ANALYSIS OF THE EFFICIENCY INDICATORS OF MULTISERVICE TELECOMMUNICATION NETWORKS BASED ON PROMISING TECHNOLOGIES

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ABSTRACT

The effectiveness of the functioning multiservice telecommunication networks based on advanced technologies is analyzed. The quality-of-service QoS (Quality of Service) and the quality of perception QoE (Quality of Experience) traffic packet flows are studied. The indicators of throughput and probabilistic-temporal characteristics of multiservice telecommunication networks based on software and hardware systems using packet switching have been studied. A new approach to the construction of a mathematical model of network efficiency is proposed. Based on the model, analytical expressions are obtained that estimate the throughput of the software and hardware complexes of the communication network and the indicators of the guaranteed quality of service and the quality of traffic perception.

Keywords:

throughput, multiservice network, quality of Experience, failure probability, calculation algorithms, system load factor, and quality of service.

INTRODUCTION

The information-communication support of the digital economy and the formation of strategic plans "Digitalization Roadmap" require new methods and mechanisms for building multi-service telecommunication networks based on the architectural concept of the next NGN and future FN networks with increased bandwidth using advanced technologies. These primarily include information and computer technologies such as SDN (Software Defined Networking), NFV (Network Functions Virtualization), WDM & DWDM (Wavelength Division Multiplexing & Dense WDM), IMS (Internet Protocol Multimedia Subsystem), artificial intelligence, cloud computing, 4G mobile technologies LTE (Long Term Evolution) & UMTS (Universal Mobile Telecommunications System), IoT (Internet of Think) 5G NR (New Radio), complex energy systems and technologies for building distributed communication networks [1, 2, 3].

Taking into account the principles of NGN and the proposed target settings for the creation of future FN networks based on the recommendations of ITU-T, Y.1540, and Y.3001 [3, 4, 5, 6] and the promising technologies used above, open up new opportunities for providing a wide range of basic, additional and intelligent services, taking into account the multiple requirements of QoS (Quality of Service) and QoE (Quality of Experience). Therefore, the tasks of analyzing the performance indicators of multiservice telecommunication networks based on promising technologies using channel, information, switching, and network resources are the most relevant.

The effectiveness of multiservice telecommunication networks based on the NGN and FN architectural concept characterizes numerous complex indicators such as throughput, probabilistic and temporal characteristics networks, reliability, system cost, and QoS quality of service parameters and QoE quality of Experience [3, 4, 5].

In this paper, we consider the solution of the problem formulated above - research and analysis of performance indicators for multiservice telecommunications networks based on advanced technologies with the use and distribution of their resources.

GENERAL STATEMENT OF THE PROBLEM

To ensure acceptable QoS and QoE experience in the common existing NGN and FN architecture of multi-service public telecommunications networks, a new advanced technology and four targets Future FNs were used. According to the Recommendation ITU-T, Y.1540, E.800 and Y.3001 and ITU-R, M.2083-3 for building a multiservice telecommunications network infrastructure as basic promising technologies [3, 6, 7, 8].

The conducted research shows [4, 9] that at the channel, network and transport levels there is an analysis of packet flows created by load sources using software and hardware systems that allow determining the performance characteristics of multiservice telecommunication networks to ensure guaranteed QoS and QoE.

Based on a system-technical analysis of the process of servicing packet flows of useful and service traffic, a new approach to building a mathematical model of the effectiveness of a multi-service communication network is considered, which is a queuing system (QS) with a common buffer storage (BS) finite capacity N_{BS}, где $1 \le N_{BS} \le \infty$. The incoming streams of traffic packets are Poisson with intensity, respectively (Data, Audio, Video - D, A, V):

$$\lambda_i = W[\lambda_d, \lambda_a, \lambda_v],\ i = \overline{1,n}, \quad (1)$$

The admissible flow packets $i-th$ useful and service traffic arrives at the moment t when there is free hardware and software systems N_k, then it occupies it for the duration of the service. After the service time threshold expires, the traffic packet flows leave the QS with the probability

$P_{i.n}$, $i = \overline{1,n}$, are lost. The QS model is a BN with a limited capacity and each queue has a limited number of waiting places L_i, $i = \overline{1,n}$ in the buffer tank. While in the queue, traffic packet flows are served according to the FIFO rule. Thus, studies of the statistical properties of information flows of traffic packets have shown [--] that traffic in communication systems is a random process $r(t)$ at time t.

Let's assume $i_a(t), i_d(t), i_v(t) -$ the number of software and hardware systems engaged in servicing voice λ_a, non-voice λ_d and video λ_v traffic packets at the moment of transmission and waiting, respectively. Since packet flows in multiservice networks occupy a single channel and switching resources. Here is the minimum speed $V_{k.\min.} \ge 2048$ Kbps, then in the case

$$[i_a(t) + i_d(t) + i_v(t)] \le N_k \quad . (2)$$

The random process $r(t)$ describing the functioning QS is given by the components [3, 4, 7]:

$$r(t) = W[\ i_a(t), i_d(t), i_v(t)],\ (3)$$

continuously dependent on the time parameter $t \in (0, T]$, and takes values in a finite state space $S[r(t)]$

To fulfill the condition

$$N_k \geq b_i \cdot [i_a(t) + i_d(t) + i_v(t)],\ i = \overline{1, n}\ (4)$$

there is a stationary state for which a system of algebraic equations can be composed. In this case, the sets of possible states $S[r(t)]$ are described as follows:

$$S[r(t)] = \{(i_a, i_d, i_v):$$
$$i_a + i_d + i_v \leq N_k,\ 0 \leq i_a \leq N_k,\ 0 \leq i_d \leq N_k, 0 \leq i_v \leq N_k\},\ (5)$$

where N_k – the number of software and hardware systems in multiservice communication networks.

Expressions (1),…,(5) describe the probabilistic state of software and hardware systems in the QS system when servicing incoming streams of voic λ_a e, non-voice λ_d and video λ_v traffic packets, taking into account numerous QoS&QoE parameters and performance criteria for multiservice telecommunication networks, 4G and 5G.

ANALYSIS OF THE EFFICIENCY FUNCTIONING MULTISERVICE COMMUNICATION NETWORKS

It is known [3, 4, 10] that the complication of the nature and the growth volume information load in multiservice networks leads to the fact that the required quality of service QoS and QoE can be provided only by using effective methods to increase throughput and reliability, as well as efficient distribution channel and switching resources.

One of these methods is the method differentiated user service, the possibilities which are already included in the standards. For example, in wireless data transmission networks such as 4G LTE and 5G NR, users are divided into service classes, they are provided with different amounts of resources and various additional types of services. At the same time, the reduction requirements for the volume channel and switching resources for each service class is carried out in a differentiated way [9, 10]. This allows operators to optimize the use and distribution of resources in the network and reduce tariffs, which leads to an increase in the number of users, as a result, the efficiency of the multiservice network as a whole increases.

Wireless cellular networks of the fourth and fifth generations 4G and 5G represent the next major stage in the development of global multi-service telecommunication networks and multimedia services with the required QoS and QoE parameters. Ensuring effective support for QoS and QoE is one of the main difficulties in managing NGN and FN networks, including 4G and 5G cellular systems with limited resources in telecommunications and wireless networks.

Based on the study, [3, 10] found that 5G networks provide higher bandwidth compared to fourth-generation 4G networks. These capabilities enable greater availability of mobile broadband. What's more, 5G networks support mMTC mass machine communications and provide highly reliable, ultra-low latency communications. Thus, due to the transition from 4G networks to 5G, the speeds and volumes transmitted useful and service traffic have changed significantly.

The above proposed mathematical model is taken into account for the system for managing and distributing resources of a segment of a wireless multiservice broadband network serving users of service N_k classes. The system has an available resource volume V, which receives $i-$th stream traffic packets, each of them corresponds to different service classes of users.

We assume that all flows are stationary Poisson processes with rates $\lambda_a, \lambda_d, \lambda_v, \ldots, \lambda_i$, $i = \overline{1,n}$.

Call service time is exponential, according to the parameters. All V resources are available to the first thread, and only k_2 from them are available to service calls of the second thread, and so on. At the same time N_k, for all threads $N_k \le V$.

Based on the operation algorithms, the functioning of the network using software and hardware systems is described by the system Kolmogorov-Chapman differential equations. Using the system model and the state diagram [3, 4], we can write out systems of balance equations that describe the stationary statistics of the system [7]:

$$(\lambda + \mu) \cdot P_n = \lambda \cdot P_{n-1} + \mu \cdot P_{n+1}, \quad n \ge 1 \quad (6)$$

where $P_n -$ the probability that the system is in state n.

In this case, the rate of arrival packet streams in the system depends on the current state of the system - on the number of packets that have already arrived. The resulting Markov process is a process of birth and death. These conditions can be formulated using the process of reproduction and death in the following form [3, 4, 7, 10]:

$$\lambda = \sum_{i=1}^{n} \lambda_i, \quad i = \overline{1,n}; \quad (6)$$

$$b_i = \begin{cases} i \cdot \mu^{-1}, & npu \quad 0 \le i \le N_m \\ N_m \cdot \mu^{-1}, & npu \quad N_m \le i \le N_m + k \end{cases}, \quad (7)$$

where k – the number of places to wait, of course; μ – intensity of service of packet streams.

For the existence of a stationary queue distribution, we assume that the system load:

$$\rho(\lambda_i) = \frac{\lambda_i}{N_k \cdot b_i} \le 1, \quad i = \overline{1,n} \quad (8)$$

In (8) the value $\rho(\lambda_i)$ reflects the degree loading. This characterizes the number of resources allocated for each service class. At the same time, if at the time of receipt of the request of the i-th service class all $\rho(\lambda_i)$ resources are occupied, the request is rejected. The denial-of-service probability is q_i, and requests can return to the system with persistence H_i e and repetition rate μ_r.

Along with $\rho(\lambda_i)$ for each service class, the amount of currently occupied resources $f_i < \rho(\lambda_i)$ is introduced, upon reaching which the ban on the access of the requirements of the $i-$th flow to network resources is lifted.

As a result, the quality functional of the wireless cellular networks segment is set and each optimal value $\rho(\lambda_i)$ and f_i is determined. The first simplification consists in the Poisson replacement of the flow of repeated requests: it is assumed that the flow of total intensity arrives $\lambda_i + x_i$, where $x_i -$ the intensity of the additional flow due to repeated attempts, which must be sought as a solution to the equation

$$(\lambda_i + x_i) \cdot H_i \cdot P_i - x_i = 0, \; i = \overline{1,n} \quad (9)$$

in which the probability P_i of denial of service for the requirements of the $i-$th flow. Since the probability P_i itself depends on the additional intensity of the incoming flow of repeated requests, the intensity value must be sought by the method of successive approximations [9,10].

The second simplification is similar to [2, 3, 10] and consists in replacing the service time all requests by one due to the recalculation intensities of arrival requests in such a way that the average value of the resource occupied by the $i-th$ requirements of the th thread remains unchanged. This means that the new flux intensities $\Lambda_1, \Lambda_2, \Lambda_3$ will be and are found as follows:

$$\Lambda_i = (\lambda_i + x_i) \cdot R_i, \; i = \overline{1,n} \quad (10)$$

where $R_i -$ the average amount of the resource used by the requirements of the i-th thread, $i = \overline{1,n}$.

After such simplifications, the process states are given by one parameter, the amount $V_{OR} -$ of the resource used. At the same time, in order to take into account restrictions on access to network resources, it is necessary to distinguish between the states when the requirements of the corresponding traffic packet flow are served or not.

Taking into account the QS functioning model and the problem statement, the mathematical formulation of the proposed approach for selecting criteria that evaluate the characteristics of multiservice networks during the transmission of the first flow $i-th$ of traffic packets can be represented by the following group of indicators:

$$Q(\lambda_i) = W[C_{\max}(\lambda_i), A_{QoS}, E(L_i), R_i, B_{QoE}, P_i], \; i = \overline{1,n} \quad (11)$$

where $C_{\max}(\lambda_i) -$ the maximum value of the bandwidth of the network hardware and software systems during the transmission of the th flow $i-$th traffic packets; $P_i -$ network failure probability when servicing the th packet flow; $E(L_i) -$ average number of traffic packet flows in multiservice communication networks, $i = \overline{1,n}$.

Expressions (11) describe the proposed MM and performance indicators software and hardware complexes of multiservice telecommunication networks.

ANALYSIS NETWORK BANDWIDTH INDICATORS

Based on the efficiency model of the transmission network, the traffic flows can be calculated their throughput rates from the known probabilities of the system operation states.

Taking into account the algorithms of the network operation and the formulation of the problem, the output $\lambda_{i.out}$ and input streams $i-$th traffic packets $\lambda_{i.in}$, the throughput of the software and hardware complexes of the transmission network, the streams of traffic packets is determined by the expression:

$$C_{\max}(\lambda_i) = N_k \cdot \sum_{i=1}^{n} \lambda_{i.\hat{a}\hat{u}\tilde{o}} \quad , \ i = \overline{1,n} \quad (12)$$

Based on (12) is $C_{\max}(\lambda_i)$ expressed as follows:

$$C_{\max}(\lambda_i) = \sum_{i=1}^{n} (\lambda_{i.in} - \lambda_{i.out} - \lambda_{i.no}) \quad , \ i = \overline{1,n} \ , (13)$$

where $\lambda_{i.no} -$ intensity of unserved streams of i-th traffic packets.

Taking into account the normalization equation $P_1 + P_2 + ... + P_n = 1$, which replaces any one equation of system (6), which contributes to the solution of system (6).

Solving equation (6) using the normalization equation, we obtain the following probabilistic characteristics of a multiservice network link [3, 7]:

$$P_0 = [1 + \sum_{i=1}^{n} \frac{\lambda^i}{i!} \cdot \mu^{-i}]^{-1} \quad , \ i = \overline{1,n} \quad (14)$$

Taking into account (14), the $i-$th probabilities of the states of functioning of the network link for the transmission of heterogeneous traffic can be determined, which is expressed as follows:

$$P_i = \frac{\rho^i(\lambda)}{i!} \cdot [1 + \sum_{i=1}^{n} \frac{\lambda^i}{i!} \cdot \mu^{-i}]^{-1}, \quad i = 1, 2, \ldots, n. \quad (15)$$

Since the state n is the state of servicing the hardware and software systems of the maximum allowable number of network links P_n, it is the probability $P_i = P_{i.otk}$ that the next request will be denied service, i.e.

$$P_{omk}(\lambda_{no}, N_{бн}) = \frac{\rho^n}{n!} \cdot [1 + \sum_{i=1}^{n} \frac{\lambda^k}{k!} \cdot \mu^{-k}]^{-1}, \quad k = 1,2,\ldots,n. \quad (16)$$

Expression (16) determines the reliability characteristics of the hardware and software systems of multiservice communication networks at the maximum load factor of the system for transmitting streams of traffic packets.

The coefficient of effective use of network hardware and software systems using the average packet length $L_{i.n}$ is expressed as follows:

$$\rho_i = \frac{\lambda_i}{N_k \cdot C_{\max}(\lambda_i)} \cdot L_{i.n} < 1 \quad , \ i = \overline{1,n} \quad (17)$$

In addition, (12), (13) and (17) are algorithms for determining the main indicators of the guaranteed quality of service QoS and QoE of traffic packet flows.

Taking into account (13), the relative capacity of the network link $C_{\max}^{îò}(\lambda_i)$ is expressed by the formula

$$C_{\max}^{îò}(\lambda_i) = 1 - P_{otk}(\lambda_{no}, N_{áí}) \quad (18)$$

One of the most important characteristics of the QE network model is the absolute throughput $C_{\max}^{àb}(\lambda_i)$, the average number of traffic packet streams that can serve the system per unit time:

$$C_{\max}^{àb}(\lambda) = \lambda \cdot \tilde{N}_{\max}^{îò}(\lambda) = \lambda \cdot \left(1 - \frac{\rho^n}{n!} \cdot P_0\right) . \quad (19)$$

Let the intensity of service one traffic packet by the software and hardware complex μ . Then the average number of traffic packets served by one subscriber and network terminals will be

$$E[L_i] = \mu^{-1} \cdot C_{\max}^{àá}(\lambda_i) . \quad (20)$$

An important characteristic of the network link model consisting of terminals N_k is the average number of occupied hardware and software systems. Taking into account the above probabilistic characteristics of the network, the transmission streams traffic packets, the average number occupied hardware and software systems is determined as follows:

$$E[N_k] = \sum_{i=0}^{n} n \cdot P_i = \frac{\lambda}{\mu} \cdot (1 - P_i) \quad (21)$$

Thus, formulas (3) , …, (21) obtained based on the network efficiency model are calculation algorithms that determine the main indicators system efficiency and QoS and QoE parameters of traffic packet flows.

CONCLUSIONS

As a result of the study of software and hardware complexes of a multiservice telecommunication network, a model is proposed that describes the efficiency of the system. The analysis showed that the model is the basis for evaluating the effectiveness of network hardware and software systems, QoS and QoE, which allows you to determine the main indicators of the throughput multiservice traffic networks.

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