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QoS Constraints Multicast Routing for Residual Bandwidth Optimization using Evolutionary Algorithm

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Abstract—**For the real time multimedia applications, the routing algorithms should be designed to avoid congestion and to ensure data delivery within specified bounds. This paper presents an approach based on an evolutionary algorithm to solve the QoS constraint multicast routing problem. The proposed approach maximizes residual bandwidth utilization while satisfying end-to-end delay and delay jitter bounds. In the proposed algorithm, the encoding for generation of multicast trees is done by employing the topological features which ensure faster and guaranteed convergence. The effectiveness of the proposed algorithm is tested through the simulated results on various weighted networks.**

Index Terms—**Bandwidth ptimization, Evolutionary algorithm, Multicast routing, Routing algorithm, Steiner tree.**

I. Introduction

The Multimedia applications are becoming more and more important as networks are now used to transmit continuous media traffic, such as voice and video, to the end user. The multicasting is used when a lot of information is transmitted to a subset of hosts. The quality and performance requirements are very high for the systems which are designed to implement data exchange between computers and also to support interaction between human users located at different places. The various parameters for quality of service (QoS) are bandwidth, cost, end-to-end delay, delay jitter etc. The researchers have been studying for many years to develop efficient multicast routing, however the effort was mainly to optimize cost while satisfying delay as constraint.

The various minimum Steiner tree heuristics [1-6] have been used to solve multicast problems. The heuristic [1] uses Prim's algorithm and is optimal for symmetric networks. The heuristic [2] starts with a tree that contains the source node. The multicast group members are added one by one to the existing tree via the least cost path. The heuristics [6,7] use the multicasting to find the solution under different QoS constraints. The delay-constrained minimum Steiner tree problem [8,9] is NP-complete. An algorithm based on integer programming [10] constructs the optimal source-specific delay-constrained minimum Steiner tree. The bounded shortest multicast algorithm [11,12] constructs minimum cost multicast tree with delay constraint. The performance of a shortest path broadcast tree algorithm [13] is compared with a heuristic for tree cost, end-to-end delay constraints and internal delay bound. The algorithms [14,15] can be used for a tradeoff between the minimum Steiner tree and the least delay tree. The algorithm [16] constructs the multicast trees with both end-to-end delay and delay jitter constraints. The distributed algorithm [17] solves the delay-constrained tree optimization problem. The algorithm [18] analyses multicast routing with resource reservation. A heuristic based on simulated annealing [19] finds minimum cost multicast tree by satisfying end-to-end delay and delay jitter.

The evolutionary algorithms (EAs) are the search and optimization algorithms based on the simulated evolutionary process of natural selection, variation, and genetics. These algorithms obtain the optimal solution by improving the solution with the progress of iterations [20,21]. These algorithms have been used for various NP-hard and NP-complete optimization problems because their many individuals can search for multiple good solutions in parallel. The ability of these algorithms to handle complex problems, involving features such as discontinuities and disjointed feasible spaces reinforces their effectiveness for various complex problems. The various formulations of EAs [22-29] have been used for the multicast routing. The approach [22] uses genetic algorithm to obtain delay bound least cost multicast tree. The method combining genetic algorithm and simulated annealing [23] is used for least-cost QoS multicast routing. The method [24] employs a genetic algorithm based solution to the group multicast problem by generating a set of possible trees for each session in isolation. The orthogonal array concept [25] is used to generate offspring through crossover. The one dimensional encoding scheme of size NxN, where N is the number of nodes, [26] makes the transformation between genotype and phenotype complicated. The route [28] is selected by selecting the node with the minimum energy consumption. The performance of EAs [29] is evaluated for the shortest path problem.

An evolutionary algorithm based approach is presented in this paper to select multicast tree for residual bandwidth maximization subjected to both end-to-end delay and delay variation bounds. The developed algorithm employs topological features for the encoding and generation of multicast trees, which leads to faster and guaranteed

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convergence. The effectiveness of the proposed algorithm is tested to obtain multicast trees for various computer networks.

II. QoS Constraint Multicast Routing Model for Residual Bandwidth Optimization

The network is simply represented as weighted connected network *N=(V,E)*, where *V* denotes the set of nodes and *E* the set of links. The existence of a link *e=(u,v)* from node *u* to node *v* implies the existence of a link *e'=(v,u)* for any $u, v \in V$, i.e., full duplex in networking terms. Let *G* a subset of *V* i.e. $G \subseteq V$ forms the multicast group with each node of *G* is a group member. The node *s*(source)$\in V$ is a source for multicast group *G*. A multicast tree $T(s,G) \subseteq E$ is a sub-graph of *N* that spans all nodes in *G*, while it may include non-group member nodes along a path in the tree. Each link $e=(u,v) \in E$ has its properties, bandwidth utilization $\lambda(e)$, link capacity $\phi(e)$ and a delay $D(e)$ as any real positive value R^+. The bandwidth utilization $\lambda(e)$ represents current traffic flowing on link. The link capacity $\phi(e)$ represents maximum data that a link can handle. The delay $D(e)$ represents the time needed to transmit information through link that includes transmission, queuing and propagation delays.

The objective is to find a multicast tree rooted at the source *s* and spanning all the member of multicast group *G* such that the residual bandwidth utilization of the tree is maximum, the delay from source to each destination is not greater than the path delay constraint Δ and delay jitter is not greater than the specified δ. The maximization of residual bandwidth utilization of tree *R(T)* for future use is measured as the fraction of total bandwidth available: Therefore, the multicast routing problem is defined as-

Maximize residual bandwidth utilization

$$R(T) = \frac{\sum_{e \in E} (\phi(e) - \lambda(e))}{\sum_{e \in E} \phi(e)} \quad (1)$$

Subjected to Path delay

$$P_{T(s,d)} = \sum_{e \in P_{T(s,d)}} D(e) \le \Delta \quad (2)$$

Delay Jitter

$$DJ = \sum_{e \in P_T(s,d_i)} D(e) - \sum_{\substack{e \in P_T(s,d_j) \\ (i \ne j)}} D(e) \le \delta \quad (3)$$

The $P_{T(s,d)}$, a path between 's' and 'd' (s,i,j…..k,d), is an ordered sequence of nodes connecting from source *s* to destination *d,* indicating the traverse of data from 's' to 'd' as:

$$(s \rightarrow i \rightarrow j \rightarrow k \; \ldots\ldots \rightarrow r \rightarrow d).$$

The graph of an 8-node 14-link network is shown in Fig. 1. As indicated, the source node *s* is '0' whereas the destination nodes are '4' and '6'. On each link, the parameters like link capacity, bandwidth utilization and link delay are specified.

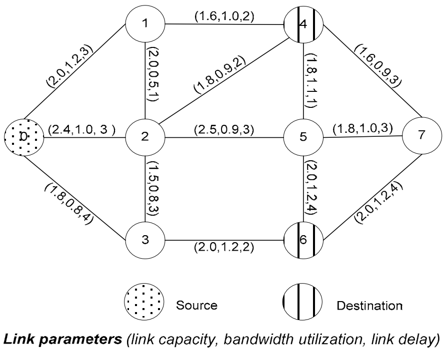

Fig. 1 The graph of a sample 8-node 14-link network

III. Multicast Routing Algorithm

The proposed multicast routing strategy is based on an evolutionary algorithm, a stochastic search method. The evolutionary algorithm is an iterative method which applies set of operators to a pool of the randomly generated population in order to improve their fitness, a measure related to the objective function. An evaluation function associates a fitness value with every individual, indicating its appropriateness for the problem. Iteratively, the application of operations such as the recombination of parts of two individuals (*crossover*) or random changes in their contents (*mutation*) is guided to tentative solutions of higher quality by a selection-of-the-best technique. The proposed routing strategy is based on genetic algorithm (GA), a popular EA that employs all the operators described above.

In a graph the nodes and the links represent the topological routing table information i.e. the node represents router and the link represents communication path between two routers. Chromosomes in the proposed algorithm are represented by sequences of positive integers that denote node numbers, through which a routing path passes. Chromosomes are stored as two-dimensional array, where the row represents the node numbers through which the path between a destination and source node is obtained. The length of row representing the path between a destination and source is varying. The flow diagram of the proposed routing strategy is shown in Fig. 2. The various stages are detailed as follows.

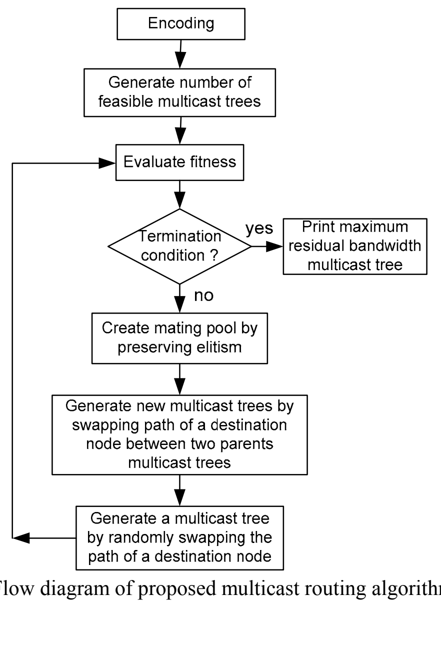

Fig. 2 Flow diagram of proposed multicast routing algorithm

A. Initial population

In initialization, the initial feasible loop free multicast trees are constructed. The initial multicast tree is first constructed and then the feasibility is checked. The tree satisfying the feasibility is added in the initial population.

The paths between the destination nodes and source node are generated randomly. The multicast tree is obtained by combining them recursively. The path between destination d_i and source 's' ($d_i \rightarrow s$) is not added directly but added only to an intermediate node that is already in the current multicast tree and in the path under consideration. This ensures the loop free multicast tree.

This procedure for generating initial solution is shown in Fig. 3.

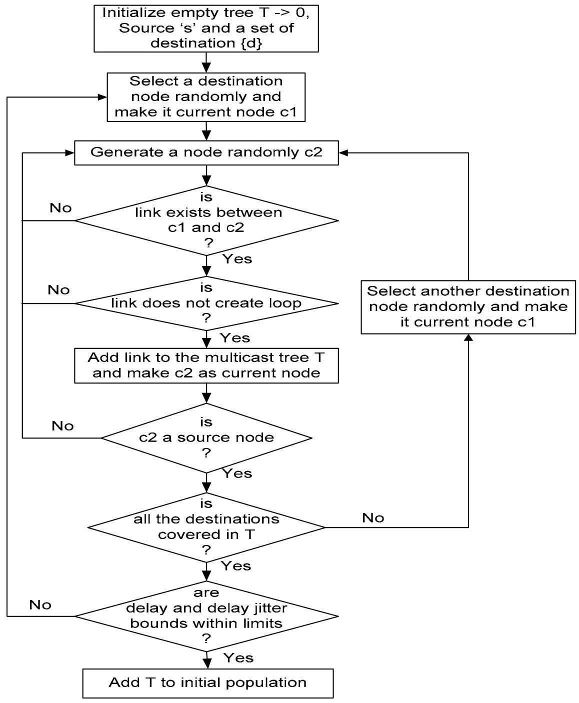

Fig. 3 Flow diagram for generating multicast tree solution

Various feasible multicast trees are obtained with this procedure. Two initial solutions as given in Fig. 4 are generated for a sample 8-node network described in Fig. 1. The end-to-end delay bound and the delay jitter are specified as 7 and 3 respectively. The 'initial solution 1' is obtained by combining the paths (4→5→2→0) and (6→3→0), which results the bandwidth as 0.48.

Similarly the multicast tree for the 'initial solution 2' is obtained by combining the paths (4→1→0) and (6→3→2→0) and resulting the bandwidth as 0.41.

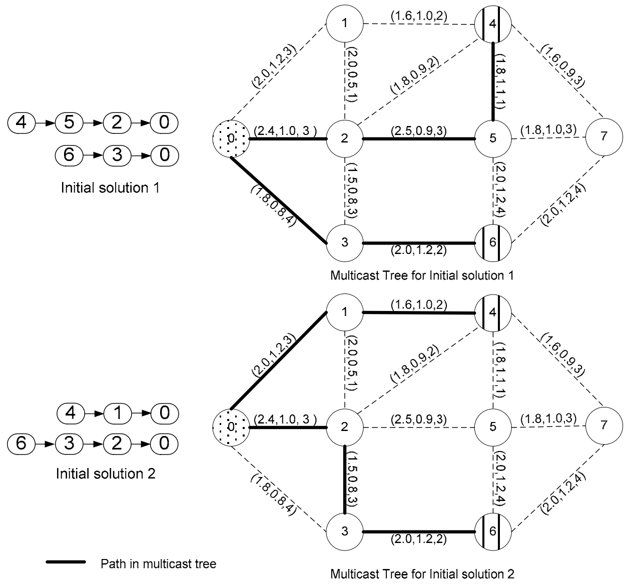

Fig. 4 Sample initial solutions generated by above procedure

B. Fitness assignment

Fitness measure associated with each multicast tree is calculated as follows-

$$fitness(i) = \frac{R_i(T)}{\sum_{i=1}^{n} R_i(T)}$$

The solutions are sorted and arranged in ascending order of fitness value. Subsequently, the cumulative fitness for various solutions is calculated.

C. Selection

The selection operator is intended to improve the average fitness of the population in mating pool i.e. the population participating in the next generation (iteration). As a principal of survival of fittest, the solution with higher fitness is having better chance to get copied in mating pool. To preserve elitism, few initial solutions of higher fitness are copied directly, whereas others are selected randomly by Roulette Wheel selection mechanism.

D. Crossover

The crossover is an important random operator and its function is to generate two offspring or 'child' solutions from two randomly selected 'parent' solutions by combining the information extracted from the parents. In the proposed method a destination node is selected randomly for the purpose of generating two offspring (child1 and child2) from two randomly selected parent solutions from mating pool. The path between the source and this randomly selected destination node between these two parents are swapped and two new multicast trees are generated.

The initial solutions, as shown in Fig. 4 are regarded as parent solutions and two offspring that are generated by crossover are shown in Fig. 5. Let the random destination node is selected is '4'. The first child chromosome (child1) is formed by appending the path for destination '6' from initial solution 1 and path for destination '4' from initial solution 2. The second child chromosome (child2) is formed by appending the path for destination '6' from initial solution 2 and path for destination '4' from initial solution 1.

The newly generated solutions are evaluated on the basis of both bandwidth and constraint. In this case the bandwidth values for child 1 and child 2 are computed as 0.38 and 0.46 respectively.

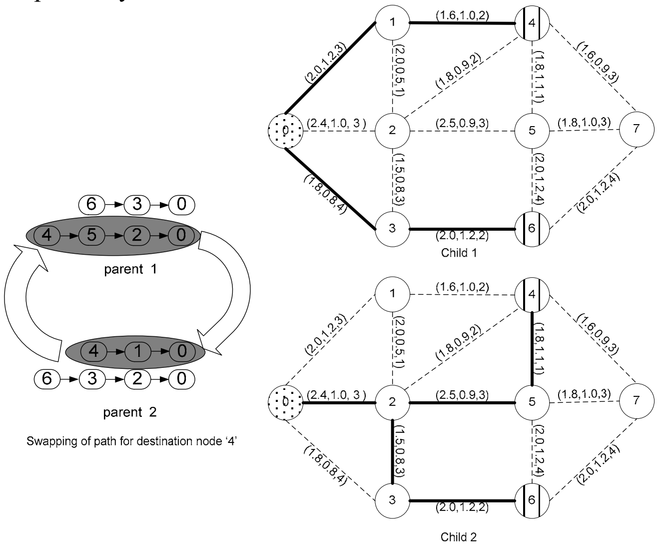

Fig. 5 Generation of multicast trees by swapping of path of a random destination node between parent multicasts trees (crossover operation)

E. Mutation

The mutation is another important operator in the genetic algorithm. The mutation alters one individual, parent, to produce a single new individual. The mutation operation avoids the search turning into a primitive random search. In the proposed algorithm a random destination node is selected and sub-path is swap by randomly generated sub-path to get new multicast tree. The newly generated solution is evaluated on the basis of fitness and constraint.

Let the initial solution 2 as shown in Fig. 4 is selected randomly from the mating pool. The destination node '4' is selected randomly and the path from source to this destination node is replaced by randomly generated path. Correspondingly, the new multicast tree is obtained as shown in Fig. 6. The bandwidth obtained is 0.44 for the offspring resulted by the mutation operation.

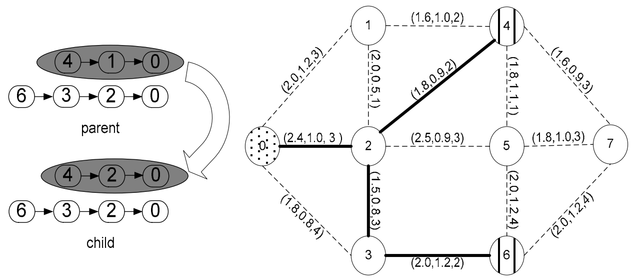

Fig. 6 Generation of multicast tree by swapping the sub-path of a random destination node from parent multicast tree (mutation operation)

IV. Results And Discussion

The study is carried out on number of graphs generated randomly including the 8-node graph described in Fig. 1. The choice of crossover and mutation rates is always critical for the genetic based optimization algorithm. The residual bandwidth optimization, for the 8-node network shown in Fig. 1, has been carried out for nine combinations obtained by crossover rates as 0.9, 0.7 and 0.5 and mutation rates as 0.025, 0.05 and 0.1. Depending upon the number of iterations and the optimum residual bandwidth, the crossover and mutation rates are selected as 0.9 and 0.05 respectively. The maximum number of iterations and the population size are selected as 100 and 25 for various studies.

For the graph described in Fig. 1, the optimal bandwidth is obtained as 0.54 in 5 iterations with maximum end-to-end delay as 7 and maximum delay jitter as 3. Correspondingly, the optimum multicast tree is shown in Fig. 7.

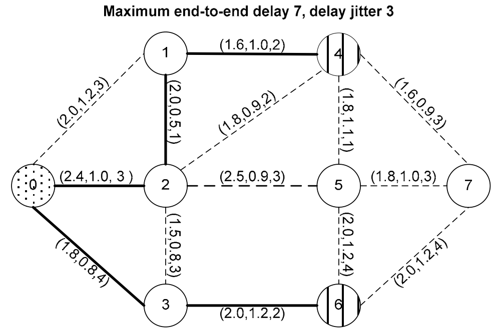

Fig. 7 The optimum multicast tree for an 8-node 14-link network

Various studies are also carried out on a 10-node 24-links random network, whose data is given in Table 1. It is assumed that all links are of equal 2.0 Mbps capacity, whereas the bandwidth utilization of link is varying between 0.5Mbps and 1.5 Mbps and link delay is varying between 1 and 5. The source node 's' is referred as '0' whereas the multicast group representing the set of destinations G is defined as {3, 7, 8}. The effects of change in delay jitter and delay bounds are summarized in Table 2 and Table 3 respectively. The Table 2 details the effect of delay jitter bound for delay bound as 20, whereas Table 3 details the effect of delay bound for delay jitter bound as 10.

As evident from the Table 2 and Table 3, whenever the limits on delay jitter or delay bound are relaxed, the value of optimum bandwidth increases and the convergence is obtained in less number of iterations. The optimal value of residual bandwidth is obtained as 0.62. The relaxing of the limits on delay jitter/delay bound increases the number of alternative paths and thus facilitate the participation of multicast trees which otherwise are infeasible in light of rigid constraints. This suggests that the number of iterations and the value of optimum residual bandwidth depend on delay and delay jitter bounds. The various trees that are resulted for the 10-node network for different delay and delay jitter bounds are given in Table 4.

TABLE 1 Data of 10-Node 24-Link Random Network

Link	Data (ϕ,λ,D)	Link	Data (ϕ,λ,D)	Link	Data (ϕ,λ,D)
0-1	(2.0,1.2,2)	2-5	(2.0,1.2,3)	5-7	(2.0,0.7,5)
0-2	(2.0,0.9,3)	3-4	(2.0,1.0,2)	5-8	(2.0,0.9,1)
0-3	(2.0,0.9,2)	3-5	(2.0,1.4,3)	6-7	(2.0,1.4,2)
1-2	(2.0,1.0,5)	3-6	(2.0,0.9,4)	6-8	(2.0,0.7,5)
1-3	(2.0,1.0,1)	4-5	(2.0,1.3,3)	6-9	(2.0,1.2,2)
1-4	(2.0,0.5,2)	4-6	(2.0,1.2,2)	7-8	(2.0,0.9,4)
2-3	(2.0,0.8,1)	4.-7	(2.0,1.3,1)	7-9	(2.0,1.3,3)
2-4	(2.0,1.4,1)	5-6	(2.0,0.6,1)	8-9	(2.0,0.7,4)

TABLE 2 EFFECT OF DELAY JITTER BOUND (DELAY BOUND : 20)

Delay jitter bound	Iterations	Max. bandwidth
5	68	0.53
8	41	0.53
10	46	0.62
12	14	0.62
15	14	0.62
18	14	0.62

TABLE 3 EFFECT OF DELAY BOUND (DELAY JITTER : 20)

Delay bound	Iterations	Max. bandwidth
10	12	0.51
12	54	0.62
15	14	0.62
18	14	0.62
20	14	0.62
25	14	0.62

As evident from the Table 2 and Table 3, whenever the limits on delay jitter or delay bound are relaxed, the value of optimum bandwidth increases and the convergence is obtained in less number of iterations. The optimal value of residual bandwidth is obtained as 0.62. The relaxing of the limits on delay jitter/delay bound increases the number of alternative paths and thus facilitate the participation of multicast trees which otherwise are infeasible in light of rigid constraints. This suggests that the number of iterations and the value of optimum residual bandwidth depend on delay and delay jitter bounds. The various trees that are resulted for the 10-node network for different delay and delay jitter bounds are given in Table 4.

Table 4 MULTICAST TREES FOR 10-NODE NETWORK FOR DIFFERENT DELAY AND DELAY JITTER BOUNDS

Delay bound	Delay jitter bound	Iteration	Max. bandwidth obtained	Tree
12	5	37	0.48	0→2→4→3 ↓→7 ↓5→8
15	7	31	0.57	0→2→3 ↓→5→7 ↓→6→8
20	10	46	0.62	0→2→3 ↓→5→7 ↓→6→8

The effectiveness of the developed algorithm is studied on different sets of source and destinations for the 10-node network for delay and delay jitter bounds as 20 and 10 respectively. Correspondingly, the statistics are summarized in Table 5. The iterations needed to obtain optimum residual multicast tree increase with the increase in the size of multicast group M.

TABLE 5 SUMMARY FOR DIFFERENT SOURCE AND DESTINATIONS FOR 10-NODE NETWORK

Source node 's'	Number of destinations in multicast group M	Destinations {G}	Iterations
0	1	{9}	4
1	2	{6,9}	7
1	3	{4,7,8}	8
0	4	{3,5,7,9}	12
4	5	{0,3,6,7,9}	20

The number of iterations in obtaining optimum residual bandwidth multicast tree depends on the number of nodes, number of links and the multicast group size. The statistics of such study that are obtained by keeping the delay and delay jitter bounds as 25 and 10 respectively are summarized in Table 6. Although the multicasting is topological problem, more iterations are needed in obtaining optimum multicast tree for increasing size of network in terms of nodes, links and multicast group. This is mainly due to the increase in number of alternative paths for increasing nodes and links. However, if the topological connectivity does not permit many paths, the optimum tree can be obtained in reduced number of iterations.

TABLE 6 STATISTICS FOR DIFFERENT NETWORKS

Node	Links	Multicast Group M	Iterations
5	9	2	15
15	39	4	24
25	69	6	42

V. CONCLUSIONS

An evolutionary algorithm based approach to obtain the optimal multicast tree for the maximization of residual bandwidth utilization under the end-to-end delay and delay jitter bounds is proposed and the effectiveness of algorithm is tested for various weighted random graphs. Encoding of solutions is directly done by node numbers and topological connectivity. The proposed encoding ensures the convergence of the algorithm. The number of iterations in resulting multicast optimum tree increases with the size of network. The higher delay and delay jitter bound facilitate alternative paths and therefore the higher value of optimum bandwidth is resulted compared to the respective bandwidth with rigid constraints.

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