Computer Communications 35 (2012) 2004–2013

Contents lists available at SciVerse ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Online reconfiguration of channel assignment in Multi-Channel Multi-Radio wireless mesh networks ☆

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ARTICLE INFO

Article history:
Received 23 May 2011
Received in revised form 14 December 2011
Accepted 4 April 2012
Available online 16 April 2012

Keywords:
Wireless mesh networks
Channel assignment
Network reconfiguration
Traffic adaptation

ABSTRACT

Efficient utilization of Multi Channel–Multi Radio (MC–MR) wireless mesh networks (WMNs) can be achieved only by intelligent channel assignment (CA) and Link Scheduling (LS). Due to the dynamic nature of traffic demand in WMNs, the CA has to be reconfigured whenever traffic demand changes, in order to achieve maximum throughput in the network. The reconfiguration of CA requires channel switching at radios which leads to disruption of ongoing traffic in the network. So, we have to consider this traffic disruption overhead while reconfiguring the network for traffic adaptation. The existing CA algorithms for MC–MR WMNs in the literature do not consider the reconfiguration overhead caused by the channel switching. In this paper, we propose a novel reconfiguration model that considers both network throughput and reconfiguration overhead to quantitatively evaluate a reconfiguration algorithm. Based on the reconfiguration model, we formulate the problem of reconfiguration of CA as a Mixed Integer Linear Program (MILP). We also propose an on-line heuristic algorithm for CA called Demand based State Aware channel Reconfiguration Algorithm (DeSARA) that finds the CA for the current traffic demand by considering the existing CA of the network to minimize the reconfiguration overhead. Through extensive simulations, we show the importance of considering the overhead in reconfiguration of CA, by comparing the performance of DeSARA with a static CA and a fully dynamic CA that does not consider the reconfiguration overhead. We also study the performance of the proposed algorithm with real network traces collected in a campus network to show its practicality.

1. Introduction

Wireless mesh networks (WMNs) have become a cost-effective option for wide scale deployment in last mile wireless networks [2]. WMNs consist of two kinds of network elements namely, mesh routers and mesh clients. While the mesh routers form the backbone, the mesh clients are the users that generate traffic in the network. Apart from clients communicating with the Internet, there are a number of user applications such as video conferencing and VoIP (Voice over IP) that result in communication between clients. As more and more clients are added to WMNs, there is a requirement to improve the transport capacity of the backbone.

The transport capacity of the backbone network can be increased by using multiple orthogonal (non-overlapping) channels for simultaneous transmissions and thereby, improving *channel spatial reuse*. To tap the full potential of multiple channels, the mesh routers are equipped with multiple radios. Raniwala et al. [3] showed that there is a non-linear increase in capacity with the increase in number of radios in a Multi Channel–Multi Radio (MC–MR) wireless network. Though there is a potential increase in capacity due to the usage of MC–MR in WMNs, a poor channel assignment (CA) scheme can lead to under-utilization of the network. Intelligent CA schemes need to be adopted in order to spatially separate the nodes transmitting in the same channel as far as possible. Nevertheless, owing to the constraint on the number of channels and the number of radios available at each router, the co-channel interference cannot be completely avoided.

A network employing multiple access techniques such as CSMA/CA for transmission of data is not bandwidth efficient due to the contention resolution mechanism employed for the channel access. Using efficient Link Scheduling (LS), the network can be made contention free thus utilizing the capacity of the network completely. This requires a link level synchronization among the nodes. As the mesh routers are static, link level synchronization between them can be achieved easily.

☆ An initial version of this paper was presented at IEEE conference on Computer Communications (INFOCOM) Workshop, 2010 [1].

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http://dx.doi.org/10.1016/j.comcom.2012.04.006

A successful deployment of WMN must not only address the issues of scalability, reliability, and efficient utilization of the underlying network resources, but also address issues related to adaptability to the changes in traffic demand. In a practical scenario, the traffic demand keeps changing with time and the WMN must be able to adapt to these changes by reconfiguring the CA. The CA designed to optimally suit one traffic demand may not optimally suit the other. If we use the optimal CA for every traffic demand without considering the current CA, it will lead to lot of reconfigurations and will heavily disrupt ongoing traffic in the network. Changing the channel on the radio takes some reconfiguration time during which no data packets can be transmitted. If the reconfigurations occur frequently, the network will be underutilized due to reconfiguration overhead. In [4], the authors have shown that though the channel switching time of the radios is in the order of micro seconds, the average traffic disruption time is in the order of seconds. Due to synchronization problem, the time at which two nodes switch the channel is not exactly the same. So, every time a link switches the channel there is period during which the link is down. In a multi-hop scenario, the end-to-end traffic disruption increases with number of hops as the routing protocol finds the situation as a link break. Hence, there is a need to minimize the overhead in reconfiguration of CA.

In our earlier work [5], the reconfiguration of CA in MC–MR WMNs is considered with the objective of reducing the number of reconfigurations in the network. The algorithm finds the similarity between two CA for two different traffic matrices and try to reduce the number of edges reconfigured. Since it is a two step process, the reconfiguration is not so effective. Also the algorithm works well if the traffic matrices are co-related. We use the reconfiguration model considered in this work in order to achieve a one step channel reconfiguration algorithm.

This reconfiguration model considers both the achieved throughput and the reconfiguration overhead to quantify the performance of a reconfiguration algorithm. We present an on-line heuristic algorithm called Demand based State Aware channel Reconfiguration Algorithm (DeSARA) for dynamically reconfiguring the CA under varying traffic conditions. We show the performance of DeSARA in different network and traffic scenarios using simulations and also using real network traces in a campus network.

The rest of the paper is organized as follows. We discuss the related work and contributions of our work in Section 2 and describe the network model and assumptions in Section 3. In Section 4, we propose the reconfiguration model and the MILP formulation for channel reconfiguration based on the proposed model. In Section 5, we present an online heuristic algorithm for reconfiguration of CA. Simulation results to evaluate the performance of the proposed online heuristic algorithm in various network and traffic scenarios are presented and discussed in Section 6. We summarize our contributions and provide directions for future work in Section 7.

2. Related work and contributions

There has been significant amount of research carried out in WMNs in recent years to exploit MC–MR in order to increase the achievable capacity of the network. New MAC layer protocols to achieve the optimal usage of multiple channels in a wireless network are proposed in [6,7]. There have been some solutions based on channel switching [8,9]. Bahl et al. [8] developed SSCH (Slotted Seeded Channel Hopping), a link layer solution for enhancing capacity of the network.

Draves et al. [10] proposed a new routing metric called WCETT (Weighted Cumulative Expected Transmission Time) which is implemented in MR-LQSR (Multi Radio-Link Quality Source Routing). MR-LQSR finds a path with diverse channels to minimize the interference on the path. This requires a static CA on the network. Though MAC and routing protocols try to utilize the MC–MR to improve the transport capacity of the WMNs, an efficient CA algorithm further improves it. There are a number of centralized and distributed solutions for CA and routing in an MC–MR network. The distributed algorithms for CA and routing [11–14] improve the performance of the network in terms of throughput but they are not optimal in terms of offered load. There are several works on interference aware CA aimed at minimizing the interference in the network [15–18]. All these proposals do not take into account the dynamic nature of traffic demand in the network and hence cannot utilize the network resources efficiently.

The work in [3,19] interlaces CA and routing, thus adding complexities of propagating the route information every time the CA is reconfigured. Raniwala et al. [3] presented a centralized heuristic algorithm for CA and routing which iterates between routing and CA until the process converges in terms of the aggregate capacity of the network. Tang et al. [19] proposed Linear Programming (LP) and Convex Programming (CP) based schemes for computing end-to-end fair rate allocation for WMNs. Alicherry et al. [20] proposed a centralized joint CA, LS, and routing for WMNs. Here, the objective is to increase the per node throughput of the network. In [21], the authors address the problem of radio resource assignment optimization problem in WMNs. They proposed an optimization framework by considering routing, scheduling, and channel assignment. The objective of their approach is to guarantee the bandwidth requirements and to optimize the transmission resource utilization. They considered both static channel assignment and dynamic channel assignment schemes. In the dynamic channel assignment scheme, the wireless interface can switch between channels on a slot-by-slot basis.

All these works address the channel assignment, routing, link scheduling, and end-to-end rate allocation in MC–MR WMNs with the objective of improving the throughput of the network. But, they do not consider the reconfiguration of CA when there is a change in the traffic demand. In an MC-MR WMN, considering the traffic demand in finding the CA and LS is beneficial in terms of achieved throughput as shown in [22,23]. The authors in [22] study the effect of different types of traffic (data size vector and data rate vector) on the network performance. But, they do not consider the reconfiguration overhead due to channel switching.

Our earlier work in [24], considers the CA in MC–MR WMNs using traffic predictions. The CA algorithm predicts the future traffic using traffic prediction methods and finds the CA by considering future traffic also. This improves the effective throughput of the network which reduces the number of reconfiguration. But the performance of the CA algorithm depends on the performance of the traffic prediction. The traffic prediction fails when the traffic is not co-related with the past pattern.

To the best of our knowledge, this is the first work on single step reconfigurations in CA and LS with dynamic traffic demands. The main contributions of this paper are as follows.

- Proposed a simple, general, and efficient model to quantify the effectiveness of a reconfiguration strategy with two conflicting objectives: maximizing network utilization and minimizing traffic disruption simultaneously.
- Proposed an on-line heuristic algorithm called Demand based State Aware channel Reconfiguration Algorithm (DeSARA) for reconfiguration of CA based on the proposed model.

3. System model and assumptions

In this paper, we limit our study to the mesh routers which form the backbone. Hereafter, the term node is used to refer to a mesh router. Similarly, we use the terms traffic matrix and traffic demand interchangeably throughout this paper. The notations used