PERFORMANCE EVALUATION PLATFORM FOR xDSL DEPLOYMENT IN A COMPLEX MULTI-SEGMENT ENVIRONMENT

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Abstract:

This paper presents a highly flexible simulation platform catering to the easy and rapid evaluation of existing and future Digital Subscriber Line (DSL) deployments as well as DSL modem performance prediction using practical modem implementations in a complex multi-segment environment. The paper outlines the methodology employed to architect and develop the core software, followed by a description of the performance prediction hooks for a variety of current and future DSL modem technologies. The graphical user interface (GUI) abstracting the core software for the user is described in terms of the various configuration options and the quick and easy graphical design of typical and complex deployment scenarios. The proposed simulator's calculations, notably theoretical SNR margin, maximum theoretical capacity and reach, plus performance evaluation using user-designed modem models, are also outlined. To support the accuracy of the new simulator, results for some example scenarios are presented and compared against other available simulators.

Keywords: *DSL simulator; twisted-pair simulator.*

1. INTRODUCTION

Digital Subscriber Line (DSL) performance is primarily constrained by electromagnetic coupling (crosstalk) of the various DSL technologies traveling along different copper pairs within a common telephone cable. Because each technology used has its own spectral content, the characteristics of the crosstalk from disturbing pairs vary considerably from one DSL deployment to another. Spectral characterization of crosstalk is, therefore, an important tool in determining the viability of different coexisting DSL technologies. Significant efforts in research and experimentation have been made by companies and recommendations committees (such as Working Group T1E1.4 [4]) in characterizing crosstalk and developing standardized test beds to ensure spectral compatibility of systems using different pairs in the same cable binder. Such recommendations are based on worst-case predictions that must be generic enough to be applied to any loop infrastructure. Extensive laboratory and/or field tests to represent a more detailed loop environment can become highly expensive and time-consuming. Furthermore, most hardware simulators that attempt to address these issues are limited in the complexity and number of scenarios they can represent, making detailed analysis of a deployment configuration in the planning phase both cumbersome and inaccurate.

The proposed simulator addresses the limited scope and functionality of current tools by extending their loop geometry capabilities and providing facilities for multi-node crosstalk injection. Hence, disturbers can enter or exit on the telephone cable(s) anywhere along the path between the central office (CO) and the customer premises equipment (CPE), with possibly varying cable binder sizes, cable types, cable lengths, and bridged taps composing the loop topology. Consequently, service providers can evaluate and isolate unsuccessful deployments early in the planning phase rather than in the field so that appropriate cost-effective alternatives can be implemented immediately. This eliminates the potential loss of customers to competing technologies.

Multi-segment environments arise for pairs in a DSL cable when the transceiver units (TU) of the remote terminal (TU-R) or the CO (TU-C) for the victim pair and the disturber pairs are not collocated. A typical case illustrated in Figure 1 shows the disturber pairs of type 1 non-collocated with the victim TU-R and disturber pairs of type 2 non-collocated with the victim TU-C.

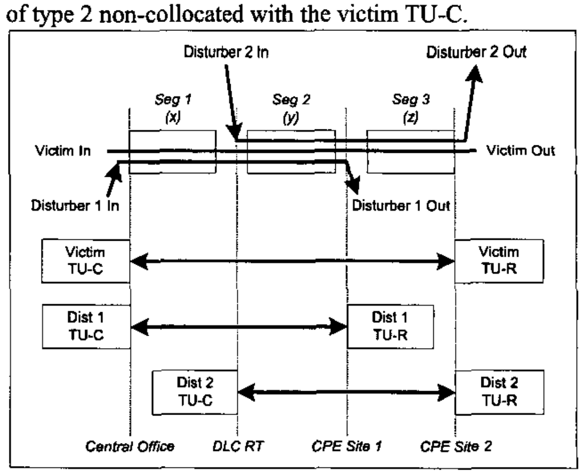

Figure 1: Basic three-segment deployment.

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In the latter, the disturbers may originate from a CO different from the victim's. The deployment shown can be broken up into three segments for analysis with lengths of x, y and z kilofeet (or kilometers). More complicated scenarios could see disturbers non-collocated with the victim at both ends of the victim link.

The proposed simulation software performs acceptability tests and a number of performance calculations for deployment configurations of any number of segments. The deployment environment is configurable in terms of the number and types of disturber systems, disturber pairs, segment types, segment lengths and segment gauges.

2. SIMULATOR ARCHITECTURE

The software reuse concept was applied to architect the channel model, the technology-specific modem implementation under investigation, and a graphical user interface (GUI). Thus, all of these components can operate as independent modules. The GUI was added mainly to simplify the parameter entry to the DSL simulator. Because all of the components function independently of each other, different modem implementations, victim systems, crosstalkers, and platform-specific GUIs can be incorporated into the simulator. A high-level diagram of the simulator is shown in Figure 2.

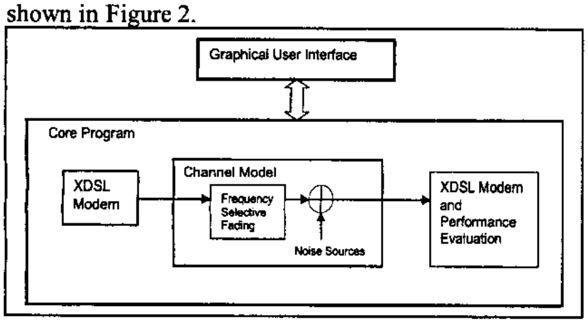


Figure 2: High-level diagram of simulator.

The channel model is completely independent of the modem. It simulates the main phenomena present in a DSL environment: frequency selective fading over twisted-pair copper wires, electromagnetic coupling between pairs in a DSL cable, and external noise sources such as white noise, impulse noise and colored background noise. A database of spectral characteristics for the disturber DSL systems described in [2] and physical line characteristics serve as its basis.

The frequency response of a twisted pair cable varies considerably with the length, wire gauge and environment. Bridged taps located along the subscriber loop, for instance, cause notches at frequencies determined by the tap location [1]. The accepted method for calculating frequency response is the use of transmission-line and two-port network theory. Primary constants of resistance, inductance, and capacitance for copper wires of different gauges [2] are used by the software in the calculation of the frequency response. This method has been employed successfully in many existing hardware-based wireline simulators. Use of software simulation eliminates errors introduced by analog circuitry and allows extendibility for future wire gauges or adjustments made to the current standards. The simulation tool recognizes standard loops (CSA, Mid-CSA, Extended-CSA, ANSI, and EIA) and allows any number of concatenations of these from the CO to the CPE. User-defined configurations can also be entered very easily through the graphical user interface with support for nested bridged taps of any depth and complexity, useful in simulating multi-drop topologies.

For the DSL family of transmission systems the limiting factor on loop range is crosstalk coupling of signal energy from like or unlike transmission systems on other pairs in the cable and not from the end-to-end attenuation of the signal [1]. This coupling is divided into near-end crosstalk (NEXT) and far-end crosstalk (FEXT) depending on the relative positions of the transmitter of the disturbing pairs and the transmitter of the victim pairs. Accurate models for the calculation of the NEXT and FEXT power spectral densities for different disturber systems, number of twisted pairs, loop length, and the combination of these using the FSAN method are used in the development of the software [2]. Annex K of [2] also outlines the modifications that need to be made to these models when multiple crosstalk injection points exist along the subscriber loop, as is often the case in large and complex loop deployments. These multi-segment scenarios are treated seamlessly by the software during simulation, so that the basic model shown in Figure 2 is maintained. The rules established in Annex K of T1.417 require modifications in the coupling lengths for the NEXT and FEXT formulas, as well as further attenuation in the NEXT and FEXT noise samples before adding them to the victim. These rules are applied in a dynamic fashion during initialization of the deployment configuration so that the software is in no way limited by the complexity or size of the multi-segment environment. This allows for the specification of a new test scenario by the user in a matter of seconds, where such a task in a laboratory environment would require several hours or possibly days.

3. SIMULATOR FEATURES

Due to its modularity, the simulator supports a wide range of features, which can be easily extended for more advanced research work. Its main features and calculations are detailed in this section.

3.1. Core Software: Channel and Modem

The calculations performed by the simulator follow the recommendations developed by Working Group

T1E1.4. In particular, spectral compatibility calculations may begin with a theoretical margin calculation using method "B" of [2] (Annex A). Although SNR margin calculations vary according to the DSL technology used, each calculation will require a frequency characterization of the crosstalk and background noise power, and the channel magnitude response, all of which are provided by the channel model portion of the software. The SNR margin, determined through the capacity equation [1], is also used by the simulator to evaluate the maximum theoretical bit rate and loop length, which are generally supported by software simulators and provide more practical metrics from a deployment perspective. Tests were performed for all disturber types specified in [2].

Although calculations based on theoretical capacity are standard practice in deployment analysis, they do not take into account modem-dependant factors such as the loss of orthogonality in a DMT-based system from excessive loop impulse response length or imperfect channel estimation in modem equalization. Such factors are even more significant in a multi-segment environment where the channel impulse response can become significantly long. The calculations are also unable to simulate the effect of impulse noise. Such effects can only be modeled properly on a platform that simulates bit transmission over a channel with each of the disturbances typical of the DSL environment present simultaneously. The software provides such an environment by performing a time-domain simulation of the transmission, using signal processing and probability to convert the spectral mask descriptions derived from the NEXT, FEXT, and background noise models into time domain samples which are free of filtering limitations imposed by hardware simulators. By measuring the actual bit error rate, this simulation allows acceptance testing of a deployment based on the BER criterion of 10^{-7} for most DSL technologies.

In addition, the software supports features, which can be used for analysis, e.g., calculation of the loop's frequency response, impulse response, and display of the crosstalk power spectral densities at multiple locations along the victim. Aside from serving as visual aids for a user interested in analyzing a deployment, they can serve as important simulation aids for research and development.

Support for the basic known background noise sources also exists. The additive white Gaussian noise level is user-programmable and may be turned off. The user may also enter a piecewise-linear colored noise PSD to be used in the performance evaluation. Impulse noise originating from the PSTN, on which the DSL system may reside, is also simulated by the software. Impulse noise profiles [2] have been included and can be modified based on the number of and duration of bursts. Furthermore, the noise sources have been added in a modular fashion so that extension of the software to environments having other known noise disturbances is possible.

3.2. Graphical User Interface

To simplify the deployment-specific parameter entry into the simulator for evaluation, a GUI was designed that wraps around the core program. The various calculations can be selected in the main window, shown in Figure 3.

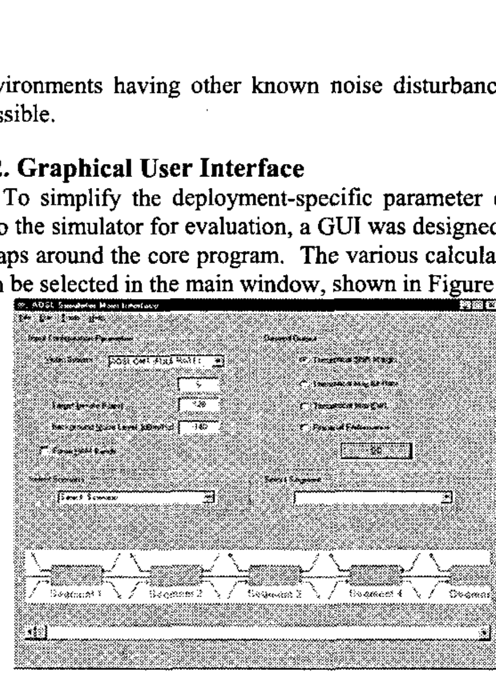


Figure 3: GUI main window.

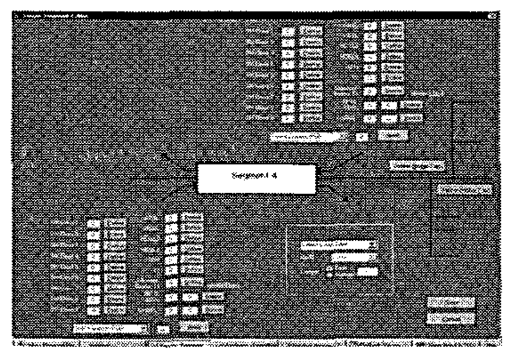


Figure 4: GUI single-segment editor window.

A scenario is created by specifying the number of segments to be used for the loop and then configuring the loop parameters according to the user's requirements. When selecting a segment to be edited, the single segment editor windows opens up (Figure 4) where the user now specifies the segment-specific information such as the loop type from a list of standard loops or by defining a custom segment with user-specified length and gauge. In addition, bridged taps and nested bridged taps are defined for each segment using tabular entry with the resultant structure displayed in this editor window as well as the main configuration window. Disturber information in the downstream and upstream directions is also entered in the single segment editor window. The number of pairs, the entry and exit points and the type of disturbers are all specified for each segment based on the user's loop topology. The main window allows the selection of the desired victim system from a drop-down list of supported technologies.

4. EXAMPLES AND RESULTS

In order to verify the proper functionality of the channel model, the proposed simulator's transfer function generated using two-port network theory was checked against many single and multi-segment loop structures. In addition, the disturber PSDs used in all of the calculations were compared against the theoretical equations and later with the PSDs of the time-domain noise samples generated by the model. These noise samples, intended for use during the modem BER performance evaluation, were free of any significant artificial spectral impurities that could influence the results.

As an example of the types of tests that were performed, Figure 5 reports results for various FEXT and NEXT crosstalk PSDs. The two plots in the top row of the figure show the NEXT and FEXT for 49 SM Class 3 disturbers on a 6000-foot AWG26 segment and the two graphs on the bottom row depict the crosstalk for 49 HDSL disturbers on a segment of the same length and type. Time-domain noise samples were generated and their measured PSDs were validated against the theoretical NEXT and FEXT PSD equations using Welch's spectral estimation method [5].

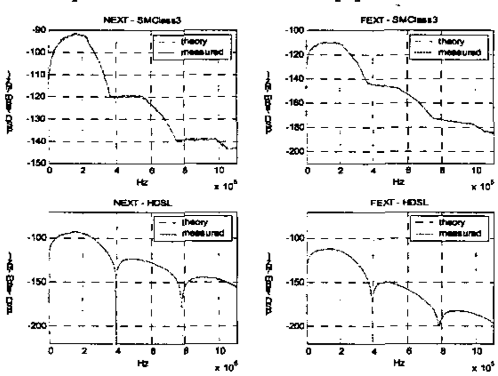
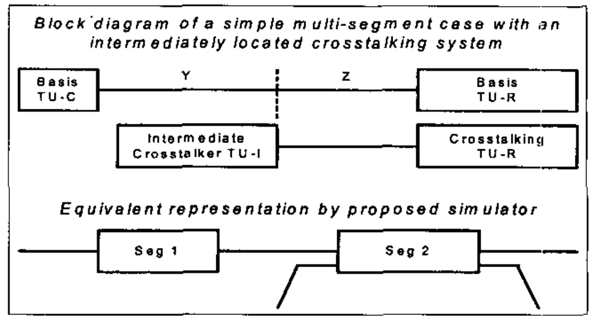


Figure 5: Comparison of theoretical and noise-sample-estimated NEXT and FEXT PSDs.

The capabilities of our simulator were also compared against other available simulators, e.g., [3], at least for the supported calculations: the SNR margin calculation, the maximum theoretical reach and the maximum theoretical bit-rate. Due to space limitations, Figure 6 shows only a few results for the predicted SNR margin calculation. The case presented is for a 2-segment AWG26 Loop with 10 HDSL Disturber Pairs across the entire length of the loop, with 10 ISDN disturber pairs originating from an intermediate TU (see Figure 6). The victim system was ADSL. The agreement between the results was exceptional, with maximum deviations capped at 0.01 dB.



(a) Loop Structure Used

Y (ft)	Z (ft)	Upstream Bit Rate (kbps)	Downstream Bit Rate (kbps)	Telcordia (dB)	Proposed Simulator (dB)
5000	2000	848	4850	***24.01***	***24.01***
8000	2000	553	4595	***32.57***	***32.56***

(b) SNR Margin Results for Upstream (in Bold)

Y (ft)	Z (ft)	Upstream Bit Rate (kbps)	Downstream Bit Rate (kbps)	Telcordia (dB)	Proposed Simulator (dB)
5000	2000	848	4850	***23.19***	***23.19***
8000	2000	553	4595	***6.53***	***6.53***

(c) SNR Margin Results for Downstream (in Bold)

Figure 6: Example SNR margin calculations.

5. CONCLUDING REMARKS

A highly flexible simulation platform was presented in this paper that allows the performance verification of new and existing DSL transmission technologies. The developed tool has been found to perform well for the DSL environment for which it was originally designed. Future work on this project will most likely continue on the same path of wireline communications in order to establish new results with variants of ADSL, VDSL and technologies based on multi-input multi-output (MIMO) DSL for broadband Ethernet for the first mile (EFM). An eventual enhancement of the platform toward broadband wireless channel environments is also planned.

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