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# MOEAQ: A QoS-Aware Multicast Routing algorithm for MANET

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ABSTRACT

Multicast routing is regarded as a critical component in networks especially the real-time applications become increasingly popular in recent years. This paper proposes a novel fast multi-objective evolutionary algorithm called MOEAQ for solving multicast routing problem (MRP) in MANET. The strengths and limitations of the well-known multicast model are analyzed firstly in this work. Specifically, the "Greedy" and "family competition" approach are integrated into MOEAQ to speed up the convergence and to maintain the diversity of population. The theoretical validations for the proposed method are presented to show its efficiency. After that, a CBT-based improved protocol is then proposed to simplify the MRP, and finally, the performance of MANET scaled from 20 to 200 nodes with different types of service is evaluated by OPNET, experimental results show that the proposed method is capable of achieving faster convergence and more preferable for multicast routing in MANET compared with other GA-based protocol well-known in the literature.



## 1. Introduction

Multicast routing has drawn a lot of attention in recent years, since it enables a source to send messages to multiple destinations concurrently. The wireless communication technologies and mobile devices have realized the important and useful applications of mobile ad hoc network (MANET) with greatly advancement. Multicast routing plays a critical role in the transmission of information, such as video and other streaming data. Nevertheless, the main difficulty in designing a routing protocol for mobile ad hoc networks is the dynamical topology which results from the random movement of mobile nodes within the source's transmission range. MANET, which is fundamentally different from conventional infrastructure-based networks, is self-configuring and formed directly by a set of mobile nodes. In MANET, the heterogeneity of networks and destinations makes it difficult to improve bandwidth utilization and service flexibility. Therefore, mobility of hosts (nodes) makes the design of multimedia distribution jobs greatly challenging.

Up to now, various works involved focus on design multicast routing algorithm. An early summary of problems and general technical solution related to multicast communication were given by Diot, Dabbous, and Crowcroft (1997). Hanzo and Tafazolli (2007) and Chen and Heinzelman (2007) present a survey of multicast routing under certain QoS constraints solutions for MANET. As an NP-Complete problem, to develop different types of heuristic algorithm for calculating near-optimum paths with multiple QoS constraints is a research focus. For example, Wang, Cao, Cheng, and Huang (2006) investigate three representative intelligent computational methods (genetic algorithm, simulated annealing and Tabu search) to construct the QoS multicast trees to support multimedia group communication separately; the proposed algorithms consider both the end-to-end delay constraint and network resource requirement; the simulation evaluates the performance of three heuristics on a small-scale real-world multimedia communication network and a randomly generated large-scale network, and then concludes that genetic algorithm shows the best performance in terms of the solution quality. In 2008, Qu, Zhao, Zhao, Zhang, and Shu (2008) propose a set of node-based rate constraints to model the interference relationship among nodes in a wireless ad hoc network and to provide rate constraints for its QoS flows, they demonstrate that, the algorithm can always admit the feasible flows as well as make full use of the bandwidth resource. Zahrani, Loomes, Malcolm, and Albrecht (2006, 2008) import logarithmic simulated annealing (LSA) as pre-processing of GA; the algorithm utilizes the partially crossover operation (PMX) under the elitist model and the landscape analysis is presented to estimate the depth of the deepest local minimal in the landscape generated by the routing tasks and the objective function; experimental results show that the algorithm is effective on the randomly generated networks. Yang, Xu, Li, and Liu (2004) and Ikeda et al. (2006) focus on creating a robust path to find solution for specified networks; the genetic algorithm is proposed and, respectively, the individuals of the population are represented by trees, algorithm uses the single point crossover and a mutation operation where the "tree junctions" are chosen randomly, the algorithm employs the elitist

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model where the individual with the highest fitness value in a population is left unchanged in the next generation, the simulation results show that the algorithm is reasonably fast on small and medium size networks. Differ from the above network architecture, Rango, Tropea, Santamaria, and Marano (2007) and Mala and Swlvakumar (2006) refer a scheme called Core Based Tree (CBT) with genetic algorithm which provides a new way for realizing multicast routing protocol in wireless networks, however, it needs much running time.

The remainder of the paper is organized as follows. In Section 2 we state some basic conceptions of multi-objective optimization and give the mathematical description for problem. A QoS-Aware Multicast Routing architecture is given in Section 3. We outline the design of proposed algorithm in Section 4. Section 5 analyses the properties of our method. Section 6 implements the proposed method into a QoS-Aware multicast protocol. The simulation results and performance evaluation are shown in Section 6 and the last section presents our conclusion.

## 2. Notations and problem formulation

To begin with we will introduce some basic conceptions of multi-objective optimization before we describe the problem that would help us know the model thoroughly.

### 2.1. Basic conceptions

**Definition 1** (*Multi-objective optimization problem, MOP). The* MOP consists of $n$ decision parameters, $k$ objective functions and m constraints, without loss of generality

$$\begin{array}{ll} \text{Maxmize} & y = f(x) = (f_1(x), f_2(x), \ldots, f_k(x)) \\ \text{Subject to} & e(x) = (e_1(x), e_2(x), \ldots, e_m(x)) \leqslant \mathbf{0} \end{array}$$

where $\boldsymbol{x} = (x_1, x_2, \ldots, x_m) \in \Omega$, $\boldsymbol{y} = (y_1, y_2, \ldots, y_n) \in \Phi$. $\boldsymbol{x}$ is decision vector, $y$ is objective vector, $\Omega$ denotes the decision space formed by $\boldsymbol{x}$, $\Phi$ denotes the objective space formed by $y$.

**Definition 2** (*Pareto Dominance ). A* vector $\boldsymbol{a} = (a_1, a_2, \ldots, a_n)$ is said to dominate $\boldsymbol{b} = (b_1, b_2, \ldots, b_n)$ if and only if $a$ is partially less than $b$, i.e.

$$\forall i \in \{1, 2, \ldots, n\}, a_i \leqslant b_i \wedge \exists j \in \{1, 2, \ldots, n\}, \quad a_j < b_j.$$

**Definition 3** (*Pareto Optimal ). A* decision vector $\boldsymbol{x}_b$ is said to be Pareto Optimal if and only if there is no $\boldsymbol{x}_a \in \Omega$ where $F(\boldsymbol{x}_a) = \boldsymbol{a} = (a_1, a_2, \cdots, a_n)$ dominates (use Definition 2's scheme) $F(\boldsymbol{x}_b) = \boldsymbol{b} = (b_1, b_2, \cdots b_n)$.

**Definition 4** (*Pareto Front). The* set of all Pareto Optimal decision vectors is called the Pareto Optimal set of the problem and the corresponding set of objective vectors is called Pareto Front.

As we know, most of problems in the world are known as nonlinear problems. In a linear problem, each component is independent, so that any improvement to any one part will lead to an improvement of the entire system. But few real-world problems like this, while most of real world problems are nonlinear, one component changing may have ripple effects on the entire system, and thus we should treat the problem as a multi-objective optimization model.

### 2.2. Problem formulation

A network can be modeled as an undirected graph $G = (V, E)$, where $V$ is the set of nodes that represent routers and $E$ is the set of arcs (arcs represent path between nodes). Each link between two nodes is bi-directional, it means that if there is a link $e = (v, u)$, the link $e' = (v, u)$ also exists. We employ the metrics of *bandwidth*$(e)$, *delay*$(e)$, packet *loss*$(e)$ ratio and delay *jitter*$(e)$, which could describe the QoS request of most services from our previous study, to evaluate each link $e$ (Liu, Tang, Wang, & Sun, 2005). Let $p(s, d)$ be a path from the source node $s$ to the destination $d$, the total bandwidth of the path $p(s, d)$ is the minimum of bandwidth of all links along $p(s, d)$ and it is denoted as *Bandwidth*$(p(s, d))$

$$Bandwidth(p(s,d)) = \min_{e \in p(s,d)} [bandwidth(e)] \tag{1}$$

$$Delay(p(s,d)) = \sum_{e \in p(s,d)} delay(e) \tag{2}$$

$$Loss(p(s,d)) = 1 - \prod_{e \in p(s,d)} (1 - loss(e)) \tag{3}$$

$$Jitter(p(s,d)) = \max[Delay(p(s,d))] - \min[Delay(p(s,d))] \tag{4}$$

QoS multicast routing problem can be defined as follows

$$\min F = \min\{-F_1, F_2, F_3, F_4\} \tag{5}$$

where

$$\begin{cases} F_1 = \min\limits_{e \in p(s,d)} [Bandwidth(e)] \\ F_2 = \sum\limits_{e \in p(s,d)} Delay(e) \\ F_3 = 1 - \prod\limits_{e \in p(s,d)} (1 - (Loss(e)) \\ F_4 = \max[Delay(p(s,d))] - \min[Delay(p(s,d))] \end{cases} \tag{6}$$

In contrast, this model imports a scalarization scheme to depict the problem rather than to aggregate the multi-metric into a single value. Ikeda et al. (2006) describe the relationship between Pareto solution and the solution space (see Fig. 1). Fig. 1 indicates that solutions obtained by GA are rare in the Pareto solution space. It can be predicted that we will get no solution in the Pareto solution space if the coefficients are not appropriate. Due to contradiction among metrics, GA will make only one of them prone to optimum.

Accordingly, it is improper to aggregate the multi-metric into a single value among multi-objective problem, and thus our definition for solving multicast problem is more preferable.

## 3. QoS-Aware Multicast Routing architecture

Fig. 2 illustrates the change of topology of MANET. It is more complex to construct a Steiner tree for the group with dynamic

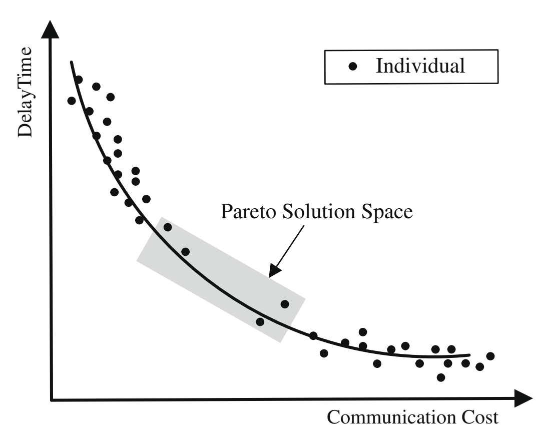


**Fig. 1.** Relationship between Pareto solution and solution space.