Mathematical Model of MPLS-Network Supporting Traffic Engineering DiffServ

"Work-in-Progress"

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Abstract

This paper presents mathematical model of traffic engineering, describing routing and distribution processes of channel resource in MPLS-TE network supporting the architecture of Differentiated Services (DiffServ). The proposed model is a further developed model. It is completed with instruments required not only for peculiarities of routing tasks in MPLS-TE network, but for channel resources distribution tasks in terms of DiffServ architecture as well. On the output of mathematical model traffic engineering task was formulated as two-layer optimization task of quadratic programming. With the purpose of received solutions scalability improvement on the basis of proposed model the corresponding method of hierarchical coordinating traffic engineering in MPLS-network supporting DiffServ technique was developed.

Keywords: Traffic Engineering, MPLS, DiffServ

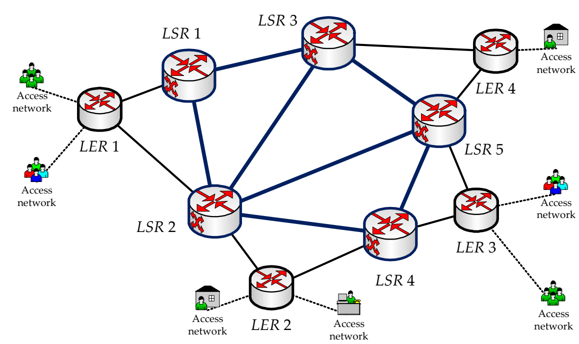
I. Introduction

According to the analysis conducted [1, 2], the main source of existing protocols improvement and new routing protocols development is a review of mathematical models and methods of routing, what, first of all, concerned with the conversion to flow models, in terms of which, as compared with graph models, more complete recording of structural and functional parameters of network and features of serviced traffics is fulfilled. With the purpose of scalability improvement, obtained within the bounds of flow models, traditionally effective is a solution based on the implementation of multi-layer (hierarchical) routing principles.

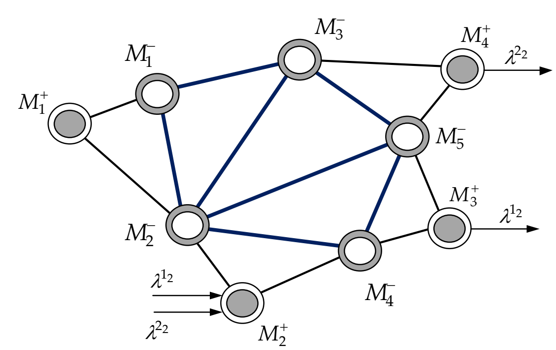
II. Routing Flow-based Model in MPLS-network Supporting Traffic EngineeringDiffServ

Let the structure of MPLS-network (fig. 1 a) be described with the help of graph $G=(M,E)$, where M – set of MPLS-routers, E – set of links in the network (fig.1 b).

Then cardinal number $|M|=m$ defines a general quantity of routers in the network and $|E|=n$ is a number of links. The whole set of nodes, in accordance with principles MPLS network formation, can be divided into two subsets: $M^{+}=\{M_r^{+}, r=\overline{1,m_{LER}}\}$ – subset of border routers (Label Edge Router, LER); $M^{-}=\{M_j^{-}, j=\overline{1,m_{LSR}}\}$ – subset of transit routers (Label Switching Router, LSR). Besides, let's agree that there are several *CoS* classes maintained in network. For *MPLS-TE DiffServ*network the number of such servicing classes equals to 8 (0÷7) [5]; capacity of priority field (3 bits) in the structure of MPLS-label is defined.



....a)



…. b)

Figure1. Example of MPLS-Network Structure (a) and Graph Model (b)

The whole set of K traffics, arriving from users (access networks), depending on which border router this traffic comes at and according to which class it will be serviced, is decomposed into subsets $\{K_r^s, r=\overline{1,m_{LER}}, s=\overline{1,S}\}$

, where K_r^s is a multitude of s-*CoS* class traffics, arriving into r - *LER*, and S is a general number of servicing classes, supported by the network. Then, every traffic from K_r^s set is matched to a range of parameters: M_r^+ – r - *LER*, at which k-traffic (source node) arrives; M_p^+ – p - *LER*, through which k-traffic leaves MPLS-network (recipient node); $\lambda^{k_r^s}$ – intensity of k_r^s-traffic, i.e. k-traffic with s-servicing class, coming into r - *LER*. Inherently, such breakdown into priority servicing classesfits in a scope of used in MPLS-network forwarding equivalence class (FEC).

In MPLS-network in a course of routing tasks solving in terms of flow models it is necessary to calculate one or a multitude of paths (Label Switching Path, LSP) between a pair of border "sender-receiver" nodes and define the sequence of set intensity traffic distribution between them [11]. In addition, with the purpose of consistency raise during the solving of separate tasks on traffic engineering it is necessary to describe the process of channel resource distribution in the developed model between traffics of different classes.

Then routing variables $x_{ij}^{k_r^s}$, which characterize the intensity of k_r^s-traffic in $(i,j) \in E$ link for every r - LER can act as desired ones. With the purpose of packets loss prevention on routers and the network in tote it is necessary to provide the fulfillment of flow saving requirements system ($k_r^s \in K_r^s$, $s = \overline{1,S}$)in a course of routing variables calculation:

$$\begin{cases} \sum\limits_{j:(i,j)\in E} x_{ij}^{k_r^s} - \sum\limits_{j:(j,i)\in E} x_{ji}^{k_r^s} = \lambda^{k_r^s}, \quad if \quad i = M_r^+; \\ \sum\limits_{j:(i,j)\in E} x_{ij}^{k_r^s} - \sum\limits_{j:(j,i)\in E} x_{ji}^{k_r^s} = 0, \quad if \quad i \neq M_r^+, M_p^+; \\ \sum\limits_{j:(i,j)\in E} x_{ij}^{k_r^s} - \sum\limits_{j:(j,i)\in E} x_{ji}^{k_r^s} = -\lambda^{k_r}, \quad if \quad i = M_p^+. \end{cases} \qquad \text{---(1)}$$

The number of equalities in the system (1) corresponds to a number of routers in the network.Moreover, aiming at the prevention of possible congestion of MPLS-network links, it is vital to meet the conditions in a course of routing variables calculation:

$$\sum_{s=1}^{S} \sum_{k_r^s \in K_r^s} x_{ij}^{k_r^s} \le \varphi_{ij} - \sum_{l=1}^{S} \sum_{\substack{g \in M^+ \\ g \neq r}} \sum_{k_g^s \in K_g^s} x_{ij}^{k_g^s} \quad (r \in M^+, (i,j) \in E) \qquad \text{…. (2)}$$

In terms of which the decentralizing is taken into account during the calculation of routing variables at every separately taken *LER*, because every border router defines *LSP* for users' traffics, arriving at it, without calculation results on neighbor *LER* since the research is evolving and more results are to be reported on the simulation process.The meaning of (2) inequality is that the traffic, routed from r - *LER*, cannot exceed by its intensity the available bandwidth of link, which is left after traffics service [6], routed from other border routers.

With an allowance of servicing organization of network traffic on the basis of classes application the condition (2) can be represented in detail as follows:

$$\sum_{k_r^s \in K_r^s} x_{ij}^{k_r^s} \le \beta_{ij}^s \varphi_{ij} - \sum_{\substack{g \in M^+ \\ g \neq r}} \sum_{k_g^s \in K_g^s} x_{ij}^{k_g^s} \quad (r \in M^+, \ s = \overline{1,S}, \ (i,j) \in E) \qquad \text{…. (3)}$$

Where β_{ij}^s – a part of link bandwidth $(i,j) \in E$, separated for traffics of s-class and treated as a control variable.In case if the distribution of linkbandwidth between traffic classes is realized identically, then (i,j) indexes in β_{ij}^s variables can be omitted and their general quantity will correspond to quantity of servicing classes in the network. The introduced parameter β_{ij}^s of the model conforms to a taken in practice decisions, when a channel resource is divided percentagewise between users' traffic classes.

According to a physical meaning of routing variables and variables, responsible for linkbandwidth distribution, they should be constrained with view restrictions:

$$0 \le x_{ij}^{k_r^s} \le \lambda^{k_r^s} \qquad \text{…. (4)}$$

$$0 \le \beta_{ij}^s \quad \text{and} \quad \sum_{s=1}^{S} \beta_{ij}^s \le 1 \qquad \text{…. (5)}$$

The fulfillment of (5) conditions ensures that linkbandwidth distribution will be properly realized without causing the congestion of link.

In terms of provision of routing and MPLS-network channel resource coordinated management the following vector can act as a desired one:

$$\vec{x} = \begin{bmatrix} x_{ij}^{k_r^s} \\ -- \\ \beta_{ij}^s \end{bmatrix} \quad (r \in M^+, s = \overline{1,S}, (i,j) \in E), \qquad \text{…. (6)}$$

Vector (6), by-turn, can be rendered in the following decomposing view

$$\vec{x} = \begin{bmatrix} \vec{x}_1 \\ \vdots \\ \vec{x}_r \\ \vdots \\ \vec{x}_{m_{LER}} \\ -- \\ \vec{\beta} \end{bmatrix},$$

Where $\vec{x}_r$ subvector coordinates are $x_{ij}^{k_r^s}$ variables, belonging to r - *LER*, and $\vec{\beta}$ subvector has coordinates β_{ij}^{s} ($k_r^s \in K_r^s$, $s = \overline{1,S}$, $(i,j) \in E$).

In a matrix form (3) conditions system can be showed as follows:

$$B_r^s \vec{x}_r \le diag(\varphi)\vec{\beta} - \sum_{g \in M^+, g \ne r} B_g^s \vec{x}_g \quad \ldots (7)$$

where $diag(\varphi)$ – diagonal matrix, whose coordinates are the values φ_{ij}; B_r^s, B_g^s ($r, g \in M^+; r \ne g$; $s = \overline{1,S}$) – coordinating matrixes, whose $\{0;1\}$ coordinates are chosen in accordance with (3) formula.

Let's take an extremum of a certain objective function as the optimality criterion in a course of calculation of decision variable vector (6). As an example can serve a following quadratic form $\min_{x,\beta} F$ at

$$F = \sum_{r \in M^+} \vec{x}_r^t H_r \vec{x}_r + \beta^t Q \beta \quad \ldots (8)$$

where H_r – diagonal matrix of weighting factors, which inherently are the metrics of corresponding links, characterizing conditional cost of use of this path by k_r^s-traffic; Q – diagonal matrix of weighting factors, characterizing conditional significance of one or another servicing class; $[\cdot]^t$ – operation of matrix transposition. Thus,within the bounds of the offered model on traffic engineering (1)–(8) main principles of multipath routing and linkbandwidth distribution processes are formalized for the benefit of users' traffic of one or another class. The model by its content corresponds to peculiarities of *MPLS-TE DiffServ*networking. As a result of the model development considering the number of possible solutions the task on routing processes optimization and network channel resource management was formed. Additional outcomes are to be published in the following phase of this ongoing research.

II. Two-layer Method of Hierarchical Coordinating Traffic Engineering in MPLS-network on the Basis of Interactions Forecast Principle

A solution of optimization task, connected with quadratic objective function minimization (8) in the presence of restricting conditions (4), (5) and (7) will be taken as a ground of the offered method. In a course of constrained optimization task solving (8) it is necessary to maximize the function by Lagrange multipliers (μ), going to task unconditional extremum, with the purpose of accountanceof border routers interactionconditions

$$L = \sum_{r \in M^+} \vec{x}_r^t H_r \vec{x}_r + \vec{\beta}^t Q \vec{\beta} + \sum_{r \in M^+} \vec{\mu}_r^t [B_r^s \vec{x}_r + \sum_{g \in M^+, g \ne r} B_g^s \vec{x}_g]$$

$\Omega(\mu) = \min_{x,\beta} L(x, \beta, \mu)$,where

…. (9)

To solve the formulated optimization task let's use the interactions forecast principle [3, 4], in terms of which, it should be agreed, routing variables, i.e. $\vec{x}_r$ ($r \in M^+$) vectors, are calculated on the lower layer of traffic engineering (on border routers (LER)). Let the task of sequence definition of ($\vec{\beta}$) channel capacity distributionwill be assigned to a network coordinator, belonging to the upper layer of the hierarchy. The calculation of $\vec{\mu}_r$ ($r \in M^+$) Lagrange multipliers vectors is referred to its functions also. Then (9) Lagrangian, noted as:

$$L = \sum_{r \in M^+} \vec{x}_r^t H_r \vec{x}_r + \vec{\beta}^t Q \vec{\beta} + \sum_{r \in M^+} \vec{\mu}_r^t B_r^s \vec{x}_r - \sum_{r \in M^+} \vec{\mu}_r^t + \sum_{r \in M^+} \vec{\mu}_r^t \sum_{g \in M^+, g \ne r} B_g^s \vec{x}_g$$

At fixed and calculated on the second layerparameters $\vec{\mu}_r$ ($r \in M^+$) and $\vec{\beta}$,taking into account $\sum_{r \in M^+} \vec{\mu}_r^t \sum_{g \in M^+, g \ne r} B_g^s \vec{x}_g = \sum_{r \in M^+} \sum_{g \in M^+, g \ne r} \mu_r^t B_g^s \vec{x}_g$,can be written as $L = \sum_{r \in M^+} L_r$,where

$$L_r = \vec{x}_r^t H_r \vec{x}_r + \vec{\beta}^t Q \vec{\beta} + \vec{\mu}_r^t B_r^s \vec{x}_r - \vec{\mu}_r^t + [\sum_{g \in M^+, g \ne r} \vec{\mu}_g^t B_g^s] \vec{x}_r$$

…. (10)

Consequently, in terms of proposed two-layer method single tasks on traffic engineering are suggested to separate by different layer of thehierarchy. It means that routing tasks should be solved on the lower layer (*LER*-layer of *MPLS*-network border routers); and linkbandwidth distribution tasks[8] between servicing classes of users' traffics are to be devolved to the upper layer (*LSR*-layer) to the network coordinator. Besides, traffic engineering on border routers of MPLS-network is fulfilled on the basis of $\vec{x}_r$ routing variables calculation while minimizing (10) formula in accordance with conditions (1), (3) and (4) at a fixed (calculated beforehand) sequence of linkbandwidth distribution between classes of users' traffics (*QoS*); this sequence is assigned by $\vec{\beta}^*$ vector (fig. 2).

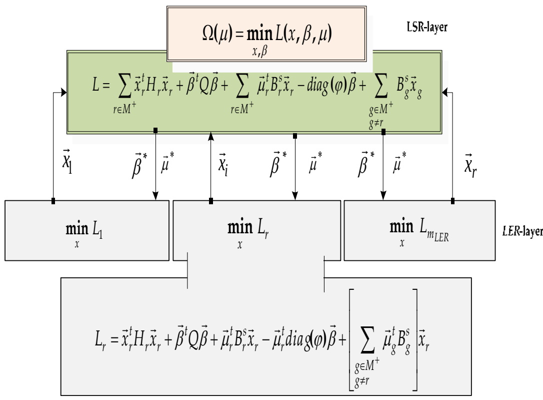


Figure 2. Computational Structure of Traffic Engineering Method in MPLS-TE DiffServ Network

Results of tasks solving on every single *LER* are gathered by the network coordinator (the upper layer), where their analysis and coordination are implemented by means of calculation (correction) of $\vec{\beta}$ vector and $\vec{\mu}_r$ ($r \in M^+$) Lagrange multipliers vectors in a course of (9) Lagrangian optimization. New obtained solutions "come down" on the first layer in a form of linkbandwidth values, destined for one or another class of traffics for iterative optimization of multipath routing process [9,10,12]. At this, if (3) conditions will be fulfilled on intermediate iterations, then it is reasonable to implement so called sequence coordination, when intermediate (suboptimal) solutions are to be put into practice, what will allow, if necessary, to decrease essentially recalculation timers of path tables.

IV. Conclusion

The paper investigated an approach on traffic engineering processes optimization in *MPLS-TE DiffServ*network on the grounds of two-layer hierarchy of separate tasks – routing and network channel resource distribution. Features of structural and functional *MPLS-TE DiffServ*networking are described in terms of mathematical flow model, represented by the system of algebraic equations (1). The research results of the offered model and hierarchical-coordinating routing method revealed the dependence of their efficiency from the change of MPLS-network structural characteristics [7], traffic rate, coming into the network, and used procedures of load balancing by the set of paths. Future studies can further explore the use of quadratic objective function in a course of routing process optimization in order to allowstrengthening the scalability of obtained solutions due to the lowering of iterations number of coordinating procedure, concerned with congestion control of the network links. Additional simulation results are to be recorded and released in the following stages of this ongoing research.

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