Multipath Redundant Transmissions of Critical to Delays Packets Based on UDP Protocol *

Ilya Noskov[1[0000−0002−5489−4092]] and Vladimir Bogatyrev[1,2[0000−0003−0213−0223]]

[1] ITMO University, Saint-Petersburg, Russia
noskovii@mail.ru
[2] Saint-Petersburg State University of Aerospace Instrumentation, Saint-Petersburg, Russia
vladimir.bogatyrev@gmail.com

Abstract. Possibilities of increasing probability of faultless and timely serving in multipath data transmission systems in computer networks based on UDP protocol using redundant transfer are researched. Efficiency of redundant multipath transmissions is analyzed in the paper based on simulation modeling in OMNeT++ environment. Process of creating simulation model of computer network is described. Opportunities of OMNeT++ environment and its libraries and frameworks are considered in the paper. Researching in this paper based on using UDP protocols for transmissions because critical to delays packets are considered for using in real-time systems. Simulation model of computer network with redundant transmissions is developed and researched. Efficiency of use this model on configurations with different redundancy coefficient is defined. The aim of this work is the study of redundant transfer efficiency in computer networks based on UDP protocol. The efficiency analysis of the redundant packet transmissions is carried out on the basis of simulating in OMNeT++ environment. The complex efficiency of the redundant packet transmission is determined on the basis of the multiplicative index, which takes into number the error-free transmissions and the average time margin relative to the maximum permissible transmission delay. Developed model allows to transmit packets via several paths and provides redundant transfer of data. Intensity and redundancy coefficient are changed while experiment was carried out. The paper provides plots which help us to understand results of experiments and gets more effective areas for using multipath redundant transmissions. Also this paper presents all histograms of end to end packets delay in different cases. The presented results can be used in the design of high-reliable computer systems including computer systems providing real-time services which use UDP as a transport protocol.

Keywords: Redundant · Multipath routing · Request redistribution · Critical to delays packets · OMNeT++.

1 Introduction

Fundamental issues of the design and develop of information and communication systems based on reliable computer networks are represented in [1-3]. Security issues of computer networks are considered in [4-6]. Performance of processing, transmission and storage of data in computer networks are described in [7, 8]. Ensuring the reliable of real-time communication systems is associated not only with supporting the availability, fault tolerance and reliability of the system structure, but also with timeliness of delivery critical to delays packets in real-time computer networks which provide computer communication in client-server architecture.

Supporting of timeliness based on traffic prioritization and load balancing of transmissions is presented in [9, 10]. Load balancing allows dynamic redistribution of requests between computer nodes via the network [11], using multipath and transport coding [12, 13], in which message or packets are transmitted by different routes depends on channel loading.

The reliability and timeliness of requests as shown in [14, 15]. The reliability can be increasing by requests replication and redundant serving of copies [16-18]. The effectiveness of redundant services is estimated by the probability of the timeliness of at least one copy of the request [13-15].

Analytical models of reliability and timeliness of redundant services in single-level and multilevel data processing and transmission systems confirm the effectiveness of redundant services proposed in [14, 15]. In the models according to [14, 15], the nodes of multipath redundant service systems are represented as a set of interconnected single-channel queuing systems of the M/M/1 type [19, 20]. Researching of multipath transmission effectiveness based on simulation modeling in AnyLogic 7 Professional is carried out in [21], with using multichannel service models in [22, 23]. Simulation models [21-23] do not consider specific and real network equipment such as routers or network switches and modern implementations of different OSI layers interconnection protocols.

The aim of this work is developing simulation models in the OMNeT++ environment, allowing to using features of real communication tools and network protocols of multipath redundant transmissions based on UDP protocol. UDP is transport layer protocol which not using handshaking dialogues and no guarantee of delivery packets. Time-sensitive applications often use UDP because dropping packets is preferable to waiting for packets delayed due to retransmission. In this applications packets are become outdated very quickly, and retransmit lost packets using TCP protocol is not suitable for systems. This systems are considered in this paper. That is why UDP transport protocol is used for developing models in the article.

2 Simulation models of multipath redundant transmissions

Proposed models were developed in the specialized environment of computer networks simulation OMNeT++. This environment contains a large library of real network protocols models and models of specialize network equipments such as routers, network switches, hubs and etc.

The OMNeT++ simulation environment provides many different network protocols and traffic generator and sink application which using these protocols. In this work the UDP (User Datagram Protocol) is used as a main transport protocol for developed models. The OMNeT++ environment implements various types of generators and sink applications of UDP traffic. The UDPBasicApp application generates packets with size and intensity to the specified in the configuration file network address [24-32]. The UDPSink application listens specified port and receives all packets that came to the socket from the source application. However, this application models do not support redundant transmission: the generator application sends only one packet to a given communication channel, and the sink application cannot recognize copies of the same packet and accepts them all, assuming that this is different packets from the source application. The OMNeT++ simulation environment is written in the C++ programming language and allows modifying the core of this environment. To build models with redundant transmissions, new classes of generator and sink applications have been developed.

The new UDP application class extends of the base class and allows to specify several addresses in configuration file in order to provide redundant transmission via sending copy of packets to these addresses. The network simulator's kernel generating and sending copies of current packet to main and backup communication channels. These copies of packet have same id number for correct identifying (without duplication) in sink application.

In UDP application configuration on clients we set port number and packet length. Also we specify several several IP-addresses for redundant transmission. Fig. 1 shows fragment of UDP generator application settings.

```
**.Client_1.numUdpApps = 1
**.Client_1.udpApp[0].typename = "UDPBasicAppCopy"
**.Client_1.udpApp[0].destAddresses =  "10.10.10.6 10.10.20.6"
**.Client_1.udpApp[0].destPort = 1000
**.Client_1.udpApp[0].messageLength = 100B
**.Client_1.udpApp[0].startTime = 0s
**.Client_1.udpApp[0].sendInterval = exponential(0.0001s)
```

Fig. 1. UDP generator's settings.

In this configuration you can set number of port, several IP-addresses for redundant transmission, length of packet etc.

The UDP sink application class extends the base receiver class of UDP traffic and allows to receive and detect same packets from different network channels. Packet will be dropped if application already received packet with same id from other channel. Port number for this application is set in the configuration file.

Simulation model of system with server, five network switches and five clients was developed in OMNeT++ environment. This model is based on a EtherSwitch model which represents model of network switch and a StandardHost model, which simulates clients and server behaviour. Fig. 2 shows this model in the OMNeT++ environment.

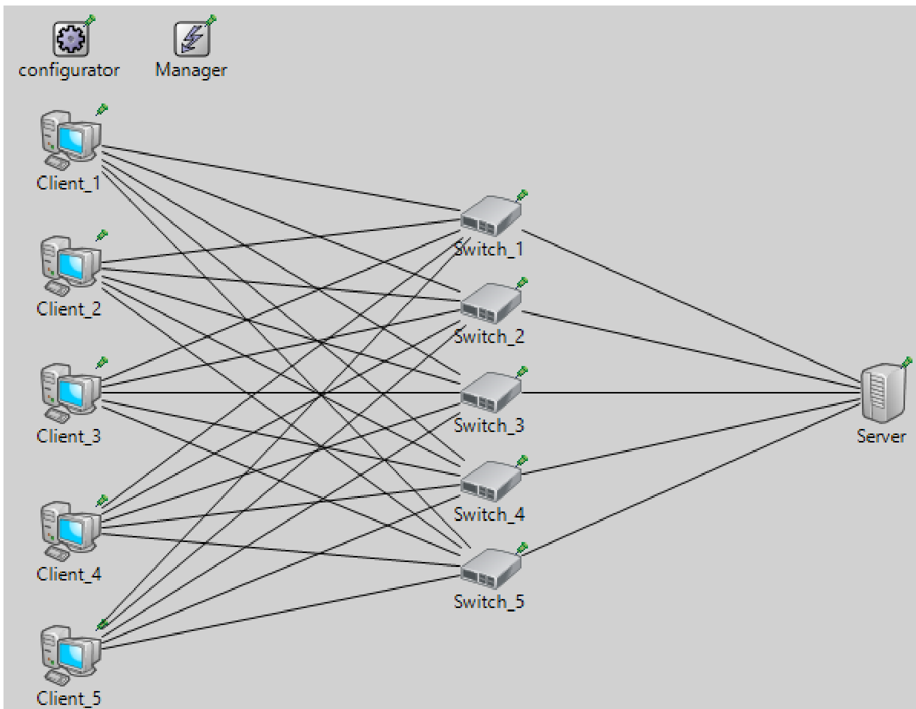

Fig. 2. Model of computer network.

Criterion M has been used for efficiency evaluation of redundant transmissions.

$$M = P(t_0 - T) \tag{1}$$

This (1) represents the average time of error-free and timely transmitted packets from the client to the server. P is a probability of timely and error-free delivery of the package. This parameter is defined via experiments. t_0 is a time limit for packet delivery in this system. T is a average transmit packet time in this computer network.

In redundant transmissions with split switches between nodes, each switch is used by more than one node. We will carry out simulation experiments with different values of the backup coefficient, which shows how many channels will be used to transmit each of packet from client.

These parameters have been used in simulation experiments with redundant transmit: L = 10 Mbit/s - throughput of communication channels between clients and switches, $t_0 = 0.0004$ s - delivery time, B = 0.0001 - probability of channel bit errors, $\lambda = 1000$ 1/s - packet arrival rate, packet length for this simulation process is 100 B.

3 Researching of critical to waiting time multipath redundant transmissions

Fig. 3 shows plots of the criterion M and redundancy transmissions K for different packet intensity (1000 1/s and 2000 1/s). From the graphs we can see that the selected criterion M takes large values at lower intensity, which indicates the small size of queues in the network switches. At greater intensity queues in the switches are growing and this leads to increase of delivery packets time in the system and reduces the efficiency criterion. Thus, in this network configuration, the transmission of packets with lower intensity is more efficient on all values of redundant coefficient. In the curve 2 you can see sharp decline at K equals 4. It allows to make conclusion that switch buffers are overflow and packets are dropped.

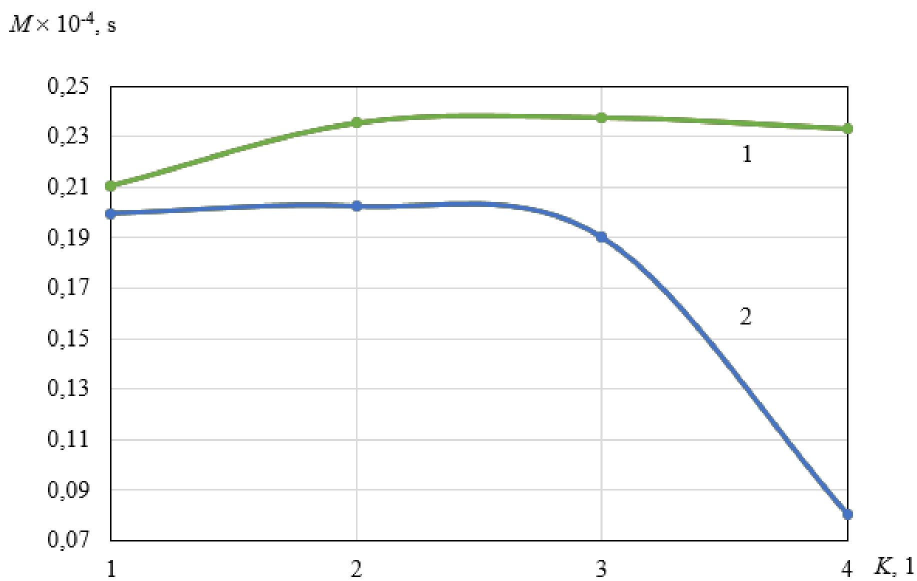

Fig. 3. The dependence of the efficiency criterion M on the redundancy ratio K: at an intensity of 1000 1/s (curve 1); at an intensity of 2000 1/s (curve 2).

Increasing the number of redundant transmissions helps us to reduce packets lost probability. But the end to end packets delay in the system also increasing.

Delays influence on probability of timely delivery packets to server and reduce value of M criterion. Fig. 4 shows histograms of end to end packets delay for different value of K at an intensity of 1000 1/s.

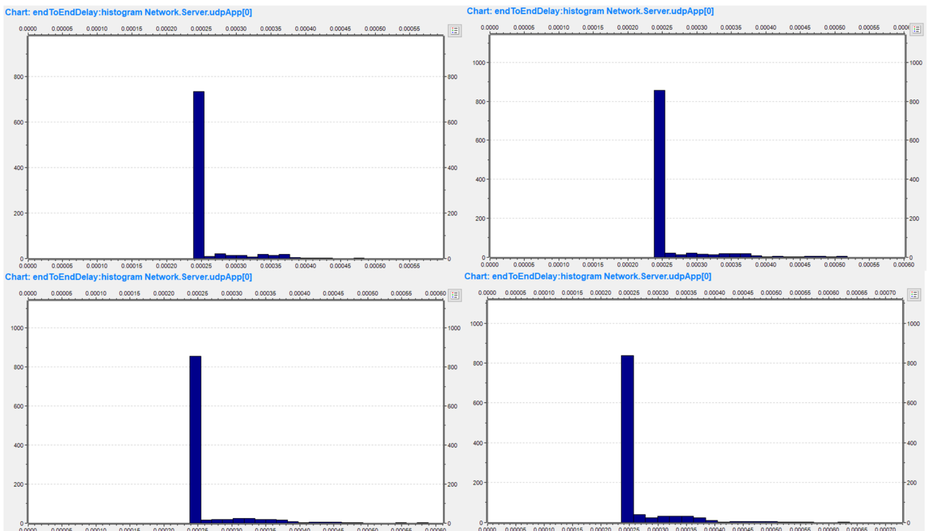

Fig. 4. Histograms of end to end packets delay for K = 1, 2, 3, 4 at an intensity of 1000 1/s (from top to down, from left to right).

Fig. 5 shows histograms of end to end packets delay for different value of K at an intensity of 2000 1/s.

As you can see delays increase with intensity increasing. While delays don't achieve a time limit for packet delivery in this system t_0 these packets continue to be relevance for system and increase timely delivery probability. Timely delivery probability is considered as more important variety of probability for real-time system because its takes into account of limit for packet delivery. That is why general probability of delivery packets are increasing for bigger K but criteria M is reduced.

Fig. 6 shows a plot of criterion M depends on packet arrival rate for various transmission redundancy coefficient. It can be seen from the plot that an increase of redundancy coefficient is not effective for all area of intensity. You can see an area in which transmission with a high redundancy coefficient is more efficient on the same network configuration.

After overcoming the intensity threshold of 2000 1/s, the redundancy model is becoming less efficient than model without reservation. Increasing traffic on the network in redundancy model leads to the growing of queues in the switches. That is why delivery time of packets is growing. The probability of delivery packages increases. With an intensity of 5000 1/s in a redundant model, delivery time

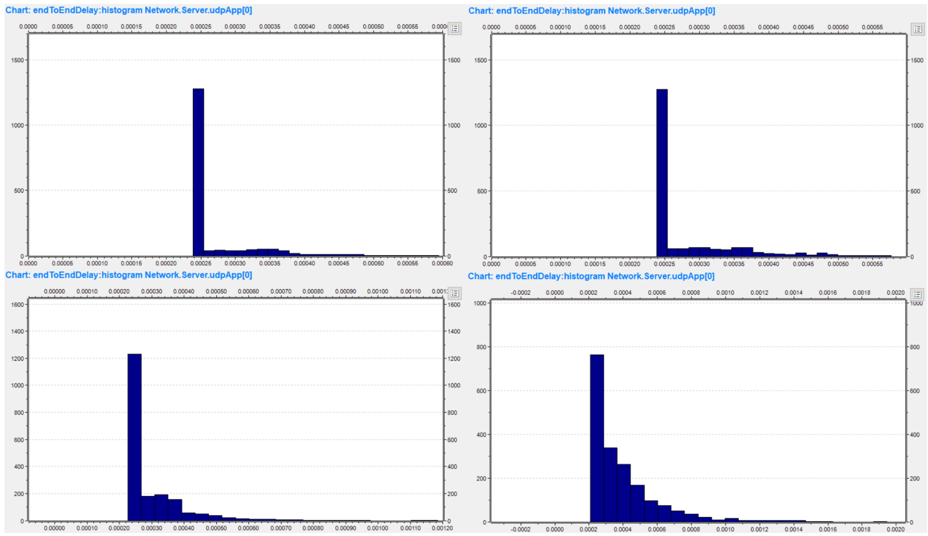

Fig. 5. Histograms of end to end packets delay for K = 1, 2, 3, 4 at an intensity of 2000 1/s (from top to down, from left to right).

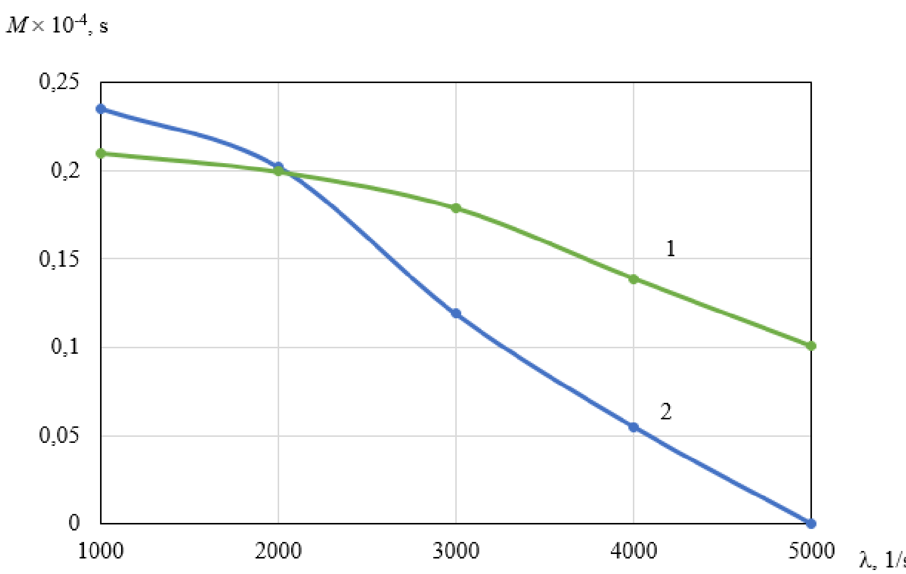

Fig. 6. The dependence of the efficiency criterion M on the intensity of packet arrival: with the redundancy coefficient K = 1 (curve 1); with the redundancy coefficient K = 2 (curve 2).

of packets doesn't increase, however, the probability of packet delivery begins to decrease due to network switches start to drop packets because incoming buffers are overflow.

In order to achieve transmission efficiency at an intensity less than 2000 1/s redundant scheme should be used. In case it is necessary to provide a greater probability of delivery when the intensity is above 2000 1/s, it is necessary to use a redundant scheme. However, in this case, the average delivery time of the packets in the system are increasing, but this case is unacceptable for real-time systems.

Fig. 7 shows histograms of end to end packets delay for different value of intensity without redundant transmissions.

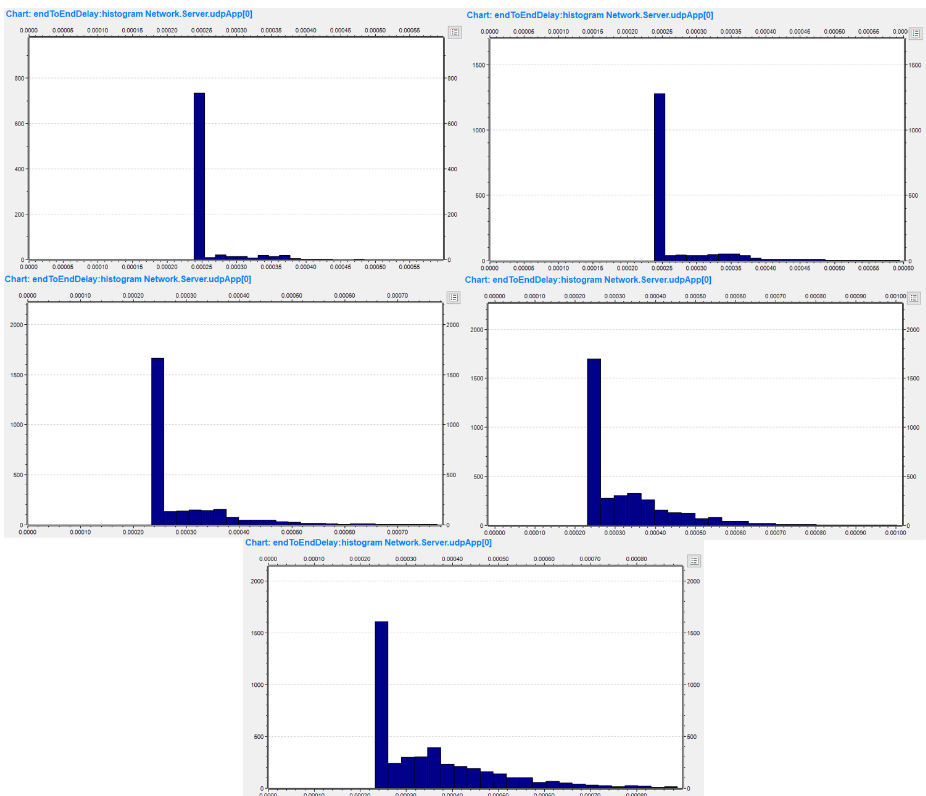

Fig. 7. Histograms of end to end packets delay for intensity = 1000, 2000, 3000, 4000, 5000 1/s without redundant transmissions (from top to down, from left to right).

Fig. 8 shows histograms of end to end packets delay for different value of intensity with K = 2.

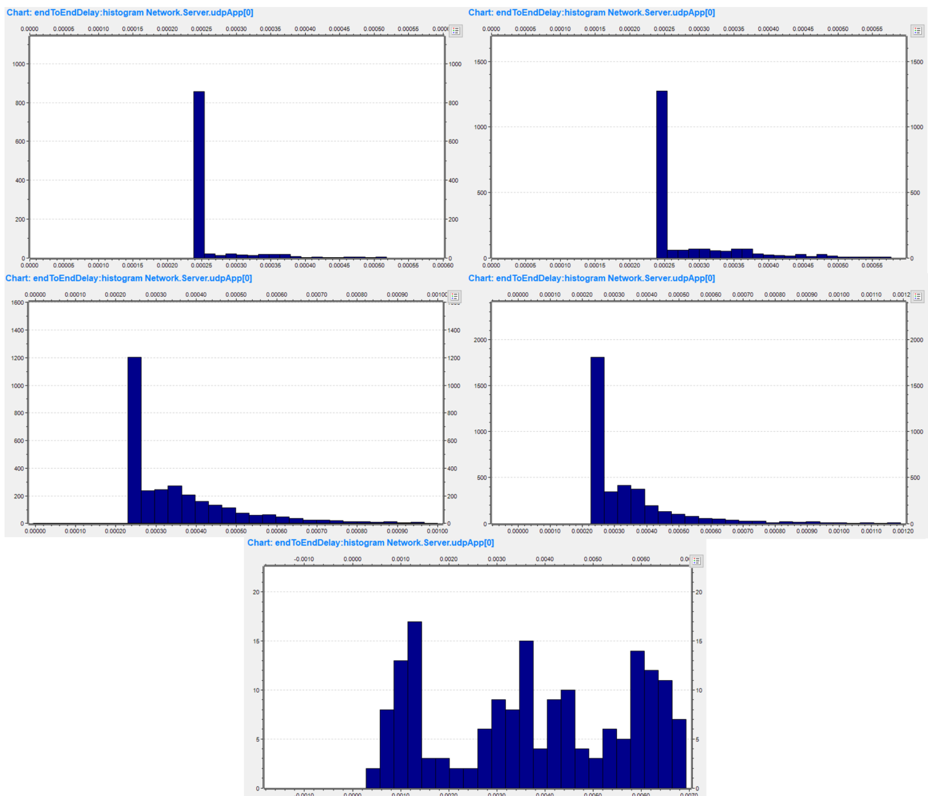

Fig. 8. Histograms of end to end packets delay for intensity = 1000, 2000, 3000, 4000, 5000 1/s with K = 2 (from top to down, from left to right).

These results can be interpreted as results above. Histogram of case with 5000 1/s intensity show us many big values of packets delay.

4 Conclusion

The simulation model of a switched computer network has been developed with the possibility of increasing the redundancy of transmit packets in the OMNeT++ environment. Carried out experiments to assess the effectiveness of packets transmit with different intensity and redundancy coefficient. Identified areas of application of effective redundancy transmissions in the aggregation of communication channels in computer networks. Developed model allows to transmit packets via several paths and provides redundant transfer of data.

The possibilities of increasing the probability of timely error-free service and reducing average delays in multipath data transmission systems are described.

On the basis of simulation, the effectiveness of redundant multipath transmissions is analyzed. Models are developed in the OMNeT++ simulation environment.

The field of using effectiveness of redundant multipath transmissions and redundant multipath packets transfer is shown.

Plots of of the criterion M and redundancy transmissions K for different packet intensity and plot shows dependence of the efficiency criterion M on the intensity of packet arrival with different redundancy coefficient are shown. Histograms of end to end packets delay for every considered cases are presented in the paper.

The presented results can be used in the design of high-reliable computer systems including computer systems providing real-time services which use UDP protocol.

References

1. Kopetz H. Real-Time Systems: Design Principles for Distributed Embedded Applications. Springer, pp. 396, 2011
2. Sorin D. Fault Tolerant Computer Architecture. Morgan Claypool 2009, P. 103
3. Zhmylev S., Martynchuk I.G., Kireev V.I., Aliev T. Analytical methods of nonstationary processes modeling // CEUR Workshop Proceedings, 2019, Vol. 2344
4. Vishnevskii, V.M., Teoreticheskie osnovy proektirovaniya (Theoretical Foundations of Design), Moscow: Tekhnosfera, 2003
5. Aliev, T.I.: The synthesis of service discipline in systems with limits. Communications in Computer and Information Science, IET, vol. 601. 2016. pp. 151-156
6. Kutuzov O. I., Tatarnikova T. M. On the Acceleration of Simulation Modeling. In 2019 XXII International Conference on Soft Computing and Measurements (SCM)), pp doi: 10.1109/SCM.2019.8903785
7. Poymanova, E.D., Tatarnikova, T. M. Models and Methods for Studying Network Traffic. In 2018 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF), pp. 1-5 (2018). doi: 10.1109 / WECONF.2018.8604470

8. Coolen, F.P.A., Utkin, L.V.: Robust weighted SVR-based software reliability growth model. Reliability Engineering System Safety 176, 93-101 (2018)
9. Anders Gunnar Mikael Johansson. Robust load balancing under traffic uncertainty–tractable models and efficient algorithms // Telecommun Syst. (2011) 48:93–107
10. Y. Challal, A. Ouadjaout, N. Lasla, M. Bagaa, A.Hadjidj. Secure and efficient disjoint multipath construction for fault tolerant routing in wireless sensor networks // Journal of Network and Computer Applications,vol.34, no.4,pp. 1380–1397, July 2011
11. Ya S.B., Tatarnikova T.M., Poymanova E.D.Organization of multi-level data storage/ In Informatsionno-Upravliaiushchie Sistemy. Volume 2019, Issue 2, 2019, Pages 68-75DOI: 10.31799/1684-8853-2019-2-68-75
12. Kabatiansky G., Krouk E., Semenov S. Error Correcting Coding and Security for Data Networks: Analysis of the Superchannel Concept. Wiley, 2005. P. 288
13. Krouk E., SemenovS. Application of Coding at the Network Transport Level to Decrease the Message Delay // Proc. of 3rd Intern. Symp. on Communication Systems Networks and Digital Signal Processing. Staffordshire University, UK, 2002. P. 1099112
14. A. V. Bogatyrev, V. A. Bogatyrev and S. V. Bogatyrev, "Multipath Redundant Transmission with Packet Segmentation," 2019 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF), Saint-Petersburg, Russia, 2019, pp. 1-4. doi: 10.1109/WECONF.2019.8840643
15. Noskov I.I., Bogatyrev V.A. Interaction model of computer nodes based on transfer reservation at multipath routing // 2019 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF) - 2019, pp. 8840607
16. Bogatyrev V.A On interconnection control in redundancy of local network buses with limited availability. (1999) Engineering Simulation, 16 (4), pp. 463-469
17. Bogatyrev V.A. Increasing the fault tolerance of a multi-trunk channel by means of inter-trunk packet forwarding (1999) Automatic Control and Computer Sciences, 33 (2) , pp. 70-76
18. V. A. Bogatyrev, S. V. Bogatyrev and A. V. Bogatyrev, "Model and Interaction Efficiency of Computer Nodes Based on Transfer Reservation at Multipath Routing," 2019 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF), Saint-Petersburg, Russia, 2019, pp. 1-4. doi: 10.1109/WECONF.2019.8840647
19. Kleinrock, L. Queueing Systems: Volume I – Theory. New York: Wiley Interscience. 1975 p. 417. ISBN 978-0471491101
20. Kleinrock, L. Queueing Systems: Volume II – Computer Applications. New York: Wiley Interscience. 1976 p. 576. ISBN 978-0471491118
21. Astakhova T., Shamin A., Verzun N., Kolbanev M.: CEUR Workshop Proceedings MICSECS 2018 - Proceedings of the 10th Majorov International Conference on Software Engineering and Computer Systems
22. Slastikhin I.A., Bogatyrev V.A., Noskov I.I. The simulation model of the system with aggregated channels and redundant transmissions on the multiple access level // CEUR Workshop Proceedings - 2019, Vol. 2344
23. Bogatyrev A.V., Bogatyrev S.V., Bogatyrev V.A. Analysis of the Timeliness of Redundant Service in the System of the Parallel-Series Connection of Nodes with Unlimited Queues//2018 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF), 2018, pp. 8604379
24. Noskov I.I., Bogatyrev V.A., Slastikhin I.A. Simulation of computer network with switch and packet reservation // CEUR Workshop Proceedings - 2019, Vol. 2344

25. VESELY Vladimır, REK Vıt, RYSAVY Ondrej. Enhanced Interior Gateway Routing Protocol with IPv4 and IPv6 Support for OMNeT++ // Advances in Intelligent Systems and Computing. 2016, vol. 2015, no. 1, pp. 65-85. ISSN 2194-5357
26. VESELY Vladimır, SVEDA Miroslav. L2 protocols in OMNeT++ // IP Networking 1 - Theory and Practice. Zilina: Zilina University Publisher, 2012, pp. 37-40
27. VESELY Vladimır, RYSAVY Ondrej, SVEDA Miroslav. Protocol Independent Multicast in OMNeT++ // The International Academy, Research and Industry Association, 2014, pp. 132-137
28. Bogatyrev, V.A., Parshutina, S.A. Redundant Distribution of Requests Through the Network by Transferring Them Over Multiple Paths. In: Vishnevsky V., Kozyrev D. (eds.) DCCN 2015. CCIS, vol. 601, pp. 199–207. doi: 10.1007/978-3-319-30843-2
29. Noskov I.I., Bogatyrev V.A. Simulating of fault-tolerant gateway based on VRRP protocol in OMNeT++ environment // CEUR Workshop Proceedings - 2019, Vol. 2522
30. Zakoldaev D.A., Korobeynikov A.G., Shukalov A.V., Zharinov I.O. Workstations Industry 4.0 for instrument manufacturing//IOP Conference Series: Materials Science and Engineering, 2019, Vol. 665, No. 1, pp. 012015
31. Zakoldaev D.A., Shukalov A.V., Zharinov I.O., Zharinov O.O. Workstations Industry 4.0 for instrument engineering products//IOP Conference Series: Materials Science and Engineering, 2019, Vol. 665, No. 1, pp. 012014
32. Korobeinikov A.G., Fedosovsky M.E., Zharinov I.O., Polyakov V.I., Shukalov A.V., Gurjanov A.V., Arustamov S.A. Method for Conceptual Presentation of Subject Tasks in Knowledge Engineering for Computer-Aided Design Systems//Advances in Intelligent Systems and Computing, 2018, Vol. 680, pp. 50-56