Effective Solution for Scalability and Productivity Improvement in Fault-Tolerant Routing

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***Abstract*—Effective solution for scalability and productivity improvement in fault-tolerant routing using the flow-based model was proposed. In practice, the fault-tolerant routing based on reservation of network resources is usually associated with decrease in overall performance and scalability of protocol solutions. In this regard, in structure of the model introduced conditions that are responsible for the fact that the primary and backup routes differed only by network elements for which redundancy provided. This was reflected in modification of objective function within the formulation and solution of optimization problem of the fault-tolerant routing. Numerical examples showed efficiency of the proposed solution.**

Keywords—flow-based model; fault-tolerance; routing; backup scheme; unicast

I. INTRODUCTION

Modern communication systems based on IP and MPLS (MultiProtocol Label Switching) technologies provide the Quality of Service (QoS) mainly with the use of routing protocols. It is necessary to say that the main cause of QoS degradation in the network is the overload. Majority of routing protocols don't provide efficient response mechanisms on the network overload. Thus to increase the efficiency of response to the possible denials of packets serving caused by links and router buffer overloads the Fault-tolerant Routing is used. Among the examples of such technologies MPLS Fast ReRoute can be mentioned. Routing protocol has to satisfy a number of important requirements such as providing network elements reservation (protection of link, node and path) and adaptation for single path routing. Thus an approach of flow-based model that satisfies these requirements is offered. In order to improve QoS different schemes of fault-tolerant unicast routing are used, which particularly based on providing the Fast Reroute concept.

Represented solution based on approach proposed in [1]-[3], and it is realized as nonlinear flow-based model in which the conditions for link overload prevention are modified for the case when only some flows can switch to backup routes but not all of them. The main drawback of the fault-tolerant routing based on the network resources reservation is the decreasing of overall performance and scalability of protocol solutions. Thus the problem of improvement of scalability and productivity in fault-tolerant routing seems to be a topical practical problem.

II. MATHEMATICAL MODEL FOR UNICAST ROUTING

Suppose that a network structure described as oriented graph $\mathbf{\Gamma} = (V, E)$, where $V = \{v_i, i = \overline{1,m}\}$ is a set of vertices – nodes (routers) of the network, and E is a set of graph arcs modeling network links. For each link $(i,j) \in E$ it is specified the capacity φ_{ij}, and with each k-th flow of packets the set of parameters associated: rate of k-th flow r^k, source node s_k and destination node d_k. Quantity x_{ij}^k is the control variable, which characterizes the portion of k-th flow 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 [4]:

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

Conditions of multipath routing realization for primary path are next

$$0 \le x_{ij}^k \le 1. \qquad (2)$$

Conditions of single path routing realization for primary path are

$$x_{ij}^k \in \{0;1\}. \qquad (3)$$

III. ENSURING OF THE FAULT-TOLERANT ROUTING CONDITIONS

In order to improve fault-tolerant routing together with primary 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 portion of the k-

th flow in the link $(i,j)\in E$ of the backup path with arguments (3).

However with the purpose of preventing the primary and backup paths overlapping with realization of different backup-schemes it was added several additional restricting conditions that connect routing variables to calculate the primary and backup path trees [5], [6]. For example, while implementing protection scheme of (i,j)-link the offered model (3) obtains such conditions [7], [8]:

$$x_{ij}^k \bar{x}_{ij}^k = 0 . \quad (4)$$

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:

$$\sum_{i:(i,j)\in E} x_{ij}^k \bar{x}_{ij}^k = 0 . \quad (5)$$

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

$$\sum_{(i,j)\in E} x_{ij}^k \bar{x}_{ij}^k = 0 , \quad (6)$$

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

IV. Overload Prevention Conditions

Using the proposed in [7], [8] model let's consider following two variants of its application, which characterized by the ability to prevent the overload of network links by flows through primary and backup routes. In the first case, when consider only primary paths flows, condition of the links overload prevention has the form:

$$\sum_{k\in K} r^k x_{ij}^k \le \varphi_{ij} ;\ (i,j)\in E . \quad (7)$$

Then the required links throughput of the backup paths flows are not guaranteed and the additional restrictions on variables $\bar{x}_{ij}^k$ are not applicable.

Then following conditions introduced:

$$\sum_{k\in K} r^k \left(\frac{x_{ij}^k + \bar{x}_{ij}^k}{x_{ij}^k \bar{x}_{ij}^k + 1} \right) \le \varphi_{ij} ,\ (i,j)\in E , \quad (8)$$

in case of single path routing realization (3). While for multipath case:

$$\frac{1}{2} \sum_{k\in K} \left(r^k \left[(x_{ij}^k + \bar{x}_{ij}^k) + \sqrt{(x_{ij}^k - \bar{x}_{ij}^k)^2} \right] \right) \le \varphi_{ij} . \quad (9)$$

V. Improving Scalability and Productivity Conditions

During the calculation of variables x_{ij}^k and $\bar{x}_{ij}^k$ while solving the problem of fault-tolerant routing in network it is reasonable to minimize the following objective function to improve scalability and productivity:

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

$$- \sum_{k\in K} \sum_{(i,j)\in E} b_{ij}^k x_{ij}^k \bar{x}_{ij}^k , \quad (10)$$

where c_{ij}^k and $\bar{c}_{ij}^k$ are links metrics which used in calculation of the primary and backup paths respectively, and third term introduced to the objective function with the purpose of minimization of difference between primary and backup paths with non-protected links, whereas $b_{ij}^k >> c_{ij}^k$ and $b_{ij}^k >> \bar{c}_{ij}^k$.

As a result of minimization of the equation (10) variables x_{ij}^k and $\bar{x}_{ij}^k$ are calculated and determine two types of paths (primary and backup) between source and destination nodes. More over the order of using these routes by flows determined in the same time with their calculation. Besides, in [7]-[9] the necessity to implement the conditions established:

$$\sum_{k\in K} \sum_{(i,j)\in E} c_{ij}^k x_{ij}^k \le \sum_{k\in K} \sum_{(i,j)\in E} \bar{c}_{ij}^k \bar{x}_{ij}^k . \quad (11)$$

The fulfillment of this condition guarantees that the primary path will be always more effective in rate, packet delay, i.e. «shorter» than the backup one within the chosen routing metrics c_{ij}^k and $\bar{c}_{ij}^k$. Optimization problem (10) with the constraints (1)-(9) and (11) belongs to the class of nonlinear programming.

VI. Numerical Research of Proposed Solution

Consider an example of implementation of the proposed schemes (1)-(11) while solving the problem of single path fault-tolerant unicast routing in the network with topology presented on the Fig. 1. The network consists of five routers and seven links with the throughput (packet per second, 1/s) shown on the links.

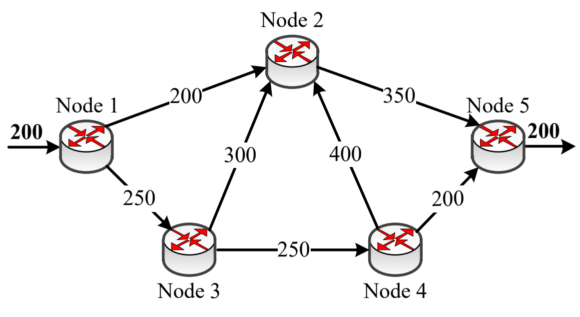

Fig. 1. Investigated MPLS-network topology.

Suppose that the source and destination nodes are Node 1 and Node 5 respectively, while the input flow rate is equal to 200 1/s. It is needed to represent the schemes of protection of the (1, 2) link. Let us assume that within the given example we implement unicast routing with minimization of the number of hops ($c_{ij}^{k} = 1$).

While solving a problem it was determined that primary path for transmitted flow is consist of two hops which include 1→2→5 nodes (Fig. 2). In realizing the protection scheme of the (1, 2) link without third term in object function (10) the backup path for this flow will contain 3 hops and include 1→3→4→5 nodes.

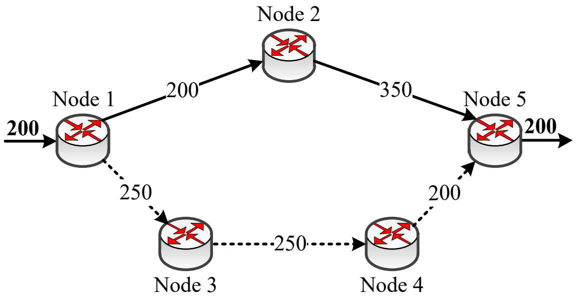

Fig. 2. Calculation primary and backup paths without third term in (10).

Implementation of the proposed schemes (4)-(11) while solving the problem of single path fault-tolerant unicast routing presented on the Fig. 3. The primary path is the same and consists of two hops (nodes 1→2→5). For protection scheme of the (1, 2) link using (10) the backup path for this flow will contain 3 hops and include 1→3→2→5 nodes. In this case primary and backup paths contain the shared link (2, 5) which avoids excessive use of network resources, i.e. throughput of links (3, 4) and (4, 5).

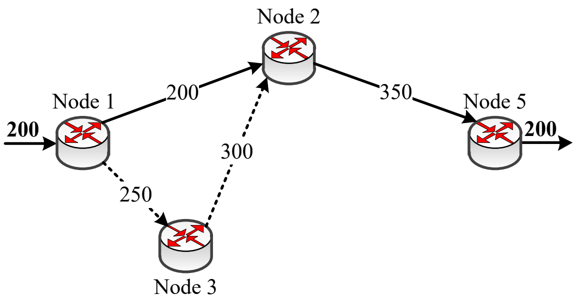

Fig. 3. Calculation primary and backup paths using (10).

Another variant of realization proposed scheme represented on Fig. 4. Here the backup path includes 1→3→4→2→5 nodes. This backup path does not satisfy the minimum number of hops demand, thus the more effective to use the previously calculated set of paths, shown on Fig. 3.

VII. Conclusion

It was presented the effective solution for scalability and productivity improvement in fault-tolerant routing using the flow-based model. Fault-tolerant routing based on reservation of network resources is the reason of decreasing performance and scalability of protocol solutions.

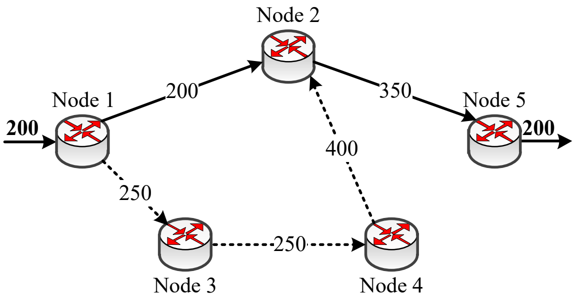

Fig. 4. Another case of calculation primary and backup paths using (10).

Represented solution with introduced conditions in structure of the flow-based model responsible for the fact that the primary and backup paths differ only by network elements must be protected. This was reflected in modification of objective function within the formulation and solution of optimization problem of the fault-tolerant routing. Functionality of proposed backup schemes with improved scalability and productivity is demonstrated by the numerical examples with proven effectiveness.

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