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A hybrid ACO/PSO based algorithm for QoS multicast routing problem

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Abstract Many Internet multicast applications such as videoconferencing, distance education, and online simulation require to send information from a source to some selected destinations. These applications have stringent Quality-of-Service (QoS) requirements that include delay, loss rate, bandwidth, and delay jitter. This leads to the problem of routing multicast traffic satisfying QoS requirements. The above mentioned problem is known as the QoS constrained multicast routing problem and is NP Complete. In this paper, we present a swarming agent based intelligent algorithm using a hybrid Ant Colony Optimization (ACO)/Particle Swarm Optimization (PSO) technique to optimize the multicast tree. The algorithm starts with generating a large amount of mobile agents in the search space. The ACO algorithm guides the agents' movement by pheromones in the shared environment locally, and the global maximum of the attribute values are obtained through the random interaction between the agents using PSO algorithm. The performance of the proposed algorithm is evaluated through simulation. The simulation results reveal that our algorithm performs better than the existing algorithms.

1. Introduction

The rapid development in network multimedia technology has enabled more and more real-time multimedia services such as videoconferencing, online games, and distance education to become the mainstream Internet activities. These services often require the underlying network to provide multicast capabilities. The multicast refers to the delivery of packets from a single source to multiple destinations. These real-time applications have a stringent requirement of QoS parameters like bandwidth, delay, jitter, and so on to ensure smooth, consistent, and fair transmission to the receivers. The central problem of QoS routing is to set up a multicast tree that can satisfy certain QoS parameters. However, the problem of constructing a multicast tree under multiple constraints is NP Complete [1]. Hence, the problem is usually solved by heuristics or intelligent optimization.

In recent years, some meta-heuristic algorithms such as the ant colony algorithm [2–9], genetic algorithm [10–12], particle swarm optimization [13–17], and Tabu search [18,19] have been adopted by the researchers to solve the multi-constrained QoS routing problems.

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In [2], an intelligent routing algorithm ANTNET based on ant colony algorithm was proposed. Their algorithm has some attractive distribution features and it can find a near-optimal path from the source node to each destination node. It also provides the required results in simulation. Although the ANTNET is a unicast routing algorithm, it can be easily applied to multicast routing with some modifications. In spite of the said merits of the ANTNET, it suffers from a serious drawback i.e. the slow convergence rate. Another ant intelligence algorithm was introduced in [3] for the computation of the QoS multicast tree. A tree growth based ACO algorithm (TGBACA) has been proposed in [8]. It generates a multicast tree in the way of tree growth and optimizes the ant colony parameters through their most efficient combinations. The major weakness of the ant colony algorithm is that it converges slowly at the initial step and takes more time to converge. This happens due to improper selection of the initial feasible parameter [3]. The overhead also increases due to merging and pruning of the trees.

Subsequently, the genetic algorithm (GA) was used to find a multicast tree satisfying the constraints of bandwidth and delay with least cost [10–12]. The GA has three operators: selection, crossover, and mutation. The individuals are stored in connective matrices by adopting the binary coding system. The initial colony is generated randomly without considering QoS constraints. The selection operation adopts Roulette wheel algorithm to select the best individuals from the parent generation to pass onto the child generation. Then, the crossover operation is used to find out the fittest among the best. A penalty function is adopted to solve QoS constraints in the multicast trees, which do not satisfy QoS constraints. Although sometimes the algorithm's performance is observed to be satisfactory, still it encounters some faults, such as the local search ability, premature convergence, and slow convergence speed. Further, the genetic algorithm does not assure to find a global optimum. It happens very often when the populations have a lot of subjects.

In [13–17], researchers have proposed some PSO algorithms to solve QoS constraint routing problem. The PSO algorithm proposed in [14] solves the QoS multicast routing problem and can obtain a feasible multicast tree by exchanging the paths. This algorithm can converge to the optimal or near-optimal solution with lower computational cost. Another algorithm based on the concept of quantum mechanics named as Quantum-Behaved Particle Swarm Optimization (QPSO) was proposed in [15]. Here, the proposed method converts the QoS multicast routing problem into integer programming problem and then finally solves using the QPSO. The QPSO finds the path from the source node to each destination node and constructs the tree by merging the paths. A tree based PSO has been proposed in [17] for optimizing the multicast tree directly. However, its performance depends on the number of particles generated. Another drawback of the said algorithm is the merging of multicast trees. The elimination of directed circles and nesting of directed circles are also very complex and are considered as some of the limitations of the PSO [17].

In recent days, many researchers have solved the QoS constrained multicast tree using Tabu search [18,19]. A Tabu search method was proposed in [18] to search for the multicast tree with the least cost that satisfies the constraints of bandwidth and delay. This algorithm obtains a complete graph of all group members at the initial step and obtains the initial Steiner tree via the generated tree of the complete graph. In this way, the k-shortest paths replace the edges to find the chances of getting better results. The method mentioned above is similar to the method of path combination. However, it does not operate directly on the multicast tree. This weakness makes it impossible to eliminate the constraints of conventional multicast routing algorithms. Hence, there arises a need to proceed further and do more amount of work in searching paths and integrating the multicast trees.

In this paper, we propose a hybrid ACO/PSO algorithm based on the swarming agent architecture for QoS multicast routing. Our work is inspired by the swarming agent algorithm proposed by Brueckner and Parunak [20] for distributed data pattern and Meng [21] for Proteomic Pattern detection of ovarian cancer. In our work, a large amount of mobile agents are generated in the search space. Two collective and coordination process for the mobile agents are proposed. One is based on the ACO [8] algorithm for guiding the agents' movements by pheromones in the shared environment locally and the another is based on the PSO algorithm [17] for obtaining the global maximum of the attribute values through the random interaction between the agents.

The rest of the paper is organized as follows: A mathematical model is proposed to model a computer network in Section 2. The proposed algorithm and its working principles are presented in Section 3. The results of the simulation are presented in Section 4. Finally, the Section 5 concludes the paper.

2. Mathematical model

This section is devoted toward development of a mathematical model and problem statement to be used in the next section.

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* $e = (u,)$ from node $u \in V$ to node $v \in V$ implies the existence of a link $e' = (, u)$ from node v to node u. Four non-negative real value functions are associated with each link $e(e \in E)$: cost $C(e)$: $E \rightarrow R^+$, delay $D(e)$: $E \rightarrow R^+$, loss rate $L(e)$: $E \rightarrow R^+$, and available bandwidth $B(e)$: $E \rightarrow R^+$. The link cost function, $C(e)$, may be either monetary cost or any measure of resource utilization that must be optimized. The link delay, $D(e)$, is considered to be the sum of switching, queuing, transmission, and propagation delays. The link loss rate, $L(e)$, is the packet loss rate on the receiving end on link e. The link bandwidth, $B(e)$, is the residual bandwidth functions. $D(e)$, $L(e)$, and $B(e)$ define the criteria that must be constrained (bounded). Because of the asymmetric nature of the communication networks, it is often the case that $C(e) \neq C(e')$, $D(e) \neq D(e')$, $L(e) \neq L(e')$, *and* $B(e) \neq B(e')$.

A multicast tree $T(s, M)$ is a subgraph of G spanning the source node $s \in V$ and the set of destination nodes $M \subseteq V - \{s\}$. Let $m = |M|$ be the number of multicast destination nodes. We refer to M as the destination group and $\{\{s\} \cup M\}$ the multicast group. In addition, $T(s, M)$ may contain relay nodes (Steiner nodes), the nodes in the multicast tree but not in the multicast group. Let $P_T(s, d)$ be a unique path in the tree T from the source node s to a destination node $d \in M$.

We now introduce the parameters that characterize the quality of the multicast tree below.