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ADAPTIVE CONTROL OF SELF SIMILAR TRAFFIC IN MULTISERVICE TELECOMMUNICATION NETWORKS

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***Abstract:** The paper analyzes approaches to increase resistance to overloads of a multi-service heterogeneous network with self-similar traffic. To solve this problem, the peculiarities of using adaptive switching systems and information distribution using Softswitch software switches and/or IP Multimedia Subsystem (IMS) software systems are considered. The test characteristics are selected and the task of testing the performance of a multi-service heterogeneous network is substantiated. Expressions are derived for describing the dynamics of changes in network quality parameters depending on the state of network nodes and network traffic statistics.*
***Key words**: multi-service network, self-similar traffic, performance tests, quality parameters, separated traffic, congestion, dynamic routing*

АДАПТИВНЕ КЕРУВАННЯ САМОПОДІБНИМ ТРАФІКОМ В МУЛЬТИСЕРВІСНИХ ТЕЛЕКОМУНІКАЦІЙНИХ МЕРЕЖАХ

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***Анотація:** У роботі проаналізовано підходи до підвищення стійкості до перевантажень мультисервісної гетерогенної мережі з самоподібним трафіком. Обгрунтована необхідність роздільної обробки трафіку як з різними статистичними характеристиками, так і з принциповими відмінностями в структурі: трафіку "Triple Play" (мова + відео + дані), а потім "Quadro Play" (мова + відео + дані + мобільні абоненти). Для вирішення вказаної задачі розглянуті особливості використання адаптивних комутаційних систем та розподілу інформації із застосуванням програмних комутаторів Softswitch та/або програмних систем IP Multimedia Subsystem (IMS). Проаналізовані математичні моделі самоподібного мережного трафіку. Вирішується задача аналітичного визначення часових характеристик мережі, які є визначальними для досягнення максимальної швидкодії і мінімального часу доставки інформації користувачу. Для основних характеристик випадкового стаціонарного процесу (математичного очікування, дисперсії, кореляційної функції) дана оцінка точності їх визначення залежно від часу спостереження за реалізацією процесу. Виведено вирази для опису динаміки змін параметрів якості мережі залежно від стану мережних вузлів та статистики мережного трафіку.*

Розглянута концепція розподіленої інтелектуальної оцінки параметрів та стану мережі. Описана чотирирівнева архітектура сучасних телекомунікаційних мультисервісних мереж: рівень доступу, транспортний рівень, рівень управління як нова концепція комутації та рівень обслуговування, який визначає склад контенту інформаційної мережі. Вибрано тестові характеристики та обґрунтовано завдання тестування продуктивності мультисервісної гетерогенної мережі. У якості основної програми пошуку несправності вибраний двохетапний пошук, оптимальний по мінімальному середньому часу, який витрачається на виявлення відмови. Показані переваги тестів продуктивності мережі над функціональними тестами.
***Ключові слова:** мультисервісна мережа, самоподібний трафік, тести продуктивності, параметри якості, роздільний трафік, перевантаження, динамічна маршрутизація*

Introduction

The modern development of telecommunication networks (TCN) is characterized by constantly growing data transmission traffic, the organization of services is less and less related to the actual transport of information [1, 2]. This approach is the basis of the process of modernization of existing and construction of multi-service networks (MSN) of new generations.

The integration process extends not only to networks of various purposes (computer, telecommunications, document telecommunications), but also to networks with different switching methods, protocols and principles of construction [3, 4].

The relevance and perspective of the unification and convergence of networks of various purposes, the harmonization of computer and telecommunication technologies is due to the constant development of information transmission technologies and the construction of networks of new generations based on them.

The objective complexity of new generation networks is due to the use of dynamic routing principles. In addition, even in the simplest models of modern networks, we are faced with a multi-parameter system, the behavior of which we can predict only at short intervals, which, as a rule, are an order of magnitude smaller than the duration of a message divided into individual packets. The latter is caused by a change in the statistical characteristics of the traffic.

The intensity of heterogeneous traffic does not obey Poisson's or Erlang's laws. It is described by a probability distribution with so-called "heavy tails" - Pareto, Weibull, gamma distribution, etc. Such traffic is called self-similar or fractal [1, 2]. In addition, with a relatively low average intensity, instantaneous bursts (spikes) of the intensity of self-similar network traffic may occur.

During the development and implementation of modern MSN, there is an objective need for separate processing of traffic not only with different statistical characteristics, but also with fundamental differences in structure: "Triple Play" traffic (language + video + data), and then "Quadro Play" (language + video + data + mobile subscribers).

Such a task is solved with the help of SoftSwitch software switches [2, 4] and using the hardware and software complex IP Multimedia Subsystem (IMS) [5, 6]. As shown in [3], the main difference between IMS and Softswitch is the function of convergence of mobile and fixed communication. Softswitch's complex solutions allow fixed line operators to provide a wide range of services, while slightly sacrificing functions. Note that IMS platforms contain a significant number of functional modules of Softswitch platforms.

Therefore, Softswitch is usually associated with the functional structure of separate parts of the communication network that use VoIP technology, open application programming interfaces (Application Programming Interface - API) and signaling protocols (SIP, H.323, H.248, SIGTRAN). This concept is discussed in detail in many articles and books, but here I would like to note the versatile nature of SoftSwitch and the wide range of technologies that are used in SoftSwitch. The core of such systems is a software switch - the control device of the complex, the features of which work practically do not depend on the types of peripherals (terminal devices, signal and transport gateways). When using IMS, there is an opportunity for service providers, operators of fixed and mobile communications to provide services to users of all types of access networks and all types of terminals through a single network based on the IP-MPLS protocol. At the same time, the quality of telecommunication-class services is ensured, and not the "best effort" quality, as in a traditional Internet service. However, IMS can only work effectively on "pure" IP networks. Therefore, IMS should be considered as an evolutionary development of SoftSwitch hardware.

As noted above, multiservice network (MSN) traffic is by definition heterogeneous. In works devoted to the development of software switches and IMS elements, this feature and related problems are not considered. This article attempts to fill this gap.

The effectiveness of the telecommunication network management system (TCN) with packet switching is largely determined by the delays of signaling and control information, which is associated with a large number of various network switching nodes with different routing and information processing algorithms [1, 7].

Currently, there is great interest in the methods of analysis and optimization of telecommunication, computer and combined networks, intellectualization, convergence, in the implementation of network control systems that "adapt", "self-adjust", "learn", etc.

However, at the same time, there are serious gaps associated with the systematization in this area of knowledge, with the use of the mathematical apparatus of the theory, and even with the development of a sound terminology.

Such a rapid kaleidoscopic change in technologies, technical solutions and the very principles of network construction is accompanied by the closure of network equipment characteristics and, as a result, extremely low efficiency in the use of network resources [5, 8, 9]. The above leads to certain complications in evaluating the technical and economic indicators of the network, in the analysis of the influence of certain parameters of the network equipment on the efficiency of its functioning.

At the same time, theoretical science does not keep up with technological developments and attempts to quickly implement new de facto solutions. As a result, the task of analytically determining the time characteristics of the network, which are decisive for achieving maximum speed and minimum time for delivering information to the user, is complicated.

One of the key defining characteristics of TCN operation is signal and control information delays that occur during data delivery through communication channels and during processing at intermediate switching nodes [5, 7 10, 11].

The purpose of the studies covered in the article is the development of algorithms and the construction of a mathematical model for evaluating the quality of functioning, finding and determining the places of failures, overloads and emergency modes in telecommunication MSN with self-similar traffic.

Mathematical models of self-similar network traffic

Self-similar traffic has a special structure that does not change with multiple scaling - in the implementation, as a rule, there is a certain number of spikes with a relatively small average level of traffic [12]. Due to such bursts of load, network characteristics deteriorate: losses, delays, jitter of packets during passage through network nodes increase. Methods for calculating requirements for networks of new generations (channel capacity, buffer capacity, etc.) based on Markov models and Erlang formulas were successfully used in the design of telephone networks. Using them for modern networks with self-similar traffic can give unreasonably optimistic solutions and lead to an underestimation of the load [6, 7]. Distributions with "heavy tails" are used to describe the probability density of self-similar flows: log-normal, gamma distribution, Weibull distribution, Pareto. The latter is used to describe self-similar traffic most often [13].

Real random processes preserve the property of self-similarity only up to a certain limit. This limit or measure of statistical stability of the process at multiple scaling is determined by the so-called Hurst parameter or self-similarity parameter. A random process $x(t)$ is statistically self-similar with the Hurst parameter *H* $(0{,}5 \leq H \leq 1)$, if for any valid value $a > 0$ process $x(at)/a^H$ has the same statistical characteristics as the process itself $x(t)$:

- mathematical expectation $M[x(t)] = {M[x(at)]}/{a^H};$ (1)

- dispersion $$D[x(t)] = {D[x(at)]}/{a^{2H}}; \quad (2)$$

- correlation function $$R(t,\tau) = {R(at), a\tau)}/{a^{2H}}. \quad (3)$$

The more H in (1)-(3), the longer the property of self-similarity is preserved under multiple scaling. At $H = 0.5$ this property is practically absent. Correlation functions of self-similar processes with a large Hurst parameter decay more slowly than those of ordinary random processes, and have, as a rule, an oscillatory character. It was established that the constant component of the correlation function (3) decreases according to the law:

$$c_1 t^{-c_2 a},$$

where c_1, c_2 - constants, a - scale parameter.

The expression for the probability density of the Pareto distribution has the following form:

$$f(x) = {}^{\alpha}/_{k} \left({}^{k}/_{x}\right)^{\alpha+1}, \tag{4}$$

where *k* and α (*k*, α < 0) – distribution parameters.

Accordingly, the probability function:

$$F(x) = 1 - \left({}^{k}/_{x}\right)^{\alpha} \ (x > k,\ \alpha > 1) \tag{5}$$

average value:

$$E(x) = {}^{\alpha k}/_{\alpha - 1},\ (\alpha > 1). \tag{6}$$

When transferring data of various types (voice, video, data, traffic of mobile subscribers), the so-called Quadro Play, it is necessary to take into account statistical characteristics (4)-(6) for both the case of synchronous and asynchronous service.

The concept of distributed estimation of network parameters and state

The architecture of modern TCN (Fig. 1) contains four levels [12, 13].

An access level gives users access to network resources. The transport layer is the main network resource, ensuring the transfer of information from user to user. The management level is a new switching concept based on the use of computer telephony technology and Softswitch. Softswitch technology provides a fundamentally new approach to the concept of building network nodes, call management, service provision and payment control. The level of service determines the composition of the content of the information network.

There are some fundamental differences between traditional data networks and modern smart networks. All these differences affect the principles of managing networks and their traffic. The following can be listed among the most significant differences:

1) using the principles of dynamic routing. As a result, all communication channels are quite difficult to describe and measure parameters;

2) high level of virtualization technology. New principles of differentiation of norms by parameters related to procedures for implementation of service level agreements (SLA) and even different concepts of quality of service (QoS) are applied;

3) high importance of equipment performance tests as a result, especially important principles of traffic modeling in test procedures, even at the level of field tests;

4) incomplete standardization and the lack of high-quality operational measuring equipment are currently an urgent problem. As a result, in the modern development of NGN networks, special devices and their components are used to test solutions and install equipment.

Development of the concept of distributed intelligent assessment of network parameters and state requires extensive use of analysis and monitoring systems. However, the existing management systems, despite their functional redundancy, do not have developed intellectual means in their composition, which allow to qualitatively predict the behavior of the computer network. Most management tools do not actually manage the network, but only passively monitor it. They monitor the network, but do not take active actions, recording only the fact of failure. The ideal solution would be the development of a system of analysis, forecasting and localization of possible failures in the work of both the telecommunications network in general and its individual elements. This property of the system will help to identify possible bottlenecks in advance and take measures to eliminate them in advance. However, such a control system is practically not implemented for operation in critical application conditions [2, 4].

The intelligent core of the system for forecasting the state of networks and their traffic is a control system. It is a control network and is divided into two sublevels:

The first sublevel is responsible for the state of each network element separately and is tied to specific equipment (router, bridge, switch, etc.).

The second sub-level of the control network is responsible for the general state of the controlled network segments and the network as a whole and does not depend on the equipment included in it.

This approach makes it possible to clearly separate specific equipment and the topology of the TCN. The control system automatically monitors objects in the network, collects the necessary statistical information for configuring the control network. Next, the system monitors all objects and forms a forecast of TCN performance in the future. The forecast is formed taking into account the vector of output signals of the control network.

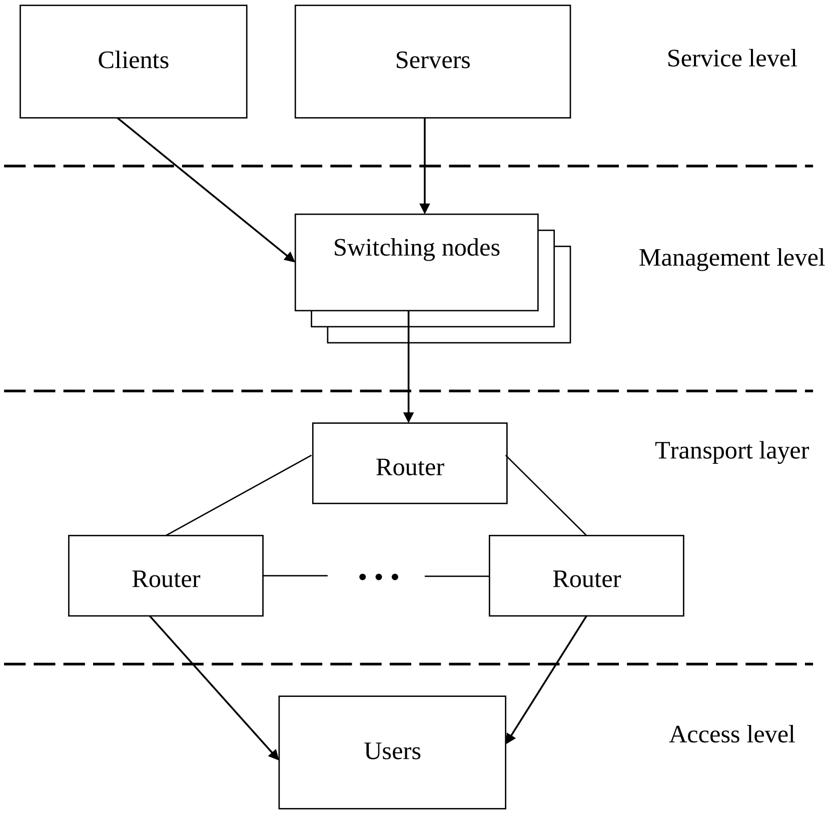

Fig. 1. Architecture levels of multi-service intelligent networks

The algorithm of the system can be divided into four main stages [14, 15]:

1) installation stage;
2) the stage of object search and collection of statistical information about the computer network;
3) stage of configuring the control network and setting its parameters;
4) network NGN monitoring stage.

The first stage is system initialization. At this stage, the initial setting of the system parameters and its self-testing take place.

At the second stage, objects are searched and statistical information about the network is collected. All received data are stored in the database of statistical information.

At the third stage, the control network is formed and configured based on the information accumulated in the database.

The first three stages are preparatory for the last, fourth stage of the algorithm's work, where there is constant monitoring of found network objects and control of the network state. The data obtained during monitoring are sent to the input of the control system. Next, a forecast of the state of each TCN object is formed, which in turn is transmitted to the input of the control system. Based on the data received at the output of the control system, a forecast of the TCN state in general is formed.

Multi-parameter problem of dynamic routing

In the case of dynamic routing of network traffic, an individual route is calculated for each packet. As a result, there is a problem of high dynamics of network settings changes. The vector of traffic parameters (profile) changes dynamically, and therefore the parameters of network nodes change. In general, the following dependence of TCN quality on network traffic parameters can be determined:

$$QoS = \Psi(\vec{L_p}), \tag{7}$$

where $\vec{L_p} = \{t_i, l_m, p_{rt}, a_c, a_{nt}\}$ - a vector of packet flow parameters;

t_i – instantaneous traffic volume;

l_m – the length of the message;

$p_{rt}, 1 \leq p_{rt} \leq n$ – message priority, n – the number installed by the provider priorities (the less p_{rt}, the higher the priority);

a_c – link layer address (MAC address);

a_{nt} – network address (IP address).

According to the de facto standards [6, 8] the following test characteristics for the telecommunications network:

1) capacity C_d:
- determined by the bandwidth of the test object (device under test – DUT);
- defines the maximum permissible load, at which there are no packet losses;

2) delivery delay L_d:
- defines the average delay and the probability distribution of the delay;
- packet delay is selectively measured;

3) packet losses F_l:
- determines the frequency of packet loss in a range of data volumes and packet sizes;
- determines the dependence of losses on the load;

4) back-to-back B_{tB} – the ability of the DUT to process frame by frame (back to back), a boolean variable «0» or «1»):
- determines whether the DUT is capable of processing a fixed-length frame sequence;
- the duration of work is measured τ_{cl} at the current load;

5) system Restore: determines the timeτ_{rec} DUT recovery after overload;

6) reboot: determines the time τ_{reset}, which passes from the moment of a hardware or software reset of the DUT to full operation.

As a result considering (7), we get a description of the dynamics of changes in quality parameters at each step in the following form:

$$QoS(C_d, L_d, F_l, B_{tB}, \tau_{cl}, \tau_{rec}, \tau_{reset}) = \Psi(t_i, l_m, p_{rt}, a_c, a_{nt}), \tag{8}$$

that is, a 12-dimensional state space. Considering that the entire load profile affects the quality parameters, we are faced with the impossibility of theoretically forming a complete description of the behavior of the quality parameters of the telecommunication MSM. The task is related to the multidimensional representation of the object, and the number of dimensions tends to infinity:

$$QoS(C_d, L_d, F_l, B_{tB}, \tau_{cl}, \tau_{rec}, \tau_{reset}) = \Psi(t_i, l_m, p_{rt}, a_c, a_{nt}) | \cup_{i \neq n} QoS. \tag{9}$$

This leads to another problem of MSN monitoring and analysis: even the simplest network models are multiparameter systems. Their behavior cannot be imitated with the necessary accuracy and reliability. For these reasons, all attempts to solve the problem of planning and deployment of TCN only by modeling and calculations according to (8), (9) will be clearly ineffective.

A way out of the situation can be found through a combination of theory and experiment. In particular, in conditions where quality parameters depend on the level of network load, the only method of their measurement is the combination of QoS analysis methods with the development of a detailed model of network traffic. The numerical experiment should be carried out under different traffic intensities, varying in a wide range: from the minimum to the nominal load, and further up to peak loads and significant network overloads. It should be noted that functional testing gives a qualitative assessment of the operation of the TCN ("works - does not work"), while performance tests make it possible to give a quantitative assessment of the operation of equipment and services. These important differences of MSN testing methods from traditional networks must be taken into account first.

Conclusion

A condition for the effective functioning of TCN is stable current management in real time of all network resources, diagnostics, control of parameters and status of the network as a whole and its individual elements.

The defining task of reliability management is solved by implementing the following partial functions: network diagnostics and monitoring, identifying faulty network components and determining the type of failure, recording failures in the relevant databases, adjusting dynamic routing tables and recommending the reconfiguration of the corresponding network segment. A two-stage search, optimal for the minimum average time spent on failure detection, was selected as the main fault finding program.

For the main characteristics of a random stationary process (mathematical expectation, dispersion, correlation function), the accuracy of their determination should be estimated depending on the time of observation of the process implementation.

It is shown that functionality measurements (functional tests) become uninformative for MSN with self-similar traffic. The ratio between functional tests and performance tests is clearly changing in favor of the latter. Therefore, testing of a significant number of NGN applications and protocols must be performed at all stages of network design and deployment. From a theoretical point of view, the tasks of optimal design of modern TCN are closely related to the application of the principles of distributed management and adaptation to the current conditions of network operation.

An important prospective task of TCN reliability management is a comparative analysis of optimal and adaptive network management methods in conditions of incomplete a priori information about the state of network and terminal nodes, statistical characteristics of network traffic.

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