

Research Article

## Method of Balanced Shared Explicit Reservation for Multicast Routing in Network

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**Abstract:** A given work proposes a method of balanced shared explicit reservation for multicast routing in communication network. A mathematical model for multicast routing supporting shared explicit reservation of link resource was presented, which is introduced by linear expressions that are responsible for ensuring the connectivity of the calculated multicast routes, as well as the absence of loops in them. The analysis of the solutions for the multicast routing tasks and the shared explicit reservation of network resources using the proposed model for different network structures, flow characteristics and the used optimality criteria is conducted. The use of the proposed model ensured the improvement of the obtained results on average by 45-65% compared to the distributed (uncoordinated) solution of multicast routing tasks and reservation of link resources used in modern network protocols. According on the results of the conducted studies it is recommended to implement the complex optimality criterion, the use of which is most effective from the point of view of both balanced use of the network resource and in terms of ensuring the maximum productivity of the network as a whole.

**Keywords:** network; model; method; reservation; optimization; routing; multicast; path.

### INTRODUCTION

The growth in the level of Quality of Service (QoS) in modern infocommunication networks is mostly connected with the increasing level of consistency of the solutions for different tasks of traffic management. Such tasks include routing and reservation of network resources. These processes are a basis for complete realization of functional in network architectures of Differentiated Services (DiffServ) and Integrated Services (IntServ). In IP networks, for solving the given network tasks different technological means are responsible: e.g. RIP, OSPF, IGRP/EIGRP [1], and for reservation of the link and buffer resource the RSVP (Resource ReSerVation Protocol) is used [1]. Additionally, the RSVP protocol operates when the routing protocols' performance has finished, which negatively affects operational effectiveness of traffic management and the level of QoS because the routing protocol can calculate a route, along which there might be no resource of the needed volume. This will lead to the initialization of both the repeated solving of routing tasks and reserving the network resource, which can have a negative impact on such important time QoS parameters as an average delay and packet jitter.

Achieving the maximum consistency in solving the tasks of routing and reserving is only possible provided we have a unified model describing these processes in their interconnection. In addition to the main requirements set to such kind of models should include accounting of the following factors:

- flow nature of modern multimedia;
- routing strategy used;
- applied style of reservation in the RSVP protocol;
- providing balanced using of the network resource.

Depending on the type of service provided, unicast or multicast routing can be realized, and depending on abilities and settings of a certain routing protocol, a single path or multipath strategy is used. In turn, the RSVP protocol supports both individual and shared reservation. Moreover, to provide individual reservation we use a Fixed Filter (FF), which is applied mostly for service of unicast flows. While providing shared explicit reservation we use a Shared Explicit (SE) filter, when it is necessary to allocate a certain amount not to one but to several multicast flows [2-4],

the list of which is explicitly given. If under reserving a set of flows is not established, then the RSVP protocol uses a Wildcard Filter (WF). During the consistent solving of routing and reserving tasks it is important to provide balanced use of network resource, which is the key requirement of the Traffic Engineering (TE) concept and an important part of QoS improvement [5, 6]. The concept of Traffic Engineering made its own adjustments into many network protocols and mechanisms of traffic management, which is proved by development and introduction of such technological solutions as TE-Queueing [7], OSPF-TE, ISIS-TE, RSVP-TE, CR-LDP [8-12]. Therefore, the given work proposes a method of balanced shared explicit reservation for multicast routing in a network, which corresponds to the above mentioned requirements.

**MATHEMATICAL FLOW-BASED MODEL OF MULTICAST ROUTING**

As shown in [13-15], when simulating processes of the multicast routing, the network structure is presented by a weighed oriented graph  $G=(V,E)$ . Then  $V = \{v_1, \dots, v_i, \dots, v_m\}$  is a set of vertices modeling the network routers;  $(i, j) \in E$  is a set of graph's arcs describing the network links. The weight of each arc  $\varphi_{(i,j)}$  is introduced; this weight characterizes the bandwidth of the communication link being modeled. The number of links corresponds to  $|E| = n$ .

To provide the maximum accountability of abilities of reserving network resources according the SE filter let us introduce the following notations:

$K$  is the set of multicast packet flows in the network;

$|K| = \bar{K}$  is the general number of flows in the network;

$r_k$  is the average rate (intensity) of the  $k$  th flow incoming to the network (1/s);

$s_k$  is the source router of packets of the  $k$  th flow ( $k \in K$ );

$$d_k^* = \{d_k^1, d_k^2, \dots, d_k^{m_k}\} \tag{1}$$

– is the set of destination routers of packets for the  $k$  th multicast flow;

$m_k$  is the general number of such routers.

Then the result of solving the multicast routing problem can be represented as a set of Boolean variables

$$x_{(i,j)}^k \in \{0;1\}, \tag{2}$$

each of which numerically measures the fraction of intensity of the  $k$  th flow in the link represented by the arc  $(i, j) \in E$ ;  $k \in K$ .

In order to ensure the delivery of packets of the  $k$  th multicast flow to all the destination routers, the conditions of the form are introduced

$$\sum_{i:(i,j) \in E} x_{(i,j)}^k = 1 \text{ under } k \in K; v_j \in d_k^*. \tag{3}$$

For the source router it is also needed to introduce the condition

$$\sum_{j:(i,j) \in E} x_{(i,j)}^k \geq 1 \text{ under } k \in K, v_i = s_k, \tag{4}$$

execution of which allows to send packets of the  $k$  th flow to one or several neighboring routers, but not less than to one.

The following conditions [14, 15] are added for each of the set of transit routers  $v_j \in V$ , which includes all routers except the source:

$$\sum_{i:(i,j) \in E} x_{(i,j)}^k \geq x_{(j,p)}^k \text{ under } k \in K; v_j \notin s_k. \tag{5}$$

The physical meaning of these conditions is that packets on the output interfaces of the transit router can appear only if they have entered at least on one of its input interfaces.

To ensure the connectivity of multicast routes and to exclude the possibility of looping when sending packets, routing variables are imposed with the conditions

$$\sum_{(i,j) \in E_\pi^q} x_{(i,j)}^k < |E_\pi^q|, \tag{6}$$

if  $E_\pi^q$  is the set of graph's arcs forming the  $q$  th circuit ( $\pi$ );  $|E_\pi^q|$  is the number of arcs in the  $q$  th network circuit. The number of terms (6) corresponds to the number of independent circuits in the network [14, 15].

**CONDITIONS FOR PROVIDING SHARED EXPLICIT RESERVATION OF LINK RESOURCE IN MULTICAST ROUTING**

In order to obtain the conditions for providing shared explicit reservation of the link resource under routing of multicast flows, we will additionally introduce a number of notations:  $K_s^{SE}$  is the  $s$  th SE group, which combines a set of multicast flows (usually having different source routers), for which shared explicit reservation of the link resource is performed in the network;  $\gamma_{(i,j)}^s$  is the fraction of the bandwidth of the communication link modeled by the arc  $(i, j) \in E$  to

be reserved for the multicast flows  $(i, j) \in E$  belonging to the  $s$ th SE group, i.e.  $k \in K_s^{SE}$ .

Ensuring consistency in addressing the tasks of routing and reserving network resources has been achieved by establishing the dependence between routing variables  $x_{(i,j)}^k$  and reservation variables  $\gamma_{(i,j)}^s$ . This dependence is represented by the conditions for reserving bandwidth in each communication link for flows of the  $s$ th SE group:

$$r_k \cdot x_{(i,j)}^k \leq \gamma_{(i,j)}^s \cdot \varphi_{(i,j)}, \quad k \in K_s^{SE}. \quad (7)$$

The condition (7) is introduced due to the fact that when using shared explicit reservation, the link resource is reserved practically for the maximal requirements of one of the flows included in the SE group [1]. The value of these bandwidth requirements actually determines the lower threshold of the product  $\gamma_{(i,j)}^s \cdot \varphi_{(i,j)}$ .

To prevent overloading of communication links, additional restrictions are introduced

$$\sum_{s=1}^S \gamma_{(i,j)}^s \leq 1, \quad (i, j) \in E, \quad (8)$$

implementation of which ensures the reservation of only the available link resource of the network.

When formulating the optimality criterion for multicast routing solutions with the support of the shared explicit reservation, it is important, firstly, to take into account the specifics of the technological implementation of these processes; and secondly, to have effective methods for solving the formulated optimization task. For this purpose, it is further proposed to compare the effectiveness of the following three criteria.

The first criterion is represented by the minimum of the next linear objective function

$$J_1 = \sum_{k \in K} \sum_{(i,j) \in E} f_{(i,j)}^k x_{(i,j)}^k + \sum_{s=1}^S g_{(i,j)}^s \gamma_{(i,j)}^s \quad (9)$$

in which  $f_{(i,j)}^k$  is the routing metric of the link  $(i, j) \in E$  when it is used by packets of the  $k$ th flow;  $g_{(i,j)}^s$  is the conditional cost (metric) of the shared explicit reservation of the link  $(i, j) \in E$  bandwidth for multicast flows of the  $s$ th SE group. In general, the metric  $g_{(i,j)}^s$  can numerically depend both on the number and priority of the multicast flows forming the  $s$ th SE group, and on the structural and functional parameters of the link  $(i, j) \in E$ . The first term in

expression (9) characterizes the total metric of the solution of the routing problems, and the second term characterizes the total conditional cost of solving the shared explicit reservation problem.

In the course of describing the second proposed criterion, we introduce an additional variable  $\beta$  that characterizes the upper threshold of the reserved bandwidth of links in the network as a whole, i.e. the following conditions hold

$$\sum_{s=1}^S \gamma_{(i,j)}^s \leq \beta, \quad (i, j) \in E, \quad (10)$$

$$0 \leq \beta \leq 1, \quad (11)$$

which actually replace the conditions (8).

The use of the second criterion is based on calculation of routing variables  $x_{(i,j)}^k$  and reservation variables  $\gamma_{(i,j)}^s$  during minimization of the introduced upper threshold of the reserved bandwidth of links in the network as a whole by analogy with [13, 16, 17]

$$J_2 = \beta, \quad (12)$$

which should promote balanced use of the link resource of the network when it is reserved.

The third criterion was the minimum of the complex objective function of the form

$$J_3 = \sum_{k \in K} \sum_{(i,j) \in E} f_{(i,j)}^k x_{(i,j)}^k + \sum_{s=1}^S g_{(i,j)}^s \gamma_{(i,j)}^s + w\beta, \quad (13)$$

where  $w$  is the weight coefficient determining the importance of the third term ( $\beta$ ) in the function (13).

The use of the objective function (13) contributes not only to the balanced reservation of the link resource of the network as a whole, but also to minimizing the use of this resource by the flows of each  $s$ th SE group.

Thus, the multicast routing task with the support of the shared explicit reservation of the link resource is formulated in an optimization form, with at least one of the objective functions (9), (12) or (13) being the criterion. The novelty of the model is the introduction of the system of conditions for preventing congestion of communication links (7), (8), (10) and (11) to implement balanced use of network resources when organizing shared explicit reservation of the link bandwidth. The formulated optimization problem belongs to the class of mixed integer linear programming problems, as the routing variables  $x_{(i,j)}^k$  are Boolean, and the reservation variables  $\gamma_{(i,j)}^s$  are real numbers.

**ANALYSIS OF SOLUTIONS FOR MULTICAST ROUTING TASK WITH SUPPORT OF SHARED EXPLICIT RESERVATION**

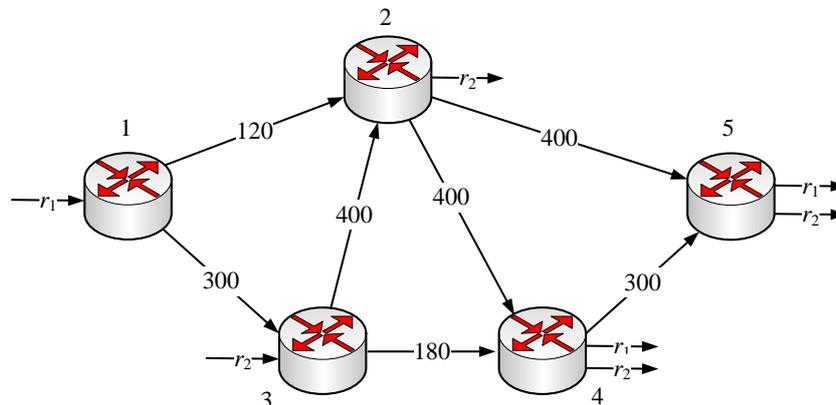
The analysis of the solutions for the multicast routing tasks and the shared explicit reservation of network resources using the proposed model (1)-(12) for different network structures, flow characteristics and the used optimality criterion (9), (12) and (13) is conducted. At the same time, the effectiveness of the solutions obtained has been estimated using the following indicator

$$P = \left[ 1 - \frac{\sum_{(i,j) \in E} \varphi_{(i,j)} \sum_{s=1}^S \gamma_{(i,j)}^s}{\sum_{(i,j) \in E} \varphi_{(i,j)}} \right] 100\%, \quad (14)$$

which has numerically characterized the percentage of the remaining unused link resource after the shared explicit reservation was made. The degree of balance in

using the link resource during its reservation was estimated according to the indicator (11).

The method of calculating and comparing the indicators (11) and (14) using the proposed model (1)-(13) is demonstrated in the following calculation example. Suppose that Fig. 1 shows the initial structure of the network, where the gaps of communication links indicate their throughputs (in packets per second, 1/s). It is necessary to calculate paths and implement the shared explicit reservation for two multicast flows: for the first flow with the intensity  $r_1$  the source was the router  $v_1$ , and the destinations were  $d_1^* = \{v_4, v_5\}$ ; for the second flow with the intensity  $r_2$  the source was the router  $v_3$ , and the destinations were  $d_2^* = \{v_2, v_4, v_5\}$ . Thus, these flows within the framework of the considered example belonged to one shared SE group.



**Fig-1: The example of the network initial structure**

The results of calculating the indicators (11) and (14) with the change (increase) in the intensities of

the two flows considered are presented for the seven selected variants in Table 1.

**Table 1: Calculation results**

No	Flow intensity (1/s)		With the criterion (9)		With the criterion (12)		With the criterion (13)	
	$r_1$	$r_2$	$\beta$	$P, \%$	$\beta$	$P, \%$	$\beta$	$P, \%$
1	50	100	0.3333	80.95	0.25	77.62	0.25	83.33
2	50	150	0.3750	71.43	0.375	68.45	0.375	76.19
3	100	100	0.5556	80.95	0.3333	78.1	0.3333	80.95
4	100	150	0.5556	69.05	0.3750	69.05	0.3750	73.81
5	150	150	0.8333	71.43	0.5	71.43	0.5	71.43
6	200	200	0.6667	61.90	0.6667	61.90	0.6667	61.90

For the fifth variant of the initial data, i.e. under  $r_1 = 100$  1/s and  $r_2 = 150$  1/s, the order of multicast routing and resource reservation is shown in Fig. 2-4. In this case, Fig. 2 shows the results obtained using the optimality criterion (9); Fig. 3 presents the results using the criterion (12); and Fig. 13 shows the results using the criterion (13). In Fig. 2-4, the

following data are indicated (from top to bottom) in the link gaps: the intensity of the first flow, the intensity of the second flow, the reserved volume of the link bandwidth. According to the SE-filter, the amount of the reserved resource in each of the links corresponded to the maximum of the intensities of the flow transmitting in it. In each Figure, the solid line shows

the multicast route for the first flow, and the dash line is for the second flow. In criteria (9) and (13), there is a metric  $g_{(i,j)}^s = 10^2 / \varphi_{(i,j)}$  to ensure that the most

productive links are used during reservation and subsequent routing.

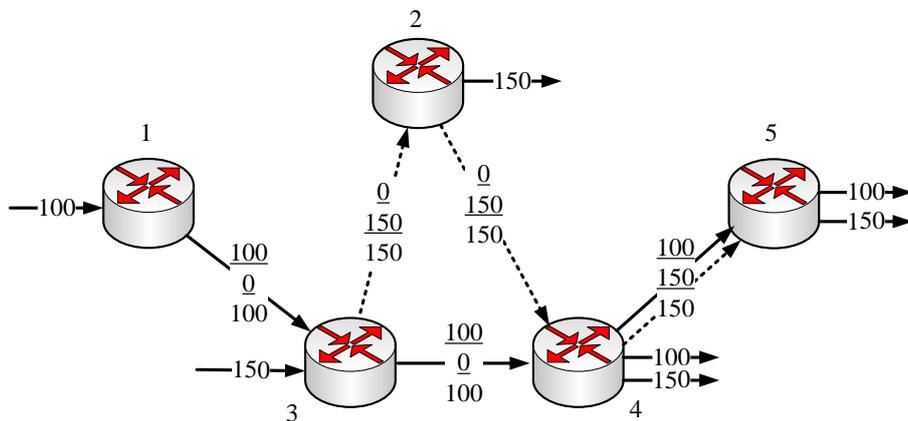


Fig-2: The order of multicast routing and the SE-reservation of resources using the optimality criterion (9)

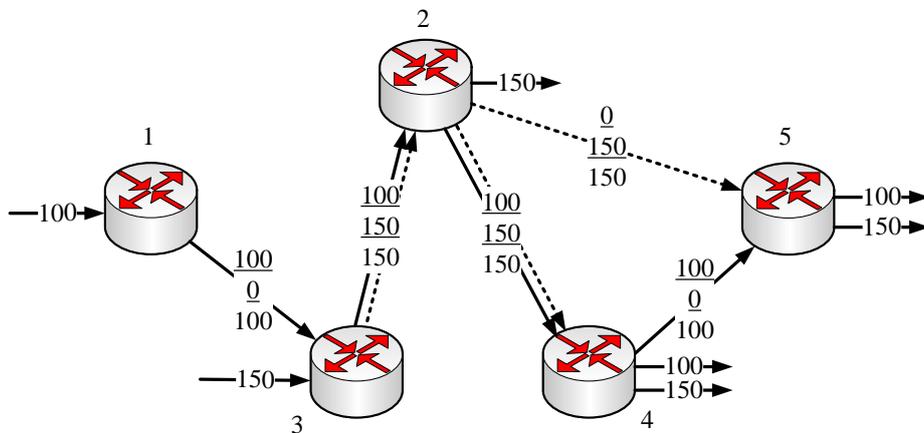


Fig-3: The order of multicast routing and the SE-reservation of resources using the optimality criterion (12)

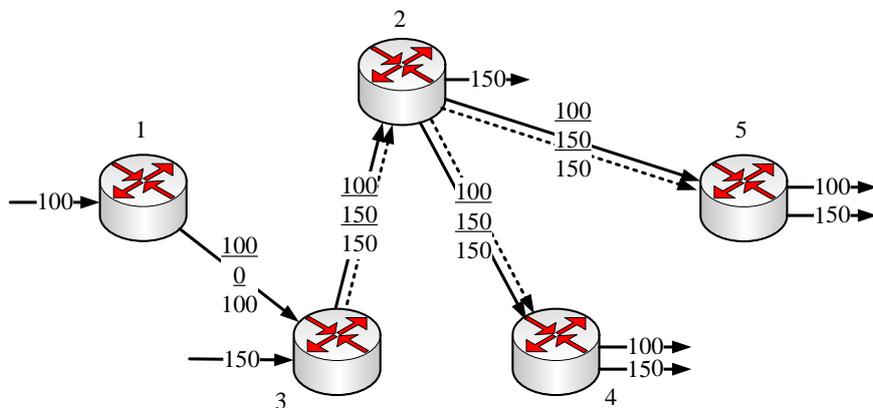


Fig-4: The order of multicast routing and the SE-reservation of resources using the optimality criterion (13)

**CONCLUSIONS**

According to the results of calculations, some of which are presented in Table I and in Fig. 2-4, and

their subsequent comparison, the following conclusions can be made:

- 1) The implementation of criterion (12) always guarantees the best values of the upper threshold for the use of the link bandwidth (11) during its reservation; however, as a rule, it is inferior to the comparable solutions in terms of indicator (14);
- 2) The use of criterion (9), as a rule, negatively affects the level of balanced use of the link resource in the network (9), but it slightly improves the indicator (14) as compared to the solutions obtained on the basis of criterion (12);
- 3) The application of criterion (13) in the overwhelming majority of cases resulted in an improvement in the indicator (14), which characterizes the volume of the saved link resource on average from 3.5% to 11%, and the level of balanced use of the communication link resource of the network (11);
- 4) With increasing network utilization (variants of calculations 6 and 7 in Table I), the effectiveness of the solutions compared with the indicator (14) was practically equalized;
- 5) With increasing network size (the number of routers and links), the number of flows and SE-groups as a whole, the gain from using the criterion (13) was increasing;
- 6) The use of the proposed model of calculations (1)-(13) ensured the improvement of the obtained results both on the indicator (11) and on the indicator (14) on average by 45-65% compared to the distributed (uncoordinated) solution of multicast routing tasks and reservation of link resources used in modern network protocols.

Thus, according on the results of the conducted studies we can recommend to implement the criterion (13), the use of which is most effective from the point of view of both balanced use of the network resource and in terms of ensuring the maximum productivity of the network as a whole.

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