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NICC Document

Vectoring – use cases and impact assessment

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Contents

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Foreword

This NICC Document (ND) has been produced by NICC DSL Task Group. This document analyses deployments of Vectored VDSL, with a focus on potential crosstalk impacts to vectoring in legacy and multi-operator environments. Solutions for these impacts are identified and discussed.

Introduction

All copper transmission systems are limited by two fundamental impairments – crosstalk and physical length, as well as impairments such as external noise. Vectoring is a new technology standardised by the ITU-T (G993.5) which enables the reduction (or elimination) of crosstalk and the recovery towards (or restoration of) the maximum rates of VDSL2 [2][3].

In order for vectoring to be most effective, all the lines within a given cable need to be allocated to a single vectored group (i.e., lines must be visible to a single vectoring engine) so that crosstalk couplings can be estimated and then pre-compensated at the transmitter (downstream) or cancelled at the receiver (upstream). There are various deployment arrangements that may result in having multiple separate vectored groups, or multiple separate DSLAMs at a cabinet. This may occur in single operator scenarios and multi-operator scenarios [8].

When it is not possible to allocate to a single vectored group all lines in a cable, then vectoring gains will be reduced due to the presence of uncancelled crosstalk.... Even if all lines in a cable are allocated to a single vectored group, vectoring gains can be reduced if some lines terminate on legacy CPEs as these lines would also create crosstalk that cannot be cancelled by vectoring.

Uncancelled crosstalk is crosstalk that cannot be cancelled by vectoring and it can cause harm unless steps are taken against it [7]. There are several possible scenarios that could lead to the presence of uncancelled crosstalk, and these scenarios may be related to the particular regulatory regime, particular deployment strategies, the particular service or CPE choices of customers, and also to vectoring implementation. There are proposed mitigation techniques that can reduce the performance degradation suffered by the vectored lines due to uncancelled crosstalk. These mitigation techniques introduce trade-offs between the peak speeds supported by the lines in the vectored group and the lines creating uncancelled crosstalk.

Given the different deployment strategies such as gradual deployments of vectoring, the competitive environment in the UK, and the availability of Sub Loop Unbundling (SLU), the NICC agreed to study the different scenarios for deploying vectored and non-vectored VDSL2 from the cabinet and its potential impact on performance, possible trade-offs and the availability of solutions.

This document makes no recommendations regarding the best way forward for the UK with respect to vectoring, but instead creates a technical foundation from which the industry can make decisions. Use cases are each considered in turn for the possible ways of handling different arrangements of single or multiple vectored groups, and with non-vectored lines.

1 Scope

This document discusses different use cases for the use of VDSL2 vectoring in a UK environment for single and multiple operator scenarios. For each use case, a number of key high-level assessment criteria are considered to allow the reader to easily compare and contrast the implications.

2 References

2.1 Normative references

The following referenced documents are indispensable for the application 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.

[N1] ND1610 Next Generation Networks, Release Definition

[N2] Recommendation ITU-T G.993.2 (2011) Very high speed digital subscriber line Transceivers 2 (VDSL2).

[N3] Recommendation ITU-T G.993.5 (2010), Self-FEXT Cancellation (Vectoring) for use with VDSL2 transceivers.

[N4] ATIS Std. 0600007 (2007), Dynamic Spectrum Management - Technical Report.

[N5] ATIS Std. 0900007 (2012), Dynamic Spectrum Management Technical Report, Issue 2.

[N6] ND1513 (2010), Report on Dynamic Spectrum Management (DSM) Methods in the UK Access Network.

[N7] Broadband Forum, TR-320 (2014), Remedies for the Impact of Uncancelled Crosstalk on Vectored VDSL2 Lines

[N8] Broadband Forum – MR-257i2 (2014), An Overview of G.993.5 Vectoring

2.2 Informative references

2.2.1 NICC

[1] K. J. Kerpez and S. Galli, “Compatibility of Vectored and Non-Vectored VDSL2,” NICC DSL WG contribution CP18(12)4, February 21, 2012.

[2] K. Kerpez and S. Galli, “Simulations of DSM for Mixed Deployments of Vectored and Non-Vectored VDSL2,” NICC DSL WG Contribution CP21(12)6, July 13, 2012.

[3] M. Dolan and J. Verlinden, “VDSL2 from the exchange in combination with (vectored) VDSL2 from the cabinet using static methods,” NICC DSL WG contribution CP22(12)4, September 7, 2012.

[4] D. Wei, “Coexistence between Vectored VDSL2 form Cabinet and VDSL2 from Exchange,” NICC DSL WG contribution CP23(12)5, September 7, 2012.

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2.2.2 ITU-T

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[11] A. Wilson, L. Sandstrom, and J. Brooks, "First Order Complexity FEXT Cancellation Performance Deployed in a 100 Pair Cable," COAST-NAI contribution NIPP-NAI-2007-018R2.

[12] ATIS Std. 0600024 (2011), Multiple-Input Multiple-Output Crosstalk Channel Model.

2.2.4 Broadband Forum

[13] K. Kerpez, and S. Galli, "Simulations of DSM for Mixed Deployments of Vectored and Non-Vectored VDSL2 – Collocated Case," Broadband Forum Contribution bbf.2012.1127.00, October 2, 2012.

[14] H. Mehmood, K. Kerpez, and S. Galli, "Simulations of DSM for Mixed Deployments of Vectored and Non-Vectored VDSL2 – Distributed Length Case," Broadband Forum Contribution bbf.2012.1128.00, October 2, 2012.

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2.2.5 Papers

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3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

Legacy CPE: A CPE that is neither downstream vectoring-friendly (G.993.2 Annex X), nor full vectoring-friendly (G.993.2 Annex Y), nor vectoring (G.993.5) capable.

RAG terminology: The RAG terminology used in this report to rate the impact against vectoring performance of some scenario has the following meaning:

- Green The considered scenario poses no specific issues related to coexistence.
- Amber The considered scenario poses specific issues related to coexistence but solutions for preserving vectoring gains are available.
- Red The considered scenario poses specific issues related to coexistence and it is not currently possible to preserve vectoring gains.

3.3 Abbreviations

ADSL	Asymmetric Digital Subscriber Line
AELEM	Alternative Electrical Length Estimation Method
ALA	Active Line Access
ANFP	Access Network Frequency Plan (BT or KCH)
BLV	Board Level Vectoring
CAL	Cabinet Assigned Loss
CLV	Cable Level Vectoring
CLVE	Cable Level Vectoring Engine
CP	Communications Provider(s)
CPE	Customer Premises Equipment
DPBO	Downstream Power Back Off
DSEL	D-Side Electrical Length
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSM	Dynamic Spectrum Management
FTTC	Fibre To The Cabinet
MDF	Main Distribution Frame
MPF	Metallic Path Facility
NGA	Next Generation Access
NRA	National Regulatory Authority
NTP	Network Termination Point
OAM	Operations Administration and Maintenance

PSD Power Spectral Density

SLV System Level Vectoring

SLVE System Level Vectoring Engine

SMC Spectrum Management Centre

UNI User Network interface

UPBO Upstream Power Back-Off

VDSL Very high speed Digital Subscriber Line (refers to any VDSL type including VDSL1, VDSL2, and vectored VDSL)

VDSL2 Very High Speed Digital Subscriber Line 2

VE Vectoring Engine

VULA Virtual Unbundled Local Access

xSLV Cross System Level Vectoring

4 Cases when all lines in a cable are in a single vectored group

In this section, the presence of a single vectored group is considered. This vectored group could range from a single operator with one or more vectored DSLAM(s), to multiple operators using multiple DSLAMs which are arranged to perform xDLV. In this case, all lines in a cable terminate on a vectored DSLAM but some lines may terminate at the subscriber end on legacy CPEs, i.e. CPEs that are not vectoring-friendly nor vectoring capable. These lines will create harmful crosstalk that will impact the performance of the vectored lines if not managed appropriately.

4.1 A single vectored DSLAM

In this scenario, the first operator at a given cabinet location deploys a single vectored DSLAM, with a vectored group sufficiently large to manage all the customers connected to that cabinet. No other DSLAMs are present in the cabinet. Some lines may also terminate on a legacy CPE, e.g. some customers may not want to change their current service or modem, the CPE may not be owned by the same service provider upgrading the DSLAM, etc. This is partially mitigated by the specification of “vector friendly” / “vector ready” CPE in the Wires-only specification ND1436.

This scenario also includes the cases of bitstream services, Ethernet Active Line Access (ALA), Virtual Unbundled Loop Access (VULA), and wires-only; where additional operators (resellers) can be accommodated for delivering services over a subset of the vectored lines operated by the first operator.

Assessment Criteria	**Comment**
Performance of the lines associated with the first DSLAM after subsequent DSLAM install	The operator will be able to realise the full gains from vectoring above 2.2MHz if none of the lines terminate on a legacy CPE. If legacy CPEs are present, then vectoring gains may be lost if nothing is done to mitigate the crosstalk from the lines terminated on legacy CPEs into the vectored lines. Solutions for restoring most of vectoring gains are available; see for example Sect. 6.2 and 6.3. Below 2.2MHz, ADSL2+ from the exchange will act as alien interferers, but with minimal impact to the capacity of vectored lines. See also complexity issues that may reduce vectoring gains.

Assessment Criteria	Comment
Complexity of solution	Dependent on number of lines served by the vectored DSLAM. Generally, there is “out of the box” vendor functionality for a finite number of lines. In the case that the vectored group is too large, there may be practical limitations on complexity that may allow only partial vectoring (e.g., not all lines in the vectored group are completely cancelled) thus leaving some lines in the vectored group suffering from uncancelled crosstalk. Techniques are available for mitigating the effects of this crosstalk, e.g. see Sect. 6.2 and 6.3. Complexity limitations may diminish in the future allowing full vectoring of an entire cable.
Roadmap / availability of solution	Available now. Note: the size of vector groups may be limited, however some existing systems can support 288 to 384+ lines in a vector group.
Impact on ANFP and other NICC documents	Can be deployed from the cabinet with no changes to ANFP. Additional performance improvement could be achieved by optimising the UPBO settings.
Competitive environment	Services such as bitstream, ALA, VULA, and wires only enable the sharing of infrastructure whilst maximizing customer line performance due to use of a single vectored group. Care should be taken to allow such services to approach a competitive environment similar to that of SLU as well as ensuring CPs can exercise a degree of control that is similar to that achieved when taking over the physical line to the customer. However, any increase in control should not have significant adverse impact on other CP customers connected to that DSLAM.
Performance and interdependency of lines associated with subsequent DSLAMs	For single DSLAM deployment, no interdependency. Deployment of a second DSLAM case is addressed in Section 4.2.

Pro	Con
• Generally, out of the box solution with maximum performance up to vectored groups of size 288 to 384+, if no legacy CPE is present. If lines terminate on legacy CPEs or multiple DSLAMs, see techniques in Sects. 6.2 and 6.3. • Requires no change in the UK regulatory framework when vectoring is deployed from a cabinet. • Existing cabinets served by a single DSLAM can be upgraded to a vectored DSLAM.	• Currently vulnerable to second DSLAM deployment which could have a significant impact on performance unless mitigation techniques can be enacted. • A single DSLAM generally precludes physical unbundling.

Overall RAG assessment = Green / Amber

Key factor driving RAG classification:

This scenario is Green when there is no uncancelled crosstalk but it becomes Amber when uncancelled crosstalk is present. Uncancelled crosstalk can occur in a number of common Vectored VDSL2 deployment scenarios which include both bundled and unbundled regulatory environments.

4.2 Multiple DSLAMs

The case addressed here is when multiple DSLAMs (vectored and non-vectored) are deployed at the cabinet by a single operator or by multiple operators and all the lines originating from the cabinet are in the same vectored group. Under this scenario, multiple DSLAMs can be “merged” into a single vectored group by coordinating all DSLAMs (vectored or not) with cable level vectoring (CLV) or cross-DSLAM vectoring (xDLV). These two cases are addressed in Sections 4.2.1 and 4.2.2, respectively. The case where the multiple DSLAMS are left uncoordinated is addressed in Section 5.1, and the case where Multiple vectored groups are coordinated via dynamic spectrum management (DSM) is addressed in Section 5.2

4.2.1 Case of multiple DSLAMs coordinated via a cable-based vectoring engine – Cable Level Vectoring (CLV)

In this scenario, a new piece of hardware (Cable Level Vectoring Engine, or CLVE) is deployed at the cabinet between a cable and one or more non-vectored DSLAMs [6]. The CLVE terminates all the VDSL2 lines from each DSLAM, and then performs cable level vectoring (CLV) by allocating all the lines in the cable to a single vectored group. Note that since the vectoring operation is performed in the CLVE (a separate piece of hardware), the DSLAMs need not to be vectored but can be simple VDSL2 DSLAMs.

If there is one CLVE per each cable originating from the cabinet, then all cabinet lines are vectored and there is one vectored group per cable (these are independent vectored groups and do not interfere with each other). Additional details of such a solution are described in [I1].

In this scenario, some lines may also terminate on legacy CPEs, i.e. CPEs that are not vectoring-friendly nor vectoring capable. These lines will create harmful crosstalk that will impact the performance of the vectored lines.

Assessment Criteria	Comment

Performance of the lines associated with the first DSLAM after subsequent DSLAM install	All lines in a cable that terminate on CLVE enjoy vectoring gains regardless of the number of DSLAMs in the cabinet, but only if there are no lines terminating on legacy CPEs. If legacy CPEs are present, then vectoring gains may be lost if nothing is done to mitigate the crosstalk from the lines terminated on legacy CPEs into the vectored lines. Solutions for restoring most of vectoring gains are available, see for example Sect. 6.2 and 6.3. If there is one cable level vectoring engine per each cable originating from the cabinet, then all lines in the cabinet enjoy vectoring gains regardless of the number of DSLAMs or cables in the cabinet, unless some lines terminate on legacy CPEs. If the distance between the DSLAMs and the CLVE devices is excessive, then crosstalk in the tie cables could affect performance. Complexity issues may reduce vectoring gains.

Assessment Criteria	Comment
Complexity of solution	With CLV it is not necessary to deploy vectored DSLAMs. If vectored DSLAMs are deployed before the CLV then the vectoring asset could be stranded. It is necessary to deploy one CLVE per cable and each CLVE must be able to handle vectored group size to be at least the number of lines in the cable. Since CLV implies a vectored group size equal to the number of lines in a cable, vectored groups can be large and there may be practical limitations on complexity that may allow only partial cancellation, thus leaving some lines in the vectored group suffering from uncancelled crosstalk. Techniques available for mitigating the effects of this crosstalk are available, e.g. see Sect.6.2 and 6.3. The DSLAM and CLVE must be designed to be transparent to the CPs configuration, and pass through necessary management functionality such as line bit rate configuration. There are issues related to ownership, responsibility, management and accountability for the solution. Complexity limitations may lessen in the future allowing full vectoring of an entire cable.
Roadmap / availability of solution	Unknown.
Impact on ANFP and other NICC documents	As per the single operator case since the CLVE would have to comply with the same rules of any vectored DSLAM, including the protection of all exchange based services. Additional NICC documents may be required to define CP management interfaces to the CLVE.
Competitive environment	CLV can enable competition if it is engineered and operationalized to do so. This would require significant levels of standardisation or cooperation between operators, possibly including a new management channel from the DSLAMs to the CLVE. Consideration will also need to be given to exchange based services that may in the cable such as ADSL2+ to ensure they operate unhindered
Performance and interdependency of lines associated with subsequent DSLAMs	The CLVE is a device shared by multiple DSLAMs, which raises the issue of how provisioning and configuration are performed. Also, it is not defined yet how to communicate through DSLAMs to the CLV for management purposes.

Pro	**Con**
• If all lines terminate on vectoring capable CPEs then all cabinet lines enjoy vectoring gains, subject only to the complexity of performing vectoring on all lines in a cable. • No need to upgrade VDSL2 DSLAMs to vectored DSLAMs.	• Not explicitly in the current ANFP. • May require agreements between operators for the provisioning of shared equipment, the CLVE. • Requires installation of as many CLVE as the number of cables originating from the cabinet. • Requires two additional DSL transceivers per VDSL2 line with respect to a vectored DSLAM and hence increased power consumption. • Increased physical and operational complexity. • Not standardised and with unknown availability.

Overall RAG assessment = Red

Key factor driving RAG classification:

CLV is neither standardised nor is its commercial availability currently known. Furthermore, in the presence of uncancelled crosstalk, vectoring gains can be lost if left unmanaged

4.2.2 Case of multiple DSLAMs coordinated via a single DSLAM-based centralized or distributed vectoring engine – Cross-DSLAM Vectoring (xDLV)

Multiple vectored DSLAMs can be interconnected to exchange the information necessary to perform vectoring on all the lines terminating on the connected DSLAMs [27]. By connecting together multiple DSLAMs, xDLV is a possible next step after Board Level Vectoring (BLV) and System Level Vectoring (SLV) in the path of increasing the vectored group size.

In a centralized architecture, the xDLV vectoring engine (VE) resides in a single vectored DSLAM that performs all the vectoring operations and exchanges information with the other vectored DSLAMs. In a distributed architecture, the computational load required for performing the vectoring operation can be balanced among multiple VEs so that load partitioning can be used to reduce the computational load per VE.

Assessment Criteria	Comment
Performance of the lines associated with the first DSLAM after subsequent DSLAM install	If all the lines in a cable terminate on a set of vectored DSLAMs that are connected with xDLV, then all lines enjoy vectoring gains regardless of the number of operators or the number of DSLAMs, but only if there are no lines terminating on legacy CPEs. If legacy CPEs are present, then vectoring gains may be lost if nothing is done to mitigate the crosstalk from the lines terminated on legacy CPEs into the vectored lines. Solutions for restoring most of vectoring gains are available; see for example Sect. 6.2 and 6.3. Complexity issues may reduce vectoring gains.

Complexity of solution	xDLV requires high speed interconnections between the VEs and the line cards located in different DSLAMs, where the required speed is proportional to the number of vectored lines and the number of DSLAMs. This may not always be possible, e.g. due to speed limitation of internetworking cables, physical distance between DSLAMs, latency requirements, etc. Standardized interfaces for sharing information between multiple DSLAMs do not exist, so xDLV is limited to same-vendor DSLAMs. xDLV can result in a large vectored group size, at most the sum of the number of ports on the inter-connected DSLAMs. If a single cable originates from the RT, then crosstalk cancellation amongst all lines in the cable requires the resulting vectored group size to be at least the number of lines in the cable. In the case of multiple cables, multiple vectored groups could be defined depending on implementation. These vectored groups may be of different sizes but should always be bounded between the minimum of the number of lines in each cable and the sum of the number of ports on the inter-connected DSLAMs. There may be practical limitations in handling such large vectored groups that may allow only partial crosstalk cancellation thus leaving some lines in the vectored group suffering from uncancelled crosstalk. A centralized VE implementation raises the issue of handling a single point of failure since failure of the single VE would cause the loss of vectoring gains of all lines terminating on the DSLAMs connected via xDLV. A distributed VE implementation suffering the failure of one or more VEs would also lose the vectoring gains on multiple lines, and possibly on all the lines terminating on the DSLAMs connected via xDLV. There could also be short term performance issues during tasks such as software upgrades and VCE restarts for troubleshooting. There are issues related to ownership, responsibility, management and accountability for the vectoring engines

Assessment Criteria	Comment
Roadmap / availability of solution	It is unclear if there are commercially available solutions, even in the same-vendor case. Multi-vendor xDLV will require a standardized interface between DSLAMs, something that may only be available in the long term.
Impact on ANFP and other NICC documents	As per the single vectored DSLAM case. Depending on the evolution of standards for xDLV, additional NICC documents maybe required to define interconnect (including work areas such as architecture and management)
Competitive environment	It is difficult to connect different operator's DSLAMs together; this currently requires all equipment to be the same version from the same vendor.
Performance and interdependency of lines associated with subsequent DSLAMs	Agreements between operators are required as using same-vendor equipment is currently the only way to implement xDLV. Handling single/multiple points of failure may require coordination between operators – see above comments on complexity Maintenance actions such as firmware upgrades may need to be coordinated among all the DSLAMs.

Pro	Con
• If all the lines in a cable terminate on a set of vectored DSLAM inter-connected via xDLV and on vectoring-capable CPEs, then all lines enjoy vectoring gains regardless of the number of operators or the number of DSLAMs – see complexity limitations. • Requires no change in the ANFP. • This functionality could be a by-product of vectored group scale evolution from system vendors.	• Unclear availability. • Multi-vendor xDLV will require a standardized interface between DSLAMs. Requires operators' coordination for handling failure of the xDLV VE (or VEs). • Lack of standardization of the interface between DSLAMs currently allows only for same-vendor proprietary solutions.

Overall RAG assessment = Amber / Red

Key factor driving RAG classification:

xDLV is currently not standardised and seems to be available only for same vendor DSLAMs (Amber). Cross vendor product availability and its standardisation roadmap are currently unknown and, in the presence of uncancelled crosstalk, vectoring gains can be lost if left unmanaged (Red).

5 Multiple vectored groups – Case when all lines in a cable are vectored

In this section, the use of multiple vectored groups operating in parallel at a given cabinet is considered. This is different from the single vectored group case, as here the lines of each vectored group create crosstalk that cannot be cancelled by the vectoring operation in the other vectored groups. In this case all lines in a cable are vectored, i.e. they terminate on vectored DSLAMs but there can still be some lines terminating on legacy CPEs, i.e. CPEs that are not vectoring-friendly nor vectoring capable. Also, those lines terminating on legacy CPE can create harmful crosstalk that will impact the performance of the vectored lines if not managed accordingly.

5.1 Multiple vectored groups – Uncoordinated independent operation

In this case each DSLAM is operated independently from all other DSLAMs, regardless of whether the DSLAMs are operated by a single or multiple operators. Essentially, there are multiple vectored groups (one per DSLAM) which are uncoordinated and each vectored group creates crosstalk that cannot be cancelled by the vectoring operation performed in the other vectored groups sharing the cable. If coordination is introduced, then this case is analogous to the cases discussed in Sect. 4.2.1 (CLV), 4.2.2 (xDLV), and 5.2 (DSM).

Assessment Criteria	**Comment**
Performance of the lines associated with the first DSLAM after subsequent DSLAM install	The capacity of each vectored group is severely impaired by the alien uncancelled crosstalk created by all other groups, even if all lines terminate on vectoring-capable CPEs. Vectoring gains are lost and every cabinet line can be expected to experience a performance similar to non-vectored VDSL2. The performance loss with respect to perfect vectoring is inversely proportionally to loop length.
Complexity of solution	As per the single operator case – see Section 4.1.
Roadmap / availability of solution	As per the single operator case – see Section 4.1.
Impact on ANFP and other NICC documents	As per the single operator case – see Section 4.1.
Competitive environment	The addition of a second DSLAM will harm the performance of customers already receiving service from an initial vectored DSLAM.
Performance and interdependency of lines associated with subsequent DSLAMs	Only in terms of performance. Most vectoring gains would be lost.

Pro	Con
• None.	• Vectoring gains are lost on all lines. • Voids all parties' investment in vectoring, particularly on short lines.

Overall RAG assessment = Red

Key factor driving RAG classification:

Performance gains from vectoring can be completely lost in this uncoordinated case.

5.2 Multiple vectored groups – Coordination via dynamic spectrum management (DSM)

In this scenario, the negative impact of uncancelled crosstalk created by multiple vectored groups can be mitigated by allowing centralized or distributed coordination of the various vectored groups using one of the various Dynamic Spectrum Management (DSM) techniques. In particular, DSM techniques allow spectral shaping and power control to mitigate the impact of crosstalk.

DSM can be implemented either via a single centralized Spectrum Management Centre (SMC) or via distributed SMCs (e.g., one per operator) with various levels of information exchange between the distributed SMCs. The performance of a centralized DSM system is usually superior to a distributed system.

Assessment Criteria	Comment
Performance of the lines associated with the first DSLAM after subsequent DSLAM install	Mitigating uncancelled crosstalk is challenging for this scenario and generally only one vector vectored group can retain full vectored speeds if other vectored groups are managed to run at speeds typical of non-vectored VDSL2. An alternative is to manage multiple vectored groups to operate all at similar data rates. This approach shows improvement over dense VDSL2 deployments but data rates are still below the highest vectored speeds.

Assessment Criteria	Comment
Complexity of solution	DSM may require some new infrastructure, although SMCs may be implemented by adding extra functionality to existing Dynamic Line Management (DLM) systems. Depending on the specific DSM algorithm (centralized or distributed algorithm) used for compatibility and the architecture that implements DSM, requirements for data exchange between SMCs may arise. If data exchange is required between operators, with multiple SMCs, then this may entail additional requirements which are for further study.
Roadmap / availability of solution	There are many well-known DSM techniques, some of which are implemented as software systems. The capability of managing the compatibility of multiple vector groups as well as vectored and non-vectored lines already appears to be an available feature. For the single operator case and there is no data exchange required and there are solutions available today (green). For the multiple operator case, and when data exchange is used, the interface would need to be negotiated between operators or development of a standard (amber). This is currently under study in the NICC as part of ND1518 (data sharing for DSM).
Impact on ANFP and other NICC documents	DSM may require some cooperation and coordination among operators. NICC documents may be updated or created to specify what information has to be shared between operators to implement DSM. DSM may require a new framework for policing and testing, which may involve updating ND1404 and ND1602. A data-sharing framework for DSM could provide information to support policing in an automated fashion, but physical layer policing may still be required to confirm systems correctly implement instructions from the SMC.
Competitive environment	Competition is possible, but either only one operator achieves full vectoring speeds, or all operators run below full vectoring speeds.
Performance and interdependency of lines associated with subsequent DSLAMs	A distributed DSM system has no specific DSLAM interdependencies, except for operators’ agreements on transmit power, margin, rate and spectral limits, etc. A centralized DSM system requires a level of management data and control between the DSLAMs and the SMC.

Pro	Con
• Allows a competitive environment at the cost of reduced vectoring gains.	• Two separate vectored groups with strong crosstalk between them generally cannot both have performance close to that of perfect vectoring. • For the first DSLAM to maintain the downstream 100Mbps+ services from vectoring, it could be necessary to limit the second DSLAM to speeds of 30M to 50Mbps to protect existing customers.

Overall RAG assessment = Amber / Red

Key factor driving RAG classification:

Full vectoring gains can be retained on one vectored group (Amber) at the cost of managing other vectored groups to run at speeds typical of non-vectored VDSL2. An alternative is to manage multiple vectored groups to all operate at similar data rates. This approach shows improvement over dense VDSL2 deployments but data rates are still below the highest vectored speeds (Red).

6 Mixture of vectored and non-vectored lines

This section considers the case when vectored and non-vectored lines share the same cable. There are cases that occur in practice that do not allow vectoring all lines in a cabinet; e.g. in the case of multiple operators that do not simultaneously implement vectoring in their DSLAMs in the shared cabinet; or when a single operator is carrying out a gradual deployment of vectoring and upgrades only a subset of its DSLAMs at a given cabinet location to vectoring; or when some lines terminate on a vectored DSLAM on one end of the line but with unmanaged legacy CPE on the other end.

In this case, the non-vectored VDSL2 lines and the vectored lines terminating on legacy CPEs create crosstalk into the newly deployed vectored lines which can degrade their performance. The available options are:

- Do nothing and accept the consequences
- Static spectrum management,
- Managing lines with DSM to mitigate impact of uncancelled crosstalk and alien noise.

In the next sections, these options for managing the groups of vectored and non-vectored lines will be described and analysed.

6.1 Vectored and non-vectored – Uncoordinated independent operation

In this case, all lines are allowed to optimize their individual performance and achieve the maximum attainable speed with no attempt to manage their impact on each other. This case has been analysed in [11], where the impact of unmanaged non-vectored lines on vectored lines has been quantified for some notable cases.

Assessment Criteria	**Comment**
Performance of the lines associated with the first DSLAM after subsequent DSLAM install	Both the vector group and the non-vectored VDSL2 lines perform at non-vectored VDSL2 speeds and nearly all vectoring gains are lost.
Complexity of solution	None.
Roadmap / availability of solution	Available now.
Impact on ANFP and other NICC documents	None.
Competitive environment	Competition is possible, but the operator deploying vectoring will not see any data rate gain if uncoordinated non-vectored VDSL2 lines share the same cable.
Performance and interdependency of lines associated with subsequent DSLAMs	Both the vector group and the non-vectored VDSL2 lines perform at non-vectored VDSL2 speeds and nearly all vectoring gains are lost.

Pro	**Weakness**
• None.	• Vectoring gains are lost. • Operators may be discouraged to deploy vectoring if appropriate tools are not introduced to reinstate vectoring gains.

Overall RAG assessment = Red

Key factor driving RAG classification:

Performance gains from vectoring can be completely lost in this uncoordinated case

6.2 Vectored and non-vectored - Static control of non-vectored lines

In this scenario, static techniques are used such as limiting the PSD of the non-vectored lines to reduce the impact of the non-vectored lines on the vectored lines. Static spectrum management protects lines from harm using a simple configuration, and therefore tends to be based on worst case assumptions. However, static solutions can be implemented in straightforward rule-sets. The use of static masks applies a maximum useable frequency cap to the un-cancelled VDSL lines of the 2nd DSLAM to protect the line rates of the 1st vectored DSLAM.

Assessment Criteria	**Comment**
Performance of the lines associated with the first DSLAM after subsequent DSLAM install	Depending on the choice of static masks allocated to the vectored DSLAM, the majority of the vectoring gains can be retained; however this may significantly restrict the maximum speeds of subsequent DSLAMs. A line terminating on a legacy CPE would be allocated a restricted PSD or the port shutdown as per existing DSLAM functionality, regardless of whether it is served by a vectored or non-vectored DSLAM.
Complexity of solution	This is a low complexity solution using PSD tools already defined in the VDSL2 standard. The PSD shapes for each operator would need to be agreed via the NICC.
Roadmap / availability of solution	All required functionality is already standardised. For the single operator case, no changes are required to the ANFP, as they can set masks lower than the maximum transmit power (green). For the multiple operator case, agreement on PSDs for each DSLAM would be required and may need changes to the ANFP.
Impact on ANFP and other NICC documents	The SSM masks for unvectored DSLAMs would require changes to the ANFP.
Competitive environment	The ability to deploy DSLAMs via SLU is preserved and so are some of the vectoring gains i.e. on one of the “vectored” DSLAMs. However the performance of the non-vectored DSLAM could be substantially lower than the single DSLAM case.
Performance and interdependency of lines associated with subsequent DSLAMs	The DSLAM configurations are independent, but would require agreement between operators to set the PSDs accordingly. There is a significant restriction on the performance of subsequent DSLAMs (red). This agreement is likely to come from an update to the ANFP.

Pro	Con
• Relatively straightforward approach using similar techniques to the ANFP use of CAL. • Each DSLAM can be configured individually, albeit to different agreed PSD for the vectored and non-vectored DSLAMs.	• Non-vectored line speeds can be about a factor of three lower than those achievable with dynamic approaches. • Definition of fairness statically defined via the PSD mask.

Overall RAG assessment = Amber

Key factor driving RAG classification:

Depending on the choice of static masks, a portion of vectoring gains can be retained at the cost of significantly restricting the maximum speeds of non-vectored lines (Amber), e.g. non-vectored line speeds can be about a factor of three lower than those achievable with dynamic approaches (see Appendix I for more details).

There is a significant restriction on the performance of subsequent DSLAMs and allowing non-vectored lines to run at less restricted speeds would cause losing vectoring gains. Furthermore, for the multiple operator case, agreement on PSDs for each DSLAM would be required and may need changes to the ANFP.

6.3 Vectored and non-vectored - Dynamic control via DSM

In this scenario, DSM techniques are used to implement an industry defined or otherwise determined operating point for the bit rates of both the vectored and the non-vectored lines and this operating point depends on certain parameters of the physical network. This will include the identification of the level of compromise (i.e. line rate reduction) that is acceptable for lines which are not vectored and the associated impact on the vectored services.

Extensive simulation work has shown that DSM can mitigate the effects of uncancelled crosstalk and allow lines in a vectored group to retain most of the vectoring gains that would be otherwise lost if DSM were not used (see [1]-[5], [8]-[10], and [11]-[26]). Specifically, these studies report that mitigation techniques based on DSM Level 1 (rate limiting) and DSM Level 2 (spectrum balancing) can be effective in managing mixed deployments (mixtures of vectored and non-vectored lines) in both upstream and downstream directions. This is likely to involve performance trade-offs between the vectored and non-vectored lines.

The achievable performance in this mixed scenario depends on the level of coordination and information sharing between the management systems of the vectored and non-vectored lines.

Assessment Criteria	**Comment**
Performance of the lines associated with the first DSLAM after subsequent DSLAM install	Most of vectoring gains can be retained when DSM is employed to manage both the vectored group and the non-vectored VDSL2 lines and the rate of the non-vectored lines is capped. More generally, DSM enables the configuration of trade-offs between the rates of the vectored lines and the non-vectored lines.
Complexity of solution	Same as in all other cases where DSM is employed. Depending on DSM implementation, requirements for some data exchange between SMCs may arise.
Roadmap / availability of solution	There are many well-known DSM techniques, some of which are implemented as software systems. The capability of managing the compatibility of multiple vector groups as well as vectored and non-vectored lines already appears to be an available feature. For the single operator case and there is no data exchange required and there are solutions available today (green).

	For the multiple operator case where data sharing is required, the interface would need to be negotiated between operators or developed in a standard.

Assessment Criteria	Comment
Impact on ANFP and other NICC documents	DSM requires some cooperation among operators. NICC documents may be updated or created to specify what information has to be shared between operators to implement DSM. Regulatory requirements may be necessary only if the parties cannot come to an agreement among themselves on how to coordinate their systems.
Competitive environment	Competition and gradual deployment are both possible, with limited performance losses on the vectored lines. The consequence of this can be a lower rate on the non-vectored lines. The acceptance of this solution may depend on the definition of fairness for the competitive environment that determines trade-offs between vectored and non-vectored lines, which may change from one case to another. DSM provides a flexible framework for enabling coexistence that can match various definitions of fairness.
Performance and interdependency of lines associated with subsequent DSLAMs	A distributed DSM system has no specific DSLAM interdependencies, except for operators' agreements on transmit power, margin, rate and spectral limits, etc. A centralized DSM system requires a level of management data and control between the DSLAMs and the SMC.

Pro	Con
• Allows gradual deployment, i.e. as a single operator partially upgrades its VDSL2 plant to vectoring at a given cabinet with multiple DSLAMs (if applicable) or in the presence of uncontrolled legacy CPE connected to vectored DSLAMS. • Allows a competitive environment with a flexible framework that can match various definitions of fairness. • Management with DSM can ensure good performance on vectored lines while non-vectored lines are capped at relatively high speeds that are usually at or above what is typically offered today as entry level products with non-vectored VDSL2 systems. • Managing vectored and non-vectored VDSL2 lines with DSM is a practically feasible operational tool that allows a rapid and	• DSM requires some cooperation among operators.

smooth transition from VDSL2 to vectored VDSL2.	

Overall RAG assessment = Amber

Key factor driving RAG classification:

Most of vectoring gains can be retained when DSM is employed to manage both the vectored group and the non-vectored VDSL2 lines and the rate of the non-vectored lines is capped at relatively high speeds that are usually at or above what is typically offered today (Amber). In order to fully realise the gains from DSM in a multi operator environment, DSM data sharing may be required between operators.

There are also distributed DSM algorithms which can be run independently by multiple Spectrum Management Centres (SMCs) and are often more useful in the field as they are computationally much simpler, do not require any data exchange between operators, and provide results that are often very close to the optimal centralized DSM algorithms.

7 Summary of scenarios

Type of scenario	**Scenario**	**RAG**
Single DSLAM	Single vectored DSLAM	G/A
Multiple DSLAMs in a single group	Cable Level Vectoring	R
Multiple DSLAMs in a single group	Cross DSLAM vectoring	A/R
Multiple vectored groups	Uncoordinated operation	R
Multiple vectored groups	Coordinated via DSM	A/R
Mixture of vectored and non-vectored lines	Uncoordinated operation	R
Mixture of vectored and non-vectored lines	Static control of non-vectored lines	A
Mixture of vectored and non-vectored lines	Dynamic control via DSM	A

8 International agreements on vectoring

7.1 Overview

As described in the above use cases, vectoring technology has a more complex set of deployment considerations when more than one operator is providing VDSL2 in a shared cable– such as may be the case where Sub Loop Unbundling (SLU) is allowed. However, as also pointed out in [N7], the challenges to vectoring caused by uncancelled crosstalk are present even in the case when a single operator deploys vectoring. Therefore, the elimination of SLU requirements alone will not eliminate all causes of uncancelled crosstalk and mitigation techniques may be beneficial even in a single operator scenario.

In the event that a multi-operator environment is sought, a number of factors should be taken into account and they include not only the benefits of vectoring in preventing speed erosion, but also the potential consequences of regulatory choices on competition.

This section outlines some of the solutions that may be considered; Section 7.2 presents examples of how some NRAs outside the UK have sought to address the challenges vectoring brings to NGA deployment.

7.1.1 Remedies where SLU is allowed

When vectoring is being deployed where SLU is allowed, the NRA may consider the following approaches to vectoring deployments:

- Require or encourage co-operation of operators for deploying xDLV as a remedy (see 7.2.4);
- Require or encourage co-operation of operators for implementing DSM-based coexistence as a remedy;
- A combination of the above;
- Withdraw or restrict SLU (see 7.2.1, 7.2.2, 7.2.3);

7.1.2 Remedies where SLU is not allowed

When SLU is not allowed, the NRA may consider the following approaches to vectoring deployments:

- Use of VULA-like remedies, to enable CPs to continue offering services and performing operations with a degree of control that is similar to that achieved when taking over the physical line to the customer (see 7.2.1, 7.2.5);
- Where the deployment of vectoring-capable DSLAMs has not yet occurred, the NRA may encourage a co-investment strategy, permitting additional operators to invest in the access network during the upgrade or build cycle.

7.2 International agreements on vectoring

This section details some examples of different regulatory statements or agreements in force in a few countries. For all the other countries not listed here, the regulatory status for vectoring is either unknown or no decision to change regulatory status has been made.

7.2.1 Belgium

The following text has been published by BIPO and accepted by the EU.

563 The obligation of sub-loop unbundling (including VDSL2 unbundling at the central office) as well as all supporting measures exclusively related to unbundling of the sub-loop are thus removed. In practice, this concerns the following measures:

- *To provide third party operators fully or partially unbundled access to the sub-loop, with or without voice;*
- *For the unbundling of direct pairs from the LEX (central office), given that the investment is not dedicated only to these pairs, access to unbundling continues to be imposed for any technology that does not interfere with the technology of vectoring. For this same reason, unbundling must be granted for VDSL2 as long as Belgacom does not make use of vectoring; Belgacom will inform the beneficiary of the withdrawal of such access for each cable involved, with a notice of six months - in order to ensure that the beneficiary can migrate its VDSL2 connections to the solution of its choice;*
- *Offer a co-location service at the level of a street junction box;*
- *Offer access to the "remote optical platform" in order to enable co-location;*
- *Provide information to the alternative operators regarding the technical infrastructure of its network in order to enable these operators to evaluate the economic model associated with the use of the sub-loop network.*

http://www.bipt.be/ShowDoc.aspx?objectID=3540&lang=nl

BIPT has also imposed a requirement on Belgacom to provide a VULA-type service over its FTTC network (WBA VDSL2).

7.2.2 Germany

The following text has been published by the Germany Federal Agency:

The key aspects introduced in the new draft are as follows: Telekom may not refuse or terminate access to the local loop, or last mile, at a sub-loop distribution frame – one of the grey street cabinets – if the competitor seeking access would then have to pay back some or all of the state funding received for broadband roll-out at the cabinet. Furthermore, competitors will be given added protection. Telekom will not be able to automatically regain control of a street cabinet accessed by a competitor even if a parallel fixed network infrastructure connecting 75 percent of the buildings within the area served by the cabinet has yet to be established. Likewise, competitors will benefit from the added protection if – at the time the final decision enters into force – they have placed a binding order with Telekom for access at a street cabinet even if they have not yet actually interconnected at the cabinet.

The Bundesnetzagentur will specify the details for and oversee the maintenance of a new vectoring list. The aim of this list is to provide all market players – both Telekom and its competitors alike – with legal certainty and fair conditions in deploying vectoring. The list will contain reliable and accurate information on planned VDSL and vectoring projects and their actual implementation over one-year periods. Under these new proposals, the Bundesnetzagentur will also be given comprehensive information and intervention rights with a view to preventing anti-competitive behaviour.

The draft decision explicitly states that the detailed regulations for vectoring must be laid down in advance by the Bundesnetzagentur in a reference offer. These regulations include in particular specific sanctions in the event of anticompetitive practices in reserving cabinets, failure to interconnect at reserved cabinets, and non-availability of the required alternative bitstream product under open access arrangements. In the interests of improved predictability and planning reliability for all market participants, however, the decision's explanatory statement already points to many individual regulations and sanctions to be included in such a standard offer.

Vectoring allows higher transmission rates to be reached in the existing copper local loop network than has thus far been the case with the already advanced VDSL technology. The new technology reduces mutual interference between adjacent copper pairs in a cable. However, the state of the art only permits access by one company to all the copper pairs in the street cabinet, making unbundled access – where VDSL technology is being used – no longer possible.

At the end of last year, Telekom submitted a request to the Bundesnetzagentur to restrict competitors' access options to the local loop at street cabinets, so as to allow it to implement vectoring in its network. The Bundesnetzagentur published its first draft decision on the introduction of vectoring in the Telekom network on 9 April 2013. The draft stated that Telekom must continue to allow its competitors access to the local loop at the street cabinets. Telekom may refuse access to this sub-loop variant under certain conditions, however, so as to enable vectoring to be implemented at the cabinet by itself or another company.

http://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/BNetzA/PressSection/PressReleases/2013/130709VectoringEC.pdf?__blob=publicationFile&v=2

7.2.3 Ireland

The following text has been published by Comreg.

Eircom shall have an obligation to grant access, based on a reasonable request for:

• Sub-loop unbundling in areas which have not been identified as susceptible to benefit from a state subsidy scheme, and which meet with the following criteria (which consist of likely indicators regarding whether a request is prima facie reasonable):

1. The request for sub-loop unbundling is at a cabinet or in an exchange area where Next Generation Access roll out and vectoring enablement has not already taken place and is not imminent or credibly scheduled; and;

2. There is a commitment to open access by the SLU operator for the provision of next generation wholesale broadband access services and;

3. There is a commitment by the Access Seeker to bandwidth enhancing technology, where it is possible.

http://www.comreg.ie/_fileupload/publications/ComReg1311.pdf

7.2.4 Italy

The Italian regulator AGCOM has recently issued publication "Delibera n. 238/13/CONS" entitled "Public consultation on the identification and analysis of the service markets related to fixed access". In this public consultation, AGCOM has maintained the SLU framework and encouraged operators to a cooperate in coordinating the implementation of vectoring.

In particular, at paragraph 384 of the "Allegato B" of the above mentioned Delibera, it is said that "if an alternative operator presents a timely request of vectoring service provision under SLU" in the same area where Telecom Italia is deploying vectoring, then "it is considered desirable that the alternative operator and Telecom Italia agree to proceed to a coordinated implementation of the vectoring technique".

http://www.agcom.it/default.aspx?DocID=10845

7.2.5 Austria

The Austrian regulator requires the incumbent (A1 Telekom) to provide a 'VULA 2' service where cabinet port rental and cabinet backhaul are purchased separately.

http://www.rtr.at/de/tk/Z1_11_Z3_11/Bescheid_Z_1_3_11_Tele2.pdf

Annex 1 - Comparison of static and dynamic management techniques

Performance

Downstream bit rates of vectored and non-vectored VDSL with Static Spectrum Management (SSM) were calculated via simulation. VDSL2 Profile 17a is simulated as allowed by the ANFP. The margin is 6 dB and the coding gain is 3 dB. AWGN at -140 dBm/Hz is added to each receiver. The ATIS MIMO FEXT model is used[12]. Loops are all 0.5 mm. All subscribers (TU-Rs) are collocated. There is 10% overhead.

Vectoring lowers the FEXT by 25 dB. There are 12 vectored VDSL2 and 12 non-vectored VDSL2 in the same binder in all cases, except one case that has 2 vectored and 2 non-vectored.

SSM limits the highest frequencies used by the non-vectored lines to 2, 5, 7, 9, 15, or 17 MHz. In these simulations DSM uses iterative waterfilling (IWF), a distributed DSM algorithm that does not require data exchange between SMCs. Results are shown in Figure 1 – Figure 5.

SSM ensures a target bit rate in the worst case, and this worst-case operating point is plotted here, but in many cases on shorter loops or with less crosstalk this target bit rate is exceeded. DSM defines a rate region, an area where a pair of vectored and non-vectored bit rates is simultaneously achievable. DSM allows an achievable region of bit rates, with SSM allowing a single point within that achievable region. DSM can also adapt to different crosstalk couplings and numbers of crosstalk disturbers. DSM can select an operating point in a given environment that can exceed SSM performance.

The flexibility of DSM can be used to tune the desired trade-offs as per operators' preferences, e.g. emphasizing the performance of either the vectored lines or the non-vectored lines and the trade-off between the different operators. Thus DSM can support higher rates for the non-vectored lines than SSM in many cases in a competitive environment since SSM significantly limits the data rates of the non-vectored lines.

Depending on the loop length, it is seen that DSM allows data rates for the non-vectored lines that are as much as three times higher (3x) than SSM would provide when a cap on vectored lines is imposed, as shown in Figure 1 – Figure 3. If instead the cap is imposed on the non-vectored lines, then DSM allows higher rates on the vectored lines as shown in Figure 4 – Figure 5.

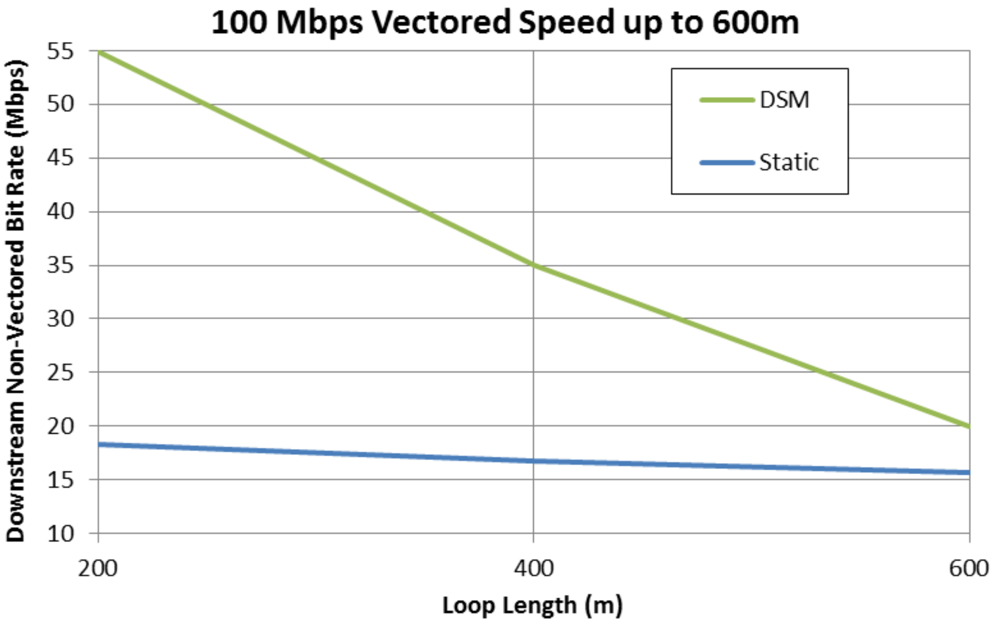

Figure 1. 1% worst-case non-vectored speeds with SSM ensuring 100 Mbps on vectored lines no longer than 600 m. A 2 MHz SSM limit on non-vectored lines ensures 100 Mbps on vectored lines no longer than 600m.

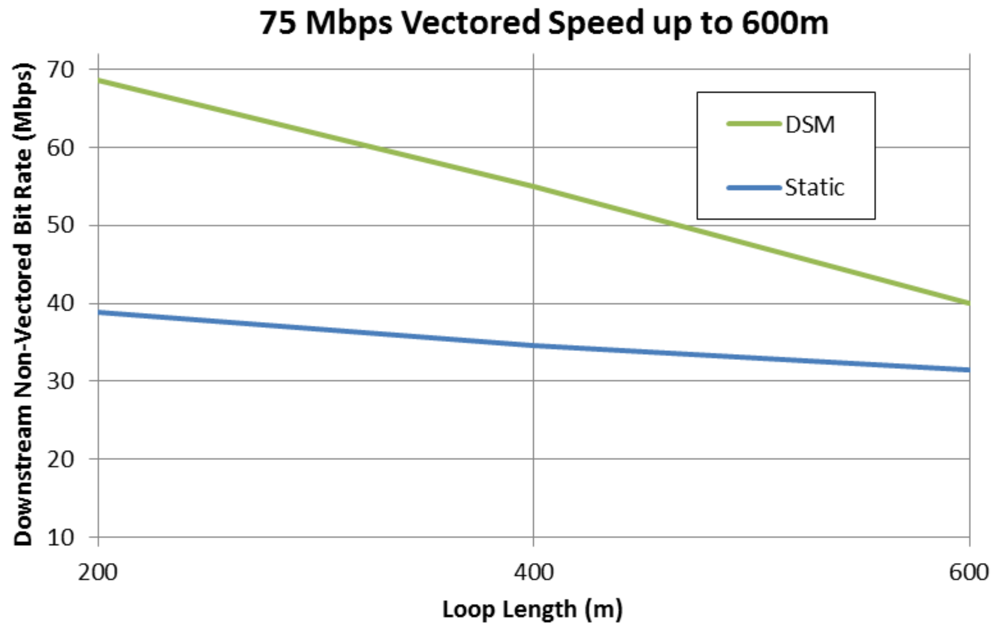

Figure 2. 1% worst-case non-vectored speeds with SSM ensuring 75 Mbps on vectored lines no longer than 600 m. A 7 MHz SSM limit on non-vectored lines ensures 75 Mbps on vectored lines no longer than 600m.

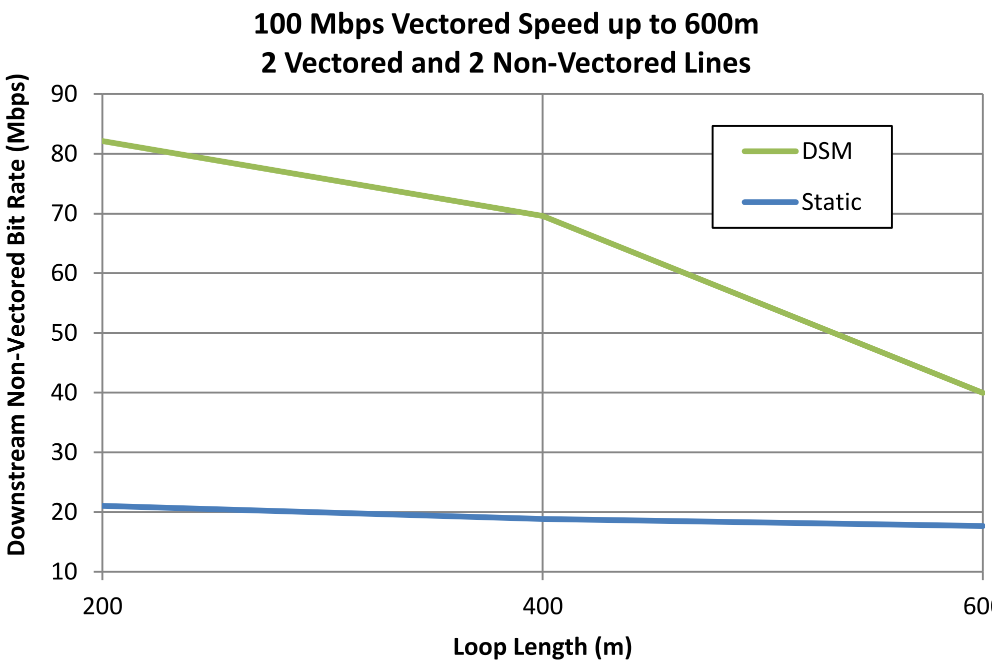

Figure 3. 2 vectored VDSL2 and 12 non-vectored VDSL2, 1% worst-case non-vectored speeds with SSM ensuring 100 Mbps on vectored lines no longer than 600 m. A 2 MHz SSM limit on non-vectored lines ensures 100 Mbps on vectored lines no longer than 600m.

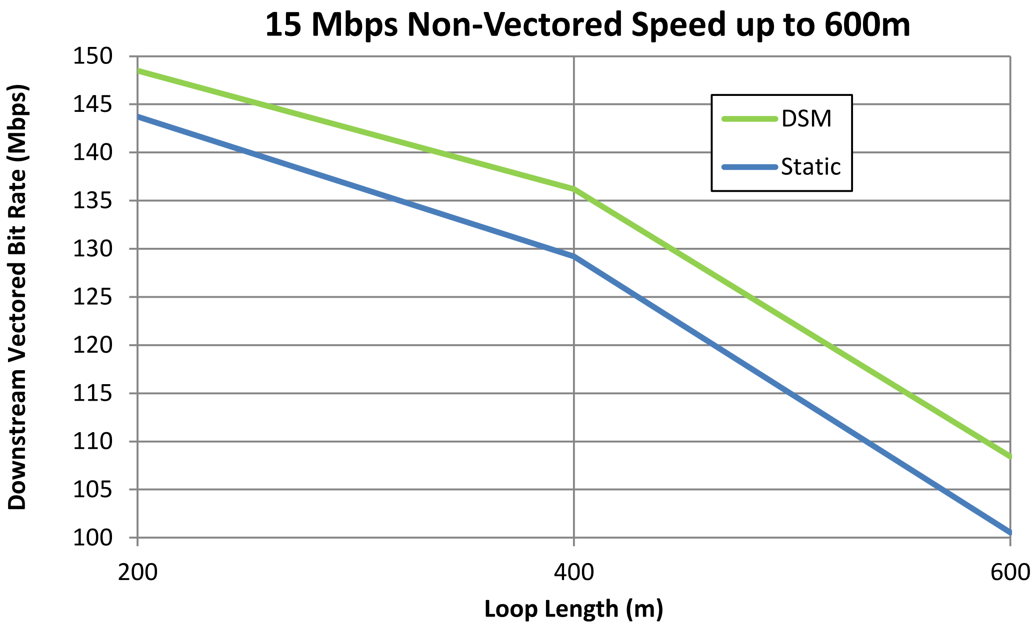

Figure 4. 1% worst-case vectored speeds with SSM ensuring 15 Mbps on non-vectored lines no longer than 600 m. A 2 MHz SSM limit on non-vectored lines ensures that they can transmit at least 15 Mbps on lines no longer than 600m.

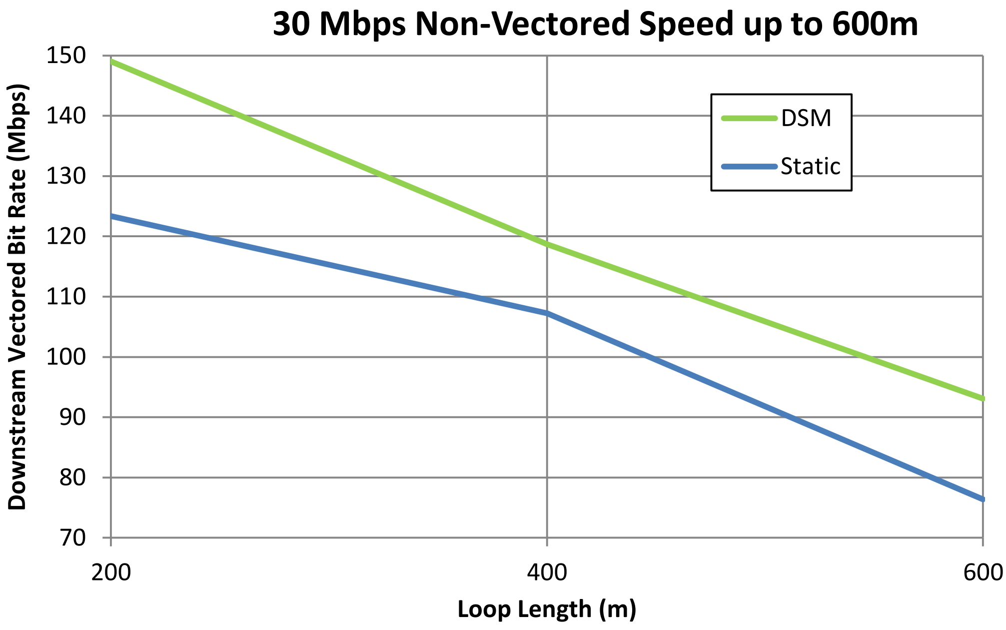

Figure 5. 1% worst-case vectored speeds with SSM ensuring 30 Mbps on non-vectored lines no longer than 600 m. A 7 MHz SSM limit on non-vectored lines ensures that they can transmit at least 30 Mbps on lines no longer than 600m.

SSM is operationally simpler than DSM. The maximum frequency based SSM uses existing controls available on most DSLAMs that can be implemented relatively easily by making changes to PSD masks or by disabling some of the bands used by the VDSL2.

Depending on what DSM architecture and algorithm are used, some cooperation among operators may be required. Furthermore, DSM may require controlling more parameters at the interface to the DSLAM than SSM. However, these parameters are generally available and are standardized by the ITU-T.

History

Document history		
V1.1.1	13th March 2015	Initial publication