XIX IMEKO World Congress
Fundamental and Applied Metrology
September 6–11, 2009, Lisbon, Portugal

DSL INTEROPERABILITY TESTING LABORATORY

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Abstract – Equipment interoperability is a key factor for the development of Digital Subscriber Line (DSL) technologies and services. The paper describes the efforts of *TLC Sannio Testing Laboratory* [1] in acquiring knowledge and competences for the validation of DSL equipment against standard requirements.

Keywords: xDSL, Interoperability, Testing Laboratory.

1. INTRODUCTION

During the last years DSL technology is showing a significant raise within the telecommunication (TLC) market. This is driven by the subscriber global demand for broadband residential and business access to internet to exploit new video and voice services provided by means of high speed connections [2]. DSL technologies allow for high speed transmission through regular telephone lines. This makes it a very cost effective solution to deploy new services as providers do not have to build new plant facilities. DSL is the leading broadband technology, holding approximately 66% of the broadband market share and available in almost every region of the world. Asymmetric DSL (ADSL) is widely deployed in most markets, while new equipment based on Symmetric High-speed DSL (SHDSL), ADSL2+, and Very-high-bit-rate DSL (VDSL) is currently spreading in the marketplace [2].

The development of more hardware and firmware solutions for broadband access equipment is a growing business within TLC companies. The evolution from best-effort internet to a multi-service broadband environment (including voice, video, and data) requires DSL equipment capable to provide higher access speed and enhanced support for differentiated traffic types. In this scenario the necessity of a standardized evaluation of DSL equipment interoperability and compliance is becoming central to the running success of DSL-based broadband services. As a matter of fact, independent test laboratories have to certify the quality of DSL equipment ensuring that it is not compromised by competition among TLC companies. Accreditation of the technical competence of a laboratory to perform specific tasks guarantees confidence in the integrity and quality of the provided services. In order to be officially recognized, a laboratory for DSL equipment testing has to verify specified requirements, by means of standardized procedures. The main issue is defining how and who establishes such specific requirements and procedures.

The Broadband Forum attends these demands by grouping over 200 leading service providers, equipment manufactures and other parties interested in developing the full potential of DSL technology. Through formal liaisons with standardization bodies such as ANSI (American National Standard Institute), ETSI (European Telecommunications Standards Institute), ATIS (Alliance for Telecommunications Industry Solutions) and ITU (International Telecommunication Union), the Broadband Forum develops a series of Technical Reports (TR) that define the core testing for DSL network and customer premises equipment to ensure the interested parties are all working in agreement. The Independent Testing Laboratory (ITL) Program (promoted by the Broadband Forum) is a reference of all worldwide DSL test laboratories that want to improve their competence in validating DSL equipments.

By knowledge of these problems and consciousness of the potentials linked to the development of DSL technology, a *TLC Sannio Testing Laboratory* [1] (Fig.1) was set up thanks to a cooperation between University of Sannio and the Province of Benevento, Italy. The laboratory aims to provide testing services to companies involved in telecommunication equipment manufacturing and, therefore, to contribute to the economic growth of the Benevento industrial district. Main goal of the *TLC Sannio Testing Laboratory* is acquiring competence to gain Broadband Forum accreditation to validate ADSL technologies

Fig. 1. Web site of the *TLC Sannio Testing Laboratory*.

equipments against interoperability test specifications.

To these aims the Laboratory is equipped with (i) a semi-anechoic chamber and suitable instrumentation to carry out electromagnetic compatibility (EMC) measurements, and (ii) instruments and facilities to validate DSL equipments.

The paper focuses on the testing of DSL equipments and the relating activity of the Laboratory which intends to manage the DSL interoperability validation phase with the highest level of automation in order to make the laboratory competitive in terms of efficiency, reliability and repeatability.

After a brief introduction on DSL technologies in Section II, the paper clarifies the importance of the DSL equipment interoperability and how the industry is addressing interoperability in Section III. Finally, the description of test methods and instrumentation of "*TLC Sannio Testing Laboratory*", for (i) assessing DSL interoperability, as well as (ii) the automation of some TR tests, is reported in Section IV.

2. THE DSL TECHNOLOGIES

DSL is one of the best last mile solutions to provide residential and business customers with high speed access. Multiple applications, including new video and voice services, take place over a single copper cable and are enabled by broadband connections through the existing telephone lines. The DSL-related technologies are changing how people communicate, transforming their way of living, working, playing and learning. The international standardizing bodies produced different standards for DSL telecommunications, grouped in the acronym xDSL and reported in Table 1. The reported speed capabilities can be achieved only under ideal conditions. The actual data rates depend on the channel characteristics (i.e., loop length) and noise conditions [3].

Asymmetric DSL (ADSL) is the most commonly adopted DSL standard [4-6]. The asymmetric transfer scheme, with a narrow bandwidth for uplink and a wide bandwidth for downlink, offers high performance for Internet World Wide Web-based services. The demand for Internet access at speeds greater than 56 kbps is growing rapidly, and ADSL fits the need perfectly with the highest compatibility with the existing telephone network facilities.

Asymmetric DSL 2 (ADSL2) [7] is the second generation ADSL and employs new enhancements and solutions, such as data rate adaptation, loop reach performance, loop diagnostics, spectrum and power management.

Asymmetric DSL 2 plus (ADSL2plus) [8] is similar to ADSL2, but effectively increases the potential downstream bandwidth depending on loop conditions. ADSL2 and ADSL2plus support the capability of reserved channels that can provide new applications previously excluded over ADSL. Some examples of such new applications are: (i) video conferencing, which requires special dedicated channels to ensure that all voice and video packets are received; (ii) digital television broadcasting; and (iii) Channelized Voice over DSL (CVoDSL), which allows more than one voice line to be reserved over a DSL connection.

Very high bit rate DSL (VDSL) [11] and VDSL2 [12] are the latest DSL standards and are designed to handle the bandwidth requirements for Triple Play services, such as voice, video, data, High Definition Television (HDTV) and interactive gaming, providing usable rates of up to 100 Mbit/s upstream and downstream.

Table 1. xDSL Standards.

Technology	*Standard*	*Maximum Speed*
ADSL	ANSI T1.413, ITU-T G.992.1/2	8 Mbps down, 800 kbps up
ADSL2	ITU-T G.992.3, ITU-T G.992.4	12 Mbps down, 1 Mbps up
ADSL2+	ITU-T G.992.5	24 Mbps down, 1 Mbps up
SHDSL	ITU-T G.991.2	5.6 Mbps down & up
VDSL	ITU-T G.993.1	55 Mbps down, 15 Mbps up
VDSL2	ITU-T G.993-2	100 Mbps down & up

High bit rate DSL (HDSL) [9] and Symmetric DSL (SDSL) are symmetrical services providing up to 8 Mbps and are widely deployed as leased line replacement for business users.

Symmetric High-speed DSL (SHDSL) [10] is a symmetrical service similar to SDSL but uses an encoding scheme that is more spectrally efficient.

In order to set up a xDSL connection (Fig.2) a Customer Premises Equipment (CPE) interfaces the subscriber network to the copper infrastructure provided by a Network Access Provider (or Local Exchange Carrier). Network Access Providers provide several customers with the data communication by means of specific equipment like the DSL Access Multiplexers (DSLAMs) and the Broadband Remote Access Server (BRAS) at the central office side. Finally, Service Providers enable the access to the high speed services.

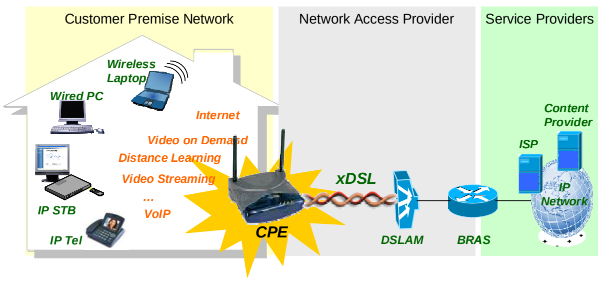

Fig. 2. xDSL access to broadband services.

3. DSL EQUIPMENT INTEROPERABILITY

Effective competition exists in the provisioning of DSL equipments, therefore, verifying conformance to standards and interoperability of CPEs with the existing network devices is a central aspect to promote evolution in DSL technology and market [13]. A wide availability of compliant CPEs motivates manufacturing efficiencies and improves the subscriber experience encouraging the growth of future DSL-based services.

3.1. General Aspects on Interoperability

DSL standards [4-12] define a common interface for products made by different manufacturers so that specified features can be provided to the users. However, the same reference standards can lead to different implementations and products, which are independently developed by different vendors. Therefore, interoperability tests are required to obtain a problem-free integration.

DSL equipment Static Interoperability means that DSLAM and CPE have to support a common and compatible set of actions. DSL equipment should interoperate properly with the same features, functions, and options when used in combination with one another in a ideal environment (i.e., loop of null length and without channel noise).

DSL equipment Dynamic Interoperability means that a couple CPE-DSLAM supports common features, functions and options in an actual network where the operating conditions, the loop length, the noise type and level can change.

The Broadband Forum promotes interoperability by establishing a series of Technical Reports (TRs) that allow sharing information and experience and providing the terminology, the test parameters and the interoperability criteria for various DSL specifications. For example, TR-023 [14] provides an overview of ADSL Testing, TR-067 [15] is the ADSL Interoperability Test Plan and TR-100 [16] is the ADSL Interoperability Test Plan designed to specifically test ADSL2 and ADSL2+ equipment. Moreover, Broadband Forum activities include independent testing through a number of recognized Independent Test Laboratories (ITLs) around the world that undertake robust testing according to the Broadband Forum's test plan specifications.

3.2. Independent Test Laboratory Accreditation

In order to become a recognized ITL [17] a test laboratory must agree to comply with a minimum set of technical and quality requirements [18] specified by the Broadband Forum and needed for DSL interoperability testing. Accreditation assessment of a DSL interoperability test laboratory gives credibility and consistency to the quality of the activities carried out by the laboratory. The requirements of the Broadband Forum include confidentiality, test quality, and use of standardized test plans and reports. In order to access to the ITL program, a laboratory must be a voting member in the Broadband Forum. The Forum first nominates the laboratory as a testing facility for DSL industry. The nominated laboratory needs to participate in the development of the test plans, test criteria, and other elements defined in the ITL contract. Then, the laboratory must agree to follow the developed methods in order to become a recognized ITL. Each laboratory determines the equipment it needs to support the minimum set of requirements.

The Broadband Forum advertises the recognized ITL laboratory, its program and running projects on a public web page. Currently there are six companies participating in the Broadband Forum's ITL program: TRaC-KTL [19], CETECOM ICT Services GmbH [20], Fraunhofer Institute [21], LAN Digital Applications Laboratory [22], Telcordia Technologies [23], and Telecom Italia Lab [24]. These labs can test a DSL equipment to ensure it meets with the requirement of the Broadband Forum TR. The general objective of any ITL laboratory is to enable telephone service providers to gain more satisfied broadband access subscribers, whereby more DSL CPE and associated services can be sold. ITL-based DSL interoperability testing program reduces manufacturer's overall cost for testing because it improves testing efficiencies and avoids duplicative testing that equipment manufacturers undertake across their various customers. So CPE vendors are interested in obtaining the results of their interoperability testing from a qualified ITL and DSL service providers usually choose certified CPEs to be used in their networks.

3.3. ADSL Technologies Test Plant

To drive interoperability of ADSL-family equipment the Broadband Forum redacted TR067 and TR100. The two TRs define test plans to carry out CPE/DSLAM interoperability testing. The test plans focus on physical layer testing, and also on the verification of selected higher layer functionalities. The tests stop at Layer3 to not go over the interoperability verification aims. The test plans define dynamic interoperability (performance), specifying simulated network conditions under which interoperability is required. Table 2 reports some TR100 test examples described below.

Table 2. Some tests defined by TR100 test plan.

Physical Layer Test Cases	***Higher Layer Test Cases***
Bitswap Performance Test (TR100 section 7.1)	Packet Throughput Test (TR100 section 8.1.1)
DSL Noise Spikes/Surges Tests (TR100 section 7.2)	Power Cycle Test (TR100 section 8.5)

The *Bitswap Performance Test* evaluates the capabilities of the CPE to manage the bit swap protocol in order to re-deploy the allocation of bits among the subcarriers when a subcarrier is affected by RFI signal.

The purpose of *DSL Noise Spikes/Surges Tests* is to verify that the DSL CPE functionality is not impacted by sudden spikes or surges of noise on the line (i.e., isolated AWGN noise burst, repetitive high level impulse noise, crosstalk noise).

The purpose of the *Packet Throughput Test* is to verify the throughput for a list of provisioned line rates (down/up) using IP Frame transfers of varying length.

Power Cycle Test verifies the behavior of the CPE after restarting. When the power is switched off and on again, the DSL link has to be re-established and higher layers must recover their functionalities, so that sent data are received correctly.

The equipments recommended by the TRs to recreate the network conditions for interoperability tests are detailed below.

1. A loop simulator sets the appropriate loop length (simulation of loop attenuation) required by the tests.
2. A traffic simulator/analyzer with matching network interfaces is used to measure end-to-end throughput, latency and packet loss.
3. Asynchronous Transfer Mode (ATM) switch/router terminates the ATM traffic and allows ATM-to-Ethernet interworking (Fig.3).
4. When the CPE under test has a USB connector only, a PC with USB and Ethernet interfaces is used to forward the CPE traffic to the LAN.
5. Noise sources for both ends of the line (loop simulator integral noise sources or arbitrary waveform generators) set the appropriate noise impairments required by the specific tests.

Fig.3 details one of the test configurations used to test DSL interoperability of CPE with Ethernet interfaces. The scheme is general both for physical layer and higher layer test cases.

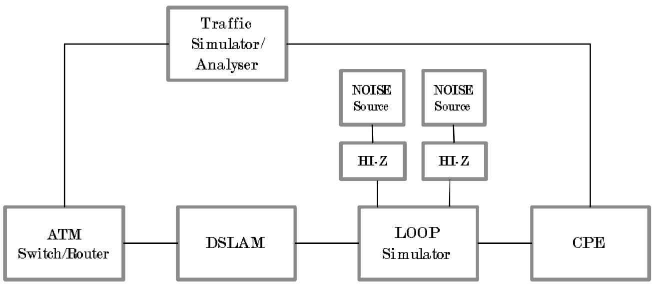

Fig. 3. Test setup for throughput tests for ADSL/ADSL2/ADSL2+ external modems (CPE) with Ethernet interfaces [15].

4. THE "TLC SANNIO TESTING LABORATORY"

The activity of *TLC Sannio Testing Laboratory* [1] fits into this scenario with the aim of becoming a centre for competence and knowledge transfer and to support the local economic and technological development. *TLC Sannio Testing Laboratory* was created within an agreement among the University of Sannio [25], the Province of Benevento [26] and some local ICT companies, (i.e., Telsey telecommunications [27]). The DSL testing program can have important impacts on the Benevento district. The project wants to encourage the University to improve competences and consolidate programs in order to support current technology requirements, supporting training opportunities for students and young engineers and know-how exchanges with local companies. The laboratory is able to attract new ICT corporations to Benevento area ensuring a measurable reduction in product time to market and it can contribute to a pervasive penetration of broadband technology in Campania region and in the southern Italy. First step toward these benefits is to make *TLC Sannio Testing Laboratory* an ITL recognized by the Broadband Forum. The start-up phase schedules (i) the set up of the testing system, (ii) the training of the operators and the engineers who will look after the laboratory activities, and (iii) the definition of DSL test cases and test procedures compliant with the Broadband Forum TR-067 and TR-100 specifications. Moreover, the training phase has to be exploited in order to automate when possible the laboratory activity. Automating the test execution makes the laboratory more competitive on the market minimizing efforts and time consumption and enhancing the reliability of the results. Moreover, it could be possible to enable the remote control of the test stations.

4.1. Test System Setup

TLC Sannio Testing Laboratory test system recreates the actual operating scenario of an ADSL access gateway (CPE). An accurate and repeatable test platform has to simulate network conditions under which dynamic interoperability is required in compliance with standard test specifications (TR specifications). Table 3 lists the instrument capability of the laboratory. The end-to-end ADSL-based network architecture encompasses the CPEs at customer premise and the DSLAM at the central office connected via the copper loop. The DSLAM terminates the ADSL physical layer connection and multiplexes the traffic on multiple DSL lines onto the ATM network. The BRAS is the last IP device between service providers and the customer network as it manages the IP traffic through the layer 2 Access Network (ATM layer). The BRAS provides aggregation capabilities (e.g. IP, PPP, ATM) between the Access Network and the Service Providers and it is also the injection point for policy management and IP QoS. The loop conditions are emulated by means of the Loop Simulator and the Noise Generator/ and noise Injector.

4.2. Test Capabilities

The starting activity of the laboratory has scheduled tests on CPEs manufactured by Telsey telecommunications [27]. According to TR-067 and TR-100 the test plan provided by the *TLC Sannio Testing Laboratory* focuses on physical layer testing and on the validation of higher layer functionalities relevant to interoperability purposes.

In the following, some tests of the TR-067 and TR-100 are presented underlining the equipment and facilities used by the *TLC Sannio Testing Laboratory*. Confidence in the laboratory test setup is ensured by regular calibration of test instruments and DSLAM.

<u>Physical Layer Tests</u>

The *Power Spectral Density Measurement* (TR-067 section 8.5.2) is one of the physical layer tests about electrical performance of CPEs. This test is performed in *TLC Sannio Testing Laboratory* using E4404B ESA-E Series Spectrum Analyzer [28] and a software developed in MatLab environment. The total power over the signal pass band is acquired by the spectrum analyzer and the software averages it in a period of at least 2 seconds and verifies that each PSD falls within the limits specified in the reference standard [5, 7].

CPE *Margin Verification Test* (TR-067 section A.2.1) verifies if BER<1.5e-7 for several loop and noise scenarios to ensure that chipset vendors do not optimize CPE performance for some specific conditions. The loop length simulation and the noise injection necessary for this test are performed by (i) the Spirent DLS 410 Loop Simulator [29] that allows to realize the test for Dynamic Interoperability on different loops (length, briged tap), and (ii) the Spirent DLS 5500 Noise Generator and the DLS5405 Noise Injection Unit [30] to apply white noise, Radio Frequency Interference or cross-talk at both the ends of the total loop.

Table 3. *TLC Sannio Testing Laboratory*: List of Instruments.

Instrument	***Role***
Spirent DLS 410	Loop Simulator
Spirent DLS 5500	Noise Generator
Spirent DLS5405	Noise Injection Unit
Agilent N2X	Traffic Generator/Analyzer
Agilent E4404B ESA-E Series	Spectrum Analyzer
LeCroy SDA600	Serial data Analyzer
Tracespan DSL Xpert 2208A	DSL Analyzer

Higher Layer Tests

Among the tests that do not operate at the physical layer, the *Packet Throughput Test* (TR-067 section 9.2.1, TR-100 section 8.1.1) and *Packet Latency Test* (TR-067 section 9.2.2) involve the Layer 3 (IP layer) of the protocol stack. The first one verifies the throughput for a selected list of provisioned line rates (down/up) using IP Frame transfers of varying length (the test passes if the percentage of frames achievable is 85%) and the second one measures if the round trip time of the given transmission chain is less than 255ms. In order to perform these tests *TLC Sannio Testing Laboratory* is equipped with the Agilent N2X [31] working as (i) traffic generator to inject on the link an information flow useful for the performance evaluation, and (ii) analyzer system capable to elaborate the significant parameters about transmitted and received data to estimate the CPE performance.

4.3. Test Automation

Creating an automated test is, usually, a time-consuming activity for a laboratory. However, automated tests have a lot of benefits in the long period. Some test steps can be performed remotely through software commands or automated using scripting programs. Eliminating work-intense and error-prone manual actions, automated tests not only increase testing capabilities, but minimize errors due to incorrect configurations and commands. So, spending time and resources to develop a software tool that controls the instruments remotely and executes the steps of a test can gain durable advantages.

To this aim a virtual instrument in Visual Basic (VB) automating some of the TR067 and TR100 tests has been realized.

A graphical user interface, based on menus, allows users to perform testing without remembering the test configurations, without accessing the test instruments separately, and gives always a feedback about the test results on the display. Detailed log files are generated for each test performed and allow the user to trace the steps of the automated test and to perform a simple and efficient analysis of the results.

At the moment the automation activity involves physical layer tests (for example TR-067 sections 8.1.2 to 8.1.8) that require a test set up with only CPE under test, noise generator/injector and line simulator to reproduce loop conditions, and DSLAM (Fig.4). The virtual instrument is able to control the DSLAM and the Noise Generator/Injector by a TELNET connection: the VB object MyWinsockControl receives as input the IP address and the remote port used by the two instruments. The communication with the Wire Line Simulator is performed by Serial Port (the VB PortCom object) and allows the tool to set the loop length, to force new initialization or CPE/DSLAM re-synchronization and to accept the noise injection. No interaction with the instruments is required during the test execution, only at the beginning the user has to connect the CPE to the test bench.

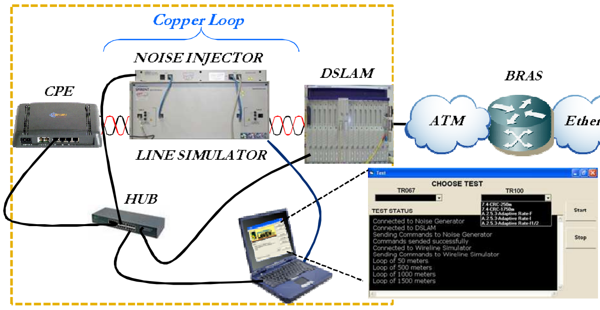

Fig. 4. Automatic test bench: the virtual instrument runs on a PC connected by TELNET to the CPE under test, the DSLAM and the Noise Generator/Injector and by Serial Port with the Line Simulator.

The virtual instrument uses, for example, the following two commands to connect and disconnect the Noise Generator/Injector respectively.

!STX: SET(M_INJ_CONNECT):VAL (1);ETX!

!STX: SET(M_INJ_DISCONNECT);ETX!

In order to control the Wire Line Simulator the following command allows to set the loop length.

:SET:CHAN:LINE <N_Fine> <N_Coarse>

The automatic test bench has been validated in order to assure the reliability and repeatability of the results. In particular, benchmark tests done using known repeatable CPEs (CPEs already tested in another ITL Laboratory), have been performed to compare the results and to demonstrate the reliability of the developed automatic test bench.

An example of automated test: verification of CRC Error Reporting

This subsection discusses a test provided by the *TLC Sannio Testing Laboratory* in automatic way for both ADSL and ADSL2+ (TR067 section 8.1.2, TR100 section 7.4).

This test is able to verify the CRC error reporting in a particular loop and specified noise conditions in case of micro-interruptions (Fig.5, 6).

The block diagram of the developed software for the

```
!STX:SET:(M_INJ_CHAN1_INTERRUPT_LENGTH):VAL(1);ETX!
!STX:SET:(M_INJ_CHAN1_INTERRUPT_EVERY):VAL(10);ETX!
!STX:SET(M_INJ_INTERUPT_TOTAL):VAL(12);ETX!
```

Fig. 5. Commands to control the Noise Generator remotely to force a micro-interruption of the loop with duration of 1ms, every 10s, for a total test time of 120s.

CRC Error Reporting Test is shown in Fig.6. The main steps of the test are: (i) force a new initialization and wait for modems to sync; (ii) wait for 2 minutes after initialization for bitswaps to settle; (iii) force "micro-interruption" of the loop at CPE side with duration of 1ms and repeat this step every 10s, for a total test time of 120s (Signal Period=10s, Test Interval=120s, a total of 12 micro-interruptions are issued). It is expected that a micro-interruption will result in at least one reported downstream CRC error. At least 12 reported downstream CRC errors are expected to pass this test.

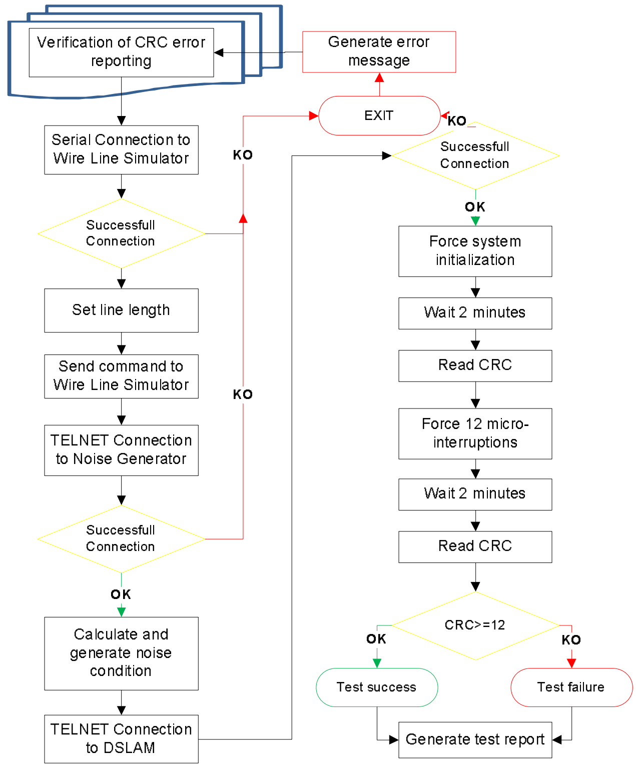

Fig. 6. Verification of CRC error reporting.

The experimental validation for this test was realized verifying the results obtained for a faulty CPE which manages the count of CRC errors incorrectly and a standard CPE which accurately counts and reports CRC errors. Many automatic trials and manual verifications guarantee the reliability of the automatic test.

5. CONCLUSIONS

Certification guarantees high level of confidence about the activities of a laboratory that provides DSL interoperability tests. To obtain certification, a DSL test laboratory has to acquire a high level of specific competences. Moreover, in order to become competitive on the TLC market, a DSL test laboratory has to simplify the test phase in terms of time, effectiveness and productivity by automating the test procedures.

The paper described the experience of the *TLC Sannio Testing Laboratory* relative to these issues. The realized automatic system gives relevant advantages in the cases where the tests have to be run repeatedly. In fact, the tests detailed in the Broadband Forum TRs require many repetitive tasks which computers can handle with speed and accuracy. The developed automated platform could be functional to a future development for a remote access to laboratory. This could make possible, for example, a remote training activity to students or technicians or the access of a customer of the laboratory in order to follow the whole validation phase of a CPE and have the results in real-time.

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