METHODOLOGY FOR A COMPREHENSIVE ASSESSMENT OF THE TELECOMMUNICATION SERVICES QUALITY OF TRANSPORT NETWORKS USING SDN/NFV TECHNOLOGIES

DOI: 10.36724/2072-8735-2022-16-12-40-45

Igor G. Buzhin,
Moscow Technical University of Communications and Informatics, Moscow, Russia, **i.g.buzhin@mtuci.ru**

Veronika M. Antonova,
Moscow Technical University of Communications and Informatics, Moscow, Russia, **xarti@mail.ru**

Eldar A. Gaifutdinov,
Moscow Technical University of Communications and Informatics, Moscow, Russia,e.a.gaifutdinov@mtuci.ru

Yuriy B. Mironov,
Moscow Technical University of Communications and Informatics, Moscow, Russia, **i.b.mironov@mtuci.ru**

Manuscript received 08 November 2022;
Accepted 30 November 2022

Keywords: *software-defined networks, virtualization of network functions, service quality of telecommunication equipment*

Methodology for a comprehensive assessment of the quality of telecommunication services of transport networks using SDN/NFV technology has been developed. The current state and development trends of communication networks have shown that the potential for growth in productivity and bandwidth of networks based on traditional technologies is practically exhausted. These problems can be solved by the technology of software-defined networks and virtualization of network functions (hereinafter SDN/NFV). This methodology can be the basis for selecting the structure and number of SDN controllers and their optimal location in the communication network based on SDN/NFV, calculating reliability indicators, obtaining loss probabilities of streams and control messages as well as time delays for processing streams in SDN telecommunication equipment. Proposals on balancing the traffic load on SDN controllers of the communication network were also given.

Для цитирования:
Бужин И.Г., Антонова В.М., Гайфутдинов Э.А., Миронов Ю.Б. Методика комплексной оценки качества телекоммуникационных услуг транспортных сетей с применением технологий SDN/NFV // T-Comm: Телекоммуникации и транспорт. 2022. Том 16. №12. С. 40-45.

For citation:
Buzhin I.G., Antonova V.M., Gaifutdinov E.A., Mironov Yu.B. (2022) Methodology for a comprehensive assessment of the telecommunication services quality of transport networks using SDN/NFV technologies. *T-Comm*, vol. 16, no.12, pp. 40-45. (*in Russian*)

Introduction

The current state and development trends of communication networks have shown that the potential for growth in productivity and bandwidth of networks based on traditional technologies is practically exhausted. These problems can be solved by the technology of software-defined networks and virtualization of network functions (hereinafter SDN/NFV).

In accordance with [1], SDN is a set of methods that allow programmatically managing network resources (for example, switches and routers of a data transmission network) and controlling their use (loading), which simplifies solving the problem of ensuring the efficient use of the transport network bandwidth and its scalability, helps to reduce operating costs by centralizing and automating management functions. SDN implements an open interface for interaction between control and data transmission levels, automated network administration. The use of SDN technology provides an opportunity to relieve from the necessity of using many service protocols and fixes the only function of data transfer on the network equipment, which makes it possible to speed up routing and increase the convenience of configuring the network. The most important aspect of SDN is the presence of a logically centralized network management that provides a global view of the topology and state of the managed network at both the L2 and L3 levels.

To ensure the required level of telecommunication service quality in the SDN / NFV design process as well as to predict the probability of flow failures, the overflow of addressing tables in SDN switches, event logs on the SDN controller and data counters, it is necessary to comprehensively assess the quality of telecommunication services under the conditions of information impact.

Thus, the development of a methodology for a comprehensive assessment of the quality of telecommunication services of transport networks using SDN / NFV technology is required.

Architecture of software-defined networks

The SDN/ NFV technology is a set of methods that allow programmatically managing network resources and controlling their use (loading), which simplifies solving the problem of ensuring the efficient use of the communication network bandwidth and its scalability, helps to reduce operating costs by centralizing and automating management functions. There are 3 layers in SDN architecture (Fig. 1): network infrastructure layer, control layer and application layer. SDN provides for the presence of an SDN controller in the network, which provides applications with an abstract representation of network resources and provides orchestration (coordination) of the network resources management. With this approach, the controller has access to the global state of the network and decides to forward network traffic, while the hardware is only responsible for actual forwarding of information to their destinations in accordance with the controller's instructions (sets of packet processing rules).

Thus, the control function of the switches is transferred to a separate central device - SDN controller. This approach allows managing and monitoring the state of the network on a logically centralized controller. In addition, it becomes possible for the control layer to separate from the physical component by using a logical representation of the network as a whole. Interaction between the data transfer layer is carried out through a single unified open interface.

SDN leads the network architecture of transport networks towards the possibility of using NFV, which provides for the transfer of software network functions to cloud storage [4], while these functions are performed on servers (including virtual machines) in data centers.

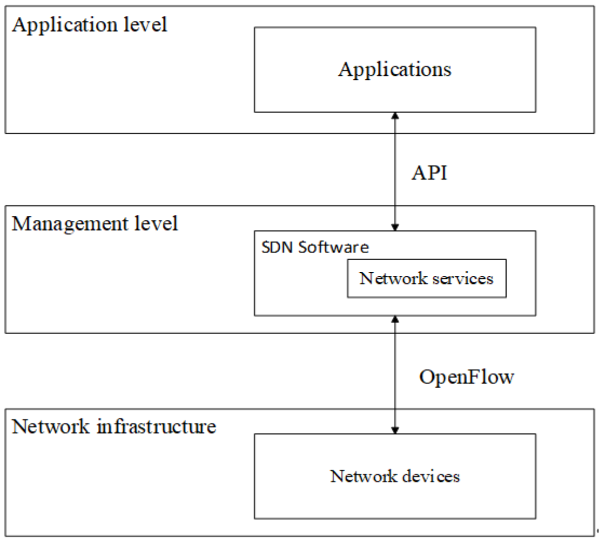

Fig. 1. SDN Architecture

In accordance with the NFV reference architecture [4], a complex of software and hardware for virtualization of network functions can be represented in a simplified form as consisting of the following basic elements (Fig. 2):

- Virtual Networking Functions;
- Network Function Virtualization Infrastructure;
- Management Software and Orchestration NFV.

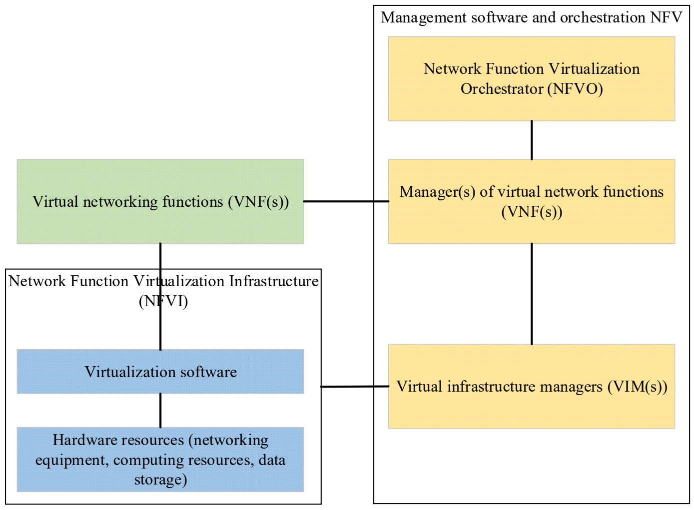

Fig. 2. Simplified Network Function Virtualization Reference Architecture

VNF(s) functions replace the functions that are performed by communication hardware in conventional communication networks that do not use virtualization.

The NFVI infrastructure includes hardware and software resources that provide an abstract representation of the hardware with virtualized functions.

Management Software and Orchestration NFV includes Network Function Virtualization Orchestrator (NFVO), Manager(s) of Virtual Network Function (VNF(s)), Virtual Infrastructure Manager(s) (VIM(s)). NFVO Orchestrator provides coordinated virtual infrastructure operation. The VNF manager provides lifecycle management of virtual networking function. One manager can manage a variety of virtual networking functions. The VIM manager provides management and control functions that allow the interaction between VNF functions and related hardware resources, including identifying hardware and software such as hypervisors, selecting virtual machines, reallocating resources between virtual machines, collecting information to provide fault and load monitoring capacities, etc.

Taking into account the listed features of the functioning of SDN/NFV technologies, the following priority research areas can be identified. The development of a methodology for planning transport networks based on SDN / NFV technologies, the development of a methodology for calculating the reliability and a redundancy plan for transport networks based on SDN/NFV taking into account various types of failure (errors of service personnel, equipment failure, software errors, etc.).

Methodology for a comprehensive assessment of the quality of telecommunication services of communication networks based on SDN/NFV technology

As mentioned above, when building a communication network using SDN / NFV technologies, it is necessary to assess the quality of service indicators and the quality indicators of the network functioning. This must be done in order to select telecommunication network equipment to achieve the required level of the quality of telecommunication services. This purpose requires developing a methodology for a comprehensive assessment of the quality of telecommunications services in a communication network using the SDN/NFV technology.

The methodology for a comprehensive assessment of the quality of telecommunications services of a communication network using the SDN / NFV technology can be divided into the following stages:

Stage 1. Calculation of the required number of SDN controllers in the communication network to ensure the required quality of service and fault-tolerant operation.

Stage 2. Finding the matrix of the shortest distances of the communication network using the SDN / NFV technology.

Stage 3. Finding the SDN node numbers in which the controllers will be located, or a message about the impossibility of placing controllers with input data due to the failure to perform fault tolerance.

Stage 4. Determination of the primary and backup controller for each of the SDN switches.

Stage 5. Determination of the SDN switch groups with the total load not exceeding the maximum performance of the SDN controllers.

Stage 6. Distribution of the received SDN switch groups among SDN controllers so that to bring the system into a state corresponding to the distribution into groups; it would take as few actions as possible.

Stage 7. Calculation of SDN / NFV segment availability factors.

Stage 8. Calculation of service quality indicators for switches and controllers of the communication network using the SDN / NFV technology.

Stage 9. Checking the received placement of controllers on communication nodes, switch groups, quality of service indicators and SDN segment availability factors in accordance with the requirements for them.

The input data of the calculation method is a graph $G = (S, E)$ that describes communication networks using the SDN / NFV technology.

Here is $|S|$ – the number of SDN switches in the network (numbered from 0 to $|S| - 1$), i.e. $S = \{S_i,\ i = 0, \ldots, |S| - 1\}$ is a set of SDN network switches (note that the switch is a network node in which, in addition to the SDN switch, an SDN controller can be located), $E = \{E_{i,j}: E_{i,j} = (S_i, S_j)\}$ is a set of connections between nodes (SDN switches) of the network, $|E|$–a is the number of connections between the nodes of the network. Also the input data is $L = \{l_{i,j},\ i, j = 0, \ldots, |S| - 1\}$ that is a set of lengths of the shortest paths in the graph between the nodes i and j. The length of a path is defined as the sum of the connections between the nodes of the network included in this path. Also it is known that $C = \{c_i,\ i = 0, \ldots, |C| - 1\}$ is a set of SDN controllers, $|C|$ is the number of SDN controllers in the network, C_{ref} is the number of SDN controllers the failure of which will not prevent the communication network from being stable, $D_i = \{S_i,\ S_i \in S\}$ is a set of SDN switches included in the domain of the i the SDN controller, S_{max} is the maximum possible number of SDN switches in a controller segment, T_{max} is the maximum possible delay between the controller and the SDN switch of the same domain, parameter λ_2 of the input stream of information coming from external networks to SDN switches (the average number of incoming packets per second from external networks), a number of n threading processor cores, the length M input data buffer, μ –flow rate, a number L of switching tables (addressing), σ stream processing speed by writing the switching (addressing) table, number of c message processor cores, message buffer length r, message processing speed γ.

Calculation method:

1. Determine the required number of SDN controllers in the communication network to ensure fault-tolerant operation according to the formula:

$$|C| \geq \left\lceil \frac{|S|}{S_{max}} \right\rceil + C_{ref}, \qquad (1)$$

where $|S|$ is the number of switches in the communication network using the SDN / NFV technology (network nodes), S_{max} is the maximum possible number of switches that can be controlled by one controller, C_{ref} is the number of SDN controllers, the failure of which should not prevent the communication network from being stable. In case of default of this condition, it is necessary to add additional controllers.

2. Finding the matrix R of the shortest paths. The search for the matrix of shortest paths is carried out using the Bellman-Ford algorithm. The input of this algorithm is the initial adjacency matrix (describes all the interconnections of the nodes of this network), at the output of the algorithm we obtain the shortest distances from each vertex of the graph (a network node) to any other.

3. Based on the calculated matrix R of shortest paths, with a known number $|C|$ of controllers in the network, the maximum possible delay T_{max} between the controller and the SDN switch of the same domain, the unlimited maximum possible number S_{max} of SDN switches in the controller segment, determine the optimal placement of controllers on the SDN network nodes. Additional data are the number Imp of attempts to accommodate, numbers N_{cur} of nodes in which the controllers are located at this stage; the

numbers N_{opti} of network nodes in which the controllers are located in the optimal variant; the number S_{pe3} of the SDN switch, which has the highest delay T to the second closest controller among all SDN switches at this stage; $NN_{cur} = [NN_{cur}[1] \geq NN_{cur}[2] \geq \cdots \geq NN_{cur}[|S|]$ being a set of ordered numbers of SDN switches, which have the greatest distances to the nearest controllers; NN_{opti} that is similar to a set of NN_{cur}, but with optimal placement N_{opti}.; C_i that is the closest controller to the switch $NN_{cur}[i]$. The following are the stages of the algorithm for calculating the placement of SDN controllers on the network nodes:

3.1. SDN controllers are placed on the network nodes in a random way. Then N_{cur} and $Imp = 1$ are calculated. It is necessary to find the number of the SDN switch which has the highest delay T to the second closest SDN controller among all switches.

3.2. If $T \leq T_{max}$, then the current placement is fixed as optimal $N_{opti} = N_{cur}$, and NN_{cur} is calculated. If $T \geq T_{max}$, then the fault tolerance condition is violated.

3.3. Compare NN_{cur} and NN_{opti}. If $NN_{opti}[i] \geq NN_{cur}[i]$, for $\forall\, i = 0, \ldots, |S|$, then the current placement is fixed as optimal $N_{opti} = N_{cur}$. Otherwise, based on the matrix of the shortest paths, the controllers C_i are moved as follows: $N_{opti}[i] < NN_{cur}[i]$: one node closer to $NN_{cur}[i]$. Then point 3.2 is carried out. The value Imp is increased by 1.

In this algorithm, the condition $T \leq T_{max}$ is necessary, since it provides fault tolerance. This algorithm can be completed, since in the first part of the algorithm (points 3.1 and 3.2) a possible solution is sought for no more than $|S|$ iterations (equal to the number of nodes in a given network), and in the second part (point 3.3) the algorithm works no more than $|S|$. The output data of the algorithm will be the numbers of the network nodes in which the controllers will be located, or a message about the impossibility of placing controllers with input data due to the failure to perform fault tolerance.

4. Determine the main and backup controllers for each of the $|S|$ switches of the communication network using the SDN / NFV technology. The input data of the algorithm will be a set of $S = \{S_i,\ i = 0, \ldots, |S| - 1\}$ communication network switches using the SDN / NFV technology, a set of $C = \{c_i,\ i = 0, \ldots, |C| - 1\}$ network controllers, a matrix R of the shortest paths and the obtained above placement of SDN controllers on the network nodes. It is necessary to go through the entire set of S network switches using the shortest path matrix R and determine the two closest (in delay T) controllers for each switch. The nearest of these controllers is defined as the main one for the given switch, the farthest one is the backup.

5. Determine the optimal groups of switches, the total load of which does not exceed the maximum performance of SDN controllers. Let P_i be the maximum performance (Packet-In packets per second) of the controller c_i Suppose also that the average number I_i of new flows per second arriving at the switch S_i and the average number I_{ij} of flows per second between switches S_i and S_j are given. It is necessary to split the graph $G = (S, E)$ into such connectivity groups so that the sum of the numbers in the nodes of each connectivity group does not exceed the controller P_i performance. Then the algorithm for determining the optimal group of switches will be as follows:

5.1. Calculate $I_i + I_{ij}$ at the nodes of each connectivity component. If $I_i + I_{ij} \leq P_i$, then the algorithm terminates.

5.2. If $I_i + I_{ij} > P_i$, it is necessary to

5.2.1. create a new graph S with vertices without connections: $G^1 = (S, E^{new})$.

5.2.2. In the graph G, select the connection E_{ij} with the maximum I_{ij}, then delete it. Add to the graph G^1. The loads are recalculated at the nodes of the graph G. It turned out to be divided into groups.

5.3. If $I_i + I_{ij} \leq P_i$ is on each connected component of the new graph, the combination is successful. Contrariwise, if $I_i + I_{ij} > P_i$ is on each connected component of the new graph, the combination is unsuccessful. The next (by load) edge of the graph G is deleted.

As a result of the algorithm, a set of optimal switch groups is allocated, the total load of which does not exceed the maximum performance of SDN controllers.

6. Distribute the obtained optimal groups of SDN switches among the controllers C in such a way that it would be required to perform as few actions as possible to bring the system into a state corresponding to the distribution into groups. To do this, SDN switch groups must be sorted in descending order of the number of loads in each switch group. The resulting sorted set of switch groups is compared with the current distribution of switches among SDN controllers (switches controlled by one controller are counted in one group). Based on the comparison of the two sets, we carry out switching (migration and switching of controller states) of switches to controllers only at the places where the two sets do not match. After completing these steps, a new distribution of switches among controllers is obtained.

7. Check the calculated number of controllers and their optimal location on the communication network for meeting the requirements:

7.1. The number of switches in one segment of the SDN (a group of switches that is under the control of one controller) should not exceed the maximum possible number of switches in one segment (maximum controller performance);

7.2. The lengths of all shortest paths in the SDN / NFV-based communication network graph should not exceed the maximum possible delay between the controller and the SDN switch of the same domain;

7.3. It is necessary that for each switch of the communication network based on SDN / NFV a single controller is assigned the role of Master;

7.4. The required number of $|C|$ controllers in the communication network based on SDN / NFV was determined from the condition:

$$|C| \geq \left\lceil \frac{|S|}{S_{max}} \right\rceil + C_{ref},$$

where $|S|$ is the number of SDN switches of the communication network (network nodes), S_{max} is the maximum possible number of SDN switches that can be controlled by one controller, C_{ref} is the number of SDN controllers, in case of the failure of which the communication network must be stable;

7.5. A selection of a set of indicators S_{max}, T_{max}, where S_{max} is the maximum possible number of SDN switches that can be controlled by one controller (selection of controller performance from its technical documentation), T_{max} is the maximum possible delay between the controller and the SDN switch of the same domain (depends on the quality of service presented to the elements of the communication network standardized in ITU standardization sector recommendations).

8. Calculation of availability factors of SDN segments. After determining the primary and backup controllers of the SDN for

each switch of the SDN (see clause 4 of this methodology) and the distribution of switches into groups (segments) (see point 6 of this methodology), it is necessary to assess the reliability of these segments. The structural reliability and reliability of communication lines between the nodes of a given segment are calculated for each dedicated segment of the SDN. The structural reliability of the SDN segments will be characterized by the system availability factor using the SDN controller redundancy. The reliability of communication lines between nodes of the SDN segment will be characterized by the availability of the communication line K_{Rij}. This requires:

8.1. To calculate the average recovery time of lines between nodes based on the formula (2)

$$\bar{t} = \frac{n_1 \cdot t_1 + n_2 \cdot t_2}{N}, \qquad (2)$$

where n_1 is the number of damages in couplings and terminal devices; t_1 is the average time of damage recovery in couplings and terminal devices, hour; n_2 is the number of damage to the cable duct; t_2 is the average recovery time for compensating the damage to cable ducts, hour; N is a number of damage.

8.2. To calculate the density of damage on the average length of the communication line between the nodes of one SDN segment based on the formula (3)

$$\bar{m} = \frac{\bar{L} \cdot N}{L_{ij}}, \qquad (3)$$

where $\bar{L}$ is the average length of connecting lines in the SDN segment; L_{ij} is the duration (length) of the communication line between network nodes i and j, km.

8.3. To calculate the availability of the communication line between nodes i and j based on the formula (4):

$$K_{Rij} = \frac{T - \bar{m} \cdot \bar{t}}{T}, \qquad (4)$$

Check the obtained reliability indicators for compliance with the relevant communication network standards.

9. Calculation of service quality indicators for SDN telecommunications equipment. To do this, it is needed to use additional input data such as parameter λ_2 of the input flow of information coming from external networks to SDN switches (the number of incoming packets per second from external networks); the number n of cores of the stream generation processor; the length M of the input data buffer; the stream μ generation rate; the number L of switching (addressing) tables; the speed σ of processing the stream by writing the switching (addressing) table; the number c of message processor cores; the message r of buffer length; the message γ of processing speed. Further, based on the mathematical models of the functioning of the SDN switch and the SDN controller, built in [2], calculate the SDN service quality indicators.

Conclusion

This paper proposes and substantiates a methodology for a comprehensive assessment of the quality of telecommunication services of communication networks based on SDN/NFV, on the basis of which the structure and number of controllers and their optimal location in the communication network using the SDN/NFV technology can be selected, reliability indicators are calculated, probabilities are obtained for loss of streams and control messages, as well as time delays for processing streams in SDN telecommunication equipment.

References

1. Recommendations ITU-T Y.3300 «Framework of software-defined networking», 2014.

2. K.E. Samouylov, I.A. Shalimov, I.G. Buzhin, Y.B. Mironov. Model of functioning of telecommunication equipment for software-configurated networks. *Modern Information Technologies and IT-Education*. Vol. 14, no. 1. 2018. doi:10.25559/SITITO.14.201801.013-026.

3. V. Vishnevskiy. Theoretical foundations of computer network design. Moscow: The technosphere, 2003. 512 p.

4. ETSI GS NFV 002 V1.2.1 «Network Functions Virtualisation (NFV); Architectural Framework», 2014.

5. HP Performance Brief for External Audiences. Electronic text data. HP, 2007.

6. V.K. Tsvetkov, V.I. Oreshkin, I.G. Buzhin, Y.B. Mironov. Model of Restoration of the Communication Network Using the Technology of Software Defined Networks. *ELCONRUS 2019,* IEEE, 2019, pp. 1559-1563. doi: 10.1109/EIConRus.2019.8656723.

7. I.G. Buzhin, Y.B. Mironov. Evaluation of delayed telecommunication equipment of Software Defined Networks. *SOSG 2019*, IEEE, 2019. p. 8706825. doi: 10.1109/SOSG.2019.8706825.

8. ONF TR-539 OpenFlow Controller Benchmarking Methodologies. *Open Network Foundation*. URL: https://3vf60mmveq1g8vzn48q2o71a-wpengine.netdna-ssl.com/wp-content/uploads/2014/10/TR-539_OpenFlow_Controller_Benchmarking_Methodologies_v1.pdf date of the application: 06.05.2018).

9. Sherwood, M. Chan, A. Covington, G. Gibb, M. Flajslik, N. Handigol, T.-Y. Huang, P. Kazemian, M. Kobayashi, J. Naous, S. Seetharaman, D. Underhill, T. Yabe, K.-K. Yap, Y. Yiakoumis, H. Zeng, G. Appenzeller, R. Johari, N. McKeown, G. Parulkar Carving research slices out of your production networks with OpenFlow. *SIGCOMM Comput. Commun. Rev*. 2010. Vol. 40, no. 1, pp. 129-130.

10. R.L. Smeliansky, E.V. Chemeritsky. On QoS management in SDN by multipath routing. SDN&NFV: The Next Generation of Computational Infrastructure. *2014 International Science and Technology Conference "Modern Networking Technologies (MoNeTec)":* Proceedings. Moscow: MAKS Press, 2014, pp. 41-46.

11. Shalimov A., Zuikov D., Zimarina D. et al. Advanced study of sdn/openflow controllers. *9th Central and Eastern European Software Engineering Conference in Russia, CEE-SECR 2013. ACM International Conference Proceeding Series*. Moscow, Russia, 2013. DOI:10.1145/2556610.2556621.

12. Vladyko A., Muthanna A., Kirichek R. Comprehensive SDN Testing Based on Model Network. *Lecture Notes in Computer Science*. 2016. Vol. 9870, pp. 539-549.

13. ITU-T Y.3300 Framework of software-defined networking [Electronic resource] // ITU. URL: https://www.itu.int/rec/T-REC-Y.3300/en (date of the application: 09.02.2019).

14. D. Kreutz, F.M.V. Ramos, P.E. Verissimo C.E. Rothenberg, S. Azodomolky, S. Uhlig. Software-Defined Networking: A Comprehensive Survey. *Proceedings of the IEEE*. Vol. 103, Is.1, pp. 14-76. DOI:10.1109/jproc.2014.2371999.

15. Y. Zhao, L. Iannone, M. Riguidel. On the Performance of SDN Controllers: A Reality Check. *2015 IEEE Conference on Network Function Virtualization and Software Defined Network*, November 18-21, 2015. San Francisco, USA, 2015. DOI: 10.1109/NFV-SDN.2015.7387410.

16. OpenFlow Switch Specification version 1.3.0. *Open Network Foundation*. URL: https://www.opennetworking.org/ (date of the application: 09.02.2019).

17. N. Gude, T. Koponen, J. Pettit, B. Pfaff, M. Casado, N. McKeown, S. Shenker. NOX: towards an operating system for networks. *SIGCOMM Comput. Commun. Rev. 2008*. Vol. 38, no. 3, pp. 105-110.

18. R. Smeliansky. SDN for network security. *Proceedings of the 2014 international science and technology conference "Modern Networking Technologies (MoNeTec)"*. SDN@NFV modern networking technologies. Moscow: Maks Press, 2014, pp. 155-159.

19. D.Kotani, K. Suzuki, H.Shimonishi. A Design and Implementation of OpenFlow Controller handling IP Multicast with Fast Tree Switching. *Proceedings of the IEEE/IPSJ International Symposium on Applications and the Internet (SAINT)*, Izmir, Turkey, 16-20 July 2012, pp. 60-67.

МЕТОДИКА КОМПЛЕКСНОЙ ОЦЕНКИ КАЧЕСТВА ТЕЛЕКОММУНИКАЦИОННЫХ УСЛУГ ТРАНСПОРТНЫХ СЕТЕЙ С ПРИМЕНЕНИЕМ ТЕХНОЛОГИЙ SDN/NFV

Бужин Игорь Геннадиевич, *Московский технический университет связи и информатики, Москва, Россия,* **i.g.buzhin@mtuci.ru**
Антонова Вероника Михайловна, *Московский технический университет связи и информатики, Москва, Россия,* **xarti@mail.ru**
Гайфутдинов Эльдар Альбертович, *Московский технический университет связи и информатики, Москва, Россия,* **e.a.gaifutdinov@mtuci.ru**
Миронов Юрий Борисович, *Московский технический университет связи и информатики, Москва, Россия,* **i.b.mironov@mtuci.ru**

Аннотация
Реализация концепции мировой экономики Российской Федерации сопровождается возрастанием объемов и расширением функциональных возможностей предоставляемых сервисов, повышением требований к информационной безопасности, что, в свою очередь, влечет за собой усложнение механизмов управления систем и сетей связи. В связи с этим появилась необходимость отделения функции управления от функции передачи данных телекоммуникационного оборудования, что является основой технологий SDN/NFV. В статье предложена методика комплексной оценки качества телекоммуникационных услуг транспортных сетей с применением технологий SDN/NFV. Для достижения поставленной цели проведен анализ архитектуры и особенностей реализации технологий SDN/NFV, проведен анализ правил функционирования телекоммуникационного оборудования. Разработана методика комплексной оценки качества телекоммуникационных услуг транспортных сетей с применением технологий SDN/NFV и алгоритмы для реализации методики на этапе проектирования транспортной сети. На основании разработанной методики может быть выбрана структура и количество контроллеров и их оптимальное месторасположение в сети связи при применении технологий SDN/NFV, рассчитаны показатели надежности, получены вероятности потерь потоков и управляющих сообщений, а также временные задержки на обработку потоков в телекоммуникационном оборудовании SDN/NFV. Разработанная методика может быть полезной для проведения исследовательских работ и на этапе проектирования сетей связи.

Ключевые слова: *SDN/NFV, сети связи, информационная безопасность, качество телекоммуникационных услуг.*

Литература

1. Recommendations ITU-T Y.3300 "Framework of software-defined networking", 2014.
2. *Самуйлов К.Э., Шалимов И.А., Бужин И.Г., Миронов Ю.Б.* Модель функционирования телекоммуникационного оборудования программно-конфигурируемых сетей // Современные информационные технологии и ИТ-образование. Том. 14, № 1. 2018. doi:10.25559/SITITO.14.201801.013-026.
3. *Вишневский В.* Теоретические основы проектирования компьютерных сетей. М.: Техносфера, 2003. 512 с.
4. ETSI GS NFV 002 V1.2.1 "Network Functions Virtualisation (NFV); Architectural Framework", 2014.
5. HP Performance Brief for External Audiences: Electronic text data. HP, 2007.
6. *Tsvetkov V.K., Oreshkin V.I., Buzhin I.G., Mironov Y.B.* Model of Restoration of the Communication Network Using the Technology of Software Defined Networks // ELCONRUS 2019, Institute of Electrical and Electronics Engineers Inc., 2019. - pp. 1559-1563. doi: 10.1109/EIConRus.2019.8656723.
7. *Buzhin I.G., Mironov Y.B.* Evaluation of delayed telecommunication equipment of Software Defined Networks // SOSG 2019, Institute of Electrical and Electronics Engineers Inc., 2019. P. 8706825. doi: 10.1109/SOSG.2019.8706825.
8. ONF TR-539 OpenFlow Controller Benchmarking Methodologies // Open Network Foundation. URL: https://3vf60mmveq1g8vzn48q2o71a-wpengine.netdna-ssl.com/wp-content/uploads/2014/10/TR-539_OpenFlow_Controller_Benchmarking_Methodologies_v1.pdf date of the application: 06.05.2018).
9. *Sherwood R., Chan M., Covington A., Gibb G., Flajslik M., Handigol N., Huang T.-Y., Kazemian P., Kobayashi M., Naous J., Seetharaman S., Underhill D., Yabe T., Yap K.-K., Yiakoumis Y., Zeng H., Appenzeller G., Johari R., McKeown N., Parulkar G.* Carving research slices out of your production networks with OpenFlow // SIGCOMM Comput. Commun. Rev. 2010. T. 40, № 1. C. 129-130.
10. *Smeliansky R.L., Chemeritsky E.V.* On QoS management in SDN by multipath routing // SDN&NFV: The Next Generation of Computational Infrastructure: 2014 International Science and Technology Conference "Modern Networking Technologies (MoNeTec)": Proceedings. MAKS Press Moscow, Russia, 2014, pp. 41-46.
11. *Shalimov A., Zuikov D., Zimarina D.* et al. Advanced study of sdn/openflow controllers // 9th Central and Eastern European Software Engineering Conference in Russia, CEE-SECR 2013. ACM International Conference Proceeding Series. Moscow, Russian Federation, 2013. DOI:10.1145/2556610.2556621.
12. *Vladyko A., Muthanna A., Kirichek R.* Comprehensive SDN Testing Based on Model Network // Lecture Notes in Computer Science. 2016. Vol. 9870, pp. 539-549.
13. ITU-T Y.3300 Framework of software-defined networking [Electronic resource] // ITU. - URL: https://www.itu.int/rec/T-REC-Y.3300/en (date of the application: 09.02.2019).
14. *Kreutz D., Ramos F.M.V., Verissimo P.E., Rothenberg C.E., Azodomolky S., Uhlig S.* Software-Defined Networking: A Comprehensive Survey // Proceedings of the IEEE. Vol.103, Is.1, pp. 14-76. DOI:10.1109/jproc.2014.2371999.
15. *Zhao Y., Iannone L., Riguidel M.* On the Performance of SDN Controllers: A Reality Check // 2015 IEEE Conference on Network Function Virtualization and Software Defined Network, November 18-21, 2015. San Francisco, USA, 2015. DOI: 10.1109/NFV-SDN.2015.7387410.
16. OpenFlow Switch Specification version 1.3.0 // Open Network Foundation. URL: https://www.opennetworking.org/ (date of the application: 09.02.2019).
17. *Gude N., Koponen T., Pettit J., Pfaff B., Casado M., McKeown N., Shenker S.* NOX: towards an operating system for networks // SIGCOMM Comput. Commun. Rev. 2008. T. 38, № 3. C. 105-110.
18. *Смелянский Р.* SDN для сетевой безопасности // Материалы международной научно-технической конференции "Современные сетевые технологии (MoNeTec) 2014". Современные сетевые технологии SDN/NFV. М.: Макс Пресс, 2014. С. 155-159.
19. *Kotani D., Suzuki K., Shimonishi H.* A Design and Implementation of OpenFlow Controller handling IP Multicast with Fast Tree Switching / D.Kotani, K. Suzuki, H.Shimonishi // In Proceedings of the IEEE/IPSJ International Symposium on Applications and the Internet (SAINT), Izmir, Turkey, 16-20 July 2012, pp. 60-67.