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A multi-objective evolutionary algorithm based QoS routing in wireless mesh networks

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ABSTRACT

The huge demand for real time services in wireless mesh networks (WMN) creates many challenging issues for providing quality of service (QoS). Designing of QoS routing protocols, which optimize the multiple objectives is computationally intractable. This paper proposes a new model for routing in WMN by using Modified Non-dominated Sorting Genetic Algorithm-II (MNSGA-II). The objectives which are considered here are the minimization of expected transmission count and the transmission delay. In order to retain the diversity in the non-dominated solutions, dynamic crowding distance (DCD) procedure is implemented in NSGA-II. The simulation is carried out in Network Simulator 2 (NS-2) and comparison is made using the metrics, expected transmission count and transmission delay by varying node mobility and by increasing number of nodes. It is observed that MNSGA-II improves the throughput and minimizes the transmission delay for varying number of nodes and higher mobility scenarios. The simulation clearly shows that MNSGA-II algorithm is certainly more suitable for solving multiobjective routing problem. A decision-making procedure based on analytic hierarchy process (AHP) has been adopted to find the best compromise solution from the set of Pareto-solutions obtained through MNSGA-II. The performance of MNSGA-II is compared with reference point based NSGA-II (R-NSGA-II) in terms of spread.

1. Introduction

Wireless mesh networks (WMN) have received due recognition because of their extended coverage, robustness, self healing, self configuring, easy maintenance and low cost broadband network services. WMN offers an attractive platform to a large variety of applications such as broadband home networking, building automation, public safety and emergency response communications, community networks and transportation systems. WMNs [1] are composed of static mesh routers and mobile mesh clients. Mesh routers provide connectivity between mesh clients which form the backbone infrastructure of WMN. The gateway functionality in mesh network enable the integration of WMN with other existing networks.

Multi-constrained QoS routing in WMN identifies feasible route in the network satisfying the multiple constraints. The constraints are usually imposed by quality of service (QoS) requirements such as minimum guaranteed bandwidth, a bounded end-to-end delay, packet loss and a limited interference among the wireless links. Many applications, such as audio, video conferencing and collaborative environments have multiple QoS requirements such as bandwidth, delay, packet loss, hop count, reliability, energy, etc. Multi-constrained routing problem cannot be solved in polynomial time because it is an NP-complete problem.

This work presents a multiobjective evolutionary algorithm approach for determining QoS routing in WMN. Multiobjective optimization problems having conflicting objective functions gives rise to a set of optimal solutions, instead of one optimal solution. No solution can be considered to be better than any other with respect to all objectives. These optimal solutions are known as Pareto-optimal solutions. The curve or surface describes the optimal trade-off solutions between objectives is known as the Pareto front. One of the major goals in multiobjective optimization is to find a set of well distributed optimal solutions along the Pareto front. Maintaining the diversity of the population not only requires a certain space distance between individuals, but also needs good uniformity for the non-dominated sets. There are several contemporary multiobjective evolutionary algorithms [2–6] which are aimed to find the Pareto-optimal front while achieving diversity in the obtained Pareto-optimal front. The major advantage of these multiobjective evolutionary algorithms (MOEAs) is that they produce a set of Pareto-optimal solutions in a single run. From this, the final solution is found by applying decision analysis technique. Analytic hierarchy process (AHP) is used for finding the best optimal solution from the set of Pareto-optimal solution. This paper focuses on the minimization of expected transmission count and transmission delay simultaneously by using MNSGA-II and AHP.

The remainder of the paper is organized as follows. Section 2 discusses the related work about the single objective and multiobjective evolutionary algorithms used in WMN and other networks. The mathematical problem formulation in multiobjective context is presented in Section 3. A meta-heuristic algorithm based on MNSGA-II to solve the multiobjective routing problem is proposed in Section 4. Section 5 present the simulation results to validate our algorithm. Finally, in Section 6 we summarize the conclusion of this article and discuss the possible lines of future work.

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2. Related work

2.1. Single objective optimization in WMN

Several routing protocols are used in WMN but most of the protocols consider only one objective either throughput or delay or hop count or packet loss or energy. Sun et al. [10] proposed on demand code aware routing scheme (OCAR) for WMN. This scheme detects a route with more network coding opportunities along the entire route rather than the two-hop regions. By using Coding Aware and Interference avoid routing metric (R_{CAIA}), OCAR handle both intra and inter flow interferences. R_{CAIA} of link l is given by

$$R_{CAIA} = \frac{1}{I_l} R_{CAETT_{nl}}, \tag{1}$$

where R_{CAETT} refers to coding aware expected transmission time. When there is no interference I_l is considered as 1 and therefore R_{CAIA} becomes equal to R_{CAETT}. The coding-aware and interference avoid routing metric of flow f_n's path L is given by

$$R_{CAIA} = \sum_{l \in L} R_{CAIA_{nl}}. \tag{2}$$

Baumann et al. [11] proposed the field based anycast routing protocol (HEAT). Here, the mesh nodes are represented as the temperature values and the gateway act as the heat sources of a temperature field. Based on the HEAT beacon messages, every mesh node calculates its temperature using the field calculation function algorithm. In this algorithm, for every node sort (ascending) its neighbor based on their temperature value and store into some array. For each node j, the value $t_j + 1$ is calculated as

$$t_j + 1 = t_j + (a_j - t_j) * k, \tag{3}$$

where a_j-temperature of currently consider neighbor, t_j-accumulated temperature, k-conductivity parameter ($k = \frac{1}{4}$).

The value of $t_j + 1$ is repeated, until the temperature of the next neighbor is less than the accumulated temperature. After the temperature calculation, the packets are routed from the mesh node to the gateway on hop-by-hop basis. A packet is always forwarded to the neighbor with the highest temperature value. An interference aware analytical routing metric is proposed by Alotaibi et al. [12]. The integer programming model is used to maximize the successfully transmitted traffic of all sources to destination pairs. This model achieved a performance improvement in throughput by 52% compared to other routing metrics.

Hou et al. [13] described the maximum available bandwidth path using a proactive hop by hop routing protocol. By using the left-isotonic path weight, the source can immediately determine the infeasible connection requests as well as the consistency and loop-freeness requirements. Simple opportunistic adaptive routing protocol (SOAR) was proposed by Rozner et al. [14]. SOAR effectively realizes opportunistic forwarding by judiciously selecting forwarding nodes and employing priority-based timers. The Adaptive rate control is used to determine an appropriate sending rate, according to current network conditions and recover the lost packets using local feedback method.

2.2. Multiobjective optimization

A complete discussion of MOEAs is presented in [4]. Zhou et al. [15] gave a detailed survey of numerous multiobjective evolutionary algorithm and emphasizes the recent developments together with algorithmic rule frameworks, selection strategies, offspring reproduction schemes and other related issues.

Abel Garcia-Najera and Bullinaria [16] introduced an improved multiobjective evolutionary algorithm (IMOEA) for vehicle routing problem. This algorithm simultaneously minimizes three objectives, namely number of routes, travel distance and delivery time. It is observed that IMOEA performs better than NSGA-II for both the bi-objective and tri-objective cases. Jiang et al. [17] proposed NSGA-II for designing a fiber Bragg grating (FBG) sensor network. The objectives considered are bandwidth and the overlap degree of spectra. This approach significantly saves the bandwidth and improves the multiplexing capability for Wavelength Division Multiplexing (WDM) Fiber Bragg Grating (FBG) sensor network. A coverage control scheme for WSN based on improved NSGA-II was proposed by Jia et al. [18,19]. The energy aware routing protocol by using NSGA-II for the Wireless Multimedia Sensor Network was developed by EkbataniFard and Monsefi [20]. This protocol outperforms the network performance by optimizing the multiple QoS parameters.

The multiobjective scheduling algorithm using R-NSGA-II was proposed by Garg and Singh [21]. The objectives considered are execution time and total cost. R-NSGA-II provides an optimal scheduling solution and it satisfies the quality of service constraints. R-NSGA-II algorithm uses the preferred distance instead of crowding distance which is used in NSGA-II. The preference distance represents the closeness of the solution for the user specified region. This algorithm generates the solution in the region of user interest rather than finding out which are not of user interest.

2.2.1. Multiobjective optimization in WMN

Camelo et al. [22] designed a multiobjective routing in WMN using NSGA-II by considering three objectives: minimizing the packet loss, end-to-end delay and power consumption. NSGA-II finds the multiple paths which guarantee QoS requirements and also support the multimedia data transmission. The multiobjective approach for joint routing and scheduling problem is described by Gomes and Huiban [23]. To satisfy the multi-access interferences the authors considered two objectives, balancing the load in the routers and communication time which corresponds to the time required to route all the router demands. The authors used column generation method to improve efficiency for computing the solutions.

Xhafa et al. [24] presented the placement of mesh router nodes in WMN using simulated annealing (SA) approach. This optimization model uses two maximization objectives, namely network connectivity and user coverage. A number of client mesh nodes are priori distributed in a grid area arranged in small cells and a number of mesh router nodes are to be deployed in the area. The simulation results confirmed that, SA approach is suitable for the placement of mesh router nodes in WMNs for different topology. A particle swarm optimization approach for optimizing dynamic router node placement of WMN is proposed by Lin [25]. The mathematical formulation of the problem is used to identify the dynamic placement of mesh routers in a geographical area while maximizing the two objectives: network connectivity and client coverage. The simulation results show that the quality of the PSO approach through sensitivity analysis as well as the adaptability to the topology changes at different times. Benyamina et al. [26] proposed a three multiobjective models of WMN planning problem using a hybrid combination of multiobjective particle swarm optimization and genetic algorithm. This model simultaneously optimizes the network deployment cost and network throughput objectives. Load-balanced model generates a broader set of non-dominated solutions and provides better throughput than the other two models.

Mostly WMN routing problem has been considered as a single objective problem, but it can have more than one objective. A number of assorted approaches have been proposed for improving WMN routing, which includes the utilization of heuristics, a single metric, a composite metric, multiple metrics and