Fast ReRoute Model for Different Backup Schemes in MPLS-Network

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***Abstract* — A fault-tolerant routing model for unicast 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 path protection. The model describes also three different types of condition of the links overload prevention for different variants of channel resource use. The above example demonstrates the advantages of using the proposed conditions of the links overload prevention in paper.**

Keywords — flow-based model, fault-tolerance, routing, backup scheme, unicast flows, fast reroute.

I. INTRODUCTION

Routing protocols always have a key part in providing the quality of service (QoS) in modern telecommunication systems which primarily function on basis of IP and MPLS (MultiProtocol Label Switching) technologies. It is important that the main source of QoS degradation is the occurring overload in the network. Unfortunately the majority of routing protocols provide the recalculation of routs in a period of tens seconds. Thus they don't provide an efficient response on overload in network. So, to increase the efficiency of response on the possible denials of packets servicing caused by overloads in links and routers buffers (turns) the fault-tolerant routing (Fast ReRoute) [1-3] is used more often. It is important that the routing protocol to satisfy a number of important requirements such as providing the implementation of various circuits of resources and network elements reservation (the protection of link, node and path); adaptation for single/multipath routing. As well as, routings protocol has to determine the order of traffic distribution by the path which has been calculated.

Thus an approach for problem solving of Fast ReRoute in MPLS-network by developing a flow model that satisfies these requirements is offered.

II. FLOW-BASED ROUTING MODEL

Let the nodes of an *m*-node network be represented by the integers 1, 2, … m, and let a link from node i to node j be represented by (i,j). Let $E=\{(i,j):\text{a link goes from i to j}\}$ be the set of links. For each link $(i,j)\in E$ its bandwidth φ_{ij} is typical, and with each traffic flow from the set K the subset is being confronted: r^k, s_k and d_k – rates of k-th flow, source node and destination node respectively. Quantity x_{ij}^k is the control variable, which characterizes are the part of k-th flow rate, running in the link $(i,j)\in E$ of primary path.

For the purpose of prevention of network nodes overload it is necessary to meet the condition of flow conservation:

$$\begin{cases} \sum\limits_{j:(i,j)\in E} x_{ij}^k - \sum\limits_{j:(j,i)\in E} x_{ji}^k = 0; \quad k\in K,\ i\neq s_k, d_k; \\ \sum\limits_{j:(i,j)\in E} x_{ij}^k - \sum\limits_{j:(j,i)\in E} x_{ji}^k = 1; \quad k\in K,\ i = s_k; \\ \sum\limits_{j:(i,j)\in E} x_{ij}^k - \sum\limits_{j:(j,i)\in E} x_{ji}^k = -1; \quad k\in K,\ i = d_k. \end{cases} \tag{1}$$

Conditions of multipath routing realization for primary path:

$$0\le x_{ij}^k \le 1. \tag{2}$$

Conditions of single path routing realization for primary path:

$$x_{ij}^k \in \{0;1\}. \tag{3}$$

Besides the model is added by conditions guaranteeing of quality of service (QoS) assurance [4] that is very important for multiservice networks.

III. CONDITIONS FOR FAST RE-ROUTE

In order to increase fault-tolerance routing together with the basic path having a root in the source node (s_k), we have to determine a backup path with the same root. From the mathematical point of view in order to determine the backup (reserved) path it is necessary to calculate additional variables $\bar{x}_{ij}^k$ characterizing a part of the k-th flow rate in the link $(i,j)\in E$ of the backup path alongside with arguments (1)

$$\begin{cases} \sum_{j:(i,j)\in E} \bar{x}_{ij}^k - \sum_{j:(j,i)\in E} \bar{x}_{ji}^k = 0; \quad k \in K, \ i \neq s_k, d_k; \\ \sum_{j:(i,j)\in E} \bar{x}_{ij}^k - \sum_{j:(j,i)\in E} \bar{x}_{ji}^k = 1; \quad k \in K, \ i = s_k; \\ \sum_{j:(i,j)\in E} \bar{x}_{ij}^k - \sum_{j:(j,i)\in E} \bar{x}_{ji}^k = -1; \quad k \in K, \ i = d_k. \end{cases} \quad (4)$$

Conditions of multipath routing realization for backup path:

$$0 \le \bar{x}_{ij}^k \le 1. \quad (5)$$

Conditions of single path routing realization for backup path:

$$\bar{x}_{ij}^k \in \{0;1\}. \quad (6)$$

However with the purpose of preventing the primary and backup paths 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 is the offered model (1)-(6) obtains such conditions [5]:

$$x_{ij}^k \bar{x}_{ij}^k = 0. \quad (7)$$

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

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

$$\sum_{i:(i,j)\in E} x_{ij}^k \bar{x}_{ij}^k = 0. \quad (8)$$

The fulfillment of the given condition guarantees the using of i-th node (i.e. all incident to it links) by either the primary or backup path. To provide protection for the primary path the following condition-equality must be added to the model

$$\sum_{(i,j)\in E} x_{ij}^k \bar{x}_{ij}^k = 0, \quad (9)$$

which equivalents to meeting of requirements regarding the absence of any common links in the primary or backup path.

Using the proposed model let's consider following two variants of its application, which characterized by the ability to prevent the overload of network links by flows which run through primary and backup routes. In the first case, when only primary paths flows consider, condition of the links overload prevention has the form:

$$\sum_{k\in K} r^k x_{ij}^k \le \varphi_{ij}; \ (i,j) \in E. \quad (10)$$

Then, the required links bandwidth of the backup paths flows don't guaranteed and the additional restrictions on variables $\bar{x}_{ij}^k$ are not apply.

In the second case the availability of links bandwidth in the organization of both primary and backup paths checks at the solution of the fault-tolerant routing. Then following conditions enter:

$$\sum_{k\in K} \sum_{(ij)} r^k \left(\frac{x_{ij}^k + \bar{x}_{ij}^k}{x_{ij}^k \bar{x}_{ij}^k + 1} \right) \le \varphi_{ij}, \ (i,j) \in E, \quad (11)$$

in time of single path routing realization, и conditions

$$\frac{1}{2} \sum_{k\in K} \sum_{(ij)} r^k (x_{ij}^k + \bar{x}_{ij}^k) \sqrt{(x_{ij}^k - \bar{x}_{ij}^k)^2} \le \varphi_{ij}, \ (i,j) \in E, \quad (12)$$

in time of multipath path routing realization.

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

$$F = \sum_{k\in K} \sum_{(i,j)\in E} c_{ij}^k x_{ij}^k + \sum_{k\in K} \sum_{(i,j)\in E} \bar{c}_{ij}^k \bar{x}_{ij}^k, \quad (13)$$

where c_{ij}^k and $\bar{c}_{ij}^k$ are links metrics which used in calculation of the primary and backup paths accordingly.

As a result of minimization of the equation (13) variables x_{ij}^k and $\bar{x}_{ij}^k$ are calculated what in practice means the determination of the two types of paths 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:

$$\sum_{k\in K} \sum_{(i,j)\in E} c_{ij}^k x_{ij}^k \le \sum_{k\in K} \sum_{(i,j)\in E} \bar{c}_{ij}^k \bar{x}_{ij}^k. \quad (14)$$

The fulfillment of this condition guarantees that the primary path will be always more effective (more powerful in rate, packet delay), i.e. «shorter» than the backup one within the chosen routing metrics c_{ij}^k and $\bar{c}_{ij}^k$. While implementing of fault-tolerance in unicast flows the optimization task (13) with the constraints (1)-(12) and (14) belongs to the class of nonlinear programming that assumes using relevant calculating methods.

IV. EXAMPLES

Let us consider example of implementation of the proposed model (1)-(14) while solving the problem of fault-tolerant single path routing in MPLS network the topology of which is presented on the Figure 1. The network consists of five nodes (Label Switch Router, LSR) and seven links which bandwidth (1/s) is shown in gaps. The source node is LSR 1, destination node is LSR 5. The traffic rate is 80 1/s. Let us assume that within the given example we implement unicast routing with minimization of the number of hops ($c_{ij}^k = 1$).

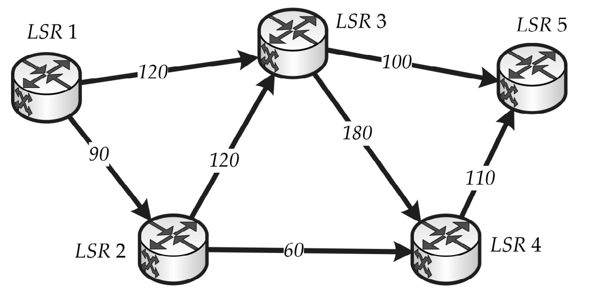
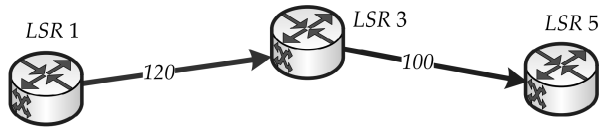
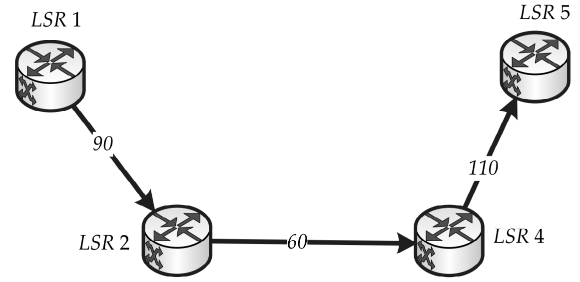


Fig. 2. Fig. 1. The example of MPLS network topology

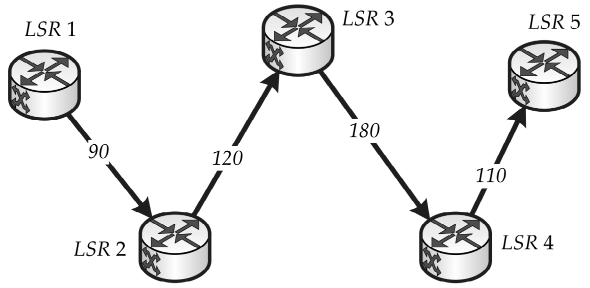
Figure 2 shows an example of the problem-solving for fault-tolerance routing in MPLS network with link protection (1, 3). Then as the primary path we take the solution presented in Figure 2 a), and the "length" of the given path is minimal and it consists of 2 hops



a – The primary path



b – The backup path if use conditions (10) only



c – The backup path if use conditions (11) only

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

If use conditions (10) only, the backup path (Figure 2 b), that now includes 3 hops, does not contain any link (1, 3) in accordance with the implemented protection scheme. Backup path (Figure 2 b) is shortest, but has bandwidth of 60 1/s, i.e. the overload arises when the flow of 80 1/s passes. Use condition (11) the solution shown in Figure 2 will be used as the desired backup path. This backup path (Figure 2 c) have 4 hops and throughput of 90 1/s, i.e. overload does not occur.

The above example demonstrates the advantages of using the proposed conditions of the links overload prevention (11) and (12) in the paper.

V. CONCLUSION

The paper proposed the development of a fault-tolerant routing model in MPLS-network by introducing new conditions and restrictions which related with the verification of the link bandwidth availability in the organization of both primary and backup paths.

The model allows for the same flow calculate two types of paths: primary and backup. Depending on the parameters of the model it is possible to implement different schemes of reservation: link, node or path protection. In the course of solving the problem of MPLS Fast ReRoute the classical metric of primary and backup routes is minimized. The non-linear restrictions, which are responsible for prevention of node, link or path intersection of primary and backup routes is introduced in the structure of the model.

The efficiency of proposed scheme while solving the problem of MPLS Fast ReRoute for different schemes of reservation is represented in examples. These conditions of check of link bandwidth availability can be used for organization of multicast flow fault-tolerant routing too [6].

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