The art of Spectral Management Frequency allocations 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 necessary for all DSL deployments, and serves a common interest of all involved DSL operators. VDSL2 is a new technology, using higher frequencies above the frequency bands of legacy systems such as ADSL. This has made it necessary to separate up- and downstream signals in frequency. The result is a more efficient use of available bandwidth, which is essential for VDSL2 to transport higher bitrates.*

However a common frequency allocation plan for all regions in the world makes no sense due to the differences in topology, which has resulted in many options in the VDSL2 standard. This paper summarizes these different options, explains the rationale behind them, and provides some guidance for selecting a proper frequency allocation plan for a specific topology of interest. Such a selection is related to both business needs and network characteristics, which are different for different countries or regions.

1. INTRODUCTION

VDSL2 is a new DSL modem technology to deliver third generation broadband services (3GBB) via existing telephony wiring. Unlike ADSL2 or ADSL2plus, it can deliver tens of Mb/s or higher, which makes VDSL2 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. If loops are longer, the maximum bitrate and maximum usable frequency of VDSL2 get lower, and beyond a certain loop 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, the loop can be shortened by deploying VDSL2 from remote locations such as street cabinets: the so called *subloop.*

Since VDSL2 has to share the cables with legacy systems like ADSL, SDSL and HDSL (deployed via other wire pairs) it can easily disturb them (and other VDSL2), especially when VDSL2 is deployed from remote locations. Spectral management is required [8] to prevent this undesired behaviour.

One such measure is a common frequency allocation plan for all involved VDSL2 modems in a cable. Such a plan identifies what frequencies are allowed for transmitting upstream and downstream signals. Separating them into non-overlapping bands enables a convenient and efficient way to separate the transmitted signals from the received to recover the data. This separation was for various reasons not crucial for frequencies below about 1 MHz (the legacy band). The HDSL and SDSL bands have up- and downstreams that fully overlap each other, but VDSL2 keeps both directions strictly separated for higher frequencies. This has simplified the design and enabled an efficient usage of the available capacity.

There is only one major problem: about 30 of these plans have been "standardized" [3] for Europe and North America, and most of them have different variants as well. Many of these plans are incompatible and cannot be mixed-up in the same loop. This means that frequency allocation plans are to be tailored to the underlying business needs an network characteristics, so they are country or region specific. It also means that a common frequency plan has to be selected for *all* wire pairs of a cable, or preferably, for all cables in the same area or country. This paper discusses the options and how to make a proper selection out of it.

2. EXAMPLE FREQUENCY PLANS

Let's start with two well-documented examples [1]. Differences in topology and historical choices for the DSL systems being deployed resulted in different plans being needed for the Netherlands and the UK. Both plans are mutually incompatible, but tailored for national needs.

2.1 DESCRIPTION

Figure 1 shows the two plans taken from [1]. The bands marked as "U" are available for upstream transmission and "D" for downstream.

- Frequency plan B8-4 (enabling different variants) has been selected for the Netherlands, and allows the use of VDSL2 up to 12 MHz (see [1], signal description "VDSL2-NL1"). All so called "12x" and "8x" variants ('profiles") of VDSL2 comply with this plan. The "8x" variants make no use of the upstream band U2, but are allowed to emit some residual power in this band. Frequencies above 12 MHz are not available in this plan.
- Frequency plan B7-1 is another one, and has been selected within the United Kingdom (see [1], signal description "VDSL2-UK1"). Frequencies above 7.05 MHz are not available in this plan.

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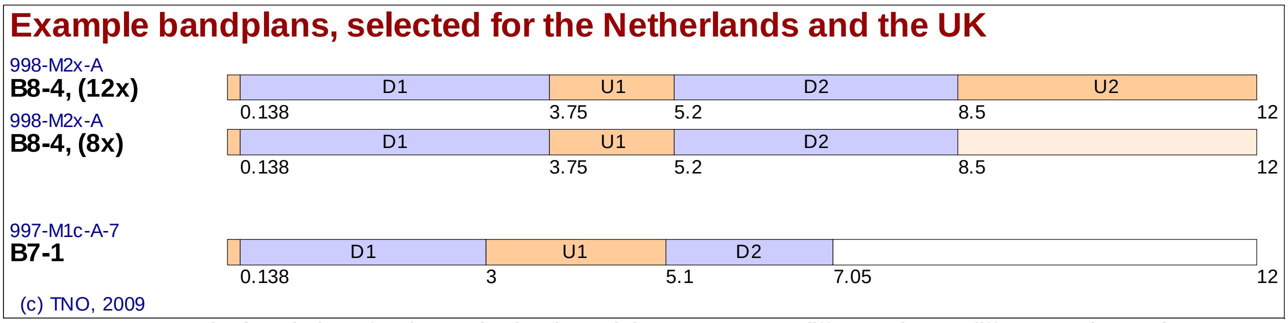


***Figure 1:**. The band plans for the Netherlands and the UK are very different due to differences in topology.*

It may be obvious from Figure 1 that if both plans are used concurrently in the same cable, the upstream and downstream bands overlap in frequency between 3 and 3.75 MHz. Both systems will interference with each other in these bands and none of them would be able to make efficient use of that overlapping band. Such an incompatible mixture should be avoided.

2.2 DIFFERENT ALLOCATIONS IN A FREQUENCY PLAN

Although the VDSL2 standard defines frequency plans up to 30 MHz, the use of frequencies above 12 MHz is prohibited in the Netherlands, and above 7.05 MHz is prohibited in the UK. Such a decision is highly related to the statistical distribution of copper distances between the remote location (from where VDSL2 is deployed) and customer premises. Roughly 90% of the customers in the Netherlands are located within 1000m from the cabinet, and 70% are even within 500m. The insertion loss of a 1000m loop can easily exceed 80 dB above 12 MHz, making higher frequencies useless for data transmission.

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.

Although higher frequencies can be used for customers connected via shorter loops, it is worth to consider not using them, and to reserve higher frequency bands for future use. Future DSL deployments from locations that are much closer to customers can use these frequencies in a far more efficient way. Examples are fiber-to-the-home scenarios where hundreds of Mb/s are transported over the last copper drop (20-200m, from curbs or basements) via an ultimate DSL technology [5]. Reserving higher frequency bands for these topologies is more efficient on the longer term than using them on the shorter term to serve only a few customers.

If a lower maximum frequency excludes the use of a second upstream band, then it may be inadequate for offering sufficient upstream bandwidth. Therefore the first upstream band in the UK plan is wider than in the Dutch plan, causing a shift of all demarcation frequencies. The consequence is a frequency incompatibility between the two plans, but this is no issue since they are used in different countries.

The above rationale illustrates why the most appropriate choice for a band plan is always country specific, and should not be copied blindly from a neighbouring country.

2.3 DIFFERENT PROFILES WITHIN A FREQUENCY PLAN

Although frequencies up to 12 MHz are allowed in the Netherlands, it does not mean that all VDSL2 implementations can use them. This depends on the *profile* that is selected/available.

A VDSL2 *profile* is a predefined set of implementation capabilities [3], which is partly characterized by the maximum power that the line driver can handle. If this maximum power is below a certain limit, the modem implementation will run out of capabilities and cannot fill the full band with signal power.

The VDSL2 standard has defined several of these profiles, and specific VDSL2 implementations may not support all possible profiles. Selecting a profile with lower output power can save energy or costs.

Table 1 summarizes the profiles that are meaningful within plan B8-4.

profile		*Maximum downstream power*	*Maximum upstream power*	*Use of legacy upstream band (US0)*
"8x"	*8a*	*17.5 dBm*	*14.5 dBm*	*supported*
	8b	*20.5 dBm*	*14.5 dBm*	*supported*
	8c	*11.5 dBm*	*14.5 dBm*	*supported*
	8d	*14.5 dBm*	*14.5 dBm*	*supported*
"12x"	*12a*	*14.5 dBm*	*14.5 dBm*	*supported*
	12b	*14.5 dBm*	*14.5 dBm*	*unused*

***Table 1.** Different profiles represent a different set of implementation capabilities, including the maximum power that can/will be transmitted*

3. SUMMARY OF STANDARD FREQUENCY PLANS

The previous section showed only two examples of frequency allocation plans, even though there are many other possibilities. This section summarizes all frequency allocation plans being identified by ITU standard G993.2. Fortunately, several of these plans are very similar: they differ mainly in the way they use the lowest frequencies (if VDSL2 needs to share the line with a POTS or an ISDN system or neither of them). There is a rationale behind all these different options, and the VDSL2 terminology below may make this rationale understandable:

- A *bandplan* is a list of frequency bands, reserved for transmitting signals. Bandplan "998" (ETSI calls it plan "E2") was the eighth plan evaluated in 1999 for offering asymmetrical bitrates (very high rates in downstream, and lower rates in upstream). Bandplan

"997" (ETSI calls it plan "E1") was the seventh plan evaluated in 1999 for offering a compromise between asymmetrical and symmetrical rates. Both plans are similar in that they enable VDSL2 to operate as an FDD system (Frequency Division Duplexing) meaning that up- and downstream signals are strictly separated in non-overlapping frequency bands.

- A *frequency allocation plan* is a subset of a bandplan, and lists all bands that are also allocated for transmitting signals. As such, a single bandplan may produce multiple frequency allocation plans.
- A *profile* is a list of implementation restrictions, such as maximum aggregate signal power, selected frequency allocation plan, the presence of certain bands, selected carrier spacing, etc. There is no need for a particular VDSL2 implementation to support all profiles, and this simplifies VDSL2 implementations significantly. Not all implementations can offer powers up to 20.5 dBm (as required for profile "8b") or can handle signals up to 30 MHz while the lowest upstream band (in the first few hundred kHz) are still in use.
- A *PSD mask* is a description of spectral signal levels that may not be exceeded by VDSL2 transmitters. Many masks can be found in [1].
- A *PSD template* is a description of the actual signal spectra, if their powers are lower then what fits beneath a PSD mask. Many templates can be found in [2]. As such multiple PSD templates may comply with the same PSD mask.

If you combine all limiting PSD masks and profiles to select a subset of one of the two bandplans, you will get a list of frequency allocation plans that may be overwhelming.
Note that the plans in Figures 2 to 4 do not cover all possible combinations. The plans identified in ITU standard G.993.2 only reflect a subset of all possibilities, based on those national needs that were raised during the meetings.

The naming convention in G.993.2 started as a combination of the originating bandplan and limiting PSD mask but various additions have weakened this convention. Currently, three groups of frequency allocation plans have been identified:

- Figure 2: Frequency allocation plans derived from bandplan “997” for region B (Europe).
- Figure 3: Frequency allocation plans derived from bandplan “998” for region A (North America).
- Figure 4: Frequency allocation plans derived from bandplan “998” for region B (Europe).

Note that multiple signal spectra can comply with the same frequency allocation plan, for instance when a transmitter runs out of power to fill all frequencies with spectra. This issue is beyond the scope of this paper.

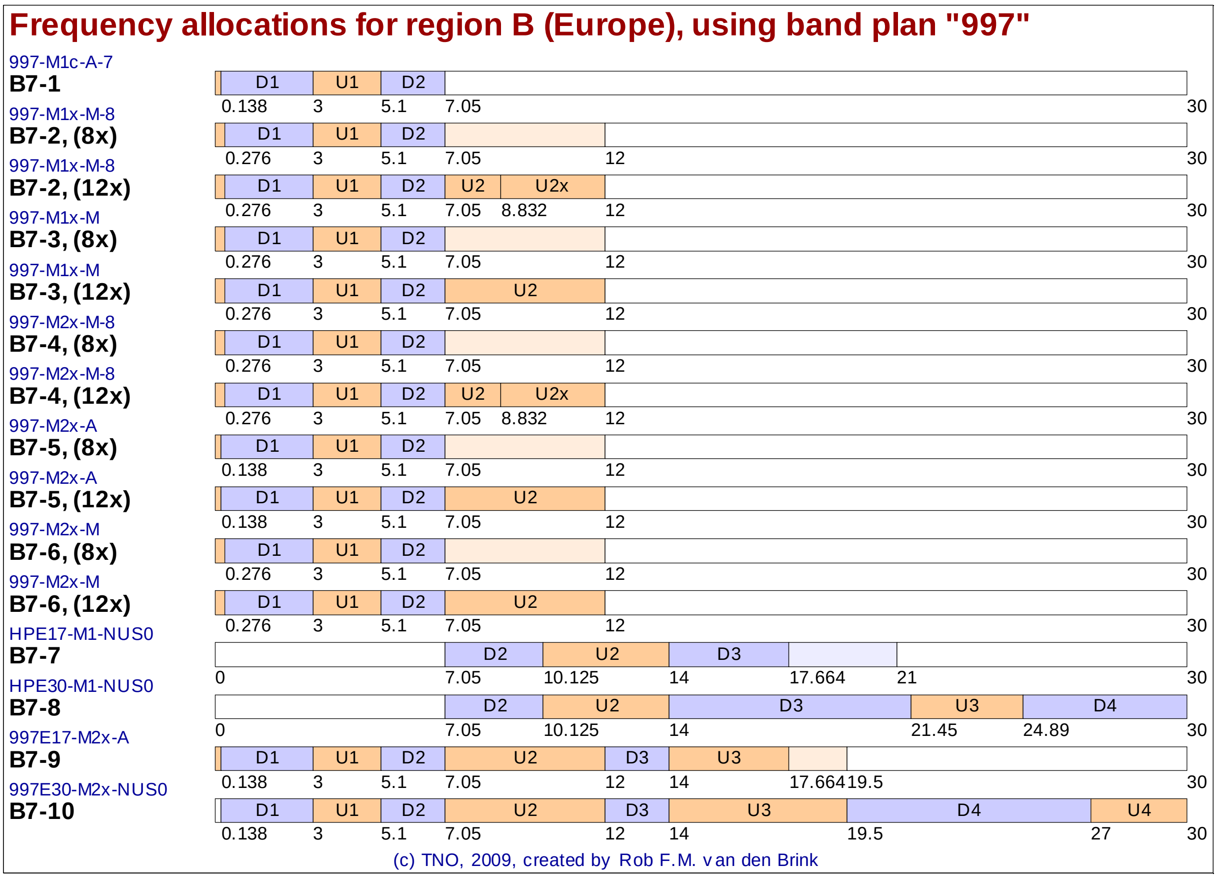


Figure 2: *Ten frequency allocation plans were identified for Europe, based on bandplan 997. If a VDSL2 modem operates in one of the “8x” profiles, the US2 band is not used at all, but may contain some residual power.*

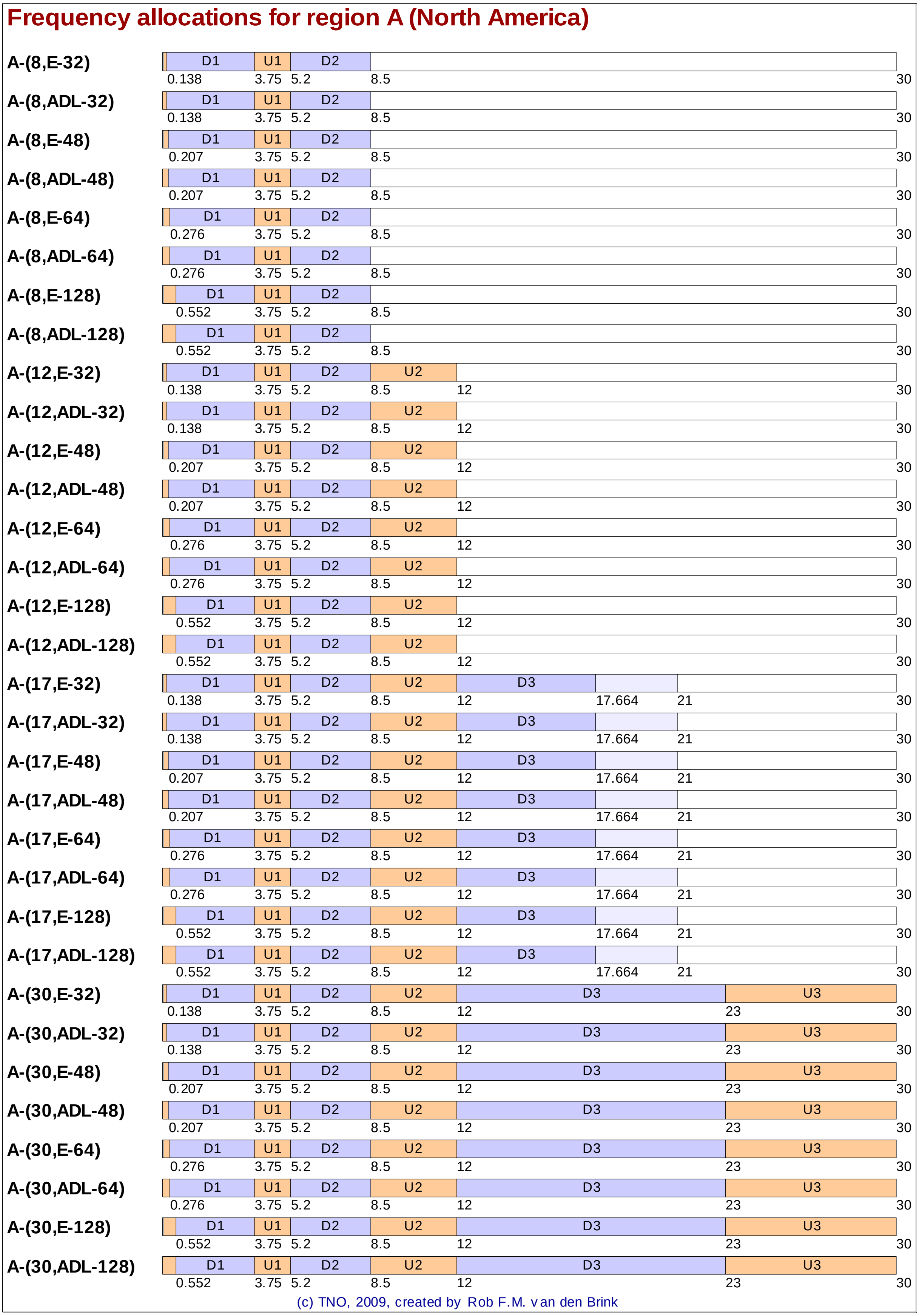


Figure 3: *Four groups of frequency allocation plans were identified for North America, all based on bandplan 998. The differences within a group are focused on differences in handling legacy upstream bands.*

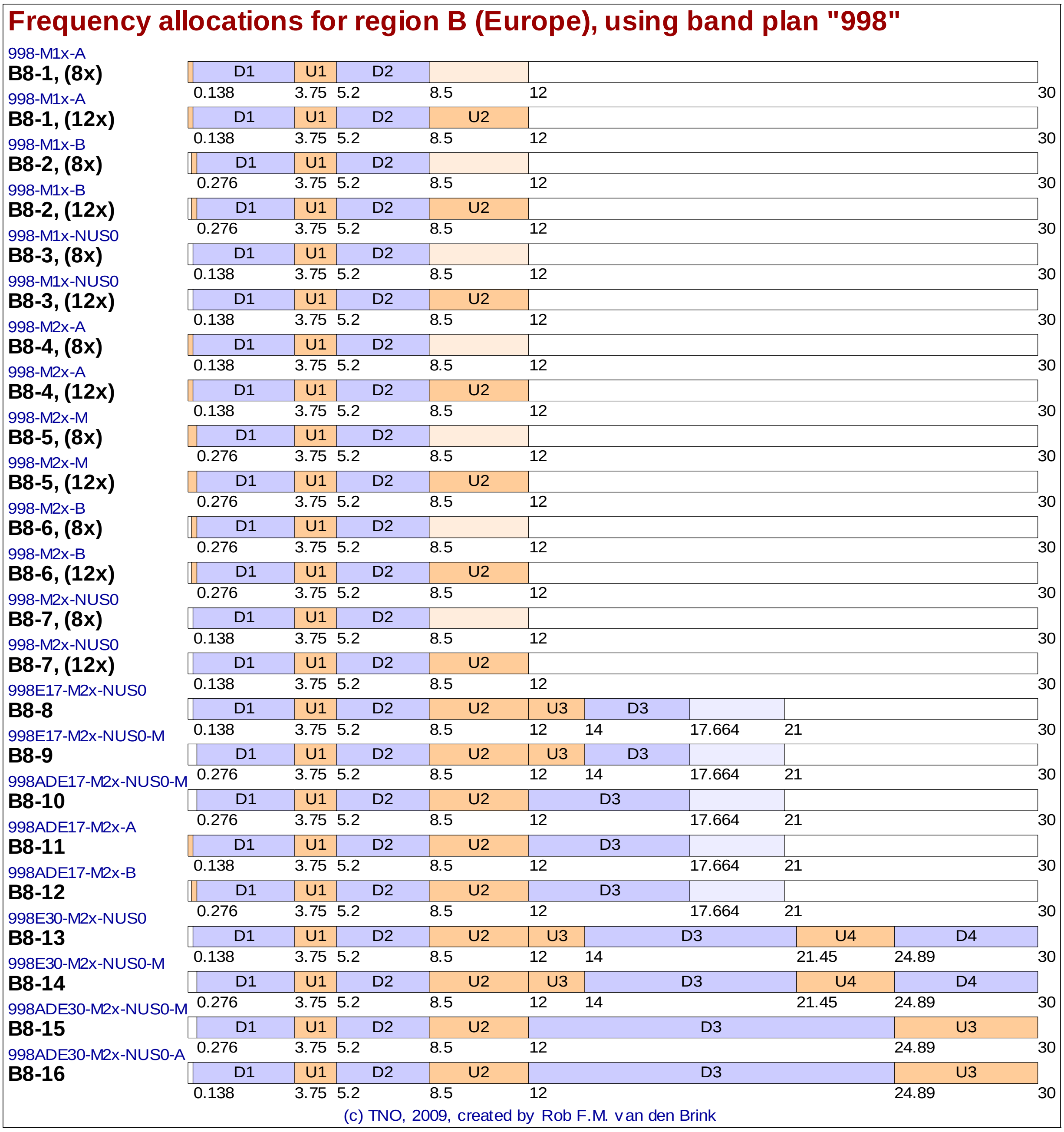


Figure 4: *Sixteen frequency allocation plans where identified for Europe, based on bandplan 998. If a VDSL2 modem operates in one of the "8x" profiles, then the US2 band is not used, but may contain some residual power*

4. GUIDANCE FOR SELECTING A SUITABLE BAND PLAN

If you have to select an appropriate band plan for a specific area, then the first question to answer is about the loop statistics of your network between the remote location (from where VDSL2 is to be deployed) and customer premises. As a rule of thumb, first calculate the maximum copper distance (from the deployment locations) that serves 90% of all customers, and use that value as a design target. Once this length is known, find the maximum usable frequency for this copper distance via your cables. This requires knowledge about the insertion loss and noise of the involved loops.

Next, reduce the number of possible band plans by excluding those that do not approximate this maximum usable frequency. For instance by restricting yourself to all 12, or 8.5 or 7.05 MHz plans. The tiny differences between the remaining ones are in bands up to 0.276 MHz. The need for VDSL2 to share the *same* wire pair with ISDN, with POTS or with no other system will exclude more band plans.

Now check if the ratio between upstream and downstream bitrates will meet your primary service demands. This requires a DSL performance simulator (e.g. SPOCS [4]) to evaluate bitrates for meaningful scenarios. The bitrates generated by a service can be very asymmetric in nature, (e.g. broadcast video), or very symmetric in nature (e.g. video conferencing). If symmetric rates are preferred over asymmetric rates in the business model (or the other way round), then some of the remaining band plans will be excluded

By using these suggestions as guidelines, it should be possible to identify a suitable band plan for your copper network. In theory, every loop provider can design its own band plan, since the presence of so many options in a "standard" may raise the question of why restrictions should be in place. Particular VDSL2 modems may be capable of supporting non-standard band plans as well, but using that makes you dependent on proprietary extensions to this "standard".

The choice of a suitable profile is less critical, since they might be all allowed from a pure spectral management point of view. This may not hold from a deployment point of view, where investment costs, power consumption and capabilities of a particular modem also play a role.

5. SUMMARY

VDSL2 is a new DSL modem technology to deliver third generation broadband services (3GBB) via existing telephony wiring. It is essential that all VDSL2 systems in a cable use the same frequency allocation plan, so that they can efficiently use available copper resources and can coexist with legacy DSL systems.

Such a plan used to be country or region specific, for serving local needs. In theory, it could even be cable specific but this might be too inconvenient in practice. What should be chosen is highly dependent on business needs, expectations for future use, on geographic statistics (what copper distance serves 90% of the customers?) and loop characteristics (loss and crosstalk). Therefore it is not recommended to merely pick a plan that is used in another country. The VDSL2 standard offers many plans from which a suitable choice can be made.

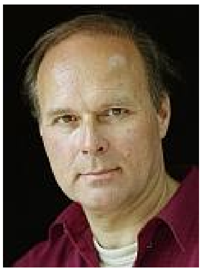
6. REFERENCES

[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] Ödling, Magesacher, Höst, Börjesson, Berg, Areizaga, "*The Fourth Generation Broadband Concept*", IEEE Communications Magazine, January 2009, p63-69
[6] 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:

[7] 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)
[8] Rob F.M. van den Brink, "*The art of Spectral Management; Access rules for VDSL2*"; TNO 35091, white paper on DSL, oct 2009.
[9] Rob F.M. van den Brink, "*The art of Spectral Management; Frequency allocations for VDSL2*"; TNO 35092, White paper on DSL, oct 2009.
[10] 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.
[11] 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 Tes 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).