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CONTRIBUTION

TITLE: **DSM Upstream Data Rate Revival: the Restoration of Symmetry**

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ABSTRACT

This contribution explains that Level 3 DSM use in bundled or unbundled environments essentially restores symmetry to what were once perceived as asymmetric DSLs (ADSL or VDSL). Unused spectra and/or lines often sense crosstalk and allow the spatial cancellation capabilities of Level 3 DSM line cards to mitigate correlated crosstalk in active spectra on used lines. Each of a binder's service providers, independently within their own vectored group of lines, have an upstream user-rate-arbitration (and consequently energy/bit) allocation decision within the existing regional band plan. Effective use of Level 3 can restore upstream data rates to the level of downstream best rates without change of the band plans commonly in use today.

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DSM Upstream Data Rate Revival: the Restoration of Symmetry

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ABSTRACT

This contribution explains that Level 3 DSM use in bundled or unbundled environments essentially restores symmetry to what were once perceived as asymmetric DSLs (ADSL or VDSL). Unused spectra and/or lines often sense crosstalk and allow the spatial cancellation capabilities of Level 3 DSM line cards to mitigate correlated crosstalk in active spectra on used lines. Each of a binder's service providers, independently within their own vectored group of lines, have an upstream user-rate-arbitration (and consequently energy/bit) allocation decision within the existing regional band plan. Effective use of Level 3 can restore upstream data rates to the level of downstream best rates without change of the band plans commonly in use today.

1. Introduction

Recent history in DSL standardization has often visited frequency band plans to a level of frustrated consternation between the interests of asymmetric and symmetric data transmission. Eventually derived frequency plans for service mixture often favor downstream data rates. DSM at all levels can assist in improving upstream data rates, thus effectively restoring symmetric transmission. This contribution in particular investigates Level 3 vectored use in unbundled or "asymmetric/symmetric" mixed environments and shows that upstream data rates can essentially be revived and DSL symmetry restored through the migration to Level 3 vectored DSL. Such migration will require each service provider to consider the relative symmetries of its customers' data rates relative to the crosstalk received from another uncoordinated service provider who similarly considers its own customers' data rates.

A currently common misunderstanding is that level 3 DSM requires the Spectrum Maintenance Center (SMC, see [1]) to control all lines in the binder. The correct understanding is that a service provider's SMC coordinates far-end-crosstalk (FEXT) cancellation for all or some subset of its lines only and need not have access to all lines in the binder. Such self-line coordination if there are enough lines can significantly decrease the effect of crosstalk from other uncoordinated service providers' lines. Section 2 illustrates the cancellation of these other noises with some simple examples, illustrating some trade-offs in use/disuse of various lines and the selected spectra thereupon. Section 3 illustrates some more complete results for binders of lines, and discovers an interesting trade-off for a service provider that the potential achievable data rates have a superlinear increase with the number of vectored upstream terminations, suggesting that unused lines have good value to any service provider in the reduction of noise on the used lines. Such a use of otherwise dormant lines introduces interesting economic derivative problems into the leasing/use of binder lines – "Should I lease or use the other `unused' lines?" Section 3 continues by observing that it is actually Level 2 optimal spectrum balancing that is least compatible with unbundling, although some level of it through polite band-preference methods can improve upon simple polite Level 1 iterative water-filling approaches. As well Section 3 finds that portending large phantom noises is hostile to unbundling and DSL interests in general, suggesting Level 3 systems as a much more promising solution in competitive (or single-service provider) situations than contriving such phantom noise.

Some DSM-capability in vendor interfaces is discussed in Section 4, where it is specifically noted that FEXT cancellation cannot be easily nor fairly decided by vendor equipment. Thus, the interfaces to the service provider's SMC are very useful and allow the service provider to make service/rate decisions, while the vendor traditionally and most prudently supports such decisions with the standardized interface[1].

2. Cancellation of the "other" noise outside the vector group

Perhaps the simplest example of noise cancellation appears in Figure 1 with only two telephone lines for illustrative purposes.

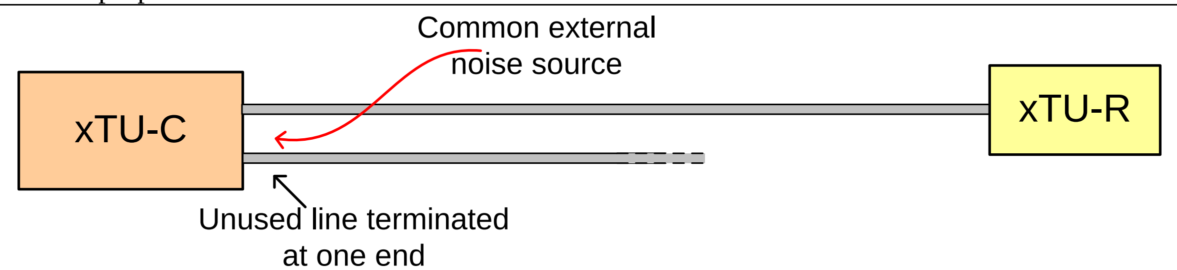


Figure 1: External noise cancellation using unused lines in the network. (A similardownstream configuration is also possible.)

One line is terminated at both ends and actively in service. The other line is terminated only at one end and used by the receiver at that end to cancel noise. Any single common external noise (for instance an AM radio station) that impinges upon both lines can be cancelled by the adaptive canceller in the

[1] Indeed, allowing vendor equipment to make such service provisioning trade-offs would indeed violate the letter and intent of service competition as well as nullify any single service providers ability to up-sell/down-sell customer rates and quality of service.

receiver. This canceller senses the second "unused" line with only the external noise and then filters and subtracts any common part of the external noise from the second line. The correlation between the noise on the two lines is important and is often called the spatial noise correlation, measured by $0 \le \rho \le 1$. No correlation ($\rho = 0$) means no cancellation is possible. Perfect correlation ($\rho = 1$) means the noise can be completely removed from the DSL service.

AM radio noises have high spatial correlation. Indeed, different radio stations at different frequencies can all be cancelled by using a single second line. However, two radio stations (say from two equally distant radio towers) at the same frequency would have some intermediate level of correlation and would only be partially cancelled at that frequency. In this latter case, $\rho < 1$. Now suppose there is only one noise source that may not necessarily be AM radio noise and may exist at several frequencies. Since the second line is not used, this single noise impinging on both lines has high spatial correlation and can be removed at the receiver from the DSL line, thus increasing data rate. This common external noise could indeed be a single 3rd line (not shown) that is producing FEXT (or any type of crosstalk). That noise could also be removed, which is a basic concept in FEXT cancellation at a receiver. Indeed a single impulse noise source could also be canceled if the proper canceller coefficients (with phase) can be determined.

Progressing to Figure 2, if the second line contains a DSL signal also, then it has a data rate that is affected and reduced by the noise. However, after a correct decision by the receiver for the second line, the error signal of Figure 2 contains only the noise and again it can be cancelled as in Figure 1. Indeed, one could reverse lines 1 and 2 and easily see that there is a trade-off in data rate between the two lines in terms of "who goes first." This simple concept of order and cancellation pervades vectored DSL with multiple lines. The service provider's SMC needs to decide which line deserves the benefit within this vectored group of its two lines.

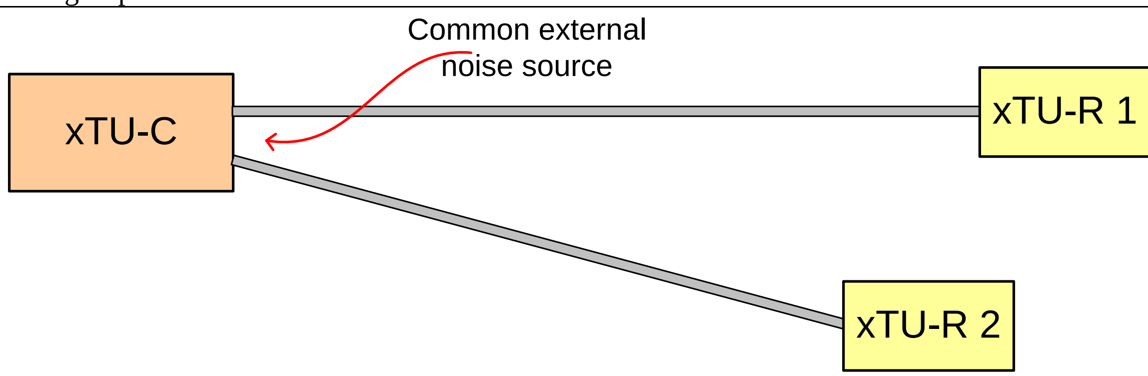


Figure 2: Two active DSL lines observing the same noise source. With coordinated reception, the noise correlation can be exploited. The service provider SMC can decide the order of decoding for the two lines based on the data rate required for each line and the channel conditions.

Let us suppose now in Figure 3 that the second line is asymmetric or does not use its full bandwidth in either direction. At unused frequencies on the second line, the situation returns to that of Figure 1. Thus, there is a spectral trade-off that essentially is a manifestation of the data rate trade-off for noises that are not generated by either line (but which impinge upon both). This trade-off is different from any trade-off between lines for mutual crosstalk between the two, for which Ginis has shown in [2] that both lines then can operate as if there is no crosstalk from the other. This first trade-off is very important in unbundled situations where the noises can come from the lines of another service provider.

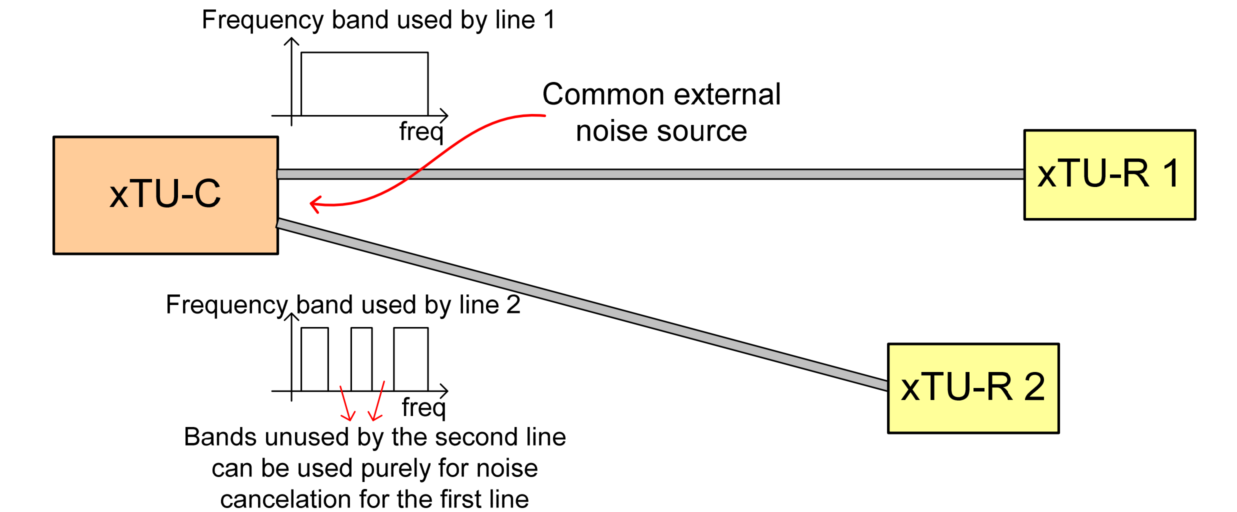


Figure 3: In the unused frequency bands for line 2, pure noise cancellation for line 1 is possible. In the remaining bands, the SMC can again choose a decoding order among the 2 lines and also exploit the noise correlation.

The situation of Figure 1 can be generalized to 3 lines with 2 unused where up to two independent noise sources can be cancelled at each and every frequency from the first used line. Or, one noise source can be cancelled from both of two used lines. The straightforward generalization is that the more unused lines, or unused spectra, terminated by the receiver, the better its ability to reject any common noise sources impinging upon its own vectored set. In particular, the crosstalk from many other service providers' lines could be reduced if the first service provider uses enough spare lines. As in Figure 3, the first service provider could also decide to use spectra on those lines for lower rate services and save some spectra for crosstalk cancellation. The trade-off in rates between any one service providers' lines then enters a domain of optimization theory that is well understood as the "vector multiple-access channel" by transmission experts for which minimum radiated power optimal solutions are known [3] for any achievable set of data rates, binder situation, and uncontrolled "out-of-domain" noise.

3. Vectored Exploitation of the Multiple Lines and Service Providers

A vectored receiver can exist across any one service provider's lines . Each or any service provider can independently decide to use such vectoring. There many lines can be terminated upstream and all used for either DSL transmission, crosstalk reference reception, or both. The level of spatial correlation of noises external to the group will increase with the number of lines (or essentially with the number of lines with unused spectra at any frequency or tone). Thus, an aggressive service provider would want to terminate as many lines upstream as possible even if not all are used[2]. This section provides some earlier performance projections that illustrates the data rate gains.

Throughout this section, plots will use a correlation coefficient ρ that the reader can translate as "1 means lots of extra lines or a very small number of noise sources" and "0 means no extra lines or unused spectra or a very large number of noise sources."

[2] The same effect can be used downstream if a downstream receiver terminates many lines, even if all but one of them are not connected to anything on the other "central office" side of the line.

3.1 100 Mbps Symmetric DSLs

The 100 Mbps symmetric FTTC configuration suggested in [4] is repeated here. The noise model consists of -130 dBm/Hz ambient noise + 12 self FEXT.

Table 1 - Desired Rate/Reach Per Configuration from [3] for 24 AWG		
Configuration	DS/US Rate (mbps)	Reach (ft)
Configuration 1	100/100	500

In the simulations, 1% worst-case crosstalk models from [5] are used with some linear-phase assumptions that will not change achievable data rates (although phase characteristic will change specific details of vectored line-terminal realization). Both options of the 7-band plan [6] were considered and are listed here:

Table 2 – Band Plans used in Simulations				
# of bands	Option Number	f2 (MHz)	f3 (MHz)	f4 (MHz)
7	1	17	25	--
	2	16	26	--

For all plots in this contribution:
gap-coding gain+margin=9.5-4.5+6=12dB
bit cap = 15
PSD mask, flat at -60dBm/Hz
line type, 24 AWG

Figures 4a,b list the data rate versus reach results for the 7-band plan. Values of ρ appear in the plots.

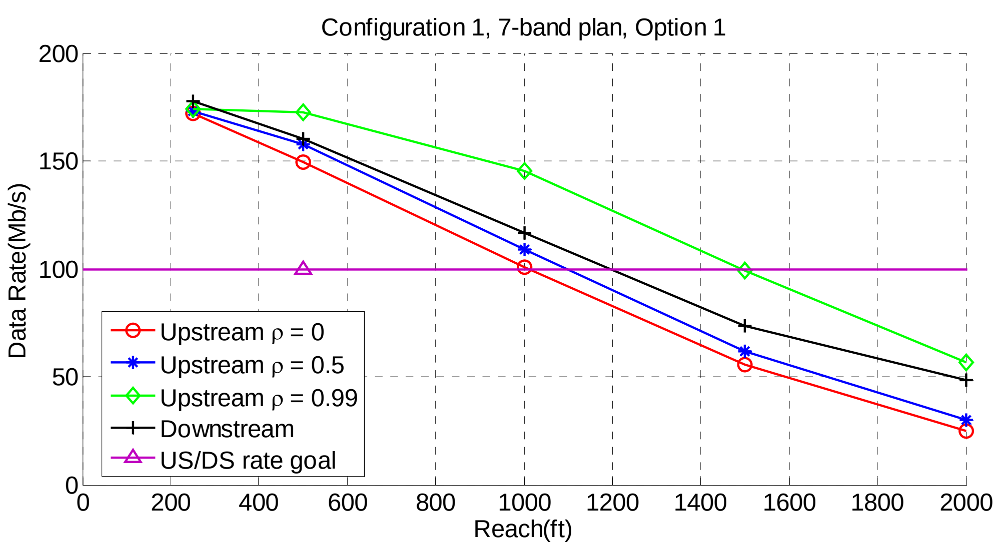


Figure 4(a) – 7 Band Plan: option 1, configuration 1

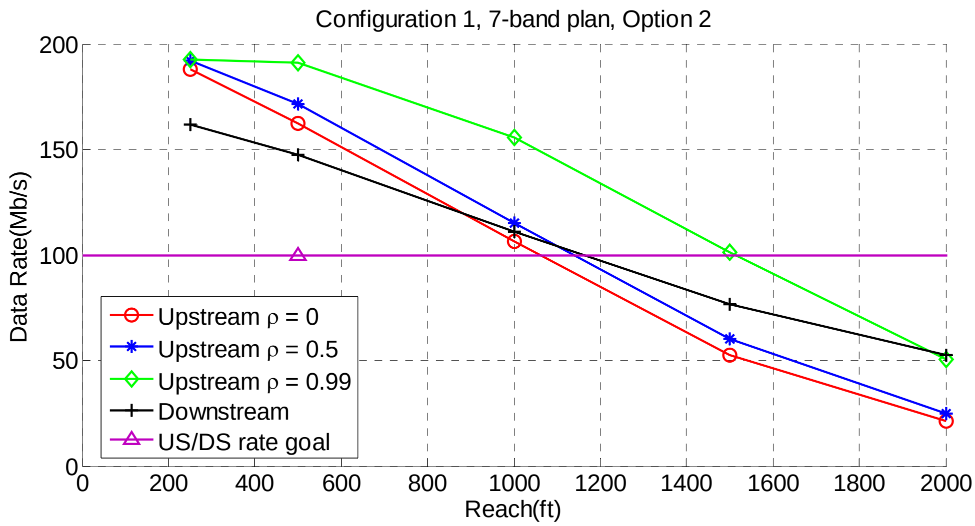
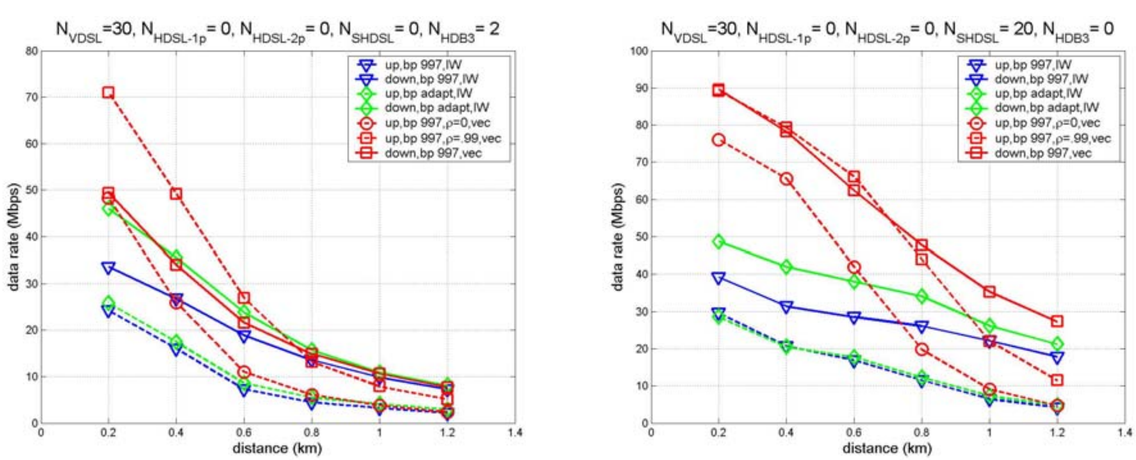


Figure 4(b) – 7 Band Plan: option 2, configuration 1

The data rates achieved with vectoring in Figures 4(a) and 4(b) are almost symmetric with the 7-band plan for both options, even for $\rho=0$. Higher value of ρ are more realistic and lead to even higher upstream data rates, essentially restoring symmetry to the group with no loss in downstream capability.

3.2 A highly competitive environment with mixture of vectoring and non vectoring

Figure 5(a) illustrates a situation in Germany with a very high-power crosstalker from what is known as an HDB3. Standard VDSL [7] with the 997 bandplan was used and both upstream and downstream data rates appear for all lines of the same length with and without differential vectoring (the upper red curves use vectoring). This European example illustrates that either 997 or 998 band plans lead to restoration of symmetry, or more generally the larger allocation of bandwidth to downstream was perhaps accidentally fortuitous in both plans when vectoring is now considered. A correlation coefficient for upstream spatial noise correlation is listed with 0 meaning no correlation and 1 meaning largest spatial correlation physically possible on the HDB3 noise. The latter is the realistic value because there are only 2 HDB3 sources (and 30 vectored lines). Figure 5(b) also appears for the case of the more modern but equally invasive SHDSL crosstalk, where spatial correlation could be expected to be intermediate to 0 and 1.



(a) (b)

Figure 5: Illustration of (a) HDB3 crosstalk and of (b) SHDSL crosstalk for .4mm lines.

Again, the rates are almost symmetric with the 997 bandplan.

3.3 A motivational paradox for service providers

Clearly, there is an advantage to any service provider to vector more lines than a competitor, even if not all those lines are used for DSL service. The larger the nmber of vectored lines, the larger the spatial correlation and the higher the data rates. This trade-off has certainly existed in unbundling without vectoring, but is now magnified with unbundling because more lines means less noise and thus higher data rates on the used customer lines. When all lines are used, then there is a spectrum trade-off as in the example of Figures 2 and 3 for the use of spectra on any line. The astute reader may recognize this is not a water-filling problem any longer, nor even close to it (nor is it an optimal Level-2-DSM spectrum balancing problem either). This spectral allocation problem however does have known solutions in information theory [3]. A competitive service provider would also want to lease as many lines as possible, particularly if symmetric service were desirable. The incumbent service provider may well want to lease those lines to the competitor if the dormant capacity is not of use. Interestingly enough, from a technical raw bandwidth standpoint, which ever service provider leases or reserves the most lines first would have a long-term advantage, particularly for upstream (or effectively symmetric) transmission.

4. Vector DSM Capability

An SMC for any single service provider needs to observe crosstalk transfers and measured noises. The information is contained with those parameters already listed in the DSM Report [1] at Levels 3 (and at lower levels). In particular, the XLog[n] and Xlin[n] parameters are important as are the QLN[n] and SNR[n], and of course the various PSD levels, margins, framing parameters and data rates. For determination of spectra and bit distributions, only the XLog[n] is necessary at the SMC. The SMC can periodically (sharing complexity over many lines) determine cancellation order and basic bits/gains tables and local swapping algorithms can maintain changes thereafter (or alarm the SMC to redo if margins drop below a threshold). The exact level and trade-off of complexity remains to be determined but is fundamental to a service provider's decision on rate allocation and thus ultimately their service profitability and thus is best not determined within acquired equipment.

Additionally, to determine actual canceller coefficients and significance for FEXT cancellation, Xlin(n) is necessary. Since cancellation of all possible crosstalk requires excessive memory and computation and the assessment depends also on service providers' DSL rate and quality-of-service decisions, the initialization of cancellers is much more efficiently computed by an SMC where computation cycles and memory (as well as disk storage of line history) can be shared across a large number of active customers. Additional parameters may enter into Level 3 DSM capability and vectored VDSL G.ploam addendums to specify such initial canceller coefficients. The authors are aware of such proprietary systems already in progress to provide such coefficients, and these might best be standardized if there is sufficient motivated and legitimate interest by the group (this contribution is information only).

5. Conclusions

Level 3 DSM essentially enables and restores high-speed symmetric (upstream) DSL to co-exist compatibly in bundled or unbundled environments. The service provider's SMC is fundamental to the efficiency of such systems and to the eventual allocation of binder bandwidth among the lines controlled by any service provider. Coordination between service providers is not necessary. All may be additionally motivated to use as many lines as possible to offer best service trade-offs among their customers. Symmetric speeds become feasible and prudent with existing band plans and allow an interesting additional opportunity for DSL services in the future with vectoring.

6. References

[1] DSM (Draft) Technical Report, *ATIS NIPP-NAI Contribution 2006-028R2,* June 2006, Savannah, GA.

[2] G. Ginis and J. M. Cioffi, "Vectored Transmission for Digital Subscriber Line Systems," IEEE Journal of Selected Areas in Communications, vol. 20, no.5, pp 305-309, 2002.

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[4] G. Sherrill, K. Sievert, and D. Veeneman, "Proposal for 30 MHz VDSL2 Band Plan Requirements,"ANSI contribution NIP-NAI-2006-023, January 18-19, 2006, Dana Point, CA.

[5] DSM Draft Report, ANSI NIPP-NAI Contribution 2005-031R5, October 2005, Las Vegas, NV.

[6] "VDSL2 Profile 30a service configurations and band plan proposal ," Redouane Zidane, NIP-NAI-2005-184R1, October 24, 2005, Las Vegas, NV.

[7] ITU-T Rec. G.993.2 Very high speed digital subscriber line 2, February 2006, Geneva.

[8] J. Cioffi, S. Jagannathan, G. Ginis, and M. Brady, "DSM is for Unbundled Networks," ANSI Contribution NIPP-NAI-2006-087.