Development, Training and Implementation of Test Automation for ADSL Interoperability and Reliability Studies

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Abstract

At Prairie View A & M University (PVAMU), we developed a new Broadband (High-Speed) Access Technologies Research Laboratory (BATRL) over the last few years. This laboratory is used in helping our premier telecommunication companies in the area of interoperability and reliability studies. It is also used for the training of our students in this emerging area of technology and for research, especially, the Digital Subscriber Line (DSL) modem technology. DSL is a new technology for providing higher data rates over the twisted telephone copper wire. The Asymmetric Digital Subscriber Line (ADSL) is one of the first derivatives of this DSL technology. The DSL Forum has defined an ADSL interoperability test specification, known as TR-048, which is supported by all key Service Providers, access IC manufacturers and Independent Test Labs. This research project follows the test plan TR-048 to produce a complete automated testing suit, which can be used in the industry.

The goal of the research project is to develop effective scripts, which can be used at PVAMU Center of Excellence for Communication Systems Technology Research (CECSTR) BATRL for ADSL Interoperability and Reliability tests for Sprint High Speed (Broadband) Communication Networks. The automation saves time, manpower and produces unbiased reports for the interoperability and the reliability tests. As part of our goal in the Electrical Engineering Department, our students are exposed to hands-on training. The students are given the opportunity to conduct the tests in the BATRL using the developed automation algorithms for interoperability and reliability tests. The results of these automated tests have been found to conform to industry standards. The lessons learned and recommendations will be discussed in this paper.

1. Introduction

In the campus of PVAMU, we developed a new Broadband (High-Speed) Access Laboratory (BATRL) over the last few years. This laboratory is developed to help our premier telecommunication companies in the area of interoperability and reliability studies. It is also used for the training of our students in this emerging area of technology and for research, especially, the DSL technology. DSL is a new technology for providing higher data rates over the twisted telephone copper wire. It describes the transmission technology that was the first developed Digital Subscriber Line for the Integrated Service Digital Network (ISDN) Basic Rate Access channel. Most recently, xDSL is used as a generic name for any DSL system. Some of the other types of DSL are Asymmetric Digital Subscriber Line (ADSL), High-Bit-Rate Digital Subscriber Line (HDSL), Very-High-Bit-Rate Digital Subscriber Line (VDSL), etc. High-Bit-Rate Digital Subscriber Lines (HDSL) is an extension to ISDN for shorter Carrier Service Area (CSA).

The performance of ADSL depends on the loop conditions like any other DSL system. Broader signal bandwidth gives more throughputs, but because of Near End Crosstalk (NEXT) noise, the subscriber loop is useful beyond the frequency band of HDSL [1]. That is why ADSL system uses two different frequency bands for upstream and downstream transmissions for avoiding NEXT noise at broader bandwidth. ADSL system is very popular for the consumer broadband services where the downstream throughput needs to be much higher than the upstream transmission. The user can have telephone services and the broadband services simultaneously using ADSL system. It helps the DSL market and hence service providers.

Distribution cables contain 25 to 1000 pairs and they are bundled into binder groups of 25, 50 or 100 pairs. In a binder group there might be T1, ISDN or HDSL disturbers and hence ADSL must cope with these noise impairments, length distribution, bridge tap and other factors like noise spike etc. Manufacturers need to make sure the system components of ADSL are interoperable and reliable. DSL Forum has defined an ADSL interoperability and reliability test specification, known as TR-048, which is supported by all key Service Providers, access IC manufacturers and Independent Test Labs. This TR-048 Interoperability and Reliability Test Plan are for broadband (high speed) modems and DSLAM for different line conditions [2]. The test plan consists of Physical Layer tests and Higher Layer tests. Currently, every manufacturer follows this guideline before they bring their products to the market. This is a very extensive test and needs long time for completing the test. Manual tests could be biased and depends on the tester's judgment.

The goal of this research project is to develop an automation process for the testing of ADSL modems. It was implemented following the test plan TR-048 to produce a complete automated testing suit, which can be used in the industry. Industry standard scripting language TCL and Perl are used for the test automations. We have used Digital Subscriber Line Access Multiplexers (DSLAM) as the central office (CO) side of the communication network and modems of different vendors as the Customer Premise Equipment (CPE) side. The loop between the CO and the CPE is simulated using Wire Line Simulator (WLS). The program controls WLS for different loop lengths and noise impairments, and retrieves data from DSLAM when CPE modem trains itself.

The automation that we developed and implemented saves time, manpower and produces unbiased reports for the interoperability and the reliability tests. As part of our goal in the Electrical Engineering Department, we expose our students to hands-on training. The students are given the opportunity to conduct the tests in the broadband (high-speed) communications laboratory using the developed automation algorithms for interoperability and reliability tests. The results of these automated tests have been found to conform to industry standards. The lessons learned and recommendations are discussed in this paper.

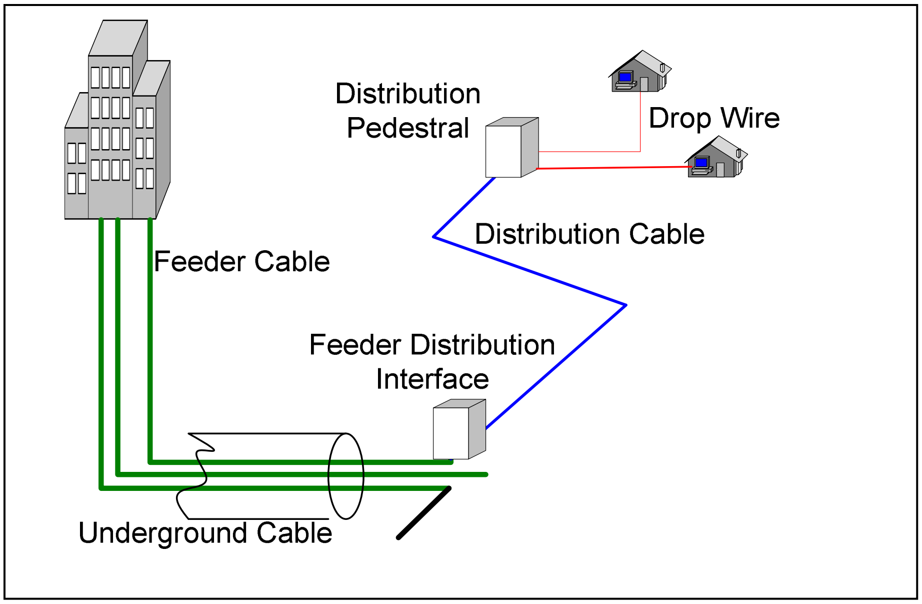


Fig.1: Telephone Subscriber Loop Environment

In this paper, Section 2 covers brief description of Telephone Subscriber Loop Environment, Section 3 briefly describes the Test Plan TR-048, Section 4 describes the Test Equipments, Automation Methods/General Algorithm. Section 5 includes the Conclusions while Section 6 includes the references. The Appendix includes sample modem reports and some Sections of the Broadband Access Technologies Research Laboratory (BATRL).

2. Telephone Subscriber Loop Environment

The term loop refers to the twisted-pair telephone line from CO (Central Office) to the customer. Larger COs may serve 100,000 telephone lines. Feeder plant cables lead from CO to the serving area interface (Feeder Distribution interface), which serves 1,500 to 3,000 lines [3]. Distribution cables contain 25 to 1000 pairs. For residential and small business areas, the distribution cables lead to drop wire that serves each customer. The feeder and the distribution cables are bundled into binder groups of 25, 50 or 100 pairs. The pairs within a binder group remain adjacent to each other for the length of the cable. As a result, the crosstalk of pairs within a binder group is somewhat greater than crosstalk between pairs in different binder groups. A bridge tap is an unterminated wire and approximately 80% of loops in US have bridge taps [1]. There are also series of inductors in some loops, called loaded loops.

A loop plant is designed a little bit differently for serving telephone service and DSL. Distance is a major factor for serving DSL. Shorter loop length achieves higher bit rate. Series inductors need to be removed because DSL does not operate on loaded loops. With the bridge taps in the loop the service becomes worse. In a binder group there might be T1, ISDN or HDSL disturbers and hence ADSL must cope with these noise impairments, length distribution, bridge tap and other factors like noise spike etc. Fig.1 shows the telephone subscriber loop environment and Fig. 2 shows a typical ADSL loop architecture.

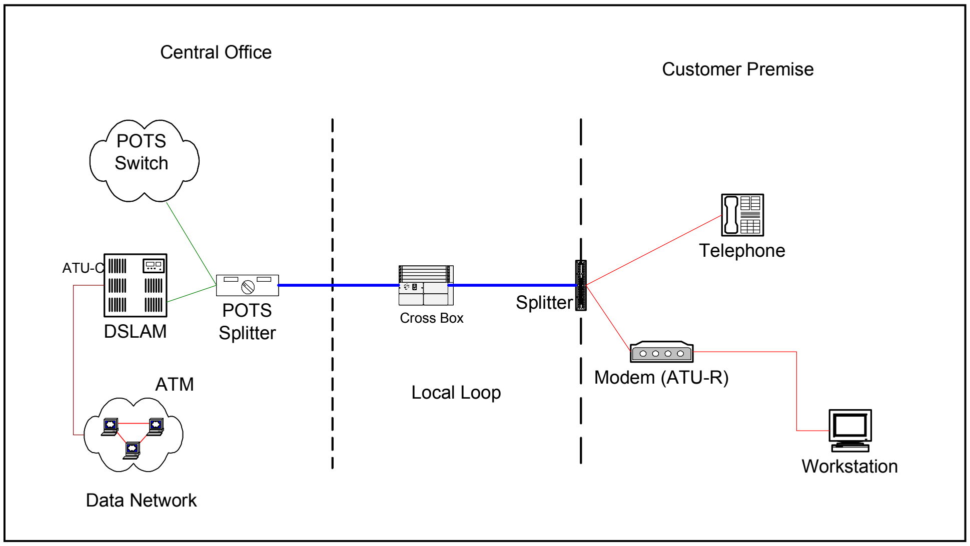


Fig. 2: ADSL Loop Architecture

3. Test Plan TR-048

At CECSTR in PVAMU, we used the DSL Forum test plan TR-048 for the testing of the DSL interoperability and reliability studies. This includes the Physical Layer and Higher Layer Test Cases.

3.1 Physical Layer Test

Physical Layer test cases basically measure the sync rate for a modem that can achieve for a certain type of line environments. This is the physical line rate between the modem and the DSLAM. This rate depends on the line quality such as the distance between CPE and CO, line noise (such as white noise, noise impulse, HDSL, ISDN impairments) etc. This line rate also depends on bridge taps. TR-048 specifies the line length with noise impairments and bridge taps that could be used for ADSL services. It also defined the expected results for which a test can be compared. The test specifications are: Loop Tests with Ports Set for Adaptive Rate, Loop Tests with Ports Set for Fixed Rate, North American Fixed Rate Tests, Full Rate Standard Loop Tests, CSA #4 Standard Loop, ANSI 13 Standard Loop test, Bridged Tap Tests, ADSL Functionality Tests, DSL Noise Spikes/Surges Tests, and Operation in the Presence of Impulse Noise Events. The defined Noise Impairments are: White Noise Impairment Only, HDSL Impairment, 24 DSL Impairment, and T1 Adjacent Binder Impairment. Fig. 3 shows TR-048 defined loops.

3.2 Higher Layer Test Cases

Asynchronous Transfer Mode (ATM), Point-to-Point Protocol over ATM (PPPoA) and Point-to-Point Protocol over Ethernet (PPPoE) connectivity are tested for higher layer test cases and also throughput and latency are measured to determine a modem's capability. These tests are significant because the performance of the ADSL line depends on the actual throughput. Users

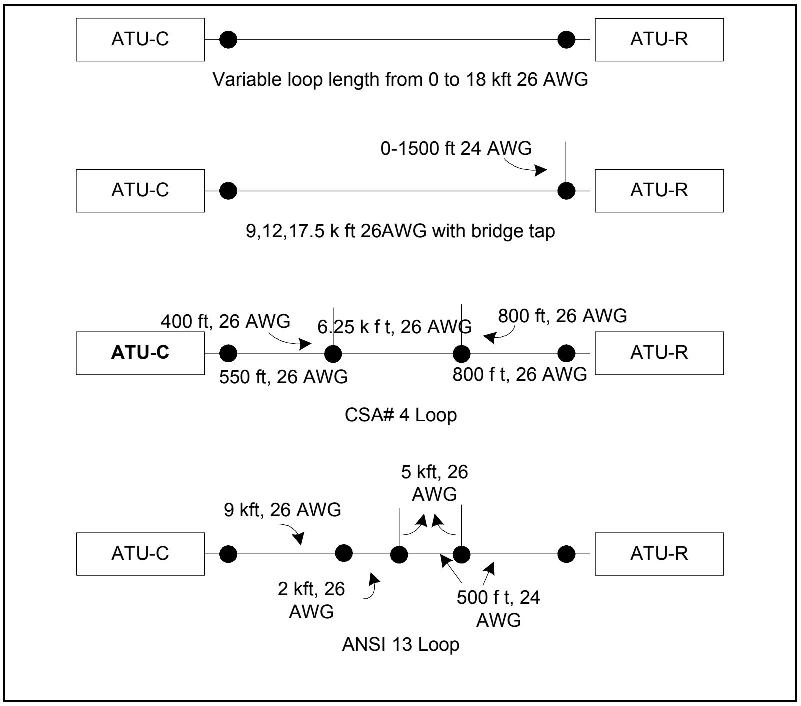


Fig. 3: Variable loops, loops with bridge tabs and Standard loops CSA-4 and ANSI-13

activities such as web browsing, downloading files, and multimedia applications using the ADSL connection depends on the throughput of the line. The connectivity tests are not time consuming but throughput and latency tests need many tests and hence 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. Among the higher layer test cases we developed automation for Packet throughout.

4. The Basic Test Setup, Automation Methods & General Algorithm

In the lab, we used Lucent's STINGER (DSLAM), Spirent Communications' Traffic Generator – SmartBits 200, Line Simulator- DLS400-IA and device under test (DUT)- Modems of various vendors. The basic setup for the test bed is shown in Fig. 4. We used serial connections for controlling the Wire line simulator, telnet connections for DSLAM and traffic generator.
In the following sections we described the test algorithms according to TR-048.

4.1 Physical Layer Test Cases

For each Test scenario of physical layer test, TCL scripts send commands to Wire line simulator and DSLAM and prepare the test environment according to the test plan. The steps are:

1. Set DSLAM parameters (downstream, upstream rate, noise margin, line mode, etc).
2. Set loop length & noise impairments for each instances of the test.

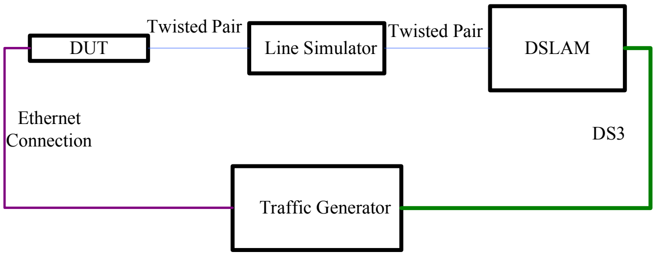


Fig. 4: BASIC TEST SET-UP

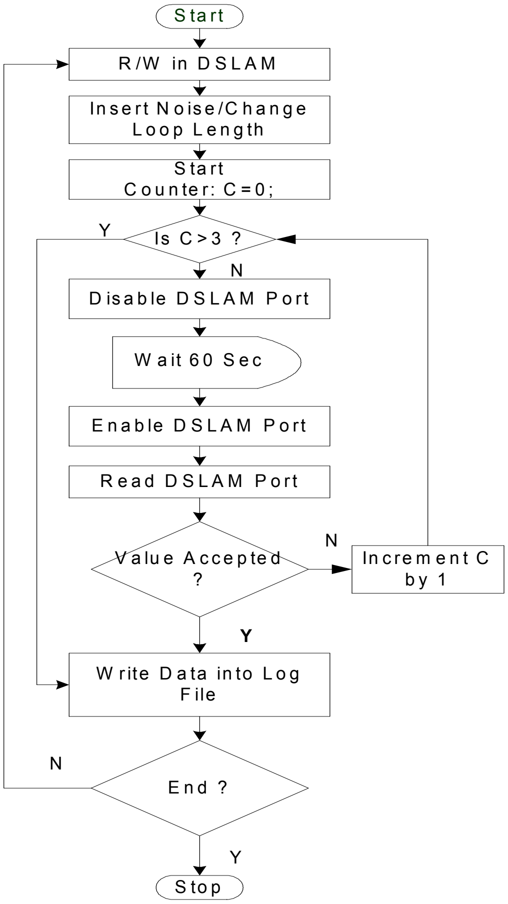
3. Disable DSLAM port.
4. Enable the DSLAM port.
5. Wait 60 seconds (modem should train itself within this time) and read Upstream, Downstream sync rate and noise margin from DSLAM.
6. If the actual downstream sync rate is less than the expected value and it is not less then 96 kbps then retest and follow step 3. Continue this process until the value is acceptable and stop after 3 recursions for that test instance.
7. Record the highest downstream sync rate and the associate upstream sync rate and noise margins for that instance in the text format.
8. Repeat steps 1 through 7 until the end of test.

Finally, we run Perl script to obtained formatted report in the Excel sheet from the saved log files.

A TCL script has all the modules of physical test cases and it produces automated test report with the help of Perl script. Fig. 5 shows a general flow chart of a physical layer test that we developed and implemented in this work.

Physical layer test also includes noise spike test. It verifies that sudden spike or noise on the line do not impact DSL functionality. We introduce noise spike for a very short time and check whether the modem needs to train itself again or not and also whether traffic resumes, if the sudden spike interrupts it. The test is operated on MID-CSA#6 loop (26AWG at 6000ft). The general algorithm for this test is given bellow:

1. Set the line parameters and noise parameters according to TR-048. For this test we keep the down and upstream DSLAM rate maximum.
2. Add TR-048 defined noise for t (initial t=1 sec) sec and measure the upstream and down stream noise and check whether the modem drops or not (if sync rate=0, modem drops)
    a. If sync rate=0, wait 60 sec and check sync rate again. If sync rate remains 0 after 60 sec, stop the test.
    b. If sync rate>0, modem trains itself and that means traffic will resume. Read the required data and save it in the log file.
    c. If t>10 sec, stop the test, else increment t by 1 sec and follow steps of 2.



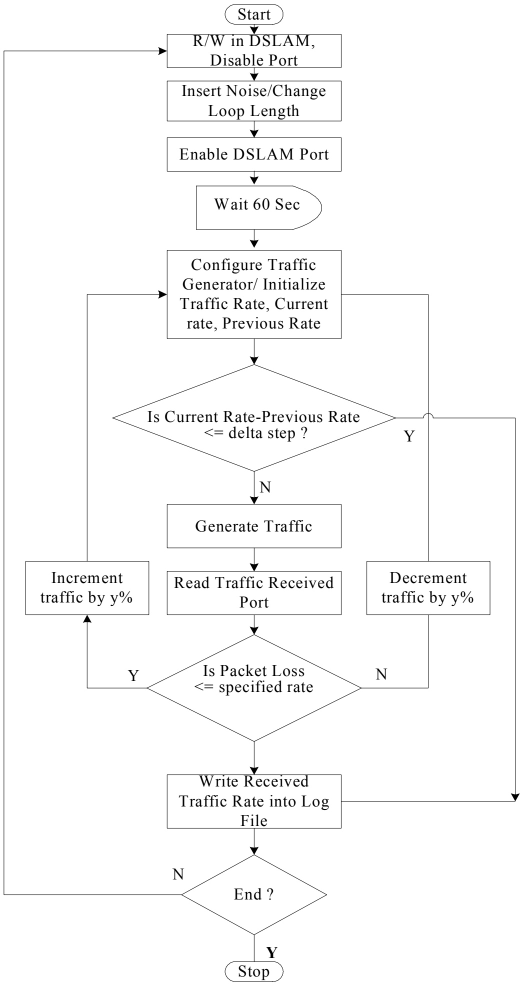


Fig. 5: General flow chart: Physical Layer Test

Fig. 6: General flow-chart: Throughput Test

4.2 Higher Layer Test: Throughout Test

Higher layer test needs traffic generator to measure the efficiency of the modem with respect to the loop length, frame size, etc. Throughput test determines the maximum transmission rate at which modem can forward traffic with no frame loss, or a user defined acceptable frame loss. By increasing the transmission rate at specified levels, we can determine the modem capacity.
We configured the traffic generator as it generates ATM traffic and received via DSALM and modem to Ethernet port of the generator and vice versa. Two types of tests are performed: one for variable length with adaptive rate with three frame sizes and one for fixed rate with fixed frame size for a standard loop. The basic algorithm is the same as that of the physical test cases. The script controls the Wire line simulators, DSLAM and the traffic generator. For the traffic generator part, the algorithm is as shown in Fig. 6. Traffic generator generates maximum allowable traffic and records the received traffic in terms of number of packet. If packet loss occurs and it is not acceptable then reduce the traffic rate by some specified percentage rate and

retest it again. The iteration goes on until there is no packet loss. If no packet loss occurs, there is a Δ rate increment and the test goes on. For the iteration where the difference between the current rate and the previous rate is equal to defined Δ step and the loss is less than or equal to specified percentage of loss, the output is recorded in the log file. Fig. 6 shows a general flow chart for throughput test.

4.3 The Reliability Tests and Statistical Results

For reliability tests we used the same test plan TR-048 but we used one modem over ports 1-24 of Stinger ADSL LIM card. We used the first slot of the Stinger for this test. This test refers the difference of performances of DSLAM ports against a single modem. In Fig. 7 all physical tests passing number for different impairments are plotted in a single plot to visualize at a glance. Table 1 shows all the necessary parameters calculated from the plots.

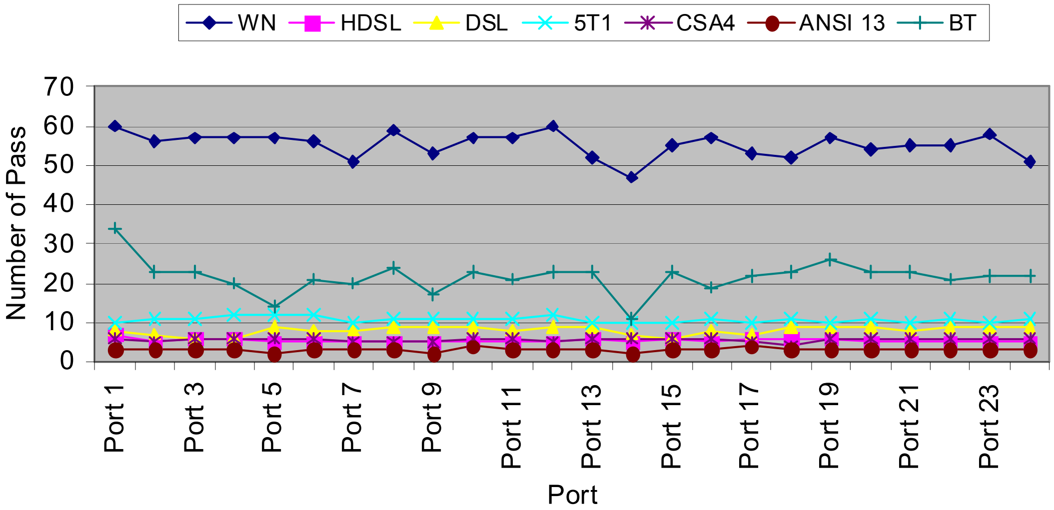


Fig. 7 Number of Pass Over Ports 1-24

TABLE 1: DATA TABLE FOR VARIOUS PARAMETERS

	AWGN	24 HDSL Impairment	24 DSL Impairment	5T1 Impairment	CSA 4	ANSI 13	BT
Average No. of Passing	55.25	5.38	8.13	10.79	5.67	2.96	21.71
Average % of Passing	69.06	44.79	67.71	77.08	70.83	36.98	45.23
Standard Deviation	3.14	0.58	1.08	0.72	0.56	0.46	4.18
Variance	9.85	0.33	1.16	0.52	0.32	0.22	17.43

Formulas for calculations:

n : Total number of ports
x : Number of pass for each port
$\overline{x}$: Arithmetic Mean(average) = sum of samples/number of total ports
σ^2 : Variance = $\frac{1}{n}\sum(x-\bar{x})^2$
σ : Standard deviation = $\sqrt{\frac{n\sum x^2-\left(\sum x\right)^2}{n(n-1)}}$

The standard deviation is calculated using the "nonbiased" or "n-1" method.

The throughputs on variable loops with three packet sizes (64/512/1518 bytes) are tested against 24 ports in the DSLAM slot 1. We also tested Sprint's service-offer rates [5] against 24 ports. Tests were categorized as downstream and upstream, each categorization has two operational modes: fast mode and interleave mode.

The reliability test has produced a significant variance for physical and throughput tests from port to port of the Stinger line interface module (LIM) card. Since the modem was kept constant, it is expected that the result would be very close to each other irrespective of LIM port. But in reality that was not the case. The standard deviations for the physical test cases and throughput tests over 24 ports give us valuable inside information of the LIM card performance, i.e. performance differs a lot from port to port [4].

5. Conclusions

The interoperability and reliability tests which follow the same TR-048 test plan are time consuming and hence an automated test plan reduces the time factor as well as the cost of modem testing. Automation process controls the DSLAM, automate line simulation with specified line conditions for specific test and generate traffic for throughput test and retrieve all the required data from DSLAM and traffic generator for physical and throughput tests. Our automated test report confirms the manual tests, which in turn validates the automation. It produces consistent results and saves manual labor and time. TR-048 is a complex test plan to test and a fully automated approach as in our case saves time and money. The students enjoyed working in this project. They valued the hands-on experience that they got. As part of the lessons learned, we have included the topic in our broadband curriculum to expose our students on how to perform interoperability and reliable tests in our Broadband Communication Systems course. We are also developing sets of experiments that can be performed in any regular undergraduate or graduate course in broadband communication systems.

6. References

[1] T Starr, J M Cioffi, P J Silverman, Understanding Digital Subscriber Line Technology, 1999, Printice Hall, NJ
[2] ADSL Interoperability Test Plan, DSL Forum Technical Report, TR-048, April 2002

[3] W. Y. Chen, DSL Simulation Techniques and Standards Development for Digital Subscriber Line Systems, 1998, Macmillan Technology Publishing, Indiana, USA

[4] S. Alam, J. Shen, C.M. Akujuobi, *CECSTR Technical Report on ADSL Interoperability & Reliability Testing*, 2004.

[5] Sprint's DSL forum version of DSL modems interoperability test plan, 2003

[6] C.M. Akujuobi, Shumon Alam, " Development of an Automation Process for ADSL Interoperability and Reliability Tests", in *Proc. IEEE 37th Southeastern Symposium on System Theory (SSST)*, Tuskegee, Alabama, March 20-22, 2005

Appendix:

SAMPLE REPORT FOR VARIABLE LOOP LENGTH

Overall Verdict: **Fail**

Pass/Fail criteria: 72 out of 80 individual tests must be passed - Actual: **60**

ADSL Link:

- Latency: Fast & Interleaved
- Target Noise Margin: 6 dB

Loop & Noise:

- Loop: 26 AWG

Noise: AWGN @ -140dBm/Hz at both ends.

Loop Length (kft, 26 AWG)	Fast Mode								Interleaved Mode							
	Upstream				Downstream				Upstream				Downstream			
	Sync Rate (kbps)			Noise Margin,	Sync Rate (kbps)			Noise Margin,	Sync Rate (kbps)			Noise Margin,	Sync Rate (kbps)			Noise Margin, Actual (dB)
	Expected	Actual	Pass/Fail		Expected	Actual	Pass/Fail		Expected	Actual	Pass/Fail		Expected	Actual	Pass/Fail	
0	800	832	P	6	8000	8000	P	4	800	896	P	0	7616	7616	P	0
1	800	832	P	5	8000	8000	P	3	800	896	P	0	7616	7616	P	8
2	800	864	P	7	8000	8000	P	6	800	896	P	0	7616	7616	P	8
3	800	896	P	6	8000	8000	P	5	800	896	P	5	7616	7616	P	9
4	800	832	P	7	8000	8000	P	7	800	896	P	5	7616	7616	P	9
5	800	864	P	5	8000	8000	P	9	800	896	P	6	7616	7616	P	11
6	800	864	P	6	8000	8000	P	6	800	896	P	7	7616	7616	P	8
7	800	864	P	6	8000	8000	P	6	800	896	P	6	7616	7616	P	8
8	800	864	P	6	7360	7552	P	0	800	896	P	6	7360	7616	P	6
9	800	864	P	5	6432	6688	P	5	800	896	P	6	6528	6944	P	5
10	800	832	P	4	5408	5376	Retest	5	800	896	P	6	5408	3296	F	0
11	768	800	P	5	4224	4416	P	5	800	832	P	5	4256	4384	P	6
12	704	640	Retest	6	3200	3360	P	6	800	736	Retest	6	3488	3712	P	6
13	608	608	P	7	2336	2464	P	6	736	672	Retest	7	2592	2688	P	6
14	512	512	P	8	1696	1728	P	6	640	608	Retest	7	1824	1856	P	7
15	416	448	P	9	1184	1184	P	6	576	512	Retest	9	1408	1376	Retest	6
16	320	384	P	10	800	512	F	7	480	416	Retest	11	960	864	Retest	6
17	256	288	P	10	512	320	F	7	384	352	Retest	10	608	512	Retest	6
17.5	224	224	P	10	384	320	Retest	6	384	320	Retest	10	480	352	F	7
18	160	192	P	11	288	128	F	6	352	288	Retest	10	416	192	F	8

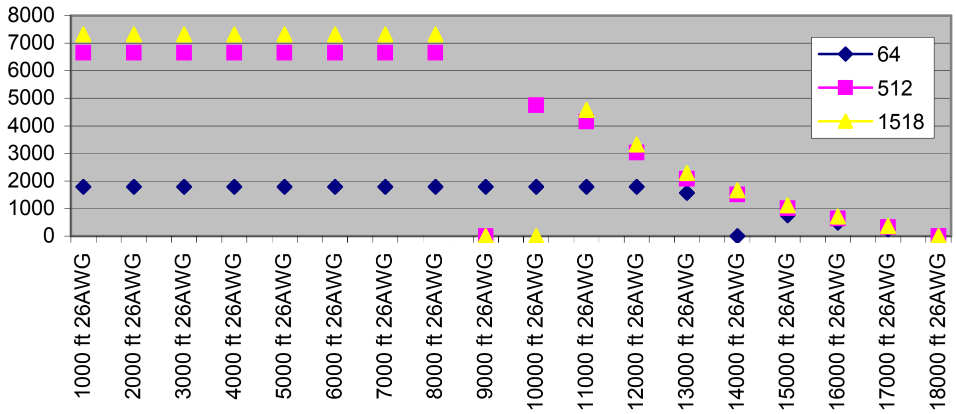


Fig.8: Down stream throughput test for variable loop length

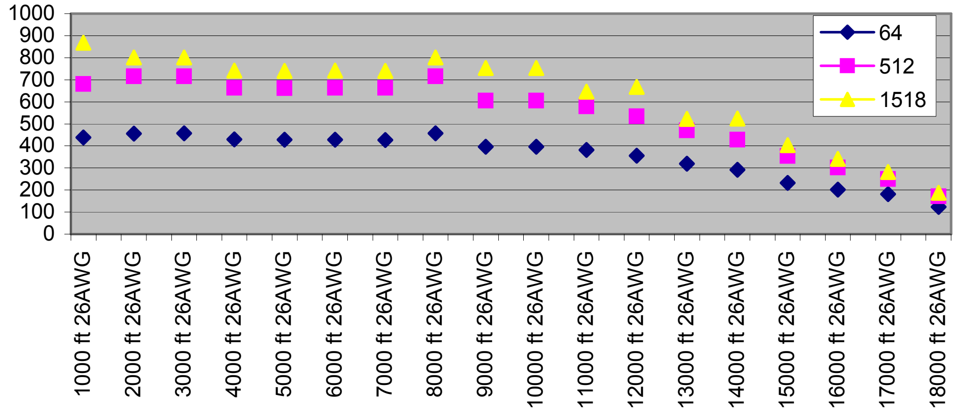


Fig.9: Up stream throughput test for variable loop length

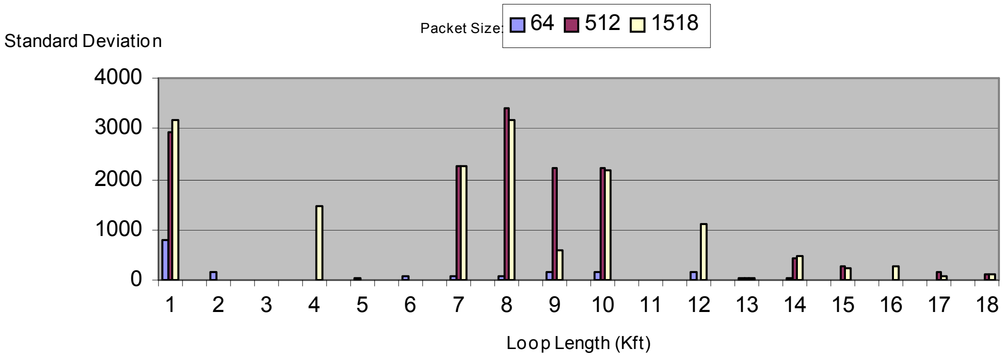


Fig. 10: Standard Deviation over port 1-24 for downstream traffic in fast mode

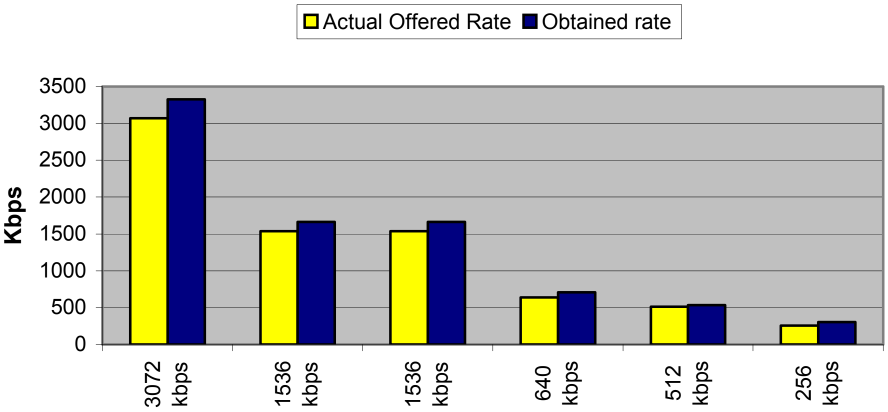


Fig. 11: Sample offered rate for Lucent CellPipe-50A- Down stream

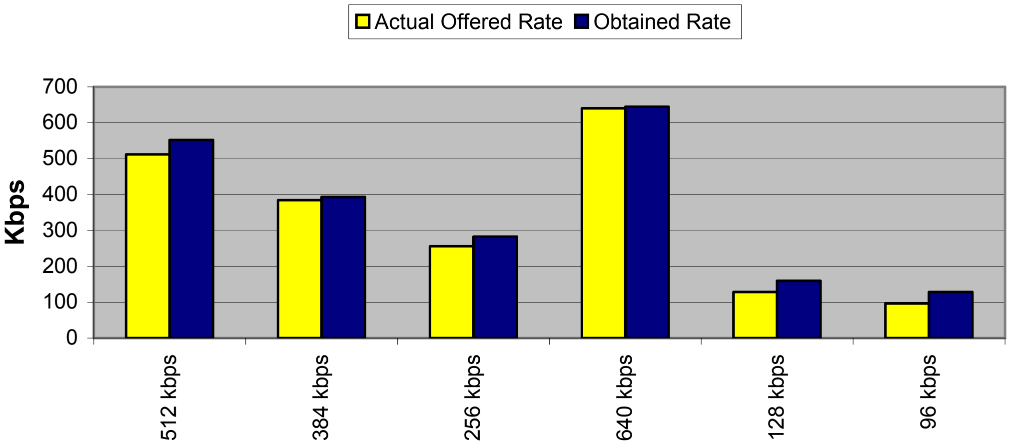


Fig. 12: Sample offered rate for Lucent CellPipe-50A-Up stream

Fig. 13: Some Sections of the Broadband Access Technologies Research Lab (BATRL) in the Center of Excellence for Communication Systems Technology Research (CECSTR) at Prairie View A&M University (PVAMU)

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Dr. Sadiku is a Professor at Prairie View A&M University and a researcher with CECSTR. He is the author of over one hundred and twenty technical papers and over twenty books including Elements of Electromagnetics (Oxford, 3rd ed., 2000) and Numerical Techniques in Electromagnetics (CRC, 2nd ed. 2001), Metropolitan Area Networks (CRC Press, 1995), and Fundamentals of Electric Circuits (McGraw-Hill, 2nd ed., 2004, with Charles Alexander). His current research interests are in the areas of numerical techniques in electromagnetics and computer communications networks.