

Decrease energy consumption of transport telecommunication networks due to the usage of stage-by-stage controlling procedure

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Abstract

A new approach to the development of advanced automatic monitoring system and adaptive control of transport telecommunication network, allowing to reduce energy consumption of switching centers during the analysis and identification of faults and failures in equipment operation is offered in this paper. Energy reduction is achieved due to the use of step-by-step procedure of finding out abnormal situations, errors optimization of identification system states, the use of multi-agent and permission of agents dependent on hierarchy level of transport telecommunication network.

1 Introduction

Today the energy efficiency reduction and introduction of energy-saving technologies into various spheres of human activity is one of the key problems for modern civilization. Conducted studies in Green-technologies sphere allow to make conclusion, that actually a great attention is paid to the given studies [Bia10, Gup03, Kha17]. The scholars such as A. Bianzino, C. Chaudet, D. Rossi, and J. Rougier studied Green technologies problems for wired communication networks upon following directions: information rate adaptation, proxy and energy interfaces, and energy compatible applications. [Bia10].

Such authors like R. Bolla, R. Bruschi, F. Davoli, and F. Cucchetti studied the possibility of energy consumption monitoring in the Internet [Bol11]. Aruna Prem Bianzino, Anand Kishore Raju and Dario Rossi suggested to improve the energy efficiency of the Internet resources by optimizing energy consumption of routers, dependent on the real load of served data traffic [Bia11]. Yi Zhang, P. Chowdhury, M. Tornatore and B. Mukherjee carried out a review of energy-saving technologies condition as well as problems of energy efficiency standardization of optical networks [Zha10].

C. Lange, D. Kosankowski, R. Weidmann, and A. Gladisch made a prediction of power consumption future distribution for broadband universal operator of cellular network [Lan11].

J. Chabarek, J. Sommers, P. Barford, C. Estan, D. Tsiang and S. Wright have proposed to take into account

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power consumption at the stage of transport telecommunication networks design and planning of access networks [Cha08].

Carla Panarello, Alfio Lombardo, Giovanni Schembra, Luca Chiaraviglio and Marco Mellia [Pan10] introduced the concept “green router” (Grouter), under which they meant a router with accumulation control functions along with physical level of source/power, and a measuring device was added to [Lom11] in the router that estimates the minimum accessible volume of served traffic and consumed energy at that.

However, these papers do not consider the problem of energy consumption reduction by transport telecommunication (TN) networks equipment owing to the more effective detection of abnormal situations arising in event of faults and failures in the equipment that it is of priority importance for telecommunications practice. A huge information traffic is generated by abnormal situations, which is to be processed by monitoring and control system at a stated time in order to identify the emerged problem that requires maximum energy costs in its traditional formulation.

Firstly, among the known methods of abnormal situations identification we should point out the methods based on estimation of attribute values distribution density. Subjects of research are considered as implementations of multidimensional random variables, distributed in attribute space by a definite law. They are based on Bayesian scheme of taking decision with the highest accuracy of clarification, and are reduced to the definition of plausibility ratio in the field of multi-dimensional space when separating boundaries are constructed between them.

The main difficulties of in the using of these methods are [Sim99]:

- need of storing all training set to calculate estimations of local densities probability distribution;
- high response to non-representativity of training set.

2 Problem statement

In general, the task aimed to identify objects could be reduced to the verification of numerous hypotheses $H_1, H_2, \dots, H_i, \dots, H_n$, where H_i is a hypothesis implying the object's belonging to Class A_i . Let's assume that the a priori distributions of these hypotheses probabilities are set. It is known what's the likelihood the object $P(H_i)$ can belong to class A_i (or how often the object of this class is appeared). Moreover, $\sum_{i=1}^n P(H_i) = 1$, as the object is to be pertained to a certain class. The conditional density of distribution is $p_i(x) = p(x_i/H_i)$.

Two hypotheses $H_1 = N$ and $H_2 = \bar{N}$ are used in the identification system under design at corresponding to them a priori probabilities of situation, emerging in the network as a normal $p_1 = p(H_1) = p(N)$ one and an abnormal $p_2 = p(H_2) = p(\bar{N})$. And also $p_1 + p_2 = 1$.

It is required to find a decision rule ensuring the top accuracy in the identification system. Using the Neyman-Pearson criterion we fix the probability of "false alarm" $P_{f.a.}$ at stable level C and claim the minimum of pass error P_{pass}^{min} of TN operating trouble. Then

$$P_{pass}^{min} = p_2 \left[1 - \prod_{i=1}^n \bar{\beta}(x_{oi}) \right] \quad (1)$$

at restriction of $P_{f.a.} = p_1 \prod_{i=1}^n \alpha(x_{oi}) = C$, const, where $\alpha(x_0)$ are Type I errors; and $\beta(x_0)$ are Type II errors.

In order to improve the energy efficiency of transport networks it is necessary to determine the possible degree of decline in the control information p_c , which is to be transmitted between nodes to specify the type of abnormality controlled conditions and using a MAS.

3 Problem solution

3.1 Defining of decision rule for identification system

During operation of TNs the status of which could be described by a large number of parameters, performance monitoring of their working efficiency is to be carried out using stage-by-stage principle of classification.

At the first stage, the TN status is checked by the summarized index and if the abnormality is detected, a stricter control is carried out at the second and next stages on which its real status is defined.

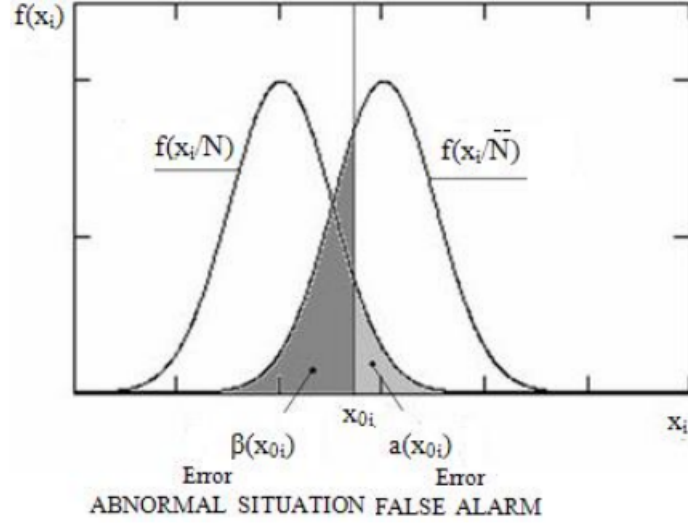


Figure 1: Density graph for feature distribution of x_i Stage

At each of the stages the control system makes Type I $\alpha(x_{oi})$ and Type II $\beta(x_{oi})$ errors (Fig. 1). Type I and II errors ("false alarm" and "abnormal situation" errors), are defined as follows:

$$\alpha(x_{oi}) = \int_{x_{oi}}^{\infty} d(x_i/N) dx_i \quad (2)$$

$$\beta(x_{oi}) = \int_{-\infty}^{x_{oi}} d(x_i/\bar{N}) dx_i \quad (3)$$

The TN is characterized with the certain states of N and \bar{N} , under which we will mean normal and abnormal operation in the process of its functioning which (in the monitoring system) are respectively displayed into the normal A and abnormal $\bar{}$ state.

Apriori probabilities of the normal and abnormal states in TN are detected correspondingly by a priori probabilities of the p_1 and p_2 states. For all the stages, with abnormal situation omission, were obtained resultant errors

$$P_{pass} = p_2\beta_1 + p_2\bar{\beta}_1\beta_2 + \dots + p_2\bar{\beta}_1\bar{\beta}_2 \dots \beta_n = p_2[1 - \prod_{i=1}^n \bar{\beta}(x_{oi})] \quad (4)$$

and "false alarm" errors:

$$P_{f.a} = p_1\alpha_1\alpha_2 \dots \alpha_n = p_1 \prod_{i=1}^n \alpha(x_{oi}) \quad (5)$$

where: $\bar{\beta}_i = \bar{\beta}(x_{oi})$, $\alpha_i = \alpha(x_{oi})$, $p_1 = 1 - p_2$ - a priori probability of a normal situation occurrence; p_2 - a priori probability of its absence.

The problem of thresholding x_{oi} for each stage is currently central. Let's make tradeoffs of thresholds. Following the Neyman-Pearson criterion we will set the probability of false alarm at certain given C level. Then, for the entire network, we get

$$P_{f.a} = p_1 \prod_{i=1}^n \alpha(x_{oi}) = C \quad (6)$$

Having minimized the probability of abnormal situation omission we get

$$P_{pass}^{min} = \min_{x_{oi}} p_2 \left[1 - \prod_{i=1}^n \bar{\beta}(x_{oi}) \right] \quad (7)$$

As a result, the decision rule ensuring the highest level of accuracy for the identification system is the Neyman-Pearson criterion which is detected for the TN by expressions (6) and (7).

3.2 Method of errors optimization of identification system conditions monitoring and determination of optimal thresholds classification

3.2.1 Solution of condition monitoring identification problem on the example of a two-stage procedure

Let us define the procedure of error detection by the feature x as the first stage of two-stage procedure, while for the second stage we will detect the error by the feature y . Generally, the identification problem solution is determined by Type I and Type II errors. Now let's write down the functions for distribution density of the feature x at TN problem-free functioning $f(x/I) = f_1(x)$ and at trouble functioning $f(x/\bar{I}) = f_2(x)$. Then the errors of Type I and Type II of the detector (stage 1) are :

$$\alpha_o = \int_{x_0}^{\infty} f_1(x) dx \quad \beta_o = \int_{-\infty}^{x_0} f_2(x) dx \quad (8)$$

Similarly, Type I and Type II errors for the recognizer (Stage 2) are defined:

$$\alpha_p = \int_{y_0}^{\infty} f_1(y) dy \quad \beta_p = \int_{-\infty}^{y_0} f_2(y) dy \quad (9)$$

Transport network (system) has the following conditions: "1" - the system is out of order, the failure was not detected; "2" - the system is operational, it was found as workable; "3" - failure was detected and recognized (abnormal situation presence); "4" - the system is workable, false detection and recognition (false alarm); "5" - system is out of order, failure was detected but not recognized (abnormal situation omission); "6" - the system is in order, a false detection and correct recognition. In view of formulae (8) and (9), formulae (6) and (7) take the form:

$$P_{f.a.} = p_1 \int_{x_0}^{\infty} f_1(x) dx \int_{y_0}^{\infty} f_1(y) dy = C = const \quad (10)$$

$$P_{pass}^{min} = \min p_2 \left(1 - \int_{x_0}^{\infty} f_2(x) dx \int_{y_0}^{\infty} f_2(y) dy \right) \quad (11)$$

Since in the expression (10) the thresholds x_0 and y_0 are linked with one functional dependence $x_0 = \phi(y_0)$, having differentiated (11) by y_0 and set it to zero, we get:

$$\frac{dx_0}{dy_0} \cdot f_2(x_0) \cdot \int_{y_0}^{\infty} f_2(y) dy + f_2(y_0) \cdot \int_{x_0}^{\infty} f_2(x) dx = 0 \quad (12)$$

At free-hand laws of x and y features distribution, particularly, at normal law, there is no possibility to obtain an exact solution of the classification thresholds optimization problem. However, in certain cases, at Rayleigh

distribution laws, in particular, the solution could be obtained in its final form. Use a first level heading for the references. References follow the acknowledgements.

Let's set densities of features x and y distribution probability in the form of Rayleigh distribution laws, Fig. 2a, Fig. 2b. The Type I and Type II errors are in the form of:

$$\alpha_0 = \int_{x_0}^{\infty} f_1(x)dx; \beta_0 = \int_a^{x_0} f_2(x)dx; \alpha_p = \int_{y_0}^{\infty} f_1(y)dy; \beta_p = \int_b^{y_0} f_2(y)dy; \quad (13)$$

$$f_1(x) = xe^{-\frac{x^2}{2}}; f_2(x) = (x-a)e^{-\frac{(x-a)^2}{2}}; f_1(y) = ye^{-\frac{y^2}{2}}; f_2(y) = (y-b)e^{-\frac{(y-b)^2}{2}}; \quad (14)$$

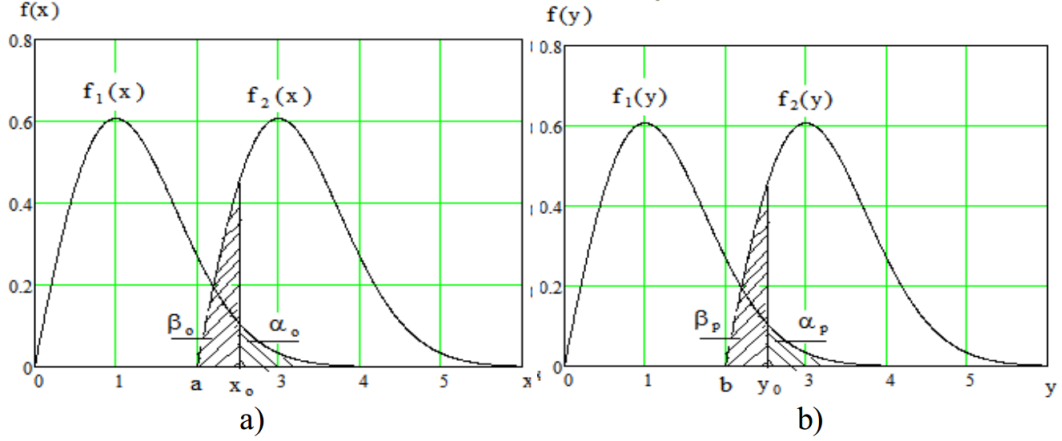


Figure 2: Density graph for feature distribution of x_i Stage

Equations (10) and (11) are transformed into expressions:

$$x_0^2 + y_0^2 = 2 \ln \frac{p_1}{C} \quad (15)$$

$$\frac{dx_0}{dy_0} \cdot (x_0 - a) + (y_0 - b) = 0 \quad (16)$$

Having differentiated (15) by y_0 by substituting the result in (16), we obtain optimal classification thresholds:

$$x_0^* = \sqrt{\frac{2 \ln p_1/C}{1 + (\frac{b}{a})^2}} \quad y_0^* = \sqrt{\frac{2 \ln p_1/C}{1 + (\frac{a}{b})^2}} \quad (17)$$

Dependences in Fig. 3a, built according to the formula (17) are circumferences of the $\sqrt{2 \ln p_1/C}$ radius. With the increase of a priori probability of network normal status p_1 , the radius is increased subject to the logarithmic law.

The dependence curves in Fig. 3b have clearly non-linear nature and show a tendency to get reduced along with a growth in the degree of the classes crossing on both features. Apparently, a similar trend is observed in other signs distribution laws.

Using (17) and (11) we get the minimum probability value of abnormal situation omission:

$$P_{min}^{pass} = p_2 \left(1 - \frac{C}{p_1} \exp \left[\sqrt{2(a^2 + b^2) \ln \frac{p_1}{C}} - 0.5(a^2 + b^2) \right] \right) \quad (18)$$

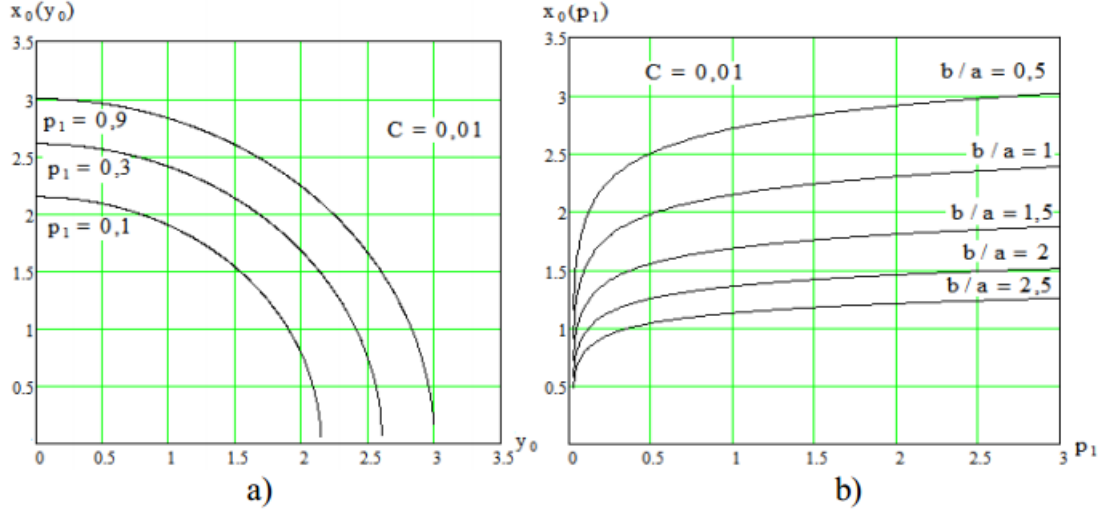


Figure 3: Dependence curves: a) optimal threshold of detector from optimal threshold of recognizer; b) optimal threshold of detector from a priori probability of network's normal status

Now let's compare the two- and one-stage procedures for detecting abnormal condition in TN by means of the respective power ratio of the solution $k_c = \bar{\beta}_2/\bar{\beta}_1$ at the same false failure probability. Then for Rayleigh's law and the optimal threshold for the detector we get $x_0^* = \sqrt{2 \ln p_1/C}$, where $b = 0$ (one-stage procedure) from equation (18) we find out:

$$\bar{\beta}_1 = \frac{C}{p_1} \exp[a\sqrt{2 \ln \frac{p_1}{C}} - a^2/2] \quad (19)$$

Similarly, we define $\bar{\beta}_2$ for the two-stage control procedure:

$$\bar{\beta}_2 = \frac{C}{p_1} \exp[\sqrt{2(a^2 + b^2) \ln \frac{p_1}{C}} - 0.5(a^2 + b^2)] \quad (20)$$

Having set the obtained result in combination with (20) in the expression for K_c , we:

$$k_c = \exp(\sqrt{\ln \frac{p_1}{C}} [\sqrt{2(a^2 + b^2)} - a\sqrt{2}] \frac{b^2}{2}) \quad (21)$$

The dependence curves $k_c = f(C)$ (at $a = 1$ and different values b) illustrating the value of control errors reduction at two-stage procedure and preset probability of normal operation p_1 , can be seen in Fig. 4a and Fig. 4c.

The advantage of k_c is defined to a large extent by a priori probability value of a system condition normal condition p_1 . The higher this probability is the higher is the advantage of k_c Fig. 4a and Fig. 4c. The physical meaning of parameter b change expresses the information content of feature recognition (Stage 2). The advantage of k_c depends on information content of the second-stage features and is increased along with the parameter b . The more k_c the higher the information content of used features at the situation recognition in the network (see Fig.4). k_c is growing with the decrease of false alarm C probability, therewith k_c is changed from one to tens of times.

The advantage of k_c depends also on features information content of the first-stage, which is grown along with the parameter α increase (Fig. 5).

The value of the errors, therefore, depends on features information content, at both the first and the second stages (see formula (17) and Fig. 5).

A stage-by-stage control procedure ensures the maximum accuracy in detecting abnormal situations in the network because it uses independent recognition features at each of the stages and, therefore, is no worse than the Bayesian procedure. At stage-by-stage control, the making decision on TN status is carried out with attracting extra features so far as necessary. A number of stages switching is reduced in the wake of stage number increase. The control is over when decision on TN on proper functioning is made.

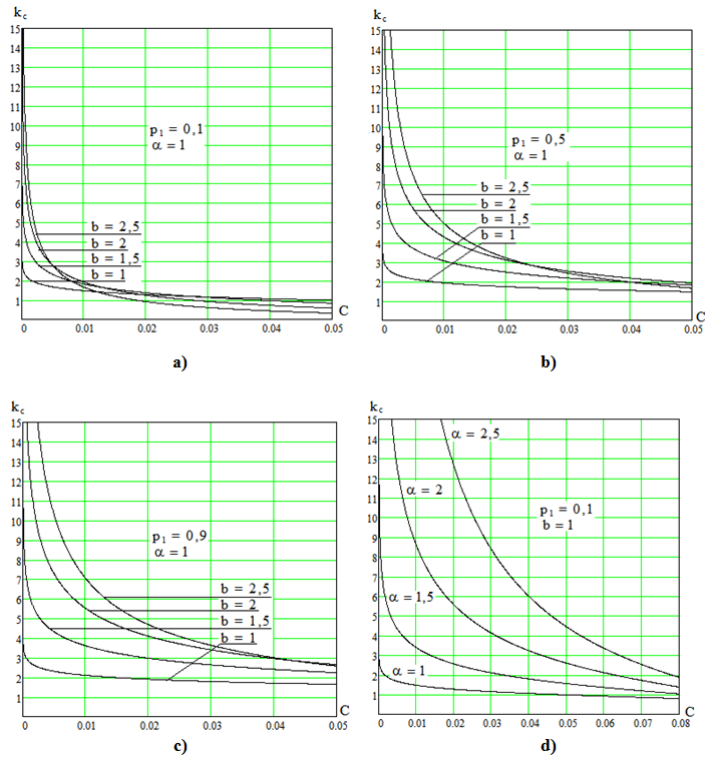


Figure 4: Dependence curves: a) k_c on C at $p_1 = 0.1$; b) k_c on C at $p_1 = 0.5$; c) k_c on C at $p_1 = 0.9$; d) k_c on C at $p_1 = 0.1$ and different parameters of a .

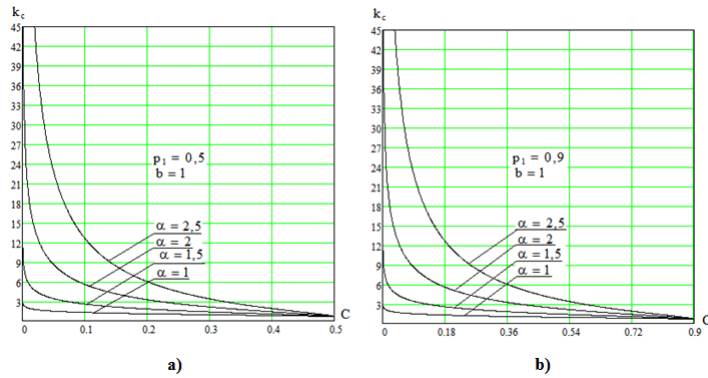


Figure 5: Dependence curves: a) k_c on C at $p_1 = 0.5$ and different parameters of a ; b) k_c on C at $p_1 = 0.9$ and different parameters of a .

4 Reduction of control information volume due to the usage of stage-by-stage classification

Since the solution on TN normal functioning at the first stage may be taken based on the local state information about the node condition (for example, used volume of buffer memory, the state of the outgoing channels) there is no need to the information exchange with other network nodes. This leads to a reduction of the management information circulating through the network.

Forasmuch as the information exchange is usually performed with the neighboring network nodes and followed by the transfer of management information, so this also leads to the reduction of its volume as the information is not brought to each remote switching node.

The value $P_{f.a.} = p_1\alpha_1(1+\alpha_2+\alpha_2\alpha_3+\dots+\alpha_2\alpha_3\dots\alpha_n)$ determines that part of the total information received

per unit, which is to be analyzed on the second and subsequent stages. It determines the degree of reduction of information volume to be transmitted between the transport network nodes to specify the type of violation:

$$\rho_c = \frac{1}{p_1 \alpha_1 (1 + \alpha_2 + \dots + \alpha_2 \alpha_3 \dots \alpha_n)} \quad (22)$$

Thus, the degree of volume reduction of control information circulating through the network depends on the TI error occurring at each stage. The ad-vantage regarding the reduction of management information volume depends on the information content of features recognition at the second and next stages since the information content of feature α_1 at the first stage is a fixed value. It is defined by free buffer space capacity, the value of which can be strictly checked by local information of each certain node. However, the increase of features information content at later stages is linked with the measurements on the network, the capacity of which determines the quality of decision-making in a gradual monitoring and leads to power consumption increase. These measurements are required to improve the information content of features. They are linked with the need to attract additional measuring resources and natural increase of analysis time.

At two-stage control procedure that part of information which is in the second stage is analyzed just the part of information which is the probability of detector "false alarm" is analyzed on the second stage:

$$P_{f.a.} = p_1 \int_{x_0}^{\infty} f_1(x) dx \quad (23)$$

The values (23) define that part of the total information flow that is to be analyzed at the second stage. It defines directly the degree of of information volume reduction which is to be transmitted from node to node for violation type specification.

At Rayleigh laws of features distribution the formula (22) takes the form:

$$\rho_c = 1/p_1 \exp\left(-\frac{\ln \frac{p_1}{C}}{1 + \left(\frac{b}{a}\right)^2}\right) \quad (24)$$

5 Example

Let us suppose that power consumption, spent per volume unit of the processed management information, is a constant fixed value. Then, by the value of management information volume reduction in switching nodes p_c we can consider power consumption reduction expended on processing of management information.

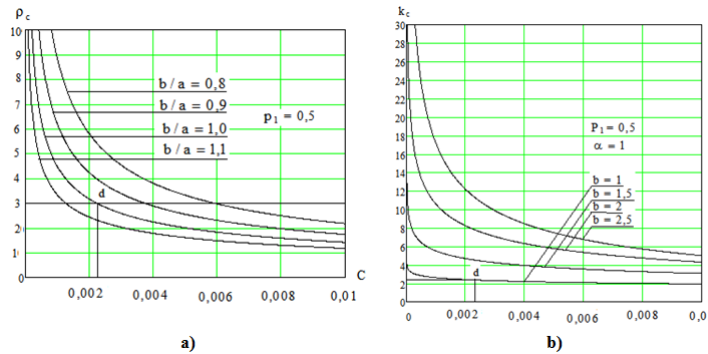


Figure 6: a)Reduction degree of volume control information depending on a given probability of "false alarms"; b)Odds of reducing errors due to two-stage procedure for a given a priori probability of the normal functioning.

Thus, the reduction degree level is equal to 3, this value is reached at C from 0.001 to 0.006 when the relative degree of classes intersection b/a from 1.1 to 0.8 and a priori probability of the normal functioning $p_1 = 0.5$.

When $C = 0.0022$ Fig. 6 (d point) the advantage of error k_c reduction is not less than two times when the management information volume reduction degree is equal to 3 Fig. 6 (d point).

Therefore, at gradual control procedure we can observe not only the advantage of power consumption but also the classification error reduction of the object states under control.

6 Conclusion

The carried out studies allow to draw the following conclusions:

1. The reduction of power consumption by transport telecommunications network at the analysis and identification of faults, malfunctions can be achieved owing to the use of gradual detection of abnormal situations. For the analysis, only that part of features measuring tools information which belong to a given stage. At the first stage according to local information which is contained in given switch node, the operating trouble presence is defined, while on the second and next stages the degree and type of failure are clarified.
2. The problem of monitoring errors optimization and detection of classification optimal threshold for general cases was solved and the example its application to two-stage procedure of abnormal situation detection at Rayleigh features distribution laws.
3. The power consumption of automatic monitoring and adaptive control system depends on the type and form of features x and y distribution density Fig. 3. Power consumption is the more than the less information content features a (detector) and b (analyzer).
4. The degree of management information volume reduction owing to the application of a stage-by-stage principle of abnormal situations detection in the network was estimated. It is defined by a given probability of a "false alarm" and its value can be from 1.1 to 3 times. It was shown that the management information volume reduction (hence also power consumption), when using abnormal situation gradual detection, depends on the given probability of a "false alarm" and correlations of features a and b information content. It is increased with the decrease of "false alarm" given probability. The advantage of k_c is determined by a priori probability value of p_1 system normal functioning (see Fig.4). The higher the probability p_1 , the greater the advantage of k_c .
5. The advantage k_c depends on the features information content both the first and second stages, it grows with the increase of parameters a and b . It was shown that the advantage is equal to values of two or more times due to the application of two-stage procedure estimating it by coefficient k_c .
6. The use of multi-agent systems and vesting the agents with authorities, depending on the level of the transport telecommunication network hierarchy, allows carrying out address screening of information features and attracting additional features for analysis of origin reasons and abnormal situations location. Only required part of complex system netmetric is used. Such approach allows to reduce power consumption of automatic monitoring and adaptive control system due to the reduction of management information volume that is to be transmitted between nodes to specify the deviation from norm of the network controlled parameter.
7. In order to reduce power consumption of modern TN it is advisable to carry out studies that are more fundamental: a) by the use of agent-oriented approach; b) the application of x and y features distribution spontaneous laws in the control system and adaptive control.

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