Study of Multi-Service Networks and Communication Systems Using Distributed Network Technology in Mountain Areas

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Abstract. It should be noted that the development of the digital economy directly depends on the introduction of advanced technologies: nanotechnology, biotechnology, complex energy systems technologies, quantum technologies, etc. At the same time, it is difficult to imagine the further development of corporate multiservice networks and communication systems without the widespread introduction of innovative technologies in a single information telecommunication infrastructure. The interaction of corporate multiservice networks and innovative technologies allows you to create a virtual transport network, with the help of which you manage transmitted useful and service packages and provide services. The FN concept involves the introduction of virtualization technologies, artificial intelligence methods and tools on a corporate network. The article analyzes the characteristics of corporate multiservice networks and communication systems using the technology of building distributed communication networks. The characteristics of corporate multiservice networks and communication systems using the technology of building distributed communication networks are analyzed and investigated, and a mathematical model of quality of service is proposed taking into account the management of information and network resources. It was found that the integrated performance indicators of multiservice corporate networks are largely determined by the reliability, information security and quality of service of IP / MPLS switching nodes and the IMS-Internet Protocol Multimedia Subsystem multimedia communication system using the signaling system and protocols for providing multimedia services and establishing session sessions. Thus, the results of QoS & QoE quality of service research and an analysis of numerical calculations of the probability and time characteristics of corporate multiservice networks based on the architectural concept of NGN and FN using the concept of SDN, NFV and IMS, requires the study of complex performance indicators of multiservice enterprise networks.

1 Introduction

One of the important areas of development of a unified info communication infrastructure based on digital information and communication technologies is the creation of highly efficient corporate multiservice networks and communication systems using the architectural concept of NGN-Next Generation Network and FN-Future Networks with increased productivity. The NGN concept is the third concept of network digitalization based on the recommendation of the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) of the Y.2000 series using the Softswitch platform and IMS (Internet Protocol Multimedia Subsystem), which ensures the convergence processes of fixed networks with circuit switching and packet switching, as well as mobile networks, in order to provide subscribers with a single set of unified communication services [1 - 4]. The Future Networks (FN) concept is the fourth concept of digitalization of communication networks - Future Networks based on the ITU-T Y.3000–3499 series recommendations, using the concepts of both SDN (Software Defined Networking), NFV (Network Functions Virtualization), and IMS.

It should be noted that the development of the digital economy directly depends on the introduction of advanced technologies: nanotechnology, biotechnology, complex energy systems technologies, quantum technologies, etc. At the same time, it is difficult to imagine the further development of corporate multiservice networks and communication systems without the widespread introduction of innovative technologies in a single information telecommunications infrastructure. At the same time, the following are important areas of ICT:

- technologies for building distributed communication networks;
- cloud computing and big data technologies;
- mobile technologies, Internet of Things technologies and geolocation technologies;
- optics technologies, methods and means of artificial intelligence

2 Problem statement

Among the above-mentioned information and communication technologies (ICT) for building highly efficient corporate multiservice networks based on the architectural concept of Next Generation Network (NGN) and FN, technologies for building distributed communication networks occupy a special place. This allows accelerating the launch of new multimedia services and applications, reducing the overall costs of their implementation. An analysis was conducted for the use of distributed communication network technologies in building corporate multiservice networks and communication systems [1, 3]. In [5, 6], the reliability and efficiency indicators of corporate multiservice networks were studied.

The article analyzes the characteristics of corporate multiservice networks and communication systems using the technology for building distributed communication networks such as SDN, NFV, and IMS, taking into account the QoS (Quality of Service) & QoE (Quality of Experience) parameters of useful and service traffic. Fig. 1 shows the functional elements and innovative technologies illustrating the technologies for building distributed corporate multiservice networks and communication systems based on the architectural concept of NGN and FN. From the structural and functional diagram, it is clear that for the purpose of building highly efficient corporate multiservice networks it is divided into two large areas.

1. The architectural concept of next-generation networks is based on the platform - the Softswitch software switch and IMS multimedia communication subsystems using the NGN-OKS-7, Sigtran, MAP, SCTP, MEGACO, INAP, H.323, BIGG, Diameter, SIP systems and protocols.

At the first stage of building corporate multiservice networks based on NGN, the tasks of voice transmission over a packet-switched network with acceptable quality are solved. To solve the problem of quality of real-time message transmission, the TCP/IP protocol stack is supplemented by the MPLS (Multiprotocol Label Switching) protocol stack [1-3]. The main provisions of the NGN concept are set out in the ITU-T Y.20xx series recommendations.

At the second stage of building corporate multiservice networks based on NGN, the tasks of convergence of fixed networks and cellular mobile networks are solved. The multimedia subsystem based on the IP protocol - IMS is used as the basic architecture for the convergence of these networks.

2. The architectural concept of Future Networks is based on the principle of "Many services - one network" and on four target settings with twelve properties. One of the main goals of building corporate multiservice networks based on FN is a significant expansion of the range of multimedia services provided.

These principles are implemented in "Smart all-pervasive networks, SUN" and cognitive networks. To build corporate multiservice networks based on FN, the following info communication technologies and information tools are used: SDN, NFV and IMS.

The interaction of these networks and innovative technologies allows creating a virtual transport network, with the help of which the management of transmitted useful and service packets and the provision of services are carried out. The FN concept involves the implementation of virtualization technology, methods and tools of artificial intelligence on the corporate network. Figures and tables, as originals of good quality and well contrasted, are to be in their final form, ready for reproduction, pasted in the appropriate place in the text. Try to ensure that the size of the text in your figures is approximately the same size as the main text (10 point). Try to ensure that lines are no thinner than 0.25 point.

3 Problem solution

Using in corporate multiservice networks one of the main principles of the FN concept is virtualization of network resources. Network resources are determined by the following dependency:

$$\eta_c(t,\lambda_i) = F[V_{i.k},\lambda_i,N_k,L_{i.n}]\ ,\quad i=\overline{1,k} \tag{1}$$

where $V_{i.k} -$ stream transfer rate $i-$ of useful and service traffic packets over virtual N_k communication channels; $L_{i.n} -$ length of transmitted streams $i-$ go packages; $N_k -$ total number of hardware and software systems for network function virtualization.
The latter indicators are closely related to the throughput of corporate multiservice networks and the operating modes of the system. The total number of hardware and software complexes for virtualization of network functions can be determined based on the required throughput $C_{треб.}(\lambda_i)$. The relationship between the throughput of corporate multiservice networks and the total number of hardware and software complexes for virtualization of network functions is as follows:

$$C_{треб.}(\lambda_i) = \frac{V_{i.k}}{L_{i.n}}\cdot(\rho_{i.вх}+\rho_{i.вых})\cdot N_k\ \ ,\ i=\overline{1,k}, \tag{2}$$

where $\rho_{i.вх}, \rho_{i.исх} -$ accordingly, the loading coefficient of virtual incoming and outgoing channels in the nodes of the corporate network during the transmission of flows of the i-th packet and $\rho_{i.вх} \le \rho_{i.исх}$, $i=\overline{1,k}$.

Expression (2) is valid under the following assumptions:

- the transmission rates of the i-th packet flows on all virtual communication channels are the same, $V_{i.k} = const$;
- the operating mode is duplex - direct and reverse communication channels are used to transmit useful and service traffic;
- the values of the coefficients are the same for the groups of incoming and outgoing communication channels, respectively: $\rho_{i.вх}$ u $\rho_{i.исх}$.

The efficiency of corporate multiservice networks and communication systems based on NGN and FN using the technology of building distributed communication networks is determined by the amount of load on outgoing communication channels using the concepts of SDN, NFV and IMS.

SDN technologies are the concept of software-defined networks (SDN). The SDN concept is currently gradually gaining popularity due to a fundamentally new approach to organizing corporate multiservice telecommunications and computer networks, since the networks of corporations and departments operating in a wide variety of economic segments solve basically the same information and telecommunications problems. The main idea of the SDN concept is to divide the network into three levels:

- data transmission level;
- control level;
- application level.

Thus, in the SDN network, the simplest network devices, SDN switches, will operate at the data transmission level, which can transmit packets according to preset or dynamically created rules. And at the control level, some software service controller will operate using the Openflow protocol, which implements complex logic for managing routing and switching using programs running at the application level. When receiving a packet that does not match any of the existing templates, the network device sends the packet header to the controller, and in response receives a rule according to which this packet and similar ones will be processed. The concept of NFV is the virtualization of the network function and as a technology, it is supposed to implement network management functions and service provision in the form of programs, not specialized equipment.

Virtualization is a new approach to building a multiservice network architecture, in which software services, applications, and functions operate on a separate physical hardware and software complex [2, 6-8]. In this case, network functions are transferred to physical servers. Then, specialized network equipment is replaced with standard hardware and software complexes on which virtual machines operate. At the same time, there is a need for uniform use of physical resources for the normal functioning of the corporate network and equal to:

$$\eta_{ф}(t,\lambda_i) = 0{,}5[\eta_c(t,\lambda_i) + \eta_u(t,\lambda_i)] \le 1, \quad i = \overline{1,k} \tag{3}$$

where $\eta_c(t,\lambda_i), \eta_u(t,\lambda_i) -$ coefficients of efficient use of network and information resources of the technology of building distributed communication networks at a given time and depending on the speed of receipt λ_i streams go packages, $i = \overline{1,k}$.

NFV technology can be used in routers, gateways, firewalls, hardware and software systems, but mainly high-performance servers. Its great advantage is that it reduces the telecom operator's dependence on highly specialized corporate network terminal devices.

It should be noted that in practice, the NFV concept defines the following:

- Migration of network functions from specialized hardware and software systems to standard commercially available COTS (Commercial off-the-shelf) server equipment based on processors with increased throughput;
- Flexible distribution of corporate network functions across several locations - data centers, network nodes, enterprise ICT systems and user premises in order to maximize operational efficiency and productivity;
- Creation of corporate multiservice networks focused on basic, additional and intelligent services, "Tpiple play services" and "Bandwidth".

Almost all functions of the operator's corporate network can be subject to NFV virtualization technology, including switching and routing, BRAS (Broadband Remote Access Server) functions, as well as firewalls, DPI (Deep Packet Inspection). NFV technology makes it possible to transfer these tasks to the upper layers of the network architecture. This cloud services layer supports NFV and other cloud services. In mobile 5G-IMT/2020 systems, NFV concepts can also be widely used to virtualize IMS subsystems, next-generation NGN EPC (Evolved Packet Core) core packet networks, RAN (Radio Access Network) subsystems, and multifunctional terminal equipment at the user's premises CPE (Customer Premises Equipment). The IMS platform is designed to manage sessions when providing any multimedia services to subscribers of fixed and mobile networks using IP/MPLS technology.

IMS is supposed to be a promising telecommunications technology for creating a single info communication space, which provides unified access to applications regardless of the access network technology, solves access security issues from terminal devices, authorization, session management and effectively manages subscriber profiles.

The IMS standard assumes the evolutionary development of a multiservice network, while providing new opportunities for optimizing the architecture of a corporate communications network. In particular, if there is a reliable transport network, one logical IMS core is sufficient for the entire network.

The most pressing issue in managing corporate multiservice communications networks is ensuring the quality of service for useful and service traffic of info communication services.

Using the values of these characteristics, it is possible to estimate the physical resources required to service a given volume of transmitted traffic with the required quality of service, or to estimate the maximum volume of traffic that can be transmitted using existing resources. The values of the characteristics under consideration depend significantly on the properties of self-similarity of useful and service traffic. A quantitative estimate of the degree of self-similarity of a traffic flow is the Hurst parameter, lying in the range $0.5 \le H < 1$. To solve the formulated problems, it is necessary to build a mathematical model (MM) for assessing quality of service indicators that takes into account the behavior of hardware and software complexes in a corporate network using SDN, NFV and IMS technologies. The mathematical formulation of the problem of the proposed MM for assessing the QoS&QoE characteristics of useful and service traffic of corporate multiservice networks and communication systems is described by the following target functions:

$$Q_{KO}(\lambda, H) = W\{Arg \max_{i} [U_{QoS}(\lambda_i, H_i), U_{QoE}(\lambda_i, H_i)] \quad , \quad i = \overline{1,k}\} \tag{4}$$

subject to the following restrictions

$$\pi_{nom.}(\lambda_i, H_i) \ge \pi_{nom.}(\lambda_i, H_i) \, , \, E[T_{i.свп}(\lambda_i, H_i)] \le E[T_{i.свв}(\lambda_i, H_i)] \, ,$$

$$C_{i.ap}(\lambda_i) \le C_{i.an.доп.}(\lambda_i) \, , \qquad i = \overline{1,k} \, , \tag{5}$$

where $\pi_{nom.}(\lambda_i, H_i)-$ probability of packet flow loss $i-$ useful and service traffic depending on λ_i and H_i;

$C_{i.ap}(\lambda_i)-$ cost of hardware and software systems of PKS networks, IMS platforms and systems NFV, $i=\overline{1,k}$;

$E[T_{i.cвn}(\lambda_i, H_i)]-$ average time of stay of streams of packets in the system when providing multimedia services depending on λ_i and H_i, $i=\overline{1,k}$; W – operator of joint transmission of useful and service traffic;

$\pi_{nom.дon.}(\lambda_i, H_i)$, $E[T_{i.cвn.дon.}(\lambda_i, H_i)]$ and $C_{i.ap}(\lambda_i)-$ accordingly, the permissible value of the probability of packet flow loss $i-$ useful and service traffic, average residence time of flows $i-$rabout packages in the system when providing multimedia services, the cost of hardware and software complexes of SCN networks, IMS platforms and NFV systems, $i=\overline{1,k}$.

Expressions (3), (4) and (5) define the essence of the considered mathematical model for assessing the QoS&QoE characteristics of useful and service traffic of corporate multiservice networks based on technologies for constructing distributed communication networks using the concepts of SDN, NFV and IMS when providing multimedia services. In addition, (3), (4) and (5) describe the features of hardware and software complexes of corporate multiservice networks based on the architectural concept of NGN and FN, which allow more accurately taking into account the telecommunication processes occurring in the studied single multi-operator infrastructure.

$$\pi_{nom}(\lambda_i, H_i) = 1 - \frac{1-\pi_0}{\lambda_i \cdot L_{i.n}} \cdot (V_{i.k} \cdot N_k) \cdot f(H_i) \qquad i=\overline{1,k} \tag{6}$$

To serve a simple packet flow with one switch and controller using OpenFlow, the network probability parameter is expressed as

$$\pi_0 = [1-\rho(\lambda,H)] \cdot [1-\rho^{N_{бн}}(\lambda,H) \cdot \rho(\lambda,H) \cdot f(H)]^{-1} \tag{7}$$

Taking into account (7) and the capacity of the buffer storage $N_{бн}$, the probability of packet loss for the simplest flow with parameters λ and H is determined by the following expression [3]

$$\pi_{nom}(\lambda,H) = \pi_0 \cdot \rho^{N_{бн}}(\lambda,H) \tag{8}$$

Based on the formula of J. Little, the average residence time of a flow of a self-similar traffic packet is determined by the expression:

$$E[T_{i.cвn}(\lambda_i,H_i)] = V_{i.k} \cdot \frac{\rho(\lambda_i,H_i)}{L_{i.n}} \cdot E[N_n(\lambda_i)] \cdot f(H_i) \cdot N_k, \quad i=\overline{1,k} \tag{9}$$

Formula (9) is an important indicator of the probability-time characteristics of corporate multiservice networks based on the NGN and FN architectural concept, and characterizes one of the many requirements of the QoS&QoE architecture of traffic packet flows. In addition to the above, an important characteristic of corporate multiservice networks based on the NGN and FN architectural concept is scalability. Thanks to it, a new hierarchical network structure has emerged, consisting of three levels called Cloud, Fog and Dew (cloud, fog, dew) Computing, for which there are not even established Russian-language terms yet. The hierarchical structure in corporate multiservice networks and Cloud-Fog-Dew is used to adapt to the following requirements:

- performance - fast response, fast processing and minimal delay;
- availability - redundancy of resources, minimal recovery time after failure of hardware and software complexes, acceptable degradation when problems arise;
- reliability - fault tolerance, data security and continuity of operation;
- manageability – ease of system scaling;
- cost – not only equipment and software, but also other costs for deployment and support of scalable systems.

Thus, the results of the study of the quality of service QoS&QoE and the analysis of numerical calculations of the indicators of the probabilistic-temporal characteristics of corporate multiservice networks based on the architectural concept of NGN and FN using the concept of SDN, NFV and IMS, require a study of complex indicators of the efficiency of the functioning of multiservice corporate networks.

4 Conclusions

The characteristics of corporate multiservice networks and communication systems using the technology of building distributed communication networks in mountainous areas are analyzed and investigated. A mathematical model of service quality is proposed taking into account the management of information and network resources.

Analytical expressions are obtained for assessing the probability of packet loss, the required bandwidth and the average packet arrival time, as well as the QoS&QoE parameters of useful and service traffic.

It is established that the complex indicators of the efficiency of multiservice corporate networks are largely determined by the reliability, information security and quality of service of IP/MPLS switching nodes and the IMS multimedia communication subsystem using the signaling system and protocols when providing multimedia services and establishing session sessions. Due to the complex landscapes of mountainous areas, this approach is of great importance.

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