

A Software for Evaluating the Operating Margin of DSL Modems

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Abstract— This work presents BrDSLWizard, a software to obtain and monitor DSL modems, including the evaluation of the operating margin. Margin fluctuations indicate changes in the condition of the DSL channel, such as increase of the crosstalk interference. BrDSLWizard provides means to obtain and statistically analyze margin data, which is useful for evaluating practical aspects of operating DSL networks.

Keywords— DSL, Modems, Margin, Gap.

I. INTRODUCTION

On typical digital subscriber line (DSL) [1] deployments, N subscribers share a binder with 25 to 100 copper-pairs. Most DSL standards adopt discrete multitone modulation (DMT), where the channel is divided into K subchannels (or tones), spaced by $\Delta_f = 4.13125$ kHz. When transmitting data, each user n simultaneously sends K symbols (for example, complex numbers as QAM symbols) organized in a vector $\mathbf{x}_n = [x_n^1, \dots, x_n^K]$. A fast Fourier transform (FFT) is used to convert these frequency-domain symbols into time-domain samples, which are sent through the channel. If some simplifying assumptions hold (see, e.g., [2]), the K subchannels can be considered independent. In this case and assuming interference and noise-free transmission, each element of the output vector $\mathbf{y}_n = [y_n^1, \dots, y_n^K]$ is given by

$$y_n^k = h_{n,n}^k x_n^k, \quad (1)$$

where $h_{n,n}^k = H_n(f)|_{f=k\Delta_f}$ is the frequency response $H_n(f)$ of the n -th channel calculated at the frequency corresponding to tone k . $H_n(f)$ is the Fourier transform of the impulse response $h_n(t)$.

In a DSL-enabled binder, a user n receives, at tone k , the signal

$$y_n^k = h_{n,n}^k x_n^k + \sum_{m \neq n} h_{n,m}^k x_m^k + z_n^k,$$

where $\sum_{m \neq n} h_{n,m}^k x_m^k$ is the crosstalk from the other $N-1$ users and z_n^k is the additive noise that models noise sources such as radio-frequency interference, thermal noise and alien crosstalk. When studying the transmission of N DSL users of a given service (e.g., VDSL2), the alien crosstalk takes in account the interference of other users (other than the N users) that typically use other services (e.g., ISDN, ADSL, etc.).

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Given that the subchannels of a DMT transmission can be treated independently, it is convenient to write

$$\mathbf{y}^k = \mathbf{x}^k \mathbf{H}^k + \mathbf{z}^k, \quad (2)$$

where $\mathbf{H}^k = \{h_{n,m}^k\}$ is a $N \times N$ matrix with direct channels in its main diagonal. An off-diagonal element at row n and column m is the crosstalk channel (in frequency-domain) between transmitter m and receiver n . The row vectors $\mathbf{y}^k = [y_1^k, \dots, y_N^k]$, $\mathbf{x}^k = [x_1^k, \dots, x_N^k]$ and $\mathbf{z}^k = [z_1^k, \dots, z_N^k]$ correspond to the inputs, outputs and noises at tone k , respectively.

Due to the random characteristic of the transmitted signals and noise sources, instead of using Eq. (2), it is more convenient to study the transmission as a stochastic process. The transmitted power spectral density (PSD) of user n at tone k is $s_n^k = \mathbb{E}\{|x_n^k|^2\}$, where $\mathbb{E} = \{\cdot\}$ denotes an expected value. Similarly, $\sigma_n^k = \mathbb{E}\{|z_n^k|^2\}$ is the noise PSD and $|h_{n,m}^k|^2 s_m^k$ is the PSD received by n from m .

The signal to noise (plus interference) ratio (SNR) at a receiver can be calculated as:

$$\text{SNR}_n^k = \frac{|h_{n,n}^k|^2 s_n^k}{\sum_{m \neq n} |h_{n,m}^k|^2 s_m^k + \sigma_n^k}.$$

II. GAP APPROXIMATION AND MARGIN

Under some assumptions [1], for uncoded PAM and QAM, the achievable bit loading of user n on tone k is:

$$b_n^k \triangleq \log_2 \left(1 + \frac{1}{\Gamma} \frac{|h_{n,n}^k|^2 s_n^k}{\sum_{m \neq n} |h_{n,m}^k|^2 s_m^k + \sigma_n^k} \right) \quad (3)$$

bits per complex dimension, where Γ denotes the gap or SNR-gap to capacity. Because this expression is very similar to the Shannon capacity equation, it is common to ignore the fact that Eq. (3) is an approximation. Assuming M-QAM, this approximation is based on the assumption that

$$\bar{P}_e \approx 2Q \left(\sqrt{\frac{3}{M-1} \text{SNR}} \right),$$

where \bar{P}_e is the error probability per dimension. Different to the capacity expression, which is not related to a specific value of \bar{P}_e , the gap Γ in Eq. (3) allows to approximately calculate the bit rate that can be achieved with a given \bar{P}_e . The notion of “gap” is more appropriate when the SNR is given in dB, since the SNR gap is

then a fixed additive term for a given error rate. Note that the gap is independent of the number of bits b , (and so independent of M for M -QAM). It purely depends on the error rate. For example $\Gamma_{dB} = 10 \log_{10} \Gamma = 9.8$ dB for all M -QAM operating at symbol error rate $P_e = 10^{-7}$. The SNR gap is a very good approximation for SNRs above about 10 dB. Below 10 dB, it starts to break down.

In practical applications, it may be convenient to increase the *margin* γ [3], [4] and, consequently, the robustness of the system. Instead of using Eq. (3), a margin $\gamma > 1$ can be obtained by using a smaller number of bits according to

$$\hat{b}_k^n \triangleq \log_2 \left(1 + \frac{\text{SNR}_n^k}{\Gamma \gamma_n^k} \right). \quad (4)$$

The margin is the amount by which the SNR on the channel may be lowered before performance degrades to a probability of error greater than the target error probability used when calculating the gap [2]. Dealing with both margin γ and gap Γ seems redundant because the margin could be incorporated into the gap by redefining it as $\hat{\Gamma} = \Gamma \gamma$. However, they play different roles in the design and operation of DSL systems. Typically, the gap is known in advance and kept fixed, while the margin measures the excess SNR for a given bit rate and can be made adaptive along operation.

From Eq. (3) and Eq. (4) and assuming the margin can be different among users and tones (which typically is undesirable) one can obtain the margin for user n and tone k as

$$\gamma_n^k = \frac{2^{b_n^k} - 1}{2^{\hat{b}_k^n} - 1}.$$

An alternative measure is the average margin $\bar{\gamma}$ [1].

III. BRDSLWIZARD

BrDSLWizard is a software developed with the objective of monitoring the state of DSL lines. Parameters such as bitloading per tone, bit rate, margin, line attenuation, transmit power, FEC and CRC errors are retrieved from the customer (CPE) modems. and used in plots as those of Figures 1 and 2. As mentioned, BrDSLWizard collects several parameters, but margin is potentially the most important from the DSL network operator's point of view. Hence, the margin was emphasized in this work. For each user the software also retrieves his geographical location. Data provided by all users are used to form a database. For different locations, the average margins, bit rates, and errors, can be analyzed to form a *heat map* (e.g., [5]). A heat map is a graph that uses color to represent the distribution of a certain parameter of interest over a map. An example of a heat map created with BrDSLWizard can be found in Figure 3. It is possible to determine statistically how these parameters vary over time.

The collected data is also used in graphs that show the evolution of a certain interest parameter over time.

One example can be seen in Figure 2, which shows the average margin evolution for both down and upstream.

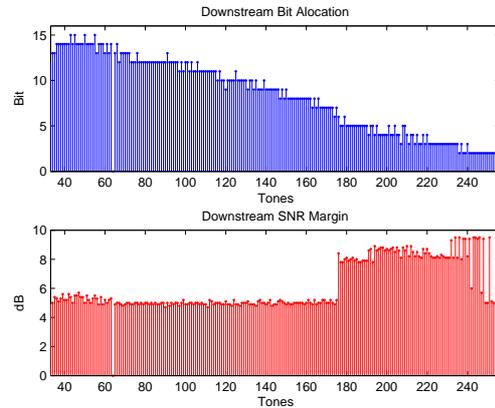


Fig. 1. Bit allocation and SNR Margin per tone for downstream direction, retrieved with BrDSLWizard.

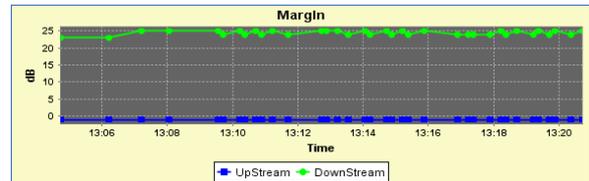


Fig. 2. Average margin data varying over time.



Fig. 3. Heat map generated with BrDSLWizard collected data. The green region represents the best bitrates achieved.

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