Improvement of Multipath Routing Flow-based Models for Different Paths Classes

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***Abstract* — Improvement of multipath routing flow-based models for different paths classes in Telecommunication Network (TCN) was presented. These models are further extension of the well known multipath routing model based on the introduction to the structure of non-linear constraints responsible for calculation the routes of different classes. Among the advantages of proposed model of multipath routing with overlapping by nodes paths, one can distinguish the fact that with the same parameters of security and fault-tolerance can be achieved higher performance and quality of service parameters in TCN in a whole.**

Keywords — multipath routing; flow-based model; multiflow; non-overlapping paths; overlapping by nodes paths

I. Introduction

An important place in using of multipath routing takes also increasing of fault-tolerance and security in TCN with traditional use of routing over multiple disjoint paths [1, 2], where are common components only the sender and receiver of packets. Using non-overlapping routes ensures that failure or compromise of a network element (node or link) will result in failure or compromise of only one rather than several routes [2], which takes place at the routing of overlapping paths. However, the implementation of multipath routing over non-overlapping paths as a result uses a network resource inefficiently that is common to multiple paths. This tends to have a negative impact on the TCN performance and quality of service in the network as a whole.

Search for a compromise on the providing fault-tolerance and security, on the one hand, and quality of service, on the other, led to the fact that in some important cases the requirements for overlapping paths can be slightly reduced and it is allowable to use paths overlapping, for example, only by TCN nodes. In these routes not only sender and receiver are common, but some transit nodes, anyway they do not contain the shared communication links. In cases where the failures and/or compromise are inclined links, but not nodes of TCN it is advisable to use overlapping by nodes paths, because it can lead to increased network performance with providing the same level of fault-tolerance or security as using the non-overlapping paths.

Therefore, scientific and practical problems associated with the development of new mathematical models of multipath routing for different paths classes are topical. In addition, these models can be the basis of relevant routing protocols to provide a required level of quality of service, improve the security of transmitted data, as well as fault-tolerance and efficient use of network resources.

II. Multipath Routing by Non-overlapping Paths

It is known that the paths used in the multipath routing are divided into following classes. The first class is the non-overlapping paths, which are defined as routes where only source and destination nodes are common. If paths contain at least one common node and (or) link they are called overlapping. If paths have common nodes they are called paths overlapping by nodes, and if they contain common links such routes belong to class of paths overlapping by links.

Development of a flow-based model of multipath routing by non-overlapping paths was based on the model proposed in [3]. Within the basic model the network structure is described by weighted oriented graph $G=(V,E)$, where V is a set of vertices (routers), and E is a set of graph arcs (communication links). Every link $(i,j)\in E$ is weighted by the parameter $c_{i,j}$ characterizing the throughput of the modeling communication link. Let S_k and D_k be source and destination nodes of the k-th flow respectively, and r^k be the k-th flow rate from the set K. Quantity $x_{i,j}^k$ is a control variable, which characterizes the part of k-th flow of the link $(i,j)\in E$. In accordance with the physics of the multipath routing problem being solved the following restrictions for the variables are needed:

$$0\le x_{i,j}^k \le 1 . \quad (1)$$

For the purpose of prevention network nodes overload it is necessary to meet the condition of flow conservation on the source, transit and destination nodes, respectively:

$$\begin{cases} \sum_{j:(i,j)\in E} x_{i,j}^k - \sum_{j:(j,i)\in E} x_{j,i}^k = 1,\ i = S_k; \\ \sum_{j:(i,j)\in E} x_{i,j}^k - \sum_{j:(j,i)\in E} x_{j,i}^k = 0,\ i \neq S_k, D_k; \\ \sum_{j:(i,j)\in E} x_{i,j}^k - \sum_{j:(j,i)\in E} x_{j,i}^k = -1,\ i = D_k. \end{cases} \quad (2)$$

Also, to prevent the communication links overload the next conditions must be met:

$$\sum_{k\in K} r_k \cdot x_{i,j}^k \le c_{i,j}, \quad (i,j)\in E. \quad (3)$$

In solving the routing problem it is reasonable to minimize the following objective function:

$$J = \sum_{k\in K}\sum_{(i,j)\in E} f_{i,j} \cdot x_{i,j}^k, \quad (4)$$

where $f_{i,j}$ is the links metric between i-th and j-th nodes of TCN.

For multipath routing by non-overlapping paths it is necessary to satisfy assumption: at each transit node input flow should enter from not more than one communication link, and therefore, it does not departure for more than one outgoing link. Accordingly, in the notation of the basic model (1)-(4) for all input interfaces of i-th transit node must be met the following conditions:

$$\sum_{j:(j,i)\in E}\ \sum_{\substack{l:(l,i)\in E,\\ l\neq j}} x_{j,i}^k x_{l,i}^k = 0, \quad (5)$$

but for all output interfaces of i-th transit node we have

$$\sum_{n:(i,n)\in E}\ \sum_{\substack{m:(i,m)\in E,\\ m\neq n}} x_{i,n}^k x_{i,m}^k = 0. \quad (6)$$

Upper bound of number of disjoint paths M_{UB}^k for multipath routing of k-th flow determined by the degree of the vertices modeling source and destination nodes, i.e., the number of arcs (links) incident to these vertices:

$$M_{UB}^k = \mathbf{min}\left(d(S_k), d(D_k)\right), \quad (7)$$

where $d(S_k)$ and $d(D_k)$ are source and destination vertices (nodes) degrees of k-th flow, respectively. While the number of non-overlapping paths for k-th flow routing using (1)-(6) can be calculated as follows:

$$M^k = \sum_{j:(j,i)\in E} \left\lceil x_{i,j}^k \right\rceil \text{ or } M^k = \sum_{n:(n,m)\in E} \left\lceil x_{n,m}^k \right\rceil$$
$$\text{for } i = S_k,\ m = D_k, \quad (8)$$

where $\lceil\cdot\rceil$ is ceiling operation which means rounding to the nearest higher whole number; $\sum_{j:(j,i)\in E} \left\lceil x_{i,j}^k \right\rceil$ is the number of output interfaces through which the k-th flow exits the source node; $\sum_{n:(n,m)\in E} \left\lceil x_{n,m}^k \right\rceil$ is the number of input interfaces through which the k-th flow enters the destination node. The limits of M^k are determined by inequality:

$$1 \le M^k \le M_{UB}^k. \quad (9)$$

III. Multipath Routing with Paths Overlapping by Nodes

In case when it is required to implement multipath routing with paths overlapping by nodes the following assumption for all input and output interfaces of i-th transit node is necessary [4]. Every input flow of a given intensity also should correspond to the output flow of the same intensity:

$$\sum_{m=1}^{N_{in}} \prod_{n=1}^{N_{out}} x_{m,i}^k \left(x_{m,i}^k - x_{i,n}^k\right) = 0, \quad (10)$$

where N_{in} is the number of input interfaces of i-th transit node; N_{out} is the number of output interfaces of i-th transit node. Also should be performed the opposite condition: each output flow of a given intensity should correspond to the input flow of exactly the same intensity:

$$\sum_{n=1}^{N_{out}} \prod_{m=1}^{N_{in}} x_{i,n}^k \left(x_{i,n}^k - x_{m,i}^k\right) = 0. \quad (11)$$

Performing nonlinear constraints (10) and (11) ensures that the flows that pass through i-th transit node come from the same number of contiguous nodes as transmitted to other adjacent nodes with exactly the same intensity. While expressions (7)-(9) can be used to control the number of routes.

IV. Conclusion

In presented research it was proposed solutions of actual scientific and practical problem associated with the development of multipath routing flow-based models for different paths classes in telecommunication network. Proposed models allow the calculation of sets of routes non-overlapping and overlapping by nodes. Among the advantages of using the proposed model of multipath routing with paths overlapping by nodes is that the under the same parameters of security and fault-tolerance it is possible to increase the performance of TCN and quality of service in a whole.

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