TWO-LEVEL METHOD OF HIERARCHICAL INTER-AREA ROUTING IN NETWORK

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Abstract *– In modern telecommunication networks the scalability improvement of routing decisions is the very actual problem. That's why, effective way is associated with the implementation of hierarchical routing. This involves carrying out a structural and functional decomposition of the network, based on the introduction and supporting of multi-level routing decisions. However, the existing protocol implementation of hierarchical routing does not contribute to maximization of the scalability of routing decisions because that only applied structural hierarchy and functional aspects are not involved. In this paper the method of hierarchical inter-domain routing based on the goal coordination principle was supposed.*

Keywords: *inter-area routing, telecommunication network, goal coordination method, iteration.*

I. Introduction

With the rapid growth of the territorial dimensions of modern telecommunication networks (number of routers, links) and development of more new multimedia applications, as well as increasing the level of required quality of service the acute problem is the improvement of scalability of routing decisions [1].

Scalability improvement contributes to reduce the volume of routing traffic circulated in the network routing solutions reduce the time problems, and also will reduce the computational complexity of the method, model or routing protocol implementation. The solution of this situation is seen in the transition to the hierarchical routing, namely structural and functional decomposition of the network [1]. In practice, the hierarchical approach has long been used as a protocol solutions, such as OSPF, IS-IS, PNNI, etc. That implies a structural hierarchy and the introduction of a hierarchy of routers, as well as the use of the backbone areas for the exchange of information between areas, which is reducing the functionality, limiting the power of the network.

Thus the two-level method of hierarchical inter-area routing in telecommunication network is presented. This method is based on consistent coordination of decisions on the upper level. The main aim of this method investigation should be to identify factors influencing on convergence of the coordination procedures, and measuring their impact.

II. Decomposed Model of Inter-Area Routing

Let's the network generally comprises of $|N| = n$ interconnected areas in the development of the decomposed inter-area routing model. Let telecommunication network structure is described by an oriented graph $G = (M, E)$, where M is a set of vertices which simulate routers in the network; E is a set of graph arcs simulate network links. Then let's every p-th single area ($p \in N$) is described by the subgraph $G^p = (M^p, E^p)$, where M^p is the set of routers in p-th area $M^p = \{M_i^p, i = \overline{1, m_p}\}$, and E^p is the set of p-th area links. For every link in network it is specified the bandwidth $\varphi_{(i,j)p}$ which measured in packet per second (1/s). The boundary between areas will pass through routers in structural decomposition of network (network splits into areas through the routers), i.e. $M^p \cap M^q \neq 0$, and $E^p \cap E^q = 0$.

Then for every p-th single area it is necessary to calculate $x_{(i,j)p}^k$ variables which determine the share of k-th flow packet rate in link $(i,j) \in E_p$, variable λ^k is the k-th flow rate ($k \in K$). The set of flows K can be split into two subsets: K_p^- is subset of outgoing flows from p-th area and K_p^+ is subset of incoming flows into p-th area.

In order to prevent packet loss on routers and in the network as a whole it is necessary to fulfill the condition of flow conservation in every single p-th area [2]

$$\begin{cases} \sum\limits_{j:(i,j)\in E} x_{(i,j)p}^k - \sum\limits_{j:(j,i)\in E} x_{(j,i)p}^k = 1; \\ \sum\limits_{j:(i,j)\in E} x_{(i,j)p}^k - \sum\limits_{j:(j,i)\in E} x_{(j,i)p}^k = 0; \\ \sum\limits_{j:(i,j)\in E} x_{(i,j)p}^k - \sum\limits_{j:(j,i)\in E} x_{(j,i)p}^k = -1. \end{cases} \quad (1)$$

The system of equations (1) should be performed for each packet flow separately. The first conditions in system (1) are introduced for all routers in p-th area which are the k-th flow income through to the p-th area, second conditions in system are introduced for all routers in p-th area which are transit routers in p-th area for k-th flow, and third conditions in system (1) are introduced for all routers in p-th area which the k-th flow outgo throw from p-th area respectively.

In addition, to prevent the links overload it is important to fulfill the following conditions [2]:

$$\sum_{k_r \in K} \lambda^k x_{(i,j)p}^k \le \varphi_{(i,j)p}, \; p \in N \quad (2)$$

In order to implement multipath routing strategy with load balancing the routing variables must satisfy the conditions:

$$0 \le x_{(i,j)p}^k \le 1. \quad (3)$$

Since the solutions of routing tasks in different areas will be performed independently, it is important to perform a variety of conditions of areas interworking to provide connectivity of inter-area routing:

$$C_{qp}^k \vec{x}_p^k = C_{pq}^k \vec{x}_q^k, \; p,q = \overline{1,n}, \; p \neq q, \; k \in K \quad (4)$$

where C_{qp}^k is matching matrix which consists of zeros and ones. This matrix determines which coordinates of vector $\vec{x}_p^k$ are responsible for interworking with q-th area.

During the calculation of vector $\vec{x}_p^k$ ($p \in N$) the objective is to minimize

$$\min F, \quad F = \sum_{p \in N} \sum_{k \in K} (\vec{x}_p^k)^t H_p^k \vec{x}_p^k \quad (5)$$

where H_p^k is diagonal matrix of weight coefficients which coordinates are generally routing metric of the networks links, $[\cdot]^t$ is transpose function of the vector (matrix) [2]. Equation (5) represents the conditional costs of organizing the routing process in telecommunication network as a whole.

III. Hierarchical Method of Inter-Area Routing Based on Goal Coordination Principle

To solve the formulated optimization problem involving with the expression (5) minimization with constraints (1)-(3), the goal coordination principle was used [3-4]. Then, turning to the problem of an unconditional extremum,

$$\min_x F = \max_\mu L,$$

it is necessary to maximize the following Lagrangian by $\vec{\mu}$

$$L = \sum_{p \in N} \sum_{k \in K} (\vec{x}_p^k)^t H_p^k \vec{x}_p^k + \sum_{p \in N} \sum_{\substack{q \in N \\ q \neq p}} \sum_{k \in K} \vec{\mu}_{pq}^k (C_{qp}^k \vec{x}_p^k - C_{pq}^k \vec{x}_q^k)$$

(6)

where $\vec{\mu}$ is the vector of Lagrange multipliers, $\vec{\mu}_{pq}$ is the subvector of vector $\vec{\mu}$ related to each condition (4).

Vector of Lagrange multipliers $\vec{\mu}$ is calculated on the upper level of hierarchy. Using this vector the expression (6) can be represented in following decomposition form:

$$L = \sum_{p \in N} L_p,$$

$$L_p = \sum_{k \in K} (\vec{x}_p^k)^t H_p^k \vec{x}_p^k + \sum_{\substack{q \in N \\ p \neq q}} \sum_{k \in K^-} \vec{\mu}_{pq}^k C_{qp}^k \vec{x}_p^k - \sum_{\substack{q \in N \\ p \neq q}} \sum_{k \in K^+} \vec{\mu}_{pq}^k C_{qp}^k \vec{x}_p^k. \quad (7)$$

All the components in equation (7) were assigned to p-th area according to a functional decomposition. Second and third components in this expression are responsible for the coordination of order routing, respectively outgoing and incoming flows for p-th area.

Thus, the total inter-area routing problem is formulated as a problem of a two-level hierarchical coordination optimization. On the lower level of the hierarchy there is a calculation of routing variables for flow transmission via links in each area, and organization of inter-area interworking. The main task of upper level of hierarchical coordination method is a coordination of the solutions obtained from the lower level, in order to ensure conditions of interworking (4) between areas by modifying vectors of Lagrange multipliers in the implementation of the gradient iterative procedure:

$$\vec{\mu}_{pq}^k(\alpha+1) = \vec{\mu}_{pq}^k(\alpha) + \nabla\vec{\mu}_{pq}^k, \quad (8)$$

where α is the number of iteration; $\nabla\vec{\mu}_{pq}^k$ is gradient of function (8), which are calculated according to the received from the lower level solutions of routing tasks $\vec{x}_p^{k*}$ ($p \in N$) in each separate area:

$$\nabla\mu_{pq}^k(x)\Big|_{x = x^*} = C_{qp}\vec{x}_p^k - C_{pq}\vec{x}_p^k. \quad (9)$$

Visually the computational structure of two-level hierarchical method of inter-area routing was shown on Fig.1.

Effectiveness of presented method a large depend on the rate of coordination procedure convergence (8)-(9), the number of coordination iterations. The less number of iterations is needed for obtaining the optimal solution, the less volume of circulated in network service (coordination) traffic and the time of solving the problem as whole [2].

The main aim of the research of this method is to determine the degree of influence of the structural and functional network parameters such as network dimension, routing strategy, and characteristics of flows circulating in network on the convergence procedure.

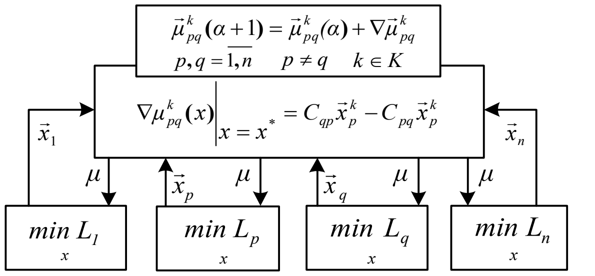

Fig. 1. Structure of two-level hierarchical method of inter-area routing

IV. Conclusion

To improve the scalability of routing decisions as well as decisions on the interworking between areas within a single telecommunication network the hierarchical coordination method of inter-area routing was proposed in this paper. Hierarchical approach of solving this problem will significantly reduce the dimension of the solved optimization problem and reduce the amount of service information about the state of the network circulating in the network. The basis of the proposed hierarchical method of the inter-area routing is based on the goal coordination principle, in which on lower level each area routing server provides calculation of the routing variables and the main task of the upper level was coordination of the lower level decisions (8)-(9) in order to ensure conditions of inter-action between the areas of telecommunication network, responsible for interconnection inter-area routes.

The effectiveness of this method is largely determined by the rate of coordination procedure convergence, namely the number of iterations. The influence of the network load on the convergence of the coordination procedure (8), (9) was research. It was carried out the dependence the number of iterations on a number of influencing factors, such as network load and dimension, routing strategy (single-path, multipath), etc. Firstly, it was considered that depending on the packet flow rate the coordination procedure converges in a finite number of steps (iterations) from 1 to 5. It was found that by using single-path routing, as compared with the multi-path routing, the method converges in about 1.5-3 times less iterations. As well study showed that network load does not significantly affect the rate of convergence procedure when single-path routing strategy is used. However, when multipath routing strategy is used, the number of number of iterations increased ratably network load increase. Solutions proposed in this paper can be adapted to the peculiarities of Fault-Tolerant Routing [5].

V. References

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