Traffic Engineering Extension for Traditional QoS Multicast Routing Algorithms

Bo Rong, Maria Bennani, Michel Kadoch
LAGRIT, Department of Electrical Engineering
Ecole de technologie superieure, Universite du Quebec
Montreal, Quebec, Canada, H3C 1K3

Ahmed K. Elhakeem
Department of Electrical and Computer Engineering
Concordia University
Montreal, Quebec, Canada, H3G 1M8

***Abstract*—To make the best use of network resources across QoS guaranteed multicast network, it is urgent to add traffic engineering mechanism to the existing QoS multicast routing protocols. In this paper, we propose a new approach of integrating QoS multicast routing with TE-oriented admission control to offer traffic engineering function. Moreover, a TE-oriented admission control algorithm, namely dynamic bandwidth allocation with adaptive constraint (*DBA-AC*), is suggested to make the best use of resources across entire multicast network by distributing traffic over different paths. Because this admission control algorithm is nonlinear and unsolvable by analytical approach, we employ OPNET simulation to study its performance.**

I. INTRODUCTION

Previous work on QoS multicast routing mainly concerned about how to develop algorithms of finding a cost optimal tree with certain QoS constraints [1,2,3,4]. For these algorithms, the admission control is only considered as a by-product of QoS routing and resource reservation. If the routing algorithm can find a route meeting the QoS requirements and the resource reservation is successfully done along the selected route, the connection request is accepted; otherwise, the request is rejected. The motivation of this paper is to propose a new approach of employing TE-oriented admission control as traffic engineering mechanism in QoS multicast routing. By this way, the admission control is no longer a by-product of routing algorithm, it can affect the routing result significantly.

The rest of the paper is organized as follows. Firstly, we discuss the integration of QoS multicast routing and TE-oriented admission control in Section 2. Then a TE-oriented admission control algorithm named dynamic bandwidth allocation with adaptive constraint (*DBA-AC*) is proposed in Section 3, and the performance of this algorithm is simulated and analyzed in Section 4. In the end, Section 5 summarizes our results.

II. INTEGRATING QOS MULTICAST ROUTING WITH TE-ORIENTED ADMISSION CONTROL

A QoS guaranteed network can be represented by a connected graph $G(V,E)$ with weights associated with edges. In the graph, the nodes stand for communication endpoints, the edges stand for communication links, and the weight on edge l is denoted by $W_l^{QoS} = (W_l^c, W_l^b, W_l^d)$, where W_l^c stands for the cost of link l, W_l^b stands for the remaining free bandwidth on link l, and W_l^d stands for the transmission delay of link l. An example of network graph is shown in Fig.1.

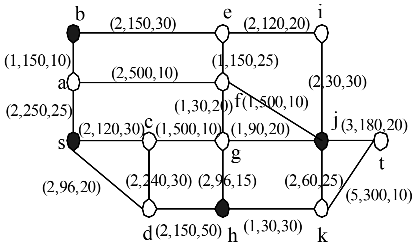

Fig. 1. An example of network graph (s is the source node; $\{b, h, j\}$ are the destination nodes.)

By treating a network as graph, a multicast session can be described as $M=(s,D,Q)$ where s is the source node, $D=\{d_1,\ldots,d_n\}$ is a set of destination nodes, and Q is a set of QoS requirements. The multicast tree T for M is a subtree of $G(V,E)$, which is rooted from s, contains all the nodes of D, and can meet the QoS constraint Q. Let T be a multicast tree of multicast session M, we define the cost of T as follows:

$$COST_T = \sum_{l \in T} W_l^c \qquad (1)$$

$COST_T$ decides the overall cost used by M. One important aim of multicast routing algorithms is to find out the least cost tree under the condition of meeting the QoS constraints. This problem is known as constrained Steiner tree problem, and corresponding heuristic algorithms can be found in [1,2,3,4]. These heuristic algorithms serve as the foundation for QoS multicast routing protocols. In general, all these heuristic algorithms can be classified into two categories, the centralized algorithms and the distributed algorithms. Until now, most published algorithms belong to centralized category. Centralized algorithms are suited to build protocols supporting explicit routing, which is an important premise for traffic engineering. Therefore, in this paper, we only concern the centralized QoS multicast routing algorithms.

Although we can use the existing QoS multicast routing algorithms to find a QoS guaranteed path for a real-time multicast connection, the routing algorithms do not ensure that the network runs efficiently. To make the best use of resources across the entire network, we propose a new approach of

0-7803-8938-7/05/$20.00 (C) 2005 IEEE

employing TE-oriented admission control as traffic engineering mechanism in QoS multicast routing. In this paper, admission control algorithms are classified to two categories, the passive ones and the active ones. The passive admission control algorithm uses a policy of *FCFS*, which treats all connection requests equally. On the other hand, the active admission control algorithm employs specific policy to control resource allocation actively, and it usually shows different priorities to connection requests of different QoS requirements. TE-oriented admission control belongs to active admission control category, and it is employed to provide QoS multicast routing with traffic engineering functions. For convenience, we define connection requests with high bandwidth requirement as high-bandwidth connection requests, and connection requests with low bandwidth requirement as low-bandwidth connection requests. A TE-oriented admission control algorithm named *DBA-AC* that can give preference to high-bandwidth connections and limit the acceptance of low-bandwidth connections will be studied in Section 3 in respect of traffic engineering.

In order to integrate TE-oriented admission control into QoS multicast routing, once a new connection request comes, we use TE-oriented admission control algorithm to preprocess the network graph before QoS multicast routing algorithm is started to find a QoS route. As a preparation for network graph preprocessing, some links are chosen from the original network graph as active links in advance. The good candidates for active links are the ones that have high bandwidth capacity and are centrally located in whole network. For example, in Fig.1, we choose {(a,f), (c,g), (f,j)} as active links. When a new connection request comes, we use TE-oriented admission control algorithm to make bandwidth admission test on these active links. If the admission control algorithm decides that there is no available bandwidth resource on some active links for the new coming connection request, these inadequate active links are deleted from the original network graph. We define the new obtained network graph as preprocessed network graph. Only after getting the preprocessed network graph for a connection request, the QoS multicast routing algorithm is started to find a QoS route that can meet all the QoS requirements of this connection request.

Load balancing [5] and bandwidth fragmentation avoidance [6] are two important measures to distribute traffic over different paths and ensure fair treatment towards users of different QoS requirements. In this paper, we use these two measures to achieve traffic engineering in multicast network. To implement these two measures, the TE-oriented admission control algorithms with preference to high-bandwidth connections should be developed for network graph preprocessing. By employing this kind of algorithms to make bandwidth admission test on active links, connection requests of different bandwidth requirements may have different preprocessed network graphs. As a result, the traffic of high-bandwidth connections is mainly aggregated on the high capacity active links, while the traffic of low-bandwidth connections is distributed evenly in the whole network.

III. OUR TE-ORIENTED ADMISSION CONTROL ALGORITHM FOR TRAFFIC ENGINEERING

In this section, we propose a TE-oriented admission control algorithm named *DBA-AC*, which can give preference to high-bandwidth connections and limit the acceptance of low-bandwidth connections. The basic architecture of this algorithm is shown in Fig.2. In this algorithm, on active link l, when the i^{th} connection request R_i with bandwidth requirement B_i arrives, the classifier should put it into one of different groups according to the value of B_i. Consider the case where bandwidth requirement of connection requests in the network can be classified by the values $b_M > \ldots > b_1 > b_0 = 0$ (b_M is the maximum value of B_i permitted in the network), each value corresponding to a QoS level k ($k=1,\ldots,M$). If $b_{k-1} < B_i \le b_k$, then the classifier put R_i into group k, which can be denoted by $R_i, B_i \in G_k$. Simply, a request belonging to G_k can be called a G_k request. After carefully choosing parameters such as M and b_k, we consider G_M as the group of highest-bandwidth connections while G_1 as the group of lowest-bandwidth connections. If R_i is accepted by the network and link l is involved in the path, we define the beginning time and ending time for R_i to be served on link l as $Tb_l(i)$ and $Te_l(i)$ respectively. Then, we say R_i or B_i is alive at time $t (t>0)$, if $Tb_l(i) < t < Te_l(i)$.

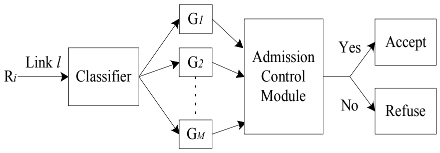

Fig. 2. The basic architecture of *DBA-AC*

After the above definitions, we intend to introduce our TE-oriented admission control algorithm of *DBA-AC* in a step by step way. Firstly, some simple admission control algorithms are discussed. Then, *DBA-AC* will be suggested as an improvement to these simple algorithms.

(1) First Come First Serve (FCFS)

FCFS is the simplest admission control policy. At any time t, on link l, the following formula must be met according to *FCFS* policy (C_l is the bandwidth capacity of link l):

$$\sum_{\text{All alive } B_i} B_i \le C_l \tag{2}$$

One major drawback of *FCFS* is that this policy cannot show any preference to high-bandwidth connections.

(2) Fixed Bandwidth Allocation (FBA)

Under the fixed bandwidth allocation policy, different groups are given different fixed bandwidth resources respectively. If C_l stands for the bandwidth capacity of link l and $BF_{k,l}$ denotes the fixed bandwidth resources allocated to group G_k on link l, the following formula holds:

$$\sum_{k=1}^{M} BF_{k,l} = C_l \tag{3}$$

Moreover, the formula employed to make the admission decision is shown below:

$$\sum_{\text{All alive } B_i \in G_k} B_i \le BF_{k,l}, \qquad k = 1,\ldots,M \tag{4}$$

This algorithm can protect the acceptance of high-bandwidth connections from being damaged by the competition of low-bandwidth connections. Nevertheless, if the request arrival rates of these groups are different from the expected arrival rates, the bandwidth utility efficiency of link *l* is not very well.

(3)Dynamic Bandwidth Allocation with Adaptive Constraint (DBA-AC)

Compared with fixed bandwidth allocation policy, besides some fixed bandwidth resource to each group, the additional shared bandwidth resource C_l^{sh} owned by all the groups is allocated in this algorithm. This shared bandwidth resource policy can be described by the formula below:

$$C_l^{sh} + \sum_{k=1}^{M} BF_{k,l} = C_l \qquad (5)$$

Moreover, in order to show preference to high-bandwidth connections, C_l^{sh} has to be shared by all groups under an adaptive constraint policy. Let $U_{k,l}$(t) denote the upper bound of the total alive bandwidth that G_k requests can get from C_l^{sh} at time *t* (*t*>0), then as shown in formula (6), the total alive bandwidth allocated from C_l^{sh} to group G_k has to be less than $U_{k,l}$(t) at any time *t*.

$$\sum_{\text{All alive } B_i \in G_k \text{ in } C_l^{sh}} B_i \le U_{k,l}(t), \qquad k = 1, \ldots, M \qquad (6)$$

After this, the adaptive constraint policy can be defined as the following:

$$U_{k,l}(t) = \frac{x_l\left[\sum_{j=k+1}^{M} W_{k,j,l}\, SLB_{j,l}^{sh}(t)\right]}{(M-k)}, \quad k = 1, \ldots, M-1 \qquad (7)$$

$$U_{M,l}(t) = C_l^{sh} \qquad (8)$$

where, $SLB_{j,l}^{sh}(t)$ is the sum of alive bandwidth occupied by group G_j in C_l^{sh} at time *t* on link *l*, x_l is the upper bound coefficient and $W_{k,j,l}$ is the relative weight.

After above definitions, we follow the flowchart in Fig.3 to make admission decision.

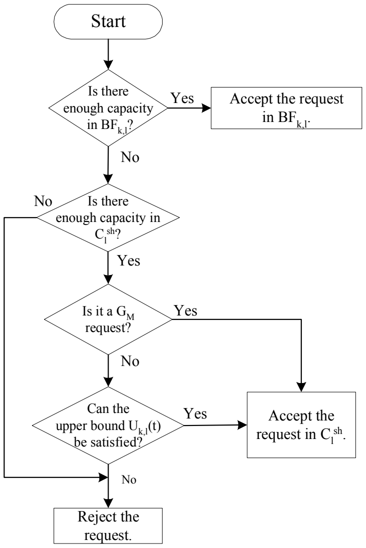

Fig. 3. Flowchart of admission decision (*DBA-AC*)

IV. PERFORMANCE STUDY OF *DBA-AC*

Different from the admission control algorithms in [7,8,9], the algorithm of *DBA-AC* is nonlinear and cannot be investigated by analytical approach. As a result, we use OPNET Modeler as simulation tool to study the algorithm of *DBA-AC*. In this section, we intend to investigate the traffic engineering capability of *DBA-AC* in a certain multicast network whose attributes are shown in Fig.1. In addition, to show the benefit of *DBA-AC* by comparison, the traffic engineering capability of *FCFS* and *FBA* is also demonstrated. We suppose there are 4 groups of connection requests in the multicast network, and in each group there are different bandwidth requirement classes.

(a)group G_1: 56Kbps (class1);
(b)group G_2: 200Kbps(class1), 500Kbps(class2);
(c)group G_3: 1.5Mbps(class1);
(d)group G_4: 4Mbps(class1), 6Mbps(class2).

Obviously, G_1 and G_2 are groups of low-bandwidth connection requests, while G_3 is the medium-bandwidth connection group and G_4 is high-bandwidth connection group. Moreover, as to each multicast connection request in our simulation, the source node and destination nodes are chosen randomly from boundary nodes $\{s,a,b,e,i,j,t,k,h,d\}$. In the meantime, the average multicast group size is 3.5, and the delay bound is a random value chosen from 50 to 100 milliseconds. Moreover, requests of each class in every group are assumed to arrive according to Poisson process independently, and the service times are exponentially distributed. To start the simulation, firstly we employ the admission control algorithm to make bandwidth admission test on active links {(a,f), (c,g), (f,j)} in Fig.1, so that difference connection requests may have different preprocessed network graphs. Following this, a source based bandwidth delay bounded multicasting algorithm [10] is used to select an appropriate path in the preprocessed network graph. The parameters used in the simulation are defined as follows.

Common part of all 3 algorithms (k=1,2,3,4):

C_l(Mbps)**:** bandwidth capacity of link *l*.
$\lambda_{k,m}$(calls/hour)**:**average arrival rate of class *m* requests in G_k.
$1/\mu_{k,m}$(hours/call)**:**average service time for class *m* requests in G_k.
$Pb_{k,l}$(%)**:** blocking probability of G_k requests on link *l*.
$Pb_{k,al}$(%): average blocking probability of G_k requests on active links, when bandwidth admission test is executed for network graph preprocessing.
$Thrput_{k,l}$(Mbps)**:** throughput of G_k requests on link *l*.
$Thrput_{k,net}$(Mbps): throughput of G_k connections in the whole network.
$Thrput_{all\text{-}net}$(Mbps): the whole throughput in the network, which can be calculated by the sum of $Thrput_{k,net}$.
Eff_l(%): bandwidth utility efficiency of link *l* during the simulation, describing how much bandwidth of link *l* is occupied by multimedia traffics.
$D\text{-}Eff_{pl}$(%): standard deviation of Eff_l among all passive links (non-active links) in the network.

Common part of FBA and DBA-AC:

$BF_{k,l}$(Mbps): Fixed bandwidth resources allocated to G_k on link *l*.

Special part of DBA-AC (k=1,2,3,4):

C_l^{sh}(Mbps)**:** The shared bandwidth capacity of all groups on link *l*.

x_l: Upper bound coefficient on link l.
$W_{k,j,l}$: Relative weight on link l.

In our simulation, we mainly concern about the performance indicators such as $Pb_{k,al}$, $Thrput_{k,net}$, $D\text{-}Eff_{pl}$, and $Thrput_{all\text{-}net}$. First of all, $Pb_{k,al}$ is used to show the impact of our admission control algorithm on active links. Secondly, from $Thrput_{k,net}$ we can know the bandwidth fragmentation in the network. Thirdly, $D\text{-}Eff_{pl}$ serves to denote the load balancing capability of our algorithm. Fourthly, $Thrput_{all\text{-}net}$ is employed to show the throughput of the whole network. With OPNET, simulation results are attained with following parameters (l stands for any active link in Fig.1).

Common part of all 3 algorithms:

Network attributes: as shown in Fig.1;
Active links: {(a,f), (c,g), (f,j)};
Source and destination nodes of each connection: chosen randomly from boundary nodes {*s,a,b,e,i,j,t,k,h,d*};
Average multicast group size of each connection: 3.5;
Delay bound of each connection: randomly chosen from 50 to 100 milliseconds.

C_l=500Mbps, $1/\mu_{k,m}$=25 minutes/call (any k or m),
$\lambda_{1,1}$(56Kbps)=7200(calls/hour), $\lambda_{2,1}$(200Kbps)=1800(calls/hour),
$\lambda_{2,2}$(500Kbps)=600~3000 (calls/hour),
$\lambda_{3,1}$(1.5Mbps)=360(calls/hour),
$\lambda_{4,1}$(4Mbps)=96(calls/hour), $\lambda_{4,2}$(6Mbps)=72(calls/hour).

Special part of FBA:

$BF_{1,l}=5\%*C_q$, $BF_{2,l}=30\%*C_q$, $BF_{3,l}=35\%*C_q$, $BF_{4,l}=30\%*C_q$.

Special part of DBA-AC:

C_l^{sh}=250Mbps, $BF_{1,l}=5\%*(C_q-C_q^{sh})$, $BF_{2,l}=30\%*(C_q-C_q^{sh})$,
$BF_{3,l}=35\%*(C_q-C_q^{sh})$, $BF_{4,l}=30\%*(C_q-C_q^{sh})$,
x_l=50, $W_{k,j,l}$=1 (any k or j).

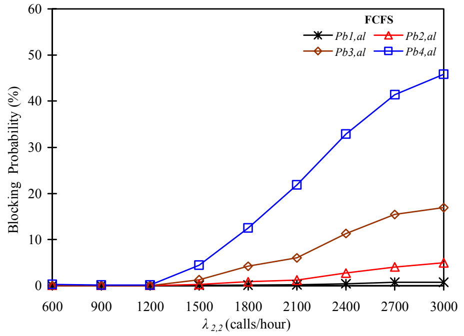

Fig. 4. Blocking probability $Pb_{k,al}$ versus arrival rate $\lambda_{2,2}$ (*FCFS*)

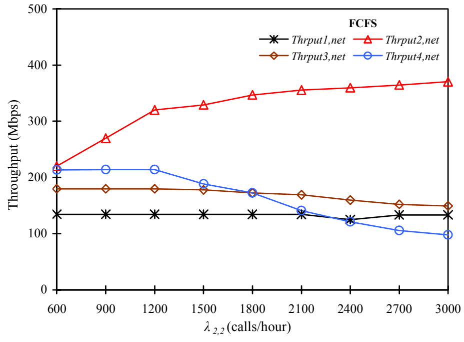

Fig. 5. Throughput $Thrput_{k,net}$ versus arrival rate $\lambda_{2,2}$ (*FCFS*)

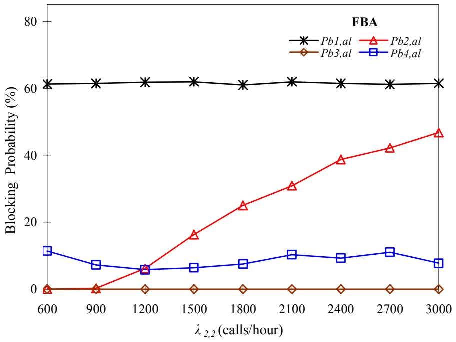

Fig. 6. Blocking probability $Pb_{k,al}$ versus arrival rate $\lambda_{2,2}$ (*FBA*)

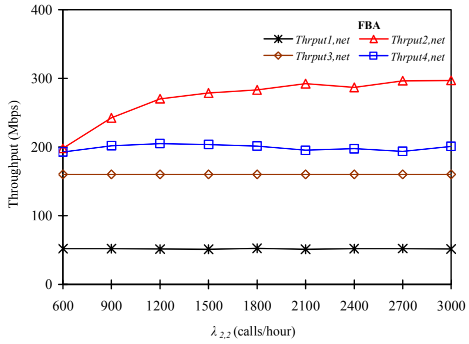

Fig. 7. Throughput $Thrput_{k,net}$ versus arrival rate $\lambda_{2,2}$ (*FBA*)

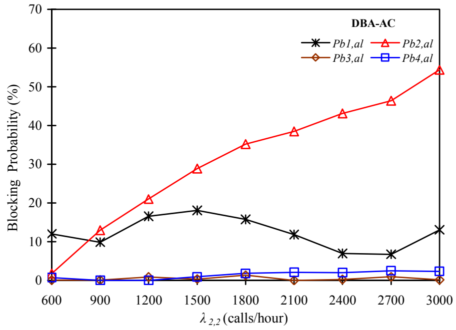

Fig.8. Blocking probability $Pb_{k,al}$ versus arrival rate $\lambda_{2,2}$ (*DBA-AC*)

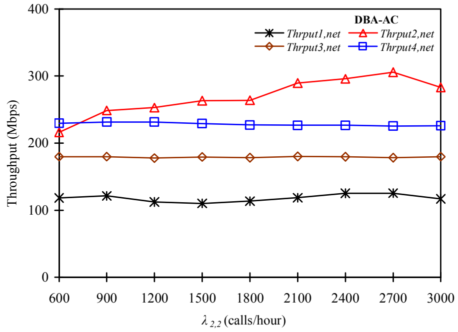

Fig. 9. Throughput $Thrput_{k,net}$ versus arrival rate $\lambda_{2,2}$ (*DBA-AC*)

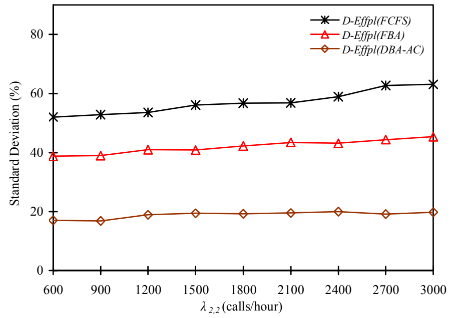

Fig. 10. Standard Deviation $D\text{-}Eff_{pl}$ versus arrival rate $\lambda_{2,2}$ (all 3 algorithms)

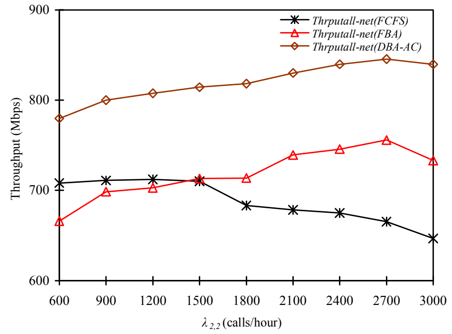

Fig. 11. Whole throughput of the network $Thrput_{all\text{-}net}$ versus arrival rate $\lambda_{2,2}$ (all 3 algorithms)

From Fig.4 we know that *FCFS* is an admission control algorithm without any preference for high-bandwidth connection requests. Furthermore, the low value of $Thrput_{4,net}$ in Fig.5, high value of $D\text{-}Eff_{pl}(FCFC)$ in Fig.10, and low value of $Thrput_{all\text{-}net}$ in Fig.11 indict that *FCFS* cannot achieve bandwidth fragmentation avoidance, load balancing, and high overall throughput in the multicast network. In a word, no traffic engineering comes from *FCFS*. As for *FBA*, Fig.6 and Fig.7 show it can guarantee the acceptance of high-bandwidth connection requests and avoid bandwidth fragmentation. However, Fig.10 and Fig.11 demonstrate the traffic engineering capability of *FBA* is not satisfying due to its low bandwidth utility efficiency on active links. Compared with *FCFS* and *FBA*, Obviously the algorithm of *DBA-AC* has better performance. Firstly, as shown in Fig.8 and Fig.9, the algorithm of *DBA-AC* is able to show preference to high-bandwidth connection requests and avoid bandwidth fragmentation. Secondly, the low value of $D\text{-}Eff_{pl}(DBA\text{-}AC)$ in Fig.10 and the high value of $Thrput_{all\text{-}net}(DBA\text{-}AC)$ in Fig.11 demonstrate that *DBA-AC* can attain good load balancing and high overall throughput in the multicast network. To sum up, *DBA-AC* is a good candidate to accomplish traffic engineering tasks in multicast network.

V. CONCLUSIONS

To deploy traffic engineering extensions in the IP multicast network is an urgent task for ISPs. In this paper, a new approach of integrating QoS multicast routing with TE-oriented admission control is studied to reach this goal. Furthermore, an algorithm named *DBA-AC* is proposed to distribute traffic over different paths and achieve high bandwidth utility efficiency in the whole multicast network. From the simulation results, we can conclude that this algorithm can control traffics of different bandwidth requirements effectively, and fulfil traffic engineering tasks successfully.

ACKNOWLEDGMENT

The authors would like to thank Bell Canada and NSERC for their financial support.

REFERENCES

[1] V. P. Kompella, J. C. Pasquale, and G. C. Polyzo, “Multicast routing for multimedia communication,” *IEEE/ACM Transactions on Networking*, pages 286-292, June 1993.

[2] Q. Zhu, M. Parsa, and J. J. Garcia-Luna-Aceves, “A source-based algorithm for delay-constrained minimum-cost multicasting,” *Proc. of IEEE INFOCOM’95*, pages 377-385, 1995.

[3] G. N. Rouskas and I. Baldine, “Multicast routing with end-to-end delay and delay variation constraints,” *IEEE Journal on Selected Areas in Communications*, pages 346-356, April 1997.

[4] X. Jia, “A distributed algorithm of delay bounded multicast routing for multimedia applications in wide area networks,” *IEEE/ACM Transactions on Networking*, pages 828-837, December 1998.

[5] Xiaohua Jia, Xiao-Dong Hu, Lu Ruan, and Sun, J., “Multicast routing, load balancing, and wavelength assignment on tree of rings,” *IEEE Communications Letters*, Volume: 6, Issue: 2, pages 79-81, Feb. 2002.

[6] Ganguly, S., Nath, B., “Bandwidth fragmentation in multimedia cellular network,” *GLOBECOM '02*, Volume: 2, pages 1527-1533, Nov. 2002.

[7] J. M. Aein, “A multi-user-class, blocked calls cleared demand access mode,” *IEEE Transactions on Communications*, vol. COM-26, pages 378–385, Mar. 1978.

[8] J. S. Kaufman, “Blocking in a shared resource environment,” *IEEE Transactions on Communications*, pages 1474-1481, October 1981.

[9] P. Mundur, A. Sood, and R. Simon, “Threshold-based admission control for multi-class Video-on-Demand systems,” In *Proceedings of the IEEE IPCCC*, pages 154–160, February 1998.

[10] Liao Jing-Yi, Qiu Zheng-Ding, “A source-based bandwidth-delay-bounded multicasting algorithm,” WCC-ICCT 2000, Volume: 2, Pages 1258-1261, Aug. 2000.