MODEL AND SIMULATION OF A SYSTEM Tx/Rx VDSL2

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Abstract *– This Project presents an intensive study on VDSL2 Systems and the parameters that affects the quality of them. Simulations of different analysis for Upstream Power Back-Off (UPBO) were done based on ITU-T G993.1, ITU-T G993.2 and ETSI TS 101 270-1 V1.4.1 Standards; the analysis presented are No UPBO, Reference Noise, Reference Frequency, Equalized FEXT, Reference Length and Reference PSD. For conclusion a performance evaluation of the different methods of analysis for UPBO and an evaluation of a VDSL system for PBO with different values are studied.*
Keywords *– VDSL2, UPBO, FEXT, NEXT, Band Plan, Performance Evaluation*

I. INTRODUCTION

Very High Data Rates Subscriber Line 2, VDSL2, is a technology that uses the current telephony facilities and the copper pairs to implement over this, services like Triple Play[1], including voice, video, data, high definition television (HDTV) and interactive games.

To model a VDSL2 Transmission and Reception System is necessary to resort to parameters specified in International Standards. VDSL2 Technology is defined by the International Telecommunications Union Standardization Sector (ITU-T) in the standards G993.1 and G993.2. This recommendation supports symmetric and asymmetric transmission up to 200Mbps using a bandwidth up to 30MHz[5]. This technology is also specified by European Telecommunications Standardization Institute (ETSI) in the standard TS 101 270-1.

This study is based on ETSI Standard.

II. CONFIGURATION CRITERION

In accordance with the mentioned standards, for the implementation of a VDSL2 system it must take some factors into consideration, which depends on design and implementation of the system. Just to mention:

- Band Plan Selection
- Power Mask Selection
- Profile Selection
- DPBO, Downstream Power Back-off (PSD Shaping)
- UPBO, Upstream Power Back-off
- Verify the model carry out standards technical specifications

Each topic has a wide theory for each model, it's only necessary to choose one specific model[2]. This study is based on UPBO.

UPBO[3] sets that the real scenario applicable to the implementation of a VDSL System is which is different to network topology where the final users are equidistant from the cabinet. Furthermore, a distributed topology represents a more suitable application for this case to evaluate the performance of the network of a VDSL System to be implemented, because it consists in placing users in different distances from the cabinet, but this scenario presents a other phenomenon, Near-Far Problem.

The coupling of no desired signals from one or more lines to another line is known as interference, and in VDSL can take two ways: Near End Crosstalk NEXT and Far End Crosstalk FEXT[4].

$$FEXT_K = \sum_{n,n\neq k} FEXT_n \qquad (2.1)$$

UPBO is implemented to solve the Near-Far Problem in the upstream sense. The main purpose of UPBO is to develop a network capable to increase the performance of its service, procuring to reduce the Power Spectral Density PSD to the equipments allocated near to the cabinet in order to put in the same level the PSD of the equipments placed further.

The standard[6] defines to the transmitted PSD in a loop L_i as:

$$TxPSD(f, L_i) = \frac{|H(f,L_R)|^2}{|H(f,L_i)|^2}\, TxPSD_0(f) \quad (2.2)$$

Where:

$TxPSD_0$	PSD Mask defined by Standard
$H(f, L_R)$	Function of transference of a required distance
$H(f, L_i)$	Function of transference to the distance L_i

In response to the identification problem, several types of VDSL UPBO analysis have been proposed, we can mention:

- Reference Noise
- Reference Frequency
- Equalized FEXT
- Reference Length

A. Reference Frequency

First, it’s defined a reference frequency f_R and the desired received PSD at that frequency S_{fR}. The Upstream PSD transmitted over the line L_i will be multiplied by a constant factor, resulting being the Received PSD (S_{fR}) equals to a constant value C. For all the values of the length L_i, $C = |H(f_R, L_R)|^2 \cdot S_{Tx,0}(f_R)$. Then, the PSD transmitted over the line L_i, S_{Tx}, can be expressed mathematically by:

$$S_{T_x}(f, L_i) = \frac{|H(f_R, L_R)|^2}{|H(f_R, L_i)|^2} \cdot S_{T_x,0}(f) \quad (2.3)$$

Transmitted PSD for any modem will be limited for the mask $S_{Tx,0}$ that is the maximum PSD allowed for any transmission. For shorter lines, transmitted PSD will be less than mask PSD. Otherwise, for larger lines, PSD will be restricted by the mask:

$$S_{TX}(f, L_i) = \begin{cases} K \cdot S_{TX,0}(f) & ; \\ \quad |H(f_R, L_i)|^2 > |H(f_R, L_R)|^2 & \\ S_{TX,0}(f) & ; \\ \quad otherwise & \end{cases}$$

$$K_f = \frac{|H(f_R, L_R)|^2}{|H(f_R, L_i)|^2} \qquad (2.4;\ 2.5)$$

The desired performance before the simulations is an improvement in long loops. The bigger f_R, the better improvement, but short lines will make the performance worse.

B. Reference Length

The reference length L_R is defined. S(f) has to be equal to PSD received in a line of length L_R. The PSD transmitted in a line of length L_i can be calculated as follows:

$$S_{TX}(f,L_i) = \frac{|H(f,L_R)|^2}{|H(f,L_i)|^2} \cdot S_{TX,0}(f) \qquad (2.6)$$

For lines of length $L<L_R$, the multiplier factor $|H(f,L_R)|^2 / |H(f,L)|^2$ is less than 1. Again, the PSD transmitted over long lines will be limited by the mask $S_{Tx,0}$:

$$S_{TX}(f,L_i) = \begin{cases} K_L \cdot S_{TX,0}(f) & ; \\ \quad |H(f,L_i)|^2 > |H(f,L_R)|^2 & \\ S_{TX,0}(f) & ; \\ \quad otherwise & \end{cases}$$

$$K_L = \frac{|H(f,L_R)|^2}{|H(f,L_i)|^2} \qquad (2.7;\ 2.8)$$

The following Behaviour is expected for this method: the shorter reference length L_R, the better performance in shorter lines, but the worse performance in long lines. Therefore, L_R closer to the length of the longer line is chosen.

C. Equalized FEXT

In this method, the transmitted US PSD are adapted in every disturber line to make a FEXT level equals in any other line: FEXT generated by a line of length L_i over a line of length L_j is constant, for any i and j. Therefore, the purpose of this method is to equalize the FEXT caused by lines, instead PSD received, just like it was proposed in the previous methods.

Reference length L_R is defined. US PSD are fixed in order to get a FEXT in any receiver similar to the FEXT originated by a line of length L_R. Assuming a FEXT model known, PSD transmitted in line of length L_i can be written as:

$$S_{TX}(f,L_i) = \frac{L_R\,|H(f,L_R)|^2}{L_i\,|H(f,L_i)|^2} \cdot S_{TX,0}(f) \qquad (2.9)$$

This method is similar to the method of Reference Length but Equalized FEXT allows getting greater PSD at lower frequencies. Shorter lines may increase their transmitted PSD by a factor of L_R / L_i, improving the performance in these loops:

$$S_{TX}(f,L_i) = \begin{cases} \frac{L_R}{L_i} \cdot K_E \cdot S_{TX,0}(f) & ; \\ \quad L_i\,|H(f,L_i)|^2 > L_R\,|H(f,L_R)|^2 & \\ S_{TX,0}(f) & ; \\ \quad otherwise & \end{cases}$$

$$K_E = \frac{|H(f,L_R)|^2}{|H(f,L_i)|^2} \qquad (2.10;\ 2.11)$$

Again, in larger lines the performance is better while larger is the reference length considered.

D. Reference Noise

It's more common than Equalized FEXT. Due to US PSD is reduced, FEXT in each line is equal to a given reference noise profile $\eta(f)$. PSD transmitted over a line of length L_i can be defined as:

$$S_{TX}(f,L_i)=\frac{\eta(f)}{k_{FEXT}\cdot f^2\cdot L_i\cdot|H(f,L_i)|^2} \quad (2.12)$$

Obtaining for every length:

$$S_{TX}(f,L_i)=\begin{cases} K_N & ; \quad S_{TX}(f,L_i)<S_{TX,0}(f) \\ S_{TX,0}(f) & ; \quad otherwise \end{cases}$$

$$K_N=\frac{\eta(f)}{k_{FEXT}\cdot f^2\cdot L_i\cdot|H(f,L_i)|^2} \quad (2.13; 2.14)$$

The same previous results are expected for this method.

III. Special Considerations

A. Considerations of scenario

The standard defines noise environments to take into reference, which involve the type of technology and the network topology.

Table 3.1 Models of Noise Scenarios defined by ETSI

Implementation	Model	Description
Cabinet FTTCab	A	Scenario with complete VDSL and ADSL technologies; Over 10 pairs of Cables
	B	Scenario with DSL tecnologies in lite version; Over 10 pairs of Cables
	C	"Legacy" ISDN-PRA (HDB3) added to model A
Exchange FTTEx	D	Scenario of high penetratrion; Over 100 pairs of cables.
	E	Scenario of medium penetration; Over 10 pairs of cables.
	F	Legacy ISDN-PRA (HDB3) added to model E

Each noise scenario is subdivided into two parts, one in which the noise is injected to LT and the other in which the noise is directed to the NT, where is situated the equipment under study.

Table 3.2 Models of Alien Crosstalk Scenarios defined by ETSI

Xtalk Profiles	Reference PSD (dBm/Hz, f in MHz)	
A and B	1U	-47,3 - 28,01√f
	2U	-54 - 19,22√f
C	1U	-47,3 - 21,14√f
	2U	-54 - 16,29√f
D	1U	-47,3 - 26,21√f
	2U	-54 - 17,36√f
E	1U	-47,3 - 27,27√f
	2U	-54 - 18,1√f
F	1U	-47,3 - 19,77√f
	2U	-54 - 15,77√f

B. *Nelder's Algorithm*

Nelder's algorithm[10] is an optimization realized on basis of the observation of the reference distance and the reference power methods base their calculations on values determined for the coefficients of the equation below:

$$UPBOPSD(f) = -a - b\sqrt{f} \quad \left[\frac{dBm}{Hz}\right] \qquad (3.1)$$

Where the method consists on fixing a value for the coefficient ***a*** and then find values for ***b***, for which there will be maximum values required. The ITU standard limits the values of coefficients ***a*** and ***b*** as is shown below:

$$40 \le \boldsymbol{a} \le 80.96 \qquad (3.2)$$

$$0 \le \boldsymbol{b} \le 40.96 \qquad (3.3)$$

Putting thresholds at the wide search of permutations of coefficients that satisfy the equation.

IV. SIMULATIONS

The values of the parameters defined by used ETSI standard will be:

Shannon Gap = 7.6dB
SNR Ref = 9.8dB
Xtalk Margin = 6dB
Coding Gain = 4.2dB
Loss = 2dB
SNRmax = 48dB
Maximum Power: Down = 14.51 dBm
Up = 11.5 dBm
Efficiency Loss = 10.00%
Background Noise = -160 dBm/Hz
NEXT = -50, reference value at 1MHz
FEXT = -45; reference value at 1MHz
Third CXT = -75

A. *Scenario 1 - FTTEX*

The environment of simulations[13] for VDSL Services is defined by the following parameters:

$$CO_{(e)} \rightarrow Node_{(c)} \quad \left\{ 2 \;\; \text{VDSL} \right.$$

$$CO_{(e)} \rightarrow NT_{(x)} \quad \begin{cases} 3 & \text{VDSL} \\ 5 & \text{ADSL} \\ 6 & \text{HDSL-2} \\ 1 & \text{HDSL-1} \\ 15 & \text{ISDN} \end{cases}$$

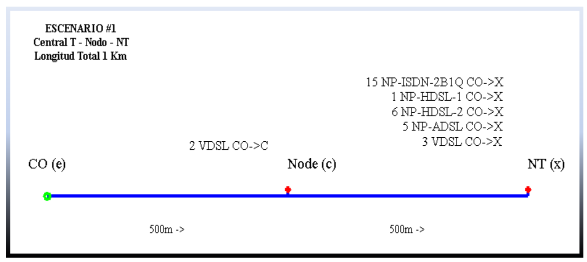

Figure 4.1 Representation of Scenario 1

Selected Band Plan for this simulation is 998, with the power mask:

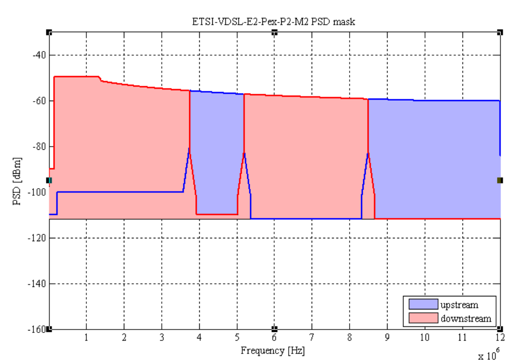

Figure 4.2 Mask E2-Pex-P2-M2 used on Scenario 1

B. Simulations Scenario 1

No UPBO

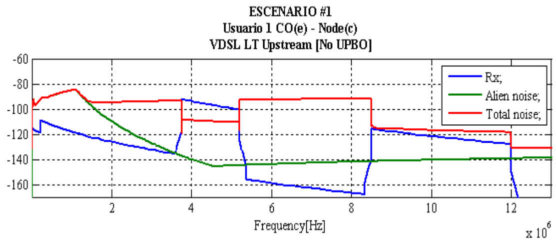

Figura 4.3 Simulation of Scenario 1, User 1, No UPBO

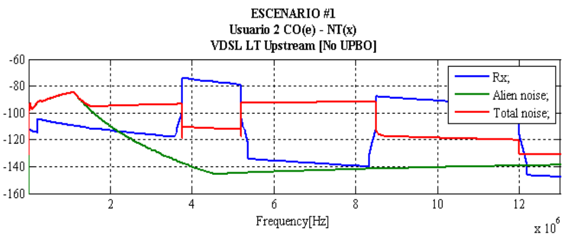

Figure 4.4 Simulation of Scenario 1, User 2, No UPBO

Reference Frequency

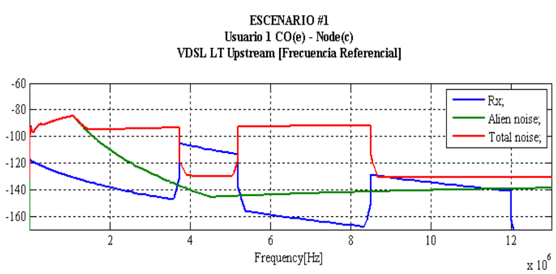

Figure 4.5 Simulation of Scenario 1, User 1, Reference Frequency

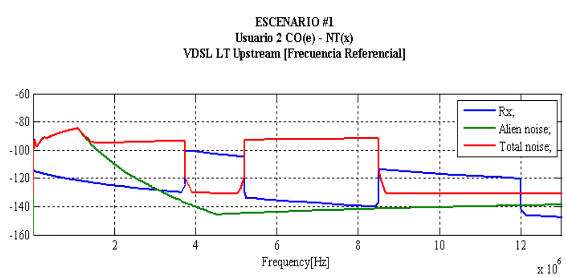

Figure 4.6 Simulation of Scenario 1, User 2, Reference Frequency

Reference Distance

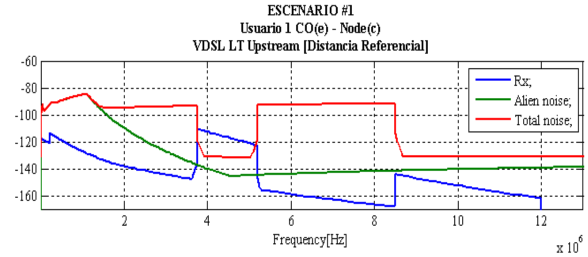

Figure 4.7 Simulation of Scenario 1, User 1, Reference Distance

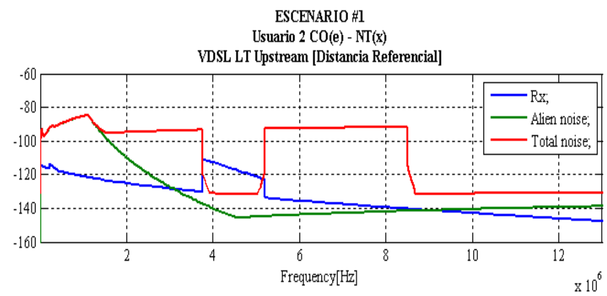

Figure 4.8 Simulation of Scenario 1, User 2, Reference Distance

Equalized FEXT

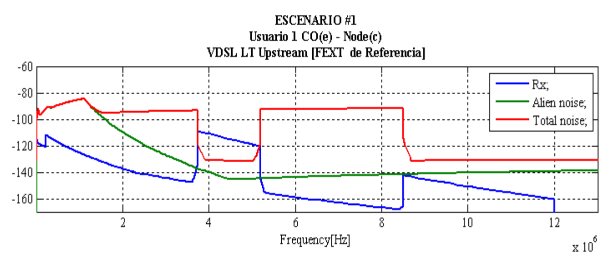

Figure 4.9 Simulation of Scenario 1, User 1, Equalized FEXT

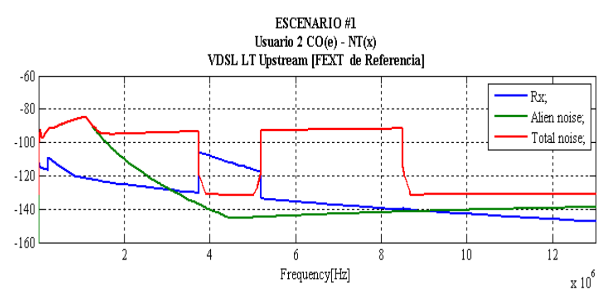

Figure 4.10 Simulation of Scenario 1, User 2, Equalized FEXT

Reference Noise

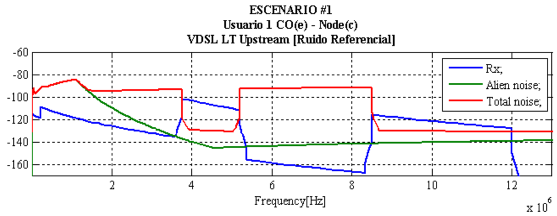

Figure 4.11 Simulation of Scenario 1, User 1, Reference Noise

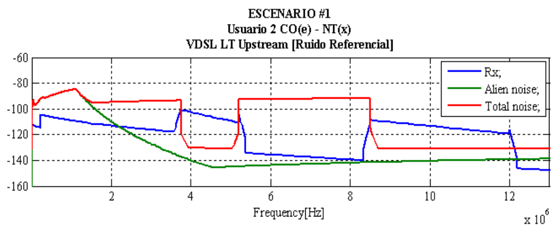

Figure 4.12 Simulation of Scenario 1, User 2, Reference Noise

C. Results of Scenario 1

Table 4.1 Results of Simulation of Scenario 1

SCENARIO # 1				
UPBO Method	USER 1		USER 2	
	UP (Mbps)	**DS (Mbps)**	**UP (Mbps)**	**DS (Mbps)**
NO UPBO	21.4156	35.7020	1.0563	30.2529
REFERENCE NOISE	14.9145	35.7020	8.0221	30.2529
REFERENCE DISTANCE	3.6259	35.7025	3.4531	30.2922
REFERENCE FREQUENCY	14.0911	35.7025	4.2943	30.2922
EQUALIZED FEXT	5.0119	35.7025	3.7528	30.2922

According to results, inside the first 500m, it can be appreciated that with or without UPBO Method the values of bit rates remain. For public users' equipments located at the end of wire, 1Km from Telephony Exchange Centre, without implementation of any UPBO method the bit rate is 1, which is almost four times less than 3.5Mbps offered by Reference Distance Method, demonstrating the worst behaviour in this scenario.

D. Scenario 2 - FTTCab

The distribution of services for scenario 2 in study is shown below:

$CO_{(e)} \rightarrow Cab_{(c)}$ — F.O.

$Cab_{(c)} \rightarrow Node_{(x)}$

5	VDSL
2	ADSL
1	HDSL-1
4	HDSL-2
10	ISDN

$Node_{(x)} \rightarrow NT_{(r)}$

6	VDSL
3	ADSL
2	HDSL-2
5	ISDN

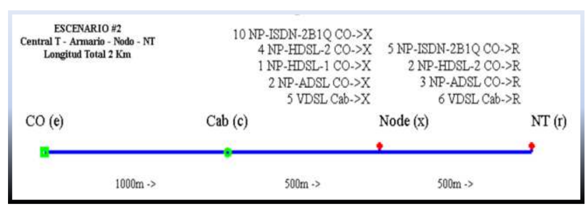

Figure 4.13 Representation of Scenario 2

Power mask as follows:

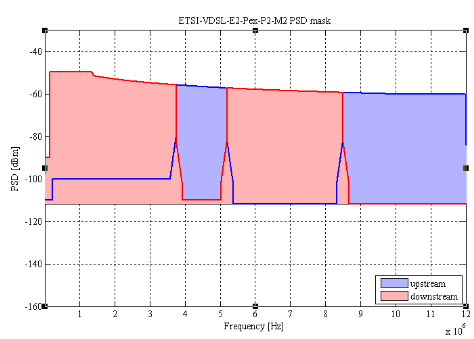

Figure 4.14 Mask E2-Pex-P2-M2 for Scenario 2

E. Simulations Scenario 2

No UPBO

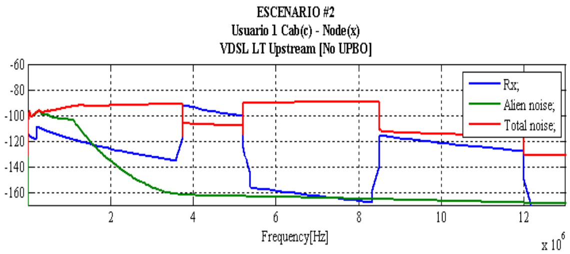

Figure 4.15 Simulation of Scenario 2, User 1, No UPBO

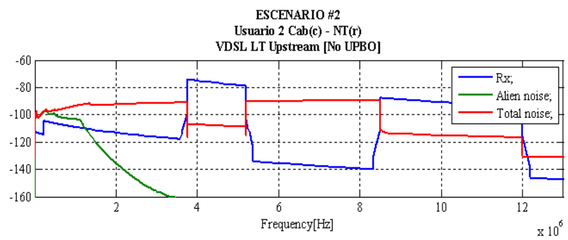

Figure 4.16 Simulation of Scenario 2, User 2, No UPBO

Reference Frequency

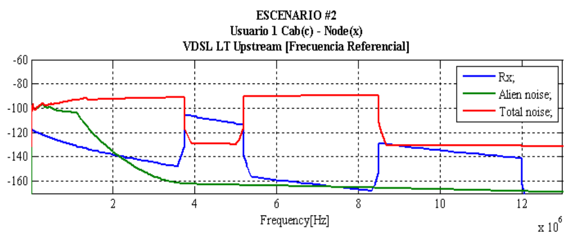

Figure 4.17 Simulation of Scenario 2, User 1, Reference Frequency

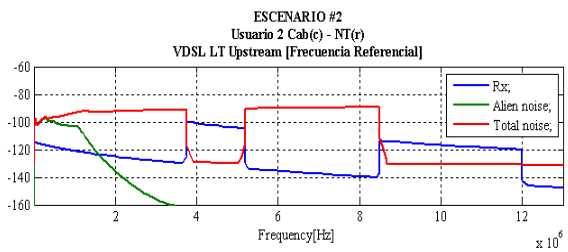

Figure 4.18 Simulation of Scenario 2, User 2, Reference Frequency

Reference Distance

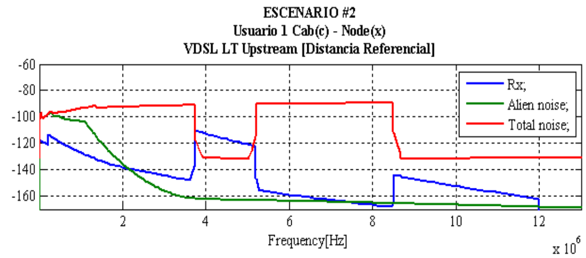

Figure 4.19 Simulation of Scenario 2, User 1, Reference Distance

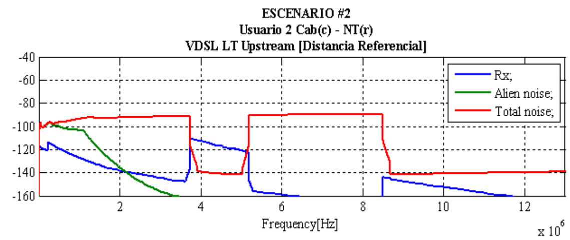

Figure 4.20 Simultion of Scenario 2, User 2, Reference Distance

Equalized FEXT

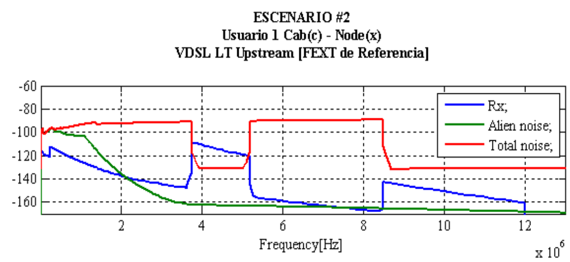

Figure 4.21 Simulation of Scenario 2, User 1, Equalized FEXT

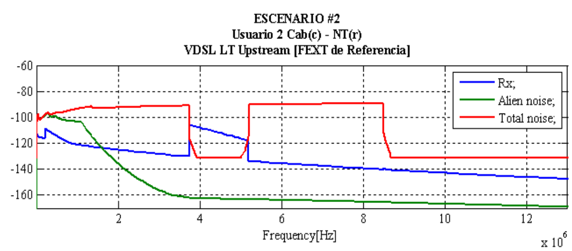

Figure 4.22 Simulation of Scenario 2, User 2, Equalized FEXT

Reference Noise

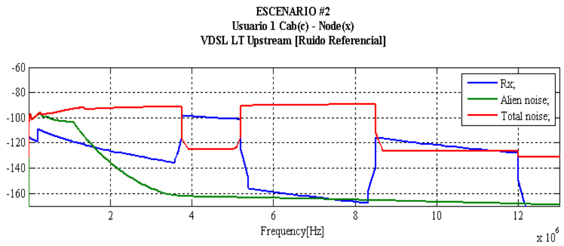

Figure 4.23 Simulation of Scenario 2, User 1, Reference Noise

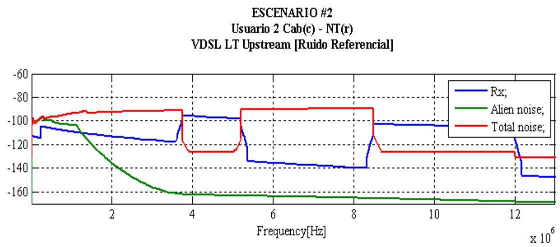

Figure 4.24 Simulation of Scenario 2, User 2, Reference Noise

F. Results of Scenario 2

Table 4.2 Results of Simulation of Scenario 2

SCENARIO # 2				
UPBO Method	USER 1		USER 2	
	UP (Mbps)	**DS (Mbps)**	**UP (Mbps)**	**DS (Mbps)**
NO UPBO	16.8032	33.7092	0.6882	29.6822
REFERENCE NOISE	13.3664	33.7092	6.9649	29.6822
REFERENCE DISTANCE	3.6209	33.7098	3.3492	29.7285
REFERENCE FREQUENCY	12.8890	33.7098	3.6588	29.7285
EQUALIZED FEXT	4.776	33.7098	3.4940	29.7285

For users of VDSL Services located among the first 1.5 Km, it can be noticed that the bit rates remain constant, except for Reference Distance and Equalized FEXT, because this methods give values until 4 times lesser tan the value obtained when no UPBO method is applied. For users inside of a 2Km radius, it is observed the improvement using any UPBO method, for the case of Reference Noise it's improved until 10 times more than the proposed scenario of the network.

CONCLUSIONS

By means of simultaneous comparison of obtained results, it can be noticed that the Method of Reference Noise is much better than the other three methods. If it's analyzed mathematically it's possible to observe the reason of greater efficiency of this method. For this analysis, it is necessary to take into consideration the expression that represents values $S_{Tx}(f, l_i) \leq S_{Tx0}$, such as seen at equation 2.13:

A. Reference Noise VS Reference Frequency

$$S_{Tx}(f, l_i) = \frac{\eta(f)}{K_{fext}.f^2.L_i|H(f, L_i)|^2};$$

$$S_{Tx}(f, l_i) = \frac{|H(f_R, L_R)|^2}{|H(f_R, L_i)|^2}.S_{Tx,0}(f)$$

If we make equal the coefficients, we can get:

$$\frac{\eta(f)}{K_{fext}.f^2.L_i|H(f,L_i)|^2} = \frac{|H(f_R, L_R)|^2}{|H(f_R, L_i)|^2}.S_{Tx,0}(f)$$

Where we notice in the right term of the equation that it's defined by a factor resulting from the division between functions of transference of both loops, the reference and in study loop, either fixed at the frequency referenced previously. This factor multiplies according to its magnitude towards the maximum value allowed for PSD by the system.

B. Reference Noise VS Reference Length

$$S_{Tx}(f,l_i) = \frac{\eta(f)}{K_{fext}.f^2.L_i|H(f,L_i)|^2};$$

$$S_{Tx}(f,l_i) = \frac{|H(f,L_R)|^2}{|H(f,L_i)|^2}.S_{Tx,0}(f)$$

If we make equal the coefficients, we obtain:

$$\frac{\eta(f)}{K_{fext}.f^2.L_i|H(f,L_i)|^2} = \frac{|H(f,L_R)|^2}{|H(f,L_i)|^2}.S_{Tx,0}(f)$$

$$\frac{\eta(f)}{K_{fext}.f^2.L_i} = |H(f,L_R)|^2.S_{Tx,0}(f)$$

Where we realised while the method of reference noise depends on variables, such as noise profile, US frequency and the length of the loop in study, the method of reference length only depends on the function of transference of the chosen loop as reference, which decreases the value of the maximum PSD allowed by the system in a factor set previously.

C. Reference Noise VS Equalized FEXT

$$S_{Tx}(f,l_i) = \frac{\eta(f)}{K_{fext}.f^2.L_i|H(f,L_i)|^2};$$

$$S_{Tx}(f,l_i) = \frac{L_R|H(f,L_R)|^2}{L_i|H(f,L_i)|^2}.S_{Tx,0}(f)$$

Making equal the coefficients, the following expression will obtain:

$$\frac{\eta(f)}{K_{fext}.f^2.L_i|H(f,L_i)|^2} = \frac{L_R|H(f,L_R)|^2}{L_i|H(f,L_i)|^2}$$

$$\frac{\eta(f)}{K_{fext}.f^2} = L_R|H(f,L_R)|^2.S_{Tx,0}(f)$$

Where we observe the reference noise has a more simple term, however, it has more variables for being evaluated if it's compared with the method of FEXT Equalized, because the last one depends on the function of transference of a loop chosen previously as reference, multiplied by the value of the reference length, which is a factor much less tan $S_{Tx,0}$ (f) because this is the maximum PSD stands by the system.

RECOMENDATIONS

It was shown the behaviour of two scenarios with the presence of a system that response to network's changes. For short distance lines, it's noticed the performance is similar in systems using UPBO methods and systems not using them. For medium and long distances, it can be perceived an improvement of the system until 10 times compared to the case not using UPBO methods. This means, UPBO methods are useful for medium and long distances, in a pre-defined controlled-noise scenario.

VDSL2 represents an optimum solution in order to reach a market with users who must use a mean without a real wideband service, because the CU networks are pioneer in matter about facilitate several access technologies, demonstrating to be an efficient mean to reach unthinkable and unimaginable bit rates, and which were expected just in modern transmission means.

REFERENCES

[1] http://es.wikipedia.org/wiki/European_Telecommunications_Standards_Institute

[2] What is needed to deploy VDSL2 systems: Practical Considerations and Performance Evaluation Hernán Córdova1, T. van der Veen2 and Leo Van Biesen

[3] On the Optimization of the Upstream Power Back-Off Parameters: Tomas Nordström, Driton Statovci

[4] Methods of Upstream Power Backoff on Very High-Speed Digital Subscriber Lines: *Krista S. Jacobsen, Texas Instruments*

[5] Loop Qualification for VDSL2 Master's Degree Project Stockholm, Sweden April 2008
MATTIAS ERNELLI

[6] Standard VDSL Technology Overview of European (ETSI), North American (T1E1.4) and International (ITU-T) VDSL standard development Vladimir Oksman Broadcom Corporation July 2001

[7] **ITU-T G.993.2** Very high speed digital subscriber line transceivers 2 (VDSL2) **Amendment 2** 02/2008

[8] ETSI TS 101 270-1 V1.4.1 (2005-10): *Technical Specification* Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements

[9] REVISED UPSTREAM POWER BACK-OFF FOR VDSL: Driton Statovci, Tomas Nordstr¨om, Rickard Nilsson; Vladimir Oksman

[10] Performance Analysis and Evaluation of VDSL2 Systems: Band-Plan Study
Hernán Córdova1, Teun van der Veen2 and Leo Van Biesen1

[11] http://joepeesoft.com/Public/DSL_Corner/DSL_Spectra_VDSL2.html

[12] http://es.wikipedia.org/wiki/VDSL2

[13] Defining Upstream Power Backoff for VDSL: Sigurd Schelstraete

[14] Fundamental of DSL Technology: Philip Golden, Hervé Dedieu, Krista Jacobsen, Auerbach Publications