Information technology of traffic modeling using the Ateb-functions theory for improving service delivery in eHealth systems and networks

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Abstract. This work is devoted to description of developed information technology for e-Health network traffic modeling by using Ateb-functions theory. Prediction model is built based on hypothesis about periodic nature of network traffic pulsations which lead to using a nonlinear oscillating system with single degree-of-freedom under the conditions of small-scale disturbances that in result gives more qualitative solution. Obtained prediction of traffic intensity is used as one of indicators in calculating most optimal routes of packets in a various simulated e-Health network topologies. In addition, this work contains description of developed technology and mechanism of its application while adaptive management decision-making.

Keywords: Traffic; Modeling; Ateb-function; Adaptive Management; Improving service delivery; eHealth systems.

1 INTRODUCTION

Modern medical care actively implements information technologies. According to the Ministry of Health of Ukraine [1], the first medical information system with a database and knowledge base arose in Ukraine in 2000. Today there are 14 such systems, among them 4 are using cloud technology. All these systems are integrated into the unified medical system of Ukraine eHealth. Number of declarations between end-user and doctor has grown dramatically, reached 20 million of people as for end of 2018 [2] and continue to grow, see figure 1. Continuous increasing of users increases load of network and amount of traffic. An important task is to ensure the quality of service for this system in such circumstances. One of the possible approaches to solving this problem is to use adaptive control in eHealth network nodes as telecommunication network nodes. The purpose of this work is to develop adaptive management to improve the quality of service at the nodes of eHealth network.

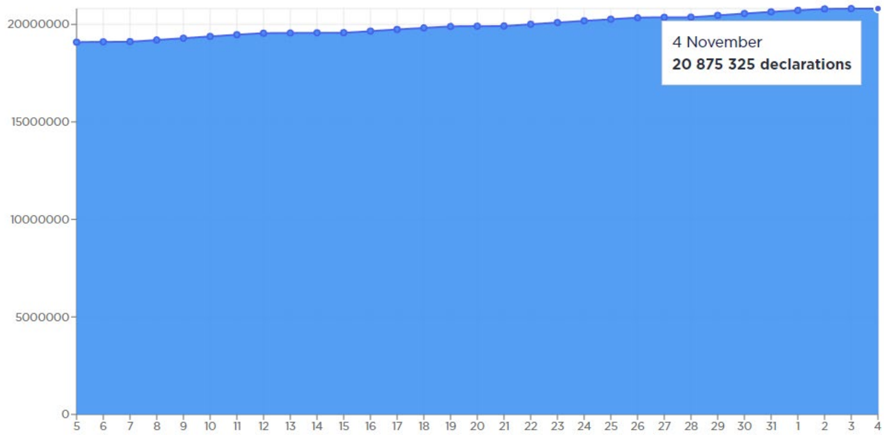

Fig. 1. Registered users in eHealth system Ukraine during October 2018 [2]

Classical approaches to the theory of computer networks are based on the assumption that the input streams are stationary, that is, in fact, a superposition of a very large number of independent stationary flows. When considering telephone networks with channel switching, it can be claimed that such an assumption will be also equitable for them. However, researchers are claiming that traffic in modern computer and telecommunication networks with packet switching has a special structure that prevents the use of standard methods based on Markov models and Erlang's formulas in the simulation.

These models do not take into account the effect of self-similarity of traffic, that is, in the implementation always there is a certain number of strong enough fluctuations against the background of low average total traffic. This phenomenon leads to an increase in the loss of packets with data, delays in their transmission when passing such traffic through computer network nodes. Thus, the actual scientific task is to search and develop new mathematical models for describing the process of servicing self-similar network traffic of data in order to develop methods that will enable to improve the maintenance of such traffic on the hardware level in eHealth systems.

An interesting approach with analytical solution of Ordinary Differential Equations for modeling social network was presented in [3].

This paper [4] investigates the methods of reducing the sensitivity to delay variations in a networked environment.The method for increasing of quality of service using multipath routing was shown in [5].

The most popular prediction method is based on neural network [6]. Another approach for forecasting in clinical consequences of cancer diseases is presented in [7] and it is developed with machine learning methods.

Our investigation combines all these ideas and creates information technology for effective adaptive management in eHealth networks nodes for improved quality of service in eHealth network.

2 QUALITY OF SERVICE IN EHEALTH SYSTEMS

The solution of QoS problem needs intelligent network for all Web system [8] and for eHealth systems especially. In this work, the research of methods of forecasting and modeling of traffic flows in computer networks was carried out for implementation to eHealth systems. These methods are widely used and developed to date, some of them are in a state of constant development, and they are continuously implemented in the latest concepts such as IoE, XaaS cloud solutions for effective processing of significant data volumes of custom content and associated metadata, BigData, and more [9]. The purpose of the study is to create information technology for monitoring and adaptive control of pulsating (non-stationary) stream traffic in computer networks by predicting load intensity and redistribution of node capacity in a given segment of a network platform.

The results of detailed determination of the eHealth systems computer network loadability parameters by computer simulation modeling for determining how the application of the methods of the developed information technology to the work of network equipment of the eHealth system influences is presented. Figure 2 depicts the scheme of work of the methods of the developed information technology.

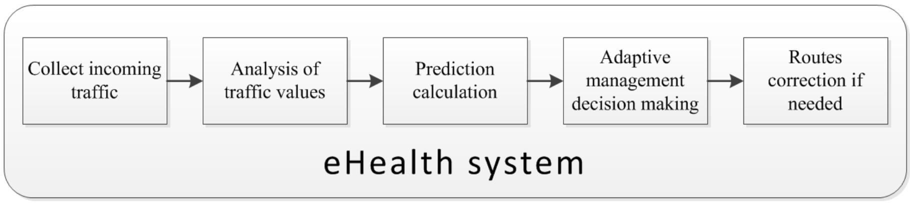

Fig. 2. Scheme of information technology application for adaptive managemant in e-Health system

The increase of the amount of traffic in its turn will increase the load on the main components of the eHealth systems and networks, in particular on routers and switches, which can lead to a decrease in the efficiency of their work and cause loss of useful information, which will adversely affect the work of eHealth systems and networks computer networks in general, and on everyday medicine and patients activities.

Statistics data shows that in the future with every year, the need to create information technologies of different types will increase, which will enable to use an intelligent management in service-oriented systems.

3 ATEB-FUNCTIONS MATHEMATICAL APPARATUS

An analysis of the numerous works of domestic and foreign scientists who devoted their scientific works to studying of oscillating processes described by systems of non-linear differential equations with a small parameter shows that they are mainly devoted to the study of quasi-linear systems. Oscillatory processes are much less investigated, those that are described significantly by nonlinear differential equations.

Therefore, in the future wide spread of application of asymptotic methods of nonlinear mechanics and an effective method of averaging, which were developed and found their development in the classical work of N.N. Bogolyubov, Yu.A. Mitropolsky [10]. In addition, the special elliptic functions of Lyapunov, Jacobi and their generalizations are used to construct solutions of a system of two differential equations with nonlinearity of a certain type.

The method of constructing solutions is based on the application of asymptotic methods and the mathematical theory of Ateb-functions [11]. There were not developing effective numerical methods for the application of these formulas in practically important problems.

Let’s investigate and describe changes in the values of traffic in a computer network in time as a nonlinear oscillatory system with one degree of freedom with low perturbation. Simulation of computer network traffic x(t) is carried out using a simple differential equation with a small parameter ε as

$$\ddot{x} + \alpha^2 x^n = \varepsilon f(x, \dot{x}, t) \quad (1)$$

where x(t) – the number of packets in the network at the time t; α – constant for determination of value of the period of fluctuation of traffic values, $f(x, \dot{x}, t)$ - any analytic function used to describe and simulate minor variations in traffic values from the main component of oscillations, n – a number that determines the degree of nonlinearity of the equation and affects on the period of the main component of the oscillation [10].

Under the use of the following conditions on α and n, $= \frac{2k_1+1}{2k_2+1}, k_1, k_2 = 0,1,2 \dots$, it was shown [8], that the analytic solution of equation (1) is represented as Ateb-functions. To solve problems of forecasting traffic in a computer network or telecommunication networks, it is important to choose the type of function f, because the type of this function takes into account the features of the chosen network. A method in which small disturbances are considered as periodic functions can be used to model a network with unsteady changes in the intensity of traffic. However, here the disturbance in the form of the sum of Dirac functions is considered. This description is better suited to the computer network with the available traffic pulsations in it. Consider the function as

$$f(x, \dot{x}, t) = \sum_{i=1}^{N} a_i \delta(t_i) \quad (2)$$

where N – number of disturbances on the interval [0;T], a_i - amplitude of perturbation, $-A \le a_i \le A$ - maximum perturbation amplitude (generated randomly), δ – delta function, t_i - the moment of time in which the i-th perturbation is generated randomly.

To construct the solution, the following equation (1) is selected initially without perturbing function

$$\ddot{x} + \alpha^2 x^n = 0 \tag{3}$$

Writing a differential equation of the second order (3) as a system of differential equations of the first order, as well as having replaced the variables$y = \dot{x}$, a differential equation of the second order (1) can be introduced as the next system of differential equations of the first order :

$$\begin{cases} \frac{dx}{dt} - y = 0 \\ \frac{dy}{dt} + \alpha^2 x^n = 0 \end{cases} \tag{4}$$

and the solution of (4) is represented by periodic Ateb-functions as

$$\begin{cases} x = aCa(n, 1, \varphi) \\ y = a^{\frac{1+n}{2}} hSa(1, n, \varphi) \end{cases} \tag{5}$$

where $h^2 = \frac{2\alpha^2}{1+n}$, a – amplitude of oscillations, $Ca(n, 1, \varphi), Sa(1, n, \varphi)$ - Ateb-cosine and Ateb-sine accordingly. Variable φ is time-related by the equation:

$$\varphi = \frac{a^{\frac{n-1}{2}}}{L} t + \varphi_0 \tag{6}$$

where L – any constant, φ_0 - the initial phase of oscillations, which are determined from the initial conditions for the equation (3).

Periodic conditions are expressed by the expressions:

$$\begin{cases} Ca(n, 1, \varphi + 2\Pi) = Ca(n, 1, \varphi) \\ Sa(1, n, \varphi + 2\Pi) = Sa(1, n, \varphi) \end{cases} \tag{7}$$

where Π is a half period of the Ateb-function. When the expressions (5) and (6) are put into equation (4) and take into account conditions (7), the following correlation for calculating the constant L in equation (6) is obtained:

$$L = \frac{2B(0.5, \frac{1}{1+n})}{\Pi(1+n)h} \tag{8}$$

Taking into account the aforementioned, the scientific novelty of this work was the use of the mathematical apparatus of the theory of Ateb-functions to describe the physical nature of traffic, which is expressed in the following formula:

$$\begin{cases} \xi = aCa(n, 1, t) - \varepsilon f(\xi, \zeta, t) \\ \zeta = a^{\frac{1+n}{2}} hSa(1, n, t) - \varepsilon g(\xi, \zeta, t) \end{cases} \tag{9}$$

where a – amplitude of oscillations, Ca(n,1,t), Sa(1,n,t) - Ateb - cosine and Ateb - sine respectively, ε – small parameter, n – Ateb-function parameter, t - time.

As a result, the research of nonlinear dynamical systems, it was found that there is a possibility to develop a new mathematical model of traffic in a computer network, using the mathematical apparatus of the Ateb-functions. Ateb-functions enable to formulate solutions to non-linear differential equations with power nonlinearity.

A carried out study of solvable equations in the form of Ateb-functions and the possibility of their applicability to create a mathematical model of computer network traffic has shown that the greatest benefit in using this model (on average up to 12%) is obtained in the case of short-term forecasting and the study of maximum nonlinear intervals of traffic in comparison with existing samples, while maintaining the relevancy (within the norm) with real samples of traffic and other known models of traffic in computer networks [12].

4 INFORMATION TECHNOLOGY WORKING RESULTS

In order to prove the truth of the results of experiments, the OMNeT++ software package, which has the means for constructing eHealth systems of different scales and topologies, was chosen as a tool for simulation [13].

This software has a large database of ready-made network elements, which already include simulation algorithms, modeling and processing steps for network information, taking into account time expenditures and their implementation by real physical devices. It is known [14] that the results of theoretical approximations are tested on the basis of the use of OMNeT ++.

In total 40 different experiments were conducted. Part of the results obtained is shown in Fig. 3 - 4.

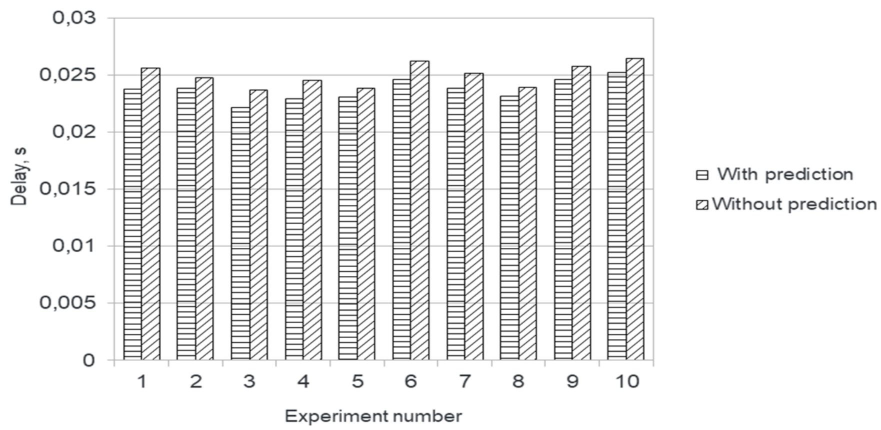

Fig. 3. Average packet delay for a set of experiments for topology # 1

For experiments, the method of short-term forecasting of traffic intensity using Ateb-functions has been embedded in simulation models in OMNeT ++ environment. The

OMNeT++ computer environment simulation software allows embedding simulation models of eHealth systems to be embedded in a program code written in the C++ programming language. The source code of the developed method for predicting traffic intensity using Ateb-functions was added to the existing code base of the model with the ability to call up the necessary functions of processing the data of forecasting and routing of packets in the packet processing functions located in the routing module in the structure of the node, designed for carrying out of simulation of computer topologies.

The results show the adequacy of carried out experiments and selected data samples and computer network for eHealth systems parameters, namely, the improvement of the network of eHealth systems by parameters of average delay of packets transmission by 12-14%.

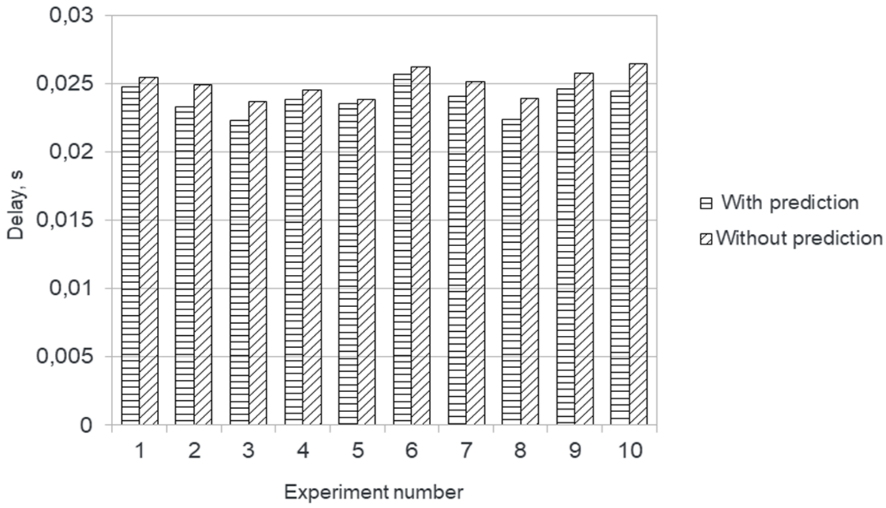

Fig. 4. Average packet delay for a set of experiments for topology # 2.

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