Improving the Performance Evaluation of ADSL systems by using a Modem Diagnosis Methodology

Jacklyn Dias, Igor Negrão, Agostinho Castro, João C. W A Costa, Gervásio Cavalcante, Jaume Rius i Riu, Klas Ericson, Fredrik Lindqvist

***Abstract*— This paper presents test methodologies to measure and evaluate performance of ADSL modems which take into account loss of packet rate, bit rate, and latency in transporting ADSL service scenario. This evaluation method can be used by ADSL provider (CO - Central Office) to guarantee the system quality and avoid low performance of service. In order to present this evaluation method, this paper considers a traffic generator, modems under test, a telephony local loop carring ADSL service, and DSLAM as the lab setup to perform such tests.**

***Index Terms*— Loop qualification, digital subscriber line, costumer premises equipments, performance evaluation.**

I. Introduction

Although there are some communications systems that claim to be the solution for providing high bit rate access to residential customers, the last mile dilemma still continues to be a problem. The major concern about this problem is related to the costs of the new infra-structure can demand in order to deployment of a new communication system. In this context, the utilization of the twisted copper wires of Plant Old Telephone Systems (POTS) is being widely exploited for providing high bit rate Internet access. Such scenario use the so called the digital subscriber line (DSL) [1] access technologies that has grown from just a few million lines in the beginning of 2000 to over many million lines in last year. Brazil is following this tendency and it is ranked in 12th position in global broadband DSL growth.

With these technologies, bit rates about 25 Mb/s and 2.5 Mb/s for downstream and upstream, respectively, in an Asymmetric Digital Subscriber Line 2+ (ADSL2+) [2], may be achieved which are sufficient to residential and some business applications. The ADSL performance is dependent basically on: subscriber local loop interference, such as noise and crosstalk; status of local loop [3] [4]; number of subscribers present at the same binder; performance of DSLAM's (Digital Subscriber Line Access Multiplexer) and costumer premises equipments (CPE). Additionally, the quality and performance of ADSL service is directly dependent on the CPE modem which is the goal of this paper. Furthermore, the target bit rate provided by the Central Office (CO) to the CPE modem will be satisfactory if CPE modem is up and running properly. The quality and performance of ADSL service may be measured and evaluated taking into account some variables and methods to measure and evaluate the CPE modem performance. To perform such tests, data rate and data delay will be fulfilled in order to evaluate the capabilities of CPE modems under tests to support ADSL transmission. For these tests, we will use three ADSL2+ CPE modems from different manufactories.

It is well-know that major DSL vendors have been working to combine VDSL2 (Very High bit rate DSL) technologies with the advances made for ADSL2+ on the same multi-DSL chipset. This integrated technology enables service providers to achieve higher data rates within their networks to support lucrative new triple play services (voice, data, and video). To deliver triple play services, service providers need to deliver maximum bandwidth. The local loop and CPE modems must support sufficient bandwidth and functionality to enable triple play services to be successfully delivered to the consumer. Testing the CPE chipsets, modems and interoperability with DSLAM line cards requires wireline simulators and noise impairment generators to emulate the copper local loop and various impairments such as crosstalk within a cable binder and radio frequency interference. This paper is aimed at testing CPE modem performance using wireline simulators, DSLAM, and a traffic/analyzer generator [5].

The present paper is organized as follows. The methodology that will be followed to perform such tests are analyzed in Section II comprising the testbed used in the lab in order to apply the methodology as well as CPE modems, variables, local loops, uncertainty analysis. Measured results and analysis of the CPE under tests are addressed in Section III. Section IV presents the main conclusions and further directions.

II. Methodology

To evaluate CPE modem performances, we submitted them to traffic such as IP (Internet Protocol) packets and compare the results of traffic achieved by the CPE under test to a reference, for example a CPE modem emulator or other reference modem. In this case, such comparison is made by analysis of four traffic variables. In order to provide this quality of service (QoS) tests required by triple play services, we have used some equipments that help to reproduce a real scenario for evaluating and measuring such as wireline simulators, DSLAM and traffic/analyzer generator. In the following, we will define the lab setup, the traffic variables which will be measured, local loops under test and describe the equipments that we will use for the experiments. Uncertainty determination and analysis are also fulfilled in this section.

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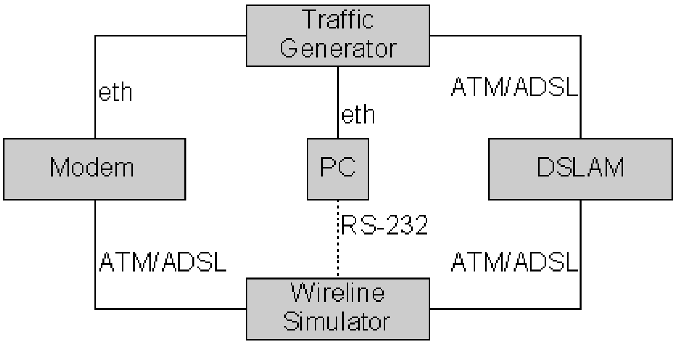

Fig. 1. Measurement Setup for Modem Performance Test.

A. The Testbed

In order to specify the measurement setup we have reproduced the setup specified in [6] with a little modification. In the case of this paper, we have not used a noise impairment generator, because we want to make a QoS test which provides an easier way to analyze the results, considering only the local loop effects. The CPE modems are connected to the traffic generator to analyze the downstream and generates the upstream traffics. Fig. 1 shows the measurement setup at our lab.

As we could see, the traffic/analyzer generator is responsible to provide downstream and upstream traffics. The ADSL wireline simulator [7] simulates a local loop to be used in the experiments. Keeping in mind that we are looking for a modem performance evaluation, thus we intend to make the customer promises equipment as the bottleneck and not the service provider (Central Office) represented by DSLAM. Furthermore, it is worth pointing out that our DSLAM, that is the equipment responsible to transmit ADSL/ATM (Asynchronous Transmission Mode) signals through local loop forward the customer, is configured to provide up to 20Mb/s and 2Mb/s bit rates for downstream and upstream, respectively, assuring that CPE modem will be stressed. The PC is responsible to manage the experiment via software.

1) Modems To Be Tested: We have chosen three different modem manufactories to be tested that are available in the commerce nowadays. Thus, we intend to compare the QoS of these modems. All the CPE modems that we have chosen are able to support ADSL2+ standard, the goal of this paper is to provide methods and techniques to performance evaluation for ADSL service providers, therefore the manufactories will not be mentioned in this paper. The CPE modems will be indicated by CPE A, CPE B, and CPE C.

B. Measured Variables

In order to provide a CPE modem performance evaluation and tests, we have chosen some variables which will be compared to a reference, e.g. a modem emulator. In this paper, CPE modem emulator will not be used as a reference, thus the results achieved by CPE under test will be compared to each other (CPE A, B, and C). These test will comprise four variables: Packet Rate (IP Packet Rate transmitted by DSLAM), Bit Rate (achieved by CPE), Lost Packet Counter (number of packets that were lost, less out-of-sequence packets) and Maximum Transfer Delay (maximum transfer time in milliseconds since the analyzer was started). By analysis of such measurement results, the modem performance evaluations will be fulfilled through comparison. Besides generating the traffic, the traffic generator it is also responsible for analyzing all the results.

TABLE I
TRAFFIC/ANALYZER GENERATOR CONFIGURATION

Fixed Variables	Upstream	Downstream
Packet Rate	125.47 p/s	1245.03 p/s
% Max. Bandwidth	1.00	10.00
% Max. Load	1.02	10.20
Datagram Bit Rate	981.64 kb/s	9780.98 kb/s
Line Bit Rate	999.71 kb/s	10000.11 kb/s
Packet Length	1000 bytes	1000 bytes

Table I shows the traffic generator's transmission setup for experiments. Thus, it is very clear that data rate and data delay achieved by CPE under test will be worst than transmitted one because such scenarios will introduce loss in the system.

C. Local Loops

In order to provide test local loop for the experiments, this paper have taken into account the Telebrás standard for Brazilian loops [8]. Then, two different local loops will be used in the measurements. These test local loops are shown in Fig. 2. The reader should note the gauge and length difference between two test local loops used in the measurements; this assumption makes possible to analyze the CPE performance differences for local loop with different physical and electrical characteristics.

D. Calculation of Uncertainty of the Measured Data

In order to predict the uncertainty of such results, a brief discussion related to statistical methods for experimental data processing [9] is presented. It is worth pointing out that the traffic/analyzer generator was configured to provide a normal distribution of data, that is, the arithmetic mean of the observations may be taken as an estimate of the true value of the measured quantity. The error of a measurement is defined as the difference between the estimate of a quantity (measured value) and the true value (real value) of that quantity; that is $e = V_{MEA} - V_{REAL}$.

However, this error definition cannot be used in this paper for the simple reason that the true value of the measurable quantity is always unknown because we are dealing with random quantities. For this reason, we shall consider the true value of the measurement as the arithmetic mean of that quantity defined in the following equation.

$$V_{MEA} = \bar{x} = \frac{1}{n} \cdot \sum_{n}^{i=1} x_i \tag{1}$$

In order to completely characterize the measured result, it should be estimated the variance ($S^2(x_i)$) and the standard

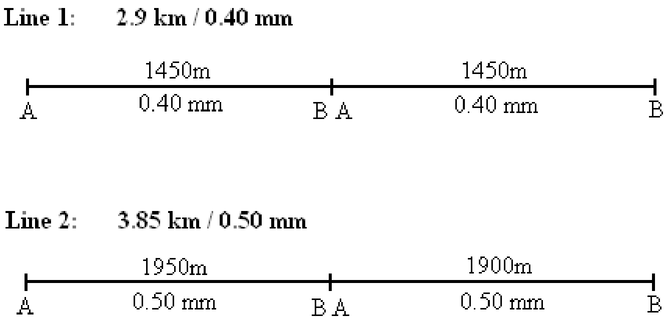

Fig. 2. Local Loops of Telebrás Standard.

deviation ($\sigma(x_i)$) of the observations for a normal distribution which are defined bellow.

$$S^2(x_i) = \frac{1}{n(n-1)} \cdot \sum_{n}^{i=1} (x_i - \bar{x})^2 \qquad (2)$$

$$\sigma(x_i) = \sqrt{S^2(x_i)} \qquad (3)$$

However we are interested in the values related to the arithmetic mean, thus we are looking for the standard deviation of the mean which will be taken as the uncertainty of the result as follows.

$$u(\bar{x}) = \sigma(\bar{x}) = \frac{S(x_i)}{\sqrt{n}} \qquad (4)$$

The uncertainty equation above should be followed by its confidence interval which is the interval that includes, with a prescribed probability called the confidence probability (α), the true value of the measured quantity. The confidence interval is constructed based on Student's distribution, which is the distribution of the quantity $t = \frac{\bar{x}-A}{\sigma(\bar{x})}$, where A is the true value, $\sigma(\bar{x})$ is the estimate of the standard deviation of the arithmetic mean. Therefore, $[\bar{x} - t_q\sigma(\bar{x}), \bar{x} + t_q\sigma(\bar{x})]$ is the confidence interval which corresponds to the confidence probability $P\{|\bar{x} - A| \leq t_q\sigma(\bar{x})\} = \alpha$, where t_q is the q percent point of Student's distribution. In this paper, the confidence probability will be taken as $\alpha = 95.45\%$ which corresponds to $t_q = 2$, thus the confidence interval will be $[\bar{x} - 2\sigma(\bar{x}), \bar{x} + 2\sigma(\bar{x})]$.

III. Analysis The Results

This section presents the measured results obtained from CPE modem performance evaluation taking into account the variables discussed in previous sections. Each CPE modem has been tested ten times throughout one hundred seconds; therefore the final result was obtained from mean of ten measurements. The test time of one hundred seconds was chosen in order to decrease the effects of dynamics errors, the error which is caused by inertial properties of the measuring devices [9].

It is worth pointing out that two scenarios were taken into account; *Local Loop 1* and *Local Loop 2* as mentioned in Section II-B.

A. Data Rates Achieved by CPE Modems

From the rates achieved by the CPE, we can conclude about the best performance CPE modem for ADLS transmission.

It should be emphasized that these rates are related to downstream and upstream packet rate from traffic/analyzer generator configured according to Table I.

1) Packet Rate: This sub-section presents the results obtained from *Packet Rate* measurements as summarized in Figs. 3 and 4 for Local Loop 1 and 2, respectively. The transmitter was configured to provide a target packet rate of 1245.03 packets per second for downstream and 125.47 packets per second for upstream. According to result for Local Loop 1, we could conclude that CPE C exhibited the best performance considering the downstream and upstream packet rate reached, that is the mean of CPE C packet rate, downstream was about 1100 p/s and upstream was about 118 p/s, has been closer the target than others CPE modems. The results show that some packets was lost during the test. After CPE C, CPE A has gotten better packet rate than CPE B which has exhibited the lower performance according to packet rate reached.

In Loop 2, it is possible to see CPE B has been better than CPE A in downstream packet rate, CPE B reached about 830 p/s while CPE A reached about 770 p/s. For upstream packet rate, CPE A has remained better than CPE B, however both CPE A and B have stayed lower performance than C in overall results.

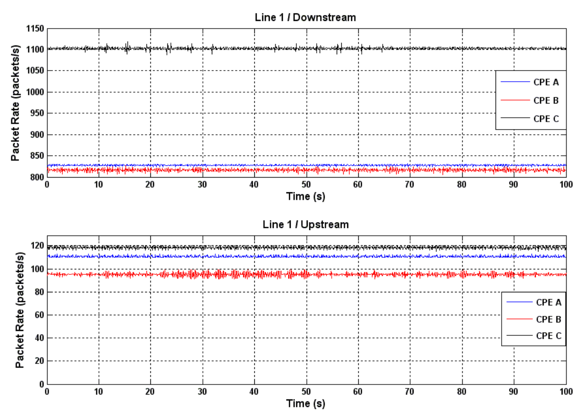

Fig. 3. Packet Rate for Loop 1.

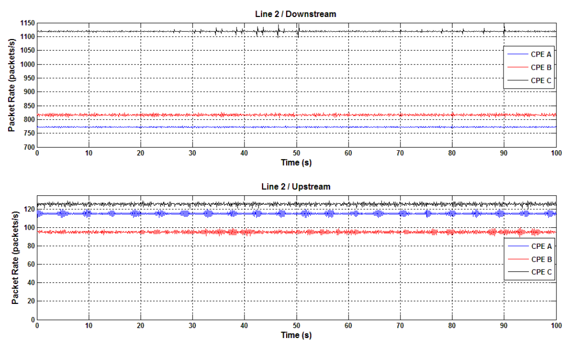

Fig. 4. Packet Rate for Loop 2.

It is worth pointing out that following variables, bit rate and lost packet counter, depends on packet rate. Bit rate reached by the CPE modems under test is equal to packet rate times packet length in bits, and lost packet is equal to lost packet rate. Therefore, following results for these variables should exhibit in the same way CPE C with the best performance.

2) Bit Rate: As it has already been discussed, CPE C ought to reach the highest bit rate, it stayed about 870 kb/s while CPE A stayed about 650 kb/s and CPE B about 640 kb/s for downstream. The results are shown in Figs. 5 and 6 for Local Loop 1 and 2, respectively. The transmitter was configured to provide a target bit rate of 9780.98 kb/s for downstream and 981.64 kb/s packets per second for upstream as summarized in Table I.

3) Lost Packet Counter: The results obtained from *Lost Packet Counter* measurements are summarized in Figs. 7 and 8 for Local Loop 1 and 2, respectively. According to such results for Local Loop 1 and 2, CPE C exhibited the best performance because it lost less packets than the others CPE modems in downstream and upstream, C lost about 15 packets while A lost about 43 and B lost about 44 packets for downstream in Loop 1. The reader should note the highest variance for CPE B in upstream. In Loop 2, CPE B lost less packets than CPE A how it was discussed in Section III-A.1.

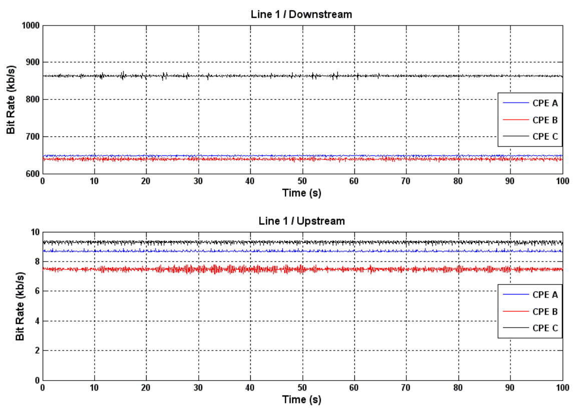

Fig. 5. Bit Rate for Loop 1.

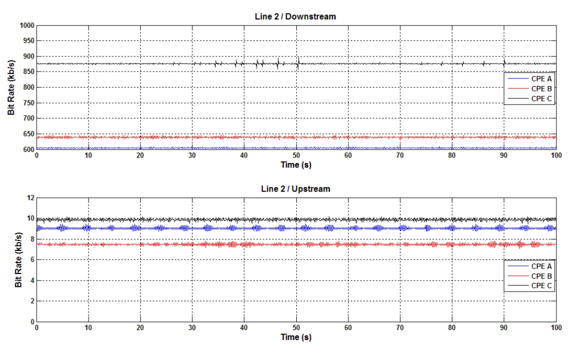

Fig. 6. Bit Rate for Loop 2.

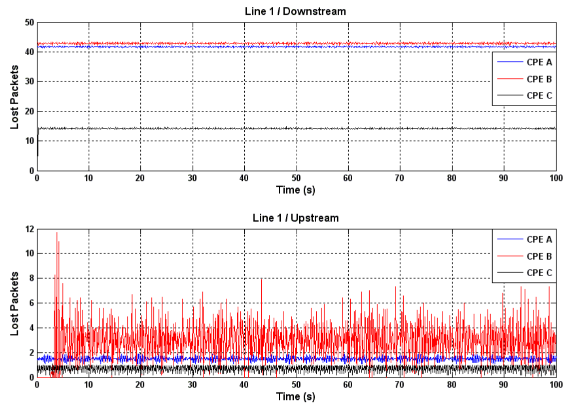

Fig. 7. Lost Packets for Loop 1.

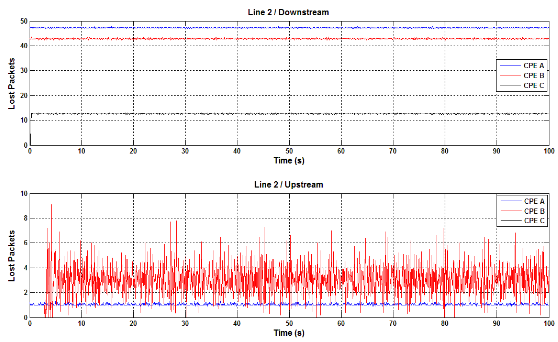

Fig. 8. Lost Packets for Loop 2.

B. Data Delay

Finally, the results obtained from *Maximum Transfer Delay* measurements as summarized in Figs. 9 and 10 for Local Loop 1 and 2, respectively. As could be seen in Fig. 9, CPE C reached lower delay than CPE A and B for downstream, however, in upstream CPE A was the best in Loop 1. In Loop 2, CPE C obtained the lowest delay in downstream which was almost similar to CPE A. The maximum transfer delay acquired by CPE C in upstream for Loop 2 was about 50 ms. Analyzing all the results, we may conclude that the measured variables indicated CPE modem C as the best CPE taking into account such test scenarios. It achieved the highest data rate and the minimum data delay. CPE modem A was better than CPE B.

C. Uncertainties Results

In order to find the uncertainties of such evaluation performance results, it follows Table II and Table III including the uncertainties for the variables (data rate and data delay) results achieved by the CPE modems for two test local loops. It is worth pointing out that the confidence probability was taken being 95.45% which corresponds to $t_q = 2$.

TABLE II
UNCERTAINTY RESULTS FOR LOOP 1.

	CPE A		CPE B		CPE C	
	Down	Up	Down	Up	Down	Up
Packet Rate (p/s)	0.08	0.04	0.21	0.11	0.18	0.07
Bit Rate (kb/s)	6.29	0.35	16.32	0.84	13.76	0.54
Lost Packet (p)	0.009	0.012	0.014	0.100	0.031	0.016
Max. Transfer Delay (ms)	0.032	0.004	0.082	5.123	0.096	0.023

TABLE III
UNCERTAINTY RESULTS FOR LOOP 2.

	CPE A		CPE B		CPE C	
	Down	Up	Down	Up	Down	Up
Packet Rate (p/s)	0.10	0.12	0.2	0.1	0.18	0.10
Bit Rate (kb/s)	7.56	0.93	15.93	0.81	13.80	0.75
Lost Packet (p)	0.010	0.005	0.013	0.093	0.037	0.000
Max. Transfer Delay (ms)	0.022	0.004	0.080	5.025	0.102	0.026

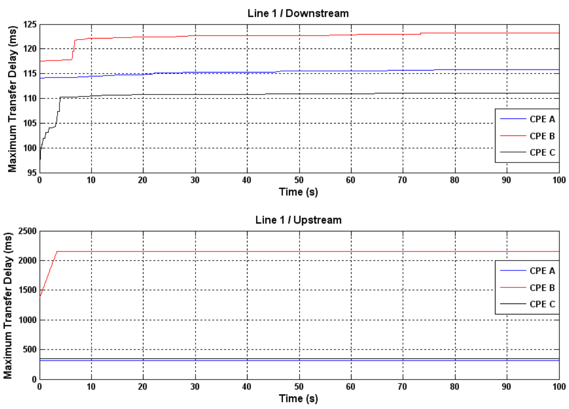

Fig. 9. Maximum Transfer Delay for Loop 1.

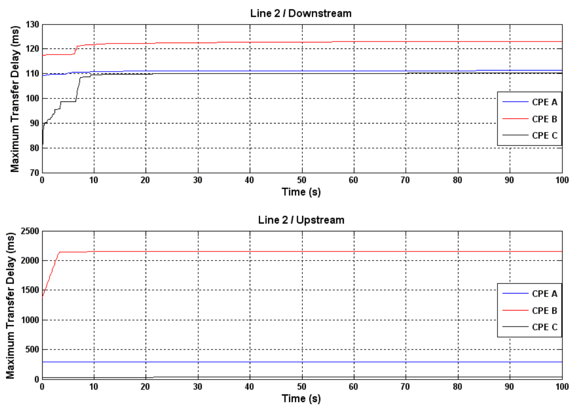

Fig. 10. Maximum Transfer Delay for Loop 2.

IV. CONCLUSIONS

The performance evaluation of ADSL systems may be interpreted as analysis of some parameters of service delivered to the customer. In this way, Telecom Operators must be able to guarantee a particular level of quality of service to their customers. In this context, many performance criteria can be used in order to characterize the service which include: availability of service, error performance, response time and throughput, lost data and speed of fault detection and correction, radio interference and crosstalk level. However, in general, these criteria are evaluated considering that all system devices work appropriately. In this way, the local loop and CPE modems must support sufficient bandwidth and functionality to enable services to be successfully delivered to the consumer (with QoS). If, for example, CPE modems do not work properly, it is become impossible to have a satisfactory performance of service offer to customers even though the performance criteria are in accordance with the required service level agreement. In order to consider this issue, this paper presented a method for improving the performance analysis of ADLS systems by using a modem diagnosis methodology. From the results presented here, the proposed methodology is based on: establishment of a testbed with adequate equipments (traffic generator, wireline simulator); adequate choice of parameters or variables of the system (this step is very sensitive in the performance evaluation process because inadequate variables or parameters can lead to incorrect analysis of performance). From the results presented in this paper, we conclude that the choice of Packet Rate, Bit Rate achieved by CPE, Lost Packet and Maximum Transfer Delay can be used in the analysis of performance evaluation of CPE modems as well as the data processing should include the mathematical treatment in order to estimate the uncertainty of measured data.

Telecom Operators should have in mind that such test and performance evaluations, in order to provide QoS, are kept up with errors and uncertainties that may mask the result, therefor it is better to know the reliability of such results. This reliability is carried out by uncertainty determination. With this uncertainty, the ADSL providers could find out the interval (with a certain probability) where the result is within. It is worth emphasizing that there are a lot of uncertainty contributors, however, in this paper was fulfilled just the uncertainty introduced by the variance of the results (random quantities with a normal distribution). Additionally, uncertainty information about the results of tests and evaluations of CPE modems gives to the Telecom Operators the knowhow needs to guarantee that ADSL service will be delivered with high quality and performance to the customer.

Further direction is aimed to include real cables, a campus network and a city telephone city.

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