL. In chapter 3 the impact analysis methodology will be described in more detail.

2.2 Assumed topology

As described in TNO report [3], the analysis is focusing on topology 3:

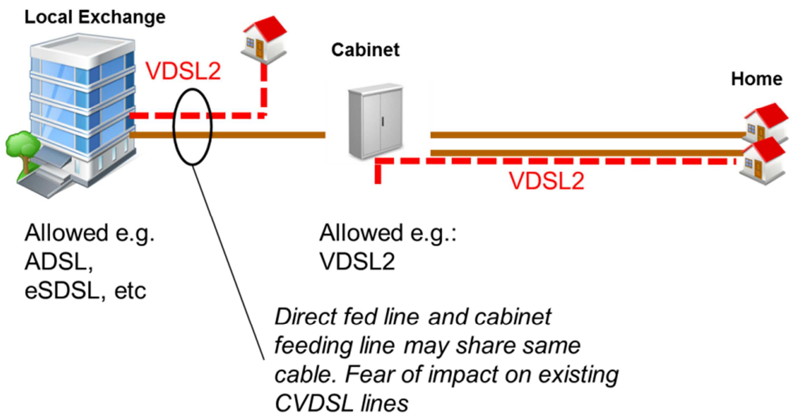

Fig 4:Topology 3, lines in a shared cable but not sharing the same route.

The assumed topology is illustrated in more detail in **Fig 5**. All connections to the Local Exchange (LEx) are assumed to be located in one single physical cable.

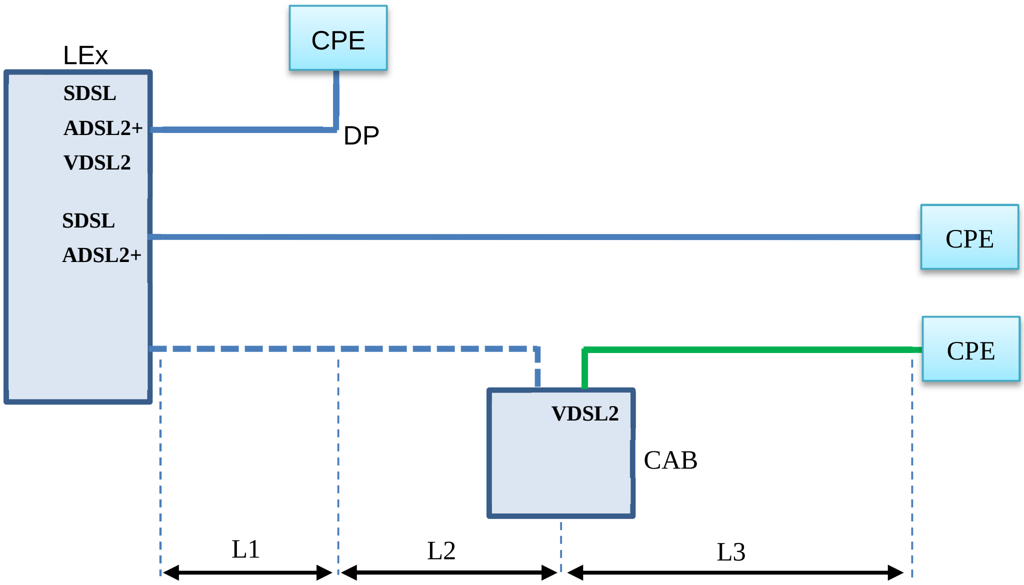

Fig 5: Illustration of the assumed topology.

For the topology we assume the following situation:

1. The cable from the LEx feeds customers via a drop point and via a cabinet.
2. In the current situation only SDSL and ADSL2+ links run through a DP. If EVDSL will be deployed, it will also run through DPs. It is assumed that customers are located zero meters from the DP (in reality this is probably 20-50 meters).
3. Part of the wires behind the cabinet are connected to the LEx, and may be used to connect customers with SDSL or ADSL2+. The other part of the wires behind the cabinet terminate at to the cabinet, and in that case customers may be connected with CVDSL via a DSLAM in the cabinet itself.
4. All CPEs behind the cabinet are co-located, i.e. they are at the same distance from the cabinet.
5. Binder separation will be taken into account (see the sensitivity analysis in chapter 4).
6. We will assume that VDSL2 will not be able to function on distances longer than 2.5 km.

2.3 Assumed system mix

Three different deployment scenarios are defined that differ in the assumed system mix, and all have the same total number of broadband systems:

- **REF**
  The reference mix, representing the current situation without EVDSL.
- **EVDSL**
  A modified mix to reflect the situation where a certain percentage of the DP

ADSL2+ lines are converted to EVDSL lines, to be able to evaluate the impact from EVDSL on CVDSL.

- **CAB_EV**
  A modified mix to reflect the situation where, starting from the REF situation, the amount of CVDSL lines is increased (at the expense of the number of ADSL2+ lines via the cabinet) as representation of natural 'cabinet evolution'.

Table 1, Reference mix "REF" and modified mixes "EVDSL" and "CAB_EV"

	"REF"	"EVDSL"	"CAB_EV"
System	***Amount***	***Amount***	***Amount***
ADSL2+ via DP	50	20	50
ADSL2+via cabinet	50	50	40
SDSL via DP	3	3	3
SDSL via cabinet	3	3	3
CVDSL	50	50	60
EVDSL	0	30	0
Total	**156**	**156**	**156**

In all situations, 50 % of the ADSL2+ lines is Annex A, and 50 % of the ADSL2+ lines is Annex M.

For CVDSL, vectoring is assumed in both upstream and downstream with a vectoring gain of 20 dB, and EVDSL is therefore an alien disturber for CVDSL. The vectoring gain will be implemented by correspondingly decreasing the number of CVDSL systems. Although this is a limited way to model vectoring, it is expected that any discrepancies with real-life vectoring are small and will therefore not have a significant impact on the analysis results.

The rationale behind adding a "CAB_EV" scenario is that comparing the impact of scenario EVDSL with the impact of scenario CAB_EV can put the results of scenario 2 in perspective and therefore help to determine at which point impact of EVDSL becomes significant. The following example with arbitrary numbers aims to illustrate this rationale: *If CAB_EV shows a negative impact of maximally 5 % on CVDSL bitrates, then a negative impact due to EVDSL between 0 and 5 % could be considered as non-significant.*

2.4 Assumed cable characteristics

The cable used in simulation is the standardized ETSI TP100 cable, a model for a 0.5 mm twisted pair copper cable as used in the UK. This cable model was chosen after consulting with the industry since there was no cable model from a "typical" Irish cable available.

For crosstalk coupling numbers in these cables, we use modified values adapted from ETSI TR 101 830-2 based on input from eircom. They aim to represent the near worst-case crosstalk conditions that are not exceeded in 99% of the cases:

- NEXT: –56.6 dB (at 1MHz).
- EL-FEXT: –45.0 dB (at 1MHz, and 1km loop).

For a sensitivity analysis, we will also observe simulation results with:

- NEXT/FEXT = -61.6/-50.0 dB (5 dB crosstalk decrease)
- NEXT/FEXT = -51.6/-40.0 dB (5 dB crosstalk increase)
- NEXT/FEXT = -46.6/-35.0 dB (10 dB crosstalk increase)

2.5 Assumed transmitter models

For SDSL we use the 2.3 Mbps variant (which is the fastest classical SDSL).

For ADSL2+ we assume two variants: ADSL2+ over POTS (Annex A) and ADSL2+ over POTS with an extended upstream spectrum

For VDSL2 we use bandplan 998ADE17 (profile B8-11) as described in the CLFMP [2]

In the following table, the assumed transmit spectra are described referring to the model names as defined in SPOCS (TNOs simulation software used for this analysis). For the ADSL2+ spectra the DMT tones used are mentioned between square brackets. If Power Back-Off (PBO) is applied, it is mentioned in the third column.

system	DSL flavour	PBO
SDSL	up: `SDSL.2304.s-(SpM-2)`	No
	dn: `SDSL.2304.s-(SpM-2)`	No
ADSL2+/A	up: `ADSL2+/A-[007:031]-(G992.5)`	No
	dn: `ADSL2+/A-[033:511]-(G992.5,FDD)`	No
ADSL2+/M	up: `ADSL2+/M-[007:063]-(G992.5,EU-64)`	No
	dn: `ADSL2+/M-[060:511]-(G992.5,FDD)`	No
CVDSL	up: `VDSL2.B8-11-(17a,998ADE17-M2x-A)`	Yes
	dn: `VDSL2.B8-11-(17a,998ADE17-M2x-A)`	Yes
EVDSL	up: `VDSL2.B8-11-(17a,998ADE17-M2x-A)`	Yes
	dn: `VDSL2.B8-11-(17a,998ADE17-M2x-A)`	No

In the downstream direction, DPBO is applied according the guidelines defined in document CLFMP (NM-2564) [2]. The resulting PSD shape depends on E-Side electrical length (corresponding to cabinet distance from the LEx).

In the upstream direction, UPBO uses the ITU tunable (a,b) model with the following parameters – as provided by eircom:

parameter	US1	US2
a	47.30	54.00
b	21.14	16.29

2.6 Assumed receiver models

The following is assumed:

1. VDSL2 target noise margin: 9 dB (eircom input)
2. SNR gap: 6.75 dB (standard SpM-2 figure)
3. Receiver noise level : -135 dBm/Hz (standard SpM-2 figure)
4. An overhead of 10% is assumed to take into account some forward error correction (FEC). Even though G.inp (retransmission) is used, a small amount of FEC will be necessary.

2.7 Used calculation method

All performance evaluations are fully compliant to the methods defined in ETSI TR 101 830-2. They have been evaluated with SPOCS, a performance simulator for DSL studies being used within different laboratories in the world and fully compliant with the ETSI calculation methods.

Overview of the calculation mechanism upstream, from DP:

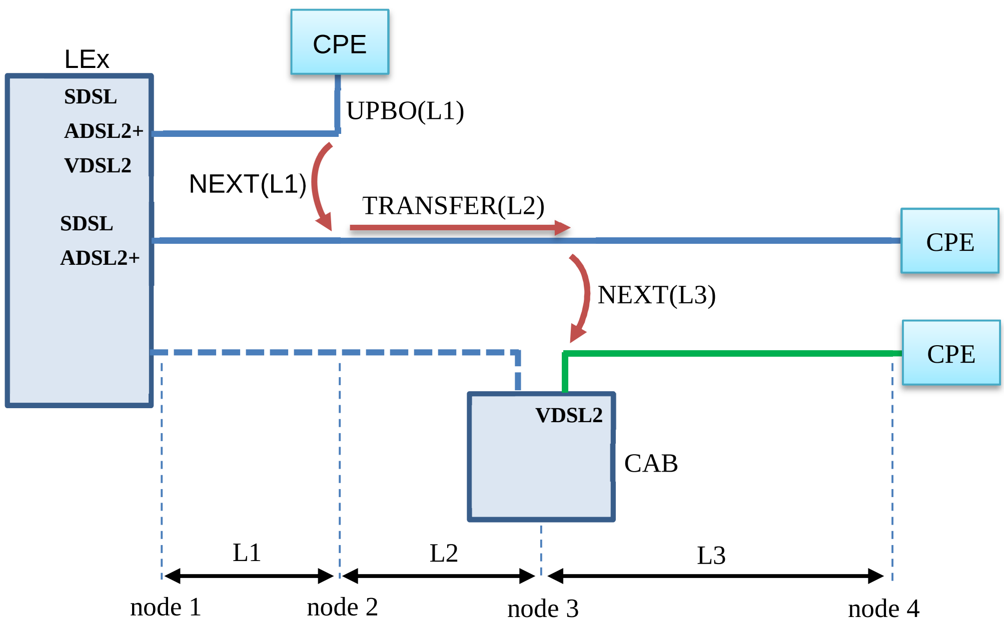

Fig 6: Base upstream calculation mechanism. The arrows show the path of the main impairment to upstream CVDSL due to EVDSL.

Overview of the calculation mechanism downstream, from DP:

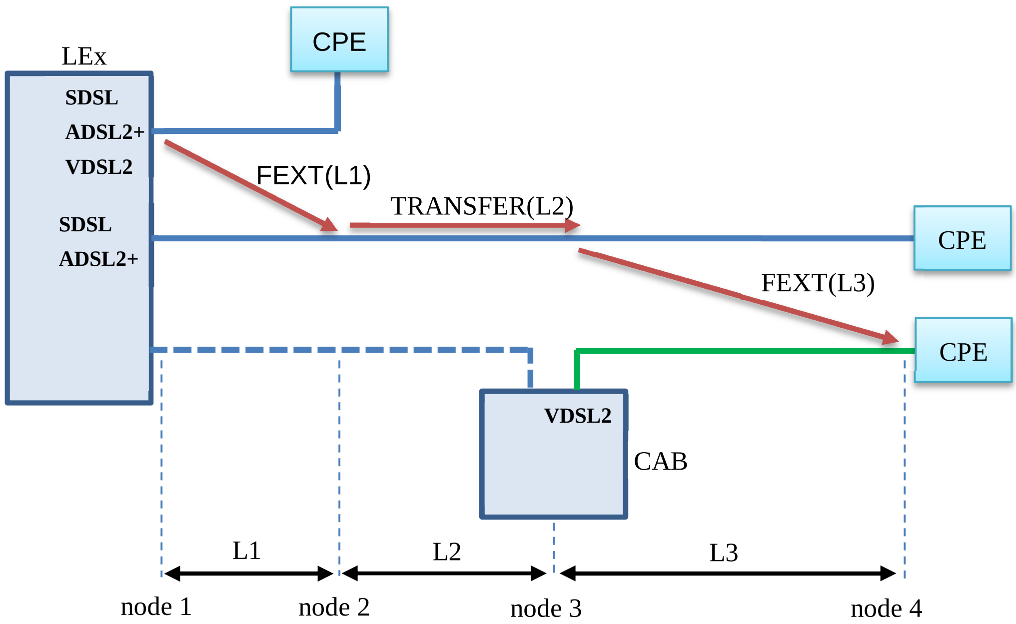

Fig 7: Base downstream calculation mechanism. The arrows show the path of the main impairment to downstream CVDSL due to EVDSL.

2.8 Resulting scenarios

A single simulation scenario results in a downstream and an upstream rate-reach curve (bitrate versus CVDSL distance, represented by L3) for:

1. a certain technology mix
2. a fixed cabinet distance (L1+L2)
3. fixed L2
4. fixed NEXT/FEXT values

In conclusion, scenarios are defined using the following methodology:

1. A cabinet can be placed at one of the following distances (L1+L2): [125 250 375 500 625 750 1000 1500 2000 2500] meter.
2. For each cabinet distance, the DP position is varied from zero meters from the LEx (L1=0)to zero meters from the cabinet (L2 =0) in 25 m steps.

Based on trial simulations, the L1/L2 ratios are restricted to those ratios that show a maximum negative impact of more than 1 % on the CVDSL rate-reach curve. Together with the 3 different technology mixes (REF, EVDSL, CAB_EV) and sensitivity analysis with 4 different NEXT/FEXT coupling values, a total of 2580 scenarios results.

3 Impact analysis EVDSL on CVDSL

3.1 A discussion on expected results

Many phenomena play a role in the final simulation results. For a good understanding of the analysis results, a discussion of these phenomena and what may be expected from the analysis results is provided in the following subsections.

The main disturbance for CVDSL will originate from other CVDSL lines, and EVDSL. We can derive expressions for the level of the CVDSL disturbance PSD at the receiver, as well as the EVDSL alien disturbance PSD at the receiver. For maximum negative impact we look for a minimum CVDSL disturbance and maximum EVDSL alien disturbance. These respective disturbance levels give an indication if EVDSL alien disturbance can become dominant over CVDSL disturbance and thus can have a significant negative impact on CVDSL performance.

The discussion in the following subsections will take some shortcuts in order to come to an estimate if EVDSL will have a significant negative impact on CVDSL performance or not.

3.1.1 Upstream: discussion of expected results

Refer to **Fig 6**: An upstream CVDSL disturber is a CVDSL line which generates crosstalk via a single FEXT-path into another CVDSL line (from CPE to DSLAM), and this crosstalk is virtually attenuated by the vectoring gain. For the CVDSL disturber PSD at a CVDSL DSLAM receiver we thus may write (all variables are in dB):

$$PSD_{dist,CVDSL} = \left[PSD_{VDSL} - UPBO(L3)\right] + FEXT(L3) - G_{vec}$$

At high distances L3, we see that UPBO(L3) does not attenuate the CVDSL spectrum anymore which maximizes the CVDSL disturbance. However, although the transmitted CVDSL upstream PSD has reached its maximum an increasing L3 will result in a decreasing FEXT(L3). If vectoring gain is also included, then for large L3 the vectored CVDSL disturbance may thus even drop below the noise floor of the receiver:

$$\min\left(PSD_{dist,CVDSL}\right) \leq N_{RX}$$

Likewise, for an EVDSL alien disturber we may write the following:

$$PSD_{dist,EVDSL} = \left[PSD_{VDSL} - UPBO(L1)\right] + NEXT(L1) - ATT(L2) + NEXT(L3)$$

For a maximum negative impact we can make the following choices:

1. At distances L1>1000 m (approximately) UPBO will be at 0 dB and will not attenuate the EVDSL upstream spectrum anymore. We can thus take UPBO(L1)=0.
2. Placing the DP at the cabinet location results in ATT(L2)=0.

The worst-case negative impact is thus for L2=0, L1>1000 m. We now find:

$$\max\left(PSD_{dist,EVDSL}\right) = PSD_{VDSL} + NEXT(L1) + NEXT(L3)$$

Given the assumed EL-NEXT and some additional ball park estimates, we expect that the resulting EVDSL alien disturbance PSD at the CVDSL receiver will exceed the receiver noise floor in many cases. It is therefore expected that EVDSL will have a significant negative impact on upstream CVDSL.

3.1.2 *Downstream: discussion of expected results*

Refer to **Fig 7**: a downstream CVDSL disturber is a CVDSL line which generates crosstalk via a single FEXT-path into another CVDSL line (from DSLAM to CPE), and this crosstalk is virtually attenuated by the vectoring gain. For the CVDSL disturber PSD at a CVDSL CPE receiver we thus may write (all variables are in dB):

$$PSD_{dist,CVDSL} = PSD_{VDSL} + FEXT(L3) - G_{vec}$$

Likewise, for an EVDSL alien disturber we may write the following:

$$PSD_{dist,EVDSL} = PSD_{VDSL} + FEXT(L1) - ATT(L2) + FEXT(L3)$$

If we take the difference:

$$PSD_{dist,EVDSL} - PSD_{dist,CVDSL} = FEXT(L1) - ATT(L2) + G_{vec}$$

For a maximum negative impact we can simply place the DP at the cabinet location which results in ATT(L2)=0:

$$\max\left(PSD_{dist,EVDSL} - PSD_{dist,CVDSL}\right) = FEXT(L1) + G_{vec}$$

We thus see that the EVDSL alien disturbance will become dominant over the CVDSL self-disturbance when FEXT(L1) becomes larger than the inverse vectoring gain. With our assumption on the vectoring gain this occurs when FEXT(L1)>-20.

Even for strong EL-FEXT assumptions the estimated total FEXT(L1), using some ball park calculations, is not high enough to result in a significant negative impact[1] on downstream CVDSL.

3.2 Definition of impact

In this analysis, negative impact is defined as the relative loss (expressed as a percentage) of CVDSL performance due to EVDSL deployment. We thus compare a CVDSL rate-reach curve, which spans all L3 values, of the REF technology mix

[1] Note that this expectation at first glance seems to be different than what was found in the initial qualitative impact analysis[3] This is due to the fact that in the current analysis we have used an assumption on non-ideal vectoring with a vectoring gain of 20 dB that was not used before. With perfect vectoring or with high vectoring gains there would still be a risk of negative impact.

with the corresponding CVDSL rate-reach curve of the EVDSL technology mix. The negative impact is calculated as the maximum loss on the entire rate-reach curve, for a certain L1 value and a certain L2 value. Or (RRC = Rate-Reach Curve):

$$\text{impact\_pct}(L1, L2) = 100 * \max_{all\ L3}\left(\frac{RRC_{REF}(L1, L2) - RRC_{EVDSL}(L1, L2)}{RRC_{REF}(L1, L2)}\right)$$

3.3 Reference performance of CVDSL

3.3.1 A single reference curve per cabinet

When a cabinet is placed on a certain distance from the LEx (L1+L2), the L1/L2 ratio is varied. For the REF scenario, this means that for every L1/L2 ratio a different CVDSL rate-reach curve is obtained. We now may expect the following.

1. **downstream**: The CVDSL downstream band is partially overlapped by SDSL and ADSL2+, but due to the low frequencies crosstalk is low. For SDSL and ADSL2+ from the LEx to the DP, a double crosstalk route is required which results in extremely low levels of alien noise on downstream CVDSL. Moreover, this alien noise is masked by the alien noise generated by SDSL and ADSL2+ lines from the LEx via the cabinet. We may thus expect that only shaping of CVDSL, as a function of the cabinet distance, determines the reference CVDSL rate-reach curve.
2. **upstream**: The CVDSL is only overlapped by SDSL and ADSL2+ on very low frequencies. The same argumentation as with the downstream case applies, but no shaping exists for upstream. We may thus expect marginal difference between all reference curves for all cabinet distances.

Simulation results, also for different NEXT/FEXT values, confirm our expectations and we can therefore conclude that, for each cabinet distance, we can use a single REF CVDSL rate-reach curve valid for all L1/L2 ratios.

3.3.2 Reference performance per cabinet

In **Fig 8** and **Fig 9** the upstream and downstream reference curves are plotted for all cabinet distances. It shows that the different REF curves, one for each cabinet distance (L1+L2), vary with cabinet distance conform our expectation from the previous section. In the following analysis we will use a per-cabinet reference curve.

Note: the variation in the downstream REF curves is mainly a result of PSD shaping (downstream PBO), which is determined by the cabinet location (L1+L2).

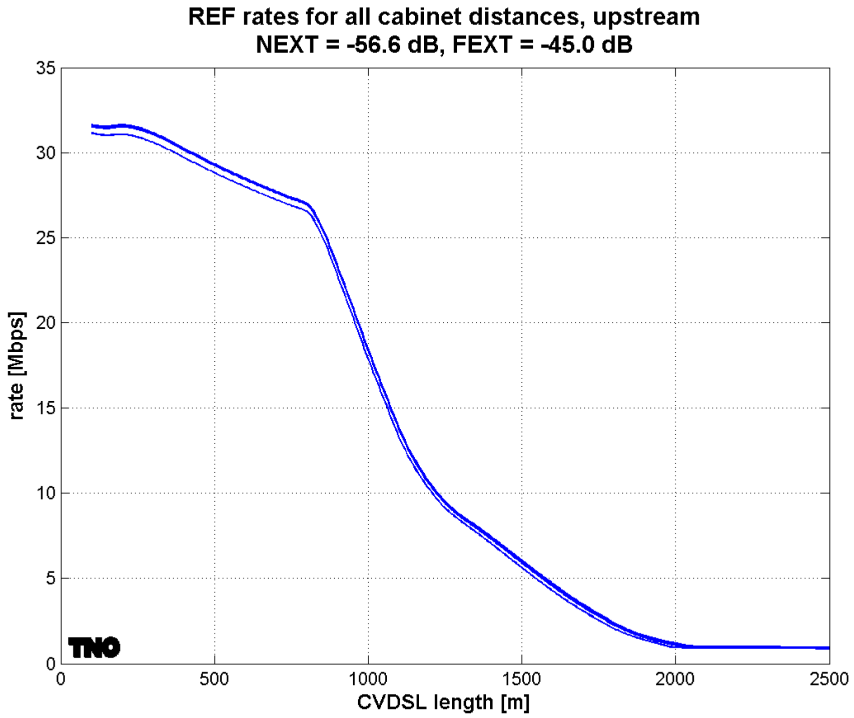

Fig 8: Illustration of upstream REF curves for all cabinet distances (note that almost all curves are plotted on top of each other).

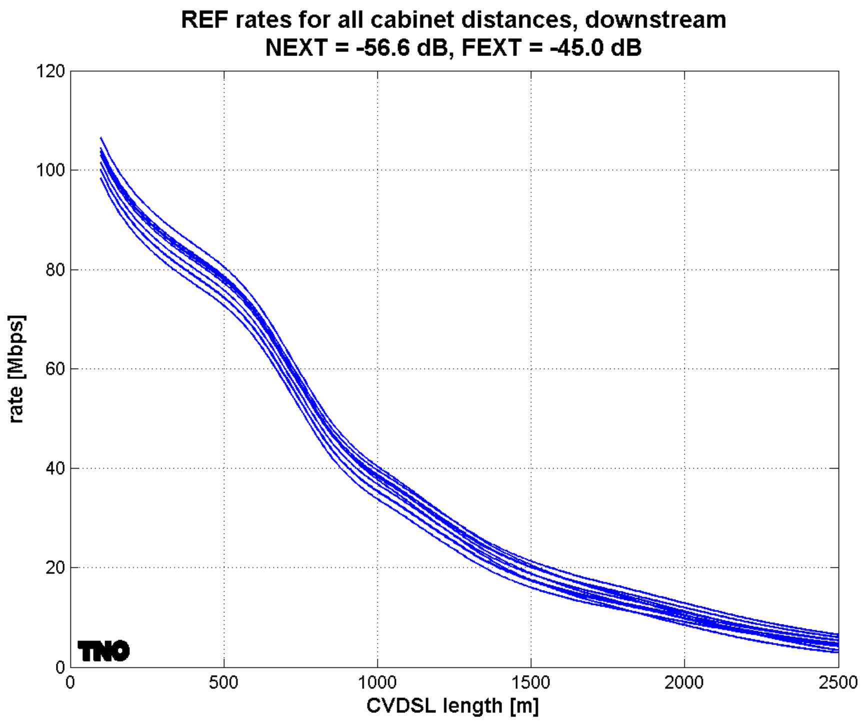

Fig 9: Illustration of downstream REF curves for all cabinet distances.

3.4 A first glance at upstream and downstream impact

We will now present a concise overview that shows for each cabinet distance, the maximum negative impact on the CVDSL rate-reach curve for all L1/L2 ratios:

```
maximum difference between REF and EVDSL for all L1/L2

  L_cab [m]      EVDSL up [%]    EVDSL dn [%]
  --------------------------------------------
    125               0.00070         0.00002
    250               0.03316         0.00001
    375               0.59734         0.00000
    500               3.58543         0.00000
    625              14.02066         0.00000
    750              29.93612         0.00001
   1000              37.10536         0.00002
   1500              37.04589         0.00001
   2000              37.01927         0.00001
   2500               0.96555         0.00000
```

For example: with a cabinet distance of 500 m, there is a L1/L2 ratio for which the maximum negative impact of EVDSL on the REF CVDSL upstream rate-reach curve is 3.59 %. We can make the following important observations:

1. As expected, see section 3.1.1, there is significant negative impact of EVDSL on the CVDSL upstream rate-reach curve. When the cabinet distance is increased, the maximum upstream impact seems to converge to approximately 37 %. After 2000 m the negative impact suddenly drops dramatically. Both phenomena will be explained in the discussion of **Fig 12**.
2. As expected, see section 3.1.2, there is hardly any negative impact of EVDSL on the CVDSL downstream rate-reach curve. This conclusions remains valid for different NEXT/FEXT values. Downstream will therefore not be regarded anymore in this analysis.

3.5 Impact analysis results: Downstream

Downstream is further disregarded in this analysis due to negligible negative impact.

3.6 Impact analysis results: Upstream

3.6.1 Deriving a single impact percentage from rate-reach curves

An example of the impact on CVDSL is shown in **Fig 10**, for a cabinet distance of 1000 m. Note that curves for L1/L2 ratios that show less than 1 % negative impact are not plotted since they are regarded as equal to the REF curve:

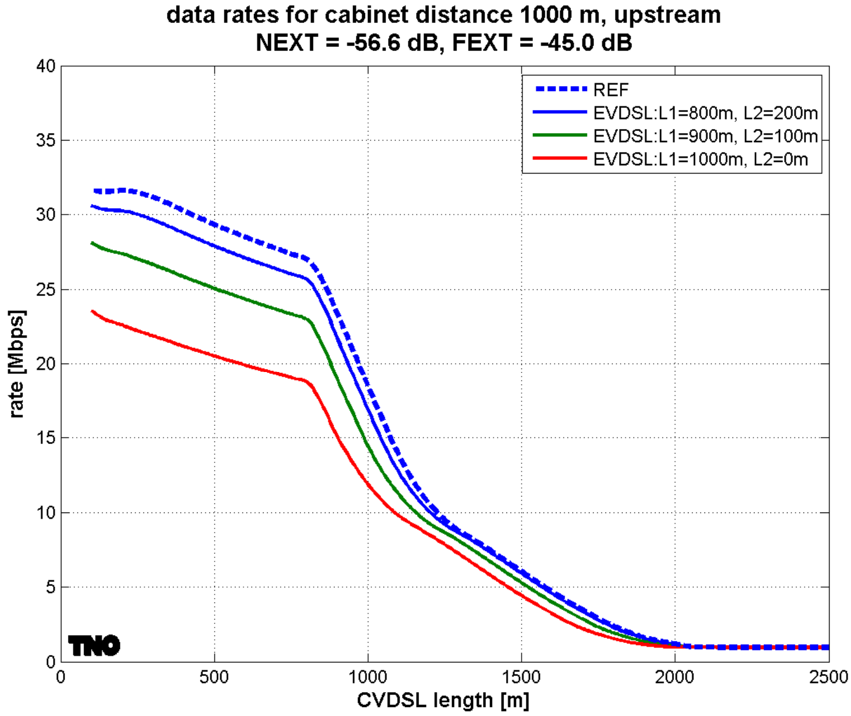

Fig 10: Illustration of CVDSL impact for a cabinet distance of 1000 m.

Fig 10 shows several L1/L2 ratios with a significant negative impact on CVDSL performance. The worst-case negative impact occurs at L2=0 (red curve). For this particular cabinet distance, the shape of the curves seem to indicate that for each L1/L2 ratio, the negative impact on the REF CVDSL rate-reach curve is more or less constant in terms of percentages. This will certainly not be the case for all scenarios.

More insight in the CVDSL performance impact is shown in **Fig 11**, where for each cabinet distance the remaining CVDSL performance, expressed as a percentage of the corresponding REF curve, is plotted for the L2 distance which shows maximum overall negative impact. Note that the curves received a small offset on the horizontal axis in order to make overlapping curves visible.

In **Fig 11** we see that there is marginal negative impact for cabinet distances up to 500 m. For cabinet distances from 625 m up to 1000 m the negative impact increases, where the point of maximum negative impact is around L3=800 m to L3=900 m. The 1000 m cabinet distance curve also shows maximized negative impact around L3=1600 m. Note that for cabinet distances above 1000 m, the negative impact at low L3 quickly drops to almost zero. These abrupt changes that can be seen in the curves are a result of various mechanisms that all have a strong relation with the SNR at the CVDSL receiver, such as:

1. UPBO of EVDSL
2. UPBO of CVDSL
3. upstream carrier shutdown of EVDSL
4. bitloading of CVDSL (depends on CVDSL receiver SNR)

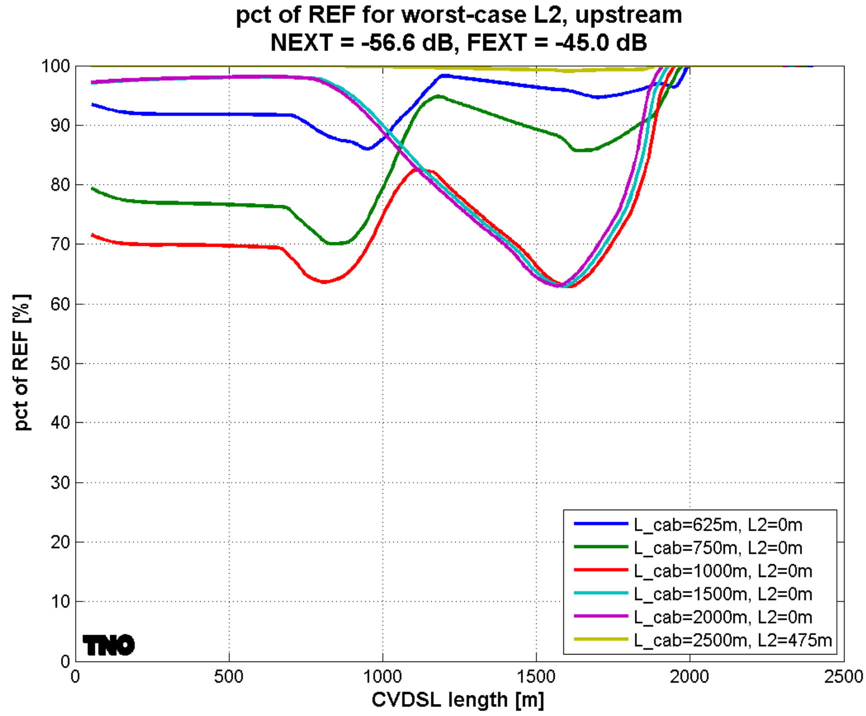

Fig 11: Worst case impact curves for all cabinet distances.

Thus far, curves were plotted for each cabinet distance and each L1/L2 ratio separately. It gives more insight to combine these results, and thus fit all different cabinet distances in a single plot. Note that in **Fig 12** the curves received a small offset on the horizontal axis in order to make overlapping curves visible.

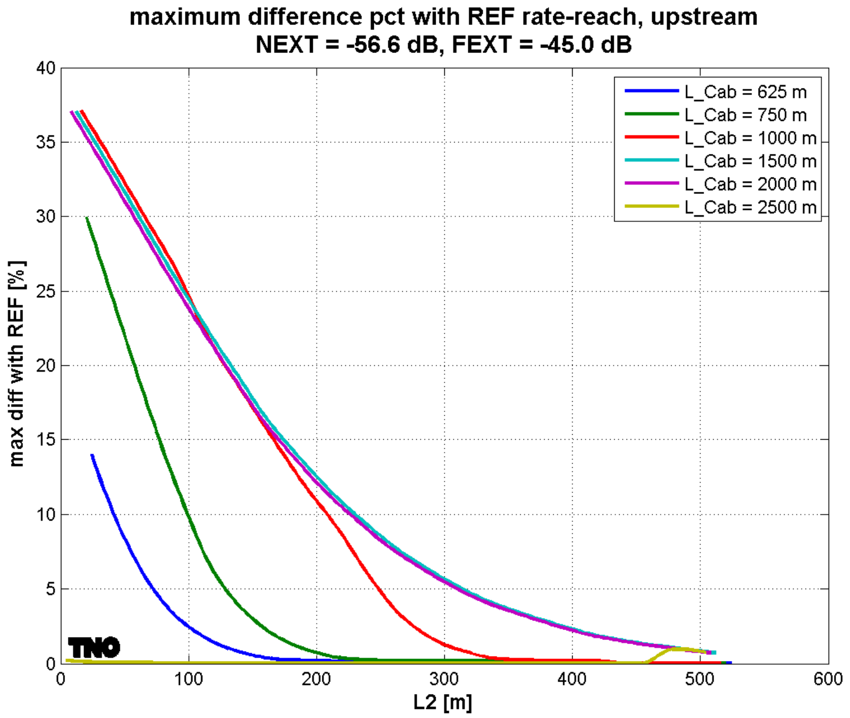

Fig 12: CVDSL impact for all cabinet distances.

The shape of the curves for different cabinet distances can be explained as follows:

- For small cabinet distances, the DP distance to the LEx is also small, and upstream PBO (UPBO) is therefore active. As a result, the negative impact on upstream CVDSL is low.
- As the cabinet distance increases, and the DP is still close to the cabinet which is represented by L2 between 0 m and 500 m in **Fig 12**, the distance between the DP and the LEx also increases and EVDSL upstream transmit power increases due to UPBO. As a result, the negative impact on CVDSL upstream increases.
- If for a certain curve in **Fig 12** L2 increases, then attenuation of the disturbing EVDSL upstream spectrum from the DP to the cabinet increases, and also the EVDSL upstream power decreases because of UPBO (note that on each curve L1 decreases when L2 increases). The impact on CVDSL therefore decreases with increasing L2.
- For cabinet distances above 1500 m, together with L2 between 0 m and 500 m, we find that L1 is at least 1000 m. EVDSL upstream power is then maximized, and for several cabinet distances above 1500 m the curves overlap.
- If the cabinet distance is increased above 2000 m another phenomenon occurs. L1 will be above 1500 m which means that several (high-frequency) upstream carriers will have an SNR that drops below 0 dB and no bitloading is possible anymore (see the Annex B for a discussion on this effect). These EVDSL upstream carriers are then switched off in the simulation and therefore do not have an impact on CVDSL anymore. For the 2500 m cabinet distance curve we thus see that:
    - With L2 = 0 m we have L1 = 2500 m and most EVDSL upstream carriers are switched off. There is no impact on CVDSL anymore.

Fig 12 shows that if a certain allowed impact percentage is chosen, a minimum L2 follows directly. This result is shown in **Fig 13**:

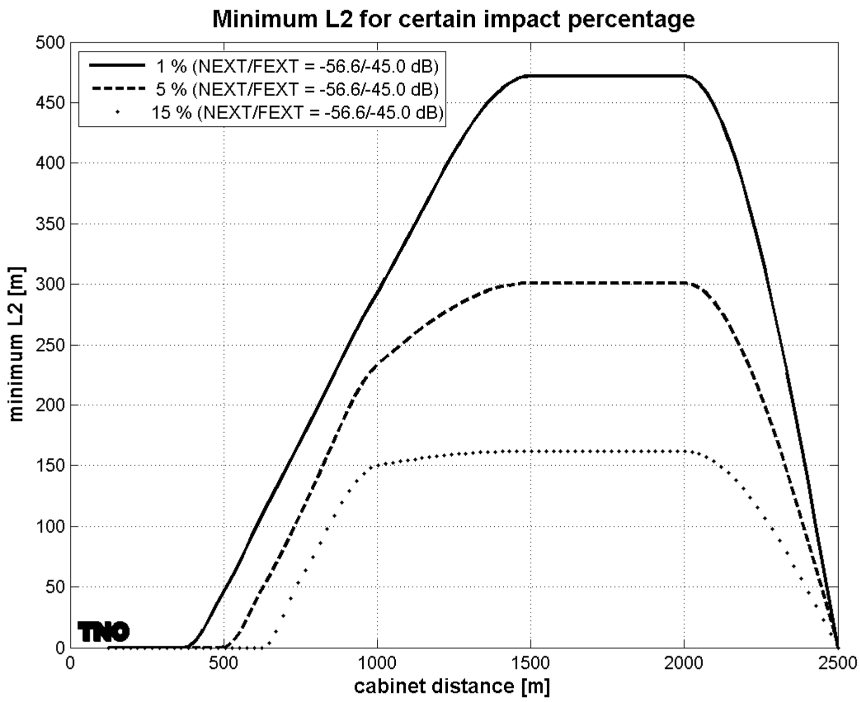

Fig 13: Minimum required L2 for a certain maximum CVDSL impact.

We thus see for example: if 15 % impact of EVDSL on the CVDSL rate-reach curve is allowed, then for a cabinet located at 1000 m from the LEx it follows that L2 must be at least 150 m. When 5 % impact is allowed, L2 must be at least 230 m for a cabinet at 1000 m from the LEx. For large cabinet distances, above 2000 m, the impact quickly drops to zero because of shutting down upstream carriers in the EVDSL lines.

The plots shown thus far give a good overview of the negative impact in different representations:

- **Fig 12** shows the negative impact versus L2 for different cabinet distances
- **Fig 13** shows the contour lines of equal impact on the “map” of cabinet distance and L2. (Note that cabinet distance is L1 + L2)

With interpolation techniques it is possible to find the impact percentages for all combinations of L1 and L2 in **Fig 13**. The impact percentage is now plotted as a color in **Fig 14**.

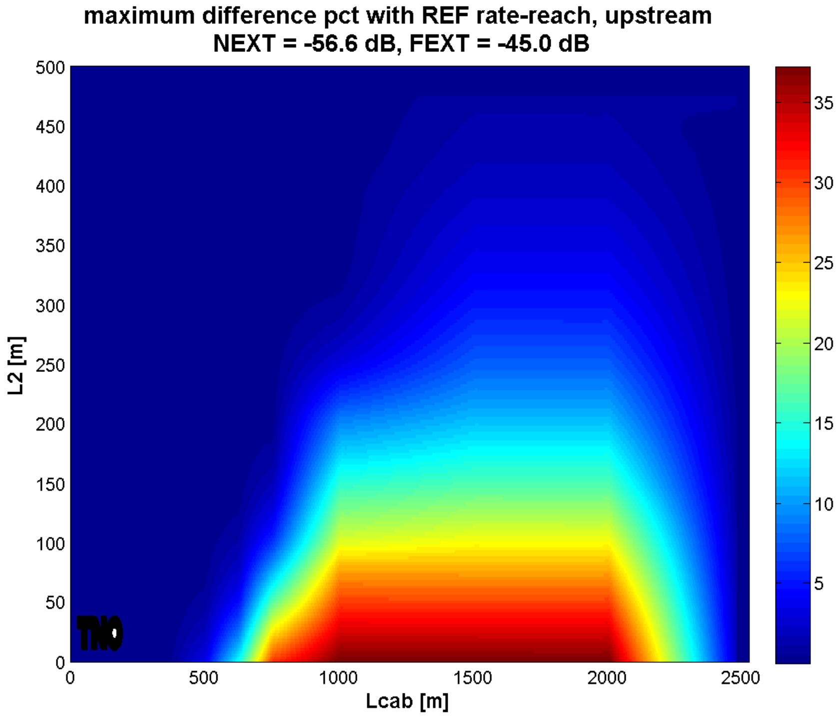

Fig 14: Impact contour plot or “heat map”.

4 Sensitivity analysis

The impact analysis was not only performed for the assumed NEXT/FEXT values presented in section 2.4, but for four different combinations:

1. NEXT/FEXT = -61.6 / -50.0 dB (-5 dB offset)
2. NEXT/FEXT = -56.6 / -45.0 dB (0 dB offset)
3. NEXT/FEXT = -51.6 / -40.0 dB (+5 dB offset)
4. NEXT/FEXT = -46.6 / -35.0 dB (+10 dB offset)

With these combinations we can analyse the effect of variations in crosstalk conditions due to variations in cable characteristics. They represent e.g. varying cable quality and binder separation.

4.1 Impact sensitivity overview per L2 distance

An overview of the maximum performance impact, as function of L2 and maximized over all cabinet distances and maximized over L3 for each rate-reach curve), is shown in **Fig 15**:

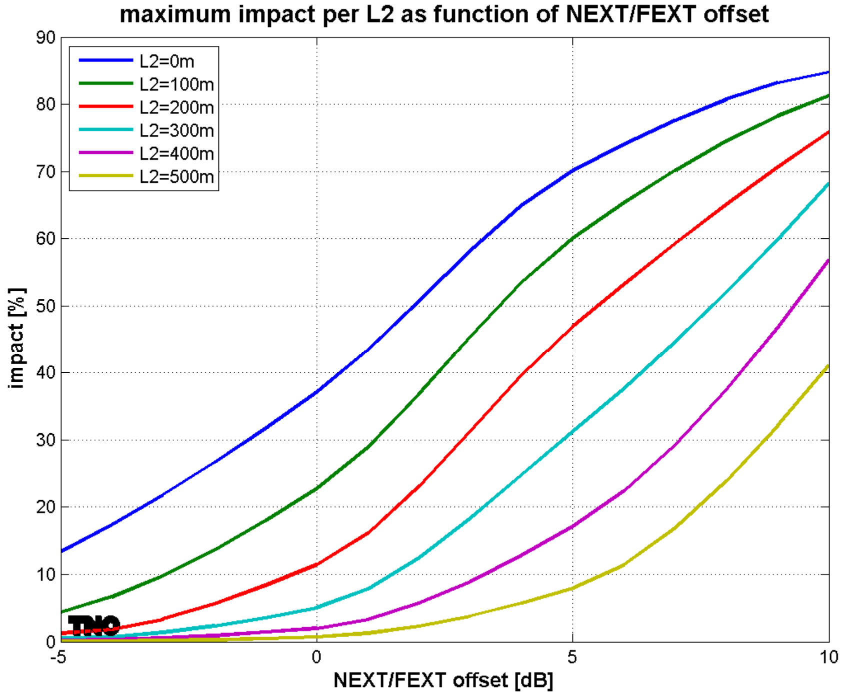

Fig 15: Impact percentages per L2 distance for different NEXT/FEXT values.

*An example to help interpret **Fig 15**: With a FEXT/NEXT offset of 0 dB, and for L2 = 100 m, there is a cabinet on a certain distance which shows a maximum performance impact of approximately 23 % on its upstream CVDSL rate-reach curve.*

As expected, the worst-case impact occurs at L2=0 for all NEXT/FEXT offsets.

Note that for higher offsets a maximum impact of up to 85 % is possible when the DP is at the same location as the cabinet (L2=0). We can conclude that the performance impact of EVDSL on CVDSL strongly depends on the actual NEXT/FEXT values.

4.2 Sensitivity of the minimum L2 to reach a certain level of impact

The minimum required distance between cabinet and DP, represented by L2, for different NEXT/FEXT values is given in **Fig 16**.

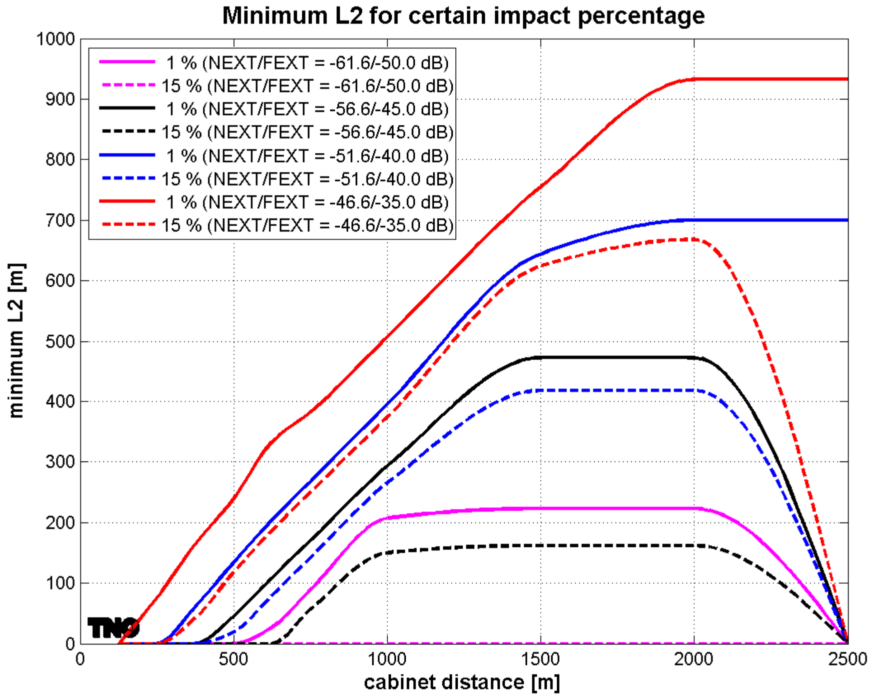

Fig 16: Minimum L2 for different impact percentages and NEXT/FEXT values.

Fig 16 confirms the expectation that when crosstalk (NEXT and FEXT) between links increases, the minimum L2 to reach a certain impact level increases.

4.3 Impact contour plots

Impact contour plots for different NEXT-FEXT values are given in **Fig 17** to **Fig 20**.

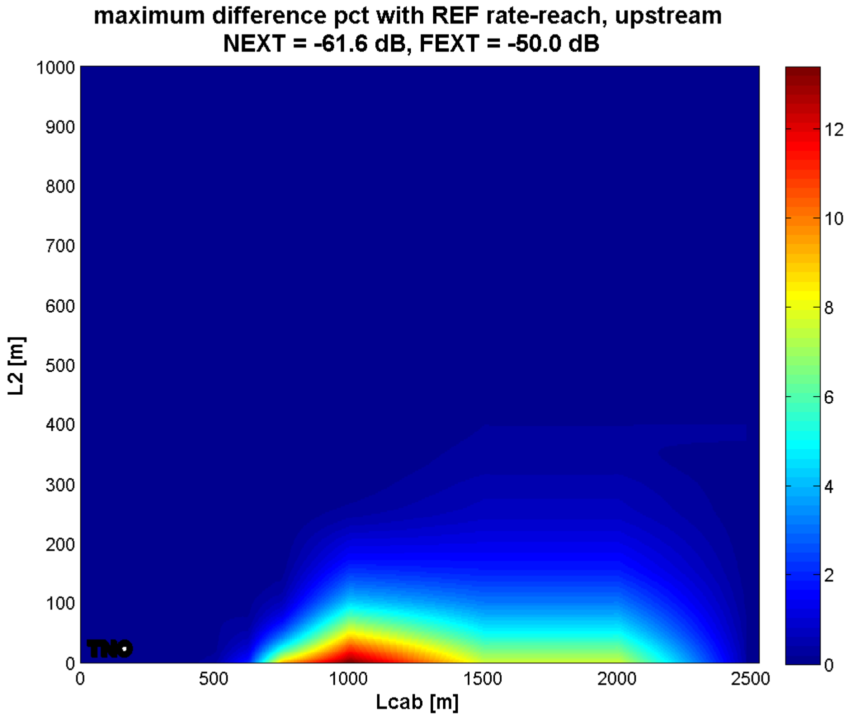

Fig 17: Impact contour plot for NEXT/FEXT= -61.6/-50.0 dB.

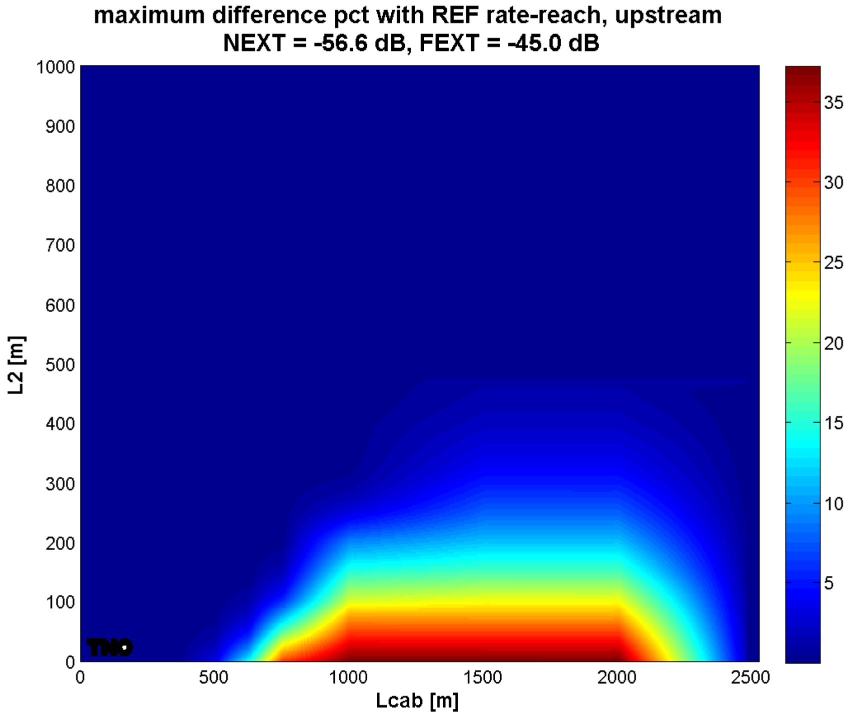

Fig 18: Impact contour plot for NEXT/FEXT= -56.6/-45.0 dB.

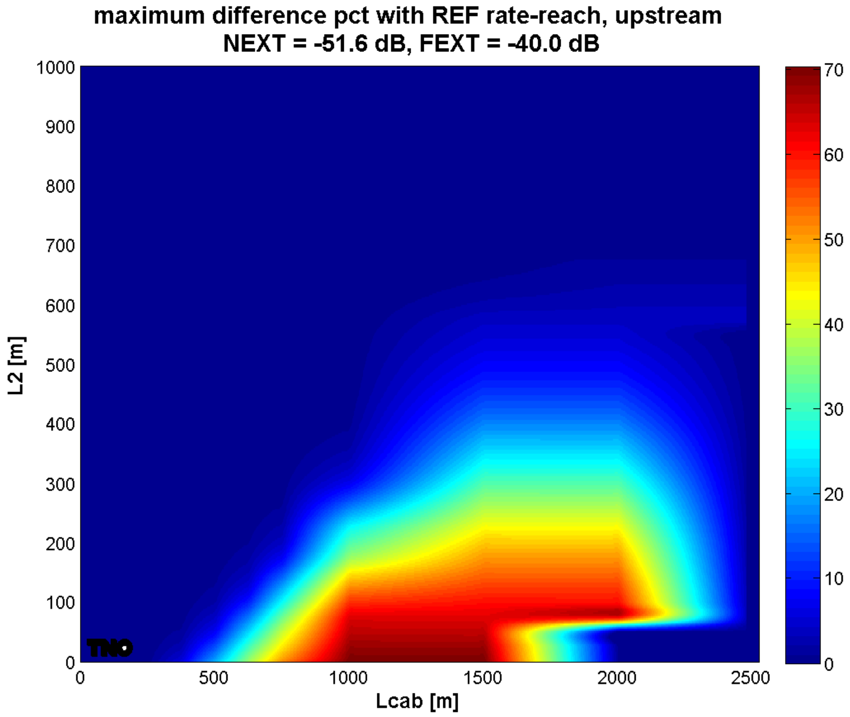

Fig 19: Impact contour plot for NEXT/FEXT= -51.6/-40.0 dB.

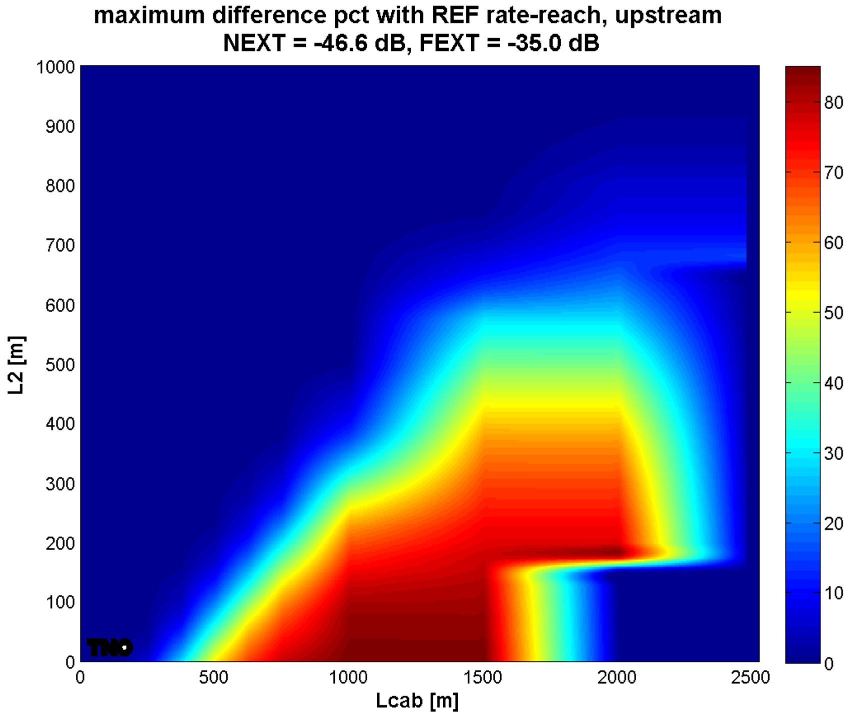

Fig 20: Impact contour plot for NEXT/FEXT= -46.6/-35.0 dB.

The low-impact region between Lcab = 1500 m to 2000 m and L2 = 0 m to 200 m is a result of EVDSL upstream carrier shutdown. Using an even finer simulation grid could give more insight in the performance difference in this region. This has not been further investigated in the context of this report.

4.4 Discussion on binder separation

In the sensitivity analysis in this chapter we varied NEXT/FEXT coupling values throughout the complete simulated topology. For binder separation however, the NEXT/FEXT coupling values for the cable behind the cabinet should be kept constant, and the NEXT/FEXT coupling from the DP cable to the through-cabinet ADSL2+ lines should be decreased (which emulates binder separation). Therefore the question is to what extent this approach represents binder separation

If the NEXT/FEXT coupling values are decreased throughout the whole topology, we may expect that:

1. **Effect 1**: Due to lower disturbance noise from ADSL2+ and CVDSL itself, a lower noise level for CVDSL in the REF technology mix results. Subsequently CVDSL becomes more vulnerable for alien EVDSL noise which leads to higher expected impact due to EVDSL.
2. **Effect 2**: Crosstalk from EVDSL to the CVDSL lines (via the path that is partly influenced by binder separation) becomes lower. This leads to lower impact due to EVDSL.

These are two effects which work in opposite direction. From the sensitivity analysis we see that impact decreases with decreasing NEXT/FEXT coupling values and thus can conclude that effect 2 is dominant. As a result, we may therefore conclude that decreasing NEXT/FEXT coupling values throughout the complete simulated topology will underestimate the effect of binder separation, since in reality, binder separation will cause effect 2 only, while in the current simulations effect 1 occurs as well.

4.5 Conclusion of the sensitivity analysis

The impact analysis is based on a set of assumptions that together are assumed to represent a representative copper line in the network.
In reality, there is large variation between copper lines and most lines will show different performance, either worse or better than the “representative” case.
The sensitivity analysis indicates that individual lines may show significant different performance, as the negative impact is highly sensitive to the NEXT/FEXT coupling values. For instance if binders are separated, the negative impact may decrease significantly.
In general: If the set of assumptions represents the “worst case” or a “bad case”, this means in reality most lines will perform better than simulated.

5 Additional simulation results

5.1 Comparison with natural cabinet evolution

Even if EVDSL is not deployed, it can be expected that the number of CVDSL lines increases. This is called ‘natural cabinet evolution’, and an increase in number of CVDSL lines results in a negative impact on CVDSL performance. This situation is specified by the CAB_EV scenario, and impact simulation results are as follows for different cabinet distances:

```
maximum difference between REF and CAB_EV for all L1/L2

  L_cab [m]     CAB_EV up [%]   CAB_EV dn [%]
  -------------------------------------------
    125              3.06484         5.07021
    250              1.73462         4.23340
    375              1.35947         4.38812
    500              1.40040         3.74795
    625              1.43367         3.20353
    750              1.46540         2.83840
   1000              1.52413         2.93910
   1500              1.57946         2.65807
   2000              1.62343         2.34266
   2500              1.64615         1.44867
```

We thus see that for the natural cabinet evolution, impact on upstream CVDSL is in the order of 1.5 %, increasing to maximally 3 % at very low cabinet distances.. Therefore, for negative impact to be considered significant in the EVDSL scenario it should be more than 1.5%.

5.2 Regarding the bitrate of EVDSL compared to ADSL2+

As additional information and input for a balanced decision by ComReg on EVDSL introduction, it is useful to know what performance gain EVDSL delivers over ADSL2+. We used the following approach:

- Starting point is the REF scenario, where an ADSL2+ link to the DP is simulated. In order to get the complexity of this simulation within the scope of this analysis, the cabinet SDSL and ADSL2+ links (which are in the same cable as the DP ADSL2+ links) are incorporated in this calculation by adding them to the DP. This results in a simulation with active links between only two locations: LEx and DP.
- For the reference EVDSL bitrates, the above scenario is modified according to the EVDSL scenario.
- We did not study the impact of CVDSL on EVDSL (which is out of scope for this study).

Thus:

Table 2, Mixes for reference DP bitrates ADSL2+ and EVDSL

	"DP ADSL2+"	**"DP EVDSL"**
System	***Amount***	***Amount***
ADSL2+ via DP	100	70
SDSL via DP	6	6
EVDSL	0	30
Total	**156**	**156**

Simulation results for downstream respectively upstream, giving a good indication of the expected actual bitrates, are shown in **Fig 21** and **Fig 22**.

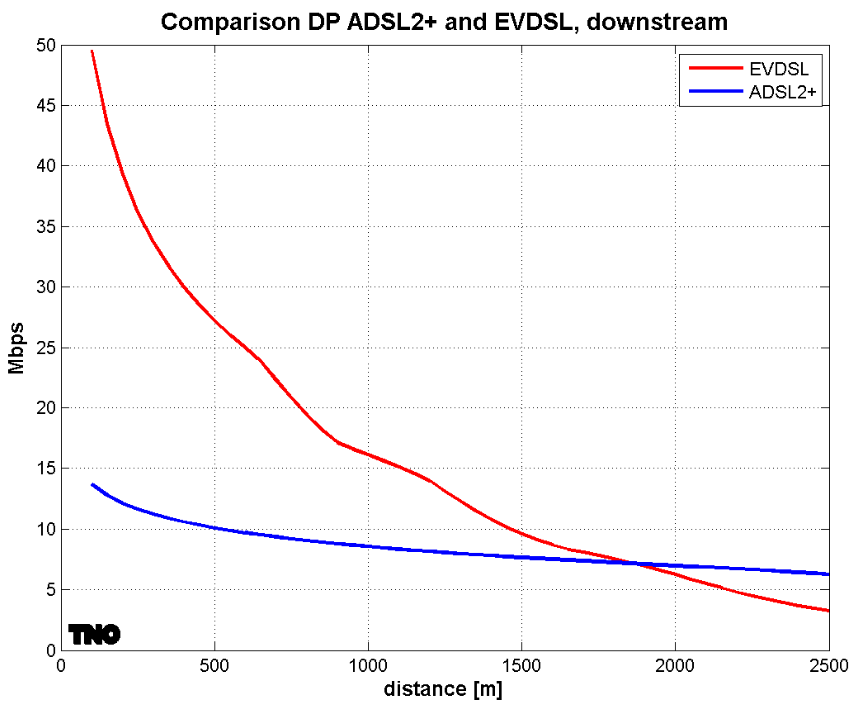

Fig 21: Downstream DP ADSL2+ versus EVDSL.

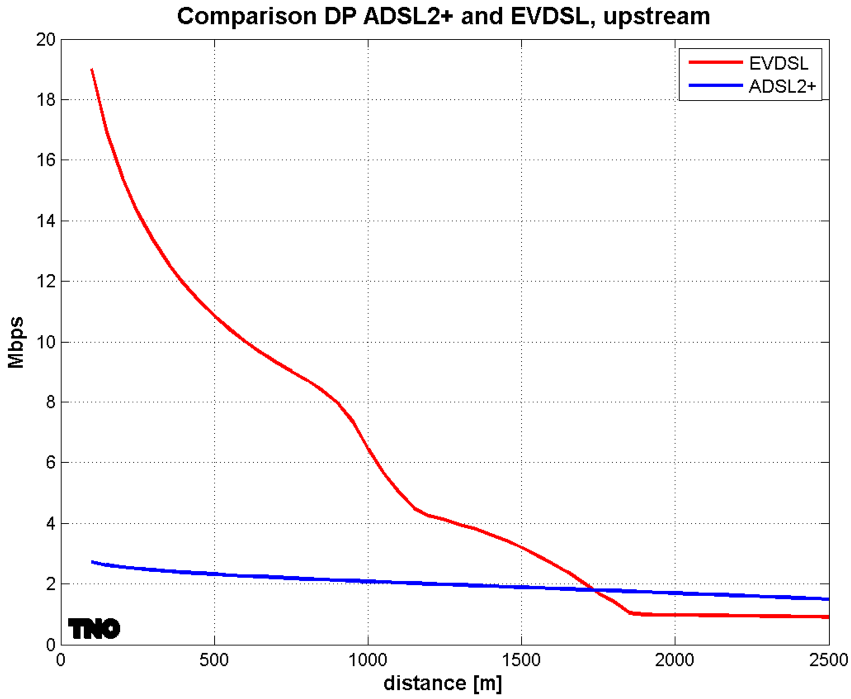

Fig 22: upstream DP ADSL2+ versus EVDSL

Observations :

- As expected EVDSL achieves significantly higher bitrates than ADSL2+, for lines that are within approximately 1500 meters from the LEx.
- There is a “crossover” point, which is the distance beyond which EVDSL offers no advantage over ADSL2+. In these curves this point lies for upstream and downstream between 1500 and 2000 meters.

5.3 Conclusions:

We see the following:

- Natural cabinet evolution (increasing the number of CVDSL lines) show a upstream performance impact of a few percent. This may provide enough ground to allow at least the same amount of impact due to EVDSL deployment.
- At low distances the EVDSL performance is much higher than ADSL2+, this performance gain decreases with increasing distance. For distances larger than approximately 2000 meters EVDSL does not provide a higher performance than ADSL2+. This is because at those distances the EVDSL spectrum will be similar to ADSL2+.

6 Conclusions and recommendations

6.1 Conclusions

We have performed an impact analysis to:

- Quantify the impact on CVDSL when EVDSL is introduced in the Irish copper access network in topology 3 [3].
- Enable a common understanding of the technical consequences of the proposed CLFMP amendment to allow EVDSL.

This impact analysis is based on standardized calculation methods.

6.1.1 Meaningful technology mixes have been defined

We have defined three technology mixes:

- a reference technology mix without EVDSL;
- a modified technology mix to study the impact of EVDSL on CVDSL;
- a modified technology mix to study the impact of a “natural” growth of CVDSL.

The simulation scenarios used in this analysis are based on a set of assumptions that were discussed with ComReg and DSL operators during an industry meeting in Dublin on 15 Dec 2014 and subsequently with BT and Eircom. These assumptions can be found in chapter 2.

6.1.2 EVDSL has significant negative impact on upstream CVDSL

For the agreed assumptions used the analysis, the following results hold:

- The impact analysis reveals that there is significant negative impact of EVDSL on upstream CVDSL. In the downstream direction, the impact was found to be near-zero.
- The negative impact on upstream CVDSL starts to become noticeable when the distribution point is within 500 meter from the cabinet and when the cabinet is further then approximately 500 m away from the Local Exchange.
- We have observed negative impact of up to 37 % performance loss, occurring when the DP is located very close to the cabinet and the cabinets are between 1000 m and 2000 m from the LEx. For cabinets further away than 2000 m the impact quickly decreases.
- A sensitivity analysis shows that the negative impact is highly sensitive to the NEXT/FEXT coupling values.

6.1.3 Additional simulations

<u>Impact in the scenario for cabinet evolution</u>

Even if EVDSL is not deployed, it can be expected that the number of CVDSL lines increases, here called ‘natural cabinet evolution’. For this scenario, negative impact on upstream CVDSL is in the order of 1.5 %, increasing to maximally 3 % at very low cabinet distances. Therefore, for negative impact to be considered significant in the EVDSL scenario it should be more than 1.5 %.

EVDSL and ADSL2+ compared

At short distances EVDSL bitrates are much higher than those of ADSL2+. This performance gain decreases with increasing distance, and for distances larger than approximately 2000 m EVDSL does not provide a higher performance than ADSL2+. This is because at those distances the usable EVDSL spectrum will be similar to ADSL2+.

6.2 Recommendations

From the conclusions it is clear that introducing EVDSL without restrictions can cause negative impact on CVDSL for certain combinations of distances (“regions”) Local Exchange to Distribution point (“L1”) and Distribution point to Cabinet (“L2”). Therefore we recommend for ComReg to:

A) Determine what level of negative impact is acceptable by trading off performance gain of EVDSL over ADSL2+ versus negative impact on CVDSL.

B) Decide where to allow EVDSL or not based on the above mentioned trade-off.

There are three possible outcomes

1. All negative impact is acceptable, meaning that EVDSL can be allowed without restrictions.
2. Negative impact is not acceptable and EVDSL will not be allowed in topology 3.
3. A certain level of negative impact is acceptable .

Outcome 1 and 2 are straightforward in a technical sense. Outcome 3 is further elaborated below:

- Determine the region, spanned by L1 and L2, where EVDSL is not allowed based on the results of this impact analysis.
- Define together with industry how these L1 and L2 should be determined in practice. For instance they could be measured (e.g. via loop attenuation) or extracted from a network database.
- Take into account that no matter how L1 and L2 are determined, there will be a finite accuracy. This may be dealt with by setting an extra safety margin.

Suggestions for making a trade-off between performance gain of EVDSL over ADSL2+ and negative impact on CVDSL:

- Decide on which DP distances (L1) EVDSL has a substantial benefit over ADSL2+. Beyond this L1 distance,1500 m for example, EVDSL could be forbidden.
- In general, for EVDSL loop distances shorter than 1000 m, the EVDSL relative bitrate gain in downstream will be larger than the negative impact on upstream CVDSL. However, the amount of affected homes passed may be larger than the amount of homes passed with EVDSL. This is something

that could be quantified and taken into account. It would even be possible to calculate a “market averaged bitrate”, weighing bitrates with home distributions in the network.

- Formulate a policy guideline allowing for negative impact if there is a good reason, such as benefits to the overall speed capabilities of the access network.

Possible additional strategies for mitigating the impact of EVDSL on CVDSL include the following:

1. CVDSL could benefit from optimised UPBO settings that are tailored for Vectored VDS2L. These settings would increase upstream transmit power, resulting in higher upstream bitrates for most lines behind the cabinet. This would also mitigate the negative impact of EVDSL in many cases.
2. The negative impact of EVDSL can be partly mitigated by “curtailing” EVDSL by limiting the upstream spectrum to 8 MHz (i.e. shutting down US2 and partially US1). This would reduce negative impact at the cost of upstream EVDSL bitrate.

A general recommendation for future proposed changes to the access rules is to include impact analyses based on agreed assumptions in any proposal. This may speed up the decision process.

7 References

[1] eircom CLFMP proposal
[2] CLFMP, document number NM-2564, September 2012, Issue 6 Revision 1
[3] TNO report 2014 R11646
Evaluation of the proposal to allow VDSL2 from the local exchange (EVDSL) in Ireland -Technical evaluation of the CLFMP amendment proposal
[4] ETSI TR 101 830-2, 2008
Spectral Management, part 2: Technical methods for performance evaluations
[5] TNO report 34373, July 23, 2007 (**not public**), Rob F.M. van den Brink
How to analyze the impact of new xDSL technologies on deployed systems? The specification of the "reference methodology" for local loop studies in the Netherlands

8 ANNEX A: Simulation approach in SPOCS

Because SPOCS does not handle ‘double crosstalk hops’ of disturbers, it cannot directly calculate the impact of the DP signals on the cabinet VDSL. We therefore have to transfer the DP upstream/downstream disturbers to the cabinet using additional scripting before invoking SPOCS. The topology thus becomes as follows:

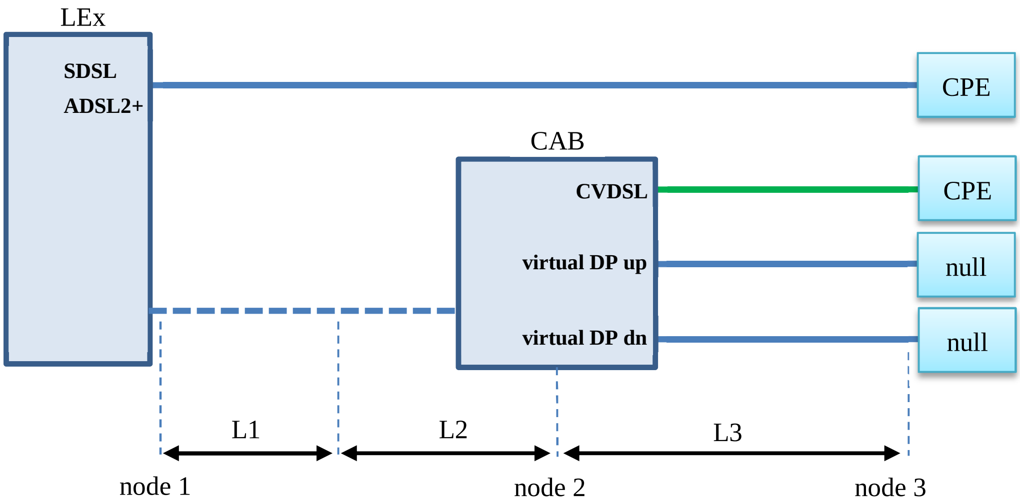

Fig 23: Final calculation mechanism

Note that the actual PSD of the virtual DP disturbers at the cabinet depend on the L1/L2 ratio at hand.

So to precalculate the virtual DP disturbers (using SPOCS library functions):

1. upstream includes UPBO(L1), upstream carrier shutdown (L1) at high distances due to zero bitloading , one NEXT(L1) and attenuation for L2
2. downstream includes FEXT(L1) and attenuation for L2

9 ANNEX B: EVDSL upstream carrier shutdown

When the DP distance increases above the distance where UPBO is active and the upstream transmit power is maximized, the upstream SNR on high frequency carriers drops quickly. If no bitloading is possible on certain carriers, then these carriers may be switched off in order to preserve power and to minimize disturbance on lines which are still able to use these carrier frequencies.

Using the simulation technology mix used for determining the DP reference bitrates for EVDSL (see *Table 2*), it was analyzed what the relation is between the lowest frequency for which SNR = 0 dB and the EVDSL distance. The solid dots in **Fig 24** represent the reference values obtained from this analysis, and the solid line is a suitable curve fitted to these dots. This smooth curve is used in the impact analysis and provides a rule at which frequency the EVDSL upstream spectrum should be cut off as a function of the DP/EVDSL distance (represented by L1).

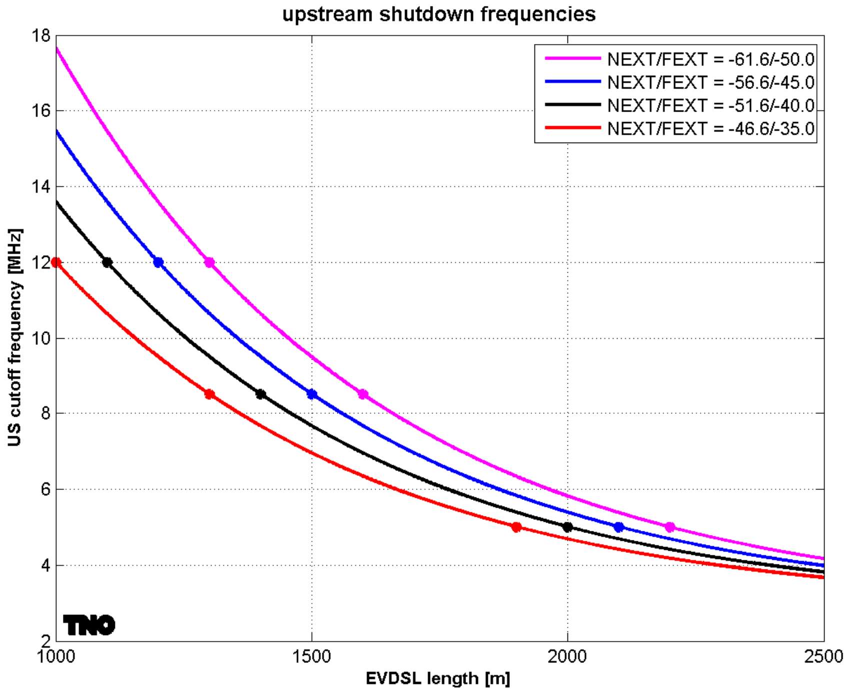

Fig 24: EVDSL upstream frequency with SNR=0 dB versus EVDSL length.

We see for the default NEXT/FEXT coupling values that US2 is shut down between 1200 m and 1400 m, and that US1 is shut down between 2100 m and 2600 m.

Note that the criterion to shut a carrier down at SNR=0 dB is on the safe side: at least a few dB SNR is theoretically required for DSL in order to code a bit on a carrier, and receiver implementation losses add more dBs on top of that (for VDSL receivers the standard recommends a Shannon gap of 6.75 dB). The impact analysis using the upstream carrier shutdown mechanism will therefore not present too low impact percentages.