Ensuring the Availability of Information Resources Through the Use of an Intelligent Communication Network with the Drift of Parameters of Autonomous Segments

Andrii Fesenko, Oleksandr Toroshanko, Yurii Shcheblanin, Inna Mykhalchuk and Mykola Pyroh

Taras Shevchenko National University of Kyiv, 60 Volodymyrska str., Kyiv, 01601, Ukraine

Abstract

The purpose of the article is the analysis of the features of functioning and the development of a mathematical model of the system for ensuring the availability of information resources due to the use of an intelligent communication network with random delays of signal and control information. The control system must ensure the operability of a network with a large amount of network equipment as a complex system in conditions of malfunctions and failures in the equipment, uncontrolled changes in operating modes, drift of network equipment parameters and its autonomous segments, disturbed actions, interference and other adverse factors. The problem of estimating the parameters and the state of a dynamic system with a delay based on differential-difference equations is considered. It is shown that the delay of the argument even for a simple differential equation of the first order with constant coefficients leads to the appearance of an aftereffect, which formally corresponds to an arbitrary variation of the order of the equation. Such differential equations are called equations with a deviating argument. The results of a numerical analysis based on the digital modelling of the control system of the parameters of the switching node are presented. The parameters of the control system for various parameters of network traffic with self-similar properties and with various random errors and distortions are studied. An approach based on regular monitoring of the parameters and state of network nodes is proposed, taking into account the delays of incoming information about the parameters and state of a specific network node and the delays of control information necessary to regulate the parameters of a network node as a control object.

Keywords [1]

availability of information resources, control system, intellectual network, estimation of network parameters, deviating argument, control information, control of reliability.

1. Introduction

Modern intelligent telecommunication networks are characterized by a large number of various equipment from various manufacturers, and a wide range of services provided, the number of which is constantly growing. The idea of intelligent networks is to separate the functions of support, creation (development), and testing of new telecommunication services from the main functions of the switching node [1, 2, 3]. Service delivery functions once reserved for traditional switching systems are migrating to switch-independent computing platforms. It should be noted here that the intelligent network in its meaning and tasks has nothing to do with the systems of the so-called artificial intelligence. In essence, this is just an architectural concept of communication networks, the most suitable for the introduction of new integrated services and their separation from switching processes [2, 4]. In addition, new services are often multi-step hierarchical procedures. The problems of managing an intelligent network with a wide range of such services have their specifics. Thus, the management tools of an intelligent

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EMAIL: andrii.fesenko@knu.ua (A. Fesenko); oleksandr.toroshanko@knu.ua (O. Toroshanko); shcheblanin.yurii@knu.ua (Y. Shcheblanin); inna.mykhalchuk@knu.ua (I. Mykhalchuk); m.pyroh@knu.ua (M. Pyroh)

ORCID: 0000-0001-5154-5324 (A. Fesenko); 0000-0002-2354-0187 (O.Toroshanko); 0000-0002-3231-6750 (Y. Shcheblanin); 0000-0002-1802-7653 (I. Mykhalchuk); 0000-0003-2588-6066 (M. Pyroh)

telecommunications network are a complex system with incomplete information about the state and parameters of the network as a whole and its autonomous segments [5, 6, 7].

2. Formulation of the research task

When transmitting data and processing it in intermediate switching nodes, there are significant delays in signalling and controlling information, as a result of which the level of information security, namely the criterion of information availability, decreases. This situation is especially unacceptable for information systems classified as objects of critical information infrastructure. To ensure the stable operation of the telecommunications network and control system, it is necessary to constantly monitor the parameters and state of the network, and search and predict faults, including a load of individual routes and nodes of autonomous network segments [8, 9, 10]. Let us consider the effect of signal and control information delays on the efficiency of searching for and determining the locations of failures, overloads, and emergency modes in communication networks. The specificity of the problem is caused by delays in the transmission of signal and control information, which are random in nature and can vary over a wide range. Argument delay even for a simple first-order differential equation with constant coefficients leads to the appearance of an aftereffect (this formally corresponds to an arbitrary variation of the order of the equation) [11]. In addition, if the original equation has a stable solution, the stability of the solution of the same equation with a delayed (so-called deviant) argument is not guaranteed. Such differential equations are called equations with deviating argument. There is no general method for solving such problems [5, 12], but it was found that the most effective method for the qualitative analysis of differential equations with a deviating argument is the approximation of derivatives by finite differences. In other words, there is a transition from the differential to difference equations. This approach is quite natural for digital systems and packet-switched telecommunication networks.

It is shown in [13] that when managing flows and processes in information and communication networks, there are delays in obtaining information about the state and parameters of the network, which are random in nature and can vary over a wide range. There are also delays in the information used to change the parameters of network nodes, routes, and autonomous parts.

The purpose of the article is to develop a control system for an intelligent telecommunications network with a large amount of network equipment and random delays in signal and control information. The control system must ensure the operability of the network as a complex system in the event of failures and failures in equipment, uncontrolled changes in operating modes, the effects of disturbances, interference and other adverse factors.

3. Mathematical model of a control system with information delays

The task of estimating the parameters and state of a dynamic system with delay, which is used as a network segment model, is a retrospective identification problem [14]. It is assumed that the segment under consideration is practically independent of other segments and is connected to them by appropriate transmission lines. Consider the problem of discretizing a differential equation with a retarded argument and ensuring the stability of the solution. An inhomogeneous differential equation with constant coefficients and a deviating argument has the following form:

$$\frac{dy_{as}(t)}{dt} = by_{as}(t-\tau_k) + u(t-\tau_m), \tag{1}$$

where $y_{as}(t)$ – desired function; $u(t)$ – excitation; b – feedback coefficient: τ_k, τ_m – delays of signal and control information, respectively, and in the general case $\tau_k \neq \tau_m$.

Under conditions of comparable smallness of network clock synchronization intervals in comparison with changes in its parameters and state, equation (1) can be discretized as follows. We approximate it by a finite difference equation of the form

$$y_{as}(n) = y_{as}(n-1) + by_{as}(n-k) + u(n-m), \tag{2}$$

where $y_{as}(n)$ – object state function; $u(n-m)$ – control signal; *k* and *m* are the delays of the status and control signals, respectively. In general, $n \neq m$.

The system function of the object, which is described by equation (2), has the following form:

$$H(z)=\frac{z^{-m}}{1-z^{-1}-bz^{-k}}, \tag{3}$$

whose characteristic polynomial has a rather specific form:

$$z^{k}-z^{k-1}-b=0. \tag{4}$$

System function (3) has zero m-th order, which is located at an infinitely distant point z-plane, and k poles, located at equal angular distances $\Delta\varphi=2\pi/k$ from each other.

In [15] asymptotic estimates for the stability of systems with a characteristic polynomial of the form (4) and the stability region were calculated. It is shown that to maintain the stability of the control system, it is necessary to reduce the absolute value of the feedback coefficient in the control loop with an increase in control signal delays. However, the problem of finding the relationship between the feedback coefficient and the delay does not have a unique closed-form solution. In addition, there are uncontrolled deviations in dynamic characteristics and deterioration in the quality of control.

Equation (2) can be considered the simplest control equation for a concentrated object with delays in state and control signals. Using the discretization method of a differential equation with a delayed argument, a typical model of a network node as an object of control has been developed, which is shown in Figure 1.

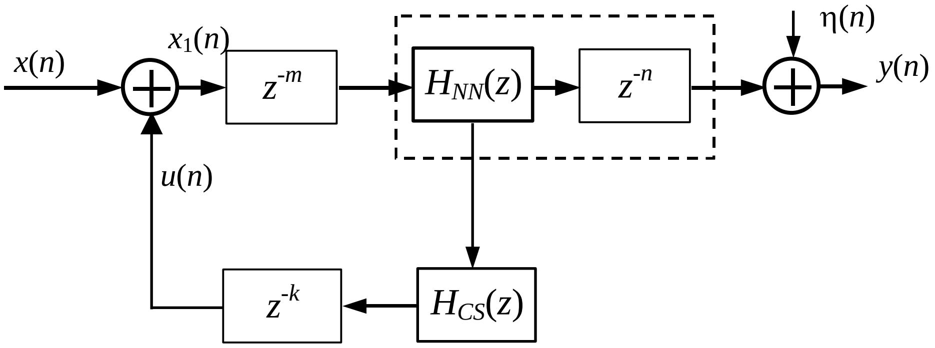

Figure 1: The structure of the control and management system of the network node

Here $x(n)$ – information signal; $u(n)$ – control signal; z^{-m}, z^{-k} – delay elements that take place in the delivery of information; in general, the delay value of information about the upstream and downstream data exchange channels do not match ($k\neq m$); z^{-l} – element for delaying the reaction of a network node to variations in its state; z^{-r} – packet processing delay in the control object; $\eta(n)$ – external noise and interference causing distortion and packet loss. A network node as a control object is a feedback system that must provide some response to variations in its state, for example, general congestion, reception congestion, bandwidth reduction, buffer underrun, improper functioning, complete or partial failure, etc. For the correct operation of reliability management systems, the response time must be tuned very carefully [10]. With a very short response period of the target node, the control system will receive a sequence of conflicting information signals. The system will be in a state of undamped oscillations and will not come to a stable state. On the other hand, if the response period is too long, the state mechanism will respond too slowly to be of any real benefit at all. To have the appropriate quality of the control process, you need to apply a certain method of adaptation, but the correct choice of time constants is not a trivial matter. Let's consider this problem in more detail.

The equation of the system in finite differences for the control data has the following form:

$$u_1(n)=u(n-m)h_{NN}(n)+u_1(n-k-l)h_{CS}(n). \tag{5}$$

Let's write the expression for the transfer function $H_1(z)=X_1(z)/X(z)$ object controlled by the control system:

$$H_1(z)=\frac{1}{1-H_{NN}(z)z^{-m}H_{CS}(z)z^{-(k+l)}}. \tag{6}$$

The corresponding expression for the transfer function $H_y(z)$ of the system as a whole has the following form:

$$H_y(z) = \frac{z^{-r}}{1 - H_{NN}(z) H_{CS}(z) z^{-(m+k+l)}} + \Xi(z). \tag{7}$$

where $\Xi(z)$ − the ratio of signal energy to the modulus of the complex spectral density of external interference $\xi(n)$,

Expression (7) in the case of large signal-to-noise ratios converges to the general transfer function (6) of a system with signal and control information delays.

3.1. Numerical analysis results

Using expressions (5-7), a digital simulation of the control system for the parameters of the switching node was carried out. The parameters of the control system were investigated for various network traffic parameters (in particular, Triple/QuadroPlay traffic with self-similar properties) and with various random errors and distortions. To ensure the global stability of the control system, the feedback coefficients were specially selected.

The main result of the simulation is the dependence of queue length variations on the response time of the network node (number of periods l, which corresponds to the delay z^{-l}) compared with the delay time of data processing and delivery (the number of periods, respectively z^{-m} ,z^{-k}). As a test information signal $x(t)$ a step function of changing the instantaneous intensity of network traffic was chosen with an additive random process superimposed on it, distributed according to the Pareto law.

The figures below show the simulation results for two values of the relative network node response delay l with a full delay in data processing and delivery $m+k=10$: l = 20 (Figure 2) and l = 10 (Figure 3). Here $q(k)$ – is a transient response of a control system with processing delays of information and control signals. As can be seen from Figures 2 and 3, with a significant difference in the response delay of the network node and the total delay in the processing and delivery of data, there is a minimum stability margin of the control system according to the buffer overload criterion.

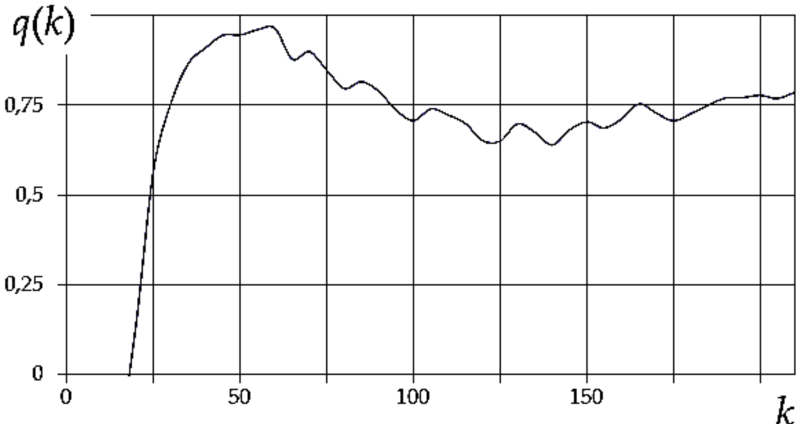

Figure 2: Simulation results with reaction delay l = 20

With bursts of network activity, caused, for example, by the bursting of self-similar traffic, the risk of buffer overload, control signal packet dropping, and, as a result, the network management system switching to the undamped oscillation mode [10] increases. At the same time, when matching the mentioned delays, a sufficient resource of control stability is provided according to the buffer overload criterion for the same statistical characteristics of a burst of network activity. It should be noted that delays in the detection and recognition of useful signals and interference or equipment failures occur not only in the description of statistical characteristics but also in the evaluation of various time parameters of signals, the application of signal accumulation principles, etc. For the optimal selection of such important characteristics of control systems as the current reaction time of the control object, it is necessary to constantly analyze the delays of signal and control information and adjust the parameters of switching nodes for them. It is quite logical to choose the value of the current reaction time of the control object close to the value of the mentioned delays. The results of digital simulation also testify to this.

This can be done, for example, using an elementary first-order difference equation with a coefficient that is set depending on the characteristics of network nodes and current traffic parameters [10, 11].

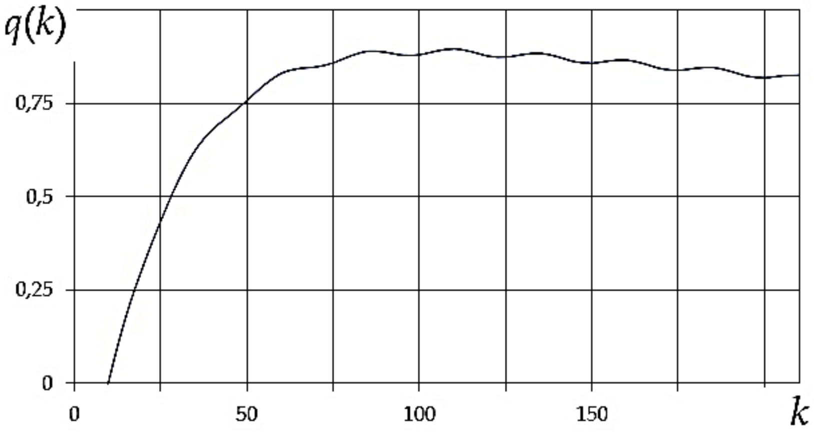

Figure 3: Simulation results with reaction delay l = 10

4. Multi-stage fault finding algorithm

Errors in the estimation of the random process parameters used as diagnostic signs to determine the state of the object lead to the fact that the fault may not be found during the first search cycle.

To increase the reliability of fault detection, it is necessary to conduct repeated and further search cycles. Failure to identify the faulty element belonging to the i-th block is possible in two cases:

- when checking the i-th block, a false result was obtained with a probability of $q_{i(1)}$;
- when checking the i-th block, a malfunction was detected, and the check k_i-th the element that refused gave a false result with a probability of $q_{ki(1)}$.

Thus, the probability of missing a failure in the i-th block is defined as:

$$P_i = q_{i(1)} + \left(1 - q_{i(1)}\right) \sum_{ki}^{n_i} p_{ki} q_{ki(1)} . \tag{8}$$

The probability of missing a failure in the first test cycle is equal to the:

$$P = \sum_{ki}^{n_i} p_i \left[q_{i(1)} + \left(1 - q_{i(1)}\right) \sum_{ki}^{n_i} p_{ki(1)} q_{ki(1)} \right]. \tag{9}$$

The probability of not detecting a malfunction during the first test cycle due to an error of the first kind, depending on the observation time T of the implementation of a random process, can reach values that do not satisfy regulatory documents. Reduction of the specified probability can be ensured by repeated control of the block which is checking and its corresponding elements.

For the adopted two-stage search program according to (9), it is possible to not find a defective element belonging to the i-th block, taking into account the multiplicity of checks

$$P_i = q_{i(m)} + \left(1 - q_{i(m)}\right) \sum_{ki}^{n_i} p_{ki} q_{ki(n)} , \tag{10}$$

where $q_{i(m)}$ and $q_{ki(n)}$ – probabilities of errors of the first kind (“missing” a malfunction) with m-times checking of the i-th block and n-times checking of the k_i-th element, respectively.

The presented dependencies (8-10) allow for the selected value of T and the required value of P_i to determine the multiplicity of checking the element and block with the corresponding probability of failure.

5. Conclusions

To ensure the functioning of electronic communication systems in the conditions of the possible presence of various defects in the communication equipment, changes in operating modes, disturbed actions, interference, actions of intruders and other adverse factors, various types of redundancy are laid in the system: structural, hardware, signal, information and others. Additional hardware or computing resources designed to manage the network and to deal with congestion should be in a state of reserve and put into operation after determining the time and place of the found overload, providing the necessary level of system functioning. Therefore, this paper proposes an approach based on regular monitoring of the parameters and state of network nodes, taking into account the delays in incoming information about the parameters and state of a particular network node and the delays in the control information necessary to regulate the parameters of the network node as a control object.

Errors in the estimation of the random process parameters used as diagnostic signs to determine the state of the object lead to the fact that the fault may not be found during the first search cycle.

Therefore, a multi-stage fault-finding algorithm is proposed to increase the reliability of fault detection. Reasoned expediency and features of its use. The practical implementation of the approach proposed in the work will ensure the availability of information resources, which is an extremely urgent task in modern conditions.

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