Model of Neuro-Fuzzy Prediction of Confirmation Timeout in a Mobile Ad Hoc Network

Igor Konstantinov, Kostiantyn Polshchykov, Sergej Lazarev, and Olha Polshchykova

Belgorod State University,
Pobeda Street 85, 308015 Belgorod, Russia
{konstantinov,polshchikov,lazarev,polshchikova}@bsu.edu.ru
http://www.bsu.edu.ru

Abstract. Confirmation timeout (Round Trip Time, RTT) is an important value in data networks. Correct prediction of this characteristic allows us to estimate the network load in order to adequately select packet sending and retransmission parameters. Approximate heuristic models are used in the Transmission Control Protocol (TCP) for Round Trip Time evaluation. The values of the coefficients in these models were obtained experimentally for fixed topology networks. Therefore, the use of these models in a dynamic topology network (mobile ad-hoc network) is inefficient. This article represents an RTT prediction model based on application of fuzzy neural network theory. This model relies upon zero-order Sugeno-Type Fuzzy Inference algorithm. The input values of fuzzy neural network are RTT values measured in the current and two previous cycles. The output value is RTT value expected in the next cycle. The proposed model is set up and examined by means of simulation experiments. In these experiments the functioning of mobile ad-hoc network which is used for communication software while counteracting emergencies was simulated.

Keywords: neuro-fuzzy prediction, round trip time, mobile ad hoc networks, dangerous construction sites.

1 Introduction

Mobile ad hoc networks (MANET) are a promising direction in the development of telecommunication technologies [1]. With its decentralized structure, ad hoc networks provide the ability to transmit information when nodes are moving randomly and under the impact of destructive factors [2, 3]. Due to rapid deployment, autonomous power of each node, high survivability and the ability to deliver messages with dynamically changing topology, ad hoc network can be used for communication on dangerous construction sites [4]. Construction of dangerous objects is carried out under the threat of destructive and damaging natural and man-made factors that can cause explosions, fire, collapse, flooding, radiation, poisoning and other emergencies.

The process of information exchange in a mobile ad hoc network is based on the implementation of the packet data transfer. One of the important characteristics in this case is RTT. Correct prediction of this value allows us to estimate the network load to adequately select the parameters of packet sending and retransmissions. Approximate heuristic models are used in the TCP for its evaluation [5, 6]. The values of the coefficients in these models were obtained experimentally for networks with a fixed topology, that is why their use in the ad hoc networks does not give the desired effect. As a result, time of information delivery increases significantly, which is unacceptable in the construction of dangerous buildings, as the life and health of builders, as well as the extent of damage to constructed facilities, depend on the operational efficiency of messages receiving in emergencies. Therefore, the development of an adequate RTT forecasting model in the mobile ad hoc network is a topical applied science problem, the solution of which is represented in the following researches.

2 Development of Neuro-Fuzzy Model

The neuro-fuzzy model is suggested to predict RTT in an ad hoc network. The following values are used in this model: M is RTT value measured in the current cycle; M^{pr1} is RTT value measured in the previous cycle; M^{pr2} is RTT value measured in the cycle preceding the previous one. The model allows us to calculate the estimated value $\widetilde{M}$ of the confirmation timeout for each of the next cycles.

Construction of the model is carried out on the criterion of minimal complexity. The following parameters correspond to this criterion: fuzzy inference algorithm is the zero-order Sugeno [7], the number of membership functions for each input value is 2, the shape of membership functions for each input value is triangular, neuronal learning algorithm is error propagation [8]. The model is using the following fuzzy rulebase:

$$If(M = X_1)and(M^{pr1} = Y_1)and(M^{pr2} = Z_1), then(\widetilde{M} = J_1); \tag{1}$$

$$If(M = X_1)and(M^{pr1} = Y_1)and(M^{pr2} = Z_2), then(\widetilde{M} = J_2); \tag{2}$$

...

$$If(M = X_2)and(M^{pr1} = Y_2)and(M^{pr2} = Z_2), then(\widetilde{M} = J_8); \tag{3}$$

where X_1, X_2, Y_1, Y_2, Z_1, Z_2 are terms number 1 and number 2 of the input values M, M^{pr1}, M^{pr2}; J_1 ... J_8 are individual conclusions of the fuzzy rules.

Type and parameters of the membership functions for each input value are shown in Fig. 1, Fig. 2 and Fig. 3.

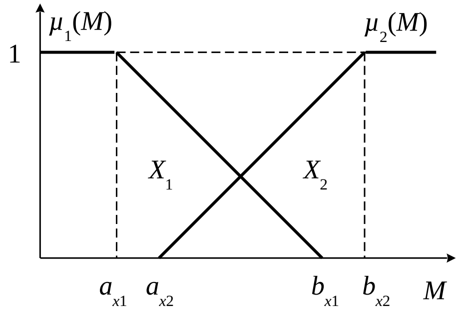

Fig. 1. Type and parameters of the membership functions for the value M

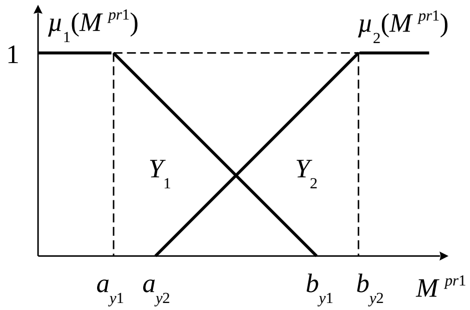

Fig. 2. Type and parameters of the membership functions for the value M^{pr1}

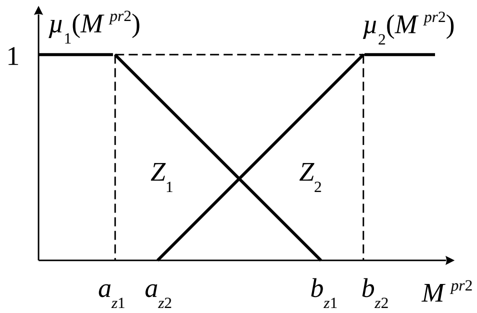

Fig. 3. Type and parameters of the membership functions for the value M^{pr2}

The model of forecasting Round Trip Time includes four structural neural layers. Fuzzification procedure is performed by means of the first layer of neurons:

$$\mu_1(M) = \begin{cases} 1, & M < a_{x1}; \\ \frac{b_{x1}-M}{b_{x1}-a_{x1}}, & a_{x1} \le M < b_{x1}; \\ 0, & M \ge b_{x1}; \end{cases} \tag{4}$$

$$\mu_2(M) = \begin{cases} 0, & M < a_{x2}; \\ \frac{M-a_{x2}}{b_{x2}-a_{x2}}, & a_{x2} \le M < b_{x2}; \\ 1, & M \ge b_{x2}; \end{cases} \tag{5}$$

$$\mu_1(M^{pr1}) = \begin{cases} 1, & M^{pr1} < a_{y1}; \\ \frac{b_{y1}-M^{pr1}}{b_{y1}-a_{y1}}, & a_{y1} \le M^{pr1} < b_{y1}; \\ 0, & M^{pr1} \ge b_{y1}; \end{cases} \tag{6}$$

$$\mu_2(M^{pr1}) = \begin{cases} 0, & M^{pr1} < a_{y2}; \\ \frac{M^{pr1}-a_{y2}}{b_{y2}-a_{y2}}, & a_{y2} \le M^{pr1} < b_{y2}; \\ 1, & M^{pr1} \ge b_{y2}; \end{cases} \tag{7}$$

$$\mu_1(M^{pr2}) = \begin{cases} 1, & M^{pr2} < a_{z1}; \\ \frac{b_{z1}-M^{pr2}}{b_{z1}-a_{z1}}, & a_{z1} \le M^{pr2} < b_{z1}; \\ 0, & M^{pr2} \ge b_{z1}; \end{cases} \tag{8}$$

$$\mu_2(M^{pr2}) = \begin{cases} 0, & M^{pr2} < a_{z2}; \\ \frac{M^{pr2}-a_{z2}}{b_{z2}-a_{z2}}, & a_{z2} \le M^{pr2} < b_{z2}; \\ 1, & M^{pr2} \ge b_{z2}. \end{cases} \tag{9}$$

Aggregation procedure is performed by the second layer of neurons:

$$G_1 = \mu_1(M) \wedge \mu_1(M^{pr1}) \wedge \mu_1(M^{pr1}); \tag{10}$$

$$G_2 = \mu_1(M) \wedge \mu_1(M^{pr1}) \wedge \mu_2(M^{pr1}); \tag{11}$$

$$\dots$$

$$G_8 = \mu_2(M) \wedge \mu_2(M^{pr1}) \wedge \mu_2(M^{pr1}). \tag{12}$$

Activation is a part of the defuzzification procedure. Calculation of the amount of aggregated results $\sum_{r=1}^{8} G_r$ and the weighted sum of the aggregate results $\sum_{r=1}^{8} J_r G_r$ are performed by means of the third layer of neurons.

The final part of defuzzification procedure is performed by means of the fourth layer:

$$\widetilde{M} = \frac{\sum_{r=1}^{8} J_r G_r}{\sum_{r=1}^{8} G_r}. \tag{13}$$

In order to obtain the coefficient values needed to calculate membership function, it is required to set the weights of neurons of the first layer. Training of the neurons of the third layer is needed for evaluating the values of individual fuzzy rules conclusions [9–15]. The receiving of training data for model setup and evaluation of neuro-fuzzy forecasting RTT are carried out on the basis of modeling of various scenarios of ad-hoc network application for communication on dangerous construction sites.

3 Modeling Information Streams Transmission

Let us consider an example in which mobile ad hoc network is used for communication in the construction of underground facilities. Fig. 4 and Fig. 5 show the area of the construction works (limited by bold dotted line).

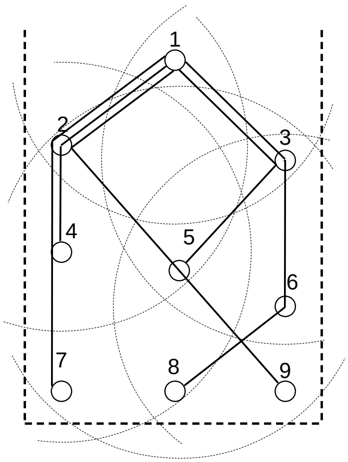

Fig. 4. The routes of transmission of information flows in a fixed network topology

This building belongs to the dangerous construction projects, because works on its construction are carried out in the conditions of a possible collapse of rocks. Works are carried out by a personnel shift which consists of:

1) head of the shift who uses ad hoc node 1;

2) eight workers equipped with ad hoc nodes with numbers 2-9.

Ad hoc units are denoted by small numbered circles, and coverage areas of these units are limited by the corresponding circles of larger radius. The following functions are performed by means of ad hoc nodes:

1) video streams to monitor the status of the facility, conditions and the course of the work;

2) exchange of voice messages to control the construction process and the coordination of countering emergencies;

3) transfer of data on the functional status and current location coordinates of the builders, as well as data of monitoring external conditions on the construction site.

In the given example the transmission of information streams is carried out in an ad hoc network for a period of time of observation which lasts 50 seconds. The characteristics of the streams are represented in Table 1 and Table 2.

Fig. 4 shows the situation where the network topology remains unchanged during the considered time interval. The routes of information streams trans-

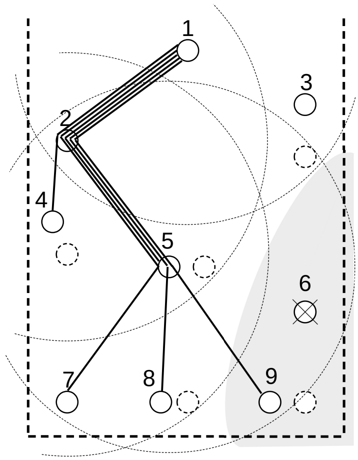

Fig. 5. The routes of transmission of information flows in a dynamic network topology

Table 1. Characteristics of the transmitted information streams

Stream number	Type of of transferred	Sending node number	Receiving node number	Transmission start time, s
1	video	4	1	0
2	data	5	1	8
3	acknowledgements	1	5	8
4	data	9	1	12
5	acknowledgements	1	9	12
6	voice	7	1	16
7	voice	1	7	16
8	video	8	1	22

Table 2. Estimated parameters

Parameter	Value
Throughput of the radio channel	1000 Kbit/s
Throughput required to transmit video	256 Kbit/s
Throughput required to transmit voice	128 Kbit/s
Size of messages transmitted by data flow	1 MB

mission correspond to the broken lines which connect the nodes-senders and nodes-recipients.

Fig. 5 shows a scenario where an ad hoc network topology changes due to the collapse of rock, which began at time t_e=4 s. Collapse zone is highlighted in gray. As a result of emergency workers who used ad hoc nodes 6 and 9 were in the collapse zone and node 6 malfunctioned (corresponding circle in Fig. 5 is crossed).

In response to the collapse, workers with ad hoc nodes 3-5, 8 and 9 have moved. The locations of these nodes at the initial time in Fig. 5 are marked by the dashed circles. In the modified network structure in Fig. 5 routes that transmit information streams (numbered 2, 3, 5–8) differ from the corresponding streams marked in Fig. 4.

Dynamism of network topology had an impact on the radio channels workload and throughput available for transmission of data flows. For example, a radio channel connecting the node 2 to node 1, except for the main streams of 1, 4 and 6, additional streams 2 and 8 started to transmit.

The responsiveness of the node 1 receiving the data file transmitted from the node 9 is of great importance in an emergency. This file contains information about the current parameters of health status and location of the worker who has been exposed to the collapse. On the basis of the data head of the shift can quickly and effectively coordinate the actions of other workers to rescue the injured builder.

For the file to be delivered, streams 4 and 5 need to be transferred. The combination of these interrelated streams is called a controlled flow (CF) [16]. The closed circuit formed by the channels through which CF is transferred is called CF-circuit (Fig. 6).

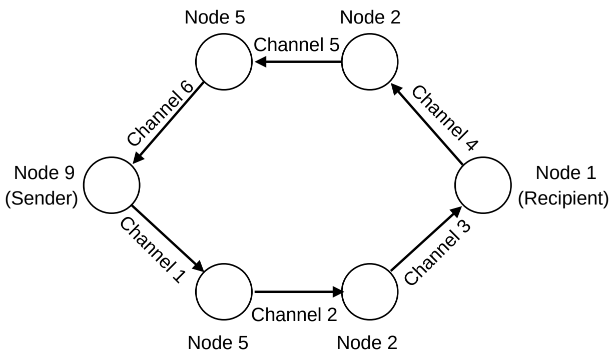

Fig. 6. CF-circuit

Duration of data file delivery from node 9 to node 1 is directly dependent on the value $E(t)$, the current CF-circuit throughput available for CF transmission.

To calculate this value, one should use the expression:

$$E(t) = min\{E_k(t)\}, \tag{14}$$

where $E_k(t)$ is the current value of the channel throughput k of the CF-circuit [17].

The value $E_k(t)$ can be figured out from the formula:

$$E_k(t) = \begin{cases} 0, & U_k(t) \geq c; \\ \frac{c-U_k(t)}{D_k(t)}, & U_k(t) < c; \end{cases} \tag{15}$$

where c is the throughput of the radio channel; $U_k(t)$ is the current value of the channel throughput k required to transmit real-time streams; $D_k(t)$ is the number of data streams, having to be transmitted over the channel by the time t, $D_k(t) \geq 1$.

The value $U_k(t)$ can be determined using the following expression:

$$U_k(t) = \sum_{l=1}^{L} u_{kl}(t), \tag{16}$$

where $u_{kl}(t)$ is the current value of the channel k throughput required for real-time stream transmission l; L is the number of real-time streams, which need to be transmitted on the CF-circuit channels.

The value of $u_{kl}(t)$ can be found from the formula:

$$u_{kl}(t) = \begin{cases} \lambda_l a_{kl}, & x_l^{start} \leq t < x_l^{stop}; \\ 0, & t < x_l^{start} \text{ or } t \geq x_l^{stop}, \end{cases} \tag{17}$$

where λ_l is the value of the bandwidth of the channel k required to transmit real-time stream l [18]; a_{kl} is the value showing whether the transmission channel is required on real-time stream l channel k; x_l^{start} and x_l^{stop} are instants of the beginning and the end of transmission of real-time stream l.

The minimum possible duration of the CF transmission can be determined using the following formula:

$$\tau_{CF} = \tau_{CF}^{stop} - \tau_{CF}^{start}, \tag{18}$$

where τ_{CF}^{start} is starting time of CF transmission; τ_{CF}^{stop} is closure time of CF-stream transmission without packet loss and an ideal correspondence between the intensity of sending data of the stream and the bandwidth of CF-circuit available for the transmission.

The value τ_{CF}^{stop} is calculated on the basis of the obtained values $E_(t)$. To do this, use the formula:

$$V = \int_{\tau_{CF}^{start}}^{\tau_{CF}^{stop}} E(t)\, dt, \tag{19}$$

where V is the size of the message transmitted by data flow.

Table 3. λ_l, x_l^{start} and x_l^{stop} values

l	λ_l, bit/s	x_l^{start}, s	x_l^{stop}, s
1	256	0	>50
2	128	16	>50
3	128	16	>50
4	256	22	>50

Table 4. a_{kl} values

k	l=1	l=2	l=3	l=4
1	0	0	0	0
2	0	0	0	1
3	1	1	0	1
4	0	0	1	0
5	0	0	0	0
6	0	0	0	0

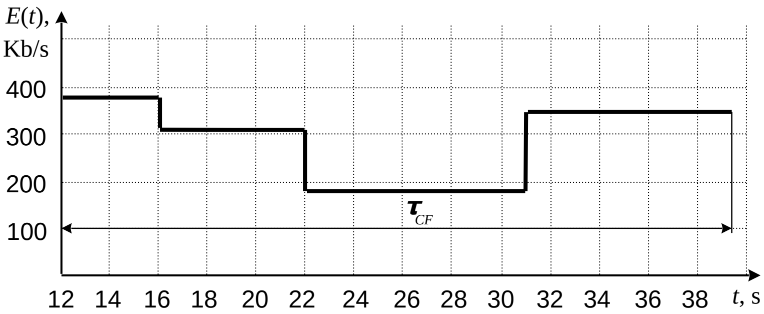

Fig. 7. The current values $E(t)$ in a network with a dynamic topology

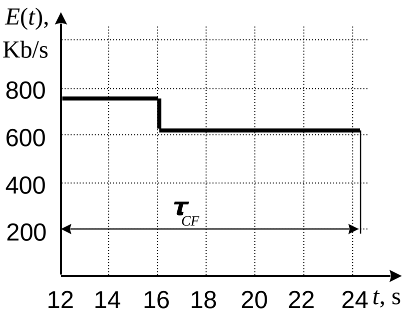

Fig. 8. The current values $E(t)$ in fixed topology network

To calculate the function $E(t)$ in the case shown in Fig. 4 and Fig. 5, we used data contained in Table 3 and Table 4.

Using these inputs, the function $E(t)$ is calculated and its form is shown in Fig. 7. The fixed network topology function $E(t)$ has the form shown in Fig. 8.

Analysis of Fig. 7 and Fig. 8 shows that the change in the network topology during information exchange leads to a significant deceleration of data file transmission duration. In a network with a dynamic topology the value τ_{CF} is set to 39.7 s, and in case of a fixed network structure it is τ_{CF}=24.2 s.

4 Setting Parameters of the Model and the Evaluation of the Effectiveness of Its Application

In real operating conditions an ad hoc network overload and packet loss frequently occur, so the actual value of the data file transfer duration can significantly exceed the calculated value τ_{CF}. To evaluate these characteristics a number of simulation experiments were made, in which various scenarios of applying an ad hoc network for providing connectivity on dangerous construction sites were simulated. For this purpose, a simulation model of information streams transmissions in a network with dynamic topology was used. It was developed in MatLab Simulink software environment. The simulation results provided evidence for setting developed neuro-fuzzy model forecasting round trip time. On the basis of these data the training matrix of the following form is made:

$$\begin{pmatrix} M_1 & M_2 & M_3 & M_4 \\ M_2 & M_3 & M_4 & M_5 \\ . & . & . & . \\ M_i & M_{(i+1)} & M_{(i+2)} & M_{(i+3)} \\ . & . & . & . \\ M_{(I-3)} & M_{(I-2)} & M_{(I-1)} & M_I \end{pmatrix} \tag{20}$$

where M_i is a round trip time of confirmation in the loop i; I is the number of cycles in each simulation experiment, I=750.

Setting neuro-fuzzy model was carried out using software tools Fuzzy Logic Toolbox. Table 5 shows the results of training the neurons of the first layer, while Table 6 contains the results of training the neurons of the third layer.

To assess the efficiency of the developed and customized models, a number of simulations for the transfer of information streams in an ad hoc network were conducted. The selection of retransmission was simulated on the basis of the suggested neuro-fuzzy forecasting RTT and the classical model of evaluation of this quantity used in TCP. The results showed that the use of neuro-fuzzy forecasting RTT in a large network load reduces deviations of timeout retransmission on 5,7-19,2 percents. This contributes to minimizing retransmissions count and average data stream transmission time by 4.2-9.6 percents.

Table 5. Learning outcomes of the first layer of neurons

Parameter	Value
a_{x1}	3.64
a_{x2}	25.18
b_{x1}	3.62
b_{x2}	27.90
a_{y1}	3.69
a_{y2}	28.10
b_{y1}	3.55
b_{y2}	27.79
a_{z1}	3.61
a_{z2}	28.01
b_{z1}	3.62
b_{z2}	27.81

Table 6. Learning outcomes of the third layer of neurons

Parameter	Value
H_1	3.91
H_2	-6.02
H_3	7.26
H_4	8.74
H_5	31.51
H_6	20.74
H_7	27.92
H_8	26.49

5 Conclusion

Thus, the model of neuro-fuzzy prediction of confirmation timeout in the mobile ad hoc network is synthesized. The model includes four neuron layers, performing fuzzy inference procedure (fuzzification, aggregation, revitalization and defuzzification). To adjust the weights neurons we used training data, reflecting the dynamics of the RTT in the ad hoc network used for communication on dangerous construction sites. Simulations have shown that the use of the proposed model for selecting timeout retransmission will significantly reduce the duration of the transmission data flows in the mobile ad hoc network.

Acknowledgements. The research have been carried out with the financial support of the Ministry of Education and Science of the Russian Federation (the unique identifier of the project is RFMEFI57815X0138).

References

1. Basagni, S., Conti, M., Giordano, S., Stojmenovic, I.: Mobile Ad Hoc Networking. IEEE Press, New York (2004)
2. Polschykov, K.O.: Functional Model of Data Flows Intensity Control in the Mobile Radio Network of the Special Setting. Scientific Herald of the DSEA. 1, 127–135 (2012)
3. Polshchikov, K.A.: About Control of Data Flows Intensity in the Mobile Radio Network for Special Purpose. Belgorod State University Scientific Bulletin. 192, 196–201 (2014)
4. Konstantinov, I., Pilipenko, O., Polshchykov, K., Ivaschuk, O: The Issue of Communication in the Process of Prevention and Liquidation of Emergency Situations at Construction Sites. Building and Reconstruction. 1, 40–46 (2016)
5. Jacobson, V.: Congestion Avoidance and Control. Computer Communication Review. 4, 314–329 (1988)
6. Rvachova, N., Sokol, G., Polschykov, K., Davies, J.: Selecting the Intersegment Interval for TCP in Telecomms Networks Using Fuzzy Inference System. In: Sixth International Conference on Internet Technologies and Applications, pp. 256–260. Glyndwr University, Wrexham (2015)
7. Takagi, T., Sugeno, M.: Fuzzy Identification of Systems and Its Applications to Modeling and Control. IEEE Transactions on Systems, Man, and Cybernetics. 15, 116–132 (1985)
8. Rumelhart, D.E., Hinton, G.E., Williams, R.J.: Learning Internal Representations by Error Propagation. IEEE Transactions on Systems, Man, and Cybernetics. 1, 318–362 (1986)
9. Konstantinov, I.S., Polshchykov, K.O., Lazarev, S.A.: Algorithm for Neuro-Fuzzy Control of Data Sending Intensity in a Mobile Ad Hoc Network for Special Purpose. Journal of Current Research in Science. 4, 105–108 (2016)
10. Konstantinov, I.S., Lazarev, S.A., Polshchykov, K.O.: Fuzzy System Synthesis and Adjustment Fuzzy to Evaluate the Effectiveness of Information Exchange Management Within Corporate Portal Network. Journal of Current Research in Science. 4, 109–115 (2016)
11. Polshchykov, K., Zdorenko, Y., Masesov, M: Neuro-Fuzzy System for Prediction of Telecommunication Channel Load. In: Second International Scientific-Practical Conference on Problems of Infocommunications Science and Technology, pp. 33–34. Kharkiv (2015)
12. Konstantinov, I.S., Lazarev, S.A., Polshchykov, K.O., Mihalev, O.V.: Theoretical aspects of evaluation of the corporative portal network traffic management. International Journal of Applied Research. 10, 45691–45696 (2015)
13. Polshchykov, K., Zdorenko, Y., Masesov, M: Method of Telecommunications Channel Throughput Distribution Based on Linear Programming and Neuro Fuzzy Predicting. Elixir International Journal. 75, 27327–27334 (2014)
14. Polshchykov, K.O.: General Models of Neuro-Fuzzy Systems Control the Intensity of Data Flows in a Mobile Radio Network. Science and Education a New Dimension. 8, 133–137 (2013)
15. Polshchykov, K.O.: Synthesis of Neuro-Fuzzy Systems of Data Flows Intensity Control in Mobile Ad-Hoc Network. In: 23rd International Crimean Conference on Microwave and Telecommunication Technology, pp. 517–518. Sevastopol (2013)
16. Konstantinov, I.S., Lazarev, S.A., Polshchykov, K.O.: Simulation Model of Information Flows Transmission in Mobile Ad-Hoc Network for Special Purpose. Belgorod State University Scientific Bulletin. 210, 156–163 (2015)

17. Polschykov, K., Olexij, S., Rvachova, N.: The Methodology of Modeling Available for Data Traffic Bandwidth Telecommunications Network. In: 10th International Conference on Modern Problems of Radio Engineering Telecommunications and Computer Science, p. 158. Lviv–Slavske (2010)
18. Polschykov, K., Kubrakova, K., Odaruschenko, O.: Methods nd Technologies Analysis of The Real-Time Traffic Transmission Requests Servicing. World Applied Programming. 3, 446–450 (2013)