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SIMULATION MODELING OF ADAPTIVE ROUTING UNDER EXTERNAL DESTROYING EFFECTS IN NGN NETWORKS

В.М. Тігарев, П.А. Швагірев, В.В. Космачевский, О.С. Лопаков, Ю.С. Барчанова. **Імітаційне моделювання адаптивної маршрутизації в умовах зовнішніх деструктивних дій на мережі зв'язку NGN.** Сучасним абонентам інфокомунікаційних послуг потрібно широкий клас різних служб і додатків, що припускає велику різноманітність протоколів, технологій і швидкостей передачі. У існуючій ситуації на ринку інфокомунікаційних послуг мережі переобтяжені: вони переповнені численними інтерфейсами клієнтів, мережевими шарами і контролюються занадто великим числом систем управління. Великі експлуатаційні витрати підштовхують операторів до пошуку рішень, що спрощують функціонування, при збереженні можливості створення нових служб і забезпеченні стабільності існуючих джерел доходів, від надання послуг зв'язку. Концепція NGN – концепція побудови мереж зв'язку наступного/нового покоління (Next/New Generation Network), що забезпечують надання необмеженого набору послуг з гнучкими налаштуваннями по їх управлінню, персоналізації, створенню нових послуг за рахунок уніфікації мережевих рішень. Мультисервісна мережа – мережа зв'язку, який побудований відповідно до концепції NGN і забезпечує надання необмеженого набору інфокомунікаційних послуг (VoIP, Інтернет, VPN, IPTV, VoD та ін.) Мережа NGN – мережа з пакетною комутацією, придатна для надання послуг електрозв'язку і для використання декількох широкосмугових технологій транспортування з включеною функцією QoS, в якій пов'язані з обслуговуванням функції не залежать від застосованих технологій, що забезпечують транспортування. Основна особливість мереж NGN – диференціація між послугами і транспортними технологіями. Це дозволяє розглядати мережу у вигляді логічно розділеної на рівні суті. Кожен рівень мережі може розвиватися незалежно, не роблячи впливу на інші рівні. Міжрівнева взаємодія здійснюється на основі відкритих інтерфейсів. Принцип логічного розділення дозволяє надавати як існуючі, так і інноваційні послуги незалежно від використовуваних транспортних технологій доступу. Базовим принципом концепції NGN є відділення один від одного функцій перенесення і комутації, функцій управління викликом і функцій управління послугами.
Ключові слова: мережа NGN, комірчаста топологія,QoS, протокол IP/MPLS, маршрутизатор, мережевий ресурс, інтервал моделювання, оптимальна і субоптимальна маршрутизація

V. Tigarev, P. Shvahirev, O. Lopakov, V. Kosmachevskiy, Y. Barchanova. **Simulation modeling of adaptive routing under external destroying effects in NGN networks.** Modern subscribers of infocommunication services require a wide class of different services and applications, implying a wide variety of protocols, technologies and transmission rates. Networks are overloaded in the prevailing situation in the market of infocommunication services: they are overflowing with numerous customer interfaces, network layers and are controlled by too many control systems. High operating costs are pushing operators to look for solutions that simplify the operation, while maintaining the possibility of creating new services and ensuring the stability of existing sources of income from the provision of communication services. The NGN concept is the concept of building next-generation communication networks (Next-generation network), providing an unlimited set of services with flexible settings for their management, personalization, creation of new services through the unification of network solutions. Multiservice network is a communication network that is built in accordance with the NGN concept and provides an unlimited set of infocommunication services (VoIP, Internet, VPN, IPTV, VoD, etc.). An NGN is a packet-switched network suitable for the provision of telecommunication services and for the use of multiple broadband transport technologies with QoS enabled, in which the service-related functions are independent of the applied transport technologies. The main feature of NGN networks is the differentiation between services and transport technologies. This allows to view the network as a logically divided entity. Each layer of the network can evolve independently without affecting other layers. Inter-layer communication is based on open interfaces. The logical separation principle allows the provision of both existing and innovative services access technologies regardless of the used transport. The basic principle of the NGN concept is to separate from each other transfer and switch functions, call control functions and service control functions.
Keywords: NGN network, mesh topology, QoS, IP/MPLS protocol, router, network resource of the network, simulation interval, optimal and suboptimal routing

Introduction

With the advent of Asynchronous Transfer Mode technology (ATM) [1], which fundamentally differs from other telecommunication technologies, it became possible to create a transport mechanism

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for transferring all types of information with QoS. As a result, such telecommunication systems are called broadband ISDN (ITU-T recommendations, series I.700-799). The competition between manufacturers and service providers has intensified the further development of the Internet Protocol (IP) technology in the struggle for telecommunications users. As a result, the Internet Engineering Task Force (IETF) working group developed MPLS [2] (Multiprotocol Label Switching) and IP v.6.0 [3] technologies, allowing the user to provide an unlimited range of applications and QoS. As a result, IP/MPLS and ATM have become the basic technologies for multiservice communication networks [4], which have differences, but also have much in common:

– any user and service information is converted into a single form – digital blocks of a certain length (packets);

– a header with data about the route is added to each digital block, which is predefined and guarantees the maintenance of the required probabilistic-temporal characteristics (information transmission rate, time delay, time jitter, probability of incorrect reception per message / packet / symbol, probability of denial of service) transmitted information;

– at the destination, the packages are combined and converted to their original form and handed to the user for further processing.

Thus, the presentation of all types of information in a single digital format and the allocation of the required network resources that guarantee QoS, before the start of the transfer of user information, are mandatory components of IP/MPLS and ATM technologies. A significant contribution to the solution of issues related to the creation of a theoretical and practical groundwork in the construction of secure telecommunication systems was made by the works of famous scientists such as W. Diffie, N. Ferguson, B. Forouzan, M. Hellman, B. Schneier, A. Shamir, C. Shannon, V. Stollings and many others.

Analysis of publications

Numerous studies [5 – 12] and other works prove the significant influence of network layer protocols on parameters QoS of applications of multiservice communication networks. This fact stimulates the developers of telecommunication equipment to research and implement new, more advanced software and hardware systems that carry out routing procedures. At the same time, such complexes are structure-forming for NGN. This means that the introduction of new routing methods always entails serious material costs and the implementation of global organizational and technical measures on existing networks. It is desirable to have universal complexes that implement routing procedures capable of supporting any technologies for generating packets of user information (ATM, IP of all versions, Ethernet, etc.). As a result, the MPLS protocol was developed, which implements the "Statistical" method of forming the information distribution plan. The use of MPLS in conjunction with other network technologies (ATM, IP of all versions, Ethernet, etc.) provides QoS of an unlimited range of applications and does not require significant material costs on existing NGN networks. The "Statistical" method of generating a distribution plan organizes the route according to the accumulated statistics of previously established connections. This is an advantage of this method and a serious disadvantage at the same time.

Unsolved problem area

Due to the lack of statistical information, we can assume that in conditions of external destructive influences on the elements of NGN networks, this method will not effectively solve the problems of routing procedures. Hence, in conditions of an external destructive impact, when approximately 30 % of the network resources of a multiservice communication network fail, more advisable to apply the "Avalanche" method [12] of forming an information distribution plan in comparison with the "Statistical" one.

Therefore, it makes sense to conduct an additional study of this result on communication networks with different structures using various mathematical and simulation models.

Purpose of the article

1. Using software products to develop a methodology, model, algorithms for the study of routing methods in conditions of external destructive influences.

2. Investigate the influence of the used routing methods on the quality of service of applications in conditions of external destructive influences.

Simulation of NGN network in conditions of limited network resources

Let:

$\lambda_{\Pi\varepsilon}^{(Q_{rq})}$ – be the rate of receipt of requests from authorized users in the ISS with the required quality of service for the ε-th application $(\varepsilon = \overline{1, E})$:

$$Q_{rq} = \{q_{rq}^{(i)}\}, \quad i = \overline{1, \zeta};$$
$$Q_{act} = \{q_{act}^{(i)}\}, \quad i = \overline{1, \zeta}, \tag{1}$$

relation (1) determines the values of the required Q_{rq} and actual Q_{act} quality of service when requesting a user application ε,

where $q_{rq}^{(i)}$ – the *i*-th parameter of the quality of service (delay time, information transmission rate, reliability, noise immunity, information security, and so on) required by the ε-th application $(\varepsilon = \overline{1, E})$ to transmit user information;

Ψ_(*t*) – external destructive impact on the NGN network for the purpose of unauthorized use of network network resources $r_c(t)$, parameters of the quality of service of user applications that the NGN network actually provides;

$q_{act}^{(i)}$ – the *i*-th quality of service parameter (delay time, information transfer rate, reliability, noise immunity, information security, and so on), which actually ensures the reliability of the NGN network.

$r_0(t)$ – common network resource MCC – a set of software and hardware and communication channels MCC, providing transmission of all types of information.

Therefore, with the given network traffic parameters the following can be stated:

$$\{r_0(t), \lambda_{\Pi\varepsilon}^{(Q_{rq})}, \Psi\_(t)\}$$

Routing

$$ROOT = \{ROOT_{TM} \uparrow ROOT_{CC}\}, \tag{2}$$

(here, the sign $\uparrow$ means the sequential execution of two procedures), containing procedures for generating a set of routing tables $(ROOT_{TM})$ and procedures for selecting outgoing traffic $(ROOT_{CC})$ in each AC when searching for a route $\mu_{MI,PS}$ between the MI and the PS.

According to (2), routing will be:

– optimal if with minimal use $r_c(t)$, that is:

$r_c(t) = \min r_c(t)$, condition is fulfilled $Q_{act} = Q_{rq}$;

– suboptimal if under the condition

$\lim\limits_{r_c(t)\to} \min r_c(t)$, requirement is met $Q_{act} \geq Q_{rq}$.

In an NGN network, a connection denial occurs when user network resources are unavailable to guarantee the QoS of selected applications. In this regard, it is of interest to study the influence of routing methods $ROOT$ (2) on the availability of user network resources under conditions of external destructive impact Ψ_(*t*).

Selection of software for simulation

There are quite a few software products for modeling communication networks: COMNETIII by CACI Products Company; OPNET from OPNET Technologies; NetCracker XA; OMNET++; NS2; NS3 (The Network Simulator); CPN (Colored Petri Nets) and many others. A detailed comparative analysis of the most well-known products of simulation of communication networks is given in works

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[13 – 15] and many others. At the same time, important criteria for choosing a particular software product are:

– convenient graphical interface;

– the possibility of varying the simulation parameters during the experiments;

– the price of a software product and many other criteria necessary for analyzing the network processes of telecommunication systems.

We will use the specialized software Opnet Modeler v. 14.0 [16]. This software product is intended for simulation modeling of communication networks. It contains an extensive library of software and hardware systems (routers, switches, routed switches of various levels, etc.) that implement network technologies and protocols well-known on the telecommunications market.

For simulation, the "Mesh" structure typical for a multiservice network (Fig. 1) [17] was chosen. It includes 5 local communication networks (Lan), 10 routers (Router1 – Router10) and one server (Server_1).

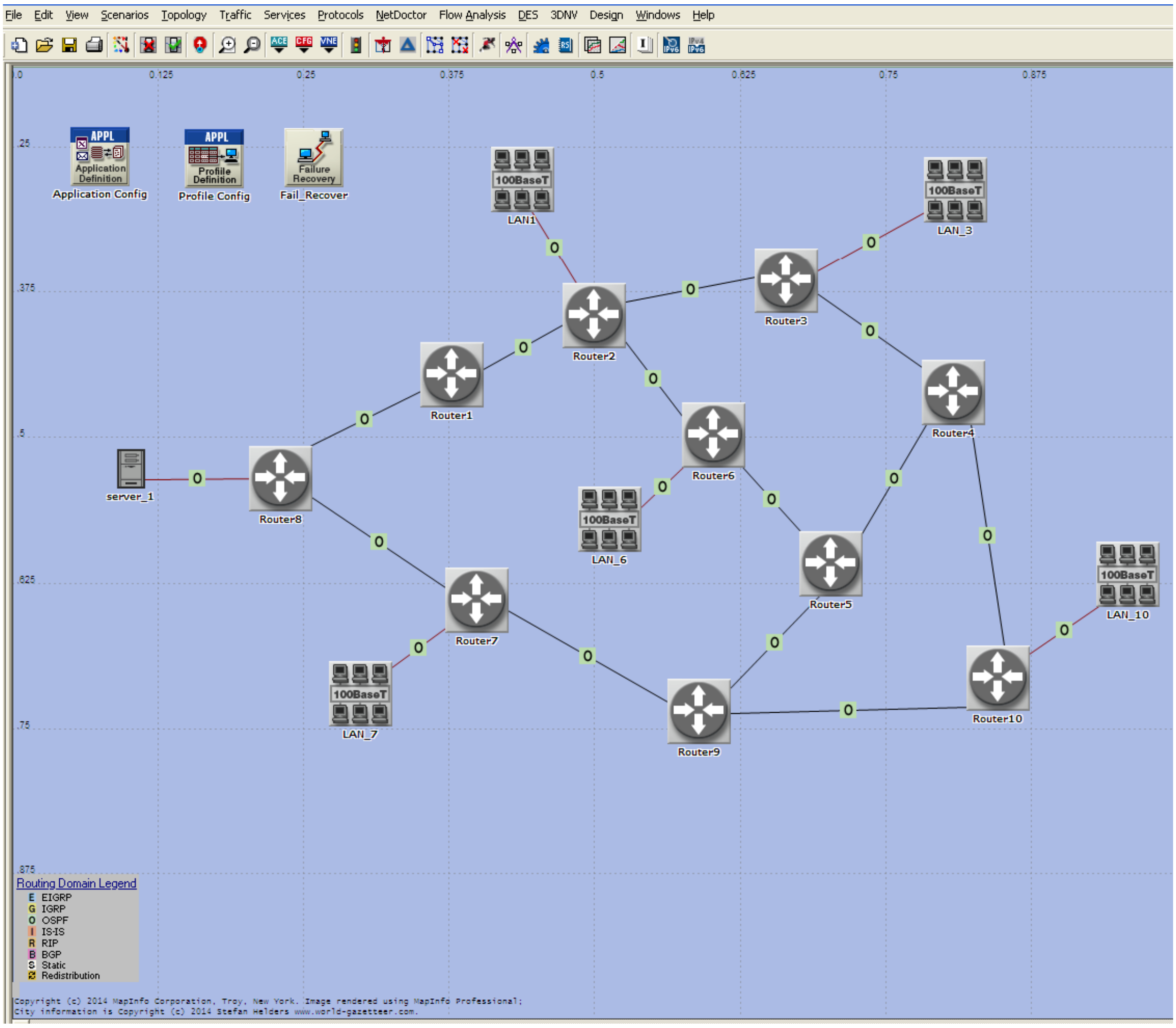

Fig. 1. The initial structure of the analyzed multiservice communication network

Each local network is organized on the basis of Fast Ethernet technology:

– contains 10 computers connected to the switch according to the "Star" principle;

– it is supported by the TCP and UDP protocols on the transport level;

– generates video conferencing traffic (Video Conferencing, VC) at a speed of 1350 kbps (frame size 128×120 pixels, frequency 10 frames/s, resolution 9 bits per pixel).

The choice of video conferencing is justified by the fact that this application imposes increased requirements for QoS (high speed and minimum latency when transferring information).

Considering that only video conferencing, organized on the basis of client-server architecture, was selected as an application, the characteristics of the Sun Ultra server were chosen as minimal – a dual-core processor with a frequency of 2 GHz with support for the Sun Solaris operating system.

The LANs and the server are connected to their respective routers using cables that support the 100 Mbps Ethernet family of technologies.

Routers interact with each other at the link level using the Point to Point Protocol (PPP) protocol and are connected by a network cable with the same pre-determined (in each simulation test) bandwidth r=1000 Mbps, r=100 Mbps and r=10 Mbps. Thus, in one simulation test, each link connecting the routers is only r=1000 Mbps, in another r=100 Mbps, and similarly in the next r=10 Mbps.

We represent the structure of a multiservice communication network [18] in the form of an undirected graph $G[A_S, M_S]$ with a set of: vertices $A_S = \{a_j\};\ i = \overline{1, S}$, corresponding to switching nodes edges $M_S = \{m_{ij}\};\ i,\ j = \overline{1, S};\ i \neq j$ corresponding to the communication line.

Let each communication line have an average throughput during the observation time T, which we will call the communication line resource. Obviously, the total average network resource of the NGN network will be determined by the expression:

$$R_0 = \sum_{i,j=1; i \neq j}^{S} r_{ij} \ \text{[bit/s]}. \qquad (3)$$

Step-by-step reduction of network cable bandwidth from 1000 Mbps to 10 Mbps reduces overall network resources (3):

$$R_0 = 12 \cdot r, \qquad (4)$$

thereby imitating the process of external destructive influence on the analyzed communication network. The routers of the analyzed network in each simulation test support only one method of generating the information distribution plan OSPF (“Avalanche”) or MPLS (“Statistical”). $ROOT_{тм}^{AV}$ $ROOT_{тм}^{ST}$

Thus, given:

– the method of forming the information distribution plan; $ROOT_{TM}$;

– shared network resource R_0 (total bandwidth r of the network cable) one test consists of a thirty-minute simulation of the functioning of the analyzed MSS.

Moreover, the MSS functions in a normal mode in the absence of external destructive influences from zero to the fifth minute, Fig. 2.

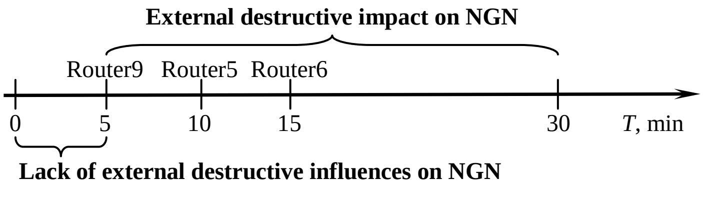

Fig. 2. The order of failure of routers

In the fifth minute, Router9 is out of order. In this state, the communication network continues to function until the tenth minute. At the tenth and fifteenth minutes, respectively, in addition to Router9, routers Router5 and Router6 are disabled.

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This process (sequential disabling of routers), in addition to a step-by-step reduction of total network resources, is represented by formula (4) and simulates an external destructive effect on the analyzed NGN network. As a result, the structure of the analyzed communication network in the process of one test changes from "Mesh" to "Linear" (Fig. 3, 4, 5, 6). The result of one simulation test is the number of VC packets N_{losses} per unit time.

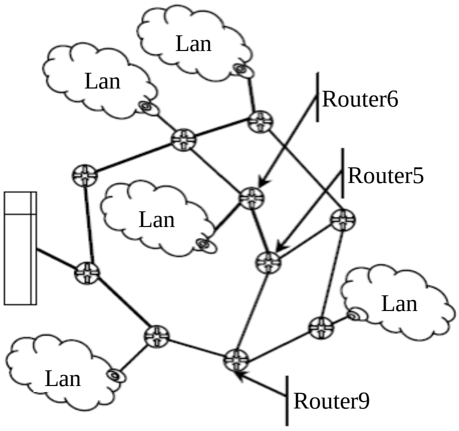

Fig. 3. The structure of the analyzed MCC from 0 to 5 minutes of modeling

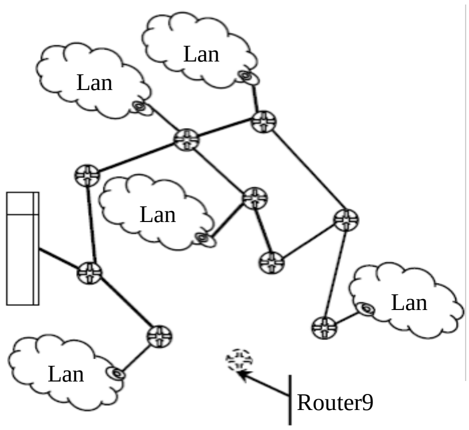

Fig. 4. The structure of the analyze MCC from 0 to 5 minutes of modeling

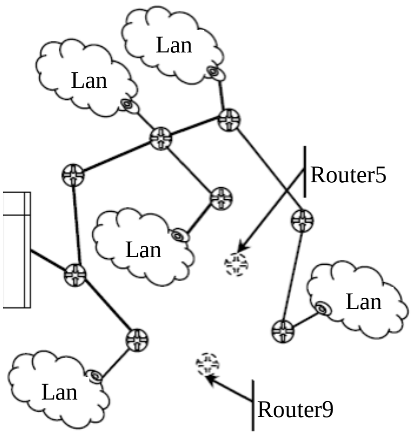

Fig. 5. The structure of the analyzed MCC from 10 to 15 minutes of simulation

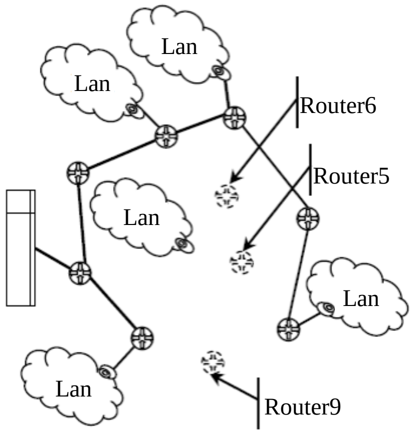

Fig. 6. The structure of the analyzed MCC from 15 to 30 minutes of simulation

The results of simulation modeling of the analyzed NGN communication network are presented (Fig. 7, 8, 9).

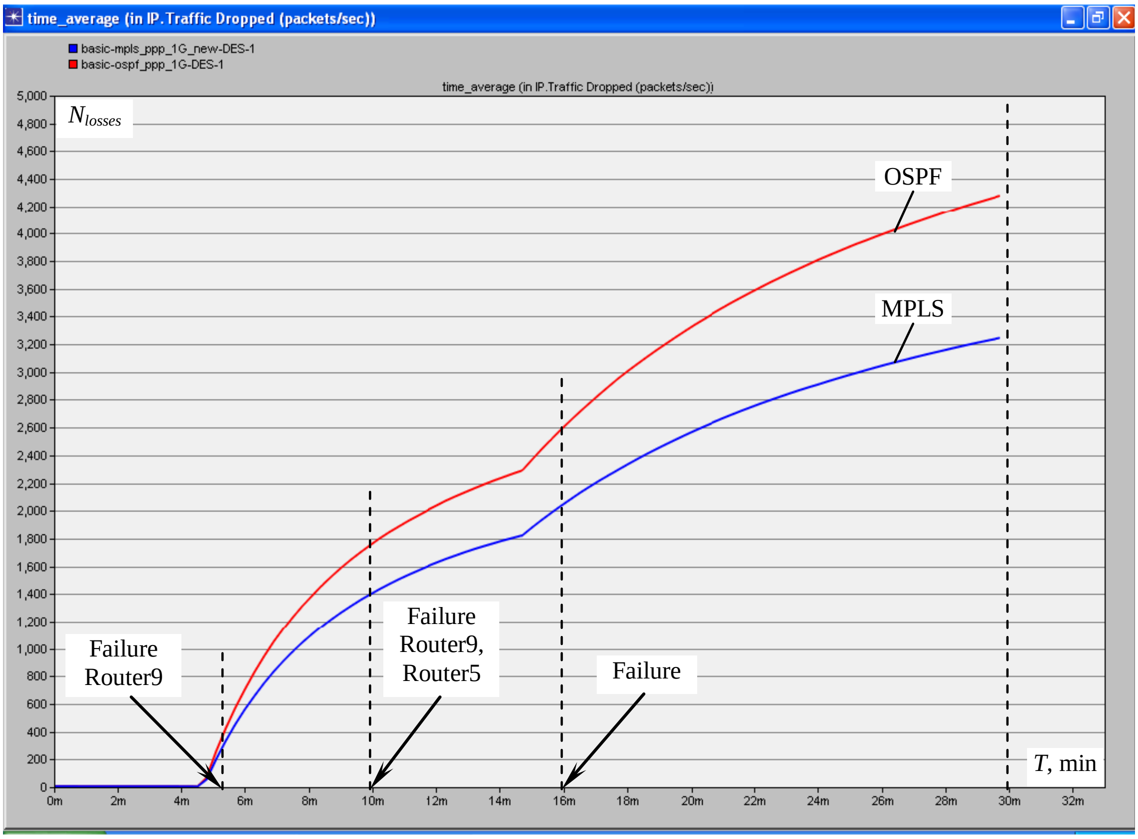

Fig. 7. Bandwidth r=1000 Mbps

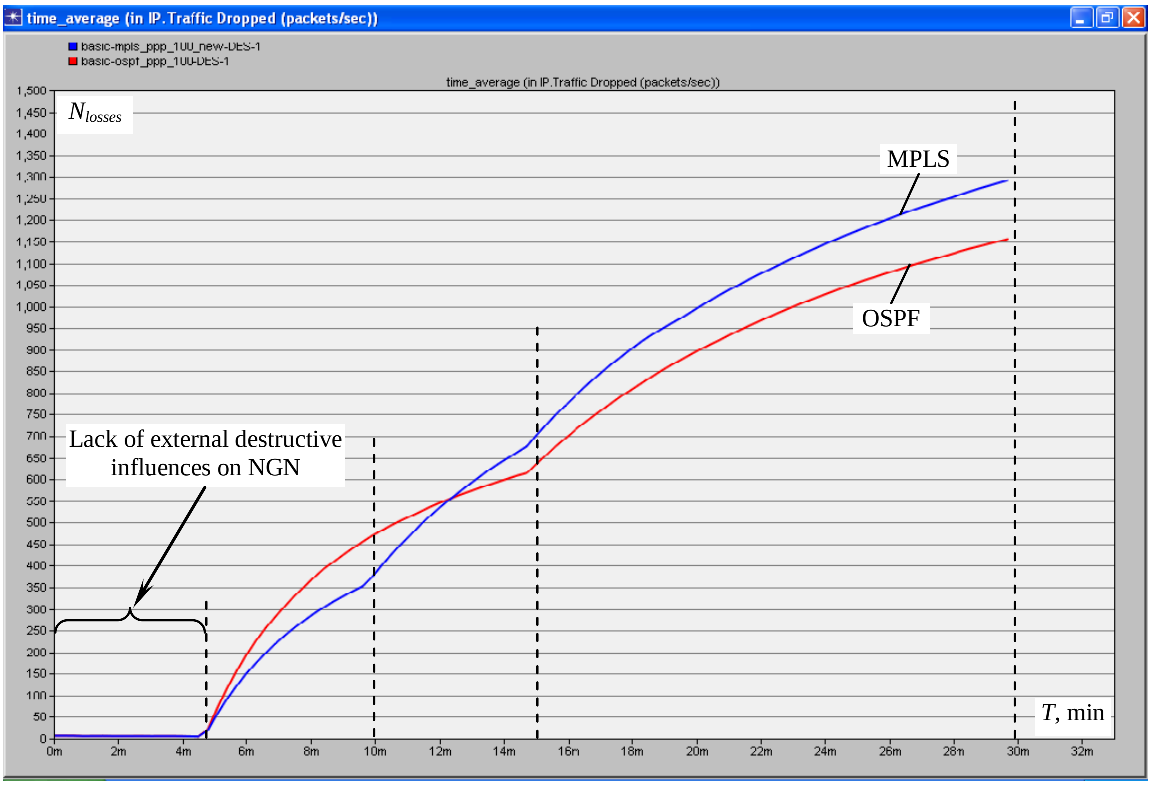

Fig. 8. Bandwidth r=100 Mbps

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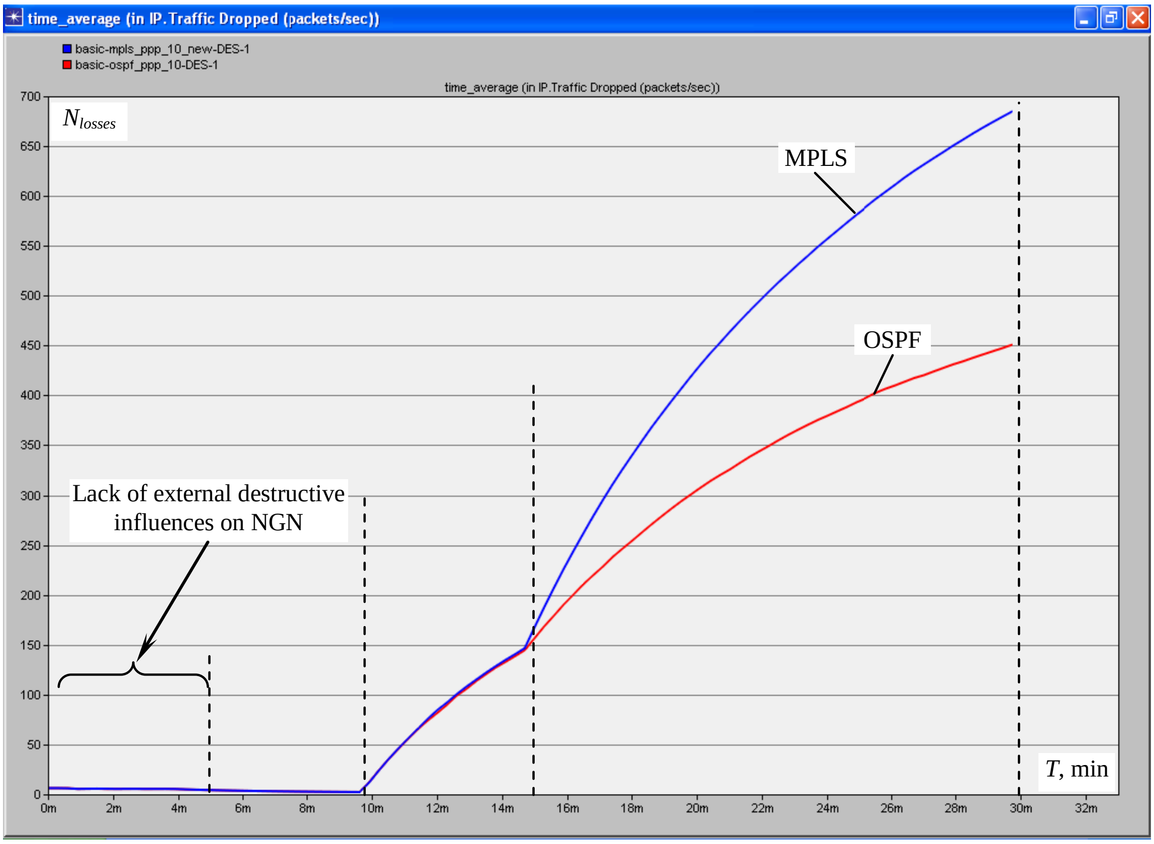

Fig. 9. Bandwidth r=10 Mbit/s

Let's build graphs of the main values of the obtained simulation results.

Let's introduce the following notation.

$R_0^{(i)}$; $i=\overline{1,4}$ – the total network resource of the analyzed MSS in one simulation test at the appropriate time interval, which is determined by:

$R_0^{(1)}=12\cdot r$ – simulation interval from 0 to 5 minutes;

$R_0^{(2)}=9\cdot r$ – simulation interval from 5 to 10 minutes;

$R_0^{(3)}=7\cdot r$ – simulation interval from 10 to 15 minutes;

$R_0^{(4)}=6\cdot r$ – simulation interval from 15 to 30 minutes;

Taking into account formula (4), we calculate the value of the variable x, which determines the degree of unavailability of the shared network resources of the analyzed network, according to the following rule:

$$x_i=\frac{R_0-R_0^{(i)}}{R_0};\ i=\overline{1,4}.$$

We will add the obtained results to Table 1. We omit the index i at x_i and normalize the values of Table 1:

$$\bar{N}=1-\frac{N_{losses}}{N^j_{losses(\max)}};\ j=\overline{1,3},$$

where $N^j_{losses(\max)}$; $j=\overline{1,3}$ maximum value N_{losses} in each of the three simulation tests: $N^1_{losses(\max)}$=4300; $N^2_{losses(\max)}$=1300; $N^3_{losses(\max)}$=750.

Table 1

Results of simulation

№ Simulation test	r Mbps	x_i	N_{losses}	
			MPLS	OSPF
1	1000	x_1=0	0	0
		x_2=0.25	1400	1800
		x_3=0.42	1800	2300
		x_4=0.5	3200	4300
2	100	x_1=0	0	0
		x_2=0.25	375	475
		x_3=0.42	675	600
		x_4=0.5	1300	1150
3	10	x_1=0	0	0
		x_2=0.25	0	0
		x_3=0.42	150	150
		x_4=0.5	700	450

Results

There the calculated results are presented in Table 2 and Fig. 10, 11, 12.The results of modeling and calculation allow us to assert that in conditions of external destructive influence $\Psi\_$ (t), in which approximately 30 % of the network resources of the NGN network fail, it is advisable to apply “Avalanche” methods of forming an information distribution plan.

Table 2

Normalized simulation results

r, Mbps	x	$\bar{N}$	
		MPLS	OSPF
1000	0	1	1
	0.25	0.67	0.58
	0.42	0.58	0.47
	0.5	0.26	0
100	0	1	1
	0.25	0.73	0.64
	0.42	0.48	0.54
	0.5	0	0.12
10	0	1	1
	0.25	1	1
	0.42	0.79	0.79
	0.5	0	0.36

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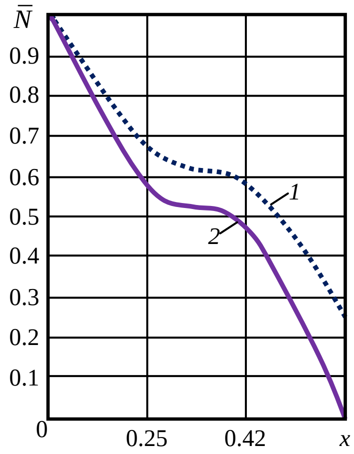

Fig. 10. Normalized simulation results at *r*=1000 Mbit/s: *1* – MPLS; *2* – OSPF

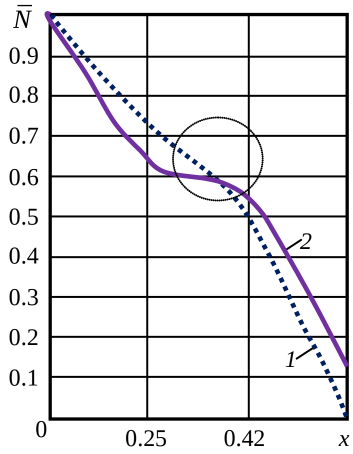

Fig. 11. Normalized simulation results at *r*=100 Mbit/s: *1* – MPLS; *2* – OSPF

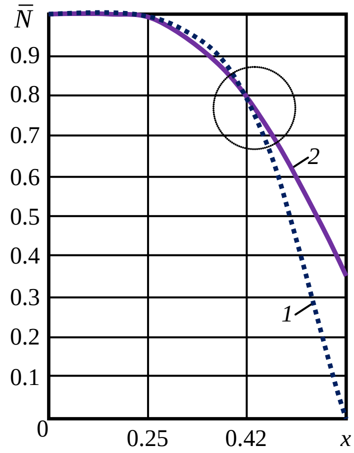

Fig. 12. Normalized simulation results at *r*=10 Mbit/s: *1* – MPLS; *2* – OSPF

Conclusions

Using various mathematical and simulation models, the research of routing methods in conditions of external destructive influences on NGN network elements was carried out. The results lead to the following conclusions.

1. Application of one or another routing method is relevant for a specific scale of external destructive impact.

2. In the absence of external destructive influence, the “Statistical sequential” routing methods provide a larger user network resource in comparison with “Avalanche” methods, therefore, increase the possibility of transferring a larger amount of user information.

3. In accordance with averaged data, in conditions of external destructive influences the analysis of the functioning of the NGN network showed that in the event of failure of more than 30 % of the elements of a multi-service communication network, the parallel routing methods can reduce the average probability of refusal of user requests for service by up to 20 %. This result is confirmed on various structures of multiservice communication networks and with using various mathematical and simulation models.

4. If in conditions of external destructive influences is impossible to change the “Statistical sequential” routing methods to “Avalanche parallel”, then at the design stage of multiservice communication networks necessary to provide at least 30 % of the reserve of their network resources.

5. If at the design stage of multiservice communication networks provide for at least 30% of the reserve of network resources, then this will allow:

– increase the ability to transfer a larger amount of user information in conditions of external destructive influences on the elements of a multiservice communication network;

– to implement the protection of user information (confidentiality, availability and integrity) through parallel (multi-path) routing methods by using geographically distributed resources in multiservice communication networks (communication channels, cryptographic software and hardware systems, databases, and so on).

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