

AN EVALUATION OF MPLS EFFICACY USING COLORED PETRI NET MODELS

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KEYWORDS

IP-routing, MPLS, performance, colored Petri net, simulation

ABSTRACT

Colored Petri net models of Internet backbones' routers with classical IP-routing and label switching technology MPLS were constructed. On the example of the model for the fragment of European Internet backbone the comparative evaluation of IP-routing and MPLS performances was implemented. For construction and investigation of models CPN Tools was used. It was shown that the involving of MPLS technology allowed the increase of traffic in 1,7 times on average.

INTRODUCTION

The technology of label switching MPLS (RFC 3031; RFC 3032; RFC 3270) is aimed to the increase of the throughput either in global or corporative networks. In the networks with packets' switching the review of routing tables for each transmitting packet by each router requires considerable expenses of time and frequently bounds the general throughput of a network. The label assigned according to MPLS technology has smaller size than IP-address and constitutes in essence an identifier of a virtual channel which is processed with effective algorithms.

The construction of analytical models of MPLS networks is hampered due to the comparative sophistication of the technology with standard specifications counting approximately five hundreds pages. That is why simulation of MPLS networks becomes a prospective direction of research. Colored Petri nets of simulation system CPN Tools (Beaudouin-Lafon et al. 2001) constitutes a combination of Petri net graph (Jensen 1997) and programming language CPN ML used for the description of net elements' attributes. Recently CPN Tools was used for modeling of switched Ethernet (Zaitsev 2004a; Zaitsev 2004b; Zaitsev and Shmeleva 2006). The method of measuring fragments (Zaitsev 2004b) allows the evaluation of nontrivial characteristics of modeled object in the process of Petri net dynamics simulation. However, the construction of MPLS models requires a special study concerning its essential distinctions with classical switching technology.

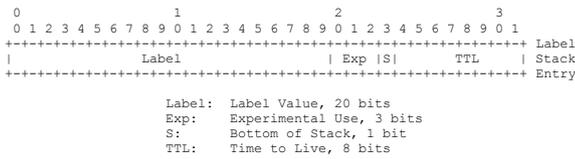
The goal of the present work is the construction of typical models of IP and MPLS routers in the form of colored Petri nets as well as the comparative evaluation of IP-routing and MPLS performances on the example of European Internet backbone model.

AN OVERVIEW OF LABEL SWITCHING TECHNOLOGY MPLS

Recently about twenty IETF documents are devoted to the specification of MPLS standards. The basic documents are (RFC 3031; RFC 3032; RFC 3270), moreover, the peculiarities of the technology are defined more accurately in RFC with numbers 2547, 2702, 2917, 3035, 3063, 3346, 3353, 3429, 3443, 3468, 3469, 3471, 3472, 3473, 3474, 3496, 3564.

The standard terminology is introduced in (RFC 3031). It was claimed the necessity of networks' paths aggregation in FEC (Forwarding Equivalence Classes) and assigning a unique label to each class identifying its belonging to a definite FEC. The label is forwarded together with a packet and after its assignment is the only object that is analyzed by routers and used for delivery of the packet. Further, on next hops, the initial label may be replaced by new labels. Thus, the analysis of packet's header is executed only once by the first router in MPLS network. At the transmission of the packet the label constitutes an index in the label switching tables defining the next hop and new label. The standard stipulates also the stack of labels. For assigning of labels special Label Distribution Protocol (LDP) is specified; it describes the way neighboring Label Switching Routers (LSR) are exchanging by routing information and constructing their label switching tables.

The format of the label and the stack of labels as well as the procedures of labels' processing by LSR are described in (RFC 3032). The label has the length of 32 bits and possesses the format represented in Figure 1. The Label Value occupies 20 bits, Time to Live (TTL) takes 8 bits, bit 23 is intended for the creation of labels' stack (it is equal to unit at the bottom of stack), bits 20-22 are reserved for experimental usage.



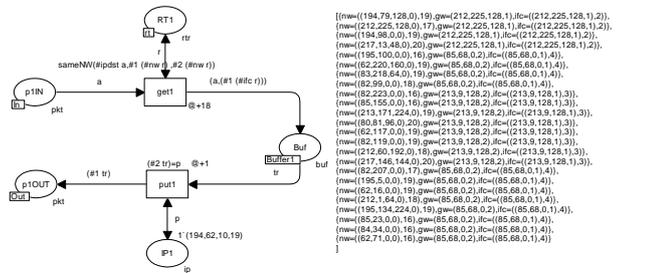
Figures 1: Standard Format of the Label

Notice that, routers situated at the border of MPLS networks are named Label Edge Router (LER); an additional classification divides them into ingress and egress also.

THE MODEL OF IP-ROUTER

Let's remind that colored Petri net (Jensen 1997) of simulation system CPN Tools (Beaudouin-Lafon et al. 2001) constitutes a combination of Petri net graph and programming language CPN ML used for description of net elements' attributes. A token of colored net constitutes an object of abstract data type named by color set.

In the present work the static routing is considered. The model of IP-router port is represented in Figure 2. The model of a concrete router is assembled by cloning of port's model in the required number of copies. As distinct from early studied models of Ethernet switches (Zaitsev 2004a; Zaitsev 2004b; Zaitsev and Shmeleva 2006), the presented model of router uses complete specifications of IP-addresses for hosts and networks. The processing of IP-addresses has required extra functions for determining the belonging of IP-address to a definite subnet listed in the routing table.



Figures 2: Model of IP-router Port

Four basic types of tokens are used in the model: type **pkt** describes packets transmitting in the network, type **rtr** – record of routing table, type **buf** – routed packets containing IP-address of the destination port, type **ip** – IP-addresses. The function **SameNW** determines the belonging of IP-address to IP-network. Descriptions of types, variables and functions are represented in Figure 3. Fusion places **rt** and **Buffer1** provides the usage of the same common routing table and output buffer by all the ports of the router.

Ports of the router work in full-duplex mode. A packet is extracted from input channel **p1IN** of a port by transition **get1** and is situated into internal buffer **Buf** of the router while the function **sameNW** determines IP-address of destination interface according to the routing table represented by place **RT1**. Transition **put1** extracts packet from the buffer according to IP-address of interface stored

into place **IP1** and puts it into place **p1OUT** modeling the output channel of the port.

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colset ip=product INT*INT*INT*INT timed; colset mask=INT;
colset nwt=product ip*mask timed; colset b=INT timed;
colset pkt=record ipsrc:ip*ipdst:ip*data:b timed;
colset nif=int; colset interf=product ip*nif;
colset gw=ip; colset buf=product pkt*ip;
colset rtr=record nw:nwt *gw:ip*fc:interf timed ;
colset lpkt=record label:INT*ipsrc:ip*ipdst:ip*data:b timed;
colset rtrs=list rtr timed;
colset lt=record ininterf:INT*L1:INT*outinterf:INT*L2:INT;
colset aux=INT timed;
fun pow(x,y)=1 | pow(x,y)=pow(x,y-1)*x;
colset buffer=product lpkt*INT timed;
fun sameNW(a1:ip,a2:ip,m:INT)=if (32-m) < 8 then ( if ((#1 a1) = (#1 a2)) andalso ((#2 a1) = (#2 a2)) andalso ((#3 a1) = (#3 a2)) andalso (((#4 a1) div pow(2,(32-m)))*pow(2,(32-m))) = (#4 a2)) then true else false ) else if (32-m)<16 then ( if ((#1 a1) = (#1 a2)) andalso ((#2 a1) = (#2 a2)) andalso (((#3 a1) div pow(2,((32-m)-8))) * pow(2,((32-m)-8))) = (#3 a2)) then true else false) else if (32-m)<24 then ( if ((#1 a1)=(#1 a2)) andalso (((#2 a1) div pow(2,((32-m)-16)))*pow(2,((32-m)-16))) = (#2 a2)) then true else false) else if (((#1 a1) div pow(2,((32-m)-24)))*pow(2,((32-m)-24))) = (#1 a2)) then true else false;
var i,c,k:INT; var q:nwt; var r:rtr;
var p,src,dst:ip; var a:lpkt; var tr:buf;
var v:aux; var la:lpkt;

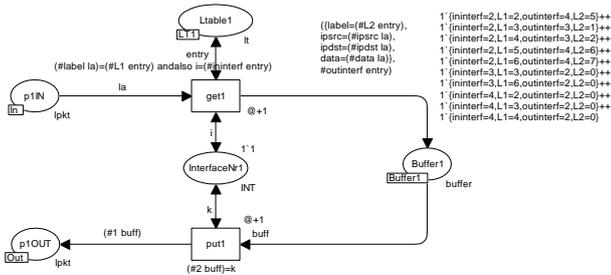
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Figures 3: Descriptions of Types, Variables and Functions of the Model

THE MODEL OF MPLS-ROUTER

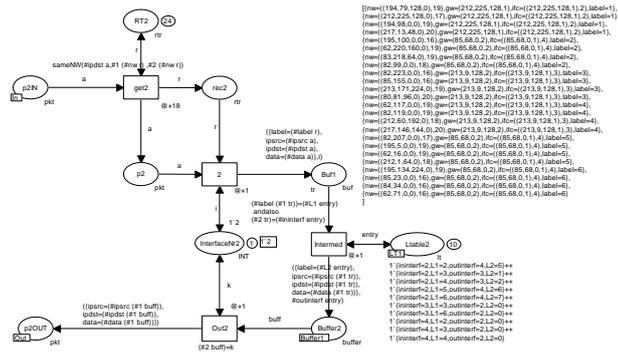
The standard of MPLS technology distinguishes two different types of routers: LSR-routers are situated inside MPLS network and realize labels' switching only; LER-routers are situated at the border of MPLS network and are used for docking with networks of other standards. The main difference consists in that LER-router calculates the initial label of a packet on the base of routing information, for instance, on the base of IP-routing tables for IP-networks. As a rule, border routers constitute the combination of LSR/LER types. For structuring of models the typical submodels of LSR and LER ports are constructed. Models of concrete routers are assembled by cloning of ports' models of required type: LSR at docking with MPLS network and LER at docking with IP-network. In the present work the algorithm LDP of FEC assigning isn't modeled; there were used FECs of labels obtained as the result of its application to the chosen network.

The typical model of LSR port of router is represented in Figure 4. The main difference from the model of IP-router port (Figure 2) consists in that the label switching table is used for forwarding of a packet. Moreover, the replacement of labels is modeled and for identification of interfaces their numbers are used. For an input packet on its label the corresponding record of labels' switching table **Ltable1** is determined. Output arc of transition **get1** replaces input label **L1** by new label **L2** and assigns the number of destination interface for forwarding of the packet. Data type **lpkt** describes packet supplied with the label, type **lt** – records of labels' switching table, type **buffer** – records of the internal buffer of packets. Notice that, in the present work the stack of labels stipulated by the standard (RFC 3031; RFC 3032) isn't modeled and only the replacement of labels is executed.



Figures 4: Model of LSR Port of MPLS Router

The typical model of LER port of router is represented in Figure 5. The port implements the initial assignment of labels according to aggregated paths of network. By the appearance the model looks like the combination of IP and LSR ports; both routing table **RT2** and labels' switching table **Ltable2** are used. The difference of routing table consists in that it contains the value of the initial label assigning to the packet obtained as the result of LDP algorithm execution. Place **Buffer2** constitutes the internal buffer of packets of router; place **Buf1** is intended as a temporary storage of packets after initial assignment of labels. Notice that, the packet is put into the output channel of port **p2OUT** without the label.



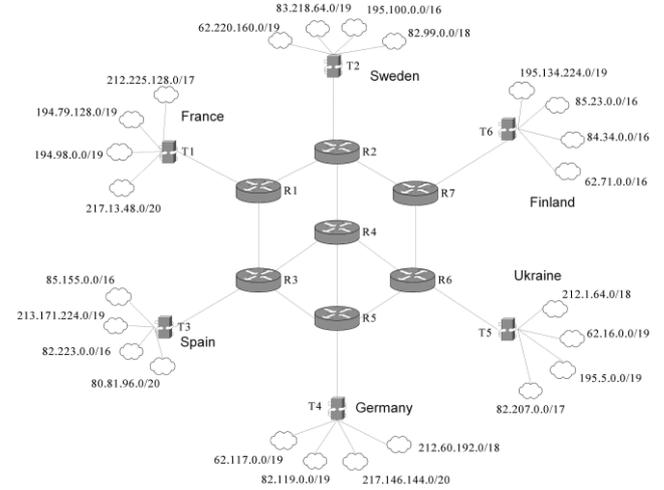
Figures 5: Model of LER Port of MPLS Router

THE MODEL OF THE EUROPEAN INTERNET BACKBONE

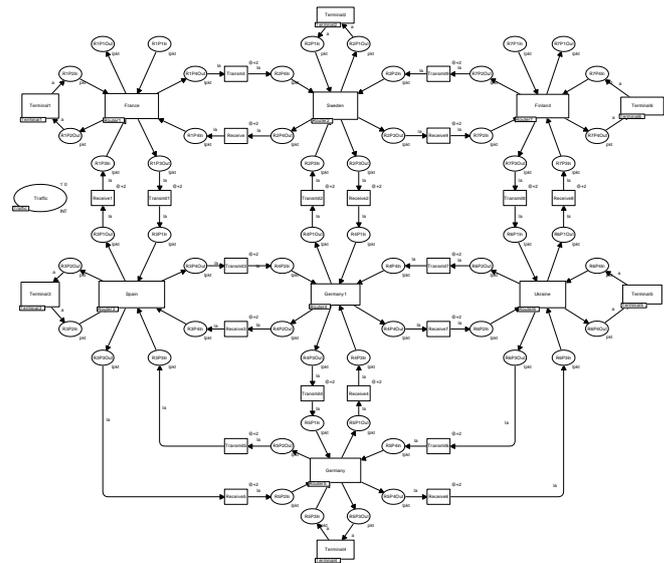
For evaluation of efficacy of MPLS technology the models of a fragment of European Internet backbone were constructed on the structural scheme of network represented in Figure 6. Notice that, in the scheme (Figure 6) terminal networks containing IP-addresses in the address space of corresponding countries are pointed out; totally 24 IP-networks are used. The backbone is constituted by 7 routers from which 6 routers (R1-R3, R5-R7) are of LER/LSR type and one router (R4) is of LSR type.

The main page of the model is represented in Figure 7. It is constructed on the structural scheme of the network (Figure 6). Two kinds of models were investigated: IP-routing obtained at substitution of **Router1-Router7** by submodels of IP-routers; MPLS-routing obtained at substitution of **Router1-Router7** by submodels of LER/LSR-routers described in the previous sections. For modeling of realistic traffic special models of terminal networks **Terminal1-**

Terminal6 were constructed; they are described in the next section. Transitions **Transmit*** model the transmitting of packets in the channels without loss of packets. Fusion place **Traffic** helps for evaluation of traffic; it is described in the next sections. Let's consider the peculiarities of IP and MPLS routing models construction.



Figures 6: Scheme of Fragment of European Internet Backbone



Figures 7: Model of Fragment of European Internet Backbone

For IP-routing static routing tables are used containing 24 records for each router; notice that, the tables of routers' are distinguished in the fields of gateways' addresses and interfaces' numbers. An example of routing table for **Router1** is shown in Figure 2.

For MPLS-routing aggregated network paths were constructed that may be obtained as the result of LDP algorithm execution. In Table 1 the basic paths of packets' delivery are listed for each pair of terminal networks; in the brackets the values of assigned labels are written.

For instance, the path of packets sent from network T1 to network T5 is defined by the sequence of labels 6-15-6. On

the Table 1 the initial marking of places **Tiebel*** and **RT*** of routers' submodels was constructed representing the labels' switching tables and labels' assignment tables correspondingly. In Figures 4, 5 the tables for router **Router1** were shown.

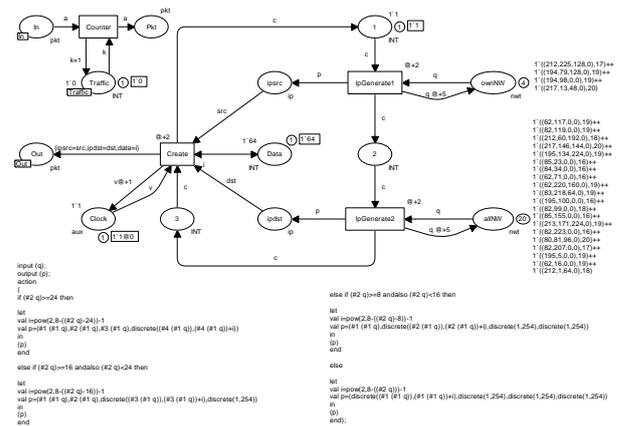
Table 1: Table of Labels' Assignment

	T1	T2	T3	T4	T5	T6
T1	0	R1(5)-R2	R1(1)-R3	R1(2)-R3(6) -R5	R1(6)-R2(15) -R4(6)-R6	R1(7)-R2(8) -R7
T2	R2(2)-R1	0	R2(2)-R4(4) -R3	R2(3)-R4(10) -R5	R2(1)-R4(9) -R6	R2(3)-R7
T3	R3(3)-R1	R3(1)-R4(9) -R2	0	R3(3)-R5	R3(2)-R4(10) -R6	R3(3)-R4(4) -R7
T4	R5(5)-R3(6) -R1	R5(11)-R4(13) -R2	R5(4)-R3	0	R5(16)-R6	R5(8)-R6(10) -R7
T5	R6(7)-R4(5) -R2(3)-R1	R6(12)-R4(10) -R2	R6(11)-R4(5) -R3	R6(10)-R5	0	R6(2)-R7
T6	R7(5)-R2(4) -R1	R7(4)-R2	R7(7)-R2(8) -R4(6)-R3	R7(8)-R6(5) -R5	R7(9)-R6	0

THE MODELS OF TERMINAL NETWORKS

The model of the realistic traffic is a significant part providing the total adequacy of constructed models to real-life processes. Colored Petri nets provide wide opportunities for description of streaming traffic with various types of random magnitudes distribution (uniform, Poisson, Erlanger) as well as protocols of interaction in client-server systems (Zaitsev 2004a; Zaitsev 2004b; Zaitsev and Shmeleva 2006). In the present work the streaming traffic was modeled. A terminal network generates periodically packets with a random address of sender and receiver. The address of sender is in the range of own IP-networks and the receiver address – in the range of addresses of the entire valid networks for modeled fragment of Internet.

Model of terminal network **Terminal1** is represented in Figure 8. The processing of input packets is modeled by the simple absorption of them using transition **Counter** in the upper-left part of the model while the calculation of the number of delivered packets is implemented with fusion place **Traffic** used for accumulation of statistical information. The generating of packets is based on the pair of places **ownNW** and **allNW** that contain IP-addresses and masks of own IP-networks and all the networks of modeled fragment of Internet correspondingly. Addresses are extracted into places **ipsrc** and **ipdst**; notice that, the usage of extracted addresses is blocked with the duration of time written on output arcs of transitions **IpGenerate1**, **IpGenerate2**. The most sophisticated action is the generating of a random IP-address on a given IP-network's address and mask. For this purpose the code segment of transitions **IpGenerate1**, **IpGenerate2** represented in the bottom of the picture is constructed. Circulation of the token in the sequence of places **1**, **2**, **3** provides the cyclic repetition of actions. Place **Clock** serves for the periodical launching of packets' generating; the time delay on the input arc of place **Clock** defines the period of the generating. Place **Data** models the content of packets. The creation of output packet is implemented by transition **Create** via uniting addresses of sender, receiver and data.



Figures 8: Model of Terminal Network

COMPARATIVE EVALUATION OF IP-ROUTING AND MPLS

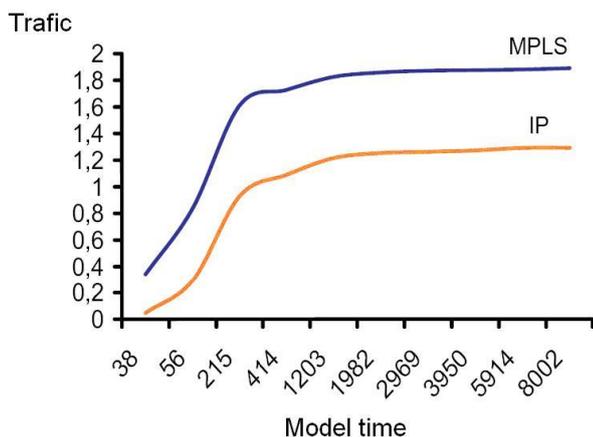
For the debugging of the model the step-by-step mode of simulation of CPN Tools (Beaudouin-Lafon et al. 2001) was used; the tracing of separate packets transmitting through network for the chosen pairs of terminal networks was implemented. For analysis of MPLS efficacy the speed modeling on the protracted intervals of time was used. The traffic was measured under the condition of peak load provided by terminal networks. Fusion place **Traffic** for traffic measuring is represented in submodels of terminal networks (Figure 8) as well as in the main page of the model (Figure 7) for the convenience of the estimating.

The topics of times' scaling were studied in (Zaitsev 2004b; Zaitsev and Shmeleva 2006). In the present work the unit of model time equaling to 0,65 ns was chosen providing the modeling of highly productive routers; the time of labels' switching was chosen as 50% of router's time that corresponds to more than twice decrease of tables' length. Three basic types of backbone routers were studied; their characteristics are represented in Table 2.

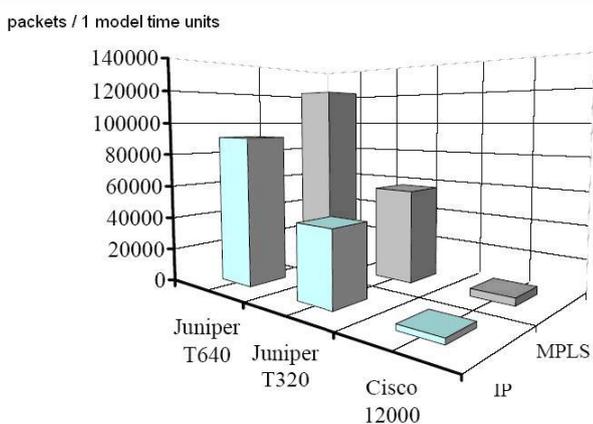
Table 2: Characteristics of Routers

Router	Throughput (packets/s)	Time of packet's processing, ns	Model time of packet's processing
Cisco 12000	25 000 000	40	60
Juniper T320	385 000 000	2,6	4
Juniper T640	770 000 000	1,3	2

On the results of traffic measurement for protracted intervals of model time the graph of comparative efficacy of IP-routing and MPLS represented in Figure 9 was obtained. Moreover, at traffic's measurement on protracted intervals of model time the diagram of network's throughput for various backbone routers represented in Figure 10 was created.



Figures 9: Comparative Evaluation of Efficacy for IP-Routing and MPLS



Figures 10: Diagram of Network's Throughput for Various Routers

The analysis of simulation results allows the conclusion that MPLS technology is in 1,7 times more effective on average than classical IP-routing. Notice that, the results were obtained for comparatively small fragment of Internet with the size of routing tables equaling to 24 records. For real-life backbones of Internet where routing tables count thousands of IP-networks the more considerable growth of throughput is foreseen.

CONCLUSIONS

Thus, in the present work the models of IP and MPLS routers were constructed in the form of colored Petri nets in the environment of simulation system CPN Tools. The evaluation of efficacy of label switching technology MPLS was implemented on the example of the model for a fragment of European Internet backbone. It was shown that even for comparatively small networks numbering dozens of nodes the increase of network's throughput in 1,7 times on average was obtained. Constructed typical models of routers may be applied for modeling of an arbitrary MPLS and IP network given by a structural scheme, hardware and software characteristics.

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Published: Proc. of International Middle Eastern Multiconference on Simulation and Modelling (MESM'2008), Amman (Jordan), August 26-28, 2008, p. 31-36.