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A REDUCTION IN WIRELESS NETWORKS USING GRAPH COLORING METHODS

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ABSTRACT

The interference imposes a significant negative impact on the performance of wireless networks. With the continuous deployment of larger and more sophisticated wireless networks, reducing interference in such networks is quickly being focused upon as a problem in today's world. In this paper we analyze the interference reduction problem from a graph theoretical viewpoint. A graph coloring methods are exploited to model the interference reduction problem. However, additional constraints to graph coloring scenarios that account for various networking conditions result in additional complexity to standard graph coloring. This paper reviews a variety of algorithmic solutions for specific network topologies.

Keywords: Interference Reduction, Wireless Networks, Graph Coloring, Vertex & Edge Coloring

1. INTRODUCTION

One of the main challenges of wireless communication is interference. Unfortunately, research in this area is so young which leads researchers to have different ideas regarding the identification of a universal measure of network interference. According to the Glossary of Telecommunication Terms - Federal Standard 1037C, interference is defined as:

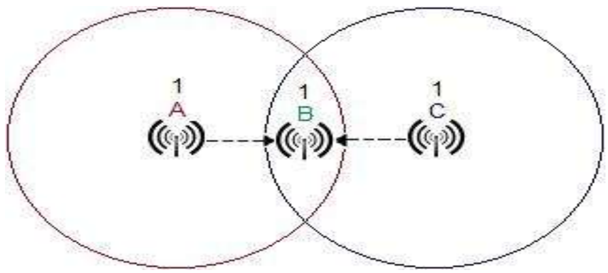
Interference: *A coherent emission having a relatively narrow spectral content, e.g., a radio emission from another transmitter at approximately the same frequency, or having a harmonic frequency approximately the same as another emission of interest to a given recipient, and which impedes reception of the desired signal by the intended recipient.*

Informally speaking, a node ***u*** may interfere with another node ***v*** if ***u***'s interference range unintentionally covers ***v***. Consequently, the amount of interference experienced by a node ***v*** corresponds to the amount of interference produced by nodes whose transmission range covers ***v***. In frequency division multiplexing cellular networks, reducing the amount of interference results in fewer channels which, in turn, can be exploited to increase the bandwidth per frequency channel. In systems using code division multiplexing, small interference helps in coding overhead. In the context of ad hoc and sensor networks, there is an additional motivation for keeping interference low. In these networks consisting of battery driven devices, energy is typically scarce and the frugal usage of it is critical in order to prolong system operability and network lifetime. In addition to enhancing throughput, minimizing interference may help in lowering node energy dissipation by reducing the number of collisions (or the amount of energy spent in an effort of avoiding them) and consequently retransmissions on the media access layer.

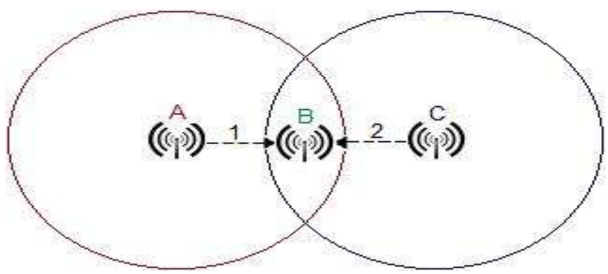
Interference can be reduced by having nodes send with less transmission power. The area covered by the smaller transmission range will contain fewer nodes, yielding less interference. On the other hand, reducing the transmission range has the consequence of communication links being dropped. However, there is surely a limit to how much the transmission power can be decreased. In ad hoc networks, if the node's transmission ranges become too small and too many links are abandoned, the network may become disconnected. Hence, transmission ranges must be assigned to nodes in such a way that the desired global network properties are maintained.

Transmitting nodes influence the ability of other nodes to receive data. A node is not able to receive data from its neighbor if it was interfered by receiving a transmission not intended for it. This mutual disturbance of communication is called interference. Reducing interference in the network leads to fewer collisions and packet retransmissions, which indirectly reduces the power consumption and extends the lifetime of the network. Therefore, reducing the interference is an important goal for wireless networks. The interference imposes a potential negative impact on the performance of a wireless network. In MANETs, each device can selectively decide which device to communicate with either by adjusting its transmission power or its antenna direction. Obviously, keeping relatively limited direct neighbours is helpful to speed up the routing protocols in addition to possibly alleviating the interference among simultaneous transmissions, and also possibly save the energy consumption.

If a network incurs a large interference, either many communication signals sent by nodes will collide, or the network may experience a serious delay at delivering the data for some nodes, and even consume more energy. So, we reach to the conclusion that the interference is a major drawback of wireless networks. The aim of reducing interference is to prevent adjacent or connected nodes, which are linked by radio signals, from receiving and transmitting signals which conflict or blend together. Thus, interference occurs when conflicting transmissions over one radio frequency are received by one or more nodes in a wireless network. This inhibits the ability of the receiver to decipher incoming signals. This concept is illustrated in Figure 1a, which shows a typical situation in which the broadcast areas of nodes A and C overlap in the vicinity of node B, causing B to receive a garbled signal composed of the signals from A and C. In such situations, it is difficult for B not only to decipher simultaneous signals, but also to reliably determine the source of the signal. The problem of reducing interference in arbitrary networks turns out to be very difficult, and for this reason, simpler network layouts have been investigated such as, multi-hop wireless mesh network layouts [1], triangular lattice topologies [9], unit disk graphs [3], hexagonal topologies [8], and other more general topologies [4]. Other key facets of the interference problem in wireless networks specify whether a proposed solution is contrived in a distributed or centralized setting, whether nodes in a given solution are self-aware of their location or whether this assumption is not necessary, and whether or not minimum separation distance between nodes needs to be factored into algorithmic solutions.



Interference occurs at B



No interference

Figure 1. Interference resolved through channel assignment

Numerous methods for reducing interference exist, such as topology control [10], power control [7], and channel assignment [1, 2, 3, 5, 6, 8, 9]. This paper will focus exclusively on the latter method, which seeks to assign channels of different frequencies to interfering nodes or edges.

In Figure 1a, for instance, simultaneous transmissions of A and C result in interference at B. This problem is resolved in Figure 1b by having nodes A and C transmit over frequencies 1 and 2 respectively, equipping node B with two radios that can transmit and receive over frequencies 1 and 2. Signals from A and C can be demultiplexed, (that is, components of different frequencies can be extracted from one signal) at node B because of differing frequencies, and node B can clearly determine if node A transmits across frequency 1 or if node C transmits across frequency 2. Therefore the intersection node A and node C's broadcast areas no longer results in interference. Through careful assignment of communication channels to nodes in a network, interference could be greatly reduced. It is important to note, however, that the number of radio frequencies is finite, and therefore, the problem of minimizing the number of channels allocated to a specific network is worthy of thorough investigation as well. In some instances, channel overlap is necessary if the number of assigned channels for a network is inadequate to connect all nodes [2].

The rest of the paper is organized as follows. In Section 2, we define the interference problem as a graph coloring problem and discuss two coloring approaches, vertex and edge coloring. Finally a summary of existing results and conclusions are presented in Section 3.

2. RELATED WORK

Arunesh Mishra et. al. in [2] propose techniques to improve the usage of wireless spectrum in the context of wireless local area networks (WLANs) using new channel assignment methods among interfering Access Points (APs). They identify new ways of channel re-use that are based on realistic interference scenarios in WLAN environments. In this paper they formulated channel assignment in WLANs as a weighted vertex coloring problem that takes into account realistic channel interference observed in wireless environments, as well as the impact of such interference on wireless users. They proposed two efficient, scalable and fault tolerant distributed algorithms that achieve significantly better performance than the state-of-the-art Least Congested Channel Search (LCCS). Through simulations, they showed that the two techniques achieve up to 45.5% and 56% reduction in interference for sparse and dense topologies respectively with 3 non-overlapping channels. They also show that the techniques effectively use partially overlapping channels to achieve an additional 42% reduction on average for moderately sized networks. They validated these results using experiments on a fully operational in-building wireless testbed network comprising of 20 APs and achieved a 40% reduction using partially overlapping channels. A straightforward extension to this work is to handle co-existing 802.11b/g APs in the same area of coverage. The overlap graph in such scenarios becomes directed in nature as the interference effects become asymmetric (802.11g APs would be more affected than 802.11b). The weights on the edges would reflect a measure of the asymmetric effect of the interference caused by one AP's BSS to another. We leave such extensions as future work. Finally they prove that the weighted graph coloring problem is NP-hard and propose scalable distributed algorithms that achieve significantly better performance than existing techniques for channel assignment.

Mathieu Couture et. al. in [3] present the first location oblivious distributed unit disk graph coloring algorithm having a provable performance ratio of three (i.e. the number of colors used by the algorithm is at most three times the chromatic number of the graph). This is an improvement over the standard sequential coloring algorithm since they present a new lower bound of 10/3 for the worst-case performance ratio of the sequential coloring algorithm. The previous greatest lower bound on the performance ratio of the sequential coloring algorithm was 5/2. However, simulation results showed that this algorithm does not provide a significant improvement over the algorithm which sequentially colors the nodes in an arbitrary order. Simulation results also showed that, in the average case, largest-first (which is also distributed and location oblivious) performs better than the algorithm they proposed. It also performs better than lexicographic coloring, which also has a worst-case performance ratio of at most three. However, no one has shown whether largest-first has a better worst-case performance ratio than five. In fact, it is also an open question whether coloring the nodes of a unit disk graph in an arbitrary order can, on the worst case, use less than five or more than 10/3 times the minimum number of colors that are necessary.

3. VERTEX VS. EDGE COLORING

When used without any qualification, a coloring of a graph is almost always a proper vertex coloring, namely a labeling of the graph's vertices with colors such that no two vertices sharing the same edge have the same color. Since a vertex with a loop could never be properly colored, it is understood that graphs in this context are loopless. The terminology of using colors for vertex labels goes back to map coloring. Labels like red and blue are only used when the number of colors is small, and normally it is understood that the labels are drawn from the integers {1,2,...}. A coloring using at most $\boldsymbol{k}$ colors is called a (proper) $\boldsymbol{k}$-coloring. The smallest number of colors needed to color a graph G is called its chromatic number, χ (G). A graph that can be assigned a (proper) $\boldsymbol{k}$-coloring is $\boldsymbol{k}$-colorable, and it is $\boldsymbol{k}$-chromatic if its chromatic number is exactly $\boldsymbol{k}$. A subset of vertices assigned to the same color is called a color class; every such class forms an independent set. Thus, a $\boldsymbol{k}$-coloring is the same as a partition of the vertex set into $\boldsymbol{k}$ independent sets, and the terms $\boldsymbol{k}$-partite and $\boldsymbol{k}$-colorable have the same meaning.

An edge coloring of a graph is a proper coloring of the edges, meaning an assignment of colors to edges so that no vertex is incident to two edges of the same color. An edge coloring with $\boldsymbol{k}$ colors is called a $\boldsymbol{k}$-edge-coloring and is equivalent to the problem of partitioning the edge set into $\boldsymbol{k}$ matchings. The smallest number of colors needed for an edge coloring of a graph G is the chromatic index, or edge chromatic number, χ' (G). A Tait coloring is a 3-edge coloring of a cubic graph. The four color theorem is equivalent to the assertion that every planar cubic bridgeless graph admits a

Tait coloring.

4. CONCLUSIONS

The dynamic algorithm, BFS-CA [1], is one of the best algorithms for use in today's ever-changing wireless network topologies. It is the most implementation-ready compared to other graph coloring algorithms. BFS-CA was also shown to have a significant improvement over static assignment of channels [1]. The weighted Hminmax and Hsum [2] algorithms, despite resorting to greedy implementations, have achieved over a 40% average reduction in interference over one "state-of-the-art" method [2]. The McDiarmid and Reed bandwidth-based weighted algorithms [9] bring together several novel ideas, however they seem difficult to eventually implement.

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