# Distribution of information flows in the advanced network of MPLS of railway transport by means of a neural model

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**Abstract.** Ensuring interoperability of railway transport is possible only due to the developed information structure. Today, Ukraine uses the information-telecommunication system (ITS) of railway transport, which is based on a data communication network. The effectiveness of its work is largely determined by the routing system. The current algorithm for choosing the shortest route, which is used in the existing routing protocol (OSPF), does not always lead to an effective result. However, there is MPLS technology, which could improve the quality of the ITS network by creating virtual channels between its nodes. The authors proposed a scheme for selecting tunnels for the flows in the MPLS network, which is based on the neural model of a multilayer perceptron of configuration 18–3–3–10 with the activation function Softmax in hidden layers and a linear activation function in the input layer. To simulate the network operation, flow data is needed: class of service (CoS), sender and recipient identifiers, average flow rate vector and tunnel data (their initial load). The final load of the tunnels is taken as the resulting output of the neural network, on the basis of which the tunnel is selected for the flow of the *k*-th class of service.

## Introduction

The interaction of individual elements of infrastructure, analysis of the railway transport work and management to date is impossible without support of the automated information systems. Ukraine introduced the information-telecommunication system (ITS) of railway transport, which is based on a data communication network [1, 2]. At the present stage, the railway transport ITS network routers use the OSPF (Open Shortest Path First) protocol, because it is a common standard supported by different hardware manufacturers and it avoids closed loops in the network development process. More often, the routing criterion in the ITS network is the data transmission time, which depends on many factors: channel bandwidth; traffic intensity that can change over time, routing delay, and others. The current algorithm for choosing the shortest route, which is widely used in the existing routing protocol, does not always lead to an effective result. Thus, there is a need to study the possibility of solving the routing problem (in particular, the distribution of traffic flows) in the ITS network of railway transport.

## **Review of performed studies**

At present, there is MPLS technology that could significantly improve the Quality of Service (QoS), create easily the virtual channels between the nodes of the railway ITS network, encapsulate various link protocols for the transmission of various traffic, including IP packets, ATM cells, SONET/SDH frames and Ethernet family technology frames [3].

It is known that MPLS technology is based on the processing of MPLS header, which is appended to each data packet [4]. An MPLS header contains one or more labels that determine the packet route. Routers that are located on the MPLS network input or output are called LER (Label Edge Router). LER at the MPLS network input adds an MPLS label to the data packet, and LER at the MPLS network output removes the MPLS label from the data packet. Routers that perform routing of data packets that rely only on the specified labels are called LSR (Label Switching Router). Labels between LER and LSR are distributed using LDP (Label Distribution Protocol). In order to get a complete picture of the MPLS network, LSRs constantly exchange labels and information about each neighboring node using the standard procedure. Virtual channels (tunnels) called LSP (Label Switch Path) are set by providers to solve various tasks, for example, for the organization of virtual private networks or for the transmission of traffic over the MPLS network through the specified tunnel. In many respects, LSP is no different from PVC in ATM or Frame Relay networks, except that LSP does not depend on the features of data link layer technologies [3].

Many scholars around the world conduct the research and implementation of MPLS technology [5-11]. For example, [12] developed an analytical model of successive queues that describes the tunneling mechanism in the MPLS network. The developed model allowed researching the processes of burst chaining of

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packets, chaining of bursts, and fragmentation of packet bursts in LSP tunnels. The influence of chaining and fragmentation processes on probabilistic-time characteristics of traffic in MPLS tunnels is shown. The comparative analysis in the MPLS network with tunnels and in the MPLS network without the use of a tunneling mechanism is conducted. On the example of the European Internet backbone, the comparative estimation of the effectiveness of IP routing and MPLS is performed [13]. The use of MPLS technology can provide an increase in traffic by 1.7 times on average.

The construction of analytical models of MPLS networks is complicated due to the comparatively high complexity of the technology; therefore, the simulation of MPLS is still a promising area of research. The colored Petri nets of CPN Tools modeling system are a combination of the Petri net graph and the CPN ML programming language used to describe the attributes of elements in [14]. However, the features of MPLS technology impose additional restrictions on the mathematical model of network management. Existing mathematical models of the MPLS network are implemented using a streaming approach and are often static. The main disadvantage of such models is nontraceability of data transmission losses and packet delay in routers queues. Elimination of these disadvantages is possible with the transition to quasi-flow models that operate not with the bandwidth requirements, but with the packet blocks of some length, peculiar for a particular type of traffic [6]. In [15], there is developed a model for distributing flows of different classes in the MPLS computer network subject to compliance with the specified values of the quality indicators: average delay and the share of lost packets.

In [17], based on the use of the method of Lagrange undetermined multipliers, there is developed an algorithm for optimizing the search for a switching path according to the LSP labels, a target function of costs, which includes bandwidth constraints for each class of service.

In [9] there is a study of dependence of the quality of solution to the MPLS TE traffic engineering problem on the flow assignment sequence for the simplified fragment of the ITS network of railway transport.

The final solution to the problem of distributing information flows in MPLS network has not been found yet. At the present stage, in order to improve the rail transport ITS, research is being carried out on the use of various network technologies and organization of traffic routing using artificial intelligence methods [1, 18, 19]. The [20] suggests an approach to identifying network flows and organizing Big Data traffic routes in a virtual data processing centre based on a neural network. For the integrated network of rail transport ITS, which in the long run should work on different technologies, the optimal route has already been determined using the software model "MLP34-2-410-34", the input of which is an array of network channels bandwidth [18].

#### Purpose

Based on the use of the neural model, to develop a methodology for rational distribution of traffic flows in the advanced network of MPLS in the rail transport ITS. In order to ensure the QoS parameters for different types of traffic, to provide a separate tunnel system for each class.

# Methodology

**Mathematical statement of the problem.** As an example, we consider an advanced network of MPLS in the rail transport ITS, the fragment of which is shown in Fig. 1.



Fig. 1. Fragment of rail transport ITS

An advanced network of MPLS in the rail transport ITS can be represented as a graph:

$$G(X,E), \tag{1}$$

where  $X = \{x_j\}$ , j = 1, n are the network nodes (MPLS switches) and  $E = \{(r, s)\}$  – set of arcs (communication channels). Let the maximum number of tunnels is  $P_{\text{max}}$  and their current load  $\{Pk_{load}\}$ .

Let us introduce the Class of Service (CoS) of the traffic flows and specify the appropriate requirements matrix for the l-th class:

$$V = \|v_{i,j}(l)\|, \ l = 0, 2,$$
(2)

where  $v_{i,j}(l)$  is the average flow rate of the l-th class of service, which is transferred from node i to node j.

In addition, the Quality of Service (QoS) parameters for each class were introduced as an average delay constraint:

$$\overline{t}(l) < T(l), \tag{3}$$

with T(0)=50 ms, T(1)=75 ms, T(2)=100 ms.

It is necessary to select a tunnel in the MPLS network:

$$K(l) = \max_{0 \le p \le P_{\max} - 1} \left\{ Pk_{load} + \sum_{(i,j) \in p} \frac{v_{i,j}(l)}{C^p} \right\},$$
 (4)

where K(l) is the maximum coefficient of use of the *l*th class tunnel;  $C^{p}$  - the bandwidth of the *p*-th tunnel (in particular,  $C^{p} = 100$  Mbps using Fast Ethernet technology) and to find the relevant flow distribution:

$$F(l) = \left[ f_{rs}(l) \right], \tag{5}$$

on the condition that the maximum possible load factor of the tunnel is:

$$K(l) \to \min , \tag{6}$$

with

$$K(l) \le 0.65$$
. (7)

Neural network as the main method of solving the problem. For the fragment of rail transport ITS (see fig. 1)  $P_{\text{max}} = 5: 8 \rightarrow 13 \rightarrow 11$  (0-th tunnel);

 $8 \rightarrow 9 \rightarrow 13 \rightarrow 11$  (1-st tunnel);

 $8 \rightarrow 12 \rightarrow 4 \rightarrow 11$  (2-nd tunnel);

 $8 \rightarrow 15 \rightarrow 13 \rightarrow 11$  (3-rd tunnel);

 $8 \rightarrow 15 \rightarrow 14 \rightarrow 13 \rightarrow 11$  (4-th tunnel).

For solving the problem, we took a multilayer neural network (NN), the structure of which is shown in Fig. 2.

The figure shows that the NN consists of five layers: input layer  $\overline{X}$ , three hidden layers containing 16, 12 and 8 neurons, respectively, and the output layer  $\overline{Y}$ . The structure of the vector  $\overline{X}$  is as follows:  $X_1$  – class of service (CoS0, CoS1, CoS2);  $X_2$  – sending station (station *i*);  $X_3$  – recipient station (station *j*);  $X_4, X_5, ..., X_8$  – initial values of the *p*-th tunnel load, where  $i = \overline{1,5}$ ;  $X_9, X_{10}, ..., X_{18}$  are average values of flow rates  $v_{ij}$  (Mbps). The resulting vector  $\overline{Y}$  shows the distribution of flows from the station *i* to station *j* (with given service class) through the MPLS network tunnels.



Fig. 2. Neural network of configuration 18-3-36-10

We proposed a scheme for selecting tunnels for the flows in the MPLS network (Fig. 3). The basis of the scheme is the software neuron model "CoSThDist". For simulation of work using NN, the following traffic flow data is needed: class of service (CoS); sender and recipient identifiers; average flow rate vector and tunnel data (their initial load). As the neural network output, we took the final load of the tunnels, on the basis of which the tunnel for the flow of the *k*-th class of service is selected. In the proposed scheme, the dashed arrow depicts the implementation of actions at the preparatory stage, which teaches the neural network and stores the prediction results. In real time, the system obtains data on traffic flows, tunnels and forms the output based on the final prediction of the neural model.

**CoSThDist software model.** For the distribution of traffic flows in the MPLS network, we created CoSThDist software model. The model has some constraints: there is chosen a simplified graph for displaying the MPLS network in the rail transport ITC (see Fig. 1); the communication channel load and the generation of average traffic rates is performed using a pseudo-random number generator; there are considered only those "sender-recipient" variants, which pass through the core of MPLS network; delays on data lines and routers of the rail transport ITS network are not taken into account; for a time no more than 10 flows are serviced.

During the simulation, five tunnels are considered (bidirectional). The tunnels laid in the direction, for example, from 8 to 11, will be called forward, and the tunnels laid in the direction from 11 to 8 - backward. The forward tunnels have indexes from zero to four, and the backward tunnels - from five to nine. Tunnels with indexes 0 and 1 have the CoS0 class (highest priority), tunnels with indexes 2 and 3 have the CoS1 class, and the tunnel with index 4 has the CoS2 class. Classes of backward tunnels correspond to classes of forward ones. So, tunnels with indexes 5 and 6 have CoS0 class and

correspond to tunnels with indexes 0 and 1, tunnels with indexes 7 and 8 (class CoS1) – to tunnels with indexes 2

and 3, and the tunnel with index 9 (class CoS2) corresponds to the tunnel with index 4.



Fig. 3. Scheme for organizing tunnel selection in the MPLS network

If the load factor of the tunnel exceeds 0.65, then the subsequent flows will no longer be directed through this tunnel.

If there are no tunnels for the flow of the specified class, this flow should be directed to the tunnel with a less-priority CoS.

The sample is generated for each class of traffic and each possible route passing through the MPLS tunnel system. The size of the total sample can be calculated by the formula:  $S_{sam} = k_1 \cdot k_2 \cdot k_3$ , where  $k_1$  – sample size for each class,  $k_2$  – number of CoS,  $k_3$  – number of possible "sender-recipient" combinations.

The input and output layers of the created NN use the Relu activation function, which has the following formula  $f(x) = \max(0, x)$  and implements a simple threshold transition to zero. The Relu activation function graph is shown in Fig. 4.

NN training is carried out in 520 epochs. The total sample is divided into training and test ones. The test sample is allocated with 20% of the size of the total sample, that is, 10240 examples.

The research on the model showed that the accuracy graph on the test sample varies strongly from 0 to 0.8, which suggests that the algorithm for selecting the best tunnels for distributing traffic flows is rather complicated for the multilayer perceptron model, however, the accuracy of the trained NN was 74.5%, that is, such NN is capable of correctly distributing traffic flows in MPLS network in 74 out of 100 cases. For the MPLS network of the rail transport ITS fragment, this accuracy should be sufficient, but for a larger number of flows, a more complicated neural model may be needed.



Fig. 4. Relu activation function graph

#### Findings

The control sample fragment and the NN prediction result are presented in Fig. 5

21 2,7,11,0.11,0.08,0.09,0.13,0.07,11.45,8.92,9.72,9.67,8.46,11.87,8.66,10.02,8.28,10.73,4,4,4,4,4,2,2,3,2,3	21	[4. 4. 4. 4. 4. 2. 2. 3. 2. 3.]
22 2,7,11,0.09,0.14,0.15,0.09,0.15,10.61,9.57,11.98,10.47,9.67,11.64,11.43,10.54,8.92,11.53,4,4,4,4,3,3,2,3,2,3	22	[4. 4. 4. 4. 3. 3. 2. 3. 2. 3.]
23 2,7,11,0.1,0.19,0.08,0.12,0.09,11.28,9.05,9.82,10.45,9.91,8.86,10.12,9.44,10.55,8.69,4,4,4,4,4,2,2,3,2,3	23	[4. 4. 4. 4. 4. 2. 2. 3. 2. 3.]
24 2,7,11,0.1,0.09,0.15,0.05,0.06,10.07,11.22,11.9,9.68,9.89,8.36,8.6,9.88,9.02,9.81,4,4,4,4,4,3,3,3,2,3	24	[4. 4. 4. 4. 4. 3. 3. 3. 2. 3.]
25 2,7,11,0.18,0.14,0.17,0.11,0.12,8.03,8.19,9.9,8.53,8.48,11.38,8.68,10.77,8.55,10.49,4,4,4,4,4,3,3,2,3,2	25	[4. 4. 4. 4. 4. 3. 3. 2. 3. 2.]
26 2,7,11,0.06,0.1,0.07,0.12,0.06,9.48,9.66,10.07,8.29,11.7,11.51,8.71,9.68,10.09,11.84,4,4,4,4,4,4,2,2,3,2,3	26	[4. 4. 4. 4. 4. 2. 2. 3. 2. 3.]
27 2,7,11,0.07,0.05,0.09,0.09,0.09,9.26,11.61,8.48,8.73,10.69,10.01,9.77,9.42,10.15,11.24 4,4,4,4,4,2,2,3,3,2	27	[4. 4. 4. 4. 4. 2. 3. 2. 2. 3.]
28 2,7,11,0.15,0.11,0.18,0.04,0.13,9.59,8.02,8.35,9.57,10.58,10.41,9.59,9.96,11.13,9.12,4,4,4,4,3,3,3,2,3	28	[4. 4. 4. 4. 4. 3. 3. 3. 2. 3.]
29 2,7,11,0.15,0.16,0.17,0.15,0.13,10.51,9.7,9.63,10.19,9.88,8.07,9.26,8.76,8.18,8.13,4,4,4,4,4,3,3,2,3,2	29	[4. 4. 4. 4. 4. 3. 3. 2. 3. 2.]
30 2,7,11,0.04,0.08,0.13,0.12,0.05,9.1,11.84,9.46,11.34,8.18,11.18,10.11,10.29,10.75,10.76,4,4,4,4,4,3,3,2,3,2	30	[4. 4. 4. 4. 4. 3. 3. 2. 3. 2.]
31 3,7,11,0.05,0.11,0.17,0.17,0.15,8.51,9.45,10.75,9.5,11.48,8.24,10.2,11.82,9.37,8.68,4,4,4,4,4,2,2,3,2,3	31	[4. 4. 4. 4. 4. 2. 2. 3. 2. 3.]
32 3,7,11,0.15,0.19,0.13,0.16,0.06,10.49,11.06,11.08,8.88,8.85,10.57,11.61,9.61,11.32,9.06,4,4,4,4,4,2,2,3,2,3	32	[4. 4. 4. 4. 4. 2. 2. 3. 2. 3.]
33 3,7,11,0.12,0.18,0.15,0.04,0.14,8.62,11.98,8.17,8.15,10.75,9.88,10.9,10.64,11.81,10.86,4,4,4,4,3,3,2,3,2	33	[4. 4. 4. 4. 4. 3. 3. 2. 3. 2.]
34 3,7,11,0.18,0.12,0.04,0.16,0.05,10.89,11.0,8.53,11.48,10.36,9.93,9.54,11.02,10.69,10.47,4,4,4,4,4,2,2,2,3,2	34	[4. 4. 4. 4. 4. 2. 2. 2. 3. 2.]
35 3,7,11,0.18,0.09,0.1,0.17,0.06,9.02,8.05,10.94,11.05,9.53,8.88,8.65,9.91,9.64,11.99,4,4,4,4,4,4,2,2,3,2	35	[4. 4. 4. 4. 4. 4. 2. 2. 3. 2.]
36 3,7,11,0.12,0.09,0.08,0.18,0.13,11.7,10.34,10.64,11.01,8.6,9.2,11.45,9.72,10.78,11.29 <mark>4,4,4,4,2,2,2,3,3,2</mark>	36	[4. 4. 4. 4. 4. 2. 2. 3. 2. 3.]
37 3,7,11,0.15,0.15,0.05,0.11,0.17,10.29,9.74,9.99,10.7,8.8,11.88,8.68,11.31,11.76,11.64,4,4,4,4,2,2,3,2,3,2	37	[4. 4. 4. 4. 2. 2. 3. 2. 3. 2.]
38 3,7,11,0.07,0.05,0.19,0.07,0.11,8.57,11.65,10.0,9.88,11.23,8.02,11.6,10.43,9.08,11.63 4,4,4,4,4,3,3,2,3,3	38	[4. 4. 4. 4. 3. 3. 2. 2. 2.]

Fig.	5.	Compari	ison o	of the	control	sample	fragment	with th	he NN	prediction

The figure shows that in some lines the NN made an error. Line 21 (see Fig. 5) shows that for input parameters: l=2 (CoS); i=7 (sender); j=11 (recipient); at current load of tunnels  $k_{load} = \{0.11, 0.08, 0.09, 0.13, 0.07\}$  and at the average flow rates  $v_{ii}(l) = \{11.45, 8.92, ...\}$ 

9.72, 9.67, 8.46, 11.87, 8.66, 10.02, 8.28, 10.73} we obtain the following traffic flow distribution  $F(l) = \{4, 4, 4, 4, 4, 2, 2, 3, 2, 3\}$ , which is demonstrated in Fig. 6.



Symbols: use of tunnel with index 2 - bright green colour; with index 3 - blue, with index 4 - purple

Fig. 6. Distribution of traffic flows by tunnels

#### Originality and practical value

**Research of the effect of the activation function on the NN prediction accuracy.** The Keras framework, used for building the NN, contains many different activation functions, among which the most popular are: Relu; Linear; Softmax; Tanh; Sigmoid. Training of the NN of configuration 18-3-16-12-8-10 was performed under the following conditions: sample size – 6 400

examples; optimizer - Adam; learning rate - 0.0001; the number of epochs - 520. The research results are summarized in Table 1.

 Table 1. NN prediction accuracy by the type of activation function

D	Activation function of hidden layers					
Parameter	Relu Softmax		Tanh	Sigmoid		
Accuracy, %	37.23	74.5	37.69	0.59		

According to the research results, it was found that the highest accuracy of the NN prediction occurs when using the activation function Softmax (74.5%). This is approximately 2 times higher than when using the Tanh activation function, with an accuracy of 37.69%. Other activation functions also provide less accuracy.

**Research of the effect of the sample size on the NN prediction accuracy.** Training of the NN of configuration 18-3-16-12-8-10 was performed under the following conditions: activation function - Softmax; optimizer - Adam; learning rate - 0.0001; the number of epochs - 520. The research results are summarized in Table 2.

Table 2. Accuracy of NN prediction by total sample size.

<b>D</b> (	Total sample size				
Parameter	2 560 6 400		25 600	128 000	
Accuracy, %	44.34	74.5	76.25	43.42	

From the table it is clear that when using the NN of configuration 18-3-16-12-8-10 it is enough to have a sample of 6400 examples. With the increase in the total sample size, the accuracy of the NN prediction rises insignificantly, and herewith one may observe over-training of the NN.

## Conclusions

1. In order to improve the quality of network operation in rail transport ITS during interaction of different railways, it is expedient to use MPLS technology and organize the selection of a tunnel by means of a multilayer neural network based on data on traffic flows and communication channels that constitute the corresponding tunnels.

2. Using the Keras framework, the program model in Python is created for traffic flow distribution in the advanced MPLS network of the analysed rail transport ITS fragment "CoTShDist". The model generates a sample for the neural network and implements this network. The input of the neural network is the flow parameters (service class, sender and recipient identifiers; average flow rate), and the tunnel load, the output vector of the neural network is distribution of flows through tunnels in the MPLS network.

3. On the created CoSThDist software model, we researched the neural network parameters. It is determined that the optimal option is the NN of configuration 18-3-36-10 (with Softplus activation function in hidden layers), which, when using the Adam Optimizer, gives 74.5% accuracy in 520 epochs for a total sample of 6 400 examples.

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