Report on Dynamic Spectrum Management (DSM) Methods in the UK Access Network

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Foreword

This document has been produced by the NICC Working Group on Digital Subscriber Lines (DSL) as a report on its study of the use of Dynamic Spectrum Management techniques in the UK DSL access network. The Working Group commenced this study in the second half of 2008 and completed it in October 2009.[1]

Executive Summary

This document reports on benefits of using Dynamic Line Management employing Dynamic Spectrum Management Level 1/Dynamic Line Management (DSM Level 1/DLM) techniques and systems in the context of the UK Access Network.

DSM level1/DLM can benefit all UK DSL stakeholders. Commercial deployments using Level 1 DSM in other countries and the UK have seen increases in the DSL Footprint[2] of DSL data rates while simultaneously effecting reductions in DSL service-provider operational expenditure. An increase in "DSL footprint" allows a greater number of DSL customers to be served at higher speeds, enhancing revenue opportunities by increasing the number of customers who can reliably receive triple-play services, single- and multi-channel video services, higher quality VoIP connection, and more customers for basic high-speed internet access. Operational expenditure reduction is evident in DSM Level 1/DLM induced improvement in line stability, often resulting in fewer end-user calls to service provider operations centres, a reduction in customer visits, and generally speaking "happier customers" who are less likely to cease their service. These types of improvements accruing to DSM/DLM use could result in a significant benefit for DSL services in the UK.

By contrast the potential exists that improper or careless use of some of these dynamic DSL management techniques by one or more of the network operators sharing the access cable plant may negatively affect other users of that plant resulting in reductions in bandwidth for a given level of DSL link stability. One of the purposes of this report is to help scope such potentially negative interactions, and to provide guidance to ensure that DSM techniques when used by DSL operators sharing the UK access network produce a benefit for all operators and for the DSL subscribers served over this network.

The NICC DSL Working Group (DSL WG) analysed some key DSM Level 1 techniques between September 2008 and June 2009. The DSL Working Group identified two specific DSM techniques of immediate interest to UK DSL operators, TRA (Tiered Rate Adaptation), AMA (Automatic Margin Adaptation), and in addition the management tool of VN (Virtual Noise). The Working Group performed the following activities to develop this report:

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[1] This document includes reference to and extracts from Technical Reports published by the Broadband Forum (at http://www.broadband-forum.org). The NICC DSL Working Group wishes to acknowledge and express its appreciation to the Broadband Forum for permission to include these references and extracts.

[2] The DSL Footprint is the geographic area around an exchange within which a particular DSL service type is viable.

1) Agreed to criteria for modelling the effects of these DSM techniques and solicited and received input on the performance of certain of the techniques from members of the Working Group.

2) Commissioned interested NICC participants to perform the specified simulations.

3) Analysed the results of the simulations and any field data provided.

4) Agreed to a series of conclusions based on the analysis.

The following summarises these conclusions developed by the DSL Working Group as a result of these initial efforts:

1) DLM or DSM Level 1 is undoubtedly a useful capability for UK DSL network operators.

2) The use of the TRA approach should be considered for any DSM Level 1/DLM deployment because of its potential to lower the impact of crosstalk as well as improving overall performance (speed versus stability versus transmit power trade-off) compared with AMA. AMA was evaluated with or without the use of VN, while TRA was evaluated only without VN. Improved politeness[3] and consequential reduction in transmit power and crosstalk levels may bring benefits to UK DSL operators and their end-users.

3) Techniques such as DSM, AL-FEC (Application Layer – Forward Error Correction) and re-transmission continue to develop and DSL service providers should consider DSM Level 1/DLM as one technique within a "toolbox" of techniques available to improve DSL transmission performance and stability.

4) Care must be used in setting the level of VN if used on a DSL Line to avoid using unnecessarily high transmit powers and consequential excessive crosstalk that is detrimental to other DSL lines in the same cable and possible excessive power consumption by the modem.

5) Use of DSL modems that fully implement the standard EXTGI and bit-swap capabilities of ADSL2/2plus and VDSL2 will enhance the performance of DSL services and the utility of DSM or DLM Level 1 techniques. NICC Member companies should be encouraged to make input into bodies such as the Broadband Forum and the ITU-T Study Group 15 Question 4 to help define test(s) for these features to help ensure a high level of vendor compliance.

6) Simulation has shown that TRA has the potential to reduce the average power consumption of an individual DSL Line, and hence can contribute to an overall reduction in network energy consumption. However, this is one particular aspect of the analysis that merits deeper investigation using experimental techniques on real equipment in order to better quantify these potential benefits. In particular, the extent to which the peak and average power consumption can be reduced whilst maintaining QoE and the necessary immunity to extrinsic noise warrants further study. This would be a useful area in which the NICC could encourage further investigative work on how the comprehensive toolkit of DLM techniques is best integrated by network providers.

7) At the time of publication DSM Level 2 and 3 techniques are at early stages of implementation and analysis of their benefits in the UK access network is left for further study.

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3 'Politeness' means that a DSL line has been configured to minimise the crosstalk radiated into other services in the Cable/Binder consistent with it meeting the service requirements (rate, reach, stability, delay, etc.) placed on that particular line by the Network Operator. A 'polite' line is one where the line behaves with decorum with respect to other services in the cable/binder by avoiding radiating unnecessarily into other DSL services sharing the same cable.

1 Scope

The present document has a scope that is restricted to the use of DSM (including DLM) with xDSL systems that are designed to international standards on the UK access network, when configured and operated to comply with the currently (i.e. at the date of publication of this document) defined BT ANFP (Access Network Frequency Plan) [1] and KCH ANFP [2].

This document is predominantly focussed on the use of DSM Level 1/DLM techniques in the UK Access Network as these are currently being deployed by Network Operators in the UK. However, issues related to effect of deployment of DSM Level 1 techniques on future use of DSM Level 2 and Level 3 methods in the access network are covered in this report. Future work in the NICC DSL Working Group may examine use of DSM Level 2 and Level 3 in more detail. It is recognised that DSM/DLM and xDSL technology and their related international standards continue to be developed. Equally, there may be further discussion in the NICC DSL Working Group on potential amendments to this Report. This document may be updated to take account of new, internationally standardised DSM approaches and/or xDSL systems and the emergence of these techniques in the UK Access Network.

2 References

The following referenced documents are indispensable for the interpretation of this document. For dated references, only the edition cited applies. For non-specific references, the latest edition of the referenced document (including any amendments) applies.

[1] *Specification of the Access Network Frequency Plan applicable to transmission systems used on the BT Access Network,* Issue 3*;* NICC; ND1602:2005/08, August 2005

[2] *Specification of the Access Network Frequency Plan applicable to transmission systems used on the KCH Access Network, Issue 2;* NICC; ND1604:2006/09, September 2006

[3] *Dynamic Spectrum Management Technical Report*, ATIS Committee NIPP ATIS-0600007, May 2007,

[4] *Guidelines on DSL Power-Saving Modes and Nonstationary Noise in Metallic Access Networks*; NICC; ND 1424:2008/02, February 2008 "

[5] *Triple-Play Services Quality of Experience (QoE) Requirements;* Broadband Forum TR-126, December 2006

[6] *Code of Conduct on Energy Consumption of Broadband Equipment - Version 3*; EUROPEAN COMMISSION DIRECTORATE-GENERAL JOINT RESEARCH CENTRE, 18 November 2008, Ispra Italy

[7] http://www.broadband-forum.org/technical/technicalwip.php; Broadband Forum Website, December 2009

[8] *Physical layer management for digital subscriber line (DSL) transceivers;* ITU-T, Recommendation G.997.1, April 2009

[9] *xDSL EMS to NMS Functional Interface Requirements ADSL2plus Configuration Guidelines for IPTV*; Broadband Forum, Technical Report 176 (TR-176), September 2008

[10] *Very high speed digital subscriber line transceivers 2 (VDSL2)*; ITU-T, Recommendation G.993.2, April 2009

[11] *Network performance objectives for IP-based services;* ITU-T, Recommendation Y.1541, February 2006

[12] *Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements*; ETSI, TS 101 270-1 V1.2.1, October 1999

[13] *Asymmetric digital subscriber line transceivers 2 (ADSL2)*; ITU-T, Recommendation G.992.3, April 2009

[14] *Asymmetric digital subscriber line (ADSL) transceivers - Extended bandwidth ADSL2 (ADSL2plus);* ITU-T, Recommendation G.992.5, January 2009

[15] *http://www.culture.gov.uk/what_we_do/broadcasting/6216.aspx;* The Department for Culture, Media, and Sport website, June 2009

3 Abbreviations

3.1 Abbreviations and Acronyms

For the purposes of the present document, the following abbreviations and acronyms apply:

Abbreviation	*Explanation*
ADSL	Asymmetric Digital Subscriber Line
ADSL2	Asymmetric Digital Subscriber Line Issue 2
ADSL2plus	Asymmetric Digital Subscriber Line Issue 2 plus
AL-FEC	Application Layer FEC
AMA	Automatic Margin Adaptation
AN	Access Node
ANFP	Access Network Frequency Plan
ATIS	Alliance for Telecommunications Industry Solutions
BERR	Business Enterprise Regulatory Reform
CP	Communication Provider
DLM	Dynamic Line Management
DMT	Digital Multi-tone
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSM	Dynamic Spectrum Management
DSM L1	DSM Level 1
EXTGI	Extended Gain (a G.997.1 parameter)
FEC	Forward Error Correction
FEXT	Far End Crosstalk
FTTC	Fibre to the Cabinet (or Curb in non-UK context)
HDTV	High Definition TV
INP	Impulse Noise Protection
IP	Internet Protocol
IPR	Intellectual Property Rights
IPTV	Internet Protocol Television
ITU-T	International Telecommunications Union, Telecommunication Standardization Sector
MAXNOMPSD	Maximum Nominal Power Spectral Density
MAXSNRM	Maximum Signal-to-Noise Ratio Margin

MIB	Management Information Base
MIMO	Multiple-input Multiple-output
MINSNRM	Minimum Signal-to-Noise Ratio Margin
MSAN	Multi-Service Access Node
NEXT	Near End Crosstalk
NGA	Next Generation Access
NOMPSD	Nominal Power Spectral Density
OLR	Online Reconfiguration
OSS	Operations Support System
PHY	Physical Layer
PLR	Packet Loss Ratio
QoE	Quality of Experience
SDTV	Standard Definition TV
SMC	Spectrum Management Centre
SNR	Signal-to-Noise Ratio
SRA	Seamless Rate Adaptation
TRA	Tiered Rate Adaptation
TSNRM	Target Signal-to-Noise Ratio Margin
VDSL2	Very High Speed Digital Subscriber Line Issue 2
VN	Virtual Noise
VoIP	Voice Over IP
xDSL	Any unspecified DSL technology

4   Introduction

Today the UK ANFP [1, 2] uses advanced Static Spectrum Management with fixed spectral masks (some as a function of loop length or category), to ensure that lines in the same cable are spectrally compatible under worst-case crosstalk assumptions. A class of techniques including Dynamic Spectrum Management (DSM), Dynamic Line Management (DLM) and Virtual Noise (VN) can be used with different algorithmic approaches (such as AMA, Automatic Margin Adaptation and TRA, Tiered Rate Adaptation) to increase DSL service stability and speed by adapting ANFP compliant DSL configurations to the actual time-variable noise on the line. However, the way in which these technologies and associated algorithms are deployed can affect the dynamics of the noise environment for all service providers' DSL lines within a cable. These interactions with the specific effects of particular DSM techniques and configurations can have implications for line stability (e.g. transmission errors, re-trains), total network capacity, individual line speeds and network power consumption. The standards bodies' work on these technologies has now matured and commercial products are available. Hence it is prudent for the NICC DSL Working Group to examine these dynamic techniques and to assess their suitability for use in the UK metallic access network produce recommendations.

DSM (or DLM) can significantly benefit all UK DSL stakeholders. Commercial deployments using Level 1 DSM/DLM in the UK and other countries and the UK have brought increases in the qualification range of

DSL data rates while simultaneously effecting reductions in DSL service-provider operational expenditure. An increase in "DSL footprint" allows a greater number of DSL customers to be served at higher speeds, enhancing revenue opportunities by increasing the number of customers who can reliably receive triple-play services, single- and multi-channel video services, higher quality VoIP connection, and more customers for basic high-speed internet access. An increase in footprint means an increase in the number of potential customers for any service, depending on loop/customer demographics. Operational expenditure reduction is evident in DSM Level 1/DLM-induced improvement in line stability, often resulting in less customer calls to service provider operation's centres, a reduction in customer visits, and generally speaking "happier customers" who are less likely to cease their service. These types of improvements due to DSM/DLM could result in a significant benefit for customers and providers of DSL services in the UK.

By contrast the potential exists that improper or careless use of these dynamic DSL management techniques by one or more of the operators sharing the access cable plant could negatively affect other users of that plant resulting in reduced stability of the subscribers lines or reductions in bandwidth for some or all the lines. This would negate the benefits of DSM Level 1/DLM. One of the purposes of this report is to help characterise such potentially negative interactions, and to provide information to ensure that DSM/DLM techniques when used by DSL operators sharing the UK access network produce maximum benefit for all operators and to the DSL subscribers served over this network.

There are also 2 higher levels of DSM (Levels 2 and 3) that are just entering field deployment following the 2007 ATIS DSM report release [3]. These higher DSM Levels promise even greater improvement in DSL footprint and larger benefit in operations profitability. These higher levels have greatest benefit in networks that have VDSL2 and/or mixtures of ADSL, ADSL2plus, and VDSL2. Such networks are evolving in the UK just as they are evolving around the world. Appropriate DSM Level 1/DLM deployment today may help enable better use of Levels 2 and 3 DSM in the future as these emerging methods derive additional benefit from the use of the appropriate DSM Level 1/DLM methods.

5 Overview of Analysis

Currently the practice of using AMA (Automatic Margin Adjustment) and TRA (Tiered Rate Adaptation) for DSM Level 1/DLM is operational in the UK network by some DSL operators. Hence, some operators have already deemed the business case for DSM Level 1/DLM deployment valid. Typically such a business case becomes viable when the volume of customers on a DSL network reaches a point that the cost of automation of DSL line profile adjustment is justified. In addition, DSL network operators are keen to use such automation to optimise the speed/stability of their DSL services, to improve customer satisfaction and competitiveness, and hence to reduce churn. More recently, DSL operators have also been motivated to reduce power consumption in order to both reduce operational costs and to contribute to the wider positive environmental impact of reduced energy consumption.

This NICC study has compared and contrasted the AMA and TRA techniques along with comparison to another algorithm for line stabilization, namely VN (Virtual Noise). The basis of the analysis and comparison was around speed, stability and power-consumption trade-offs. This report is a generic comparison of these DSM Level 1/DLM techniques. It does not address specific service requirements since each DSL network operator will have their own specific service offerings with associated performance targets, service-level agreements etc. The DSL network operator would adapt the parameters within the DSM Level 1/DLM algorithm to meet the specific needs of their own services. The DSL network operator may also use additional techniques in conjunction with DSM Level1/DLM to meet these service targets. Examples may include techniques such as Application-Layer Forward Error Correction (AL-FEC) or packet-layer re-transmission techniques to compliment DSM Level 1/DLM for IPTV service delivery over DSL.

AMA monitors a DSL modem for code violations (packet errors) and/or poor margins that indicate poorly performing lines. When code violations exceed prescribed thresholds, the line is re-initialised, normally with a higher margin or with other techniques such as interleaving. If the margin is increased then power usage (and consequent crosstalk level) increases and/or data-rate decreases at each subsequent margin increase step taken by the algorithm. If the DSL is already operating at full power, the data rate will decrease with the increase in margin.

TRA works by retraining the modem not with more margin, but with an acceptably narrow range of allowed data rates so that the DSL does not try to run too fast or too slow, thus stabilising the service. As per AMA, TRA also makes use of forward error correction when it can. While AMA may produce an increase in stability, the increase in power used (and also reduction in data rate) can create more crosstalk (and

consume more power). TRA instead does not increase the power (or does so by a small amount) to effect stability. TRA notes the maximum stable data rate, limits the DSL modem to that rate in the subsequent re-training, and allows the DSL modem to adapt to the situation of interest while not exceeding a speed that would cause it to become unstable and possibly retrain often and/or have unacceptable error rates. The minimum rate in TRA is set at a level such that the modem cannot be left at a very low speed because of a rare noise event that occurs so infrequently that it would not affect customer satisfaction. Thus while the DSL customer still receives a "best effort" service, TRA provides a rationale that provides the customer a best data rate upon which they can rely for best stable DSL service.

Virtual Noise (VN) is an untested future option in ADSL2/ADSL2plus and VDSL2 [11], [14], [15] transceivers to combat fluctuating noise. To use this feature it is necessary for the network operator to define a 'virtual noise' (VN) profile that is used by the DSL receiver as an additional input when determining how many bits can be loaded onto a particular DMT carrier. In some cases, an effectively equivalent implementation called "artificial noise" is intentionally added by the transmitter to the transmit DSL signal so that its level upon reaching the receiver forces the same effect as if VN had been used. For purposes of this report, the two are the same and referred to as VN.   If the VN level defined for a particular carrier is lower than the actual local noise then it has no effect. If however it is greater than the actual noise level then the number of bits assigned to the carrier in question is constrained by the higher VN level. The purpose of VN is to protect the user's service from errors or retrains that might otherwise disrupt QoE. This protection is obtained by preventing the modem training at high rates if the noise level is temporarily lower than the noise level that is expected to be encountered during the session where/if this lower noise would otherwise make the service unstable when subject to error bursts damaging to the users QoE.

The analysis of the aforementioned techniques (AMA, TRA and VN) has used two very different simulation approaches and has covered a number of network topology scenarios and noise combinations [see Annexes C and D of this report].   These models have also taken account of dynamic or time variant noise environments. In all scenarios examined, there was never a situation where AMA or VN (or a combination) had been able to out-perform TRA in terms of the speed/stability trade-off or reduced power consumption. Hence the conclusion, based on simulation, is that TRA appears to be the better approach for DSL operators considering using a DSM Level 1/DLM system. In this context, "better" means optimal performance in terms of speed/stability, being more polite[4] to other UK DSL systems sharing the same copper network and potentially being more environmentally friendly in terms of minimising power consumption. In addition to the results from this wide-ranging and thorough analysis via simulation, TRA has also been deployed on real UK copper loops and demonstrated that it worked very well when compared to no DSM Level 1/DLM. AMA has also been deployed in the UK and performed well compared to no DSM Level 1/DLM. Field comparison of AMA- and TRA–based implementations in the UK access network has not been performed.

For all of the approaches analysed, correct parameter selection together with accurate equipment implementation enables best DSM Level 1/DLM performance.

6 Statement of Problem and Issues

DSM algorithms can be selected to achieve an appropriate balance between speed (or network capacity), stability (number of re-trains) and power consumption. The "optimum" scenario that balances the trade-offs between these three areas will depend on the service provider and the service they intend to deliver over a particular customer's line (e.g. IPTV or just Internet access). However it is generally fair to say that all service providers would like to:

   (a) Maximise speed for the majority of end-users (and hence maximise DSL speed vs. distance)
   (b) Maximise capacity on their network
   (c) Maximise stability (and hence minimise customer service centre call volumes, complaints, truck rolls & churn and maximise customer satisfaction)
   (d) Minimise power consumption on both the individual line and hence on the overall network.
   (e) Have a practical solution in terms of the ability of Communications Providers (CPs) to implement the approach without significant implications for existing architectures and deployed equipment[5]

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[4] "polite" in this context means generating less crosstalk noise within the network and thus having less of an impact on neighbouring DSL systems on adjacent copper lines.

[5] Operational implications are considered important and need to be taken into account in the final guidelines.

(f)   Have clarity on how compliance to any suggestions can be achieved

Hence the issue is to determine whether there are significant benefits to all CPs using the UK access network in terms of some or all of the parameters (a) to (d) above from the deployment of DSM technology. In particular, recognizing that any guidance defined by NICC is not mandatory on any CP, are there benefits when using the preferred DSM technology in an environment of mixed DSM and non-DSM implementation. Additionally, advantages of practises recommended in this report over other ANFP compliant practises can be quantified.

Reference [5] gives details of the QoE (Quality of Experience) and network QoS requirements for a number of services that can be delivered over DSL networks (an extract of salient issues from TR-126 is in Annex B of this report). Reference [4] from Ofcom is also relevant to UK operation of DSM since an unstable line with widely varying unpredictable speeds would be in conflict with the spirit of [4] and several of the principles therein.

For the purposes of undertaking modelling studies to determine potential benefits, the following targets have been defined for speed, stability and power consumption, but there is no implication that the throughput of some lines can be sacrificed to facilitate the meeting of these targets on other lines.

6.1 Speed

Maximise reach for 3Mbit/s and 10Mbit/s for support of SDTV and HDTV (or multi-channel SDTV) respectively. Also, maximise the percentage of customers that can achieve 16Mbit/s to facilitate marketing of "very high speed" broadband capabilities.

> *RATIONALE :* 3Mbit/s & 10Mbit/s are consistent with [5] with respect to target speeds for MPEG4 video transport. At one stage the UK Advertising Standards Authority (ASA) implied that a service should not be advertised unless at least 10% of customers could achieve it. In this respect 16Mbit/s is more realistic a target than say 24Mbit/s. 20Mbit/s is probably the absolute top-end that a minority of customers (~ 2-3%) could expect to receive.

6.2 Stability

Stability focuses on outages and packet error rates. An outage is a physical-layer disruption in service that leads to a loss of connectivity and consequent retraining of the DSL modem connection, typically measured by its probability of occurrence[6].

Outage Probability

- Internet Access: < 0.5%
- Video   < 0.1%

Equivalent to Outage Probability for daily retrains (2 min/retrain)

- Internet Access: < 4/day
- Video: < 1/day

Code violations (packet errors)

- Internet Access: < 500/15-min
- Video: < 250/15-min

Percentage of the customer base considered stable: > 90%

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[6] See appendices for QoE requirements on video "loss distance" etc.

RATIONALE: Different service providers will have different business plans with regard to the services they plan to deploy and these will have different requirements with regard to stability. At the more challenging end will be the delivery of streamed IPTV where some requirements can be gleaned from [2]. However, references [4] and [6] both make it very clear that "zero errors" at the DSL PHY layer is unrealistic and it is fully expected that higher application layer techniques (such as AL-FEC or packet re-transmission) will be needed to augment DSL PHY layer techniques for good IPTV service delivery. For ISPs who simply want to deliver best-effort Internet access (but at high speed) the requirements are less onerous but actual acceptable levels are more driven by real-world experience based around statistics from their customer support centres in comparison to the size of their customer base.

6.3 Power Consumption

- Target for average transmit power:

<100 mW (ADSL1 and ADSL2plus downstream)
< 20 mW (ADSL1 and ADSL2plus upstream)
< 25 mW (VDSL2 downstream)
< 20 mW (VDSL upstream)

A goal of DSM is a reduction in consumed power to achieve any fixed level of speed and stability.

RATIONALE: The recent electricity price rises have made power (and associated cooling) expenses an even more significant part of a Communication Provider's operating expenses so there is a desire to cap this. Further more, some DLEs with high DSL take-up are already suffering from overheating (temperatures reaching ~40 degrees Celsius). Finally, this is in keeping with the general trend for the telecommunications industry to be more green [6][7]).

7 BASIS FOR COMPARISON – SIMULATION APPROACH OVERVIEW

The details of the simulation approach used in the analysis that has led to conclusions described in this document are given in Annex C. The following is a summary of the simulation approaches used in the analysis performed by the NICC DSL Working Group.

Four fixed noise and time dependent noise scenarios were modelled:

Fixed Noise Scenarios

- 'Scenario 0' – This scenario modelled the performance of DSM Level 1 techniques on ADSL2plus service in the presence of intermittent noises. In this scenario the simulations were run on a single loop with a length of k*160 meters where k varied between 1 and 39. That is the loop varied between 160m and 6240m in length.

- 'Scenario 1' – This scenario modelled the performance of a group of five ADSL2plus lines in the same cable/binder that crosstalk into each other. The length of the loops were equal, and simulations were performed with loop lengths equal to 1.2 km and 2 km

- 'Scenario 2' – This scenario modelled the performance of a group of five 'short' ADSL2plus lines supported from a cabinet and 5 longer ADSL2plus lines supported from the exchange. All 10 simulated loops shared the same cable/binder.

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[7] See
http://sunbird.jrc.it/energyefficiency/pdf/CoC%20Brodband%20Equipment/Code%20of%20Conduct%20Broadband%20Equipment%20V3%20final.pdf

- 'Scenario 3' – This scenario modelled the performance in the upstream direction of a group of five 'short' VDSL2 lines and 5 longer VDSL2 lines. All 10 simulated loops shared the same cable/binder.

Time dependent Scenario

There is a binder full of 20 ADSL2plus lines. Any, all, or none can be excited at various times and crosstalk is modelled by assuming that the lines initialise randomly at various times of the day. On those simulations where Virtual Noise is modelled, it applied to all lines at the level equal to one crosstalk disturber.

For each of the scenarios the following were modelled. The details are in Appendix C.

- Cable Model

- Crosstalk Coupling Model

- Number and Type of Interferes

- Number and Type of Interferes

- PSD of victim and disturbers

- Background Noise

- Intermittent Noise

- Cable Length Model

- DSL Protocol Performance Parameters

8 DSM/DLM Algorithm Modelling

The details of the Assumptions in the models made with respect the DSM algorithms modelled are in Annex D of this document.

The areas covered in these models include assumptions regarding:

- The functionalities, capabilities and configuration of the two DSM Level 1 algorithms TRA and AMA

- The functionalities, capabilities and configuration of Virtual Noise

- DSM Level 2 loading Algorithms

9 RESULTS

The scenarios described in Section 7 with the assumptions and parameter settings as described in Annexes C and D were modelled. The results were reported to the NICC DSL Work Group in a series of contributions at meetings in January, February, and March 2009. The scenarios support simulations that are believed to be representative of aspects of actual DSL deployment. The models for the work group show that TRA performed better than AMA as the environment becomes more 'dynamic' with respect to time varying noise. However, being based on simulations, the results seen in the field may not be as great as shown in this report. These simulations provide the basis for the recommendations made in Section 10 of this report. The subsections below summarise the results of these simulations.

9.1   Scenario 0 and 1 Results

Figure 1 summarises the results of the models for scenarios 0 and 1. This figure plots the difference over the line-length range of 1.5-4 km of TRA and AMA lengths for the same data rate for both scenario 0 and 1 situations. The parameter sigma characterises the random intra-line time-variation of the base-line noise.

Figure 1 plots results for the three noise environments that were to be modelled by the NICC DSL WG; that is the ANFP 3.0 noise model, -140dBm/Hz and -155dBm/Hz. The plots show that the improvement for TRA vs. AMA increases as the degree of time-variation of the intermittent noise, as measured by sigma, increases. The improvement is always at least a few hundred meters and can increase to over a km in the best cases.

It is noted that in the unrealistic case of no noise variation and a 0dB margin AMA and TRA should behave identically.
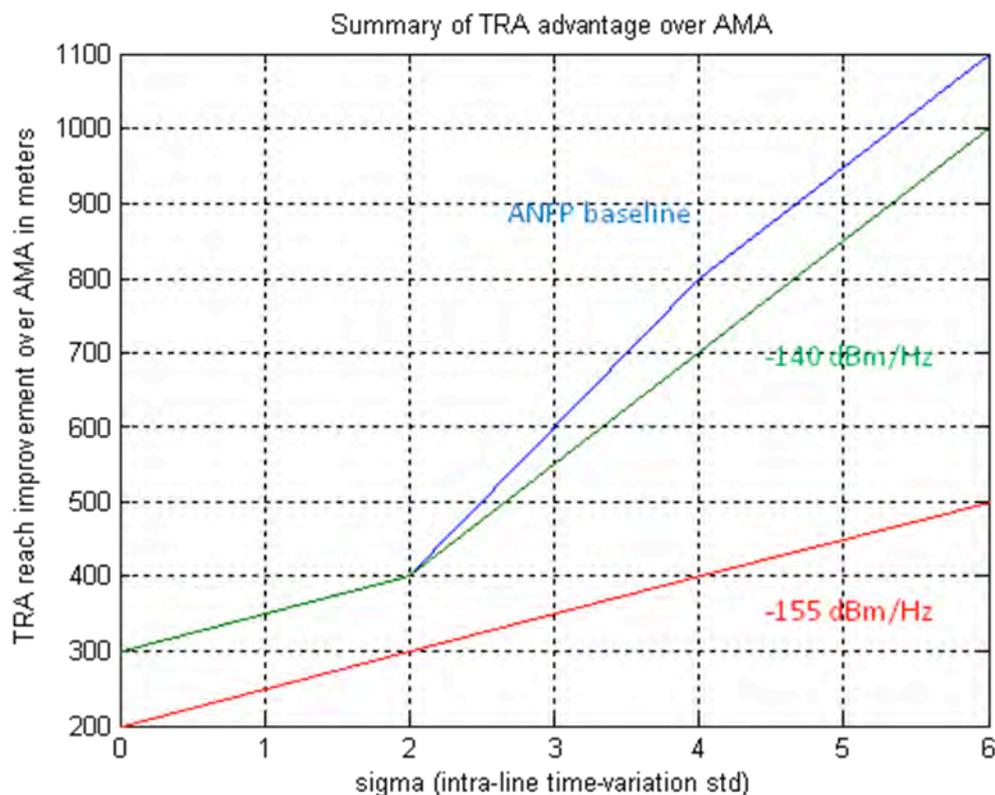
Figure 1 TRA reach improvement vs. AMA for various intra-line time-variation standard deviations.

9.2   Scenario 2 Results

Figure 2 illustrates the rate regions for Scenario 2 for AMA and TRA for Scenario 2 when the crosstalk noise is lowered 9dB below the ANFP baseline noise case. The ANFP issue 3 specification specifies use of certain power spectral density masks as a function of position with respect to the exchange. Figure 2 presumes use of these ANFP masks for the curves whose legend is in the square boxes. These curves indicate a TRA rate-region improvement in the rate region over AMA in the presence of intermittent noise. Also other curves in Figure 2 show the rate region when the ANFP masks are ignored. These curves show that the ANFP protects CO-based performance at the expense of remote-based performance, as it was designed to do.
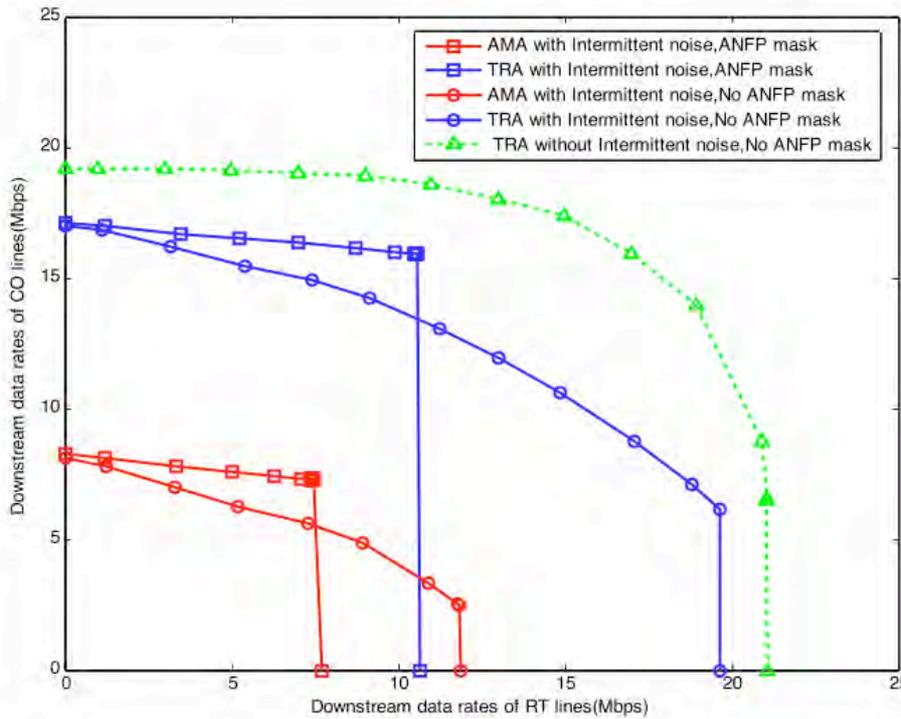
Figure 2 - Rate-region improvement of TRA versus AMA (in presence of intermittent noise) - Static Crosstalk lowered by 9dB NICC ANFP baseline noise case.

9.3   Scenario 3 Results

The results for simulations of Scenario 3 are summarised in Figure 3, Figure 4, Figure 5, and Figure 6. These four figures illustrate the upstream rate regions for different combinations of loop length between the exchange based (longer loops) and the remote based (shorter loops).
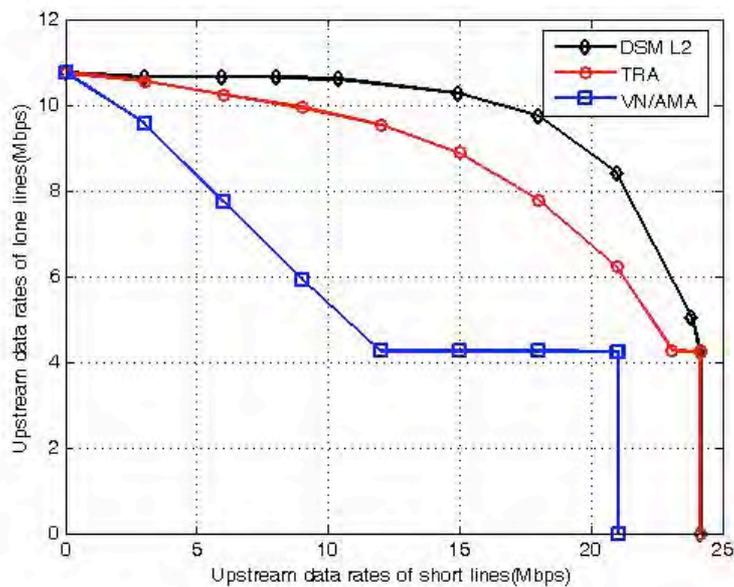
Figure 3 - Rate regions for Scenario 3 with xs=600m and xl=1200m. VN/AMA curve is with VN index=1 for line 1, 2, 3, 4, 5.
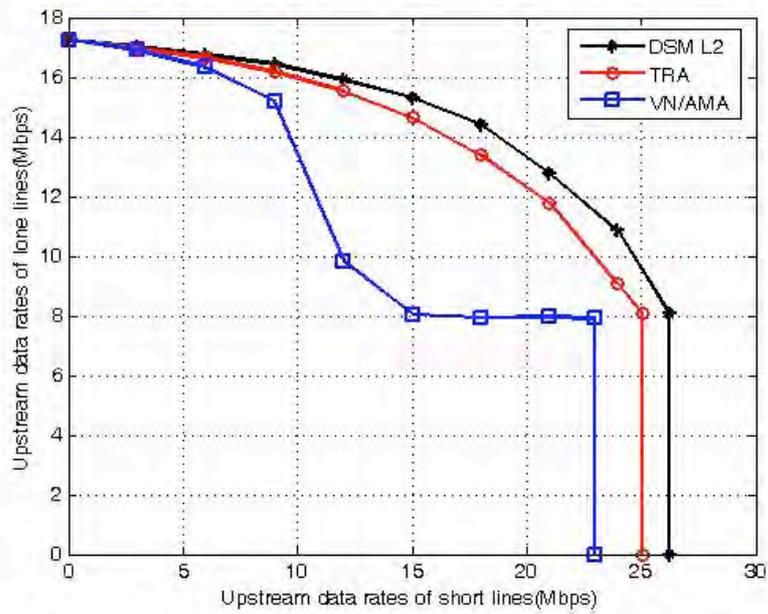
Figure 4 - Rate regions for Scenario 3 with xs=420m and xl=1000m. VN/AMA curve is with VN index=1 for line 1, 2, 3, 4, 5.
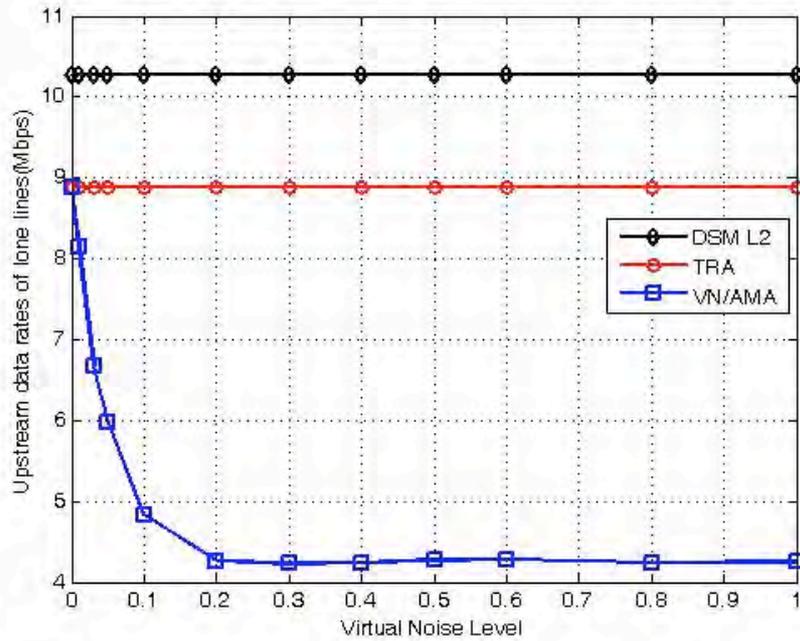
Figure 5 – Data rates for 1200m lines in Scenario 3 vs VN index, xs=600m
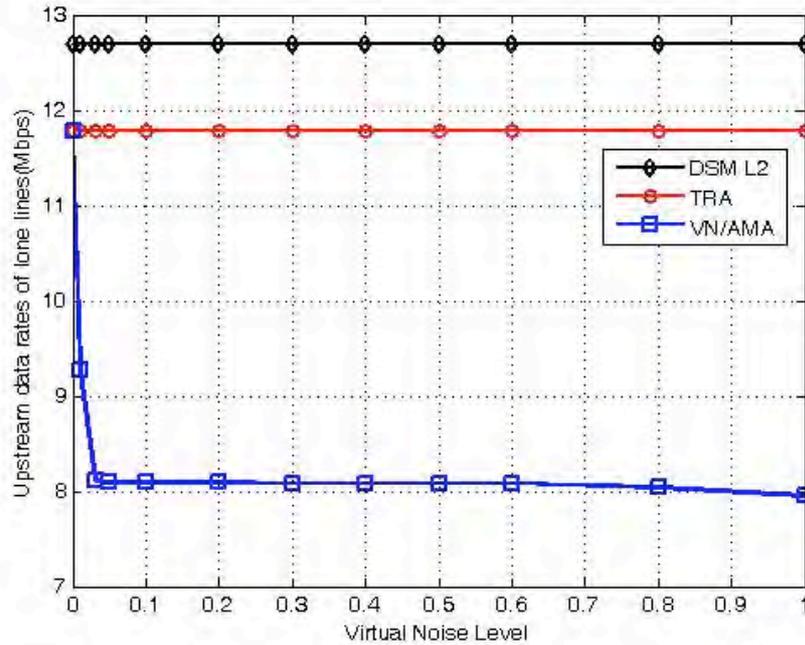
Figure 6 – Data rates for 1000m lines in Scenario 3 vs VN index (xs=420m)

9.4   Time-Varying Scenario Results

Figure 7 illustrates the consumed-power level for a 13 Mbps data rate as the level of activity in the binder is varied from 1 active DSL (on the left) to all 20 active DSLs (on the right). For the TRA+VN plot, VN is set equal to 1 FEXT (VN = 1 FEXT). When the first user awakens (once per day in the NICC scenario), that user will need more power with VN=1 FEXT since that is a noise level above the situation on the line upon first awakening. The second line then sees a higher crosstalk because the first line is using more power and thus that first line's radiated crosstalk is higher into the 2nd line. Thus, that 2nd line must transmit at a higher level than would be needed also. Each line in turn, by using extra transmit power, affects all the subsequent lines to awaken and train. The binder of DSLs more rapidly becomes FEXT limited with VN=1FEXT with all at full power even for 13 Mbps data rate very quickly. This group of lines is then also radiating maximally at 13 Mbps into other binders as well.

For TRA alone (that is VN=0), the first user to awaken uses only enough power to have 6 dB margin against the background noise of -140 dBm/Hz, and thus transmits a very low power and generates a very low crosstalk for the 2nd line to awaken. When that 2nd line awakens and thus radiates crosstalk, the two lines react and converge on an equilibrium of power that is higher on each, but still well below what happens in the VN>0 case. The process, known as iterative water-filling, means that each line does normal bit/gain swapping and converges to the lowest power level that can achieve 13 Mbps.
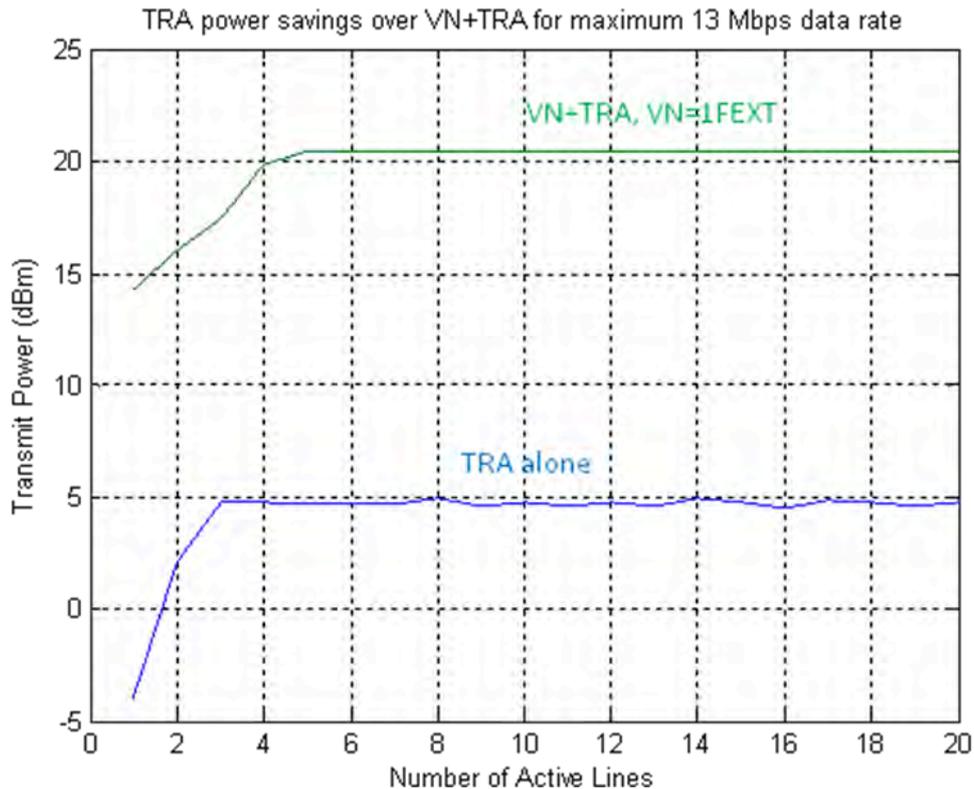
Figure 7 – Power use by TRA alone (no virtual noise) versus the use of Virtual Noise at NICC Time-Varying Scenario level of 1 FEXT.

TRA's power savings is over 15 dB in all cases, a factor of 32 less power at the same data rate of 13 Mbps. This means that other adjacent binders now see 15 dB less crosstalk also. Those other binders then can have higher data rates. The best setting for power consumption is indeed VN=0, and this will maximally protect all other DSLs not in this particular binder.

10 General Observations Regarding DSM in the UK Network

DSM Level 1/DLM is undoubtedly a useful technology capability for UK DSL network operators. The use of the TRA approach should be seriously considered for support as an approach to be considered in any DSM Level 1/ DLM deployment because of its increased politeness as well as effective performance (speed versus stability versus transmit power trade-off) compared to the AMA and VN approaches. Politeness and subsequent reduction in transmit power and crosstalk levels can in theory bring benefits to all UK DSL operators and their end-users.

The UK DSL market has over the past few years been characterised by marketing the potential maximum speed of a product e.g. "Up to 24 Mbit/s" for ADSL2plus. This marketing practise has been the focus of an Ofcom Code of Conduct to ensure that DSL operators give an indication to the customer of the actual speeds they may achieve on their own line if they purchase such a product. Neither the marketing approach nor the customer *a-priori* line checks would be affected by a move from AMA to TRA for DSM Level 1/DLM. If the customer's line is over 4km long then it is unlikely to support 16 Mbit/s irrespective of whether TRA or AMA is used for DSM Level 1. Hence at an individual line level, the use of TRA requires no changes to existing marketing nor line-qualification approaches, nor to fundamental service proposition inherent in UK rate-adaptive DSL products. In fact, since a higher percentage of customers are likely to achieve a higher speed for a given line length and level of stability then the service offering is likely to be improved.

The DSM methods studied within the NICC DSL Working Group all require that network and customer DSL equipment makes the correct use of key DSL control parameters such as the maximum SNR margin parameter and the correct use of bit-swapping. Bit-swapping is the dynamic technique used within DMT

transceivers (the basis for ADSL, ADSL2plus and VDSL2) that enables the transmission system to re-allocate information and transmit power from DMT "sub-channels[8]" that degrade as the noise environment changes. Via bit-swapping, the user's payload data can then be transmitted over alternative DMT sub-channels that have a better signal-to-noise ratio in order to maintain the aggregate speed of the delivered data without errors. The speed at which a DMT transceiver can bit-swap to adapt to time-variant noise will dictate its ability to cope with changing noise (such as changes to crosstalk or RFI levels). These methods make use of existing management functionalities that have been standardised for many years so a DSL equipment vendor's products should comply with them. Within DMT DSL systems (ADSL, ADSL2plus, VDSL2) the interface for bit-swap control messages is well specified in standards. However, the use of bit-swap is under the control of the receiver[9], and this control is a proprietary feature. Consequently, though the situation is improving over time, non-compliant implementation of standardised bit-swap can lead to unsatisfactory performance in the presence of fluctuating noise.

TRA has been deployed in ADSL2/2plus networks both with and without the "extended gain" capability known as EXTGI. TRA has also been deployed in ADSL networks. However, DSL equipment that fully supports EXTGI will have better DMT bit-swapping capabilities and hence is better able to react to dynamic changes in the noise environment.

The EXTGI[10] parameters used in the DMT modulation of ADSL2plus and VDSL2 should be supported to optimise the performance of bit-swapping in the DSL modem described above. The ITU ADSL2 standard G.992.3 standardised EXTGI in 2002. This standard states that only an EXTGI of 0 dB is mandatory in the Recommendation. The gi value thus must be in the range from -14.5 dB to +2.5dB if EXTGI is 0 dB. However, a DSL equipment vendor can choose to select MAXNOMPSD at -40 dBm/Hz and NOMPSD at -60dBm/Hz and then EXTGI must be supported at 20 dB since the standard requires EXTGI support at the level of the difference between these nominal and maximum levels. This choice of MAXNOMPSD and NOMPSD then widens the gain/swap range so that the transmitted spectra can "slide" up and down with the level of noise. Thus, a good DSM Level 1-capable ADSL2plus (or VDSL2) modem would make the selection to transmit at NOMPSD = -60 dBm/Hz and thus would support EXTGI=20 dB. MAXNOMPSD is set by the DSL network operator's management system and the value typically used is -40 dBm/Hz.

A number of observations are made regarding the use of Virtual Noise (VN) techniques in the UK network:

1) VN is new and not yet deployed.

2) VN is an optional capability in ITU-T DSL PHY layer Recommendations.

3) VN is proposed to help achieve the following DSL service goals
   a) Protecting service with onerous requirements (e.g. IPTV).
   b) Mitigation of time varying network noise effects.

4) Care must be exercised in the use of VN on a DSL Line.

   a) When applied to a DSL Line, VN may reduce the attainable speed of that line while possibly also increasing power consumption for that line.

   b) There is a risk of increased crosstalk into neighbouring lines in the same cable/binder if VN is used, especially when higher settings of VN are used.

   c) VN should be set to be no greater than the worst-case noise that is encountered routinely on a line. "Worst-case noise" is difficult to define and is an area requiring further study.

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[8] Sometimes referred to as DMT carriers, tones or bins.

[9] The DMT sub-channel "gain" (known as gi, where i=DMT sub-channel reference and g is usually in the range -14.5 to + 2.5 dB) to be used in the bit-swapping is then passed to the transmitter via a reverse control channel so that both transmitter and receiver are aligned in their use of the copper transmission channel in a way that seeks to avoid the noisiest parts of the channel.

[10] EXTGI is a receiver computed parameter based upon other transmitter specified parameters that tells how much additional positive gain is possible so that gains can be as high as 2.5 + EXTGI (where 0<=EXTGI<=25.6 dB).

5) NICC simulations to date have not quantified VN incremental benefits in increasing DSL line stability or the impact on service bit-rate.

6) When there is more experience with VN use in closed-loop dynamic line management algorithms, a study of the impact of VN in the UK DSL access network may be appropriate to address the following questions:
a.What are the incremental benefits to using VN when the technique is used in conjunction with other techniques such as TRA or AMA?
b.How might VN be managed by dynamic methods and what advantages are there to such VN management techniques?
c.Does the accuracy of noise measurements necessarily have an impact on the setting of VN levels?
d.How do the accuracies of margin estimation, maximum sustainable rate estimation, and measured noise levels influence the outcome of Dynamic Line Management by AMA, TRA with or without VN.
e.What is the effect of VN on overall network power consumption (both Network equipment and CPE ends).?

7) If VN is used it is not likely to be used in isolation but in conjunction with DSM Level 1/DLM techniques that may incorporate TRA or AMA approaches.

As higher-speed, fibre-rich Next Generation Access systems begin to be deployed, there is a risk that NGA like services may increase the speed disparity among end-users in the UK since they will take a long time to achieve significant customer coverage. Hence copper-based broadband technologies will co-exist with fibre access systems for many years. Any technologies that can increase the bandwidth available via DSL access systems will help to reduce the variance in broadband speeds available to end-users in "Digital Britain"[15]. This NICC Report has focussed predominantly on DSM Level 1/DLM.

11 Conclusions and Recommendations

11.1 Conclusions and Recommendations for DSL Network Operators

1) DSM Level 1/DLM techniques should be a key element of the management of a DSL deployment. The use of the TRA approach should be considered for any DSM Level 1/DLM deployment because of its increased politeness as well as effective performance (speed versus stability versus transmit power trade-off) where aggregate/average performance synchronisation rate is the key to product delivery. Politeness and subsequent reduction in transmit power and crosstalk levels can bring benefits to all UK DSL operators and their end-users. The following are situations where it is recommended that DSL operators should consider the use of TRA for any DSM Level 1/DLM functionality in their DSL deployments:

(a) OSS design to support the deployment (e.g. new FTTC/VDSL2 build to provide NGA type services).
(b) Deployment of DSM Level 1/DLM functionality on an existing DSL network that currently does not have any DSM Level 1/DLM capability. This implies retrofitting the DSM Level 1 capability to integrate with the existing network's element management systems. Typically DSL operators begin to evaluate DSM Level 1/DLM technologies when their customer volumes reach a sufficiently high number to justify the investment in automating DSM Level 1 techniques instead of using manual approaches.
(c) Deployments of new DSL products (e.g. moving from ADSL to ADSL2plus to VDSL2) where it may be opportune to review and revise any legacy approaches and adopt TRA instead.
(d) Upgrading existing AMA-based DSM Level 1/DLM systems. Since TRA leverages existing standards and associated element manager MIBs and capabilities it does not (unlike VN) need any changes to existing DSLAM/MSAN equipment. Hence "upgrading" to TRA does not necessitate the replacement of existing network equipment in exchanges. It would however require the AMA DSM Level 1 systems to have their algorithms modified to TRA and any consequent OSS and process issues would need to be evaluated.

2) Techniques such as DSM, AL-FEC and re-transmission continue to develop and DSL service providers should consider DSM Level 1/DLM as one technique within a "toolbox" of techniques available to improve DSL transmission performance.

3) Better bit-swapping and OLR11-1 performance testing with the well-specified bit-swap controls like MAXSNRM, MINSNRM, TSNRM and reported actual margins would be a good area in which service providers could seek to influence standards bodies in terms of driving best practise for performance testing.

4) It is recommended that DSL operators and their wholesale customers include requirements for EXTGI in their procurement of DSL equipment.

5) Care must be used in setting the level of VN on a DSL Line.

    a. When VN is used at an excessive level on a DSL Line it can have a detrimental effect on DSL performance on both that line and on other lines in the same cable/binder.

    b. When VN is used at an excessive level on a DSL Line it can have a detrimental effect on power consumption on the line

    c. VN is a new technique for which there is little or no field data available to guide appropriate setting of VN by a network operator.

6) The Broadband Forum is undertaking work on best practises with respect to DSL Quality Management (DQM) [7]. This work includes definition of management interface requirements for the DSLAM/DSL Access Node. It is recommended that DSL network operators track this work as it matures in case it offers additional insights that could be relevant to DSM deployment in the UK.

11.2 Recommendations for DSL Equipment Vendors

1. It is recommended that vendors use -60 dBm/Hz for NOMPSD since this provides gains in terms of bit-swapping speed. Vendors can do this and be consistent with the ITU standards. Selecting the lowest nominal transmit PSD level is most polite and creates maximum bit-swapping range.

2. To achieve a good DSM Level 1/DLM implementation, some conditions should be satisfied:

    a) The performance data collection system should be scalable such that neither the Network Elements nor the EMS introduce bottlenecks.
    b) An effective data-analysis algorithm utilising the relevant parameters should be implemented.
    c) The Network Elements and/or EMS should not unduly constrain[12] the number of stored parameters and the number of line profile configuration commands that can be issued simultaneously.

11.3 Recommendations for NICC Member Input to Potential Work by Other Bodies

1. It is recommended that the NICC members support defining tests for standards compliance (including EXTGI) with NICC members making input to bodies such as the Broadband Forum or ITU to help to ensure a high degree of vendor compliance.

2. Simulation has shown that use of TRA for DSM Level 1/DLM has the potential to reduce power consumption on DSL lines. However, this is one particular aspect of the analysis that merits deeper

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[11] On-Line Reconfiguration

[12] The ability to support a minimum of around 60 DSL line profiles has been shown to be sufficient and is therefore recommended. It is preferable for equipment and associated management systems to be able to support a few hundred profiles to maximize DSM Level 1/DLM design flexibility.

investigation using experimental techniques on real equipment in order to better quantify these potential benefits. This would be a useful area in which NICC could encourage further work.

11.4 Areas for Potential Further Study by the NICC DSL Working Group

The following areas have not been addressed in this report and are for further study:

1) What are the incremental benefits to using VN when the technique is used in conjunction with other techniques such as TRA or AMA?
2) Can VN be managed by dynamic methods and what advantages are there to such VN management techniques?
3) What are the requirements with regard to the accuracy of noise measurements on the setting of VN levels, and what are the associated sensitivities?
4) What is the effect of VN on overall network power consumption?
5) As DSM Level 2 and DSM Level 3 technologies and associated standards become widely available the DSL WG may address the benefits of these techniques in the UK Access Network since they may offer the prospects of even higher transmission rates over the existing copper pair infrastructure in the UK.

Annex A (Informative):
Overview of the Levels of Dynamic Spectrum Management

A.1 DSM Level 1

A main benefit of DSM Level 1 is its ability to 'tune', that is to optimise the configuration of, each line. This is known as "re-profiling". DSM re-profiling is based on analysis of on-line and historical observations of the DSLs critical physical-layer performance parameters that support a self-constructed statistical characterisation of any single service-provider's lines. While early ANFP studies addressed overall worst-case statistical models of the UK network in attempting to provide static power-spectral density ANFP masks, the "dynamic" element of each line operating within the existing ANFP requirements had not yet been well studied in the UK. The existing ANFP requirements need not be changed, but they can be augmented based on the analysis of the use of these new dynamic techniques and systems that can optimise performance of DSL lines operating within the ANFP requirements. Appropriate exploitation of dynamic capabilities allows improved line stability and also enables lower power use by the DSL transmitters, which means lower overall network power consumption. Reduced power consumption is consistent with calls for reduction of power use in DSL by the NICC group [4] and by recent EU guidelines [6]. Thus DSM offers a mechanism to address such admirable goals. Further, the consequent lower emitted energy reduces crosstalk into other DSLs, offering further benefit for all DSL in a cable beyond the existing ANFP's requirements. A system level overview of a generic DSM system is illustrated below:
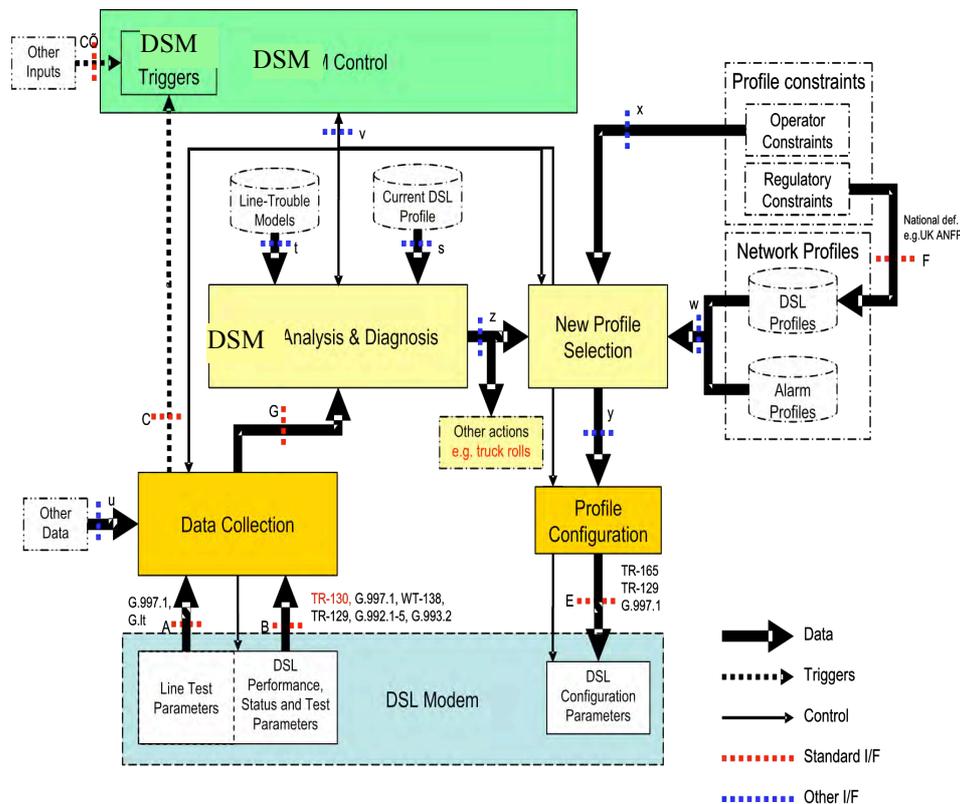
Figure A1: Generic DSM System Architecture

DSM Level 1/DLM addresses line stability via "re-profiling", that is the reconfiguration of individual DSL lines taking into account the dynamic operations environment. DSM level 1/DLM uses existing standardised capabilities of all DSLs (including even early standard-compliant ADSL1 systems), see [8], [9], and [10] for the standardised quantities used in addition to [3]. The following table and figure give an example of the main profile parameters used with ADSL2plus technology. The profile parameters and their interaction are explained in detail in [8].

Bitrate Attributes	Downstream		Upstream
Maximum	10 Mbit/s		1 Mbit/s
Minimum	2.3 Mbit/s		0.4 Mbit/s
Margin Attributes	**Downstream**		**Upstream**
Target	**8 dB**		**8 dB**
Maximum	**16 dB**		**16 dB**
Minimum	**0 dB**		**0 dB**
SRA downshift	**<target-min>/2**		**<target-min>/2**
SRA Upshift	**<max-target>/2**		**<max-target>/2**
Error Protection Attributes	**Downstream**		**Upstream**
INP	**2**		**0.5**
Max-delay	**8 ms**		**2 ms**

Table 1: ADSL2plus Profile Example

There are many ways of implementing DSM Level 1/DLM. When implemented and configured properly DSM Level 1/(DLM) methods may benefit both individual DSL subscribers and the network operators sharing the access network. However incorrect usage of certain DSM Level 1/DLM methods could be potentially detrimental to users sharing the copper access network.

Increasing the forward-error-correction (FEC) capabilities of an unstable line is a DSM L1/DLM tool already used by most network operators. It has the advantage that increased FEC settings cannot adversely affect the performance of other lines in the cable. However, use of increased FEC settings is limited as the range of possible FEC setting is constrained in both the xDSL standards and actual field equipment realisations that may implement FEC capabilities less than the maximum ranges allowed in the current standards. Often, the best available FEC configuration cannot stabilise a problem line. Thus other DSM Level 1 methods inevitably must be used.

There are several approaches for DSM Level 1/DLM methods for improved line stability and improved statistical DSL rate/range that can be used to enhance any available FEC capabilities. These DSM methods include: Automatic Margin Adaptation (AMA), Tiered Rate Adaptation (TRA), correct use of the maximum SNR margin parameter, and correct use of bit-swapping. All of these methods are already standardised.

Rate-adaptive ADSL2plus adjusts the actual speed of a line in response to a change in noise environment. As described in [3], DSM Level 1/DLM can go a step further and adjust other DSL profile parameters such as margin, interleaving delay, INP and max/min speed range. The overall objective of DSM Level1/DLM is to automatically configure lines dynamically to ensure high quality (low error rates) and stability. These DSM L1/DLM algorithms determine the best configuration profile for a service, depending on the measured line conditions. If line problems are detected, settings can be adjusted automatically, minimizing (or avoiding) service interruptions. This can help to reduce help-desk calls, technical support operating expenditures and customer churn.

For some DSM L1/DLM algorithms, the automatic tuning of the DSL line's profile is based on the collection of detailed historical performance data. Performance is assessed over time and the line is reconfigured as necessary. Performance can be based on the number of errors on a line detected by the receiver and the number of retrains (that is when a modem loses synchronization with the far-end modem and has to reconnect at a lower speed). An example approach is where the DSL Provider's lines are regularly classified (e.g. daily) on these performance measures. A line's categorization can then be tracked over time. The DSM Level 1 system can then vary parameters such as INPMIN and DELAY-MAX, max/min speed range and target margin in an attempt to improve the balance between maximum throughput performance and stability. Adjustment of these parameters can optimise the performance of service delivery over DSL service in terms of speed, packet errors and line stability.

With DSM Level 1, the profile-tuning process takes place automatically and no action is required by the DSL Network Provider or end-user. However, end-users may notice a brief loss of service (of the order of a minute or so) whilst the line re-trains following a profile change. Such interruption to user service can be avoided if the changes are made during times when the line is observed to be idle.

Many DSM Level 1 approaches base their re-profiling decisions on the historical operating performance of the line as well as the current performance, as these systems collect and record the operating status of the line (actual margin, code violations, synch loss events etc.) periodically, such as every 15 minutes. This historical performance information can also be used by the Network Operator for other purposes such root cause failure diagnosis and identifying eligible customers for upgrades to higher levels of service.

A.2 DSM LEVEL 2

DSM Level 2 allows a service provider to optimise all of their customers' DSL lines in a particular cable with the goal of maximizing the performance of the DSL services for the individual customers while minimizing the crosstalk into other DSL lines in the cable, both their own and those utilised by other Network Operator. DSM Level 2 is defined in the ATIS DSM Report [3] which Recommends methods of politeness and PSD masking to achieve these goals.

The ATIS DSM Technical Report [3] contains a list of the DSM Level 2 Data and Control parameters that may be supported by a DSM-capable transceiver. This DSM Technical Report does not contain specific requirements for DSM Level 2 algorithms, as these are proprietary and left to the designer of the DSM system (referred to in the ATIS DSM TR as an SMC - Spectrum Management Centre). Examples of DSM Level 2 SMC algorithms are provided for information in Annex A of [3].

DSM Level 2 increases capacity utilisation by adapting the transmit spectra of DSL lines to the actual time-variable crosstalk interference making use of information about network topology. The gains in rate/reach performance are most significant for deployment scenarios where crosstalk is the dominant noise source and where a significant reduction in crosstalk can be achieved. DSM Level 2 in the DSL context optimises transmit power levels and spectral allocation across multiple copper pairs in the cable. The resulting crosstalk avoidance can produce beneficial tradeoffs amongst tiered services, especially when the transmitters are not collocated, like in mixed local exchange/cabinet transmission within the same cable.

A.3 DSM LEVEL 3

DSM Level 3 or "vectoring" as it is sometimes called, is defined in the ATIS DSM Report [3]. DSM Level 3 provides techniques that allow cancellation of crosstalk on a DSL line by coordinating the transmission and reception of signals across all or a subset of the line in a cable. Unlike DSM Level 1 and 2 techniques, where existing G.997.1 (G.PLOAM) management interfaces and xDSL standards largely suffice to enable

the methods, standardization of modem equipment to conform to Level 3 is required to enable the techniques and is an ongoing in ITU project, "G.Vector." DSM Level 3 may merit more detailed investigation in the UK by NICC in the future, as the ITU-T G.993.5 Recommendation emerges and enters field deployment. However, some degree of preliminary understanding is appropriate in this report to consider implications of the future use of DSM L3 techniques rather to avoid retroactive modifications to guidelines and perhaps frequency plans after equipment and component vendors commercialise their products.

A reference model for a vectored system is illustrated in 5, using the terminology of ITU-T Recommendation G.997.1 [8]. This model shows a system with 2 subscriber lines, but it can be extended to an arbitrary number of lines by replicating the shown modules. In a vectored system, the Access Node (AN), located at a central office (CO) or remote terminal (RT) or other location, transmits to and receives from a number of NTs. The common element of all forms of vectoring is coordinated transmission and/or reception of signals at the AN. (Thus, the signals may be represented as a *vector* where each component is the signal on one of the lines.) This coordination is made possible through an interface between xTU-C-1 and xTU-C-2, which is here called ε-1-2 to indicate that the coordination takes place between lines 1 and 2. Coordinated management of the lines is performed by the NMS through the Q-1 and Q-2 interfaces.
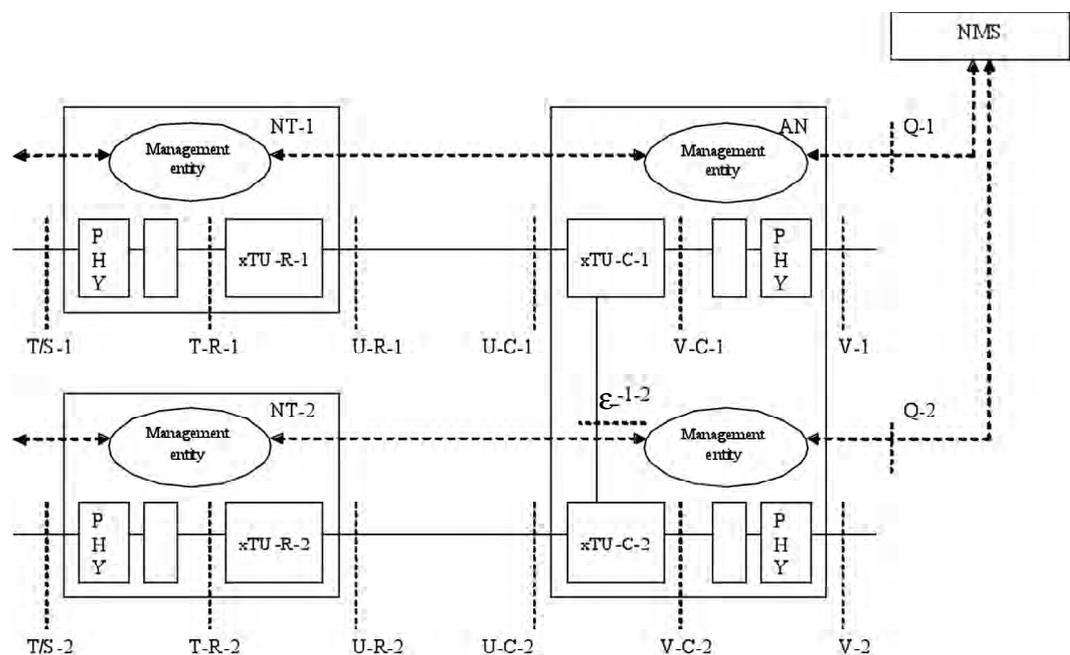
Figure 5: Reference model for vectored system.

Vectoring is not another name for DSL bonding, that is utilising the coordinated capacity of multiple DSL lines to same premise to carry one subscriber's data; bonding may be used with or without vectoring. The use of vectoring over bonded lines is often defined as *bonded vectoring* or as *MIMO DSL*. *Distributed vectoring* is defined as the use of vectoring over lines that are not bonded and which terminate at separate customer premises and this is the focus of the text that follows (and of the G.993.5 project in the ITU-T.)

Vectored DSL systems improve their performance from the use of joint signal processing in the downstream direction (coordinated transmission), or from the use of joint signal processing in the upstream direction (coordinated reception). Such joint signal processing allows for the mitigation of external noise that would otherwise degrade the SNRs of the lines. Noise sources may be divided into *in-domain noise* arising from transmitters within the vectored system, and *out-of-domain* noise, which arises from sources external to the group of vectored pairs in the vectored system (for example, alien crosstalk from lines of an alternative service provider, AM noise, HAM band transmitters).

Vectoring can mitigate crosstalk using the following techniques:

1. Mitigation of in-domain FEXT noise in the downstream direction by using precoding at the AN.
2. Mitigation of in-domain FEXT noise in the upstream direction by using cancellation at the AN.
3. Mitigation of out-of-domain noise in the upstream direction by using cancellation at the AN.

Vectoring will achieve its greatest benefit when appropriate use of DSM L1 and L2 techniques has already reduced other forms causes of instability and thus the dominant degradation on the loop is FEXT or out of domain noise.

A.3.1   Downstream vectoring

FEXT will become the limiting factor for downstream rates for VDSL2 systems with short loops when DSM Level 1 and Level 2 methods are already properly used to address line stability. Several methods have been proposed for using multi-user precoding at the AN to mitigate FEXT in the downstream direction. These methods "pre-subtract" or "pre-compensate" for the FEXT while meeting transmitted power constraints. These techniques can achieve performance close to the theoretical maximum under certain conditions.

A.3.2   Upstream vectoring

In the upstream direction, vectoring is beneficial in the following cases:

a) In short loops and high-bandwidth systems such as VDSL2 after stability has been addressed with Level 1 and 2 DSM, FEXT can become the limiting factor for upstream rates. The effect of FEXT is particularly strong in situations with lines of differing length, where currently, in non-vectored VDSL system, upstream power "back-off" (UPBO) must be used to prevent excessive FEXT, at the cost of sacrificing performance for some or all users.
b) When an external noise source strongly affects multiple lines of the vectored system, then the out-of-domain noise on these lines is strongly correlated. This strong correlation, which is sometimes also called spatial correlation, can be exploited to suppress the out-of-domain noise and thus improve performance.

Several methods have been proposed for multi-user decoding at the AN to mitigate FEXT and/or to suppress out-of-domain noise in the upstream direction. These include:

1. Generalised decision-feedback equalisation,
2. Multi-user zero-forcing decision-feedback equalisation,
3. Linear filtering,
4. Error whitening.

In the absence of out-of-domain noise, linear filtering can achieve performance close to the theoretical maximum. However, if a common external noise source affects multiple lines, then non-linear multi-user decoding techniques can significantly improve performance.

ANNEX B SERVICE REQUIREMENTS (Informative)

By way of background, the following information extracted from [5][1] is intended to give the reader an appreciation of some of the key service requirements. However the reader is referred to [5] for the complete rationale behind these requirements:

Video Service

Standard Definition Video Performance Objectives:

Table B-1 lists the QoE performance objectives for MPEG-4 AVC or VC-1 encoded standard definition video materials. Assumptions are:

- MPEG-4 AVC or VC-1 codec
- MPEG-2 transport stream with seven 188-byte packets per IP packet
- no or minimal loss concealment (tolerable loss rates may be higher depending on degree and quality of STB loss concealment)
- metrics are end-to-end from head-end encoder output to after any application layer protection mechanisms at the customer premises

Transport stream bit rate (Mbps)	Latency	Jitter	Maximum duration of a single error	Corresponding Loss Period in IP packets	Loss Distance	Corresponding Average IP Video Stream Packet Loss Rate
1.75	<200 ms	<50 ms	<= 16 ms	4 IP packets	1 error event per hour	<= 6.68E-06
2.0	<200 ms	<50 ms	<= 16 ms	5 IP packets	1 error event per hour	<= 7.31E-06
2.5	<200 ms	<50 ms	<= 16 ms	5 IP packets	1 error event per hour	<= 5.85E-06
3.0	<200 ms	<50 ms	<= 16 ms	6 IP packets	1 error event per hour	<= 5.85E-06

Table B - 1: Recommended Minimum Transport Layer Parameters for Satisfactory QoE for MPEG-4 AVC or VC-1 encoded SDTV Services

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[1] The text of Annex B is reproduced from Broadband Forum TR-126 with the permission of the Broadband-Forum.

High Definition TV: Transport Layer Performance Objectives:

We propose a value of four hours as the minimum Loss Distance for HDTV services, assuming that not all errors will result in a visible impairment, because:

- loss of B-frame information is sometimes below threshold of detection by the viewer
- error concealment will be used with HD decoders

Table B-2 below lists the QoE performance requirements for MPEG-4 AVC or VC-1 encoded high definition video materials.

Assumptions for Table B - 2 below:

- MPEG-4 AVC or VC-1 codec,
- MPEG-2 transport stream with seven 188-byte packets per IP packet
- STB has some level of loss concealment
- encoder output to after any application layer protection mechanisms at the customer premises
- metrics are for the IP flows containing video streams only, IP streams for other applications may have different performance requirements

Transport stream bit rate (Mbps)	Latency	Jitter	Maximum duration of a single error	Corresponding Loss Period in IP packets	Loss Distance	Corresponding Average IP Video Stream Packet Loss Rate
8	<200 ms	<50 ms	<= 16 ms	14 IP packets	1 error event per 4 hours	<= 1.28E-06
10	<200 ms	<50 ms	<= 16 ms	17 IP packets	1 error event per 4 hours	<= 1.24E-06
12	<200 ms	<50 ms	<= 16 ms	20 IP packets	1 error event per 4 hours	<= 1.22E-06

Table B - 2: Recommended Minimum Transport Layer Parameters for Satisfactory QoE for MPEG-4 AVC or VC-1 encoded HDTV Services

The PLR in the range of 10^{-6} recommended for video services may require special error control techniques to achieve the target.

The network layer performance objectives are summarised in the figures below showing packet loss ratios as a function of bit rate and time between uncorrected loss events for isolated packet loss events. Also shown are plots representative of SD video with a loss distance of one hour between packet loss events and HD video with a loss distance of 4 hours between packet loss events. The figure assumes that each IP packet carries 7 MPEG data packets, each 188 bytes long. The plots implicitly assume that error statistics are stationary and time invariant.
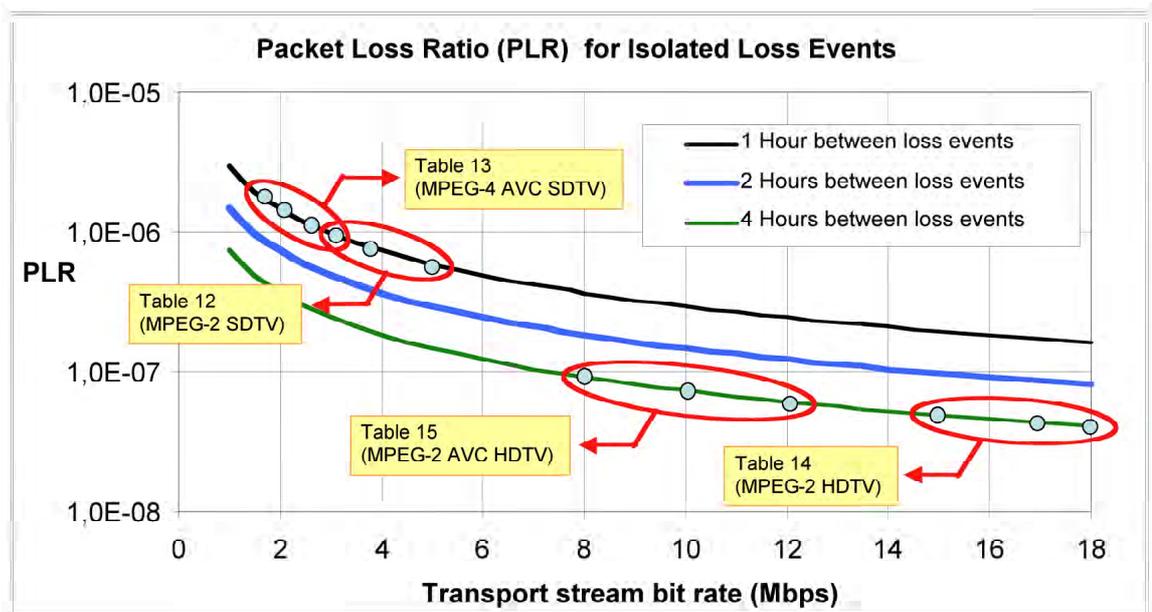
Figure B - 1: PLR required to meet average time between loss events of 1, 2 and 4 hours assuming isolated lost packets.

The figures below show packet loss ratios as a function of bit rate and time between uncorrected loss events for typical DSL burst loss events of 8 ms and 16 ms, respectively. The "ripple effect" in the charts is the result of rounding to an integer number of lost/corrupted IP packets. For example, 8 ms of lost video data in an MPEG-2 transport stream at a bit rate of 3 Mbps:

Total MPEG packets per second = 3 Mbps / 8 bits per byte / 188 bytes per MPEG packet

= 1994.7 MPEG packets per second

Total IP packets per second = 1994.7 / 7 MPEG packets per IP packet

= 285 IP packets per second

A loss of 8 ms corresponds to = 285 IP packets per second * 0.008 seconds

= 2.28 IP packets lost.

Because an entire IP packet is lost if a part of a packet is lost, this is rounded to the next integer = 3 IP packets. And because the lost bytes are not necessarily aligned to IP packet boundaries, this would be further rounded to 4 IP packets.
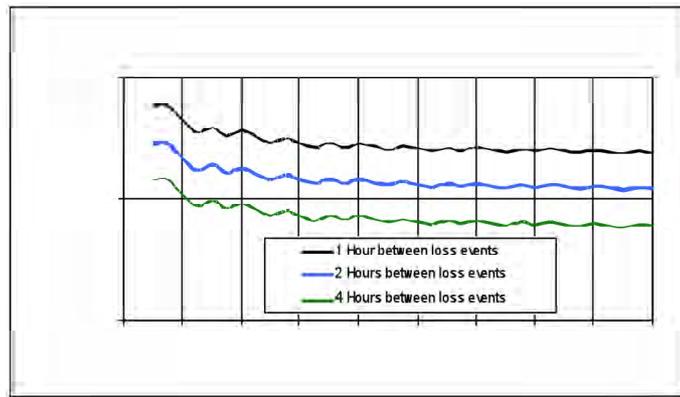
Figure B - 2: PLR required to meet average time between loss events of 1, 2, and 4 hours assuming each event is an uncorrectable DSL error that loses 8 milliseconds of contiguous data.
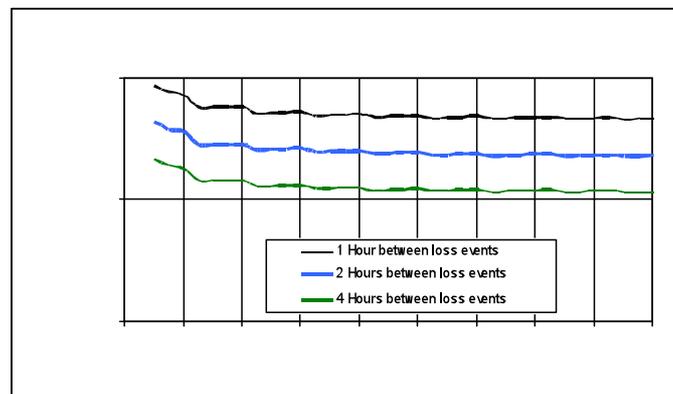
Figure B - 3: PLR required to meet average time between loss events of 1, 2, and 4 hours assuming each event is an uncorrectable DSL error that loses 16 milliseconds of contiguous data.

Severe Error Limits for SD and HDTV Services:

In addition to average packet loss rates impacting picture / audio quality and availability metrics, it may also be advantageous to define a second set of limits on severe impairments. These limits would apply to quality degradations that fall between the impairments generated by the packet loss limits specified above and total service outage (i.e. black screen) metrics specified by the dependability metrics. These gross impairments could include video frame drops, frame repetitions (freeze frames), or short duration (less than 10 seconds) loss of intelligible audio or video or control (e.g. due to protection switching). Metrics are TBD based on industry input and could be specified by frequency of the error event per time unit – e.g., a maximum of one severe error per day and the duration of the impairment.

IMPLICATION FOR NICC DSM WORK: Assume most IPTV service providers are now focussed on MPEG4 compression (as opposed to MPEG2).

Focus on transmission speeds of 3 Mbit/s for SDTV and 10 Mbit/s for HDTV or n*SDTV channels. Targets above for packet loss, maximum duration impact of a single error & loss distance can be related to DSM stability metrics (code violations etc.). Retrain counts can be related to outage probability since an outage is a retrain.

Voice Service

There are four key VoIP QoE impacting factors are :

- o   delay (including delay variation or jitter),
- o   the speech codec,
- o   cell/packet loss,
- o   echo.

Services	User QoE Performance Targets	
	QoE metrics	QoE targets
Conversational voice (CBR and VBR)	Conversational Voice	
	R-factor	ΔR PSTN - Packet < 3R
	delay	< 150 ms
	distortion	Ie < 3R
	Path Interruptions Due to Failure	
	Frequent Interruption	80ms (affects speech intelligibility)
	Infrequent interruption	3 sec (perceived as call drop)

Table B - 3: Voice QoE Requirements Guidelines

Note the QoE performance targets listed in the table above are for the complete end-to-end voice call. Since an end-to-end voice call will typically traverse multiple networks, the impairment objectives shown in the Table B - 3 above will need to be distributed across all the networks and cannot normally be consumed by a single network. ITU-T Recommendation Y.1541 [12] provides guidance in this area.

IMPLICATION FOR NICC DSM WORK: No specific requirements covering stability beyond the general availability and line interruption metrics. Onerous targets for video services (with longer session/call hold times e.g. 2 hours versus 4 minutes) will probably also subsume any voice service requirements.

Internet Access Service

Currently, broadband access is used mainly for access to the Internet and there are no guarantees on the quality of service of the transport layer as the Internet itself is based on best-effort transport. Since the transport service is best effort, and services could be provided from outside the transport service provider's control, no quality of service guarantees can be made. However, target QoE metrics and values can be established for these applications and services in order to satisfy user expectations.

Web-browsing and interactive gaming applications are common representatives of best-effort data services offered. The table below provides the performance guidelines for these services.

BE Application	Degree of symmetry	Typical amount of data	Round trip system response time	Jitter
Interactive games	Two-way	< 1 KB	< 100 ms	<10ms
Web browsing	Primarily one-way	< 100 KB, typically 10KB	Preferred < 2 seconds / page Acceptable <4 seconds	n/a

Table B - 4: Summary of Best-effort Application QoE Guidelines

IMPLICATION FOR NICC DSM WORK: No specific requirements covering packet loss or re-train events, so need to base these on service provider requirements and experience to keep customer service calls below an acceptable level.

Annex C (Informative) BASIS FOR COMPARISON – SIMULATION APPROACH OVERVIEW

C.1 Non Time Varying Scenarios

DSM Level 1 (or Dynamic Line Management) investigates line stability for intermittent noises. The data rate versus length curve is of interest for DSM level 1/DLM in this document.   Level 1 comparisons may investigate a comparison of data rate versus length for the given outage probability specified in [5]. **This will be called**

Scenario 0.
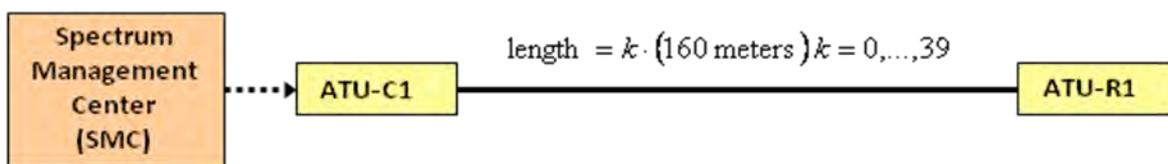
Figure C - 1: Scenario 0

Level 2 DSM adds the management of DSLs in the presence of mutual crosstalk. Various crosstalking situations are of interest including scenarios with a mixture of DSM level 2 and non-DSM level 2 equipment. The proposed cable length scenarios to explore for DSM Level 2[1] appear in the next 3 subsections.

ADSL2Plus (Downstream) from the DLE, Equal Lengths - Scenario 1
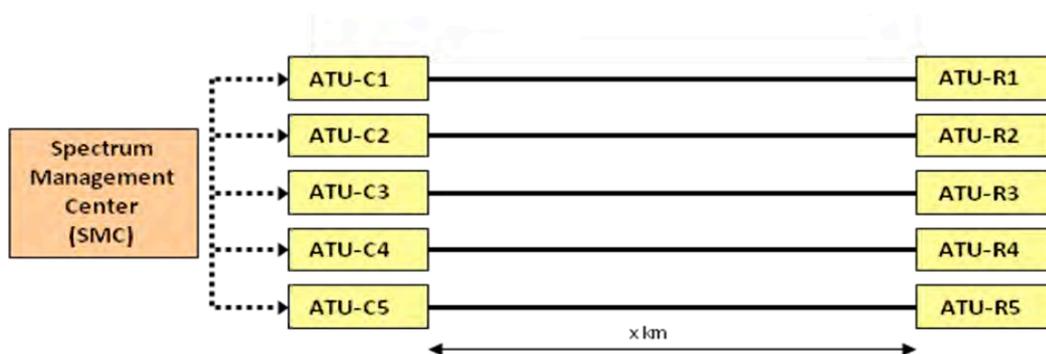
Figure C - 2 – Scenario 1

The length x km is to be set at both 1.2 and 3.0 km. Line 1's data rate is to be evaluated with Lines 2, 3, and 4 at ADSL2plus data rates of 5 Mbps (x= 1.2 km) and 4 Mbps (x=3 km) and Line 5 has respectively 12 Mbps and 9.5 Mbps. Additionally, Line 1's data rate is to be evaluated with ADSL1 operating in rate-adaptive mode (to 8 Mbps) on lines 2, 3 and 4 for the 3km scenario and with rate-adaptive ADSL2plus on these lines for the 1.2km scenario.

RATIONALE: The UK ADSL2plus market has been characterised by advertising maximum headline speeds in the 16-24 Mbit/s range. Line lengths much longer than the above will not achieve such speeds so it represents the high-end scenario used by marketers. In addition, a "typical" line length is nearer to about 3km (around 30dB attenuation) so this is also included.

ADSL2Plus from the Exchange and Cabinet, (Scenario 2)
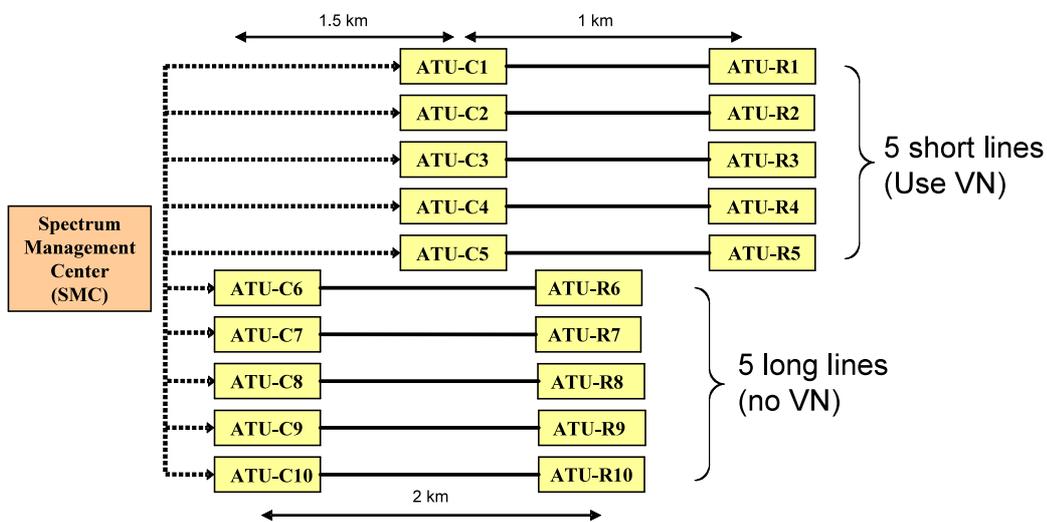
Figure C - 3: Scenario 2

NOTE: ATU-C1 to ATU-C5 will need to operate using power back-off with a CAL value of 16

User Index	1	2	3	4	5	6	7	8	9	10
DLE/PCP Location(km)	1.6	1.6	1.6	1,6	1.6	0	0	0	0	0
CPE Location(km)	2.75	3.0	3.2	3.2	3.0	1.15	1.15	2.3	2.0	2.2

RATIONALE: Explores the impact of differential lengths including cabinet deployment for typical UK cable lengths

VDSL2 (Upstream), Differential Lengths (Scenario 3)
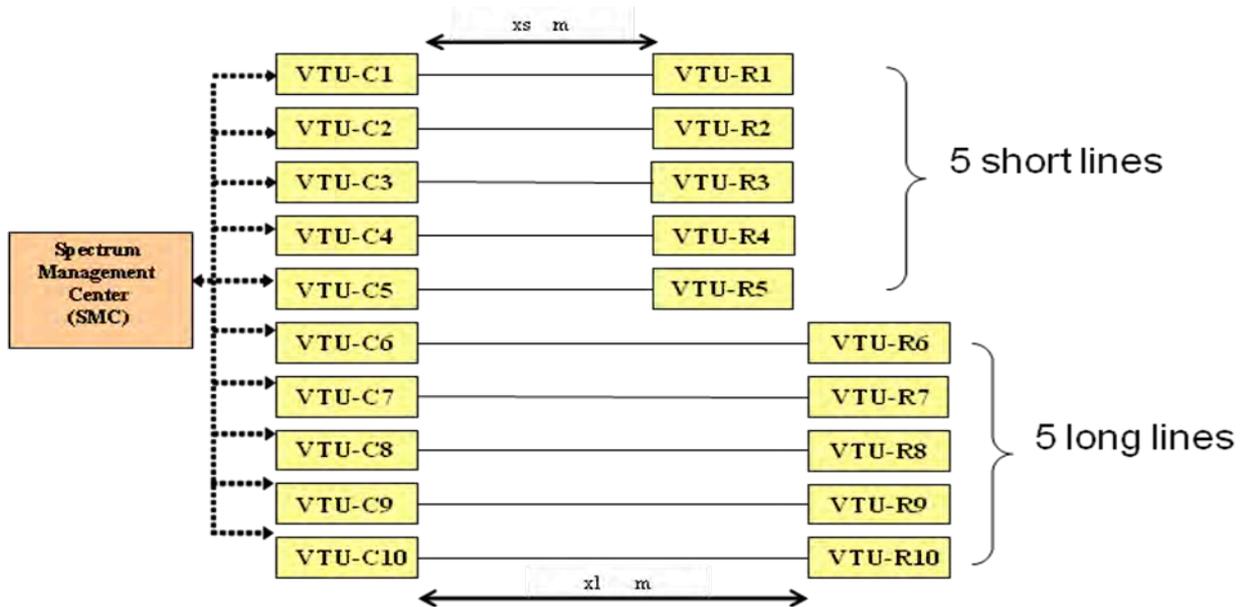
Figure C - 4: Scenario 3

Where xs = 600 m when xl = 1200m and xs = 420 m when xl = 1000m. The CAL value used is 16.

RATIONALE: Explore the impact of differential lengths with cabinet deployment for typical UK cable lengths. Note that typical lengths are around 430m (~50% penetration) and 1km (~90% penetration) so additional simulation results should be added for these lengths.

C.2   Time Dependency Scenario

There is a binder full of DSL lines, but any, all, or none can be excited at various times. The situation might be described as the first customer to awaken in the morning and turn on their DSL connection would have little crosstalk noise and thus a large data rate possible. However, when another customer energises, the first customer could become unstable and retrain. Subsequent 2nd and 3rd crosstalkers are likely to cause less harmful noise, so the Virtual Noise is set at the level of the 1st excited crosstalker (which might be say 20 dB above the background noise). Since the management system does not know which line will turn on first, all have the same Virtual Noise set to one crosstalker. A VN level of "1 FEXT – 6dB" will also be evaluated for this scenario and any overall reduction in transmitter power levels arsing from use of DSM Level 2 techniques. It is to be expected that if VN levels are set routinely well below the typical worst case actual noise seen during diurnal cycle, then it should have no impact on overall network throughput. Additional evaluation of VN benefits and issues is for further study.

The baseline noise can be either of -140 dBm/Hz or -155 dBm/Hz and the situation of transition of noise from the baseline if the DSL's measured noise margin remains negative for at least 10 seconds for the applied dynamic spectrum management strategy under evaluation, which may include TRA, AMA, or VN. DSL modem dynamic response (i.e., "swapping") mechanisms evaluated may include ADSL1 embedded operations channel (best 3-of-5) at one swap per 800ms or ADSL2/2+ (or VDSL2) 16 kbps HDLC embedded operations on-line reconfiguration channel transmission methods.

This scenario may be changed or enhanced as the work on this topic moves forward.

RATIONALE: Explore the impact of "the first disturber" situation, diurnal cycle and abrupt changes (e.g. switching lines on and off). Also facilities modelling of the implications of modem bit-swap time and capabilities.

C.3   Cable & Noise Environment

C.3.2   Cable Model

The cable model should assume 0.5mm Cu cable with characteristics defined by cable type known as BT100 a.k.a BT_dwug as described in ETSI TS 101 270-1 V1.2.1 (1999-10) [13], and more precisely defined in [1] gives the model as:

$$
[BT\#1]
$$

$$
Z_s(f) = \left(\frac{1}{\sqrt[4]{R_{oc}^4 + a_c \cdot f^2}} + \frac{1}{\sqrt[4]{R_{os}^4 + a_s \cdot f^2}} \right)^{-1} + j \cdot 2\pi f \cdot \left(\frac{L_0 + L_\infty \cdot (f/f_m)^{Nb}}{1 + (f/f_m)^{Nb}} \right) \quad [\Omega/\text{km}]
$$

$$
Y_p(f) = (g_0 \cdot f^{Nge}) + j \cdot 2\pi f \cdot (C_\infty + C_0 / f^{Nce}) \quad [\text{S/km}]
$$

The final row of Table 23 from [1] gives the cable parameters as:

Wire_type	Roc	Ac	Ros	as	Lo	L∞	fm	Nb	g0	Nge	Co	C∞	Nce
BT_dwug	179	35.89e-3	0.0	0.0	0.695e-3	585e-6	1e6	1.2	0.5e-9	1.033	1e-9	55e-9	0.1

RATIONALE : This is what was previously agreed within the NICC DSL Working Group

C.3.3   Crosstalk Coupling Model

NEXT coupling will be modelled by:

$$
\text{NEXT}(f, n) = -55 + 15 \log_{10}(f/100\text{kHz}) + 6 \log_{10}(n/49)
$$

Where f is frequency in kHz and n is the number of disturbers and the result is expressed as a power coupling factor in dB.

FEXT coupling will be modelled by:

$$FEXT(f,n,l) = -50 + 20 \log 10(f/100kHz) + 6 \log 10(n/49) + 10 \log 10(l/km)$$

Where f is frequency in kHz n is the number of disturbers, and l is the length of shared cable in km, and the result is expressed as a power coupling factor in dB. The constant (-50) in this equation represents 5 dB greater coupling than generally assumed in the USA.

These equations express the coupling levels with 1% probability.

Where disturbers (either NEXT or FEXT) of different types are added together the combination should be added by the FSAN method:

$$X_{combined}(f) = ((X_A(f))^{1/0.6} + (X_B(f))^{1/0.6})^{0.6}.$$

where X_A and X_B XB are the absolute crosstalk powers to be combined at frequency f.

Any NEXT should be added to the FEXT using simple power addition. Modelling should include the effect of attenuated NEXT (i.e. NEXT from pairs that may terminate either closer to or further away from the exchange than the victim system). Results should be presented for specific scenarios described in Annex A with individual crosstalk coupling reduced by 9 dB when combining with the intermittent noise of Section C.4.8 to avoid compounding worst-case effects.

RATIONALE: This is what was previously agreed within the NICC DSL Working Group

C.3.4   Number and Type of Interferers

For DSM Level 1/DLM:, fixed noise sources remain the same as in previous ANFP studies (cp38-2), namely these mixtures of stationary crosstalk noise

ADSL2plus   20 pairs

VDSL   12 pairs with NTEs collocated with ADSL2plus

HDSL(1168 kbit/s)   2 pairs with NTEs at 3.2544 km from exchange (fixed)

HDSL (784 kbit/s)   3 pairs with NTEs at 3.5256 km from exchange (fixed)

Basic rate ISDN (2B1Q)   6 pairs with NTEs collocated with ADSL2plus

Additionally for DSM Level 1, a situation of only 20 ADSL2Plus is also considered for additional information.

For DSM Level 2: The ADSL2Plus and VDSL2 components are replaced by the situations in Section 3 where the mutual interaction of the more realistic dynamic DSL spectra use is of interest.

C.3.5   PSDs

Both victims and disturber systems have been previously assumed to have their nominal or template PSDs as defined in the relevant ITU-T standards. However, with DSM Level 2 in the above situations, mutual interference between the lines is important and so in real DSL deployments, the spectra of DSLs is related to the length of line, the crosstalk sensed from other lines, and the level of politeness used with respect to the desired data rate. Thus in DSM, the crosstalk coupling models in Section 4.2 should be applied to the actual spectra of each line as in the scenarios of Section 3 rather than a nominal or template PSD.

RATIONALE: This is the approach that was previously agreed within the NICC DSL Working Group (see [3]) for static spectrum management, but now needs more realistic update for DSM.

C.3.6   Background Noise

Is assumed at two levels of –140 dBm/Hz and -155 dBm/Hz in the downstream direction. -140 dBm/Hz should continued to be solely used for upstream calculations.

RATIONALE : -140 dBm/Hz is what was previously agreed within the NICC DSL Working Group (see [3]) and is what is used in the ANFP and many international DSL standards.   -155 dBm/Hz is also included for additional simulations since -140 dBm/Hz was based on typical early modem noise floors and also on early network surveys that used test equipment with rather high internal noise floors. Modern modems are often able to exploit very low noise floors, which are found on many lines in practise.

Using both noise levels will also lead to more realistic range of rate/reach distributions in the simulations since certain equipment and lines have noise levels at -140 dBm/Hz and above

C.3.7   Time-Varying AM Radio Interference Noise

For further study.

C.3.8   Intermittent Noise

Intermittent noise can lead to chronic-line situations that can cause a DSL to be unstable, as defined in Section 2.2. This type of noise can occur randomly on a single line and change the line's observed noise spectra with respect to the other noises of this section that were observed when the modem first trained.

Intermittent noise can occur randomly on a single line and change the line's observed noise spectra with respect to the baseline noise that was observed when the modem first trained. The word "initialization" here will mean any of these events: full training, fast retraining, SOS, etc. that leads to a disruption in service data rate to the DSL customer. The model presumes that the intermittent noise was not present during this initial training of the modem. Thus intermittent noise is treated as a relative increase in other noises that are modelled elsewhere in this section. This intermittent noise can of course subsequently be, and may likely be, present during re-initialization of the DSL connection. The random nature of the model attempts to capture whether the noise is present during re-initialisation or occurs between initialization and any subsequent re-initialisation (that is, possibly causing a re-initialization when it occurs). When the intermittent noise occurs after initialisation, it may be sufficiently large that the DSL modems' existing protection mechanisms (i.e. error correction, retransmission and/or bit/gain-swapping) may not be able to adjust to nor mitigate the noise, which leads to a re-initialisation or as termed earlier in Section 2.2, an "outage." Lines with no intermittent noise have no outages and would thus not retrain because of noise variation. These other "stable" lines have little impact on customer-problem resolution, while the "unstable" lines with too many outages or re-initialisations have impact. Thus a relatively small percentage of unstable lines may

dominate DSL operational complexity, and further such complexity may limit DSL service rate vs. range and thus significantly impact the level of DSL service offering.

The intermittent-noise model uses the sum[2] of the distributions (inter-line and intra-line) of two random-variables for the power spectral density (PSD) offset in dB to the PSD of any other noise present upon a first initialisation without intermittent noise. This PSD offset is added independently at each tone n. This tone index is not shown in the formulas below but the parameters of the two distributions can be modelled as tone-dependent in sophisticated DSM examinations[3] and as in the appendix of this document, particularly at Level 2 or 3 of DSM. The total noise PSD is:

$$PSD_{\text{int }ermittent} = \underset{\substack{Other\\Noise}}{P\,S\,D}_{base} + \underset{\substack{Inter-Line\\\text{var }iation}}{\Delta P} + \underset{\substack{Intra-line\\\text{var }iation}}{\partial P}$$

the crosstalk components included in the level of PSD_{base} can be reduced by 9 dB in the model to avoid compounding worst-case crosstalk with worst-case intermittent noise effects.

The first "inter-line-variation" noise-offset component, ΔP, has a truncated exponential distribution of mean nominally at 5 dB and maximum value 25 dB that models the variation in intermittent noises on different lines, even if those lines are the same length l. Other values of the mean are also possible in integer steps from 0 to 5 dB. A value of zero implies that there is no inter-line variation and all lines essentially exhibit the same average level of time variation. Performance evaluation averages over 1000 lines of this same length by sampling this first distribution, once for each line, to obtain the first inter-line offset to the PSD_{base} level. This offset is called ΔP_i for the ith line of this same length l.

The distribution formula for the first truncated exponential inter-line distribution is

$$f_{\exp}(\Delta P_i) = \frac{\lambda e^{-\lambda \cdot \Delta P_i}}{1 - e^{-\lambda \cdot \Delta P_{\max}}} \text{ with nominal } \lambda = 5\,\text{dB and } \Delta P_{\max} = 25\,\text{dB}.$$

The second intra-line distribution for this same length line reflects long-term time variation of the intermittent noise on any single line and is a zero-mean Gaussian distribution with 4 dB standard deviation. If the baseline noise is not crosstalk, this intra-line noise models different combinations of several possible noise sources that add together in various degrees of on/off states to contribute to the noise of one line. This additional intra-line offset is called δP_i. This offset's distribution can be sampled many times to compute average performance for any single line of the 1000, and the process repeated over all 1000 lines for inter-line noise to obtain an average performance for the given line length l. However, the choice of the Gaussian distribution would simplify calculation of performance so that a closed form computation of outage probability can replace a process of sampling the second distribution.

---

[2] Strictly speaking, the second offset in the sum will be conditioned upon the value for the first offset in the sum as is developed presently.

[3] When different offsets are added on different tones, this can indicate either a frequency dependence of the intermittent noise's magnitude or that a shaped PSDMASK has been used, rendering some frequency bands more (higher PSDMASK values) or less (lower PSDMASK values) tolerant to intermittent noises. However, to understand the model initially, the reader might find it easiest to think of the most common situation where the PSDMASK is flat at all used frequencies (say -40 dBm/Hz for ADSL) and that the intermittent noise have the same strength on all tones. This makes the dropping of tone index consistent with all tones being the same and simplifies the equations to follow.

The formula for the intra-line second distribution is

$$f_{Gauss}\left(\delta P_i\right) = \frac{1}{\sqrt{2\pi\sigma^2}} \cdot e^{-\frac{(\delta P_i)^2}{2\sigma^2}}$$ where nominally $\sigma = 4\,\text{dB}$.

Other values of interest for the standard deviation are $\sigma = 0,1,2,3,4,5 \text{ and } 6\,\text{dB}$. Setting the indicator to zero would imply the only noise event on a given line is the possible on/off introduction of a noise of offset ΔP . The value of δP_i will be truncated if sufficiently negative to cause a PSD that would be less than the PSD_{base} level. This distribution's argument is in decibels, and so it is its nominal standard deviation is 4 dB. This second intra-line offset term is relative to the first inter-line offset, so if the first offset is larger then so will be the variation scale even if the standard deviation of 4 dB is retained.

To compute performance over lines of different length the double offset process is repeated for lines of length $l = k \cdot 160\text{m for } k = 0,...,39$.

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C.3.9   Linear Noise combining:

A possible noise situation of interest is where two intermittent noises are added linearly. Thus, the model above is used to generate one noise (perhaps a baseline noise increased by appliances turning on/off in different ways on different lines) and a second noise where the baseline is crosstalk noise that may vary in its average level between lines (ΔP) and possibly on the same line with time as well (δP). Different baselines, and inter-line-noise means, and also intra-line-noise standard deviations, may be used for the two components that are then added together linearly:

$$PSD_{total} = 10 \cdot \log_{10}\left(10^{0.1(PSD_{\text{int}\,ermittent}[1])} + 10^{0.1(PSD_{\text{int}\,ermittent}[2])}\right)$$.

Either one of the intermittent noise components could cause a retrain or outage. A true exact calculation of the outage probability can be complex in the case of linear combinations of two intermittent noise components. However, two cases are of most interest:

(1) One of the intermittent noises dominates, in which case the other is not relevant
(2) Both intermittent noises individually have about the same probability of outage (this of course does not count the case where neither would have caused an outage by itself, but together they both do, presumably a very tiny probability and thus non-significant event)

An outage in either of these linear-combination cases would then be approximated by the sum of the probabilities that either one occurs. In the first case, the more dominant intermittent noise causes instability more often and thus summing its probability with a much smaller 2nd intermittent-noise probability is about equal to the dominant intermittent-noise event's probability. In the second case, the worst situation would be that the outage probability is doubled.

Since different values for the inter-line mean and intra-line standard deviation can be independently chosen for each noise, any correction to the sum-probability approximation could be evaluated by varying the choices for mean and standard deviation for each of the components, rather than trying to introduce a highly complex mathematical approximate (or very long-time-running computer simulation).   The probability of outage target in evaluating all DSM methods would then, in the worst case, use one-half the target value.

Frequency-dependence of intermittent noises or programmed PSDMASKs: When systems with frequency masks or PSDMASKs are used in shaped power-back-off methods, a fixed level of intermittent noise will be more harmful at those frequencies for which it is largest or at those frequencies for which the PSDMASK has been reduced if the intermittent noise has constant offset with frequency. By reference to a baseline noise that is frequency dependent, the intermittent noise is then also by default frequency dependent. More sophisticated models may later thus allow variable mean of the exponential distribution with their dependency thus on the tone index.   The specific values suggested here allow reasonable evaluation of various DSM methods in terms of relative performance.

A frequency-dependent inter-line offset has been suggested as a desired generalisation of this model. Appendix A addresses the generalisation of this model to frequency dependent offsets.

RATIONALE : This model captures the time-variation of intermittent noise level on a single line (intra-line) and also captures the variation in intermittent noise power between different lines (inter-line) of the same length to model degree of instability of line.

C.4   DSL Performance Modelling

VDSL2 and ADSL2plus systems have been assumed to be operating with the following efficiency:

  (a) Assumed Shannon gap for a perfect binary signalling system: 9.75 dB

  (b) Design coding gain for systems in FAST mode: for ADSL2plus: 5 dB, for VDSL2: 3 dB

  (c) Fraction of adjusted Shannon capacity delivered to customer: 100%

  (d) Framing overhead: 0%

  (e) Implementation gap (difference between real system and theoretical system): 2 dB

  (f)   Minimum exploitable information density: for ADSL2plus: 1 bit/s/Hz, for VDSL2: 2 bit/s/Hz.

Only capacity that is "in-band" for the system simulated is included

RATIONALE: This is what was previously agreed within the NICC DSL Working Group .

Annex D (Informative) - DSM/DLM Algorithm Modelling

D.1   Swapping Assumptions

Gain swapping is the process of changing the gains with respect to values set upon initialization of the transmit energies. Gain swapping over a range of -14 dB to +2 dB is mandated in standards. Larger ranges are allowed optionally through a parameter called "EXTGI" in ITU standards. This document will presume the standard compliant range of -14 to +2 dB.

Bit swapping is the process of changing the number of bits allowed on a tone from the minimum of 0 to a maximum of 15 bits/tone with 0 bits per tone causing very small (or no) energy to be applied to the tone. A system with bit-swapping disabled would not swap. **Nominal** bit-swapping will be able to swap one bit from a degraded tone to a better tone in 800ms. **OLR Type 1** bit-swapping of ADSL2plus and VDSL2 can swap up to 50 bits from degraded tones to better tones in 1 second.

RATIONALE: A standardised capability for equipment compliant with ITU standards.

D.2   Level 1 DSM Algorithms: TRA and AMA

Automatic Margin Adaptation (AMA) sets the DSL-circuit noise margin at increasingly higher levels on an unstable DSL line in an effort to protect unstable lines against time-varying large increases in noise. Therefore, AMA upon a reset triggered by intermittent noise exceeding the existing margin will increase that margin by an increment upon ensuing retrains, an example being an increase by 3 dB from 6 dB to 9 dB. Continued intermittent noise exceeding that new threshold causes a subsequent increment, in the example then to 12 dB, and in like fashion finally to a maximum level, typically 15 dB, whereupon AMA will attempt no further margin increases. The minimum rate for AMA is set very low at 160 kbps and the maximum is set at the highest level allowed by the xDSL (8 Mbps for ADSL1 and 24 Mbps for ADSL2PLUS). The data rate upon retraining with AMA's converged margin (6, 9, 12, or 15 dB) is then set at the level corresponding to the configuration of the DSL with the large noise present that caused the retrain. The data rate achieved with a prescribed level of outage probability is then recorded.

Tiered Rate Adaptation (TRA) always retrains with a fixed target margin (typically 6 dB), but instead sets the minimum and maximum rate range with line-dependent data rates for the service (rather than using the same min and max rates for all lines as in AMA). The maximum TRA rate is set so that the modem is likely to be stable for the given observed level of intermittent and other noises on the line. This means that the maximum rate setting will lead to the prescribed level of outage probability in Section 2.2 and is recorded as the data rate. The minimum TRA rate is set at a level such that the modem is not left at a very low speed when training with large improbable noises present. Such a level might be 10% less than the maximum level. Typically a set of overlapping tiers of {Rmin, Rmax} rate regions are available for use in TRA, whence it's name. TRA would then select one of the tiers as appropriate for any particular line.

TRA and AMA may be investigated with either no bit-swapping, nominal bit swapping or OLR-type 1 bit-swapping.

D.3   AMA and TRA rate-reach computation with intermittent noise

The AMA and TRA calculations compute the data rate versus length curve for the noises specified in Section 4. Specifically, intermittent noise is of concern for dynamic management. Calculations of AMA or TRA performance use the 1000 line samples per line of the inter-line intermittent noise for each line length between 0 and 7 km with a 160m increment. The stability criteria is set equal according to Section 2.2.

A TRA or AMA outage, or retrain, will occur if the added noise causes a negative margin.   Figure 1 illustrates the progression in time of a particular line of length *l*: The noise offset to the baseline (or background) noise can increase to a level that exceeds the threshold for a retrain, causing an outage. The probability of such occurrence needs to be acceptably low, shown as 0.1% in Figure 1.

The operational margin parameters used in the DSL AMA or TRA systems are:

MINSNRM (assume 0 dB, a retrain occurs when margin is below this level)

TARSNRM (often 6, used as the margin "target" for determining a data rate between the minR and maxR allowed on any restart/initialization, but AMA will increase this incrementally by multiples of the increment (for example to 9, 12, or 15 dB) if necessary to reduce retrains.)

MAXSNRM (The gain and bit-swapping procedures or training-time bit distribution are set to maintain the margin at or below this setting during operation. If the gain level of -14dB with respect to the level set at initialization is not sufficient to maintain margin below this MAXSNRM level, then the excess margin above MAXSNRM at any frequency is to be minimised. This setting is largely of interest only for Level 2 DSM.)
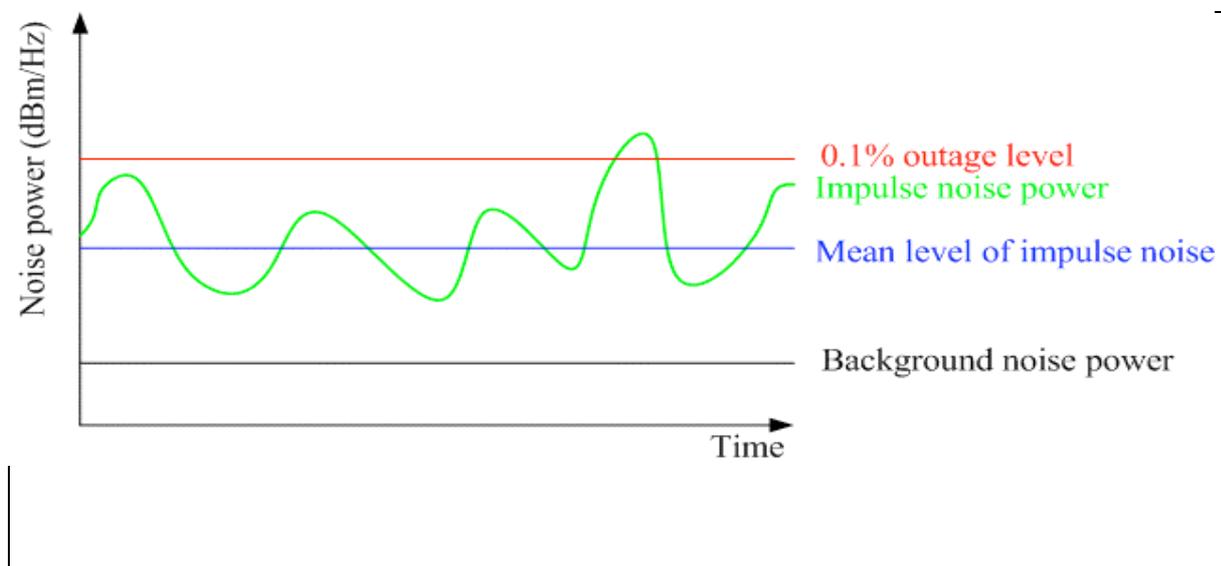

Figure D - 1: Illustration of Noise Relative to Outage Level

Along with the presence of background noise and crosstalk from other users, AMA and TRA calculations assume the presence of Section 2.7s intermittent noise.

TRA calculations assume that the DSL connection operates at the maximum data rate (maxR) when the noise power approaches the noise power level at which an outage event occurs (and at which noise level the modem would retrain). The minR of TRA is chosen slightly less than this number (say 10%) to avoid the

modem becoming "stuck at" a very low speed for a noise event of probability less than the specified outage probability. For each line, the outage noise level is determined from the value of the intermittent noise power and the consequent data rate is then computed. This data rate is averaged over the 1000 lines with intermittent noise for any given length *l*.
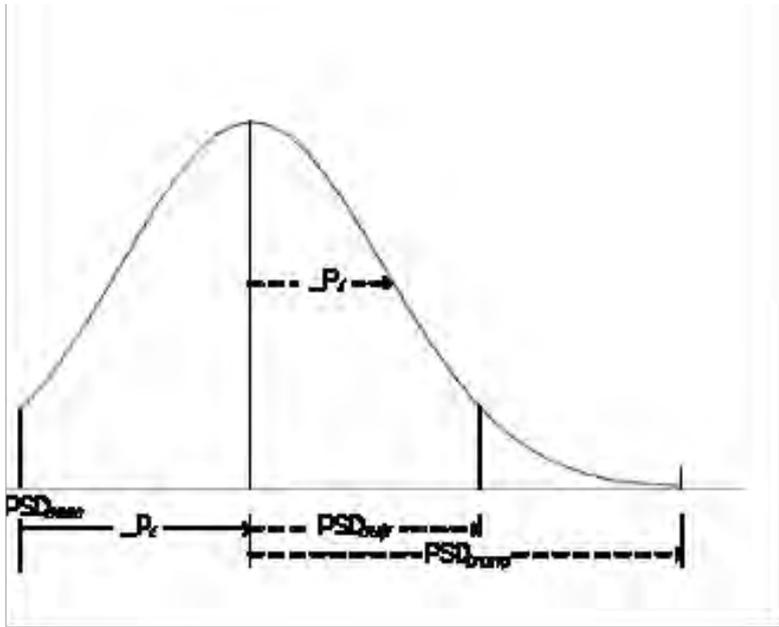

Figure D - 2 – illustration of the intermittent noise distribution and model.

Figure 2 illustrates the rate calculation for TRA (and also will be used momentarily for AMA). The intermittent-noise distribution is referred to the level with respect to a "clean" initialization occurring when the intermittent noise was not present (which is different than the later situation for retraining when such the intermittent noise is present and caused the retrain). Thus, the left limit in Figure 2 refers to the PSD present (so any mixture of crosstalk and background noise, but specifically those mixtures allowed in Section 4 excluding intermittent noise) upon such a "clean" initialization. The rate possible on the DSL connection is the highest allowed at the given target margin level with no intermittent noise present. The upper truncation point is applied to suggest that very large Gaussian sample values of probability less than .01% are eliminated from the model (even noise has certain limitations on how large it can be in practice, like perhaps the upper range of an ADC). The lower truncation point is the baseline noise PSD with no intermittent noise present.

The intra-line noise offset sample for line *i* is ΔP_i and allows computation of the noise PSD level PSD_{out} that corresponds to the outage according to

$$\frac{Q\left(-\frac{\Delta P}{\sigma}\right)-Q\left(\frac{PSD_{truc,i}}{\sigma}\right)}{Q\left(-\frac{\Delta P}{\sigma}\right)}=1-.0001=.9999 \, .$$

or equivalently

$$PSD_{trunc,i} = \sigma \cdot Q^{-1}\left[.0001 \cdot Q\left(-\tfrac{\Delta P}{\sigma}\right)\right] \, ,$$

and then

$$\frac{Q\left(-\frac{\Delta P_i}{\sigma}\right)-Q\left(\frac{PSD_{out,i}}{\sigma}\right)}{Q\left(-\frac{\Delta P_i}{\sigma}\right)-Q\left(\frac{PSD_{trunc,i}}{\sigma}\right)}=1-P_{out}$$

or equivalently

$$PSD_{out,i} = \sigma \cdot Q^{-1}\left[P_{out} \cdot Q\left(-\frac{\Delta P_i}{\sigma} \right) + \left(1 - P_{out} \right) Q\left(\frac{PSD_{trunc,i}}{\sigma} \right) \right]$$

This PSD corresponding to outage can be computed independently for each of two noises in the case of linear combining with the target outage probability $P_{out} \rightarrow PSD_{out}/2$, so then .001/2=.0005 for video and .005/2=.025 for data.   The larger of the two outage PSD's then corresponds to the lower data rate, and is then selected for further calculation because this lower data rate would be more stable, for the DSL connection (that is correspond to fewer trains than the given target outage probability).

For TRA, the data rate is then computed as the data rate achieved at MINSNRM for this computed threshold of unacceptable outage noise level of $P_{out} \rightarrow PSD_{out}/2$. This process is repeated for 1000 lines of each length, and the data rate achieved $R_{TRA,i}$ is then averaged over these 1000. Thus,

$$R_{TRA}(l) = \frac{1}{1000} \cdot \sum_{i=1}^{1000} R_{TRA,i} \quad l = k \cdot 160\,\text{m} \quad, \ k = 0,...,39 \,.$$

In AMA, the unstable lines will increase the margin from their programmed levels when they experience higher levels of noise.   The threshold PSD_{out} of Figure 1 is useful in computing AMA's average rate for any given margin. The TSNRM determined, for example with increments of 3 dB for AMA, then follows from:

TSNRM for AMA	PSD_{out} condition
6 dB	$6\,\text{dB} \leq PSD_{out} < 9\,\text{dB}$
9 dB	$9\,\text{dB} \leq PSD_{out} < 12\,\text{dB}$
12 dB	$12\,\text{dB} \leq PSD_{out} < 15\,\text{dB}$
15 dB	$15\,\text{dB} \leq PSD_{out}$.

The AMA lines will then retrain to a new data rate corresponding to that margin applied to the noise present at the time of, and which caused, the retrain. This noise level present during retraining has a non-zero probability of being between $PSD_{out,i}$ and $PSD_{trunc,i}$. For each of the 1000 lines, a linear approximation of the probability curve in Figure 2 between the P_{out} at $PSD_{out,i}$ and .0001 at $PSD_{trunc,i}$ is made according to

$$P_{AMA,i} = Q\left(\frac{PSD_{out,i}}{\sigma} \right) - [0,1] \cdot \left[Q\left(\frac{PSD_{out,i}}{\sigma} \right) - Q\left(\frac{PSD_{trunc,i}}{\sigma} \right) \right]$$

where $[0,1]$ denotes a random selection between 0 and 1.

The sampled probability is then converted into a noise level as

$$PSD_{AMA,i} = \sigma \cdot Q^{-1}\left(P_{AMA,i}\right) \quad ,$$

which is then used to compute the AMA data rate with the applicable margin at the AMA specified target margin. Again, the larger of the two outage noise levels is retained if there are multiple intermittent noises added linearly. Then, the same averaging is used (R_0 is the same as in TRA case):

$$R_{AMA}(l) = \frac{1}{1000} \cdot \sum_{i=1}^{1000} R_{AMA,i} \quad l = k \cdot 160\,\mathbf{m} \quad , \; l = k \cdot 160$$

Frequency dependency can be used in the offsets and thus the nominal 5 dB mean of the exponential distribution and the nominal 4 dB standard deviation of the Gaussian distribution become frequency dependent. For instance for a high baseline noise at some frequency index *n*, for which a large offset might mean very large and impractical noise, the mean of the exponential distribution can be reduced and also the standard deviation of the Gaussian may be reduced relative to other frequencies for which the baseline noise is lower. In such cases, an outage occurs for a non-swapping DSL connection if PSD_{out} is exceeded on any

tone. In a nominal swapping DSL connection, PSD_{out} must be exceeded simultaneously on at least 10

tones. In an OLR-type 1 swapping DSL connection, PSD_{out} must be exceeded simultaneously on at least

500 tones In calculation, the data rates for TRA and AMA can be computed consistently by assuming that the 10 (or 500) tones were selected to be any set of 10 (or 500) within the band without significant change to the computed values.

RATIONALE : Allows theoretical comparison of the two methods with reasonable assumptions on intermittent noise that do not overly complicate the calculation.   Change of distribution within reasonable limits should not change the comparison that is illustrated by this calculation.

D.4   AMA and TRA rate-reach computation with time-varying AM noise

For further study.

D.5   Level 2 DSM:

Level 2 DSM plots focus on rate/reach gains and power savings for stable DSLs as a function of their mutual crosstalk interference and may or may not be combined with intermittent noise models.   When combined with intermittent noise models, the mean (5 dB for Level 1 DSM) of the Exponential component $\Delta P_i(n)$ and

the standard deviation (8 dB for Level 1) of the Gaussian component $\delta P_i(n)$ of intermittent noise may

become explicitly frequency dependent (since both are referred to a baseline noise component that may now be highly variable with frequency). More on frequency dependency occurs in the Appendix of this document.

D.6   Virtual Noise (VN) Modelling

The worst-case crosstalk noise is that occurring when in each of the scenarios in Section 3 all transmitted DSL signals are at the maximum allowed PSD level in the applicable ITU standard for ADSL1 (G.992.1),

ADSL2Plus (G.992.5), and VDSL2 (G.993.2).   When intermittent noise is present, virtual noise is set at $VN(n) = \max\left(PSD_{out,i}(n), PSD_{xtalk}(n)\right)$. Virtual Noise occurs only in recent updates of the ADSL2Plus standard (G.992.5) and VDSL2 (G.993.2). Comparisons with it thus should use OLR Type 1 swapping, which is also present only in those same standards (actually in earlier versions of those same standards). VN cannot be used in ADSL1, but nominal bit swapping is standard in ADSL1 (G.992.1).

Virtual noise modeling uses a VN index:

VN = index varied from 0 to 1 (1=Alcatel method [ETSI TM6 2008-TD-32 (April, Antwerp)]

   •   0.25 = [ITU BT Contribution 2008-AB-070, (June, Antwerp)]), margin = 6dB
VN index

      Fraction (0<x<1) of worst-case value

      0 = no VN ; 1= worst-case choice.

      A wide range of VN choices then is covered in between.

Simulations should use a VN level 6dB below the worst case noise as one data point at a 0.1% probability of retrain.

No L2 mode (so noise change is modem retraining/initialising)

For Scenario 1 of this report, VN is applied only on line 5 to show the effect of a single VN line upon other lines.   The sum of the data rates on the other lines as well as the smallest data rate thereof can be plotted versus VN index. For Scenario 2 of this report, VN is applied only on the remote-terminal lines. Again the sum of the remaining lines and the worst-case can be plotted versus VN index. **For** Scenario 3 of this report, VN is applied only on the odd lines and the sum of the remaining (even) lines and the worst-case among them may be plotted versus VN index.

With intermittent noise present, VN would be set to the PSD_{out} described above.

D.6.2   Calculations with VN

Power vs VN index curves are computed assuming the fixed-rate targets for all the lines in the Scenarios of Annex C of this report. The VN index is swept from 0 to 1, and as the virtual noise level increases, the power required by the lines to achieve their rate targets is computed using iterative water filling. The power required by TRA is computed using iterative water-filling, based on the actual noise level on the line.

The data rate curves plot the sum of data rate for non-VN lines assuming the fixed-rate target for the other lines shown in the target scenarios and computing the data rates using Iterative water-filling.

D.6.3   DSM Level 2 Loading Algorithm

An SMC control indicating Level 2 operation recommends to a particular DSL connection's loading algorithm that more polite loading on frequency bands of relatively lower PSDMASK is desirable in order to improve overall performance in the cable/binder. This algorithm can be descriptively dubbed "multi-level-water-filling." If this Level 2 control is not set, that is, if Level 2 DSM operation is not requested by the management system, the management system is by default recommending that the Level 1 loading algorithm known as water-filling or some approximation thereto is sufficiently polite for use on that particular line.

The basic water-filling or "Level 1" algorithm can be theoretically written

$$Power(n) = \max\left\{0, K - \frac{\Gamma \cdot Noise(n)}{\left|Channel(n)\right|^2}\right\}$$

where the power is for all tones *n* such that it is either zero or the difference between a frequency-independent constant *K* and the scaled (by the gap Γ) channel noise-to-signal ratio. The constant *K* is the "water level."

Figure D-3 illustrates a so-called "Greedy" or "Levin-Campello" algorithm used to approximate water-filling. This algorithm is optimum for the situation where an integer number of bits must be assigned to each tone. A table of energies is maintained for each tone (typically, this is a single column of energies in memory that is scaled by a factor related to the inverse gain-to-noise ratio on each tone to generate efficiently a table column for each tone in implementation, thus saving memory at the expense of a single multiply). This table contains the incremental energy required to add each successive bit to the tone. Bits are assigned to tones in a greedy manner by placing the next bit to be loaded on the tone requiring least incremental energy to carry that bit. Dynamic loading algorithms usually continuously compare the tone currently requiring the most energy for its highest-order bit transmitted to all next-incremental energies on other tones. If the channel or noise changes make another bit-distribution's incremental energy less (or more attractive), then standardised bit-swapping control allows the moving (swaps) of the bit into a lower incremental energy position. Such algorithms may also adjust gain levels over standardised levels and the communicate gain changes to the transmitter through a standardised control channel, known as "gain swapping," even if no bit swaps occur.

The DSM Level 1 water-filling-approximated loading algorithm thus tends to send bits in the best (often lower frequency) tones first.
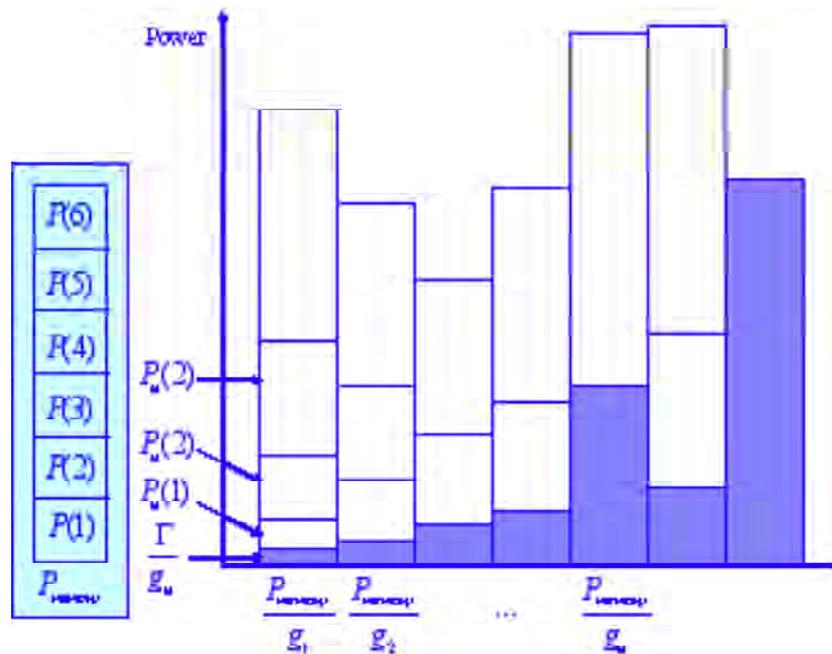

Figure D - 3– DSM Level 1 Loading Algorithm's use of bit-loading tables (sometimes called the "Levin-Campello" method, see [DSL Advances, Starr et. al., 2003, Prentice Hall]).

In the case where the SMC sets the DSM Level to 2 indicates that the modem should best use the more polite DSM Level 2 loading algorithm as described in this subsection. In this case the modem initially runs a greedy or Levin-Campello algorithm. However, when the initial algorithm is completed, the modem moves bits from the tones with lower PSDMASK1 and reallocates those bits (and their crosstalk producing energy) to tones with relatively higher PSD as long as it is possible within the constraints of the supplied Level 2 DSM PSDMASK2. Figure D- 4 also contrasts the spectra produced by the Level 1 and Level 2 algorithms.
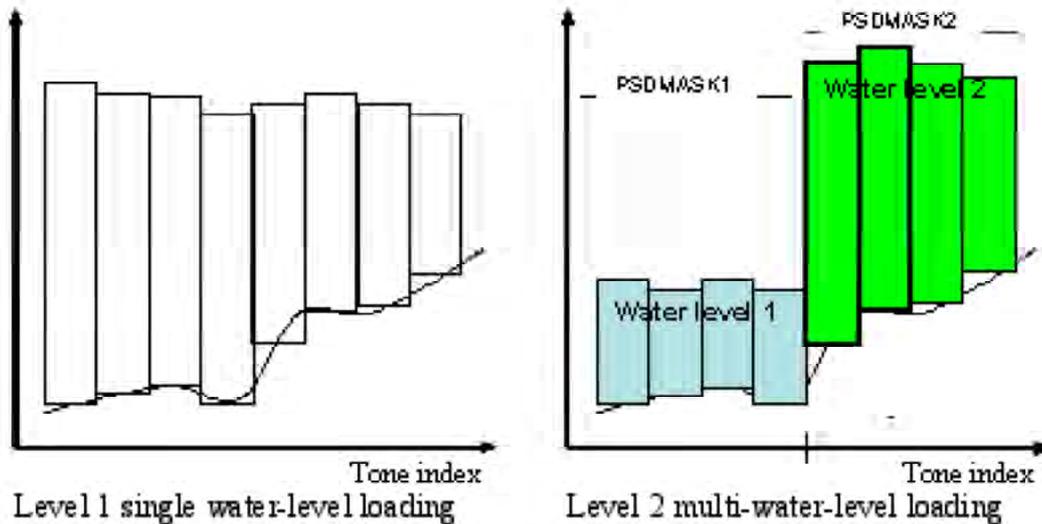

Figure D - 4 – Comparison of the Level 1-User (water-filling) and Level 2 (multi-level-water-filling) Loading Algorithms' consequent spectra.

The following shows the detail of the multi-water-level loading algorithm. When the bits are removed from the lower PSDMASK band and placed into the higher-PSDMASK band; water-filling is approximately and INDEPENDENTLY maintained in both bands.

The Level 2 Multi-Water-Level Loading Algorithm

1. Run greedy algorithm

2. Two bands of tones (higher-SNR and lower-SNR) are determined.

3. While (PSD < PSDMASK, Total power < Maximum power)

   Remove bits from the higher-SNR band and place them into the positions of least incremental energy on the tones of the lower-SNR band.

The complexity of the Level 2 algorithm as implemented in a modem is the same as, or often less than, the usual bit-swapping and the same energy table as in the greedy algorithm is used. However, in the case of the Level 2 algorithm, the criterion for moving bits prohibits use of the best tones if they can be vacated.

D.7   DSM Level 3 Loading Algorithm

DSM Level 3 corresponds to the management of spectra for the emerging G.993.5 or Level 3 DSM transmission systems now in standardisation. This Level 3 loading algorithm is to be determined.

History

Document history		
ND-1513	2010-01	First Issue: Report on Dynamic Spectrum Management (DSM) Methods in the UK Access Network