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DEVELOPMENT OF SOFTWARE-BASED ROUTER MODEL WITH ADAPTIVE SELECTION OF ALGORITHMS FOR QUEUES SERVICING

Об'єктом дослідження є процеси управління ресурсами черг у мережевих пристроях телекомунікаційних мереж.

Одним з найбільш проблемних місць є неефективне управління чергами в мережевих пристроях, що призводить до погіршення якості обслуговування. В їх основі покладені переважно децентралізовані алгоритми управління ресурсами, що реалізуються на окремих вузлах мережі. Другим важливим недоліком є реалізація статичної ручної стратегії розподілу канальних ресурсів, процес управління яких не завжди адекватний профілю вхідного трафіку. Крім того, в процесі управління не координуються рішення, отримані на окремих мережевих вузлах в конкретні моменти часу.

Для усунення зазначених недоліків пропонується використати удосконалений метод обслуговування черг у мережевих пристроях, одне з ключових відмінностей пропонованого підходу полягає в тому, що ведеться контроль за часом перебування в чергах пакетів. І в умовах перевищення допустимого часу очікування пакет передається на чергу із нижчим пріоритетом та першочерговим обслуговуванням. Це дає можливість підвищити ефективність розподілу мережевих ресурсів за критерієм якості обслуговування.

Для реалізації даного підходу розроблено модель програмно-керованого маршрутизатора, яка на відміну від відомих, має модульну структуру та дає змогу в режимі реального часу відтворювати роботу телекомунікаційної мережі будь-якої конфігурації. Прототип маршрутизатора передбачається використати для адаптивного обслуговування навантаження магістрального рівня. У порівнянні з аналогічними системами, створеними на основі обладнання CISCO, заявлена модель забезпечує конкурентні переваги за гарантованою якістю обслуговування визначених потоків реального часу з одночасним зменшенням вартості та складності їх налаштування. За умов достатньої продуктивності апаратного забезпечення прототипу маршрутизатора, заявлена модель реалізується розробленим програмним забезпеченням. Це забезпечує виграш за оперативністю доставки відповідних потоків реального часу, а саме зниження затримок при їх опрацюванні сягає 40 %, зниження джитеру – 35 %.

Ключові слова: *мультисервісна мережа, якість обслуговування, розподіл ресурсів, модель програмно-керованого маршрутизатора.*

1. Introduction

Modern telecommunication networks (TCN) are oriented on giving users the wide spectrum of services, each of them is characterized by diverse requirements to network resources at transmitting. The continual growth of information stream results in modernization of telecommunication networks both in the part of equipment of nodes of a network and as to the continuous spread of throughputs of transmission channels for the increasing volume of streaming traffic and provision of the quality of its transmission. The increase of volumes of real time (voice, video) creates a series of problems and needs using new methods of resource optimization, management protocols and, correspondently, changing equipment.

Just that is why the study of the structure and peculiarities of traffic in one of its local segments may be the base for elaborating approaches and convergence of algorithms of automation, safety and effective functioning of new prototypes of programmed multiservice networks with the high level of access. Such mechanisms must be based on improved methods of resources distribution with the high scalabiity, speed of operation, flexibility, protection, high operation complexity and resource consumption. The one of methods of providing the servicing quality of different types of traffic is the use of the servicing system with priorities. At that the servicing system, based on fixed priorities, has an essential shortcoming. It is not able to provide the necessary level of QoS for low-priority streams.

That is why it is urgent to study provision of the real-time servicing quality by increasing the effectiveness of prioritization of servicing classes in the process of managing queues; and also elaborating new methods, algorithms and models of managing information streams in software-based nodes of a multiservice telecommunication network.

2. The object of research and its technological audit

The object of the research is the processes of managing resource queues in network devices of telecommunication networks.

At choosing the transport telecommunication technology and concrete network protocols, especially those that NGN is based on, it is important to take into account their possibilities as to maintenance and provision of the

Quality of Service, QoS. From the point of view of the especial urgency of end-to-end QoS, the first place in the architecture of managing the traffic is occupied by solutions of just the network level of the standard model of interaction of open systems. Among processes of the network level, the important role is played by tasks of managing queues that is why just the ineffective management of queues in network devices results in the uncontrolled growth of delays and level of loosing packets. As it was demonstrated by the conducted analysis, the modern network equipment realizes a lot of mechanisms of managing queues from the point of view of their formation and servicing (FIFO, PQ, CQ, WFQ, CB WFQ), and preventing overload (RED, WRED, ECN, SPD). Their main peculiarity and key shortcoming is the prevalence of hand settings at configuration of the equipment. It doesn't give a possibility to react operatively to the state of load of a router and network in whole and also to the variation of traffic characteristics.

3. The aim and objectives of research

The aim of the work is to develop the functional model of a software-based router for the adaptive selection of a queue servicing algorithm at appearing fluctuations of the user load.

The following objectives must be realized for attaining the set aim:

1. To develop the software-hardware platform of a multiservice corporative network with the adaptive configuration of resources.
2. To study the effectiveness of the offered solutions and to elaborate recommendations as to the practical use of the results, received in the work with modern and prospective telecommunication networks.

4. Research of existing solutions of the problem

Mainly all works, devoted to methods of optimization of using network resources, have mostly theoretical character, connected with creation of new managing algorithms that makes them hardly realized in a real network of an operator of connection. Another shortcoming of existing methods is the use of the complex approach to managing information streams without taking into account peculiarities of each type of traffic, generated by different network additions [1]. The increase of the quality of servicing information streams is also partially achieved by improving the hardware component – use of buffer sorting memory or sorting networks [2]. The program way of improving QoS indices is in using combinations of base disciplines of servicing queues at the network level [3] and improving the algorithm of managing information streams WRR (Weighted Round Robin) in nodes of telecommunication networks. At the same time the intensity of the real-time traffic may be high that results in their rejection. At that the essential share of memory of the input buffer may remain practically not involved. As a result – the ineffective use of the router's resource and low servicing quality [4].

The existent technical methods of managing the traffic in network devices (shaping and policing) show themselves low-effective at processing the traffic. Especially, for decreasing losses the policing algorithm needs the increase of the channel throughput, in which result its use decreases (utilization decreases), and shaping algorithm introduces delays. It may be unacceptable at processing real-time streams [5].

Work [6] offered the stochastic parametrized model of traffic, based on the earlier known stochastic curve. There was offered the method that allows to receive optimal (by coefficient of using a network) parameters of this model at known requirements to the servicing quality and properties of a multiservice network. The advantage of the developed model comparing with traditional ones is proved by the conducted calculations and modeling using the real multimedia traffic. Work [7] considers methods of evaluation of the servicing quality in multiservice networks of data transmission with the mixed type of traffic. There are analyzed the base factors that influence the servicing quality: delays and losses. These factors are considered in connection with different types of data streams: elastic and non-elastic. Research [8] offers the mechanism of prioritization of the traffic and its further processing in nodes of a network. The optimization criterion is the decrease of a packet delay in the device's buffer.

Several authors offer to solve the other problem by the dynamic change of a queue size individually for each class of traffic. Such method may help, but has a serious defect that is in the mechanism of memory allocation [9]. Allocation of memory queues may show itself long-term taking into account a number of queues and dynamics of the load intensity. Moreover, in the process of memory allocation other processes, for example, ones of packets will be forced to wait till the process of memory allocation finishes [10].

Thus, the results of the analysis allow to make a conclusion that it is necessary to introduce new algorithms of managing the traffic for the synchronous satisfaction of different requirements to QoS parameters of multiservice services in the connection system. These algorithms in their turn must take into account peculiarities of different types of services and provide the effective use of network resources. Flexible solutions, based on estimating and forecasting resources' state, volume of loads and provided by their correct balance, are needed in network devices.

5. Methods of research

At the moment, there exists a large number of tools for modeling of network processes that allow to test the proposed algorithms and assess the effectiveness of a particular solution. However, the major disadvantage of most of these tools is that they use statistical methods and analytical dependencies to calculate the state of the system at a certain point in time. Thus, the hour of the real work of the network can be modeled for dozens of seconds. This method shows low effectiveness during the study.

That is why in the work, a software model has been developed; it should not only describe the processes that take place, but also provide flexible mechanisms for research and management of the model in real time with the ability to generate real data streams and process the data using the principle of the hardware architecture of network devices.

The most typical element in the structure is the stream of packets. So, the «STREAM» object is highlighted first. It represents a multidimensional array, where in the column the first value is some unique key (time count for packets). Other values are a set of parameters that characterize

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a particular item (packet type, priority, recipient address, required minimum and desired bandwidth, acceptable QoS values, etc.). A number of methods has been implemented in this object: the Hurst parameter determination, the determination of the velocity of the stream, the determination of its statistical characteristics, etc.

For each case, the stream should be set according to its rules. For example, for multiservice technology services, there is a sequence of packets distributed according to a certain law described by real properties and their priority over a certain period of time. Therefore, it is necessary to create an object – «Generator of the initial stream». It must read the required stream from a given source or generate the stream itself according to the principles provided.

Similarly, there is a «working element» in all structures. This is a software-based network device (router, switch) that handles packets according to hardware architecture, and includes elements that make up the concept of resource constraints in the system: the bandwidth of a channel in an IP network. This object is very specific for each task. But it can be described globally through the following parameters: working resource (the capacity of the processor physical (virtualized) machine, maximum possible throughput), status (standard operating parameters), status change (new task, failure) load rate (processor, buffer resource, communication channel, etc.). Since we always have a group of «working elements» that work together, one needs to create an integrating object – «System», which describes the work of all the elements in complex. Its parameters will be: an array of «working elements», system status, status change in the system, general and average load rates. The last main object is «Distributor» – an object that, through «flows», interacts between objects «initial stream generator» and «system», while solving the problem of distribution of streams. Its parameters are a number of objects that solve various typical tasks. Let's list them below. The most important object-parameter is the object «Management», which solves the problems of distribution of the input (output)stream of packets in the «Distributor» between the output (input) streams. To evaluate the adequacy of the proposed scientific decisions, the following object-parameter «Optimization» has been allocated. In this case, a software-based router with a future perspective has the ability to accumulate information from past cases, initial data and refine the decisions made based on this volume of information. For this function, the object-parameter is «Memory». Possibilities of applying prognostic control bring the appearance of an object-parameter «Prediction». All these objects describe the general principles of interaction of the model with the tasks of forecasting, optimization, etc. Real methods of forecasting, optimization, etc. are being provided by inherited objects, which allows the user to easily change the method used without changing the structure of the entire model.

This software model of the network device was implemented based on the software of the dynamic object-oriented programming language C^{++}. The general view of the software model is presented below using the UML diagram – Fig. 1.

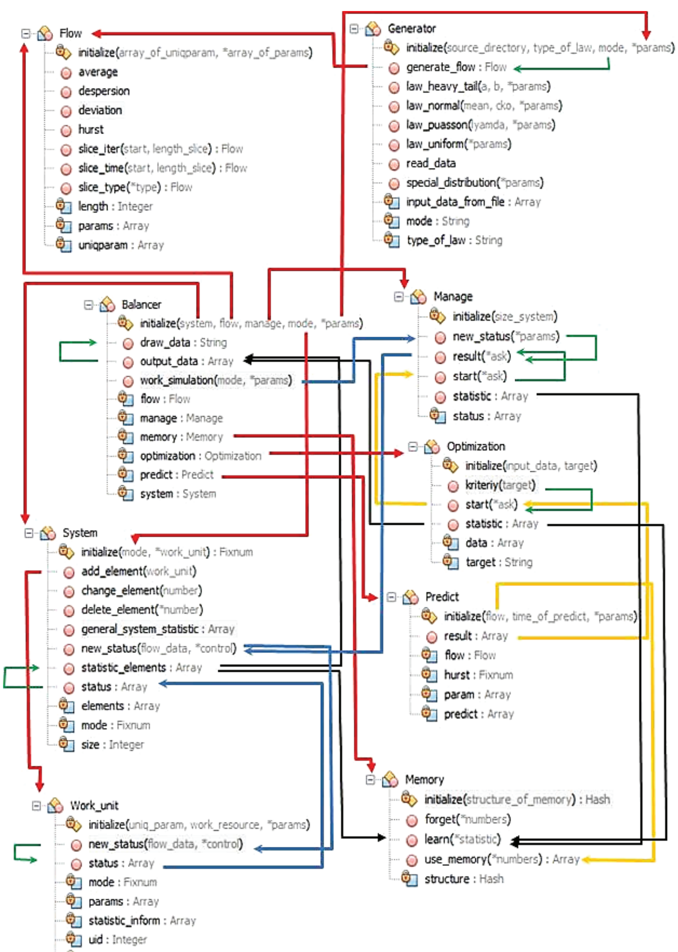

Fig. 1. UML diagram of the software model of the virtual test platform of the new generation network

It should be noted that the colors of the arrows do not carry any additional information, but only facilitate perception. To evaluate the effectiveness of the proposed solutions in the work, a virtual test platform was created using the QtCreator tool (version 5.2). The advantage of this tool is that programs based on it can be compiled to operate on any operating system such as Windows, Linux or Mac

The basis for developing virtualized network components is the network APIs that is provided to programmers in the form of sockets. A socket is an object that combines the IP address of the terminal device and the TCP port of the software process on the basis of the operating system of terminal device. The data is transmitted between the sockets in the streaming mode as they are received by the transmitter. In the developed platform, the socket corresponds to the physical port of the real network node. Thus, abstraction is provided from the channel level and all attention is focused on data processing at the network level. To completely abstract from the channel level, a virtual IP packet with which test platform nodes can work has been created. The network stack involved in the developed test platform is shown in Fig. 2.

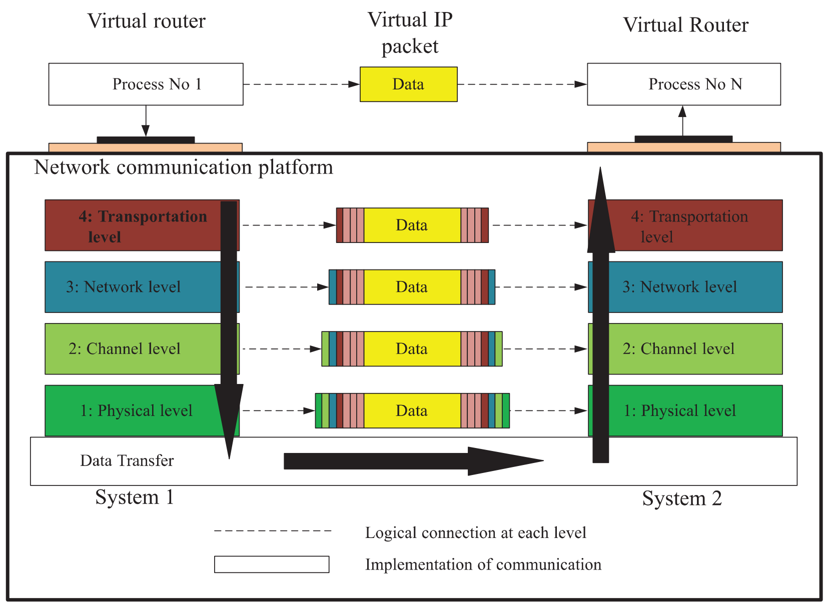

Fig. 3. The network stack of the developed test platform

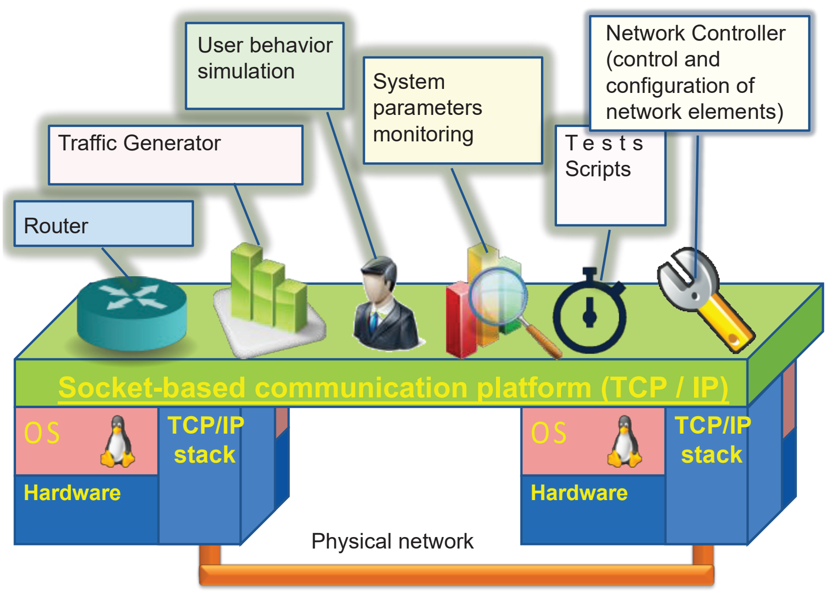

Fig. 2. The network stack of the developed test platform

Based on the developed test platform, the software model of the IP router (hereinafter referred to as the VNR-virtualized network router) and the network traffic generator are developed. The architecture of the developed VNR is presented in Fig. 4 and consists of objects that simulate specific functions of the router. Such processes as receiving and transmitting packets are modeled in parallel streams [11].

To read packets from a buffer, a separate stream has been used; it simulates routing functions. Such stream can implement any given queue processing algorithm. The stream reads the packet from the queue, analyzes its IP address and searches for it in the routing table. If a record in the routing table is found, the thread increases the value of the TTL field by one, and also changes the value of the ToS field, namely, the value of the delay recorded in this field, adds up to the delay received by the packet during its processing on the current router.

The central element in the VNR architecture is a buffer without lock, implemented on the basis of the Boost library version 1.53. For each class of traffic in the buffer, a separate queue with a given length is created. The packets arrive into the buffer through sockets. The socket corresponds to the port of the physical router. Each socket is processed in a separate stream that receives the information as it arrives and creates a virtual IP packet (Fig. 3).

When the packet is formed, the thread will double-check the CRC checksum and write the packet into the buffer queue corresponding to the class of traffic, after which the stream is preparing to receive a new packet. Based on this mechanism, one can simulate any type of packet or protocol.

After that, the packet is sent to the destination via the corresponding source port.

Output ports are managed by a separate thread, which implements the functions of the outgoing port manager. The user is able to configure the model real-time through a graphical interface, which allows you to dynamically change packet processing speed, routing rules, port parameters, and set routes through several serially connected network devices. The main window for setting VNR parameters is shown in Fig. 5.

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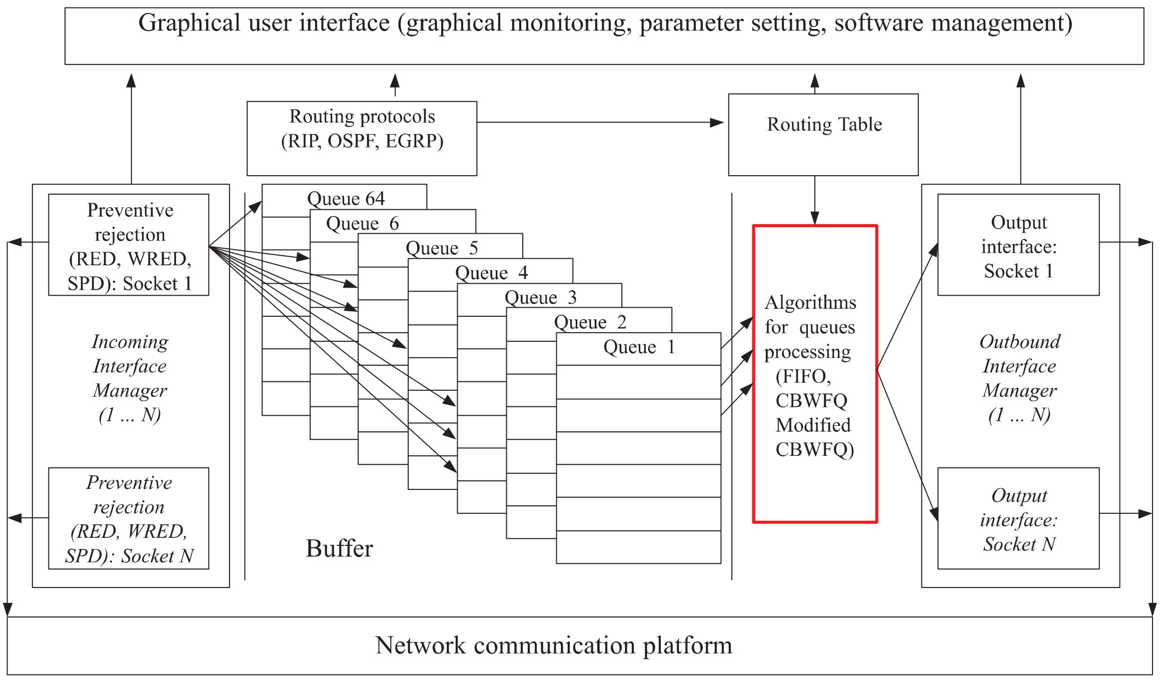

Fig. 4. Virtual Network Router Architecture (VNR)

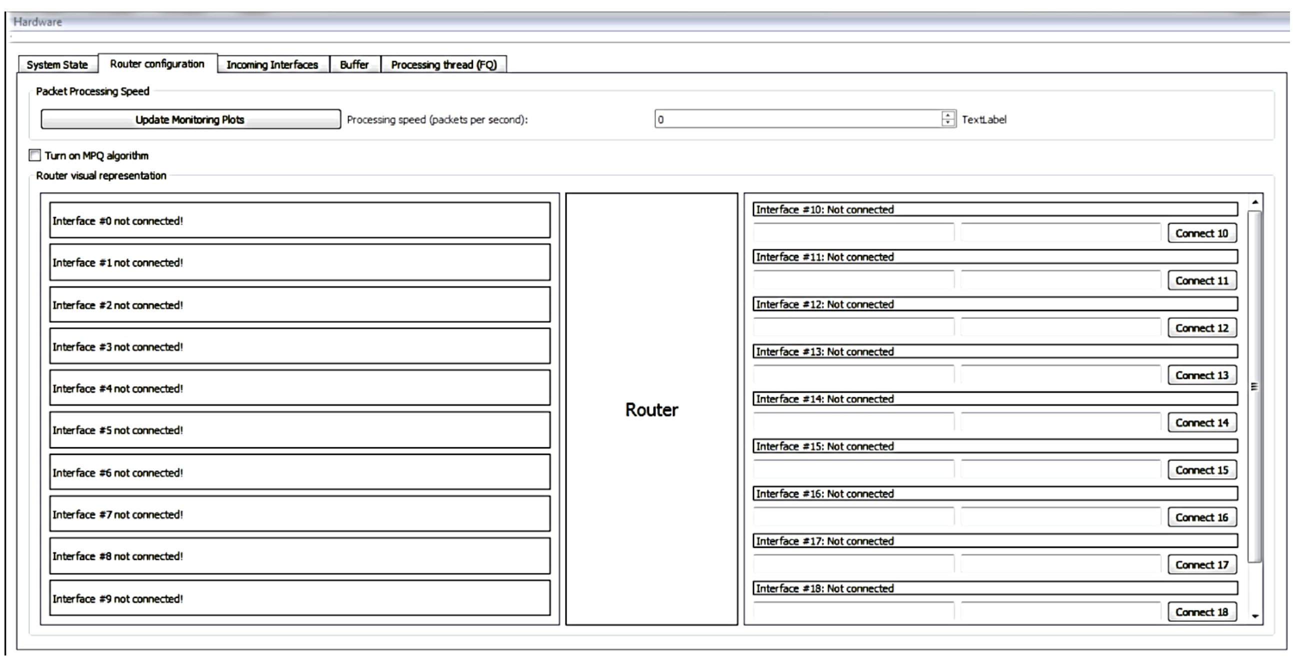

Fig. 5. Main window for setting VNR parameters

To conduct experiments in this work, a universal traffic generator has been created, based on which the developed test platform has been used. Using sockets, the generator connects to the switch and creates virtual IP packets of a given size and sends them to a virtual router. The generator lets you choose the traffic profile depending on the experiment. The first-generation type is generation based on random sequences. For this purpose, the Boost library contains a number of random numbers generators that operate on the basis of the Erlang distribution rules, Preto, and the ability to generate Brownian traffic distribution values. For the analysis of network traffic, the intrusion called TCPUMP is used. As a result of collection, this utility received data on streams and packets received on selected transport network ports of the National University «Lviv Polytechnic» (Fig. 6).

Traffic was collected for four hours and five minutes. As a result of the analysis of the data received, it was discovered that in the transport network there are basically six types of traffic that correspond to the specifications of ITU-T. Most of the traffic is real-time streaming of VoIP and IPTV.

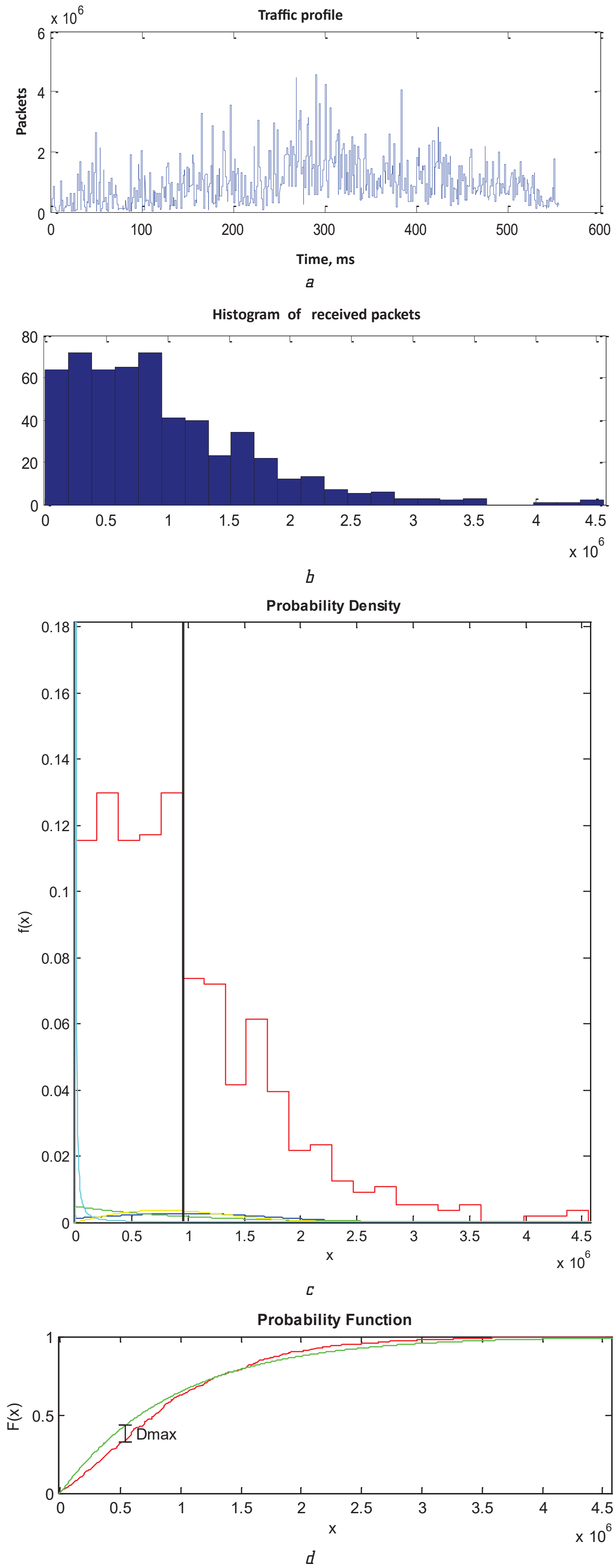

Fig. 6. Probabilistic-statistical analysis of outgoing traffic of the corporate infocommunication network: *a* – the profile of incoming traffic; *b* – Histogram of received packets; *c* – the density of traffic distribution; *d* – the function of distribution of traffic

6. Research results

In [12, 13], the modified method for managing queues M-CBWFQ (Modified – Class-Based Distributed Weighted Fair Queuing) was developed in multiservice nodes of functionally-oriented corporate network.

One of the key differences of the proposed solution is that the time spent in packet queues is monitored and, in case of exceeding the allowable waiting time, the packet is transferred to the queue with a lower priority and priority service, which enables to increase the efficiency of distribution of network resources by the criterion of quality service. To test the effectiveness of the proposed M-CBWFQ algorithm, the test platform has been configured in accordance with the diagram in Fig. 7, *a*.

The built-in test platform consists of four routers, that are interconnected, and from two generators of traffic. Each router and generator are installed on a separate physical machine, the parameters of which are as follows: the model of the processor – Intel E2200, 3 GB RAM.

All physical machines are connected via one local network, the maximum LAN speed of which is 100 Mbps. Each router is configured to handle an average of 100 packets per second from all inbound interfaces.

This means that about 10 milliseconds will be needed to handle one packet. This performance is chosen to visualize the real-time packet service process. Accordingly, traffic generators were configured. To evaluate the effectiveness of the M-CBWFQ algorithm, a route that runs through all created routers has been created. This route begins with the generator (VNG1) and passes through all VNRs. The last VNR sends all packets back to VNG1. VNG has a port that allows you to receive packets.

Thus, the VNG can mark the packet and, having received it back, calculate the total delay (RTT) of the packet along the route. VNG1 is designed to generate multiservice traffic.

The traffic profile is derived from monitoring the real transport network. The traffic profile is presented in Fig. 7, *b*. VNG1 is designed to generate multiservice traffic of Fig. 7, *c*.

The size of each packet in this thread is 1,400 bytes. The parameters for generating this stream are based on the averaging of the parameters of the IPTV streams received as a result of monitoring the local network using WireShark. The second generator is configured to deliberately introduce a random delay in all IPTV stream packets (Fig. 7, *d*), which allows you to visually assess the effect of the M-CBWFQ algorithm. It's worth noting that each virtual router allows you to dynamically enable and exclude the M-CBWFQ algorithm directly in the process of servicing the traffic. The simulation was done for 200 seconds.

The scheme for setting up the test platform to verify the effectiveness of the proposed M-CBWFQ algorithm is shown in Fig. 7, *e*.

Fig. 8, *a* shows the duration of the loop bypassing each packet that returned to the first generator.

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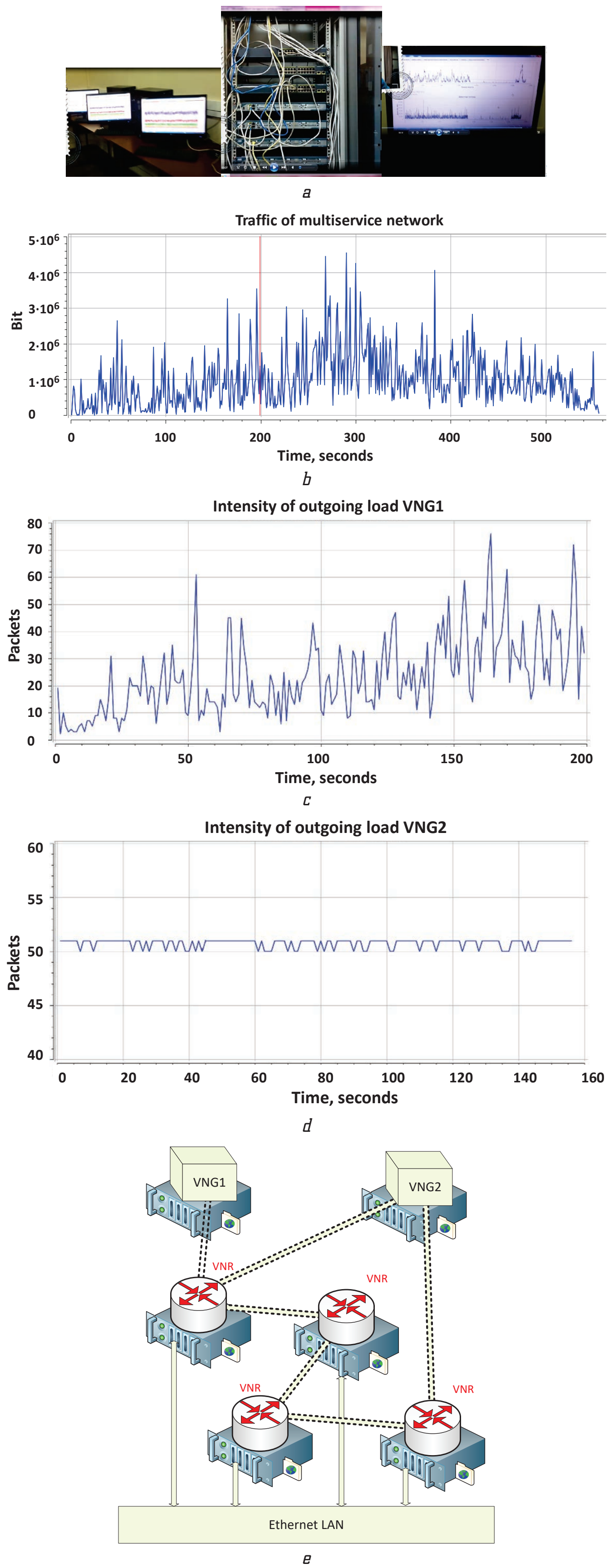

Fig. 7. Software-hardware complex of multiservice functionally oriented corporative network: *a* – test platform of the network; *b* – profile of input traffic; *c* – intensity of outgoing load on VNG1; *d* – intensity of outgoing load on VNG2; *e* – scheme of setting the test platform for checking the effectiveness of the offered algorithm M-CBWFQ

Fig. 8, *b* shows the duration of the loop bypassing by each packet of the generated IPTV stream on the second oscillator.

The experiment consisted of two stages.

At the first stage, the CBWFQ algorithm was used for all VNRs.

The second stage began 80 minutes after the first stage was completed, in which M-CBWFQ automatically switched on.

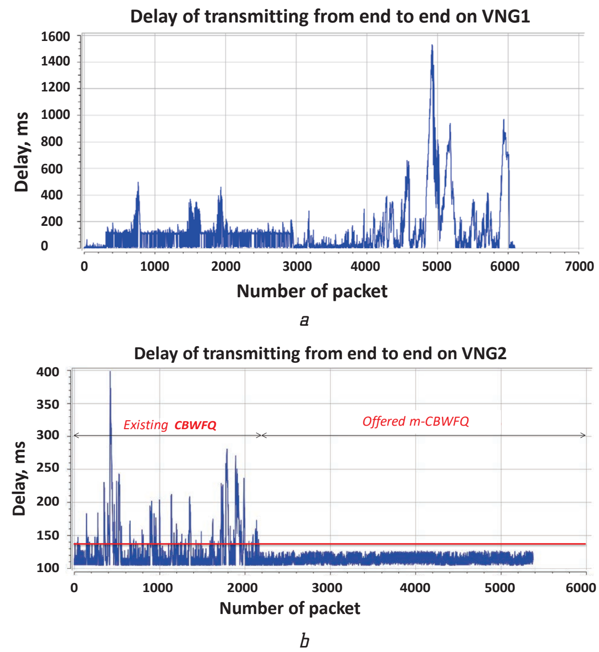

Fig. 8. Comparison of quality indices of servicing of the existent and offered methods of managing queues:
a – duration of loop bypassing by packets of aggregated stream at the first generator VNG1;
b – duration of loop bypassing by packets of IPTV stream at the second generator VNG2

In the first stage of the experiment, the average value of the loop traversal duration for aggregate packets consists of both delayed IPTV stream packets and delayed aggregate stream packets.

From the received stream diagrams for looping for the IPTV stream, it can be concluded that the delay in IPTV packets at some points increased up to 150–300 ms, which is 150 ms more than a critical delay.

In the second stage, when the M-CBWFQ algorithm is enabled, the average delay of IPTV packets dropped by 2 times and guaranteed a high-quality video stream perception with losses of up to 3 %. IPTV packets of a stream that exceeded the critical delay were serviced by the router in a high priority queue and continuously serviced this queue until the queue became empty.

After that, the router switched back to service the packets from low priority queues (Fig. 9).

The proposed solutions will allow for the dynamic adaptive adjustment of the quality management system, ensuring the guaranteed quality of all info-communication services in new generation networks based on software-based routers and switches.

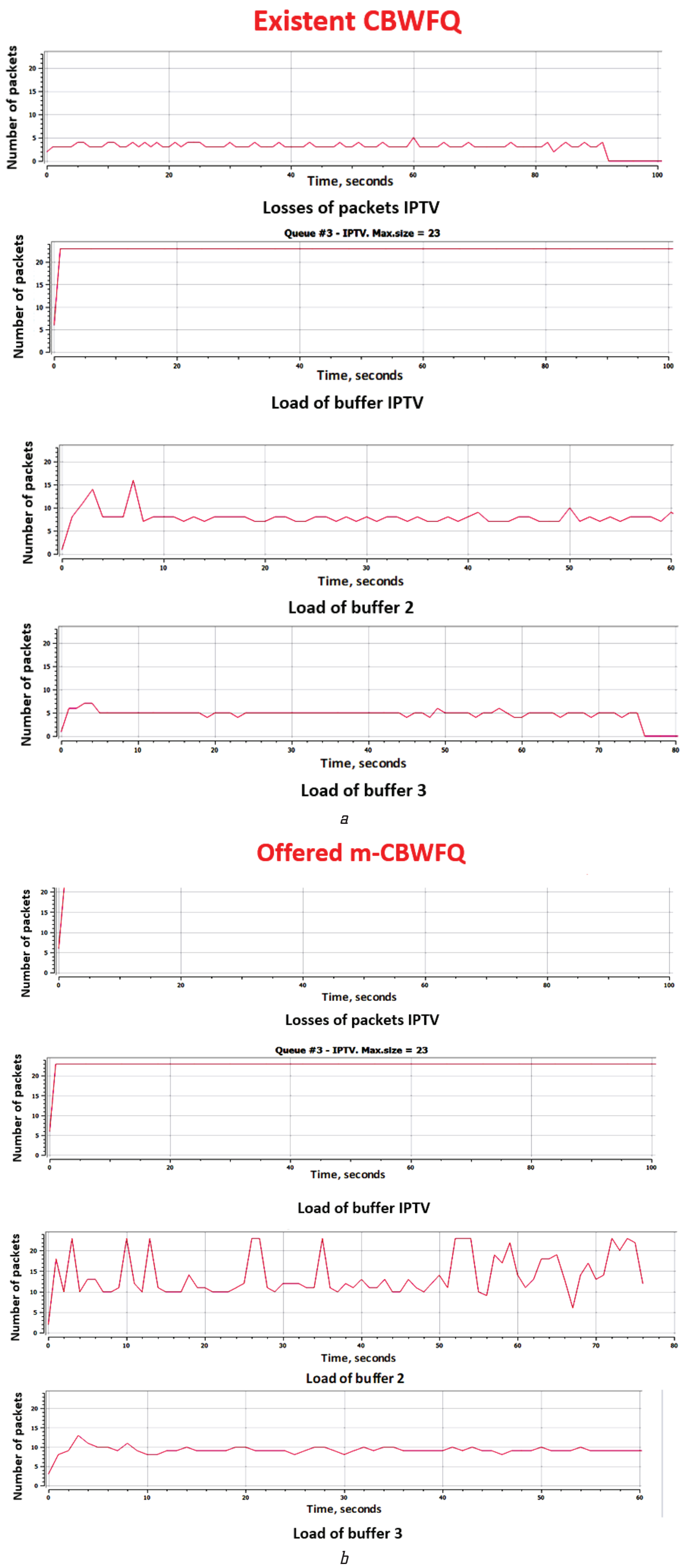

Fig. 9. Comparison of load of queues of different priority:
a – load of buffers and losses under conditions of using the existent method CBWFQ;
b – load of buffers and losses under conditions of using the offered method M-CBWFQ

7. SWOT analysis of research results

Strengths. Comparing with analogous systems, created based on CISCO equipment, the presented router model provides competitive advantages at the guaranteed quality of servicing real-time determined streams with the synchronous decrease of cost and complexity of setting network devices and transmitting data. Under conditions of the enough productivity of hardware of the router prototype, selected by applied reflections of determined use, the presented technology is realized by the developed software. It provides an advantage by the efficiency of delivering correspondent real-time streams, namely decrease of delays at their processing reaches 40 %, jitter decrease – 35 % (for example, at transmitting IPTV traffic). At that there is a possibility for realizing the highly effective encoding for protecting data of networks of special destination. The base indicators for the received estimations became the results of measuring the traffic on routers by CISCO company, series 2800. These technologies have especially important advantages under conditions of the dynamically changing and scaled structure of network systems, especially ones that need the essential efficiency of delivering real-time data.

Weaknesses. For attaining the high productivity of the router, it is necessary to set the developed software on highly productive servers. It results in increasing the production cost.

Opportunities. The presented model is realized with program emulation on server platforms with the necessary productivity level, and also in the perspective:

– The change of software of existent routers as products with potential possibilities as to their probabilistic improvement;
– Time characteristics, especially at servicing great volumes of loads.

The solution is prospective for networks that need using effective encoding methods that create additional delays in network nodes. The offered model provides conservation of the quality of given multimedia services at the expanse of increasing the adaptivity of the transport segment of a telecommunication network at the operative spread of covering territories by systems of wideband radio access. And also at their scaling in field and hardly accessible conditions using non-stationary of quazi-stationary nodes.

Threats. At introducing this product in production, an enterprise must purchase powerful servers that the developed software of the software-based router is set on.

The direct competitors are Cisco Systems solution (near 32 % of the market), D-link (near 17 % of the market). For today

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competitors have no possibility to reproduce technological results without an access to the methodical and algorithmic support of the presented technology without conducting correspondent studies, tests, modeling. Goods-substitutes are absent (conclusion by the resuts of the laboratory experimental tests). The main barrier for entrance to the market is the absence of connections with producers, namely technological line for producing a series of commutators and routers with the software that realizes the presented model.

8. Conclusions

1. The software-based router model with the set of modern mechanisms and algorithm of servicing information streams has been developed. Based on it, there has been widened the set of functional possibilities of the device, especially, mode of deployment of virtual nodes with a possibility of flexible management of structural parameters and possibility of automated renewal of work capacity. There has been also formed a dependence between structural-fuctional parameters and one of service quality.

For assessing the effectiveness of the offered solutions, there has been created the software-hardware platform of the functionally oriented corporative network using QtCreator (version 5.2). Based on the developed test platform, the developed software-based router model with the function of adaptive choice of an algorithm of servicing queues under conditions of occasional splash of the traffic, typical for multiservice networks of the new generation, has been realized. The adequacy of the developed models is proved based on the study of probabilistic properties of the traffic of a multiservice corporative network and comparison with work characteristics of real routers.

2. As a result of the conducted imitation and practical experiment it has been proved, that the use of the developed models and methods of giving infocommunication services in telecommunication networks results in improving the quality of servicing real-time streams, namely decreases a servicing delay in 2 times and probability of loosing packets by 3 %.

References

1. Dynamic weighted round robin in crosspoint queued switch / Divanovic S. et al. // 2013 21st Telecommunications Forum Telfor (TELFOR). Belgrade, 2013. P. 109–112. doi: http://doi.org/10.1109/telfor.2013.6716184
2. Yfoulis C. A., Xanthopoulos C. Dynamic Router Buffer Sizing: An SLA-Based QoS Evaluation // 2010 Third International Conference on Communication Theory, Reliability, and Quality of Service. Athens, 2010. P. 104–109. doi: http://doi.org/10.1109/ctrq.2010.25
3. Khan A. A., Mir and Najeeb-ud-din R. N. Buffer aware arbiter design to achieve improved QoS for NoC // TENCON 2017 – 2017 IEEE Region 10 Conference. Penang, 2017. P. 2494–2499. doi: http://doi.org/10.1109/tencon.2017.8228281
4. Research of on-board optical burst switching weight-weighted round robin assembly algorithm based on the QoS guarantee / Liao S. et al. // 15th International Conference on Optical Communications and Networks (ICOCN). Hangzhou, 2016. P. 1–3. doi: http://doi.org/10.1109/icocn.2016.7875732
5. Barreiros M., Lundqvist P. Policing and Shaping. QOS-Enabled Networks: Tools and Foundations. Vol. 1. Wiley Telecom, 2016. P. 101–116. doi: http://doi.org/10.1002/9781119109136.ch6
6. Deploying QoS-assured service function chains with stochastic prediction models on VNF latency / Lei T. H. et al. // 2017 IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN). Berlin, 2017. P. 1–6. doi: http://doi.org/10.1109/nfv-sdn.2017.8169837
7. Quality of service in networks with self-similar traffic / Hirchoren G. A. et al. // 2017 XVII Workshop on Information Processing and Control (RPIC). Mar del Plata, 2017. P. 1–5. doi: http://doi.org/10.23919/rpic.2017.8214328
8. Qianlin L., Hongwei D., Qing C. Performance evaluation of polling scheme with different priority service // 2016 8th IEEE International Conference on Communication Software and Networks (ICCSN). Beijing, 2016. P. 58–63. doi: http://doi.org/10.1109/iccsn.2016.7586599
9. Bisoy S. K., Pandey P. K., Pati B. Design of an active queue management technique based on neural networks for congestion control // 2017 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS). Bhubaneswar, 2017. P. 1–6. doi: http://doi.org/10.1109/ants.2017.8384104
10. Bahaweres R. B., Fauzi A., Alaydrus M. Comparative analysis of LLQ traffic scheduler to FIFO and CBWFQ on IP phone-based applications (VoIP) using Opnet (Riverbed) // 2015 1st International Conference on Wireless and Telematics (ICWT). Manado, 2015. P. 1–5. doi: http://doi.org/10.1109/icwt.2015.7449215
11. Investigation the modified priority queuing method based on virtualized network test bed / Beshley M. et al. // The Experience of Designing and Application of CAD Systems in Microelectronics. Lviv, 2015. P. 1–4. doi: http://doi.org/10.1109/cadsm.2015.7230779
12. Method for processing multiservice traffic in network node based on adaptive management of buffer resource / Romanchuk V. et al. // 2018 14th International Conference on Advanced Trends in Radioelecrtronics, Telecommunications and Computer Engineering (TCSET). Lviv-Slavske, 2018. P. 1118–1122. doi: http://doi.org/10.1109/tcset.2018.8336390
13. Investigation and Simulation of System for Data Flow Processing in Multiservice Nodes Using Virtualization Mechanisms / Klymash M. et al. // 2017 IEEE First Ukraine Conference on Electrical and Computer Engineering (UKRCON). Kyiv, 2017. P. 989–993. doi: http://doi.org/10.1109/ukrcon.2017.8100397

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