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COMPUTATIONAL INTELLIGENCE IN PERFORMANCE EVALUATION AND FAULT PROGNOSIS IN TELECOMMUNICATION ACCESS NETWORKS

METODY INTELIGENCJI OBLICZENIOWEJ W OCENIE WYDAJNOŚCI I PROGNOZOWANIA USZKODZEŃ DOSTĘPOWYCH SIECI TELEKOMUNIKACYJNYCH

A b s t r a c t

Telecommunication connections are highly reliable and manageable, however, the handling of several parts of the networks is problematic. One of these parts is the access network. The variegation of the applied technologies and the individual connections to the customers in access networks makes the preliminary estimation of the performance of the telecommunications services and troubleshooting difficult. There are existing methods which can handle such problems, but the telecommunications companies (TELCO) are continuously looking for newer and more efficient methods. In this paper some existing methods for performance evaluation and the prediction of the probable failures of the wire pairs of telecommunications access networks are reviewed and novel methods that are based on the measurements of the wire pairs and use computational intelligence, fuzzy inference methods and evolutionary models are introduced.

Keywords: *telecommunications access networks, performance evaluation, fault prediction, fuzzy rule bases*

S t r e s z c z e n i e

Połączenia telekomunikacyjne są z reguły wysoce niezawodne i łatwe w zarządzaniu, jednak obsługa pewnych typów sieci, w tym tzw. sieci dostępowych, może przysparzać problemów. Zarówno różnorodność stosowanych technologii, jak też specyfika indywidualnych podłączeń klientów sprawiają, że wstępna ocena wydajności usług telekomunikacyjnych oraz wykrywania uszkodzeń napotyka trudności. Choć dostępne są metody rozwiązywania tego typu problemów, to firmy telekomunikacyjne stale poszukują nowych, bardziej skutecznych rozwiązań. W niniejszym artykule zawarto przegląd istniejących metod oceny wydajności i prognozowania uszkodzeń par przewodów w dostępowych sieciach telekomunikacyjnych, a także zaprezentowano nowe metody oparte na pomiarach tych przewodów, z użyciem technik inteligencji obliczeniowej, rozmytych metod wnioskowania oraz algorytmów ewolucyjnych.

Słowa kluczowe: *telekomunikacyjne sieci dostępowe, ocena wydajności, predykcja uszkodzeń, baza reguł rozmytych*

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1. Introduction

Telecommunication connections are highly reliable and manageable, however, handling of several parts of the networks is problematic. One of these parts is the access network. The variegation of the applied technologies and the individual connections to the customers in access networks makes the preliminary estimation of the performance of the telecommunications services and the troubleshooting difficult. There are existing methods which can handle such problems, but the telecommunications companies (TELCO) are continuously looking for newer and more efficient methods. In this paper some existing methods for performance evaluation and the prediction of the probable failures of the wire pairs of telecommunications access networks are reviewed and novel methods that are based on the measurements of the wire pairs and use computational intelligence, fuzzy inference methods and evolutionary models are introduced.

1.1. Access networks and data transmission technologies

In the communication between two endpoints, plurality of telecommunications technologies and networks are used. The applied transmission technologies of optical and microwave (microwave chains and satellite) connections of the core/backbone network between the exchanges or nodes are very reliable. As these systems serve for the transmission of the communication of numerous customers at the same time, technical safety has a big role during the planning, installation and upkeep. Besides the substantial operation safety, these systems are continuously managed, thus the technical staff observe faults immediately, and dispose of the substitution and the reparation of the errored session or system. The parameters of the technologies used in core or backbone networks are well described, so the performance of its connections are known at the moment of installation, moreover, they are already known at the moment of designing.

The customers are connected to the local exchanges or data communication nodes by the access networks. ‘The access network is an implementation comprising those entities (such as cable plant, transmission facilities etc.) which provide the required transport bearer capabilities for the provision of telecommunication services between a Service Node Interface and each of the associated User-Network Interfaces’ [21]. In contrast with the connections of the core networks which perform mass communication, the individual connections of the access networks are dedicated to single customers. This results in such a variety of physical connections and lines of the access networks that significantly encumbers the unificability of the handling of singular lines. The operating and handling methods are the same for each connection, however each line is individual with specific physical performance and operational parameters. At this rate, the performance evaluation of the singular connections that can be changed also physically during the time by the replacement of their several sessions, without the installation of the technological equipment of the services is not easy. Moreover, the exact connection between the measurable parameters and the performance does not exists, performance can only be estimated. The situation of the prediction of probable faults is very similar. Lots of physical parameters of huge and complex access networks have to be continuously monitored in order to determine the declination of the connection’s quality and forecast the possible faults. The exact mathematical formulas are missing in this case as well, forecasts can be given by previous experiences.

Nowadays, metallic cables can hardly be found in core networks, or are totally missing. They are replaced by modern fibre optical cables. However, due to economical reasons, symmetrical copper wire pairs based cables dominate the access networks and by present trends, these cables will be in operation for decades. Plain old telephone service (POTS) is more and more displaced by new types of communication services, as for example IPTV, VoIP or Internet access. The previous technologies of symmetrical copper wire based networks were made for the demands of POTS and are not able to provide new types of services, therefore the family of DSL (Digital Subscriber Line) technologies were evolved. The members of the DSL technologies enable the provision of different modes of data transmissions.

Asymmetric communication can be performed by ADSL (Asymmetric Digital Subscriber Line) technology [6]. Its data transfer rate (bit rate in other words) is different in upload and download. In accordance with the average use of the Internet, the upload bit rate is lower than the download. Internet connection, VoIP and also IPTV services are provided by this technology mainly to residential customers and SOHO (Small Office/ Home Office) users.

The symmetrical data transmission method of the access networks is SHDSL (Single-pair High Speed Digital Subscriber Line) [7]. This technology is used by those customers whose amount of data to upload is equal to or more than the amount of downloaded data.

These new transmission and communication systems are effective, however, they have high expectations of the networks they use. xDSL technologies are quite efficient in data transmission, but as they use a wider bandwidth and higher frequencies, the possibility of failure is also higher. However, not only this fact is the reason for the failures. Symmetrical cables which are used in this type of transmission are very sensitive to the effects from the environment and as most of them are rather old, failure of the wire pairs is common.

Towards the optimization of the operation, TELCOs are continuously looking for new methods that help them to perform effective performance evaluation and fault prediction in access networks. There are no exact mathematical models and solutions for these problems, handling is possible by expert systems for example. Such incorrectly determined problems can be managed by fuzzy reasoning methods.

1.2. Fuzzy systems

Some of the technological and logistical problems can hardly be handled by traditional logic systems. Fuzzy set theory and fuzzy logic, which is close to the human thinking and describes the phenomena of the world in an easy way, was proposed by L.A. Zadeh in 1965 [20]. Zadeh's logic system is such a many-valued logic in that the number of the values is infinite between the maximal 1 and the minimal 0, as opposite to Aristotle's two valued logic, which uses only the 1 and 0 (YES and NO) as permitted values.

Using fuzzy sets and fuzzy logic, rule systems defined by human language, that contain linguistic variables instead of precise numbers and values can be mathematically handled easily. Such linguistic variable is for example the height of the body if its values are not numerical, but linguistic, e.g. short, normal and tall. [11] The rules are IF...THEN typed as it can be seen in Section 3.3. and the connections between them are OR (ELSE). As the expressions in the rules contain fuzzy sets, substituting the logical operations with fuzzy set operations, fuzzy reasoning system is resulted, that allows the mathematical handling of the rules and rule bases defined by human language.

Fuzzy inference methods are successfully applied in many fields of science from automatic vehicle control [12] to handwriting character recognition [13]. The subject of fuzzy set theory and fuzzy logic is expansively described in [10].

2. Performance evaluation of the wire pairs in access networks using fuzzy rule bases

Performance evaluation in telecommunications is the process of the determination of the transmission capacity of a system or a connection. Its aim is the determination of the maximal available data transfer rate. TELCOs need this data in order to give preliminary offers for their respective customers. Service Providers use several methods of performance evaluation, however, these methods are expensive or imprecise. In this section, some current techniques will be briefly presented and a fuzzy based novel method will be introduced.

2.1. Widely used methods of performance evaluation [15]

In overviewing the related literature, we found several essentially different approaches to the performance evaluation of wire pairs. The most important methods will be briefly overviewed whilst pointing out problems involved with all these methods which essentially motivate our new approach. The key problem of performance evaluation may be found in the contradictory requirements of accuracy and low cost. The main types of such evaluation are described. In each case, the order of magnitude of the cost and an estimation of the achievable accuracy will be indicated.

Physical parameters of the first layer of the OSI (Open System Interconnection) reference model [14] seriously affect the possibilities of the higher layers. It is obvious that all of the performance evaluation techniques have to be based on the physical parameters of the wire pairs. Each technique uses these parameters, however, some of them measure them precisely while others use experimental information in the evaluation. Certainly, there are different performance evaluation methods for different types of telecommunications services. In this paper, we present techniques of DSL services. These techniques are grouped by the applied data and methods.

Evaluation by expert's estimation. In the periods when singular DSL technologies were launched, evaluation by expert knowledge was prevalent in the practice of telecommunications companies. In this method, technicians who had already had experiences with DSL installations in a single area were asked about their opinion on the available bit rates at given geographical addresses. Technicians tried to remember the results of former installations within the same geographical area and gave a rough estimation. In some cases their answers were totally wrong because real parameters of the connections were not taken into consideration. The cost of this technique is only the cost of a phone call in each case but the precision of its result is doubtful and accidental.

Evaluation by distance. Evaluation by distance is more precise than the previous method. This technique is based on the distance between the customer's premises and the telecommunications node. In this way, experiences of previous installations are taken into consideration, however this knowledge is recorded to geographical maps. Concentric circles around the nodes approximate the borders of areas with different available bit rates. This method is cheap but the drawn borders only approximate the real performance.

Evaluation with data from technical inventories. More accurate evaluation can be performed by data from technical inventories. In this case, data regarding the cable length and wire diameter are used. The drawback of the system is that the data are not controlled, so if they are wrong then the estimation will completely fail. Circumstances relating to other parameters, which influence the performance, e.g. noise, are not taken into consideration. Moreover, in cases when data are missing from the inventories the method cannot give any result. This method has reasonably low price, but its accuracy remains under the current expectations.

Measurement based methods. Accurate evaluation methods are based on instrumental measurements of the wire pairs of the access networks. As the transmission methods and also the used frequency bands of various DSL techniques differ from each other, their instrumental methods are also variable, however, their theoretical bases are similar. During the evaluation generally attenuation, noise, insertion loss, capacitance and symmetry are measured. In some cases, reflections of impulses injected into the wire pairs are used. Measurements are usually performed in batches. According to the practice of telecommunications service providers measurements are not performed wire by wire but batches of pairs are evaluated in each case when the instruments are connected to the cable. In this way, all of the pairs of an MDF are evaluated in a period of the time. However, after a particular time, TELCO have all performance data of its network, changes are not followed. These methods are suitable to deliver a rather accurate evaluation of the expected performance but the necessary measurements involve lots of physical wire parameters, and the evaluation is also performed for unnecessary wire pairs and because of this, the cost is high [16, 17].

Technological pre-survey. The technological pre-survey is the most precise technique for the determination of performance, because in this method, the equipment of the technology is temporarily installed and the maximal available bit rate is measured. Actually, this method is not a performance evaluation but measurement of real performance and it is performed only in case of VIP or industrial customers.

Because of the problems indicated in the above critical remarks, it is necessary to look for a performance evaluation method that delivers acceptably accurate results while keeping the total cost of the evaluation within a reasonable range. We propose a totally novel approach satisfying the double criteria as it will be presented in the next sections of the paper.

2.2. A novel, fuzzy based SHDSL performance evaluation

The lack of the precise connection between the wire pairs' physical parameters and the available data transfer rate, and the numbers of parameters make the usage of fuzzy inference methods desirable in this problem. For the construction of such a system, the smallest set of influencing physical parameters were determined, then fuzzy rule bases were constructed. In the evaluation, a Mamdani type fuzzy inference method was used [18].

2.2.1. Determination of the parameters that affect the data transmission power

SHDSL technology is described in the ITU-T recommendation No. G.991.2 [6]. The recommendation lists the performance primitives, however two of them are in connection with the physical parameters of the wire pair. These are the loop attenuation defect and the SNR (Signal to Noise Ratio) margin defect. The formula of the loop attenuation is the following:

$$LA_{\text{SHDSL}}(H) = \frac{2}{f_{\text{sym}}}\left\{\int_0^{\frac{f_{\text{sym}}}{2}} 10\log_{10}\right\}\left[\sum_0^1 S(f - nf_{\text{sym}})\right]df - \left(\int_0^{\frac{f_{\text{sym}}}{2}} 10\log_{10}\left[\sum_0^1 S(f - nf_{\text{sym}})\left|H\left(f - nf_{\text{sym}}\right)^2\right|\right]df\right) \tag{1}$$

In Formula (1), f_{sym} is the symbol rate, $1/H_f$ is the insertion loss of the loop and S_f is nominal transmit PSD [6]. The only physical line parameter in the formula is insertion loss. The other performance primitive is the SNR margin defect which has relationship with the noise of the wire pair. In accordance with the recommendation, noise is the other influencing physical parameter.

The set of influencing parameters were checked by instrumental measurements. During the work insulation resistance, loop resistance, near- and far-end crosstalk, noise, signal to noise ratio, line impedance, attenuation to crosstalk ratio, insertion loss and longitudinal balance were measured. Frequency dependent values were measured form 10 kHz to 2 MHz in 10 KHz wide steps. The maximal bit rates were also measured by the installation of SHDSL equipment to singular wire pairs. Bit rates were measured up to 5.7 Mbit/sec.

At first sight, it seemed that there is a connection between the measured line parameters and the measured bit rate values only in the case of the insertion loss. Some examples of it can be seen in Fig. 1. Fig. 1 shows the cumulated results of measurements carried out for eight wire pairs in different cables but all in the same region, namely in Győr-Moson-Sopron County in Hungary. Similar measurements have been done in five more regions. Wire pair parameters were measured at 200 discrete points of the frequency band from 10 kHz to 2 MHz in 10 kHz steps. As the actually observed transmission method (SHDSL) uses only a frequency up to 1.5 MHz, the measured values in higher frequencies are not relevant, so those are not pictured in the figures. Similar to the practice of TELCOs, as they offer the bit rates in ranges, measured data transmission rates were divided into five groups. These groups are marked by S1, S2, ..., S5, where S1 means the range of the lowest and S5 the range of the highest bit rates. In Fig. 1 it can be seen that in the same region, the groups of the maximal available bit rate can be differentiated by the level of insertion loss. The higher the insertion loss values, are the lower the available bit rate is.

The situation regarding the noise is more difficult. Fig. 2 presents the results of similar measurements on the sample set of wire pairs representing the noise data. It is somewhat surprising to observe that insertion loss clearly marks several groups of wires but noise data is rather homogeneous within the same region while the results of similar measurements carried out in a different region of the same county resulted in a set of characteristics essentially different from the first ones, being however similarly homogeneous within the same region. This means that noise does not make differences between the bit rate of the measured wire pairs of the same region. As the noise is almost the same, it modifies the available bit rate at the same rate for all connections in the same area.

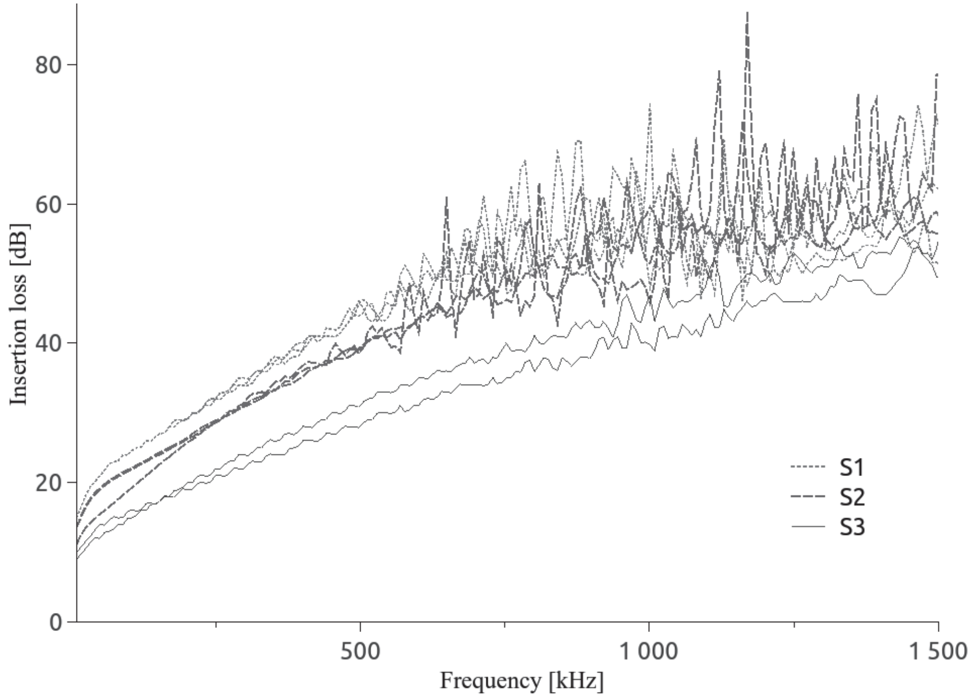

Fig. 1. Examples of measured insertion loss values [8]

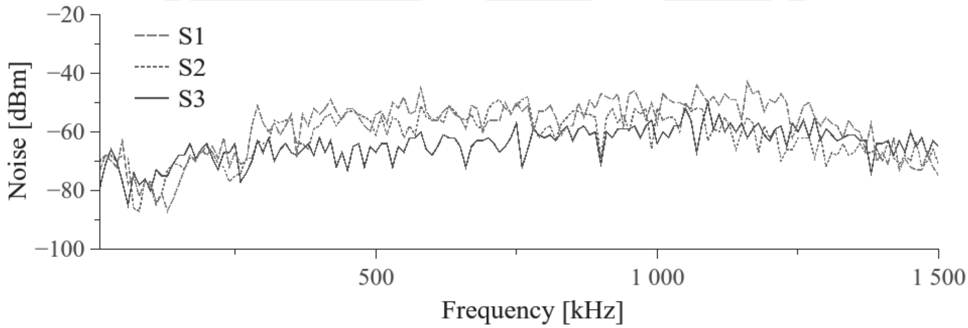

Fig. 2. Noise values of different wire pairs (region *A*) [8]

Fig. 3 shows examples of measured noise values of another region. These graphs are similar to each other, but are different from the ones in Fig. 2. These experiences have two issues. One of them is that the noise is an area dependent parameter has the same effect on the bit rate of each line in the same region. The other one is that performance evaluation can be performed area dependently based only on the values of the insertion loss, while the shape of the noise is handled as a steady parameter of the area and is previously known.

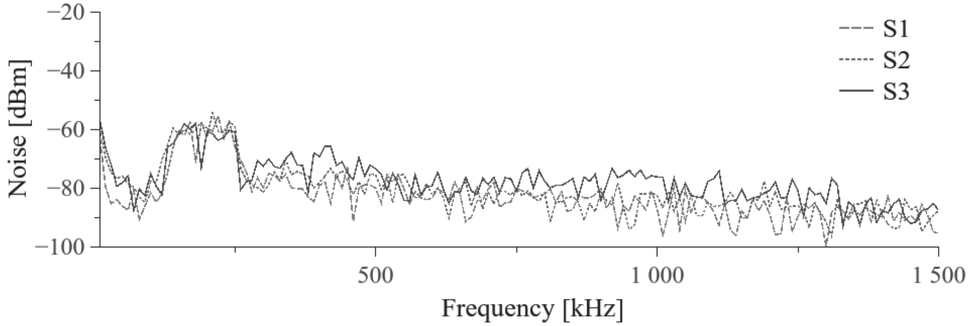

Fig. 3. Noise values of different wire pairs (region B) [8]

2.2.2. Fuzzy rule bases of the evaluation

As was seen in the previous section, the data transfer rate of the SHDSL connections are influenced by two physical parameters, these are the insertion loss and the noise. It was also shown that the values of noise are area dependent, thus in the same or similar noise environments the performance can be evaluated by the exclusive usage of the measured insertion loss values. If the domain of the noise is taken into consideration during the construction of the rule bases (as it takes place automatically during the data collection from single areas), area dependent rule bases can be constructed. These rule bases are based on the measured data transfer rate and insertion loss of the relating areas. Antecedent (input) parameters are the values of insertion loss measured at six discrete frequencies and the consequents (outputs) are the groups of the available bit rates. Different rule bases were created for the same areas.

For swift tests, statistical type rule bases were constructed. These rule bases contain five rules according to the five states of the output, and have six antecedent dimensions with triangular fuzzy sets. Measured data were separated by the measured bit rates, thus groups were created that belonged to singular bit rate groups. The average of the collected insertion loss values of the same frequency and belonging to the same group were selected as the core points of the antecedent fuzzy sets, and the closures of the supports were the minimum and maximum measured values. A graphical example of the creation of an antecedent set can be seen in Fig. 4 and an example of the statistical type rule can be seen in Fig. 5.

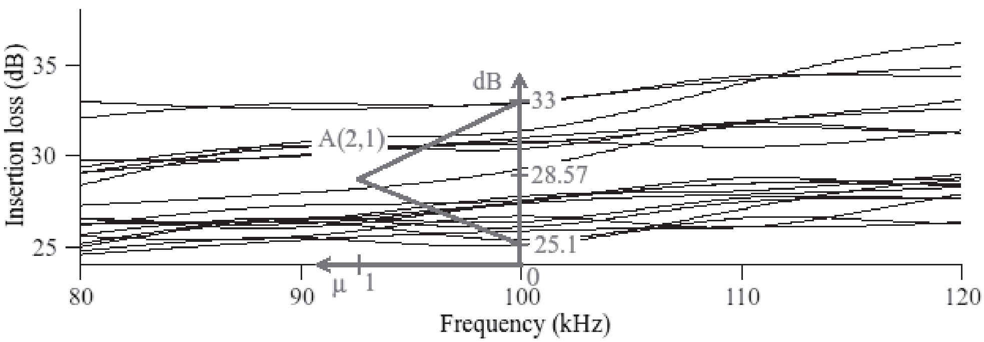

Fig. 4. Creation of an antecedent set [8]

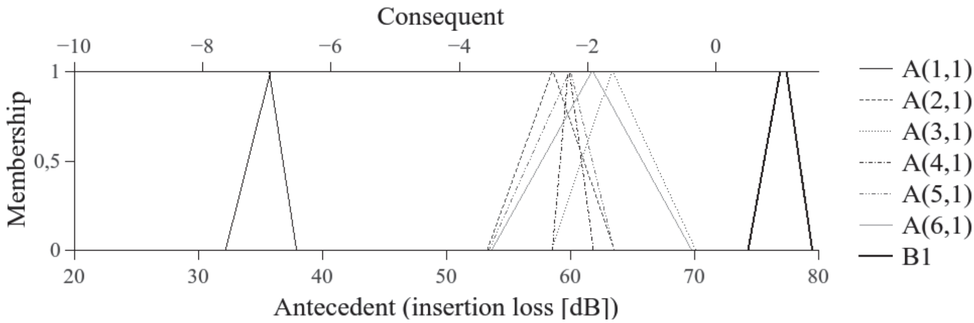

Fig. 5. The first rule of the statistical typed rule base [8]

Evolutionary algorithm [19] was used during the creation of the final rule base. Measured and collected data were used as teaching samples for the algorithm. Final rule bases contain ten rules and the same six antecedent dimensions as the statistical typed ones. All of the antecedent and consequent membership functions are trapezoid. A graphical example of the consequent side of one of the rules of the evolutionary rule base can be seen in Fig. 6.

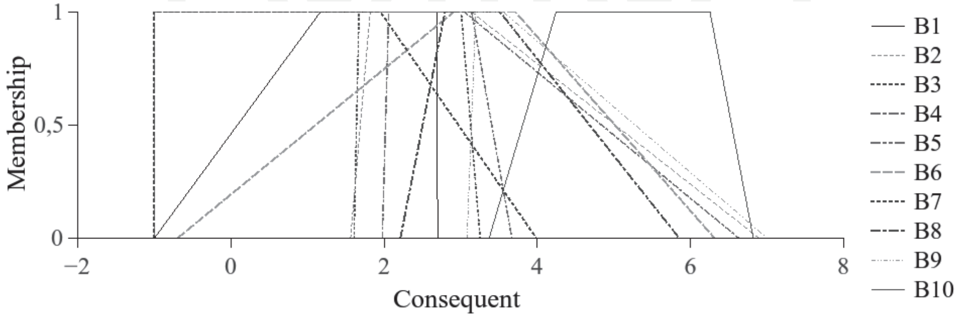

Fig. 6. Example of the consequent sets of the evolutionary rule bases [8]

Both types of rule bases were designed for the Mamdani inference method [18] that uses Zadeh's norms during the evaluation and for centroid defuzzification.

2.2.3. Comparison with other performance evaluation methods

Tests of both types of rule bases were performed. Our results were compared to the results of other performance evaluation methods. For the determination of the accurate maximal bit rate, SHDSL equipment (node and transceiver unit) was installed to the tested lines and the available bit rates were measured. All evaluation methods use ranges of bit rates in the evaluation. These ranges can be different in singular evaluation techniques. Experts use more but smaller ranges and e.g. the distance based methods use less but wider ones. These circumstances make the comparison difficult, so in Table 1 the discrepancies are given in terms of the ranges of the methods used. As an example, in the case of wire the pair signed by F the length based method (4th column) failed the estimation. It rated the pair F into the lower neighboring bit-rate range instead of the correct one. The examined connections are signed by capital characters from A to R.

Negative aberrations are dominant, positive failure was only seen in one case. This behavior fits to the logic of performance evaluation. Underestimation is safer than overestimation. However, results differing from the measured values are not right.

As Table 1 shows, fuzzy based evaluation methods are not worse than other ones, moreover, the fuzzy evaluation by the evolutionary rule base is definitely better than the others.

There are some ‘inputs out of range errors’ among the results of the evaluation by the statistical rule base. This is because this statistical rule type base is sparse. If some of the values of the observations are in uncovered areas of the rule base, the inference system is not able to evaluate the performance of the observed line correctly. Another edification of the tests is that sparse rule bases cannot be directly used in the performance evaluation of telecommunication connections.

Table 1

Comparison of different performance evaluation methods [15]

Wire pair	Measured bit rate [kbit/sec]	Discrepancy by expert	Discrepancy by length from inventory	Discrepancy by fuzzy method (statistical rule base)	Discrepancy by fuzzy method (evolutionary rule base)
A	2376	–2	0	1	0
B	2056	–1	–1	0	0
C	4040	1	–1	–1	–2
D	4040	–1	–1	–1	–2
E	3144	0	–2	0	0
F	3144	0	–1	0	0
G	5704	–2	–2	input out of range	0
H	2056	–1	–1	0	0
I	3144	–1	0	input out of range	1
J	4936	–1	–2	0	0
K	4040	0	–1	–1	–2
L	4360	0	–1	–1	–1
M	1736	0	0	0	0
N	2056	0	–1	input out of range	0
O	4804	0	–1	0	0
P	4360	0	–1	0	0
R	4616	–3	–1	0	0

3. Fuzzy based fault prognosis [22]

With few exceptions, some decades ago telecommunication meant phoning or in case of business or government customers, using telex services. Telecommunication networks were designed and installed in order to fulfil these demands. The appearance of the digital technologies in telecommunications, the spread of the data communication services and mainly the big boom of the internet made the use of new, high speed technologies necessary.

One of the ways of raising the data transmission rate is the use of optical cables. The optical cables displaced the old metallic cables in the core networks or in the interexchange networks and these cables are used in cases of installing new access networks. However, telecommunication providers are not able to renew their whole network at the same time, and it would also be economically wrong to ignore the existing and useful copper wire pair based access networks that are able to produce a large amount of income without significant investment.

Another way of installing high-speed connections is the use of new technologies in the old, metallic networks. Such technologies are the members of the xDSL (Digital Subscriber Line) family that are definitely evolved for copper based access networks [4]. These are able to create relatively high-speed connections by use of several transmission methods. SHDSL systems (Symmetrical High-speed Digital Subscriber Line) [7] are able to make symmetrical digital data transmission by using TC-PAM (Trellis Coded Pulse Amplitude Modulation) modulation, where the bit rate of upload and download are equal. This type of transmission is mainly used to fulfil the demands of business customers. In the field of data transmission of private customers in copper wire based access networks, ADSL technology (Asymmetric Digital Subscriber Line) [6] is used. It can provide a sufficient bit rate with the use of a single wire pair, however, in accordance with the mode of the communication of the customers, the bit rates of the different directions (upload and download) are different.

In the communication between the endpoints, not only DSL technology is used, in different sessions different transmission methods are applied. In the core networks and in the interexchange networks for example, SDH and ATM systems carry the packages of data. However, faults can happen in the whole connection, according to empirical observations most of the faults occur in the access network used by the DSL systems, furthermore, these faults are individual so each of them needs separate handling and troubleshooting.

Upkeep and troubleshooting of access networks are time consuming and in many cases, problematic. Errored connections are not able to produce income and if the failures are not fixed within a certain time, telecommunication companies have to pay penalties to the customers. The fact the troubleshooting process generally starts after the fault report leads to logistics problems. Other expenses derive from the unplannable routes and the difficulties of the organization of daily work. Workforce management is not optimal as urgent and important troubleshooting tasks turn up during an organized shift. Problems can be decreased if the faults are handled by planned upkeep of the networks or if they are predictable. Telecommunication companies (TELCO) use several techniques for failure prevention.

The connections of the business customers are continuously monitored by the telecommunication service providers to keep the level of service at a given rate. The failures are often observed by the TELCOs before the customer would notice them. These so called proactive systems are generally able to detect the possible reasons of the failure [5], however the failure is not predicted, so that these systems do not avert the failures. There is no such kind of proactivity in the case of private customers. The procedure of the repair is started by the service provider after the complaint of the customer is received. However, the forehand reparation can have some economic advantages. On the one hand, there are no deadlines for the reparation and so the work can be performed in a planned way bounded with other tasks, on the other hand, the cancellation of the income in the errored period can be avoided.

Hereinafter, some existing automatic fault detecting methods, and results of such work until now are presented that aims to create a method that is really proactively able to forecast the line failures of ADSL connections.

3.1. DSM (Dynamic Spectrum Management) based systems and copper pair troubleshooting by Principal Component Analysis

The performance of the different DSL systems is mainly influenced by two physical factors. One of them is the insertion loss (in connection with the attenuation) and the other one is the noise [8]. The insertion loss is principally depending on the length and the diameter of the cable, so that in particular cases, it must be considered as a steady parameter. The effect of the insertion loss can be reduced by the reduction of the length of the cable – in this case, the DSLAM is installed closer to the subscriber – or the rise of the diameter of the wire. The other influencing parameter is the noise. It comes from different sources. Its parts that originate from the wire pair itself are the thermal noise and the effects of reflections and echoes. Environmental noise effects are the impulse noise or the noise coupled into the wire pair by the broadcast radio channels and the crosstalk [1]. At the higher frequencies, the effect of the crosstalk is significant [2].

A powerful tool of the cancellation of crosstalk effects is Dynamic Spectrum Management (DSM). These methods use different power spectral masks in the case of ADSL connections that use DMT modulation [3] in order to raise the throughput of the whole system.

Telecommunication providers use DSM based management systems in order to improve the quality of their ADSL services. During iterative interferences, these systems are able to keep the bit rate continuously at the maximal level that is available for the given connection, however, they are not qualified for the forecast and the prevention of the probable failures separately.

Another method proposes the use of DSLAM data in correlation with humidity data [9]. Humidity changes the properties of symmetrical wire pairs, e.g. symmetry or insulation resistance. These changes have effect on noise. The worse the wire pair parameters are the higher the noise is. As noise is increasing, transmission parameters of DSL systems are declining. This declination is observed and recorded by DSLAMs. The method in [9] suggests the use of this recorded information to discover the problematic cables and launch the troubleshooting process proactively before the customers report faults.

3.2. A novel method for improving the ADSL service level

Telecommunication providers perform the reparation of the ADSL connections in a reactive way. The search of the reasons for the failure and the reparation of the failure starts after the customer’s complaint is received. In this case, the provider is expected to keep the deadlines for the reparation, so that in lots of cases, he is not able to perform his operation in a planned way. It is disadvantageous mainly in rural areas where the completion of the tasks that come up in the same area would be practical to be made at the same time.

Proactive work needs a system that is able to predict the probable failures. The creation of such systems is greatly helped by the management and monitoring systems, which control the telecommunication networks and connections [5] (Fig. 7).

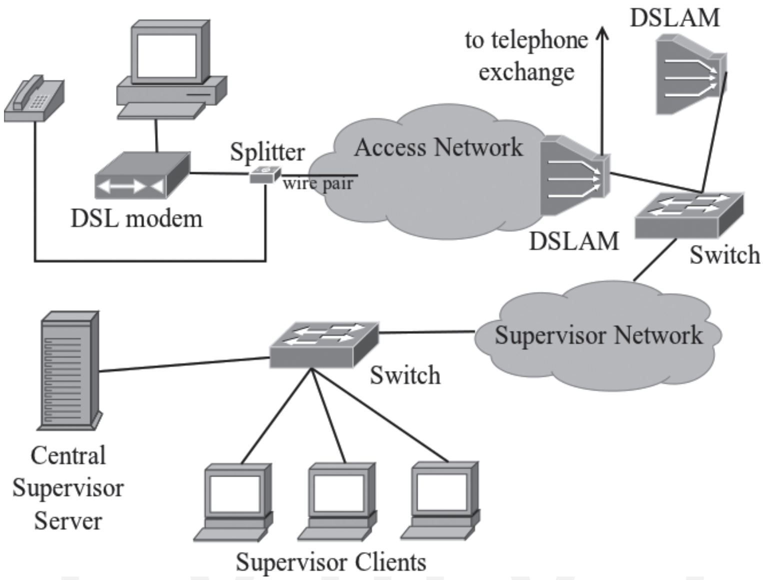

Fig. 7. ADSL model and its supervision system

The two main functions of a supervision system are the setup of the transmission parameters of the connections and the monitoring of the operational parameters of the terminals. Because of the wide range of monitorable parameters and the variance of the monitoring systems of the different manufacturers, only the most important parameters from the point of view of the problem are mentioned here.

Output Power. In downstream, it is the output power of the DSLAM and in upstream, it is the output power of the modem. The output power of the different DMT channels can be different. These values are modified in order to find the best transmission spectral mask during the DSM process that was mentioned previously.

Attenuation. The attenuation is the difference in dB between the received and the transmitted power for a single DMT channel [6]. The average of the measured values of all channels is indicated by the supervision system separately for upstream and downstream.

SNR Margin. The Signal to Noise Ratio Margin in dB refers to the power of the received noise compared to the noise power that the system is designed to tolerate [6]. Also, this value is an average and is separately given for upload and download.

Current rate. The Current rate is the actual bit rate of the upload and download transmissions. In the case of connections in good conditions, the actual rate reaches the bit rate fixed by the network operator.

Attainable Rate. This is the maximal available bit rate. This value is calculated from the line parameters. Also, it is calculated for upload and download. The small gap between this value and the current rate refers to the bad conditions of the wire pair of the access network.

FECS. The number of seconds when at least one received frame was corrected.

ES. The number of seconds when at least one received frame was uncorrectable.

LOSS. Loss is the number of seconds when no frame was received by the DSLAM.

UAS. UAS is the number of seconds without payload.

FIC. (Full Init Count) FIC is the number of resynchronizations in a given period of time. Practically it is equal to the number, the connection lost errors.

FFIC. (Failed Full Init Count) FFIC is the number of unsuccessful attempts for resynchronization.

Table 2

Examples of some measured parameters

Line ID	Attenuation (downstream) [dB]	SNR margin (downstream) [dB]	Attainable rate [kbit/s]	Current rate [kbit/s]	Connection lost errors (previous day)
XT006361	13	23	3508	2560	0
XT009560	56	8	1648	1105	526
XT009564	41	8	1408	842	3
XT006375	33	20	10432	2925	2
XT006458	8	16	12544	5888	0
XT006383	28	14	13540	6746	0

We have examined real ADSL connections in operation. During the tests, 400 connections were examined over a two months period. The values of the parameters mentioned above were measured and recorded hourly. Some of them are shown in Table 2. In case of line numbered XT009560, the high values of connection lost errors show that this line is out of order. The ADSL connection is lost more than 500 times a day. However, this error ratio is very high, the customer did not reported the problem. It can be because of his Internet using habits. The other lines in Table 2 are well operable, however, there are 2 connection lost errors in the case of line XT006375 and 3 in the case of XT009564.

Another cautionary symptom is the unstable current rate. If this parameter is continuously changing from one measurement to another, the physical parameters of the line are presumably wrong.

The measurements suggest two conclusions. The first is that there is a possibility for creating a quick proactive method based on the measured FIC values and the variation of the current rate. The second can be based on the variation of the attenuation and the SNR margin, however, it needs further examinations.

3.2.1. FIC and current rate based proactive method

TELCOs do not use proactive methods in their ADSL maintenance processes, however in several cases, e.g. in cases of connections leased from other telecommunications companies, it would be reasonable. We propose a method that can terminate several types of errors and ensure good quality of the service for a long time before the customers would notice a errors.

In cases of the deterioration of the wire pairs the connection becomes unstable. 'Connection lost' errors arise that last for short periods of time. These errors can occur also in case of lines in good condition because of various reasons, e.g. if the user restarts the modem or if there is a momentary blackout. The variation of the current rate indicates well that the ADSL connection works at top of the technical possibilities of the wire pair. A small rise in the noise or a small change in other parameters worsens the conditions so that the bit rate cannot be held.

It was shown by our examinations that the consideration of these two parameters is enough to predict upcoming failures of the connection. In this case, we recommend two types of action.

The first is a quick action in order to avoid further errors, however, it does not eliminate the reasons for the error. In this case, the target of the SNR margin is raised, so the bit rate of the connection is lowered by the network operator. Because of this action, small failures of the physical line cannot destroy the connection.

The other type of action is the reparation of the physical line. As the reparation of the line can be started before the customer's complaint, it can be executed in a planned way and there are no deadlines and risks of penalty. Fig. 9 shows the result of one of the tests were performed before the reparation of the telecommunications line.

Table 3 shows some numerical data of several wrong connections.

Table 3

Data of wrong connections

Line ID	Attenuation [dB]	Variation of SNR Margin [dB]	Variation of Current rate [kbit/s]	Max. FIC
XT008419	22.6	4	568	84
XT007320	41.0	7	1288	45
XT007476	59.0	6	912	37
XT007990	41.0	5	294	31
XH006699	54.5	5	812	13
XT007998	51.0	7	3136	25

Recorded data of line XT007998 can be seen in Table 3. The measured values were bad and varying until the action. After this time, the connection became steady. Although the maximal available bit rate was declined from 5000 to around 1500 kbit/sec, the number of the FIC fell to zero. The declination of the bit rate is acceptable during the days of the physical reparation of the line.

3.3. Fuzzy based failure prediction

Although, at the moment there is not yet enough recorded data for rule based construction, we plan to create a fuzzy based failure prediction system.

By the experiences of operation of telecommunication networks and DSL systems, it can be said that the erosion of metallic cables based connections goes hand in hand with the erosion of the attenuation and/or noise. These effects are in connection not only with the aging of the cables themselves, their main reasons are the failures of the junctions or physical failures of the cables (e.g. leaks of the cable jacket and soaking). As DSL systems are highly sensitive to attenuation and noise, these failures of the transmission medium lead to the failure of the service. In most of the cases, the failures do not happen suddenly, this phenomenon is a slower flow. It means that the erosion of these parameters can be observed before the full failure of the DSL connection. Taking also economic and logistic points in consideration, in the case of the first emergence of the failures mentioned, there is no need for sudden repair in all cases, proposed repairs can be performed in view of available failures. For giving forecast of the available failures the next fuzzy based failure prediction system is planned.

The worst but yet acceptable values of the attenuation and the noise will be diagnosed for all levels of service. These values will serve as limits of action (LI) (Reaching LI an immediate repair is needed). Regularly monitoring the attenuation and the noise parameters of the connections the observed values will be recorded and compared to the LIs. Analysing the speed of the declination of these values the rates of failure (RF) will be calculated. Having the rates of failures and the momentary distance from the LI (DLI) the next rules can be used for the conclusion.

R1. IF DLI(attenuation) is ***small*** *AND RF(attenuation) is* ***high*** *THEN action is needed.*

R2. IF DLI(noise) is ***small*** *AND RF(noise) is* ***high*** *THEN action is needed.*

R3. IF DLI(att.) is ***high*** *AND RF(att.) is* ***low*** *AND DLI(noise) is* ***high*** *AND RF(noise) is* ***low*** *THEN action is NO needed.*

The curiosity of this rule base is that noise as antecedent dimension is missing from rule R1 and attenuation as an antecedent dimension is missing from rule R2, although both of them are present in rule R3. The reason for this is that action is needed in cases of the deterioration of attenuation OR in case of the deterioration of noise. There is OR connection between

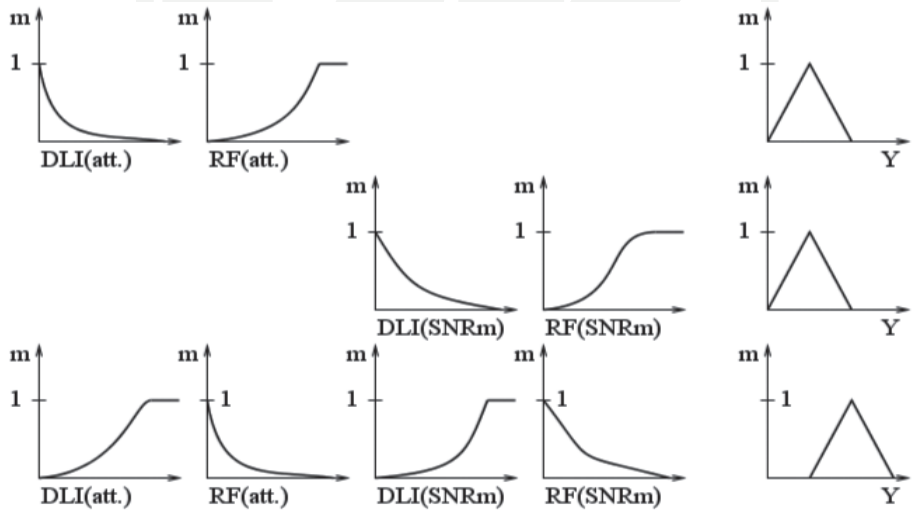

Fig. 8. A graphical example of the rule base described in Section 3.3

them, so they cannot be handled in the same rule where there are only AND connections in the antecedent side. Fig. 8 shows this odd structure of the rule base. The fuzzy sets of the linguistic variables of high and low are planned to be constructed from the recorded data, so the graphical example of the rule base (Fig. 9) is only a fictive illustration, however these shapes are expected.

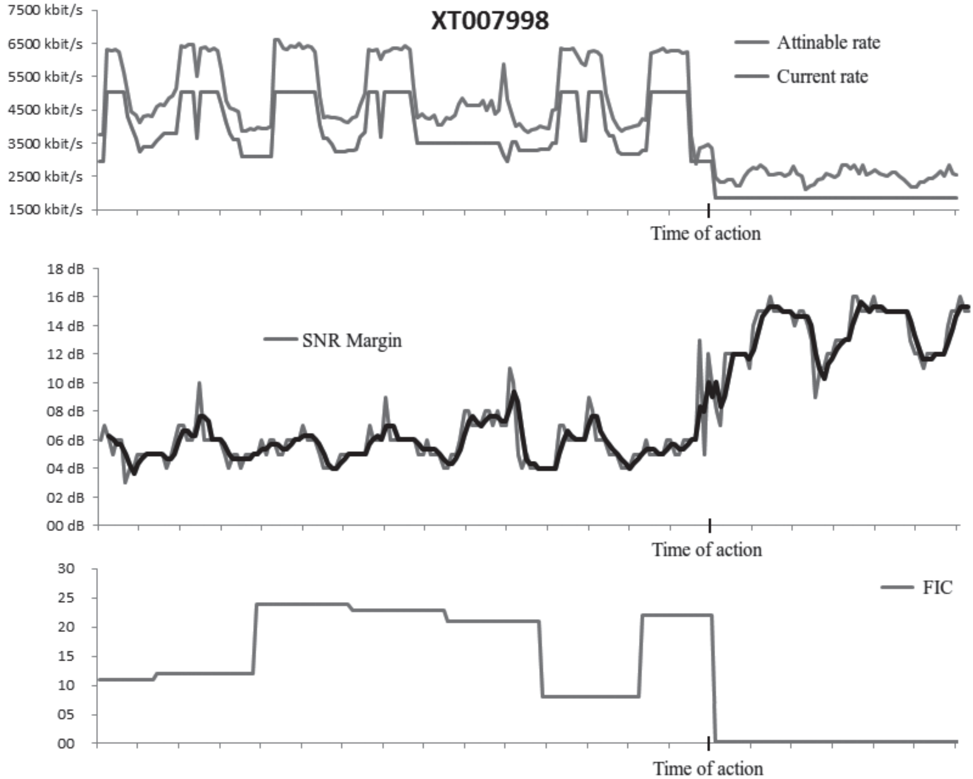

Fig. 9. The behavior of the line XT007998 before and after the interposal

For the final conclusion, the Mamdani inference method is to be used. The crisp conclusion means not only the YES or NO for the necessity of the action but it refers also to the urgency of the action in cases of bad telecommunications connection or the possibility of long term failure in cases of a good connection.

4. Conclusions

Novel fuzzy based approaches were introduced in telecommunications fields.

First, one is a performance evaluation technique that applies evolutionary algorithm created rule bases, based on measured data. The results are better than other methods that were used during the comparison.

The second presented method is a fault prediction technique. Supervision systems monitor lots of operational parameters of the networks. These data can be used in preliminary error recognition, and thus early repair of the elements of the networks can be performed. It has more advantages. In addition to detecting that several parts of the network are in bad condition, the harmful effects of the predicted error can be avoided. The results of the tests of this method are successful, however this method is able only for the prediction of errors which are expected in the very near future.

As for further plans, in the near future the limits of action of each level of DSL service will be diagnosed by results of long-term measurements and fuzzy rule bases will be constructed for giving failure predictions of ADSL connections.

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Appendix

ADSL. Assymetric Digital Subscriber Line. A broadband digital telecommunications transmission technique for the symmetrical wire pairs of access networks used for connecting to the Internet.
Access network. Telecommunications network which connects the subscribers to their respective service provider.
ATM. Asynchronous transfer mode. A broadband digital telecommunications concept for transmitting video, voice and data.
Bit rate. Data transfer rate. The number of the transmitted bits in a second (or in a unit of time).
DMT. Discrete Multi-tone Modulation. A digital multi-carrier method to transmit the data in small amounts in paralell subchannels of the whole frequency band.
DSL. Digital Subscriber Line. A group of transmission methods for connecting the subscribers to the Internet via the symetrical wire pairs of the access network.
DSLAM. Digital subscriber line access multiplexer. A piece of equipment which connects multiple DSL lines to higher level communications channels.
DSM. Dynamic Spectrum management. A method to increase the maximal available bit rate of DSL connections.
IPTV. Internet Protocol Television. Television services using IP networks.
MDF. Main Distribution Frame. A distribution frame which crossconnects the wire pairs of the symmetrical cables of access networks.
OSI. Open Systems Interconnection. A joint standard of ITU-T and ISO.
POTS. Plain Old Telephone Service. The traditional telephone service for voice communications with 3.4 kHz wide bandwidth.
PSD. Power Spectral Density. The power of a signal per unit of frequency.
SDH. Synchronous Digital Hierarchy. Telecommunications protocol for transmitting multiple bit streams over optical connections.
SHDSL. Single-pair High Speed Digital Subscriber Line. A symmetrical transmission member of the DSL family.

SNR. Signal to Noise Ratio.
TC-PAM. Trellis Coded Pulse-Amplitude Modulation. A modulation method used in SHDSL described in ITU-T G-Series.
TELCO. Telecommunications Company.
VoIP. Voice over IP. Protocol for voice transmission over IP networks.
xDSL. An alternative name for DSL.

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