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Analysis of Hierarchical Routing Models

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Abstract

In this study, flow-based routing model is investigated. The aim of this study is to increase scalability of flow control, routing and network resources solutions, as well as to improve Quality of Service and performance of the whole system. A method of hierarchical routing is proposed. The goal coordination method a l s o used in this paper. Two routing models (model with quadratic objective function and model with traffic engineering) were fully analyzed. The basic functions of the hierarchical routing model levels based on goal coordination method were addressed Both models' convergence is also explained. The dependence of the coordination iterations number on the packet flow rates for both models is graphically shown. The results shows that the method of efficiency is improved by increasing the link metric. Applying the proposed method can improve the scalability of routing decisions in the telecommunication network. Additionally, the proposed method can reduce the number of iterations in the implementation of hierarchical routing, and reduce the service traffic volume in the network.

Keywords: Routing models, Goal coordination method, Traffic engineering, Number of iterations, Quadratic objective function.

تحليل موديلات التوجيه الهرمي في الشبكة

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الخلاصة

في هذه الدراسة تم بحث نموذج التدفق القائم على تحديد المسار.إن الهدف من هذه الدراسة هو لتوسيع قابلية التحكم بالتدفق والتوجيه وحلول مصادر الشبكة ولتحسين نوعية الخدمة والأداء للنظام بأكمله .وتم اقتراح طريقة التوجيه الهرمي، و استخدمت طريقة تنسيق الهدف، كما تم تحليل وبشكل كامل نموذجين من التوجيه ،نموذجا لوظيفة الموضوع التربيعي وآخر لهندسة المرور. إن الوظائف الأساسية لمستويات نموذج التوجيه الهرمي التي تعتمد على طريقة تنسيق الهدف ،قد وجهت لكلا النموذجين وتم توضيح التقارب،وتم اظهار وبشكل بياني ،تنسيق عدد التكرارات القائم على معدلات تدفق الحزم لكلا النموذجين.كما تضمنت هذه الدراسة اقتراحا لطريقة تحسين الكفاءة من خلال زيادة معايير الرابط في الشبكة،حيث يمكن لهذه الطريقة المقترحة أن تحسن من قابلية قرارات التوجيه في شبكات الاتصالات اللاسلكية .فضلا عن ذلك ، يمكن للطريقة المقترحة ان تقلل من عدد التكرارات في عملية تطبيق التوجيه الهرمي وكذلك تقليل حجم خدمة المرور في الشبكة.

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1- Introduction

Today telecommunication networks are rapidly evolving and becoming a focal point for modern researches. These researches are aimed at ensuring the better levels of quality of service in telecommunication network and increasing the scalability of routing decisions [1,2].

The hierarchical structure of telecommunication network is dictated by the need of improving reliability, quality of service and overall system performance. A distinctive feature of the hierarchical structure in telecommunication network is the presence of multiple sources, i.e. the calculation of routes occurs on multiple routers. Consequently, minimizing overloads and packet loss in the network would require the decomposition of routing problems into a number of smaller tasks. However, this solution causes other problems, for example increasing of networks' service traffic, which in turn leads to undesired delays. To ensure scalability, we used the model for hierarchical routing.

2. Model of Hierarchical Routing

In order to describe structural features of telecommunication network Figure-1 a graph $G=(M,E)$ is used as set of vertices M represents the routers.

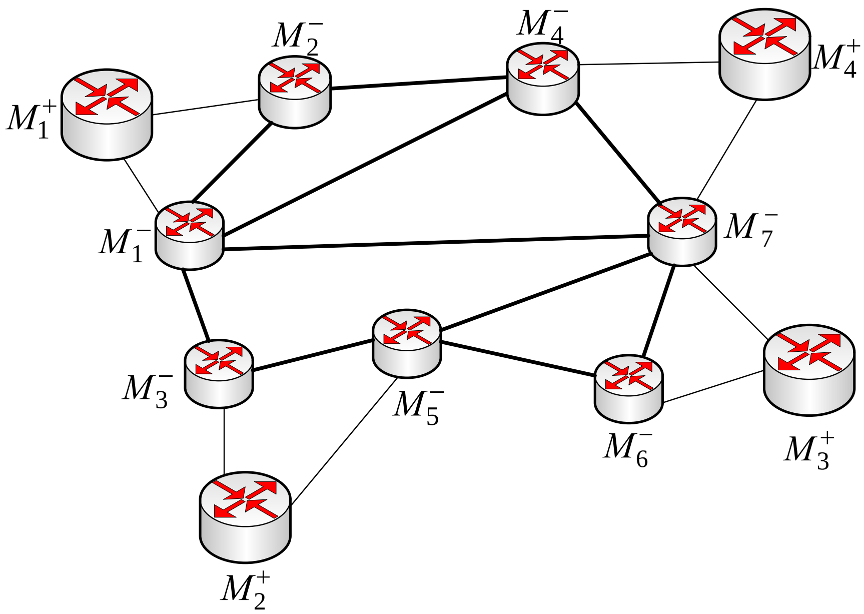

Figure 1- Example of telecommunication network

Set of edges E represents links between routers. The whole set of routers can be divided into two subsets. $M^+=\{M_r^+, r=\overline{1,m_+}\}$ is subset of border routers (Label Edge Router, LER). Whereas $M^-=\{M_r^-, r=\overline{1,m_-}\}$ is subset of transit routers. Variable φ_{ij} is the capacity of the link $(i,j)\in E$. To solve the routing problem in telecommunication network we need to use the definition of a control variable $x_{ij}^{k_r}$ which contain portion of packet flow transmitted from source to destination along link $(i,j)\in E$. Variable k_r is packet flow that is arriving through r^{th} LER to the network. Variable λ^{k_r} is the rate of k_r flow.

In the proposed model it is necessary to provide the flow conservation condition [2-7]:

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

The system (1) must be satisfied for each packet flow. The multipath routing can be realized [3-6]:

$$0 \le x_{ij}^{k_r} \le 1. \quad (2)$$

The conditions (1) can be represented in vector-matrix form

$$\mathrm{A_r}\vec{\mathrm{x}}_{\mathrm{r}} = \vec{\mathrm{a}}_{\mathrm{r}}, \quad (3)$$

where $\vec{x}_r$ is a vector whose coordinates are control variables $x_{ij}^{k_r}$; A_r is matric formed according to condition (1), $\vec{a}_r$ is vector formed according to condition (1).

2.1 Decomposed representation of hierarchical routing model with quadratic objective function

In addition, to prevent overload in the links it is important to fulfill the conditions

$$\sum_{r\in M_r} \sum_{k_r \in K} \lambda^{k_r} \cdot x_{ij}^{k_r} \le \varphi_{ij}. \quad (4)$$

Condition (4) oriented to the centralized routing while all variables $x_{ij}^{k_r}$ ($r \in M$, $(i, j) \in E$) are defined on unified routes server. In implementing of hierarchical routing, (4) takes the following form [6,7]:

$$\sum_{k_r \in K_r} \lambda^{k_r} x_{ij}^{k_r} \le \varphi_{ij} - \sum_{\substack{s\in M^+ \\ s\ne r}} \sum_{k_s \in K_s} \lambda^{k_s} x_{ij}^{k_s}. \quad (5)$$

The conditions (4) can be represented in vector-matrix form

$$B_r\vec{x}_r \le \sum_{\substack{s\in M^+ \\ s\ne r}} C_{rs}\vec{x}_s, \quad (6)$$

where $\vec{x}_r$ is a vector which coordinates are control variables $x_{ij}^{k_r}$; $\vec{x}_s$ is a vector which coordinates are control variables $x_{ij}^{k_s}$; B_r, C_{rs} are matrices which were formed according to condition (4).

During the calculation of variables x_{ij}^{k} while solving the problem of routing in network it is reasonable to minimize the following objective function

$$\min \mathrm{F} = \sum_{\mathrm{r}\in \mathrm{M}^+} \vec{\mathrm{x}}_{\mathrm{r}}^{\mathrm{t}} \mathrm{H}_{\mathrm{r}} \vec{\mathrm{x}}_{\mathrm{r}}, \quad (7)$$

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

To solve the optimization problem which was formulated, we used goal coordination method [7]. Applying goal coordination method will allow minimizing the using of link resource. Then turning to the problem of an unconditional extremum

$$\min_{x} F = \max_{\mu} L,$$

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

Using this method the Lagrangian (8) can be represented as:

$$L = \sum_{r \in M^+} \vec{x}_r^t H_r \vec{x}_r + \sum_{r \in M^+} \mu_r^t (B_r \cdot \vec{x}_r) - \sum_{r \in M^+} \mu_r^t \sum_{\substack{s \in M^+ \\ s \neq r}} C_{rs} \vec{x}_s. \quad (9)$$

Supposing that the values μ_r are fixed, (9) takes the form

$$L = \sum_{r \in M^+} L_r \quad (10)$$

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

2.2 Decomposed representation of hierarchical routing model with load balancing

The model with load balancing is used in order to prevent overload of links where the model must fulfilled the condition:

$$\sum_{r \in M^+} \sum_{k_r \in K} \lambda^{k_r} x_{ij}^{k_r} \le \alpha \varphi_{ij}, \quad (11)$$

where α - upper border threshold of link resource utilization in load balancing.

Condition (11) oriented to the centralized routing while all variables $x_{ij}^{k_r}$ $(r \in M,\ (i, j) \in E)$ are defined on unified routes server. In implementing of hierarchical routing, (11) takes the following form:

$$\sum_{k_r \in K_r} \lambda^{k_r} x_{ij}^{k_r} \le \varphi_{ij} \alpha_r - \sum_{\substack{s \in M^+ \\ s \neq r}} \sum_{k_s \in K_s} \lambda^{k_s} x_{ij}^{k_s} \quad (12)$$

where $\sum_{r \in M^+} \alpha_r = \alpha.$

During the calculation of variables x_{ij}^{k} while solving the problem of routing in the network it is reasonable to minimize the following objective function

$$F = \sum_{r \in M^+} \alpha_r. \quad (13)$$

In order to solve the optimization problem which was formulated, we used goal coordination method [7]. Applying goal coordination method will allow the minimization of using the of link resource. Then turning to the problem of an unconditional extremum

$$\min_{\vec{x}, \alpha_r} F = \max_{\mu} L,$$

where

$$L = \sum_{r \in M^+} L_r, \quad (14)$$

$$L_r = \alpha_r + \mu_r^t (B_r \vec{x}_r) - \sum_{\substack{s \in M^+ \\ s \neq r}} \mu_s^t C_{rs} \vec{x}_s. \quad (15)$$

The Lagrangians (8) and (15) takes the separable form. The general routing problem was decomposed into a number of routing tasks (according to the number of border routers). Optimization is realized by the two-level scheme [3]-[6]. The task of minimizing (8) and (15) defines the lower level of calculations. The main task of upper level is to coordinate the solutions obtained from the lower level also to prevent overload of links (4) and (11) (for both models) and packet loss. Either router or the separate server can serve as a coordinator.

On the upper-level Lagrange multipliers are modified using following expression:

$$\mu_r(n+1) = \mu_r(n) + \nabla\mu_r, \quad (16)$$

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

$$\nabla\mu_r(x)\Big|_{x=x^*} = B_r\vec{x}_s^* - \sum_{\substack{s\in M^+ \\ s\neq r}} C_{rs}\vec{x}_s^*. \quad (17)$$

Visually the hierarchy of routing tasks can be represented as in Figure-2.
The coordinator modifies the gradient of the function (17) in case of overload thus increases the value of the Lagrange multipliers vector (16), i.e. to the value of the Lagrange multipliers vector at the previous iteration is added the changed value of the gradient function (17). Then coordinator sends new values to routers. Routers take into account the Lagrange multipliers vector modifying in the construction of new outing tables. Recalculation of routings variables occurs until there is no problem of link overload.

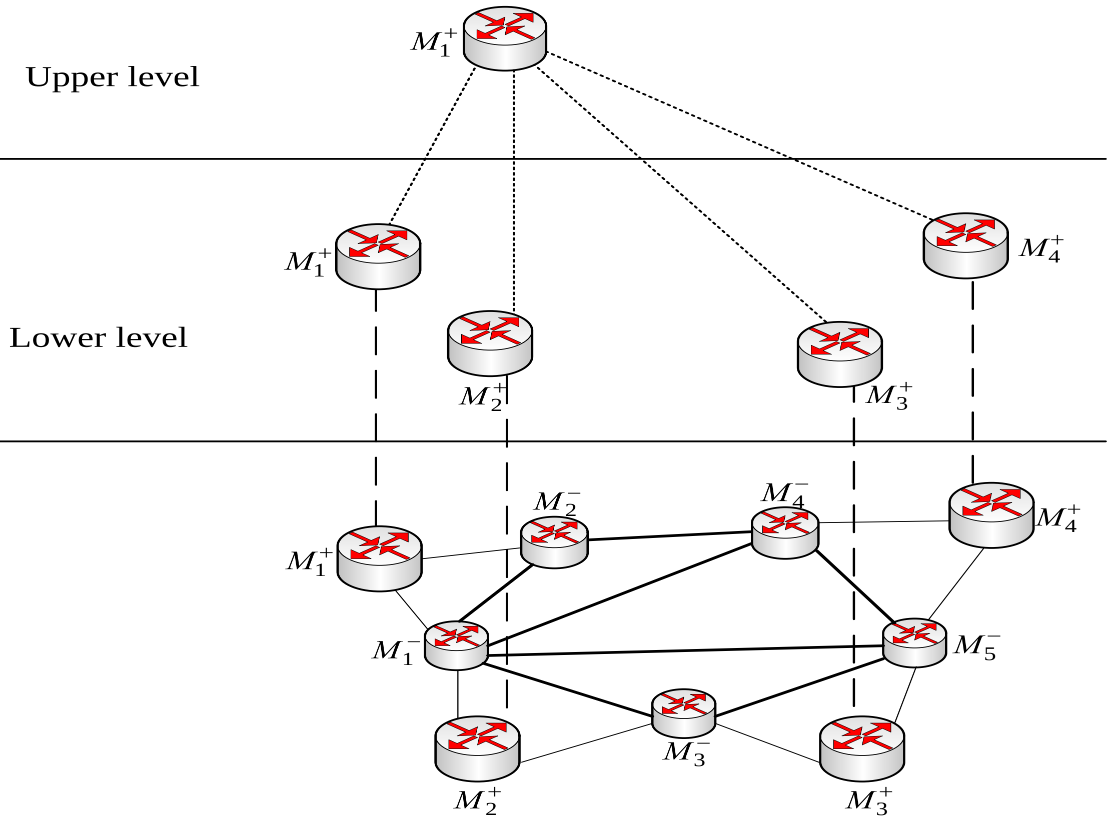

Figure 2 - The hierarchy of routing tasks

3.1 Research of the of hierarchical routing model with quadratic objective function

In this research work a number of network structures with variable numbers of nodes and links were considered to analyze the factors which influence on the convergence of the coordination method [6]. For example let us consider the network structure shown in Figure-3.

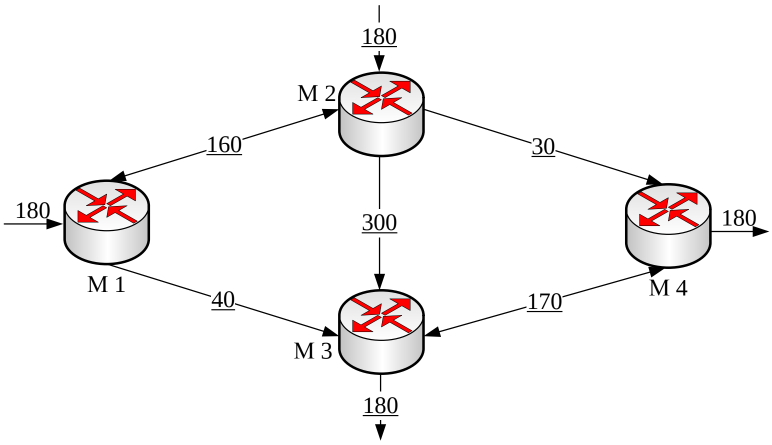

Figure 3 - Structure of telecommunication network

The network consists of four nodes (routers) ($M1 \div M4$) and five links with the bandwidth (packet per second, 1/s) shown on the graph arcs. The dependence of the number of iterations (10) on flow rates was set during the research. The number of flows equaled two. The router-source of first flow is first router. The router-receiver of first flow is fourth router. Second flow transmitted from second router to the third router. The maximum flow rate from each source was 180 1/s, because if flow rates are more than 200 1/s there is a link overload. The dependence of the number of iterations on flow rates is shown on Figure-4.

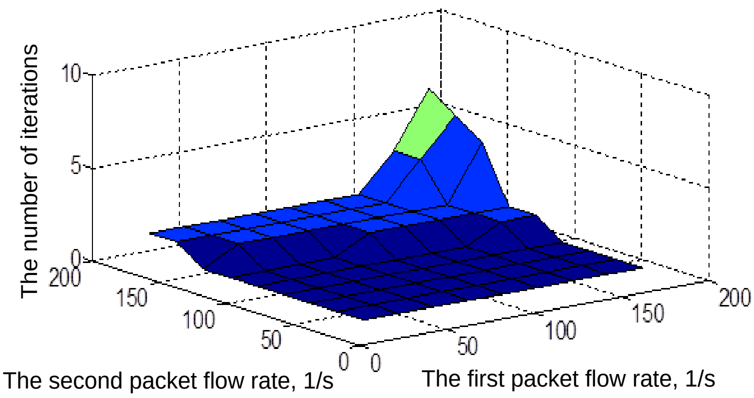

Figure 4 - The dependence of the number of iterations on the flow rates

Figure 4 shows that the method converges in the first iteration if the sum of flow rates is less than 200 1/s. This means that there is no link overload. But when the sum of the flow rates more than 200 1/s there is the link overload and method converges after more than one iteration. Maximum number of coordination iterations is 7 when packets flow rates equals 180 1/s. Thus the flow rate influence on the convergence of this two-level routing method.

Now we will increase the number of nodes and links for research influence of network dimension on convergence of method. Let's use the structure of telecommunication network which represented on Figure-5 for research.

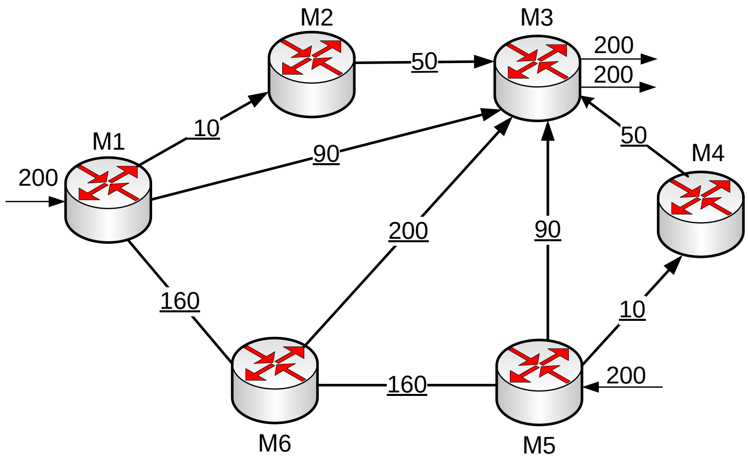

Figure 5- Example of telecommunication network

The network consists of six nodes (routers) ($M1 \div M6$) and nine links with the bandwidth (packet per second, 1/s), shown on the graph arcs. The dependence of the number of iterations (10) on the flow rates was set during the research. The number of flows equal two. The router-source of the first flow is first router. The router-receiver of the first flow is the third router. The second flow transmitted from fifth router to the third router. Maximum flow rate from each source was 200 1 / s. The dependence of the number of iterations on the flow rates is shown on Figure-6.

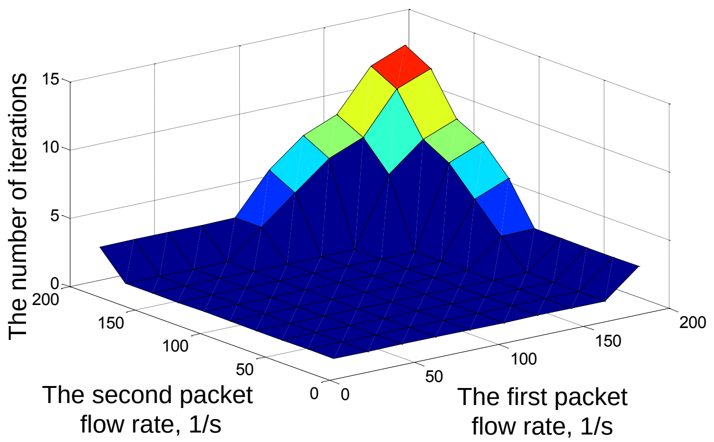

Figure 6 - The dependence of the number of iterations on flow rates

Figure-6 shows that when the network load is 50% there is no link overload. This means that the method converges at the first iteration. However, the number of iterations significantly increases when the network load is more than 50%. The maximum number of iterations is 13 when the flow rates are equal to 200 1 / s.

Let's use the structure of telecommunication network Figure-7 for research. Let's increase number of links in network. The network consists of six routers and eleven links with the (packets per second, 1/s) are shown on the graph arcs. The dependence of the number of iterations (10) on flow rates was set during the research. The number of flows equaled two. First flow transmitted from the first router to the third router. Second flow transmitted from fifth router to the third router. The maximum flow rate from each source was 200 1 / s.

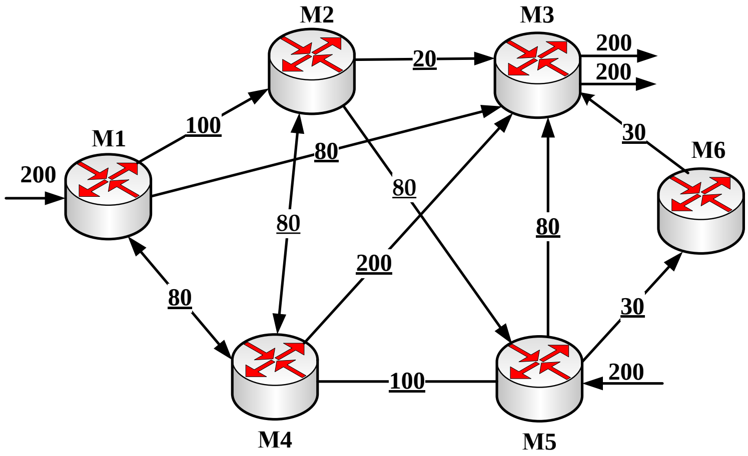

Figure 7- Example of telecommunication network

The dependence of the number of iterations on flow rates is shown on Figure-8.

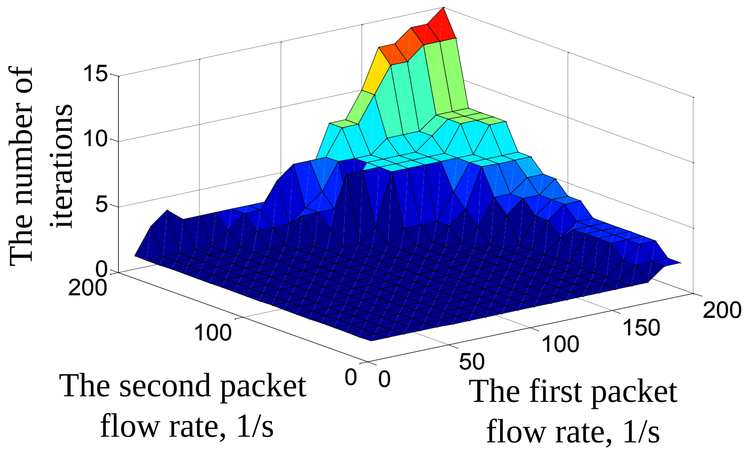

Figure 8- The dependence of the number of iterations on flow rates

Figure-8 shows that when the network load is less than 50% there are no overloaded links. This means that the method converges at first iteration. However, the number of iterations significantly increases when the network load is more than 50%. The maximum number of iterations is 15 when the flow rates are equal to 200 1 / s.

3.2 Reduce number of iterations

The optimal solutions are obtained by aspiration of the gradient (17) to zero. The major factors influencing on the number of iteration increase were defined. Increasing of the coordination iteration number leads to a proportional increase of the service traffic volume and the time of solutions routing problems. Therefor it's necessary to ensure the minimization of coordination iterations number without reducing the proposed solutions effectiveness [6]. That is why, in this work, we propose for each packet flow to provide an increase of link metric usage proportional to the distance (the number of nodes) of these links to the corresponding router-sender or router-receiver:

$$M_i^* = M_i^n + q \cdot p_i, \qquad p_i = \min(hop_i^s, hop_i^d) - 1, \tag{18}$$

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-sender and i^{th} link; hop^d – a number of transit routers between the router-receiver and i^{th} link.

Using the expression (18) in the framework of hierarchical routing model with goal coordination method, the dependence of the number of iterations on the packet flow rates was also researched. For telecommunication network structure which represented in Figure- 3 the dependence of the number of iterations on the flow rates is shown in Figure-9.

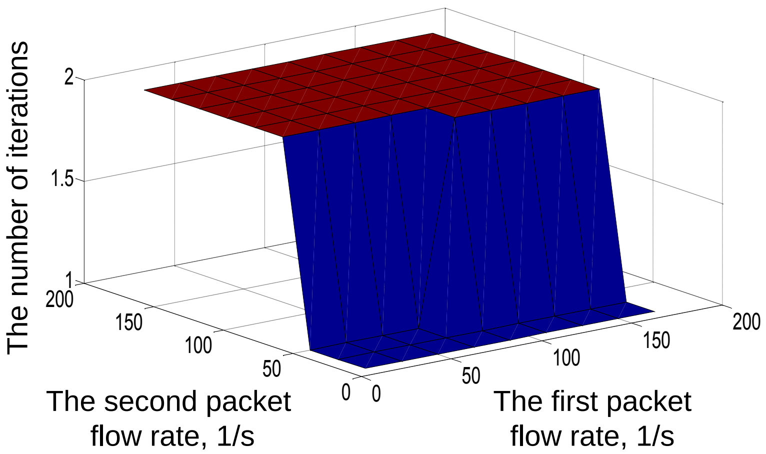

Figure 9 -The dependence of the number of iterations on the flow rates for telecommunication network structure which represented in Figure- 3.

Figure-9 shows that maximum number of iterations (after using condition 18) equals two. This value is 6 times less than the number without using the expression 18 Figure-4. For telecommunication network structure which represented in Figure-5 the dependence of the number of iterations on flow rates is shown in Figure-10.

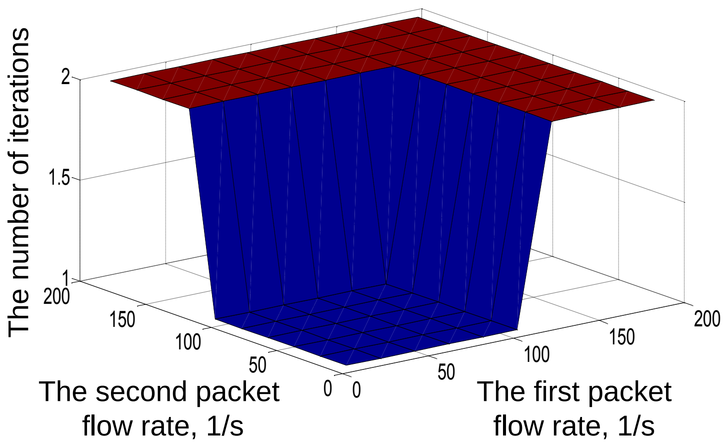

Figure 10 - The dependence of the number of iterations on the flow rates for telecommunication network structure which represented in Figure-5

Figure-11shows that maximum number of iterations(after using condition 18)equals two This value is 4 times less than the maximum number without using the expression18 Figure-6.

For telecommunication network structure which represented in Figure-8 the dependence of the number of iterations on the flow rates is shown in Figure-11.

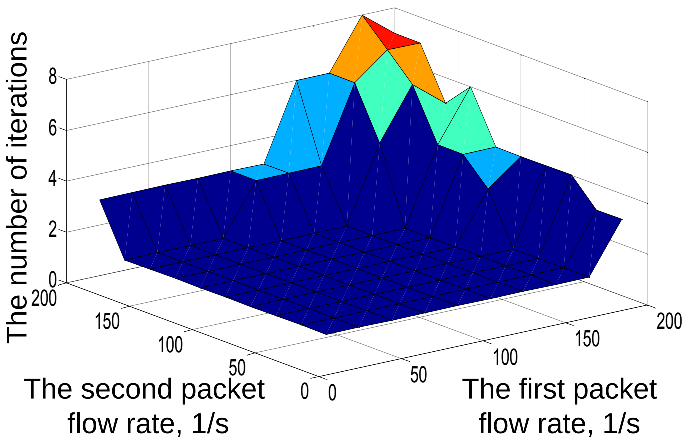

Figure 11- The dependence of the number of iterations on flow rates for telecommunication network structure which represented in Figure- 8

Figure-11 shows that maximum number of iterations (after using condition 18) equals two. This value is 3 times less than the maximum number without using the expression 18 Figure-9.
Thus, it can be concluded that using condition 18 allows increasing the number of coordination iterations from 2 to 6 times according to the packet flow rate, network load, dimension and connectivity.

3.3 Research of the hierarchical routing model with load balancing

The research of hierarchical routing model with load balancing (11) -(15) performed for networks structures with a variable number of nodes (routers) and links. For example, let us consider the network structure shown in Figure-5.

Dependence of the number of iterations on the flow rates is shown on Figure- 6. The network consists of six nodes (routers) ($M1 \div M6$) and nine links with the bandwidth (packet per second, 1/s) are shown on the graph arcs. The number of flows equals two.

The source node for the first flow is the first router ($M1$). Destination node for the first flow is third router ($M3$). The source node for second flow is fifth router ($M5$). Destination node for the first flow is the third router ($M3$). The maximum flow rate from each source was 200 1 / s.

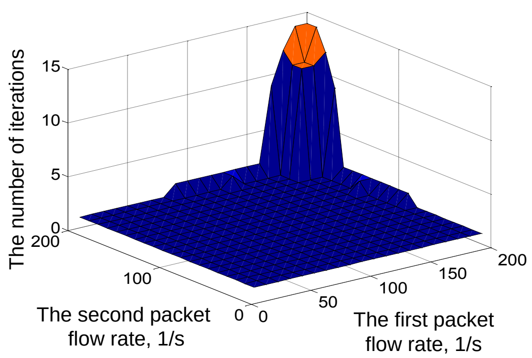

Figure 12- The dependence of the number of iterations on the flow rates for model (11) -(15)

Figure-12, shows that when the network load is 90% there is no link overload. This means that the method converges at first iteration. However, the number of iterations significantly increases when the network load is close to the maximum. The maximum number of iterations is 9 when the flow rates are equal to 200 1 / s from each router sender. For the second telecommunication network which structure represent in Figure-7, the dependence of the number of iterations on the flow rates is visually shown on Figure-13.

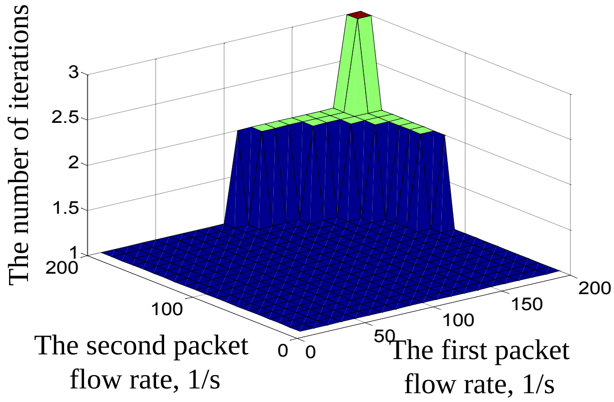

Figure 12 - The dependence of the number of iterations on the flow rates for model (11) -(15) for structure of telecommunication network Figure-7.

The network consists 6 routers and 11 links. Bandwidth of links is shown on links (1/s). The number of flows equals two. The first flow transmitted from the first router to the third one. The second flow transmitted from the fifth router to the third router. The maximum flow rate from each source was 200 1 / s.

Figure-13 shows that if the network loads less than 90% there are no overload links. However, the number of iterations significantly increases when the network load is close to the maximum. The maximum number of iterations is 3 when the flow rates are equal to 200 1 / s.

The comparative analysis for the three models is represented in Table-1.

Table 1- Dependence of the number of iterations on packet flow rates for telecommunication network structure which represented on Figure-7

№ of calculation	First packet flow rate, 1/s	Second packet flow rate, 1/c	The number of iterations in model (4) -(10)	The number of iterations using (18)	The number of iterations in model (11) -(15)
1	20	20	1	1	1
2	40	20	1	1	1
…	…	…	…	…	…
10	200	20	3	1	1
…	…		…	…	…
57	140	180	7	3	1
58	140	200	8	3	1
…	…	…	…		…
92	200	40	3	1	1
93	200	60	3	1	1
…	…	…	…		…
98	200	160	9	6	2
99	200	180	12	7	2
100	200	200	13	8	3

Conclusion

In this work, the convergence of hierarchical routing based on goal coordination method was studied. The study considered two models, The first model with quadratic objective function (4)-(10), and the second model with load balancing (11)-(15). The research of model with quadratic objective function revealed that this model is effective only when the network load is small (less than 50%). When the network load is more than 50%, the number of coordination iterations increase, therefor the service traffic volume increases too.

That is why for iterations number decreasing, the method (18) was represented. After using method (18) when network load over 50% the number of iterations is less 3-5 times depending on packet flow rates. But when the method is applied on large networks Figure- 7 the maximum number of iterations is equal 8 Table- 1 which is considerably a big number comparing to the average iterations. That is why in this paper the model with load balancing was considered. Using this model (11) -(15) was able to reduce maximum number of iterations to 3 Table- 1. Thus, depending on the size and connectivity of the networks should choose routing model (18) or routing model with load balancing (11) -(15) for more efficient packer flow transmission through the links.

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