Testing DSL Forum TR-048 for design engineers

Compliance with the DSL Forum TR-048 interoperability-test plan is one step to achieving truly interoperable DSL CPE. The industry is working to bring CPE modems to the retail markets, and TR-048 unifies CPE, DSLAM, and chip-set vendors, and service providers under one ADSL interoperability-test plan.

By Michael Song, Aware Inc

Interoperability has proven critical to the success of many new technologies. The DSL (digital-subscriber-line) industry recognized the need for standard testing of DSL modems, and the DSL Forum, which comprises telecommunications, equipment, computing, networking, and service-provider companies, set out to develop recommendations for interoperability testing of DSL equipment.

The DSL Forum published its steps for DSL equipment interoperability testing in a test plan called Technical Report 048, or TR-048. TR-048 defines interoperability tests between CPE (customer-premise-equipment) modems and DSLAMs (digital-subscriber-line access multiplexers). TR-048 specifies a common set of loop conditions and loop-topology tests, ensuring that equipment manufacturers, chip-set vendors, and network operators achieve repeatability and consistent results. The ITU (International Telecommunication Union) also recognized the need for DSL equipment interoperability and testing, and incorporated TR-048 into its ADSL2 G.dmt.bis (G.992.3, G.992.4) standard, which it ratified in 2002.

By testing to the TR-048 test plan, design and test engineers achieve validation of their modem designs and the assurance of an interoperable product with consistent and reliable performance in real-world conditions. Besides interoperability with multiple DSLAMs, the goals for CPE interoperability testing include validating modem design, determining overall performance, and benchmarking against DSLAMs used in service-provider networks. To achieve these goals, the test engineer must test the CPE modem with various loop lengths, varying bridge taps, noise impairments, and disturbers. Additionally, throughput and latency testing, as well as Layer 2 and Layer 3 testing, provide more information on CPE performance in real-life conditions.

Test cases

TR-048 consists of physical-layer test cases and higher layer test cases. The physical-layer test cases include loop tests with various impairments and disturbers for ports set for adaptive rate, ports set for fixed rate, selected G.dmt loops, and loops with bridge taps, as well as functional, margin, bit-swap, noise-spike and -surge, and electrical-compatibility tests. The higher layer cases test for ATM connectivity, packet throughput rates, latency, PPPoE (Point-to-Point Protocol over Ethernet) and PPPoA (Point-to-Point Protocol over ATM) connectivity, and end-to-end connectivity.

Physical-layer loop tests

Physical-layer tests involve loop tests and functional tests. The loop tests are required to test the modem with factors such as distance and interference. One loop test monitors operation from very short distances to the theoretical distance limits. TR-048 also requires testing loops with a 140-dBm white-noise impairment and disturbers that often reside in the same binder groups as the copper pair carrying DSL services, such
as 24HDSL, 24 DSL (ISDN), and 5 T1 Adjacent Binder impairments (*Figure 1*; see *all figures at the end of the article*).

TR-048 tests are performed in fast or interleaved mode. Interleaving compensates for high error rates or excessive interference on the DSL link. Spreading out bursts of bit errors reduces the likelihood of overloading error-correction mechanisms. However, the improved error performance comes at the expense of increased latency. Fast mode is used when conditions cannot tolerate high latency. The test-output results are collected for each test and compared with expected values, as defined by the TR-048 pass/fail criteria. Finally, the upstream and downstream margins for reference are recorded.

**Rate-adaptive loop tests**

TR-048 details requirements for loop tests with ports set for an adaptive rate. These tests perform a loop-reach test under various noise conditions to characterize a modem under real network conditions and to determine its performance. They measure the data rates and noise margins in the upstream and downstream for straight loops at 26 AWG thickness with white-noise impairment and other disturbers. Example steps in this test include:
- Insert $-140$ dBm of white noise at both the CPE and central-office ends of the loop.
- Test in 1000-ft increments ($0$ to $18,000 + 17,500$ ft).
- Perform the test in both fast and interleaved modes.

**Fixed-rate loop tests**

Loop tests with ports set for fixed rates verify modem training and measure noise margins in the upstream and downstream for North American and European straight loops at fixed rates. These tests aim to verify that a modem can link at a minimum set of upstream and downstream data rates with white noise. It is important to ensure that network operators can meet customer-service levels. Consider the following steps for a North American fixed-rate test:
- Fix the downstream rate to 256 kbps and the upstream rate to 128 kbps.
- Apply a white-noise disturber ($-140$ dBm) at both CPE and central-office ends of the loop.
- Test in 3000-ft increments ($0$ to $15,000 + 17,000$ and $17,500$ ft).
- Perform the test in both fast and interleaved modes.
- Determine whether the modem trains, then measure rates for reference.

**Standard loop tests for CSA 4 and ANSI 13**

Two standard loop tests, CSA 4 and ANSI 13, consist of bridge taps and varying wire gauges. Testing and passing these loops assure that a modem can handle difficult loop-plant conditions (*Figure 2*). The test is performed several times with various disturbers. Example steps include:
- Apply a white-noise disturber ($-140$ dBm) at both CPE and central-office ends of the loop. Test the loops.
- Apply a white-noise disturber and an additional 24HDSL disturber. Test the loops. Repeat by replacing 24HDSL disturber with 24DSL impairment and 5 T1 Adjacent binder impairment.
Fixed loops with varying bridged taps

Fixed-loop tests are necessary because many local loops contain bridged taps of varying lengths. These “unterminated loops” cause reflections that can distort data transmission via DSL. Unterminated loops, called bridged taps, often occur when a telephone company runs lines from the central office to a neighborhood but doesn’t “cap” the open lines (Figure 3). The main loop uses 26 AWG wire, and the bridge tap uses 24 AWG wire. An example test is to:

- Apply a white-noise disturber (−140 dBm) at both CPE and central-office ends of the loop.
- Perform the test with main loops set at 9000, 12,000, and 17,500 ft with a bridged tap of varying length at the CPE end.
- Test the loop with bridged taps at varying lengths of 0 to 1500 ft.
- Perform the test in fast mode.

European loops for full and fixed rates with impairments

European loops for full and fixed rates with impairments test CPE modems’ rates for various European loops and noise impairments as well as to verify that the modem trains with the DSLAM at fixed rates with various European disturbers. Examples for various loop tests include the ETSI-0 loop test, the ETSI-1 loop test, and the European impairments with fixed port rates test. The steps that the ETSI-0 loop test entails are:

- Determine that there is no insertion loss at a zero-length loop
- Apply a white-noise disturber (−140 dBm) at both CPE and central-office ends of the loops.
- Perform tests in both fast and interleaved modes.

The steps for the ETSI-1 loops test, which comprises several tests and employs different loop insertion-loss values at 300 kHz, are:

- Apply a white-noise disturber (−140 dBm) at both CPE and central-office ends of the loops.
- Perform tests in both fast and interleaved modes
- Implement the required noise disturbers—ETSI-A, ETSI-B, and Euro-K (Figure 4).
- Establish link.

The steps for the European impairments with fixed port rates test, which employs ETSI-1 loops with varying insertion loss values at 300 kHz and different loop lengths are:

- Apply a white-noise disturber (−140 dBm) at both CPE and central-office ends of the loops.
- Perform tests in both fast and interleaved modes.
- Test using required noise disturbers—ETSI-A, ETSI-B, and Euro-K.
- Establish link.
- Determine whether the modem trains, then measure rates for reference.

Functional tests

Functional and other physical-layer tests are useful in CPE testing, because they test how the CPE will react in real-world situations, such as when a line is noisy, bursty errors occur, or a power outage occurs.

The bit-swap test determines the CPE’s capability to perform bit swapping when a bin in the ADSL frequency spectrum degrades without having to retrain the modem or
reduce the data rates. A modem bit swap occurs when noise interference occurs in the ADSL frequency band, such as from AM radio waves. An ADSL-diagnostic-tools check uses software that the modem vendor supplies to determine data rates and margins. A dying-gasp test determines whether a CPE modem sends a “dying gasp” message to the DSLAM when you simulate a power outage by removing the modem input power from a modem that has a trained link. Modular-connector pins and Ethernet-connector pinout tests verify proper connections for the ADSL-signal connection and the Ethernet connection. Other physical-layer tests that TR-048 requires exhaust any possible condition that may occur to disrupt normal modem operation, including noise tests, stress tests, and electrical compatibility. They include DSL noise-spike and -surge tests, CPE in the presence of impulse noise, CPE stress tests, electrical-compatibility tests, and CPE margins during links with incremental noise-impairment tests.

**Layer 2 and 3 tests**

The higher layer test cases in TR-048 address the CPE’s capability to perform ATM, PPPoA, and PPPoE connectivity; determine usability; and measure throughput and latency. These tests are significant because they impact the performance that a user will experience when browsing the Web, downloading files, and using the DSL connection.

The connectivity and usability tests are not time-consuming and are usually performed manually. The throughput and latency tests require many tests; therefore, automated testing is a desirable method for performing them. The packet-throughput test determines the CPE modem throughput by varying frame packets across a line. The fixed-rate latency test and multiple-rate latency test measure the data-transmission round-trip times. The first test trains at a fixed rate and sends varying packet sizes across the ADSL link. The second method trains at multiple rates and sends a single frame size across the link.

**Annex A**

Annex A in TR-048 aims to compensate for varying attenuation and noise levels among individual loop simulators, noise-impairment generators, and wiring. These varying levels result in different data rates. Annex A compensates for these occurrences by measuring the attenuation and noise levels, adjusting for error, and finely adjusting the data rate based on remaining error against the requirements.

The wiring and cabling of test equipment is another source of crosstalk interference. Use Category 5 UTP (unshielded twisted pair) and STP (shielded twisted pair) to minimize interference. Separate the downstream and upstream cables, as they can induce crosstalk. And be careful of noise interference from monitors, power supplies, and other equipment sources.

**Testing to TR-048**

Several methods for testing to TR-048 include manual testing, do-it-yourself automation testing, and fully automated testing. The first step in any of these methods is setting up the test environment. The setup generally comprises a line simulator with noise cards, a DSLAM, a router, a traffic analyzer, and the CPE under test. Many setups also use a PC to control the test equipment.

The next step is to configure the line simulator to the desired loop length and noise impairments. The DSLAM is configured to perform the required test by setting fast/interleaved mode and the rates that the test specifies. Once the link initializes, the DSLAM or CPE collects the data rates and margins. Additional statistics may also be recorded, such as error counts.
The router directs traffic to and from the traffic generator through the ADSL link during throughput, latency, and other upper layer tests. The CPE under test links with the DSLAM through the line simulator.

**Manual testing**

The DSL Forum’s TR-048 specification includes more than 200 physical-layer loop tests as well as dozens of upper-layer tests. Generally, TR-048 loop tests are performed as many as three times for consistency and repeatability. This practice means that performing the mandatory tests in the TR-048 specification for one CPE against one DSLAM may require as many as 600 tests. Testing multiple DSLAMs or multiple firmware codes on the same DSLAM against multiple pieces of CPE exponentially increases the number of required tests.

Manual TR-048 testing is time-consuming and labor-intensive. The results are often unrepeatable and inconsistent, and vary among operators. More DSLAMs, CPE, or firmware codes add more layers of complexity to TR-048 testing. The bottom line is lost efficiency, lost time, and mixed test results.

**Do-it-yourself automation testing**

One way to mitigate the downside of manual testing is to perform do-it-yourself automation. This process requires writing programs or scripts to automate line simulators, initiate DSL links, and generate traffic. It also requires compiling and formatting test results to develop an organized view of the test outcomes. Do-it-yourself automation testing is a viable alternative for many test labs, service providers, and CPE developers with adequate resources and knowledge of TR-048 tests and scripting languages as well as the time to incorporate DSLAMs into the automated process. The challenge with this method is that time and resources must be committed to keep up with changes to equipment, firmware, and tests. It is critical to find and retain the resources to first automate the tests in-house, then to update the tests as new firmware and equipment are added.

**Fully automated testing**

Time and cost are the greatest pressures in TR-048 testing. Keeping these factors in mind, many CPE design engineers are increasingly using a turnkey automated test platform to perform most TR-048 tests. Automated test platforms automate the line simulator with line conditions required in the test, configure and automate link initialization, automate throughput and latency tests from the traffic generator, gather statistics on the DSLAM, and compile results.

The benefits of automated testing include:
- reduced modem-validation testing time, because automated testing can take only hours;
- savings on engineering resources, because automated tests run overnight;
- consistent, repeatable, and accurate test outputs with operator-independent results (Figure 6); and
- improved test-results analysis, identification of failed tests, and detailed test reports (Figure 7), translating into better modem performance.

Automated test platforms enable DSL-equipment developers to pretest their CPE and DSLAMs to verify performance, ensure interoperability, and diagnose problems against the same interoperability standards that major telephone companies worldwide use.
On the horizon

The DSL Forum TR-048 test plan defines tests for interoperability between DSL CPE modems and DSLAMs in service providers’ and network operators’ DSL networks. TR-048 is the first technical report from the DSL Forum to be referenced in the new ITU G.bis (G.992.3, G.992.4) standards for ADSL. Its inclusion is an important landmark for the DSL Forum and TR-048. It signals that TR-048 compliance is required for all standard-compliant CPE modems.

TR-048 is a complex test plan to test and comply with, yet the rewards of compliance far outweigh the difficulties. Although several methods are used to perform TR-048 testing, a fully automated approach will save time and money and simplify the testing process. And it may make TR-048 compliance a reality for DSL-equipment developers.

References
4. ANSI T1.413, Network and Customer Installation Interfaces – Asymmetric Digital Subscriber Line (ADSL) Metallic Interface.

Author’s biography
Michael Song, a product manager at Aware Inc, defines and implements the market strategies for Veritas DSL Test Systems products. Prior to joining Aware, he worked in sales and product management in the telecommunications- and Internet-infrastructure industries. He holds a BSEE from the University of Illinois and an MSEE from Tufts University.

Figure 1—
TR-048 performs DSL link tests with disturbers that often reside in the same binder groups as the copper pair carrying DSL services, such as this 5 T1 Adjacent Binder impairment.
Figure 2—
Testing and passing these CSA #4 and ANSI #13 loops assure that a modem can handle difficult loop-plant conditions.

Figure 3—
Testing to this loop is important because bridged taps cause reflections that can distort data transmission via DSL.
Figure 4 — European noise models simulate ETSI-A (a), ETSI-B (b), and Euro-K (c) loop conditions.
Figure 5—
A typical test set-up for TR-048 interoperability testing comprises a line simulator with noise cards, a DSLAM, a router, a traffic analyzer, and the CPE under test.

Figure 6—

An automated TR-048 test result summary provides insight into achieving consistent, repeatable, and accurate test outputs with operator-independent results.

Figure 7—
Individual test summaries aid in improved test-results analysis and identification of failed tests, assisting in modem debugging.