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# QoS Routing in Multicast Networks Based on Imperialism Competition Algorithm

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**Abstract**

At the age of multimedia communications and high speed networks, multicast is one of the mechanisms which we can employ to enjoy the power of internet. On the other hand, increase in real-time multimedia applications, has emerged the need for Quality of Service (QoS) in multicast routing. Two important parameters in QoS-supported multicast communications are bandwidth and end- to-end delay. The main goal of multicast routing is finding a least-cost tree which is called Steiner Tree. This problem belongs to NP-Complete problems, so it is necessary to use heuristic-based or artificial intelligence – based algorithms to solve it.
Imperialism Competition Algorithm (ICA) is a method in evolutionary mathematics which finds the optimum solution for different optimization problems.
In this paper, we use ICA to solve QoS multicast routing problem and create the minimum Steiner tree while considering QoS parameters such as end-to-end delay and bandwidth.

***Keywords:*** *Multicast, Quality of Service, Minimum Steiner Tree, Imperialism Competition Algorithm*

## 1. Introduction

At the age of multimedia communications and high speed networks, multicast is one of the mechanisms which we can employ to enjoy the power of internet. When more than one receiver would like to receive from one or more sender(s) in a transmission, multicast would be the best and most efficient solution [1].

To support the efficiency of multimedia group communications, the most important phenomenon which should be considered is the multicast routing with support of QoS constraints. A QoS supported multicast routing algorithm should create a multicast routing tree which is able to send information from a source to all of the destinations with guarantee of QoS. Such tree transmits the data flow of each link only once and just produces copies of flows when it is needed. QoS requirements for various multimedia applications are different; for example, in transmission of multimedia flows in video conference, each link should guarantee an amount as minimum available bandwidth. Also, end-to-end delay is another important parameter to guarantee that any data which has been sent by source would be received by destination during a certain deadline. In addition of QoS parameters, the tree cost is usually a level to measure the utilization of network resources and counts as a deterministic criterion to evaluate multicast trees. A least-cost tree can transmit multicast messages with minimum network resources (such as node processor and buffer and bandwidth) utilization [1].

The problem of finding the least-cost multicast tree is called Minimum Steiner Tree problem which is a subset of tree optimization problems. Furthermore, in most of the multicast algorithms, it's necessary to consider one or more QoS parameters. These algorithms are convertible in to constrained Steiner tree problem which is a subset of tree optimization problems (with constraints). The problem of finding Steiner tree is one of the famous NP-Complete problems [2].

Numerous heuristic-based algorithms have been proposed to solve the Steiner tree problem. Some of most well-known methods in this field are: KMB[1] [3], RS[2] [4] and TM[3] [5]. There are also some heuristic-based algorithms to solve the multicast routing problem with least cost and considering end-to-end delay. Some of the most popular of them are: KPP[4] [6] and BSMA[5]

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[1] Kou-Markowsky-Berman
[2] Rayward-Smith
[3] Takahashi-Matsuyama
[4] Kompella-Pasquale-Polyzes

[7]. Originally, KPP is the developed version of KMB algorithm which considers the delay constraint during the creation of complete graph. According to Salama et al. [8] studies, the best deterministic heuristic delay constrained low cost algorithm to solve the Steiner tree problem is BSMA. This algorithm replaces a route among existing routes with a new low-cost route considering the delay constraint. This procedure continues until the final tree cost doesn't decrease anymore. It's notable that all proposed heuristic algorithms consider only one QoS parameter without paying attention to considering more QoS parameters. In addition, the simulation results given by Salama et al. shows that none of proposed heuristic algorithms can provide optimized Steiner tree in optimized execution time.

Since deterministic heuristic algorithms for QoS multicast routing are usually very slow, methods based on computational intelligence such as Genetic Algorithm [9], Simulated Annealing [10], Ant Colony Optimization [11],[12] and Taboo Search [13], [14] may seem more suitable.

Also, recently there have been studies in this field using competitive co-evolutionary algorithm [15], firefly algorithm [16], and combination of genetic algorithm and ant colony optimization [17].

In this paper, we use Imperialism Competition Algorithm (ICA) [18] to find low-cost Steiner tree with considering end-to-end delay and bandwidth constraints. ICA is a method in evolutionary computation field which searches for optimized solution for different optimization problems. With the mathematical modeling of social-political process, this algorithm tries to provide a method to solve optimization problems. Considering answers as countries, this algorithm tries to improve these answers in a repetitive process and finally finds the optimum answer of problem.

In this paper we try to employ ICA to find a new method for solving the multicast routing problem with considering delay and bandwidth constraints. In proposed method, firstly, the potential answers will be considered as countries and organized in a structure called "Imperial" which is included an "empire" and some "colonies". Then, these countries start their competition to reach to the least cost using operations like "assimilation" and "revolution", after running of algorithm for a specified number of iterations, finally we will have a country which has the least cost and can consider it as the problem answer.

[5] Bounded Shortest Multicast Algorithm

The reminder of this paper is organized as follows: The problem description and formulation is given in section 2. In section 3, we briefly study the ICA. We then introduce the proposed method to find Steiner tree in chapter 4.chapter 5, gives the performance evaluation of the proposed method and finally section 6 concludes this study.

## 2. Problem description and formulation

In this section, we describe and formulate an example of multicast routing problem with considering delay and bandwidth constraints. A network is modeled as a directed connected graph G= (V, E), where V is a finite set of vertices (network nodes) and E is the set of edges (network links) representing connection of these vertices. Let $n = |V|$ be the number of network nodes and $l = |E|$ be the number of network links. The link e = (u, v) from node $u \in V$ to node $v \in V$ shows the existence of a link e'= (v, u). Three non-negative real valued functions are associated with each link $e \in E$: cost $C(e): E \rightarrow R^+$ which represents the utilization of the link that should be optimized, Delay $D(e): E \rightarrow R^+$ which is considered to be the sum of switching, queuing, transmission and propagation delays, and available bandwidth $B(e): E \rightarrow R^+$ which represents the residual bandwidth of the link. Let $s \in V$ be the source node and $M \subseteq V - \{s\}$ be the set of destination nodes. A multicast tree $T(s, M)$ is a sub graph of G ($T \subseteq G$) routed at s and spanning all the members of M. We refer to M as the destination group and $s \cup M$ as the multicast group. Furthermore, the multicast tree may contain relay nodes, called Steiner nodes.

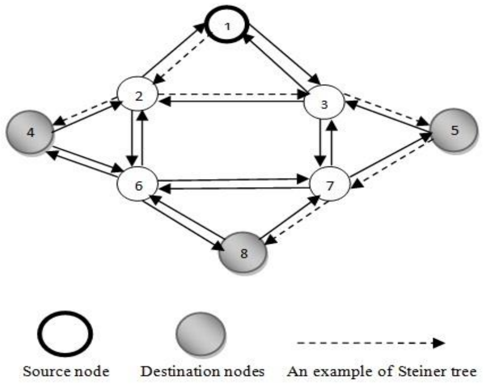


Fig.1. An example of network graph, multicast group and Steiner tree

A Steiner node is a node that belongs to the multicast tree but not to the multicast group. Assume $P_T(s, d)$ represents a unique path in the multicast tree from the source node s to the destination node $d \in M$. The total cost of the multicast tree T(s, M) is defined as the sum of the costs of all links in tree:

$$C(T(s,M)) = \sum_{e \in T(s,M)} C(e) \quad (1)$$

The total delay of the path $P_T$(s, d) in the multicast tree T(s, M) is defined as the sum of link delays along the path:

$$D(P_T(s,d)) = \sum_{e \in T(s,M)} D(e) \quad (2)$$

The bottleneck bandwidth of the path $P_T(s,d)$ is simply defined as minimum residual bandwidth at any link along the path:

$$B(P_T(s,d)) = \min\{B(e), e \in P_T(s,d)\} \quad (3)$$

Assume $\Delta_b$ represents the end-to-end delay constraint and $\Gamma_b$ the bandwidth constraint of each destination node. The bandwidth-delay-constrained least-cost multicast problem is defined as minimizing C(T(s, M)) while:

$$\begin{cases} D(P(s,d)) \le \Delta_b & \forall d \in M \\ B(P(s,d)) \ge \Gamma_b & \forall d \in M \end{cases} \quad (4)$$

Figure1 illustrates an example of a network graph, a multicast group, and a Steiner tree.

## 3. Imperialism Competition Algorithm

Imperialism Competition Algorithm (ICA) is a method in evolutionary computations which searches for optimum answer in different optimization problems [18]. With the mathematical modeling of social-political process, this algorithm tries to provide a solution to solve mathematical optimization problems. This algorithm belongs to evolutionary optimization algorithms.

Like other evolutionary algorithms, this algorithm starts with creating a number of random initial population which is called “countries” here. Some of the best members of the population (which are called “elites” in Genetic Algorithm) are selected as “empires” and the residual members are considered as “colonies”. Each “imperial” includes an empire and a number of colonies. According to their power, the empires try to assimilate their colonies in a specific manner. Also, with a predetermined probability, sudden changes in features of a country may end to a phenomenon called “Revolution”. Revolution rescues the algorithm from sticking in local optimization valleys and sometimes improves the situation of a country.

The total power of an imperial depends on both parts which have formed it: empire (as central core) and its dependent colonies. Mathematically, this dependency has been modeled by sum of empire power added by a percent of average power of its colonies.

After formation of initial imperials, the imperialism competition begins between them. In this competition, any imperial that couldn’t increase or at least prevent reduction of its power, would be eliminated from the contest. Hence, the survivance of an imperial depends on its capability to assimilate other imperials colonies and possess them. As the result of imperialism competitions, stronger imperials will be more powerful and weaker imperials will be eliminated. To gain more power, Imperials have to improve their colonies. After a while, colonies approaches to empires and a sort of convergence will occur. The ultimate level of imperialism competition happens when there would exist a unique imperial which owns colonies which are statistically very similar to their empire.

Generally, the advantages of ICA are briefed as:

- The novelty of algorithm basic idea
- Equal or even better capability for optimization in comparison with other algorithms
- The acceptable speed for discovering the optimum answer

## 4. Proposed Method

In this section we introduce and describe the proposed method which we have developed using ICA. Firstly, we define problem assumptions, then study the proposed cost function and finally, describe the proposed algorithm.

We assume the network is modeled as a weighted graph which is shown by G (V, E) which V is a set of vertices (network nodes) and $E \subset V \times V$ is a set of edges (network links). The weight of each link is defined by 3 parameters: Cost (C), Delay (D) and Bandwidth (B).

We also assume that $M \subseteq V$ is multicast group and $s \in V$ is the source node.

### 4.1 Pre-processing phase

The pre-processing phase is the start point of the proposed algorithm. In this phase, we can remove all the links which their bandwidths are less than the bandwidth constraint. If in the refined graph the multicast group nodes are in a connected sub-graph, then this sub-graph will be used by algorithm as the network topology, else this topology does not satisfy the bandwidth constraint which makes the source node negotiate with the corresponding application to relax the bandwidth threshold. Furthermore, this phase can reduce the size of the network graph by removing all degree-one nodes which do not belong to the multicast group.

### 4.2 Initial countries and start of algorithm

To solve this problem, we use connectivity matrix to represent the countries; so, existence an edge

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between any two nodes in graph is showed by 1 and lack of edge is showed by 0. To create initial countries, or in the other word, initial Steiner trees, we us Floyd algorithm which is a dynamic algorithm and finds the shortest paths between source and any of destinations, then make the initial trees. To start the algorithm, we create $N_{country}$ initial countries randomly. Then, we select best $N_{imp}$ members which have the least cost, as empires and consider the rest of them as colonies and divide colonies between empires in a way that any colony would be assigned to an empire.

### 4.3 Cost Function

To solve the problem using the proposed algorithm, we need to search for the best country. In fact, finding such a country means to find the best amounts for problem parameters which produce least amount of cost function. So, we need to define cost function in a way that includes all important parameters in multicast routing with consideration of QoS constraints. As we mentioned, these parameters are: Cost (C), Delay (D) and Bandwidth (B). Therefore, we proposed this cost function:

$$F(T(S,M)) = \sum_{e \in T(S,M)} C(e) \times \prod_{d \in M} \phi_D(D(P(s,d)) - \Delta_d) \times \prod_{d \in M} \phi_B(B(P(s,d)) - \Gamma_b) \quad (5)$$

$$\phi_D(z) = \begin{cases} 1 & z \le 0 \\ \rho_1 & z > 0 \end{cases} \qquad \phi_B(z) = \begin{cases} \rho_2 & z < 0 \\ 1 & z \ge 0 \end{cases}$$

Where, $\Delta_d$ and $\Gamma_b$ indicate delay and bandwidth constraints and $\phi_D$ and $\phi_B$ are penalty functions for delay and bandwidth violation respectively. $\rho_1$ and $\rho_2$ are penalty degrees for delay and bandwidth constraint violations. We have tried different values of $\rho_1$ and $\rho_2$ to find which values would provide best optimality. The best result was achieved by setting them to 1.5.

### 4.4 ICA steps to find minimum Steiner tree

After specifying of empires and colonies and formation of initial imperials, main operations of ICA begin as follows:

1. **Assimilation:** in this step, in each imperial, the empire tries to assimilate colonies toward itself; hence, the connectivity matrix entries of colonies should be changed in a way that calculated cost based on cost function approaches to empire cost. To implement this phenomenon, we select random entries of each colony connectivity matrix and replace them by same entries in empire connectivity matrix.
2. **Revolution:** to increase the probability of finding the optimum answers and to avoid sticking in local optimality trap which may be caused by using assimilation operation, it's necessary to extend the search space; so we will use revolution and move each country to a quite new position without considering the empire situation. To implement this operation in this case, we use "NOT" operand on random entries of connectivity matrix of colonies and empires.
3. **Intra-imperial competition:** in this step, in each imperial, the cost of empire will be compared with the cost of each colony and if there is a colony which has less cost than it's empire, that colony will become the new empire of that imperial.
4. **Inter-imperials competition:** in this step, first, the total cost of each imperial will be calculated. This cost includes sum of empire total cost and a ratio of the average cost of all the colonies of an imperial.

   $$F_{total}(IMP) = f(imp) + \zeta \ mean(f(col)) \quad (6)$$

   Then, after the comparison of this amount between all the imperials, the weakest imperial which has the most cost, will be determined. Afterwards, a colony from that imperial will randomly be selected and moved to another imperial which has been determined by roulette wheel selection based on its total cost. After this transfer, if the weakest imperial has no colony anymore, its empire will be also moved to another imperial.
5. **Report the best result:** in this step, the best result that means the country with least cost will be reported as the answer. If the termination terms wouldn't be met, the steps 1-4 will be repeated.
6. **Termination terms:** we can consider several terms to conclude the algorithm, such as: achieving to a predetermined goal, remaining only one imperial as the result, reaching to a specified number of iterations, or not having improvement in result during a specified number of iterations. In this case, we have considered a specific number for iterations and after that algorithm announces the best result as answer and will be concluded.

## 5. Performance Evaluation

In this section, we have performed comprehensive simulation studies on various random generated networks with 10-100 nodes to evaluate the performance of the proposed ICA-based algorithm. To generate random networks, we have used a random graph generator based on the Salama graph generator [8]. In all of these networks, the size of the multicast group has been considered equal to 30% of the number of network nodes.

Table 1, shows the average of the simulation results regarding total tree cost for the proposed algorithm and also some taboo search based-algorithm like Ghaboosi-haghighat and Armaghan-haghighat and some heuristic-based algorithms such as KPP1, KPP2 and BSMA. We see that the average tree cost has been improved in comparison by heuristic-based methods, but it is approximately equal to taboo-search-based methods.

Table1: Average of simulation results for some random graphs

| ***Class of algorithm*** | ***Algorithm*** | ***Average tree cost*** |
|---|---|---|
| ICA | Proposed method | 782.510 |
| Taboo search | Ghaboosi-Haghighat [13] | 781.802 |
| Taboo search | Armaghan-Haghighat [14] | 767.255 |
| Heuristic | KPP1 [6] | 950.860 |
| Heuristic | KPP2 [6] | 957.268 |
| Heuristic | BSMA [7] | 915.315 |

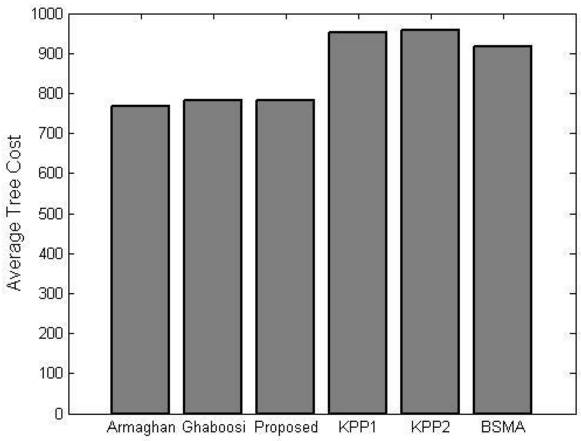


Fig.2 Comparison of average tree cost for some random graphs

## 6. Conclusions

In this paper, we have used ICA to solve the multicast routing problem with consideration of delay and bandwidth constraints and have provided minimum Steiner tree. In proposed method, first in pre-processing phase, all the graph links which their residual bandwidth are less than bandwidth constraint, would be eliminated and If in the refined graph the multicast group nodes are in a connected sub-graph, then this sub-graph will be used by algorithm as the network topology. Then, we create initial countries using Floyd algorithm and start the ICA steps including "assimilation" and "revolution" operations. These steps are repeated for a specific number of iterations and finally the least cost tree which has been found regarding the proposed cost function has been declared as result.

The evaluations and studies we have performed by simulating the proposed algorithm, shows that the final Steiner tree has a minimum cost which is approximately equal to taboo search-based methods and less than heuristic-based methods. Also, this method with considering and studying of a wide range of possible answers and supporting the QoS constraints, provide a reliable and optimum answer.

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