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Rechargeable router placement based on efficiency and fairness in green wireless mesh networks

Xiaoli Huan [a], Bang Wang [a,*], Yijun Mo [a], Laurence T. Yang [b]

[a] School of Electronic Information and Communications, Huazhong University of Science and Technology (HUST), Wuhan, China
[b] School of Computer Science and Technology, Huazhong University of Science and Technology (HUST), Wuhan, China

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ABSTRACT

The wireless mesh networks are currently emerging as a promising solution for broadband access, while their deployment and operational costs are also ever increasing significantly due to the continuous electrical power consumption. The alternative is to deploy rechargeable mesh routers using renewable energy sources. In this paper, we study the rechargeable router placement problem for a green mesh network. The problem is formulated as an optimization with the objective of minimizing the number of deployed routers, while fulfilling QoS requirements on wireless coverage, traffic demand, energy efficiency and user fairness. Specifically, we introduce the network failure rate to evaluate the network performance and adopt the proportional fairness-based approach to do the cell association between users and routers. We first propose two cell association algorithms from two perspectives: the *Nearest Cell Association Algorithm* (NCA) for energy efficiency consideration and the *Proportional Fairness Cell Association Algorithm* (PFCA) to achieve a balance between the network performance and the user fairness. We then design two heuristic placement algorithms embedded with the proposed cell association methods to find approximate solutions for the rechargeable router placement problem. Simulation results verify that the proposed PFCA algorithm can guarantee the user fairness with a slight increase of deployment cost. Furthermore, compared with the optimal placement achieved by exhaustive search, ours can achieve good performance with greatly reduced computation complexity.

1. Introduction

In recent years, *Wireless Mesh Networks* (WMN) have widely developed for the advantage of its low-cost and flexible topology for broadband access services. With the expansion of network scale and the increase of traffic demand, the energy consumption of electrical power supply for WMNs becomes an important issue. To solve the problem of ever-increasing energy consumption, an alternative is to introduce rechargeable routers that can harvest green energies, such as solar or wind power. Since energy supplies of rechargeable routers are not consistent but dynamic due to varying environment conditions, how to effectively place routers to guarantee wireless coverage and network *Quality of Service* (QoS) is becoming more challenging for green mesh networks.

The traditional node placement problem assumes routers to have consistent power supply through wired electricity and can be formulated as different optimization problems based on the objectives and a set of constraints. Some studies consider topologies where gateways are fixed a priori [1]. While others attempt to optimize the

* Corresponding author.
E-mail addresses: wangbang@hust.edu.cn (B. Wang), moyj@hust.edu.cn (Y. Mo), ltyang@gmail.com (L.T. Yang).

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number of gateways given a fixed layout of mesh routers [2]. These studies mainly focus on the objectives of cost minimization under given constraints or performance improvement, such as coverage, connectivity [3], delay [4], and throughput [2].

Since the increasing demand of services have led to a significant growth in the energy consumption, recent research efforts have studied energy saving mechanisms in wireless networks. In cellular mobile networks, some have proposed the base station sleeping strategies, that is, switching off some base stations according to traffic variations [5]. Recently, the green wireless mesh networks in which routers are rechargeable by renewable energy supplies have become a cost-effective alternative solution for energy saving. Most previous studies related to green wireless mesh networks have focused on the resource management and traffic routing to ensure energy sustainability [6,7]. However, the efficient rechargeable router placement under QoS constraints for a green WMN has not been well studied.

In this paper, we investigate the rechargeable router placement problem in a green WMN. Our concern is how to efficiently place rechargeable routers to ensure that the dynamic harvested energy can fulfill the network QoS requirement while ensuring the fairness among users in a green mesh network. This is a challenging problem not well studied before. For rechargeable routers, their energy supplies are not consistent but dependent on realistic environment conditions. It is possible that some routers may not have enough energy to support all of its already connected *Mesh Clients* (MCs), and have to drop some of them temporarily. Though the short-term disconnections between routers and MCs are assumed to be acceptable in real-world conditions, the question is how to define the *acceptability*. In this paper, we first introduce a long-term performance metric, called *network failure rate* for a green WMN, which is defined as the ratio of disconnections and all possible connections. Instead of the strong coverage constraint that all users should be connected to at least one router at any time, we consider the cell association to meet the coverage constraint as long as the failure rate is under a given very low threshold. However, the temporary disconnection event brings out the other issue: The failure rate requirement may be satisfied by sacrificing the QoS of a certain MC. Specifically, a certain MC may be failed for connection for a long time period on account of its high energy consumption, which would seriously affect users' quality of experiences. It is thus highly desirable to find an improved cell association method to fairly assign traffic flows among users. In this paper, we borrow the concept of *proportional fairness* that have been commonly used for radio resource allocation in mobile networks [8,9] into a cell association algorithm to ensure fairness on accessing to traffic among users.

In this paper, we propose two cell association algorithms, namely, *Nearest Cell Association Algorithm* (NCA) and *Proportional Fairness Cell Association Algorithm* (PFCA). The former focuses on minimizing the energy consumption in each association, which may cause unfairness among different users. While the later considers to achieve a balance between the network performance and the user fairness on getting traffic flows. Based on the greedy algorithm and simulated annealing algorithm, we design two heuristic placement algorithms embedded with the proposed cell association methods to find approximate solutions for the rechargeable router placement problem. Simulation results show that compared with the optimal placement achieved by exhaustive search, ours can achieve good performance at a relative low cost with greatly reduced computation complexity. Furthermore, the proposed PFCA algorithm can guarantee user fairness with a slight increase of placement cost.

The remainder of the paper is organized as follows. We present the system configuration and problem formulation in Sections 3 and 4, respectively. The cell association algorithms and heuristic placement algorithms are provided in Section 5. Simulation results and performance comparisons are given in Sections 6, and 7 concludes the paper.

2. Related work

The node placement problem in WMNs is to minimize the deployment expenditure or to optimize the network performance by appropriately determining the number and position of routers under a set of constraints. Three types of scenarios are commonly considered for studying the node placement problem in a WMN, and the node placement problem in different scenarios are accordingly formulated as different optimizations with various objectives and constraints.

In the topologies where gateways are a prior fixed and routers are required to be effectively placed, objectives manly concern on the performance enhancements, such as maximizing network connectivity, user coverage [3], or minimizing energy consumption [10], and communication delay [4], as well as the cost minimization in terms of the minimum number of deployed mesh routers [11–13]. In [11], authors explore the mesh router placement problem with multiple transmission rates and co-channel interference. While in [12], Zhang et al. study the multi-hop relay node placement with channel capacity constraint. Authors in [13,14] consider the minimal node placement in a non-uniform propagation scenario by specifying connectivity based on the per-link estimated signal quality. Ref. [14] jointly addresses the router placement and channel assignment. As for the topologies where a pre-located layout of mesh routers is given and appropriate locations for placing gateways are to be selected, previous studies have focused on the deployment cost minimization [15] or network throughput optimization [2]. The third scenario is that the positions and types of all mesh nodes are unknown and the network design has to be done from scratch. In [16], Amaldi et al. present an *integer linear programming* formulation to select a small number of locations for placing routers from certain candidate sites. Besides the single-objective problem discussed above, there are also a portion of literature synthesizing two or more contradicting objectives and obtaining Pareto non-dominated solutions, which is referred as multi-objective problem [17].

Recently, the issue of energy saving has attracted lots of attention in wireless networks [18]. Base station sleeping has been recently proposed to dynamically switch off some