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QOS-based multicast routing using a tree-based imperialist competitive algorithm

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Abstract

Multicast routing based on quality of service (QOS) is one of the basic challenges in networks, especially the future generation of high-performance networks. Multicast routing needs a multicast tree to deliver the multicast packet to the destination. Routing should be realized to increase the lifetime of the network. Finding a multicast tree to satisfy routing constraints including bandwidth and end-to-end delay is considered an NP-complete problem. Therefore, it is not possible to reach the multicast tree in polynomial time. Solving this problem requires intelligent methods. In this study, a new method for tree-based optimization using the imperialist competitive algorithm is proposed to solve the multicast routing problem, paying special attention to delay, cost, and the Steiner tree problem. The proposed method directly transforms the multicast tree into an optimal tree. The proposed method has been implemented in the MATLAB platform and tested on several instances. The results proved the remarkable performance of the proposed method for tree-based multicast routing.

Keywords: multicast routing, tree algorithm, imperialist competitive algorithm, network lifetime

Introduction

Over the past few years, the rapid development of network multimedia technologies has led to the spread of real-time multimedia services such as video conferencing, online games, distance education, etc. in the context of Internet networks. Most of these services require network multicast capability. Multicast refers to the delivery of packets from one source to multiple destinations. In multimedia applications such as audio/visual conferences, the data stream is sent from a source node to a set of destination nodes in a multicast group. The key objective is to maximize multicast throughput between a limited group of specified sources and destinations.

Quality of service requirements in ad hoc networks has several characteristics such as cost, delay, delay variation, packet loss, and hop count. Due to the rapid increase in the demand for multimedia services and the challenges of effective multicast communication, multicast routing problems have recently received the attention of the research community in the fields of computer communication and operational research. The researchers in [1] evaluated the problem by considering bandwidth and delay limitations using a genetic algorithm. Also, the results of the queen bee and genetic algorithms regarding energy-efficient clusters in wireless sensor networks were compared.

Also, multicast routing using an algorithm based on directed graph search called MRASDH has been introduced [2]. The proposed method optimizes the multicast trees directly with the ant algorithm merges all the created subgraphs and forms a new directed graph as a new search space. In the new search space, the simulated annealing (SA) algorithm has been used to develop a multicast tree and provide optimization conditions.

A tree-based DE algorithm is introduced in [3]. The central core of the algorithm is implemented by a tree and reduces the calculation time significantly. The focus of this study has been on the development of a tree-based DE algorithm in multicast routing. It is also assumed that all the destination nodes have the same limits of delay and bandwidth.

In another research, a genetic algorithm for multicast routing in multimedia networks with minimum cost has been introduced. The expanded tree also satisfies the bandwidth and delay constraints. In the presented algorithm, K, the shortest path from the source node to the destination node is used as a gene representation. The simulation results show that the proposed algorithm can find a better solution, faster convergence, and high reliability. Also, the increase in the number of network nodes does not lead to a decrease in the efficiency and capability of the algorithm. The key goal of this study is to develop an algorithm to find multicast paths with bandwidth and delay limitations through simultaneous optimization of end-to-end delay and bandwidth [4].

In another study, the method of obtaining suitable Steiner trees for efficient multicast routing is investigated. First, a new scheme for generating a weighted multicast parameter using an efficient combination of two independent criteria, i.e. cost and delay, is introduced. The proposed approach in this study is called the multicast tree algorithm for the weighted parameter. According to the simulation results, the use of the proposed method has led to the same results as the Steiner tree algorithm. Also, the multicast algorithm has been compared with similar algorithms for known problems [5].

In a paper titled "Swarm intelligence algorithm for QoS-based multicast routing", an intelligent swarm agent based on a hybrid ant colony optimization/particle swarm optimization (ACO/PSO) algorithm is presented to optimize the multicast tree. By generating a huge number of mobile agents in the search space, the algorithm starts. The algorithm guides the movement of agents in a common environment locally, and the global maximum is obtained through the random interaction of agents using the algorithm. The performance of the proposed algorithm in this study has been evaluated through simulation. According to the simulation results, the results of the proposed algorithm are better than those of the compared algorithms [6].

In an article titled "Tree-based chemical reaction optimization algorithm for QoS multicast routing", a chemical reaction optimization (CRO) algorithm for solving multicast routing is presented. In the proposed method, trees are represented as molecules in a chemical reaction. The collision between molecules and the released potential energy affects the optimal results selected. Experiments on different randomly generated networks show that the proposed algorithm works better than other heuristic methods. As mentioned, each tree represents a molecule. Then, ineffective intermolecular collisions on the substrate are considered to produce new molecules. The algorithm ends with the production of the best molecule [7].

In the article entitled "Quality of service in multicast routing using the imperialist competitive algorithm", the problem of multicast routing considering the limitations of delay and bandwidth has been investigated using the optimal Steiner tree. First, in the pre-processing phase, all graph links with remaining bandwidth less than the bandwidth limit can be deleted. If the multicast group nodes are connected to the subgraph, the subgraph is used by the algorithm in the network topology. Then, the primary countries are created using Floyd's algorithm. Subsequently, the stages of imperialist competition, including absorption and revolution operators are launched. After several iterations, according to the cost function, a tree with the lowest cost is found and declared as the final result [8]. In another study, the queen-bee algorithm has been used to create efficient energy clusters in wireless sensor networks. The role of the queen-bee algorithm is similar to the natural role of the queen-bee and has a major contribution to reproduction. To avoid premature convergence and avoid reaching the final optimal solution, a normal mutation rate and a strong mutation rate have been used. This leads to sufficient diversity in the produced offspring and while reaching the optimal solution, it reduces the probability of reaching premature convergence [9].

The proposed protocol in the paper titled "QoS-based multicast routing protocol for network detection using competitive evolution algorithm" is a distributed protocol in which each node maintains only its local information. Routing search is a step-by-step method inspired by the small-world phenomenon that exploits cognitive behaviors to gather experimental route information. Since multicast routing is an NP-complete combinatorial optimization problem, a cognitive evolutionary algorithm is applied to construct the multicast tree. The cognitive evolutionary algorithm uses a new coding method and genetic operators matching the problem. The results show that the proposed method has significant advantages compared to traditional protocols due to the use of cognitive factors [10].

Over the past few years, significant attention of the scientific community has been directed to the development of search and optimization algorithms, including meta-heuristic methods. In this regard, the imperialist competitive algorithm is one of the prominent methods in the field of evolutionary computing to find the optimal answer to various optimization problems. In this algorithm, each country is represented by a vector and represents a point in the n-dimensional space. According to the optimization function, the point with the lowest cost is considered the colonizer, and the rest is the colony. Also, the Steiner tree is the tree with the lowest cost in the network, and the sum of all its weights is minimum. The main advantage of this tree is saving network resources. Finding such a tree in the network is a fundamental challenge. Due to the lack of a definite answer for it, approximate and heuristic solutions are suggested for it. In this study, by presenting a new algorithm based on the imperialist competitive algorithm, a suitable solution for solving the multicast routing problem has been presented. According to the mentioned materials, the innovation aspect of the upcoming research is the use of the imperialist competitive algorithm in solving the multicast tree routing problem. The initial idea to complete the research of this study is inspired by [4] and [1].

The multicast routing algorithm should form a new multicast tree in the shortest possible time. As a result, the speed of the algorithm in finding the multicast tree is a suitable measure for comparing two multicast routing algorithms in ad hoc networks. Multicasting in a communication network means receiving a simple message from an application and delivering a copy of the message to multiple receivers in different locations.

One of these important challenges to achieve this goal is to minimize the network resources consumed by multicasting. Multimedia applications impose new requirements on the network and require relatively high bandwidth for a long time compared to traditional applications. Due to the inclusion of multipoint communication, multicasting tends to involve heavy interactions in the network. Therefore, the implementation of fast multicast routing while meeting QoS requirements is an important research issue. QoS requirements can be categorized in the form of link constraints, route constraints, and delay constraints. The optimization problem with two or more constraints is known as NP-complete.

Due to the rapid development of network and multimedia technology in military, urban, and medical fields, the optimal utilization of network resources has become a necessity. Also, due to the multicast nature of applications, designing efficient algorithms for multicast routing is very important. One of these fundamental questions is how to design a multicast tree. Since finding the optimal multicast tree is an NP-complete problem, it seems useful to use heuristic methods. In this study, a new algorithm based on the imperialist competitive algorithm is introduced as a suitable solution to solve the QOS multicast routing problem.

A proposed algorithm for multicast routing

The proposed method in this research is inspired by the imperialist competitive algorithm, which is a new path in multicast routing based on quality of service. The key objective is to minimize the required resources using the multicast structure. This goal is achieved by minimizing the cost of the routing tree. The Steiner tree problem is an attempt to find a tree with the least cost in the network. The sum of all weights of this tree must be minimal and connect one or more sources to one or more destinations. The weight values are applied to the edges of the tree and can include one or more quality of service constraints such as bandwidth, delay, and cost. It has also been proven that finding such a tree in the network is an NP-complete problem.

In the proposed method, each multicast tree is considered as a country. First, a matrix is developed based on the number of different destinations. Each row is considered a distinct path from the source to the destination. The fitness function is calculated for each tree. If the value of the fitness function is equal to or better than the best value, the said tree is selected as the optimal tree and recorded in the array. We are looking for the best path from the source to the destination to achieve the main goal of solving the multicast tree problem. The steps of generating the optimal tree considering the fitness function are as follows.

a) Create network topology

A random network is developed using mesh topology.

b) Initial population

By using the depth-first search algorithm, all possible trees are formed. Existing trees form the initial population. Each tree is considered as a country. A tree (country) is randomly selected and its fitness value is determined. Therefore, the fitness function is calculated once for each tree.

c) Choosing a tree (country)

The fitness function is calculated for each tree (country). If the value of the fitness function is equal to or better than the best value, the said tree is selected as the optimal tree and recorded in the array.

d) Fitness function

The fitness function of the proposed algorithm is calculated as follows.

$$F = \alpha \times \frac{1}{cost(T_i)} + \beta \times \frac{1}{delay(T_i)} + \mathrm{n} \times \frac{1}{dj(T_i)} + m \times 1/pl(T_i) \qquad (1)$$

where α, β, n, and m are the weight coefficients of the fitness function. The condition for stopping the algorithm is to reach the maximum number of iterations. According to Relation (1), a higher value means a better multicast tree. Therefore, a country with the lowest cost is suitable for us. After building a new optimal tree and calculating the value of the objective function for the new tree, it is determined whether the created tree is the optimal tree of the set of trees or not. How to combine trees in the algorithm and choose different routes in the network topology is described below in the form of an example.

Figure (2) shows a network equipped with 20 nodes. Node 1 is considered as the source node and Nodes 16, 9, and 15 are considered as destination nodes. From Node 1 to Node 16, three routes are marked in black. Also, from Node 1 to Node 9, two routes are highlighted in green. Two routes are marked in red from Node 1 to Node 15. We consider each of the existing trees as a country.

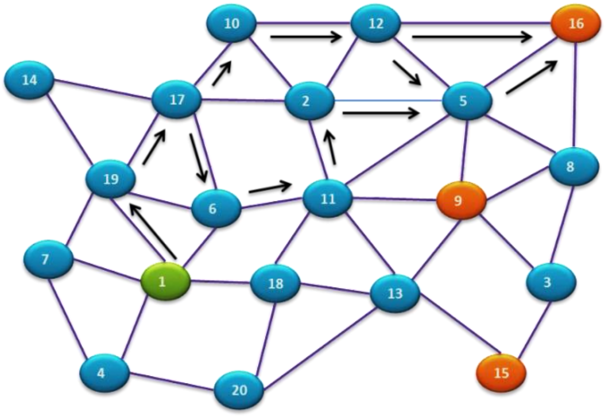

Figure 2: Multicast routes in the proposed method

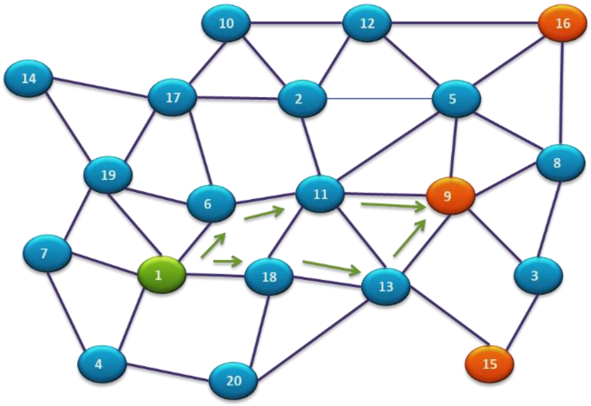

Figure 3: Routes identified in the proposed method

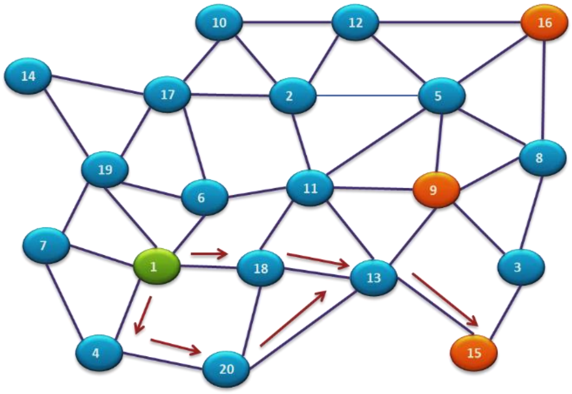

Figure 4: The specified routes in the proposed method

Number of nodes in the network = {20}, source node = {1}, destination node = {16, 9, 15}

The following array shows the available routes for each of the destinations. There are three routes between Nodes 1 and 16. There are two routes between Nodes 1 and 9 and two routes between Nodes 1 and 15.

Routes between Node 1 and 16 = 3, {1, 19, 17, 10, 12, 16}, {1, 19, 17, 6, 11, 2, 5, 16}, {1, 19, 17, 10, 12, 5, 16}

Routes between Nodes 1 and 9 = 2, {1, 6, 11, 9}, {1, 18, 13, 9}

Routes between Nodes 1 and 15 = 2, {1, 18, 13, 15}, {1, 4, 20, 13, 15}

The number of possible trees in the network = 3*2*2=12

A maximum of 12 possible trees are conceivable in the network. To obtain new trees, we calculate one row of the array for all the rows in the array using Relation (2). To move the algorithm away from the local optimum, a new tree is generated based on Relation (2) for the algorithm to reach the global optimum. Suppose that countries *i* and *j* are represented as $T_i = \{T_{i1}, T_{i2}, \dots, T_{in}\}$ and $T_j = \{T_{j1}, T_{j2}, \dots, T_{jn}\}$, respectively. The production of a new tree is realized as follows.

$$T_i = T_i + (T_j - T_i)(\alpha + \beta)$$

According to Relation (2), each route is calculated separately. Also, α and ß represent constant coefficients. To calculate (Tj-Ti) if the obtained value is less than the minimum available route; we consider the same minimum value of the route. For the higher value obtained (in the example above, it should be more than 3), we consider the same value of the higher route. After obtaining a new tree, the fitness function is applied to it. Then all the trees are sorted from the lowest to the highest value. Then the new tree is compared with the previous trees. If the obtained fitness function is equal to or better than the best value, it is selected as the optimal tree and recorded in the array. This procedure continues until finding the final optimal tree for multicast routing. The QOS routing process consists of two phases. In the first phase, the set of routes from the source node to all destinations is calculated. In the second phase, the optimal multicast tree is found according to the proposed algorithm.

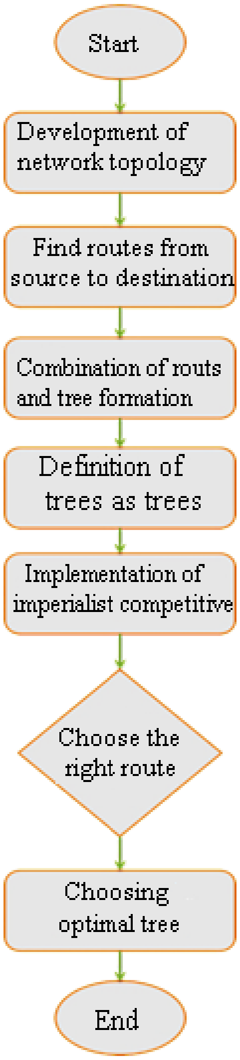

Figure 5: Flowchart of the proposed method

Network simulation is adapted from the method proposed by Waxman. The network has 25 nodes. The result of the proposed method is a tree with the lowest cost with delay constraints. However, our study focuses on a multicast routing algorithm to satisfy four or more criteria. MATLAB 2015 software was used for the simulation. The multicast nodes are randomly selected using the algorithm. Also, the source and destination nodes and the weights of the edges of the multicast tree are created randomly. For comparison, genetic and queen-bee algorithms have been used. The cost of the tree is calculated based on the randomly generated mesh network. In each iteration, a mesh tree (network of nodes) is generated and each algorithm is processed on that tree.

Results

The outputs obtained from the simulation of the proposed method were compared with the results of the queen-bee and genetic algorithms in the MATLAB environment. According to the simulation results, with the increase in the number of multicast group nodes, the execution time of the imperialist competitive algorithm grows more than the genetic optimization and queen-bee algorithms. However, the imperialist competitive algorithm regarding the relative error percentage, the quality of the resulting answers, and the time to reach the global optimal answer has a more suitable performance than other genetic algorithms and the queen-bee.

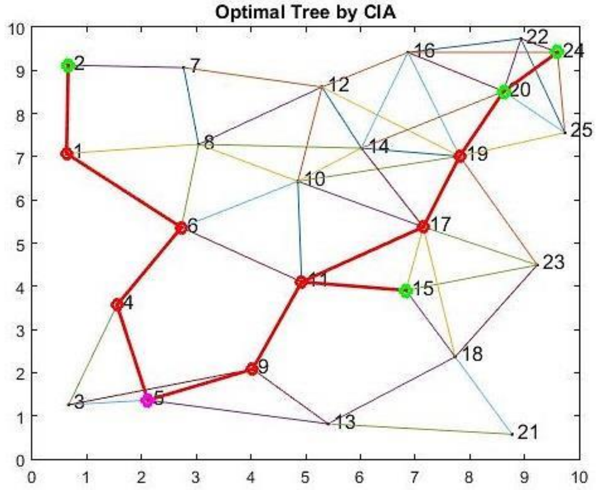

Figure 6: Development of a multicast tree using the imperialist competitive algorithm

Figure (6) shows the optimal multicast routing in the imperialist competitive algorithm. Node 2 is selected as the source. Also, Nodes 24, 20, and 15 are included as destinations. The optimal tree produced by the imperialist competitive algorithm has fewer routes than the genetic and queen-bee algorithms.

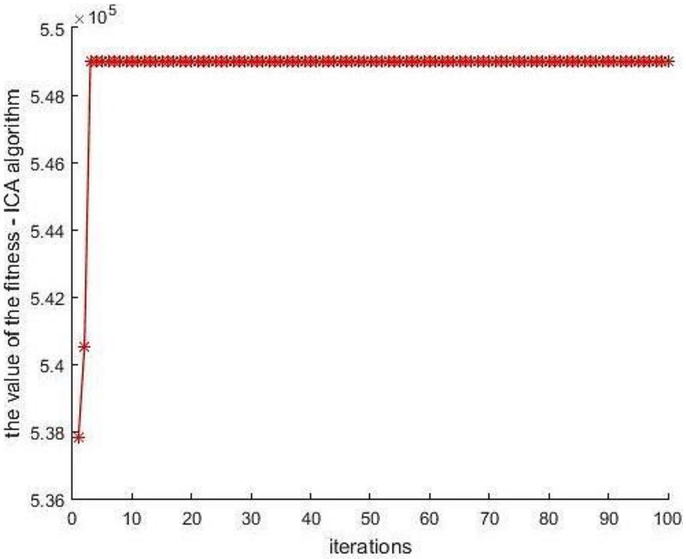

Figure 7: The fitness function of the imperialist competitive algorithm

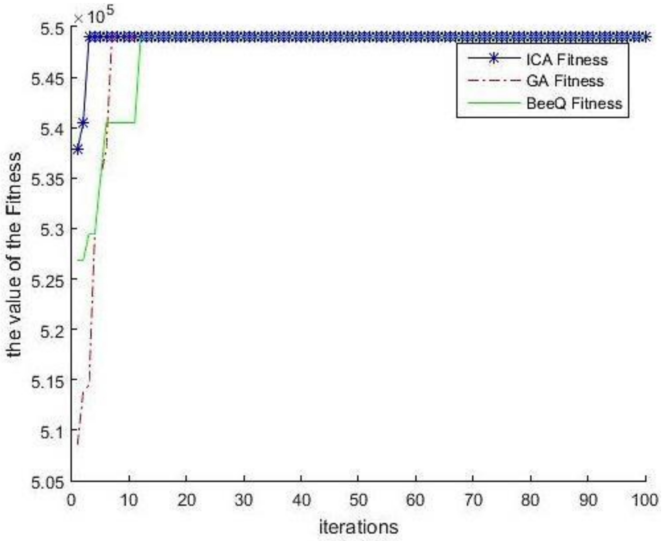

Figure 7: Comparison of the fitness function of imperialist competitive algorithm with genetic and queen-bee algorithms

Figure 7 compares the value of the fitness function of the imperialist competitive algorithm with genetic and bee algorithms. The proposed algorithm has a faster convergence than genetic and queen-bee algorithms. As shown in the figure, the value of the fitness function in the proposed algorithm does not decrease with the increase in the number of rounds. By increasing the value of the fitness function, the multicast tree becomes more favorable. When the generation process grows, the value of the function tends to a constant. This trend shows the effective convergence of the algorithm.

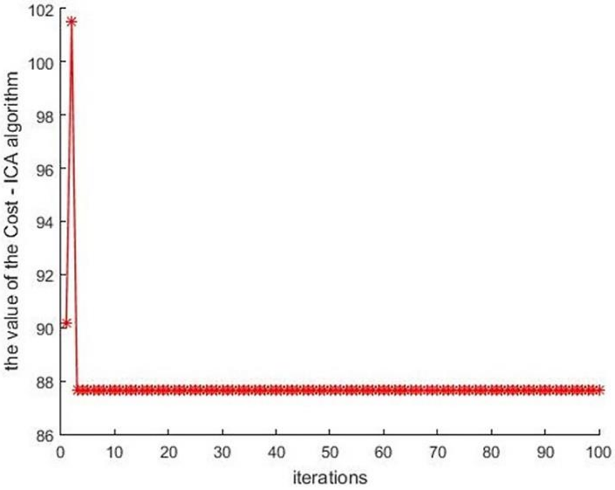

Figure 8: Cost of imperialist competitive algorithm

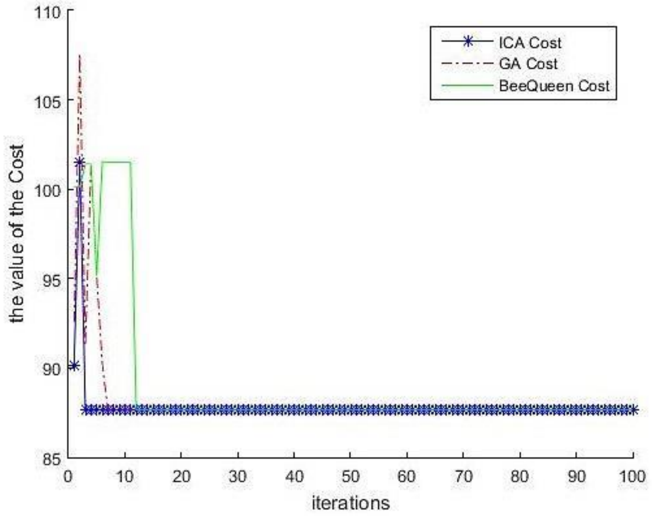

Figure 9: Cost comparison of imperialist competitive algorithm with genetic and queen-bee algorithms

Figure (9) compares the tree construction cost of the imperialist competitive algorithm with genetic and queen-bee algorithms. According to the plots, the proposed algorithm costs less in the early rounds than the genetic and queen-bee algorithms. In addition, the proposed algorithm can find the optimal solution faster. Although the cost curve tolerates more fluctuations at the beginning of the process, it eventually reaches a lower fixed value. Also, the proposed method can realize a routing based on service quality. The response of the proposed algorithm on large-scale networks is shorter than other algorithms. Also, the cost of making an acceptable tree is taken into account.

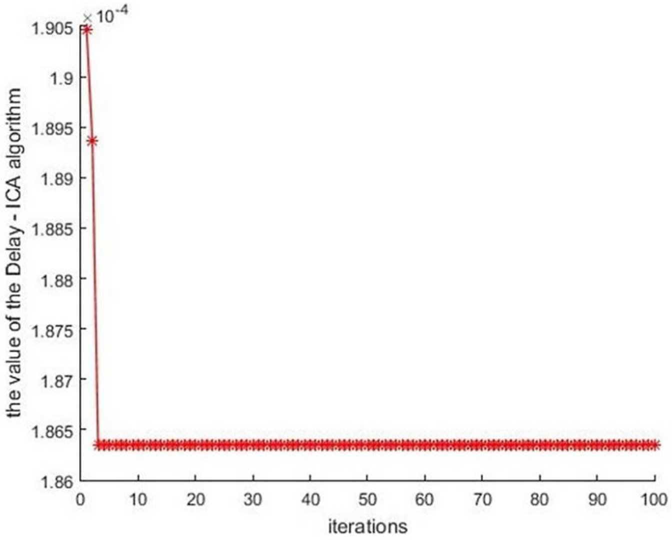

Figure 10: Delay of imperialist competitive algorithm

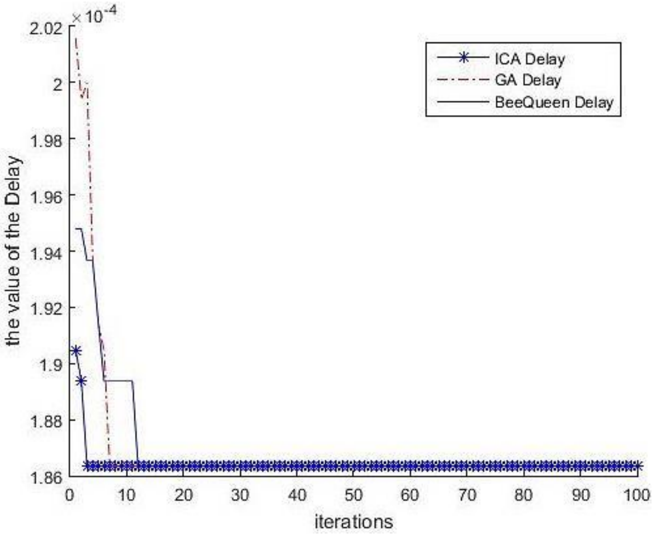

Figure 11: Comparing the delay of the imperialist competitive algorithm with genetic and queen-bee algorithms

Figure 11 compares the delay of the imperialist competitive algorithm with genetic and queen-bee algorithms. The proposed protocol has less delay than other genetic and queen-bee algorithms. The role of delay reduction is more prominent when sending packets with higher rates. The key reason for delay reduction is the reduction of tree depth.

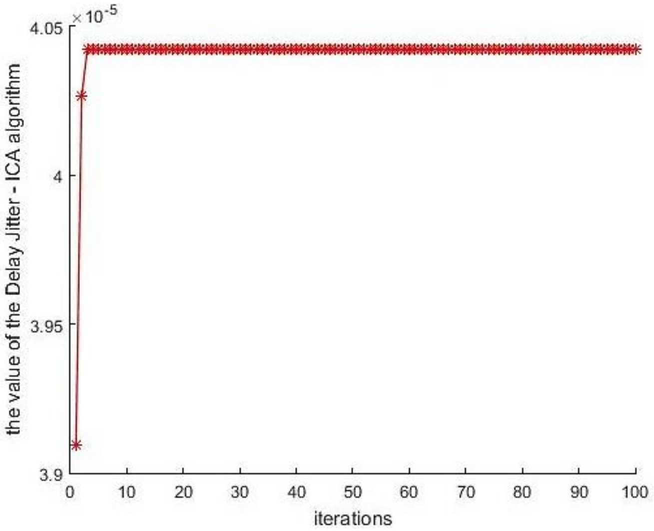

Figure 12: Delay fluctuations in imperialist competitive algorithm

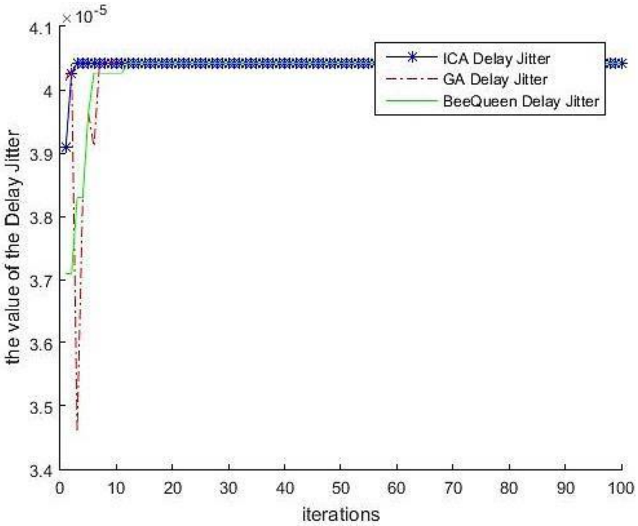

Figure 13: Comparison of delay fluctuations of the imperialist competitive algorithm with genetic and queen-bee algorithms

Figure 13 compares the delay fluctuations of the imperialist competitive algorithm with genetic and queen-bee algorithms. The delay fluctuations of the proposed algorithm are less than genetic and queen-bee algorithms. The imperialist competitive algorithm can find the optimal solution faster. Although the delay curve of this algorithm tolerates more fluctuations at the beginning of the process, it eventually reaches a lower fixed value.

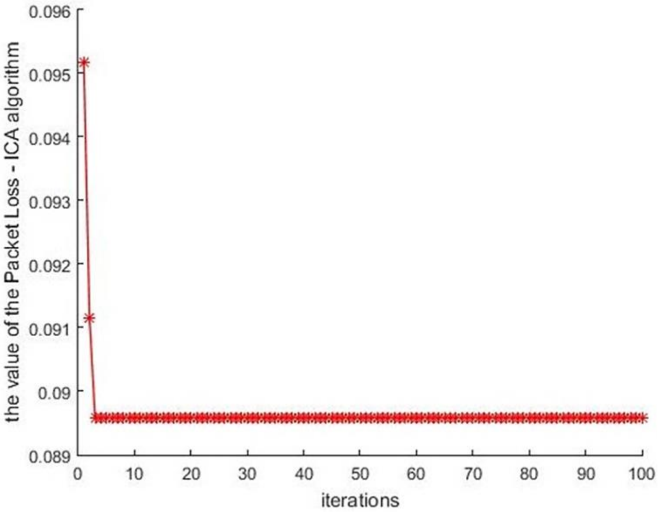

Figure 14: The number of lost packets in the imperialist competitive algorithm

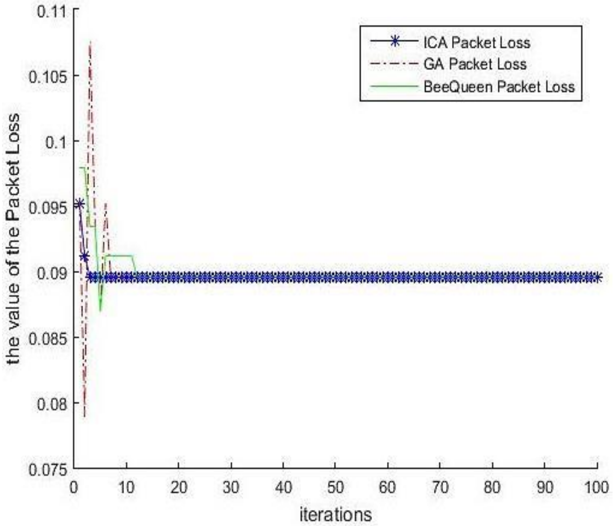

Figure 15: Comparison of the number of lost packets of the imperialist competitive algorithm with the genetic and queen-bee algorithms.

Figure 15 compares the number of lost packets of the imperialist competitive algorithm with genetic and queen-bee algorithms. The number of missing packets is higher in the first rounds of tree generation. Although this measure decreases in the second round, it stabilizes in the fourth round. The value of this measure is higher for genetic and queen-bee algorithms and reaches a constant value in the ninth and twelfth rounds, respectively.

Conclusion

So far, many heuristic and non-heuristic algorithms have been proposed for the multicast routing problem. In most of these algorithms, the only goal of minimizing the cost has been mentioned. In most of these algorithms, the cost function is equal to the efficiency of network resource consumption as one of the prominent parameters in traffic engineering. Several other studies have considered criteria such as bandwidth, end-to-end delay, etc., and have proposed good algorithms in this regard. Nevertheless, there is a need for scalable algorithms to provide a suitable answer in an acceptable time. The proposed method tries to select the optimal tree by choosing the appropriate routes between the source and the destination and applying the imperialist competitive algorithm. First, the number of available routes between the source and destinations is determined. Then the upper and lower limits are applied to the routes. The lower and upper limits are the value of 1 for each route and the number of available routes, respectively. After applying the imperialist competitive algorithm, the optimal route and the optimal tree are selected. According to the simulation results, it has been proven that the proposed algorithm does not get stuck in the local optimum. With the increase in the number of multicast group nodes, the execution time of the imperialist competitive algorithm increases more than the genetic optimization and queen-bee algorithms. However, the imperialist competitive algorithm regarding the percentage of relative error, the quality of the resulting answers, and the time to reach the global optimal answer has a more suitable performance than other genetic algorithms and the queen bee.

Multicast routing based on quality of service (QOS) is one of the basic challenges in networks, especially the future generation of high-performance networks, and many methods have been used to solve this problem. This inspired us to review and analyze the latest methods in this field and use the results obtained in future research. During the research process, many ideas and opinions crossed our minds but were not implemented due to lack of time. These cases are recommended as suggestions for future research, including further investigation of the issue and increasing the reliability of the results with the help of other routing algorithms, including cuckoo and ant colony, and comparing the results with the upcoming research. Also, the investigation of routing algorithms and the design of optimal hybrid algorithms are recommended for future works.

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