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Research Article

Fault-Tolerant Unicast, Multicast and Broadcast Routing Flow-Based Models

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Abstract: Flow-based models of unicast, multicast and broadcast fault-tolerant routing in telecommunication networks were proposed. The novelty of models is a description of multiproduct case, as well as in consideration of flowing nature of modern network traffic, allowing to implement previously known conditions for communication links overload prevention for the case of unicast, multicast and broadcast routing type. The models represented by a system of linear equations and inequalities, which makes them effective in terms of algorithm implementation. As part of the proposed models tasks of unicast, multicast and broadcast routing are focused on solving optimization problems. Numerical examples showed efficiency of the proposed models in terms of serving multiple flows with different characteristics concurrently and adaptation to changes of network parameters (e.g. channel capacity). The proposed model can be used for solving the unicast, multicast and broadcast routing problems, and the mathematical description of more complex processes and problems, such as those associated with the design of telecommunication networks (selection of topology and bandwidth of communication links).
Keywords: Flow-based model, Fault-tolerance, Routing, Backup scheme, Unicast, Multicast, Broadcast flows

INTRODUCTION

Routing protocols is a significant part in providing the quality of service (QoS) in modern communication systems which primarily based on IP and MPLS (MultiProtocol Label Switching) technologies. It is important to note that the main source of QoS degradation is the occurring of network overload. Unfortunately the majority of routing protocols provide the recalculation of routes in a period of tens seconds. Thus they don't provide an efficient response on the network overload. So, to increase the efficiency of response on the possible denials of packets serving caused by overloads in links and routers buffers the fault-tolerant routing is used (e.g. MPLS Fast ReRoute technology). 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/multipath routing. Thus an approach as flow-based model that satisfies these requirements is offered.

Modern networks are multiservice, i.e. they provide several services concurrently on the basis of one transport platform. In addition to transmit traffic packets of IPTV service, distance learning, database replication, Web services multicast routing is used. In order to improve QoS different schemes of fault-tolerant unicast, multicast and broadcast routing are used, which in particular are also based on provisions of the Fast Reroute concept. Represented schemes demonstrate an approach proposed in [1-3], and they are based on nonlinear flow model in which the conditions for link overload prevention are modified for the case when only some flows can switch to backup routs but not all of them.

Fault-Tolerant Routing Models

Mathematical Model for Unicast Flows Routing

Let us describe a network 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 network links. Let $E = \{(i, j): \text{link goes from i to j}\}$ be the set of links. For each link (i, j) it is specified the throughput φ_{ij}, and with each k-th traffic flow the set of parameters associated: r^k, s_k and d_k – rate of k-th flow, source node and destination node respectively. Quantity x_{ij}^k is the control variable, which characterizes the part of k-th flow of 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]:

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

Conditions of multipath routing realization for primary path are next

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

Conditions of single path routing realization for primary path are

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

Besides, the model is supplemented by conditions of QoS assurance [5] that is very important for multiservice networks.

Mathematical Model for Multicast/Broadcast Flows Routing

In developing of multicast routing model let us use the same concept as for unicast. Each k-th flow connected with several parameters: an average flow rate at the network entrance – r_k; source node – s_k;

$$d_k^* = \{d_k^1, d_k^2, ..., d_k^{m_k}\} \tag{4}$$

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

In broadcast routing model every k-th flow is connected with an extended (in comparison to (4)) set of destination nodes

$$d_k^{**} = \{d_k^1, d_k^2, ..., d_k^{m-1}\}, \tag{5}$$

Where all the network nodes except for s_k are included.

While solving the problem of multicast routing it is necessary to calculate a set of Booleans (3). Each of them characterizes the proportion of intensity of k-th flow in the link $(i, j) \in E$; $k \in K$, where K denotes a set of flows in the network.

Routing variables (3) are limited by several constraints [6]:

$$\sum_{j:(i,j)\in E} x_{ij}^k \ge 1 \ \ if \ \ k \in K, \ v_i = s_k, \tag{6}$$

and also

$$\sum_{i:(i,j)\in E} x_{ij}^k = 1 \ \ if \ k \in K; \ v_j \in d_k^*. \tag{7}$$

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

$$\sum_{i:(i,j)\in E} x_{ij}^k \geq x_{jp}^k \text{, } k \in K\text{; } v_j \notin s_k \text{.} \tag{8}$$

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

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

$$\sum_{(i,j)\in E_\pi^i} x_{ij}^k < \left|E_\pi^i\right|, \tag{9}$$

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 (9) guarantees that the number of arcs used in multicast routing, composing any cycle is always smaller than the total number of arcs in this cycle.

Ensuring of the Fault-Tolerance Routing Conditions

In order to improve fault-tolerance 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 part of the k-th flow in the link $(i,j) \in E$ of the backup path with arguments (3), (6)-(9).

However with the purpose of preventing the primary and backup paths overlapping with realization of different backup-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 (3), (4), (6)-(9) obtains such conditions [7,8]:

$$x_{ij}^k \bar{x}_{ij}^k = 0. \tag{10}$$

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:

$$\sum_{i:(i,j)\in E} x_{ij}^k \bar{x}_{ij}^k = 0\text{.} \tag{11}$$

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

$$\sum_{(i,j)\in E} x_{ij}^k \bar{x}_{ij}^k = 0\text{,} \tag{12}$$

Which guarantees the meeting of requirements regarding the absence of any common links in the primary or backup path?

OVERLOAD PREVENTION CONDITIONS

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 consider only primary paths flows, condition of the links overload prevention has the form:

$$\sum_{k\in K} r^k x_{ij}^k \leq \varphi_{ij}\text{; } (i,j) \in E\text{.} \tag{13}$$

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 entered:

$$\sum_{k\in K} r^k \left(\frac{x_{ij}^k + \bar{x}_{ij}^k}{x_{ij}^k \bar{x}_{ij}^k + 1} \right) \le \varphi_{ij} \, , \; (i,j) \in E \, , \tag{14}$$

in case of one path routing realization (3).

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:

$$F = \sum_{k\in K} \sum_{(i,j)\in E} c_{ij}^k x_{ij}^k + \sum_{k\in K} \sum_{(i,j)\in E} \bar{c}_{ij}^k \bar{x}_{ij}^k \, , \tag{15}$$

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

As a result of minimization of the equation (15) 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. More over the order of using these routes by flows determined in the same time with their calculation. Besides in [7,8] the necessity to implement the conditions established:

$$\sum_{k\in K} \sum_{(i,j)\in E} c_{ij}^k x_{ij}^k \le \sum_{k\in K} \sum_{(i,j)\in E} \bar{c}_{ij}^k \bar{x}_{ij}^k \, . \tag{16}$$

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 $\bar{c}_{ij}^k$. While implementing of fault-tolerance in multicast flows the optimization task (15) with the constraints (1)-(14) and (16) belongs to the class of nonlinear programming.

NUMERICAL EXAMPLES

Let us consider an example of implementation of the proposed schemes (1)-(16) while solving the problem of single path fault-tolerant unicast routing in the network the topology of which is presented on the Figure 1. The network consists of five nodes (routers) and seven links with the throughput (packet per second, 1/s) shown on the graph arcs. For first flow: the source node is Node 1, destination node is Nodes 5. The rate of first flow is 80 1/s. For second flow: the source node is Node 2, destination node is Nodes 4. The rate of second flow is 60 1/s. Let us assume that within the given example we implement unicast routing with minimization of the number of hops ($c_{ij}^k = 1$). It is needed to represent the scheme of protection of the (1, 3) link.

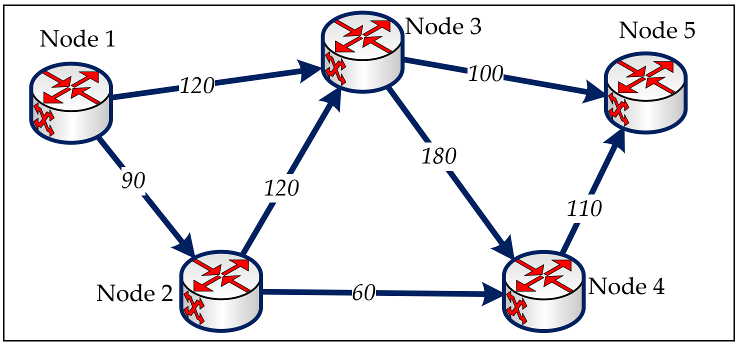
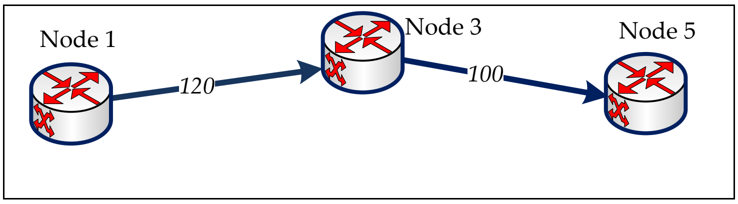
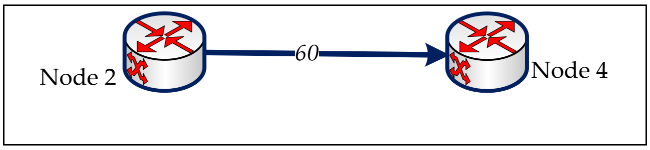


Fig-1: The example of MPLS-network topology



a – The primary path for first flow



b – The primary path for second flow

Fig-2: Set of primary paths for two flows

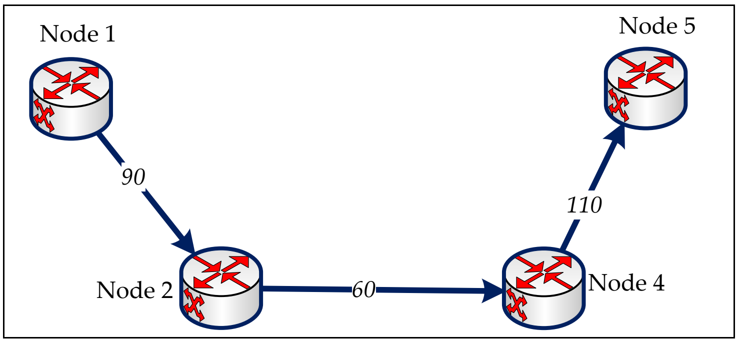


Fig-3: The backup path for first flow without using the condition (14)

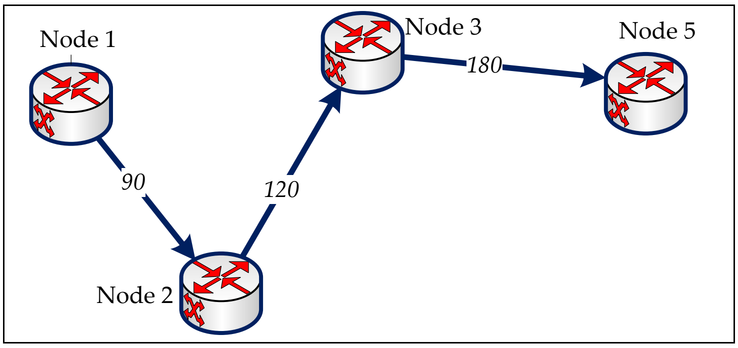


Fig-4: The backup path for first flow using the condition (14)

While solving a problem it was determined that primary path for first flow is consist of two hops which include 1→3→5 nodes. The primary path for second flow includes just one link 2→4. In realizing the protection scheme of the (1, 3) link without condition (7) the backup path for first flow will contain 3 hops and include 1→2→4→5 nodes. But using the link (2, 4) by both first and second flows will cause its overload due to additive flow intensity of 140 1/s. It's possible to avoid the overload in the case of using the overload prevention condition (7). Then the backup path for first flow will consist of 1→2→3→5 nodes without network overload.

Let us consider an example of implementation of the proposed schemes (10)-(14) while solving the problem of single path fault-tolerant multicast routing in the network the topology of which is presented in the Figure 5. The network consists of six nodes (routers) and eight links with the throughput (packet per second, 1/s) shown on the graph arcs. For first flow: the source node is Node 1, destination nodes are Nodes 3, 5 and 6. The rate of first flow is 100 1/s. For second flow: the source node is Node 2, destination nodes are Nodes 4 and 6. The rate of second flow is 200 1/s. Let us assume that within the given example we implement multicast routing with minimization of the number of hops ($c_{ij}^{k} = 1$).

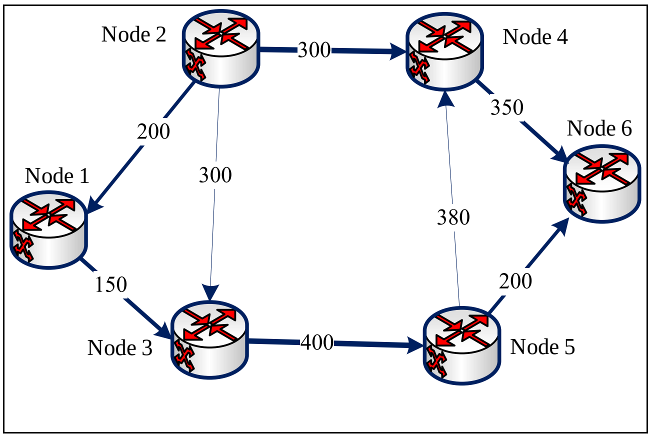


Fig-5: The example of MPLS-network topology

Fig-6 shows an example of the problem-solving for fault-tolerant routing in the network with (2, 4)-link protection. Then as the primary path for first flow we take the solution presented in Figure 6 a), and the "length" of the given path is minimal and consists of 3 hops. Then solution for primary path for second flow presented on Figure 6 b), and the "length" of the given path is minimal and it consists of 2 hops.

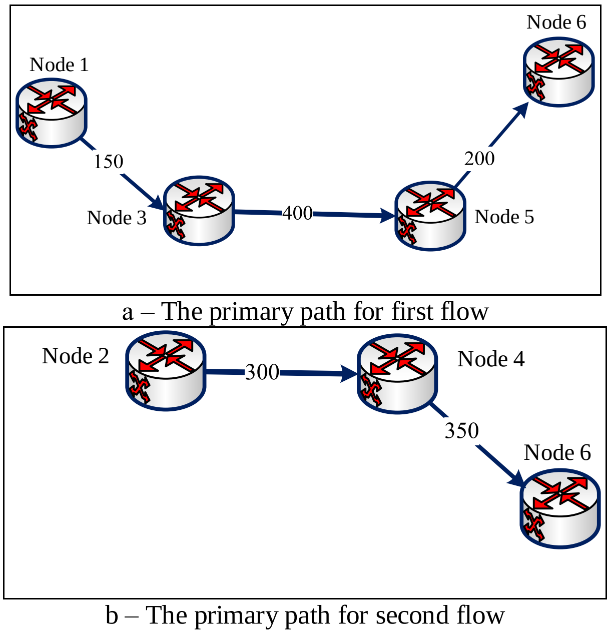
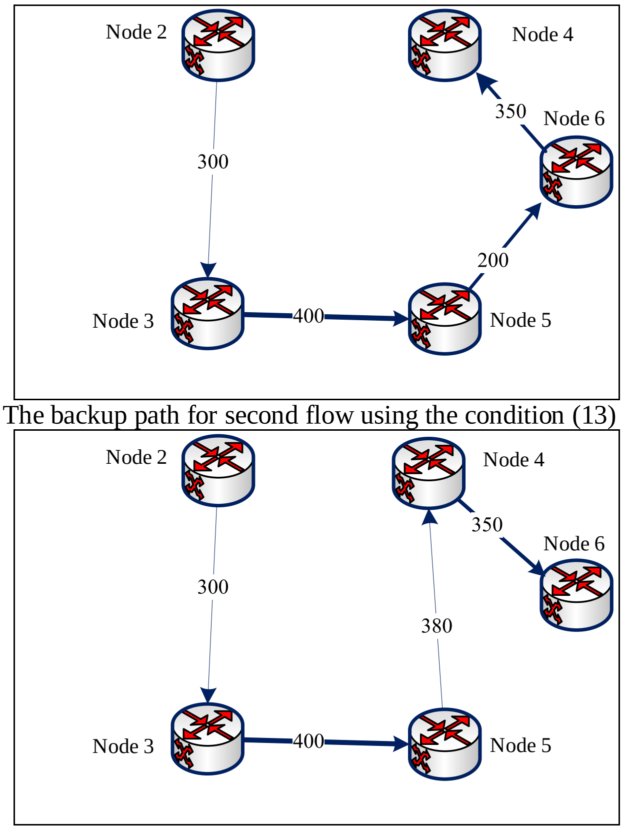


Fig-6: Set of primary paths for two flows

If only conditions (13) used for implementation of (2, 4) link protection scheme, the backup path for second flow (Figure 7 a) includes 3 hops and does not contain any link (2, 4) in accordance with the implemented protection scheme.



b – The backup path for second flow using conditions (14) only

Fig-7: Implementation of (2, 4)-link protection scheme

Backup path (Figure 7 a) is shortest and consists of 3 hops, but has throughput of 200 1/s, because of the (5,6)-link throughput. Thus due to presence of two flows with the rates of 100 and 200 1/s an overload will occur in this link. Using the condition (14) the solution shown on Figure 7 b will be used as the desired backup path. This backup path (Figure 7 b) has 4 hops, i.e. overload does not occur, because shared links (3, 5) and (5, 4) have throughput larger than 300 1/s.

The above examples demonstrate the advantages of using the proposed conditions (13) and (14) for the links overload prevention. In the considered case for multicast routing the fault of (2, 4)-link has not caused a change in the transmission route for first flow. However, it is not a rule, sometimes in order to prevent network overload under fault of one of its elements (node, link, or path) within the proposed solution, reroute can simultaneously include several but not all flows within the network.

CONCLUSION

The schemes for protection of node, link and path under fault-tolerant unicast, multicast, and broadcast routing are presented for a multiflow case. The schemes demonstrate an approach proposed in [7,8], and they are based on a nonlinear flow model in which the conditions for link overload prevention (14) are modified for the case when only some flows can switch to backup routes, but not all of them. This approach increase the efficiency of practical realization of solutions related to unicast, multicast and broadcast fault-tolerant routing in modern multiservice networks and can be used in MPLS Fast ReRoute technology. Efficiency of updating routing information increased by the proposed solution, and allows reducing the time of updating to tens of milliseconds, while current solutions suppose to have timers of 60 – 90 seconds. Functionality of proposed backup schemes is demonstrated by the numerical examples with proven effectiveness for the multiflow case.

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