A Primer on ADSL & Interoperability
Introduction to Interoperability

In the simplest of terms, interoperability is a word used to describe a state of two or more devices that interchange information (data, voice, or video). In the context of this paper, we will focus on network devices that implement a physical layer technology called Asymmetric Digital Subscriber Line or ASDL. The concepts in this white paper can be applied to other physical layer technologies or other protocols in Open System Interconnect (OSI) model including applications. For example, figure 1.0 provides a description of the protocols implemented in an end-to-end broadband connection.

It is important to note that although two devices can be connected and claimed to be interoperable, they must be able to achieve their full range of services in the end-to-end connection of information transfer. Specifically, when two devices are connected together at some point in a customer’s network they must allow the customer to support pre-existing and expanded services. They must not negatively or adversely impact current offerings.

![Figure 1.0]
The History of ADSL

In the early 1980's, research of a Digital Subscriber Line (DSL) to provide access to the Integrated Service Digital Network (ISDN) was initiated. The objective was to provide an efficient transmission system covering all non-loaded telephone loops. Using advanced digital signal processing techniques, DSL needed to have much higher efficiency as compared to existing transmission systems such as T1 or DDS. The environment of the existing telephone loop plant was investigated, and statistical data surrounding loop composition and serving distance was collected. Next, loop primary constants were measured for construction of channel models and an empirical Near End Crosstalk (NEXT) model was established.

The transmission throughput of DSL for ISDN Basic Access channel was defined to carry 2 B and 1 D channels. The transmission throughput including overhead was 160 kbps. Different modulation and line codes were proposed and corresponding performance results were compared using computer simulation based on developed channel and Near End Cross Talk (NEXT) models. There were proposals for time duplex, frequency duplex, and echo cancellation based duplex schemes. There were also different line codes, such as NRZ, 2B1Q, etc. After much study and debate, mainly through the T1E1.4 standards committee, the echo cancellation-based 2B1Q line code was selected for ISDN's DSL.

In the late 1980's after wrapping up the DSL standards, the industry felt that the semiconductor technologies and digital signal processing techniques could provide an even higher transmission throughput for shorter loops. The project was named High-bit-rate Digital Subscriber Lines (HDSL). It was defined as a Carrier Serving Area (CSA) range repeaterless T1 technology using a dual duplex system with two twisted pairs for full duplex T1 throughput. Finally, it also implemented an echo cancellation-based 2B1Q line code. The transmission rate was defined to be five times that of DSL.

In the early 1990's, Joe Lechleider (Bellcore) realized that the transmission throughput of DSL could be further improved if the effect of NEXT could be avoided. He also observed that, at least for video on demand services, the transmission throughput could be asymmetrical. Subscribers received lots of information from the CO but only sent back control signals. Subsequently, he proposed the idea of a frequency division duplex ADSL that had an upstream channel located above the Plain Old Telephone System (POTS at 4 Khz.) and a downstream channel located above the upstream channel. As a result, with splitters the POTS channel could remain intact.

Industry participants completed many computer simulations. It was discovered that up to 7 Mbps could be achieved in the downstream direction based on various transmission environments. This transmission throughput could accommodate up to 4 MPEG compressed video channels. QAM,
Carrierless AM/PM (CAP), and Discrete Multi-tone (DMT) line codes were proposed for this passband ADSL system. Simulation and theoretical studies showed their performances were very similar. As a result, ANSI concluded that the selection of the line code would be based on the performance of hardware prototypes.

Three ADSL prototypes were presented for performance evaluation. Among the systems submitted: AT&T for CAP, Bellcore for QAM, and Amati Communications (subsequently acquired by Texas Instruments) for DMT. After testing the different implementations, Bellcore found that the highest performance came from Amati’s DMT echo-cancelled modem. Based on these performance test results, the DMT line code was selected as a basis for line coding in the ADSL standard (now T1.413 issue 2). To accommodate telephony services, DMT ADSL was defined to deliver up to four simplex channels and three duplex channels. The channel structure was flexible and could be negotiated at the initialization of the transceiver. The first complete document of the DMT-based ADSL standard was finished by ANSI in early 1996 and was called T1.413 issue 1.

What is ADSL?

Copper is capable of carrying higher frequency signals (4 kHz to approximately 2 MHz), however, these signals attenuate more rapidly with distance than do signals at voiceband frequencies. Even so, for loop lengths of up to approximately 18,000 feet it is possible to get enough signal strength to carry information bits at the higher frequencies. ADSL uses a guard band to separate the voiceband POTS from ADSL frequencies, as shown in Figure 1.1. This allows POTS and ADSL to co-exist on the same wire.

Additionally, downstream performance is adequate for Video on Demand (VOD) applications where downstream speeds of 1.5 Mbps would suffice for MPEG movies. Subsequent demand for VOD has declined due to lack of immediate need. However, today ADSL has found new life with Internet access. The inherent asymmetry makes it well suited for Web browsing applications, where the downstream content information is likely to require greater bandwidth than upstream requests. The upstream and downstream rates have improved to 640 kbps upstream and approximately 6 Mbps downstream (depending on loop length and loop conditions). As per the ADSL Forum, the following are the range of downstream speeds depending on the distance:

- Up to 18,000 feet 1.544 Mbps
- Up to 16,000 feet 2.048 Mbps
- Up to 12,000 feet 6.312 Mbps
Upstream speeds range from 16 kbps to 640 kbps. Rate adaptation, an improvement over the original specification, allows two DSL modems to adjust the upstream and downstream rates based on the loop conditions. With the need to utilize the local loop for both analog voice and digital data, newer and more efficient line codes were required.

DMT-based ADSL modems can be thought of as 256 “mini-modems,” 4 KHz each, that run simultaneously. DMT uses many carriers that create sub-channels, each sub-channel carries a fraction of the total information. The sub-channels are independently modulated with a carrier frequency corresponding to the center frequency of the sub-channel and processed in parallel. Each sub-channel is modulated using QAM and can carry from 0 to a maximum of 15 bits/symbol/Hertz. The number of actual bits carried per sub-channel depends upon the line characteristics. Certain sub-channels can be left unused due to external interference. For example, an AM radio station causing radio frequency interference in a particular sub-channel can cause that sub-channel to be unused. DMT is illustrated in Figure 1.1.

![Figure 1.1](image)

The theoretical maximum upstream bandwidth is:

\[
25 \text{ channels} \times 15 \text{ bits/symbol/Hz/channel} \times 4 \text{ KHz} = 1.5 \text{ Mbps}
\]

The theoretical maximum downstream bandwidth is:

\[
249 \text{ channels} \times 15 \text{ bits/symbol/Hz/channel} \times 4 \text{ KHz} = 14.9 \text{ Mbps}
\]

However, based on real world applications, typical performance of the downstream rate over various loop lengths and cable gauges can be summarized in the table below:

<table>
<thead>
<tr>
<th>DS Data Rate</th>
<th>Wire Gauge</th>
<th>Distance</th>
<th>Wire Size</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 or 2 Mbps</td>
<td>24 AWG</td>
<td>18,000 ft</td>
<td>0.5 mm</td>
<td>5.5 km</td>
</tr>
<tr>
<td>1.5 or 2 Mbps</td>
<td>26 AWG</td>
<td>15,000 ft</td>
<td>0.4 mm</td>
<td>4.6 km</td>
</tr>
</tbody>
</table>
DMT offers several advantages as the line-coding technique for ADSL. Among them are:

- **Performance**
  
  DMT increases modem performance because independent sub-channels can be manipulated individually with consideration to the line conditions. DMT measures the S/N ratio separately for each sub-channel, and accordingly assigns the number of bits carried by the sub-channel. Typically, the lower frequencies can carry more bits because they are attenuated to a lesser extent than higher frequencies. This procedure increases the overall throughput even under adverse conditions.

- **Robustness to line impairments**
  
  During initialization, DMT monitors the line conditions and computes the bit-carrying capacity of each sub-channel based on its S/N ratio. If a sub-channel is experiencing external interference such as Radio Frequency Interference (RFI) and crosstalk, it may not be used at all in favor of other sub-channels.

- **Rate Adaptation**
  
  DMT can dynamically adapt the data rate to line conditions. Each sub-channel carries a certain number of bits depending on its S/N ratio. By adjusting the number of bits per channel, the DMT can automatically adjust the data rate.

- **Standards-based modulation technique**
  
  DMT is endorsed by all major telecommunications standards bodies including ITU, ANSI, and ETSI.

- **Implemented by many technology providers**
  
  Since DMT is part of the standards process in ANSI and ITU, many technology providers can implement and refine the technology as performance advancements are made.

As a physical layer technology, ADSL can carry a multitude of data link layer protocols. However, the most commonly deployed in today’s network is Asynchronous Transfer Mode (Modulation?) or ATM. This allows higher layer protocols such as IP to be abstracted from the intricacies of the physical medium.

### What is Interoperability?

As discussed, interoperability of products is the ability of two or more systems, when connected together, to function seamlessly. Normally, interoperability is achieved when two different technology providers or system manufactures develop solutions independently to a published specification. In the
In the case of ADSL, the specifications are T1.413 issue 2 and the ITU suite of documents (i.e. 992.1 and 992.2).

**Figure 1.2**

Interoperability from a system perspective is achieved by establishing inter-working on each layer of the OSI model starting from layer 1. For example, two vendors begin the process by establishing a simple "steady-state" ADSL connection. Although the systems can communicate at the lowest level, it does not guarantee the passing of cells from an ATM perspective (at the data link layer) nor does it provide an assurance that performance of the system will be acceptable enough for general deployment of services (i.e. “deployable interoperability”). In emerging markets, technology from the same vendor is usually applied at both ends of the wire to assure the appropriate level of interoperability between end systems. For example, a CPE and DSLAM pair will be developed and marketed together as a coupled system. In addition, both will normally implement the same physical layer technology from the same technology vendor. However, as a market matures, this approach limits consumer options. Therefore, mass adoption of a technology is limited since competitive pressure related to cost and advanced features are not applied.

Today, ADSL technology providers and end system vendors are actively working towards interoperability to ANSI’s T1.413 Issue 2 standard. The T1.413 Issue 2 standard provides a foundation for industry participants to achieve mass adoption and consumer acceptance of vendor differentiated platforms. Although not complete, there has been significant progress towards making “deployable interoperability” a reality. For example, in 1998 Texas Instruments and Alcatel achieved the first interoperability milestone by connecting two ADSL modems together and achieving “steady-state” operation. Both vendors developed their technology independently to the T1.413 standard. Since 1998, TI and Alcatel have expanded their efforts to encompass full system level testing and performance optimization.
Texas Instruments, Cisco Systems, and other manufacturers are working together to ensure that systems can attain “deployable interoperability” once they are made generally available to the market. Interoperability of systems is critical to the success of any given mass market technology because it enables choice on behalf of the customer. Interoperability enables a de-coupling of Customer Premises Equipment (CPE) and infrastructure equipment. Consequently, it allows consumers to purchase solutions in a retail environment that are assured to function once connected to the service provider’s network.

Now, let’s take a look at some of the challenges technology and equipment vendors face when working towards ubiquitous interoperability of broadband solutions.

**ASDL Interoperability Challenges**

There are many challenges that face vendors in attempting to achieve interoperability. Since the adoption of the ADSL T1.413 Issue 1 four years ago, vendors have progressed beyond one of the most difficult challenges toward interoperability, which is a desire to succeed. Vendors have realized the benefit of interoperability for two reasons. First and foremost, the technology is being challenged by a rival residential broadband technology — cable modems. Given current trends, cable modems stand to capture a significant share of the market. Second, Request for Quotations (RFQ’s) and Request for Proposals (RFP’s) issued by service providers regularly containing the requirement for demonstration of interoperability, even the incumbent DSL technology providers can no longer avoid the questions on interoperability. The fear of service providers is that they might invest in a DSL technology provider that can not communicate with any other vendor.

Still, there are other issues that must be faced by vendors which may or may not have been faced depending on the vendor. The following sections address some of these issues and attempt to provide an update on the current position.

**Interpretation of the standards**

The T1.413 Issue 2 standard and the ITU standards (both G.992.1 and G.992.2) have made progress towards clarification of the more ambiguous areas within the T1.413 Issue 1 standard. While a significant part of these clarifications actually came through simplifications such as the elimination of loop-timing at the ATU-C and others, the text in these standards is more precise than in the T1.413 Issue 1 specification. These clarifications to the text were achieved through refinements during the later specification process and via much debate in the T1E1.4 meetings.
Even though there have been significant improvements to the ADSL specifications there are limitations to these standards that were not present in previous telecommunications standards. For example, standards related to technologies such as T1, E1, or ISDN, which were primarily driven by organizations including AT&T and Bellcore, and later adopted by T1E1.4 and the ITU, were written with very precise language using the term "shall" to indicate required functions/features. Optional features in these standards were also clearly indicated that were not present in DSL standards text. In fact, it is extremely difficult to determine which features are optional and which are required in the DSL standards because the mandatory features do not include the term "shall" and the optional features are not clearly identified.

Finally, an area where the ADSL standards are entirely lacking, and where the historical telecommunications standards are clearly superior, is in the area of error recovery. The ADSL standards contain very little text on remedies if errors occur during any state. By contrast, in the ISDN standard, if an optional field in the "bearer capability" information element of a setup message was incorrect, the standard identified exactly what type of recovery action should be taken. However, with regard to this last point, assuming all vendors only send valid messages, one must ask if consistency in error recovery is an important part of interoperability as long as the previous criteria in this paper are achieved. In fact, one can make the argument that the error recovery in the ISDN standards was so extensive that it required greater complexity to implement than the normal valid path.

Before closing the discussion on interpretation, there has been one additional important area where interpretation of the ADSL standards has been significantly improved. This area relates to the private agreements that have been developed between vendors. The announcement between Texas Instruments and Alcatel in July of 1998 was the first such announcement between disparate vendors. This announcement was the result of a cooperative arrangement where both parties interactively worked through the interpretation of the standard with changes being made by both parties. While the details of these changes can not be disclosed based upon this private agreement, this effort ultimately resulted in the two vendors having implementations that formed a baseline for other vendors to begin achieving interoperability. Successes that have been achieved at interoperability events and other private arrangements are largely a result of this early effort.

Who fixes/changes what?

Fixes or changes to a vendor's product as a result of interoperability testing typically relate to either hardware or software. These changes may be required either to improve performance or in some extreme cases to achieve even basic connectivity. To date, there have been surprisingly few disagreements among vendors in the interpretation of the standards and regarding who is responsible for correcting what issue. This could very well be due to the early work done by companies such as
Alcatel and Texas Instruments that worked closely at a mutual understanding of the standards through performing interoperability testing that later was propagated to the rest of the industry. Some of the issues that have been faced during interoperability testing that were quickly brought back in line within one or a number of vendors' products include:

- Improper generation of RACK tones by not supporting the alternating power levels;
- Vendors not honoring the QUIET periods that are negotiated during training that allow an Echo Canceller based modem to operate with a Frequency-Division-Multiplexed (FDM) Modem;
- Vendors not supporting valid combinations of information contained in the R/C-MSGs and RC-RATES messages;
- Vendors having real and imaginary parameters passed to/from the constellation encoder/decoder in the reverse order;
- Vendors not supporting ATM cell alignment on a byte basis;
- Vendors clocking in the ATM cell data bits in the wrong order;
- Vendors not generating compliant signals during training;
- Vendors not supporting the full Reed-Solomon Forward Error Correction (FEC) parameters;
- Vendors not supporting the full Interleaver depth as part of the FEC;
- Vendors not responding with the proper AOC/EOC messages and in some cases not responding at all;
- Vendors not supporting the mandatory bit-swapping capability;
- Vendors performing timing recovery too late in the ATU-Rs training sequence;
- Vendors performing timing recovery too early in the ATU-Cs training sequence.

Surprisingly, even with the number of issues that have been encountered during interoperability testing with various vendors, Texas Instruments and others contend they only have only a single version of software that is interoperable — with no specific conditional branches required for operation with other implementations. This is a strong message indicating that interoperability is being achieved and the issues that relate to interpretation of the standards have been resolved.

When a vendor makes a change to support interoperability, that change is controversial if it impacts silicon. With the evolution of the standards, there have been several recent features that have already begun to affect vendor’s silicon implementations. Examples include companies that require silicon modifications to support ATM cell byte alignment, implementation of the G.hs DPSK encoder/decoder,
and implementation of some of the G.lite profile negotiation for splitterless operation. Fortunately, such modifications have not often been needed. For vendors that implement a programmable solution, this has never been the case. This confidence in achieving interoperability and future-proofed solutions will likely result in companies using programmable solutions offering interoperability guarantees. In contrast, companies that do not implement programmable solutions will not be capable of offering such guarantees.

**Prioritizing development resources**

Prioritizing development resources and assigning them to the task of achieving interoperability is extremely important. Some of the common reasons why a company does not devote the required attention to this effort include:

- The effort required to achieve interoperability is underestimated.
- The company assumes their market position is strong enough without the need to demonstrate interoperability.
- Potential silicon issues that affect interoperability during the early stages of the training sequence of the physical layer keep the company from reaching the critical mass of issues that arise during later parts of the modem training phases, data transfer phases, and performance-enhancing phases.
- The company simply does not have the qualified resources to accomplish interoperability because they either underestimated the task or they relied on other technology vendors to develop their products rather than build their own competencies.

In support of interoperability, Texas Instruments has dedicated the necessary resources. Several of the notable contributions that Texas Instruments has made towards interoperability include:

- Announced interoperability with Alcatel in July of 1998;
- Announced interoperability with PairGain in February of 1999;
- Wrote and continues to support the test plan used by the UAWG;
- Has attended every UAWG Interop Event to date;
- Hosted the UAWG Interop Event in December 1998 in Dallas.

**Performance optimization**

During the development of ADSL sub-systems, technology providers may optimize a modem for different attributes. For example, some optimize for longer reach while others may optimize for higher performance over shorter loops. Moreover, technology providers may include proprietary extensions to their designs that enhance management or extend the feature set of their modem implementations. While each approach is valid, they do impact the modem’s ability to interoperate with other implementations when connected. Figure 1.3 provides an example of performance over 26 AWG that can be achieved using line simulators (i.e., in a test environment). Figure 1.4 shows the same modem pair operating over 24 AWG.

This performance is achieved with the same technology provider’s modem implementation is at each end of the wire. If different modems are connected together, the characteristics of the roll-off in the upstream or downstream directions may be impacted negatively. Thus far, interoperability testing has shown that upstream performance may be impacted by as much as 15%. Alternatively, downstream interoperability has shown a performance improvement in some cases. Work will continue between technology providers throughout 1999 to enhance the performance of modems once they are connected to other vendor’s implementations.
The Need for Interoperability

Achieving interoperability between one vendor’s DSLAM and another vendor’s CPE modem is a critical milestone toward enabling broad market deployment of ADSL. Interoperability will allow service providers to deploy DSLAMs of their choice in their central offices (COs), while enabling consumers to purchase modems based on price points and features sets from local retail outlets. It also enables computer manufacturers to include DSL-based broadband capabilities as part of their product offerings on a large scale without concerns of regional or geographical implementations. In short, interoperability eliminates risk – on the part of the service provider, the consumer and the computer manufacturer.

For this reason, the industry working groups (UAWG and ADSLF) have recently focused their efforts on enabling interoperability around the G.992.1 (G.dmt) and G.992.2 (G.lite) standards for full-rate ADSL and ADSL Lite, respectively. However, a question may arise – if there are ADSL standards, why is there a need to “enable” interoperability? After all, if everyone follows the standard, interoperability should be automatic. The answer lies due some practical issues:

- One method of generating confidence for a particular implementation of the standard is to prove through adequate testing that it interoperates with other implementations and is conformant to the standard.

- Vendor interpretations of the standard can differ, especially if there are ambiguous areas in the text. While every effort is made to avoid and/or remove ambiguities in the standard, sometimes these ambiguities are exposed only when two vendors try to connect up to each other.

- ADSL standards, like any other, are developed based on a collection of technical contributions from domain experts that are debated and discussed among peers. These contributions are sometimes based on theoretical reasoning, at other times, they are based on results gained from trials and lab simulations. However, especially in the early stages of the standard, they are not put to the test of real world experience. Real world tests on a large scale are necessary to validate the development of the standard. Interoperability tests are a way to validate and clarify the new standard text.

- Vendors may inadvertently fail to implement (or mis-implement) portions of the standard. Certification that a product meets the standard can be determined only through testing.
Approaches to Interoperability

There are two approaches to ADSL interoperability:

The “Plugfest” approach. This approach is typically favored by the data communications industry. The idea is for companies involved in developing products for a standard to gather in a single location (often before a standard is fully ratified) to attempt communication between devices as a means of validation, and to some degree, vendor debugging. The test goals and procedures are decided prior to the event, so that all participants are in agreement. Plugfests typically occur during the standards development process until the standard is final and a small number of devices can work together under certain circumstances. The drawback of Plugfests is that as new devices are added to the testing matrix, these devices must successfully connect to all other existing devices to be considered interoperable. As the number of devices increase, the matrix grows exponentially, so that it eventually becomes impossible to accomplish satisfactory testing at a single event.

The “Certification” approach. This approach is favored by the telecommunications community, in large part due to their history of ensuring high levels of reliability for the public switched telephone network (PSTN). The service providers prefer certification because they are often regulated entities and therefore, answerable to the public about the reliability of service they offer. This mentality extends to ADSL as well. Certification involves a stable standard against which a set of interoperability tests can be established. These tests must be agreed upon by the industry. Vendors then submit their equipment to a test house to execute these tests and receive notification of success or failure. The drawback of certification is that it can turn into a time consuming (and often expensive) process.

The UAWG has chosen to adopt the Plugfest approach to begin interoperability efforts for G.992.2 (G.lite) in the early cycle of standards development. The ADSLF has chosen to adopt the Certification approach of developing test cases against the standards for both full rate ADSL and ADSL Lite. The UAWG is cooperating with the ADSLF on joint definition of test cases for ADSL Lite.

UAWG Efforts

The UAWG has recently completed several “Plugfests” among multiple vendors. The objectives of these Plugfests are to:

- Validate the text of the G.992.2 (G.lite) standard.
- Enable manufacturers to gain confidence in their implementations.

The UAWG has put its interoperability test plan in the public domain. The test plan covers the following areas:
Test 1 – Initialization procedures. The purpose of this test is to verify interoperability of the initialization procedures. The test is divided into four separate sub-tests, corresponding to the four major phases of the initialization sequence: 1) activation and acknowledgment, 2) transceiver training, 3) channel analysis, and 4) exchange. Successful completion of this test occurs when the two ATUs under test simultaneously reach the SHOWTIME state.

Test 2 – Basic data transmission operation. The purpose of this test is to verify interoperability of basic data transfer between the ATU-C and ATU-R operating to the G.992.2 (G.lite) terms of reference. Tests of basic data transmission are divided into three sub-tests: 1) fixed data rate operation with no forward error correction (FEC), 2) fixed data rate operation with specific FEC parameters, and 3) vendor optional connection at 9000 foot 26 AWG wire loop (CSA Loop 6).

Test 3 – ADSL Overhead Channel (aoc) transmission and processing, and Fast Retrain procedure under momentary off-hook state. The purpose of this test is verify the fast retraining procedure, and implicitly, aoc operation (since fast retraining results in profile exchanges over the aoc).

Test 4 – G.994.1 (G.hs) initialization procedures. The purpose of this test is to verify operation of handshaking procedures during initialization. Handshaking is used among modems to determine the capabilities at either end.

Test 5 – L3-L0 transition and Embedded Overhead Channel (eoc) transmission and processing. The purpose of this test is to verify sections of the power management implementation (in particular the L3-L0 transition), and implicitly, eoc operation since this involves message exchanges over eoc.

Test 6 – Interoperability between a G.992.2 (G.lite) ATU-R and a full-rate (T1.413 i2) ATU-C.

ADSL Forum (ADSLF) Efforts

Within the ADSLF, the Testing and Interoperability Working Group is chartered with developing detailed test plans with the goal of generating standards that would ensure interoperability among various implementations. As with other ADSLF efforts, the interoperability test standards are contribution-driven from industry sources. When approved, the ADSLF proposes to make these test plans publicly available so that independent test houses can come forward with proposals to execute these plans and certify products. A common set of test plans would ensure uniformity in the certification process. At the heart of the test plans are a set of implementation options and electrical design specifications called ADSL Protocol Implementation and Conformance Specifications (APICS). The APICs are based on the ANSI T1.413i2 and G.992.2 (G.lite) standards for ADSL and ADSL Lite, respectively.
The ADSLF proposes three areas of testing to ensure that products meet the standards and that they interoperate without observable problems under different load conditions – conformance, performance and interoperability. Each of these test areas are independent of each other, and one is not necessarily more important than the other. However, the combination of all three types of testing will provide the highest degree of confidence.

**Conformance.** Conformance testing attempts to evaluate an implementation against a specific protocol specification. Conformance testing is extensive since it consists of verifying a Device Under Test (DUT) against every feature and function defined in the specification. A conformance test suite can target a specific layer or protocol. A device can meet conformance at one layer but not at another. Conformance testing can also be used whenever an interoperability problem arises between different pieces of equipment, to further explain the nature of the problem. Conformance testing can be automated by connecting a conformance test equipment to the DUT and executing a series of APICs.

**Performance.** Performance testing attempts to evaluate an implementation under different traffic and load conditions to see how well it performs. The performance metrics for ADSL include the following parameters:

- Line attenuation
- Noise Margin
- ADSL Line Status
- Transmit Blocks
- Corrected Blocks
- Uncorrectable Blocks
- Counters for current and previous Loss of Signal, Loss of Frame, Loss of Power, Errored Seconds.
- Bits/Carrier (DMT only)
- Equalizer Settings (CAP only)
- Interleave Delay
- Rate Adaptation

**Interoperability.** Interoperability testing attempts to evaluate an implementation against other implementations; regardless of how well it meets the protocol specification. There are multiple levels of interoperability:

- Physical Media Dependent (PMD) layer
- ATM Transmission Convergence (TC) layer
- ATM over ADSL Layer
- PPP over ATM over ADSL Layer
The ADSLF has defined two categories of interoperability testing:

**Static Interoperability Conformance Testing** is verifying the operation of the pair of modems to operate in a benign environment, i.e. (10-foot loop, and no noise intrusions). This is achieved through APICS and will increase the likelihood that an ADSL system will interoperate at the physical layer.

**Dynamic Interoperability Performance Testing** is the ability of a pair of modems to interoperate in an environment related to a real copper plant, while implementing the different levels of inter-operability. It is intended to measure the joint performance of DUT over an appropriate range of operating parameters. Dynamic interoperability conformance is directly related to performance measurements, where interoperability is evaluated as the various performance test conditions are varied and exercised.

**Conclusion**

In order for ADSL to be successful as a mass-deployed technology worldwide, it is imperative that all standards-based solutions interoperate with each other. The telecommunications industry learned its lesson with the fractured worldwide implementation of ISDN and multiple interpretations of those standards. Interoperability efforts, such as those from Cisco and Texas Instruments, make strides in achieving worldwide functionality. But true mass deployment will only be achieved when service providers commit to the installation of standards-based equipment and make cross-system interoperability a requirement.

There will be some companies who do not deliver a standards-based solution and will attempt to deploy in the marketplace. There will be service providers who endorse this approach in the name of capturing early market share. However, these efforts only serve to deplete the overall opportunity for the industry, and consumers. The goal of “always-on” communications is too near, and too critical to sacrifice for a few dollars and differentiated solution.

Cisco and Texas Instruments applauds the work completed to date by the responsible ADSL solution vendors. Both companies will continue their efforts moving forward, as the potential and application of ADSL grows and is deployed.