Impact of Non-Stationary Noise on xDSL Systems: an Experimental Analysis

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ABSTRACT

Broadband services require data rates that can only be achieved by using relatively high spectrum frequencies. At such high frequencies, the DSL (Digital Subscriber Line) signal is more susceptible to external noise sources, such as radio frequency interference and impulsive noise. This paper aims to characterize how the impulsive noise impacts on services and applications for a broadband system using an ADSL2+ loop. The first approach was to use the impulsive noise defined in the standards G.996.1 (Test Procedures for DSL Transceivers) from ITU-T and TR-048 (ADSL Interoperability Test Plan) from DSL Forum. In this approach we have also used a HDSL (High Bit Rate DSL) and white noise disturbers on the line. The impulsive noises c1 and c2 (defined in G.996.1) are injected into the circuit at the CO (Central Office) end and CPE (Customer Premises Equipment) end of the loop simulator. Additionally, it was analyzed the spikes of noise's impact on the ADSL2+ line. In this case, pre-defined models of NEXT (Near-end crosstalk) and white noise are injected on CO and CPE side, simultaneously. Metrics like packet rate, lost packet count, bandwidth, short-term average transfer delay, and errored seconds are used to characterize the DSL loop under the noise impairments.

Keywords: broadband networks, nonstationary noises, DSL systems, measurements, test procedures.

1. INTRODUCTION

Users have become more and more accustomed to the availability of broadband access. Broadband access refers to a variety of advanced transmission methods that allow high speed access to the end users. Broadband is not just internet access. It brings a big group of new services. Many new services are based on multimedia applications, such as voice over internet protocol (VoIP), video conferencing, video on demand (VoD), and internet protocol television (IPTV). IPTV and others services uses digital broadband networks such as ADSL2+ (Asymmetric DSL) and VDSL (Very High Rate DSL) for transmit data. Once DSL use relatively high spectrum frequencies, its signal is susceptible to external noise sources. Thus, the understanding about the behavior of different kinds of noise and their effects on network performance are extremely useful on the design of well established DSL systems (ADSL, ADSL2+) as well as those of upcoming generation (VDSL, VDSL2).

During the last years, crosstalk has been considered the major impairment to DSL services. However, other types of noise have gained importance, such as radio frequency interference (RFI), impulsive noise (IN), repetitive electrical impulse noise (REIN), and isolated burst of electrical noise (IBEN) among others [1] [2]. Particularly, there are some investigations about the RFI impact in xDSL communications. In [3] the authors detail a theoretical approach, and describe a corresponding implementation, to mitigate strong narrowband RFI in the analog domain, i.e., before the modem's ADC (analog-to-digital converter). In [4] and [5] the authors have presented a digital frequency domain RFI cancellation scheme for DMT (Discrete Multitone) based VDSL systems. In [6] is presented two novel narrowband and wideband common mode noise cancellation techniques for xDSL systems.

IN has been investigated for many researches for a long time. In [7] is presented the cell error performance of ATM over

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DSL in the presence of IN. In [8] is reported an analysis of errors statistics of transmitted data for ADSL and SHDSL (Single-Pair High Speed DSL) in the presence of IN. In [9] the authors have presented a framework for estimation of data errors due to IN in xDSL systems, where the analysis is based on a DSL-oriented impulsive noise model derived from studies in the German and British telephone networks. In [10] the author has simulated an ADSL transmission performance under the impact of the IN and he has showed results for channel error characteristics for AWGN (Additive White Gaussian Noise) and IN impairments.

In spite of the many investigations have been done about the impact of non-stationary noise in DSL systems, just few studies have been conducted addressing their impact in terms of experimental analysis. This may be credited to the inaccessibility to a proper infrastructure to handle practical experiments. For this purpose, an experimental setup was built at UFPA that consists of noise generator, traffic generator, wireline simulators, modems and DSLAM (digital subscriber line access multiplexer).

This paper aims to characterize how the IN impacts on services and applications for a broadband system using an ADSL2+ loop. Additionally, the impact of spikes of noise on ADSL2+ loop is analyzed using pre-defined models of NEXT and white noise. The objective of the noise impact experimentation is to observe the behavior of an ADSL2+ system under more realistic but controlled line conditions.

The remainder of the paper is organized as follows. In Section 2, the experimental methodology used is presented, including the equipments, metrics and approaches used to characterize the noise impairment. Section 3 contains the results obtained and conclusions are drawn in the final section.

2. EXPERIMENTAL METHODOLOGY

2.1 Test bed

Test setup used to perform measurements is showed in Fig. 1. Using this setup is possible to simulate an ADSL2+ environment and to analyze its performance characteristics under the noise impairments. Aspects like temperature and humidity are controlled and they do not have effect in the obtained results. The connections between the equipments were done as short as possible.

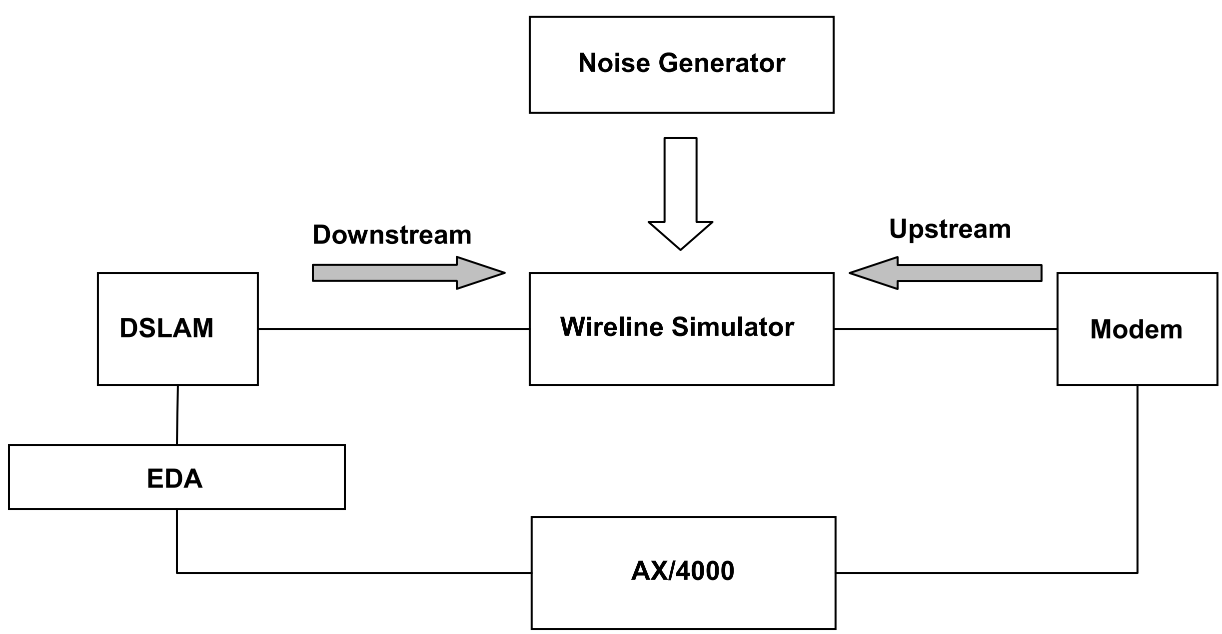

Fig. 1. Test setup used in the measurements.

Equipments used in test setup are described in Fig. 1 and their functions are detailed in Table 1.

Table 1. Equipments and its functions.

Equipment	Function
Noise Generator – DLS 5500 from Spirent Communications.	Generation of IN, white noises and crosstalk.
Wireline Simulator – ADSL2+ ETSI DLS 410E3 from Spirent Communications.	Reproduction of the AC and DC characteristics of twisted pair copper telephony cable using passive circuitry (R, L & C).
DSLAM – Ericsson EDN312xp.	CO functions in the system.
EDA (Ethernet DSL Access) – Ericsson ECN320.	
Modem – Ericsson ADSL2+ Home Gateway HM410dp.	CPE functions in the system.
AX/4000 – from Spirent Communications.	Generation and analysis of traffic (downstream and upstream) in the system.

Traffic generated on AX/4000 was an IP stream with a datagram length of 980 bytes and rates for upstream (798.19 kbps) and downstream (4100.26 kbps), according the ADSL2+ standard [11]. The frequency range used was the ADSL2+: 4.3125 kHz to 2.208 MHz. The loop used on wireline simulator will vary depending on the used approach (see Section 2.3).

2.2 Metrics for performance analysis

Metrics collected were obtained using the AX/4000 and DSLAM. Using two cards of 100 Mbps, the AX/4000 can generate traffic and analyze both data streams: downstream and upstream. The metrics used in this paper are described in Table 2.

Table 2. Metrics used for characterize the noise impairments.

Metric	Meaning
Packet Rate	Number of packets transmitted over run time.
Lost Packet Count	Number of packets that were lost (less out–of–sequence packets).
Bandwidth	Ratio of the current and maximum bit rates. In this case, the maximum bit rate is the rate available on the AX/4000's card (100 Mbps).
Short-term Average Transfer Delay	Average transfer time in microseconds for a given period of 0.1 s.
Errored seconds (ES)	A one-second period with one or more errored blocks/bits or at least one defect.
Severely errored second (SES):	A one-second period which contains ≥ 30% errored blocks. Using bits, it is a one-second period which has a bit-error ratio $\geq 1.10^{-3}$.

Packet rate, lost packet count, bandwidth, and short-term average transfer delay are collected by AX/4000. Using the AX/4000 as a traffic analyzer, the metrics available are for Layer 3 IP (Network Layer) only.

ES and SES are collected by DSLAM and their definitions are according [12]. The definition of the block used in this paper is a set of consecutive bits associated with the path; each bit belongs to one and only one block [12].

2.3 Approach 1 – DSL operation in the IN presence

Two approaches were used in this paper. The first one was based in section 8.8 of [13] and it has the objective of to observe the DSL operation in the presence of IN events. In this case, it is used two kinds of IN defined in [14]: c1 and c2.

The IN interfering signals (c1 and c2) are simulations that are derived from a consideration of real loop conditions and measurements. Because the IN characteristics of the loop plant are not completely understood, the estimation method is based on measured data from several sites [14].

Before testing, the DSL units are trained with the disturber interference defined in [13] and showed in Table 3. The wireline simulator is set to a loop with 2700 m of 0.4 mm wire.

Table 3. Disturbers used for characterize the DSL operation on the IN presence.

Disturber	Characteristic
White Noise	PSD (Power Spectral Density) level of -140 dBm/Hz over the frequency range of 12 kHz to 2.208 MHz.
20 HDSL Next	20 HDSL Next disturbers with the total power (-45.8 dBm) in the frequency range of 0 to 1.544 MHz.

Disturbers are injected at the CO end of the loop, and after the modem training, 20 HDSL Next disturber is lower from the reference level by 4 dB. After verify the ADSL2+ normal operation (traffic is being transmitted and received by AX/4000 and there are not errors in transmission), 15 c1 impulses spaced at least 1 second apart were injected into the circuit at the CO end. It was used two different c1 maximum amplitudes: 50 mV and 100 mV. This procedure was repeated on CPE end. The method described was used for the c2 impulse also.

All the tests are done injecting the IN impairment in t = 20 s. So, it is possible to observe the DSL transmission with and without noise impairment.

2.4 Approach 2 – DSL operation under spikes of noise

Noise analysis was based in section 8.7 of [13] and it has the objective of observing the ADSL functionality under sudden spikes of noise on the line. Table 4 shows the disturbers used in this experiment.

Table 4. Disturbers used for characterize the DSL operation under the spikes of noise.

Disturber	Characteristic
HDSL Next (CO side)	-75.0 dBm in the frequency range of 0 to 1.544 MHz.
White Noise (CO side)	PSD level of -140 dBm/Hz over the frequency range of 12 kHz to 2.208 MHz
24 HDSL Next (CPE side)	24 HDSL Next disturbers with the total power (-45.3 dBm) in the frequency range of 0 to 1.544 MHz.
White Noise (CPE side)	PSD level of -90.0 dBm/Hz over the frequency range of 12 kHz to 2.208 MHz

In this approach, the wireline simulator is set to a loop with 1800 m of 0.4 mm wire. Firstly, the CO side impairments were continuously injected and it has allowed the CPE and DSLAM to train. After verify the ADSL2+ normal operation, the CPE impairments were injected during four different time intervals: 3 s, 5 s, 8 s, and 10 s. During the impairments injection, the metrics were collected.

3. RESULTS

Results for approach 1 are showed in Fig. 2, Fig. 3, Fig.4, Table 5, and Table 6. In Fig. 2, it is showed the downstream packet rate using c1 impulse for 50 mV and 100 mV on CO side. It can be observed that the IN injection has not impact on DSL transmission, once the small variation of packet rate is expected for DSL. There are the same results for upstream traffic, and these results are also observed for three different situations: c1 injection on CPE side; c2 injection on CO side; c2 injection on CPE side.

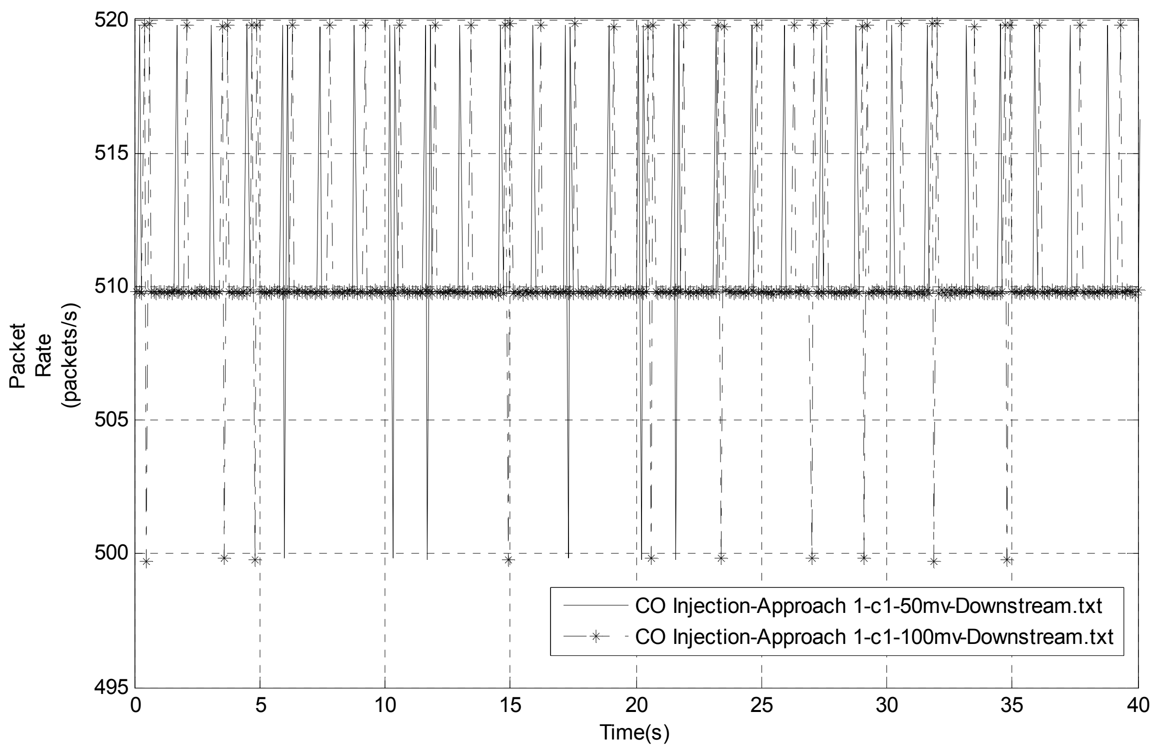

Fig. 2. Downstream packet rate for c1 injection on CO side – approach 1.

Downstream lost packet count using c1 injection for 50 mV and 100 mV on CO side is showed in Fig. 3. It can be observed that c1 impulse does not cause any lost packet on transmission. Like the packet rate metric, this same behavior happens in upstream traffic and in others three different situations: c1 injection on CPE side; c2 injection on CO side; c2 injection on CPE side.

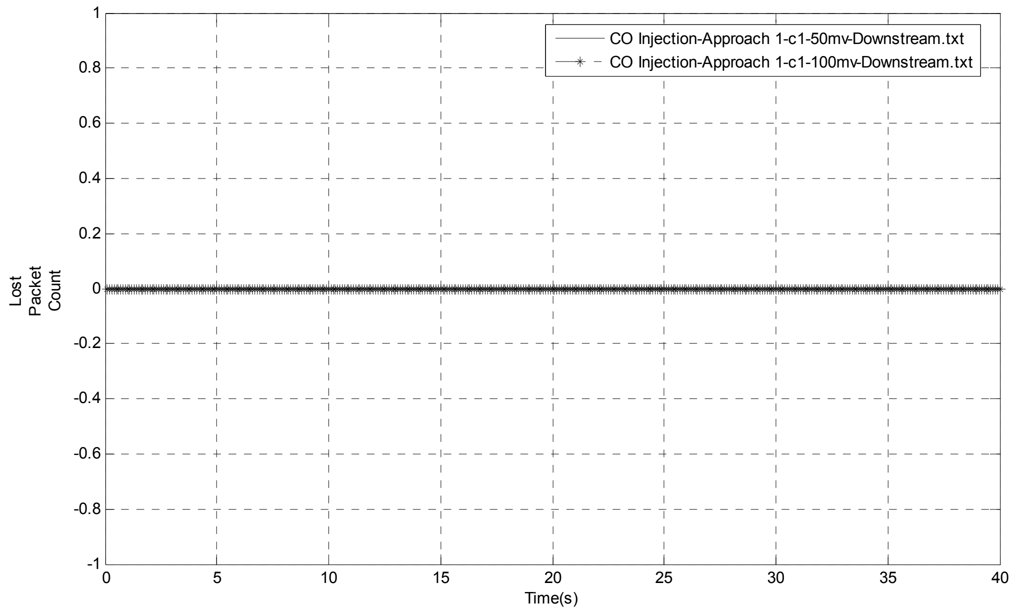

Fig. 3. Downstream lost packet for c1 injection on CO side – approach 1.

Downstream bandwidth using c1 injection for 50 mV and 100 mV on CO side is showed in Fig. 4. The bandwidth variations showed in Fig. 4 are DSL's normal characteristics. Again, the injected c1 impulse has not influence on DSL transmission. The same results happen for upstream traffic and others three different situations: c1 injection on CPE side; c2 injection on CO side; c2 injection on CPE side.

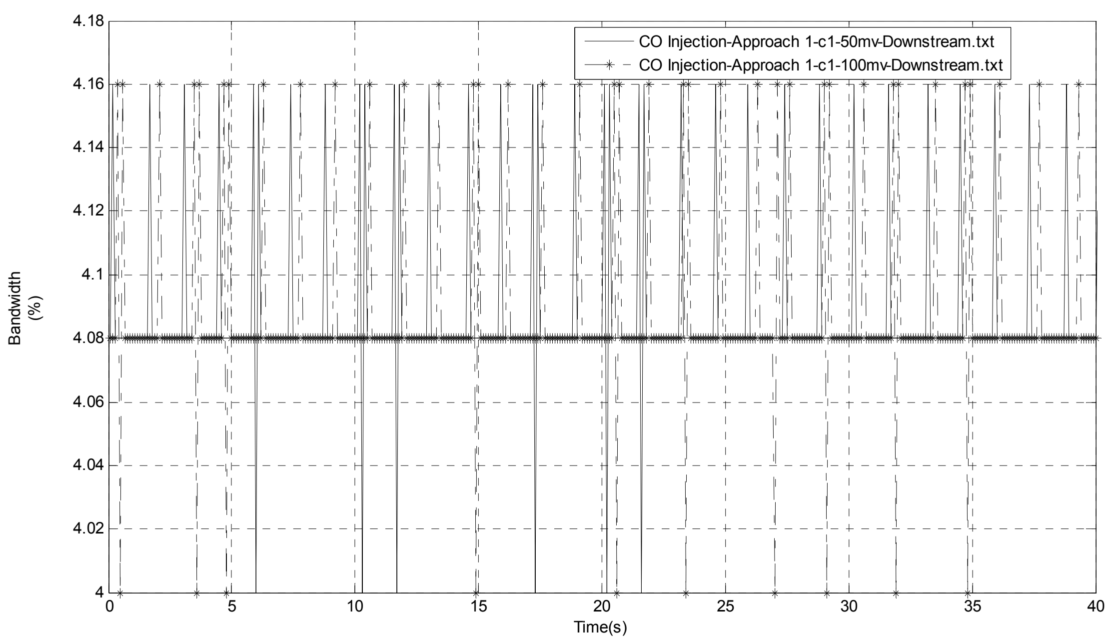

Fig. 4. Downstream bandwidth for c1 injection on CO side – approach 1.

Table 5 shows the results obtained for short-term transfer delay (values in microseconds). It can be observed that the c1 and c2 impulses do not have significant impact on transmission delay.

Table 5. Short-term average transfer delay – approach 1.

				Downstream	Upstream
CO Injection	No Noise		Mean	23508.061	24988.996
			Standard Deviation	18.196	74.822
	c1 impulse	50 mV	Mean	23506.913	24988.470
			Standard Deviation	17.923	73.357
		100 mV	Mean	23506.192	24988.472
			Standard Deviation	15.987	69.812
	c2 impulse	50 mV	Mean	23507.736	24988.785
			Standard Deviation	16.265	73.921
		100 mV	Mean	23508.312	24988.544
			Standard Deviation	18.788	73.617
CPE Injection	No Noise		Mean	23331.902	25309.403
			Standard Deviation	16.837	62.658
	c1 impulse	50 mV	Mean	23331.822	25312.860
			Standard Deviation	16.065	70.133
		100 mV	Mean	23330.573	25310.208
			Standard Deviation	14.779	65.004
	c2 impulse	50 mV	Mean	23331.083	25312.225
			Standard Deviation	15.643	64.472
		100 mV	Mean	23330.46	25307.913
			Standard Deviation	15.699	72.934

ES and SES were collected for c1 and c2 impulses, but there were not any occurrence for these impulses. Analyzing the results obtained in approach 1, it seems there is some problem in the used methodology. We have checked our methodology using other kind of IN available in noise generator equipment. In this case, we have collected ES and SES for IN model based in BT/DT (British Telecom / Deutsch Telekom) measurements [15], which the interarrival statistics of real IN events are examined and modeled. Table 6 shows the results obtained for this test. The BT/DT IN was injected with an initial power of -24.2 dBm. So, the power was increased (1 dB step) until -16.2 dBm. In Table 6 are showed only the input powers where there were occurrences of ES or SES. The results show that the methodology used for this approach is adequate, once there was IN impact detected using ES and SES metrics.

Table 6. ES and SES for BT/DT IN model – approach 1.

		CO Injection		CPE Injection			
		-20.2 dBm	-19.2 dBm	-20.2 dBm	-19.2 dBm	-18.2 dBm	-17.2 dBm
Downstream	ES	0	1	7	3	16	51
	SES	0	1	6	3	9	0
Upstream	ES	1	32	0	0	0	0
	SES	0	10	0	0	0	0

Fig. 5 shows the results obtained for the approach 2. The behavior showed in Fig. 5 for the packet rate has repeated for the other metrics and for the others times of noise injection, i.e. , after the noise injection on CPE side, the CPE starts training and the transmission is interrupted until the complete adaptation for new line characteristics. This result is expected according [13], once in all situations the CPE and DSLAM have returned to initial state of transmission.

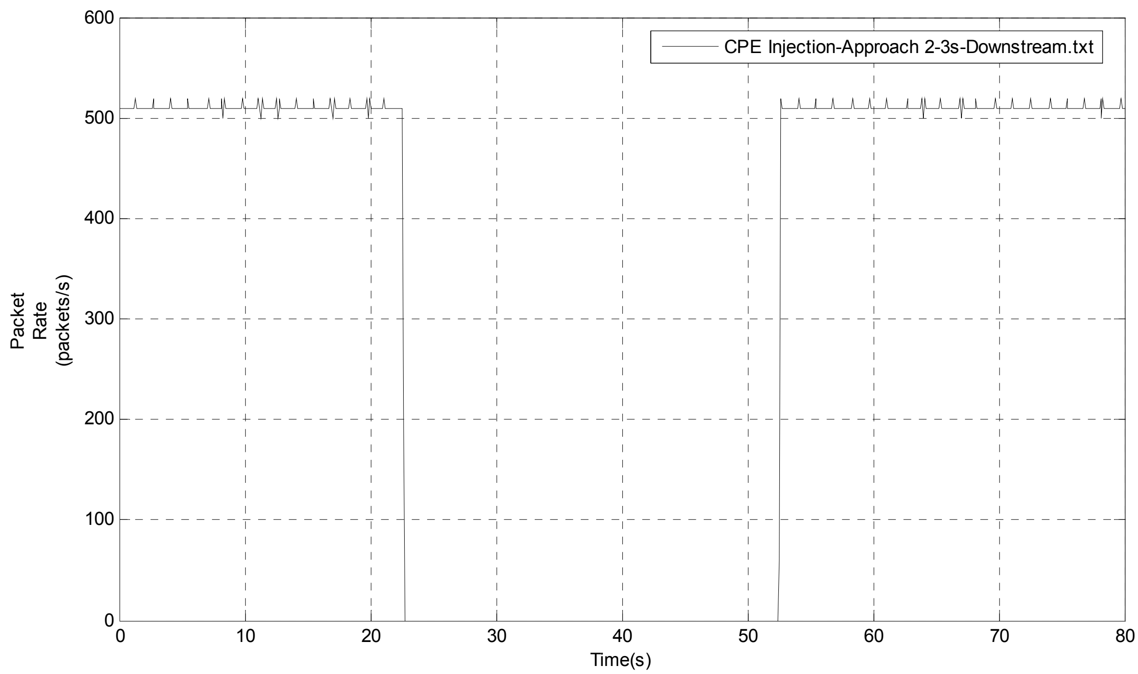

Fig. 5. Downstream packet rate for noise injection on CPE side – approach 2.

4. CONCLUSION

This paper has presented an experimental analysis of the IN impact on DSL transmission. The results have showed that c1 and c2 impulses with amplitudes up to 100 mV are not appropriate for DSL performance tests. The methodology used in this paper for IN impact was tested using other IN model and it has showed that the methodology is correct.

Layer 3 IP Metrics such as packet rate, lost packet count, bandwidth, and short-term average transfer delay are not suitable for detailed analysis of IN impact. It is necessary the utilization of others metrics that can be applicable in lower layers, such as ES and SES.

Additionally, it was verified the DSL functionality under sudden spikes of noise. The results have showed that DSL transmission had the expected behavior according [13].

Further studies are in progress to analyze the impact of others kinds of IN on DSL transmission. Measurements of IN impact for multimedia applications, such VoIP and IPTV are also in progress.

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