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PAY&REQUIRE AS CONCEPT OF VARIABLE COST ROUTING IN DYNAMICALLY RECONFIGURED NETWORKS

PAY&REQUIRE JAKO KONCEPCJA TRASOWANIA O ZMIENNYM KOSZCIE DLA DYNAMICZNIE REKONFIGUROWANYCH SIECI

A b s t r a c t

This article presents a new concept of providing service quality with a level required by customers as outcome of an agent system decision making. Decisions are based on network state information and customer requirements concerning transmission quality with accepted costs of transmission. The proposed mechanism, which is called Pay&Require, combines features of decentralized routing systems in computer networks and the newly implemented concept of centralized control determined as SDN (Software-Defined Networking).

Keywords: routing, QoS, agent systems, SDN, PBR, Pay&Require

S t r e s z c z e n i e

W artykule zaprezentowano koncepcję zapewniania jakości usługi na poziomie wymaganym przez klienta będącą wynikiem procesu decyzyjnego system agentowego. Decyzje oparte są na rzeczywistym stanie sieci oraz wymaganiach klienta dotyczących jakości transmisji z zaakceptowanym kosztem. Zaproponowany mechanizm, nazwany Pay&Require, jest kombinacją zdecentralizowanego trasowania w sieci i nowej koncepcji scentralizowanego zarządzania siecią nazwanej SDN (Software-Defined Networking).

Słowa kluczowe: ruting, QoS, systemy agentowe, SDN, PBR, Pay&Require

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1. Introduction

A modern network ensures the efficient and effective information transfer between different types of users: individuals or corporate. For many years research was carried out in order to define and implement mechanisms and architectures, which would provide the diversifying qualities of carried out data transmission, and additionally possibility to define and implement transmission according to determined QoS (Quality of Service) parameters.

Service providers usually charge a fee based on the maximum bandwidth possible to obtain. Unfortunately, this bandwidth is rarely available mainly due to the temporary load of individual nodes and links in the network. Temporal throughput is determined by the least efficient bond in transmission between sender and recipient. Different types of methods and architectures were defined, which enable the management of network traffic using different approaches to the concept of service type, priority and category of transmitted information. For classical IP networks models of IntServ and DiffServ services were proposed, for multiservice network a complete ATM technology was defined, displaced by MPLS. Nowadays, there are novel concepts, such as Software-Defined Networking (SDN), in which the assumed control of the transport layer separation causes a greater network performance. In the case of SDN it was assumed that management is carried out centrally i.e. there is a central repository storing essential rules for network management, created based on information collected from all over the network. Centralization does not always seem to be a good solution due to performance issues (scalability of solution), safety of collected and stored information (one node collecting information).

For the implementation of decentralized network management it is possible to propose the use of agent system concept. The agent approach for the implementation of routing in the graph was proposed in the work [1]. The recalled agent approach in the present article was enriched with the Pay&Require (P&R) concept, in which the separation of the transport layer was assumed (devices physically responsible for transport) from the control (the logic of the system), and additionally decentralization of the control carried out in the network. For that purpose an agent technology was used, which enables the avoidance of the application of a central repository. One of the key aspects of this concept is the fact that the user pays for a particular required connection quality. An important aspect of the article is a reference to Software-Defined Networking, which is still a novel concept, but it seems that it may provide a solution widely accepted in defining the future of computer networks.

In order to analyse the proposed concepts as well as to determine whether the use of P&R is reasonable, an emulating environment of the proposed mechanism was carried out, and the study results conducted on the network model (built for the project's purposes) were presented in this article.

2. The concept of SDN decentralization

SDN (Software-Defined Networking) [2, 3, 9, 10, 11, 12, 14] is a network architecture, in which control layer and data transmission are separated. The separation of layers allows for the introduction of a certain level of abstraction that facilitates the configuration process – the administrator does not need to have a specialized knowledge concerning the configuration of the transport layer, just knowledge of the control layer management, which takes care of the correctness of information provided to the transport layer. The management process is centralized, and the architecture is independent of the topology or the applied network technique. Centralized management is supposed to be among others able to obtain information about full network topology. Important is the assumption that the interface of information exchange between layers is supposed to be available on the principles of open standards and protocols. As a result, modification of the network by external applications will be possible. It consists in the fact that there are established rules concerning (e.g. packet management) the operation of the transport layer.

Generally, the effect of the implemented SDN concept is supposed to be: increased flexibility of solution, centralization of control, simplification of the construction of network equipment and independence from individual producer solutions.

The solution applying SDN concept significantly facilitates network management, but it also has some imperfections. The primary one is a large amount of data that must be stored in a central repository. This results in a situation that when you want to download some rules, it is necessary to search through an entire database of substantial size. Also, the use of storage mechanisms in the cache may not resolve the problem. The downloading and uploading process causes an additional load on the network, which can lead to slow transmission and this in turn can directly cause delays. The suggested solution seems to be also susceptible to failures mostly caused by the centralized repository of the rules. A breakdown of a connection to the repository will cause the entire network to fail.

Additionally, there is a problem of transfer security. Assuming that the control information is sent with the same connections as customer data, it is necessary to think about ensuring the security of the system operation. Let us consider the case where a customer eavesdrops on the control data and then their modified version is sent to the network in order to prevent proper operation of the network or for other reasons, causing disruption to the entire network. In this case, it is necessary to apply appropriate security – e.g. transmission encryption or other mechanisms. These types of mechanisms will cause additional delays in the transmission (exchange) of rules. Another problem constitutes the fact that when decisions are supposed to be taken with regard to individual packets the process of searching for relevant rules

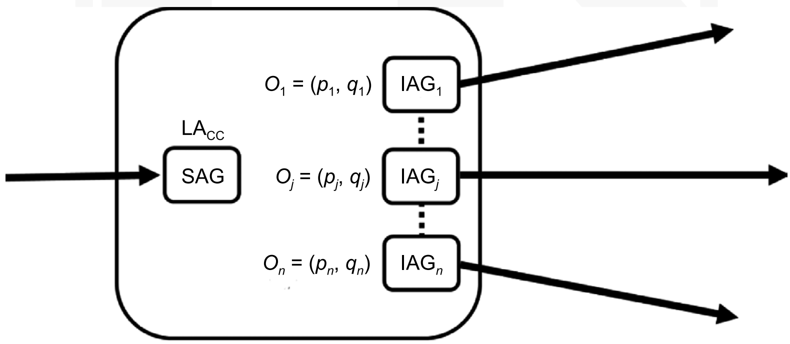

Fig. 1. Scheme of decision making process for packets routing

in a central repository will last long enough so that it will not be possible to call it real-time processing.

All these imperfections result from applying centralized system, created according to the SDN concept. It seems that a decentralization of such a system would solve these problems. Since an agent approach is one of methods of creating decentralized systems, it is necessary to consider exactly this approach for the implementation of a decentralized quality support system for the customer (user).

3. The concept of an agent system as SDN decentralized

To implement the concept of a decentralized SDN it is possible to use the agent approach, which is a known method for implementing decentralized systems. The adoption of the agent system concept requires defining agents appearing in the system. In the proposed solution the following types of agents were introduced:

– NAG – agent in one copy on each node (router). Its task is to manage a given node particularly in directing packets in the right direction.
– SAG – agent that represents the stream of information. Depending on a specific solution, this agent can be a packet carrying information or a packet setting the way (routing).
– IAG – agent that represents the output interface.

The SAG agent further way choice algorithm can be carried out as follows (Fig. 1):

– SAG agent comes to a given node (router).
– IAG agent presents the offer for SAG agent in relation to a further way commencing on a linked interface with this IAG agent.
– SAG agent based on its needs chooses the most convenient offer from those offered by IAG agents. After choosing the recalled offer the SAG agent continues its way through the chosen interface. The NAG agent can help the SAG agent in decision-making regarding the choice of offer.

It remains to define the algorithm by which a decision is taken by the *SAG* agent of the proposed offers by the IAG agent. Of course, it depends on the form of offer and the way of its determination by the IAG agent.

In the presented solution the market approach to determine choice of offer was proposed. For this purpose the Pay&Require conception was developed.

4. The Pay&Require concept

The main aim of the Pay&Require approach is to provide the quality of service (transmission) that meets client requirements. It is worth applying a market approach as a form of customer-supplier negotiations of services/resources.

Requests to provide quality services required by a customer can be implemented in such a way that the user pays for the guaranteed transmission quality i.e. the actual transmission parameters for a packet from the source node to the destination node. This quality is guaranteed by the application of an appropriate routing protocol version, which combines static and dynamic protocol, as well as agent technique. In this case, the concept of quality refers to the most often used parameters of the QoS network such as delay, delay fluctuation, transmission time or the level of packet losses. Introducing such a concept of quality makes it possible to determine certain rates for guaranteed quality (and not, as it is in computer networks for maximum possible to obtain bandwidth, which in many cases is never achieved). It can be assumed that all packets from a given user will be transmitted at a fixed path defined statically in the network layer. To obtain a situation in which there will be a separate route for each user is in practice usually impossible and users must share the same path. When there are many users in the network who require a high level of quality and packets from these users are transmitted in the same route, it may happen that some of the connections will be overloaded. A deterioration of transmission, below the level for which individual users paid, will be a consequence of this occurrence. Then a change of routes should be carried out, i.e. establishing new routes for recalled users. For that purpose a control layer was defined (system logic), which monitors the state of individual connections and in the case of deterioration in quality, it reconfigures the network by defining new routing tables. [1, 4]

The proposed solution agents (NAG) residing on routers, are concerned with monitoring the state of the connections and the configuration of the network layer. One router reports to each agent (or group of routers). Agents exchange information necessary for defining the process of the current form of the routing tables in order to obtain their mutual cohesion and send recalled updated (reconfigured) routing tables to routers which after receiving the tables start to route packets according to the adopted P&R algorithm of the defining paths. In the end packet which do not require the quality on a high level can be directed by a completely different path on which e.g. long delays appear, and the customer will pay less for such a path agreeing to the lower quality of the transmission. As a result, the quality of service will be adapted to requirements, which are expressed by the amount of fees a customer (packet) is ready to incur. In consequence it is possible to state that such an approach also enables pricing (by SAG agents) based on market methods. At fixed prices the users can systematically bid individual levels of quality, and hence the path depending on the demand and availability of paths at the given moment. The proposed approach enables the application of different market methods to buy quality, which will affect the dynamic pricing of individual paths – it will enable development and make use of the supply and demand model of price determination.

From an agent point of view the control layer system constitutes agents, which will reside on routers as well as monitor and change corresponding parameters. As a result of the application of the agent approach decentralization was obtained, which causes reduced susceptibility to network failures (there is no central database containing rules). It is possible to consider two solution levels to the decentralization problem:

- Level 1 – each agent has full knowledge of network topology. This type of approach means that each agent provides to all agents across the network information about the networks connected to the router, on which it resides, in effect each agent has a full information about all routers. In order to achieve consistency of such information, it is necessary to exchange large amounts of data at every change in the network. However, in the case of failure there is no need to exchange additional information the agent can immediately and independently update relevant data or reconfigure the network.

– Level 2 – every agent has only the necessary information i.e. about networks connected to the given router. This approach assumes that the agent stores in its local base only this information that is necessary from the point of view of its function. As a result, when you start an agent it can start working in a relatively short time. In the case of breakdown or a change of network topology there may be a need to obtain additional information. An essential extension can be such a solution in which each agent residing on the router has partial information about the entire network and full information about the nearest neighbourhood.

5. Implementation of a model solution

A study of the proposed agent routing concept, using the Pay&Require approach, was carried out by creating a solution for level 1, in which every agent has exactly the same set of information and knowledge about the entire network topology. It seems that this case will allow us to state whether an application of the proposed concept will affect the quality of data transmission. In individual nodes (routers) an SAG agent selects appropriate further routes (paths) by comparing the conditions offered by the IAG agents associated with individual output routers. In the studied solution each SAG agent that represents packets sent by an established sender has a determined level of price lpacc approval – an established level of maximum price, and quality which is determined by $\mathrm{Par}_{\min}$ and $\mathrm{Par}_{\max}$ parameter defined as percentage deviation from quality level.

Table 1

Exemplary features of links for various service levels

Rate	Bandwidth [Mbit/s]
4	100
3	50
2	10
1	5
0	1
–1	link inactive

On every router there are IAG agents – each of them is connected to one interface it represents. Every IAG_j agent presents to SAG agent the connection offer $O_j = (p_j, q_j)$ where p_j – price of the connection offered by IAG_j agent, and q_j – quality of the offered connection. Next the SAG agent (if necessary with the help of the NAG agent) determines a set of acceptable Of_{acc} offers:

$$Of_{\mathrm{acc}} = \{Of : Of = (p,q),\ p \le l_{p_{\mathrm{acc}}} \wedge q \in [Q_{\min}, Q_{\max}]\} \tag{1}$$

where

$$Q_{\min} = q - (\mathrm{Par}_{\min} * q), \quad Q_{\max} = q + (\mathrm{Par}_{\max} * q)$$

Next the SAG agent selects the best Of_k from acceptable offers, according to the rule:

$$Of_k = \min_{Of_j \in Of_{\text{acc}}} \{p_j : Of_j = (p_j, q_j)\} \tag{2}$$

Summing up: the presented offers by the IAG agents determine a further connection (related to quality and price) and the SAG agent chooses the best quality offer out of those which price is within acceptable limits.

6. Implementation of the emulation studied examples

For the purpose of the project an emulator was prepared, consisting of software providing functions of control layer and routers in the transport layer. The Vyatta system (VyOS) was used for routing. The first activity which the control layer carries out is to download the initial router configuration concerning the interfaces. The downloaded configuration is carried out for each router individually. When the software has downloaded configuration of all routers an analysis of the information takes place. The analysis consists of searching for active connections between individual routers.

It was assumed that between routers there are point-to-point connections. Software stores information about all connections between the routers. Next, a bandwidth of individual connections is established in order to carry this out, through every single connection a file of fixed size is sent (e.g. 10 MB). The size of the file can be chosen arbitrarily, however, in the study it was stated that 10 MB was an appropriate size. Information concerning transmission time and average bandwidth in bit/s was obtained in this way. Information of this type is stored for each link. Then based on measured bandwidth an evaluation of the route is appointed. A rating scale resulting from measured parameters was defined. This scale can be freely modified by the administrator – it is possible to define any rating scale.

For the presented emulation purposes a quality scale expressed by the allotted bandwidth was used, presented in Table 1. A maximum bandwidth of 100 Mbit/s is caused by limitations of virtualizing software used for emulation. Evaluation is assigned to individual links.

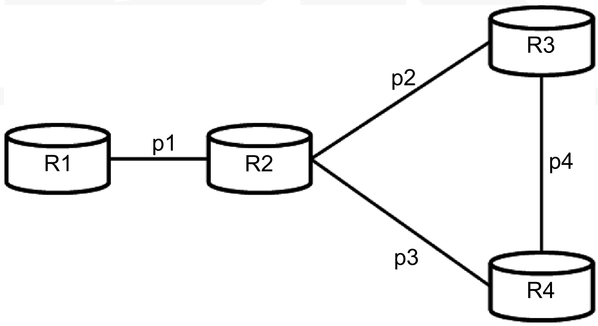

Fig. 2. Network example – characteristics of routing algorithm

The next step is to define paths. Paths lead from the source to the destination router through other routers. In order to outline all possible paths the following algorithm is applied:

1. Take the first free path of length 1 (linking only two routers). Proceed to point 2.
2. Outline all possible non-repeating paths (no loops - point-to-point connection can be used only once) for length +1. Follow step 2 for so long until there is no longer path to choose from – you cannot proceed further because all available point-to-point links were used.
3. Repeat the step from 1–2 for all point-to-point connections.

In Figure 2 a network used for the emulation was presented. Let R be a set of routers, R = {R1, R2, R3, R4}, let P be a set of connections between routers, P = {p1, p2, p3, p4} where p1 = {R1, R2}, p2 = {R2, R3}, p3={R2, R4}, p4={R3, R4}.

PR1={{p1}}

PR1={{p1},{p1,p2},{p1,p3}}

PR1={{p1},{p1,p2},{p1,p3}}

PR1={{p1},{p1,p2},{p1,p3},{p1,p2,p4},{p1,p3,p4}}

PR1={{p1},{p1,p2},{p1,p3},{p1,p2,p4},{p1,p3,p4},{p1,p2,p4,p3},{p1,p3,p4,p2}}

Evaluations are assigned to individual paths. It is possible to consider two possible approaches:

– appoint an average evaluation of the path based on evaluations of individual point-to-point connections on a way from the source (the first router in a given path) to the destination (the last router).
– as the evaluation of entire path taking the lowest evaluation of a point-to-point connection on the way from the source to the target.

Use of the second approach seems to be preferable because a connection with the lowest bandwidth will reduce the bit rate on the entire route. Evaluations of paths are stored along with information about the number of routers which a packet must go through in order to reach transmission target in a given path. This information will be used later to take a decision about the choice of paths in a situation where several paths have the same evaluation. Another step is to select a path for the customer. In the application information about a client ID and expected service level are stored (in accordance with a rating scale). At first, there is a verification to which routers the customers are connected (network configuration enables transmission between individual customers). Next all possible paths are outlined from one customer to all remaining customers (this process is carried out for all customers). For accepting a given route its evaluation decides – if this is what a client expects or higher (when there is no expected), then this route will be selected.

In the case that there is no route with the quality level for which the customer paid, or higher, a message will appear about the lack of routes. In the future it is necessary to consider how to solve this problem (e.g. a refund, negotiating with the customer). From acceptable paths one is chosen – the one which has a low hop count. If there is more than one route with the same rating then the first from the list will be chosen. When all paths will be chosen for all customers, it will be followed by a configuration of routing layer (routers).

Routing and forwarding in computer networks is based on information brought in the header of packet, i.e. for transmission purposes. In case of classical routing the device compares the address of the network to which the packet is supposed (longest prefix matching) to be sent with addresses included in its own routing table and based on this information router redirects the packet to the next router or target device. In Figure 3 a scheme of computer network is presented, which will be used to describe the operation method. In the case of the described network between PC1 and PC2 computers and a PC3 computer there are two paths. The first path leads through R1-R2-R3, and the second leads through R1-R4-R3. Metrics were assigned to individual connections. It was assumed that if all the metrics have a lower value, the connection is better. Therefore, according to the rules of classical routing the transmission between PC1-PC3 and PC2-PC3 will proceed exactly along the same route (R1-R4-R3).

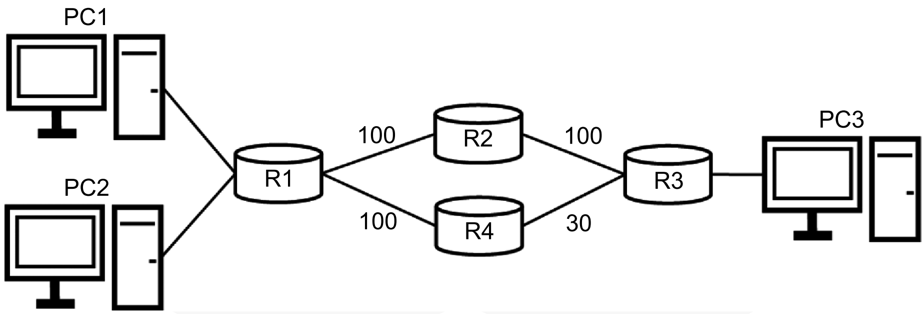

Fig. 3. Network example – classic routing and P&R comparison

In computer networks the PBR concept was defined (Policy Based Routing). [5–8, 13]. This technique allows the administrator to define complex routing rules, i.e. a decision about the next change can be taken not only based on destination address, but also e.g. on source of transmission, port number. PBR enables the definition of more than one routing table – for each user (groups) the administrator can independently define which transmission path will be stored. Of course, a substantial matter is that there should be more than one path between the source and target – then PBR makes sense. By analysing the case presented in Figure 3 the administrator has the possibility to configure routers, so that packets from a PC1 computer sent to a PC3 can travel a different route (e.g. R1-R2-R3) than packets from PC2 sent to PC3 (e.g. R1-R4-R3). Therefore, with the use of PBR it is possible to diversify the routes depending on the transmission source. PBR technique was used in the emulator for the routing purpose. After conducting the configuration of the transport layer (the routing tables) the network begins to operate in accordance with customer expectations.

7. Research results

Emulation was started by setting the network of 4 routers (Figure 2). To router R1 and R3 – 4 users were connected. Users were simulated with the following requirements concerning quality: two users needed the best quality (=4) – to router R1 and R3 one such user per router was connected, two users needed low quality (=2) – to router R1 and R3 one such user per router was connected.

An aim of the emulation was to present changes in the choice of paths depending on the bandwidth of the individual connections. In the case of the used network a total separation of transfer does not appear, since between router R1 and R2 an alternative connection does not appear. In the emulation paths outlined between users connected to R1 (high and low quality) and R3 were taken into account. It was started by checking selected paths in a time when there is no fault in the network.

Figure 4 presents the result for the network with maximum operating parameters. A chosen route was marked with a thickened line in this case for both customers the same path was chosen. This path has the smallest number hops, and parameters concerning quality are comparable with the available paths. Another stage of the emulation assumes a degeneration of the connection parameters between R1 and R2. This fault did not cause a change in the chosen path since an alternative connection does not exist in the above network for R1-R2. It means that still the chosen path corresponds to the one presented in Figure 4. The next emulation was carried out when a bandwidth decreased between R2 and R4. In the case of a customer requiring the best quality the path did not change – this path has the maximum quality (Fig. 4). In turn, the path for a customer requiring low quality changed. A chosen path was presented in Fig. 5. It is possible to observe that a chosen path is longer than the one which was chosen in a previous emulation. It is due to the fact that the user paid for low quality and such quality he received. In the previous emulation there were no possibilities to provide quality at the expected level – only the best quality

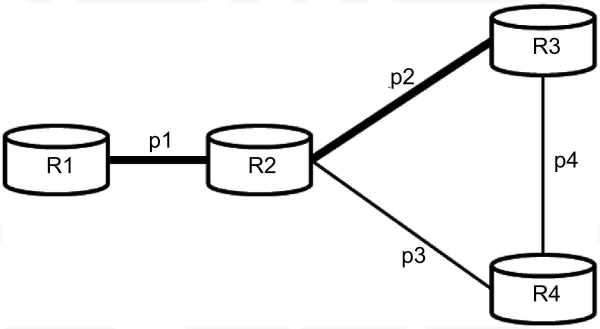

Fig. 4. The selected path for the network operating with maximum throughput

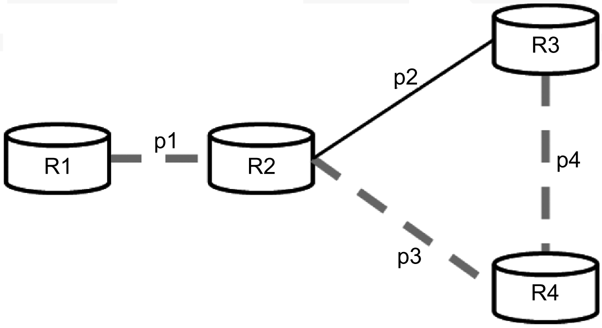

Fig. 5. The selected path for the customer who accepts low quality in case of network with worse R2-R4 link parameters

appeared and so the user also received it. This type of decision results from the characteristics of the algorithm of path choice.

The next emulation was a reduction in bandwidth R3-R4. In this case, this fault did not cause the path change of the user requiring the best quality – the earlier path is still the best choice (Fig. 4). However, in case of the user expecting low quality the same path was chosen as in case of the deterioration connection parameters R2-R3 (Fig. 5). Choice of this type results from the fact that this path still provides the expected quality i.e. low level.

The last emulation case was a reduction in bandwidth between R2 and R3. In this case, for the user requiring best quality a chosen path was presented in Figure 6. Next for the user requiring low quality a chosen path was presented in Figure 7. Such a choice of path results from the fact that route R1-R2-R4-R3 guarantees quality at a high level, despite the fact that number of routers through which the packet must pass is higher. In turn, route R1-R2-R3 in this case has low quality what is a result of the degeneration connection parameters between R2 and R3.

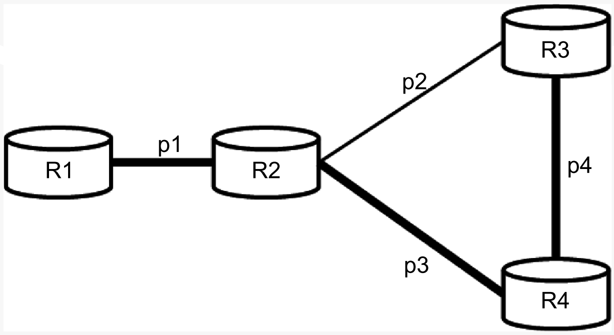

Fig. 6. The selected path for the customer who accepts high quality in case of network with worse R2-R3 link parameters

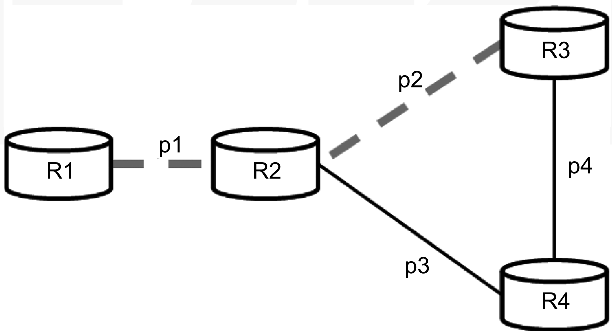

Fig. 7. The selected path for the customer who accepts low quality in case of network with worse R2-R3 link parameters

Figure 8 presents comparison of transmission times in the case of classical routing and Pay&Require. In order to determine times two measuring tools were used: ping and transmission of a file with a fixed size of 100 MB. Ping was carried out 1000 times for each case, and file transfer was carried out 30 times. In order to determine the reference time measured when the network operated with maximum parameters and the same path was chosen for both customers. Results for both qualities are similar and the differences are slight.

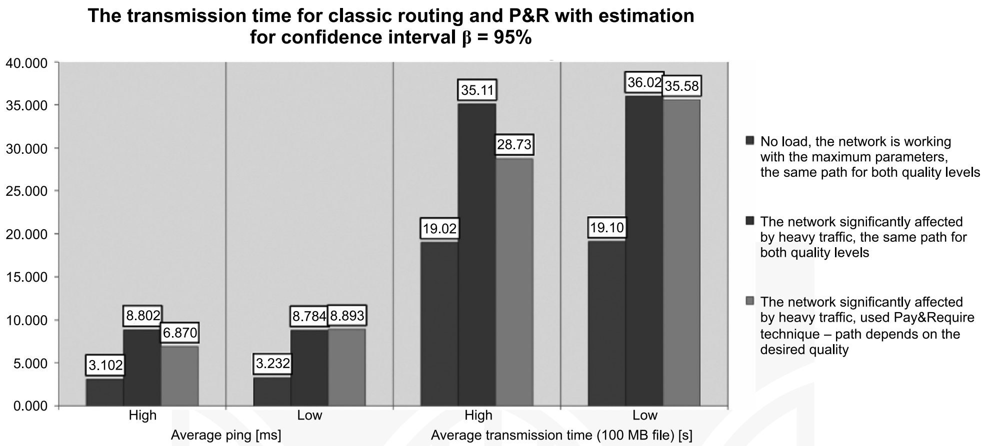

Fig. 8. Comparison of the transmission time for classic routing and P&R

In a further step it is necessary to state how transmission time changes in the case of overload network. The network was overloaded by the initiation of many simultaneous transmissions of large data between devices connected to R1 and R3. At the same time measurements of transmission time were carried out in the case of requiring high and low quality. It is possible to observe a big increase in transmission time – in the case of ping the time increased almost threefold.

In turn, the average transmission time of a file with sizes of 100 MB increased almost twofold. Because of the above two measurements it is a point of reference for the last research stage.

In the last stage a measurement of times for the same overload network was carried out using Pay&Require. The customer requiring high transmission quality received a different path than the one requiring low quality. The path for low quality is the same as the one which packets that overload the network are sent. It is possible to observe that transmission time for low quality in comparison to the previous case practically did not change, however, in the case of the best quality a significant improvement was obtained. Transmission times significantly decreased. Unfortunately, the connection between R1 and R2 constitutes a section that affects transmission quality, since every transmission between R1-R3 must go through it. Therefore, it is possible to suspect that if there was an alternative for connection R1-R2, then transmission time for the best quality would be reduced and similarly for transmission in the case of the unloaded network.

The conducted research suggests that the Pay&Require concept has merit and constitutes an alternative to methods of providing quality and pricing in computer networks.

8. Conclusions

The Pay&Require concept presented in this article may constitute an alternative to methods providing quality and pricing in computer networks. The user pays for guaranteed transmission parameters, which are practically implemented as a result of the choice of appropriate path for transmission. Quality parameters of individual paths are systematically monitored and, if such a need occurs, paths are modified, because of decentralized function of the agent system.

The presented concept refers to Software-Defined Networking technology, which constitutes a good starting point for a definition of a new mechanism for the separation of the control layer from the transport layer. There was an attempt to remove SDN imperfections specified in the article, such as centralization of the solution. In the case of the P&R mechanism a decentralization of control and agent technique was used. It was necessary to carry out a study aimed at the state of the legitimacy of the application of the P&R concept.

Research results show that the use of the P&R mechanism to provide specific quality parameters caused the desired effects, i.e. a significant improvement was obtained in relation to classical routing. Thus, it is possible to state that quality was provided at a level expected by the customer. The conclusion from the conducted study is clear, i.e. the established effects of the P&R mechanism application were achieved, therefore this approach is promising and should be developed. It is necessary to carry out further research for more complex networks in order to verify the performance of the algorithm and optimization of its operation in different conditions.

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