DOI: 10.24412/2413-2527-2023-234-34-40

A Comparison Study of FIFO, PQ, and WFQ Disciplines Using OPNET Simulation

M. Sh. Mahmood
Scholarship and Culture Relations Directorate Ministry of Higher Education and Scientific Research Baghdad
Baghdad, Iraq

PhD M. M. Khalil
University of Diyala
Baqubah, Iraq
maadalomar@gmail.com

Abstract. **As part of the resource allocation methods, each router must implement a queuing discipline that specifies how packets are buffered before being transmitted. To manage which packets are transmitted (bandwidth allocation) and which packets are dropped, various queuing disciplines can be applied (buffer space). A packet's delay is influenced by the queuing discipline by how long it must wait before being transferred. Priority queuing, weighted fair queuing, and first-in-first-out queuing are a few examples of common queuing techniques. Using simulation, this work clarifies the comparative analysis of different fields and spots a light on which to choose and when.**

Keywords: **resource allocation, packet buffering, priority queuing, weighted fair queuing, OPNET Simulator, MATLAB.**

Introduction

Routers are crucial networking tools that control how data is transmitted over a network. The input and output interfaces on routers are where packets are received and sent, respectively. A router may run out of room to store recently arrived packets because its memory is limited. This happens if the rate at which packets arrive is higher than the rate at which they leave the router's memory. New packets are either discarded or ignored in such a scenario. Routers must have some sort of queuing discipline that controls how packets are buffered or dropped as needed as part of the resource allocation processes.

Several disciplines may be used by the routers to decide which packets to keep and which packets to drop in order to manage the deployment of router memory to the packets in such congested conditions. As a result, routers use the following crucial queuing disciplines:

1. First-in-first-out (FIFO). The idea of FIFO [1] queuing is that the first packet that arrives at a router is the first packet to be transmitted. Given that the amount of buffer space at each router is finite, if a packet arrives and the queue (buffer space) is complete, the router discards (drops) that packet. This is done without regard to which flow the packet belongs to or how vital the packet is.

2. Priority Queue (PQ) is a simple variation of the basic FIFO queuing. The idea is to mark each packet with a priority; for example, the mark could be carried in the IP Type of Service (ToS) field. The routers then implement multiple FIFO queues, one for each priority class. Within each priority, Packets are still managed in a FIFO manner. This queuing discipline allows high-priority packets to cut to the front of the line. The Fair Queuing (FQ) [1] discipline aims to maintain a separate queue for each flow currently being handled by the router. The router then services these queues in a Round-robin manner.

3. Weighted Fair Queuing (WFQ) [2] allows weight to be assigned to each flow (queue). This weight effectively controls the percentage of the bandwidth link each flow will get. We could use ToS bits in the IP header to identify that weight. The cheapest and most common approach is scheduling mechanisms and packet discarding policies. A queue scheduling discipline manages the allocation of network resources among different traffic flows by selecting the next packet to be processed [3, 4]. Also, when packets arrive faster than they can be processed, arriving packets are dropped, thus controlling the network's congestion [5, 6]. Furthermore, it can reduce the impact of ill-behaved flows on other flows, especially when having a mixture of real-time and non-real-time traffic [3, 5].

Applications

In [3], some applications that use protocols such as FTP, HTTP, and e-mail are not sensitive to delayed transmitted information. In contrast, other applications like voice and video are vulnerable to loss and delayed information [7]. For QoS (Quality of Service) network devices must be able to differentiate among classes of arriving traffic and satisfy their individual requirements [8]. This method can handle contention for network resources when the network is intended to service widely varying types of traffic and manages the available resources according to policies set out by the network administrator [9]. Each router must implement some queuing discipline that governs how packets are buffered while waiting to be transmitted as part of the resource allocation mechanisms [10, 11]. Various queuing disciplines can be used to control which packets get transmitted (bandwidth allocation) and which packets get dropped (buffer space) [11, 12]. The queuing disciplines also affect to the packet latency by determining how long the packets wait to be transmitted. This study has discussed three queuing disciplines, FIFO queuing, Priority, and Weighted Fair queuing. The modelling is experienced over the network that carries applications (FTP, Video, and VoIP). It is investigated how the choice of the queuing discipline in the routers can affect the performance of these applications.

Creation and configuration of simulation network

The simulation network model There are five Ethernet workstations, one Ethernet server, and two Ethernet routers represented in Figure 1. A PPP DS1 bi-directional link connects the two routers. The workstations and server are linked to the routers through bi-directional 10Base-T lines. For protocols available at the IP layer, the QoS Attribute node defines attribute configuration details. These requirements can be referred to by individual nodes using symbolic names. It describes the FIFO, Priority, and Weighted Fair queuing profiles. The IP packets receive their ToS. It stands for a session property that enables the IP queues to give the right service to packets. The FTP applications configuration is done under the Best-effort ToS. Best-effort delivery denotes that a packet is attempted to

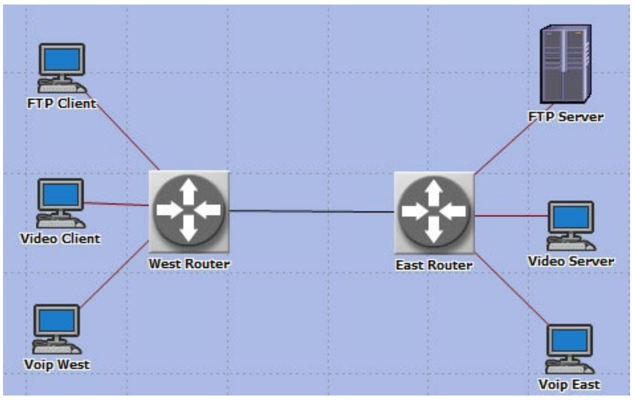

Fig. 1. The simulation network model

be delivered but is not always successful. The VoIP applications are configured using PCM quality speech to voice as a method for digitizing speech before sending it over the network [4]. The following statistics are gathered to evaluate the performance of the applications specified in the simulation network model:

- IP protocol — traffic dropped (packets/sec);
- video conferencing — traffic received (packets/s);
- voice — traffic received (Byte/s);
- voice — End-to-End delay.

Simulation results and performance comparison

Real-time IP applications, such as videoconferencing and voice traffic, require significant bandwidth with minimal packet delay and loss [5].

For more accurate results, we wrote a code in MATLAB for each queue type and compared results with OPNET Simulator, below is an example code for an FIFO queue in MATLAB:

```
% Set up parameters
N = 100; % Number of customers
S = 5; % Service time
lambda = 1; % Arrival rate

% Initialize variables
arrival_times = zeros(N, 1);
service_times = S * ones(N, 1);
departure_times = zeros(N, 1);
queue_lengths = zeros(N, 1);

% Simulate the queue
for i = 1:N
  % Determine arrival time
  if i == 1
    arrival_times(i) = 0;
  else
    arrival_times(i) = arrival_times(i-1) + exprnd(1/lambda);
  end

  % Determine departure time
  if i == 1
    departure_times(i) = arrival_times(i) + service_times(i);
  else
    departure_times(i) = max(arrival_times(i), depar-
ture_times(i-1)) + service_times(i);
  end

  % Compute queue length
  if i == 1
    queue_lengths(i) = 0;
  else
    queue_lengths(i) = sum(departure_times(1:i-1) > arri-
val_times(i));
  end
end

% Compute average queue length
avg_queue_length = mean(queue_lengths);

% Plot results
figure;
plot(arrival_times, queue_lengths, '-');
xlabel('Time (units)');
ylabel('Queue length');
title(sprintf('FIFO queue with service time %g', S));
fprintf('Average queue length: %g\n', avg_queue_length);
```

In this code, we simulate a queue with a fixed service time *S*, where customers arrive according to a Poisson process with rate lambda. We keep track of the arrival times, service times, departure times, and queue lengths for each customer.

At each iteration of the simulation loop, we first determine the arrival time for the current customer. If this is the first customer, their arrival time is set to 0. Otherwise, we draw an inter-arrival time from an exponential distribution with mean 1/lambda, and add it to the previous customer's arrival time.

Next, we determine the departure time for the current customer. If this is the first customer, their departure time is set to their arrival time plus the fixed service time *S*. Otherwise, we take the maximum of the current customer's arrival time and the previous customer's departure time, and add the fixed service time *S*.

Finally, we compute the queue length for the current customer. If this is the first customer, the queue length is 0. Otherwise, we count the number of customers who have already departed by the current customer's arrival time.

After the simulation loop, we compute the average queue length over all customers, and plot the queue length as a function of time.

In simulation the following parameters need to be kept in mind:

1. Providing adequate bandwidth for all voice, video, and data applications that are transmitted over the standard network.

2. Classifying the arriving packets and giving a classification based on their priority. Voice packets are given the highest priority since they are delay-sensitive. Video packets might be given a slightly lower priority, and FTP packets are given the lowest priority.

3. Queuing refers to a process that takes place in the routers and switches where different queues or buffers are created for the different packet classifications.

Dropped IP data packets

The discarded IP data packets for three different queuing techniques — FIFO queue, Priority queue, and Weighted Fair queue — are displayed in Figure 2 as a function of time in seconds. The simulation lasts for 150 seconds. The Priority queue

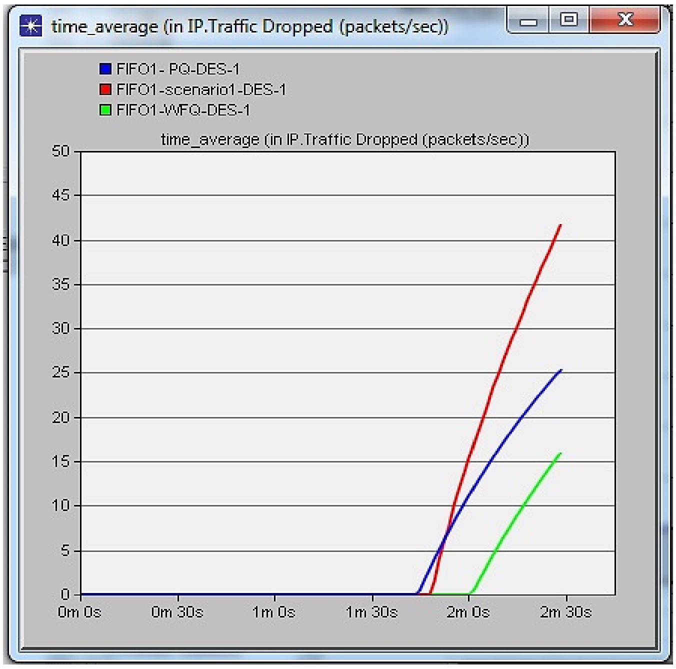

Fig. 2. IP Traffic Dropped

experiences less packet loss than the FIFO queue. Compared to Priority queue and FIFO queue, the loss of packets is lower in the Weighted Fair queue discipline. This is so that FIFO only cares about when a packet arrives, not from which flow it originates. The services offered by PQ and WFQ disciplines vary depending on the packets' ToS values and make use of different FIFO queues.

According to [13] packet loss can be calculated using equation

$$P_l = \frac{1}{N}\sum_k n_k \, ,$$

where N is the total number of packets; P_l is the packet loss probability; n_k is the number of lost packets during the time k.

Likewise, delay time is dependent on packet length and speed when they enter and exit the bus:

$$T_s = T_w + 2\frac{P_g}{V_b} + P_r \, ,$$

where T_s stands for total service time; T_w for packet waiting time in queue; V_b for packet bus input and output speed; P_g for packet length; P_r for packet processing time.

VIDEO CONFERENCING TRAFFIC RECEIVED

The average video conferencing traffic received over time is shown in Figure 3 (in Byte/s). Videoconference communication is transmitted (received) according to tight priorities in the queue while using priority queuing. High priority packets are forwarded first. The packets in the medium priority queue are forwarded if there are no packets in the high priority queue. The simulated graph makes it obvious that WFQ receives the most traffic. The FIFO has moreover seen more traffic than Priority queuing.

VOICE TRAFFIC RECEIVER

In comparison to FIFO (Fig. 4) demonstrates that the Priority and Weighted Fair queues are the most suitable scheduling systems for handling voice traffic. More specifically, voice traffic that was delivered and received to be identical, proving that no packets have been lost as shown in Figure 4.

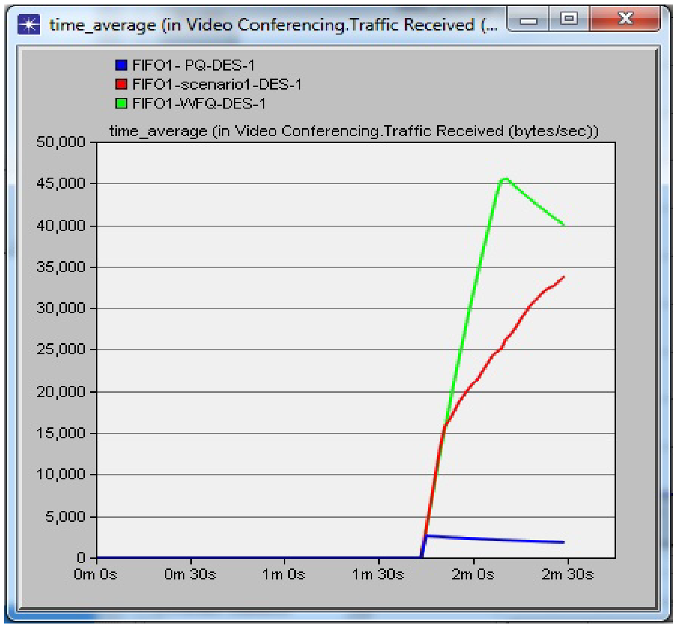

Fig. 3. Video conferencing traffic received

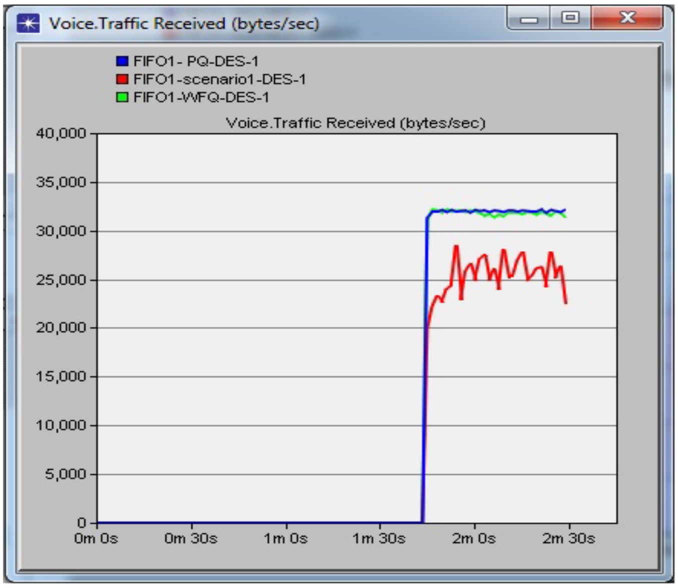

Fig. 4. Voice traffic received

END-TO-END DELAY

The outcome of the End-to-End (ETE) delay for a voice packet is shown in Figure 5. The time it takes for packets to be sent from source to destination is known as end-to-end delay. It is obvious that the PQ and WFQ have smaller ETE delays than FIFO, and ETE should be kept to a minimum to allow for natural communication.

The Figure 5 shows that in order to support voice, video, and data services on a network, a single traditional FIFO queue (per output interface) is insufficient. This is due to the tendency of data sources using the Transmission Control Protocol (TCP) to increase their sending rate until (a part of) the network is congested, resulting in excessive delays and packet loss.

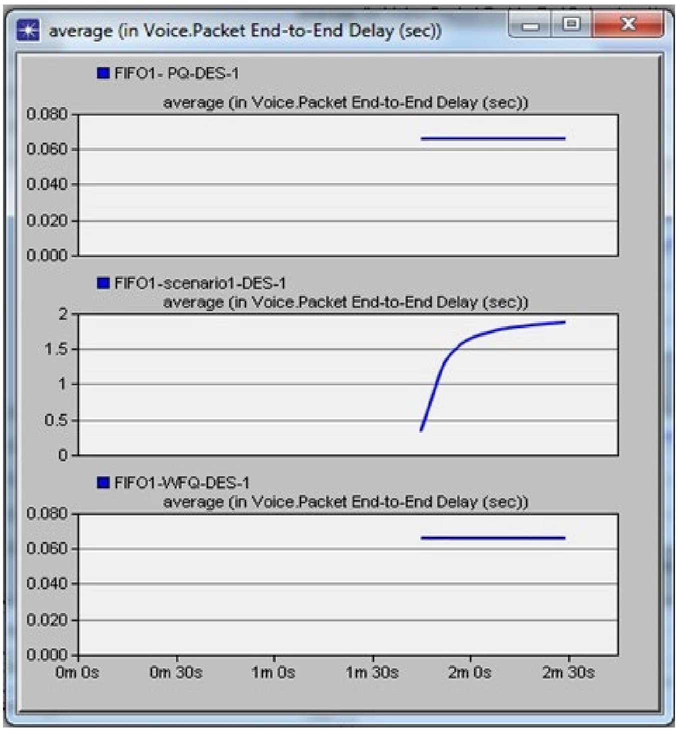

Fig. 5. End-to-End delay for voice packet

Conclusion

This study presented a simulation-based performance evaluation and comparison of three queuing scheduling disciplines for different traffic sources. Also, we explain the effects of different queuing disciplines over FTP, video, and VoIP performance using OPNET and analyses simulations of the results to make conclusions. Therefore, applications that are sensitive and affected by the delay of information, such as video and voice, need small queues in the routers. Small queues reduce delay, which is essential for real-time traffic. Large queue router architectures must service non-real-time traffic such as electronic mail, file transfers, and backups. Furthermore, the Weighted Fair queues and Priority queues are the best scheduling strategies for managing voice traffic. In the Priority queue discipline, there is less IP data packet loss than in the FIFO queue. IP data packets are not lost in the Weighted Fair queue discipline. As a result, further research is still needed to thoroughly analyze these queuing disciplines and demonstrate the effects of self-similar traffic and the deployment of traffic shapers at the network's edges. To study the considered issues using modern models of queuing systems, approaches and methods based on the use of iterative methods with phase-type distributions, with «heating» and «cooling» are recommended [14–17].

References

1. Velmurugan T., Balaji S., Chandra H. Comparison of Queuing Disciplines for Differentiated Services Using OPNET, *Proceedings of the 2009 International Conference on Advances in Recent Technologies in Communication and Computing (ARTCom), Kottayam, India, October 27–28, 2009*. Institute of Electrical and Electronics Engineers, 2009, Pp. 744–746. DOI: 10.1109/ARTCom.2009.128.

2. Balogh T., Medvecký, M. Performance Evaluation of WFQ, WF^{2}Q+ and WRR Queue Scheduling Algorithms, *Proceedings of the 34th International Conference on Telecommunications and Signal Processing (TSP 2011), Budapest, Hungary, August 18–20, 2011*. Institute of Electrical and Electronics Engineers, 2011, Pp. 136–140. DOI: 10.1109/TSP.2011.6043756.

3. Gospodinov M. The Affects of Different Queuing Disciplines over FTP, Video and VoIP Performance, *Proceedings of the Fifth International Conference on Computer Systems and Technologies (CompSysTech`2004), Rousse, Bulgaria, June 17–18, 2004*. New York (NY), Association for Computing Machinery, 2004, Art. No. IIIA-19, 5 p. DOI: 10.1145/1050330.1050381.

4. Kurose J. F., Ross K. W. Computer Networking: A Top-Down Approach. Eight Edition. Harlow, Pearson Education, 2021, 791 p.

5. Semeria C. Supporting Differentiated Service Classes: Queue Scheduling Disciplines (White Paper). Sunnyvale (CA), Juniper Networks, 2001, 27 p. Available at: http://www.telco-cloudbridge.com/wp-content/uploads/2013/06/QoS-Queing.pdf (accessed 07 Mar 2022).

6. Gustafsson E., Karlsson G. A Literature Survey on Traffic Dispersion, IEEE Network, 1997, Vol. 11, No. 2, Pp. 28–36. DOI: 10.1109/65.580915.

7. Tawfeeq F. N. Network Congestion and Quality of Service Analysis Using OPNET: A Thesis Submitted to the College of Information Engineering of Nahrain University in Partial Fulfillment of the Requirements for the Degree of Master of Science In Information Engineering, University of Baghdad, 2009, 122 p. DOI: 10.13140/RG.2.2.11267.20007.

8. Das Gupta J. Performance Issues for VoIP in Access Networks: A Dissertation in Partial Fulfilment of the Requirements for the Degree of Masters of Computing, University of Southern Queensland, 2005, 171 p.

9. Aboelela E. Networks Simulation Experiments Manual. Third Edition. Burlington (MA), Morgan Kaufmann Publishers, 2011, 208 p.

10. Schoenmakers B. A Simple Publicly Verifiable Secret Sharing Scheme and Its Application to Electronic Voting. In: *Wiener M. (ed.) Advances in Cryptology (CRYPTO '99): Proceedings of the 19th Annual International Cryptology Conference, Santa Barbara, CA, USA, August 15–19, 1999. Lecture Notes in Computer Science*, Vol. 1666. Heidelberg, Springer-Verlag, 1999, Pp. 148–164. DOI: 10.1007/3-540-48405-1_10.

11. Vaidya B., Rodrigues J. J. P. C., Lim H. Secure Multimedia Streaming over Multipath Wireless Ad hoc Network: Design and Implementation. In: *Nishi K. (ed.) Multimedia*. London, IntechOpen, 2010, Pp. 281–301. DOI: 10.5772/7638.

12. Butcher D., Li X., Guo J. Security Challenge and Defense in VoIP Infrastructures, *IEEE Transactions on Systems, Man, and Cybernetics — Part C: Applications and Reviews*, 2007, Vol. 37, Is. 6, Pp. 1152–1162. DOI: 10.1109/TSMCC.2007.905853.

13. Ben Rejeb S, Choukair Z., Tabbane S. The CAC Model and QoS Management in Wireless Multiservice Network, *International Journal on Computer Science and Engineering*, 2010, Vol. 2, No. 2. Pp. 333–339.

14. Ryzhikov Yu. I. Raspredelenie chisla trebovaniy v sisteme massovogo obsluzhivaniya s «razogrevom» [Distribution of the Number of Requests in a Queuing System with «Warm-up»],

Problemy peredachi informatsii [Problems of Information Transmission], 1973, Vol. 9, Is. 1, Pp. 88–97. (In Russian)

15. Takahashi Y., Takami Y. A Numerical Method for the Steady-State Probabilities of a G1/G/C Queuing System in a General Class, *Journal of the Operations Reseach Society of Japan*, 1976, Vol. 19, No. 2, Pp. 147–157.
DOI: 10.15807/jorsj.19.147.

16. Khomonenko A. D., Khalil M. M., Kassymova D. T. Probabilistic Models for Evaluating the Performance of Cloud Computing Systems with Web Interface, *Trudy SPIIRAN [SPIIRAS Proceedings]*, 2016, Is. 6 (49), Pp. 49–65.
DOI: 10.15622/sp.49.3.

17. Khomonenko A. D., Lokhvitskiy V. A., Khalil M. M. Calculation of Waiting Time Distribution in Multi-Channel Non-Markovian Queuing Systems with «Cooling» and «Heat-up», *Hi-tech and Earth Space Research [Naukoemkie tekhnologii v kosmicheskikh issledovaniyakh Zemli]*, 2017, Vol. 9, No. 4, Pp. 88–94.

DOI: 10.24412/2413-2527-2023-234-34-40

Сравнительное исследование дисциплин FIFO, PQ и WFQ с использованием OPNET Simulator

М. Ш. Махмуд
Управление по научным и культурным связям
Министерства высшего образования
и научных исследований Багдада
Багдад, Ирак

к.т.н. М. М. Халил
Университет Диялы
Баакуба, Ирак
maadalomar@gmail.com

***Аннотация*. В рамках методов распределения ресурсов каждый маршрутизатор должен реализовать дисциплину организации очереди, которая определяет, как пакеты буферизуются перед передачей. Для управления тем, какие пакеты передаются (распределение пропускной способности), а какие пакеты отбрасываются, могут применяться различные дисциплины очередей (буферное пространство). На задержку пакета влияет дисциплина очередей, в зависимости от того, как долго он должен ждать перед передачей. Приоритетная организация очереди, взвешенная справедливая организация очереди и организация очереди по принципу «первым пришел — первым обслужен» — вот несколько примеров распространенных методов организации очереди. Используя моделирование, эта работа проясняет сравнительный анализ различных областей и проливает свет на то, что и когда следует выбирать.**

***Keywords:* распределение ресурсов, буферизация пакетов, приоритетная организация очереди, взвешенная справедливая организация очереди, OPNET Simulator, MATLAB.**

Литература

1. Velmurugan, T. Comparison of Queuing Disciplines for Differentiated Services Using OPNET / T. Velmurugan, S. Balaji, H. Chandra // Proceedings of the 2009 International Conference on Advances in Recent Technologies in Communication and Computing (ARTCom), (Kottayam, India, 27–28 October 2009). — Institute of Electrical and Electronics Engineers, 2009. — Pp. 744–746. DOI: 10.1109/ARTCom.2009.128.

2. Balogh, T. Performance Evaluation of WFQ, WF^2Q+ and WRR Queue Scheduling Algorithms / T. Balogh, M. Medvecký // Proceedings of the 34th International Conference on Telecommunications and Signal Processing (TSP 2011), (Budapest, Hungary, 18–20 August 2011). — Institute of Electrical and Electronics Engineers, 2011. — Pp. 136–140. DOI: 10.1109/TSP.2011.6043756.

3. Gospodinov, M. The Affects of Different Queuing Disciplines over FTP, Video and VoIP Performance // Proceedings of the Fifth International Conference on Computer Systems and Technologies (CompSysTech`2004), (Rousse, Bulgaria, 17–18 June 2004). — New York (NY): Association for Computing Machinery, 2004. — Art. No. IIIA-19, 5 p. DOI: 10.1145/1050330.1050381.

4. Kurose, J. F. Computer Networking: A Top-Down Approach. Eight Edition / J. F. Kurose, K. W. Ross. — Harlow: Pearson Education, 2021. — 791 p.

5. Semeria, C. Supporting Differentiated Service Classes: Queue Scheduling Disciplines (White Paper). — Sunnyvale (CA): Juniper Networks, 2001. — 27 p. URL: http://www.telco-cloudbridge.com/wp-content/uploads/2013/06/QoS-Queing.pdf (дата обращения 07.03.2022).

6. Gustafsson, E. A Literature Survey on Traffic Dispersion / E. Gustafsson, G. Karlsson // IEEE Network. 1997. Vol. 11, No. 2. Pp. 28–36. DOI: 10.1109/65.580915.

7. Tawfeeq, F. N. Network Congestion and Quality of Service Analysis Using OPNET: A Thesis Submitted to the College of Information Engineering of Nahrain University in Partial Fulfillment of the Requirements for the Degree of Master of Science In Information Engineering. — University of Baghdad, 2009. — 122 p. DOI: 10.13140/RG.2.2.11267.20007.

8. Das Gupta, J. Performance Issues for VoIP in Access Networks: A Dissertation in partial fulfilment of the requirements for the degree of Masters of Computing. — University of Southern Queensland, 2005. — 171 p.

9. Aboelela, E. Networks Simulation Experiments Manual. Third Edition. — Burlington (MA): Morgan Kaufmann Publishers, 2011. — 208 p. — (The Morgan Kaufmann Series in Networking).

10. Schoenmakers, B. A Simple Publicly Verifiable Secret Sharing Scheme and Its Application to Electronic Voting // Advances in Cryptology (CRYPTO '99): Proceedings of the 19th Annual International Cryptology Conference (Santa Barbara, CA, USA, 15–19 August 1999) / M. Wiener (ed.). — Heidelberg: Springer-Verlag, 1999. — Pp. 148–164. — (Lecture Notes in Computer Science, Vol. 1666). DOI: 10.1007/3-540-48405-1_10.

11. Vaidya, B. Secure Multimedia Streaming over Multipath Wireless Ad hoc Network: Design and Implementation / B. Vaidya, J. J. P. C. Rodrigues, H. Lim // Multimedia / K. Nishi (ed.). — London: IntechOpen, 2010. — Pp. 281–301. DOI: 10.5772/7638.

12. Butcher, D. Security Challenge and Defense in VoIP Infrastructures / D. Butcher, X. Li, J. Guo // IEEE Transactions on Systems, Man, and Cybernetics — Part C: Applications and Reviews. 2007. Vol. 37, Is. 6. Pp. 1152–1162. DOI: 10.1109/TSMCC.2007.905853.

13. Ben Rejeb, S. The CAC Model and QoS Management in Wireless Multiservice Network / S. Ben Rejeb, Z. Choukair, S. Tabbane // International Journal on Computer Science and Engineering. 2010. Vol. 2, No. 2. Pp. 333–339.

14. Рыжиков, Ю. И. Распределение числа требований в системе массового обслуживания с «разогревом» // Проблемы передачи информации. 1973. Т. 9, Вып. 1. С. 88–97.

15. Takahashi, Y. A Numerical Method for the Steady-State Probabilities of a G1/G/C Queuing System in a General Class /

Y. Takanashi, Y. Takami // Journal of the Operations Reseach Society of Japan. 1976. Vol. 19, No. 2. Pp. 147–157. DOI: 10.15807/jorsj.19.147.

16. Khomonenko, A. D. Probabilistic Models for Evaluating the Performance of Cloud Computing Systems with Web Interface / A. D. Khomonenko, M. M. Khalil, D. T. Kassymova // Труды СПИИРАН. 2016. Вып. 6 (49). С. 49–65. DOI: 10.15622/sp.49.3.

17. Khomonenko, A. D. Calculation of Waiting Time Distribution in Multi-Channel Non-Markovian Queuing Systems with «Cooling» and «Heat-up» / A. D. Khomonenko, V. A. Lokhvitskiy, M. M. Khalil // Наукоемкие технологии в космических исследованиях Земли. 2017. Т. 9, № 4. С. 88–94.