Fault-Tolerant IP Routing Flow-Based Model

Oleksandra Yeremenko, Nadia Tariki, Ahmad M. Hailan

Abstract - **In this paper the fault-tolerant IP routing flow-based model presented. In solving the technological problem of fault-tolerant IP routing it is necessary during minimization of object function to solve either linear programming problem or Boolean programming problem with limitations defined. Proposed model also provides the support of traffic balancing functions on the virtual router interfaces, which also has a positive impact on the availability and productivity of telecommunication system as a whole.**

Keywords - **Routing, Fault-Tolerance, Flow-Based model, Nodes, Transport Network, Access Network.**

I. INTRODUCTION

In accordance with the principles of Next Generation Networks (NGN) development, Telecommunication system (TCS) includes a transport network (TN), functioning basically on IP/MPLS technologies, and a set of access networks (AN). There are several technological solutions used to increase fault-tolerance of TCS such that MPLS Fast ReRoute, IP Fast ReRoute, Fast IGP (BGP) convergence, and Fault-Tolerant IP Routing [1, 2]. Fault-Tolerant IP Routing protocols include Hot Standby Router Protocol (HSRP), Virtual Router Redundancy Protocol (VRRP), XL Router Redundancy Protocol (XRRP), Common Address Redundancy Protocol (CARP), and Gateway Load Balancing Protocol (GLBP). The main purpose of these protocols is to improve the accessibility of transport network routers functioning as "default gateway" for access networks. Usually, it is accomplished by forming for each access network a so-called virtual router (Virtual Router, VR), which joins some interfaces of edge routers. The task of control protocol, such as VRRP, is the analysis of TCS state and determining the virtual router interface through which access network is currently connected to transport network. To increase the availability and reliability of connection may be permitted load balancing across multiple interfaces of the virtual router.

However, existing solutions in this field have a number of significant drawbacks. Firstly, the flow-based nature of traffic circulating in the network is not considered, and it is not provided consistent solution of interrelated problems of "default gateway" selecting and routing in transport network. In this regard, it is further proposed Fault-Tolerant IP Routing Flow-Based Model, which is a certain enhancement of the approach proposed in [3, 4].

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II. DESCRIPTION OF FAULT-TOLERANT IP-NETWORK AS GRAPH

Let the structure of telecommunication system is described by the graph $G=(M,L)$ (Fig. 1). At the same time $M=R\bigcup V$ is the set of vertices, which includes two disjoint subsets: $R=\{R_i, i=\overline{1,m}\}$ is the set of vertices modeling transport network routers, and $V=\{V_j, j=\overline{1,v}\}$ is the set of vertices modeling the access networks in TCS.

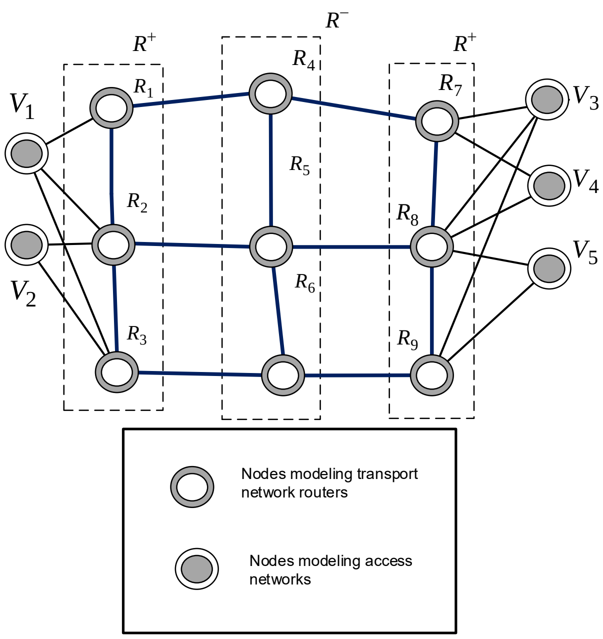

Fig.1. Example of telecommunication system structure description as graph G=(M, L)

In turn, the set R also includes two subsets: R^+ is the set of vertices, modeling edge routers of transport network, i.e. routers, which can be connected to the access networks, where $m^+=|R^+|$ is total number of edge routers in TN; R^- is the set of vertices, modeling transit routers of transport network, where $m^-=|R^-|$ is total number of transit routers in TN.

R_j^+ is a subset of set R^+ modeling those edge routers, or rather their interfaces, that form a virtual router for j-th access network, described by the vertex V_j. Then $m_j^+ = \left|R_j^+\right|$ is total number of edge routers (their interfaces) that make up the virtual router for j-th access network. For example, as shown on Fig. 1 for the first access network as a virtual router used a set of routers represented by R_1, R_2, and R_3 vertices, i.e. $m_1^+ = 3$; for the second network virtual router formed by routers interfaces, modeled by nodes R_2 and R_3, i.e . $m_2^+ = 2$. Thus, sets R_j^+ ($j = \overline{1, v}$) can overlap, since the interfaces of the same edge router can be part of different virtual routers.

In turn, the set of arcs $L = E \bigcup W$ of the original graph G also includes two subsets: $E = \left\{E_{i,j}, i, j = \overline{1, m}, i \neq j\right\}$ a set of links in transport network, $W = \left\{W_{i,j}, i = \overline{1, v}, j = \overline{1, m^+}\right\}$ a set of access lines connecting the access network and transport network edge routers. Then $\left|E\right| = n$ is the number of links in transport network. Each arc $E_{i,j} \in E$ of the graph, modeling corresponding link of transport network, has associated link bandwidth $\varphi_{i,j}$.

III. FAULT-TOLERANT IP ROUTING FLOW-BASED MODEL

Let K be the set of flows incoming to the edge routers from the access networks. Then, for each k-th flow from the set K correspond the following parameters: V_s^k is the access network, which is source of the k-th flow; V_d^k is the access network which is destination of the k-th flow; λ^k is the mean intensity of the k-th packet flow, measured in packets per second (1\s).

As a result of solving the problem of Fault-Tolerant IP Routing using the proposed model, it is necessary to calculate the three types of control variables:

$x_{i,j}^k$ is routing variable characterizing the fraction of k-th flow in communication link represented by arc $E_{i,j}$;

$y_{i,j}^k$ is access variable characterizing the fraction of k-th flow in access line represented by arc $W_{i,j}$, i.e. from i-th access network to j-th edge router of TN;

$z_{j,i}^k$ is access variable characterizing the fraction of k-th flow in access line represented by arc $W_{j,i}$, i.e. from j-th edge router of TN to i-th access network.

Number of routing variables $x_{i,j}^k$ corresponds to product $\left|K\right| \cdot \left|E\right|$. While the total number of access variables $y_{i,j}^k$ and $z_{j,i}^k$ can be determined as $v \cdot m^+ \cdot \left|K\right|$.

To the control variables in accordance with their physical meaning a number of restrictions imposed. When using single path routing of flows in TN next conditions take place

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

For implementation of multipath routing conditions (1) replaced by expressions of the form

$$0 \le x_{(i,j)}^k \le 1. \quad (2)$$

Implementation of multipath routing in accordance with the Traffic Engineering technology provides ensuring a balanced network load and improves the quality of service in telecommunication system as a whole [5, 6].

When connecting the access network in current time to only one virtual router interface the access variables restricted as follows

$$y_{i,j}^k \in \{0;1\}$$

and

$$z_{j,i}^k \in \{0;1\}. \quad (3)$$

With possibility of balancing the traffic over all available interfaces of virtual router condition (3) replaced by analogue (2):

$$0 \le y_{i,j}^k \le 1$$

and

$$0 \le z_{j,i}^k \le 1. \quad (4)$$

Moreover, such conditions occur:

$$\sum_{R_j \in R_p^+} y_{p,j}^k = 1, \; V_p = V_s^k; \quad (5)$$

$$\sum_{R_j \in R_h^+} z_{j,h}^k = 1, \; V_h = V_d^k. \quad (6)$$

These conditions are introduced in order to prevent packet loss at areas “access network – TN virtual router” (5) and “TN virtual router – access network” (6).

To ensure consistency in calculation of control variables, responsible for the implementation of Fault-Tolerant IP Routing, it is important to fulfill the conditions of flow conservation [3]

$$\begin{cases} \sum\limits_{j:E_{i,j} \in E} x_{i,j}^k - \sum\limits_{j:E_{j,i} \in E} x_{j,i}^k = 0; k \in K, R_i \in R^-; \\ \sum\limits_{j:E_{i,j} \in E} x_{i,j}^k - \sum\limits_{j:E_{j,i} \in E} x_{j,i}^k = y_{p,i}^k; k \in K, R_i \in R^+, V_p = V_s^k; \\ \sum\limits_{j:E_{i,j} \in E} x_{i,j}^k - \sum\limits_{j:E_{j,i} \in E} x_{j,i}^k = -z_{i,h}^k; k \in K, R_i \in R^+, V_h = V_d^k. \end{cases} \quad (7)$$

Conditions (7) ensure that there are no packet losses on the transport network transit routers and TCS as a whole, as well as the fact that flow of any user from the access network will be accepted and served by the transport network.

To prevent possible overload by bandwidth in transport network links in model introduced following conditions:

$$\sum_{k\in K}\lambda^k x_{i,j}^k \le \varphi_{i,j}, \quad E_{i,j}\in E. \qquad (8)$$

As optimality criterion of obtained solutions for fault-tolerant routing is advisable to choose a minimum of the following linear objective function

$$J=\sum_{k\in K}\sum_{E_{i,j}\in E} c_{i,j}^k x_{i,j}^k+\sum_{k\in K}\sum_{W_{i,j}\in W} b_{i,j}^k y_{i,j}^k+\sum_{k\in K}\sum_{W_{j,i}\in W} a_{j,i}^k z_{j,i}^k, \qquad (9)$$

where $c_{i,j}^k$ is the set of routing metrics, $b_{i,j}^k$ and $a_{j,i}^k$ are the set of access metrics that determine the conditional cost of using the access networks, formed virtual routers and their interfaces. The choice of these metrics determined by characteristics of transport network links and access lines (such as their throughputs), as well as the importance (priority) of transmitted packet flows.

Then the first term in the expression (9) describes the conditional cost of the use of transport network links, while the second and third terms reflect the conditional cost of using the access lines for incoming traffic to the network or outgoing traffic from the transport network, respectively.

Using the criterion (9) together with condition (7) provides consistency in solving such important tasks as defining the “default gateway” and routing in transport network. Consistency in their solution allows ensuring higher performance and quality of service in TCS as a whole.

IV. Conclusion

Thus, in solving the technological problem of Fault-Tolerant IP Routing it is necessary during minimization (9) to solve either linear programming problem, taking into account conditions (2) and (4), or Boolean programming problem with limitations (1) and (3). Protocol responsible for solving formulated optimization problems in dependence with the state of TCS can select interfaces of virtual routers (“default gateways”) through which will be connected access networks to transport network. Proposed model with the implementation of conditions (4) also provides the support of traffic balancing functions on the virtual router interfaces, which also has a positive impact not only on the availability, but on the productivity of TCS as a whole also.

In the case of one of the routers failure, which interfaces are part of the virtual router, solution of formulated optimization problem (1)-(9) is performed, which allows to select the appropriate “default gateway” and determine the new order of flow routing in the transport network.

To increase fault-tolerance of telecommunication system at the level of transport network it is advisable to supplement the proposed model by the terms of protection schemes Fast ReRoute [7]. While to ensure quality of service not only in terms of performance but also in terms of average delay and (or) packet loss probability in the model must be introduced conditions proposed in [5, 6].

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