Igor ZHUKOVYTS'KYY*, Victoria PAKHOMOVA
Dnipropetrovsk National University of Railway Transport
Lazaryan 2, 49010, Dnipro, Ukraine
Corresponding author. E-mail: ivzhukl@ua.fm

RESEARCH OF TOKEN RING NETWORK OPTIONS IN AUTOMATION SYSTEM OF MARSHALLING YARD

Summary. In the automation systems of sorting process the use of computer networks of Ethernet technology is possible. But its traditional drawback is a probabilistic nature of the network access, which does not guarantee the information transmission in specified time intervals. However, there are other technologies that are free from this defect, for example, the Token Ring technology. A methodology, for determination of the network parameters in the automation system on marshalling yard at the restriction of the average time for application waiting in the queue at the station network has worked out. Using the token method of access to the ring, the state diagram of network stations was compiled. This is the basis for simulation model of the Token Ring network, which was developed in the GPSS environment. As a result of simulation the dependencies of the maximum queue length at the network station on the frame length, intensity, and distribution of time for application receipt from the station were obtained.

1. INTRODUCTION AND PROBLEM DEFINITION

The marshalling yard to a great extent determines the capacity of railway transport and its operating efficiency. Automation of marshalling yard is performed at two levels: the organizational management and the control of technological process [1]. At a time the Ukrainian marshalling yards are integrated as a single automated system for the control of Ukrzaliznytsia's freight transportations (SAS CFT UZ), the basic integral subsystems of which are the computer networks [2]. In addition, for organization of subsystems interaction a network server and local workstation networks providing access of various users to the resources at higher levels were introduced. During the processing of car traffic volumes at the marshalling yard it is proposed to form the documents on the basis of information flows coming from the ground equipment used in the systems of railway automation: light signals, turnouts, sensors, track circuits, speed controllers, and others.

Different countries use the series of Ethernet technology network on railway transport [3 – 6]. But, the traditional drawback of using Ethernet in control systems is considered a probabilistic nature of devices access to the network [7 – 9]. This fact does not guarantee the information transmission in the specified time intervals. However, there are other technologies [2, 10] that are free from this defect, for example the technology Token Ring [11] based on the token method of access to the ring [12].

As an example of using such network let us consider one of the promising subsystems of the marshalling yard connected to the SAS CFT UZ that is intended for operation management at the marshalling yard. This subsystem provides full control of each car, that is, on the territory of the marshalling yard. The network structure is the promising direction of such subsystem. It is reasonable to allocate five sites on the automation object [13–14]. The information from these sites will be processed by the controller assigned to the site in accordance with a territorial basis. So, for receiving and processing of the information coming from the ground equipment the five stations of the Local

Area Network (LAN) will be involved. Further specialized microcontrollers with communication capabilities will be taken as the network stations. The sensors located at each turnout will be considered as the ground equipment for data take off. Moreover, the introduction of two-channel sensors on both sides of each switch is expected. This solution can detect not only the fact of car passing over the sensor, but also the direction of its movement. Placing the stations of the LAN (complete/partial) can be done both at the marshalling yard itself and in the relay room.

Variant 1: Stations of the LAN are located directly at the technology object, as it is shown in the Fig. 1. Physical and logical topology of such network is a ring; this option has equal advantages and disadvantages.

Variant 2: The hub MSAU (Multi Station Access Unit) is located in the relay room. The signals from the ground equipment go to the hub directly through the specialized microcontrollers (workstations of network), located at the marshalling yard. Physical topology of such network is star-ring (Fig. 2). This allows making the network more reliable.
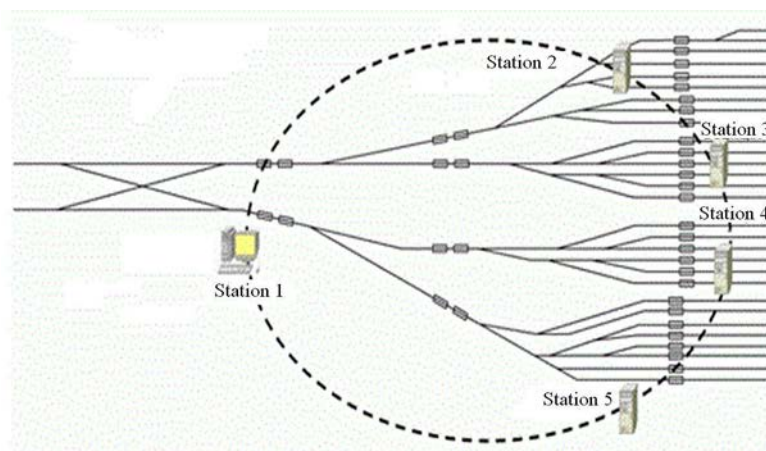

Fig. 1. Location of the Token Ring network stations at the technological object
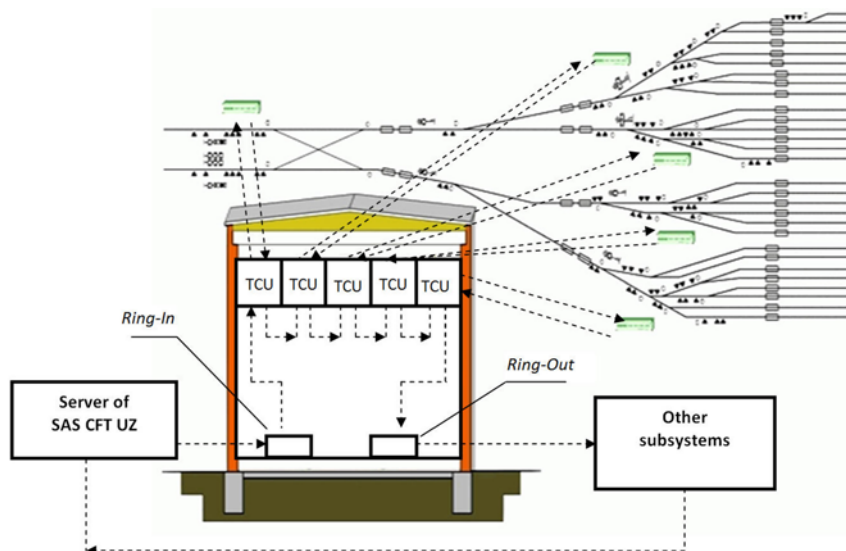

Fig. 2. Location of the Token Ring network stations in the relay room

The stations that are connected to the ring through the hub are joined with it by the lobe cable. Other network stations are connected in the ring by the direct links, which are called trunk cables. Hub ports designated for such connection are called Ring-In and Ring-Out. In addition, hub placing in one room makes it possible to simplify the process of network maintenance, especially in cases of failure

of one of the stations and when an urgent replacement is needed. To prevent the influence of this station on the ring operation, the stations are connected to the ring trunk through the special equipment that are called TCU (Trunk Coupling Units). Their functions include the formation of workaround that eliminates trunk approach to the MAC-node of the station in case of its refusal. This example (to simplify the model) does not consider connection of the network with the real-time server and automated control system at the top level.

2. FORMAL MODEL OF THE NETWORK STATION

The statechart diagram was developed for data link layer of the network station according to the token method of access to the ring at the data transmission speed of 4 Mb/s, which is shown in Fig. 3.

The statechart displays the complete process of token moving from station to station of the LAN. The chart contains the following nine states.

Listening is the main state of network station, wherein it awaits the reception of the token from the neighboring station. As the logical network topology is a ring, the token can be obtained only from the previous station.

Token receipt is a state, in which the network station receives the expected token from the previous station and conducts its further processing, depending on who is the recipient of the token. It also checks for the presence/absence of data.

Empty "token" – in case of empty token the station checks the presence of applications in the queue. If there are no applications, the station transmits the token to the next station. In case, there are applications for data transmission at the station, it "fills" the token with data, that is it attaches the data of a certain length to the token, changing the token status to "Token with data."

"Token with data" is a state, in which the network station after the token receipt determines whether it was addressed to it. In case of a positive answer the status "Token with data" is changed into "Data receipt". Then the station transmits the token to the next network station. If the token with data was sent by the station itself (it made a round all in the ring), then this token is transferred to the state "Processed data removal."
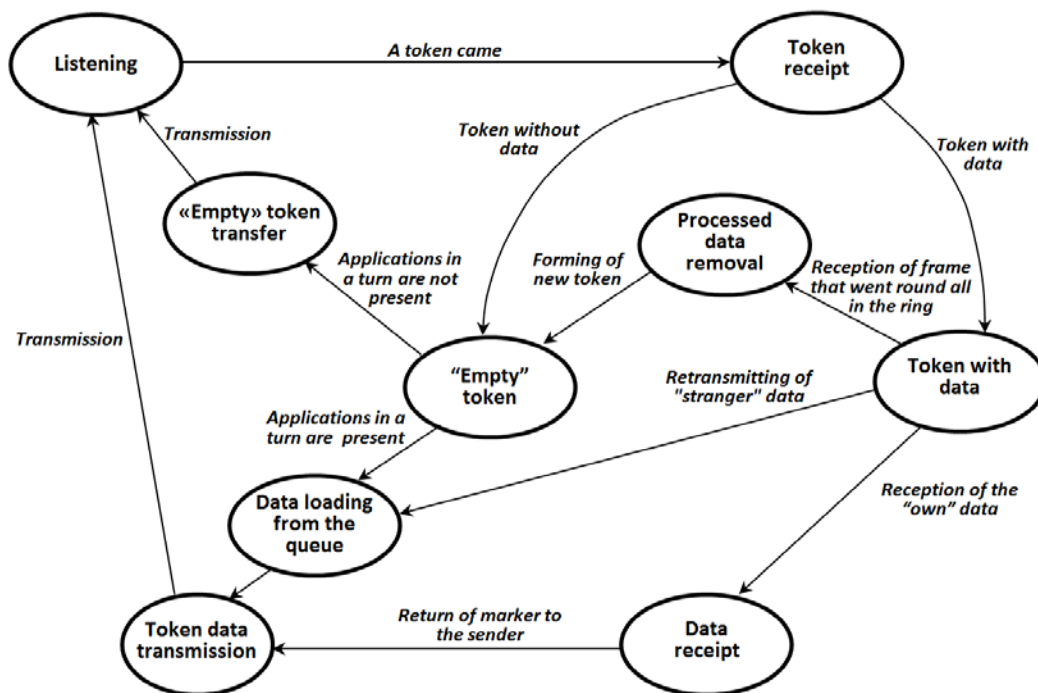

Fig. 3. Statechart diagram of the data link layer of the station according to the token method of access to the ring at 4 Mb/s

Processed data removal – after removal of the received token, the network station forms a new token and goes into the state "Empty token."

Empty token transfer is the transfer of token that does not have a data block to the next station upon the condition of application absence in the queue.

Data loading from the queue is adding to the token, a block of data, upon the condition of the applications availability in the queue.

Transfer of token with data is a condition when the transfer of the token with data block to the ring takes place.

Operation of the Token Ring network with each station may be represented as queuing system (QS) M/D/1 (Fig. 4). It is assumed at the same time of the application service in the network Token Ring at 4 Mb/s (it is equal to the time of token rotation on the ring) the intensity of applications receipt from the ground equipment to the station will be proportional to the intensity of applications arrival from network station to the ring.
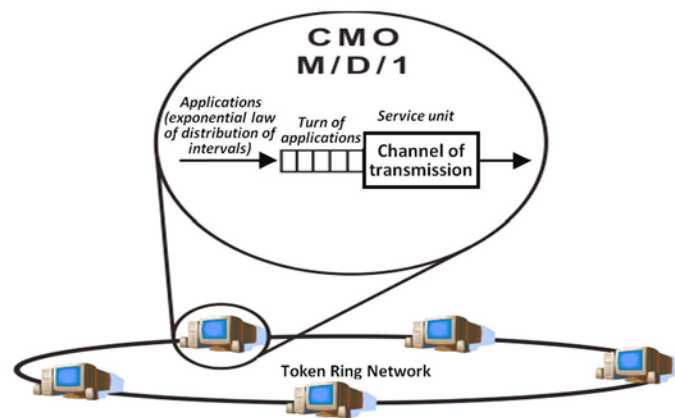

Fig. 4. Formal model of interaction of a Token Ring network with each station

3. SIMULATION MODEL "TOKEN RING-4"

To develop a simulation model for the LAN according to the token method of access to the ring at the data transmission speed of 4 Mb/s, the GPSS (General Purpose Simulation System) language was used. This language has some advantages over other common languages of simulation modeling.

The restrictions adopted in the simulation model "Token Ring-4" are as follows: physical data transmission speed 4 Mb/s; there is no control processes (one can observe a steady phase); simulation is performed on the data link layer of the network; the non-preferential service of the token; seven is the maximum number of workstations (due to the restrictions of the GPSS version); the propagation time of signal in the cable is not taken into account; errors during transmission are ignored.

The initial parameters of the simulation model "Token Ring-4" are as follows: the data transmission speed; the number of network workstations; distribution of time applications receipt from the station; intensity of applications receipt; frame length.

The resulting characteristics generated by the simulation model "Token Ring-4" are: queues statistics of each network station (average and maximum number of applications in the queue, average and maximum time of finding applications in the queue); use factor of network stations; use factor of data transmission channel; the total number of processed applications.

GPSS system allows one to monitor performance of the simulated object (in this case performance of the LAN according to the token method of access to the ring) throughout the modeling process. The system makes it possible to monitor the status of queues, devices, and logic switches. After the simulation process a standard report containing the data on workstations, data transmission channel, and information on the application queues from the network stations will be displayed.

With the help of the GPSS system during simulation one can build graphs that reflect the specific characteristics of the main objects of the GPSS language. For example, the graph of the maximum length of application queue from the station number 3 to the Token Ring network is shown in Fig. 5.
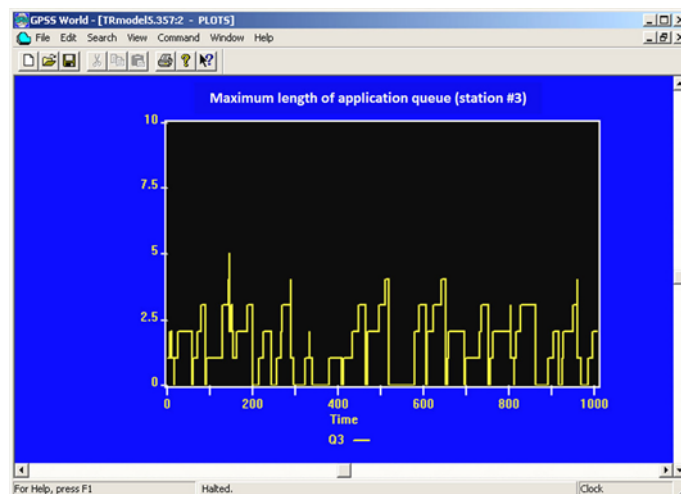

Fig. 5. Maximum length of application queue from the station number 3 to the Token Ring network

4. MODEL EXPERIMENTS

4.1. Complete factorial experiment

For experiments on the simulation model "Token Ring-4" the experimental design theory was used. The following parameters were taken as the input factors: number of stations (N); the intensity of the application receipt from the network stations (λ); data frame length (L). Time distribution of applications receipt from the station is exponential. Set up complete factorial experiment (CFE2^3). It was formulated the regression equation corresponding to the CFE2^3:

$$\widehat{y} = b_0 x_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{123} x_1 x_2 x_3, \qquad (1)$$

where x_i – is the encoded value of i factor; b_i – is the coefficient at the i factor; b_{ij} – is the coefficient at the double influence of the i and j factors; b_{ijk} – is the coefficient at the triple influence of the i, j and κ factors; $\widehat{y}$ – is the report. The maximum length of application queue of the station to the Token Ring network was taken as this report.

Four experiments were conducted. Test of homogeneity of statistical material was performed using the Cochran test. The resulting regression equation has the following form:

$$\widehat{y} = 11 + 5x_1 + 5x_2 + 7x_3 + 3x_1 x_2 + 5x_1 x_3 + 4x_2 x_3 + 3x_1 x_2 x_3. \qquad (2)$$

Resulting empirical model is the adequate one according to the t-criterion.

4.2. The influence study of the frame length on the operation of the Token Ring network

Studies were conducted using the simulation model of the Token Ring network. The model comprises of five stations in the automation system of sorting process at the marshalling yard. Such factor as the intensity of the applications receipt from the station is the fixed one (60 applications/s); the remaining factor (frame length) is the varied one. The maximum number of applications in the queue was taken as the studied characteristics of the network (for example, the station no. 3). Simulation time is 20 seconds. The simulation was conducted under different time distributions of the applications receipt from the stations to the network. Fig 6 shows the dependence of maximum length

of the station application queue of the Token Ring network on the frame length at different time distributions of application receipt from the station. On the basis of the obtained data we can conclude on the distribution of time of application receipt from the station. The most "extreme" for the network according to the token method of access to the rings was the normal distribution; the least was the even one.

Fig.6 shows that with increasing frame length, the length of application queue increases correspondingly. Moreover, for example, if the frames of 3000 octets length circulate through the ring, then in the automation system of sorting process at the hump the maximum queue length at even time distribution of application receipt from the station to the network will make 11 applications, 18 applications at exponential distribution, and 23 applications at normal distribution.
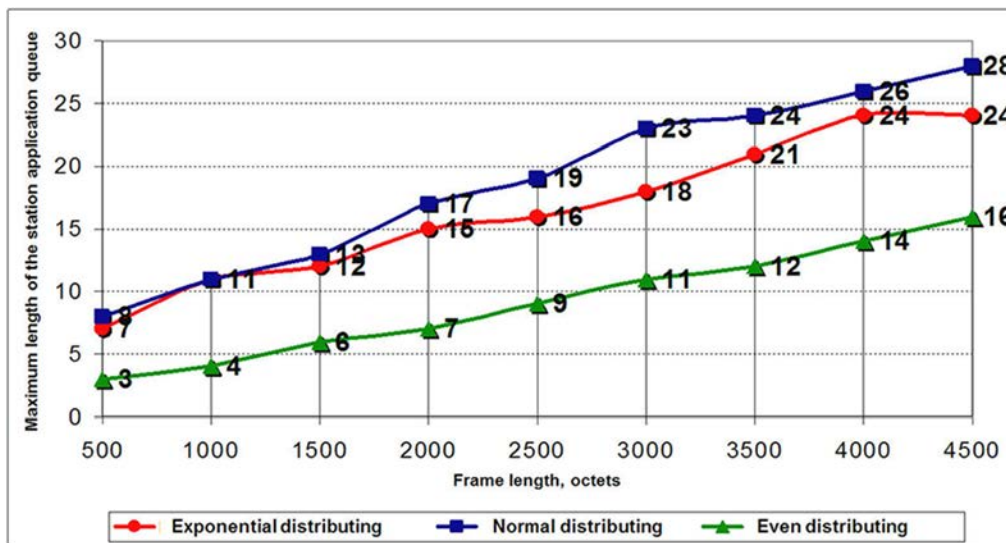

Fig. 6 - Dependence of maximum length of the station application queue of the Token Ring network on the frame length at the intensity of application receipt from the station 60 applications/s

4.3. Influence study of the application receipt intensity and the frame length on the maximum length of the station application queue to the network Token Ring

In order to conduct this study let us fix such factor as the length of the frame. The study was conducted using the simulation model at the exponential time distribution of application receipt from the station to the Token Ring network, which contains five workstations in the automation system of sorting process at the marshalling yard. The remaining factor (intensity of applications receipt from the stations to the network) will be varied. Simulation time is 20 seconds. The simulation results are presented in the Fig. 7. The figure shows that if, for example, the intensity of applications receipt from the station to the network is 60 applications/s, and the frame length is 1000 octets, the maximum length of the station application queue in the automation system of sorting process at the marshalling yard is 11 applications.

4.4. Determination of the Token Ring network parameters meeting the set limit

For the systems that operate in real-time the reaction time, the main component of which is the waiting time of application in the queue is the critical one. Between the waiting time and length of the application queue at the network station there is the following dependency:
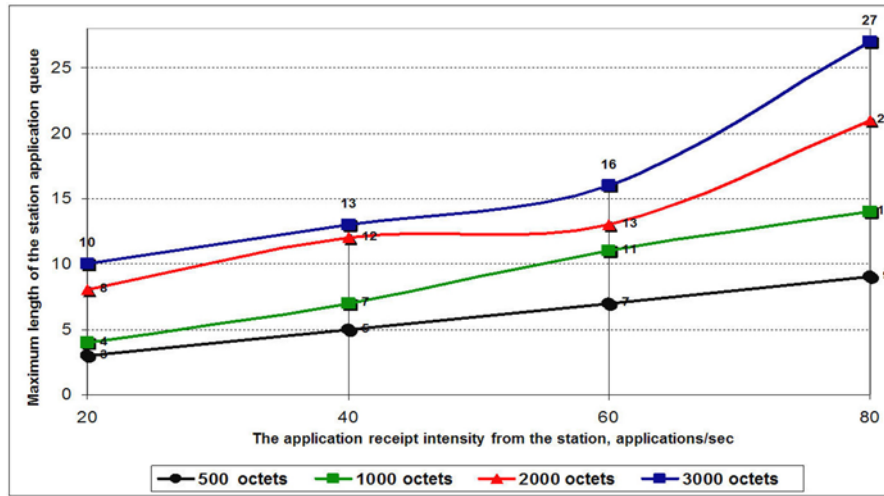
$$T_w = \frac{w}{\lambda}, \tag{3}$$

Fig. 7. Influence study of the application receipt intensity from the station to the Token Ring network and the frame length on the maximum length of the application queue

where T_w is the average waiting time in the application queue; w is the length of the application queue of the network station; λ is the intensity of applications receipt from the stations to the network.

The purpose of this part of the study is to determine the parameters of the Token Ring network in the automation system of sorting process at the hump, at which the average waiting time in the application queue does not exceed T_w^{allow}. According to T_w^{allow} the maximum length of the application queue of the Token Ring station will be equal to w_{max}, then the obtained regression equation (2) will take the following form:

$$11 + 5x_1 + 5x_2 + 7x_3 + 3x_1x_2 + 5x_1x_3 + 4x_2x_3 + 3x_1x_2x_3 \leq w_{max}. \tag{4}$$

Let us solve the resulting inequality with respect to x_1:

$$x_1 \leq \frac{w_{max} - 11 - 5x_2 - 7x_3 - 4x_2x_3}{5 + 3x_2 + 5x_3 + 3x_2x_3}. \tag{5}$$

For convenience of analysis the reverse transition from the encoded factor values to the natural ones was made:

$$N \leq \frac{(w_{max} - 11 - 5 \cdot \dfrac{\lambda - \lambda^0}{h_\lambda} - 7 \cdot \dfrac{L - L^0}{h_L} - 4 \dfrac{\lambda - \lambda^0}{h_\lambda} \cdot \dfrac{L - L^0}{h_L}) \cdot h_N}{5 + 3 \cdot \dfrac{\lambda - \lambda^0}{h_\lambda} + 5 \cdot \dfrac{L - L^0}{h_L} + 3 \cdot \dfrac{\lambda - \lambda^0}{h_\lambda} \cdot \dfrac{L - L^0}{h_L}} + N^0, \tag{6}$$

where N is the number of network station, , L is the frame length, and λ is the intensity of the application receipt from the station respectively; N^0, L^0, λ^0 are the basic levels of the network stations number, the frame length, and the intensity applications receipt from the station respectively; h_N, h_L, h_λ are the intervals of varying the number of network stations, the frame length ,and the intensity of application receipt from the station respectively.

Substituting the numerical values of the known variables let us go to the graphical representation of the obtained dependencies. Fig. 8 shows the region of acceptability for parameters of the Token Ring network (number of stations, intensity of applications receipt from the station) at the adopted limit for the average waiting time of application in the queue $T_w^{allow} = 0,25$ s. This region is restricted by the function $N=f(\lambda, L)$ at L=3000 octets, abscissa (λ=0) and ordinate axis (N=0).

Fig. 8 shows that for example, at $\lambda=60$ applications/s the number of stations of the Token Ring network in the automation system of sorting process at the marshalling yard should not exceed five.
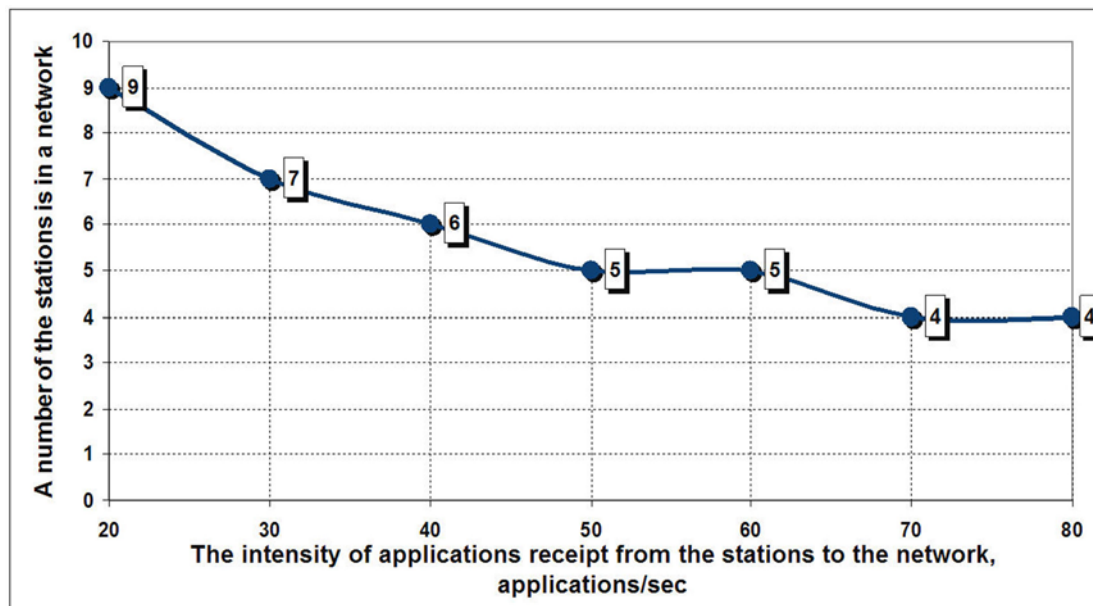

Fig. 8. Function $N=f(\lambda, L)$ for the Token Ring network that provides the restrictions for the average waiting time in the queue 0.25 s at the frame length 3000 octets

Fig. 9 shows the region of acceptability for parameters of the Token Ring network (number of stations, intensity of applications receipt from the station, frame length) at the adopted restriction for the average waiting time in the application queue 0.25 s. This region is restricted by the planes $N=0$, $\lambda=0$, $L=0$ and the surface $N=f(\lambda,L)$. The figure shows, for example, that at $\lambda=60$ applications/s and $L=3000$ octets the number of network stations should not exceed five.

5. CONCLUSIONS

1. Owing to the fact that the analytical simulation is very cumbersome and difficult to develop, the simulation model of the Token Ring network was selected. On the basis of the fact that the networks belong to the systems, which may cause different kinds of queues, it was decided to use the QS as the mathematical tool.
2. To implement the model of the Token Ring network the language GPSS was selected. Its main advantages are the practice of language use, good documentary support, and its focus on building the QS models.
3. The basis of the simulation model of the Token Ring network is a developed diagram of the data link layer of the station according to the token method of access to the ring at the speed 4 Mbit/s. The diagram includes nine states that fully describe the token motion from station to station of the network. The Token Ring network operation with each station is represented as a queuing system of M/D/1 type.
4. Using the simulation model "Token Ring-4" the CFE2[3] was conducted. The number of network stations, intensity of application receipt from the station, and the length of the frame were taken as factors. A response is the maximum queue length at the network stations. The empirical model obtained with the help of the simulation model "Token Ring-4" is considered as adequate by the *t*-criterion.
5. The purpose of the first part of the study using the simulation model "Token Ring-4" is to get the dependence of maximum length of the applications queue on the frame length, distribution of time,

and intensity of application receipt from the station to the network. For example, at the frame length of 4000 octets and intensity of application receipt from the station 60 applications/s, the application queue length at the exponential time distribution will be 24 applications.

6. The purpose of the second part of the study using the simulation model "Token Ring-4" is the determination of network parameters of the Token Ring network during implementation of restrictions at the average waiting time of application in the queue 0.25 s. Within this framework it was built the surface $N=f(\lambda,L)$, which provides restriction implementation.
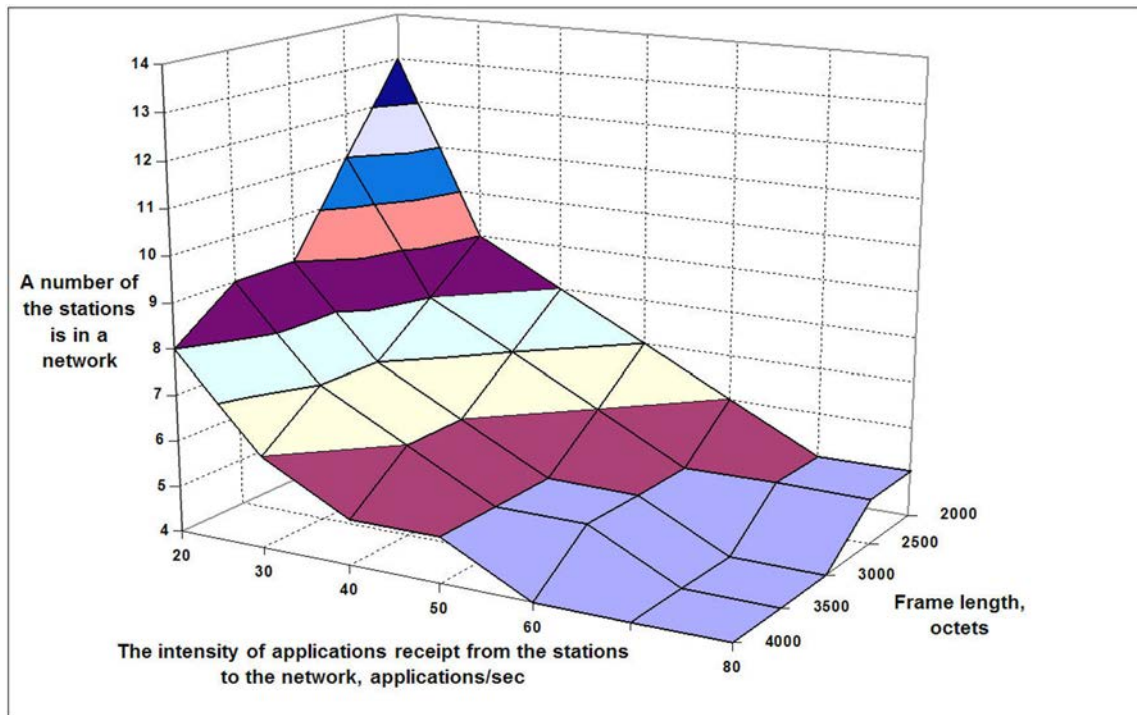

Fig. 9. Surface $N=f(\lambda, L)$ for the Token Ring network, that provides the implementation of restrictions for the average waiting time of application in the queue 0.25 s

References

1. Шафит, Е.М. & Жуковицкий, И.В. Современные принципы построения АСУ сортировочных станций. *Залізничний транспорт України.* 2000. No. 3. P. 22–26. [In Russian: Shafit, E. & Zhukovyts'kyy, I. Modern principles of automation of marshalling yards. *Railway Transport of Ukraine*].

2. Пахомова, В.М. *Можливості розвитку комп'ютерних мереж в автоматизованих системах залізничного транспорту.* Дніпропетровськ: Дніпропетровський національний університет залізничного транспорту. 2015. 203 p. [In Ukrainian: Pakhomova, V. *Development possibilities of computer networks in the automated systems of railway transport.* Dnipropetrovsk: Dnipropetrovsk National University of Railway Transport].

3. He Deqiang, etc. Delay analysis of train onboard detection sensor network. *Theoretical and Applied Information Technology*. 2013. P. 1185-1190.

4. Zhou, J. & etc. Reliability analysis of switched ethernet based train communication network. *Chemical and Pharmaceutical Research*. 2013. No. 5(9). P. 584-591.

5. Kawasaki J. Outline of INTEROS development. *East Japan Railway Culture Foundation*. 2014. No. 19. P. 40-45.

6. Tarek, K. Refaat. Ethernet Implementation of Fault Tolerant Train Network for Entertainment and Mixed Control Traffic. *Transportation Technologies*. 2013. No 3. P. 105-111.

7. Новиков, Ю.В. *Локальные сети: архитектура, алгоритмы, проектирование*. Москва: ЭКОМ. 2000. 312 p. [In Russian: Novikov, Yu. *Local networks: architecture, algorithms, design.* Moskow: ECOM].

8. Олифер, В.Г. *Компьютерные сети. Принципы, технологии, протоколы*. Санкт-Петербург: Питер. 2010. 944 p. [In Russian: Olifer, V. *Computer networks. Principles, technologies, protocols.* St. Petersburg: Piter].

9. Zhang, L. VirtualClock: A new trac control algorithm for packet switching networks. In: *Pmc. ACM SIGCOMM*. Sept. 1990. P. 19-29.

10. Rexf'ord, J. Hardware+efficient fair queueing architectures for high-speed networks. In: *Pm. IEEE INFOCOM*. 1996. P. 638-646.

11. Jain, R. Performance Analysis of FDDI, Token Ring Networks: Effects of Parameters and Guidelines for Setting TTRT. *SIGCOMM'90*. 1990. P. 264-275.

12. ANSI/IEEE Std 802.5-1998E *Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 5: Token ring access method and Physical Layer specifications. (Revision of ANSI/IEEE 802.5-1995). Adopted by ISO/IEC and redesignated as ISO/IEC 8802-5:*1995.

13. Пахомова, В.Н. & Прудко, А.А. Анализ локальных вычислительных сетей сортировочных станций на основе имитационной модели TOKEN RING. *Збірник наукових праць Дніпр. держ. техн. ун-ту залізн. тр.-ту*. 2002. Vol 12. P. 131–136 [In Russian: Pakhomova, V. & Prudko, A. Analysis of the Local Area Networks of the marshalling yards based on the simulation model TOKEN RING. *Bulletin of the Dnipropetrovsk State Technical University of Railway Transport*].

14. Пахомова, В.Н. & Прудко, А.А. О возможности использования технологии TOKEN RING в ЛВС на сортировочной горке. *Інформ.-керуючі системи на залізничн. транспорті*. 2004. No.6. P. 38–43. [In Russian: Pakhomova, V. & Prudko, A. On the use possibility of the TOKEN RING in the Local Area Network at the marshalling yard. *Information and control systems at the railway transport*].