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**AN ADAPTIVE CONTROL SYSTEM OF TELECOMMUNICATION NETWORK
RESOURCES BASED ON FUZZY LOGIC**

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МЕРЕЖІ НА ОСНОВІ НЕЧІТКОЇ ЛОГІКИ**

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Abstract. In modern telecommunication systems and networks, causal relationships in the gnoseological (cognitive) plan are not clearly traceable, which leads to uncertainty when choosing or building a mathematical model due to incompleteness of the source data (knowledge). It gives rise to multicriterial uncertainty, which, in turn, makes it impossible to solve the problem of a telecommunications network optimal control properly. In such conditions it is difficult to build an adequate model of a telecommunication network based on deterministic and probabilistic-statistical mathematics, since there are no objects that can accurately display information vagueness. Therefore, it is of interest to develop and research telecommunication systems and networks models using the apparatus of fuzzy sets theory and their influence on decision-making processes on network element state. The paper shows that the use of fuzzy logic to control the resources of a telecommunications network made it possible to create an easily scalable management system, the logic of which allows the easy build and change of its structure on a systematic basis by expanding (changing) the rule base. To adjust the membership functions to the nature of the traffic, you can apply special operations on fuzzy sets: concentrating and stretching.

Key words: traffic, fuzzy regulators, fuzzy adaptive controller, linguistic variables, membership function, concentration operation, stretching operation.

Анотація. У сучасних телекомунікаційних системах і мережах причинно-наслідковій зв'язки в гносеологічному (когнітивному) плані не чітко простежуються, що призводить до невизначеності при виборі або побудові математичної моделі через неповноту вихідних даних (знань). Це породжує багатокритеріальну невизначеність, що, у свою чергу, робить неможливим правильне вирішення проблеми оптимального керування телекомунікаційною мережею. За таких умов складно побудувати адекватну модель телекомунікаційної мережі, що базується на детермінованій та ймовірностатистичній математиці, оскільки не існує об'єктів, які могли б точно відобразити невизначеність інформації. Тому представляє інтерес розробка та дослідження моделей телекомунікаційних систем і мереж з використанням апарату теорії нечітких множин та їх впливу на процеси прийняття рішень щодо стану елементів мережі. В роботі показано, що застосування нечіткої логіки для керування ресурсами телекомунікаційної мережі дозволило створити легко масштабовану систему керування,

логіка роботи якої дозволяє легко нарощувати і змінювати її структуру на систематичній основі, шляхом розширення (зміни) бази правил. Для налаштування функцій належності під характер трафіка можна застосувати спеціальні операції над нечіткими множинами: концентрування і розтягування.

Ключові слова: навантаження мережі, нечіткі регулятори, нечіткий адаптивний контролер, лінгвістичні змінні, функція належності, операція концентрації, операція розтягування.

Аннотація. В современных телекоммуникационных системах и сетях причинно-следственные связи в гносеологическом (когнитивном) плане четко не прослеживаются, что приводит к неопределенности при выборе или построении математической модели из-за неполноты исходных данных (знаний). Это порождает многокритериальную неопределенность, что, в свою очередь, делает невозможным правильное решение проблемы оптимального управления телекоммуникационной сетью. В таких условиях трудно построить адекватную модель телекоммуникационной сети, основанную на детерминистической и вероятностно-статистической математике, поскольку нет объектов, которые могли бы точно отображать неопределенность информации. Поэтому представляет интерес разработка и исследование моделей телекоммуникационных систем и сетей с использованием аппарата теории нечетких множеств и их влияния на процессы принятия решений о состоянии элементов сети. В работе показано, что применение нечеткой логики для управления ресурсами телекоммуникационной сети позволило создать легко масштабируемую систему управления, логика работы которой позволяет легко наращивать и изменять ее структуру на систематической основе, путем расширения (изменения) базы правил. Для настройки функций принадлежности под характер трафика можно применить специальные операции над нечеткими множествами: концентрирования и растяжения.

Ключевые слова: нагрузка сети, нечеткие регуляторы, нечеткий адаптивный контролер, лингвистические переменные, функция принадлежности, операция концентрации, операция растяжения.

Ensuring service quality of increasing traffic flows requires appropriate analyzing methods and network monitoring that constantly address incomplete and increasing telecommunication systems needs.

Transmission path models and information distribution systems are multidimensional and usually are based on the theory of mass service systems and Markov process. Such problem solution is approximate, even with several assumptions and availability of basic statistical information. When monitoring and managing complex processes and telecommunications network elements in real time, the above-mentioned apparatus can be ineffective in cases when the source information is statistically unstable, incomplete or absolutely absent.

Telecommunications network traffic is not uniform, and it changes over time. When using a rigid logic loading control system, excessive requirement increases for the telecommunications network limited resources by one or several users can degrade service quality for other network users.

Telecommunications network resources control is carried out in a network with indistinctly specified parameters, since the parameters of switching nodes and transmission system paths may vary.

The main reasons are the constant impact of internal and external factors of telecommunications network (variation in the parameters of telecommunication systems equipment, changes in operating conditions, etc.).

In modern telecommunication systems and networks, causal relationships in the gnoseological (cognitive) plan are not clearly traceable, which leads to uncertainty when choosing or building a mathematical model due to incompleteness of the source data (knowledge) [1]. It gives rise to multicriterial uncertainty, which, in turn, makes it impossible to solve the problem of a telecommunications network optimal control properly.

In such conditions it is difficult to build an adequate model of a telecommunication network based on deterministic and probabilistic-statistical mathematics, since there are no objects that can

accurately display information vagueness. Therefore, it is of interest to develop and research telecommunication systems and networks models using the apparatus of fuzzy sets theory and their influence on decision-making processes on network element state.

The use of fuzzy regulators to control various (in particular, non-stationary and nonlinear) objects shows their high efficiency and, in some cases, significant advantages compared to linear digital regulators.

The main difficulty in creating fuzzy regulators is that changing the parameters of telecommunications network (control object) causes the necessity of control rules modification with their subsequent, time-consuming iterative adjustment.

For dynamic control of load flows in a telecommunications network special technical means are needed to adapt to the constantly changing conditions of automatic and automated network management, i.e. adaptive telecommunications network resource management systems. The main goal of adaptation or adaptive control of telecommunications network parameters is to improve service quality in operation-changing conditions.

When managing the resources of telecommunications network, a fuzzy adaptive controller, based on the prediction of state information distribution devices and transmission paths, determines the parameters values necessary to stabilize the service quality at a given level.

Figure 1 is a diagram of a system with a fuzzy adaptive regulator (Fig. BLR - a set of linguistic rules).

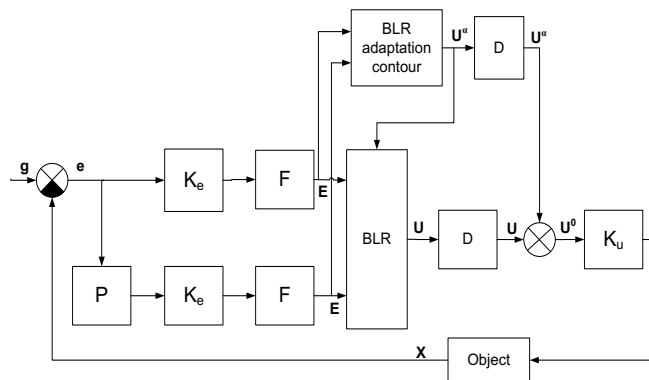


Figure 1 – Functional diagram of a system with a fuzzy adaptive regulator

The fuzzy adaptive controller is based on the linguistic variables table (productive rules) of the main control loop describing the packet movement dynamics with possible changes in the network operation conditions (load, throughput). The fuzzy adaptive controller knowledge base model incorporates parametric uncertainty and expert knowledge when describing a telecommunications network and provides flexible routing and transmission rate control in order to ensure given service quality.

The control adaptation procedure consists in the correction of some fuzzy production rule from the table of linguistic variables of fuzzy controller main circuit, which caused current undesirable reaction of the control object. Consider this procedure in more detail. Suppose that some fuzzy production rule taken from the table of linguistic variables of the fuzzy controller main circuit was the reason for the current output of the control object being inadequate (from the point of view of the table of linguistic variables of fuzzy adaptation circuit). The description of this fuzzy production rule creates a matrix:

$$R_{n-k}^a = E_{n-k} \times E_{n-k} \times U_{n-k}, \quad (1)$$

where n is the index of current polling time of the object; k - determined from the dynamics of the object; F-operator transition from a clear variable to a fuzzy one.

Current inadequate response of the control object is established by some fuzzy production rule from the table of linguistic variables of the adaptation contour, fuzzy description of which also constitutes a matrix:

$$R_n^a = E_n \times E_n \times U_n^a. \quad (2)$$

Obviously, unsatisfactory fuzzy production rule must be replaced with the corrected one:

$$R' = E_{n-k} \times E_{n-k} \times U^H, \quad (3)$$

Thus, a new fuzzy production rule will be entered the table of linguistic variables of the basic circuit, which for current parameters of the control object is preferable to the remote one. And for the adaptation control corresponding to unsatisfactory fuzzy production rule, it seems appropriate to use a clear value in accordance with the following algorithm:

$$\begin{aligned} u_n &= D\{U_n\}; \\ u_n^a &= D\{U_n^a\}. \end{aligned} \quad (4)$$

The use of fast inference algorithm [2] provides the total execution time of fuzzy adaptation procedure to the control output generation no more than the control output generation time in the fuzzy controller using Zadeh method based on the compositional inference rule.

If control object parameters are stationary, it is possible to apply fuzzy adaptation contour for the governing rules initial generation of the linguistic variables table of the main contour [3]. Software simulation of the control system is used in this case and the table of linguistic variables of the main circuit does not contain rules until beginning the training. Fuzzy logic control system training is performed until the algorithm is fully developed and the fuzzy production rules correction is stopped. After training has completed, the main circuit table contains the necessary number of rules for outputting the control object to the set task with desired quality of transition process.

When the nature of traffic changes, it is necessary to change the form of membership functions of fuzzy sets [4]. To adjust the membership functions to the nature of traffic, you can apply special operations on fuzzy sets, concentrating and stretching $[\mu(u)]^c$.

Concentration operation

$$\text{CON}(A) = A^c \quad c > 1, \quad (5)$$

and the membership function is

$$\mu_{A^c}(x) = (\mu_A(x))^c. \quad (6)$$

Stretching operation

$$\text{DIL}(A) = A^c \quad 0 < c < 1, \quad (7)$$

the membership function describes the expression

$$\mu_{A^c}(x) = (\mu_A(x))^c. \quad (8)$$

The degree of change in the shape of the membership function is determined by the exponent c , which is called the coefficient of relative importance. Operation of concentration and stretching can be applied to each segment of the membership function (Fig. 2).

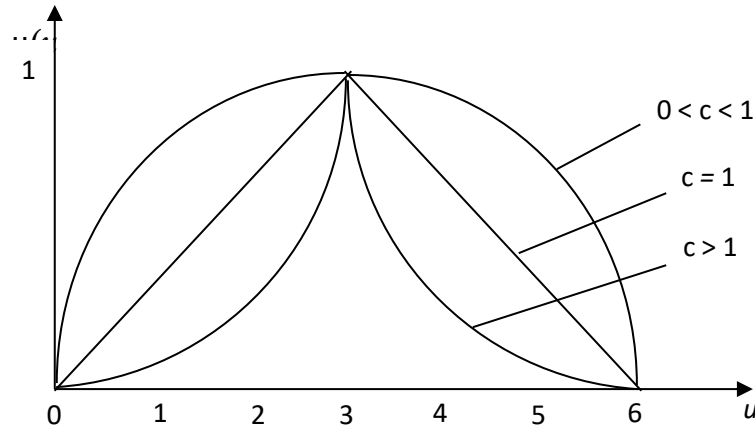


Figure 2 – Improving membership functions using concentration and stretching operations

Let the universal set $U = [0, 1]$ where two fuzzy subsets are given, whose membership functions for each linguistic quantity are determined by the formulas

$$\begin{aligned} \mu_1(u) &= (1 - u)^c, \quad u \in [0, 1]; \\ \mu_2(u) &= u^c, \quad u \in [0, 1]. \end{aligned} \quad (9)$$

When the values of the input variables with the quantization step h are received by the fuzzy controller, the input variables are variable into the universal set and the membership function is calculated for these variables. Possible values of variables for the current time point in the figure are marked by dots on the universal set.

We take ranges of input signals change symmetrical, which will simplify the normalization (recalculation of signal values into the values of elements of a single universal set)

$$Y_{\max} = -Y_{\min}; \dot{Y}_{\max} = -\dot{Y}_{\min}; \ddot{Y}_{\max} = -\ddot{Y}_{\min}. \quad (10)$$

The expression for the normalization will be written in the form

$$\left. \begin{aligned} u_1^* &= -(Y^* - Y_{\min}) / 2Y_{\min} \\ u_2^* &= -(\dot{Y}^* - \dot{Y}_{\min}) / 2\dot{Y}_{\min} \\ u_3^* &= -(\ddot{Y}^* - \ddot{Y}_{\min}) / 2\ddot{Y}_{\min} \end{aligned} \right\} \quad (11)$$

The linguistic rules for managing the controller on fuzzy logic are formulated as follows:

$$\text{If } (Y^* = a_1^j) \text{ and } (\dot{Y}^* = a_2^j) \text{ and } (\ddot{Y}^* = a_3^j), \text{ then } (m^* = a_c^j), \quad j = \overline{1,2}, \quad (12)$$

where a_1^j, a_2^j and a_3^j are the linguistic estimates of the error, the first derivative of the error and the second derivative of the error, which are considered as fuzzy term-sets defined on the universal set $j = \overline{1,2}$; a_c^j – linguistic assessments of the control action on an object, which are chosen from the

term set m . Linguistic estimates are chosen from the term-sets of linguistic variables Y^* , \dot{Y}^* , \ddot{Y}^* and m^* :

$$a_i^j \in \{negative(1), positive(2)\}. \quad (13)$$

The membership function of the control action to a fuzzy term set “negative”, in accordance with linguistic rules, is limited from above by the value:

$$A = \min[\mu_1(u_1^*), \mu_1(u_2^*), \mu_1(u_3^*)]. \quad (14)$$

The membership function of the control action to a fuzzy term set “positive” is limited from above by the value:

$$B = \min[\mu_2(u_1^*), \mu_2(u_2^*), \mu_2(u_3^*)]. \quad (15)$$

The resulting membership function for the resultant impact is determined by the expression

$$\mu_c(u) = \mu_{1c}(u) \vee \mu_{2c}(u), \quad (16)$$

maximum formation

$$\mu_c(u) = \max[\mu_{1c}(u), \mu_{2c}(u)]. \quad (17)$$

For fuzzy regulators using membership functions with two terms, it is possible to simplify the comparison of the values of $A(t)$ and $B(t)$ and the calculation of u_c .

If instead of entire area of resultant figure bounded by “resultant membership function”, the areas of the rectangles are defined under the straight lines designated A and B, which restrict the membership functions of the input linguistic variables, then instead of integration, the products are calculated

$$A \times x_1, B \times (1 - x_2) \text{ and } \frac{A}{2} \times x_1^2, \frac{B}{2} \times (1 - x_2^2). \quad (18)$$

Where x_1 and x_2 are the abscissa of the intersection points of the straight lines A and B with the corresponding membership functions.

If $A \leq B$ (Fig. 3)

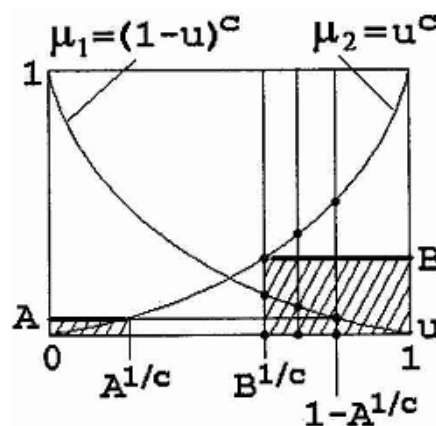


Figure 3 – Squares of rectangles under lines that limit the membership functions of input linguistic variables from above

Then the abscissa of the center of gravity of the resulting figure is determined by the expression

$$u_c = \frac{\frac{B}{2} + \frac{1}{2} \left(A^{\frac{2}{c}+1} - B^{\frac{2}{c}+1} \right)}{B + A^{\frac{1}{c}+1} - B^{\frac{1}{c}+1}} \text{ at } A \leq B. \quad (19)$$

If $A \geq B$ (Fig.4)

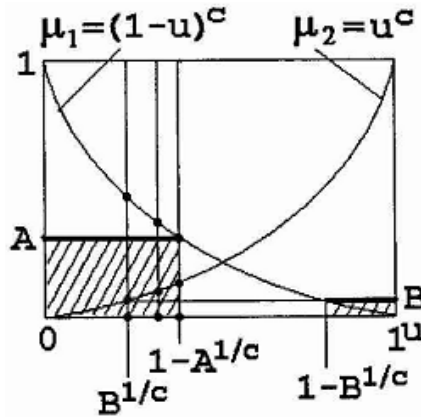


Figure 4 – Squares of rectangles under lines that limit the membership functions of input linguistic variables from above, with $A \geq B$

then the abscissa of the center of gravity of the resulting figure is determined by the expression

$$u_c = \frac{\frac{A}{2} - A^{\frac{1}{c}+1} + B^{\frac{1}{c}+1} + \frac{1}{2} \left(A^{\frac{2}{c}+1} - B^{\frac{2}{c}+1} \right)}{A - A^{\frac{1}{c}+1} + B^{\frac{1}{c}+1}} \text{ at } A \geq B. \quad (20)$$

If we take $A = 0,01$; $B = 0,4$ and $c = 2$; then For $A = 0,4$ and $B = 0,01$ and $C = 2$. The model of comparison unit of quantities and calculations is shown in Fig. 5.

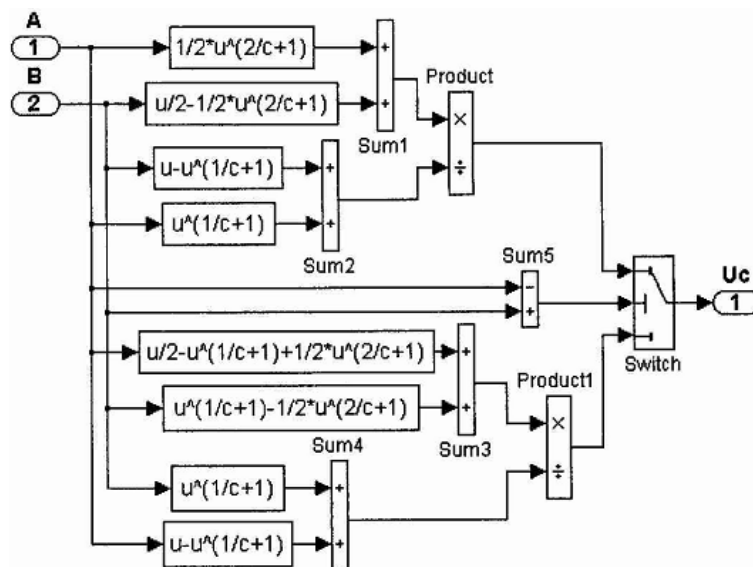


Figure 5 – Functional diagram of comparison of quantities and calculations

In the process of adaptation, the parameters of fuzzy controller are optimized for the selected quality criterion.

If it is necessary to ensure the accuracy of tracking the buffer loading of the router or the utilization rate of the transmission paths of the transmission systems (minimize the current error), then one of the quadratic quality criteria is used, for example

$$J = \frac{1}{T} \sum_{i=0}^{T-1} Y_i^2 \Rightarrow \min, \quad (21)$$

where the error Y_i is calculated with the quantization step h_0 , and the number T determines the observation interval.

If a fuzzy controller is implemented in the interactive system MATLAB, then the value of the root-mean-square error is calculated (DRMS block) and the quality criterion is described by the expression

$$J = \sqrt{\frac{1}{T} \sum_{i=0}^{T-1} Y_i^2} \Rightarrow \min. \quad (22)$$

With the explosive nature of the traffic, it is necessary to ensure the speed of the resource management system and, as a quality criterion; we take the control time determined from the transition curve

$$J = t_p \Rightarrow \min. \quad (23)$$

It is necessary to introduce restrictions on the curve describing the response of system, for example, on the magnitude of the overshoot, the number of oscillations in the process oscillatory by transition.

To adapt the resource management system of telecommunications network, various conditional and unconditional optimization algorithms can be applied. Minimizing the quality criteria automatically leads to optimal parameters of a fuzzy controller.

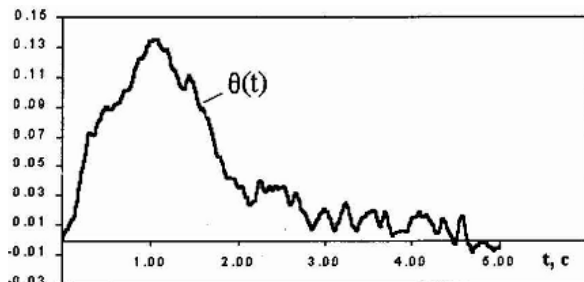
Because of the simulation, the minimum value of the quality criterion J is obtained with the following parameters $c = 7,32$;

$$[\theta_{\min}, \theta_{\max}] = [-1, 1]; [\dot{\theta}_{\min}, \dot{\theta}_{\max}] = [-1,44, 1,44]; [\ddot{\theta}_{\min}, \ddot{\theta}_{\max}] = [-82,29, 82,29];$$

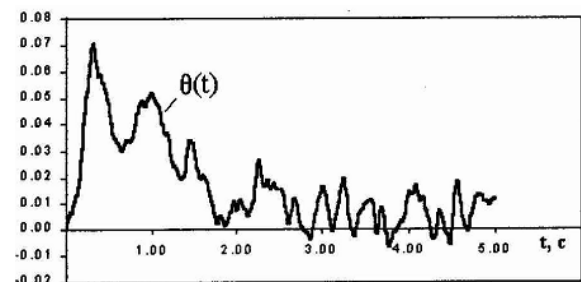
$$[m_{\min}, m_{\max}] = [-0,3, 0,3].$$

Quadratic quality criterion of the control system before optimization is $J = 0,0856$, after optimization $J = 0,0462$.

Fig. 6 a shows the dependence of the control system error on fuzzy logic before optimization, after optimization Fig. 6 b.



a)



b)

Figure 6 – The dependence of the control system error on fuzzy logic

The use of fuzzy inference system allowed us to create an easily scalable system for managing the resources of telecommunications network, the logic of which allows us to easily increase and change its structure on a systematic basis by expanding (changing) the rule base.

The conducted studies show that the use of adaptive control systems based on fuzzy logic in the tasks of managing resources of telecommunication network opens up new management possibilities based on simple heuristic rules and adaptation to the conditions of non-stationary and extreme traffic in the network.

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