A Validation Method of a Real Network Device Model in the Riverbed Modeler Simulator

Dagmara Mazur(✉)

Faculty of Cybernetics, Military University of Technology,
ul. gen. Urbanowicza 2, 00-908 Warszawa, Poland
dagmara.mazur@wat.edu.pl

Abstract. The paper proposes a validation method of a model of a real routing device. In the developed method assessment of the device model accuracy is made with the use of statistical inference method. The paper presents results of research on the adequacy of the router model operation in the Riverbed Modeler simulator in relation to the operation of the real router in a real computer network environment. The router model was validated for the behaviour of selected queuing mechanisms. The obtained research results indicate the need to adapt the router model in the Riverbed Modeler simulator in the field of tested mechanisms before the model will be used to carry out research on these mechanisms on a large scale.

Keywords: Simulation · Validation · Riverbed Modeler
Queuing mechanisms

1 Introduction

The development of the Internet and web applications forces the evolution and appearance of new protocols and network mechanisms. Development or new technologies creation can be performed using real networks or simulators. Conducting research in both environments has its advantages and disadvantages.

Modifications of an existing protocol, implementations of a new protocol or a network mechanism in real network devices involves high costs. The construction of large real networks also means large financial and time outlays. However, studies conducted in such networks allow to get accurate and detailed results that may be observed in the target production environment.

By using simulators one can create only the model of real devices. Such a model is only an approximate playback of phenomena or behaviours of a given device. Computer simulation refers to mapping the actual behaviour of the device through a computer program [1]. Simulators allow only to conduct research in a virtual and not real environment. On the other hand, simulators have many advantages [2] and some of them are as follows: possibility to study a very complex phenomena, relatively easy way to change device parameters, a significant

P. Gaj et al. (Eds.): CN 2018, CCIS 860, pp. 26–39, 2018.
https://doi.org/10.1007/978-3-319-92459-5_3

reduction of financial outlays needed to carry out the research and short time required for reconfiguration of all devices. There are many simulators available on the market, some examples are as follows: ns-3 [3], Riverbed Modeler [4], OMNeT++ [5], REAL [6], NetSim [7], QualNet [8], J-Sim [9], and SSFNet [10].

The aim of this paper is to present a developed method of checking whether a given real network device model properly reflects this device in the scope of a tested application. The developed method allows to answer the following questions: whether the results of tests performed in the simulator coincide with the results which were obtained in the real environment; whether a given model of the device can be used for tests carried out on a large scale, without the use of real devices and a computer network.

2 Related Works

In the literature one can find results of tests carried out using various simulators confronted with results obtained in real networks. The paper [11] focuses on the comparison of results obtained in the OPNET Modeler simulator (OPNET Modeler is the previous version of the Riverbed Modeler simulator), the ns-2 simulator, and the real network. The research concerns the network transmission study for two types of data streams: the Constant Bit Rate (CBR) and the File Transfer Protocol (FTP). The another paper [12] also concerns a transmission of the CBR data stream, but the FTP data stream is not taken into account. Moreover, the authors compared results obtained in simulators considered in the previous publication with results obtained in the QualNet simulator. The paper [13] presents results of research on packets queuing mechanisms in the ns-2 simulator and compares them with results of testing the same mechanisms in a real network. Respectively, work described in the paper [14] focuses on model credibility verification for network devices used for military purposes in the OPNET Modeler simulator. The research concerned packets queuing mechanisms operation in terms of the performance.

This paper presents research results on the adequacy of queuing mechanisms operation implemented in the router model in the Riverbed Modeler simulator. Simulation results are compared to research results achieved during testing the operation of these mechanisms in a real network. The Riverbed Modeler simulator was chosen for this research due to its popularity in academic, commercial and industrial environments. The paper expands work presented in [13] and [14] with different set of selected queuing mechanisms, and focuses on the comparison of mechanisms behaviour. Additionally, in the developed method assessment, the accuracy of the device model is performed with the use of statistical inference method.

3 The Validation Method

The validation [15] is a process in which it is assessed whether a model intended to represent any real phenomenon in the expected manner reflects this phenomenon in the field of the tested application.

Figure 1 shows a scheme of the validation process of the real device model. The first step in the validation process is to conduct independent research in a real and simulated environment. In the next step obtained research results are compared with each other. If the developed device model does not reflect the real phenomenon in the expected way, attributes of the device model should be adjusted, and the research should be repeated in the simulated environment. Then, the comparison of test results should be repeated. The device model attributes are iteratively adjusted until the developed device model is reflecting the real phenomenon in the expected way.

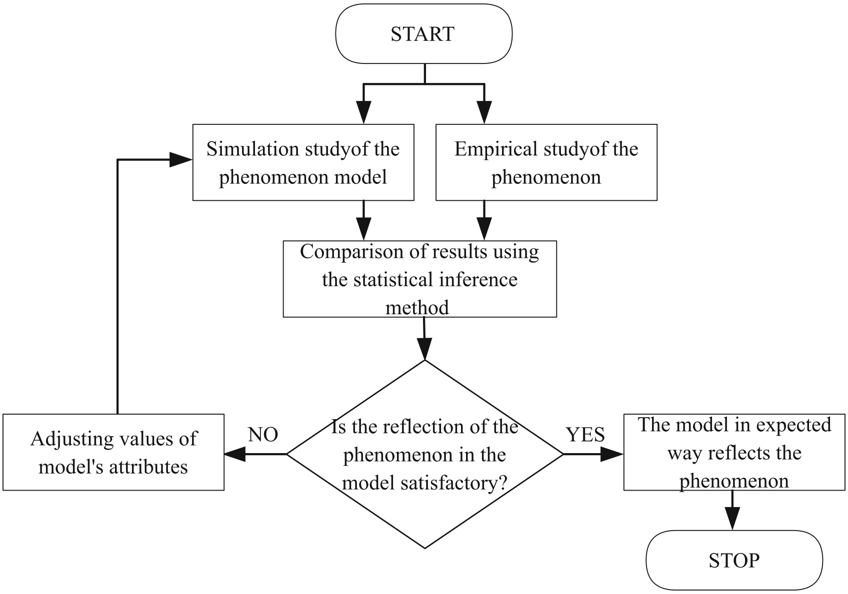

Fig. 1. Scheme of the developed validation process of the real device model.

Assessment of the accuracy of the reflection of the real phenomenon in the device model can be based on selected, measurable technical parameters. These parameters are characteristic for the researched phenomenon. The evaluation accuracy of the device model may focuses on the behaviour study of the device model (characteristics of a given phenomenon) or quantitative study of these behaviours (values of given technical parameters).

The statistical inference method should be used for the device model evaluation when quantitative study is subject to the research [16]. The method itself allows to determine whether there is a significant statistical difference between data samples received in the real and simulated environment. The method consists of the following stages:

STAGE I: Formulating the null and alternative hypotheses, H_0 and H_1 respectively.

The null hypothesis H_0 is the one to be checked. The alternative hypothesis H_1 is the one to be accepted when the null hypothesis is rejected.

STAGE II: Setting a level of significance α.

The level of significance α means probability of making mistake which consists in rejecting the hypothesis H_0 despite H_0 is true.

STAGE III: Selecting a statistical test to check the null hypothesis H_0.

The statistical test selection depends on data samples type.

STAGE IV: Calculation of the value T of the selected statistical test based on data samples.

STAGE V: Finding a critical value t for the fixed level of significance α.

The critical value t comes from statistical tables. Based on value t a decision is made about acceptance or rejection of the null hypothesis H_0.

STAGE VI: Making decision about acceptance or rejection of the null hypothesis H_0 at the given level of significance α.

The null hypothesis H_0 should be accepted when $|T| < t$. However when the condition $|T| < t$ is not met and the condition $|T| \geq t$ is true then the null hypothesis H_0 should be rejected and the alternative hypothesis H_1 should be accepted.

The acceptance of the null hypothesis ends the validation process with a positive result. The positive result means that the existing approximations of reality in the device model do not significantly affect the mapped real phenomenon. Moreover, the statistical method application proves positive result of the validation to be objective. The validated simulator model can be used to carry out the same research in the case of a large scale network.

4 Completed Research

4.1 Research Environment

Research consist in checking the adequacy of operation of the router model in the Riverbed Modeler simulator in relation to the operation of the real device. The router model was validated for the behaviour of selected queuing mechanisms. To conduct these research two environments should be prepared: real and simulated ones. The physical topology of the real network is shown in the Fig. 2, and the topology of the simulated network is shown in Fig. 3.

The real computer network has been equipped with two Cisco 2620 routers: R1 and R2, two switches: S1 and S2 and traffic generator TG and traffic receiver TR. The generator and the traffic receiver were realized using application IP Traffic - Test and Measure [17]. In order to obtain correct research results traffic generator TG and traffic receiver TR must indicate simultaneously the same system time. Therefore, their operating system clocks were synchronized with the clock of the external NTP server [18]. Both switches were connected with other network elements using ethernet link with the bandwidth of 100 Mb/s, and both routers were connected using serial link with the bandwidth of 128 kb/s. This allowed the creation of a so-called bottleneck on the serial link, which is necessary to observe the characteristic operation of selected queuing mechanisms.

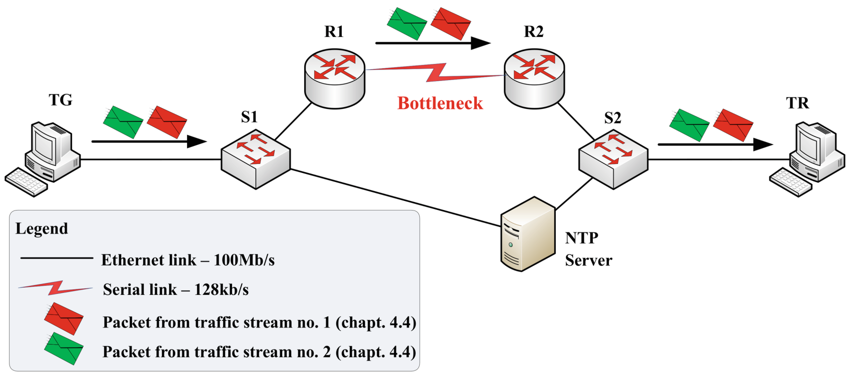

Fig. 2. Physical topology of the real network.

Analogically to the real computer network, the computer network in the Riverbed Modeler simulator was built. The simulator network consists of two Cisco 2620 routers: R_1 and R_2, two switches: S_1 and S_2, traffic generators and traffic receivers (ethernet_ip_workstation_adv [19]): TG_1, TG_2, TR_1, and TR_2. There are more traffic generators and receivers than in the case of the real network. This is because the Riverbed Modeler simulator traffic generator can generate only one type of traffic – one traffic stream. In the simulated network, traffic generators and receivers are not connected to the NTP server, because their clocks are synchronized by the simulator. As in the real network, both switches were connected to other network elements using ethernet link with the bandwidth of 100 Mb/s, and both routers were connected using serial link with the bandwidth of 128 kb/s.

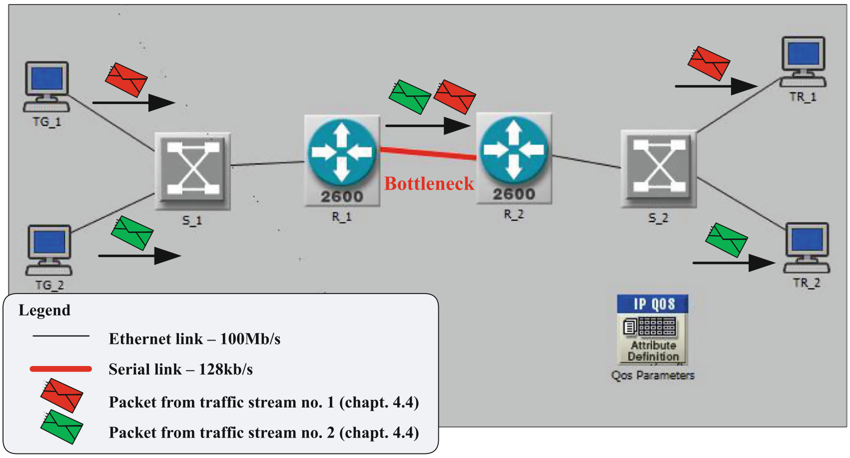

Fig. 3. Physical topology of the simulated network.

4.2 Phenomena and Metrics Selected for the Validation of the Router Model

In order to validate the Cisco 2620 router model in the Riverbed Modeler simulator, there were selected following mechanisms and phenomena:

1. Priority Queuing (PQ) [20]: appropriation of the whole bandwidth by the highest priority traffic.
2. Custom Queuing (CQ) [20]: preservation of the allocated bandwidth to a given queue and rejection of packets that exceed the bandwidth allocated to the given queue when the interface is saturated.
3. Low Latency Queuing (LLQ) [20]: limitation of the bandwidth on the priority queue and rejection of packets that exceed the bandwidth allocated to the given queue when the interface is saturated.

The accuracy of the reflection of the above mechanisms in the validated router model was evaluated on the basis of the throughput parameter.

4.3 Routers Configuration

As part of the router model validation three tests: A, B, C were performed. The routers configuration during each test is described below:

1. Test A: PQ mechanism was configured on router R1 and R_1.
2. Test B: CQ mechanism was configured on router R1 and R_1; In this mechanism two queues were created; The first queue was intended for high-priority traffic operation and was allocated 2/3 of the available bandwidth to it; The second queue was dedicated to low-priority traffic and was allocated 1/3 of the available bandwidth to it.
3. Test C: LLQ mechanism was configured on router R1 and R_1; In this mechanism two queues were created; The first queue is a priority queue, which was intended for high-priority traffic operation and was allocated 64kb/s of available bandwidth to it; The second queue was intended for low-priority traffic and it was no restrictions imposed on it on the allocation of available bandwidth.

4.4 Traffic Generators Configuration

Two traffic streams of constant bit rate (CBR) were generated during each test (A, B and C). It means that the Packet Size and the Inter Arrival Time parameters were configured for both generated traffic stream. Each test was executed in the real network and in the Riverbed Modeler simulator. Table 1 presents detailed settings for the parameters of both traffic streams, and Fig. 4 shows the time ranges in which traffic flows were generated.

Additionally in both traffic stream generators the MTU size parameter was set the same. The MTU size parameter is a crucial factor which could influence on a traffic streams characteristic. The generators ability to generate expected

Table 1. Traffic streams parameters.

Number of traffic stream	Throughput at layer 2 level of the ISO/OSI model	Throughput at layer 4–7 level of the ISO/OSI model	Priority of traffic stream [20]
Traffic stream no. 1	100 kb/s	89,2 kb/s	High (ToS = 6)
Traffic stream no. 2	80 kb/s	69,2 kb/s	Medium (ToS = 4)

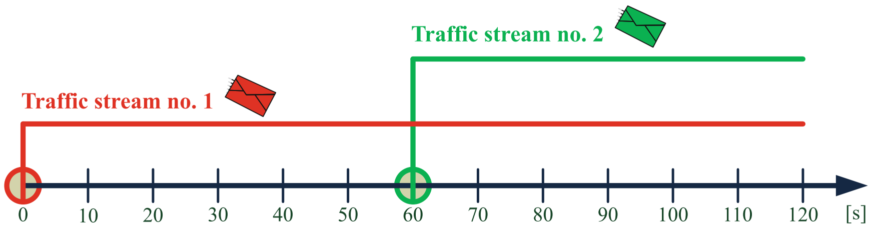

Fig. 4. Time intervals of generating traffic streams.

traffic streams characteristic was automatically validated by observation of the traffic stream no 1 in the first 60 s of each test.

It should be noticed that the total sum of the throughput of both traffic streams exceeds the available bandwidth of the serial link. Such throughput values of traffic streams allow to observe the characteristic operation of each tested queuing mechanism. Higher throughput values of traffic streams would also give this opportunity.

4.5 Research Results

All performed tests A, B, and C were carried out in the real network and in the Riverbed Modeler simulator. After the first series of tests, it turned out that the throughput values of traffic streams sent by router R_1 in the simulator are about 25% smaller than the values received on the router R1 in the real network. The study of this case revealed the fact that both routers (R1 and R_1) with configured the queuing mechanism on its interface, automatically reserve only 75% of the interface bandwidth for the needs of defined queues. In turn the real router was using the remaining 25% of the interface bandwidth when no traffic exist outside defined queues. The observed behaviour is the first discrepancy found in the implementation of the router model in relation to the real device.

After customizing the configuration of router model in the Riverbed Modeler simulator all tests were repeated in the real and simulated network. Adjusting the configuration of the router model depends on setting the value of 100 in the field max-reserved-bandwidth on its serial interface [21].

Data samples received from the real and simulated environment were checked using the statistical inference method described in Sect. 3. Tests A, B and C were in the scope of the statistical verification. One can find below the procedure used for each stage of the mentioned method.

STAGE I: The following research hypotheses were formulated:

The null hypothesis H_0 – The average of traffic stream throughput in the real environment is not significantly statistically different from the average throughput obtained in the Riverbed Modeler simulator.

The alternative hypothesis H_1 – The average of traffic stream throughput in the real environment is significantly statistically different from the average throughput obtained in the Riverbed Modeler simulator.

STAGE II: Assumed $\alpha = 0,05$ as a level of significance.

STAGE III: Statistical Student's t-test was selected, because all obtained results have a normal distribution, sets of traffic stream throughput results in the real environment and in the Riverbed Modeler simulator have similar numbers, variances of results obtained in both environments are similar – homogeneous and this results are measured on interval scale (interval) – samples can be ordered and have a unit of measure [kb/s].

STAGE IV: A statistical Student's t-test T value calculation with the following equation:

$$T = \frac{\overline{X_1} - \overline{X_2}}{S_{x_1 - x_2}} \tag{1}$$

$$S_{x_1 - x_2} = \sqrt{\frac{(n_1 - 1) \cdot s_1^2 + (n_2 - 1) \cdot s_2^2}{n_1 + n_2 - 2} \cdot \left(\frac{1}{n_1} + \frac{1}{n_2}\right)} \tag{2}$$

where:

$\overline{X_1}$ – the average value of the traffic stream throughput in the real environment

$\overline{X_2}$ – the average value of the traffic stream throughput in the Riverbed Modeler simulator

s_1^2 – the variance of traffic stream throughput in a real environment

s_2^2 – the variance of traffic stream throughput in the Riverbed Modeler simulator

n_1 – the samples number of traffic stream throughput in a real environment

n_2 – the samples number of traffic stream throughput in a real Riverbed Modeler simulator

STAGE V: The critical value t is read from the Student's t-distribution tables for the level of significance $\alpha = 0,05$ and the number of degrees k of freedom expressed by the formula:

$$k = n_1 + n_2 - 2 \tag{3}$$

STAGE VI: When the following condition is met:

$$|T| < t \tag{4}$$

Acceptance decision on the null hypothesis H_0 is making and the alternative hypothesis is rejecting H_1. Otherwise, the alternative hypothesis H_1 is accepted.

Expected Behaviours of Configured Queuing Mechanisms. Figures 5, 6 and 7 show respectively operating schemes of configured PQ, CQ, and LLQ mechanisms in the real and simulated network. Each queuing mechanism is implemented on routers R1 and R_1 for respective test execution (A, B, and C). Routers R1 and R_1 receive packets on input interface from traffic streams no. 1 and no. 2. Packets from each traffic stream are classified based on the assigned priority (ToS field values) and placed in the appropriate queue. Below describes how each queuing mechanism continues to work according to the configuration described in Sect. 4.3.

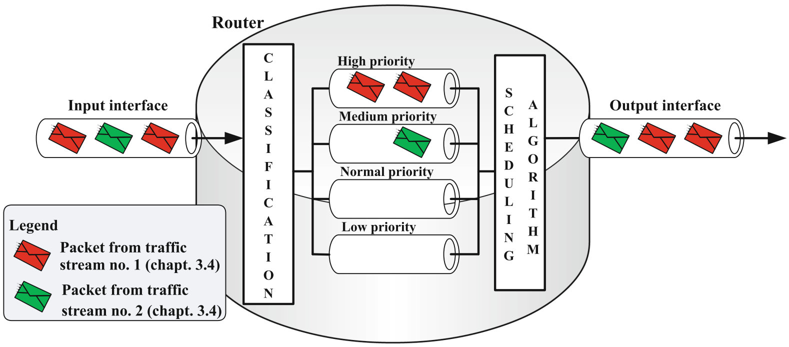

Fig. 5. The scheme of operation of the configured PQ mechanism.

PQ mechanism (Figure 5): Packets from traffic stream no. 1 are routed to the high priority queue, and packets from traffic stream no. 2 are routed to the medium priority queue; then the scheduling algorithm is putting the packets in the router's interface as per the rule: packets from a high priority queue have priority over packets from other queues.

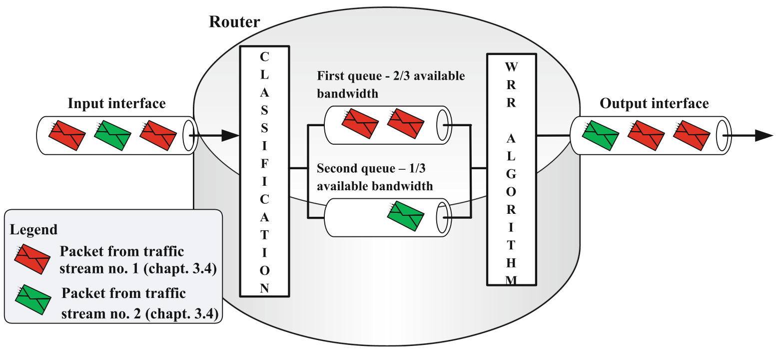

Fig. 6. The scheme of operation of the configured CQ mechanism.

CQ mechanism (Figure 6): Packets from traffic stream no. 1 are routed to the first queue, and packets from traffic stream no. 2 are routed to the second queue; then the Weighted Round Robin algorithm (WRR) is putting packets in the router's output interface. Packets from the first queue should be sent as first until their total number of bits reach the value set for this queue (2/3 of the serial link bandwidth).

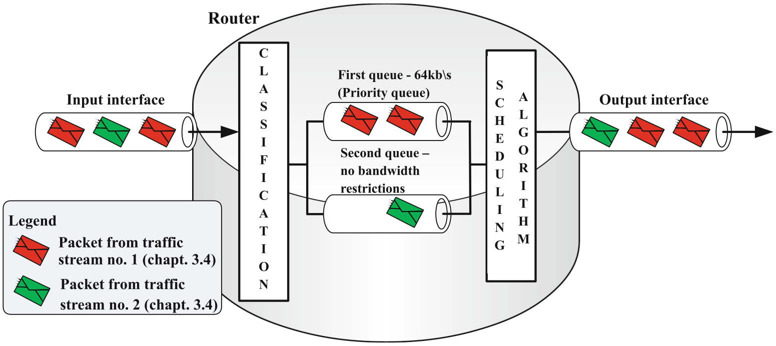

Fig. 7. The scheme of operation of the configured LLQ mechanism.

LLQ mechanism (Figure 7): Packets from traffic stream no. 1 are routed to the first queue – priority queue, and packets from traffic stream no. 2 are routed to the second queue. Then the packets are scheduled in the router's output interface. Packets from the first queue should be sent as first until their total number of bits reach the value set for this queue (64 kb/s – at the layer 2 level of the ISO/OSI model).

Test A – Research Results. Figure 8 shows results of the conducted test A. Research results shown that the throughput of the traffic stream no. 1 on router R_1 is less by about 4kb/s than the throughput of the traffic stream no. 1 on router R1. Mentioned difference in the throughput is observed from the moment when the traffic stream no. 2 appears on the input interface of the R_1 and R1 routers. As a consequence, the described phenomenon causes the traffic stream no. 2 in the Riverbed Modeler simulator to be about 4 kb/s higher than in the real network. This means that the traffic stream no. 1 in the Riverbed Modeler simulator does not cover the whole bandwidth.

The source of observed decreases and increases of the throughput on the router's output interface in the Riverbed Modeler simulator may be the automatic application of mechanisms to optimize packet traffic efficiency at the crowded router interface. Examples of such mechanisms include: compression of packet headers, packet fragmentation or frame size modification at the layer 2 level of the ISO/OSI model. During the research both simulated and real routers were not modified with mentioned mechanisms.

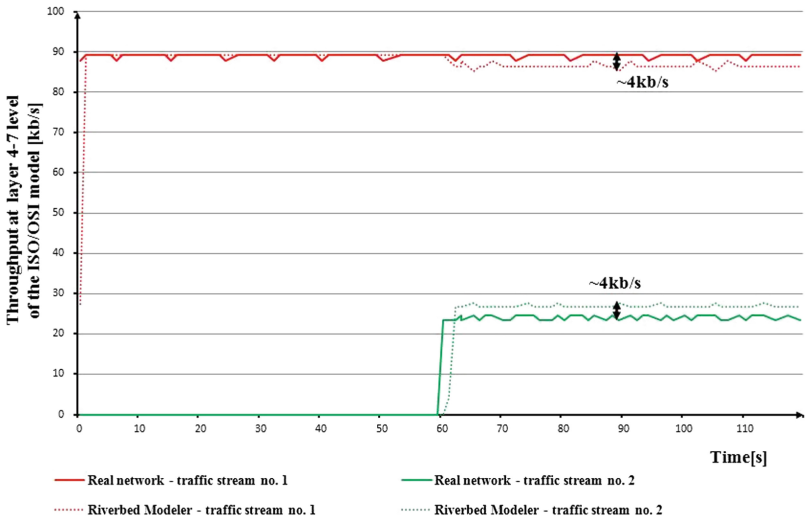

Fig. 8. Graph of the throughput dependence on the time after conducting the test A.

After usage the statistical inference method, it turned out that for both traffic streams the alternative hypothesis was accepted. The results of the average throughput of the traffic stream no. 1 and no. 2 in the real environment significantly differ statistically from the results of the average throughput of the traffic stream no. 1 and no. 2 obtained in the simulator. This means a negative result of the validation of the Cisco 2620 router model in the Riverbed Modeler simulator. Current implementation of the router model cannot be used for conducting the research of the PQ mechanism on a large scale network.

A detailed analysis of the code of the implemented PQ mechanism in the Riverbed Modeler simulator and its impact on the obtained research results will be the subject of further research.

Test B – Research Results. Figure 9 shows the results of the conducted test B. The research results shown that the Cisco 2620 router model in the Riverbed Modeler simulator perfectly reflects the behaviour of the real router for the CQ mechanism. After 60 s of test B duration, the throughput of the traffic stream no. 1 is equal to the bandwidth allocated to the first queue (approximately 77 kb/s – 2/3 of the available bandwidth), and the throughput of the traffic stream no. 2 is equal to the bandwidth allocated to the second queue (approximately 37 kb/s – 2/3 of available bandwidth). The rest of packets from both streams is discarded.

As a result of usage the statistical inference method, it turned out that for both traffic streams the zero hypothesis was accepted. The results of the average throughput of the traffic stream no. 1 and no. 2 in the real environment do not significantly differ statistically from the results of the average throughput of the traffic stream no. 1 and no. 2 obtained in the simulator. This means a positive result of the validation of the Cisco 2620 router model in the Riverbed Modeler simulator. Current implementation of the router model can be used for conducting the research of the CQ mechanism on a large scale network.

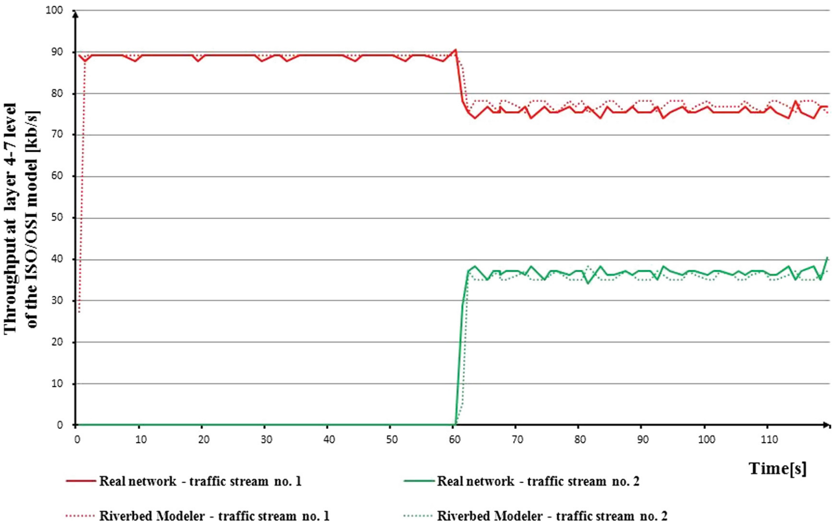

Fig. 9. Graph of the throughput dependence on the time after conducting the test B.

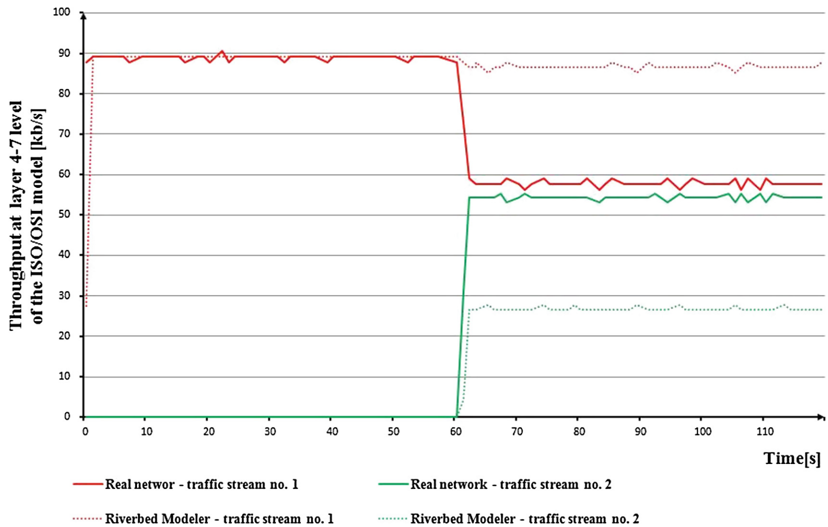

Fig. 10. Graph of the throughput dependence on the time after conducting the test C.

Test C – Research Results. Figure 10 shows the results of the conducted test C. The research results shown that the Cisco 2620 router model in the Riverbed Modeler simulator does not introduce a bandwidth limitation for the first queue (priority queue). Therefore, the research results conducted for the LLQ and PQ mechanisms in the simulated network overlap with each other for both traffic streams.

Despite such divergent research results, procedures of the statistical inference method was conducted. The result of the Cisco 2620 router model validation in the Riverbed Modeler simulator is negative as the null hypothesis was rejected. Current implementation of the router model cannot be used for conducting the research of the LLQ mechanism on a large scale network.

5 Summary

The paper describes the validation method of the real device model. In the developed method assessment of the accuracy of the device model is made with use of the statistical inference method.

The use of the developed method was demonstrated on the example of validation of the Cisco 2620 router model. The paper presents research results on the adequacy of operation of the router model in the Riverbed Modeler simulator in relation to the operation of the real router in the real computer network. The router model was validated for the behaviour of the PQ, CQ and LLQ mechanisms. Accuracy assessment of the router model was made on the basis of the throughput parameter.

After the first series of tests, it turned out that throughput values of traffic streams received in the simulator were about 25% smaller than values received in the real network. The developed model did not reflect the real phenomenon in the expected way, so the configuration of the device model in the simulator was adapted in accordance with the scheme of the validation process shown in Fig. 1. Then the accuracy research of the model was repeated. For this purpose, the statistical inference method was used, in which Student's t-test was selected to verify the research hypothesis.

After another iteration of the conducted research, the validation of the Cisco 2620 router model received a positive result only for the CQ mechanism. For the PQ and LLQ mechanisms, the results of the average throughput of the traffic stream no. 1 and no. 2 in the real environment significantly differ statistically from the results of the average throughput of the traffic stream no. 1 and no. 2 obtained in the simulator. This involves a negative result of the validation of the Cisco 2620 router model in the Riverbed Modeler simulator. The current implementation of the router model cannot be used for conducting a research of the PQ and LLQ mechanisms on a large scale network. Thus, another validation of the router model in the field of the PQ and LLQ mechanisms should be preceded by a modification of the implementation of these mechanisms in the simulator; and that will be the subject of the further research.

References

1. Balci, O.: Validation, verification, and testing techniques throughout the life cycle of a simulation study. In: IEEE Winter Simulation Conference, pp. 215–220 (1994)
2. Breslau, L., Estrin, D., Fall, K., Floyd, S., Heidemann, J., Helmy, A., Huang, P., McCanne, S., Varadhan, K., Xu, Y., Yu, H.: Advances in network simulation. IEEE Comput. Magaz. **33**, 59–67 (2000)
3. NS, Discrete Event Network Simulator. http://www.nsnam.org. Accessed 21 Feb 2018
4. Riverbed Modeller, Network Simulator. https://www.riverbed.com/. Accessed 21 Feb 2018
5. OMNeT++, Discrete Event Simulator. https://www.omnetpp.org/. Accessed 21 Feb 2018
6. REAL, Network Simulator. http://www.cs.cornell.edu/skeshav/real/overview.html. Accessed 21 Feb 2018
7. NetSim, Network Simulation and Emulation Platform. http://www.tetcos.com/index.html. Accessed 21 Feb 2018
8. QualNet, Network Simulator. www.scalable-networks.com. Accessed 21 Feb 2018
9. J-Sim, Java-based simulation system. http://www.physiome.org/jsim/. Accessed 21 Feb 2018
10. SSFNet. http://www.ssfnet.org/. Accessed 21 Feb 2018
11. Lucio, G.F., Paredes-Farrera, M., Jammeh, E., Fleury, M., Reed, M.J.: OPNET modeler and NS-2: comparing the accuracy of network simulators for packet level analysis using a network Testbed. In: ICOSMO, vol. 2, pp. 700–707 (2003)
12. Puneet R., Srinath P., Raghuraman R.: Bridging the gap between the reality and simulations: an Ethernet case study. In: IEEE 9th International Conference on Information Technology (ICIT 2006), pp. 52–55 (2006)
13. Andreozzi, S.: Differentiated services: an experimental vs. simulated case study. In: IEEE Seventh International Symposium on Computers and Communications, pp. 383–390 (2002)
14. Boltjes, B., Thiele, F., Fernandez Diaz, I.: Credibility and validation of simulation models for tactical IP networks. In: IEEE Military Communications Conference, pp. 1–10 (2006)
15. Heidemann, J.: Expanding confidence in network simulations. IEEE Netw. Magaz. **15**, 58–63 (2001)
16. Kowalski, L.: Statystyka. Bel Studio, Warsaw (2005)
17. IP Traffic - Test and Measure. https://www.zticommunications.com/iptraffic/. Accessed 21 Feb 2018
18. RFC 958: Network Time Protocol (NTP). http://tools.ietf.org/html/rfc958. Accessed 21 Feb 2018
19. Adarshpal, S.S., Vasil, Y.H.: The Practical Riverbed®User Guide for Computer Network Simulation. CRC Press, Boca Raton (2013)
20. Odom, W., Cavanaugh, M.: Cisco QOS Exam Certification Guide. Cisco Press, Indianapolis (2004)
21. Cisco website. http://www.cisco.com/c/en/us/support/docs/quality-of-service-qos/qos-packet-marking/10100-priorityvsbw.html. Accessed 21 Feb 2018