Smart Vectoring

White Paper
http://www.assia-inc.com

Contents

Executive Summary

Operators now face several challenges in deploying vectored VDSL2, a new technology that opens many opportunities for innovative broadband services. These challenges arise in all deployment phases, from planning to the actual physical deployment; from maintenance to daily optimization in the presence of non-crosstalk noises, as well as crosstalk noise from legacy services. Operators need tools to cope with such challenges, achieve the highest return on their investment, and better compete in the marketplace with other access technologies.

This white paper addresses the important steps a service provider must take when planning a seamless transition from today's DSL network to vectored VDSL. After reviewing the most important challenges faced by service providers and dispelling some misconceptions about vectoring that still exist, this paper describes the capabilities and practices necessary to overcome these challenges.

Service providers require solutions to help accelerate vectored VDSL2 deployments, while driving high performance and ensuring rapid profitability. Furthermore, service providers have to deploy vectoring across networks made up of multivendor hardware equipment, and to upgrade the network gradually, managing vectored and non-vectored lines as needed.

Service providers require a comprehensive approach that helps support their critical business objectives, and that provide the following:

- Maximum return on investment: Service providers must be able to accurately qualify customers and networks for vectored services and plan gradual rollouts to manage costs and deliver new services to targeted customers likely to upgrade.
- Selective and targeted capital expenditure: The performance of legacy line-cards and DSLAMs can be improved while delivering vectoring incrementally or "en masse." This contrasts with other approaches that advocate replacing all line cards and customer premises equipment (CPE) with vector-capable hardware.
- Minimal IT integration costs: Service providers can seamlessly integrate required software systems with a variety of existing management platforms and operations support systems, minimizing IT integration cost.
- Support for customer self install: Software-based solutions enable self-install through the use of both centralized management (for line pre-qualification and optimization) and self-help customer-facing applications, thus minimizing the likelihood of self-installation failure.
- A proven and complete solution: Service providers must be able to manage both vectored and non-vectored lines with a single unified tool, addressing all the key issues related to DSL management and improving the performance of hardware-based solutions by complementing them with a wider set of required capabilities.
- Improved customer satisfaction: Automatic optimization and interference management of all lines result in fewer trouble calls and dispatches, and streamlined customer care operations.

These lead to higher customer satisfaction ratings both during and after the transition to vectoring.

- Support for multivendor networks: Software-based management normalizes high vectoring performance gains across selected hardware equipment, so service providers can choose their best-of-breed equipment vendors strategically, and avoid vendor lock-in.
- Support for Dynamic Spectrum Management (DSM): DSM techniques reduce the effects of disturbances across the network while maximizing performance of each line. DSM is a field that was pioneered over a decade ago and has since been deployed across tier one networks worldwide.

Smart Vectoring is a solution offered by ASSIA that combines professional services and the DSL Expresse management system with features designed to support vectoring, and which delivers all of the benefits listed above.

1 Overview

Vectoring technology is a major milestone for broadband access and creates many opportunities for new services. Vectored VDSL2 can deliver “dedicated” (not shared) rates to the customer in excess of 100 Mbps over existing copper plant. This allows service providers to deliver a range of innovative services and evolve their networks to meet the growing demands of broadband consumers. Vectoring also gives service providers a competitive advantage in delivering super-fast access compared to other operators that deploy shared connectivity solutions at a much higher cost—for instance, fiber-to-the-home (FTTH) installations.

This paper gives an overview of the benefits that vectoring can bring to service providers and the main practical challenges associated with its deployment. After dispelling several misconceptions about vectoring, this white paper describes the capabilities and practices necessary to overcome these challenges.

Smart Vectoring is a solution offered by ASSIA that combines professional services and DSL Expresse management software with new key features that are necessary for seamless vectored DSL services’ delivery to networks of all sizes. A wide range of features are supported, from planning the network upgrade to deploying vectored DSL services in a gradual fashion without disrupting legacy services or incurring excessive startup costs, and to managing vectored DSL to achieve the highest performance with the lowest maintenance costs.

Smart Vectoring delivers enormous value to service providers planning or already offering vectored VDSL2 services. This document outlines the key business metrics that are positively affected by Smart Vectoring.

For a **detailed business case** for Smart Vectoring and other additional information, please visit www.assia-inc.com/smartvectoring or contact info@assia-inc.com.

2 What Vectoring Brings to Service Providers

Until now, one of the major obstacles to delivering very high-speed communications services over copper has been crosstalk interference among neighboring pairs. For example, in the case of a lightly loaded cable (where lines are affected by little or no crosstalk), VDSL2 allows service providers to deliver 100 Mbps to all users within a 550 meter radius. When service penetration grows and the cable carries more VDSL2 services, unmanaged crosstalk becomes the primary source of performance degradation and the median radius for 100 Mbps is reduced to 150 meters (see Figure 1). Furthermore, the variability of VDSL2 data rates widens when unmanaged crosstalk becomes dominant, reducing the service level that can be guaranteed to customers.

Vectored VDSL2 is an extension to VDSL2 that removes the crosstalk among wire pairs in a so-called "vector group." Once crosstalk is removed, the performance of VDSL2 becomes independent of the number of VDSL2 lines in a cable and approaches (ideally) that of a single VDSL2 line which is unaffected by crosstalk – see the top solid line of Figure 1 below[1]. Thus, service providers can deliver 100 Mbps to all users within a 550 meter radius regardless of the density of their deployment, i.e. independently of the "cable fill" or fraction of pairs carrying VDSL2 services in each cable.

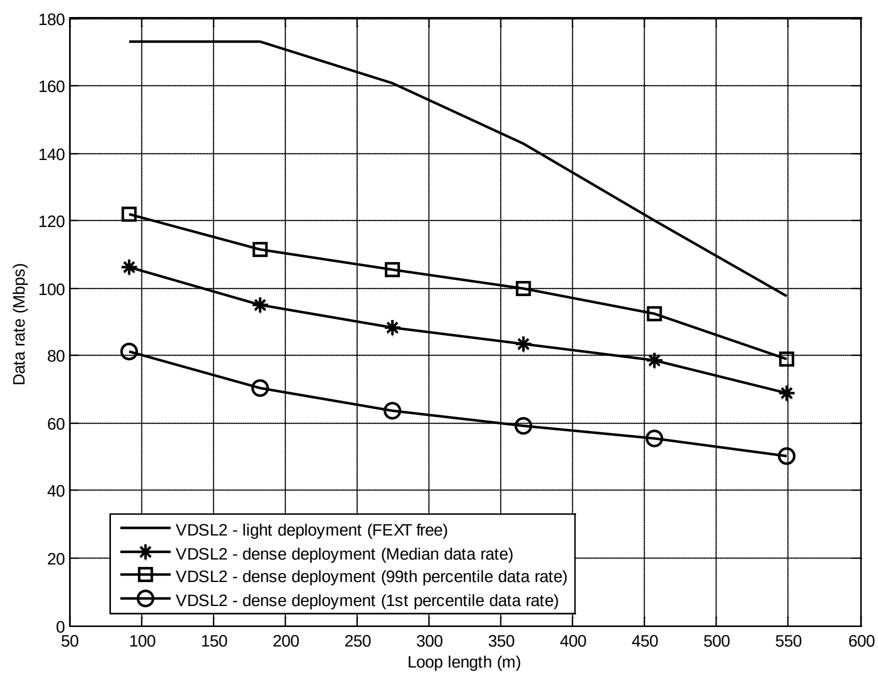

Figure 1: Rate-reach plot over AWG 26 pairs of non-vectored VDSL2 lines for the two cases of light (single line) and dense deployment (48 percent cable fill). Profile 17a with ATIS MIMO model.

[1] In practice, vectoring data rates will be lower than the ideal crosstalk-free case due to imperfect crosstalk cancellation, the presence of crosstalk from non-vectored DSLs, and other non-crosstalk noises.

Another important advantage of vectoring is that, unlike non-vectored VDSL2, the wide variability in rate experienced by each customer is drastically reduced so that service providers are able to confidently offer higher data rates to a much larger percentage of customers.

Power saving is another important outcome of vectoring. Transmitter power can be reduced on lines in a group because the receiver experiences a crosstalk-free signal, and excessive margin is not required for a robust connection. This makes vectored lines more “polite” and so less crosstalk is created into neighboring lines carrying other services. Vectoring’s intrinsic politeness coupled with power management that adaptively controls the transmit power of each port translates into lower operational costs. For example, assuming an average cost of US $0.15 per kWh, network operators can realize electricity cost savings of up to US $0.5 million per year for every one million DSLs.

Finally, it is important to note that vectoring, like any other DSL service, provides the unique benefit of ensuring a dedicated bandwidth to each user, whereas most other broadband access technologies provide a bandwidth that is shared among all users, e.g. coax, wireless, fiber-to-the home. This higher and dedicated data rate at longer ranges enables service providers to fully meet consumers’ increasing demand for higher speeds, to keep pace with the ever-increasing speed of wireless and wired home networks, and to remain competitive with other broadband access providers.

3 Practical Challenges when Deploying Vectoring

Service providers interested in a network upgrade to vectored VDSL2 need to build a solid business case to justify the investment, including the associated future revenues and costs. Vectoring is different from past DSL technologies and poses new opportunities and challenges to service providers looking to transition to this new technology. Here we offer an overview of the main challenges encountered when deploying vectoring, while the key features required to cope with these challenges will be described in section five.

3.1 Planning

The first step in deploying vectoring is to plan for the upgrade. For this purpose, service providers require reliable projections of rates and services that can be delivered after the upgrade. Such information is critical for choosing the sites, nodes or neighborhoods where upgrades can produce the highest return on investment. To obtain the most accurate projections, actual DSL management data must be collected from the field, and this collection has to cover a statistically significant number of lines in the candidate markets for vectoring and span a period of several weeks for proper capture of network time variation.

In addition, planning tools must allow analysis at various scales, e.g. prediction of rates and services should be performed at the level of a terminal, a node, a site or even a neighborhood – and ideally extend it to larger groups such as zip-codes, cities, and metropolitan areas. Such analysis is an important factor in deciding which locations have the highest priority for vectoring upgrades, and for deciding the upgrade method—for example whether a new cabinet needs to be built. These results can be further enriched by combining the service predictions with marketing data (e.g. expected take-rate within a given region) to produce a detailed cost-benefit analysis. This analysis guides the selection and prioritization of sites, areas or regions for upgrade.

Another important aspect of planning is the ability to determine which part of the network requires grooming prior to the deployment of vectoring, e.g. flagging cable sections suffering from degradation, identifying the lines that require correction, and identifying the eventual presence of legacy lines. This capability provides projections for multiple alternative scenarios, and allows service providers to determine whether performing an equipment-only upgrade is sufficient or if line grooming also is necessary.

Once vectoring is deployed, additional planning capabilities are available to service providers. For example, a detailed knowledge of the crosstalk environment is available thanks to additional diagnostic parameters to improve channel capacity estimation accuracy. The availability of accurate channel capacity allows service providers to better plan for applications with particular quality of service (QoS) requirements such as femto/small-cell backhauling, VoIP, IPTV, etc.

3.2 Gradual deployment

There is no economic argument for the complete and concurrent replacement of the existing plant with a vectored plant and therefore practically speaking, vectored DSL is expected to share binders with non-vectored DSL for some time. In most cases, this is the consequence of gradual deployment. For example, legacy DSL equipment at the customer site cannot be instantly replaced with vectored DSL equipment; a remote firmware upgrade may be a preferred option, but can still fail for some of the lines, or prove too expensive. There may also be two or more DSLAMs sharing a cabinet and the service provider may decide to upgrade only one of them to vectoring. Finally, there also may be customers who do not want to change their current service. In some cases, unbundling may lead to multiple service providers having a mixture of vectored and non-vectored equipment in the same cabinet. In conclusion, a complete upgrade to vectoring is not possible overnight and can only be accomplished slowly—especially in brownfield environments.

As a consequence, operators must have tools to manage the simultaneous presence of vectored lines, non-vectored lines, and lines terminating on legacy CPEs[2] while existing DSL equipment is replaced by vectored DSL over time. This capability is truly necessary and is independent of whether local regulations allow or forbid sub-loop unbundling.

3.3 Non-crosstalk noise

There are several types of non-crosstalk noise, which we refer to here as “alien noise,” that plague DSL systems: radio frequency interference (RFI), impulse noise from electrical services in the home, interference from broadband power line communications (PLC), and so on. Noise sensitivity is generally highest when the DSL signal is most attenuated, i.e. at the higher VDSL frequencies. Furthermore, since vectoring cancels the crosstalk from disturbers in the vectored group, the receiver is then exposed to alien noise which becomes the dominant noise source impairing vectored lines.

Alien noise is often time-varying: radio ingress varies from day to night, impulse noise varies with the AC cycle and with appliances’ electrical state, power line modems for in-home networking create time-varying interference, and so on. The effects of alien noise on vectoring can include severe transmission errors and even service outages, often leading to a very poor customer experience. This noise can also be exacerbated by degradation and other types of copper wiring impairment that can occur both inside the consumer’s residence and in the outside plant. As a consequence, alien noise can lead to severe line instability. Even in a fully vectored scenario (no crosstalk from non-vectored lines, no legacy CPEs), alien noise like impulsive noise or time-varying PLC interference can be very disruptive as the time-invariant “blanket” of crosstalk that used to hide them has been removed by vectoring.

In the presence of time-varying alien noise and in the absence of powerful management tools, lines are often either under-provisioned by being programmed to run at a speed lower than what they can support, or over-provisioned by being programmed to run at a speed that is too high to maintain stability. Under-provisioned lines lead to lost revenue opportunities for higher-speed services. Over-provisioned lines lead to higher operational and maintenance costs, high volume of unhappy customer calls, and high churn rates. Often, instability issues are addressed by increasing excess margin which in turns leads to rate/reach reduction.

Furthering the inefficiency of current practices, the traditional approach to managing DSL stability issues has been for the DSL technician to leverage so-called “golden profiles,” which are a limited

[2] Legacy CPEs are CPEs that are neither vectoring-friendly not vectoring capable.

number of line configurations that are statically applied and are supposed to resolve the issue as it manifests itself in the present, ignoring the time-varying nature of the problem. Similarly, service qualification rules are traditionally based on attenuation on a single frequency, ignoring the dynamic time and frequency behavior of each line. There are many shortcomings in this static approach:

- Due to the time-varying nature of a DSL network and its surrounding environment, the best DSL configuration today will likely be different in the near future. Setting a static profile on a line may trigger a repeat call and result in a dissatisfied customer.
- Every line in a DSL network is different and performs differently under the same configuration. It is unrealistic to expect that a small set of profiles can fit and fix all network issues. Further, qualification rules that ignore time and frequency variations in line performance lead either to under-provisioning of the network and lost commercial opportunity, or over-provisioning of the network with attendant increases in complaint rates and customer dissatisfaction.
- Even in a situation where these profiles are defined, adapting them to all the hardware platforms deployed throughout the network and inputting them manually into the DSLAMs for all the lines requiring modification (assuming such lines were easily identified) requires excessive manpower and dramatically increases operational costs.

A vectored DSL network operating at the highest nominal speeds and without the proper management may have a number of lines experiencing poor quality or instability that can be as much as three times worse than in the case of a non-vectored network, according to expert analysis by ASSIA engineers. Such a high rate of instability or throughput loss would bear a prohibitive cost on service providers. Coping appropriately with this issue is extremely important for a successful migration from a non-vectored to vectored network.

The treatment of the disruptions caused by alien noise requires management algorithms that appropriately configure each line for impulse noise protection, either FEC or G.inp, judiciously applying the correct configuration parameters for those schemes. This requires monitoring each line individually, collecting historical data and dynamically optimizing configuration parameters to achieve the highest possible performance level on each line. This dynamic capability to optimize lines is necessary for all types of DSL, but it becomes extremely important in the case of vectoring since alien noise is the dominant impairment.

3.4 Diagnostics and fault detection

The availability of management tools for diagnostics and fault detection is important for all types of DSL, but for vectoring it is especially critical. Fortunately, vectoring offers improved diagnostics capabilities. The availability of sophisticated diagnostic and fault detection tools is of paramount importance for VDSL2 and vectoring since these services are more sophisticated and less fault-tolerant than previous technologies, such as ADSL2+. Furthermore, vectoring is a new technology and unexpected issues can be encountered in the field as deployments roll out.

Vectored systems can be managed to allow improved diagnostics based on the knowledge of crosstalk couplings between pairs. Vectored DSL systems can report the actual crosstalk coupling among pairs through the management interface, both for upstream and downstream. The availability of this quantity (also known as XLIN) in both upstream and downstream directions leads to many new capabilities in diagnostics, troubleshooting, management, and planning.

XLIN makes it possible to identify lines that create excessive crosstalk. Typically, such lines are characterized by faults (e.g. poor balance) that lead to poor performance and that are prime targets for maintenance actions. It is possible that such pairs also generate crosstalk into non-vectored lines (which cannot be eliminated) so that the identification of such extreme crosstalkers and subsequent actions based on this information can improve the performance of the copper network over time. This can substantially reduce the time spent by technicians trying to identify an offensive and noisy line. XLIN also allows accurate separation of noise sources that may be causing crosstalk from known lines and noise from external sources. Furthermore, causes of line instability such as retrains and errors caused by varying crosstalk can be traced through XLIN as well.

Good diagnostics and fault detection tools allow physical layer performance diagnostics by analyzing data collected from DSLAMs and Element Management Systems (EMSs). Such capabilities allow service providers to be more proactive and responsive to the needs of the consumer, and ensure customers have the best experience for the applications they are using.

At the end of the day, good diagnostics and effective management help reduce the number of customer calls, improve field-technician performance, and decrease the number of repeat calls and dispatches – thus reducing the operating costs and customer churn.

4 Some Misconceptions about Vectoring

Before diving into descriptions of solutions for resolving the challenges mentioned in the previous section, it is important to address a few current misconceptions about vectoring.

4.1 MISCONCEPTION: Hardware-based "zero-effort" solutions are all you need

A major misconception is that hardware-based implementations of vectoring that cancel crosstalk originating from non-vectored legacy lines allow service providers to migrate their copper network to vectoring with "zero-effort."

This claim is far from reality as the ability to cancel crosstalk from non-vectored legacy lines using hardware-based methods is confined to a very limited set of conditions that make such a "zero-effort" approach insufficient for a seamless and smooth transition of the copper network to vectoring. Furthermore, since this capability is not standardized and is vendor-proprietary, the implicit consequence of this claim is that service providers must resort to a single vendor for their vectoring equipment.

Upon closer examination, these hardware-based solutions share the following drawbacks:

- Cancellation of crosstalk from legacy lines is ineffective in several cases:
  - Always in the upstream, unless vectoring-friendly CPEs are available on all the legacy lines. However, if vectoring-friendly CPEs were available on all legacy lines then there would be no need for such a solution.
  - In both upstream and downstream, when there are legacy lines in the same binder that terminate on a different DSLAM (multi-DSLAM cabinet).
- In those few practical cases when cancellation could be effective, the **additional limitations of a hardware-based solution** are:
  - All line-cards must be vectored from the beginning, which does not allow for gradual line-card replacement.
  - Deployment requires a high penetration of vector-capable CPEs from the start, forcing the service provider to make a sizeable investment in time and capital expenditure in upgrading CPEs. In some cases, this may not even be possible, for instance when CPEs are not owned by the same service provider deploying the vectored DSLAM.
  - Since hardware-based solutions are proprietary by vendor, the service provider is prevented from adopting a multivendor sourcing strategy.
  - The hardware-based solution cannot address performance degradation issues in the downstream caused by in-home non-crosstalk (alien) noises (see section 3.3).
  - The hardware-based solution is not widely deployed yet and is still undergoing testing; its full capabilities are still unclear.
  - Upgrades of CPE firmware may be necessary.

- In canceling crosstalk from non-vectored legacy lines, pay special attention to the following potential issues with hardware-based solutions:
  - o Cancellation can be less effective when the number of legacy CPEs is large compared to the number of vectored lines;
  - o Cancellation can be less effective while a non-vectored DSL is initialized (which is an event that can happen fairly frequently and for numerous reasons, e.g. the addition of a new line, a modem reset, and so on).

Given the limitations listed above, service providers must be cautious about relying solely on hardware-based solutions, as such solutions leave unsolved many more issues than they actually fix, and have many unknowns about performance and capabilities. For example, none of the major issues discussed in section three are addressed or simplified by adopting a hardware-based solution. At best, hardware-based solutions only solve part of the transition issues. Software-based solutions are required to complement the capabilities and adoption challenges of hardware-based features.

4.2 MISCONCEPTION: Vectoring does not require management

There are proponents of hardware-based solutions that suggest that vectoring does not require management. An argument that is often used to advocate for "no management" is that the ITU-T standard for impulse noise protection, G.inp solves all problems due to alien noise. While G.inp provides tools for coping with alien noise, management is still needed for the correct use of those tools. At a minimum, diagnostics are needed for fault resolution, and profile optimization is needed to choose the correct combinations of G.inp and other profile parameters.

The effect of crosstalk is not uniform across DSLs, and depends on a large number of factors, such as loop length, frequencies used, cable geometry, and the density of DSLs in a cable binder. As a result, the data rate performance of non-vectored DSL can have a very wide variation in the field, especially for the shorter loops, where crosstalk dominates. As lines also exhibit time variations (channel faults, noises coming and going, lines joining and leaving, etc.) the best practice is to decide what profile to apply through long-term observations and thus dynamically adapt choices to achieve better target stability and data rate.

Although it is true that vectored DSL reduces the non-uniformity of crosstalk effects and makes data-rate performance more predictable, thus somewhat simplifying certain management functions, management is still required. In fact, alien noise becomes dominant in vectoring as the crosstalk disappears making it more important than ever to use long-term monitoring and apply dynamic re-profiling that exploits historical data. Also, simultaneous management of many vectored lines is necessary to automatically direct the available resources to customers with the most demanding service requirements.

ASSIA's experience in managing nearly 70 million DSLs indicates that management is required for vectoring and especially for the following situations:

- Coping with alien noise that vectoring exposes when it cancels crosstalk
- Dealing with the proximity of vectored and non-vectored lines

- Enabling gradual upgrades to vectoring
- Attaining the highest possible speeds from vectored lines
- Optimizing lines for the support of specific real-time applications, such as femto-/small-cell backhauling, IPTV, VoIP, and others

Vectored DSL also expands the capabilities of loop re-profiling. Improved practices for re-profiling vectored lines lead to improved overall network operation and a reduction of line instability issues, which may otherwise generate customer calls and consequent technician dispatches. Such practices include configuring transmit spectra and power to enable coexistence among vectored and non-vectored lines, and management of non-crosstalk noise sources. These practices always require a dynamic re-profiling capability using historical data, and sometimes require access to multiple lines, since optimization cannot always be performed on a line-by-line basis.

Ideally, a DSL management system must support an efficient and automated way to apply the following process across all lines in a DSL network, and for a multivendor network:

- *Collecting* operational and performance parameters from all DSLs in the network on a periodic basis, and storing these parameters for long periods of time (days to months).
- *Analyzing* the stored parameters to either diagnose faults (e.g. copper impairment, DSL equipment fault, and so on), or to obtain performance projections, such as identifying lines that are eligible for upgrade. These analyses can then be provided to other operations support systems (OSS), or to customer care agents requiring such information.
- *Re-profiling* DSLs to meet coexistence objectives, satisfy quality of service requirements for each line, and maximize data rate based on the lines' service requirements. Only those lines that are not meeting coexistence or service objectives are re-profiled.

Meaningful operational benefits are obtained only when the steps above are performed regularly on all lines in the network, preferably on a daily basis. The step of collecting management data daily from the DSL access network is followed by the diagnostics phase, which is performed for all lines, and by the re-profiling phase, which is performed only for those lines that do not meet service objectives.

DSL service optimization is critical for ensuring that the customer has the best service experience. Optimization must be performed in an automated way and must be based on close monitoring of the DSL. Such optimization is especially important when provisioning a new technology like vectoring for which there is still little field experience to help minimize customer complaints and consequent truck rolls.

Detection and correction of DSL problems also must be automated to avoid the costly steps of customer calls and manual interventions for fixing issues. Periodic data collection provides the necessary input for line supervision that enables early discovery of issues. Proactively solving an emerging problem before the customer notices any degradation is essential to prevent customer dissatisfaction and churn. Problematic lines must be reconfigured to address the fault, or a detailed line analysis must inform the field team to take corrective actions in the most efficient way.

Software-based management must allow for scanning up to 20 million lines per day in a single network, for identifying DSLs that are underperforming, and for automatically optimizing profiles during the appropriate maintenance window. The ability to reconfigure DSLs in a proactive rather than reactive manner is a key feature for coping with vectored networks that, as outlined earlier in section 3.3, are much more exposed to time-varying alien noise than non-vectored network. Furthermore, another advantage of software-based management approaches is the truly transparent handling of multivendor networks so that a service provider can adopt the multivendor sourcing strategy that best fits its needs and finally be free from being locked-in to solutions that rely on proprietary tools.

4.3 MISCONCEPTION: DSM-based management requires burdensome IT integration

As discussed in the previous section, management is necessary for the existing DSL plant, as well as for ensuring a smooth transition to vectoring. The support of DSM techniques for dynamically optimizing the operation of DSLs further requires a sophisticated and advanced management platform capable of continuously reacting to varying line conditions for applying the best set of configuration parameters.

A common misconception is that such an advanced management platform requires a painful integration process with the OSS and management models used by service providers, and thus the integration of any advanced management system with existing provisioning, accounting, and diagnostic tools creates a burdensome IT integration effort.

The fact is that an advanced management platform can perform a very large range of functions with minimal integration effort. Such a platform only needs to be provided with basic provisioning data for the lines and DSLAMs in the network for it to perform data collection, analysis and optimization of all lines. Many options are available for further facilitating such simple integration. Examples of such options include:

a) Using web services for easy interfacing between the management system and the provisioning system.

b) Alternatively using text-based files exported by the provisioning system and imported by the management system.

c) Maintaining line and DSLAM information by either providing incremental updates, or by periodically providing a fresh list of line and DSLAM data.

This minimal integration effort allows the management platform to deliver the full benefits of automated optimization, and also to provide users with analysis results through a graphical user interface. Service providers that desire a deeper OSS integration can make further use of web services for retrieving line or network analysis results from the management platform. They also can export data from the management platform’s database for purposes of data warehousing. Those are optional integration steps that service providers can schedule progressively.

5 Smooth Transition to Next-Generation Networks with Smart Vectoring

ASSIA Smart Vectoring is a solution that accelerates the profitable and immediate deployment of 100 Mbps vectored DSL services. It runs on all DSL types, even non-vectored, and helps accelerate vectoring deployments by continuously preparing the entire DSL network for the introduction of vectoring, and by delivering speed increases in the most profitable places, at the right time. Smart Vectoring combines professional services and DSL Expresse management software with new features specifically designed to support vectoring.

ASSIA professional services are planned to help ASSIA customers leverage the latest advances for optimum business value. ASSIA experts work with service providers around the world to ensure their networks run at optimum efficiency, and consumers have the best possible experience, thus lowering costs and reducing churn. The ASSIA Professional Services portfolio includes training, deployment planning, network tune up, business intelligence, operational assessment, customized troubleshooting, and quality of experience evaluation.

DSL Expresse is a field-proven and award-winning product that is being used around the world to manage more than 70 million DSLs. If service providers already have DSL Expresse, then the additional Smart Vectoring features can be integrated quickly. However, even without DSL Expresse, Smart Vectoring can be easily leveraged by service providers, because ASSIA has developed its platforms for smooth integration with existing OSS. The Smart Vectoring southbound interface supports SNMP, TL1, and other standard management languages for full integration with any vendors' DSLAMs and EMSs. A web services northbound interface is provided for integration with other OSS, and access to diagnostic and management interfaces is supported via standard web browsers, so operators can enjoy immediate benefits with minimal integration effort. This section provides an overview of the key capabilities delivered with Smart Vectoring.

5.1 Planning for an effective transition to vectoring

Smart Vectoring includes provisions for accurate vectoring planning, aimed at addressing the needs of service providers for evaluating and for planning a network upgrade to vectored VDSL.

A fundamental aspect of planning is the ability to perform a network assessment to accurately predict the data rates and the corresponding services that can be delivered on lines upgraded to vectored VDSL. Such an assessment gives the service provider a line-by-line projection of the data rates that can be reliably delivered on a DSL after it is upgraded.

Using actual field data, Smart Vectoring produces a projection for the highest possible downstream and upstream data rates of each line under consideration using proprietary algorithms for predicting line data rate capacity with vectoring. ASSIA then maps these rates to service products that would be offered to the corresponding customer. For an example of this analysis, see Figure 2.

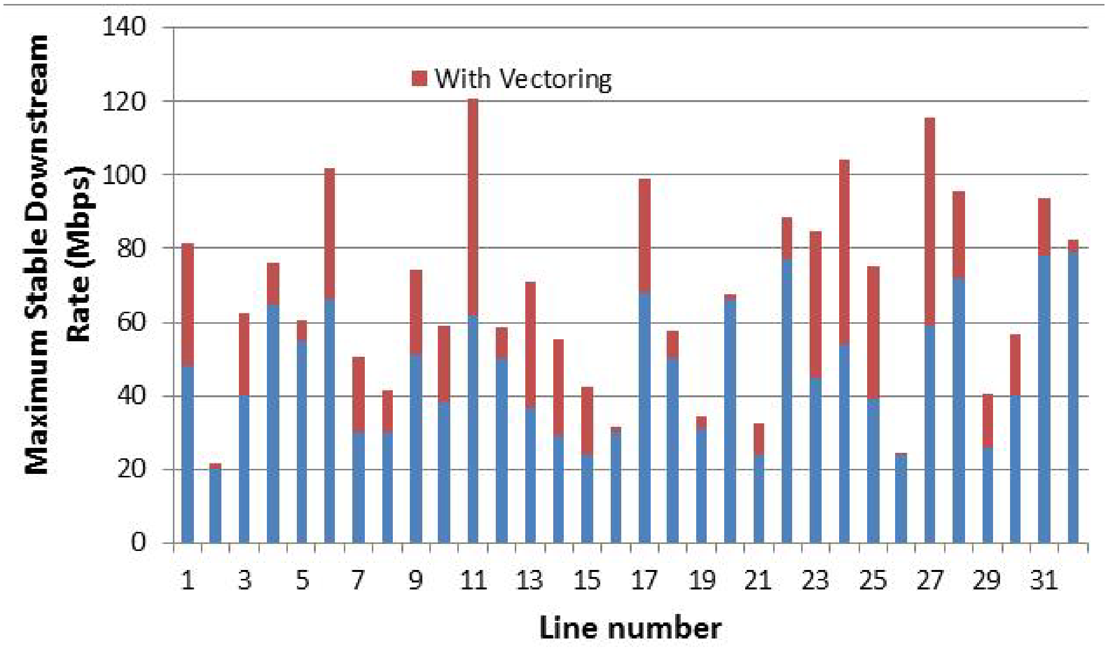

Figure 2: Rate estimation for lines on a specified DSLAM

Smart Vectoring is a valuable tool that yields projections for multiple alternative scenarios, such as:

- Performing **only equipment upgrade** to support vectoring in a homogenous environment, and not planning for line "grooming,"[3] for instance where a service provider does not mix vectored and non-vectored lines.
- Performing **equipment upgrade and line "grooming"** to eliminate any identified copper issues.
- Performing **equipment upgrades** at the DSLAM, but **anticipating coexistence** of the vectored lines with lines served either by legacy, non-vectored DSLAM equipment or by legacy CPE equipment (see also section 5.2).
- Constructing **new cabinets** for vectored DSLAMs, resulting in shorter copper loops.

A key feature of Smart Vectoring is its ability to produce an analysis of rates and services at each level – a terminal, a node, a neighborhood, or even for larger groups defined by zip-codes, cities, metropolitan areas and even regions. Such analysis allows improved understanding of the decision a service provider must make on investment priorities. For instance, deciding which locations have the highest priority for vectoring upgrades and what upgrade method to use.

Smart Vectoring planning can help generate very substantial value for service providers. ASSIA's experience from recent lab and field trials suggests that there are significant gains that can be achieved through Smart Vectoring planning in the following three ways:

[3] Line "grooming" is a maintenance campaign to prepare the copper plant for the introduction of vectored VDSL.

a) **Acceleration of vectored-service deployment**. ASSIA solutions for allowing vectored and legacy lines to coexist in the same cable enable service providers to plan for earlier roll-out of vectored services (see also section 5.2). Service providers can plan a gradual conversion to vectored VDSL2 equipment, mitigate the impact of legacy CPE modems, and launch vectored services even in “brown-fields.” Acceleration of a roll out by several months has a large positive impact on revenue from such new services.

b) **Increased take-rate of vectored services**. Smart Vectoring planning can accurately identify the consumers who are capable of receiving vectored speeds, and interested in purchasing such services. It helps prioritize investment to those geographies that are more likely to produce a high take-rate. It also minimizes false negatives in qualifying consumers for vectoring services. Finally, accelerating the roll out of vectoring gives the service provider an early competitive advantage over slower competitors, which leads to an increased market share and higher take-rate.

c) **Reduction of capital expenditures for vectoring upgrades**. Smart Vectoring planning increases the efficiency of the vectoring upgrade program by identifying exactly those cable faults likely to negatively impact vectored services. Delivering targeted recommendations for required maintenance reduces the technician time for preparing the outside plant, and lowers the capital expenditure required to complete the vectoring upgrade.

5.2 Support for a gradual deployment of vectoring under both physical and virtual unbundling regulatory regimes

Vectoring performs crosstalk cancellation only among the lines in a vector group, so vectored lines may experience un-cancelled crosstalk from nearby lines that are either non-vectored or in a separate vector group or terminated on legacy CPEs. If nothing is done to mitigate the effects of un-cancelled crosstalk in mixed scenarios, then vectored lines may suffer performance degradation.

This argument has been often used to advocate for an “extreme” solution to save the full benefits of vectoring, e.g. market competition restrictions on sub-loop unbundling (SLU), the deployment of very large vector groups, and so on.

Such solutions are not only extreme but also incomplete, as un-canceled crosstalk is present regardless of SLU provisions. For example, even in the case of a single service provider, we see the following causes of un-cancelled crosstalk presence that arise from non-vectored VDSL2 lines:

- Since vectoring allows for a drastic increase of the cable fill, each cabinet can potentially serve more customers which in turns means that more DSLAMs per cabinet would be needed. Although today a few proprietary implementations seem to allow creating a single vector group spanning multiple DSLAMs, such solutions are still being tested, are not standardized, and further require that all DSLAMs are from the same vendor, thereby preventing the adoption of a multivendor sourcing strategy.
- Since gradual deployment is inevitable, as previously discussed in section 3.2, an operator may have to face one or both of the following situations:

  - Only a subset of DSLAMs in a cabinet may be upgraded in the first wave of deployments, leading again to the temporary presence of non-vectored disturbers when not all the lines support vectoring at both the DSLAM and CPE.
  - It is not always possible to upgrade or replace all legacy CPEs at the time a service provider is upgrading its DSLAMs. Some customers may not want to change their current service, the CPE may not allow firmware updates, the CPE may not be owned by the same service provider upgrading the DSLAM, and so on.
- Computational complexity/cost limits in practice vector group size and the cancellation of crosstalk performed by vectoring is never complete (even in a fully vectored system). This inevitably creates un-cancelled crosstalk, as in the presence of non-vectored disturbers.

Since all crosstalk cannot be completely eliminated regardless of SLU provisions, pragmatic solutions are needed today to ensure an immediate economic advantage in deploying vectoring. Without it, deployments may be delayed and opportunities missed.

Furthermore, given the diversity of regulatory provisions around the world and the growing presence of service providers across multiple countries, service providers need effective solutions for a smooth transition to vectoring, regardless of regulatory regimes. Smart Vectoring is a flexible platform that allows network-wide optimization under both physical and virtual unbundling regulations. These two regulatory regimes are addressed next, however the considerations in this white paper are relevant even for the very simple case of a single service provider rolling out vectoring gradually and operating a mixed VDSL2 and vectored VDSL2 network.

5.2.1 Physical unbundling

The coexistence of vectored VDSL2 with legacy DSL is an issue of practical importance that arises in a variety of situations – see section 3.2. Without proper countermeasures in place, even a single non-vectored DSL in the same binder with a group of vectored DSLs can eliminate most of the performance gains of vectoring. In such a situation, upgraded vectoring services cannot be offered until all non-vectored DSLs are upgraded or removed, adding delays and costs to the vectoring roll out effort and possibly deterring some service providers from upgrading.

Service providers need effective tools for managing coexistence. Although certain hardware vendors claim to have solutions to the problem of coexistence, the reality is that such solutions are effective in only a small number of cases (see section 4.1). On the other hand, there is a consensus in publicly available material that DSM is a very effective technique for enabling coexistence between vectored lines and other disturbers, such as VDSL2 lines that are non-vectored and terminate on legacy CPEs.

Smart Vectoring delivers a framework for preserving most of vectoring gains in mixed vectored/non-vectored scenarios. For example, DSM-based techniques used for Smart Vectoring enable the following coexistence results:

- Vectored lines suffer 10 percent to 20 percent data rate degradation from realistically achievable rates, while non-vectored lines are capped at high speeds seldom delivered today (40-50 Mbps).

- If vectored lines are set to operate at a 100 Mbps target rate, then vectored lines suffer no degradation at all up to 500 m, while non-vectored lines are capped at even higher speeds (40 Mbps to 95 Mbps).

As an illustrative example of the conclusions above, Figure 3 shows the downstream data rate for vectored and/or non-vectored lines for three distances, and for several scenarios (from top to bottom):

1. VDSL2 data rates for a full binder of non-vectored VDSL2 lines.
2. Vectored VDSL2 data rates for a full binder of vectored lines, FEXT-free performance (ideal).
3. Vectored VDSL2 data rates for a full binder of vectored lines, with imperfect crosstalk cancellation (realistic).
4. Vectored VDSL2 data rates for a mixed case where the full binder is equally split between vectored and non-vectored lines, when there is no management. The data rate of the legacy VDSL2 lines is shown in parenthesis, under the label.
5. Same as point 4 above, but with DSM used to optimize data rate of both vectored and non-vectored lines.
6. Same as point 5 above, for the case when vectored lines are set to operate a target of 100 Mbps. In this case, legacy VDSL2 lines can operate at much higher speed.

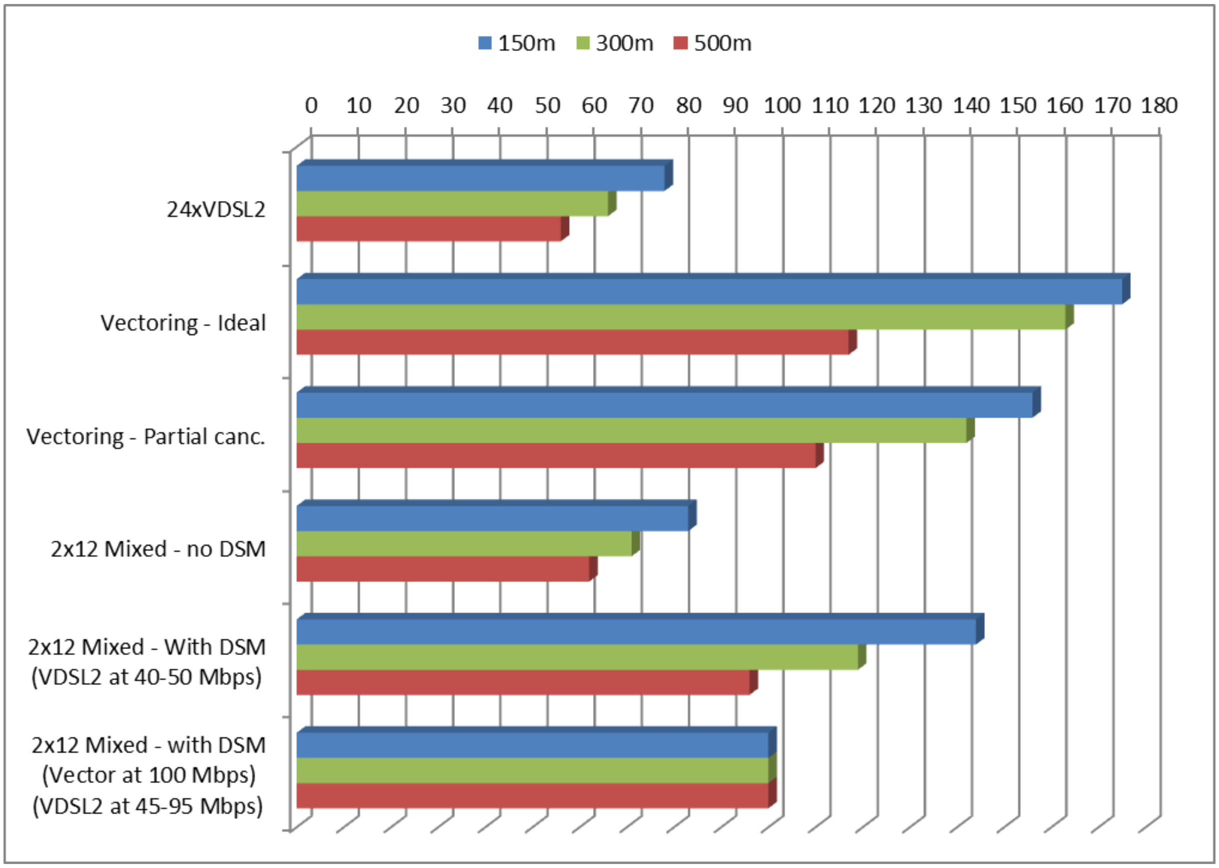

Figure 3: Simulation results for mixed vectored and non-vectored lines. AWG 26 pairs, Profile 17a, and ATIS MIMO model.

The top three bars in Figure 3 clearly show that vectoring can at least double the data rate of densely deployed VDSL2. However, the fourth bar also shows that unmanaged crosstalk from legacy lines can basically void nearly all vectoring gains. With Smart Vectoring, DSM is used to manage this crosstalk so that nearly all vectoring gains are restored, while legacy VDSL2 lines can still be managed to operate at speeds that are seldom delivered over today's copper network. Note that these results could have not been achieved via hardware-based solutions since those solutions solve only a small subset of the mixed cases that can be found in the field (see the limitations mentioned in section 4.1).

In summary, Smart Vectoring DSM-based management software empowers service providers with a complete solution that allows them to start deploying vectoring today—and without the need for special hardware equipment or regulatory intervention.

5.2.2 Virtual unbundling

In a number of countries, the adopted regulatory model is based on virtual unbundling that establishes a single owner (wholesaler) for the copper network, and allows competitive service providers (resellers) to deliver services over the wholesaler's network,

Performance monitoring and line configuration are generally supported through management interfaces to a DSLAM. Under virtual unbundling, only the wholesaler has access to the DSLAM and so the wholesaler must completely define the network operating conditions and the management capabilities available to resellers. The questions that naturally arise under virtual unbundling are how can resellers differentiate their services, and how can they leverage previous investments in management tools?

In many cases, resellers have already made significant investments in service provisioning and management tools that use information nominally available from standardized management interfaces. Service providers must continue to use these tools even with virtual unbundling to avoid depending solely on the wholesaler's management platform. This effectively empowers resellers to achieve a level of service differentiation that current implementations of virtual unbundling do not permit.

Smart Vectoring includes multi-tenant management software that allows the wholesaler to provide resellers with a degree of control of their lines that is similar to that achieved when taking over the physical line to the customer. This is a typical win-win scenario as the wholesaler provides a valuable service to resellers at a fee, and the resellers are able to differentiate their services and leverage previous investments in service provisioning and management tools.

5.3 Continuous and automatic optimization of line performance

Smart Vectoring leverages DSL Expresse to ensure that vectored DSL delivers the highest possible performance level on each line in a stable manner. The DSL Expresse Profile Optimization module algorithms select the most suitable settings for the vectored DSL to maximize rates and stability. These settings include parameters for vectoring operation, and for selecting the optimal noise mitigation strategy. With such automated, dynamic management, the number of vectored lines experiencing poor quality can be significantly reduced.

Noise mitigation strategies for coping with instability are based on the use of forward error correction (FEC) plus interleaving or retransmission. FEC introduces redundant bytes that allow error correction, and interleaving reorders the data to convert burst errors caused by impulse noise into isolated errors, which allows the FEC to perform better. Thus, the protection provided by FEC and interleaving comes at the cost of reduced throughput (due to the transmission of redundant data) and latency (due to the operation of reordering). This cost is incurred all the time, even if the line experiences no alien noise. Therefore, FEC/interleaving is ideally suited for frequent and brief noise bursts, brief enough so the data reordering done by the interleaver allows the FEC to effectively correct errors that are sufficiently spread apart.

In retransmission, data are grouped together in retransmission packets, and when such a packet is correctly received, an acknowledgement is sent to the transmitter. If no acknowledgement is received by the transmitter for a certain packet, then that packet is retransmitted. This error recovery approach only generates an overhead (the retransmitted packet) when a fault actually occurs on the line. Therefore, a line experiences throughput degradation only for the duration of the noise bursts as the cost of protection is paid as needed. For this reason, retransmission is ideal for long noise bursts occurring relatively infrequently.

The treatment of the disruptions caused by alien noise requires management algorithms that appropriately configure each line for impulse noise protection, judiciously choosing between

FEC/interleaving and retransmission and wisely applying the correct configuration parameters for those schemes.

As an example, Figure 4 shows the results of automatic re-profiling in a commercial network with existing DSL equipment. Downstream rates are shown on the left. Stability appears on the right, and is defined by a combination of code violations in a 15-minute period, and modem retrains in a 12-hour period. The light and dark blue stability categories are suitable for real-time applications such as IPTV and femto/small cell backhauling. In these real-life results, ASSIA DSL Expresse increased the fraction of users that could receive speeds in excess of 10 Mbps from roughly 5 percent of the network to nearly 60 percent of the network. At the same time, the fraction of users with poor quality IPTV services was reduced by nearly 75 percent, from 37 percent of the network to 9 percent. This capability becomes vital with vectoring because of its higher sensitivity to impulse noise and other time-varying noises that can cause line instability. And reducing instability translates into reduced operating expenses and extended rate reach.

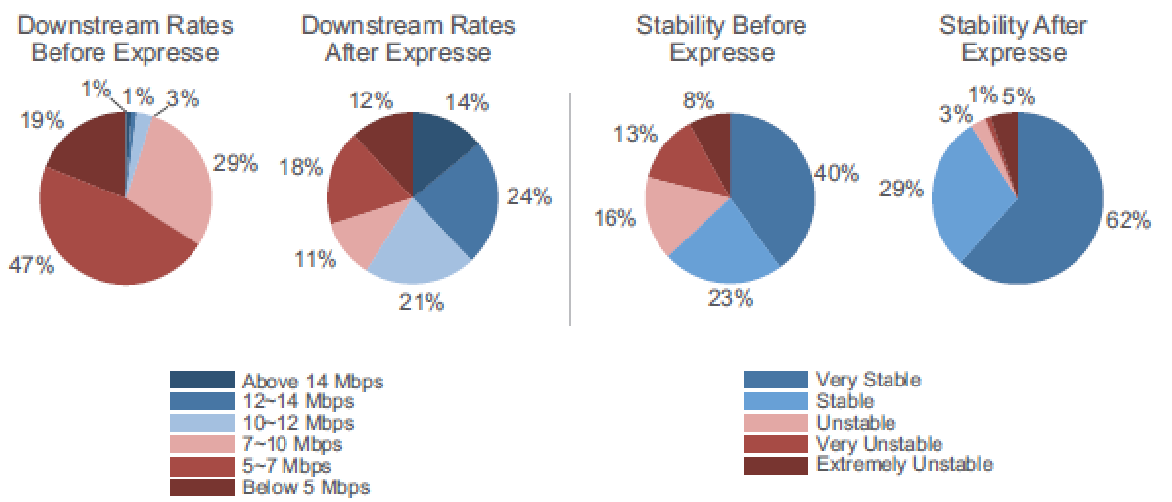

Figure 4: Field results on the effectiveness of DSL Expresse

DSL Expresse also provides further guidance through vectoring diagnostics that address lines experiencing quality issues even after profile optimization. Taking advantage of new data parameters reported by vectored DSLs, diagnostic algorithms accurately identify line faults and can often point directly to the underlying cause.

The underlying philosophy of DSL Expresse is to provide a proactive optimization of DSLs rather than a purely reactive one, as most other tools on the market that allow service providers to take action only after the customer has already complained. Although DSL Expresse is run proactively on all lines in an operator’s network on a daily basis, it can also be run reactively in the case of newly provisioned lines, or at the request of technical or customer support personnel. The same approach is followed by Smart Vectoring which fully leverages the features of DSL Expresse.

Smart Vectoring management makes very good financial sense for a service provider. Based on ASSIA's rich experience, the gains from management will actually be even larger with vectored services. There are three categories of financials gains that are the most prominent:

a) **Reduction of churn rate for vectored services**. Smart Vectoring management raises customer satisfaction with vectored services and hence reduces churn. This is achieved by reliably delivering promised service levels, proactively identifying issues and correcting them even before the consumer notices, and equipping call centers and field teams with the right tools to quickly resolve issues

b) **Enabling a multivendor sourcing strategy**. Smart Vectoring delivers a multivendor management platform that helps service providers avoid vendor lock-in. This platform enables service providers to compare equipment performance by vendor. It also delivers the highest possible optimization results on all lines, regardless of the underlying equipment type. In essence, it provides a way to manage the network independently of equipment brands.

c) **Reduction of operating expenditures for vectoring services**. Smart Vectoring reduces the load on call-center and technician teams, and can also improve the efficiency of such teams. Both call and dispatch rates are reduced with proactive optimization. Tools delivering clear guidance to call centers help lower false dispatches, and call time. Recommended actions delivered to technicians reduce the amount of technician time spent per ticket.

5.4 Support for self-install

Operators are very interested in facilitating Customer Self Install (CSI) as much as possible, especially as a means to lower total installation cost and reduce customer inconvenience. The methodologies used for supporting CSI for ADSL/ADSL2+ can help when transitioning to VDSL2/vectored VDSL2, but they are not enough for ensuring a high level of success with CSI. Additional techniques must be introduced for coping with a more complex technology which is susceptible to more impairments than older DSL technologies. The ultimate challenge is not only to achieve a high CSI success rate, but also to make sure that CSI yields to a QoS as good as the one obtained via professional installation.

ASSIA products provide support for CSI by leveraging both centralized management and direct customer support. Centralized management is essential in identifying lines that would be good candidates for CSI, for instance by looking at historical data on stability, data rates, QoS, neighborhood information. ASSIA support for CSI starts with line pre-qualification and before shipping hardware to customer. When upgrading service to VDSL2 or vectored VDSL2, historical data is essential for an assessment of whether a line would be a good candidate for CSI. When pre-qualification and remote automatic optimization fail, customer involvement may be necessary and it should always be leveraged before resorting to a truck roll.

CSI is a multi-step process:

- Prequalification (performing one-sided diagnostics, leveraging historical data on stability, data rate, and QoS) is key to a good prediction of CSI success likelihood. When new service is being provisioned, pre-qualification can still be performed using neighborhood information – often faults are correlated across neighboring lines;

- Once the CPE is in place, then advanced management performs additional troubleshooting and link optimization;
    - Detecting whether the CPE is the problem;
    - Exploiting, when available, special functionalities (conditioning and diagnostics) of the CPE or the residential gateway;
    - Automatically optimizing the link using DSM techniques if the connection has low QoS.

If CSI still fails or underperforms, it is then important to involve the customer and guide him in performing some simple tasks. If CSI is troublesome and the customer installs the CPE but QoS problems arise (e.g. instability, lower than expected data rate, high count of errors), then a customer can be guided to correct the issue before a technician dispatch is considered. ASSIA DSL Expresse management software is an essential tool for performing real-time analysis to direct the customer to perform simple tasks such as installing/replacing a micro-filter, or changing the location of the CPE. If a residential gateway is available and the home network is up and running, then troubleshooting can be applied on all the home network devices, as sometimes it is a configuration issue that prevents a home network from functioning at its best.

In the more severe cases when connectivity issues arise and the CPE does not connect to the DSLAM, then ASSIA's approach is to empower the consumer with smart and easy-to-use on-demand diagnostic tools that generate actionable recommendations, and exploit alternative paths to send on-site diagnostics data to ASSIA's management server.

For a detailed business case for **Smart Vectoring** and other additional information, please visit www.assia-inc.com/smartvectoring or contact info@assia-inc.com.