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On the impact of interference models on channel assignment in multi-radio multi-channel wireless mesh networks

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ABSTRACT

We study the impact of three different interference models on channel assignment in multi-radio multi-channel wireless mesh networks, namely the protocol model, the signal-to-interference ratio (SIR) model and the SIR model with shadowing. The main purpose is to determine the minimum number of non-overlapping frequency channels required to achieve interference-free communication among the mesh nodes based on a realistic interference model. We propose novel, effective, and computationally simple methods for building the conflict graph based on the SIR model with shadowing, and for finding channel assignments from the resulting conflict graph. We find that channel assignment using a realistic interference model (SIR model with shadowing) requires more frequency channels for network throughputs at different node-degree constraints as compared to using simpler interference models.

1. Introduction

The protocol model [1] is widely used to model interference for channel assignment in wireless mesh networks. This simple model assumes that interference is a binary phenomenon that occurs within the interference range of the nodes of any active link. The SINR (signal-to-interference-and-noise ratio) model, also known as the physical model [1], is more accurate. It considers the cumulative effect of interference at the receiving node where a packet is received correctly if its SINR is above a certain threshold, commonly known as the SINR threshold. Neither the protocol model nor the SINR model reflects the reality of signal propagation in wireless links. In a real wireless channel, the RF signal is reflected from and around nearby objects, which causes the signal strength to fluctuate in space. This effect is commonly known as *shadowing* and is usually accounted for by adding a random component to the received signal strength. An improved physical model that accounts for shadowing will be referred to as *SINR model with shadowing*. We use SIR (signal-to-interference ratio) instead of SINR since co-channel interference is generally much stronger than noise. Our goal is to use the realistic *SIR model with shadowing* to devise an interference-free channel assignment method for multi-radio multi-channel (MRMC) wireless mesh networks (WMNs).

To achieve our objective, we propose a novel and computationally simple method of building the conflict graph based on the SIR model, then extend it for the SIR model with shadowing. We also develop new computationally simple heuristics to find a small number of frequency channels for interference-free channel assignment by finding *weighted maximal independent sets* (WMaISs) in the conflict graph. Note that in these SIR models interference is controlled but still exists. By "interference-free" communication we mean that the incoming packet's SIR is above the required SIR threshold for correct reception at the receiver.

To minimize the number of frequency channels required, we use our *Select x for less than x* topology control algorithm (TCA) [2] for building the connectivity graph. We

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assume a single mesh gateway (GW), which is the sink for all flows. All mesh nodes, except the GW, are sources of flow that can take multiple paths to the GW. We formulate this multi-path routing problem as a mixed integer linear program whose objective is to maximize the network throughput while maintaining fairness among the multiple flows under flow conservation, half-duplex, and node-degree constraints. By *network throughput*, we mean the total amount of flow that reaches the GW from all sources. We formulate the interference-free channel assignment problem as a minimum coloring problem, known to be NP-hard for general graphs [3]. Given the conflict graph generated by the SIR model with shadowing, the minimum coloring problem requires finding the smallest number of WMaISs where the number of frequency channels required is equal to the number of WMaISs. Our results show that channel assignment using the SIR model with shadowing requires the highest number of frequency channels for network throughputs at different node-degree constraints as compared to using other interference models, due to its more realistic nature.

To the best of our knowledge, this is the first work to propose a method for finding a small number of frequency channels needed for interference-free communication in MRMC WMNs under realistic conditions. Related preliminary work has been presented in [4]. Our contributions include (i) the development of a simple and effective method for implementing a conflict graph based on the SIR model with shadowing, which significantly reduces the overall computational complexity, (ii) novel, computationally simple and effective heuristics for finding a small number of non-overlapping frequency channels for realistic interference-free channel assignment for MRMC WMNs, and (iii) showing that more realistic interference models require a significant increase in the number of frequency channels needed for interference-free communication.

The rest of the paper is organized as follows. Section 2 presents related work. Section 3 explains the creation of the conflict graph using three different interference models. The solution of the channel assignment problem using WMaISs is presented in Section 4. Performance evaluation with results is given in Section 5. Conclusions and some directions for future work are given in Section 6.

2. Related work

Several channel assignment schemes have been proposed which use the protocol model for modeling interference in MRMC WMNs [5–11] due to its simplicity and ease of implementation. However the study in [12] concludes that cumulative interference must be taken into account to obtain accurate performance results for multi-hop wireless networks and recommends the use of the cumulative interference model, i.e. SIR model. The study also states that although the physical model is necessary for accuracy, it is not suitable for large-scale multi-hop wireless networks due to its high computational complexity. We enhance the SIR model to include shadowing and use it in finding interference-free channel assignments using a minimum coloring heuristic that repeatedly solves the WMaIS sub-problem to determine a small number of frequency channels required. WMaISs have previously been used for resource allocation in multi-hop wireless networks, e.g. for link scheduling in MRMC multi-hop wireless networks [13] and in ultra wideband wireless ad-hoc networks [14]. Schemes using minimum coloring for resource allocation in wireless networks have also been proposed. The problem of determining the minimum number of frequency bands required for multi-radio multi-hop wireless networks such that all co-located transmitters and receivers can be simultaneously activated is addressed in [15]. Instead of using the link interference graph, a minimum coloring method is used to find a feasible spectrum allocation directly from the network connectivity graph. A simplistic interference model based on duplexing constraints in which a node is restricted from simultaneously transmitting and receiving on the same frequency band is used. In [16], the authors use minimum coloring for TDMA link scheduling in a multi-hop wireless network to maximize its throughput. They construct the conflict graph using the protocol interference model or the RTS/CTS interference model [17]. Minimum coloring for the link interference graph is used in [18] to solve the problem of obtaining tight delay guarantees for throughout-optimal link scheduling in wireless ad-hoc networks. A scheduling algorithm is proposed in [19] that uses minimum coloring to determine a minimum length schedule for maximizing the network throughput in TDMA based wireless mesh networks. The interference model used assumes that transmissions may interfere in two ways which are typically referred to as primary and secondary interference [20]. The authors assume that there are enough orthogonal channels available to eliminate all the secondary interference, i.e. the interference that arises between two links when the receiver of one link is within the interference range of the transmitter of the other link. They consider the primary interference only while constructing the link conflict graph in which the links conflict with each other if they share a common sender or receiver.

Unlike any previous channel assignment schemes for MRMC WMNs, our work is the first to propose a channel assignment method that is based on a realistic interference model, i.e. the SIR model with shadowing. Our method determines a channel assignment that provides interference-free communication among the mesh nodes in a MRMC WMN to achieve the maximum network throughput while maintaining fairness among the multiple network flows.

3. Interference models

The conflict graph F can be built using the three different interference models once the links involved in routing are known. The vertices in F correspond to the links in the connectivity graph C. An edge between vertices l_{ij} and l_{pq} in F indicates that the links l_{ij} and l_{pq} in C cannot be active simultaneously. Node locations are assumed to be known.

3.1. Conflict graph based on protocol model

Let d_{ij} denote the distance between nodes n_i and n_j, R_i be the transmission range of node n_i, and R'_i be the