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Measurements of routing protocols performance for high-throughput computer networks in OPNET environment

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Abstract

In recent years, we are observing the rapid development of information systems, especially distributed systems. One of the important components of these systems is the communication infrastructure, consisting of both the topology and routing protocols. The article presents an analysis of commonly used routing protocols in high-throughput computer networks conducted in OPNET environment. Possibilities of analysis of these protocols for different topologies are presented. From the point of the functioning of the routing protocol performance view, measurements were made for relevant parameters such as convergence time, bandwidth etc. In addition, there was proposed the use of the butterfly topology to create an effective environment for routing in computer networks based on the classic three layer connection system.

Keywords: computer networks, routing protocols, OPNET.

Pomiary wydajności protokołów routing dla wysokoprzepustowych sieci komputerowych w środowisku OPNET

Streszczenie

W ostatnich latach jesteśmy światkami gwałtownego rozwoju systemów informatycznych, zwłaszcza systemów rozproszonych. Jednym z istotnych składników tychże systemów jest infrastruktura komunikacyjna, składająca się zarówno z topologii połączeniowej, jak również z protokołów routingu. W artykule przedstawiono analizę powszechnie wykorzystywanych protokołów routingu w wysokoprzepustowych sieciach komputerowych przeprowadzoną w środowisku Opnet. Zaprezentowano możliwości analizy takich protokołów dla różnych środowisk topologicznych. Dokonano pomiarów istotnych parametrów takich jak czas zbieżności, obciążenie łącza, itp. z punktu widzenia wydajności funkcjonowania protokołów routingu. Dodatkowo, zaproponowano wykorzystanie topologii Butterfly dla stworzenia efektywnego środowiska routingu w sieciach komputerowych bazujących na klasycznym trójwarstwowym systemie połączeniowym.

Słowa kluczowe: sieci komputerowe, protokoły routingu, OPNET.

1. Introduction

At present, known means for increasing the carrier networks performance often focus on the physical aspect, by increasing the number of connections or devices. Intentionally, changes in the logical structure are omitted due to the complexity of required works in this field. Such actions are a result of the adoption of the model, in which each stage of the project is considered as an independent operation, and obtained results are only input in the next step. Such approach coherent with a static or incremental design [1, 2] introduces too far reaching simplification and doesn't allow to fully use the potential of the available solutions. From this perspective, it seems reasonable to adopt an evolutionary model [2], in which on different stages of the design process should be analyzed various parameters of the proposed facility and made necessary changes to it. Ensuring a high level of correlation parameters in the context of requirements of the users requires periodic modification of the proposed object. In this concept there is necessity of performing analysis of routing protocols in the context of considered physical topology. Unfortunately, in most cases, the design and selection of the physical topology is performed independently on the selection of the routing mechanism. Therefore, in the paper, measurements of relevant parameters such as convergence time, bandwidth, etc. were made from the point of view of efficiency operation of routing protocols in selected topological environments. The paper analyzes also the action of routing protocols for butterfly topology, as solutions which perfectly fits into a universally applicable three-layer structure of computer networks.

At the present time we cannot imagine designing of technical solutions without using of modern design and simulation environments. The complexity of design tasks, the number of included parameters and limitations in many cases makes it impossible to solve them in a different way than with the support of high-performance computer systems with high performance computing. Significant meaning has also the cost of the tests and simulations in real environments. In many cases, it would not be possible to create such an environment, especially when developing new technical solutions, testing new mathematical models and analyzing of properties e.g. communication protocols and their influence on existing infrastructure. Therefore, the undoubted advantage of computer simulations is the possibility of multiple repetition, changes the values of various parameters, the introduction of additional restrictions and simultaneous, continuous analysis of the impact of changes on the tested object or environment efficiency. It should also be kept in mind not only the technical aspect or science, but also educational aspect of this systems.

Taking into account the above statement, results of performance analysis of routing protocols in selected topological structures in the OPNET simulation environment were presented in the paper.

2. Test environment

OPNET is a professional simulation environment, enabling both the analysis and testing of existing networking solutions, and creating your own as well [3]. Ensuring a reliable representation of real devices and network protocols allows for detailed study of functioning of the network technology, without necessity of creating a real test environment or disrupting existing production environments. An additional advantage is the ability to define/choice of technologies and protocols that are necessary for the test, which significantly eliminates the possibility of influence by the other elements of the system on obtained results of the simulation.

There are two network topologies for research purposes i.e.: partial mesh (Fig. 1) and interconnected rings (Fig. 2). These topologies are one of the most commonly used in high-throughput networks [4]. The first one provides protection for data transfer between two or more available connections between the nodes, with much lower cost of its construction in comparison to full mesh topology [4]. The second topology is the one of interconnected rings. Such topology is commonly used in urban networks, wide area networks, and more and more often in campus networks. In the elaborated study of development of the broadband network for Podkarpackie 2007-2013 [5] this topology was chosen as the best one from the point of view of cost to reliability.

For the partial mesh topology, there were created twenty points transmission (default routers) with 12 free ports connected by the rules every even to every odd. This ensures 10 connections to one router. Whereas, in the interconnected rings topology, 20 routers grouped into six different rings was used.

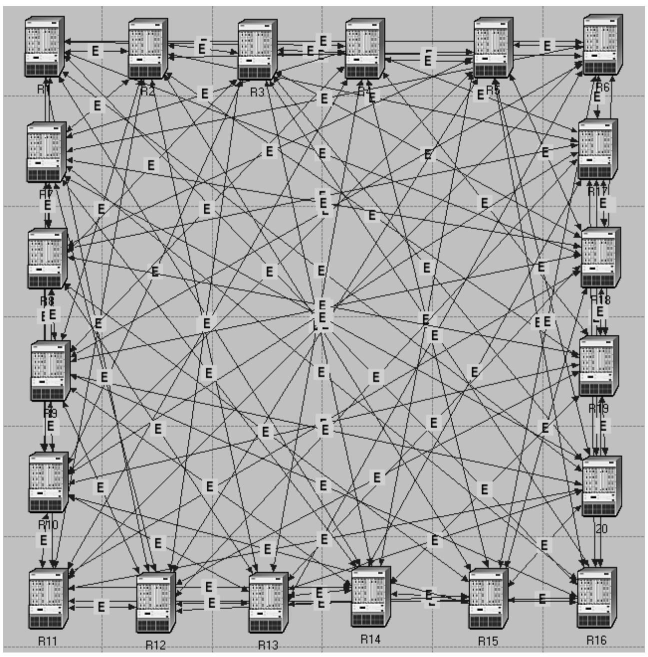

Fig. 1. Partial mesh topology diagram
Rys. 1. Schemat topologii częściowej kraty

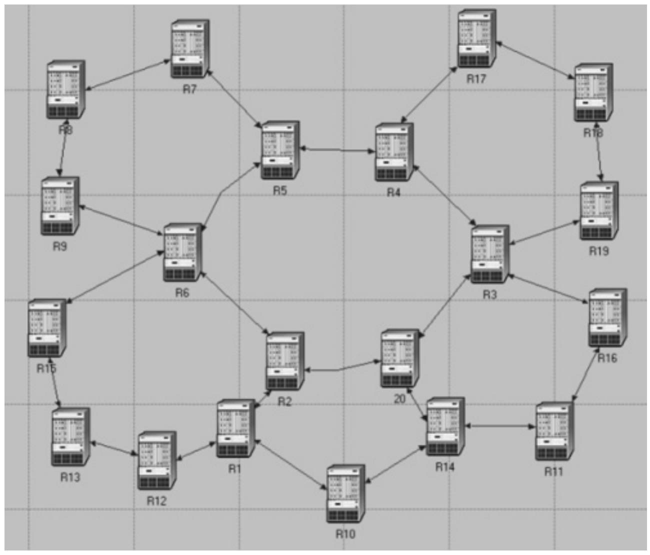

Fig. 2. Topology diagram of interconnected rings composed of 6 rings
Rys. 2. Schemat topologii połączonych pierścieni składającej się z 6 pierścieni

3. The simulation

In the simulations we took into account all of the most common routing protocols such as OSPF, ISIS, RIP and EIGRP [6].

Preliminary assumptions of tests expected that each simulation will take the same time. In addition, the load balancing service was set at the packet base, which meant that decision about equable distribution traffic was based on the data of each packet separately in order to simulate as much real network traffic as possible. Apart from network interfaces, loopback addresses were also automatically assigned to each router. The sim efficency [7] was disabled as well in order to not effect on routing protocols operation.

The scope of the study included the analysis of the following parameters:
1. Traffic generated by the tested routing protocol (sent/received).
2. Router CPU load during the running test of a routing protocol.
3. The number of entries in the routing table and the average time between them for two extremely chosen routers.
4. Network convergence activity for the four events:
   - Arbitrarily chosen one connection after the time of 100 seconds from the network launch (in simulation time) will be disconnected and connected again after 250 seconds.
   - Three arbitrarily chosen connections will be disconnected after the time of 350 seconds (the time in the simulation) and connected again after 500 seconds.
   - One device will fail after the time of 700 seconds and will be repaired after the time of 850 seconds.
   - Two devices will crash after the time of 950 seconds. They will be repaired after the time of 1200 seconds.

Important factors affecting on the network operating were analyzed: the number and the average time of entries in the routing table, router CPU load, the number of sent and received bits by routing protocols and network convergence time.

Most of bits were generated by ISIS protocol at running time for the partial mesh topology, while the least by RIP protocol in the interconnected rings typology. Other protocols have generated a similar number of bits, but that number did not affect significantly on functioning of the network. It does not exceed 1.5% of the available bandwidth.

The highest observed router CPU load did not exceed 0.1%. Note, however, that other running functionality and current data flow effect on the router CPU load significantly in the real conditions.

Taking considered topologies into account, the largest number of entries reported in the routing table of the router running with OSPF protocol in the partial mesh topology - 141 entries. The least entries were implemented by RIP in the interconnected rings topology - 49 entries. For other protocols, the number of entries reached the level of 80 for the partial mesh topology and 20% less for the interconnected rings topology.

The results of the analysis of the convergence process activity for OSPF were shown below (Fig. 3).

Analyzing above diagrams should be noted that blue columns represent the commencement of the convergence process activity, while dots indicate the moment of event occurrence and the time of finishing this process (the next dot). Thus, the area between dot located on the white area and the dot located on the blue area means coherent topology. Mapping event times both on the vertical and horizontal axis, shows in a better way the dynamic of change and periods of the convergence process activity and periods of stabilization.

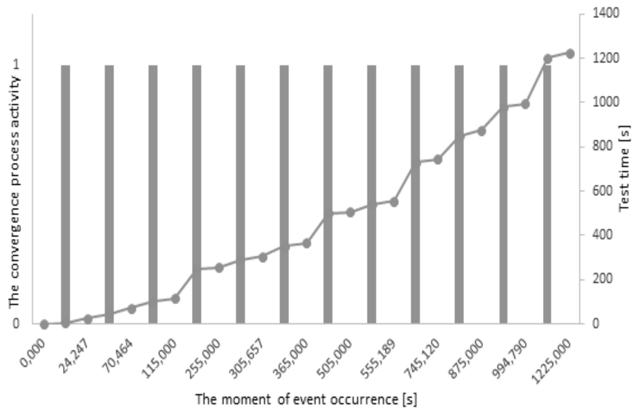

Fig. 3. The convergence process activity for OSPF in the partial mesh topology
Rys. 3. Aktywność procesu konwergencji dla protokołu OSPF w topologii częściowej kraty

It can be concluded that both tested topologies demonstrated similar rate of finishing the convergence process. In both cases, the best protocol was the EIGRP.

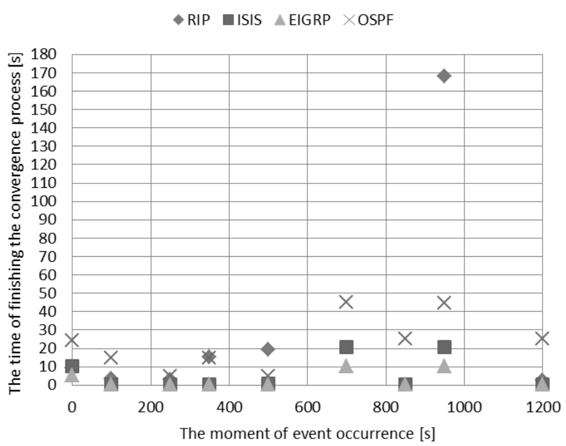

Fig. 4. Network convergence time in the partial mesh topology
Rys. 4. Czas konwergencji sieci w topologii częściowej kraty

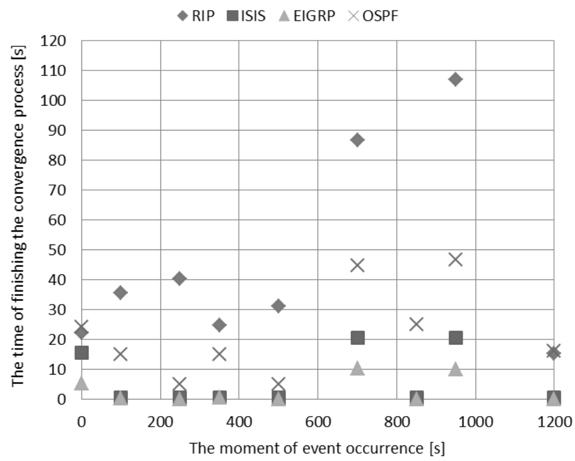

Fig. 5. Network convergence time in the interconnected rings topology
Rys. 5. Czas konwergencji sieci w topologii połączonych pierścieni

There are diagrams in Figure 4 and 5 showing the time of finishing the convergence process from the start of events: 0 seconds –network launch, 100 seconds – the failure of one connection, 250 seconds – repair of a single connection, 350 seconds – the failure of three connections, 500 seconds – repair these three connections, 700 seconds – the failure of one router, 850 seconds – repair device, 950 seconds – the failure of two routers, 1200 seconds – repair of two routers.

4. The three-layered network structure and butterfly topology

So far, the butterfly topology was used in the design of super-computers, wherein individual elements represented computing nodes [8]. This structure is characterized by a very good fault tolerance parameters. Moreover, this topology naturally fits to a three-layer structure of computer networks (Fig. 6).

The three-layer model consisting of access layer, aggregation layer (distribution) and core layer is widely known and recognized by many manufacturers of network devices as the basic model used in the design of computer networks [9]. The major advantage of the above mentioned topology is a smaller number of connections relate to the partial mesh topology, maintaining their redundancy at a similar level. The possibility of easily division of the network into 3 layers allows for quick and unambiguous definition of the functions performed by these layers.

It should be noted that the proposed butterfly topology is the inverted butterfly topology in fact. Due to technological progress and decreasing equipment costs, we are dealing at the moment with the phenomenon of the collapse of the distribution and access layers into one layer. However, the authors suggest leaving the distribution layer, due to its impact on the reliability, performance and network convergence time after a failure. In order to reduce costs further associated with the construction of such a structure, the distribution layer is realized by virtually mechanisms such as: Virtual Router (VR), Virtual Router Redundancy Protocol (VRRP), Virtual Routing and Forwarding (VRF). Additionally, in the proposed topology, interlayer connections between the core routers were added as compared to the original butterfly topology to improve the network reliability and performance.

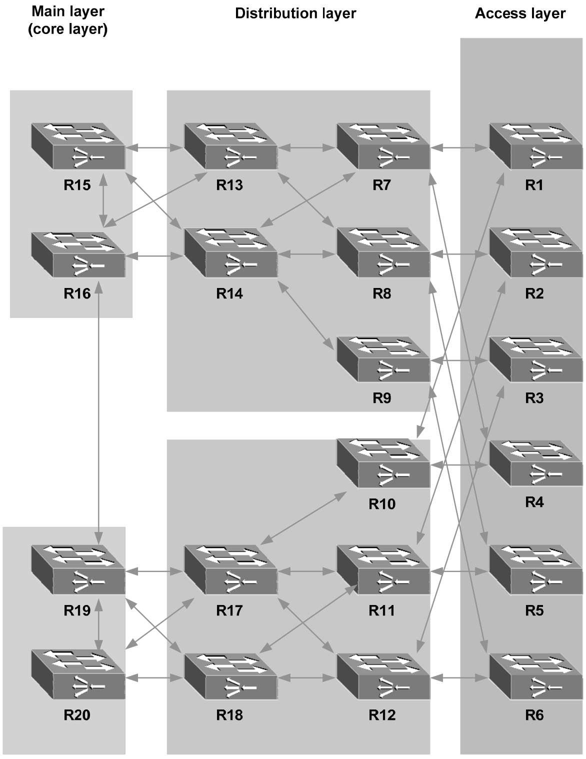

Fig. 6. Butterfly topology in terms of the three-layer structure of the network
Rys. 6. Topologia butterfly w ujęciu trójwarstwowej struktury sieci

Below, there were present simulation results for the model based on the butterfly topology in the context of the convergence time for different routing protocols (Fig. 7).

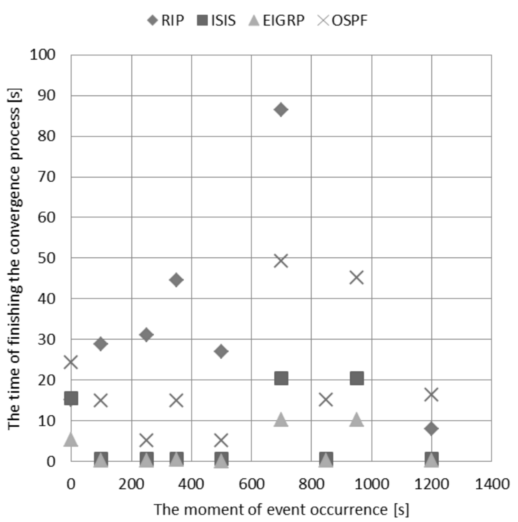

Fig. 7. Convergence time of the network butterfly topology
Rys. 7. Czas konwergencji sieci topologii butterfly

It should be noted that the majority of routing protocols achieved better results than previously considered topology. Additionally, the best response times to failure was given by EIGRP for all events in this case. Analyzing obtained results, it can be concluded that the considered topology may very well be used for high-performance networks such as partial mesh and interconnected rings topologies.

5. Conclusions

Using some of the most popular topologies used in computer networks i.e. partial mesh and ring, significant differences in influence of topology on failure factors in tested network were shown. Network convergence time measured after the incident in the tested topology was different. Thus physical topology becomes an important factor that should be taken into account while selecting, designing and implementation of the routing protocol and confirms the impact of the network structure on its implemented functionality. It should be noted that on the occasion of simulation tests, the ranking of routing protocols forming in the following order EIGRP, OSPF, ISIS, RIP was highlighted. However, it is true for the selected topology for the network environment of enterprise-class. These results correspond to the validity of routing protocols defined by the administrative distance used in real routers.

Taking above statements into account it can be confirmed that the simulation environment OPNET is a very good tool for testing network solutions before their direct implementation in a real network. Perfect reflection of real working conditions and a wide range of possible functionalities to apply and working conditions makes the designers and administrators can use this tool to design and test different solutions also in critical conditions. Remember about potential educational possibilities of that environment.

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