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Solving mesh router nodes placement problem in Wireless Mesh Networks by Tabu Search algorithm

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ABSTRACT

Wireless Mesh Networks (WMNs) are an important networking paradigm that offer cost effective Internet connectivity. The performance and operability of WMNs depend, among other factors, on the placement of network nodes in the area. Among the most important objectives in designing a WMN is the formation of a mesh backbone to achieve high user coverage. Given a number of router nodes to deploy, a deployment area and positions of client nodes in the area, an optimization problem can be formulated aiming to find the placement of router nodes so as to maximize network connectivity and user coverage. This optimization problem belongs to facility location problems, which are computationally hard to solve to optimality. In this paper we present the implementation and evaluation of Tabu Search (TS) for the problem of mesh router node placement in WMNs. The experimental evaluation showed the efficiency of TS in solving a benchmark of instances.

1. Introduction

Wireless Mesh Network (WMN) [1] is an important paradigm in today's networking infrastructures. WMNs can be used either as stand alone networks or as extensions of wired networks to provide Internet connectivity to mesh client nodes through mesh router nodes and gateways. Their low cost of deployment and maintenance make WMNs very attractive technology for a large range of applications such as urban areas, community networking, metropolitan area networks, municipal networks, corporative networks, medical systems, transport systems, surveillance systems, enterprise and campus applications, etc. [6]. In general, WMNs can provide Internet connectivity to users of a certain geographical area. The main feature of WMN is its mesh topology and multi-hop communication through a mesh topology, in which every node (e.g. mesh router) is connected to one or more nodes, enabling thus the information transmission in more than one path. The path redundancy is a robust feature of this kind of topology. These characteristics of networks with mesh topology make them very reliable and robust networks to potential node failure. However, as in other types of wireless networks, connectivity and stability are critical factors to the performance of WMNs.

Internet connectivity of mesh client nodes is achieved through mesh routers and gateways, therefore the placement of such nodes is crucial to achieve optimized performance of the network. Assuming that each mesh router can have its own radio connectivity coverage, a mesh router/client node is connected to a mesh router node if it is within its radio coverage. Therefore, the connectivity of the mesh router nodes and the user coverage depend on the placement of mesh

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router nodes. It is for this reason that one needs to formulate and solve some optimization problems to achieve desired performance in WMNs. The efficient resolution of such problems, especially those related to node placement, is useful during the design phase of the WMNs. On the one hand, one can ask how many mesh router nodes have to be deployed in the given geographical area and, on the other, where to place the mesh router nodes in the grid area. The former is directly related to minimizing the cost of the deployment of the WMN while the later aims at achieving maximized performance of WMN, for a given number of mesh router nodes.

The design of WMNs, however, is not an easy task and could be challenging if many objectives are to be met under several restrictions. Indeed, the network performance and operability depend, among other factors, on the placement of network nodes (mesh routers, gateways, ...) in the geographical area. Different kinds of restrictions could be formulated for the problem. For instance, there could be topological restrictions on the deployment area, client nodes could be distributed arbitrarily on the area without following any pre-established pattern, and router nodes can have different radio coverage. Additionally, there could be investment cost restrictions. Whatever the restrictions could be, the most important objective in designing a WMN is to establish a mesh backbone to achieve high user coverage. In this work, we consider WMNs in which mesh client nodes are fixed nodes whose positions are *a priori* known. The applicability of this kind of WMN arises in many real life scenarios such as in urban areas (neighbourhoods and communities), enterprise and campus areas, etc. Furthermore, we assume as input a given number of mesh router nodes (which could have their own radio coverage). It should be noted that a more generalized version of the problem would be to minimize the number of mesh router nodes to deploy to achieve full connectivity and full client coverage. Nevertheless, even if the network designer would know the number of mesh routers to deploy, that's not enough: the locations of routers to deploy should be computed as well. In fact, while not at optimality, the number of routers to deploy can be computed based on estimation. Therefore, the computation of the router locations is more important and challenging here.

It is commonplace to assist decision making at network design process through optimization. In the case of WMNs, given a number of router nodes to deploy, a 2D deployment area and positions of client nodes in the area, an optimization problem can be formulated aiming to find the placement of router nodes in the deployment area so as to maximize network connectivity and user coverage. The former can be measured by the size of the giant component (i.e. the largest connected component) in the mesh router nodes network while the user coverage accounts the number of client nodes that fall within the radio coverage of routers. Naturally, the largest the size of the giant component, the largest is the mesh backbone (mesh routers connected to mesh clients).

An optimization problem that can be taken as a reference here is that of facility locations, which in a general setting seeks an optimal placement of a number of facilities that give service to a certain number of clients. The similarity with mesh routers node placement in WMNs is straightforward by considering mesh routers as facilities, which give service, i.e. Internet connectivity, to mesh clients nodes. The problem of facility placements has been long investigated in optimization and logistics domains. Facility location problems are known to be computationally hard to solve to optimality in their general formulations and thus heuristic methods are the alternative to cope in practice with their resolution.

In this paper we present the implementation and evaluation of Tabu Search (TS) for solving the mesh router nodes placement considered as bi-objective optimization problem (maximizing the size of the giant component and maximizing the user coverage). Unlike other local search methods, TS is known for its adaptive search mechanisms aiming to overcome getting stuck into local optima. We implemented several forms of adaptive memory (short and long term) as well as tabu solution tagging as effective mechanisms to avoid cycling among visited solutions in the search space. Also several types of neighbourhoods are considered by defining different movement types. We evaluated the TS method through a set of instances for the problem. Instances of small to large size were generated using different distributions of mesh client nodes (uniform, normal, exponential and Weibull).

The rest of the paper is organized as follows. In Section 2 we consider the node placement problems in a general setting and show the formulation of the mesh router nodes as a special case of node placement problem. In Section 3, we overview the main features of the TS method and present its instantiation for the case of mesh router nodes problem. Some implementation issues are also discussed. We present the experimental evaluation of TS method in Section 4 and end the paper in Section 5 with some conclusions and indications for future work.

2. Mesh routers placement in WMNs as a node placement problem

In this section we recall some basic concepts from node/facility placement problems and formulate the mesh router nodes as node placement problem (see also [4]). Node placement problems arise in many applications such as facility location, logistics, services, etc. In such problems, we are given a number of potential facilities to serve to costumers connected to facilities. The aim is to find locations of facilities such that the cost of serving to all customers is optimized for some metric function(s). In traditional versions of the problem, facilities could be hospitals, polling centres, fire stations serving to a number of clients and aiming to optimize some distance function in a metric space between clients and facilities. One classical version of the problem is that of p-median problem, defined as follows: Given a set $\mathcal{F}$ of m potential facilities, a set $\mathcal{U}$ of n users, a distance function $d : \mathcal{U} \to \mathcal{F}$, and a constant $p \leq m$, determine which p facilities to open so as to minimize a metric, for instance the sum of the distances from each user to its closest open facility.

Facility location problems are showing their usefulness to communication networks, and more especially to WMNs [1,12,6] where facilities could be servers, routers, etc., offering connectivity services to clients. In WMNs mesh routers