Analysis of Fast ReRoute Model For Multicast And Broadcast Flows in MPLS Network

Kinan M. Arous, Alla A. Romanyuk, Natalia A. Korolyuk

Abstract – **A fault-tolerant routing model for multicast and broadcast flows in MPLS-network is proposed. The flow-oriented model is represented by algebraic equations and inequalities characterizing the state of MPLS-network, i.e. load of its communication links. The proposed model includes the possibility to implement three basic backup schemes in accordance with the concept of Fast ReRoute: link, node and routing tree protection. The performance of the proposed fault-tolerant routing model is demonstrated in calculated examples.**

Keywords – **Flow-based model, Fault-tolerance, Routing, Backup scheme, Multicast flows.**

I. INTRODUCTION

In providing IPTV service, distance learning, database replication, Web services, distribution of corporate information in modern telecommunications networks (TCS) the key role belongs to multicast and broadcast routing protocols [1]. Besides in terms of possible network equipment failures or overload of individual communication links and TCS routers the requirements for fault-tolerance of routing decisions become of primary importance. In MultiProtocol Label Switching (MPLS) improvement functions for fault tolerance of the routing process are regulated according to the concept of Fast ReRoute [2].

In the implementation of fault-tolerant multicast or broadcast routing in MPLS the key requirement is also consideration of the flowing nature of multimedia traffic, the transmission of which such kind of routing is oriented to. In this regard, the article suggests further development of flow-oriented models for multicast and broadcast routing by giving it fault-tolerant functions.

II. MATHEMATICAL MODEL FOR MULTICAST AND BROADCAST FLOWS ROUTING

In the developing of multicast routing model let us describe a TCS structure as oriented graph $\Gamma = (V, E)$, where $V = \{v_i, i = \overline{1, m}\}$ is a set of vertices – nodes (routers) of the network and $(i, j) \in E$ is a set of graph arcs modeling communication links (CL) in TCS. For each CL modeled by the arc $(i, j) \in E$ there is a given throughput measured in packets per second (1/s) and defined as $\varphi_{(i,j)}$. Each k-th flow is connected with several parameters: an average flow rate at the network entrance - r_k; source node - s_k;

$$d_k^* = \{d_k^1, d_k^2, ..., d_k^{m_k}\} \qquad (1)$$

– set of destination nodes, where m_k is the number of packet receivers of k th flow.

While solving the problem of multicast routing it is necessary to calculate a set of Booleans

$$x_{(i,j)}^k \in \{0;1\}, \qquad (2)$$

Each of them characterizes the intensity part of k th flow in CL $(i, j) \in E$; $k \in K$, where K denotes a set of flows in the network [3].

Routing variables (2) are limited by several constraints:

$$\sum_{j:(i,j)\in E} x_{(i,j)}^k \ge 1 \quad if \;\; k \in K, \; v_i = s_k, \qquad (3)$$

and also

$$\sum_{i:(i,j)\in E} x_{(i,j)}^k = 1 \quad if \; k \in K; \; v_j \in d_k^*. \qquad (4)$$

Each transit node $v_j \in V$, which can be any node, except for the source one, is given the following conditions:

$$\sum_{i:(i,j)\in E} x_{(i,j)}^k \ge x_{(j,p)}^k \quad \text{при} \;\; k \in K; \; v_j \notin s_k. \qquad (5)$$

The fulfillment of these conditions allows to have a flow in any communication link ($(j,p) \in E$) coming from the relay node only in that case when this flow comes on the given node at least via one incoming CL ($(i, j) \in E$).

In order to prevent cycle forming we add conditions into the proposed model:

$$\sum_{(i,j)\in E_\pi^i} x_{(i,j)}^k < \left|E_\pi^i\right|, \qquad (6)$$

where E_π^i is a set of arcs forming i-th cycle according to their orientation; $\left|E_\pi^i\right|$ - denotes power of the set E_π^i.

The fulfillment of the condition (6) guarantees that the number of arcs used in multicast routing, composing any cycle is always smaller than the total number of

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arcs in this cycle.

In order to prevent overload of communication links with routed flows the following conditions must be meet:

$$\sum_{k\in K} r_k x^k_{(i,j)} \le \varphi_{(i,j)}, \quad (i,j)\in E. \qquad (7)$$

In the description of broadcast routing model every k-th flow is connected with an extended (in comparison to (1)) set of nodes that receive packets

$$d_k^{**} = \left\{d_k^1, d_k^2, \dots, d_k^{m-1}\right\}, \qquad (8)$$

where all the TCS nodes except for s_k are included.

Besides while solving the task of broadcast routing it is also necessary to calculate Boolean routing variables $x^k_{(i,j)}$ (2), which are limited by constraints similar to (3), (4), (6) and (7) with saving the initial physical sense. Furthermore it is worth taking into account the fact that the condition (4) applies to all the network nodes (except for source node), i.e. $v_j \in d_k^{**}$, the flow-oriented model of broadcasting routing does not need additional introduction of the conditions (5), because it is assumed that every network node (8) receives a flow of the given intensity r_k (4).

III. TERMS FOR PROVIDING FAULT-TOLERANCE IN ROUTING DECISIONS

In order to increase fault-tolerance of multicast and broadcast routing together with the basic routing tree having a root in the source node (s_k), we have to determine a backup routing tree with the same root. From the mathematical point of view in order to determine the backup (reserved) routing tree it is necessary to calculate additional variables $\bar{x}^k_{ij}$ characterizing a part of the k th flow in the link $(i,j)\in E$ of the backup routing tree alongside with arguments (2). The variables $\bar{x}^k_{ij}$ are also limited by the constraints similar to (2)-(7).

However with the purpose of preventing the primary and backup routs intersection with realization of different backups-schemes we add several additional restricting conditions that connect routing variables to calculate the primary and backup path trees. For example, while implementing protection scheme of (i,j)-link the offered model (1)-(8) obtains such conditions [2, 4]:

$$x^k_{ij}\bar{x}^k_{ij} = 0, \qquad (9)$$

The fulfillment of these conditions guarantees the use of (i,j)-link by the single routing tree, either the primary or backup.

In realization of the protection scheme for *i*-th node the model is added by the following term:

$$\sum_{i:(i,j)\in E} x^k_{ij}\bar{x}^k_{ij} = 0, \qquad (10)$$

The fulfillment of the given condition guarantees the use of *i*-th node (i.e. all incident to it links) by either the primary or backup routing tree.

To provide protection for the primary routing tree the following condition-equality must be added to the structure of the model

$$\sum_{(i,j)\in E} x^k_{ij}\bar{x}^k_{ij} = 0, \qquad (11)$$

what is equivalent to meeting of requirements regarding the absence of any common TCS channels in the primary or backup routing trees.

During the calculation of variables x^k_{ij} and $\bar{x}^k_{ij}$ while solving the problem of Fast ReRoute in TCS it is reasonable to minimize the following objective function:

$$F = \sum_{k\in K}\sum_{(i,j)\in E} c^k_{ij}x^k_{ij} + \sum_{k\in K}\sum_{(i,j)\in E} \bar{c}^k_{ij}\bar{x}^k_{ij}, \qquad (12)$$

where c^k_{ij} and $\bar{c}^k_{ij}$ are links metrics used in calculation of the primary and backup routing trees accordingly. As a result of minimization of the equation (12) variables x^k_{ij} and $\bar{x}^k_{ij}$ are calculated what in practice means the determination of the two types of routing trees between a nodes (source and destination) – the primary and backup ones. More over the order of using these routs by flows of users is determined simultaneously with their calculation. Besides in [6] the necessity to implement the conditions is established:

$$\sum_{k\in K}\sum_{(i,j)\in E} c^k_{ij}x^k_{ij} \le \sum_{k\in K}\sum_{(i,j)\in E} \bar{c}^k_{ij}\bar{x}^k_{ij}. \qquad (13)$$

The fulfillment of this condition guarantees that the primary routing tree will be always more effective (more powerful in rate, packet delay), i.e. «shorter» than the backup one within the chosen routing metrics c^k_{ij} and $\bar{c}^k_{ij}$. While implementing of fault-tolerance in multicast and broadcast flows the optimization task (12) with the constraints (2)-(11) and (13) belongs to the class of mixed integral nonlinear programming that assumes using relevant calculating methods.

IV. ANALYSIS OF FAULT-TOLERANT ROUTING OF MULTICAST FLOWS

Let us consider several examples of implementation of the proposed model (1)-(13) while solving the problem of fault-tolerant routing in MPLS network the structure of which is presented on the Figure 1. The network consists of five nodes (Label Switch Router, LSR) and seven communication links the throughput (1/s) of which is shown in the gaps. The source node is LSR 1, destination nodes are LSR 3, LSR 4 and LSR 5. The intensity of the multicast flow is 70 1/s. Let us assume that within the given example we implement multicast routing with minimization of the number of hops ($c_{ij}^{k} = 1$).

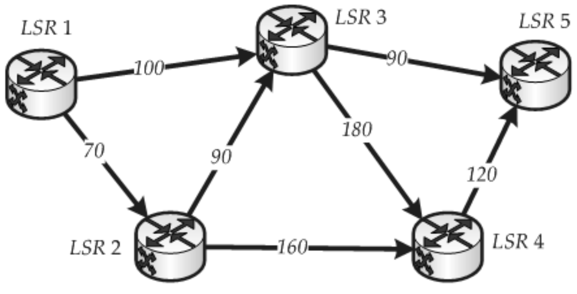
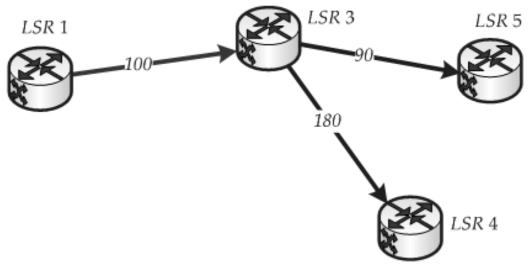
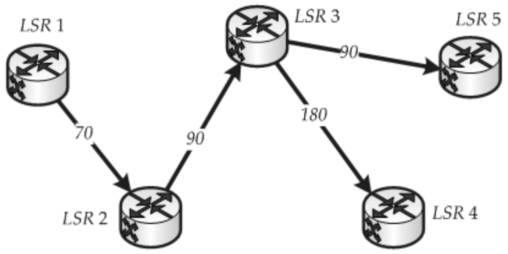


Fig. 1. The example of MPLS network structure

Figure 2 shows an example of the problem-solving for fault-tolerance routing in MPLS network with link protection (1, 3). Then as the primary routing tree we take the solution presented in Figure 2 a), and the "length" of the given tree is minimal and it consists of three hops 3. The backup routing tree (Figure 2 b), that now includes 4 hops, does not contain any link (1, 3) in accordance with the implemented protection scheme. Both the primary and backup routing trees can serve multicast flow with the intensity of 70 1/s.



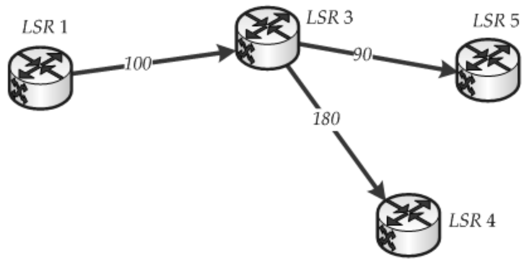
a – The primary routing tree



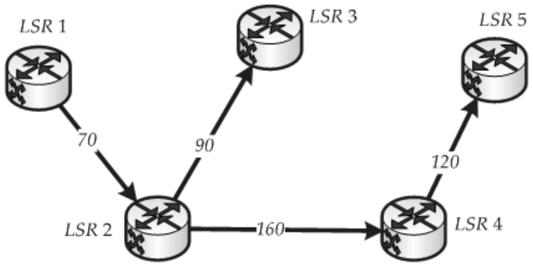
b – The backup routing tree

Fig. 2. Implementation of link protection scheme (1, 3)

Figure 3 presents an example of problem-solving for fault-tolerance routing MPLS network with protection of the primary routing tree. Then Figure 3 a) shows the primary routing tree, and Figure 3 b) presents the backup routing tree and they have no common communication links. In accordance with condition (13), the metric of the primary routing tree (3 hops) remains smaller than the metric of the backup routing tree (4 hops).



a – The primary routing tree



b – The backup routing tree

Fig. 3. Implementation of the protection scheme for the routing tree

III. CONCLUSION

Thus, the proposed model (1)-(13) allows calculating two types of routing trees: the primary and backup one for the same multicast or broadcast flow. Depending on the conditions used in the model (9), (10) or (11) it is possible to implement various backup schemes with link, node and the routing tree protection. While solving the problem of MPLS Fast ReRoute the additive metric of the primary and backup routes is minimized. At the same time metric can be represented by the functions of the key functional characteristics of communication links: throughput, delay, packet loss level, etc.

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