A Proposed Genetic Algorithm for Multicast Routing

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Received on: 10/8/2009
Accepted on: 6/5/2010

Abstract

Many Internet applications (such as video conferences) are one-to-many or many-to-many, where one or multiple sources are sending to multiple receivers. These applications need certain Quality of Services to be guaranteed in underlying network. This paper presents a genetic multicast routing algorithm which finds the low-cost multicasting tree from a designated source to multiple destinations with Quality of Service (*QoS*) (i.e., bandwidth and end-to-end delay) constraints. Experimental results show that the proposed algorithm finds the minimum-cost multicast routing tree while satisfying *QoS* constraints and could finally converge to the global optimal solution for a large-scale network.

Keywords: Multicast; Routing; Genetic Algorithm (*GA*); Cost; Quality of Service (*QoS*) (bandwidth and end-to-end delay constraints)

مقترح خوارزمية جينية لتوجيه البث الخاص بعدة مستقبلين

الخلاصة

ترسل العديد من تطبيقات الانترنيت (مثل المؤتمرات الفيديوية) من مصدر أو عدة مصادر إلى عدة مستلمين. تحتاج هذه التطبيقات إلى جودة خدمات معينة مضمونة في الشبكة الأساسية. يقدم هذا البحث خوارزمية جينية مقترحة لتوجيه البث الخاص بعدة مستقبلين والتي تجد شجرة البث بعدة مستقبلين الأقل كلفة من مصدر معين إلى عدة مستقبلين مع ضوابط جودة الخدمات. تظهر النتائج الاختبارية بان الخوارزمية الجينية المقترحة تجد كلفة شجرة التوجيه للبث الخاص بعدة مستقبلين بالحد الأدنى في حين توافق قيود جودة الخدمة ويمكن أن تتقارب أخيرا إلى الحل المثالي الشامل بالنسبة لشبكة واسعة النطاق.

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https://doi.org/10.30684/etj.28.15.8
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I. Introduction

The growth in network applications, such as video conferencing has generated new requirements for communication models such as multicast communication. Multicast is a kind of group communication which requires simultaneous transmission of messages from a source to a group of destinations.

A) Background

Kadaba Bharath-Kumar and Jeffrey M. Jaffe [1] studied algorithms for effectively routing messages from a source to multiple destination nodes in a store-and-forward computer network. The focus was on minimizing the Network Cost, its measure is also compared to the Destination Cost. M. Hamdan and M.E. El-Hawary [2] presented a constrained multicast routing scheme based on *GA*. They considered two constraints, a constraint on end-to-end delays and a bounded delay variations. Lin Chen et al [3] proposed a new multicast routing algorithm based on *GA* that takes delay and also degree constraints into account to construct Degree-Delay Constrained least-cost multicast routing Tree. It is clear from the wide variety of anticipated multicast applications that no single tree can satisfy requirement of all of them, therefore the proposed *GA* is capable of providing *QoS* to their members and play an important role in future communications networks.

B) Objectives

The objectives of this paper are to propose a genetic multicast routing algorithm that discovers a multicast tree from a designated source to a set of destinations that discovers a minimum cost multicast tree and satisfies the bandwidth and end-to-end delay constraints. Then building a simulator to implement and study the designed algorithm. Results show that the algorithm is capable of being implemented practically on real world networks.

C) Organization

The rest of the paper is organized as follows; In Section II, a network model, *QoS* constraints and Objective Function are explained. The proposed *GA* for the multicast routing with several key components is described in Section III. In Section IV, Experimental Results with various network topologies and the performances of the proposed *GA* are explicated. After that, Analysis of Results is discussed in Section V. Finally, Section VI presents Conclusions and Suggestions for Future Work.

II. Network Model

The network can be represented as the undirected and connected weighted graph $G = (V,E)$ where V is the set of network nodes (vertices), E is the set of connected links (edges). A link $e_{ij} \in E$ connecting nodes v_i and v_j will be denoted by (v_i,v_j). It is characterized by an ordered triple (B_{ij},D_{ij},C_{ij}) representing capability of bandwidth, delay and cost between nodes v_i and v_j. A multicast tree is defined by $T = (V_T,E_T)$, where $V_T \subseteq V$, $E_T \subseteq E$, and $T \subseteq G$, and there exists a path $P_T(s,v_k)$ from the source node s to each destination node $v_k \in D = \{v_1,v_2,\ldots,v_n\}$ in T. Here, D is the set of destinations and n is the number of destinations.

- *QoS* constraints

1 – Bandwidth: It is required that the minimum value of link bandwidth in the multicast tree T must be greater than or equal to the required bandwidth (B_{req}), [4] along the path from a source node s to each destination node $v_k \in D$. That is:

$$B_T = \min_{(i,j)|e_{ij} \in E_T} B_{ij} \geq B_{req} \qquad (1)$$

2 – Delay bound: The maximum value of path delays (from a source to each destination) is smaller than or equal to the acceptable path delay (D_{acc}), i.e.,

$$D_T = \max_{(k|v_k \in D)} \left(\sum_{\substack{(i,j)|e_{ij} \\ \in P_T(s,v_k)}} D_{ij} \right) \leq D_{acc} \qquad (2)$$

- Objective Function

Tree Cost: The total cost (T_c) of multicast tree must be minimized (while satisfying the above two *QoS* constraints):

$$T_c = \min \sum_{(i,j)|e_{ij} \in T} C_{ij} \qquad (3)$$

III. The Proposed *GA* for Multicast Routing

The proposed *GA* technique for multicast routing is described in this section. It consists of several key components: initial whole population, encoding and representation, fitness function, selection, and variation operators (i.e., mixing, crossover, repair function, and mutation). Fitness function and genetic operators iterate until the termination conditions are satisfied. Overall procedures of the proposed *GA* are depicted in Figure (1).

A) Initial Whole Population

In order to generate good solutions, random initialization is used to initialize the population. Physically, the random initialization chooses genes (nodes) from the topological information database in a random manner during the encoding process. When initializing the population, the algorithm starts from the source. Source is a constant in the program. The algorithm selects one of the neighbors provided that it has not been picked before. It keeps doing this operation until it reaches all destinations.

B) Encoding and Representation

A chromosome consists of sequences of positive integers that represent the Identifications (*IDs*) of nodes through which a routing path passes and variable-length chromosomes are employed. Each locus of the chromosome represents an order of a node (indicated by the gene of the locus) in a routing path. The gene of first locus in each chromosome is always reserved for the source node. Each chromosome in population denotes a multicast tree. Obviously, a chromosome represents a candidate solution for the multicast routing problem since it guarantees a path between the source node and any of the destination nodes.

C) Fitness Function

The proposed fitness function only involves network link costs, in other words, the objective function (3) is considered. The *QoS* constraints are directly incorporated in the course of constructing and assembling the trees. Given an initial population $H = \{h_1, h_2, \ldots h_N\}$, the fitness value of each chromosome is computed as follows: Let T_k be a multicast tree represented by the chromosome h_k, and C_{T_k} be the sum of the link costs of the tree T_k. The fitness value of the chromosome h_k, $F(h_k)$, is given by

$$F(h_k) = [C_{T_k}]^{-1} = \left[\sum_{(i,j) \in T_k} C_{ij} \right]^{-1} \qquad (1)$$

D) Selection

The selection (reproduction) plays an important role in improving the average quality of the population by giving the high-quality chromosomes a better chance to get copied into the next generation. The selection of chromosome is based on the value of fitness function. Ordinal selection such as tournament selection (in the tournament selection, individuals of a population are divided into sub-groups and next the individual with the best fitness is selected out of each of the sub-groups [5]) is preferable in this regard to prevent premature convergence.

E) Mixing

A dimensional mixing model was interrelated with a selection model to identify regions of the proposed *GA* parameter combinations where the proposed *GA* is predicted to reliably converge to the global optimum. By mixing operation, the crossover operator now transfers complete multicast trees from both parents to form an offspring that has a higher number of multicast trees than either one of its parents.

F) Crossover

The crossover operator is used to reorganize the arrangement of genes in the chromosome for the next generation. It processes the current solutions so as to find better ones. In the proposed *GA*, the crossover produces diverse chromosomes by exchanging the partial chromosomes (i.e., sub-trees) without positional consistency of potential crossing sites between two chromosomes. This dictates one-point crossover as a good candidate scheme for the proposed *GA*. Two (dominant) chromosomes chosen for crossover should have at least one common gene (node) except for source and a set of destination nodes.

G) Repair Function

The repair function treats infeasible chromosomes that contain lethal genes that possibly form loop. Infeasible chromosomes may occur by variation operator (i.e., crossover), that violates the constraints and tree conditions and thus it needs fixing. It must be denoted that none of the chromosomes of the initial population or after the mutation is infeasible because once a node is chosen, it is excluded from the candidate nodes forming the rest of the multicast tree.

H) Mutation

The population undergoes mutation by an actual change or flipping of one of the genes of the candidate chromosomes. Physically, it generates an alternative partial route from the mutation node to the chosen destination according to mutation probability. After mutation, the upper partial route represents the surviving portion of the previous route and it produces a new path from the mutation node to the selected destination.

IV. Experimental Results

The proposed *GA* initializes the population size according to the equation: $k \times |V|^{1.5}$, where k is a fixed number and is set to 3 and if the value of $|V|^{1.5}$ is not positive integer, the proposed *GA* takes the integer number from it and will be increased by one. Pair-wise tournament selection (i.e., tournament size = 2) without replacement is employed [6]. In all the experiments, the crossover probability is set to 0.75 and the mutation probability is set to 0.15. Each experiment is terminated when all the chromosomes in the population have converged to the same solution [7]. Both bandwidth and delay constraints are set to 10.

Network topologies with 10 nodes and 30 links, 20 nodes and 118 links, and 40 nodes and 472 links are generated to test the proposed *GA*. Each link has a bandwidth, a delay, and a cost is associated with them. The performances of it with 10, 20, and 40 nodes and increasing number of destination nodes from 2 to 7, 2 to 11 and 4 to 17 are shown in Figures (2), (3) and (4) respectively.

V. Analysis of Results

The quality of solution is taken into account in Figures (2), (3), and (4) for a range of networks with 10, 20, and 40 nodes. This algorithm finds a multicast routing tree in a limit time. The multicast group is randomly selected in the graph and the size of it is considered 20%-70%, 10%-55%, and 10%-42.5% for 10, 20, and 40 nodes network topologies respectively.

In most cases, the bandwidth is increased and the delay is decreased as the number of destinations increases. Sometimes the cost of tree is decreased because there are the same intermediate nodes among the destination nodes which can be used to reach these destination nodes. The number of generations is increased as the number of destination nodes increases which is a normal case. The results show that the proposed *GA* gets close to optimum very quickly. This is a promising result for the proposed *GA* because the encoding method does not allow of any redundancy when constructing a multicast tree due to preventing reentry of the nodes that are already included in the current sub-tree, the genetic operators newly designed provide higher exploratory power and a fair measure of genetic diversity.

VI. Conclusions and Suggestions for Future Work

The proposed *GA* reaches a good solution much faster than initialized randomly when the initial chromosomes are generated with preference for genes of shorter routes and can be easily extended to solve the multiple constrained multicast problems. It can find a minimum-cost multicast tree with *QoS* constraints from a designated source to multiple destinations. The synergy achieved by integrating the new components (i.e., representation, mixing, crossover, repair function, and mutation) provides a search capability that results in improved quality of the solution and enhanced rate of convergence.

QoS multicast routing is the foreland research project in networks and information technology. The algorithm can expand to multi-constraints *QoS* multicast routing problem based this algorithm and can be developed in order to apply the algorithm to dynamic multicast routing problems. The fitness function of the chromosome can be changed and other parameters may be taken into account when calculating this function. The delay constraint can be improved by taking delay variation with end-to-end delay as two important metrics for *QoS* besides bandwidth constraint. The proposed *GA* can be enhanced and take the average degree of the node into account which aims to construct a low-cost shortest path tree by considering link sharing between different destinations.

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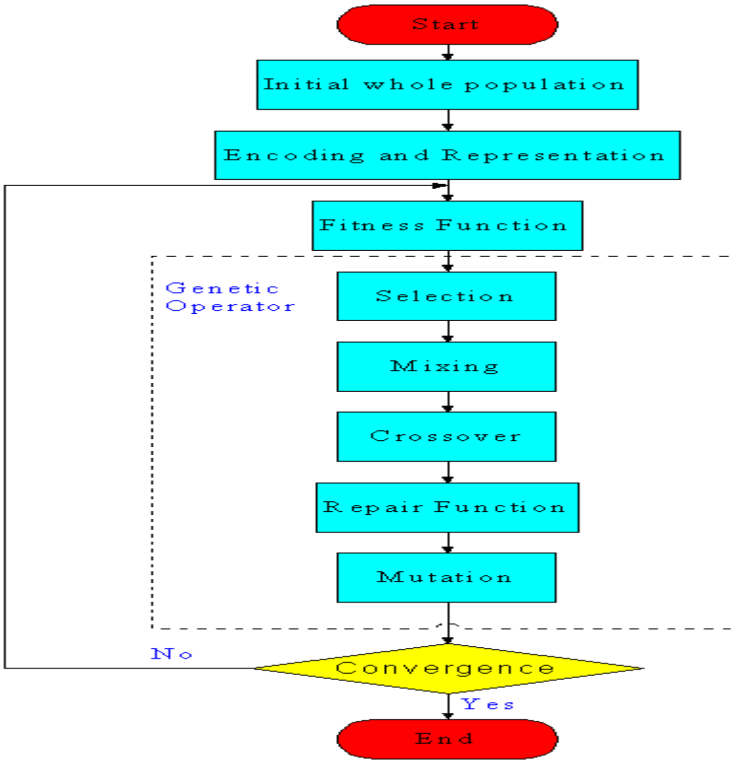

Figure (1) Overall procedures of the proposed *GA*

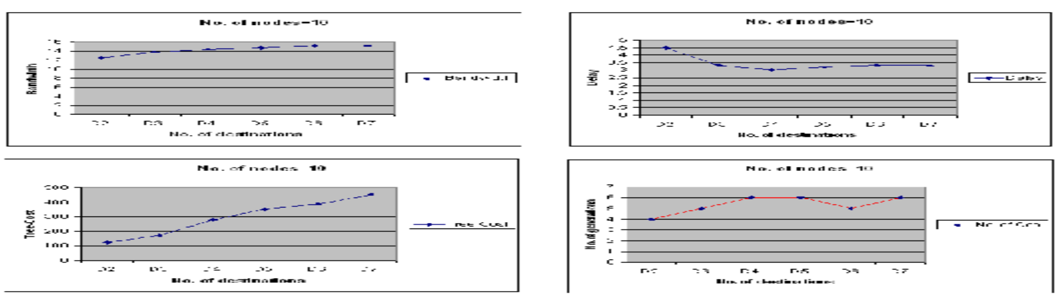

Figure (2) Performance of the algorithm with 10 nodes

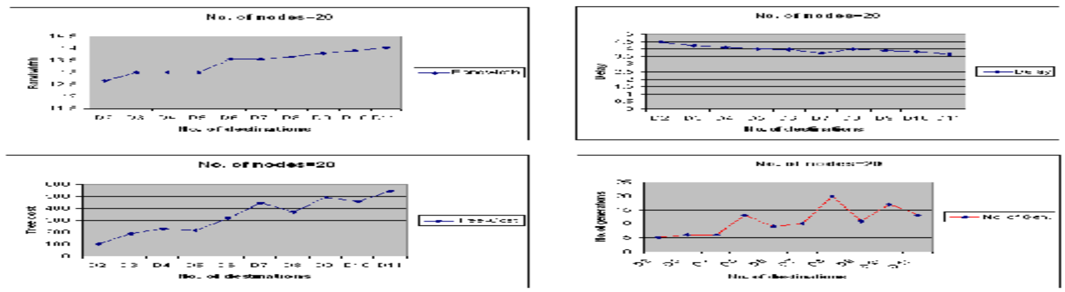

Figure (3) Performance of the algorithm with 20 nodes

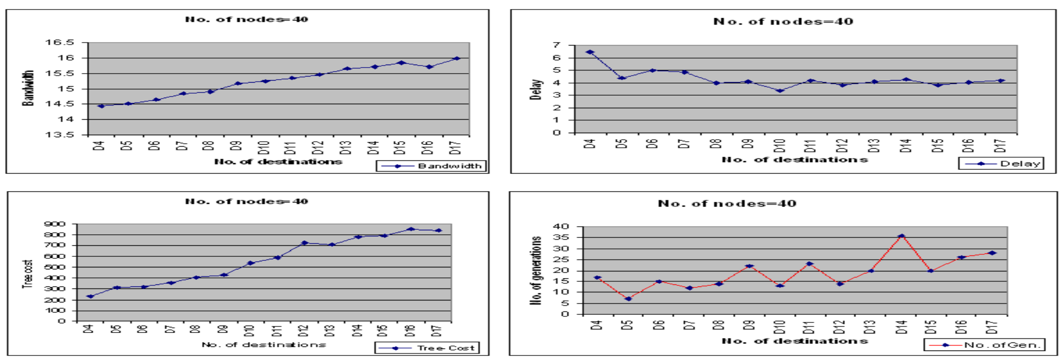

Figure (4) Performance of the algorithm with 40