The art of Spectral Management Access rules for VDSL2

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

Abstract: *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 a necessity for all DSL deployments, and serves a common interest of all involved DSL operators. Such rules were relatively simple for legacy deployments such as ADSL, SDSL and HDSL, but are far more complicated for VDSL2. This is mainly a consequence of deploying VDSL2 from remote locations (e.g. street cabinets), where it should coexist with legacy equipment deployed from the central office. This paper summarizes the signal limits essential for VDSL2 and discusses the reasoning behind them. Such limits can only be effective if they are tailored to underlying business needs, geographic characteristics of the network, the installed base of legacy equipment, loop characteristics etc. As such, access rules need to be country or region specific and cannot be copied blindly from neighbouring countries.*

1. INTRODUCTION

VDSL2 is a new DSL modem technology to deliver third generation broadband services (3GBB; requiring tens of Mb/s) via existing telephony wiring. Unlike ADSL2 or ADSL2plus, it can deliver tens of Mb/s or higher, which makes VDSL2 appropriate for offering typical 3GBB services such as 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. If loops are longer, the maximum bitrate and maximum usable frequency of VDSL2 get lower, and beyond a certain length the bitrate advantage of VDSL2 over ADSL2plus vanishes. When the *local loop* (i.e. the loop from central office to customer premises) is too long then the loop can be shortened by deploying VDSL2 from remote locations such as street cabinets: the so called *subloop*.

VDSL2 is currently on the verge of a massive roll-out in several countries. A typical deployment involves offering VDSL2 from central offices to nearby customers only (local loop), and from remote locations such as street cabinets (sub loop) for all the other customers. By feeding these remote locations via fiber and by using VDSL2 only for the last copper drop (typically <1 km), the bitrates required for 3GBB can be offered to all customers.

2. PURPOSE OF ACCESS RULES

VDSL2 has to operate in a multi-DSL environment, especially when the copper loops have been unbundled for granting access to different DSL operators. VDSL2 will then share the same cable with legacy systems (different flavours of ADSL, SDSL and HDSL), and these legacy systems are to remain operational.

VDSL2 uses a much wider spectrum (up to 12 MHz or even higher) than today's legacy systems (up to 2.2 MHz) and is to be deployed from remote locations. Because of this, a major challenge is to ensure that all DSL systems can coexist in the same cable. This requires several measures to prevent disproportional disturbance between various modems. These measures have the following purposes:

a) *Taking care of the past*, by preventing VDSL2 in a sub loop from disturbing legacy systems in the local loop in a disproportional manner. This will be the case when one legacy system is replaced by one VDSL2 system, and the performance of other legacy systems suddenly drops because of that change.
b) *Optimizing present deployment*s, by preventing other VDSL2 systems from being deployed in the same cable in an incompatible manner. VDSL2 will then be unable to make optimal use of available capacity.
c) *Preserving for future innovations*, by preventing VDSL2 from using higher frequency bands in such an inefficient manner that it blocks a more appropriate use of these bands for future DSL deployments.

The generic solution is to limit the transmit signals of VDSL2 by means of rules, an approach that is similar to the well known speed limits from ordinary traffic rules. Traffic rules may not be favourable for individuals but they reduce the number of road accidents, the amount of chaos, and thus increase the flow of traffic. In the case of DSL, we speak about *access rules*: DSL systems have to comply first to these rules before their access to the copper network is granted. Access rules should be *mandatory* for all players; otherwise a single violation may degrade the performance of all the others. And although such limits may be inconvenient for individuals, they are essential to serve the interests of all involved players. This is analogous to traffic rules to prevent road accidents.

VDSL2 is equipped with all kinds of capabilities to limit its signal levels, including:

- *frequency allocation*, to restrict the use of frequencies to allocated bands, for serving purposes (b) and (c);

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- *downstream power back-off* (DPBO, also known as "PSD shaping"), for an extra reduction of the downstream PSD's, to serve purpose (a);
- *upstream power back-off* (UPBO), for an extra reduction of the upstream PSD's, for serving purpose (b).

These capabilities facilitate a flexible control of modem behaviour via the VDSL2 management system. But there are so many options per capability, that it is not obvious what to choose. The underlying business needs, geographic properties of the network, installed base of legacy equipment, loop characteristics etc. all determine the type of modem behaviour that is appropriate. Therefore the preferred limits for the above capabilities are country or region specific and should not be copied blindly from limits used in neighbouring countries. We will explain them one by one.

3. FREQUENCY ALLOCATIONS

A convenient way to recover data from received signals is by keeping the frequency bands for upstream and downstream strictly separated. The use of higher frequency bands by VDSL2 makes it necessary (due to higher near-end crosstalk) to keep up- and downstream bands strictly separated. This has simplified the design and enabled efficient usage of available capacity.
Such a strict separation is not relevant for lower frequencies, and is therefore not common for the "legacy band" below 1 MHz, used by ADSL, HDSL, SDSL, ISDN, etc. However, all flavours of the VDSL2 standard [3] keep both directions strictly separated for higher frequencies.
There is only one major problem: about 30 of these frequency plans have been "standardized" for Europe and North America, and most of them have different variants as well. When different plans are used for different wire pairs in the same cable, and parts of their bands overlap in frequency, then it will harm the maximum bitrate of all involved VDSL2 systems. In other words, many of these plans are spectrally incompatible.
This means that a *common* frequency plan has to be applied to *all* wire pairs of a cable, or preferably, for all cables in the same area or country. Differences in business needs, topology and historical choices for the DSL systems being deployed mean that different countries require different frequency plans to make the most appropriate choice. Examples are the business trade-off between symmetric or asymmetric ratios between up and downstream bitrates, or topology aspects such as the typical distances between cabinet locations and customer premises. Therefore it is not recommended to copy frequency allocation plans blindly from plans in neighbouring countries.

Figure 1 illustrates two well-documented examples, taken from [1].

- Plan B8-4 (both variant 8x and 12x) has been selected for the Netherlands, and enables the use of VDSL2 up to 12 MHz (see [1], signal description "VDSL2-NL1"). The bands above 12 MHz are reserved for future use, most likely for future DSL systems to be deployed from remote locations within 200m of the customer premises.
- Plan B7-1 has been selected within the United Kingdom (see [1], signal description "VDSL2-UK1"). The average lengths of secondary loops (between remote location and end-users) are longer in the UK than in the Netherlands. Therefore the choice to restrict the frequency band to 7.05 MHz was more appropriate for the UK topology. Frequencies above 7.05 MHz are reserved for future use, most likely for future DSL systems to be deployed from locations that are closer to the end users.

It may be obvious from Figure 1 that both plans cannot be used concurrently in the same cable. If they are used concurrently, the upstream and downstream bands overlap in frequency between 3 and 3.75 MHz. Both systems will interfere with each other in these bands, and neither of them would be able to make efficient use of the overlapping band. This illustrates that selecting a frequency plan for an individual VDSL2 modem is not enough. It should also be *mandatory* for all players in the same network to exclude the use of incompatible plans.

Finding the most appropriate frequency plan for a specific topology is beyond the scope of this paper. An overview of all options from [3] can be found in [8].

4. DOWNSTREAM POWER BACK-OFF

When DSL systems are deployed from different locations along the same cable (e.g. from central offices as well as from street cabinets) a new type of problem may occur. The

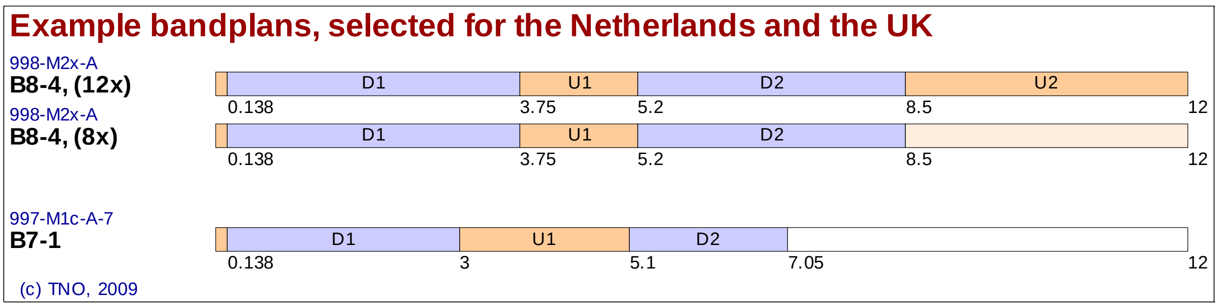

Figure 1: *The band plans for the Netherlands and the UK are very different since the geographic characteristics of their topologies are very different. Bands D1 and D2 are available for the downstream; bands U1 and U2 (and U0) are available for the upstream. The use of frequencies above 12 MHz (Netherlands) or above 7.05 MHz (UK) is prohibited.*

DSL systems deployed from remote locations can easily disturb the deployments from central offices in a disproportional manner.
Figure 2 illustrates this for a loop of 3.5km, with a street cabinet at 3km from the central office:

- DSL system "1" transmits its downstream signals from location "A" to serve location "C". This signal propagates through the line, and its level attenuates with distance due to the insertion loss of the loop. Only a small proportion of this transmit power will arrive at location "C", and this signal level is already significantly reduced when it passes location "B".
- DSL system "2" does the same on another wire pair, but now from location "B". It will disturb system "1" (and visa versa) due to crosstalk between the wire pairs.
- However, system "2" transmits at full power, from a location where the signal of system "1" has been attenuated. Since the level of system "2' dominates the level of system "1" at location "B", it will be very easy for system "2" to drown out system "1".

It may be obvious that this difference in signal level causes a disproportional disturbance of system "2" to system "1". Conversely, it can simply be prevented by reducing the transmit power of system "2" to (roughly) the attenuated signal power of system "1" at location "B". This is exactly what occurs when downstream power back-off is applied (DPBO).

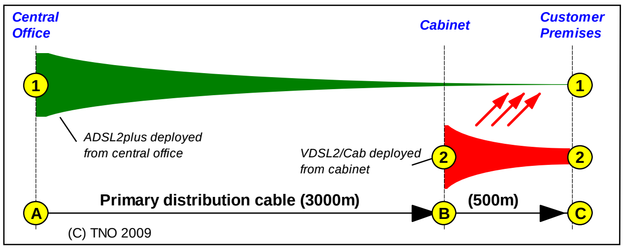

Figure 2: *Signals injected at full power from location "B" dominate the (attenuated) signal levels injected from location "A", due to the insertion loss of the loop.*

The aim of downstream power back-off is to reduce the transmit power of VDSL2 modems in remote locations in such a manner that they do not generate more disturbance in the loop than legacy modems do (like ADSL) from central offices. This is only needed for the frequency bands used by these legacy modems, e.g. up to 2.2 MHz. The amount of required power back-off is frequency dependent, due to the loop characteristics, and therefore power back-off is also known as "PSD shaping".

Figure 3 illustrates how power back-off may look like in practice for VDSL2 modems deployed from cabinets that are 2 km away from the central office. It shows two spectra: a "Source spectrum" that would have been transmitted without any downstream power back-off, and a "Transmit spectrum" that occurs when DPBO is applied. The figure shows that the amount of power back-off increases with the frequency and that it can be more than 40 dB at some frequencies. Frequencies above 2.2 MHz are not used by legacy systems and do not require power back-off in this example.

The shape of power back-off is frequency-dependent, and is more or less related to the insertion loss of the loop between central office and street cabinet. If this loop length is shorter or longer than 2 km, another shape is to be applied. In theory, each cabinet location requires its own shape, but a discrete set of PSD shapes (e.g. one for each dB insertion loss between central office and street cabinet) may be favourable in practice. All VDSL2 modems in the same cabinet should then apply the same shape.
Note that the required amount of power back-off also depends on the desired amount of legacy protection (related to underlying business needs), and on the desired protection frequency band (related to the installed base of legacy equipment).

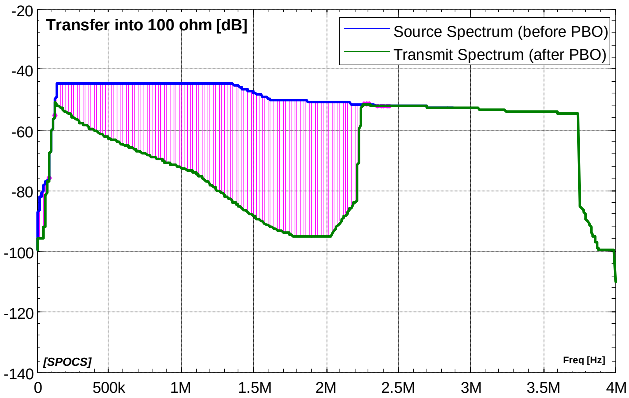

Figure 3: *The reduction (power back-off) of VDSL2 signals needed from remote locations can be significant. This reduction is frequency dependent, is only needed for usable legacy frequencies (below 2.2 MHz) and is also dependent on the copper distance between the central office and the remote deployment location (a street cabinet at 2 km in this example).*

It may be obvious that these power reductions in favour of legacy systems will be disadvantageous for VDSL2: the maximum downstream bitrate for VDSL2 will reduce due to the reduction of its transmit power, and the system will become more sensitive to impulse noise. However the bitrate reduction of VDSL2 is minor compared to the bitrate gain for legacy systems. For instance, the impact of VDSL2 on the maximum bitrate of ADSL2plus can easily be reduced by a factor 2 or 3 when DPBO is not applied.
Finding adequate PSD shapes for a specific topology is beyond the scope of this paper. The same applies for making convincing impact analyses via simulations [2,4] to prove that the selected shaping is indeed adequate. More information about DPBO can be found in [9].

5. UPSTREAM POWER BACK-OFF

The aim for upstream power back-off (UPBO) is somewhat similar to that for downstream PBO: to reduce the power from nearby modems in favour of distant modems. UPBO improves upstream performance for distant customers when they are located at different copper distances.
UPBO is only meaningful for upstream frequencies that are strictly separated from downstream frequencies, in combination with topologies where nearby and distant customers are very far away from each other. This makes

UPBO mainly a VDSL2 issue, and is not so relevant for legacy equipment such as ADSL, SDSL and HDSL.
If UPBO is not applied, the following will be observed:

- Nearby customers have the highest performance, since the insertion loss of their loop is low. The highest bitrates can therefore be achieved on the shortest loops.
- Nearby transmitters will also cause the highest crosstalk to signals from distant transmitters, since these distant signals are attenuated by the insertion loss of longer loops and are therefore (much) weaker.

By reducing the power of nearby transmitters (this is what UPBO does), the crosstalk to distant transmitters will reduce as well, which improves their signal-to-noise ratios (SNRs). This power reduction brings a (small) penalty for nearby modems, but can offer a significant improvement in VDSL2 bitrates for distant customers. Since nearby customers already have the highest VDSL2 bitrates, this penalty may hardly be an issue in practice.

This problem is not so relevant for most deployments from the central office (ADSL, SDSL, HDSL) partly because the connections to the involved customers are commonly grouped in a distribution. Figure 4 shows a typical distribution topology, where many customers are being served via a common (long) primary cable. Street cabinets (or splices) are used to fan-out this cable into multiple secondary cables before a customer premises is connected. For instance a 900 wire pair cable bridges a distance of 3 km and fans out into many 100 wire pair cables to abridge the last 200-800m.
In such a topology, customers are located at different distances, but due to the (long) length of the primary cable the difference between the shortest and longest loop via that distribution is insignificant (less than 9% in our example). Therefore the problem that DSL modems at distant locations will perform worse in the upstream is not an issue of concern in most deployments from the central office.

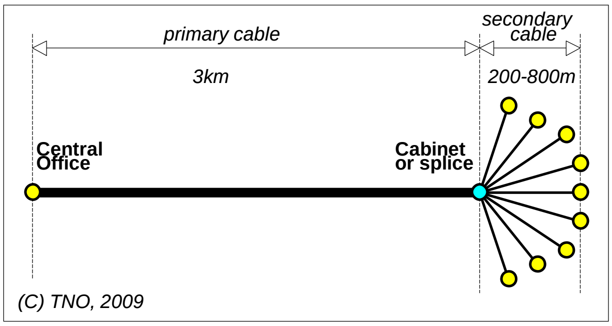

Figure 4: *A typical ADSL topology via a long primary cable and a short secondary cable. This allows for ignoring the difference between longest and shortest loop via the same primary cable, and thus there is no need for upstream power back-off for ADSL.*

However, this simplification does not hold anymore for deployments from remote locations such as VDSL2 from street cabinets. Figure 5 shows a typical topology that describes this situation. Customer premises are never collocated at the very end of a secondary cable, but *distributed* along the loop. The difference between the shortest and longest loops can be significant in such topologies.

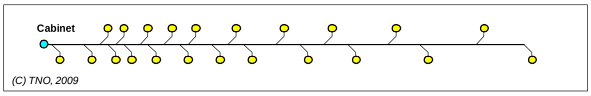

Figure 5: *A typical VDSL2 topology is a secondary cable where all customer premises are distributed along that line. This makes it essential to apply upstream power back-off to VDSL2, otherwise distant customers cannot be served.*

If all customer VDSL2 modems are transmitting at exactly the same level, then the nearest one to the cabinet will not only be heard the most loudly, but also cause the most disturbance to a remotely located VDSL2 modem. Similar to downstream power back-off, the solution for this is to allow distant modems to transmit at full power, and to reduce the transmit power for nearer modems; in other words: upstream power back-off (UPBO).
Figure 6 illustrates this principle by means of an acoustic representation of UPBO. The upstream transmit power decreases gradually when the transmitter gets closer to the receiver. This improves the performance from distant modems, at a small penalty for nearby customers.

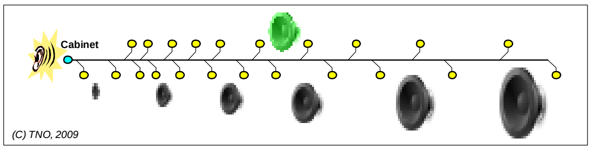

Figure 6: *Signals from systems near the receiver can easily disturb (attenuated) signals from systems at longer distances. If they are distributed along the line, then the amount of upstream power back-off should keep pace with the associated insertion loss.*

Figure 7 shows how effective UPBO can improve the upstream bitrates of distant customers. It holds for a subloop with only 20 VDSL2 systems, using realistic assumptions for insertion loss, crosstalk coupling and distribution along the line for a particular loop.

- The solid line represents the predicted upstream bitrate for the hypothetical case that all 20 VDSL2 customers are (virtually) co-located at a certain distance. This distance is subsequently swept from 50 to 1600m.
- The round markers represent the predicted upstream bitrate for the more realistic case that the customers are distributed along the line (5 at 150m, 6 at 300m, etc, as shown in Figure 8). In this case all modems transmit at full power.
- The square markers represent the same as above, assuming that upstream power back-off has been applied.

It can be concluded from Figure 7 that UPBO brings a significant bitrate improvement for most customers (above 300m) at a small decrease in bitrate for near customers (less than 9% at 150m in our example). The nearby customers still have an advantage over the distant customers. The bitrate under a well-designed UPBO regime can approximate the hypothetical bitrate when all 20 VDSL2 modems are (virtually) co-located. This was achieved in our example up to 800m, but this depends on the selected UPBO regime.

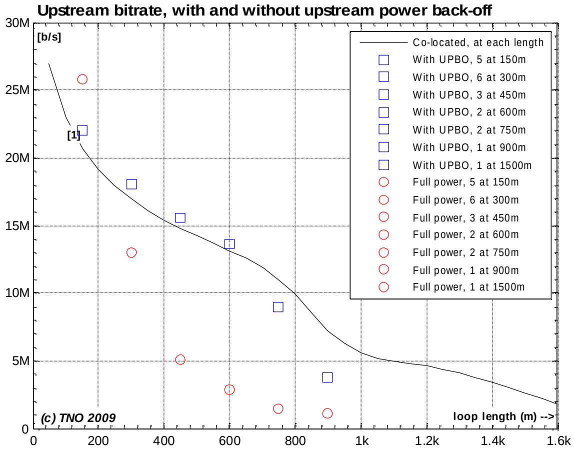

Figure 7: *Predicted bitrates for upstream VDSL2 for comparable scenarios with distributed customer locations. The round markers indicate the achievable bitrate without upstream power back-off (UPBO), and the square markers when UPBO is applied. The solid line represents an over-simplification of such a prediction, assuming that all customers are collocated (so that UPBO is not needed anymore)*

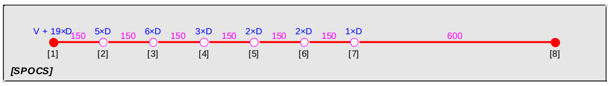

Figure 8: *Assumed distribution of VDSL2 customers along the line, for evaluating the predictions in Figure 7.*

Finding an adequate UPBO regime for a specific topology is beyond the scope of this paper. The result is anyhow frequency dependent, and should be applied to all upstream frequencies that are not overlapping with downstream frequencies.

The meaning of "adequate" is highly related to underlying business needs. It depends on the desired coverage of customers (for a given geographic density of customers along the loop, and given loop characteristics) and on the desired locations for deploying VDSL2 (from street cabinets, from the central office or both). This illustrates (again) how country- or region-specific these UPBO limits should be.

It may be obvious that these power reductions in favour of VDSL2 can only be effective when applied to all modems in the loop. Therefore an UPBO regime for VDSL2 must be made *mandatory* by means of adequate access rules.

More information about UPBO can be found in [10].

6. SUMMARY

VDSL2 is a new DSL modem technology for delivering third generation broadband services (3GBB) via existing telephony wiring. It is essential that the signals of all VDSL2 systems in a cable do not exceed the (spectral) limits of well-designed access rules. Such rules are to serve a common interest of all involved DSL operators: to let it coexist with legacy DSL systems and to make optimal use of available copper resources.

The design of these spectral limits is highly dependent on underlying business needs, and on the geographic & electrical characteristics of the network. This includes:

- A common frequency allocation plan to enable efficient usage of available copper resources when VDSL2 is implemented.
- Downstream power back-off, to protect legacy systems (like ADSL) when VDSL2 is deployed from remote locations.
- Upstream power back-off, to serve both nearby and distant VDSL2 customers.

However, there are so many possibilities that limits can only be adequate if they are country- or region-specific. The limits should not be copied blindly from those used in neighbouring countries. The limits can only be effective if they are specified via mandatory access rules for all involved parties.

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 VDSL2*"; 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.

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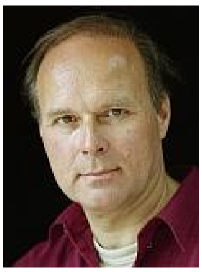

Since 1996, he has played a very prominent role in DSL standardisation in Europe (ETSI, FSAN), written more than 100 technical contributions to ETSI, and took the lead within ETSI-TM6 in identifying / defining cable models, test loops, noise models, performance tests, and spectral management. He is the 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).