Flow-based Model of Hierarchical Multicast Routing

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***Abstract* — In this paper the flow-based model of multicast routing was researched. To improve the scalability of the network the hierarchical approach of the network is used because usage of centralized schemes is very resource-intensive. Due to disagreement of solutions obtained on routers and thus appearance of the link overloading and the subsequent package lost we proposed to use the goal coordination method. The usage of this method allows distributing flows through links without its overloading and improving quality of service and increasing the efficiency of network management.**

Keywords — flow-based model; multicast; routing; the goal coordination method; multicast tree.

I. Introduction

Multimedia applications will become more and more important and popular in the future networks. Several emerging applications of the current and next generation Internet, e.g. IP radio, IP TV, and video and audio conferencing, etc., involve one-to-many and many-to-many data communications called multicasting [1], [2]. Multicast routing requires some distribution tree rather than a simple point-to-point path through the network. Currently, in practice set of protocols of multicast routing, e.g., DVMRP (Distance Vector Multicast Routing Protocol), Multicast Extensions to OSPF (MOSPF), PIM (Protocol Independent Multicast), etc. [3] is widely used. For the successful provision of certain services in the data transmission it is necessary to carry out additional requirements on the transmission parameters. Such requirements are the requirements of quality of service, or QoS-requirements. The problem of QoS-based hierarchical multicast routing has not been addressed to date. Thus in this paper we propose an approach to solve this problem through the use of the flow-based model of hierarchy.

II. Flow-based Model of Multicast Routing

Let us describe a network structure as oriented graph $G=(M,E)$, where M is a set of vertices – nodes (routers) of the network E is a set of graph arcs modeling network links. For each link $(i,j)\in E$ ((i,j): link goes from *i* to *j*), the bandwidth $\varphi_{(i,j)}$ which measured in packet per second (1/s) is specified.

Solving the problem of multicast routing it is necessary to calculate the set of Booleans for every router-sender:

$$x_{ij}^{k_r}\in\{0;1\}, \qquad (1)$$

where k_r is flow entering to network from *r*-th node ($k_r\in K$). λ^{k_r} is k_r-th flow rate.

With each k_r-th flow the set of parameters associated: s_{k_r} is source node (router-sender);

$$d_{k_r}^{*}=\left\{d_{k_r}^{1},d_{k_r}^{2},...,d_{k_r}^{m_{k_r}}\right\} \qquad (2)$$

is set of destination nodes (router-receiver), where m_{k_r} is the number of receivers of k_r-th packet flow[3], [4].

Routing variables (1) are limited by several constraints:

$$\sum_{j:(i,j)\in E}x_{ij}^{k_r}\geq 1 \quad if \quad k\in K, \qquad (3)$$

if i-th router is source node and also

$$\sum_{i:(i,j)\in E}x_{ij}^{k_r}=1 \quad if \quad k\in K, \qquad (4)$$

for destination nodes.

Constraint (3) is introduced to the source node and its implementation directs that flow from that node (incoming to service) will be transmitted to one adjacent node at least. Condition (4) aims to provide packet flow delivery to each destination node and flow should arrive to the node only from one adjacent node.

Each transit node which can be any router, except for the router-sender, is given by the following conditions:

$$\sum_{i:(i,j)\in E}x_{ij}^{k_r}\geq x_{jp}^{k_r} \quad if \quad k_r\in K. \qquad (5)$$

The fulfillment of these conditions allows to have a flow in any link ($(j,p)\in E$) coming from the transit node only in that case when this flow comes on the given node at least via one incoming link ($(i,j)\in E$).

In order to prevent cycle forming conditions added into the proposed model:

$$\sum_{(i,j)\in E_{\pi}^{i}} x_{ij}^{k_r} < \left|E_{\pi}^{i}\right|, \tag{6}$$

where E_{π}^{i} is a set of arcs forming i-th cycle (π) according to their orientation; $\left|E_{\pi}^{i}\right|$ – denotes power of the set E_{π}^{i}. The fulfillment of the condition (6) guarantees that the number of arcs used in multicast routing, composing any cycle is always smaller than the total number of arcs in this cycle [3],[4].

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

$$\sum_{r\in M}\sum_{k_r\in K}\lambda^{k_r} x_{ij}^{k_r} \le \varphi_{ij}\cdot, \quad (i,j)\in E\,. \tag{7}$$

Condition (7) 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, (7) takes the following form [6],[7]:

$$\sum_{k_r\in K_r}\lambda^{k_r} x_{ij}^{k_r} \le \varphi_{ij} - \sum_{\substack{s\in M\\ s\neq r}}\sum_{k_s\in K_s}\lambda^{k_s} x_{ij}^{k_s}\,. \tag{8}$$

The condition (8) can be represented in vector-matrix form

$$B_r\vec{x}_r \le D_r\vec{\varphi} - \sum_{\substack{s\in M\\ s\neq r}} C_{rs}\vec{x}_s, \tag{9}$$

where $\vec{x}_r$ is a vector which coordinates are variables $x_{ij}^{k_r}$; $\vec{\varphi}$ is a vector of links bandwidths with coordinates φ_{ij} ; B_r, D_r, C_{rs}, are matching matrices because the dimension of vectors $\vec{x}_r$ ($r\in M$) and $\vec{\varphi}$, and also the numbering of their coordinates in general may not coincide.

The objective is to minimize

$$\min\ F,$$

$$F = \sum_{r\in M}\vec{x}_r^{t} H_r \vec{x}_r, \tag{10}$$

where H_r is diagonal matrix coordinates of which are metric of the links, $[\cdot]^{t}$ is transpose function of the vector (matrix) [6],[7].

III. Hierarchical Routing Using Goal Coordination Method

To solve the optimization problem which was formulated (related to minimizing (10) with constraints (3)-(8)) we used goal coordination method [5]. Then turning to the problem of an unconditional extremum

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

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

$$L = \sum_{r\in M}\vec{x}_r^{t} H_r\vec{x}_r + \sum_{r\in M}\vec{\mu}_r^{t}(B_r\vec{x}_r - D_r\vec{\varphi} + \sum_{\substack{s\in M\\ s\neq r}} C_{rs}\vec{x}_s), \tag{11}$$

where $\vec{\mu}$ is vector of Lagrange multipliers, and $\vec{\mu}_r$ – is $\vec{\mu}$-th subvectors related to each of the conditions (10).

Using this method the Lagrangian (11) can be represented as:

$$L = \sum_{r\in M} L_r\,, \tag{12}$$

$$L_r = \vec{x}_r^{t} H_r\vec{x}_r + \vec{\mu}_r^{t}(B_r\vec{x}_r - D_r\vec{\varphi} + \sum_{\substack{s\in M\\ s\neq r}}\vec{\mu}_s^{t} C_{sr}\vec{x}_r), \tag{13}$$

supposing that the values $\vec{\mu}_r$ are fixed and formed on upper level of hierarchy.

Thus objective (10) takes a separable form. The general routing problem was decomposed into a number of routing tasks (13). Optimization is realized by the two-level scheme [6],[7]. On the lower level there is a calculation of routers of packet flows transmission through the links by nodes-sources. The main task of upper level is coordinate the solutions obtained from lower level in order to prevent overloading of links (8) by modifying vector of Lagrange multipliers in performing a gradient iterative procedure:

$$\vec{\mu}_r(\alpha+1) = \vec{\mu}_r(\alpha) + \nabla\vec{\mu}_r\,, \tag{14}$$

where α is a number of iteration; $\nabla\vec{\mu}_r$ is a gradient of the function calculated from the results of calculation routing tasks in each router-sender which was obtained at the upper level [6],[7]:

$$\nabla\mu_r(x)\Big|_{x=x^*} = B_r\vec{x}_r^{\,*} - D_r\vec{\varphi} + \sum_{\substack{s\in M\\ s\neq r}} C_{rs}\vec{x}_s^{\,*}\,, \tag{15}$$

where $\vec{x}_r^{\,*}$ ($r\in M$) is a result of solving obtained at the lower level of the hierarchy on the current iteration.

IV. ANALIZYS OF HIERARCHICAL MULTICAST ROUTING

The research of hierarchical multicast routing used proposed flow-based model (1)-(15) performed for networks structures with a variable number of nodes (routers) and links. For example let us consider the network structure shown in Fig.1.

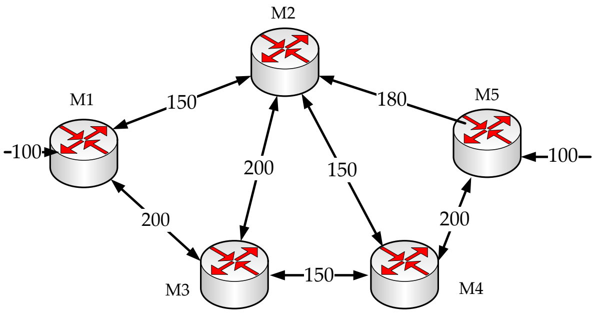

Fig. 1. Network structure

The network consists of five nodes (routers) ($M1 \div M5$) and seven links with the bandwidth (packet per second, 1/s) shown on the graph arcs. The number of flows equaled two. The source node for first flow is first router ($M1$). The source node for second flow is fifth router ($M5$). The flow rates varied from 10 1/s to 100 1/s (if flow rates are more than 100 1/s from each source node there is links overload). Multicast routing requires some distribution tree rather than a simple point-to-point path through the network. The objective of multicast routing algorithms is to construct and maintain the distribution tree, called the multicast tree.

For example let us consider the case when the rate of each flow equals 100 1/s. Fig. 2 shows first flow's multicast tree. On the graph arcs we can see fraction where the numerator is the packet flow rate and the denominator is the link bandwidth.

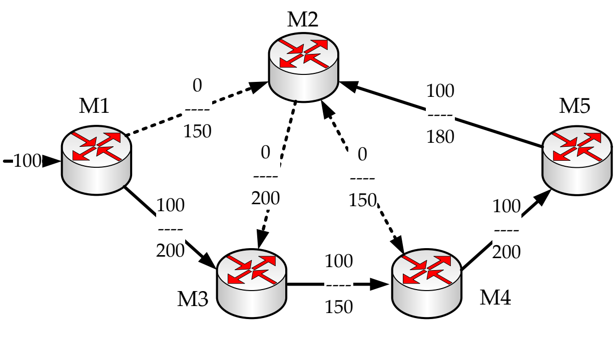

Fig. 2. First flow's multicast tree

In Fig. 2 solid lines are arcs the first flow was transmitted through and dashed lines are arcs the first flow wasn't transmitted through. Fig. 2 shows that first flow was transmitted through more productive links. For example there are two links between routers *M1* and *M2*, and between routers *M1* and *M3* which directly connected with source node. First flow was transmitted though link *M1*÷ *M3* because bandwidth of this link is 200 1/s.

Fig. 3 shows second flow's multicast tree. On the graph arcs we can see fraction where the numerator is the packet flow rate and the denominator is the link bandwidth. In Fig. 3 solid lines are arcs the first flow was transmitted through and dashed lines are arcs the first flow wasn't transmitted through.

Similar to the first flow transmission second flow's source node calculates the multicast tree with the largest link bandwidth. Thus links with lower bandwidth remains unused.

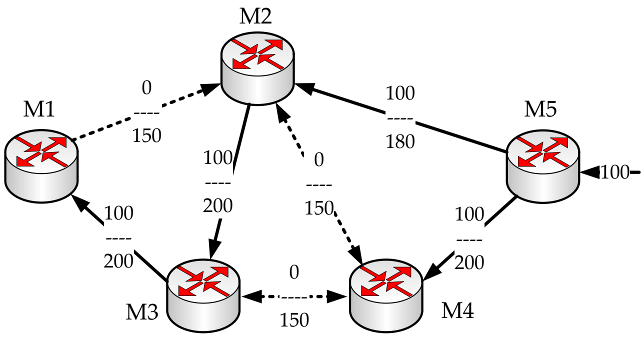

Fig. 3. Second flow's multicast tree

Fig. 4 shows the resulting multicast tree. On the graph arcs we can see fraction where the numerator is the total packet flow rate and the denominator is the link bandwidth. . In Fig. 4 solid lines are arcs the first flow was transmitted through and dashed lines are arcs the first flow wasn't transmitted through.

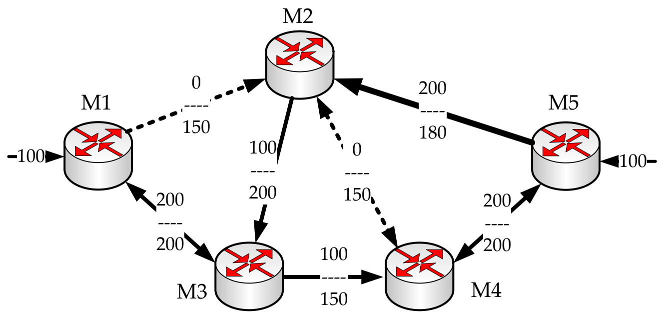

Fig. 4. The resulting multicast tree

Due to disagreement of solutions obtained in the first and fifth source nodes there is an overload of link between routers *M2* and *M5* (Fig. 4). This is explained by the desire of source-nodes use links with larger bandwidth for flows transmission. Thus it is necessary to coordinate routing solutions on upper level of hierarchy (14)-(15) in order to prevent further links overloading.

Fig. 5 shows coordinated solution of the multicast routing for first flow (multicast tree).

On the graph arcs we can see fraction where the numerator is the packet flow rate and the denominator is the link bandwidth.

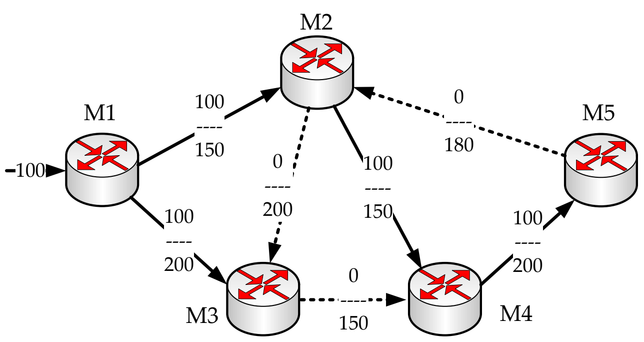

Fig. 5. First flow's coordinated multicast tree

Solid lines are arcs the first flow was transmitted through and dashed lines are arcs the first flow wasn't transmitted through. Fig. 5 shows that the first flow's multicast tree changed and flow transferring through before overloaded link (between routers *M*2 and *M*5) is no longer produced.

Fig. 6 shows coordinated solution of the multicast routing for second flow (multicast tree).

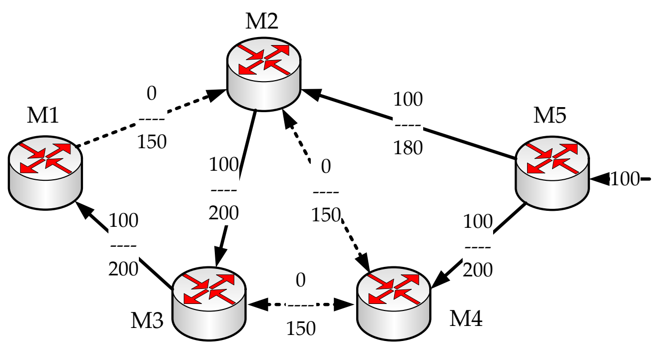

Fig. 6. Second flow's coordinated multicast tree

Fig. 6 shows second flow's multicast tree. On the graph arcs we can see fraction where the numerator is the packet flow rate and the denominator is the link bandwidth. In Fig. 6 solid lines are arcs the first flow was transmitted through and dashed lines are arcs the first flow wasn't transmitted through. The second flow's multicast tree after coordination didn't change.

Fig. 7 shows the resulting multicast tree. On the graph arcs we can see fraction where the numerator is the total packet flow rate and the denominator is the link bandwidth. Solid lines are arcs the first flow was transmitted through and dashed lines are arcs the first flow wasn't transmitted through. There is no overloaded link after coordination.

Thus after coordination (14)-(15) on the upper level of hierarchy first flow multicast tree changed. This change allows carrying out both flow transmissions without link overloading.

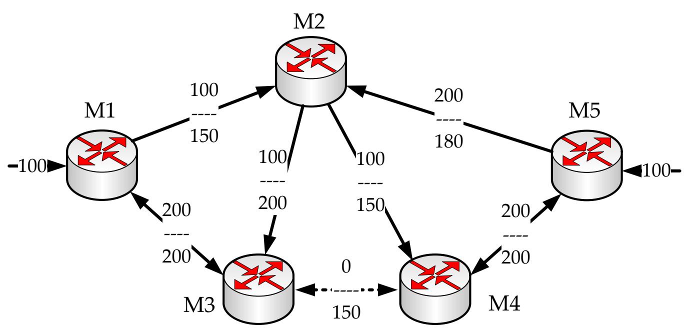

Fig. 7. The resulting multicast tree

After investigation, it can be concluded that the hierarchical multicast routing method convergence, the flow transmission from source nodes to all destination nodes occurred in two iterations when packet flow rate equal 100 1/s.

V. Conclusion

In this paper we studied the hierarchical multicast routing method (1)-(10). The research results are presented in Fig. (2)-(7). Fig. 4 shows that the link between routers *M2* and *M5* is overloaded due to uncoordinated transmission packet flows. Due to the overload coordinator at the upper level of the hierarchy (13)-(14) coordinate routing decisions are obtained from lower level of hierarchy in calculating routing variables (1). A coordinator can act either as a separate server or a network router. After the coordination the previously overloaded link between routers *M2* and *M5* (Fig. 4) is not overloaded because the first packet flow multicast tree (Fig. 5) was changed.

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