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The robust joint solution for channel assignment and routing for wireless mesh networks with time partitioning

Jonathan Wellons *, Yuan Xue

Department of Electrical Engineering and Computer Science, Vanderbilt University, United States

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ABSTRACT

Joint channel assignment and routing is an essential yet challenging issue for multi-radio multi-channel wireless mesh networks. Though several works are presented in the existing literature to approach this problem, the key question – how to ensure that the resulting network performance can closely track the optimal solution under high traffic variability without incurring too much overhead, remains unanswered.

In this work, we present a new solution called "Robust joint Channel Assignment and Routing with Time partitioning (RCART)" for WMNs. RCART consists of three steps: (1) *Time Partitioning and Traffic Characterization*, which accomplishes the goal of partitioning time into periodic intervals with consistent properties which can be routed efficiently, (2) *Robust Routing*, which finds a robust routing scheme that provides an upper bound on the worst-case network performance for traffic demands that fall into a convex region, (3) *Channel Assignment*, which allocates radios to fixed channels during the time interval identified in step 1 and based on the knowledge of traffic distribution from step 2, using the worst-case congestion ratio as a robustness metric in its objective. Introducing time partitions as an additional control variable in the robust mesh routing RCART solution significantly improves average-case performance. Performance evaluation is conducted for RCART using real traffic demand traces. The results show that our RCART solution significantly outperforms the existing works without time partitioning or with simpler traffic profile models.

1. Introduction

Wireless mesh networks (WMNs) have proven to be a versatile solution to last-mile Internet service as well as dense urban coverage (e.g., [1–8]). The key benefits are the low cost and the ease of deployment due to their extensibility and flexibility. A WMN consists of wireless routers and access points (APs) forming a backbone which may be rooted to a broader network such as the Internet at one or more locations. The access points aggregate and forward traffic to and from transient clients. To increase the network capacity, wireless mesh routers are usually equipped with multiple radios and can operate over multiple channels simultaneously.

Simultaneous transmission by neighboring nodes on the same channel of a wireless network will lead to packet collision and directly impact the network performance in terms of data delivery ratio and delay. In a wireless mesh network, it is essential to balance the traffic across different parts of a network to minimize the number of transmissions made in a vicinity, which reduces the occurrence of traffic congestion and wireless contention. This needs to be done through an joint design of routing, which distributes the traffic to different paths of a network, and channel assignment, which distributes traffic across all available channels.

The problem of joint channel assignment and routing is non-trivial due to the inter-dependencies among routing,

* Corresponding author.
E-mail addresses: jonathan.wellons@vanderbilt.edu (J. Wellons), yuan.xue@vanderbilt.edu (Y. Xue).

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channel assignment and scheduling. On one hand, designing an effective routing scheme requires knowledge of the network's packet delivery capacity in different parts of the network, which depends on the results of channel assignment and scheduling. On the other hand, balanced channel assignment needs the information of the traffic load in the neighborhood, which in turn depends on the routing scheme. Traffic through an access point, even when aggregated over many clients, is inherently difficult to predict [9] in wireless networks. An effective joint channel assignment and routing solution must accommodate this variable traffic under the constraints of the scarce wireless channel resources.

The proposed approaches address the above challenges in joint channel assignment and routing in different ways. For instance, heuristic algorithms (e.g., [10,11]) apply techniques from the domain of local optimization to improve the routing configuration over time. Although they may be adaptive to the dynamic environments of wireless networks, these algorithms typically lack provable assurance on global network performance in terms of resource utility and fairness. In addition, these algorithms cannot be robust with respect to rapid changes in traffic dynamics, giving rise to poor worst-case performance. On the other hand, there are algorithms which formulate joint channel assignment and network routing as an optimization problem [12]. These algorithms assume that traffic is fixed or known in advance, which is unrealistic considering the high variability in wireless traffic. To adapt to the dynamic traffic load, [13] has proposed a fully distributed traffic balancing solution based on the idea of back pressure routing. At equilibrium, this solution closely tracks the theoretical optimum. However, this approach requires significant overhead and network updates. Further, whether its convergence speed can catch up with the traffic dynamics in a WMN remains to be tested. The work of [14] infers the traffic demand with maximum probability based on history and optimizes the channel assignment and routing strategy for the predicted traffic demand. Underlying predictive approach is the assumption that past behavior is a good indicator of the future. The quality of a predictive algorithm is therefore tightly related to the traffic erraticity [15].

Recent works [16,17] on oblivious wireless mesh routing address the traffic dynamics from a different perspective. Rather than predicting or tracking the traffic variability, oblivious routing intends to select a routing strategy which optimizes the worst-case network performance (as a ratio to the optimal network performance) under a set of possible traffic demands. Purely oblivious routing includes in its consideration all possible traffic demands, which may include unusual and unrealistic patterns of traffic. This can lead to poor routing quality under typical traffic patterns. Predictive methods has been incorporated into oblivious routing – it is capable of considering the worst case over a smaller range of traffic demands tailored to the history of traffic in a network rather than all possible demands. For example, the work of [17] has developed a robust wireless mesh routing algorithm, which only optimizes for traffic demands that fall into the predicted ranges. The performance of this approach is closely linked with the traffic range estimation. A more focused traffic range will have better average performance if traffic falls into the range, but it will have a higher risk of missing the future traffic demands and potentially suffering unaccounted-for worst case performance. The work of [15] designs an algorithm which alternates between purely oblivious and predictive routing depending on the erraticity of the traffic. Neither work accounts for multiple channels or provides a solution that can work efficiently with a channel assignment algorithm. Furthermore, the traffic models used in those works can not exploit the benefits of the strong traffic correlation in wireless networks.

In addition, a major gap is present in existing work on wireless routing – time partitioning. We observe that traffic sources in many contexts are subject to cyclic behavior: meetings, classes and human work, mealtime, break and sleep cycles. Thus traffic behavior over an (e.g.) 24-hour period is subject to periodic variations in the number of users, their spatial distribution, their traffic demands and the variation inherent in each of these factors. We illustrate this with Fig. 1. This figure shows traffic received at 4 APs in a real wireless network using a CRAWDAD trace [19]. The data is drawn from a 30-day period and is grouped by hour showing the extremes of the 30 samples taken at the same hour on each day. Notice that individual flows vary by different amounts, and their ranges vary. In particular, it is not sufficient to assume traffic flows simply scale together. Thus a routing optimized for one point in time, may perform poorly at other times. In this work, we advance, implement and confirm the usefulness of applying different routing schemes at different times of the day.

To date, the following essential issue in wireless mesh network remains unanswered – how to perform joint channel assignment and routing under high traffic variability so that the resulting network performance can closely track the optimal solution without incurring too much overhead. Though oblivious mesh routing in the existing literature provides a promising formulation, it faces the following two challenges: (1) the routing performance in terms of robustness and efficiency is dependent on the accuracy of the traffic characterization. Because the correlation between demands on different APs varies at different times

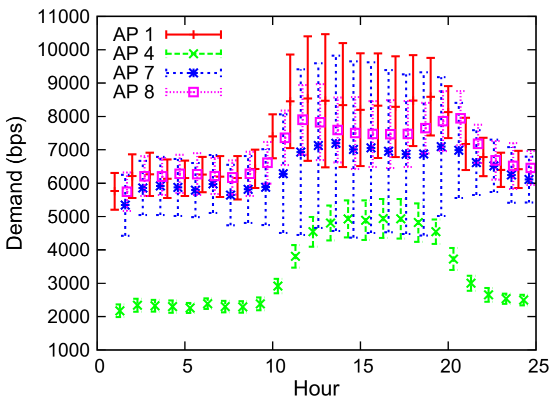

Fig. 1. Varying traffic patterns at four APs over 30 days.