MARKETING REPORT

MR-257
An Overview of G.993.5 Vectoring

Issue: 1
Issue Date: May 2012

Issue History

Issue Number	Issue Date	Issue Editor	Changes
1	May 2012	Peter Silverman ASSIA Inc.	Original

Comments or questions about this Broadband Forum Marketing Report should be directed to info@broadband-forum.org.

Editor	Peter Silverman	ASSIA Inc,
White Paper Chairs	Vanessa Nacamura	Nokia Siemens Networks
	Sarah Banks	Cisco Systems
Chief Editor	Michael Hanrahan	Huawei Technologies

TABLE OF CONTENTS

List of Figures

List of Tables

Executive Summary

Current broadband penetration approaches 600 million lines worldwide and continues to grow at a rate of over 12% per year [4]. As is shown in **Figure 1**, DSL remains the dominant broadband access. VDSL2 (ITU-T G.993.2 [6]) provides a growing proportion of both the DSL component as well as the final leg of the broadband access connection in the "FTTx" solutions listed by Point-Topic in **Figure 1**. Not only is deployment of broadband increasing rapidly but also the bandwidth and quality of service requirements of the applications demanded by users continues to increase. While relatively recently bandwidths in the range of 5 to 10 Mbps toward the customer were considered to provide an acceptable premium broadband service, today significantly higher bandwidths are required to support requirements for services such as High Definition IPTV and bandwidth requirements continue to increase as application capabilities evolve. Bandwidths considerably in excess of 30 Mbps toward the customer premises are necessary to deliver the emerging advanced services.

In 2010, ITU-T published the G.993.5 Recommendation, *Self-FEXT Cancellation (Vectoring) for use with VDSL2 transceivers[5]*, informally known as G.Vector that allows DSL connections to meet these enhanced requirements. VDSL2 deployments based on this new Recommendation facilitate achieving the quality of service required for premium services such as multiple channels of HDTV (MR-180 [3]). Systems based on the G.993.5 Recommendation have the potential of being deployed in the field as an enhancement to existing DSL deployments thus reducing capital investment cost as well as simplifying operations at the network operators. G.993.5 achieves its improvements by canceling, using a mathematical process known as Vectoring, the majority of DSL's crosstalk noise. Since the DSL Lines in a cable no longer interfere with each other the total throughput of each line and the total throughput of all lines in the cable is significantly increased. G.993.5 is capable of supporting connection speeds in excess of 100 Mbit/s at distances up to 500m (1500 ft) from a fiber fed DSLAM using VDSL2 on typical telephone wiring[1]. Even with loops as long as 1200m (4000 ft) rates toward the customer ('downstream') that exceed 40 Mbps over a single copper pair are supported.

With its potential for increased bandwidth using VDSL2 technology, G.993.5 is being considered by a number of carriers to enhance their DSL based network services. MR-257 provides an introduction to this vectored VDSL2 technology, its applicability and the opportunities and issues raised by its field deployment.

[1] E.g, PE 0.5 mm or 24 AWG twisted pair.

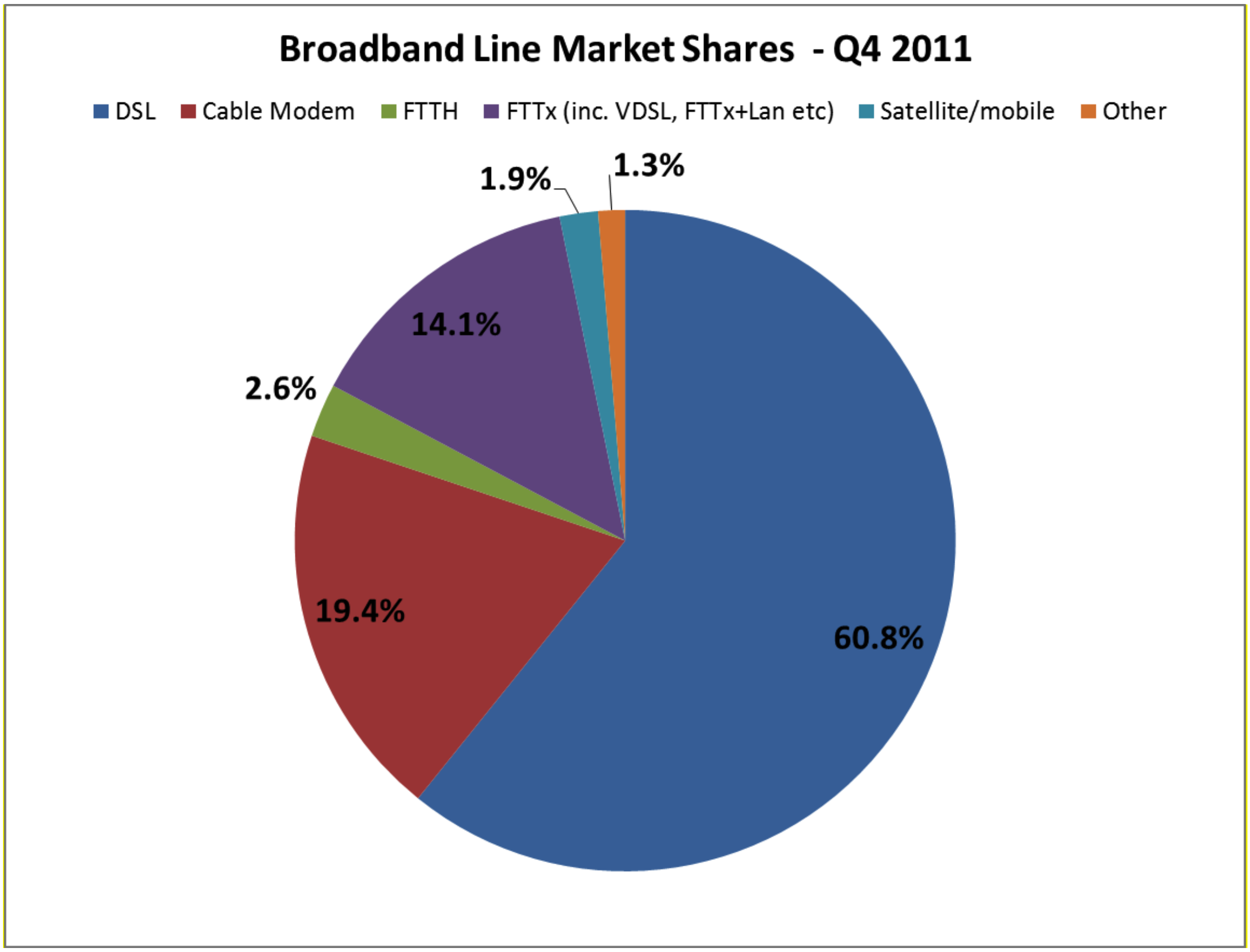

Figure 1 - Broadband access-connections for Q4 2011, (source Point Topic: 2011 Year End report - 2012)

DSL access over copper twisted pair provides many advantages for the Network Operator. These include operational ease of deployment, reuse of existing copper infrastructure thereby reducing the resource requirements to deploy new fiber, and ease of termination at the customer's premises. Reuse of existing copper has many advantages. Data throughput over DSL is dedicated rather than shared to the customer and DSL's use of fiber to connect remote DSLAMs reduces fiber-deployment by sharing it between 10's to 1000's of customers connected to a remote DSLAM. In many cases, especially 'brown-field' situations, the resource requirements for deploying fiber all the way to the customer's premises can exceed the benefits of the enhanced services to the Network Operator and thus the deployment of fiber does not occur. In such situations DSL over copper for the final segment of the broadband connection may be the only viable broadband solution. However unless DSL supports the bandwidth requirements for the newly emerging services, the economic situation described above results in a large group of 'have-nots' whose broadband service is second rate compared to those served by fiber solutions.

The ITU-T G.993.5 Recommendation, *Self-FEXT Cancellation (Vectoring) for use with VDSL2 transceivers[5]*, informally known as G.Vector, provides a solution to this problem. As G.993.5 compliant equipment is developed the potential for improved bandwidth over VDSL2 connections is large. However the Network Operator deploying G.993.5 must address a number of operational and architectural issues in order to realize the benefits of Vectored DSL. Among these issues are (1) dealing with complexities in cable and binder management introduced by vectoring, (2) selecting which lines will benefit most from vectoring and (3) ensuring that non-crosstalk related noise that cannot be canceled is ameliorated by DSL Quality Management (DQM) techniques.

MR-257 covers the following topics related to G.993.5 Vectored DSL.
Section 2 provides an overview of the technology that supports vectoring
Section 3 illustrates potential benefits of Vectored VDSL2 with respect to line rate and loop reach
Section 4 describes the status of Vectored VDSL2 deployment
Section 5 provides an overview of potential deployment architectures for Vectored VDSL2
Section 6 discusses the operational issues faced by the Network Operator and potential solutions.

1 What is Vectoring - A Technical Overview

VDSL2 is the leading DSL access technology targeting broadband deployments at high bit rates. Although the wide bandwidths supported by VDSL2 have limitations in reach, the majority of the customers may be served through the use of fiber fed cabinets enabling customers located within a serving radius to receive services such as IPTV with VDSL2. With the use of self-FEXT[2] cancellation provided by vectoring, significant improvements in signal-to-noise ratio may be achieved such that higher bit rates may be offered for a given loop length.

Figure 2 illustrates the deployment of a VDSL2 based service from the network to a subscriber. A fiber optic link or other backhaul technology provides a high-speed data connection to the DSLAM, and the individual wire pairs in the access cable provide the direct connection to individual homes. The digital subscriber line access multiplexer (DSLAM) may be located in a Central Office (CO) or in a cabinet at a remote terminal location. If a fiber optic link provides the data connection to the DSLAM, and it is located in a cabinet, it is referred to as fiber-to-the-node (FTTN); when located inside a building it is referred to as fiber-to-the-building (FTTB). In addition to VDSL2, other signals such as ADSL2 or ADSL2plus, or simply just plain old telephone service (POTS) may exist in the cable.

[2] Self-FEXT - See definition for SELF Crosstalk in section 7.

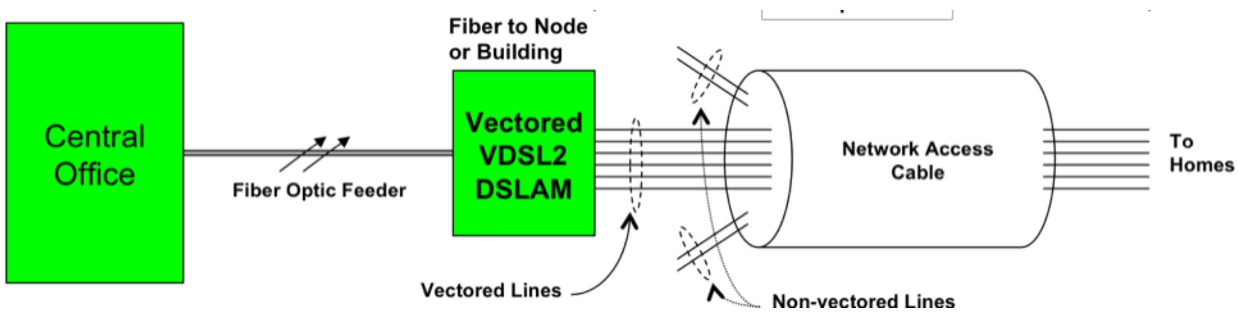

Figure 2 - Reference Fiber Fed DSL Network Access Architecture.

The range of deployment for any DSL line depends on the loop length and the noise in the cable. Loop attenuation increases directly with increasing frequency and increasing cable length; as a result, the usable bandwidth decreases with increasing loop length. In addition to signal loss, the other major cause of bandwidth reduction for DSL is crosstalk among the signals in the same cable: namely near-end crosstalk (NEXT) and far-end crosstalk (FEXT); both NEXT and FEXT are shown in the cable diagram in Figure 3.

NEXT coupling is generally more severe than FEXT coupling. However, since VDSL2 uses separate frequency bands for upstream and downstream transmission, the upstream and downstream bands on all the wire-pairs in the cable never overlap so there is no self near-end crosstalk from similar signals in the cable. Hence, for VDSL2 self far-end crosstalk (SELF FEXT) is the dominant crosstalk disturber.

The levels of FEXT coupling between the wire-pairs will vary from pair to pair and from frequency to frequency. The matrix in Figure 3 represents a Channel Matrix that defines the individual pair to pair couplings, on a per sub-carrier basis, of the far-end crosstalk in the cable and the diagonal component represents the direct channel response. Therefore, with respect to each particular line in the cable, this matrix represents the FEXT from other lines in the cable that interferes with the VDSL2 performance on that particular line.

If the cable is fed with only VDSL2 signals from the one DSLAM and the crosstalk couplings between the wire pairs in the cable were known at the VDSL2 frequencies, then the transmission of the VDSL2 signals from the DSLAM may be controlled and processed so as to cancel the self injected crosstalk. The result would be a significantly improved Signal-to-Noise Ratio (SNR) at each receiver and higher achievable bit rates. Therefore, the goal of Vectoring is to learn and maintain the crosstalk channel matrix at appropriate frequencies in the VDSL2 bands and apply the signal processing necessary to cancel the crosstalk injected by the other VDSL2 signals into the desired VDSL2 signal for each end user.

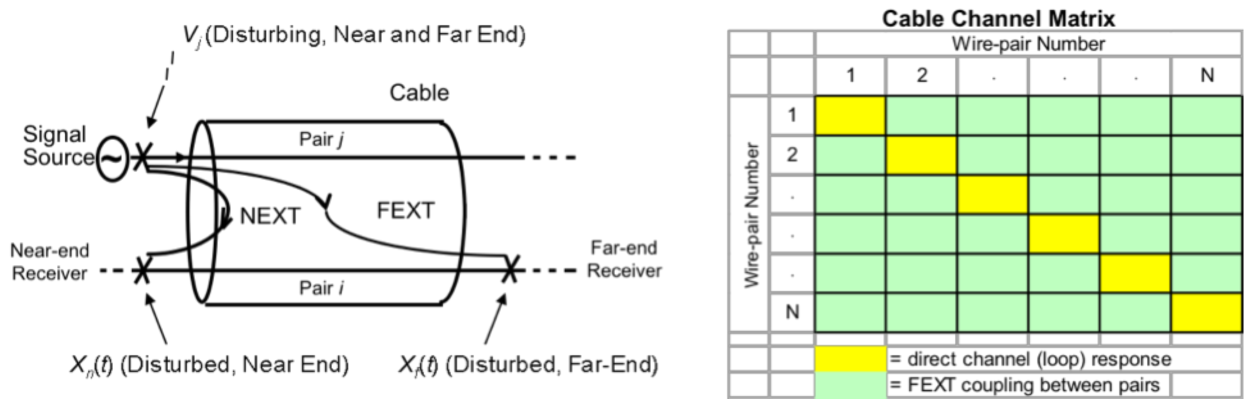

Figure 3 - Crosstalk in Access Cable.

The "Vectored VDSL2 DSLAM" shown in Figure 3 is VDSL2 based supporting self-FEXT cancellation by vectoring. The "Vectored VDSL2 DSLAM" contains an array of collocated VDSL2 transceivers that are connected to a group of lines in the cable referred to as the *vectored group*. Assuming the channel coupling matrices for the vectored group is known, the synchronous transmit data samples are processed through the pre-coder matrix as shown in the block diagram in Figure 4. Based on the channel matrix of the vectored group, the pre-coder matrix implements the inverse of the crosstalk channel matrix such that when the data samples are received at the far-end receiver, the far-end crosstalk injected in the cable by the other transmitters is cancelled at the CPE receiver.

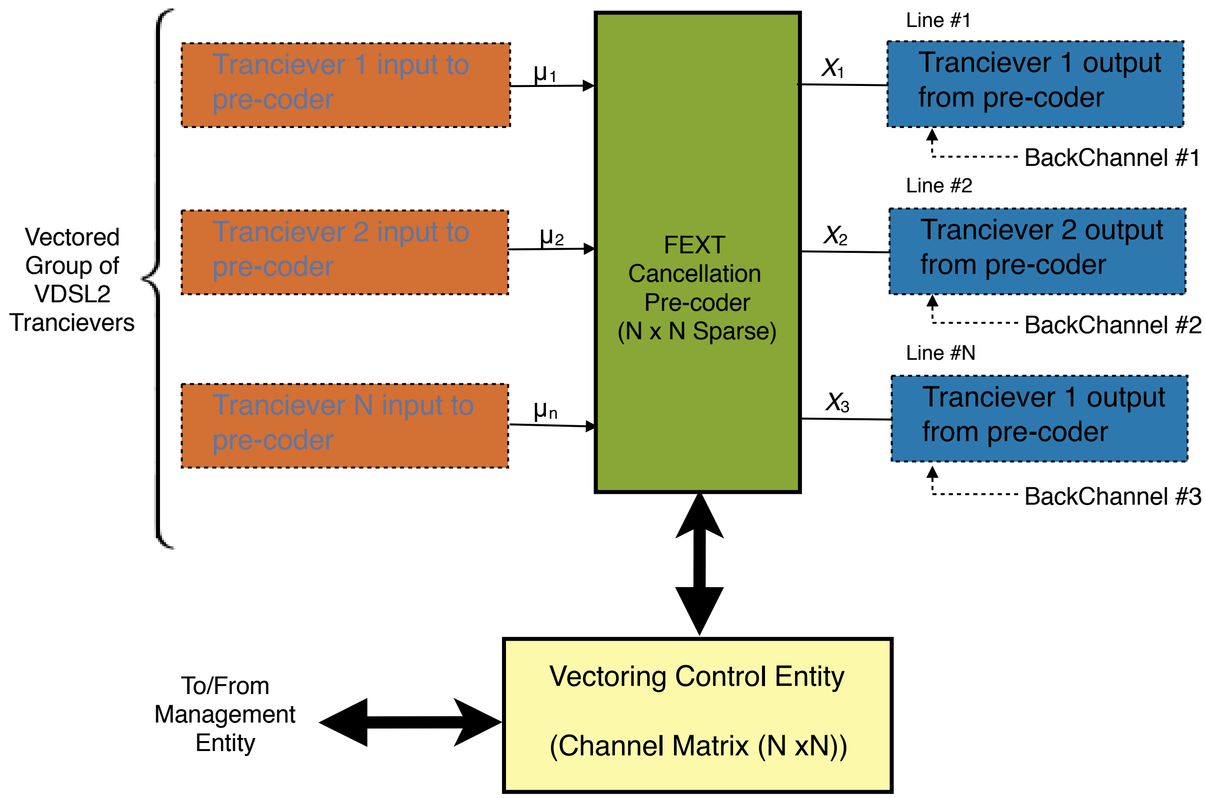

Figure 4 - Downstream FEXT Cancellation Pre-coding in DSLAM

To facilitate learning and tracking of the components in the Channel Matrix, error feedback information is communicated from the receiver to the Vectoring Control Entity (VCE) in the DSLAM. For downstream FEXT cancellation, error samples are reported from the receiver in the CPE to the Vectoring Control Entity in the DSLAM via a dedicated signaling channel on each line. The error samples contain the information collected by VDSL2 receivers regarding the FEXT from other VDSL2 lines. For upstream FEXT cancellation, all of the processing is done locally in the DSLAM.

With regard to vectoring it is important to note that the cancelled crosstalk is only is generated by the signals within the vectored group of subscriber lines. In Figure 2, the group of lines connected to the Vectored VDSL2 DSLAM is the vectored group. If all of the crosstalk in the vectored group is cancelled, then the performance would only be limited by the background noise, which may be the crosstalk coming from other wire-pairs in the cable that are not connected to the Vectored VDSL2 DSLAM; these are labeled as the *non-vectored* lines in Figure 2. Any crosstalk coming from the non-vectored lines into the vectored lines is termed alien crosstalk. The vector processing described above cancels only the crosstalk within the vectored group; it does not cancel the alien crosstalk.

1.1 Capabilities – Loop Reach and Rate

VDSL2 defines numerous profiles that correspond to the maximum available bandwidth of the transmit signal. The following two examples provide illustrations of the performance of G.993.5 based vectoring on the VDSL2 17 Mhz profile Annex A 17a (G.993.2 [6]), and the Annex B 17 Mhz profile 17a (G.993.2) and the Annex B 30 Mhz 30a band profile (G.993.2).

1.1.1 Performance of G.993.5 for the VDSL2 Annex A 17a band profile

Figure 5 shows the frequency band-plan defined Annex A for Profile 17a that defines the frequency bands of upstream and downstream transmission up to 17 MHz.

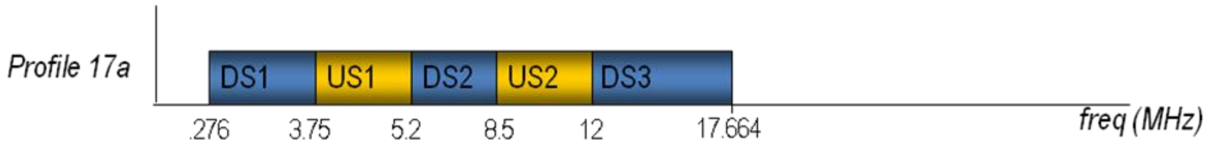

Figure 5 - Example band plans for profile 17a

Figure 6 shows an example of VDSL2 downstream performance with vectoring while operating with Annex A profile 17a on a 26 gauge cable having 80 users out of a possible 100 in the cable. In this scenario, the loop lengths for the users are randomly distributed from 50m to 1000m within the cable. The results show that, with vectoring, 100 Mb/s service is possible over 26 gauge loops of up to 500 m (approximately 1500 ft) and that 50 Mb/s service is possible up to approximately 900 m (2700 ft). The results in Figure 6 show that for a service rate of 50 Mb/s, vectoring provides an increase of 3 times the reach (approximately 600 m or 1800 ft) relative to the 99% worst-case crosstalk environment without vectoring. Therefore with the use of pair bonding and vectoring, 100 Mb/s service may be extended up to 900 m (2700 ft) when the Annex A profile 17a is used.

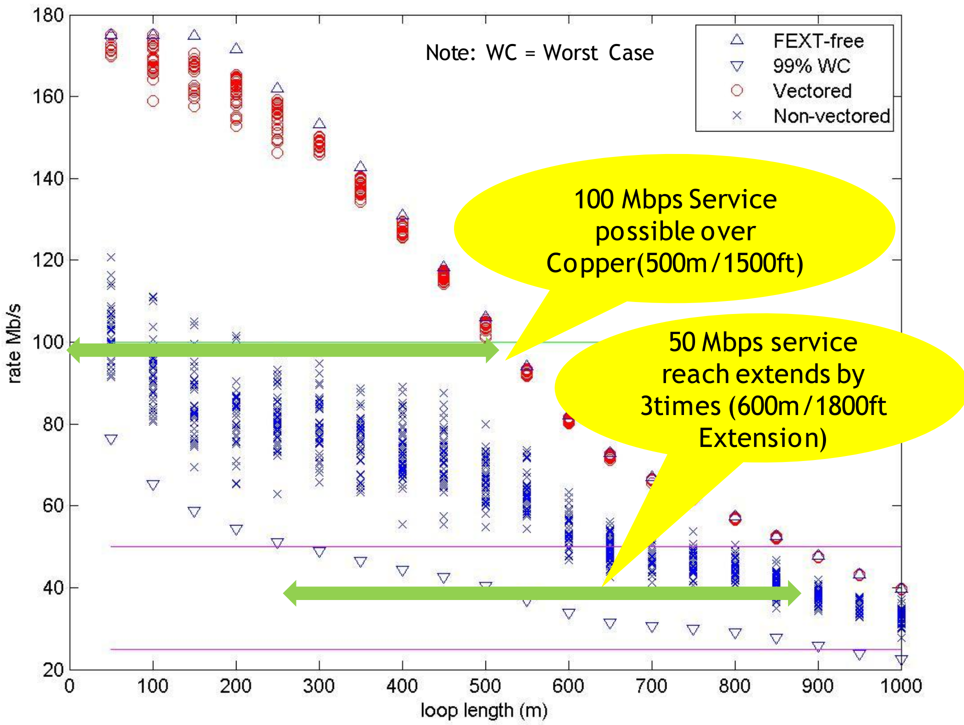

Figure 6 - DS Rates – Profile 17a, 26 AWG, -136 dBm/Hz noise, 80 users, and 47 cancelled

1.1.2 Performance of G.993.5 for the VDSL2 Annex B 17a and 30a band profile

Two additional examples of VDSL2 performance are provided based on VDSL2 Annex B used in Europe. Figure 7 shows an example where the VDSL2 Annex B 17 Mhz profile 17a is used with vectoring on 0.4 mm cable. The simulation assumes two cases, one where the VDSL2 is deployed on the same cable with analog voice and the other where the VDSL2 is deployed on the same cable deployed with ISDN. The curves identifying operation over analog voice are labeled 'BB17a' and those identifying operation over ISDN are labeled 'BA17a'.

The top curves in Figure 7, labeled 'Fextfree' represent the bit rates for when full crosstalk cancellation from vectoring is achieved. The lower curves show the bit rates without crosstalk cancellation for the scenarios of 15 and 49 self-disturbers[3]. As seen in Figure 7, 100 Mb/s downstream transmission with vectoring is feasible at 500 m of 0.4 mm cable and 50 Mb/s transmission is feasible at 900 m.

[3] That is there are 15 or 49 other VDSL2 lines operating in the same cable.

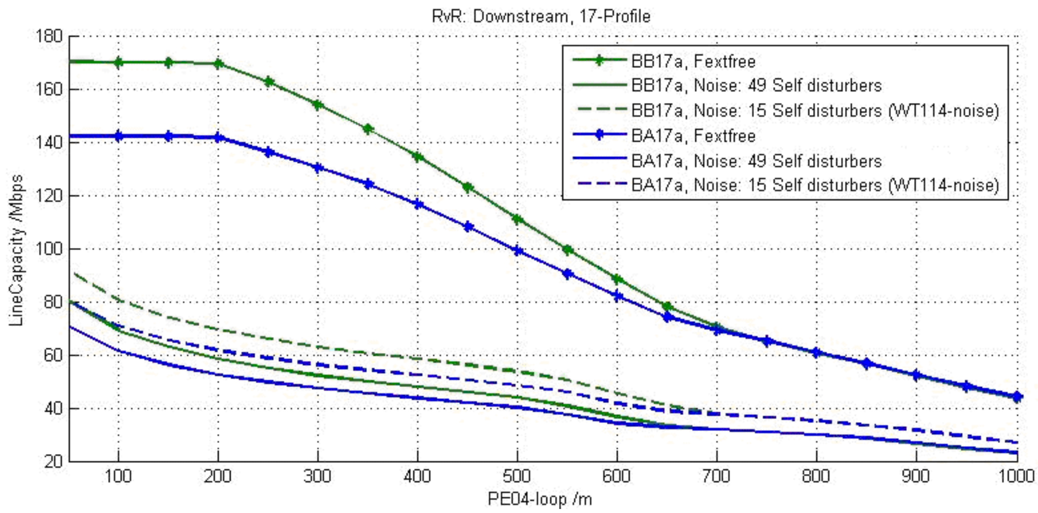

Figure 7 - VDSL2 Annex B Profile 17a downstream loop reach and rate

Similar to the above, Figure 8 shows the downstream performance with use of the VDSL2 30 Mhz profile 30a when both operating on the same cable with analog voice and operating on the same cable with ISDN. The main difference is that significantly higher capacities are achievable at the shorter distances. Downstream rates over 200 Mb/s are achievable using this profile on loops up to 300 m in length.

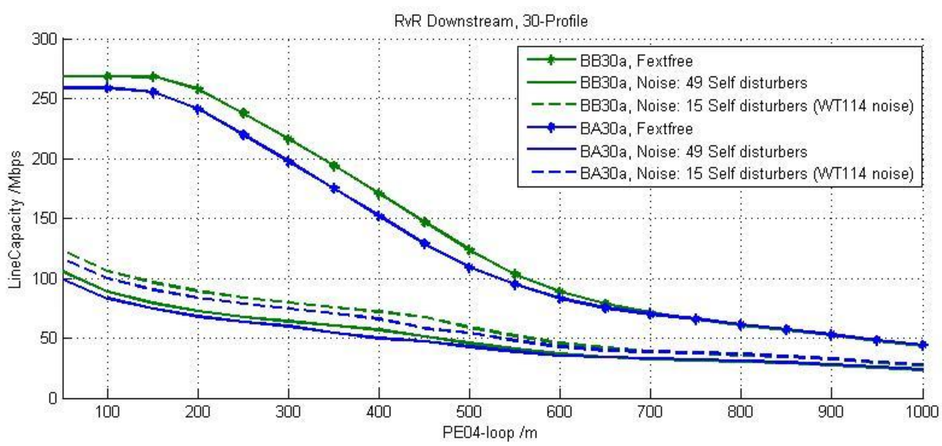

Figure 8 - VDSL2 Annex B Profile 30a downstream loop reach and rate

2 Status of the technology in the market

2.1 Standardization

The normative text in the ITU-T G.993.5 Recommendation specifies the downstream error(f) signal and a method for transporting it, as required for interoperability of multi-vendor implementations. Additionally methods of deriving the Channel Matrix using the SNR(f) (signal-to-noise ratio per tone) information available with the existing VDSL2 (G.993.2) parameters have been documented in an informative annex to G.993.5. Many implementation choices are not related to interoperability and are left to the discretion of the implementer.

The VTU-R (CPE modem) to VTU-O (DSLAM modem) backchannel carries the 'error(f)' samples gathered on the CPE which contain the information needed to build the Channel Matrix. The backchannel allows further refinement of the crosstalk channel estimation and tracking of crosstalk channel changes in Showtime. The VDSL2 initialization has been enhanced in G.993.5 to allow estimation of crosstalk channels, both in downstream and upstream directions. Initialization occurs such that a new line activating does not harm the lines already active so benefits from vectoring on the new line are achieved immediately. The VTU-O and VTU-R enter Showtime with the larger part of the crosstalk already cancelled.

The G.993.5 Recommendation also defines management parameters, which allow the operator to configure the frequency bands not to be vectored, or to obtain the downstream crosstalk channel characteristics.

3 Architecture

Table 1 lists network architecture requirements for the vectoring systems in typical deployment scenarios. Figure 9 illustrates these deployment scenarios.

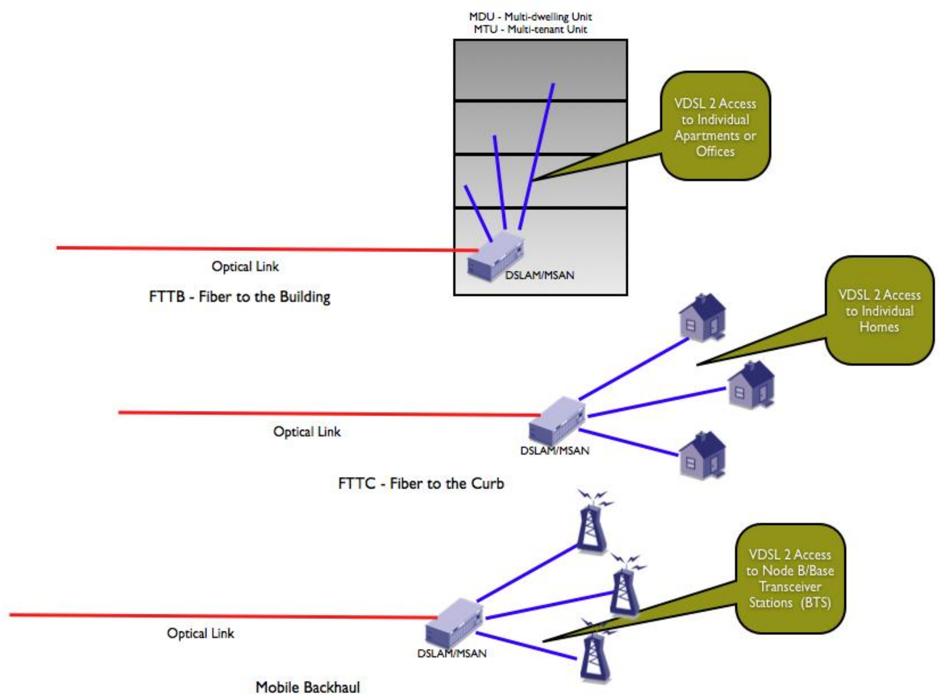

Figure 9 - Schematic of Deployment Architectures

Table 1 - Vectoring – Applications and Network Architecture

Network Architecture	**FTTB**	**FTTC**	**Mobile Backhauling**
Application	MDU/MTU	MSAN/DSLAM	BTS/Node B
VDSL2 profile	30a (17a)	17a (30a)	17a/30a
CO granularity (# of ports)	4-64	24-256	2-16
CPE (# of bonded ports)	1-2	1-2	1-2
Loop length	< 300m	< 1km	< 1km

The products are expected to be available in 2 general architectures:

1. Board Level Vectoring
2. System Level Vectoring

In the first architecture, the number of vectored lines is limited to the number of lines on a line-card(e.g., 64). This approach is referred to as "Board Level Vectoring". Products using this approach are ideally suited for FTTC, FTTB, or small FTTN deployments. In the second architecture, performing vectoring across multiple line-cards can vector a larger number of lines. This approach is referred to as "System Level Vectoring", and is ideally suited for larger FTTN nodes. System level vectoring still faces some challenges due to the computational requirements - for example, current System Level Vectoring prototypes are still limited to a relatively small number of lines.

4 Issues for the carrier and the regulator

The following Table 2 summarizes the management issues raised for Management of Vectored DSL that are common to both Vectored DSL and other network services:

Table 2 – Management Goals and Functions Common to Both Vector DSL and Other Network Services

Topic	Potential issues
Management goals that are common to both Vectored DSL and other networked services	• Minimizing technician dispatches to the field and customer’s premises and the costs of cable conditioning and reconfiguration, • Minimizing equipment complexity including the number of remote cabinets, • Maximizing automated network operations, while minimizing changes to existing operations support systems, • Maximizing service performance, network reliability and robustness.
Management Functions common to both	• Service management: service level

Vectored DSL and other network services	agreement and quality of service, • Inventory and assignment: what version of equipment is connected to which line, • Configuration: "get" and "set" equipment configuration parameters, • Performance monitoring: history log of operating performance and errors, • Fault reporting: failure alarm and automated "snapshot" taken upon failure, • Diagnostics: testing on demand,

However Vectored VDSL2 also raises specific network operator issues that especially affect deployment of Vectored DSL. Table 3 summarizes those issues.

Table 3 – Management Concerns that Especially Affect Vectoring

Topic	Potential issues
Physical Plant Management	• Simplifying Binder group management and managing the size of the vectored group, • Service in areas with legacy VDSL -- issues for related to upgrades to DSLAMs, and legacy CPE, • Wiring inside customer premises
Noise Management	• Impact of alien noise both stationary and impulse on vectoring, • Addition and removal of VDSL2 on other lines, and power failure.
Simultaneous use of Bonding and vectoring	
Management and Diagnostics	• Measuring and monitoring performance gain, • Diagnosing vectoring function, • Diagnosing cable characteristics, • Diagnosing noise characteristics
Vectoring Management	• Use of DSL Quality Management (DQM) techniques including DLM and DSM Level

	1 and 2. (G.993.2 [6],TR-198 [2])

The following sub-sections provide additional detail on the issues raised in Table 3.

4.1 Binder Management Issues

To reduce inventory cost and power consumption, the network operator may equip vectored VDSL2 line cards as needed to meet service demand. As a result, a DSLAM may be initially equipped with only one line card, to which customers from any of the several distribution binder groups will be connected. As demand grows, more line cards will be added, one at a time. Again, customer lines from all binder groups will be connected to the newest line card as customers order service. As a result, each binder group may ultimately be served by several different line cards.

Furthermore, as some customers terminate service and others take service ("service churn") the DSLAM line card ports may be reassigned to serve the new customers. These reassignments will be arbitrarily assigned to available ports without consideration of which binder group the line is in because existing network line assignment systems do not enforce mapping rules between line cards and binder groups.

As a result, all of the vectored VDSL2 lines in a section of distribution cable must be within the same vectored group. A DSLAM may support one or more vectored groups. If the forecasted number of vectored VDSL2 lines exceeds the number of ports on a DSLAM line card, then it is necessary for the vectored group to span multiple line cards. Depending on the projected service take-rate and distribution area size, DSLAMs that support vectored groups typically ranging from 20 to 200 or more ports may be needed."

In some cases it will be necessary to subdivide a distribution area to avoid lines being too long to provide the necessary service bit-rate. In this case, it should be feasible to place the multiple remote cabinets so that the cable sections served by each cabinet do not intersect with the cables served by the other cabinets. If two cabinets served the same cable section, then vectoring coordination would be needed between the two cabinets; this is not expected to be feasible.

4.2 Physical loop unbundling

In some jurisdictions the regulatory authority may enable competition in the broadband access with physical loop unbundling. When physical loop unbundling is implemented, the incumbent operator rents loops to competitive operators allowing them to connect their own access equipment to the loop to offer broadband access to end-customers. To achieve the maximum benefits of crosstalk cancelation with vectoring, it is necessary to synchronize all the VDSL2 links in the binder. If two operators are deploying VDSL2 links from different DSLAMs in the same binder, this ceases to be possible. Each vectored group from one operator in the binder will appear as alien disturbers for the other vectored groups deployed by the other operator. As a result, in the case of physical loop unbundling and if different operators are deploying VDSL2 lines in the same binder, the gain that can be achieved by vectoring will be reduced.

4.3 Alien noise

With nearly all FEXT from in-domain disturbers being cancelled by vectoring, the remaining alien noise (e.g. Radio Frequency Interference (RFI), impulse noise from electrical services in the home, alien crosstalk.) will become the primary limitation for performance. In some lines, little performance gain may be realized by vectoring because the noise that can't be cancelled is nearly as high as or higher than the noise that can be cancelled. Worse yet, the vectoring could provide little gain or improved stability due to the anticipated future variability of alien noise (not the noise currently present). Service providers wish to assure a minimum service level is maintained in the presence of moderate-worst-case conditions. Thus, performance will be limited by an assumed statistical level of noise. This is analogous to a person who stays inside all day because he is afraid it might rain later that day, even though it never rains.

The issue of current or anticipated future variability of alien crosstalk is particularly relevant for VDSL2 deployments in a regulatory regime where subloop unbundling is mandated (as is the case in many countries in the European Union). Where VDSL2 is already deployed, new deployments of vectored VDSL2 from a different DSLAM at the same location will provide little gain. Where VDSL2 is not yet deployed, new deployments of vectored VDSL2 will initially provide the full performance gain, however this gain will be destroyed by deployment of VDSL2 (vectored or not) from another DSLAM at the same location. It is therefore necessary that regulators consider unbundling/wholesale market remedies that allow all involved network operators and end-users to take advantage of the higher data rate services enabled by vectored VDSL2.

The potential loss of performance gain can be minimized and line stability can be maintained by:

- Effective means in vectored VDSL2 modems for measurement and long-term monitoring of alien noise to develop a more accurate statistical model. This must address both stationary and impulse type noise.
- Analytical tools to help determine the source of the alien noise. For example, if the alien noise is caused by broadcast AM radio, then it may be possible to eliminate the noise by grounding the cable sheath. Also, if the noise is caused by out-of-domain VDSL2 crosstalk, then the disturbing line might be moved in-domain by serving this line from the same vectored DSLAM.
- Dynamic spectrum management (DSM) techniques to find the most effective settings for the interleaved Reed Solomon forward error control, and the transmitted PSD as well as use of the vectoring application and user-priority controls in G.993.5 for best tradeoff among users' desired data rates and the possible combinations of admissible user data-rate combinations.
- Advanced techniques such as erasure decoding and ITU-T G.998.4 [7] physical layer retransmission to mitigate impulse noise.
- Terminating the vectored VDSL2 at the side of the house to avoid noise on the inside wire.
- Receiver-based cancellation of the alien noise is particularly important. For example, a common-mode noise cancellation or other types of noise-cancellation functions at the customer-end receiver would be particularly helpful since this type of noise is more often found at the customer end of the line.

4.4 Service in areas with legacy VDSL

VDSL-based services are already provided to thousands of communities. In these areas, service providers may wish to use vectored VDSL2 to provide higher speed services without replacing the existing DSLAMs. It should be possible to introduce vectoring by upgrading the firmware and line cards in a legacy DSLAM. The new DSLAM should be able to support vectored VDSL2 lines in addition to continuing to provide the "old VDSL2 service" to legacy VDSL2 customers with their existing CPE.

When vectored VDSL2 is introduced in an existing VDSL2 service area, it may be highly desirable to not disturb the legacy VDSL2 service customers. While some of the existing customers may choose to upgrade to the new, higher bit-rate service, other customers may wish to remain unchanged. These legacy customers should not be forced to replace their existing CPE modems.

However, the presence of legacy VDSL2 lines and new, vectored VDSL2 lines in the same cable presents the problem of out-of-domain crosstalk from the legacy lines into the new, vectored lines. Possible techniques to reduce the impact of noise from non-vectored lines into the vectored lines include:

- A firmware update could be automatically downloaded to all legacy VDSL2 CPE modems so that they operate in a "vectoring friendly" mode." In this mode, the legacy VDSL2 lines would continue to operate with the same performance as before, but the "vectoring friendly" CPE would ignore the vectoring pilot sequence sent to them.
- Dynamic spectrum management techniques could be applied to both legacy and new, vectored lines to shape the respective PSDs to reduce the alien crosstalk. For example, the legacy lines would have the transmitted PSD at higher frequencies reduced as much as possible.

4.5 Bonding and vectoring

The use of more than one VDSL2 line to provide service to a customer (bonding) enables much higher bit rates or service to longer lines. For residential services, bonding will usually consist of at most two lines, but up to twelve lines might be bonded to serve a business customer.

For the same line length, bonding two lines will approximately double the downstream and upstream service bit-rates. Alternatively, bonding may be used to increase line length. For the same bit-rate, bonding two lines enables approximately 50% longer lines than using one line.

Bonding in combination with vectoring could make 100 Mb/s service cost-effective for many more customers. Bonding may be used selectively for only the longest or highest-bit-rate lines. Thus, the majority of customers, who are on short-to-medium length lines, would be served by a single line, and the added cost of two-line bonding would be necessary for only a small minority of lines.

4.6 Wiring inside the customer premises

Legacy VDSL2 deployments often convey the VDSL2 signal via inside wire to a VDSL2 modem located in a Residential Gateway (RG) inside the house. Since many homes do not have two pairs of inside telephone wire connected throughout the house, 2-line bonding would not be supported. Also, much of the alien noise on VDSL2 lines is coupled into the inside wire. These problems and also the additional VDSL2 signal attenuation due to the inside wire may be avoided by placing the vectored VDSL2 modem at the side of the house in a Network Interface Device (NID).

4.7 Addition and removal of VDSL2 signals on other lines

VDSL2 signals may appear and disappear at any time due to addition or removal of service, power failure, or a customer turning their modem on or off. Since it will take some time for the vectoring function to learn the new FEXT, the vectoring process must be designed to assure that errors do not occur in these situations.

4.8 Measuring and monitoring performance gain

In real-world conditions, we may find that vectoring sometimes does not achieve the expected performance gain in some cases. Vectored VDSL2 modems should provide built-in functions to measure the vectoring gain and maintain a performance log. If the vectoring performance gains fall below a threshold, an automatic "snapshot" should be taken of the line and noise conditions to aid later diagnosis.

4.9 Diagnosing the vectoring function

The vectoring function requires extensive diagnostic capabilities to help learn how it behaves and misbehaves under various conditions. It should be possible to read:

- the version of vectoring function supported by the CPE modem on each line
- the type(s) of alien noise cancellation supported by the CPE modem
- if the line is part of a bonded group
- estimated FEXT coupling characteristics between all vectored lines
- the measured alien noise as observed at both ends of the line
- the set of line couples where FEXT cancellation is being performed
- automatic "snapshot" of conditions upon a fault

4.10 Diagnosing the cable characteristics

In addition to the usual attenuation per tone and H(f) characteristics, the vectoring function should make use of the standard G.993.5 XLINps reports [5] that provide additional measurement of the cable characteristics which could be helpful in detecting and locating cable faults. If possible, it is very helpful to know the estimated distance to a fault.

4.11 Diagnosing noise characteristics

With vectoring, detailed frequency and time domain characterization of alien noise measurement will be more important than ever.

4.12 Vectoring management

The following management capabilities are provided in the ITU-T G.997.1 Recommendation [8] to manage G.993.5:

- Disable vectoring
- Designate high or low priority for FEXT cancellation
- Set upper and lower bound frequencies for vectoring

Vectoring also impacts other aspects of DSL management, as alien noise has a relatively larger effect on performance when vectoring is implemented and vectored and non-vectored lines may need to coexist. Vectoring can be performed without the use of other DQM techniques. However use of DQM techniques relating to line and spectrum management will often provide performance benefits.

5 Conclusion

Vectored DSL as defined in ITU-T Recommendation G.993.5 supports line speeds of greater than 100 Mbps on loops up to 500 meters in length, enabling the most advanced application services to be carried over copper. With appropriate placement of DSLAMs, use of management tools and techniques such as bonding of Vectored lines and use of DQM techniques, Vectored DSL becomes an important tool for network operator to provide broadband services such as IPTV to all their customers. Although deployment of Vectored DSL raises new operational issues for the network operator, the management tools provided in both in the ITU-T Recommendation and in the work of Standards Development Organizations such as the Broadband Forum are ensuring that G.993.5 is emerging as a complete ecosystem that will quickly enable its potential. The emergence of Vectored DSL provides the DSL based service provider with the tools that facilitate supporting the bandwidths required for higher valued premium services over their existing copper based networks and helps ensure that deployment of DSL increases as Broadband Services continue to evolve.

6 References

The following references are of relevance to this Marketing Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Marketing Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.
A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

Document		Title	Source	Year
[1]	TR-188	*DSL Quality Suite*	BBF	2010
[2]	TR-198	*DQS: DQM systems functional architecture and*	BBF	2011

		requirements		
[3]	MR-180	*Achieving Quality IPTV over DSL*	BBF	2012
[4]	BBF Press Release 21 June 2011	*2011 BROADBAN GROWTH FASTEST IN FIVE YEARS, accessed at http://www.broadband-forum.org/news/download/pressreleeases/2012/BBF_IPTV2012.pdf*	BBF	2011
[5]	G.993.5	*Self-FEXT Cancellation (Vectoring) for use with VDSL2 transceivers*	ITU-T	2010
[6]	G.993.2	*Very high speed digital subscriber line Transceivers 2 (VDSL2)*	ITU-T	2011
[7]	G.998.4	*Improved impulse noise protection for DSL transceivers*	ITU-T	2010
[8]	G.997.1	*Physical layer management for digital subscriber line (DSL) transceivers*	ITU-T	2009

7 Definitions

The following terminology is used throughout this Marketing Report.

Alien Noise	Alien Noise is any noise not due to crosstalk from within the vectored group
Bonding	Use of multiple DSL lines inverse multiplied at the DSL level to carry a single application payload to a customer over multiple copper loops. DSL Bonding is defined in ITU-T Recommendations G.998.1, G.998.2, and G.998.3
Crosstalk	Interfering signal received in one copper pair of a cable from services in other copper pairs of the same cable
Error Sample	The measurement made by a DSL receiver supporting Vectoring that indicated the effect of crosstalk received into loop serving the DSL Line
Far-End Crosstalk	Crosstalk between DSL services at the far end of the copper loop away from the DSL transmitter
Near-End Crosstalk	Crosstalk between DSL services at the near end of the copper loop near the DSL transmitter
Node-B	Hardware that is connected to the mobile phone network that communicates directly with mobile handsets. Base Transceiver Station (BTS) is used to refer to GSM base stations.
Pre-coder	The function in a vectored System for the downstream direction that performs the mathematical operations to allow vectored noise cancelation to occur on a DSL service

Self Crosstalk	Crosstalk from the same type of service. E.g. for VDSL2 crosstalk from another VDSL2 service in the same cable is Self Crosstalk. For example, SELF Far-End Crosstalk is Far-End Crosstalk from another VDSL2 service in the same cable.
Showtime	The state of a DSL connection when application payload data can be transmitted over the connection
Vectored Group	A group of DSL lines in a cable on which vectoring is performed to cancel crosstalk between members of that group.
Vectoring	The method of canceling crosstalk on DSL line by determining the level of crosstalk received in the line and canceling it by mathematical algorithms that modify the encoded data to reduce or eliminate the received crosstalk.
Vectoring Control Entity	The function in a vectored System that manages vectoring for the lines in a DSLAM

8 Abbreviations

This Marketing Report uses the following abbreviations:

AWG	American Wire Gauge
BTS	Base Transceiver Station
CO	Central Office
CPE	Customer Premises Equipment
DQM	DSL Quality Management
DS	Downstream
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexor
DSM	Dynamic Spectrum Management
FEXT	Far End Crosstalk
FTTB	Fiber to the Basement
FTTC	Fiber to the Curb
FTTN	Fiber to the Node
H(f)	The channel attenuation at a particular frequency
IPTV	TV over Internet Protocol
MDU	Multi-dwelling Unit
MSAN	Multi-service Access Unit

MTU	Multi-tenant Unit
NEXT	Near End Crosstalk
POTS	Plain Ordinary Telephone Service
PSD	Power Spectral Density
RFI	Radio Frequency Interference
SNF(f)	Signal to Noise Ratio at a particular frequency
US	Upstream
VCE	Vectoring Control Entity
VDSL	Very High Speed Digital Subscriber Line
VDSL2	Very High Speed Digital Subscriber Line Issue 2 (ITU-T Recommendation G.993.2)
VTU-O	VDSL Transceiver Unit – Office – a VDSL2 transceiver in the network
VTU-R	VDSL Transceiver Unit – Remote – a VDSL2 transceiver in the customer's premises

Notice

End of Broadband Forum Marketing Report MR-257