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Research paper

Improve the scalability and performance of fault-tolerant for failable stability routing in networks connection

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Abstract

Practically, the execution of fault-tolerant routing dependent on the reservation of system assets is generally connected with a decline in general execution and versatility of convention arrangements. In such manner, a spilling model has been recommended that is centered around expanding the versatility and execution of fault-tolerant routing arrangements. The structure of the model incorporates conditions that are in charge of the way that the principle and reinforcement courses vary just in those system components for which the reservation is composed. This is reflected in the change of the objective function in the formulation and solution of the optimization problem of fault-tolerant routing. The given numerical examples confirmed the effectiveness of the proposed solution.

Keywords: *Flow; Model; Fault Tolerance; Routing; Scheme; Redundancy.*

1. Introduction

Modern telecommunication networks (TCN) based on IP and MPLS technologies (Multiprotocol Label Switching), provide quality QoS (Quality of Service) through using conventions damage routing. It should be noted that the main the cause of QoS degradation is overload online. Most routing protocols do not provide effective response mechanisms network overload. Thus, to improve effectiveness of responding to possible packet service failures caused by overload in the correspondence channels and lines of routers fault tolerant routing is used.

Among examples of such technologies there may be divided MPLS Fast Re-Route [1]. With this protocol routing must satisfy a number of important requirements such as providing redundancy network elements (channel, node, route protection) and adaptation for single-path routing. In this way, a streamlined approach is proposed. Show meeting the predefined prerequisites. To improve the quality of service, enjoy various fault tolerant schemes unicast routing which in particular based on the provision of the Fast Re-Route concept.

The solution presented is based on the approach proposed in [2], and is implemented as a non-linear flow model in which the conditions for prevent overload of the communication channel cited for the case when only some streams can switch to the backup route, but not all of them. The main disadvantage of failure sustainable routing based reservations network resources is to reduce the overall performance and scalability protocol solutions. Thus, the problem of addressing scalability and performance in fault tolerant routing is actual practical task. In this article received its further development of mathematical model of fault-tolerant routing in TCS, in framework which managed to ensure satisfaction following requirements formulated depending on the results of the analysis:

- accounting stream structure of modern multimedia traffic;
- implementation of basic redundancy schemes network resources: protection of the channel, node, route, starting capacity;
- increase of fault tolerance received solutions for different routing strategies:
- unicast and multipath unicast routing;
- modification of the conditions for the prevention of reloading of communication channels for the case when only part of flows will be switched from the main routes on backup; formulation of conditions for improving the scalability and performance of solutions related to the implementation of fault-tolerant routing in TCN.

2. Research results basic unicast routing model in TCS

The proposed mathematical model of fault-tolerant routing is focused on the implementation of both single-path and multi-path unicast routing. When describing the basic flow model of unicast routing [3], the structure of the TCS is represented using an oriented graph. In addition, a number of functional parameters are associated with each km unicast stream: r_k is the average flow rate at the entrance to the network; S_k - sender node; d_k - the only recipient node. In solving a unicast routing problem, it is necessary to calculate a set of variables $X^k_{(i,j)}$, each of which characterizes the intensity fraction of the k-th stream in the communication channel represented by the arc (i, j) ∈E; k ∈ K, where K is the set of flows in the network. When single-path flow routing is true:

$$x^k_{(i,j)} \in \{0;1\}.$$

(1)

In the case where the possibility of implementing multi-path solutions is envisaged, conditions (1) are replaced by expressions of the form

$$0 \le x^k_{(i,j)} \le 1 .$$
(2)

In addition, in order to prevent packet losses on the routers and in the TCS, flow conservation conditions are generally introduced [3]:

$$\begin{cases} \sum_{j:(i,j)\in E} x^k_{(i,j)} - \sum_{j:(j,i)\in E} x^k_{(j,i)} = 0;\ k \in K,\ M_i \ne s_k, d_k; \\ \sum_{j:(i,j)\in E} x^k_{(i,j)} - \sum_{j:(j,i)\in E} x^k_{(j,i)} = 1;\ k \in K,\ M_i = s_k; \\ \sum_{j:(i,j)\in E} x^k_{(i,j)} - \sum_{j:(j,i)\in E} x^k_{(j,i)} = -1;\ k \in K,\ M_i = d_k. \end{cases}$$
(3)

3. Conditions for ensuring protection (redundancy) of network elements in fault-tolerant routing

To determine the backup path in order to implement the node, channel and path protection schemes in general, it is necessary, along with unknown $X^k_{(i,j)}$, to calculate additional route variables $X^k_{(i,j)}$, which characterizes the share of the k-th stream flowing in the channel (i, j) ∈E, but already a backup route. The variables $\overline{X}^k_{(i,j)}$ are also subject to restrictions similar to (1) - (3). In accordance with the results proposed in [2], when implementing the channel protection scheme (i, j) ∈E, the following model should be entered into the proposed model:

$$x^k_{(i,j)}\overline{x}^k_{(i,j)} = 0 ,$$
(4)

Performance of which guarantees the use of the channel (i, j) ∈ E by only one route either the main, or standby, regardless of the implemented strategy: single-path or multipath unicast routing. When implementing the protection scheme of the i-th node, the model is supplemented with the following condition:

$$\sum_{i:(i,j)\in E} x^k_{(i,j)}\overline{x}^k_{(i,j)} = 0 ,$$
(5)

Performance of which guarantees the use of the i-th node (i.e., all the channels incident to it) either by the main or backup route. To ensure the protection of the path (s), equality conditions are introduced into the structure of the model.

$$\sum_{(i,j)\in E} x^k_{(i,j)}\overline{x}^k_{(i,j)} = 0 ,$$
(6)

Which is equivalent to satisfying the requirements regarding the absence of common nodes and channels in the primary and backup routes (except the sending and receiving nodes).

4. Channel overload prevention conditions communication in the implementation of various schemes redundancy elements TCS

In the course of modeling the processes of the fault-tolerant routing of unicast flows, certain difficulties arise when formalizing the conditions for preventing overload of communication channels under conditions when only some of the considered flows switch from the main to the backup routes. In the framework of the proposed flow model [4] of fault-tolerant routing, while preventing overload of communication channels, the case is taken into account when not all, but only some of the flows will switch to backup paths. Therefore, it is proposed to introduce the following conditions to prevent overload:

$$\sum_{k\in K} r_k \left(\left(x^k_{(i,j)} + \overline{x}^k_{(i,j)}\right) \Big/ \left(x^k_{(i,j)}\overline{x}^k_{(i,j)} + 1\right)\right) \le \varphi_{(i,j)} ,\ (i,j) \in E ,$$
(7)

If implemented one-way routing of unicast streams.
In the most general case, including option (7), i.e. in the case of the implementation of both single-path and multi-path routing of unicast streams, the condition for preventing overload of each specific communication channel will be as follows:

$$\frac{1}{2}\sum_{k\in K} r_k \left((x^k_{(i,j)} + \overline{x}^k_{(i,j)}) + \sqrt{(x^k_{(i,j)} - \overline{x}^k_{(i,j)})^2} \right) \le \varphi_{(i,j)}$$
(8)

Thus, the fulfillment of conditions (7), (8) makes it possible to prevent overloading of communication channels in a telecommunication network, even in the case when all, and only some streams will switch from the main to the backup route. In this case, some of the bandwidth of the communication channels of the backup routes will always remain untapped for these flows, thereby implementing the protection scheme (bandwidth in the organization of fault-tolerant routing in TCS).

5. The choice of the criterion for optimal solutions by fault-tolerant routing in TCS

Due to the fact that, in general, the selection of routes (both primary and backup) in a broadcast communications system should be possible from multiple points of way, it is advisable to formulate the problem of fault-tolerant routing as a streamlining one. An important point in the formulation of any optimization problem is the choice of the optimality measure of the acquired arrangements, the type of which, on the one, should adequately reflect the physical meaning process model, and on the other hand, provide the possibility of obtaining the desired results with given requirements (acceptable accuracy, computational complexity in real time, etc.).
The classic approach when solving the route, the main tasks in TCS are to minimize the all-out measurement of the determined route, where, under the measurement, as appeared by the aftereffects of the investigation, as a rule, the decreased (standardized) parameters of the channel limit (ways), normal bundle delays and different markers of the nature of administration in TCS show up.
At times, criteria are utilized that are specifically identified with guaranteeing ideal burden adjusting (for example guaranteeing a fair heap of assets) on the system, since it is realized that the lower the channel/line load, the better qualities go up against pointers of nature of administration. Be that as it may, for this situation, the strategy is confounded. Differentiated accounting of functional parameters of individual channels (speed and reliability), which is very important for solving problems of fault-tolerant routing.
In [4] during the calculation of route $X^k_{(i,j)}$ and $\overline{X}^k_{(i,j)}$ when solving problems of fault-tolerant routing in TCS use the optimality criterion associated with minimizing the following objective function:

$$F = \sum_{k\in K}\sum_{(i,j)\in E} c^k_{(i,j)} x^k_{(i,j)} + \sum_{k\in K}\sum_{(i,j)\in E} \overline{c}^k_{(i,j)}\overline{x}^k_{(i,j)} ,$$
(9)

Where $c^k_{(i,j)}$ and $\overline{c}^k_{(i,j)}$ are the route metrics of the channels main and backup routes, respectively. Function (9) numerically describes the total costs of the formation and use of the main and backup routes between a pair of nodes sender and recipient (s). Besides, in the course of the study of model (1) - (9) in [4] it was established that it is necessary to supplement it with the condition:

$$\sum_{k\in K}\sum_{(i,j)\in E} c_{(i,j)}^{k} x_{(i,j)}^{k} \leq \sum_{k\in K}\sum_{(i,j)\in E} \overline{c}_{(i,j)}^{k} \overline{x}_{(i,j)}^{k} , \quad (10)$$

Performance of which guarantees that the principal the path (multi-path) will always be no worse than the backup within the selected metrics $c_{(i,j)}^{k}$ and $\overline{c}_{(i,j)}^{k}$, each k-th stream should initially use a shorter in terms of the number of hops (for $c_{(i,j)}^{k}=\overline{c}_{(i,j)}^{k}=1$) or more efficient productivity (at $c_{(i,j)}^{k}=\overline{c}_{(i,j)}^{k}={10^7}/{\varphi_{(i,j)}}$) path [5].

As the examination appeared, the utilization of perspective (9) gives a sufficient reaction to the issue of fault-tolerant controlling, regardless, unique questionable focuses were seen that could bolster inimically affect the plentifulness of the reasonable utilization of model (1) - (10) when all is done.

First of all, it concerns the reduction of the overall performance of the TCS in view of the fact that the use of backup paths is somehow connected with the use of an additional network resource (channel and buffer), which for this reason cannot be used by other streams.

On the other hand, the needs to calculate the main routes is also a set of backup paths associated with an increase in the computational load on the TCS routers, as well as the need to support route tables of increased dimensionality in which data are stored, both about the main and backup paths. In this case, the paths of these two types must not only be calculated, but also maintained in an active state. In general, these factors, along with a decrease in TCS performance, adversely affect the scalability of solutions related to fault-tolerant routing. This is especially critical for TCS of a large dimension and with an extensive network structure (high connectivity of nodes), which results in the calculation of paths (main and backup) with a large number of communication channels and routers.

These shortcomings are common to virtually all technologies related to improving the reliability of the network as a whole, and are a kind of "fee" for ensuring a given level of fault tolerance of final solutions. To minimize these shortcomings, it is desirable that, as a result of the calculations, the backup path differed as little as possible in the composition of the channels and nodes from the main one - ideally, only on the problematic network element to be further protected. This should help ensure that the minimum bandwidths of the network channels will be subject to redundancy, which will positively affect its performance and quality of service indicators in general. In addition, in the network nodes for each stream, not the two route tables (for the main and backup paths) can be stored, but one, but with the minimum necessary adjustments regarding the differences between the main and backup paths.

In this regard, this paper proposes to change the criterion (9), replacing it with the minimum of the following objective function

$$F=\sum_{k\in K}\sum_{(i,j)\in E} c_{(i,j)}^{k} x_{(i,j)}^{k}+\sum_{k\in K}\sum_{(i,j)\in E} \overline{c}_{(i,j)}^{k} \overline{x}_{(i,j)}^{k}- -\sum_{k\in K}\sum_{(i,j)\in E} b_{(i,j)}^{k} x_{(i,j)}^{k} \overline{x}_{(i,j)}^{k} , \quad (11)$$

In which the introduction of the third term is precisely connected with ensuring the maximum coincidence of the backup path with the main composition of the channels and nodes included in them; $b_{(i,j)}^{k}$ - sufficiently large in its value penalty factor ($b_{(i,j)}^{k} \gg c_{(i,j)}^{k}$ and $b_{(i,j)}^{k} \gg \overline{c}_{(i,j)}^{k}$).

The minus sign before the third term is introduced for the reason that the degree of coincidence of the reserve and main paths should be maximized, and the metrics of these paths (the first and second term in (11)) should be minimal.

6. Characterization of optimization problems of fault-tolerant routing and their solution methods

Thus, the solution of the technological problem of fault-tolerant routing within the framework of the proposed improvement of the flow model (1) - (11) is reduced to the solution of the optimization problem associated with minimizing the objective function (11) with a system of constraints:

- (1) or (2) responsible for implementing one or multipath routing respectively;
- (3) describing the conservation conditions unicast routing current;
- (4) - (6) entered for the implementation of possible protection schemes for network elements (channel, node and ways, respectively);
- (7), (8), which formalize the conditions of prevention rotational overload of communication channels of the network, including a case where only some of the streams are switched are placed on reserve tracks;
- (10), which is responsible for the fact that the main the path (multi path) will always be no more awful than the reinforcement inside chose measurements.

Contingent upon the kind of the target work and the limitations forced, dictated by the methodology being executed (single direction or multi-way), the figured streamlining issue may identify with some class of scientific programming issues, suggesting the utilization of a fitting arrangement technique (Table 1). Because of the way that requirements (4) - (6) presented for the execution of bolstered assurance plans for system components and conditions (7), (8) identified with the aversion of system correspondence channel over-burden are non-straight, the improvement issue regardless will have a place with the class of non-direct programming issues. Likewise, while executing single-way steering, course factors will be boolean, and in this manner the enhancement issue to be comprehended will as of now have a place with a subclass of issues of (Mixed Integer Nonlinear Programming MINLP).

Table 1: Characterization of Optimization Problems for the Failure of Stable Routing and Their Solution Methods

Class optimization task	Solution Methods
routing strategy: one path	
Mixed integer nonlinear programming	rounding method, branch and bound method, sequential linearization methods, annealing simulation method, genetic algorithm, various mixed (hybrid) methods
Routing Strategy: multipath	
Nonlinear programming	method of Lagrange multipliers, the penalty function method, gradient methods, and others.

7. Numerical analysis of increasing scalability and performance of solutions for fault-tolerant routing

Let us analyze the impact of the improvement of the proposed flow model, which consists in replacing the objective function (9) with the updated version (11), on the scalability and performance of solutions for fault tolerant routing. To do this, consider the network structure shown in Fig.1.

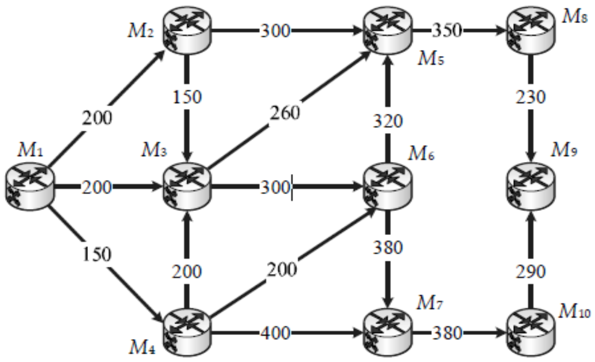

Fig. 1: An Example of A TCS→ Structure under Investigation with Ten Nodes and Sixteen Communication Channels.

So for a unicast stream of packets transmitted with an intensity of 150 1 / s from the first router to the ninth, the optimal main route in the metric of the number of hops will be, for example, the path M1→ M2→ M5→ M8→ M9. Then the backup path while protecting the channel (2, 5) and using the objective function (9) will be the path M1→ M4→ M7→ M10→ M9, which would entail the need to allocate a throughput of 150 1 / s for the stream in each of the eight communication channels and backup paths (Fig. 2). Reserve path for clarity in Fig. 2 is indicated by a dotted line.

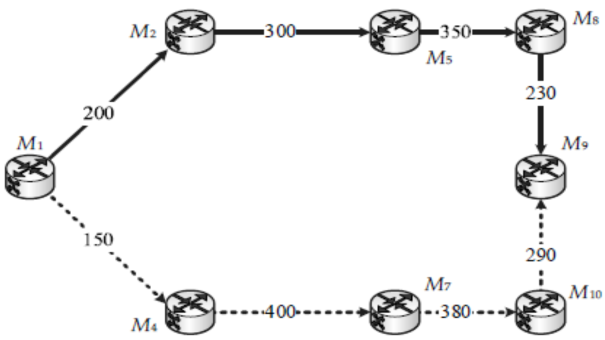

Fig. 2: The Results of the Calculation of the Primary and Backup Paths Using the Expression (9).

In the course of optimizing the process of fault-tolerant routing using the modified objective function (11), the result of solving the task set will change somewhat. This is due to the fact that, in accordance with the physical meaning of the objective function (11), the backup path tends to differ minimally from the main one in terms of the composition of the used communication channels and their workload.

The transition to the use of the objective function (11) in this case will increase the scalability of the desired solutions and the performance of the TCS as a whole, since the total number of communication channels used during the failover routing will be reduced to six when using the backup path M1→ M2→ M3→ M5→ M8→ M9 (Fig. 3).

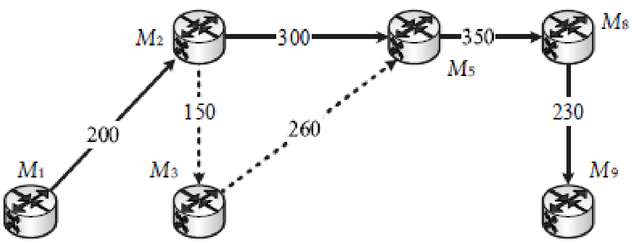

Fig. 3: The Results of the Calculation of the Primary and Backup Paths Using the Expression (11).

8. Conclusion

In accordance with the needs to implement the requirements put forward for future solutions in the field of fault-tolerance routing solutions, the article further developed the flow model of fault-tolerant routing in a telecommunications network, aimed at implementing the basic redundancy schemes for network elements and their throughput.

The proposed model provides a solution to the problem of fault-tolerant routing by minimizing the additive metrics of the main and backup routes. At the same time, functions of key functional characteristics of communication channels can be used as a metric: throughput, delay, packet loss level, etc.

The novelty of the proposed model is the modification of the objective function to be minimized by introducing a quadratic term responsible for ensuring that the backup path differs as little as possible in the composition of channels and nodes from the main one - ideally only by the problematic network element to be further protected. This contributed to the fact that the minimum volumes of network bandwidth will be subject to reservation, which will positively affect its performance and quality of service indicators in general. The study of the proposed model, first, confirmed its performance in terms of obtaining the desired solutions in real time, secondly, a number of numerical examples demonstrated the advantages of the proposed improvements regarding the prevention of possible overload of communication channels, increasing the scalability and performance of the resulting solutions in whole.

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