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TRAFFIC ENGINEERING IN A SOFTWARE-DEFINED NETWORK BASED ON THE DECISION-MAKING METHOD

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Однією з основних задач управління в комп'ютерній мережі є організація ефективної системи доставки інформації, яка набуває особливої актуальності в програмно-конфігурованій мережі. Засоби традиційної маршрутизації не задовольняють вимогам якості обслуговування та вимогам рівномірного розподілу навантаження по каналах зв'язку. Маршрутизація в традиційних мережах здійснюється засобами пошуку найкоротшого шляху по заданому параметру, але вони не забезпечують достатньої оперативності при зміні маршрутів в мережі. Ще одним недоліком є необхідність передачі регулярних оновлень маршрутної інформації шляхом передачі службового трафіку, в результаті чого навантаження різко зростає, зменшуючи смугу пропускання.

В даний час найбільш ефективним способом забезпечення заданих параметрів якості обслуговування та перспективним рішенням для організації ефективної маршрутизації в умовах невизначеності являється програмно-конфігурована мережа. Це нова мережева парадигма, що надає можливість спростити процес управління мережею, значно підвищити використання ресурсів мережі та зменшити операційні витрати. Однією з основних переваг такої мережі є управління на верхніх рівнях еталонної моделі, що дозволяє спростити як процес управління мережею, так і процес управління трафіком в корпоративних мережах і мережах центрів обробки даних.

Запропоновано новий підхід конструювання трафіку в програмно-конфігурованій мережі з використанням теорії прийнятті рішень орієнтований на маршрутизацію саме в таких мережах. При виникненні «проблемної ділянки» та потреби її обходу використовується теорія прийняття рішень в умовах невизначеності, так як ймовірність вибору оптимального шляху для обходу враховує особливості трафіку, що передається. Такий метод дає змогу зменшити втрати нееластичного трафіку, що є важливою складовою від загальної кількості переданої інформації. З практичної точки зору, отриманий в роботі алгоритм, в порівнянні з відомими алгоритмами конструювання трафіку, підвищує рівень якості обслуговування в програмно-конфігурованих мережах

Ключові слова: конструювання трафіку, програмно-конфігурована мережа, нечітка логіка, пропускна здатність, завантаженість каналів, реконфігурація мережі

1. Introduction

New mega-trends in information and communication technologies demand greater flexibility, greater throughput capacity, and a faster performance from networks. However, further increases in the infrastructure of networks are only a temporary solution and they lead to complications in network management as well. That is why conventional approaches to network architecture, and to control over it, will become ineffective in the near future, which necessitated searching for, as well as adopting, new network models to routing organization [1].

A software defined network (SDN) is one of the most promising solutions for efficient routing. This is a new networking paradigm, which has new promises for application and provides an opportunity to simplify the process of managing the network, greatly increase the use of network resources and reduce operating costs.

The difference from networks of conventional architecture is in in the fact that a software defined network has two key features that make it possible to have a global representation about the state of the network and execute flexible centralized control over it:

– the plane of network management and the data transmission plane are separated;

– operators can program the behavior of packet transmission in it.

One of the main approaches to optimize the performance and improve reliability of the network is traffic engineering (TE) [2].

Existing methods of traffic engineering, although widely used in networks with conventional architecture, do not take into consideration the unique features of software defined networks and are not, therefore, enough effective for them.

Thus, it is a relevant current task to find new ways for traffic engineering that would be able to utilize the full potential of benefits of the software defined networks [3].

2. Literature review and problem statement

Modern computer networks differ by large dimensionality and a varied composition of hardware. Given this, the process of managing computer networks becomes complicated, specifically traffic engineering. With the increasing dimensionality of computer networks and the increased amount of network traffic, it is a relevant task to engineer traffic taking into consideration its type, as well as the parameters of quality of service (QoS), and to reduce energy consumption.

One of the main advantages of SDN is control at the level of flows that makes it possible to simplify both the process of network management and the process of data traffic management process in corporate networks and data centers networks [9].

To reduce the duration of TE [4–6] and improve QoS [7], it is necessary to organize the centralized generation of a set of paths based on a multipath routing within SDN.

Paper [8] proposed an algorithm of a «reverse wave», which generates all the possible paths, that do not intersect, between a pair of nodes in the network. When choosing the required path for TE, an optimal path is chosen from the entire set.

Work [9] suggested a method to orchestrate traffic in SDN, which, due to the presence of a central controller in the network, makes it possible to reduce the time to form the set of paths for accessing network resources and to simplify re-routing.

The presence of a set of routes makes it possible to almost eliminate a delay or loss of packets in the process of traffic re-routing. In this case, the more paths the SDN controller generates, the less the probability of delay or packet losses.

However, the proposed techniques have a common flaw, namely the generation of a set of paths does not take into consideration the congestion of the paths and the type of traffic that is transmitted.

Paper [10] proposed the technology of traffic engineering Hedera, aimed at raising the efficiency of using network resources (specifically, throughput capacity). At present, the most popular solution for multipath routing in SDN is the scheme Equal-Cost-Multi-Path (ECMP) [11]. A given approach has a significant drawback, namely, it does not take into consideration the congestion of network resources and the type of transmitted traffic.

Study [12] reported the new problem to optimize the process of traffic engineering Online Branch-aware Steiner Tree (OBST), for optimal use of throughput capacity, scalability of multicast transmission in SDN, and for redirecting traffic if needed.

Paper [13] presented adaptive methods for traffic engineering, which include solutions for the fuzzy planning flow (AWFQ, FWQ) and the regressive arrival control (REAC) to ensure the stable operation of the network.

Effective resource management using the methods of adaptive traffic management make it possible to constantly equalize and monitor traffic distribution and to recover a network from errors and attacks.

A SDN controller makes it possible to control traffic for assessing the general network conditions using fuzzy logic that provides the adjustment and making a decision given current conditions for data transfer.

MiceTrap [14] demonstrates the advantages of previous approaches to processing large data flows, while not making it possible to compromise the quality of service – one of the most important parameters for a network.

Modern computer networks employ two types of traffic: elastic and non-elastic. Elastic refers to such a type of traffic that can adapt to changes in delay and throughput capacity over a wide range of values, while continuing to meet the needs of applications (such as file sharing, email). For such a traffic, important is the reliability of delivery. Non-elastic refers to such a type of traffic that adjusts poorly, if at all, to changes in delay and throughput capacity (such as real-time traffic, audio or video conference). For such a traffic, important is the time delay and the percentage of lost packets.

To reduce the percentage of packet loss during transmission, it is necessary to identify the type of traffic and choose the best route for data transfer at the start of allocation. The Atlas method [15] is able to classify a VoIP packet uniquely, rather than classify it as a generic VoIP stream.

Paper [16] suggested an approach to traffic engineering between multiple paths for SDN (MSDN-TE). This approach is based on the use of multiple paths for data transfer considering the actual congestion in the process of rerouting.

The main purpose of the algorithm MSDN-TE is to avoid the congestion in a network by redistributing data between routes.

However, in large networks, the number of paths may depend on network topology, and a constant redirecting of data between the paths is not a solution to the problem of network congestion, as there may emerge a «bottleneck» where the path throughput capacity would be critical. It is the formation of such «bottlenecks», as is the case for MSDN-T, that leads to the loss of most of the packets that are transmitted.

The main problem in the organization of traffic engineering in a software defined network, as well as in conventional networks, is an incorrectly determined TE strategy (choosing the correct alternative) at a node to the sender in accordance with QoS parameters. In the process of routing, it is not possible to avoid situations of path congestion, failure, or moving a node in mobile networks, which cannot always be resolved by conventional techniques. In this work, to address such events, based on the task of choosing the optimal TE variant for the initial node, we propose using the theory of fuzzy sets and decision making methods under conditions of uncertainty focused on routing in a software-defined network.

3. The aim and objectives of the study

The aim of this study is to devise a technique of traffic engineering, which, through the use of fuzzy logic when choosing paths, would make it possible to decrease the percentage of packet loss in the non-elastic traffic in a software-defined network.

To accomplish the aim, the following tasks have been set:

– to develop a TE technique with the elements of fuzzy logic based on a decision-making method;

– to run a comparative analysis of the proposed TE method with those known.

4. Development of a technique of traffic engineering in a software-defined network

Paper [17] outlined the basic principles of TE to reduce data loss and maximize the efficient use of communication channels:

– organization of multipath routing;

– coordinated control using the theory of decision making in SDN;

– the use of short-term prediction of the character of traffic behavior.

Consider a software defined network in the form of an undirected graph (Fig. 1):

$$G=(V,E,W,C,P), \quad (1)$$

where $V=\{1,\ldots,n\}$ is a non-empty ultimate set of vertices, n is the order of the graph; $E=\{(i,j)\in V\times V\}$ is the set of edges; $W:V\to R$ is the weight function, which assigns each vertex with real number ($w_i>0$ is the weight of a vertex $i\in V$); $C:E\to R$ is the weight function that assigns each edge with a real number ($c_{ij}>0$ is the weight of an edge $(i,j)\in E$); $P:E\to(0,1]$ is the weight function that assigns each edge with a real number from a semi-interval $(0,1]$ ($0<p_{ij}\le 1$ is the probability of a non-failure operation of edge $(i,j)\in E$).

It is necessary to organize traffic engineering such as to reduce the percentage of information loss during its transmission.

In order to organize effective routing, we shall create the entire set of paths that do not intersect. That will make it possible to optimally organize the allocation of information between paths, considering the metrics for each path and the type of traffic.

When forming each path, it is important to compute the generalized metric (2), so that the allocation of data between routes at a node-sender is performed considering QoS for each type of traffic [18]:

$$W=\left[\frac{k_1}{B_e}+k_2\times D_c\right]\times r, \quad (2)$$

where B_e is the effective throughput that is defined as the product of throughput by congestion; D_c is the delay time; k_1 and k_2 are the weight coefficients of throughput and latency; r is the reliability, the percentage of information that has been successfully transmitted to the next node.

A highly-congested network constantly undergoes changes in the state of connections. Such changes are difficult to predict as there are a number of reasons that can cause an unexpected load on a communication line, which was relatively free prior to it, and allowed data transfer while retaining the high level of quality service. Among these reasons are the following:

– failures in routers operation;

– load on key transmission channels from other users;

– increase in the number of the network's subscribers.

In the first case, at a failure in the work of one of the routers, it is required to forward packets to other channels. In this case, certain connections may become significantly loaded. In the second variant, delays may occur due to frequent simultaneous connections to one of the resources by a large number of users. Such disruptions can be expected for a series of social factors such as a growing popularity of individual nodes, the increased activity of users over a certain time of the day or different kinds of hacking. The mobile or Mesh networks can also face the third option when, following the connections from additional subscribers, there may appear problems with certain transmission channels, though such possible disruptions are typically anticipated in these networks.

Paper [19] proposed and substantiated, when forming the routes, to use the modified algorithm. By applying this algorithm, one finds all routes (alternatives) between pairs of nodes. Based on the information about nodes along each route, as well as links between them, a controller can choose a route with optimal metric (2), taking into consideration the states of channels at the time of request.

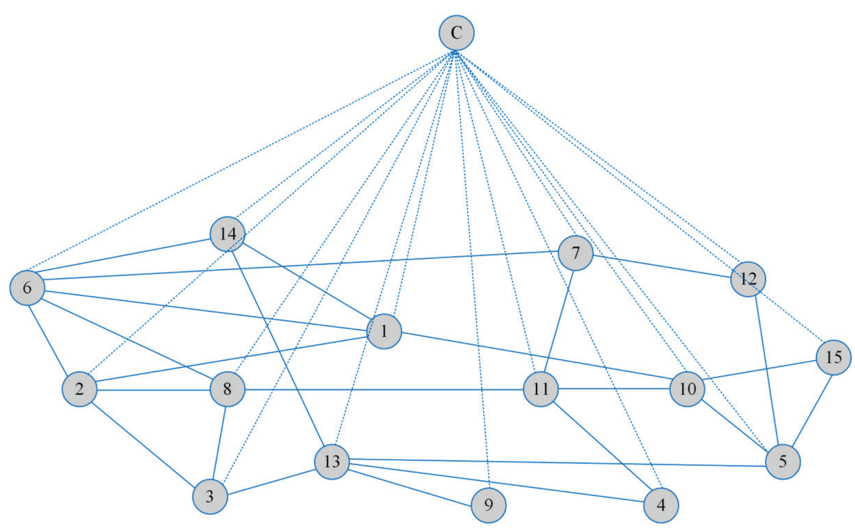

Fig. 1. Undirected graph

Based on the theory of decision making, one finds, as the best alternative, the alternative from a set of non-dominant alternatives with the greatest value for the membership function:

$$x^* = \arg\max_{x_i \in X} \mu_R^{nd}(x_i), \qquad (3)$$

where $\mu_R^{nd}(x_i)$ is the membership function of the i-th alternative to the set of non-dominant alternatives.

We shall build a fuzzy subset of non-dominant alternatives $\mu_R^{nd} \subset U$, whose elements are non-dominant with not any other alternative, the membership function to set μ_R^{nd} is determined from formula:

$$\mu_R^{nd}(x_i) = \min_{x_j \in X}\left\{1-\mu_R^S(x_j,x_{i)}\right\} = $$
$$= 1-\max_{x_j \in X}\left\{\mu_R^S(x_j,x_i)\right\},\ x_i \in X, \qquad (4)$$

where $\mu_R^{nd}(x_i)$ is the membership function of the i-th alternative to the set of non-dominant alternatives.

For each alternative x_i the value $\mu_R^{nd}(x_i)$ is understood as the degree of non-dominance of this alternative, that is, the degree at which x_i is not dominated by any other alternative from set $\mu_R^{nd}(x_i)=\alpha$. It means that no any alternative x_i may be better than x_i with a dominance degree larger than α; in other words, x_i can dominate other alternatives, but with a degree not above $1-\alpha$. It is naturally to assume that the rational (best) is the selection of alternatives that have a possibly greater degree of membership to set μ_R^{nd}.

Represent a set of alternatives $X=\{x_1,x_2,...,x_n\}$. Based on the set of alternatives, we construct a fuzzy superiority ratio R with a membership function $\mu_R(x_i,x_j)\in[0,1]$ – any reflexive fuzzy relation, such that $\mu_R(x_i,x_i)=1,\ x_i \in X$.

For any pair $x_i,x_j \in X$ values $\mu_R(x_i,x_j)$ are interpreted as the degree of superiority of the i-th alternative over the j-th, equality $\mu_R(x_i,x_j)=0$ can mean both that $\mu_R(x_j,x_i)>0$, that is, an alternative x_j is dominant over alternative x_j, and that $\mu_R(x_j,x_i)=0$, that is the alternatives are not comparable. Reflexivity is conditioned by the fact that any alternative is not worse than itself.

To build ratio *R,* we use assessments for alternatives obtained using the above method. A problem on decision-making implies choosing the most preferred alternatives from a set X on which we assigned a fuzzy superiority ratio *R*.

We build a fuzzy strict superiority ratio with respect to R:

$$\mu_R^S(x_i,x_j)=$$
$$=\begin{cases}\mu_R(x_i,x_j)-\mu_R(x_j,x_i), & \mu_R(x_i,x_j)>\mu_R(x_j,x_i),\\ 0, & \mu_R(x_i,x_j)\le\mu_R(x_j,x_i),\end{cases} \qquad (5)$$

where $\mu_R^S(x_i,x_j)$ is the membership function of the fuzzy strict superiority ratio.

The best alternative is determined from formula (6):

$$\mu_D(u_j^* = \max_{j=1,n}(\mu_D(u_j)), \qquad (6)$$

where $\mu_D(x^*)$ is the membership function of the best alternative; $\mu_D(x_j)$ is the membership function of the j-th alternative.

In accordance with the intersection operation of fuzzy sets, a membership function for each alternative is derived from formula:

$$\mu_D(u_j)=\min_{i=1,m}(\mu_{A_{Ci}}(u_j)),\quad \overline{j=1,n}, \qquad (7)$$

where $\mu_D(x_j)$ is the membership function of the j-th alternative; $\mu_{Ci}(x_j)$ is the assessment of the j-th alternative for criteria *Ci.*

The choice of the necessary route is such that it most satisfies the entire set of criteria. That is, we can record the following expression:

$$D = A_{C_1} \cap A_{C_2} \cap ... \cap A_{C_m}, \qquad (8)$$

where A_{C_j} is the fuzzy set for the i-th criterion.

In our case: A_{c1} – path congestion; A_{c2} – failure of the intermediate device; A_{c3} – delay in information transmission.

Determine the degree of conformity of each route to each criterion and construct fuzzy sets:

$$A_{C_i} = \left\{\mu_{C_i}(x_1),\mu_{C_i}(x_2),...,\mu_{C_i}(x_n)\right\}, \qquad (9)$$

where $\mu_{C_i}(u_j)$ is $[0,1]$ – estimation of the j-th alternative for the i-th criterion, the degree of compliance.

At the initial stage, when engineering traffic, the process of path formation is important. Fig. 2 shows the process of path formation.

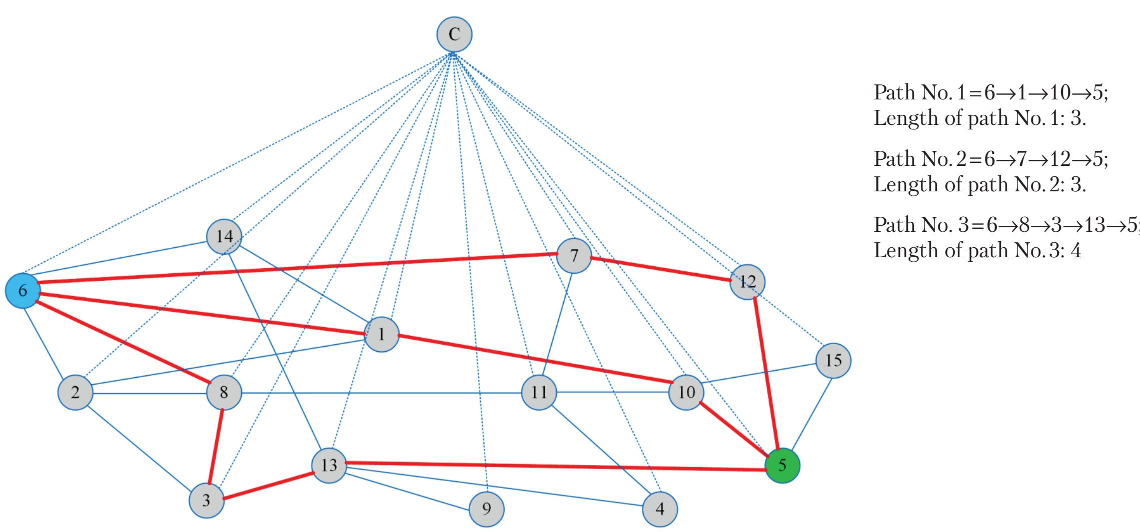

Fig. 2. Route formation according to QoS

Following the formation of paths, at the initial stage of routing, one selects a path based on the decision-making theory in accordance with formula (3).

Represent the algorithm for choosing the best alternative in line with the proposed method for traffic engineering in the form of a pseudocode:

```
if node_fail = True then
    foreach bypass do
        bypass.& ¬ Find_fuzzy_value(bypass)

best_bypass ¬ Find_best_bypass(bypass.value)
return best_bypass
```

The basic idea of the proposed method for traffic engineering in a software-defined network is as follows:

– build a set of paths that do not intersect by using an algorithm of a «reverse wave» [8];

– compute the generalized metric for each of the constructed paths using formula (2);

– at TE, a SDN-controller, using the elements of fuzzy logic and the theory of making decisions, choosed the best alternative among a set of alternatives (paths) applying formula (3);

– in the routing process, in case there is need to bypass the problematic section, one used a decision-making theory (5), which makes it possible to circumvent it without forming a new path.

The result of the simulation is the formed matrix of choice and congestion of paths according to the QoS parameters.

5. Results of experimental study of TE in SDN

In this work, we have developed a program for the simulation of an SD network, by using which we performed a comparative analysis between the proposed technique and those existing.

Modeling the process of traffic engineering was carried using the graph, which consists of 15 nodes, and that receives the input traffic of different character (elastic and non-elastic). We have built, between initial node 6 and end node 5, a set of non-intersecting paths using the modified algorithm of a «reverse wave». By applying the proposed TE technique, we allocated information among paths taking into consideration the QoS parameters, and derived the results of losses for the non-elastic packets.

We have run a comparative analysis of the proposed algorithm of traffic engineering and the uniform traffic distribution algorithm ECMP, which is now one of the most commonly used solutions, and the algorithm of random distribution (Fig. 3).

Table 1 gives an example of data allocation among the formed routes, taking into consideration the type of traffic that is transmitted and in accordance with the value for membership function (3).

Table 1

Path selection taking into consideration the value for a membership function

Path No.	Packet No.														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	7.9	6.8	6.8	6.7	6.9	6.4	6.9	5.7	5.8	5.4	4.9	4.9	3.1	5.4	6.2
2	4.1	3.4	4.7	6.8	7.2	6.7	2.8	2.8	3.8	4.1	5.3	5.5	4.2	4.3	4.5
3	6.4	7.4	6.3	6.2	6.7	6.6	5.9	6.1	5.1	5.2	5.5	5.4	6.0	5.6	5.0

In this case, the packets are transmitted along the following routes:

Path 1={1, 3, 4, 5, 7, 9, 10, 15}.

Path 2={11, 12}.

Path 3={2, 6, 8, 13, 14}.

Path 2 is almost not used, as a given path has a «bottleneck», which would cause a congestion along the entire network in general. Such a decision was made by the network controller based on fuzzy logic.

Table 2

Path selection using the algorithm ECMP

Path No.	Packet No.														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	7.9	6.8	6.8	6.7	6.9	6.4	6.9	5.7	5.8	5.4	4.9	4.9	3.1	5.4	6.2
2	4.1	3.4	4.7	6.8	7.2	6.7	2.8	2.8	3.8	4.1	5.3	5.5	4.2	4.3	4.5
3	6.4	7.4	6.3	6.2	6.7	6.6	5.9	6.1	5.1	5.2	5.5	5.4	6.0	5.6	5.0

In this case, the packets are transmitted along the following routes:

Path 1={1, 3, 7, 9, 10, 15}.

Path 2={4, 5, 6, 12}.

Path 3={2, 8, 11, 13, 14}.

Table 3

Path selection using random distribution

Path No.	Packet No.														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	7.9	6.8	6.8	6.7	6.9	6.4	6.9	5.7	5.8	5.4	4.9	4.9	3.1	5.4	6.2
2	4.1	3.4	4.7	6.8	7.2	6.7	2.8	2.8	3.8	4.1	5.3	5.5	4.2	4.3	4.5
3	6.4	7.4	6.3	6.2	6.7	6.6	5.9	6.1	5.1	5.2	5.5	5.4	6.0	5.6	5.0

In this case, the packets are transmitted along the following routes:

Path 1={1, 4, 7, 10, 13}.

Path 2={2, 5, 8, 11, 14}.

Path 3={3, 6, 9, 12, 15}.

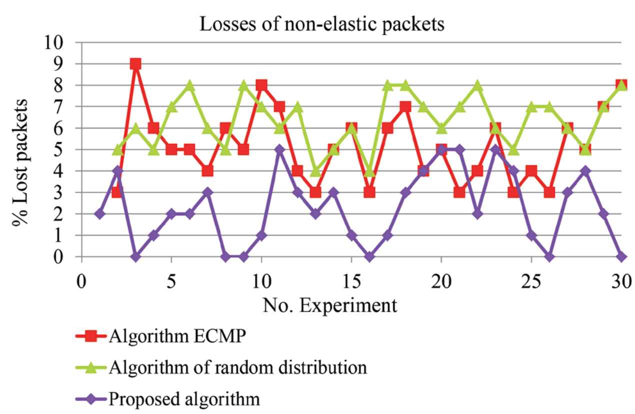

Fig. 3. Losses of non-elastic packets

Based on the results from experiment (Fig. 3), we can conclude that the proposed technique to choose a path, based on the method of decision making, decreases the percentage of losses of the non-elastic traffic in the routing process. This is due to the optimal choice of the path for data transfer at the initial node using fuzzy logic and decision making.

6. Discussion of results of studying the operation of the algorithm for traffic engineering in SDN

In this work we have developed a TE technique that makes it possible to reduce the percentage of losses of non-elastic packets through the use of elements of fuzzy logic in choosing the optimal path for information transmission. The results obtained from a comparative analysis in the form of tables of path congestion and a diagram confirm the effectiveness of the proposed TE technique. It simplifies the process of selecting the optimal route, which makes it possible to reduce the probability of packet loss. By using the proposed technique of traffic engineering in a software defined network we managed to significantly reduce the percentage of losses of non-elastic traffic by applying fuzzy logic and decision making at the initial node, by 35 % on average.

To choose the right path to transmit information, in order to reduce the percentage of packet loss, it has been proposed to use the theory of fuzzy sets.

The devised technique could be useful for mobile networks of great dimensionality for reducing the loss of information in the routing process. However, it should be noted that there is no procedure for the uniform loading of channels that can be considered a flaw of this study.

The further improvement of the traffic engineering technique implies consideration of the channels load forecasting in order to increase the throughput of the network.

6. Conclusions

1. By using the methods of decision making under conditions of uncertainty, we have proposed a TE technique, which is used for solving the task on selecting the optimal path for routing at the initial node, in terms of reducing packet losses in the process of information transmission.

2. The proposed technique, when compared with known algorithms, makes it possible to reduce the percentage of non-elastic packets loss in SDN by 35 %.

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