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MODEL OF DATA TRAFFIC QOS FAST REROUTING IN INFOCOMMUNICATION NETWORKS

The **subject** of research in the article is the processes of fast rerouting with the protection of the Quality of Service level in infocommunication networks. The **aim** of the work is the development of a mathematical model of Fast ReRouting with the protection of the Quality of Service level by the bandwidth and probability of packet loss for data traffic. The following **tasks** are solved in the article: development and research of a fast rerouting flow-based model with the protection of the Quality of Service level of data traffic in the infocommunication network. The following **methods** are used: the graph theory, the teletraffic theory, the queuing theory, and mathematical programming methods. The following **results** were obtained: the fast rerouting flow-based model was developed and investigated, which, due to the introduced protection conditions on indicators of bandwidth and packet loss probability, allows providing the Quality of Service along both the primary and backup multipath. **Conclusions**: Within the framework of the proposed flow-based model, the fast rerouting technological task was formulated as an optimization problem with the constraints of the conditions of implementation of the multipath routing strategy, conditions of flow conservation, and conditions of protection of the link, node, and level of Quality of Service in terms of bandwidth and packet loss probability. The application of this solution contributes to the optimal use of the available network resource while providing the specified level of Quality of Service in terms of bandwidth and probability of packet loss along both the primary and backup routes in the case of a failure of the infocommunication network elements. The proposed flow-based model can be used as the basis of the algorithmic software of existing routers and/or controllers of Software-Defined Networks, which are responsible for the calculation of the primary and backup paths in the fast rerouting of data traffic sensitive to such Quality of Service indicators as bandwidth and packet loss probability.

Keywords: fast rerouting; Quality of Service; bandwidth; packet loss probability.

Introduction

One of the important tendencies in the development of infocommunications is the design of fault-tolerant networks, capable of maintaining their high efficiency in conditions of probable failures of switching equipment, which can be caused by hardware and software failures, network attacks, natural disasters, fighting, etc. [1–7]. The solution of this important scientific and applied problem requires the coordinated work of all available functional technological and protocol means of the Open Systems Interconnection (OSI) reference model. At the Network Layer, the key role is played by protocols and methods of fast rerouting (Fast ReRouting, FRR), when not only the primary but also the set of backup routes are switched on for packet transfer, when the primary route or its individual elements – nodes and/or links [8–14] fail. Therefore, the backup path does not have to intersect with the primary path for protected (redundant) network elements [11–14].

Often, the backup path requires Quality of Service (QoS) level to be at least as high as that achieved when using the primary path. The analysis performed [4, 11–14] showed that this was generally concerned with the protection of network bandwidth, which is one of the main QoS indicators. However, a priority area for the development of fast rerouting facilities, especially in multiservice infocommunication networks (ICNs), is to expand the list of Quality of Service indicators for which values are protected along the primary path with adequate reservation of the network resource [15-19]. Reserving network bandwidth, as a primary Quality of Service indicator, should be complemented by the protection of other key QoS indicators, such as average delay, jitter, and packet loss, which is especially important when transmitting multimedia traffic. These requirements and aspects should be taken into account at the level of modification of mathematical models and methods, which is the theoretical and algorithmic-software basis of promising rapid routing protocols with the protection of the Quality of Service over the set of indicators.

Analysis of existing solutions of fast rerouting in infocommunication networks

It should be noted that there are a number of works that address solutions for fast rerouting with the implementation of the link, node, path, and even bandwidth protection schemes [4–7, 11–14]. The advantages of these solutions are optimization statement and solving of the fast rerouting task. In this case, the formulation of fast rerouting tasks in the form of linear programming problems is positively reflected in reducing the computational complexity of further protocol implementation of the proposed solutions. However, these solutions, which are represented by the corresponding mathematical models and methods, are mostly limited to the case of single path routing of packet flows in the network. This significantly improves the load balancing of the available network resource and the overall Quality of Service. In [14], we succeeded in adapting the solution of the problem of multipath fast rerouting with elements and bandwidth protection of the ICN while maintaining the linearity of the mathematical model used due to some expansion of the number of control routing variables that govern the result of solving the task. The common disadvantages of this class of fast rerouting methods can also be attributed to the protection of only one QoS metric – ICN bandwidth.

Solutions that are focused on protecting the Quality of Service on several QoS indicators are presented in [15–17]. Thus, in [15] it is proposed to carry out the coordinated solution of the problems of load balancing on

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the basis of the concept of Traffic Engineering, ensuring the level of Quality of Service of the traffic of different classes and restoration after failures in Software-Defied Networks. In order to extend the QoS indicators that are subject to protection during fast rerouting, tensor models and methods are proposed in [16, 17] to protect the level of Quality of Service through the bandwidth and average end-to-end packet delay, which is particularly important when serving multimedia flows. In addition, [18] proposed a solution to the problem of fast rerouting of VoIP flows with protection of the Quality of Service, which is perceived at the level of the user (Quality of Experience, QoE), according to the quality rating R. On the other hand, for data traffic is not critical the controlling of the growth of packet delay, but it is important to ensure that it has an acceptable packet loss rate [19, 20]. Therefore, the aim of the work is the development of a mathematical model of Fast ReRouting with the protection of the Quality of Service level by bandwidth and packet loss probability for data traffic.

Fast rerouting flow-based model with the protection of the Quality of Service level by the bandwidth and probability of packet loss

Suppose, within the framework of the selected fast rerouting model [16, 17], the structure of the infocommuncation network is described by a graph $\Gamma=(U,V)$ where $U=\{u_i; i=\overline{1,m}\}$ is the set of vertices modeling the routers and $V=\{(i,j); i,j=\overline{1,m}; i\neq j\}$ is the set of arcs representing the communication links in the ICN. Then each k-th flow transmitted in the network is associated with a number of functional parameters: s_k – the source node; d_k – the destination node; K – the set of flows transmitted over the network ($k\in K$). Each link bandwidth $(i,j)\in V$ will be defined as $\varphi_{i,j}$ and measured in packets per second (1/s). It should be noted that each node (router) of the network has several interfaces through which it transmits packets to its neighbor incident nodes. Then $\varphi_{i,j}$ actually determines the bandwidth of the j-th interface of the i-th node.

In order to implement fast rerouting on the network [11, 14], it is necessary to provide the calculation of two types of routing variables $x_{i,j}^k$ and $\bar{x}_{i,j}^k$ each of which characterizes the intensity of the k-th packet flow transmitted in the communication link $(i,j)\in V$ that is included in the primary or backup route, respectively. A number of constraints are imposed on the control variables entered according to their physical meaning. Therefore, in case of implementation a multipath routing strategy, the following conditions must be met:

$$0\le x_{i,j}^k\le 1 \quad \text{and} \quad 0\le \bar{x}_{i,j}^k\le 1. \tag{1}$$

To ensure consistency in the calculation of the routing variables responsible for implementing fast rerouting on the network, it is important to ensure that the flow conditions are met, taking into account the possible packet loss caused by the queue buffer overload on the network routers. These conditions for the nodes that are part of the primary path (s) have the following form [17]:

$$\begin{cases} \sum\limits_{j:(i,j)\in V} x_{i,j}^k=1, \quad k\in K, \quad i=s_k; \\ \sum\limits_{j:(i,j)\in V} x_{i,j}^k-\sum\limits_{j:(j,i)\in V} x_{j,i}^k(1-p_{j,i}^k)=0, \quad k\in K, \quad i\neq s_k,d_k; \\ \sum\limits_{j:(j,i)\in V} x_{j,i}^k(1-p_{i,j}^k)=\varepsilon^k, \quad k\in K, \quad i=d_k, \end{cases} \tag{2}$$

where ε^k – the fraction of the intensity of the k-th flow served by the network using the primary path, that is, the packets of which were successfully delivered to the destination node; $p_{i,j}^k$ – the probability of packet loss of the k-th flow on the j-th interface of the i-th node when it is used in a primary path.

Restrictions similar to conditions (2) are also imposed on routing variables and backup routes:

$$\begin{cases} \sum\limits_{j:(i,j)\in V} \bar{x}_{i,j}^k=1, \quad k\in K, \quad i=s_k; \\ \sum\limits_{j:(i,j)\in V} \bar{x}_{i,j}^k-\sum\limits_{j:(j,i)\in V} \bar{x}_{j,i}^k(1-\bar{p}_{j,i}^k)=0, \quad k\in K, \quad i\neq s_k,d_k; \\ \sum\limits_{j:(j,i)\in V} \bar{x}_{j,i}^k(1-\bar{p}_{i,j}^k)=\bar{\varepsilon}^k, \quad k\in K, \quad i=d_k, \end{cases} \tag{3}$$

where $\bar{\varepsilon}^k$ – the fraction of the intensity of the k-th flow served by the network when using the backup path; $\bar{p}_{i,j}^k$ – the probability of packet loss of the k-th flow on the j-th interface of the i-th node when it is used in a backup path.

As you know, each type of traffic and service discipline has its own interface model, which is represented by a particular queuing system, such as M/M/1/N, M/D/1/N, etc. In this article, as an example, to determine the probability of packet loss on congested network router interfaces, the use of M/M/1/N queuing capabilities will be used. Then the packet loss probabilities on the interfaces of the primary ($p_{i,j}^k$) and backup ($\bar{p}_{i,j}^k$) paths can be calculated as:

$$p_{i,j}^k=\frac{\left(1-\rho_{i,j}^k\right)\left(\rho_{i,j}^k\right)^N}{1-\left(\rho_{i,j}^k\right)^{N+1}} \quad \text{and} \quad \bar{p}_{i,j}^k=\frac{\left(1-\bar{\rho}_{i,j}^k\right)\left(\bar{\rho}_{i,j}^k\right)^N}{1-\left(\bar{\rho}_{i,j}^k\right)^{N+1}}, \tag{4}$$

where $\rho_{i,j}^k=\dfrac{\boldsymbol{\lambda}_{i,j}}{\varphi_{i,j}}$ and $\bar{\rho}_{i,j}^k=\dfrac{\bar{\boldsymbol{\lambda}}_{i,j}}{\varphi_{i,j}}$ – the coefficients of the link (i,j) utilization when using the k-th flow in the primary or backup route, respectively; $\boldsymbol{\lambda}_{i,j}$ and $\bar{\boldsymbol{\lambda}}_{i,j}$ – the intensities of the aggregated flow directed to the link (i,j) when used by the k th flow in the primary or backup route, respectively, calculated as:

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$$\begin{cases} \lambda_{i,j} = \lambda_k^{\langle req \rangle} x_{i,j}^k + \sum\limits_{p \in K, p \neq k} \lambda_p^{\langle req \rangle} \max[x_{i,j}^p, \overline{x}_{i,j}^p]; \\ \overline{\lambda}_{i,j} = \lambda_k^{\langle req \rangle} \overline{x}_{i,j}^k + \sum\limits_{p \in K, p \neq k} \lambda_p^{\langle req \rangle} \max[x_{i,j}^p, \overline{x}_{i,j}^p], \end{cases} \quad (5)$$

where $\lambda_k^{\langle req \rangle}$ – the average k-th packet flow intensity that sets QoS requirements for the bandwidth.

The physical meaning of expressions (5) is that the calculation of the coefficients of link utilization, and with it a QoS indicator such as the probability of packet loss (4), will be carried out for the worst case in terms of the intensity of the aggregated flow. The second addition to the right-hand side of expressions (5) is introduced for this purpose: in determining the intensity of an aggregated flow, the maximum intensity of each of k-th packet flow in an arbitrary link (i, j) is taken into account when using either the primary or the backup route.

It should be noted that for each individual k-th flow its packet intensity directing to the link (i, j) belonging to the primary or backup path is determined by the corresponding expressions

$$\lambda_{i,j}^k = \lambda_k^{\langle req \rangle} x_{i,j}^k \text{ and } \overline{\lambda}_{i,j}^k = \lambda_k^{\langle req \rangle} \overline{x}_{i,j}^k . \quad (6)$$

Then the intensity of lost packets of the k-th flow on the j-th interface of the i-th node when it is used by the primary or backup path will accordingly be determined as

$$r_{i,j}^k = \lambda_k^{\langle req \rangle} x_{i,j}^k p_{i,j}^k \quad \text{and} \quad \overline{r}_{i,j}^k = \lambda_k^{\langle req \rangle} \overline{x}_{i,j}^k \overline{p}_{i,j}^k . \quad (7)$$

According to the results obtained in [13, 14], we introduce a number of conditions describing the implementation of protection (reservation) schemes of network elements and the level of Quality of Service in the network with fast rerouting:

1. Link protection conditions $(i, j) \in V$:

$$0 \le \overline{x}_{i,j}^k \le \delta_{i,j}^k , \quad (8)$$

where

$$\delta_{i,j}^k = \begin{cases} 0, \text{ when protecting the communication channel } (i, j); \\ 1, \text{ other case.} \end{cases} \quad (9)$$

2. Node protection conditions (in general, condition (8) in the case of protection of multiple communication links incident to the protected node):

$$0 \le \overline{x}_{i,j}^k \le \delta_{i,j}^k \text{ at } u_j \in u_i^* , \; j = \overline{1, m} , \quad (10)$$

where $u_i^* = \{u_j : \exists (i, j) \in V; i \neq j\}$ – the subset of routers that are adjacent to the router u_i and the selection of values $\delta_{i,j}^k$ is made similar to the condition (9).

3. Conditions of implementation of the network bandwidth protection scheme as the main QoS indicator, with fast rerouting taking into account possible packet losses on the router interfaces [14]:

$$\sum_{k \in K} \lambda_k^{\langle req \rangle} \max[x_{i,j}^k, \overline{x}_{i,j}^k] \le \varphi_{i,j} \quad \text{at } (i, j) \in V . \quad (11)$$

4. Conditions for protecting a QoS indicator such as the packet loss probability of the k-th flow in the network, which, based on models (1)–(4), have the form [17]:

$$1 - \varepsilon^k \le p_k^{\langle req \rangle} ; \quad (12)$$

$$1 - \overline{\varepsilon}^k \le p_k^{\langle req \rangle} , \quad (13)$$

where $p_k^{\langle req \rangle}$ – the QoS-requirements for maximum allowable values of packet loss probability of the k-th flow in the network.

Then, in the framework of the above model, it is proposed to present the task of fast rerouting with QoS level protection in optimization form, whereas a criterion of optimality of the obtained routing solutions it is advisable to choose a condition related to maximizing the overall performance of the infocommunication network:

$$J = \sum_{k \in K} (c^k \varepsilon^k + \overline{c}^k \overline{\varepsilon}^k) \to \max , \quad (14)$$

where c^k and $\overline{c}^k$ – the weighting coefficients that characterize the importance (priority) of the k-th flow in the network. In this case, the condition $c^k > \overline{c}^k$ must be satisfied so that the QoS level for the k-th flow along the primary path is not worse than the QoS level for the same flow along the backup path.

Restrictions in the course of solving the formulated optimization problem (14) were the conditions of implementation of the multipath routing strategy (1), the conditions of flow conservation (2), (3), the conditions of protection of the link and/or node (8)–(10), the conditions of the overload prevention of communication links – protection of network bandwidth (11), conditions for ensuring protection of the Quality of Service level by the indicator of packet loss probability (12), (13).

A calculation example of the application of a fast rerouting flow-based model with the protection of the Quality of Service level by the bandwidth and packet loss probabilitiy

The features of using the fast rerouting model (1)–(14) will be demonstrated by the network structure shown in fig. 1. The network consisted of sixteen routers (R1 ÷ R16) and twenty-four communication links. The operation of each of the interfaces of the ICN routers was modelled by the queuing system M/M/1/N, and the buffer capacity was 30 packets. Fig. 1 shows the bandwidth of the communication links (1/s).

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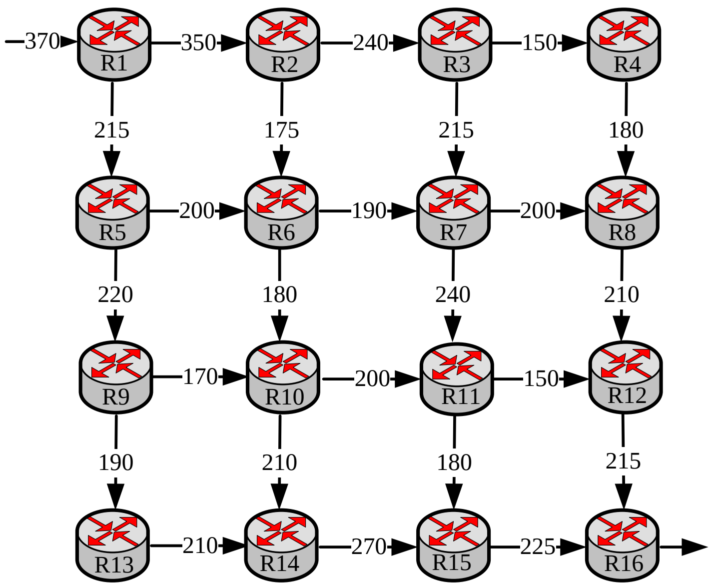

Fig.1. Structure of the investigated infocommunication network

Suppose that a packet flow of $\lambda_k^{\langle req \rangle} = 370$ 1/s intensity is sent by the router R1, which must be transmitted to R16 (fig. 1). QoS requirements for the reliability of packet delivery are determined by the permissible packet loss probability on the network: $p_k^{\langle req \rangle} = 10^{-3}$. During fast rerouting, protection is required:

- node R10 and incident communication links, respectively (fig. 2);

- the Quality of Service level on the selected two QoS indicators ($\lambda_k^{\langle req \rangle}$ and $p_k^{\langle req \rangle}$).

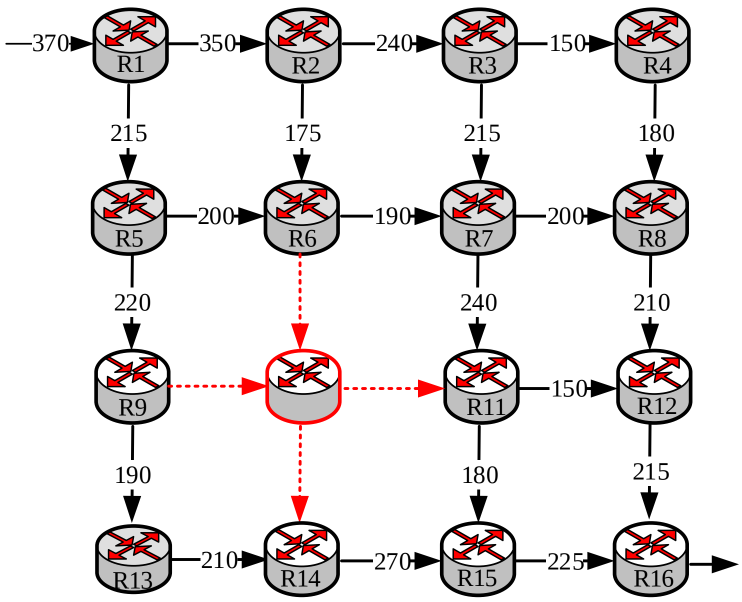

Fig. 2. Structure of the investigated information network while protecting the R10 router and its incident communication links

Thus, in solving the fast rerouting problem using the proposed model (1)–(14), the primary (fig. 3) and backup (fig. 4) multipaths were calculated, while the backup did not contain the protected node R10. Along the primary and backup paths, QoS requirements were met, both in terms of the bandwidth and the probability of packet loss under conditions (11)–(13). Fig. 3 and fig. 4 show over the communication links the results of calculations, which are represented as fractions, where the numerator shows the packet flow intensity (1/s) and the denominator shows the capacity of that link (1/s). In addition, the separate arrows that come out of nodes such as R1, R12, and R15, fig. 3, and R1, R7-R9, R12 and R15 in fig. 4 shows packet loss rates on the interfaces of these routers. Fig. 4 shows the packet loss rates at the interfaces of these routers.

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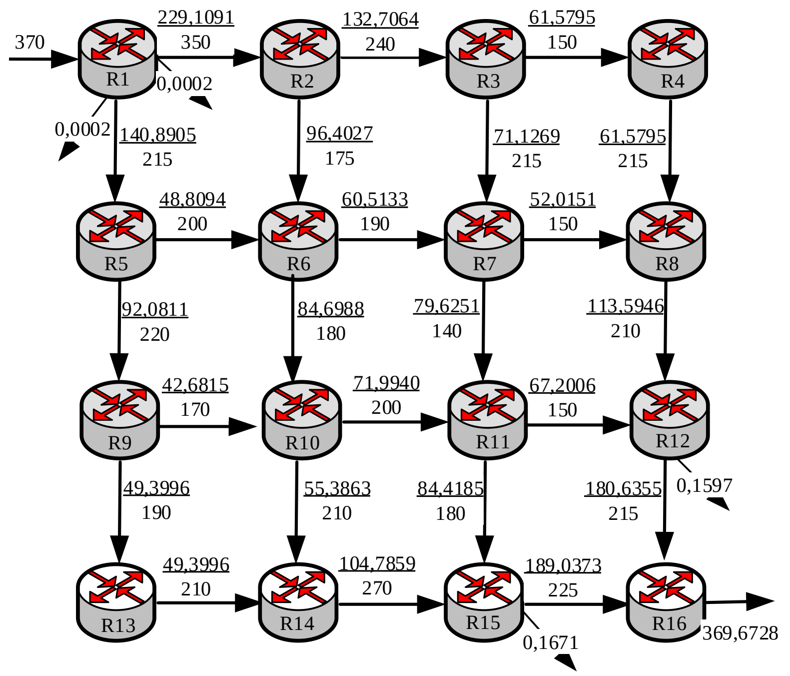

Fig. 3. The order of routing of the packet flow transmitted by the primary multipath

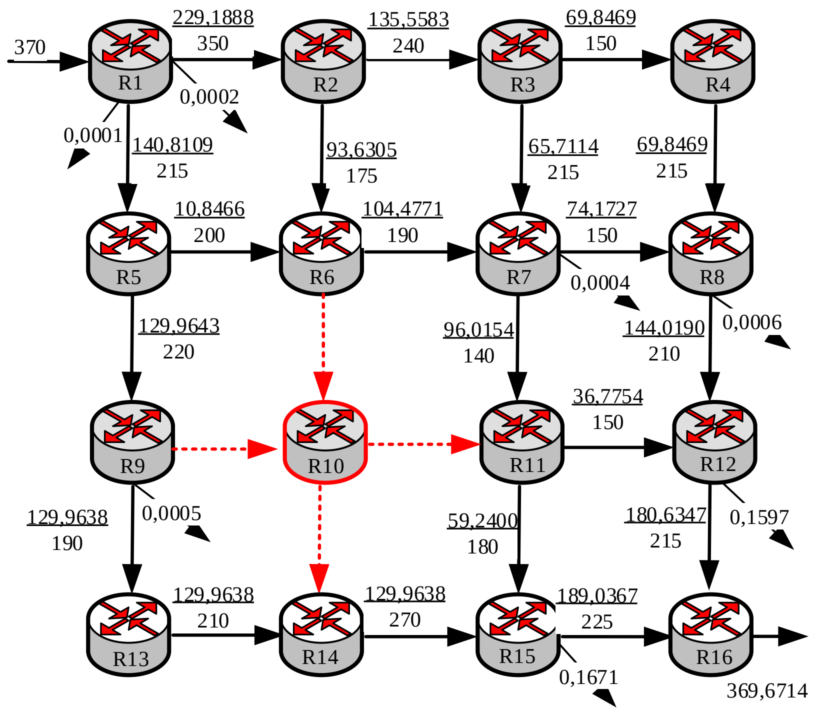

Fig. 4. The order of routing the packet flow transmitted by the backup multipath

For the sake of clarity and evaluation of the adequacy of the solutions obtained, all the results of the study are summarized in table. 1. As shown in fig. 3 and fig. 4, the value requirements of the Quality of Service indicators were carried out along the primary and backup multipath. In this case, the packet loss probability in the network when using the primary multipath was $8{,}84\times10^{-4}$, and for the backup $-8{,}8815\times10^{-4}$.

Thus, according to the obtained results, using the developed model (1)–(14), the solution of the problem of fast rerouting was obtained, within which the protection of the node R10 and the given QoS level by the bandwidth (370 1/s) and the packet loss probability (10–3) indicators have been provided. The results obtained confirmed the adequacy and performance of the proposed fast rerouting flow-based model (1)–(14).

Table 1. *The order of routing of the packet flow transmitted by the primary and backup multipaths*

Communication channel	Bandwidth ability communication channel, 1/s	QoS-requirements: $\lambda_k^{\langle req \rangle} = 370$ 1/c, $p_k^{\langle req \rangle} = 10^{-3}$.			
		Calculation results for the main multi-path		Calculation results for backup multi-path	
		The intensity of packet transmission ($\lambda_{i,j}^k$), 1/s	The intensity of the packet loss on the router interface ($r_{i,j}^k$), 1/s	The intensity of packet transmission ($\bar{\lambda}_{i,j}^k$), 1/s	The intensity of the packet loss on the router interface ($\bar{r}_{i,j}^k$), 1/s
(1,2)	350	229,1091	0,0002	229,1888	0,0002
(1,5)	215	140,8905	0,0002	140,8109	0,0001
(2,3)	240	132,7064	0	135,5583	0
(2,6)	175	96,4027	0	93,6305	0
(3,4)	150	61,5795	0	69,8469	0
(3,7)	215	71,1269	0	65,7114	0
(4,8)	215	61,5795	0	69,8469	0
(5,6)	200	48,8094	0	10,8466	0
(5,9)	220	92,0811	0	129,9643	0
(6,7)	190	60,5133	0	104,4771	0
(6,10)	180	84,6988	0	0	0
(7,8)	150	52,0151	0	74,1727	0
(7,11)	140	79,6251	0	96,0154	0,0004
(8,12)	210	113,5946	0	144,0190	0,0006
(9,10)	170	42,6815	0	0	0
(9,13)	190	49,3996	0	129,9638	0,0005
(10,11)	200	71,9940	0	0	0
(10,14)	210	55,3863	0	0	0
(11,12)	150	67,2006	0	36,7754	0
(11,15)	180	84,4185	0	59,2400	0
(12,16)	215	180,6355	0,1597	180,6347	0,1597
(13,14)	210	49,3996	0	129,9638	0
(14,15)	270	104,7859	0	129,9638	0
(15,16)	225	189,0373	0,1671	189,0367	0,1671

Conclusions

This paper addresses an up-to-date scientific and applied task that is related to the optimization of fast rerouting processes based on the development of a fast rerouting flow-based model with the protection of the Quality of Service over bandwidth and packet loss probability, which is especially important in data traffic transmission. In the framework of the proposed flow-based model (1)–(14), the technological fast rerouting problem was formulated in an optimization form with the optimality criterion (14) and the constraints that the conditions of implementation of the multipath routing strategy (1), the conditions of flow conservation (2), (3), link and node protection conditions (8)–(10), QoS assurance and protection conditions for bandwidth (11) and packet loss probability (12), (13).

The given optimization problem belongs to the class of nonlinear programming problems, as the key constraints that are represented by the conditions (2), (3), (11)–(13) are nonlinear. To solve it, we used the functionality of the MatLab package (Optimization Toolbox). The performance of the proposed fast rerouting model (1)–(14) and adequacy of the received network solutions were confirmed by a specific numeric example, in which protection of the one network node and Quality of Service for bandwidth and packet loss probability with the implementation of multipath routing strategy have been performed.

The proposed flow-based model (1)-(14) may form the basis of the algorithmic software of existing routers and/or controllers of Software-Defied Networks responsible for the calculation of the primary and backup paths during fast rerouting. It is advisable to use routing protocols based on the fast rerouting of data traffic sensitive to Quality of Service indicators such as bandwidth and packet loss probability.

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МОДЕЛЬ ШВИДКОЇ QOS-ПЕРЕМАРШРУТИЗАЦІЇ ТРАФІКУ ДАНИХ В ІНФОКОМУНІКАЦІЙНИХ МЕРЕЖАХ

Предметом дослідження в статті є процеси швидкої перемаршрутизації із захистом рівня якості обслуговування в інфокомунікаційних мережах. **Мета** роботи – розробка математичної моделі швидкої перемаршрутизації із захистом рівня обслуговування за показниками пропускної здатності та ймовірності втрат пакетів для трафіку даних. В статті вирішуються наступні **завдання**: розробка та дослідження потокової моделі швидкої перемаршрутизації із захистом рівня якості обслуговування трафіку даних в інфокомунікаційній мережі. Використовуються такі **методи**: теорія графів, теорія телетрафіка, теорія масового обслуговування та методи математичного програмування. Отримано наступні **результати**: розроблено та досліджено потокову модель швидкої перемаршрутизації, яка завдяки введеним умовам захисту за показниками пропускної здатності та ймовірності втрат пакетів дозволяє забезпечити рівень якості обслуговування вздовж як основного, так і резервного мультишляхів. **Висновки**: В рамках запропонованої потокової моделі технологічна задача швидкої перемаршрутизації була сформульована як оптимізаційна з обмеженнями, якими виступали умови реалізації багатошляхової стратегії маршрутизації, умови збереження потоку, умови захисту каналу, вузла та рівня якості обслуговування за показниками пропускної здатності та ймовірності втрат пакетів. Застосування отриманого рішення сприяє оптимальному використанню доступного мережного ресурсу при забезпеченні заданого рівня якості обслуговування за показниками пропускної здатності та ймовірності втрат пакетів вздовж як основних, так і резервних маршрутів при відмовах елементів інфокомунікаційної мережі. Запропонована потокова модель може використовуватися як основа алгоритмічно-програмного забезпечення існуючих маршрутизаторів та/або контролерів програмно-конфігурованих мереж, які відповідають за розрахунок основних і резервних шляхів при швидкій перемаршрутизації трафіку даних, чутливого до таких показників якості обслуговування як пропускна здатність та ймовірність втрат пакетів.

Ключові слова: швидка перемаршрутизація; якість обслуговування; пропускна здатність; ймовірність втрат пакетів.

МОДЕЛЬ БЫСТРОЙ QOS-ПЕРЕМАРШРУТИЗАЦИИ ТРАФИКА ДАННЫХ В ИНФОКОММУНИКАЦИОННЫХ СЕТЯХ

Предметом исследования в статье являются процессы быстрой перемаршрутизации с защитой уровня качества обслуживания в инфокоммуникационных сетях. **Цель** работы – разработка математической модели быстрой перемаршрутизации с защитой уровня обслуживания по показателям пропускной способности и вероятности потерь пакетов для трафика данных. В статье решаются следующие **задачи**: разработка и исследование потоковой модели быстрой перемаршрутизации с защитой уровня качества обслуживания трафика данных в инфокоммуникационных сетях. Используются следующие **методы**: теория графов, теория телетрафика, теория массового обслуживания и методы математического программирования. Получены следующие **результаты**: разработана и исследована потоковая модель быстрой перемаршрутизации, которая благодаря введенным условиям защиты по показателям пропускной способности и вероятности потерь пакетов позволяет обеспечить уровень качества обслуживания вдоль как основного, так и резервного мультипутей. **Выводы**: В рамках предложенной потоковой модели технологическая задача быстрой перемаршрутизации была сформулирована как оптимизационная с ограничениями, в качестве которых выступали условия реализации многопутевой стратегии маршрутизации, условия сохранения потока, условия защиты канала, узла и уровня качества обслуживания по показателям пропускной способности и вероятности потерь пакетов. Применение полученного решения способствует оптимальному использованию доступного сетевого ресурса при обеспечении заданного уровня качества обслуживания по показателям пропускной способности и вероятности потерь пакетов вдоль как основных, так и резервных маршрутов при отказах элементов инфокоммуникационной сети. Предложенная потоковая модель может использоваться как основа алгоритмически-программного обеспечения существующих маршрутизаторов и/или контроллеров программно-конфигурируемых сетей, которые отвечают за расчет основных и резервных путей при быстрой перемаршрутизации трафика данных, чувствительного к таким показателям качества обслуживания как пропускная способность и вероятность потерь пакетов.

Ключевые слова: быстрая перемаршрутизация; качество обслуживания; пропускная способность; вероятность потерь пакетов.

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