# Advanced DSL Management

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## ABSTRACT

Today's digital subscriber line deployments are often conservatively engineered to function in a statistically worst case environment. Crosstalk is treated as unknown and uncontrollable random noise, even though it is manmade. Other impairments are often treated by simply adding margin to crosstalk. While this simplistic practice currently suffices, it often provisions unnecessarily low bit rates. This article shows methods that can increase these bit rates and decrease DSL failure rates. Data can be collected about individual telephone lines and cables from loop databases, by automated test equipment, or from DSL modems. This data may then be fed into an advanced DSL management system with a database of DSL loop and noise characteristics, and an analysis engine that tailors DSL deployments to the actual individual line characteristics, to increase provisioned DSL bitrates while simultaneously increasing reliability and lowering maintenance costs. The maximum service can be provisioned with high accuracy, eliminating many service activation failures. Automated maintenance routines can even isolate faults before a customer experiences them. Dynamic spectrum management (DSM) treats crosstalk as the manmade noise it is, and jointly optimizes DSL transmit spectra and signals to minimize crosstalk *and* maximize received signals, allowing substantially higher DSL speeds than current practice. This opens the door for new services, including symmetric enterprise services and full video service, with minimal physical plant upgrade.

## INTRODUCTION

Digital subscriber lines (DSL) transmit over ordinary copper twisted-pair telephone loops at high frequencies (up to several megahertz) to provide broadband digital services. These loops were engineered for plain old telephone service (POTS) below 4 kHz, and their properties vary widely at high frequencies. Current DSL deployments assume a statistically worst case scenario. This approach can be improved in the future, both because it is conservative, and because it somewhat inaccurately lumps many problems together making diagnoses difficult.

There are many impairments to DSL transmission [1], with loop loss and crosstalk first and foremost. DSL signals are attenuated and distorted by transmission through the loop, particularly at high frequencies and on loops with bridged tap. Some of the power of a DSL transmitting on a loop travels through a crosstalk coupling path and generates crosstalk noise into other DSLs on loops in the same cable. There are also radio ingress and impulse noises, which are sometimes worse than crosstalk. Electromagnetic interference (EMI) due to radio ingress appears as narrowband noise spikes in the frequency domain, and impulse noise occurs as brief spikes in the time domain. All these impairments vary in severity by tens of decibels from loop to loop.

The attenuation and distortion of a loop is readily calculated if the loop make up (including gauge types, bridged taps, and cable section lengths) is known [1]. This then allows precise calculation of the received DSL signal, since the transmitted signal is known. Then if the received noise is known or measured as a function of frequency, the DSL's bit rate and performance level can be precisely and unambiguously calculated [2]. This data can be gleaned from databases, measurements, and by querying DSL modems. Analyses can vary the loop make-up and noise components to determine their individual impact and debug the DSL line. This knowledge allows high precision in DSL provisioning, service assurance, and automated maintenance, avoiding many expensive unanticipated field failures.

Advanced DSL management combines gathering and storing data about DSL frequencies with analyses of this data to deploy and maintain DSL. It has the potential for dramatic increases in DSL performance, and is a compelling way to manage the telephone plant as it transitions to digital services [3, 4]. Rather than throwing extra crosstalk margin at a DSL line to handle most problems, isolating the particular difficulties and handling them properly results in better service and less effort wasted on dealing with provisioning errors. Carrier-grade service may be assured.

Crosstalk is created by DSL lines coupling into each other, and dynamic spectrum management (DSM) [1, 4, 5] can balance multiple DSL signals, minimize crosstalk, and jointly optimize

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the loop plant. Using DSM and deploying wider-band DSL types such as ADSL2+ and enhanced G.shdsl can increase DSL bit rates by a factor of two or three. And this is on the same loops, with no plant upgrades. DSM is a key part of advanced DSL management that can greatly increase DSL speeds, opening the door for new services such as 10 Mb/s business service or video.

Advanced DSL management may be particularly useful for competitively upgrading the North American loop plant, which has relatively old and long copper loops. While some aspects of advanced DSL management are already happening, this article advocates a complete picture of advanced DSL management, including DSM.

## Current DSL Provisioning

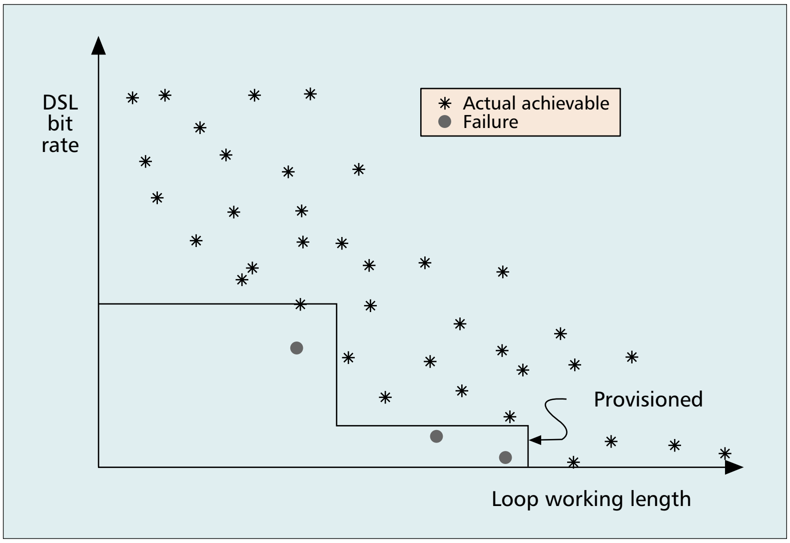
DSL is a relatively new service from the local exchange carriers (LECs). Current practice assumes that there is little knowledge about a particular loop's transmission parameters except a rough estimate of loop length. All DSL services must withstand a statistical worst case environment [1], assuming 99 percent worst case crosstalk couplings that are only exceeded on 1 percent of cables, and binders filled with the worst case types of crosstalkers. This conservative practice denies some customers DSL service who could have otherwise gotten it (false negatives) [3], in order to achieve a low number of expensive unexpected failures (false positives). However, it fails to completely eliminate false positives, since it does not account for the many different factors that can cause failures such as high levels of radio ingress or impulse noise. Worse, many DSLs are set to transmit higher power than necessary, creating unnecessarily high levels of crosstalk, instead of responding properly to the actual impairments on each particular loop.

DSL lines are typically maintained by using tests developed for POTS lines, which ignore frequencies above 4 kHz. DSL lines that fail because of the environment at high frequencies can sometimes be repaired by knowledgeable technicians with expensive manual tests, or the DSL service may simply be abandoned.

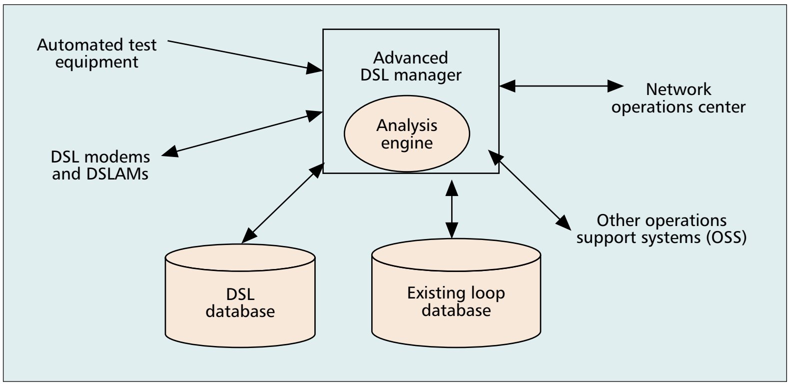
Figure 1 illustrates typical current DSL provisioning. The loop working length determines if a customer can get high rate service (~ 1.5 Mb/s), low rate service (~ 400 kb/s), or no service. Telephone loops vary considerably at high frequencies, with noise and crosstalk levels typically differing by 20 dB or more on different loops. The achievable bit rates that could be offered to customers are usually significantly higher than those currently provisioned. Moreover, some unexpected service failures are inevitable. DSL modems do self-adapt to their loop, for example by lowering the bit rate if need be. But this doesn't give a service provider much specific information or control.

## A Vision of Advanced DSL Management

Advanced DSL management measures the loop, crosstalk couplings, and received noise on an individual basis. The measurements can identify pairs with crosstalk and noise well below the worst case, and systems on these pairs may transmit at higher bit rates or over longer distances than current practice. Failures may be predicted and stopped before they ever occur.




■ **Figure 1.** *A conceptual view of current practice for provisioning DSL.*




■ **Figure 2.** *Infrastructure components of advanced DSL management.*

Properties of most copper loops are generally time invariant, so they can be measured at DSL frequencies and stored in a database. Such a database allows DSL service provisioning with high accuracy, relatively easy diagnosis of failures, and opens the door for future joint optimization of multiple DSLs and controlling crosstalk. Advanced DSL management can lower the cost of DSL provisioning and maintenance, while also providing a platform for future services.

Some infrastructure is needed for advanced DSL management, as shown in Fig. 2. Data may be collected by installing automated test equipment in the central office (CO), or extracted from DSL modems and DSL access multiplexers (DSLAMs) that may need upgrading. There should be communications paths from the DSLAMs to a station that can access the database and analysis engine, as well as communications with existing software systems and databases. The DSL database will need to be populated and maintained. There is a cost for this. However, it can be shared over the many lines in a CO, and it should be

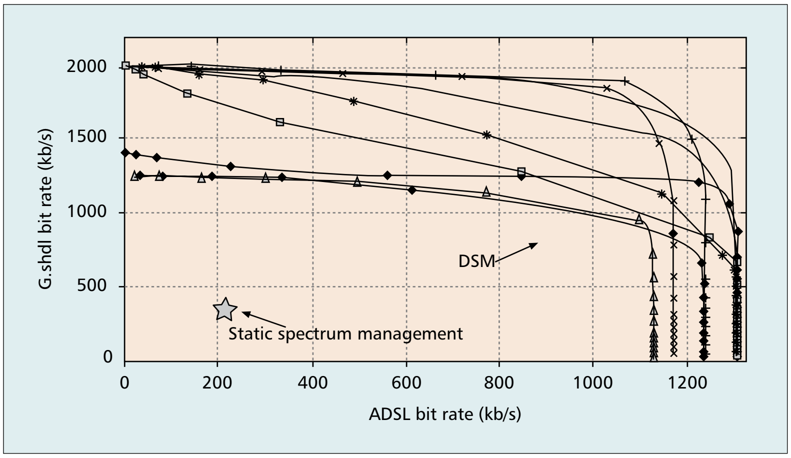



**Figure 3.** *Downstream ADSL and G.shdsl bit rates as ADSL and G.shdsl transmit power varies; 18,000 ft 26 gauge loop with four ADSLs and four G.shdsls. Different curves have different measured crosstalk couplings. The gray star is with worst case crosstalk couplings and full transmit power.*

considerably less costly than a brute force manual upgrade of the outside plant. Adding communications and knitting it together with intelligent algorithms and control creates a management system that is a "force multiplier," leveraging the existing copper loop plant and outside plant maintenance craft forces to obtain precise control over facilities and services.

## Crosstalk: Static vs. Dynamic Spectrum Management

Crosstalk is noise induced by electric and magnetic coupling of signals between nearby twisted pair loops in the same cable. Crosstalk is often the dominant impairment to DSL transmission. Crosstalk varies because there may be different types of crosstalk sources (ADSL, T1 lines, E1 lines, G.shdsl at different bit rates, etc.), different numbers of crosstalkers, and different crosstalk couplings between loops.

### Static Spectrum Management: Worst Case Crosstalk

Current spectrum management rules [6], called *static spectrum management*, engineer DSL to withstand the highest possible number of crosstalkers (i.e., 24 in a 25 pair cable) of the worst possible source type in a cable with worst case crosstalk couplings. This is appropriate in the early days of DSL when there is no detailed knowledge of the individual environment, since systems can only be ensured to work if they can withstand the worst possible case. However, this has often been questioned as overly conservative. To counter, it has been shown that predictions assuming worst case crosstalk are often comparable to actual field performance [7]. But performance in the field may be limited by a myriad of impairments including radio ingress, impulse noise, and temperature. This practice of treating all impairments as though they are crosstalk lacks accuracy.

### Dynamic Spectrum Management

Dynamic spectrum management [1, 4] incorporates parameters of the loop plant environment and loop transmission systems that are time- or situation-dependent, particularly individual crosstalk sources and couplings. DSM is currently being studied in American DSL access standards committee working group T1E1.4. Much DSM work on DSM has been performed by Professor John Cioffi and others at Stanford University [4].

Measurements of pair-to-pair near-end crosstalk (NEXT) loss [1] show substantial variation, with an 11 dB standard deviation. Actual crosstalk couplings vary substantially with frequency and are often 20–30 dB below the worst case model assumed in static spectrum management [6].

Rather than always assume worst case crosstalk, DSM is tailored to the crosstalk couplings and crosstalk sources in an individual cable binder, allowing DSL to provide the highest possible service rates while ensuring spectral compatibility. Loops that are identified to have low crosstalk coupling may carry higher bit rates than the worst case. Also, many DSLs can lower their transmit power substantially without degrading their own quality of service, lowering the crosstalk into other DSLs and allowing higher service levels for them. This leads to an overall joint optimization of multiple DSL transmit spectra, which lowers crosstalk and can typically increase bit rates by a factor of two or three [4] on long loops with existing DSLs, or on shorter loops using wider bandwidths. A sample of DSM simulation results [5] is in Fig. 3. Here the spectra were iteratively optimized jointly for many different transmit power levels of four G.shdsls and four ADSLs using measured crosstalk in the same cable binder. The reference bit rates with 1 percent worst case crosstalk (gray star) were 397 kb/s for G.shdsl and 230 kb/s for downstream ADSL. Allowing DSLs to adapt individually can lead to better performance than this reference, but this performance is unpredictable without joint knowledge.

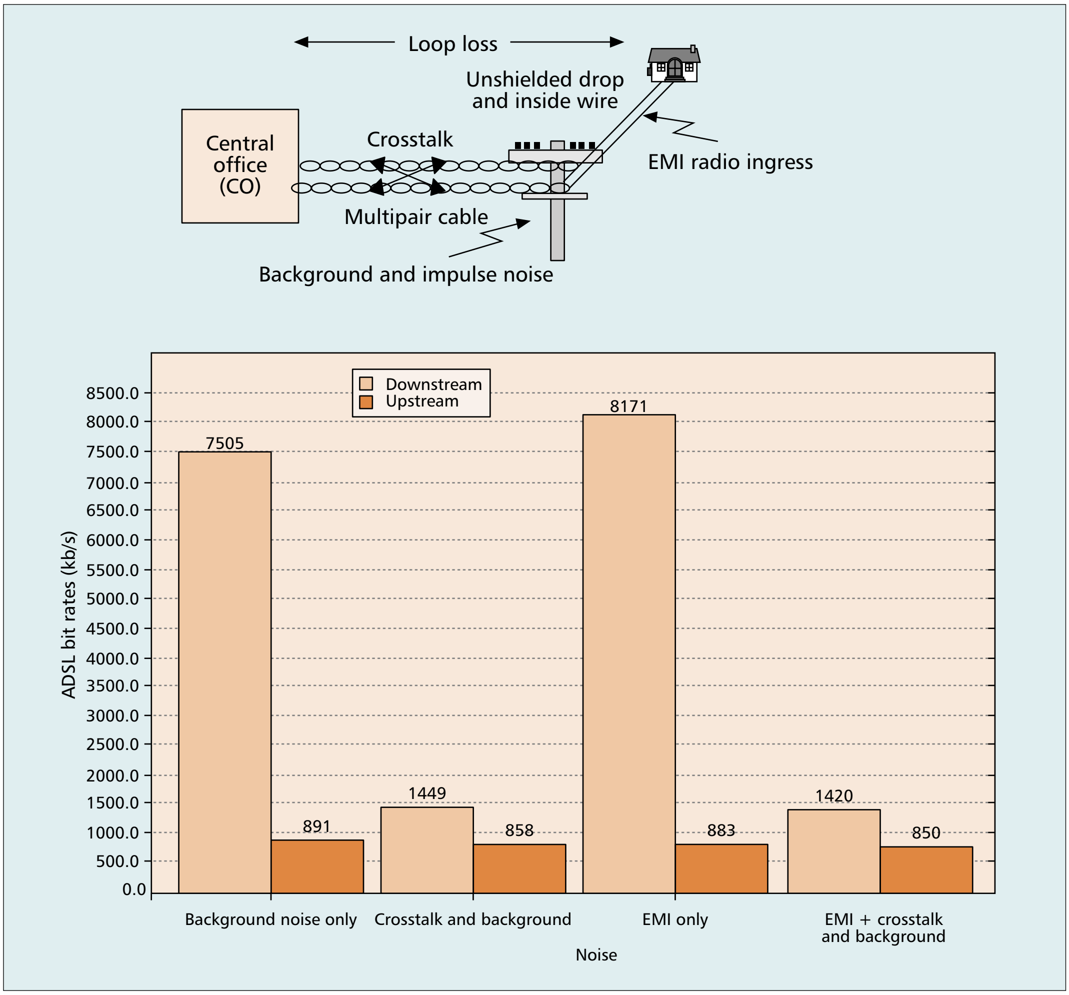
DSM could be administered by a spectrum management center (SMC) associated with a service provider, or with a DSLAM line-up in a wire center (centralized DSM). Or the DSL modems themselves could be allowed to autonomously adapt to their crosstalk environments (autonomous DSM). It may be most advantageous to centrally control some parameters such as overall transmit powers and bandwidth, while allowing other parameters to autonomously adapt, such as the transmitted spectra, with techniques like iterative waterfilling [4, 5]. Bit rates can be monitored and coordinated to determine optimal power levels.

A progression of DSM capabilities has been envisioned [4, 6]:

**Level 0** — No DSM.

**Level 1** — Data rate, and possibly transmit power and margin, are reported and controlled.

**Level 2** — Received signal and noise spectra are reported, and the transmitted power spectra are controlled.




■ **Figure 4.** *DSL impairments. ADSL bit rates were calculated on a measured 9008 ft loop with 9 dB margin and –140 dBm/Hz background noise. The dominant noise on this loop is seen to be crosstalk.*

*The response of a loop is easily determined with a double ended measurement with equipment at both CO and customer ends. Or the loop response may be inferred from a single-ended measurement.*

**Level 3** — Signals and noise are reported, and transmit signals are controlled in real time, allowing multi-user time-varying vectored signals [5].

Various aspects of all these DSM levels are implemented in some current systems. More detail on DSM can be found in [4, 5].

## Diagnosing DSL Impairments

Flashy high speeds and fast new services are ultimately desirable, but lower costs, faster and more accurate provisioning, and better service assurance are needed now. Many of the conceptually simple bugs that plagued early DSL service offerings have been worked out, but fundamental loop transmission impairments have not disappeared.

### DSL Impairments

Figure 4 illustrates DSL impairments [1], which are mainly loop and bridged tap loss, crosstalk, electromagnetic interference (EMI) radio ingress, impulse noise, and background noise. Although often overshadowed by crosstalk, measurements have found many locations with high enough levels of radio ingress or impulse noise to halt DSL service if not handled properly. Crosstalk occurs in multipair shielded cables; radio ingress couples into unshielded drop and inside wire. Impulse noise can be measured by long-term (an hour or more) monitoring of raw bit errors. Background noise is typically low-level additive Gaussian noise. Other measurements are briefly discussed next.

### Loop Identification, Loop Loss, and Bridged Tap

The response of a loop is easily determined with a double-ended measurement with equipment at both CO and customer ends. Or the loop response may be inferred from a single-ended measurement of one-port parameters in the frequency domain [8].

Single-ended loop measurements using enhanced time-domain reflectometer (TDR) techniques [9] can even determine the loop makeup "stick diagram" showing the lengths and gauges of all sections, including bridged tap. A loop identification was performed using measurements of 19 loops at a wire center, with each loop picked to have working length such that 5 percent, 10 percent, …, 95 percent of all loops at the wire center were shorter. The difference in downstream ADSL bit rates with the actual

| Impairment | Identification | Plant remediation | Electronic remediation |
|---|---|---|---|
| Bridged tap | Identify loop makeup, calculate performance with and without bridged tap | Remove bridged tap | Reallocate spectral power away from bridged tap nulls |
| Crosstalk | Calculate performance with and without crosstalk; identify crosstalker types and powers | Swap pairs | Lower crosstalker's power; implement DSM, perform joint DSL spectral optimization |
| Electromagnetic interference (EMI) radio ingress | Identify EMI power; calculate performance with and without EMI | Upgrade drop and/or inside wire | Window DMT signals; implement EMI cancellation |
| Impulse noise | Long-term (hours) error monitoring | Upgrade inside wire | Increase interleaver depth |

**Table 1.** *An outline of DSL impairments, their identification, and possible remediation.*

loops, and the estimated loops (including bridged taps, gauges, etc.) were calculated. All but two of the 19 estimated bit rates were within 3 percent of the actual bit rates, with only one off by more than 10 percent.

### Crosstalk Identification

Different types of crosstalk sources (HDSL, ADSL, T1 lines, etc.) have different transmit spectra, so they may be identified from the crosstalk spectra received on a loop [10]. A single high-power crosstalker can almost always be identified, multiple low-power crosstalkers are more difficult. The crosstalk coupling can then be estimated. Crosstalk couplings can also be identified directly in the time domain by accessing transmitter and receiver sequences simultaneously, or at a single receiver receiving known sequences such as sync symbols [11].

### EMI Radio Ingress Identification

EMI, also called radio ingress, is radio signals coupling into unshielded drop and inside wiring. AM radio ingress is common from 535–1605 kHz, with short-wave broadcast, amateur radio (HAM), and other signals at higher frequencies. Radio ingress is generally narrowband spikes in the frequency domain that can be separated from the broader and more continuous crosstalk and background noise spectra. Then the power and impact of the radio ingress can be calculated.

### The DSL Analysis Engine

At the heart of advanced DSL management are models and routines for analyzing DSL transmission that have been finely honed over the last couple of decades to accurately determine margins, bit rates, and other performance measures of any type of DSL. This accuracy is greatly aided by the fact that copper loops are largely time-invariant (temperature variations can change loop attenuation by a few decibels, but this is easily modeled). Standards-based models of DSL performance [2, 6] can be tweaked to closely match the performance of actual DSL equipment. Measured noise and loop responses can be input for the most accurate analysis, or certain elements can assume typical model parameters.

The received DSL signal is determined by the loop, and the received noise can be broken down into crosstalk and background noise, EMI radio ingress, and impulse noise. Furthermore, algorithms can identify the individual sources of crosstalk [10, 11]. The routines can input individual noise components to determine their impact, as shown in Fig. 4. Many parameters such as power and bandwidth can be varied.

### Remediation

Using the analysis engine, the impact of each constituent noise component can be determined, and the major trouble can be identified. The type of remediation is then narrowed to a short list, as outlined in Table 1. The potential improvement offered by each type of remediation can be calculated to see what makes sense on a given loop. For example, the effectiveness of removing bridged tap from the loop can be determined.

*Electronic remediation* could be implemented from a central maintenance station or even implemented automatically. Determining the proper remediation through analysis is more cost effective than actually performing multiple fixes until the right one is found. If it is determined that signals transmitted over the measured loop and received with only background noise can at best achieve poor performance, this can be noted rather than wasting effort trying to fix an unfixable situation. Loop information can be stored in a database so that repeat troubles can easily be identified and fixed the next time they occur.

## Data Collection

A major component of advanced DSL management is a database of loop information for DSL provisioning and maintenance. This database is envisioned as having a wealth of information on loops, noise, and the histories of deployed DSLs extending far beyond existing loop databases; all of it invaluable for maintaining or deploying new DSL services. It would store loop makeups or loop responses, data on deployed DSLs, binder information, measured noise, information on crosstalk between lines, and so on. In order to populate such a database, data must be gathered. There are three sources for this information: existing loop and DSL databases, measurements from dedicated DSL test equipment, and data from DSL modems or DSLAMs.

### Database Mining

Existing loop plant databases contain information on loop makeups and deployed services [3]. These databases are traditionally used to provision POTS service. An example of such a database is the Loop Facilities Assignment and Control System (LFACS), which stores a view of the loop plant for the regional Bell operating companies. The service and physical loop-related information in these databases may be usefully mined for DSL loop qualification. For example, loops need to be disqualified for DSL if they are loaded, or if they are served by only narrowband digital loop carrier. This service-related information is available in LFACS, and is uniquely useful for determining a significant percentage of the causes that disqualify loops for DSL.

For some percentage of loops, the complete loop makeup may not be available in the loop plant database. Usually the loop makeup was manually determined and entered into the database. But in some cases, the loop makeup is incomplete, out of date, or absent. An ideal DSL qualification engine would combine service-related parameters and whatever loop makeup data is available from the existing loop plant database with automated test or DSL modem data.

### Automated Test

The Mechanized Loop Testing (MLT) system uses a metallic test bus and relays to allow switched access to any loop connected to an end office switch in a CO. A given subscriber loop can briefly be taken out of service and metallically connected to a central test head where single-ended measurements are made on the customer's loop. Many loops can be automatically tested in one night. Current test heads run a battery of tests aimed at maintaining and diagnosing the customer's narrowband (4 kHz) POTS. These narrowband tests can indicate if a loop is totally defective and give a rough estimate of attenuation, which is somewhat useful for DSL. However, they give no information about noise at DSL frequencies, nor do they determine loop makeups. For this, an upgrade to a broadband test head is needed [3], enabling single-ended measurements such as wideband noise spectra and loop makeups. Also, by accessing two pairs simultaneously, crosstalk couplings could be directly measured.

Dedicated automated test equipment can accurately perform single-ended tests, and may access any loop from the CO. However, this may not be the least expensive solution, since it requires a physical test device in the CO. Also, sometimes attenuation and distortion are introduced by the metallic test bus. A direct connection at a DSLAM, or at dedicated POTS splitter frames, avoids the metallic test bus.

### Extracting Data from DSL Modems

Because telephone loops are highly variable at high frequencies, DSL modems are adaptive and inherently "learn" the channel response and noise within their bandwidth. Data from DSL modems is double-ended, with upstream and downstream noise data, at both the CO and the customer end. Data on multiple DSL lines may be retrieved by querying a DSLAM at a CO.

ADSL modems use discrete multitone modulation (DMT) to subdivide the 1.1 MHz channel into 255 narrowband (4.3125 kHz) channels. Receivers must know the received signal power and signal-to-noise ratio (SNR) of each tone, and since the transmit signal is known, the loop magnitude response and noise power spectrum are known with fine granularity. These spectra can similarly be deduced from the gain control, equalizer coefficients, and adaptation statistics in single-carrier transceivers.

The DSL Forum has specified a management information base (MIB) with elements that reflect details of an ADSL channel, including bit loading, SNR of each tone, and attenuation of each tone. Many existing ADSLs can report this MIB data.

Existing ADSL MIB data [12] comes in different formats and sometimes lacks accuracy. New ADSL2 — International Telecommunication Union (ITU) G.992.3 and G.992.4 — modems must be capable of reporting power spectra with specified accuracy: transfer function $H(f)$, quiet line noise $QLN(f)$, and $SNR(f)$. Aggregate parameters are also reported: loop attenuation, signal attenuation, SNR margin, attainable net data rate, and aggregate transmit power (far-end). Loop data can be garnered in *initialization mode*, using standard ADSL training, or *diagnostics mode* can be invoked on demand and run single-ended. Additionally, ADSL2 modems can control the following parameters: the power transmitted by each tone, bit loading (number of bits and gain on each tone), total transmit power, and minimum/target/maximum bit rate and SNR margin. ADSL2 modems are level 2 DSM compliant as defined earlier.

A new project in ITU-Telecommunications Standardization Sector (ITU-T) SG15 Q4 is single-ended loop test (G.selt). G.selt modems will report single-ended measurements from a single DSL modem before DSL service is activated or analyze DSL lines that are not working. In the future, G.selt modems may measure frequency-dependent impedance, TDR signals, noise spectrum at the CO, impulse noise counts, and so on. This may be done to determine loop length, loop makeup, crosstalker types, crosstalk couplings, radio ingress, impulse noise, linearity, SNR and bit rate capacities, load coils, and other parameters. G.selt modems are likely to provide data to a separate analysis engine, which interfaces with a DSL operations support system (OSS).

## The Bottom Line

Advanced DSL management will take some effort to implement, including populating and maintaining a new database, possibly new CO test equipment, and new ADSL2 or G.selt DSL modems. So, is it worth the effort? This section discusses the cost savings and revenue increases possible through advanced DSL management.

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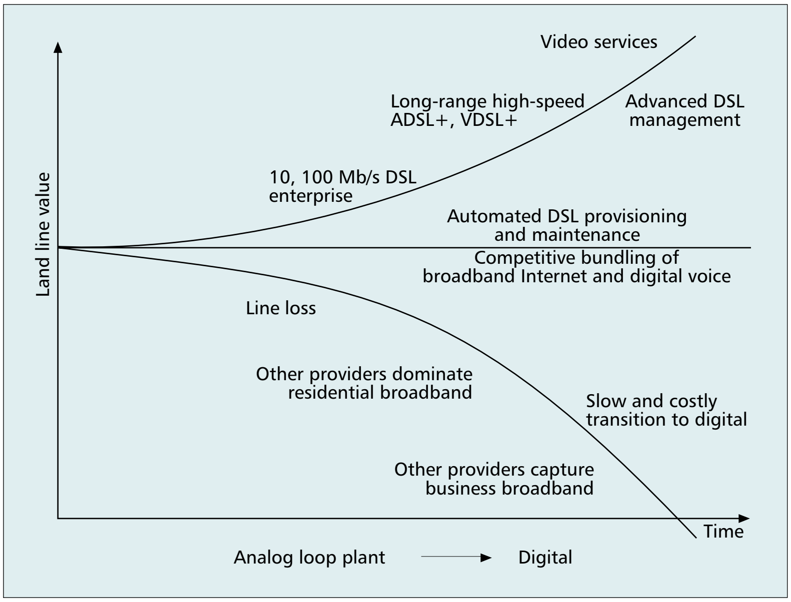


**Figure 5.** *Possible future directions of the telephone plant as it transitions to digital.*

## COST SAVINGS

DSL deployments were initially plagued by myriad relatively simple practical provisioning errors. Many of these have been solved and are now easy to handle; what remain are largely fundamental transmission problems. The combination of loop measurements, a new DSL database, and analysis routines is capable of eliminating most of the remaining unexpected DSL provisioning failures [3]. Precise loop qualification and service activation may be administered from a central station. Truck rolls can be greatly reduced. Unnecessary costs of DSL provisioning could be dramatically decreased.

Significant ongoing maintenance savings are also expected. Advanced DSL management automatically identifies the most costly and difficult to diagnose problems. The element causing a problem can be isolated (loop, noise, modems, etc.). The correct remediation (e.g., remove bridged tap) can be determined analytically before expending effort in the field. The system can help instruct an entry-level technician on what needs to be done before dispatch, or avoid dispatch entirely. Costs should be far less expensive than manual tests, and storing measurement data can avoid rework.

## INCREASED RELIABILITY

Without monitoring a particular DSL line, its environment can only be guessed within some tens of decibels. Impairments discussed earlier can cause a great number of unexpected bit errors. Today's common practice of DSL "set it and forget it" provisioning has resulted in some poorly functioning lines and dissatisfied customers. Advanced DSL management can identify potential problems with most DSL lines before a customer ever sees them, allowing DSL to be a carrier-grade service with solid service level agreement (SLA) guarantees. This can reduce churn, stopping DSL customers from switching to other alternatives such as cable modems, in turn stopping access line loss.

## NEW ENTERPRISE SERVICES

LECs are fighting to defend business services against inroads from new competitors. Increasing DSL service assurance reliability will clearly make it more attractive to businesses. Higher-speed symmetric (same rate in both directions) DSL is also clearly attractive to businesses, and to the increasing number of heavy users of Internet file sharing (music, videos, etc.). This has stimulated much recent interest. The IEEE 802.3ah Ethernet in the First Mile (EFM) committee is finishing a new standard for symmetric DSL. A more optimized new multimegabit DSL ($M^2DSL$) is being worked on in Standards Committee T1E1.4. $M^2DSL$ on longer loops may use multiple pairs that are bonded or "vectored" together with DSM techniques. Advanced management of $M^2DSL$ may lower the number of pairs needed at longer ranges, decreasing costs of creating ubiquitous high-speed symmetric broadband service. There is even work on using DSM techniques to provide 100 Mb/s symmetric DSL out to about 1500 ft [4].

## NEW VIDEO SERVICES

Conventional wisdom since the mid-1990s is that there is "no business plan" for video services from telephone companies. Time does not stand still, and recent conferences and papers are reexamining and promoting DSL video. Advanced DSL management offers a clearly critical means for developing and maintaining a viable platform for video over copper.

Virtually every TV signal exists somewhere in a compressed digital format. Satellite TV services real-time encode video signals at about 3 Mb/s per typical TV channel, with 6–8 Mb/s for sports and about 1.5 Mb/s for animation or talking heads; and all are slowly improving. Some VDSL deployments have provided about three TV channels per customer, switched at the CO and capable of video on demand, to "equal" cable TV. Thus, video service may be provided with downstream rates on the order of 12 Mb/s.

ADSL2+ is an emerging new standard in the ITU that doubles the downstream bandwidth of ADSL to 2.2 MHz, and may use higher-order constellations for high downstream bit rates. Today's ADSL is limited to about 8 Mb/s over 6000 ft. ADSL2+ is not very much better unless it is effectively managed or on a very short loop. Average downstream bit rates of managed ADSL2+ using DSM with three self-crosstalkers were calculated to be 17 Mb/s at 6000 ft, 8 Mb/s at 9500 ft, and 6 Mb/s at 11,000 ft. Video-enabling 12 Mb/s service goes to about 7500 ft, about 50 percent of the North American loop plant served from a CO. Including carrier service area (CSA)-range remote deployments, managed ADSL2+ enables video service to most customers now, with little outside plant investment, at about the same cost as today's ADSL. This contrasts with VDSL deployments having 3000–4000 ft range that sometimes require substantial fiber installation.

## SUMMARY: INVESTMENT JUSTIFIED BY BIG PAYOFF

A coordinated implementation of advanced measurement, database storage, analysis, and control of DSL loop and transmission parameters enables a "force multiplier" effect, leveraging existing copper by adding intelligence, control, and communications. This is less costly than physical plant upgrades, and is complementary as the management system can grow along with plant upgrades. Investment is needed for enabling more data exchange and control with DSL modems, populating and maintaining a DSL database, maybe new test equipment, and implementing an analysis system; but this should be recovered by virtue of savings on DSL provisioning and maintenance costs alone. Additional revenue from new service offerings, such as 10 Mb/s symmetric enterprise service and video services, increases motivation. Customer retention and the ability to effectively address competition is the icing on the cake.

The number of analog POTS access lines may actually be declining now. The future of all communications is clearly digital, and wire-line services should transition to deliver reliable broadband digital service to compete with wireless offerings. DSL is allowing a move in this direction, but it needs to provide more services at lower costs with higher reliability. Figure 5 is a simplistic outline of the transition of the telephone loop plant from analog to digital, with cost decreases from test and management driving the middle curve. Adding DSM and intelligent management will enable higher-speed services, with a level of reliability and cost effectiveness that will profitably leverage the copper loop plant to the upper curve for years to come.

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## BIOGRAPHIES


KENNETH J. KERPEZ (kkerpez@telcordia.com) received his B.S. in electrical engineering from Clarkson University in 1983, and his M. S. and Ph. D. in electrical engineering systems from Cornell University in 1986 and 1989. Since then he has been at Telcordia Technologies, where he initially performed pioneering work on characterizing and coding for HDSL and ADSL. His most recent work is on DSL spectral compatibility and VDSL. He has also worked on wireless, hybrid fiber/coax access systems, and home networking. He is the author of hundreds of technical papers and is a frequent contributor to the T1E1.4 DSL standards committee.

DAVID L. WARING [SM] is a chief scientist at Telcordia Technologies, Inc. He has extensive expertise in access technologies and systems, working with major carriers and equipment suppliers worldwide. He currently leads research into "last mile" local access and broadband customer premises networking technologies, including topics of broadband loop testing, home networking, power line carrier, and free space optical (FSO) systems. He has also performed work for the National Security Agency (NSA) relating to critical infrastructure protection (CIP), and leads a National Institute of Standards and Technology grant program on CIP. He received a B.Sc. degree in electrical engineering from Drexel University in 1977 and an M.Sc. degree in electrical engineering from Georgia Tech in 1978.

STEFANO GALLI (sgalli@research.telcordia.com) received his Ph.D. and M.S. degrees in electrical engineering from the University of Rome "La Sapienza" in 1998 and 1994, respectively. After completing his Ph.D., he continued as a teaching assistant in signal theory in the Information and Communications Department of the University of Rome and, at the same time, he consulted for Italian telecommunications companies. In October 1998 he joined Bellcore (now Telcordia Technologies, an SAIC company) in Morristown, New Jersey, in the Broadband Networking Department where he is now a senior scientist. His main research efforts are devoted to the physical layer analysis of xDSL systems, wireless communications, wireless/wired home networks, power line communications, and optical CDMA. He has published over 50 papers in peer reviewed international journals and conferences, and holds a U.S. patent on loop qualification for DSL services. He also served as a Guest Editor for the *IEEE Communications Magazine* Feature Topic "Broadband Is Power: Internet Access through the Power Line Network," and is currently serving as a member of the Technical Program Committee of VTC Spring 2004.

JAMES DIXON received a B.S. degree (with highest honors) in electrical engineering from Lehigh University, Bethlehem, Pennsylvania, in 1981, and an M.Eng. degree in electrical engineering from Cornell University, Ithaca, New York, in 1982. From 1981 to 1984, he was a member of technical staff at AT&T Bell Laboratories, Whippany, New Jersey, where he was involved in the development and design of digital transmission systems for the local loop. In December 1984 he joined Telcordia Technologies (then Bellcore), Morristown, New Jersey, as a research scientist. His work there has concentrated in the areas of digital signal processing, digital transmission over the local loop plant, and home networking. Most recently, his research interests have been in the area of wireless communications.

PHIROZ H MADON is currently a senior research scientist at Applied Research, Telcordia Technologies, where he has specialized in research on network management for new technologies, prototypes, and innovation. His recent work includes the BellSouth DSL Loop Qualification System, Joint Network Management System (JNMS), TPACS Wireless Network Provisioning System, and research and development of prototype provisioning and service activation systems for satellite networks, DSL networks, and cable modem networks. In the 1990s he was a TIRKS software development manager. In the 1980s he did pioneering work on ATM, AIN, and caller ID services. He has an M.S. in computer science from Rutgers University. He did his Bachelor's in electrical engineering at the Indian Institute of Technology, Bombay.



*Adding DSM and intelligent management will enable higher speed services, with a level of reliability and cost effectiveness that will profitably leverage the copper loop plant for years to come.*