Fuzzy based Prequalification Methods for EoSHDSL Technology

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Abstract: The aim of the study was to create a prequalification system which can prognosticate the available maximal data transmission speed on a copper wire pair over EoSHDSL without installing a real EoSHDS connection. In order to find the relationship between line parameters and bit rates it was necessary to make comparative measurements.

The widest spectrum of the line parameters was analyzed, because at the beginning of the work the influence of parameters on the issue could not be determined.

Analyzing the results of the measurements, it clarified that the connection between line parameters and available data rate is not strict. In lots of cases different data rates belonged to similar line parameter values or the same data rate was set by different line parameters. Moreover, the groups of line parameters belonging to the same bit rate were overlapped. To handle this uncertainty fuzzy systems are most appropriate, so fuzzy logic was chosen for solving the problem.

During the work around 140000 measured data were collected. Being in possession of measured results an initiative rule base was set up without using any algorithm. This rule base did not give acceptable results. In order to higher the precision a second rule base was created using bacterial memetic algorithm.

The method was tested on real telecommunication networks. All the tests were successful.

Keywords: *telecommunication, EoSHDSL, prequalification system, fuzzy system, rule base, memetic algorithms*

1. Introduction

The prequalification of quality is demanded in all fields of telecommunication. Industrial companies, banks, financial organizations look for highly safe services in good quality. Observance of preliminary agreements between them and telecom companies is compulsory also in view of business aspects, so it is very important to know the technical possibilities beforehand.

In order to get the needed information different prequalification systems are used by telecom suppliers to figure the available level of service. These systems are able to prognosticate quite efficiently but they are expensive.

This article would like to give a short review of a work aimed at working out a computer aided prequalification system which could be more inexpensive than others. However the results may be widely generalized the study was based on a specific transport medium (symmetrical twisted pair) and on a specific data transmission technology (EoSHDSL). The reason for the choice was that the copper based twisted pair is the mostly available transmission medium, so thus it provides good possibilities for making of numerous measurements. It is important to mention that – according to the principles of prequalification – only twisted pairs in working order were selected which were in good condition. Chosen technology (EoSHDSL) has a good perspective because its huge permeation is expected in local networks that will function for years.

In this paper EoSHDSL data transmission technology and transmission parameters of symmetrical twisted pairs will be briefly introduced, selection of the mathematical model fitting with the problem and its use will be shown. The control tests will be detailed as well. At the end of the article the results of the work and the further possibilities of the suggested method's utilization will be presented.

2. Telecommunication parameters that have influence on data transmission speed

2.1. Ethernet over SHDSL technology

The EoSHDSL technology establishes connections between Ethernet endpoints using SHDSL transmission on symmetrical copper wire pairs. This method has opportunities for bounding more wire pairs in order to reach higher data transmission speed. In this case the whole data transmission rate (DTRW) is calculated as the sum of each lines' bit rate (DTRL):

$$DTRW = \sum_{i=1}^{n} DTRL_i \ , \tag{1}$$

where n is the number of used lines, and $n<9$.

Since SHDSL technology (described in ITU-T G.991.2. [1][2]) is used on every pairs, also the searches are needed to make from this point of view.

Figure 1 shows an application model for a typical SHDSL system [1]. In such an application STU-R (SHDSL Transceiver Unit at the Remote end) is connected to one or more user terminals through the S/T reference points. These terminals can be data transmission equipments or telecommunication devices. The connection between STU-R and STU-C (SHDSL Transceiver Unit at the Central Office) is digital local loop (DLL) ending on U-R and U-C reference points. This local loop may contain one or more SHDSL signal regenerator units (SRU). STU-C is connected to a Central Office network through the V reference point.

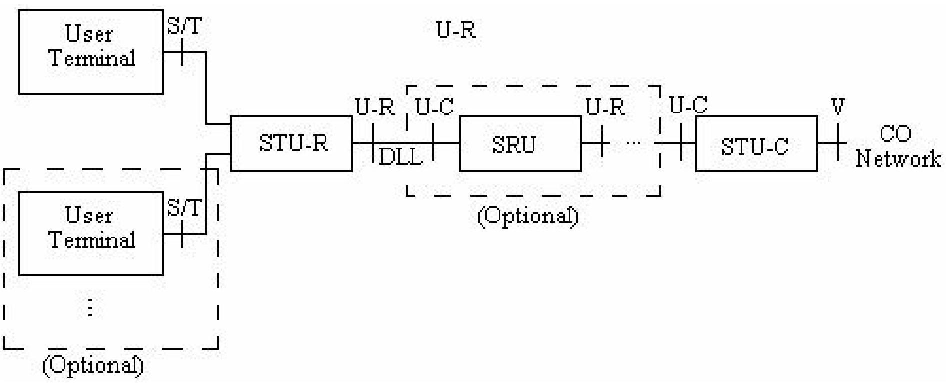

Figure 1. Typical SHDSL application model

With respect to prequalification the part of line between U-R and U-C reference points have to be examined in which in this case the usage of SRU is not allowed. If the distance between STU-R and STU-C requires using SRU-s then each DLL is needed to be prequalified separately. In this case the speed of the whole line (*DTRL*) is equal to the bit rate (BR) of the worst segment (*DTRS*), as it is seen on formula (2):

$$BR_{DTRL} = \min[BR_{DTRS\,i}]_{i=1}^{n}, \tag{2}$$

where n is the number of segments.

EoSHDSL uses 32 constellation Trellis Coded Pulse Amplitude Modulation on the DLL. It is seen on its Power Spectral Density diagram (Figure 2) that the upper limit of the frequency is under 1400 kHz.

All parameters influencing the quality of connection are set out in the ITU-T recommendation number G.991.2. Three of them are connected with the copper wire pair used for transmission. These are Loop Attenuation, Signal-to-Noise Ratio margin (SNR margin) and Return Loss.

Loop Attenuation defect is declared by the STU if the value of the loop attenuation is higher than the preliminary configured threshold. G.991.2 recommendation defines this value as it is seen on formula (3) [1]:

$$LA_{SHDSL}(H) = \frac{2}{f_{sym}} \left\{ \int_{0}^{\frac{f_{sym}}{2}} 10 \times \log_{10}\left[\sum_{0}^{1} S(f - nf_{sym})\right] df - \int_{0}^{\frac{f_{sym}}{2}} 10 \times \log_{10}\left[\sum_{0}^{1} S(f - nf_{sym}) \left| H(f - nf)^2 \right| \right] df \right\}, \tag{3}$$

where f_{SYM} is the symbol rate, $1/H(f)$ is the insertion loss of the loop, and $S(f)$ is the nominal transmit PSD.

It can be seen that the value of the Loop Attenuation is influenced by only one parameter that is connected to copper wire pair beside the configured ones. This parameter is the insertion loss.

Signal-to-Noise Margin defect is declared if the SNR margin is declined under the configured value. "SNR margin is defined as the maximum dB increase in equalized noise or the maximum dB decrease in equalized signal that a system can tolerate and maintain a BER of 10^{-7}."[1]

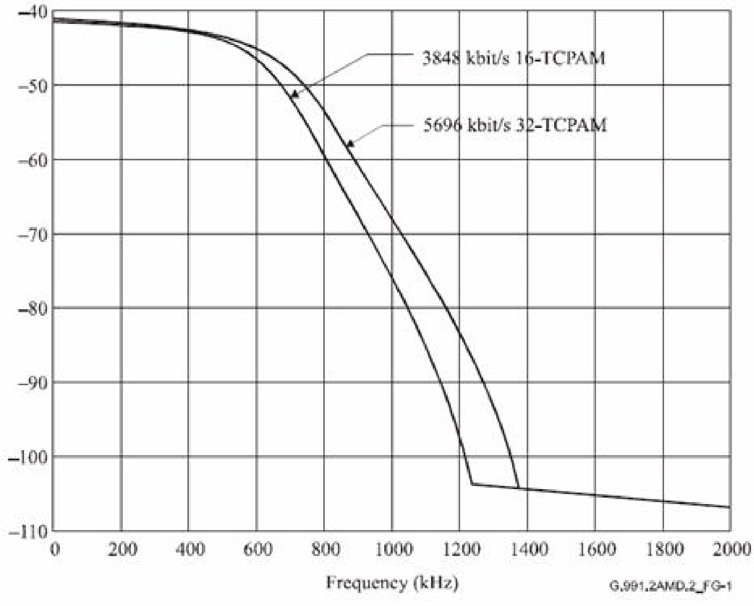

Figure 2. Nominal PSD masks for 0-DB power backoff [2]

The level of signal is set up during the synchronization process, so assuming a constant signal level the change of SNR (Signal-to-Noise Ratio) margin apparently depends only on the actual change of the line noise.

Return Loss is representative for termination impedance distortion. It shows how good the used termination impedances are. In case of measurements performed with an impedance analyzer, the return loss is defined as formula (4) [1]:

$$\mathrm{ReturnLoss(f)} = 20\log\left|\frac{Z_{\mathrm{TEST}}(\mathrm{f}) + Z_{\mathrm{REF}}}{Z_{\mathrm{TEST}}(\mathrm{f}) - Z_{\mathrm{REF}}}\right|, \tag{4}$$

where $Z_{TEST}(f)$ is the measured complex impedance at frequency f at the loop interface of the tested device and Z_{REF} is the reference impedance (135 Ω).

2.2. Line parameters that have influence on data transmission speed

Influencing parameters mentioned by G.991.2 recommendation can not be measured on empty wire pairs [4]. What measurable on these lines and influenced on parameters mentioned before are Line Noise, Insertion Loss and Return Loss of the line terminated with measuring instrument [3].

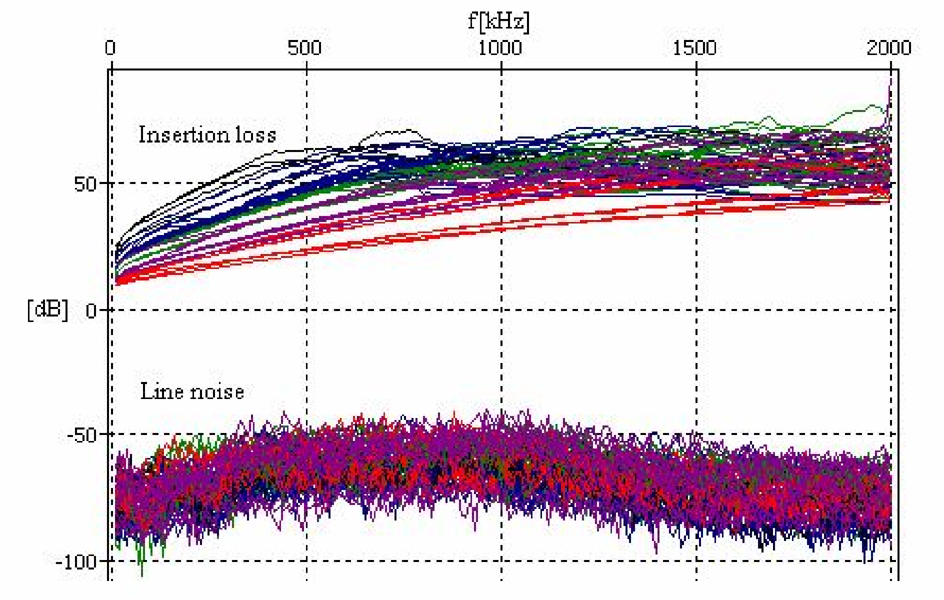

Figure 3. Line Noise (lower) and Insertion Loss (upper)

Line Noise has an effect on Signal-to-Noise Ratio and Insertion Loss affects Loop Attenuation.

The correlation supporting the prequalification must be found between the change of data transmission speed and the change of parameters listed above.

Examination of the Line Noise (results are shown in Figure 3) unequivocally confirmed that due to the circumstances existing on examined lines, Line Noise does not take part in forming differences between the speed groups (that are signed by different colours on the graph).

The role of **Return Loss** is very similar to the role of Line Noise. It can be seen on the graphs (Figure 4) that there is no exact correlation between data speed and Return Loss.

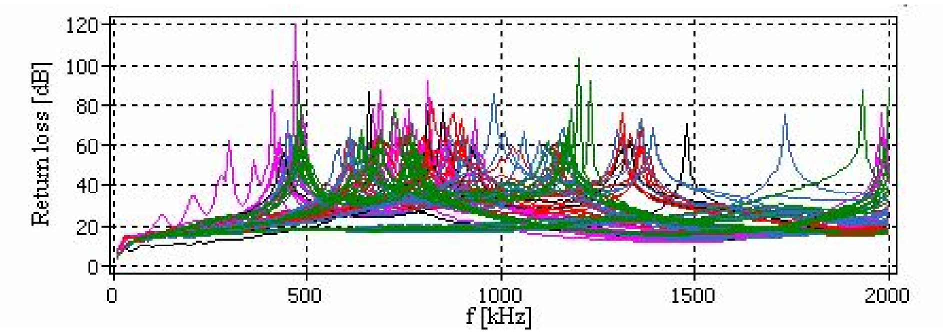

Figure 4. Return loss

However, the role of **Insertion Loss** is obtrusive. The graphs of Insertion Loss in Figure 3 can be grouped easily by the evolving data transmission speed.

2.3. Input parameters for prequalification method

According to subsections 2.1. and 2.2. it can be fixed that values of Insertion Loss measured on certain wire pairs up to frequency 1500 kHz are minimally satisfactory input parameters for such a prequalification system that qualify empty copper wire pairs in order to predict probable EoSHDSL data transmission speed. Later, the results confirmed that it is not necessary to know all values of the frequency spectrum, it is enough to have Insertion Loss values on some properly chosen frequencies.

3. Fuzzy Logic as the effective computational intelligence tool for handling impacts of influencing parameters

3.1. The choice of a mathematical tool

Looking over the input data it can be seen that they are not consequent and they have no univocal correspondence with data transmission speed. A measurement result as an input can be connected to different bit rates as outputs and more different input values can be belonged to the same output speed value. Moreover, the number of input values is large. (More than 140000 measured values were processed only in this study.)

Solving problems like this is very difficult using traditional mathematical methods. Fuzzy logic seems to be the most appropriate way [5][6][7][10][11][12].

3.2. Principles of building the rule base

The rule base was built based on measured values of line parameters that influence the EoSHDSL bit rate.

In order to evaluate the results, the lines were rated into five speed groups. These five groups represent the outputs of the rule base. Output groups essentially mimic the offers of telecommunication providers, guaranteeing the lowest and allowing to reach the highest values. Speed groups are shown in Table 1.

Table 1. Data transmission speed groups used in the solution

DTS group	Minimum [kbit/s]	Maximum [kbit/s]
G1	520	840
G2	904	1544
G3	1608	2440
G4	2504	3144
G5	3208	5448

It could be possible to raise the number of the DTS groups by placing more measures. In this case the steps of the rule base outputs could be finer and the steps of 64 kbit/s of the technology may be reached.

The input field is described by continuous functions on the 1,5 MHz wide range of the frequency. For the solution sampling this band and evaluating the samples are sufficient. In order to keep the computing costs low and heighten the accuracy, the Insertion Loss values at six points of frequency are compared with the fuzzy sets being on the antecedent side of the rule base, so the rule base is based on six variables. These six points (except the first in Table 2) divide the interval into parts of the same length. With this method the input containing continuous functions was reduced to a six dimensional space.

Table 2. Discrete frequency values where Insertion Loss is measured for input

Measuring points	100 kHz	500 kHz	750 kHz	1000 kHz	1250 kHz	1500 kHz

Building the rule base, the frequency values are shown in Table 2 were considered. The rules evaluate a six dimensional observation vectors and result in one of the five DTS groups. The dimensions of the observation vectors are the Insertion Loss values measured on the chosen points.

3.3. The first rule base and its efficiency

First a “hand made” rule base was implemented according to subsection 3.2. without using any algorithm. This rule base contained five rules with six dimensional antecedents.

Rules were created as easily as it was possible. According to the measurement results the maximum (M+), the minimum (M-) and the average (A) values were defined for each DTS group on every frequency points (Table 2). Using these values, the lower value of the support was M-, the upper value was M+ and the core point was A for each DTS groups and each frequency values. In this mode triangular shaped fuzzy sets were created.

Figure 5 and Figure 6 give examples from the rule base (note that axis X is reversely directed). As long as Figure 6 shows the complete antecedent side of the fifth rule, the fuzzy sets of Figure 5 do not belong to the same rule, but it displays the third dimension of each rule.

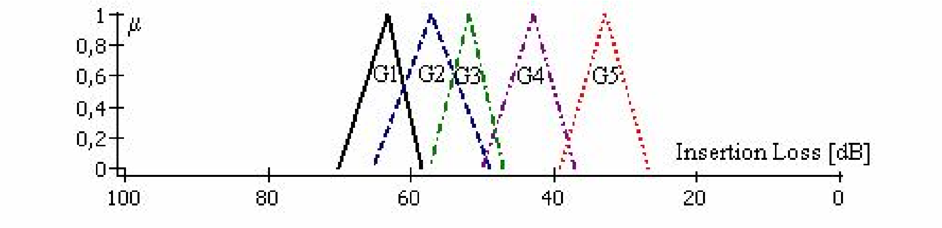

Figure 5. "Hand made" fuzzy sets on 750 kHz

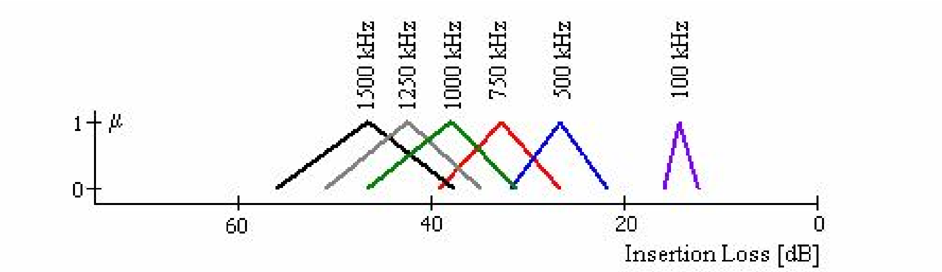

Figure 6. The antecedents of the fifth rule

Tests were run on 20 lines of real telecommunication networks with this rule base and the results were compared with measured DTS values. It turned out that results were equal with measured data only in 63%. The rule base provided incorrect results in 37%. This fact claimed to retune the rule base.

3.4. Final rule base generated by algorithm

The moderate success of the rule base described in the previous subsection is not enough to use it in industrial expert systems. A new rule base was needed to create. Optimization of the rules demanded so much work that an automatic method was applied. Bacterial memetic algorithm [8] was applied on training patterns. This technique is a nature inspired, population based, global optimization algorithm. It combines the bacterial evolutionary algorithm with a local search technique. The bacterial evolutionary algorithm performs global search, however, the solution found by the algorithm converges pretty slowly. The local search technique is a gradient based algorithm, which can find a more accurate solution, however, this method often find only the local optimum, nearest to the initial point of state space. Combining the evolutionary and gradient based approaches might be useful in improving the performance of the basic evolutionary algorithm, which may find the global optimum with sufficient precision in this combined way. Combinations of evolutionary and local-search methods are usually referred to as memetic algorithms [9].

The parameter setting for the bacterial memetic algorithm can be seen in Table 3.

Table 3. Parameters for Bacterial Memetic Algorithm

Number of rules	10
Size of the population	20
Number of clones	8
Number of generations	3000
Number of gene transfers	12

This rule base contains 10 rules with six dimensional antecedent and consists of trapezoidal fuzzy sets. The fuzzy sets are normal as it can be seen in Figure 7.

For fuzzy inference the Mamdani reasoning method is used [6] where t-norm is the minimum and t-conorm is the maximum operator. The crisp output value is calculated by the Center of Gravity defuzzification technique.

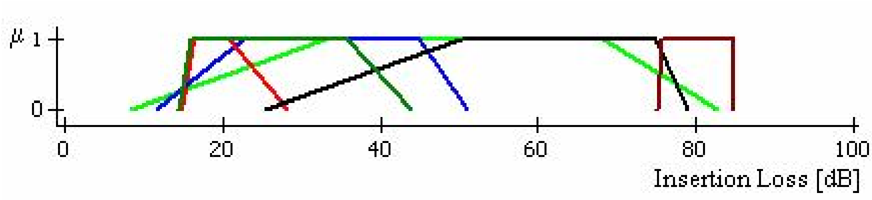

Figure 7. Example of antecedents from the final rule base

Success percentage of the tests (on real telecom networks) of this rule base was 100%. This accuracy is due to correct choice of number of output groups to available training patterns. Having more patterns also the number of DTS groups could rise.

4. Conclusions

In this study a solution was searched for a recent telecommunication problem. Inspecting the physical parameters of symmetric copper wire pairs which compose the base of the telecommunication local networks, the proper set of input parameters was defined. Two rule bases were created for solving the problem, but as it turned out, the complexity of the task demanded to use the second rule base, which was made by bacterial memetic algorithm. Finally, tests were made for defining the accuracy of the method.

Observations of working out this method showed that the complexity of such telecommunication problems justifies the utilization of fuzzy logic and needs the use of rule base identification algorithm.

The implemented system was tested on industrial telecommunication networks. The experiences verified that the suggested method is operable.

Improving the resolution of the method is possible. In order to build a system with more detailed output it is necessary to have much more preliminary line measurement and to create new rules based on the new results.

However this method was worked out for EoSHDSL systems, it is able to handle other telecommunication problems as well. Certainly, in this case it is crucial to observe those systems, to find the proper input parameters and to create new rule base according to the observations.

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