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Channel assignment in multi-radio wireless mesh networks using an improved gravitational search algorithm

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ABSTRACT

Wireless mesh networks have emerged recently to improve networking performance and other networking services. The combination of multi-radio nodes with multi-hop mesh architectures leads researcher to overcome some constraints of single-radio networks such as incapability of effective scale to exploit the increasing available system bandwidth. Therefore, a good channel assignment (CA) in multi-radio mesh networks can reduce the number of interference co-channels and improve the network throughput. In this paper, an improved version of gravitational search algorithm (IGSA) is proposed to solve CA problems; a local operator is combined with the gravitational search algorithm to find the best solution. In this study, the main goal is to minimize the overall interference and to increase the network throughput with ensuring network connectivity. The obtained results confirm the high performance of our algorithm in comparison with other related works.

1. Introduction

Wireless mesh networks (WMNs), as a promising technology, have an enormous potential to transform our daily life. These networks are considered flexible solutions to a wide range of applications (Akyildiz et al., 2005). The multi-hop nature of WMNs and the rapid growth of throughput demands lead to multi-channels and multi-radios structures in mesh networks, but the interference of co-channels, as a main problem reduces the total throughput, especially in multi-hop networks. Therefore, the use of orthogonal channels and multiple-radios are two efficient solutions for decreasing co-channels interference and improving the network throughput. In multi-radio multi-channels nodes, each node is equipped with more than one radio; the communication channels are selected based on the channel assignment algorithm. Therefore, the multi-radio nodes can initiate more than one communication simultaneously.

The channel assignment algorithm is an important factor in improving the network performance. This algorithm tries to increase the utilization of available channels and also to consider the network connectivity as an important issue. High connectivity leads to reliable routing and low co-channel interference. In this paper two different scenarios in which we try to reduce the overall interference for channel assignment are used.

(a) *Connected*: all nodes are connected through at least one communication link.
(b) *Topology preservation* (Subramanian et al., 2008; Cheng et al., 2012): links in the original single channel networks will also exist in the final multi-channel network topology.

Topology preservation is a robust method against link failure and network partitioning. This strategy is suitable among many different networks such as ad hoc networks, sensor networks and the new emerging mesh networks. Many works in the field of topology preservation are reported in Draves et al. (1997), Gastpar and Vetterli (2002), Gupta and Kumar (2000) and Peng et al. (2012).

It is proved that the channel assignment for WMNs is a NP-hard problem. In recent years, stochastic global optimization methods have been widely used for complex NP-hard problems such as channel assignment in WMNs. The problem of channel assignment has been considered by many researches in the past decade. In Raniwala et al. (2004) and Marina and Das (2005) a mapping color problem algorithm is used to optimize channel assignment for mesh networks. In Kyasanur et al. (2006) a taxonomical classification of various channel assignment is presented as follow: static, dynamic, quasi-static (hybrid), in which some interfaces are assigned static cases and the dynamic assignment is applied to the others. The static (fixed) channel assignment is almost constant so that the interfaces use channels either permanently or for long time intervals with respect to the interface switching time. But in the dynamic assignment, it is needed to switch channels among available channels. When two mesh nodes communicate

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with each other, in fact they have switched to the same channel. Therefore, the existence of a coordination mechanism is very important to set the nodes on a common channel.

The static channel assignment strategy can be further subdivided into two categories: common channel assignment (CCA) and varying channel assignment (VCA) (Draves et al., 1997; Raniwala et al., 2004). In CCA the same set of channels are assigned to all radio interfaces. In this scheme, in fact the connectivity of the network is similar to that of a single channel approach. In the second category, the VCA scheme, radios of different mesh nodes have different sets of channels. In this scheme, one could have an optimum number of interference and network throughput. Our strategy in this paper follows this scheme and in fact our solution is based on the VCA with topology preservation. The VCA is divided into two different algorithms: centralized channel assignment and a topology control approach. Mogaibel et al. (2012), Ning et al. (2012), Zhou et al. (2012) propose a cross-layer algorithm by considering both MAC layer and network layer. They integrate channel assignment with the routing algorithm and passes channel information between the routing layer and medium access control (MAC) layer. Also the work in Jahanshahi et al. (2011) is targeted at promoting the adoption of cross-layer design for joint channel assignment and multicast tree construction problem based on binary integer programming.

Kumar et al. (2011) present a novel approach for link scheduling and channel assignment (CA) to improve the overall capacity and throughput of WMNs. Links are sorted and placed in a particular group based upon link cost metric (LCM). The LCM value is used to group the links together and placed in appropriate group for CA.

Raniwala et al. (2004) assumed that the traffic load is deterministic and proposed a channel assignment based on a centralized algorithm in which the network connectivity is guaranteed. While this scheme provides a manner for channel allocation incorporating connectivity and traffic patterns, it leads to a ripple effect (Cheng et al., 2012) whereby already assigned links have to be revisited. Therefore, the time complexity of the scheme is increased.

Marina and Das (2005) proposed a polynomial time greedy heuristic algorithm, by the name of connected low interference channel assignment (CLICA), in which, a priority index is calculated for each mesh node and then channels are assigned based on the connectivity and conflict graphs. Subramanian et al. (2008) proposed two link organization algorithms for the channels assignment with topology preservation. The first one is based on the graph coloring algorithm using Tabu search. Their Tabu based algorithm comprises two stages. In the first stage, Tabu algorithm tries to find a good channel assignment without worrying about radio constraints. In the second stage, there is a node with the maximum violations of the interface constraints. Then the same channel is shared among a combination of the assignments of two radios in order to prevent the conflict increasing through the end iterations. Therefore, the algorithm complexity is increased and the system performance is reduced significantly. The second method, proposed in Subramanian et al. (2008), by the name of distributed greedy algorithm (DGA), is based on the greedy approximation algorithm for Max K-cut problem in graphs by considering the radio constraints through iterations.

Das et al. (2005) find a fixed channel assignment which maximizes the number of bidirectional links that can be occur simultaneously, subject to interference constraints. They proposed two mixed integer linear programming models for solving the fixed channel assignment problem with multiple radios. Cheng et al. (2010) proposed an integer line programming solution as well as a heuristic algorithm for the channel assignment problem. Although, they preserved the original topology, all available channels were not used thus the network throughput was not improved. Tang et al. (2005) studied interference-aware topology control and QoS routing with dynamic traffic. They presented an effective heuristic algorithm to minimize interference based on survivable topology control (INSTC). Their channel assignment method tries to minimize the interference among all K-connected topologies.

Raniwala and Chiueh (2007) proposed a multi-channel WMN architecture (called Hyacinth). They showed that intelligent channel assignment is critical to the performance of Hycanith. They proposed a distributed algorithm which utilizes only local traffic load information to dynamically assign channels. Das et al. (2006) discussed the static channel assignment problem for multi-channel multi-radio static WMNs. They presented four metrics based on which mesh channel assignments can be obtained. They also focused on minimization of the average and maximum collision domain sizes. Then, they showed that the channel assignment problems are closely related to combinatorial optimization such as Max K-cut and min K-partition.

Cheng et al. (2012) considered the assignment strategy with topology preservation. They tried to minimize the co-channel interference in the network and formulated a channel assignment algorithm called DPSO-CA which is based on the particle swarm optimization (PSO) algorithm. In fact, the DPSO-CA is a channel assignment in which genetic algorithms operators are employed. In this method, in order to reach the optimal channel assignment PSO algorithm is hybridized with GA operators, i.e. mutation and crossover.

In this paper, in order to enhance the results obtained in Cheng et al. (2012), an improved version of gravitational search algorithm (IGSA) is proposed to solve the problem of channel assignment for WMNs. The gravitational search algorithm (GSA) has been inspired by the Newtonian laws of gravity and motion (Rashedi et al., 2009). We have improved the GSA by introducing a new local search for integer programming. Our aim is to achieve an optimum channel assignment for a WMN by IGSA.The proposed algorithm has a high performance in finding the best solution because it has the abilities of exploration and exploitation simultaneously. In IGSA a new local search operator is proposed.

The rest of this paper is organized as follows. The network's models are described along with some definitions in Section 2. In Section 3, we introduce the basic concept of GSA algorithm and the proposed IGSA. Experimental results and comparison with other works are given in Section 4. Finally, in Section 5, the conclusions are presented.

2. Network model and notations

In this section, the network parameters are introduced and the channel assignment problem is explained in detail.

2.1. Notations and definitions

The notations and definitions which are used in this paper

- $K = 1, 2, \ldots, kmax$, number of available channels.
- N, total number of network nodes.
- R_i, number of radios on node $i \epsilon N$.
- $G = (V, E)$, the undirected graph (the original topology), V is the set of nodes and E is the set of links.
- $G' = (V', E')$, the final topology of the network after channel assignment which $V' = V$ and $(i, j; k) \epsilon E'$ if and only if $k \epsilon K_i \cap K_j$ and $(i, j) \epsilon E$.
- $G_c = (V_c, E_c)$, a conflict graph.

- *Topology preservation*: the original topology would be preserved after the channel assignment, if the following constraint is satisfied:
  For each $(i, j) \epsilon E$ there is at least one $k \epsilon K_i \cap K_j$ and $(i, j; k) \epsilon E'$.