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THE METHOD OF DETERMINING OF TRANSMISSION PROPERTIES OF NETWORKS BASED ON REGULAR GRAPHS TOPOLOGY

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Summary: The paper presents a methodology of study the properties of the transmission networks modeled by 3'rd and 4'th degree chordal rings, developed by the authors. Research methodology is based on two kinds of tests. First of them, measured the amount of data transmitted in different network structures using the HTTP protocol. The second, was measured quality of the received video stream, by the SSIM (Structural similarity) method. For testing, the set of virtual machines, connected by virtual network of 3rd and 4th chordal rings topology were used.

Keywords: network, chordal rings, graph, quality, capacity.

1. INTRODUCTION

Due to the rapid growth of the traffic occurring on the Internet, which doubles every year [7, 10, 14], it is necessary to increase the capacity of existing networks. To ensure the quality of the transmission it is necessary to increase the network capacity and reduce the delays in data transmission, what is particularly important in the transmissions of images [11]. To meet these demands, more new generation of sophisticated equipment is introduced, which enables faster data transmission. An example of such activities is application of optical networks with expanded optical domain where optical routers and switches are [8, 9]. Many of the operating systems are not built with the usage of the latest technology. But also in such case it should be looked for the appropriate solution to ensure the quality of transmission. It was found that besides the usage of the equipment the significant impact on network bandwidth have also the usage of communication protocols, the management of network resources, that allowing to adapt this structure to changing conditions and requirements and as the implemented topology of the network [3, 13].

The network transmission is a primary component of Information and Communications Technology systems (ICT). The ICT systems consists of a routing equipment and software, providing the necessary processing power, storage, and routing, with the usage of appropriate network end device. The ICT consist of a large number of intelligent nodes, which aim is to provide users a specific range of services, by ensuring relevant quality, speed and reliability of the system. The main issue in design and analysis of ICT systems is a topology of the different layers which are interconnected between each other (Interconnection Network), this especially impacts the effectiveness of whole system [12].

The network structures can be modeled with the usage of graphs [4, 5, 6]. In telecommunication systems the basic network topology is a ring topology. In network formed into ring nodes are represented as a switching modules or specialized computers, and the edges are a bidirectional independent transmissions channels which connects these nodes. This type of graph is called an undirected graph of single Hamilton cycle (ring graph), so that there are always two ways to connecting two arbitrary network nodes. The direction of the traffic flow in this type of graph can be clockwise or counter-clockwise. In practice this connection is realized using optical fibers. The usage of this topology improves the reliability of the transmission, because the failure of a link or node does not cause the failure of whole corruption system, but it will be the cause of decrease of the efficiency of data transfer in the network. The advantage of this network structure is also standardization of nodes, small number of intermediating links and good scalability [2]. Moreover, as is clear from the theory of reliability, the ring topology has the best reliability to cost factor [1, 15].

However, the network structure based on ring structure has the worst transmission properties. For example, if a part of this structure shall be nodes and we want to ensure the exchange of data between any node, it is necessary to flow the network traffic through all the intermediating nodes. Thus, each of these nodes must receive and send data to the next nodes, which causes the reduction of the transmission speed and increases of the delay of transmitted data.

The addition of additional connections between the nodes, called chords, causes increase of the network bandwidth. This structure, called „chordal ring", Arden and Lee used to build multicomputer network, to speed up the computational processes.

Usage of a chordal ring led to reduction in the number of the intermediary transmitting nodes. The reduction of the number of nodes provided the minimization of the occurring the delays, and by appropriate choice of the length of these chords, the network can be optimized for increasing its capacity. Chordal ring is a special case of regular graph, in which each vertex has the same degree. The usage of chordal rings enables to: standardization of equipment nodes, obtaining symmetry calls. Moreover, it provides ease of routing, good scalability and easy network management. The whole of this task reduces the total cost of building and operating the network.

The aim of this publication is to present the testing methodology, samples of regular structures and results obtained from the study with conclusions justifying the usage of the chosen topology connections in real life case scenario.

2. EVALUATION METHOD OF NETWORK TRANSMISSION PROPERTIES

In order to evaluate the important parameters of networks, which are bandwidth and the delay of transmitted information it is necessary to carry out the samples from the test topology described by regular graphs. These studies were performed using a set of virtual machines connected to each other via VPN which simulates the real network.

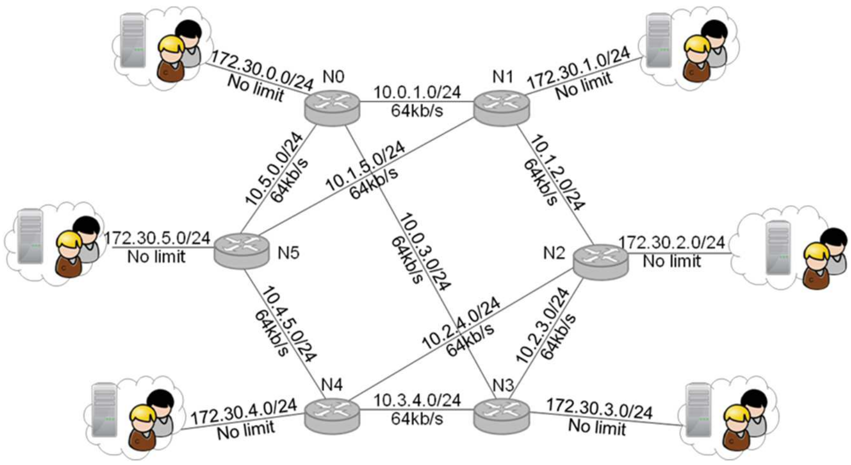

Fig. 1. Diagram of an exemplary network

Vertices of graph and thereby nodes of network are the routers. This nodes are connected between each other by links which are performing the role of the edges of the graph (Fig. 1). Assumption of uniformity of the traffic on the network was used. For each of the routers proper subnet was set, which contains server and clients (the number of which is equal and predetermined). In order to access the data files stored in the servers connected to other routers, each user sends a query to them. The server sends answer with the desired data. During testing was also carried streaming – servers sent video files addressed to clients belonging to other subnets. In this way traffic was generated. It was used to test the network.

The analyzed networks were built based on the software routers installed on virtual machines running under the operating system Vyatta [15]. It is a Linux distribution designed to use it as a router or firewall. For virtualization was used the open-source software called VirtualBox. It has a wide range of configuration of network interfaces of virtual machines. For the interconnection of routers was used "Internal Networking" mode, which allows to create Ethernet connections between virtual machines. To manage the configuration of the whole network and as the software of servers and clients set of original programs implemented in Java and Python was used.

To eliminate influence of the computing power of computers on which tests were carried out bandwidth between nodes in an experimental way was limited to 64 kb/s. The IP addresses of the routers interfaces were determined statically and a dynamic open routing protocol OSPF was used [14]. An example of the routing table for one of the nodes is in Figure 2.

To examine the structures of the network, in respect of their–transmission properties two test scenarios were used. The first measured the amount of data transmitted in different connecting structures using the HTTP protocol, while the other one performed real-time transmission of video streams and then the quality of the received images was measured.

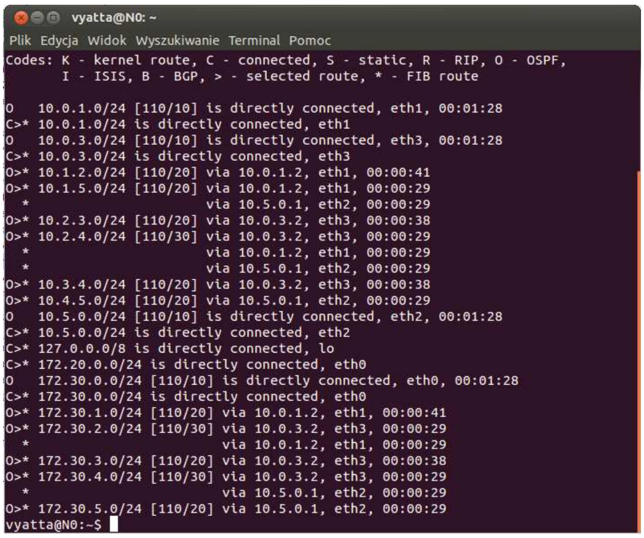

Fig. 2. An example of the routing table

To test the network modeled by regular graphs the HTTP protocol was used, because it is generally used in the Internet by the majority of the users when web browsing and the machine performing the services offered by the network. To specify the type of traffic which is most common on the Internet the amount of traffic associated with the seven most popular web services was rated. It was also based on the survey carried out in 2012 [14]. This sites were: Google, Facebook, Biadu, Youtube, Twitter, Yahoo! and Wikipedia. For each of them the most popular subsites or most often queries (in case of search engines) were determined. Then measured the average content size of servers answer or caused by requests. In the case of Youtube only loading the page was taken into account (without downloading videos). The results of these measurements allowed to determine the conditions for testing the network which is shown in the diagram (Fig. 3).

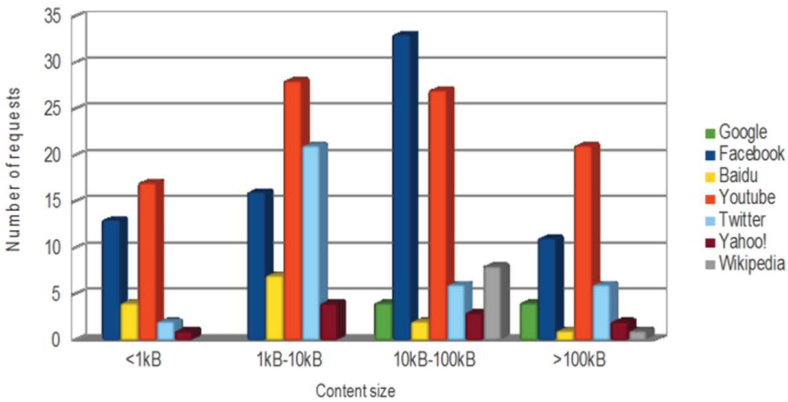

Fig. 3. The size distribution of the HTTP response content for selected pages

The chart shows that the largest number of inquiries related to the website YouTube and social networking sites like Facebook, and a little less- Twitter. Size of transferred data was correlated with the type of the observed portal. In case of YouTube can be considered that the distribution of the transmitted data was reasonably uniform for the entire test range of 1 kB to 100 kB. In the case of Facebook, most data had size ranged from 10 kB to 100 kB, while the majority of data from Twitter had a size of 1 kB to 10 kB. Based on this analysis, taking into account the possibility of used computers and required bandwidth, it is assumed that the test data a size is between 1 kB and 32 kB.

Tests using the HTTP protocol were carried out assuming the following initial conditions:

- networks were described with fourth-degree regular graphs consists of 24 nodes;
- clients send requests to web servers, and download speed of response was measured (the size of data without the size of the HTTP headers was taken into account).

The average data transfer rate was calculated according to the formula:

$$V_{TR}[\mathrm{kB/s}] = \frac{\sum_{i=0}^{n-1}\sum_{j=1}^{m} Dane_{ij}(T)}{(n-1)\cdot m\cdot T} \tag{1}$$

where:

counter determines the amount of data during the test,

n – amount of servers,

m – amount of clients in the node,

T – time of the test.

- HTTP requests were generated by 5 users in each node with the assumed uniform distribution of probability selection of target servers to which queries were addressed;
- for the submitted queries users received a response about the size of 1 ÷ 32 K;
- the study was conducted for timeouts changed in the range of 10000 ÷ 50000 ms;
- the frequency of sending queries varied in the range 0.02 ÷ 0.2 Hz;
- as the result of the test assumed the arithmetic mean of the results obtained from the three replicates of the same test.

The study of the network transmission properties were performed via the streaming transmission according to the following rules.

Between the servers and clients were transmitted video streams. For the tests were used records, obtained from the database LIVE and the database EPFL, while maintaining the cumulative 15-second duration on transmission of a single stream. These samples (30 frames per second) were stored in YUV format.

To carry out the tests in conditions similar to those that occur in real networks, has been carried out pre-conversion films used for H.264 [15]. For this purpose, used two tools Mencoder and avaconf. During converting the recordings resolutions were reduced, established the number of frames per second, it means that the frequency with which static images were sent to the recipient was fixed. In addition, experimentally were chosen the parameters: CRF (Constant Rate Factor), responsible for the quality of the converted images and also parameter specifying the maximum interval between frames, containing all the frame of images [9].

The principle of testing consisted on sending servers streams in H.264 format to all clients on the network, with the assumed uniform distribution of the choice of source servers. Streams carrying video information were organized in a NAL unit (Network Abstraction Layer). The first byte of each of them served as a header and specified the type of data transmitted in this unit. The remaining bytes from passing information are specified by the header (Fig. 4).

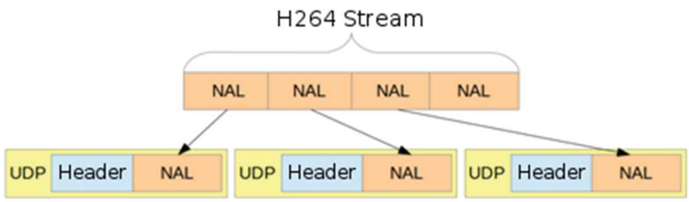

Fig. 4. Flow diagram

Based on the analysis of NAL units, complementing it with a header, server sent to clients video information in UDP packets. The headline contained a stream number, frame number and time of sending the package. Sending information held in the pace at which the stream should be played on the receiving side. The client application after receiving the package checked that the established maximum time delay (timeout) has not exceeded. If this time has not been exceeded, the usable content of the NAL unit was appended to the previously received stream while preserving the order of packets received correctly. Otherwise, the package was dropped, which resulted in the deterioration of the quality of the received images.

Each received stream was decoded and were created single movie frames. Reference streams were also decoded, and then both of these streams were compared frame by frame using the method of SSIM (Structural Similarity Index Method). SSIM method is used to determine the coefficient of similarity of images. This factor can take a numeric value in the range 0÷1, where 1 means identical pictures, 0 – lack of similarity. Each frame was analyzed broken into three constituent colors (Red, Blue, Green). Factors were calculated for each of these components separately and returned as the arithmetic average calculated for all frames of all streams transmitted in a single study.

To illustrate changes in quality of images comparing it to the original images, Figure 5 and Figure 6 shows examples of such packet loss for movie stream sent during the test.

In order to verify properties of network transmission modeled using chordal ring topology some tests were carried out assuming the following conditions:

- servers connected to the nodes sent to the client video streams in H.264 format, through a 24 nodes network, and the connections were described by chordal rings third and fourth degree;
- the type of transmission used was "unicast", it means that one server sent packets to exactly one customer;
- in each subnet streaming took away whatever 5 users, with the assumed uniform probability distribution of the users choice of servers;
- customers received the streams with variable frame rates with experimentally titrated CRF parameter;

- the study was conducted for timeouts which changed between 1000÷5000 ms;
- the result of the test was a qualitative SSIM value arising from the comparison of sent and received frames from streams.

Fig. 5. Original picture without compression

Fig. 6. Reconstructed picture with the SSIM = 0.549

3. TEST RESULTS

The Figure 7 shows an example of network topologies described by fourth-degree graphs, which have been tested.

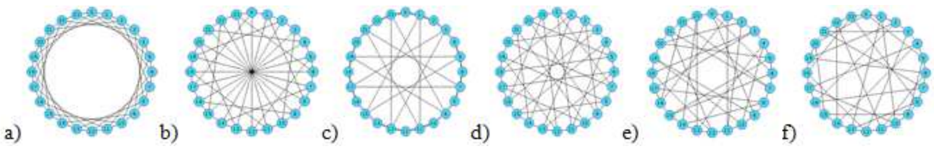

Fig. 7. Example of network topologies described by fourth degree graphs

4. THE NETWORK TEST WITH THE USAGE OF THE HTTP PROTOCOL

The following graphs show the average data transfer rate from the point of view of the network user described by the tested graph as a function of changes in the frequency of sending queries to the server for different waiting times to receive packets.

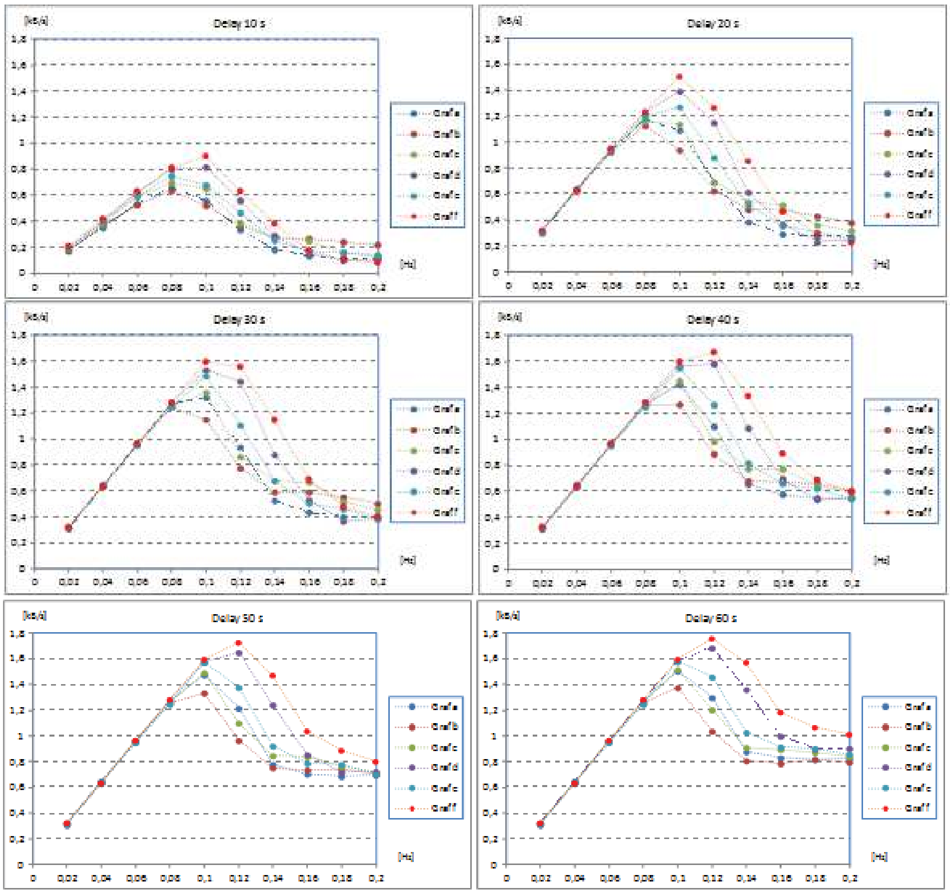

Fig. 8. The average data transfer rate

Based on these results it can be concluded that an important parameter which influence the speed of data transfer is the waiting time (delay) of the transmitted data. It is easy to spot that if this time is short (10 s) the network throughput is twice less than in the case when the time is for example 60 s. With the increase of the frequency of sending the queries to the server, which send the requested information to customers, initially an increase in data rate was observed until the network reaches a maximum saturation. After that the transfer rate decreased, which is related to the blocking effect of network excessive sheer volume of transferred data. For example, Figure 8 shows the change in rate in the network described by “f” graph type. Lengthening of waiting time for packages does not bring significant profits, while only slowing down the whole processes in the network.

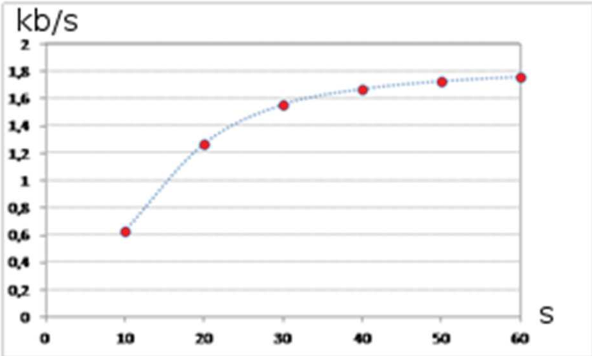

Fig. 9. The rate of change in the network

Tests have shown that regardless of the assumed network topologies (Fig. 9), their bandwidth at a given period of time, waiting for the packages is the same, but the differences appear when the frequency of the query begins to rise above a certain threshold (0.8 Hz). The highest throughput was achieved when the network was using the “f” topology graph and this is due to the fact that it has both the smallest diameter and average path length [7, 10].

5. EXAMINATION OF THE SIMILARITY COEFFICIENT TRANSMITTED AND RECEIVED VIDEO STREAMS

For different values of the acceptable waiting time for receiving packets after transmission through the test network were carried out to measure the similarity of the streams studied as a function of the FPS (Frame per Second) parameter. These tests were carried out for the parameter CRF = 35 (Fig. 10).

From the obtained results of the network research it can be concluded that with increasing of the waiting time for receiving packets improves images quality. This is because it increases the probability of reaching the destination by more packets. Increasing the number of frames sent per unit of time, increases the fps differences between calibrating and incoming frames, which results in increasing the amount of data transmitted over the network leading to its saturation resulting in loosing of packets.

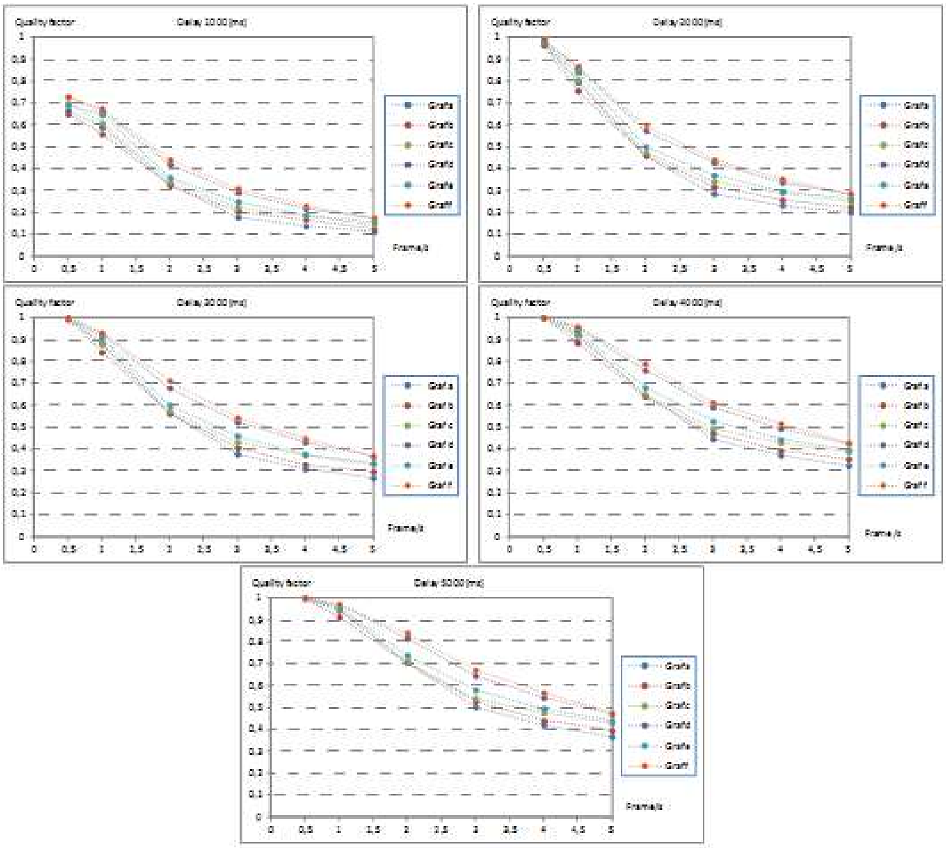

Fig. 10. Examination of the similarity coefficient received video streams

The studies showed that when using the HTTP protocol its best performance is achieved when the network has topology described on a graph "f". This is confirmed by the fact that the parameters determined by the diameter of the motor network and the average path length of the graph describing the topology of a given connection. The size of the diameter gives an overview of the maximum delay for transmitted data, which will be the sum of the delays from the intermediating nodes which results from implemented by the routing function [12]. On the resulting delay consists other things like times needed to analyze the header, packet buffering, and in the case of fiber optic networks – time need to make OEO conversions (Optical – Electrical – Optical). The size of the average delay of transmitted data is closely associated with the average path length characteristic for the following structure. The smaller it is, the average path length transmitted data before reaching the destination, which results in smaller usage of network resources, which allows you to share unused resources for more users.

6. SUMMATION

The article discusses the methodology of the study of properties of transmission in networks modeled by chordal graphs. For this purpose two types of tests where performed. One of them relied on the measurement of the amount of data transmitted in different network structures using the HTTP protocol, while the second was the measurement of the quality of the received images in a video stream by the comparative method called SSIM (Structural Similarity).

The obtained tests results confirmed the validity of the assumption that both the diameter and the average length of the paths have a decisive impact on the throughput and delays of the data sent over the network.

The tests were performed according to the concept proposed by the author involving the usage of a set of virtual machines connected to each other in virtual chordal rings network topology. To make sure that the method is correct, additional tests were conducted using a network modeled by chordal rings using real devices. The obtained results confirmed that the results obtained from simulations. Analyzing the results of both tests we can make an attempt to estimate the received packets minimum waiting time to get establish the capacity and acceptable image quality as a function of the frequency of transmitted frames when streaming. The conclusion is that the proposed method using a set of virtual machines allows for the examination to make the topology optimization before they are put into service.

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METODA BADANIA WŁAŚCIWOŚCI TRANSMISYJNYCH SIECI O TOPOLOGII GRAFÓW REGULARNYCH

Streszczenie

W artykule zaprezentowano opracowaną przez autorów metodykę badania własności transmisyjnych sieci modelowanych przy pomocy grafów cięciwowych trzeciego i czwartego stopnia. W tym celu użyto dwóch testów. Jeden z nich polegał na pomiarze ilości danych przesyłanych w różnych strukturach sieciowych przy pomocy protokołu HTTP, natomiast w drugim mierzona była jakość odebranych obrazów w strumieniach video metodą porównawczą SSIM (Structural SIMilarity). Testy były wykonane według opracowanej przez autora koncepcji polegającej na wykorzystaniu zbioru maszyn wirtualnych połączonych pomiędzy sobą wirtualną siecią o topologii pierścieni cięciwowych trzeciego i czwartego stopnia.

Keywords: sieci, pierścienie cięciwowe, graf, jakość, wydajność