The Increasing Convergence of Coordination Procedure in The Implementation of Multipath Hierarchical Routing

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***Abstract*—To avoid overload of links, as well as packet loss in the network uses the coordination method. This method is based on the possibility of converting the original minimization problem in a simpler maximization problem and the solution of this problem using a two-level iterative computational structure. In this paper the analysis of convergence of the two-level hierarchical routing method with coordination is given.**

Keywords* — *Coordination method, Iteration, Hierarchical Routing, Flow, Metrics.

I. Introduction

The hierarchical structure of telecommunication network is dictated by the need of improvement of reliability, quality of service and overall system performance. A distinctive feature of the hierarchical structure of telecommunications networks is the presence of multiple sources, i.e. the calculation of routes occurs on multiple routers. For minimization overloads and packet loss in network the routing problems are decomposed into a number of smaller tasks. However, this solution causes other problems, for example increasing of service traffic in network, which in turn leads to delays. To ensure scalability, use a model of hierarchical routing.

II. Model of Hierarchical Routing

For every router-sender (source) in the network let us define as control variable $x_{ij}^{k_r}$, where $x_{ij}^{k_r}$ equals share of packet flow rate k_r in link (i, j); k_r is packet flow that is arriving through r^{th} boundary router to the network. Variable λ^{k_r} is the flow rate k_r. Variable φ_{ij} is the link capacity. In order to prevent packets loss at the router and in the network it is necessary to provide the flow conservation condition [2], [3]

$$\begin{cases} \sum\limits_{j:(i,j)\in E} x_{ij}^{k_r} - \sum\limits_{j:(j,i)\in E} x_{ji}^{k_r} = 1, \text{if } i^{th} \text{ is router-sender;} \\ \sum\limits_{j:(i,j)\in E} x_{ij}^{k_r} - \sum\limits_{j:(j,i)\in E} x_{ji}^{k_r} = 0, \text{ if } i^{th} \text{ is transit router;} \\ \sum\limits_{j:(i,j)\in E} x_{ij}^{k_r} - \sum\limits_{j:(j,i)\in E} x_{ji}^{k_r} = -1, \text{if } i^{th} \text{ is router-receiver.} \end{cases} \quad (1)$$

The system (1) must be satisfied for each packet flow. In addition, in order to prevent overload of links it is important to fulfill the conditions

$$\sum_{r\in M_r}\sum_{k_r\in K} \lambda^{k_r}\cdot x_{ij}^{k_r} \le \varphi_{ij}. \quad (2)$$

It should be imposed boundaries to the route variables

$$0 \le x_{ij}^{k_r} \le 1. \quad (3)$$

The Eqs. (1)-(3) can be represented in vector-matrix form

$$A_r \cdot \vec{x}_r = \vec{a}_r, \quad (4)$$

$$B_r \cdot \vec{x}_r \le \sum_{\substack{s\in M\\ s\ne r}} C_{rs}\vec{x}_s, \quad (5)$$

where $\vec{x}_r$ is vector which coordination is variable equals $x_{ij}^{k_r}$.

As the criterion of the optimality for calculation of the vector $\vec{x}_r$ can be chosen the minimum of next objective function:

$$\min F,$$
$$F = \sum_{r\in M_r} \vec{x}_r^t H_r \vec{x}_r, \quad (6)$$

where H_r is diagonal matrix, which coordinates are metric of the links, $[\,]^t$ – transpose function of the vector (matrix).

III. Method of Hierarchical Routing with Coordination

To solve the optimization problem which was formulated, it is used coordination method [4]. Application of the objective function will allow minimizing the using of link resource. This method allows to organize multipath routing with consistent inclusion of the most productive routes if the one that already in use is overloading.

Taking the unconditioned extremum problem, it is necessary to maximize the Lagrangian by the Lagrange multipliers:

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

$$L = \sum_{r\in M_r} \vec{x}_r^t H_r \vec{x}_r + \sum_{r\in M_r} \mu_r^t \Big(B_r \cdot \vec{x}_r - \sum_{\substack{s\in M\\ s\neq r}} C_{rs}\vec{x}_s\Big). \qquad (7)$$

Using this method the Lagrangian (7) can be represented as:

$$L = \sum_{r\in M_r} \vec{x}_r^t H_r \vec{x}_r + \sum_{r\in M_r} \mu_r^t (B_r \cdot \vec{x}_r) - \sum_{r\in M_r} \mu_r^t \sum_{\substack{s\in M\\ s\neq r}} C_{rs}\vec{x}_s. \qquad (8)$$

Supposing that the values μ_r are fixed, (8) takes the form

$$L = \sum_{r\in M_r} L_r \qquad (9)$$

where $L_r = \vec{x}_r^t H_r \vec{x}_r + \mu_r^t (B_r \cdot \vec{x}_r) - \sum_{\substack{s\in M\\ s\neq r}} \mu_s^t C_{rs}\vec{x}_s.$

Thus, the function (9) takes the separable form. The general routing problem was decomposed into a number of routing tasks. The task of maximizing (7) defines the lower level of calculations. It is carried out a modification of Lagrange multipliers on the upper level, whose main task is to coordinate the solutions obtained from the lower level to prevent overload of the transmission network paths (2). Gradient procedure for modification of Lagrange multipliers is

$$\mu_r(\alpha+1) = \mu_r(\alpha) + \nabla\mu_r, \qquad (10)$$

where $\nabla\mu_r$ is the gradient of the function calculated from the results of calculation routing tasks in each router-sender which was obtained at the upper level

$$\nabla\mu_r(x)\Big|_{x=x^*} = B_r \cdot \vec{x}_s^* - \sum_{\substack{s\in M\\ s\neq r}} C_{rs}\vec{x}_s^*. \qquad (11)$$

Visually the computational structure of two-level hierarchical method of coordination routing has been shown in Fig. 1.

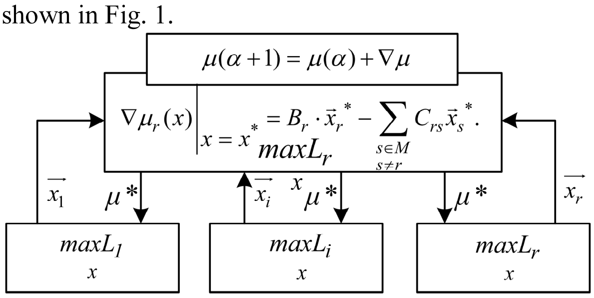

Fig. 1. Computational structure of two-level hierarchical method of coordination routing

IV. The Increasing Convergence of Coordination Procedure

Under this method the number of iterations determines the inertia of the control and service traffic volume. Therefore it is important to minimize the number of iterations in the calculations [5].

To improve the convergence of the coordination procedure let's consider the effect of the link's metric on a quantitative result of convergence of hierarchical routing. In order to avoid an overload of links which are remote from the source (destination) let's use a principle of metric's changing.

$$M_i^* = M_i^n + q \cdot p_i,$$
$$p_i = \min(hop_i^s, hop_i^d) - 1; \qquad (12)$$

where M_i^n – i^{th} link's nominal metric; q – the coefficient of changing; hop_i^s – a number of transit routers between the router-source and i^{th} link; hop^d – a number of transit routers between the destination router and i^{th} link.

The metric of i^{th} link changes depending on the number of transit nodes between source (destination) and i^{th} link. Directly connected to the router-source (destination) links are with nominal metric.

Visually the principle of metric's changing has been shown in Fig. 2.

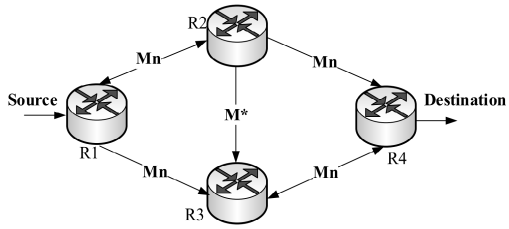

Fig. 2. The changing of metric depending on the number of transit nodes

However, if the source and destination node will be other routers on the network that's why metric of other links has to be change.

V. Research of Method of Hierarchical Routing with Coordination

In research work structures of network with variable numbers of nodes and links were considered to analyze the factors which influence to the convergence of the coordination method's rate [3]. Also the number of flows and their rates has been varied. Let's consider a variation of network has been shown in Fig.3 more detail. Network consists of 4 nodes and 5 links. Bandwidth of links is shown on links (1/s). The number of flows equaled two.

If some links are overloaded there is a coordination of solutions on the upper level of hierarchical routing model. Therefore, routers need to recalculate routes with considering coordinating solutions coming from the upper level. The number of the coordinator's actions to modify the Lagrange multiplier is the number of iterations. It depends on the the packets flow's rate. This dependence was calculated in research [3].

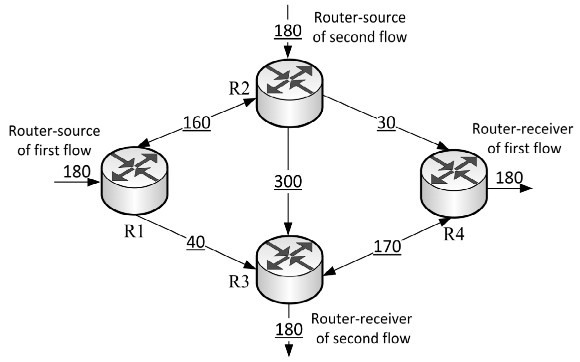

Fig. 3. Structure of network were considered in research

Visually dependence of the iteration number on transmitted packets flows rates has been shown in Fig. 4.

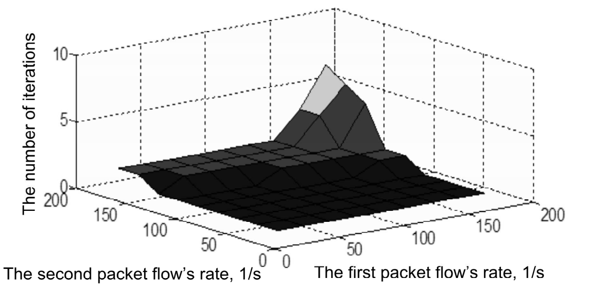

Fig. 4. The dependence of the number of iterations on transmitted packet flows rate

Fig. 4 shows that the method converges in first iteration if sum of flows rates is less than 200 1/s. This means that there are no overloading links. But if it is an increasing of packets flows rate there is the overload of links and method converges more than one iteration. Maximum number of the coordinator actions is on of packets flows rate equals 180 1/s. It is 7 iterations.

More details distribution of flows through the links is represents on Fig. 5, Fig. 6, Fig. 7. The initial distribution of flows is represented on Fig. 5.

Fig. 5 shows the distribution of flows equal 180 1/s from each router-sender. On links there are (from top to bottom) share of the packets flow rate from first source (1/s), share of the packets flow rate from second source (1/s), bandwidth of the link(1/s).

When source transmits the packets flow through links it does not know about transmitting from another source. It tends to take all the bandwidth of the link.

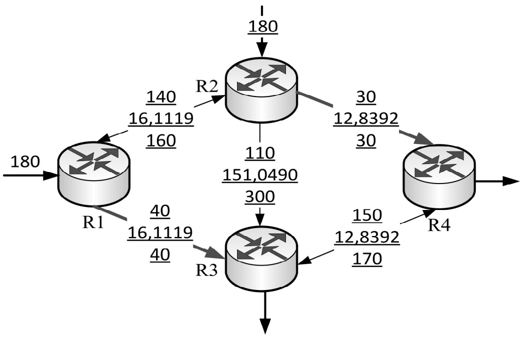

Fig. 5. The initial distribution of intensities

So, there is an overload of two links. They are the link between routers R1 and R3 and link between routers R2 and R4. In order to prevent the repetition of overload of links results of each source's calculations are going to the coordinator where they have analyzed and coordinated. The distribution of packets flows intensities after fourth iteration is represented on Fig.6.

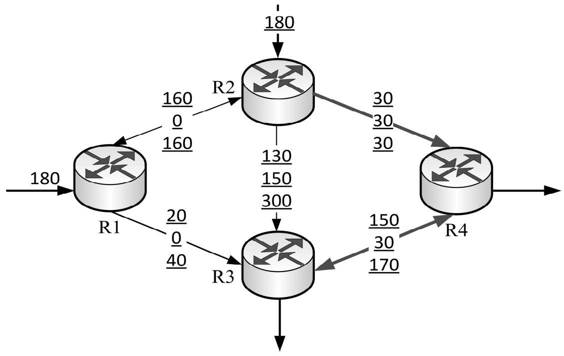

Fig. 6. Distribution of flows after fourth iteration

Fig. 6 shows the distribution of flows after fourth iteration. The distribution of flows has changed after fourth iteration. Link between routers R1 and R3 which has been overload in initial calculation are not overload after fourth iteration. But there is an overload other links. They are the link between routers R2 and R4 and link between routers R3 and R4. The final (after seventh iteration) distribution of packets flows is represented on Fig. 7.

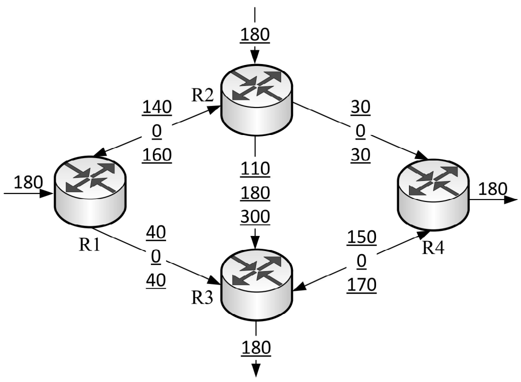

Fig. 7. The final distribution of flows (after seventh iteration)

After seventh iteration there is no overload of links because it is the coordinated distribution of intensity.

To improve quantitative result of convergence of hierarchical routing let's consider the effect of the link's metric on network which is represented on Fig. 3. Since the transmission of packets flows takes place simultaneously from two sources each source will have a different change of the metric. For the first source changing of metric visually has been shown in Fig. 2. For the second source changing of metric visually has been shown in Fig. 8.

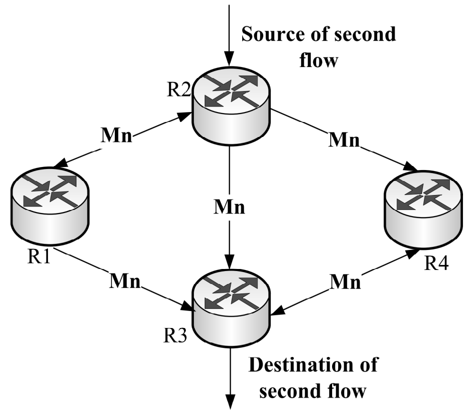

Fig. 8. The changing of metric depending on the number of transit nodes for the second source

Let's see whether the metric of links influences on the number of iterations. For clarity the coefficient of changing q equals 100. Fig. 9 shows the dependence of the iteration number on intensities of transmitted packets flows with changing metric of links. The changing of metric of links greatly influenced on the speed of the method's convergence. The Fig. 9 shows the improvement of the efficiency of the hierarchical routing coordination.

During the investigation of flow's distribution throw network links with changing metric it was observed that the initial distribution is the same as in the network without changing metric. Analogously the final distribution of the flow (after seventh iteration) is the same as final distribution of the flow throw links with changing of metric.

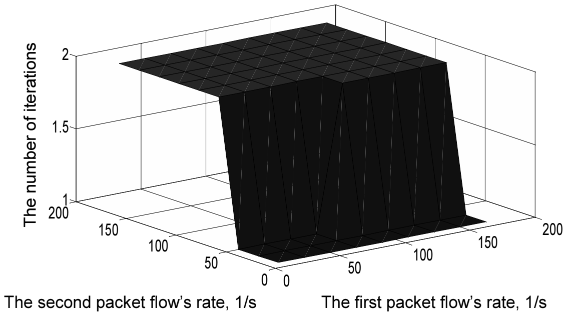

Fig. 9. The dependence of the number of iteration on transmitted packets flows rate

VI. Conclusion

There was study of two-level routing's with coordination convergence. The direct link between the convergence of the method of hierarchical routing and the intensity of transmitted packet's flows was investigated and shown on Fig. 3. There isn't overload if network utilization less than 0,5 and therefore the number of iterations is equal to 1. The increasing intensity leads to growth of the number of iterations. If network utilization is by 0,55 or more the number of coordinating iterations nonlinearly increases due to an overload of communication links. Thus routing method convergence occurs only in 3-7 iterations.

It was also investigated the dependence of the quantitative results of convergence on the metric of links. The quantitative result coordinating procedure has been improved a half to three times depending on the network load. Maximum number of iterations is two. Reducing the number of coordinating iterations positively influences on the performance of the network. Reducing iterations leads to increased efficiency and reduces the amount of control traffic.

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