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SYNERGETIC APPROACH TO THE STUDY OF CONTROL SYSTEMS

Abstract: The paper considers a new direction of scientific research – «synergetics». The key provisions and its development as a science are considered. The focus is on open feedback systems as objects of research. The properties of these systems – openness, nonlinearity, dissipation and multidimensionality, allow the use of a synergistic approach in the study. Due to new trends in information technology in recent years, interest in the new architecture of Software Defined Networks has grown. A programmable controller is used as a control mechanism for SDN networks. The connection between the logical controller and the physical network is made using the OpenFlow protocol.

The graph of the network topology is presented as a set of key parameters that come to the controller. From the set of parameters, the key ones used in the study are selected. The dynamics of the ratio of key parameters under the condition of optimizing the network infrastructure is studied. The dynamics of the network corresponding to the stability condition is investigated by the methods of synergetic control theory. SDN network control is formed by methods based on the principle of self-organization of nonlinear systems. As a result, synergetic control is synthesized to increase the resistance of the control system to destructive influences. Based on the selected dynamic invariant, the possibility of providing the selection of the parameter of the SDN network management system for the transition to a controlled state is shown.

Keywords: Control system, Software Defined Network, SDN, optimization, system stability, synergetic control, synergetic, attractor.

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Introduction

Synergetics is an interdisciplinary field of research. The task of synergetic is to study processes and phenomena based on the principles of self-organization. The science of «synergetic» is a young science. The term first appeared in 1973 in a report by Professor G. Haken of the University of Stuttgart [1]. The main provisions of synergetic, according to the theory of G. Hacken are:

- the system consists of identical or dissimilar parts that interact with each other,
- systems are nonlinear, open, prone to oscillations,
- systems become unstable and have qualitative changes,
- there are spatial, temporal and functional structures that can be chaotic.

The main position of synergetic is the idea of the possibility of spontaneous emergence of order and organization out of disorder and chaos, as a result of the process of self-organization. An important factor in self-organization is the feedback of the system and the environment. At the same time, the system begins to self-organize and counteract its destruction by the environment.

The formation of self-organization is largely determined by the nature of the interaction of random and necessary factors of the system and the environment. The system does not self-organize smoothly and gradually, but has turning points – bifurcation points. Significant fluctuations are observed in the systems near the bifurcation points, and the role of random factors increases sharply.

The object of research is open systems with feedback. The main properties of these systems are openness, nonlinearity, dissipation and multidimensionality. In the study of control systems of an open system, the conditions of linearity are not met, and there is a need to study the general principles of origin and development of complex dynamic systems. The nonlinear control system has fixed and unstable stationary states. Moreover, the same steady state of such a system under some conditions can be stable, and under others unstable. The problems of managing such systems are relevant, complex and almost inaccessible to the classical issue management system. This raises the problem of finding ways to influence the processes of self-organization in nonlinear dynamic systems [2,3].

Modern approaches in information technology, such as cloud computing, data center organization and virtualization, require new solutions for networking. In this regard, in recent years, interest in the new architecture of Software Defined Networks (SDN) has grown. Software- defined networks distribute the processes of data transmission through the network infrastructure and centralized network management. Unified software (controller) is used as a control mechanism, which is installed on the server. The connection between the logical controller and the physical network is made using the OpenFlow protocol [4].

There are such problems of operation of SDN it is providing fault tolerance and the second concerns a choice of certain topologies and protocols of routing. However, Software Defined Networks are becoming indispensable, allowing to increase the bandwidth of channels, simplify network management, redistribute the load, increase the scale of the network.

The analysis of network control methods substantiates the relevance of the direction of the proposed study. The growth of content and its diversity, the development of services and the scope of their coverage have led to a paradigm shift in computing – in place of client-server architecture came data centers, clouds, file systems and databases were transformed into storage. In addition, the efficiency of the control system is determined by the level of safety, environmental friendliness, the ability to perform their tasks, tasks and other parameters that are described in [5-7]. To ensure efficiency, studies are carried out with various mathematical models and methods [8-9].

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Even a small network with access to the global network, from the point of view of operation and problem identification, can pose quite serious problems [10]. Now, the implementation of software-configured networks at certain network levels can contribute to a significant optimization of the network infrastructure [11] and provide a more rational use of network capabilities [12-14].

An SDN network management system can have an infinite number of parameters, therefore, the parameter space, as in many multi-parameter stability problems, is divided into regions of stability and instability. Using the theory of stability of dynamic systems and the synergetic approach in the mathematical description of the processes [15-16] that occur in the control system, it is possible to analyze and ensure the reliability of the system, regarding unforeseen changes in the structure of the system and operating conditions. In contrast to the classical methods of mathematical analysis, which allows one to study smooth continuous processes [17-18], the synergetic approach is a universal tool for studying jump-like transitions, discontinuities, and sudden qualitative changes in the behavior of the system.

The purpose of the work

There is a study of the control system of the program – defined network to destructive information influences by maintaining the necessary network parameters based on a synergetic approach. To achieve this goal, the following partial tasks must be solved: justification and choice of parameters that determine the dynamics of the SDN control system; synthesis of synergistic management of network interaction processes; simulation of SDN control system with synergistic control.

Statement of the main material

When modeling the development of SDN systems, it is very interesting to study their behavior under the influence of various external perturbations. The modern approach is characterized by the study of disturbances in the structure of the system itself. It is necessary to determine whether the behavior of the system will change significantly as a result of unplanned (including unwanted) changes in control mode.

Loss of stability can be called a catastrophe – a jumping change that occurs when a smooth change in external conditions [2]. From a mathematical point of view, the instability and threshold nature of self-organization are related to the nonlinearity of the equations describing the system. For linear equations there is one stationary solution, for nonlinear several. Thus, the threshold nature of self-organization is associated with the transition from one stationary state to another.

Let the behavior of the SDN control system be described by the set of ordinary differential equations:

$$\begin{cases} \dot{x} = f\left(x, y\right) \\ \dot{y} = g\left(x_1, y\right), \end{cases} \tag{1}$$

The condition of non-trivial solution leads to the following characteristic equation for the operator: $L = \begin{bmatrix} a & в \\ c & d \end{bmatrix}$: $\Delta = \begin{vmatrix} a-\omega & в \\ c & d\text{-}\omega \end{vmatrix} = 0$ or

$$\omega^2 - \left(a + в\right)\omega + aв - вc = 0. \tag{2}$$

Given the notation $\mu = Sp(tr)L$ – follows the matrix of the operator L, – the determinant of the matrix of the operator L, Δ – the characteristic equation has the following form: $\omega^2 - \mu\omega + \Delta = 0$.

Integrating this equation, it is easy to obtain $\eta = c_0 |\xi|^{в0}$, de $в_0 = \frac{\omega_2}{\omega_1}$.

We will assume that ω_2 – it is a large root of the characteristic equation.

If ω_2, ω_1 one sign, then we are dealing with integral curves of the parabolic type. If ω_1, ω_2 negative, then, as it follows from equations (6), they decrease with time. It is easy to see that the equilibrium state corresponding to the node (at $\omega_1 < 0,\ \omega_2 < 0$) is stable according to Lyapunov, since the depiction of the point on all integral curves moves to the origin.

Consider the case of ω_1 ³ ω_2 valid but different characters. In this case we have $\frac{d\eta}{d\xi} = -в_0 \frac{\eta}{\xi}$. Integrating, we obtain

$$\eta = c_0 |\xi|^{-в0}. \tag{3}$$

Expression (3) defines the properties of hyperbolic type curves having both axes as coordinates.

The considered family of integral curves has a single singular point at the origin, through which only two integral curves pass, which are asymptotes. Such a special point is called a special point of the saddle type.

Let us investigate the behavior of a point near the equilibrium state. At $\omega_1 > 0,\ \omega_2 < 0$ this point, located on the ξ axis, will be spaced from the origin, and placed on the η axis – indefinitely close to the origin, without reaching it at the end of the moment. Therefore, a special saddle type point is always unstable.

Special instability points are called bifurcation points, because in the evolution of the system, it is in these places that the choice suddenly begins, and the system begins to evolve in one or another new direction. In the mathematical sense, bifurcation points determine qualitative changes in the solution of an equation that describes a complex system when the equation parameter is changed. From the point of bifurcation, several (two or more) stable or unstable branches of solutions emerge.

In the architecture of Software Defined Networks, the functions of control and data transmission are divided into two separate levels, which are implemented on separate physical devices. The control layer is represented by a controller that uses the Open Flow protocol to control switches that represent the data transmission layer. Thanks to the north and south interface, as well as the ability to program the functions of the data plane, the controller creates a network operating system, you can install various applications for intelligent network management and provide quality network parameters, including: quality of service, adaptability, reliability, stability, availability and efficiency. The level of provision of these parameters depends on the implementation of applications installed on the controller, as well as the architecture of the controller.

In the SDN paradigm, you can achieve a higher level of visibility and fine-tuning of the entire network. The SDN controller can program data plane infrastructure devices to monitor and manage network packets. We use the SDN controller to implement periodic collection of statistics. In addition, you can get a centralized view of the state of the network through open APIs and report changes in real time.

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Consider a model of a realistic structure of the SDN network, which shows that the SDN controller is responsible for processing requests from all switches in the network. After network initialization, the SDN controller receives the most important data (topology, bandwidth, time delay, etc.). An advanced routing algorithm works on the controllers. When new requests are received, the controllers calculate the optimal path and update the SDN bandwidth resources.

The input controller receives a graph (Figure 1.) of the network topology [19] presented as:

$$Q = (X, Y, H, V) \tag{4}$$

where $X = (x_1, x_2, \dots x_n)$, set of nodes, where each node represents a switch in the SDN network.

$Y = (y_1, y_2, \dots y_n)$, the set of edges.

$H = (h_1, h_2, \dots h_n)$, the set of the edge's bandwidth.

$V = (v_1, v_2, \dots v_n)$, the set of the delay of each edge.

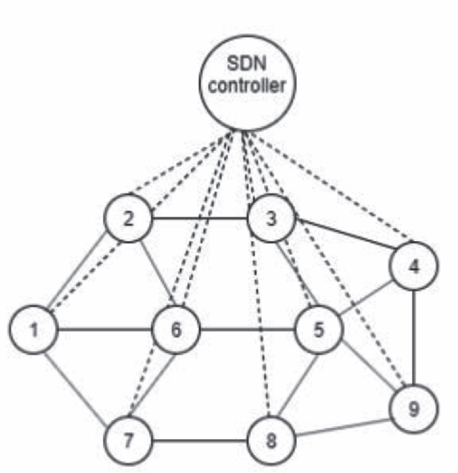

Fig. 1. Undirected graph network

We synthesize a system with control parameters k_1 – bandwidth, k_2 – delay. The system of nonlinear differential equations (1) will turn into the form:

$$\begin{cases} \dot{x} = k_1 x - xy, \\ \dot{y} = -k_2 y + x^2, \end{cases} \tag{5}$$

It is possible to investigate system (4) using the phase plane method [12] from the qualitative theory of differential equations. Each state of the dynamic system described by equations (5) corresponds to a pair of values (x, y) and vice versa. A Cartesian coordinate system in which all states (or phases) of a dynamic system (5) are mapped is called the phase plane. The set of points $M\ (x(t), y(t))$ on the phase plane whose position corresponds to all possible states of the system is called the phase trajectory. The totality of the latter is a phase portrait of the system.

When $k_2 >> |k_1|$ there are cooperative processes based on adiabatic approximation $\dot{y} \approx 0$ and are accordingly described by the synergistic equation:

$$\dot{x}(t) \cong k_1 x - \frac{1}{k_2} x^3 \tag{6}$$

This parameter corresponds to the cooperative state:

$$x^2 - kx \cong 0 \tag{7}$$

Equation (6) has a bifurcation point – a bifurcation of the solution at the critical value $k_{1c}=0$ of the control parameter k_1. Further movement of the system will take place on one of two equal-probability branches of steady motion.

Let us now examine the management of a system in which a steady state will be achieved in a short period of time. To do this, we introduce the appropriate control, resulting in a mathematical model of the system is transformed into the form:

$$U\,(x,\, y) \tag{8}$$

Where $U\,(x,\, y)$ is the control law by which transients will be started in the system of nonlinear differential equations (1)?

Enter the following variable in the system:

$$\psi(x, y) = x^2 - k_2 y, \tag{9}$$

which must satisfy the condition:

$$T\dot{\psi}(t)+\psi = 0 \tag{10}$$

After substituting the variable (9) into equation (10), given the initial system of differential equations (8), we get the feedback:

$$U = \left(\frac{2k_1}{k_2} - 1\right)x^2 - \frac{2}{k_2}x^2 y + k_2 y + \frac{1}{k_2 T}\psi \tag{11}$$

Therefore, a synthesized system of nonlinear differential equations (8), which provides a given level of operation of the system with regard to control (9), looks like:

$$\begin{cases} \dot{x} = k_1 x - xy, \\ \dot{y} = \dfrac{2k_1}{k_2}x^2 - \dfrac{2}{k_2}x^2 y + \dfrac{1}{k_2 T}\psi, \end{cases} \tag{12}$$

Research results

We study the change of state of the control system (5) depending on the parameters. Using phase plane method and PPLANE8 module tools and MatLab application package. Let the parameters of the studied system of nonlinear differential equations (5) take the values *k1 = 0.25, k2 = 10.25*, then the graph of dependence and phase portrait of the system look as shown in Fig. 2.

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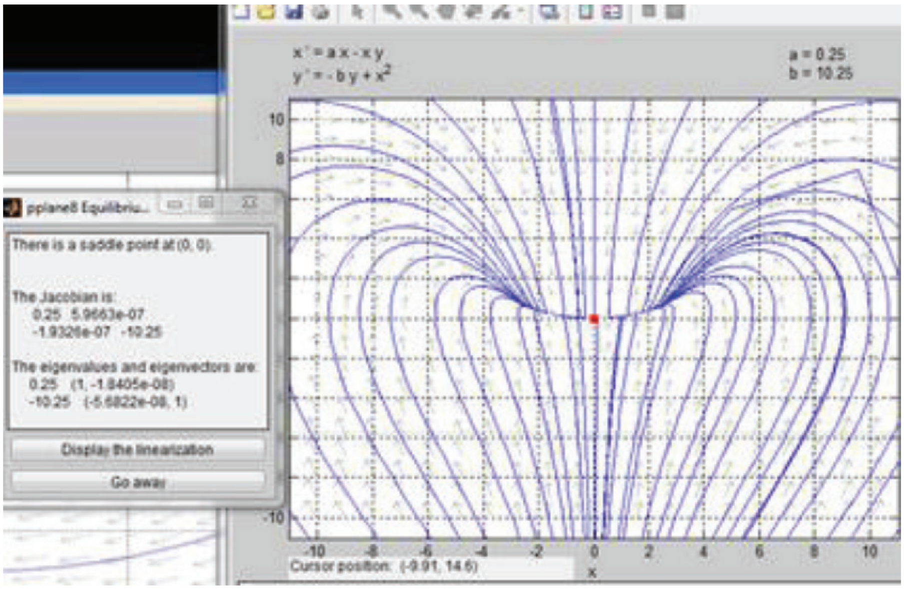

Fig. 2. The phase portrait of the system corresponding to equation (4).

The phase portrait of the system (5), constructed with $\frac{k_2}{k_1}=100$ the image in Fig. 2, which shows that the trajectory first goes to (7), and then moves along it to stationary points $x=\sqrt{k_1k_2}, y=k_1$ and $x=-\sqrt{k_1k_2}, y=k_1$ accordingly, that is, a cooperative process. With $\frac{k_2}{k_1}=1$ we can be seen that the system immediately goes to the stationary points around and the transition process is weak.

Further we will analyze the change in the state of the control system as a result of the action of the synthesized synergistic control (12) for the system (4). Let the parameters of the nonlinear system of differential equations (12) become *k1 =0.5, k2=5, T=1,* $\psi=1$. The simulation results are shown in Fig. 3.

System (12), starting with its operation under arbitrary initial conditions x_0, y_0 and, accordingly $\psi_0=x_0^2-k_2y_0$, necessarily after a period T approaches the attractor $\psi(x,y)=0$ and corresponds to a bifurcation of the «fork» type.

The phase portrait of the system in Fig. 2 that $\frac{k_2}{k_1}=1$ and $T=\frac{0.5}{k_2}$ shows, unlike the case $U=0$, the necessary attractor is formed, in which the process of self-organization occurs. By choosing $U(x, y)$ feedback, you can provide any kind of bifurcation, that is, other instances of self-organization.

The result of the influence of the synthesized synergistic control of the SDN network is the emergence of self-organization processes, under the action of which the transition from chaotic dynamics to a steady state takes place. In this case, the system from any state goes to the attractor $\psi(t)=0$, which moves to the point of burst of the synergistic effect of the desired state of parameters, which achieves a specified level of effective operation of the control system.

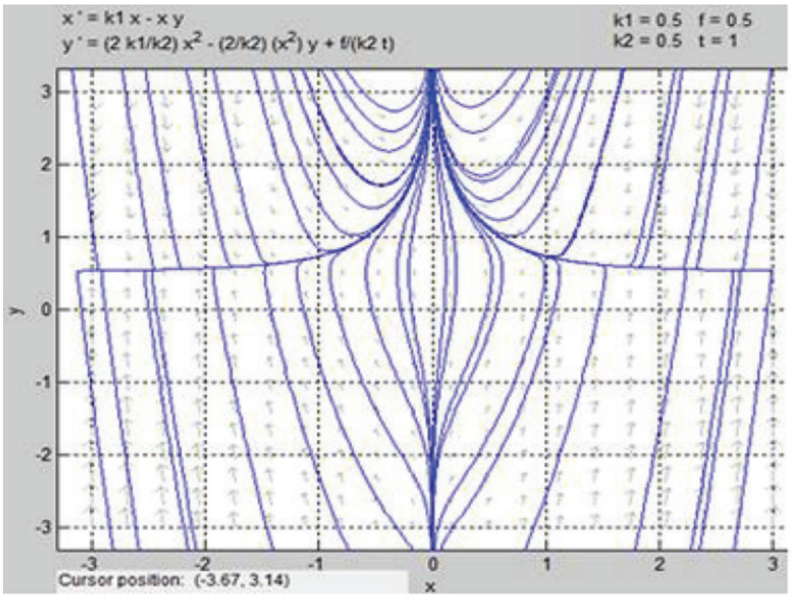

Fig. 3. Phase portrait of the system as a result of the action of synthesized synergistic control (11)

Conclusion

A synergetic approach to the study of SDN network system control is considered. Methods of maintaining a software-defined network in a stable state have been studied. This method is based on the emergence of a synergistic effect due to the start of feedback processes in the control system. The burst point of the synergetic effect is an attractive attractor of the system, on which the reduction of degrees of freedom of the initial system of nonlinear differential equations is realized. This point simplifies the process of maintaining the required state of the control system.

The practical value of the study lies in the possibility of timely prediction of the resulting discrepancy in the structure of the system. As well as determining the moment of entry into the critical area, which serves as a signal for the development and implementation of measures to influence the object. The result of the study allows to predict the moment of transition of the system to new technologies, to promote the emergence of new technologies within the old ones, to influence the course of scientific and technological progress.

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