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NICC Document

Data Sharing for DSM

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Foreword

This NICC Document (ND1518) has been produced by the NICC DSL TG.

Introduction

This document describes the use of sharing data between operators for the purpose of DSM in VDSL2 and vectored VDSL2 environments.

DSM and DLM technology has the potential to enhance services by lowering crosstalk, increasing speeds and improving stability and diagnostics. Sharing data on cable-plant and DSL configuration and performance allows DSM level 2 and 3 multi-line optimisations and DSM level 1 single-line optimisations, to enhance the performance of all lines. DSM data sharing can enhance the overall customer experience and therefore presents revenue value to all providers and operators involved. It can enable automated operations and therefore lower complexity to all providers and operators involved. DSM data sharing can increase the number of customers in the UK who can reliably receive triple-play services, single- and multi-channel video services, higher quality VoIP connection, as well as basic high-speed Internet access. Data sharing for DSM may only be enabled by installing or upgrading management systems. This can entail some complexity.

1 Scope

The present document captures the following aspects of using shared data (loop records, configuration data and performance metrics) for the purpose of DSM; in VDSL2 and Vectored VDSL2 environments:

a) Use cases that describe the relevant scenarios and conditions (granularity, frequency and degree of participation related to the data exchanged) involving data sharing for DSM in which data sharing can provide end-user and CP benefits. Shared data and control parameters are identified for each use case.
b) The potential technical impacts of data sharing for DSM, both for operators that participate in data sharing as well as for operators who do not participate in data sharing.
c) A high-level framework for data sharing for DSM and related considerations.

2 References

2.1 Normative references

2.2 Informative references

[1] ATIS-0900007: “Dynamic Spectrum Management Technical Report, Issue 2, 2012”.

[2] Ofcom 2010 Voluntary Code of Practice: Broadband Speeds.

[3] ITU-T Recommendation G.997.1 (06/2012): “Physical layer management for digital subscriber line transceivers”.

[4] ND-1513, Report on Dynamic Spectrum Management (DSM) Methods in the UK Access Network, 2010.

[5] ND-1516, Vectoring – use cases and impact assessment, March 2015.

[6] Broadband Forum TR-197, “DQS: DSL Quality Management Techniques and Nomenclature”, August 2012.

[7] ND-1602, Specification of the Access Network Frequency Plan (ANFP) applicable to transmission systems used on the BT Access Network, V5.1.1.

[8] ND-1604, Specification of the Access Network Frequency Plan applicable to transmission systems used on the KCH Access Network, Issue 2.

3 Definitions, symbols and abbreviations

3.1 Definitions

Access Node (AN): The equipment that terminates the network-end of the broadband lines, aggregates traffic and connects to the network, e.g., the DSL Access Multiplexer (DSLAM) or Multi-Service Access Node (MSAN).

Access Node Operator (ANO): The provider of the network access communications equipment including head-end equipment such as DSLAMs and MSANs. In a DSL access network, the ANO may also be called the “DSLAM Operator.”

Control parameters: Settings that effect changes to configurations, usually DSL line or DSLAM configurations. Control parameters may be written to. A control parameter may be a low-level line setting (e.g., PSD mask), a profile that includes multiple line settings, or a general indication of preference (e.g., higher speed vs. stability).

CP: Communications Provider.

CPE Modem Provider: The provider of the CPE modem to the end-user.

Crosstalk: Electromagnetic energy that couples into a metallic cable pair from signals on other pairs in the same binder or cable.

Customer Premises Equipment (CPE): Telecommunications equipment located at the customer premises on the customer side of the network interface.

Distribution Point (DP): the final flexibility point in the BT access network before the line reaches its customer.

D-Side Electrical Length (DSEL): electrical length from the SLCP to the NTP.

DSL line data: Indicates properties of the DSL line. May include DSL line and DSLAM settings as well as data about the DSL transmission environment and DSL performance.

Electrical Length: For a given loop loss at a given frequency, the electrical length is the length of cable that has that given loop loss at that given frequency.

End-User: The end user being served by the DSL service.

E-Side Electrical Length (ESEL): electrical length from exchange MDF to SLCP.

Infrastructure provider: an entity who is both the MPF provider and the ANO.

Loop data: Indicates properties of the subscriber loop: electrical length, loop make-up, etc. May or may not include properties of multiple loops, such as indicating which loops share a cable or a cable binder.

Metallic Path Facility (MPF): Facility including the Telephone cabling between customer premise NTP and the Main Distribution Frame or Sub-loop Distribution Frame.

MPF Provider: The provider responsible for the provision and maintenance of the access cable and related cable infrastructure.

Shared data: Parameters that are reported in support of data sharing for DSM. Shared data is read-only and may include the following: line test, diagnostics, status and performance monitoring parameters, inventory data, line and channel configuration data, loop data and other data.

Spectral compatibility: The capability of multiple line transmission system technologies to coexist in the same cable and operate satisfactorily in the presence of crosstalk noise from each other.

Spectrum management: The term refers to techniques that are intended to minimise the potential for interference and maximise the utility of the metallic transmission.

Vectoring: The coordinated transmission and/or coordinated reception of signals of multiple DSL transceivers using techniques to mitigate the adverse effects of crosstalk to improve performance.

Working length: The sum of all loop segment lengths from the Exchange or Cabinet to the network interface at a customer location, excluding non-working bridged tap.

3.3 Abbreviations

AAA Authentication, Authorisation, and Accounting

ADSL Asymmetric Digital Subscriber Line

ALA Active Line Access

ANFP Access Network Frequency Plan (BT [7] or KCH [8])

AN Access Node

ANO Access Node Operator

ATIS Alliance for Telecommunications Industry Solutions

BNG Broadband Network Gateway

BRAS Broadband Remote Access Server

CAL Cabinet Assigned Loss

CP Communications Provider(s)

CPE Customer Premises Equipment

DP Distribution Point

DPBO Downstream Power Back Off

DSEL D-Side Electrical Length

DSL Digital Subscriber Line

DSLAM Digital Subscriber Line Access Multiplexer

DSM Dynamic Spectrum Management

EO Exchange Outlet

ESEL E-Side Electrical Length

FEXT Far End Cross Talk

INP Impulse Noise Protection

IWF Iterative Water Filling

Mbps Megabits per second

MDF Main Distribution Frame

MLWF Multi-Level Water Filling

MPF Metallic Path Facility

MSAN Multi-Service Access Node

NTP Network Termination Point

OAM Operations Administration and Maintenance

PSD Power Spectral Density

SRA Seamless Rate Adaption

TG Task Group

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 version 2

4. Data Sharing for DSM High-Level Framework

4.1 Framework

Figure 1 shows a simplified view of the DSM data sharing framework, which allows functions to be performed either by CPs, ANOs, MPF providers, or by centralised systems. Note: The figure is limited to 2 ANOs, but there may be 1 or multiple.

Figure 1 shows two CPs: CP A either performs no DSM/DLM, or allows a centralised system or ANO to perform DSM/DLM. CP B performs their DSM/DLM functions themselves and relies on the data and control to share data to enable these functions. Also, there are two ANOs, with ANO 1 performing DSM/DLM functions, but ANO 2 performing no such functions.

The MPF Provider and the Access Node Operator (ANO) may be two separate entities. Or, there may be a single “Infrastructure Provider” or “Wholesaler” who is both the MPF Provider and the ANO and who is responsible for providing both the metallic facilities and the DSLAMs. Additionally, a third party may be involved with hosting centralised systems or other functions.

Simplified Diagram

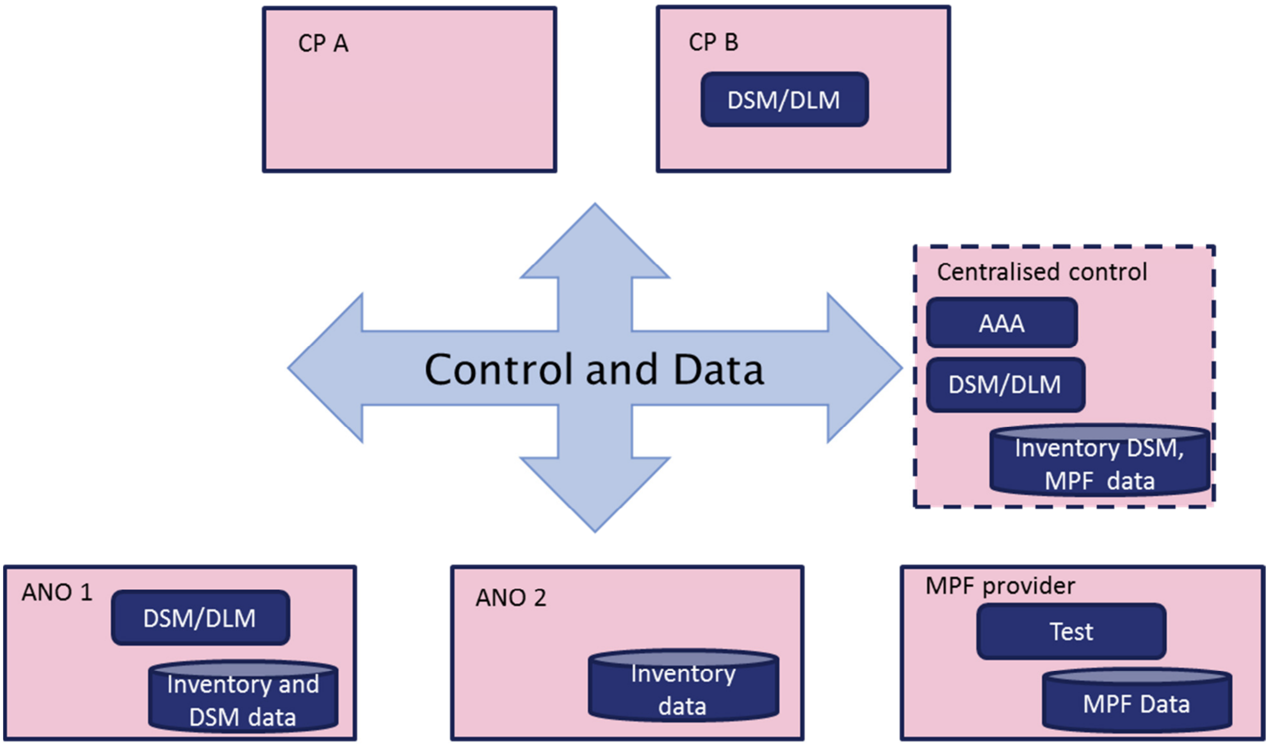

Figure 1. Simplified view of DSM data sharing

The "data and control interface(s)" in Figure 1 connect between the CPs, ANOs and MPF provider.

Data and control may include multiple messaging data models or interfaces, or may be implemented by an abstraction layer or an adaptation layer which converts signals on one side of the interface to equivalent signals on the other side of the interface. An abstraction layer hides the details of equipment interfaces to present a simplified interface toward management systems. An adaptation layer directly translates signals from one format to another format. The abstraction or adaptation layer could be implemented using a new, yet to be standardised, Northbound DSM data sharing interface and multiple Southbound adapters to different equipment and systems. In a centralised architecture, a centralised system can provide such an abstraction or adaptation layer. Centralised data sharing could also be implemented with the various parties accessing a logically centralised database, but this logically centralised database may physically consist of distributed servers, cloud infrastructure, hosted service, etc.

A centralised system can provide for multi-tenancy, perform AAA functions, resource allocation and perform arbitrage between the various parties. A centralised system may be managed by an MPF provider, ANO, CP, or third party. A centralised system may be implemented in multiple physical devices and only be logically centralised.

A distributed architecture may have no centralised system. In a distributed architecture functions such as AAA and resource allocation would be performed by the ANOs, MPF providers and perhaps also by the CPs. DSM data sharing with a distributed architecture may have issues with data concurrency, fidelity and/or obsolescence. Also, data may lose fidelity or become obsolete during multi-party data exchange; e.g. if data is first sent from party1 to party2 and is then sent from party2 to party3.

Some control parameters (e.g., high-level indication of performance, service level, or desired trade-offs) are readily implementable with a centralised implementation but may be difficult with a distributed implementation. With a centralised implementation, there may be no distinction between sharing data per line or for multiple lines.

There may be different levels of data sharing, distinguished by different sets of data and by the resolution and accuracy of the data.

Figures 2 and 3 show a particular set of functions being supported by CP A versus those supported by CP B, and similarly a particular set of functions supported by ANO A versus those supported by ANO B. However, any given CP or ANO may support any of these functions. All ANOs are likely to perform some testing of their equipment. Note: The explanatory text follows the diagrams.

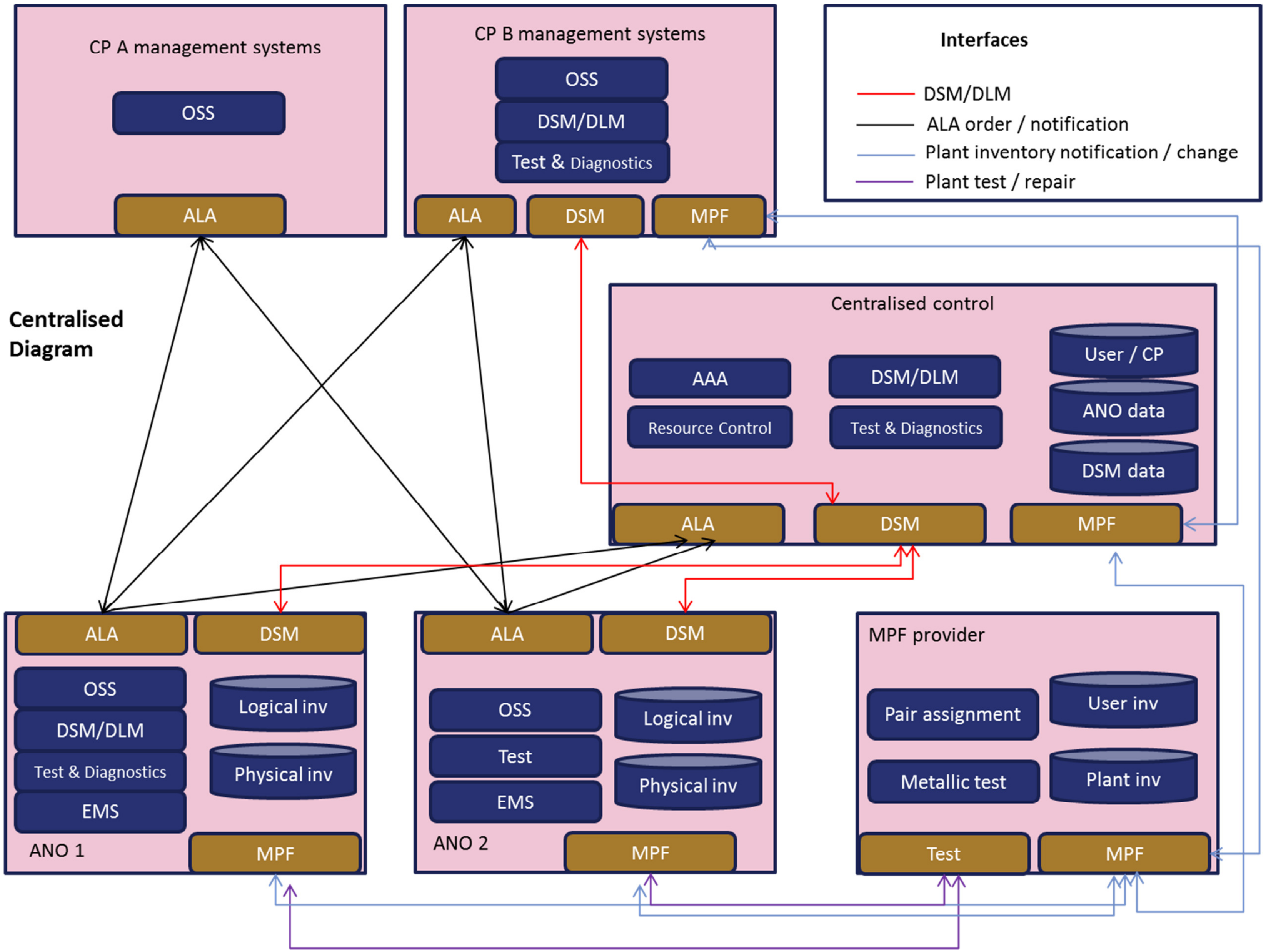

Figure 2 - Centralised Implementation

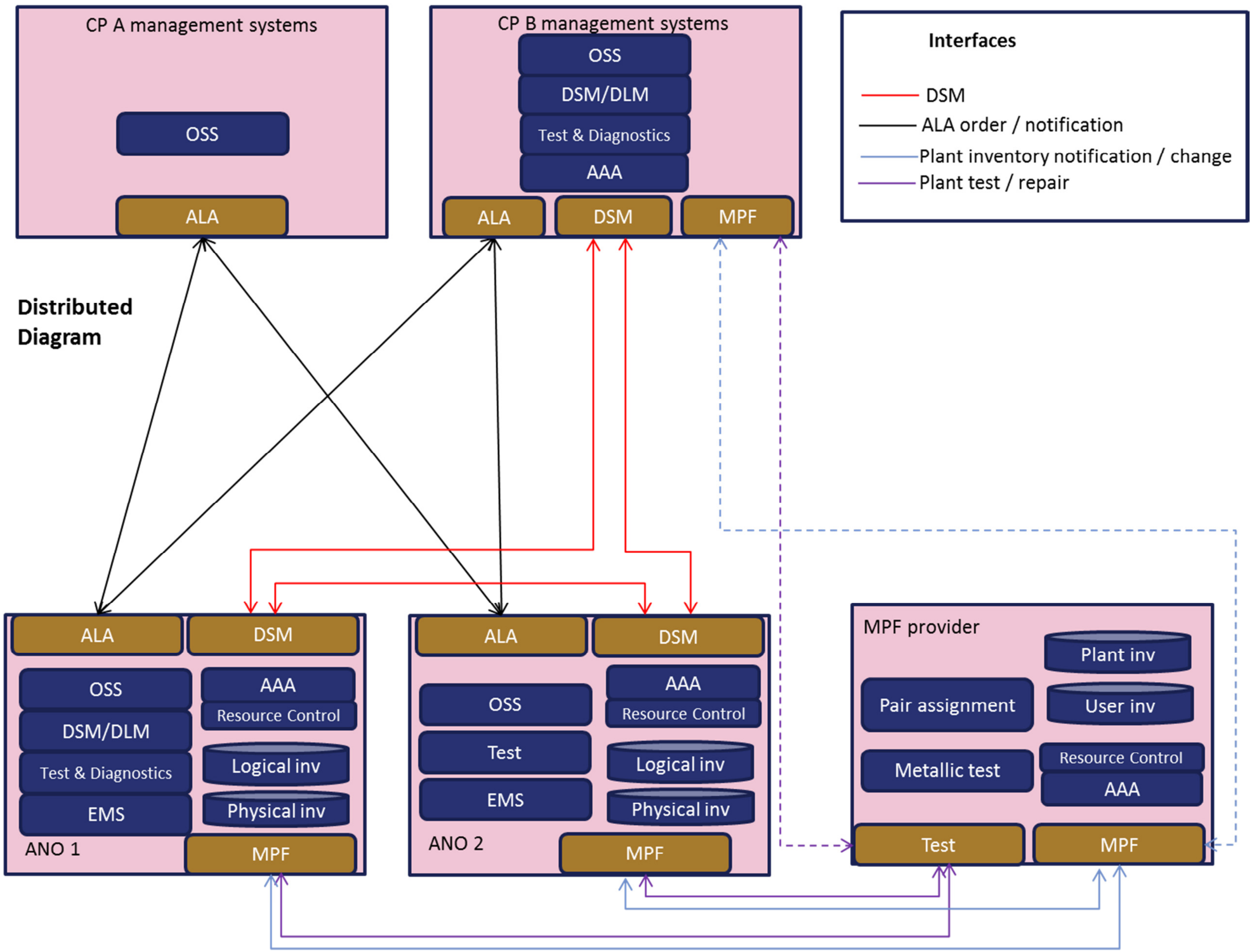

Figure 3 - Distributed Implementation

Description of Interfaces

Note: That interfaces are bi-directional.

DSM/DLM: Requests for DSM or DLM information and requests for configuration changes for DSM or DLM.

ALA (Active Line Access) order / notification: request add/remove/change service (CPs), request service provisioning/de-activation (ANOs).

Plant inventory notification / change: plant information exchange and requests for change of plant such as ordering a loop or sub-loop.

Plant test request / repair: requests for loop test or repair.

Description of Functional blocks within the diagrams

OSS: Operations Support System; specific to the functionality in systems which are used for data sharing for DSM.

EMS: Element Management System; specific to the functions for managing DSLAMs.

AAA: Authentication, Authorisation and Accounting. Verifies user credentials, admits requests and limits access, maintains transactional records for billing and other purposes.

Resource control: ensures that available resources are not overloaded and allocates available resources. For ANOs, resources are generally DSLAMs and network connections, including DSLAM ports, internal DSLAM bandwidth, network facing bandwidth, DSLAM internal computational capabilities and the size and frequency of admissible management messages. For MPF providers, resources are the metallic facilities themselves as well as the management systems for these.

DSM/DLM: Dynamic Spectrum Management / Dynamic Line Management. Determines DSL line settings for multi-line / single-line DSL spectrum management and performance optimisation.

Test & Diagnostics: Interprets and analyses metallic, DSL and network test, diagnostics, status and performance data. May issue commands for retrieving data or requesting tests.

Logical inv: DSLAM and DSL configuration settings.

Metallic test: Performs measurement of electrical characteristics of MPF.

Pair assignment: Provision of MPF or SLU MPF.

Physical inv: DSLAM equipment data such as assignments, equipment inventory and firmware versions.

Plant inv: Data about the actual MPF, cables/pairs, loop make-ups, terminations, etc.

User inv: Data about users/CPs and MPF assignments to users/CPs.

User / CP data: Data about users/CPs that reside in a centralised system.

ANO data: Data about ANOs, DSLAMs and DSLAM settings that reside in a centralised system.

DSM data: Data related to, used by and created by DSM including line performance, diagnostics, status and configuration data.

4.2 Related Considerations

In some cases data will need to be aggregated and processed, with only processed results shared and visible to the consuming entity as this will be required to meet commercial and security concerns. The aggregated and processed data should only be accessible after user authentication and authorisation. Such requests need to be managed or limited to be within allowed volumes of requests and allowed types of requests. Restrictions on visibility of shared data must be enforced in order to preserve privacy of data and network operations.

Some cases involve control capabilities and many of these should be limited to ensure that configuration changes are implementable in a fair way that does not adversely impact other operators. If a CP requests control capabilities, such as varying DSL line parameters or profiles, then the central control systems can manage these requests and verify that such an action is permissible, or translate the request into a permissible action. The central control systems may also need to queue or limit the numbers of requests based on the capacity of the underlying systems and network functions in order to avoid overloading the equipment.

In many cases involving multiple lines, the lines could be logically grouped so that lines that could interact with each other (e.g., by crosstalk) are managed in the same group.

Some operators may participate in sharing data for DSM and some operators may not. Management functions may be performed by retailers or by wholesalers, regardless of whether they participate in sharing data for DSM or not.

Data may be shared for DSM both with sub-loop unbundling (SLU) and with virtual unbundling and LLU from the exchange.

Data sharing may operate in accordance with a set of rules. Rules may be administered by a central authority, or they may be distributed. Such rules may involve a definition of fairness. The risk of adverse impact on service on lines that do participate from those who don’t has not been fully quantified at this stage. There is some quantification in Appendix A.

The reporting frequencies of data can vary and with type of parameter and use case. Some data may be reported every 15 minutes (e.g., counters), some less frequently (e.g., Hlog), some very infrequently (e.g., loop records). Only incremental changes may need to be reported for some type of data (e.g., loop records).

5. Use Cases on DSL Data Sharing for DSM

Unless otherwise noted, the shared data is used by the CP(s) and the control parameters are requested by the CP(s) for implementation by the Access Node Operator (ANO).

5.1 Use Case 1, DSM Level 2 in multi-operator environments

DSM level 2 involves joint multi-line optimisation of signals and crosstalk, including balancing the transmit power of multiple lines and performing spectral optimisation. DSM level 2 can be controlled from a central spectrum management centre (SMC), or it may be implemented in a distributed fashion. The distinction between centralised and distributed here is architectural; either architecture can implement any DSM algorithm. DSM techniques and algorithms are not described here, they can be found in references [1], [4] and [6]. See Section 4.1 for a wider discussion on centralised versus distributed architectures.

It is possible that some CPs may use centralised DSM, some may use distributed DSM and some may not participate in using DSM at all.

5.1.1 Use case 1.1, Centralised DSM Level 2 Architecture

DSM level 2 can be controlled from a central spectrum management centre (SMC), which has a full view of the network and is typical of scenarios involving a single operator. DSM level 2 may also be controlled by a central SMC in multi-operator scenarios. In this centralised case the SMC can run any centralised DSM algorithm, including Optimal Spectral Balancing (OSB) [1], apply calculated PSD masks to each line and oversee the resulting performance impacts among the multiple lines. Centralised DSM may presume the ability to collect nearly all data from the access nodes and may presume a relatively strong level of control.

With a central SMC, DSM data sharing can be used by CPs to indicate general preferences to the SMC; e.g., to indicate that certain service levels are desired on certain lines. The SMC then uses these preferences to guide the implementation of DSM and run a DSM algorithm to determine desired line settings. The SMC then either directly configures the access nodes with these line settings, or requests the ANO to implement preferred line settings. Then the SMC can use DSM data sharing to inform the CPs about the settings and performance that were actually enabled by the central SMC and the ANO.

The central SMC may be operated by the Metallic Path Facility (MPF) provider, Access Node Operator (ANO), or by a third party, or a CP.

Shared data for case 1.1		
Data	**Shared Data Source(s)**	**Range of data**
Transmit power	Access Node Operator, CPs	Per line
Spectral data: QLN(f) [3]§7.5.1.27, SNR(f) [3]§7.5.1.28, Hlog(f) [3]§7.5.1.26, Xlin(f) [3]§7.5.1.39	Access Node Operator	Per line
Transmit power, spectra, PSD masks	Access Node Operator	Per line
Line performance: actual bit rate, attainable data rate (ATTNDR [3]§7.5.1.41, [3]§7.5.1.19 & [3]§7.1.20)	Access Node Operator	Per line

Control parameters associated to case 1.1
General indication of performance preferences on certain lines; such as specifying a phy-layer priority indicator.

Specific indication of desired service level on certain lines. May indicate a specific desired bit rate or range of bit rates or other service qualities such as latency, margin, power etc.

5.1.2 Use-case 1.2, Distributed DSM Level 2 Architecture

In multi-operator scenarios DSM level 2 may be implemented in a distributed fashion. Given sufficient knowledge about the DSL environment and operating point, individual CPs can perform their own DSM level 2 algorithms. Examples of distributed DSM level 2 algorithms are distributed Multi-Level Water-Filling (MLWF) and Iterative Water-Filling (IWF) [1].

Distributed DSM level 2 can be enabled with DSM data sharing. Each operator can run DSM level 2 on their lines if they can access data about other lines, identify performance targets and request transmit power or PSD adjustments. Further information can tell an operator if their line is creating crosstalk that adversely impacts other lines and then the operator can decrease their line's transmit power or spectra to ameliorate this problem.

While distributed DSM algorithms can operate with no shared data, increasing levels of DSM data sharing allow increasing effectiveness. As operators can access more data about other lines they can better adjust their lines' power and spectra to lower crosstalk and increase performance. The use case with a distributed architecture here assumes some non-zero level of data sharing.

Shared data for case 1.2		
Data	**Shared Data Source(s)**	**Range of data**
Transmit power	Access Node Operator, CPs	Multiple lines
Spectral data: QLN(f) [3]§7.5.1.27, SNR(f) [3]§7.5.1.28, Hlog(f) [3]§7.5.1.26, Xlin(f) [3]§7.5.1.39	Access Node Operator	Multiple lines
Performance data on other lines.	Access Node Operator, CPs	Multiple lines
Records indicating the serving area each line is in.	MPF provider or CPs	Multiple lines in a serving area
Loop records identifying what cables each line is in	MPF provider	Multiple lines in a cable
The physical address of each subscriber	MPF provider or CPs	Multiple lines in a neighbourhood

Note that transmit power may be indirectly controlled, e.g., by limits on transmit PSD or max margin.

Control parameters associated to case 1.2
A single-line assignment of transmit power.
Multi-line assignments of transmit power.
A single-line assignment of transmit PSD or PSD mask.
Multi-line assignments of transmit PSDs, or PSD masks.

5.1.3 Technical impacts specific to this use case

There are trade-offs between the performances of the different lines administered by the different operators; this can bring up questions of fair resource allocation. Examples of these can be seen in references [1] and [4]. One method of ensuring fairness is if DSM is configured to ensure that each line performs at least as well as it would with no DSM.

DSM level 2 can work fully within the confines of the existing ANFP [7&8], or some additional flexibility of the transmit spectrum could be allowed while ensuring performance levels of all lines. An example of such flexibility is dynamic UPBO in ANFP [7].

In some cases, requests for changes to transmit power or PSD may be limited or modified by rules that could be applied by the access node operator, to stay within accepted boundaries. In these cases the CP should be informed about the actual values that were applied.

The choice of a CP in participating in DSM level 2 and the level of data sharing in distributed implementations can impact the performance of the CP's lines, as well as the performance of neighbouring lines.

5.2 Use Case 2, DSM for Vectored VDSL2

ND1516 examines different deployment scenarios for vectored VDSL, including mixed deployments of vectored and non-vectored lines in the same cable and discusses the use of DSM level 2 in these scenarios.

In addition to the cases here, with vectoring it is important to manage the now dominant background, ingress and non-stationary noises with dynamic re-profiling using historical data and multi-line optimisation. The elimination of crosstalk essentially bolsters the effects of non-crosstalk noises; and so DLM/DSM level 1 as described in Section 5.2 can be particularly useful with vectoring.

5.2.1 Case 2.1, Identify isolated vectored / non-vectored groups

This use case considers a vectored group and a second group of lines that are either a vectored group or a non-vectored group of lines. Here, compatibility is simply enabled if there are not multiple such groups, or if there is little or no crosstalk between any two such groups in a given cable or area. Availability and use of such data can increase the speed of deployment and the footprint, of possible new vectored deployments.

Shared data for case 2.1		
Data	Shared Data Source(s)	Range of data
Loop records, vector group	MPF provider	Multiple lines

assignments		
Neighbourhood data or serving area data and vector group IDs	MPF provider and Access Node Operator	Multiple lines

Control parameters associated to case 2.1
N/A

5.2.2 Case 2.2, DSM level 2 for lines outside a vector group

Section 5.1 discusses DSM level 2; while the case here is specific to DSM Level 2 for vectoring. If not all VDSL2 lines are in a single vectored group, then DSM level 2 can enable a level of spectral compatibility with lines outside of the vectored group. DSM can be used to manage crosstalk between a vectored group and a group of non-vectored lines, or between two separate vectored groups and configure transmit spectra for compatibility. Shared data generally improves DSM level 2 performance.

Shared data for case 2.2		
Data	Shared Data Source(s)	Range of data
Transmit power	Access Node Operator, CPs	Multiple lines
Spectral data: QLN(f) [3]§7.5.1.27, SNR(f) [3]§7.5.1.28, Hlog(f) [3]§7.5.1.26, Xlin(f) [3]§7.5.1.39	Access Node Operator	Multiple lines
Performance data on other lines.	Access Node Operator, CPs	Multiple lines
Vector group ID, or indication of non-vectored lines	Access Node Operator	Multiple lines
Records indicating the serving area each line is in.	MPF provider or CPs	Multiple lines in a serving area
Loop records identifying what cables each line is in	MPF provider	Multiple lines in a cable
The physical address of each subscriber	MPF provider or CPs	Multiple lines in a neighbourhood
Indication of use of DSM (yes or no, type of DSM)	CPs, Access Node Operator	Multiple lines

Note that transmit power may be indirectly controlled, e.g., by limits on transmit PSD or max margin.

Control parameters associated to case 2.2
Multi-line assignments of transmit power.
Multi-line assignments of transmit PSDs, or PSD masks.

5.2.3 Case 2.3, Estimate the level of crosstalk into each line

Shared data on the level of crosstalk into each line allows dynamic restrictions that are more restrictive on lines that have higher crosstalk couplings. Crosstalk couplings are symmetric, so crosstalk coupling into a line can be used to estimate crosstalk coupling from that line.

Crosstalk couplings, Xlin(f), may be read directly from vectored lines. Crosstalk couplings may also be estimated by reading QLN(f) and estimating crosstalk. Another method of estimating crosstalk is by analysing time series of performance events across data on a pool of multiple lines; e.g., if one line's performance is impacted exactly at the same time that another line starts up or increases transmit power this indicates a significant crosstalk coupling.

Shared data for case 2.3		
Data	Shared Data Source(s)	Range of data
Xlin(f) [3]§7.5.1.39 (crosstalk couplings between vectored lines)	Access Node Operator	Multiple lines
QLN(f) [3]§7.5.1.27 for each of multiple lines	Access Node Operator	Per line
On / off times of each line	Access Node Operator	Multiple lines
Cause of each resynch (LPR_INTRPT [3]§7.2.1.8.1, HRI_INTRPT [3]§7.2.1.8.2 and SPONT_INTRPT [3]§7.2.1.8.3 counters)	Access Node Operator	Multiple lines
Data gathering logs (ITU-T G.993.2-2015) NOTE: data gathering logs are time-stamped	Access Node Operator or CPs	Multiple lines

Control parameters associated to case 2.3
N/A

5.2.4 Case 2.4, Are some line speeds limited anyway?

Some vectored lines may have a limit set on their maximum speed (e.g. 100Mbps), either due to the equipment or to assigned service levels. Knowledge of the limitations on these lines can allow lower restrictions on lines that may crosstalk into them.

Shared data for case 2.4		
Data	Shared Data Source(s)	Range of data
DSL line settings, BRAS settings	Access Node Operator or CPs	Multiple lines

Control parameters associated to case 2.4
N/A

5.2.5 Case 2.5, Diagnostics and line optimisation specific to vectored lines

Shared DSM data can identify problems with insufficient crosstalk cancellation or excessive crosstalk. This knowledge can be used to re-direct vectoring resources (e.g., increase FEXT cancellation) toward under-performing lines. It is also possible to use crosstalk coupling (Xlin(f)) data to separate crosstalk from other noises and identify background noise at each end of the line.

Shared data for case 2.5		
Data	Shared Data Source(s)	Range of data
QLN(f) [3]§7.5.1.27, SNR(f) [3]§7.5.1.28, Hlog(f) [3]§7.5.1.26, Xlin(f) [3]§7.5.1.39, fault monitoring [3]§7.1, performance monitoring [3]§7.2, thresholds [3]§7.3 diagnostic [3]§7.5, status parameters [3]§7.4 and self-test results [3]§7.5.	Access Node Operator and CPs	Per line

Control parameters associated to case 2.5
FEXT_CANCEL_PRIORITY, FEXT_CANCEL_ENABLE, VECTOR_BAND_CONTROL, profiles

5.2.6 Technical impacts specific to this use case

Vectoring complicates Sub-Loop Unbundling (SLU). So, sharing data to manage unbundling could help ease the introduction of vectoring. Examples can be seen in [5] and Appendix A.

5.3 Use Case 3, DSM for VDSL from the Exchange

This use case is specific to ensuring compatibility of exchange-based VDSL with cabinet-based VDSL. Issues related to exchange-based VDSL are described in more detail in ND1517 and currently this scenario is not allowed under the ANFP [7&8].

5.3.1 Case 3.1, Identify cases where exchange lines do not overlap with cabinet lines

Pure EO lines have no crosstalk with cabinet-based lines. Crosstalk between exchange lines and cabinet lines may also be determined via estimates of crosstalk using data read from DSL lines, e.g., QLN(f) shows crosstalk from an exchange line, or time-series of line performance data showing that cabinet lines are affected when exchange lines turn up. This data could expand the scope of exchange VDSL deployments.

CAL-based cabinet PSD shaping (or DPBO) could be relaxed to improve cabinet performance if records or data indicate no crosstalk between exchange and cabinet lines and if monitoring data can verify that there is no crosstalk between exchange and cabinet lines.

Shared data for case 3.1		
Data	Shared Data Source(s)	Range of data
Loop records identifying what cables each line is in	MPF provider	Multiple lines in a cable
Records indicating the serving area each line is in	MPF provider	Multiple lines in a serving area
QLN(f) [3]§7.5.1.27 (to identify crosstalk to/from cabinet lines)	Access Node Operator	Per line
Time series of multi-lines performance data.	Access Node Operator or CPs	Multiple lines

Control parameters associated to case 3.1
PSD mask, UPBO settings
DPBO settings; DPBOSHAPED, DPBOESEL

5.3.2 Case 3.2, Enable partially dynamic or semi-static approaches for exchange and cabinet VDSL

Partially dynamic or semi-static approaches to exchange/cabinet VDSL compatibility can require some knowledge of the loops and DSLs.

In the upstream direction, an example is to define UPBO as a function of the exchange loop length minus the ESEL of the cabinet that the exchange lines run through: UPBO (DSEL). Another example is to use only part of the upstream bandwidth, U0 and the lower-frequency part of US1. These have been described theoretically (ND1517) but details of implementation are not established.

In the downstream direction, overlap of exchange VDSL and cabinet vectored VDSL is a concern, such overlap could be physically avoided or managed by, for example; spectral shaping, DSM.

Shared data for case 3.2		
Data	Shared Data Source(s)	Range of data
Upstream; Loop records indicating cabinet locations, ESEL [3]§7.3.1.2.13(a.2) of nearby cabinets	MPF provider	Per line
Downstream: loop records or measurements indicating ESEL [3]§7.3.1.2.13(a.2)	MPF provider	Per line

of overlapping vectored cabinets.		

Control parameters associated to case 3.2
UPBOSHAPED (UPBOPSD-pb, UPBOKL, UPBOKLF) [3]§7.3.1.2.14
A1, A2, B1, B2 [3]§7.3.1.2.14
Transmit power, PSD mask [3]§7.3.1.2.9 and §7.3.1.2.12, DPBO settings; DPBOSHAPED, DPBOESEL [3]§7.3.1.2.13

5.3.3 Joint DSM optimisation for exchange and cabinet VDSL

DSM level 2 can enable compatibility between exchange lines and cabinet lines that share distribution cables. This requires data from multiple lines, possibly across CPs. See Section 5.1, DSM Level 2 in multi-operator environments.

5.3.4 Technical impacts specific to this use case

ND1517 discusses issues with exchange VDSL. Shared data may be useful for managing both cabinet and exchange VDSL since there may be many lines and multiple CPs.

5.4 Use Case 4, Dynamic UPBO

In order to implement dynamic UPBO, the CP and/ or ANO needs to know UPBO settings across the CP's lines as specified in the ANFP [7]. Dynamic UPBO could potentially be extended to allow performance increases with vectoring and other cases or if UPBO data is known across multiple ANOs or CPs.

5.4.1 Case 4.1, Dynamic UPBO as in ANFP [7]

Shared data for case 4.1		
Data	Shared Data Source(s)	Range of data
Multiple lines settings	CPs or Access Node Operator	Multiple lines

Control parameters associated to case 4.1
UPBO parameters: A1, A2, B1, B2 [3]§7.3.1.2.14

5.4.2 Case 4.2, UPBO for vectored lines

UPBO settings should be relaxed for improved performance when all or most lines are vectored.

Shared data for case 4.2		
Data	Shared Data Source(s)	Range of data
Vector group identification by the VCE, indication of vector mode enable.	Access Node Operator	Per line
Loop records identifying what cables each line is in	MPF provider	Multiple lines

Control parameters associated to case 4.2
UPBOSHAPED (UPBOPSD-pb, UPBOKL, UPBOKLF) [3]§7.3.1.2.14
A1, A2, B1, B2 [3]§7.3.1.2.14

5.4.3 Case 4.3, Turn off UPBO in pure collocated cases

UPBO can be turned off entirely if it is known that all cross-talking lines are about the same length, such as if they all terminate in the same building basement. This can significantly increase upstream performance on short loops.

Shared data for case 4.3		
Data	Shared Data Source(s)	Range of data
Records indicating lines lengths, cables, or serving areas.	MPF provider	Multiple lines

Control parameters associated to case 4.3
UPBOSHAPED (UPBOPSD-pb, UPBOKL, UPBOKLF) [3]§7.3.1.2.14
A1, A2, B1, B2 [3]§7.3.1.2.14

5.4.4 Case 4.4, Monitor UPBO for ANFP compliance

UPBO settings should comply with the ANFP [7&8] and this could be verified with automated systems.

Shared data for case 4.4		
Data	Shared Data Source(s)	Range of data
Records indicating line lengths	MPF provider	Per line
UPBOKLE [3]§7.5.1.23.1, UPBOKLE-R [3]§7.5.1.23.2	Access Node Operator	Per line

Control parameters associated to case 4.4
N/A

5.4.2 Technical impacts specific to this use case

UPBO is ensconced in the current ANFP [7&8] and although UPBO essentially implements a level of "fairness" between users that is static; this existing static level is the baseline for future changes.

5.5 Use Case 5, DSM level 1 / DLM

DSM level 1 monitors, controls and optimises transceiver and line settings independently on each DSL. DSM level 1 is synonymous with Dynamic Line Management (DLM) [1,2,4,6]. Each CP can run DLM / DSM level 1 on their lines if they can access line data and perform re-profiling. This can lower the number of trouble calls, to the CP and to the Access Node Operator or MPF Provider.

DSM level 1 allows a CP to select trade-offs between stability, delay and bit-rate for individual services or lines. For example, to enable DSL lines to support backhaul needs of small-cells and femtocells; by enabling low-delay profiles for small-cell or femtocell backhaul and supporting SLAs.

Shared data for case 5		
Data	**Shared Data Source(s)**	**Range of data**
Line test data, from narrowband POTs, broadband test equipment	MPF Provider, Access Node Operator	Per line
Single-Ended Line Test (SELT), or Double-Ended Line Test (DELT) data	Access Node Operator	Per line
DSLAM port status & CPE status	Access Node Operator	Per line
Data rate [3]§7.5.2.1, noise margin [3]§7.5.1.13 & [3]§7.5.1.16,	Access Node Operator	Per line
DSL line fault monitoring, performance monitoring, test, diagnostic and status parameters	Access Node Operator	Per line
Counts of anomalies, CVs [3]§7.2.2.1 & [3]§7.2.2.2, SES [3]§7.2.1.1.3 & [3]§7.2.1.2.3, retrains [3]§7.2.1.3	Access Node Operator,	Per line
Counts of sent/received packets, errored packets, discarded packets, packet loss rate – at layer 2/3	Access Node Operator,	Per line, on DSL line interfaces only
Delay, jitter, congestion stats (particularly for small-cells) – typically available only at layer 4 or above.	Access Node Operator, CPs	Per line

Control parameters associated to case 5
Indication of desired trade-offs between bit rate, delay and line stability. (Indirectly indicates control to a DLM system)
Profile selection.
Max/min data rate, margin, max/min/target noise INP settings, other line settings.

5.5.6 Technical impacts specific to this use case

There are trade-offs between stability, delay and bit-rate. There may also be trade-offs in power consumption.

In this case the data pertaining to a line is made available to a specific CP, the one controlling the line. The choice of a CP in participating in DSM level 1 and the level of data sharing, generally only impacts the performance of that CP's own lines.

6. Technical Impacts

This section examines and discusses the technical impacts for operators that participate in data sharing as well as for operators who do not participate in data sharing. These impacts can appear differently to different participating entities: CPs, Access Node Operators and MPF providers.

DSM generally has the highest performance if complete DSM-related data on all lines is available to and from all providers and operators. If only partial data is shared, e.g., if some providers or operators do not participate in data sharing, then the effectiveness of DSM is generally diminished, to an extent that depends on the situation.

6.1 Impacts to CPs

CPs - Potential Technical Impacts	
CPs that participate in data sharing	**CPs that do *not* participate in data sharing**
Incur complexity of implementing DSM data sharing interfaces	LLU continues present mode of operation (PMO)
Enhanced DSL performance via DSM	
Decreased operations complexity	
Operations for VDSL2 can proceed with management similar to LLU	VDSL2 has little or no DSM capabilities and management

6.2 Impacts to Access Node Operators (ANOs) and MPF Providers

ANOs and MPF Providers - Potential Technical Impacts	
ANOs and MPF Providers that participate in data sharing	**ANOs and MPF Providers that do *not* participate in data sharing**
Incur complexity of making DSLAM data available to multiple parties. [See Note 1]	No direct communication with CPs
Incur complexity of making DSLAM control parameters changeable by other entities (requiring federated 3rd party access). [See Note 2]	N/A
Automated communication can lower operations complexity	Indirect communications; may require multiple manual actions to resolve a trouble
Can offer higher-tier products to CPs, e.g. enhanced management	Continue present mode of operation (PMO)

Incur complexity of making loop record data available to multiple parties	Continue present mode of operation (PMO)
Lower operations complexity by automated troubleshooting using loop record data, including DSM optimisations and fault correlation	Troubleshooting may require multiple manual interactions with CPs and customers. Annoyed customers may cancel service.

Note 1:
A typical data collection process for an ANO may involve systems such as DSLAMs, Element Managers, Data Collectors and CPE. These provide data collection to a single point and aggregation of time periods to reduce data scale. Some of these systems may be combined. Specific data items required for inclusion in any sharing may already be collected and require little additional effort, or other cases may require changes to elements of the systems to enable collection, or may have to be collected more frequently than the ANO currently carries out the operation. Some systems may currently only be scaled to collect data for specific lines (e.g. those that are considered faulty) and hence need rescaling to provide data for all lines, other systems may already have sufficient capacity.

For data sharing an additional process/system may be required for packaging data by CP or data consumer and possible rekeying, reformatting and aggregating. Re-keying may be especially necessary to prevent unwitting distribution of commercially sensitive data.

Although the parameters that may be collected are standardised there may be variations in formatting of the data and the data may be collected on different time periods. If the data sharing interface requirements in terms of formatting and time periods for aggregation are different to the internal requirements of existing ANO systems consuming this data the ANO may produce different sets of data for internal and external consumption. The vendor differences may also be reflected in small but systematic differences in values obtained, where standards allow for flexibility or equipment differs slightly which may mean that additional identifiers of particular vendor equipment could form additional data to be included. Further standardisation can ease this situation, such as current efforts to standardise YANG data models for G.fast in the Broadband Forum.

In cases where only a limited set of data parameter sets or data on a limited set of lines are shared, a system will need to filter data to ensure only the correct data is passed to each party involved in the data sharing.

Data sharing interfaces could be defined including services level agreements covering availability, reliability and latency of data availability.

Note 2:

There are many implications to an ANO that may wish to, or be required to share DSLAM data. For example, providing federated access to a 3rd party to DSLAM data and by implication access to the ANO's control plane, either for monitoring, or control (or both) may require new systems. The issues relate not only to systems but changes that fundamentally alter business models, roles, responsibilities, commercial relationships and obligations. These implications are beyond the scope of this document.

6.3 Overall impacts

DSM data sharing can increase the overall footprint of DSL services in the UK. DSM data sharing can improve competitiveness with other broadband media. A subscriber using a given CP may be more likely to upgrade to super-fast broadband over VDSL with that same CP than to switch both their CP and their service level.

DSM data sharing can also automate DSM-related operational interactions between operators which can save OpEx relative to using manual processes, for example by enabling new and additional machine-to-machine communications for reporting the various ITU-T G.997.1 DSLAM test, diagnostic and status parameters from the ANO to the CP. DSM data sharing may improve customer satisfaction by speeding trouble resolution and lowering the number of troubles that occur in the first place. Joint use of standardised data and control simplifies interactions, while the definition of a limited set of shared parameters also limits the scope of interactions. However, DSM data sharing can itself introduce new types of faults and the data sharing apparatus itself needs to be reliable. Also, data must be properly formatted for interchange.

Data sharing for DSM may only be enabled by installing or upgrading management systems. This can entail some complexity. Virtualisation and cloud computing are enablers. Most operators already have some type of DSM/DLM system which may only need an upgrade. Also, the data needs to be retrieved and made available and there should be arrangements for this.

There are different sensitivities if:

- DSM is substituting for accepted spectrum management or other multi-operator rules. In this case as many lines as possible that have interacting crosstalk should participate in DSM data sharing; since otherwise it is difficult to verify that a line that is not participating is not degraded.

- DSM is operating completely within accepted spectrum management or other multi-operator rules; e.g., with no relaxation of any PSD masks. In this case, when a line is being optimised then the more information it has about other lines the better the optimisation can be, but no lines will be degraded beyond previously allowed levels.

7. Related uses of shared data

This section discusses some ancillary uses, in addition to DSM, that can be supported with the same apparatus used for data sharing for DSM. This apparatus may need to be extended or augmented in some cases for these ancillary uses.

Note that these operations are generally already performed in current practice, but may be enhanced.

7.1 Line diagnostics and monitoring

Each CP can have automated real-time access to DSL line monitoring and fault data via the data sharing apparatus and arrangements. This is useful for CPs network monitoring as well as repair and troubleshooting operations. Real-time data on performance metrics and service attributes enables classic network monitoring such as real-time reporting of "alarms." Longer-term data on Quality of Service (QoS) and Quality of Experience (QoE) can be used for service-level monitoring, to ensure continuous service quality. This can be useful for monitoring small-cell backhaul over DSL lines, which have tight delay and jitter requirements.

CPs, ANOs and MPF providers can all decrease operations costs by automating fault isolation, troubleshooting and dispute resolution. The root cause of a fault may be found and isolated to the right domain: the MPF provider's network, the DSLAM, the outside plant copper, congestion on a network segment, the CP's CPE, home network, etc. Backhaul network monitoring may also be involved and performed by access node operators, CPs, or both. Initial investment is required before such cost savings could accrue.

Data sharing for CPs monitoring operations will need to be secure and reliable, with high availability. Real-time monitoring will need uninterrupted real-time data feeds. Data needs to be exchanged in a format that is understood by all parties.

Some ANOs already offer some of this line diagnostic functionality.

7.2 Fault Correlation

Shared data can be used to correlate multiple faults across multiple lines and multiple service providers; and this can further be used to help coordinate dispatches.

Consider a fault that is common to multiple lines in a given section of cable, for example a wet or damaged cable that causes multiple simultaneous DSL faults. Pooled data across multiple CPs and/or ANOs and MPF Providers can be used to identify that the fault occurs in a single shared cable section. A single dispatch to fix that cable section is much better than dispatching to each troubled line separately. A similar use is to locate a noise source that is simultaneously affecting several lines, especially un-cancellable noises on vectored lines.

A neighbourhood may be defined by a group of subscribers that are located close to each other. A group of lines in the same neighbourhood often share the same cabling and so have similar DSL environments; this allows direct comparisons between the performances of lines in the same neighbourhood. Shared data can be used to compare a given line's bit rate to the neighbours' bit rates to identify "soft" faults, such as lines that are performing below where they should be. Attainable data rate or highest current bit rates on neighbouring lines can be used to estimate attainable data rate on a given line. A dispatch can then fix these identified lines to improve customer satisfaction. However, some locations may be close together geographically but far apart in terms of network topology, or vice-versa, thereby confusing such neighbourhood groupings. Note also that the Ofcom 2010 Voluntary Code of Practice: Broadband Speeds [2], presents procedures for service providers to interact with customers “if the actual access line speed is at or below the minimum guaranteed access line speed.”

Fault correlation requires data from multiple lines, preferably all the lines sharing a cable, or in the same neighbourhood area. Such information could be misused, for example to take customers away from another CP. Fault information from shared analyses should be presented in a way that does not compromise any provider’s proprietary customer and service information. One way of ensuring this would be to have a single trusted party, such as the centralised control, performing the fault correlation analyses and only disseminating the final fault determination.

7.3 Policing

Data can also be used for verifying and ensuring compliance with technical transmit power and spectrum rules. Excessive crosstalk can be traced to an errant transceiver, miss-configuration, or a bad cable. It is also possible to encourage or enforce politeness, so that DSLs do not transmit excessive power in order to limit crosstalk; for example by limiting the maximum SNR margin (MAXSNRM [3]§7.3.1.3.3 & [3]§7.3.1.3.4).

Policing with DSM data is only effective if the data is available, up-to-date and accurate.

7.4 Services Differentiation

DSM data sharing and control can help the development of new service offerings. For example, CPs can offer services with varying QoS levels and enable business class services with defined QoS levels. In addition to DSL settings, this may involve Layer 2, BRAS/BNG and backhaul settings; however these may be outside of the scope of data sharing for DSM.

CPs can select DSLAM profiles and trade-offs for speed and delay vs. line stability depending on their desired optimisations for their defined services. Profile selection involves trade-offs in speed vs. margin, delay, SRA, INP, retransmission, etc. If these profiles are not already present for a DSLAM, then they would need to be instantiated, which may not be possible with older DSLAMs that support a limited number of profiles.

7.5 Network Planning, including small-cell and femtocell services planning

With shared data, CPs can improve their network planning capabilities and use their own qualification rules. Network planning can be enhanced by knowing speeds attainable on other DSL lines in the same geographic area or neighbourhood. CPs can also identify lines that qualify for upsell opportunities, e.g., to VDSL or vectoring.

Network planning for small cell deployments can also be assisted by determining attainable DSL bit rates to use for backhaul. Design of small cell layouts can be advanced if the backhaul speeds of the feeding DSLs are accurately estimated by such techniques.

As stated in Section 7.2, estimations based on neighbourhood location are not always accurate and the data needs to be presented in a way that does not compromise any provider’s proprietary customer and service information.

Appendix A (Informative): Examples of Performance with DSM Data Sharing

This appendix shows three scenarios where sharing data for DSM improves DSL performance, and presents simulation results that quantify these improvements. The three scenarios shown here only examine compatibility of vectored and non-vectored lines. These are examples of Use Case 1, DSM Level 2 in multi-operator environments, and Use Case 2, DSM for Vectored VDSL2.

Examples of DSM performance for non-vectored VDSL and ADSL, with no vectored lines, are shown in Annex C of the ATIS DSM report [3], however these are limited to either 0% participating (no DSM) or 100% participating (full DSM).

Simulation Assumptions

Downstream VDSL2 is simulated with the ANFP [7] PSD limit; the transmit PSD is the ITU-T G.993.2 998ADE17-M2x-A limit PSD mask lowered by 3.5 dB. This transmit PSD is further upper limited to ≤ -55.0 dBm/Hz so that total aggregate transmit power is limited to 14.0 dBm. The BT loop model of 0.4 mm cables is used. There is 6 dB margin, 3 dB coding gain, ideal bit loading, 10% phy-layer overhead, and -140 dBm/Hz noise added to all simulations. Vectoring is imperfect, and lowers FEXT within the vector group by 25 dB. The ATIS MIMO FEXT is used and all FEXT is same binder.

Monte-Carlo simulations are run, and in each case some of the users' lines are randomly chosen to be totally inactive (they don't carry VDSL) according to a simple independent Bernoulli distribution. Also, in each run some of the lines participate in data sharing and use DSM, and some lines do not participate and do not use DSM. For each case run in the simulation, participating and non-participating lines are randomly selected according to a simple independent Bernoulli distribution with varying probability of participating or not. All lines, participating and non-participating, are in the same binder and FEXT couplings are randomly chosen according to the ATIS MIMO model for each case.

Then, 10,000 cases of different randomly generated FEXT couplings and randomly selected active / inactive and participating / non-participating lines are run to generate each data point in the results shown here.

Scenario 1: DSM data sharing for improving vectored line rates with non-vectored crosstalk

For this scenario, the loop topology has user endpoints uniformly spaced along a route of minimum length d0 = 300m, with endpoints spaced d = 25m apart as shown in Figure 4. Note that many users' lines are randomly selected to be inactive. Each of the 12 endpoints may have up to one active vectored line and one active non-vectored line.

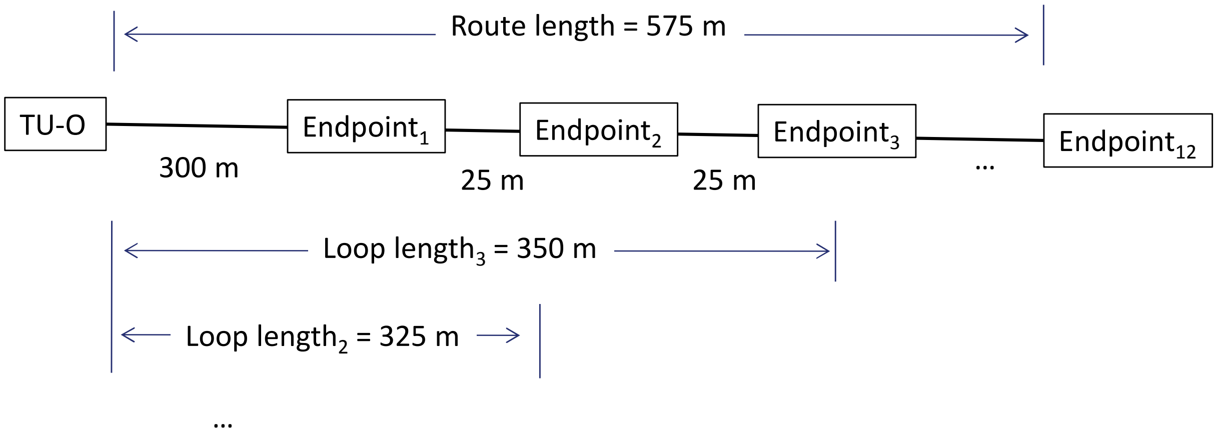

Figure 4. Topology of Case 1.

There is either an average 10% or 25% VDSL cable fill (penetration), so that Pr(line active) = 0.1 or 0.25.

The percent of participating lines varies. "Participating" lines share data that enables iterative water filling (IWF) [1][4], and perform DSM using IWF. The shared data is knowledge of the presence of vectored line(s) in the same binder, and either the knowledge of crosstalk impacts with a centralised system, or the ability to distribute target bit rate data and have some control of multiple lines start-up times in a distributed system.

All non-vectored lines run at a speed of at least 30 Mbps, including those participating in DSM and those not participating. All vectored lines, and all non-participating non-vectored lines, simply transmit maximum power and PSD. With no DSM participation, non-vectored lines are unconstrained and often run faster than 30 Mbps. DSM controls non-vectored participating lines to run at 30 Mbps and controls their transmit spectrum to maximise the performance of the vectored lines, unless there is sufficient data sharing participation to ensure that there are no vectored lines in which case the participating non-vectored lines transmit maximum power and PSD.

The vectored line bit rates in this scenario are shown in Figure 5 and Figure 6 for 10% and 25% average VDSL cable fill (penetration). Increasing participation in DSM data sharing increases performance; with DSM data sharing providing up to a 52% speed increase.

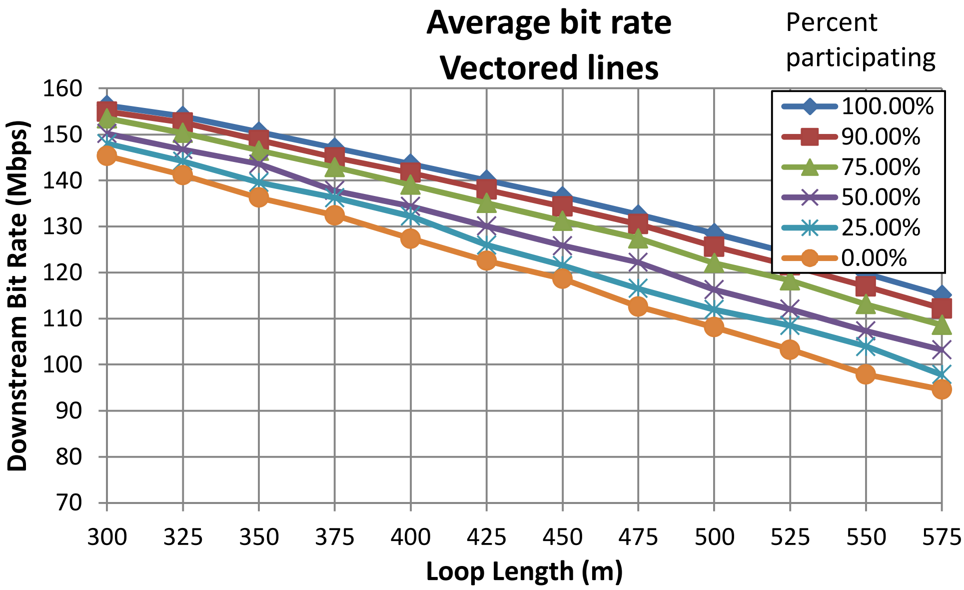

Figure 5. 10% average VDSL penetration. All lines transmit maximum power and PSD, except only for non-vectored lines that participate in DSM data sharing which are limited to 30 Mbps.

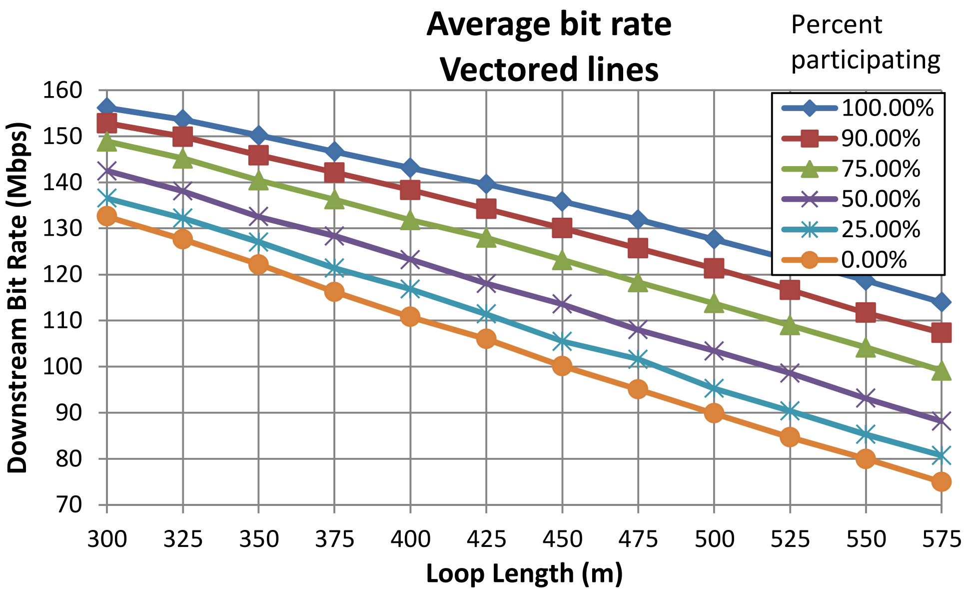

Figure 6. 25% average VDSL penetration. All lines transmit maximum power and PSD, except only for non-vectored lines that participate in DSM data sharing which are limited to 30 Mbps.

Scenario 2: DSM data sharing for improving non-vectored line rates while ensuring compatibility with vectored lines

This is the same as Scenario 1 except that non-participating non-vectored lines use the simple Static Spectrum Management (SSM) rule that they only transmit below 2 MHz, this limit ensures 100 Mbps vectored line speeds up to 600m [5]. DSM performs IWF as in Scenario 1, and ensures at most a few percent degradation in vectored speeds while improving non-vectored performance.

Figure 7 shows non-vectored line speeds in this scenario, for the case of 15% average VDSL penetration, and 100% participation in DSM data sharing, with two levels of data sharing. The lower level of data sharing exchanges data indicating the presence of vectored lines in the binder (or not), while the higher level indicates the presence of vectored lines as well as information on crosstalk impacts that enables DSM using IWF as discussed in the previous scenario. Data sharing for DSM can double non-vectored line speeds in this scenario.

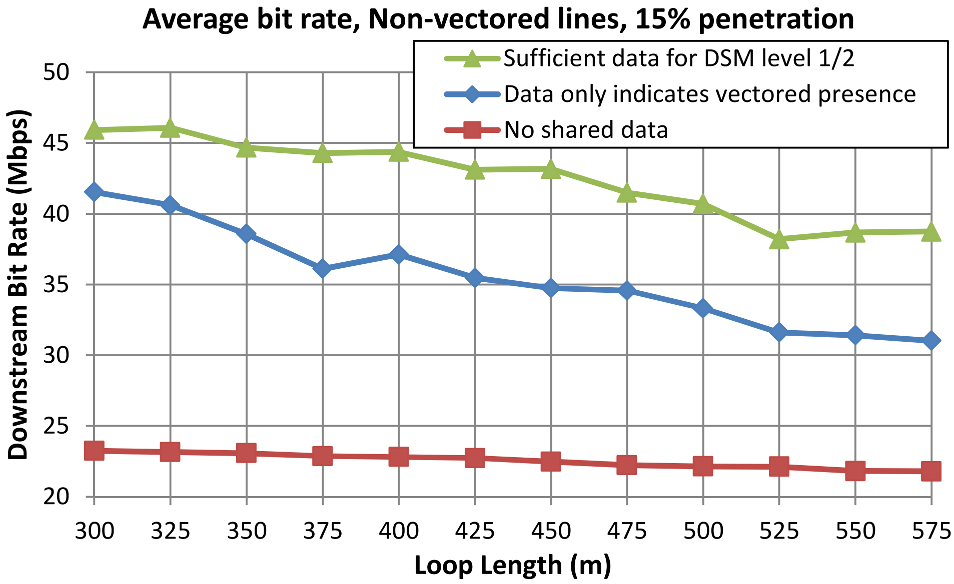

Figure 7. 100% participation with two levels of DSM data sharing, and with no shared data and no DSM. Non-participating non-vectored lines are limited by SSM to transmit only below 2 MHz for compatibility with vectored lines.

Scenario 3: DSM data sharing for improving non-vectored line rates while ensuring compatibility with vectored lines on unequal loop lengths

This scenario is simulated the same as the previous scenario except for the loop topology and the DSM algorithm used, and also performance of non-vectored lines is shown instead of performance of vectored lines. There are two sets of lines with up to 12 active vectored lines 200m long, and up to 12 active non-vectored lines 800m long. All lines originate at the same cabinet.

“Participating” vectored lines share data and perform DSM using Multi-Level Waterfilling (MLWF) [1], with parameter “Fcuts” = 6.5 MHz, which re-allocates transmit power from below 6.5 MHz to above 6.5 MHz to lower crosstalk without lowering speed.

Participating non-vectored lines perform DSM using iterative waterfilling (IWF). Non-participating non-vectored lines only transmit below 2 MHz, this simple SSM limit ensures 100 Mbps vectored line speed up to 600m [5].

The bit rate of vectored lines is unlimited, and vectored line speeds are all about 155 Mbps, with a minimum rate of 150 Mbps with high cable fill.

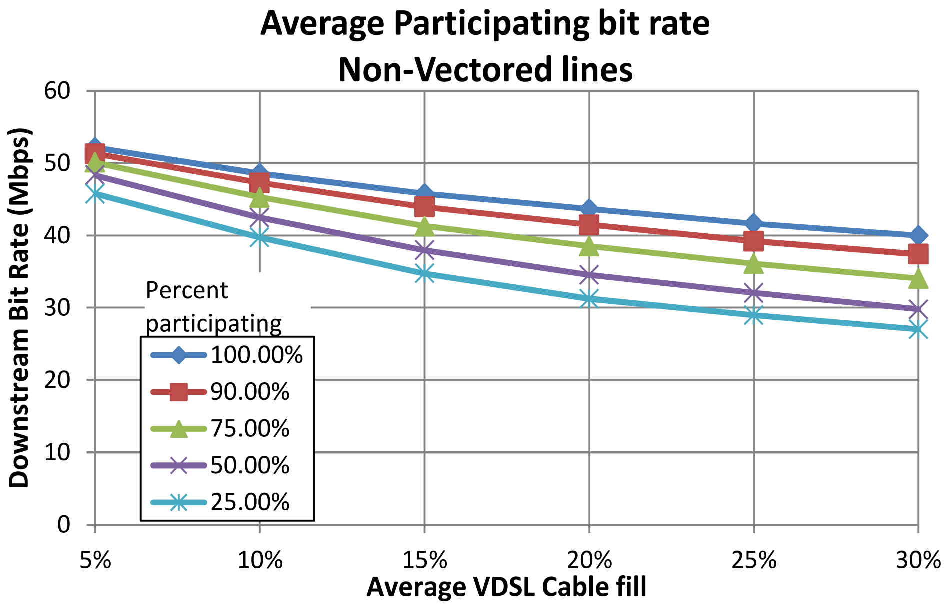

Figure 8. Average non-vectored participating line bit rates for scenario 3 with unequal loop lengths.

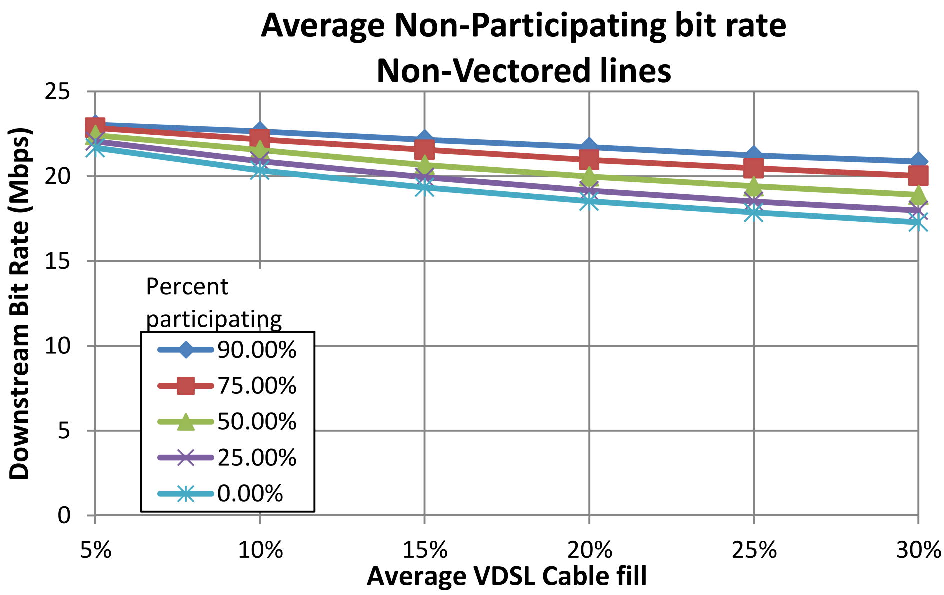

Figure 9. Average non-vectored non-participating line bit rates for scenario 3 with unequal loop lengths. Non-vectored non-participating lines are limited by SSM to transmit only below 2 MHz for compatibility with vectored lines.

Results for Scenario 3 in Figure 8 and Figure 9 show 50% to 123% speed gains from sharing DSM data, with increasing gain as participation in data sharing increases.

History

Document history		
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