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MAXIMUM WEIGHT SCHEDULING IN WIRELESS AD HOC NETWORKS WITH HYPERGRAPH INTERFERENCE MODELS

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Abstract: This paper proposes a hypergraph interference model for the scheduling problem in wireless ad hoc networks. The proposed *hypergraph* model can take the sum interference into account and, therefore, is more accurate as compared with the traditional binary graph model. We provide an improved bound for the expectation of the stationary delay under the maximum weight scheduling (MWS) policy in one-hop wireless networks. Finally, by adjusting certain parameters, the ***hypergraph*** can achieve a systematic tradeoff between the interference approximation accuracy and the user node coordination complexity during scheduling. As an application of the ***hypergraph*** model, we consider the performance of a simple distributed scheduling algorithm, i.e., maximal scheduling, in wireless networks. We propose a lower bound stability region for any maximal scheduler and show that it achieves a fixed fraction of the optimal stability region, which depends on the interference degree of the underlying hypergraph. Further, different from the global ***signal-to-interference-plus-noise ratio (SINR)*** model, the hypergraph model preserves a localized graph-theoretic structure and, therefore, allows the efficient scheduling algorithms to be extended to the cumulative interference case. We also demonstrate the interference approximation accuracy of *hypergraphs* in random networks and show that *hypergraphs* with small hyperedge sizes can model the interference quite accurately. Finally, the analytical performance is verified by simulation results.

Keywords: Ad hoc networks, interference, scheduling, stability, wireless networks, Wireless link scheduling, delay, maximum weight schedule, stability, queue size.

I. INTRODUCTION

In many wireless communication systems, wireless links share a common communication medium and simultaneous link transmissions may cause interference. Researchers address the interference problem by devising link scheduling policies (algorithms) that optimize performance objectives of choice. Throughput has been considered as one of the most important performance metrics and the throughput performance of various scheduling algorithms has been intensively studied. Recently, researchers are increasingly interested in the delay performance of link scheduling algorithms [1] [2]. This paper studies the expected delay and the sum of the expected queuesizes1 under the well-known maximum weight scheduling (MWS) policy. Link interference may have different consequences in different families of wireless communication technologies.

The paper focuses on one of the important cases, known as the *protocol interference model*, in which the transmission of a link (i.e., a transmitter-receiver pair) can be successful only when there is no interference from other link transmissions. In [3], ***Tassiulas et al.*** proposed the MWS policy and showed that it is throughput optimal when applied to the protocol model. Under the MWS policy, the set of links that are scheduled for transmission on each time slot corresponds to a weighted maximum independent set (WMIS) of the interference graph, where the weight of a node is the queue length of the corresponding wireless link. Later, researchers considered a generalization, the MWS-w policy, which is also throughput optimal [2].

The difference is that, in MWS-w where w = (wi)i is a positive vector, the weight of each node i is equal to its queue length multiplied by wi. It has been observed experimentally that the queue sizes and delays are small under the MWS policy for the 2-hop interference model, which is a special case of the protocol interference model [2]. It is worth pointing out that the WMIS problem is NP-hard in general. Hence, the good throughput and delay performance does not come for free. This paper not only presents improved single-parameter bounds, but asks how much more improvement can be made. Applying the analytical framework used in [2] [4], we first generate a family of bounds. Then, we find the tightest bound by minimizing over the entire family. As a result, we show that the new bound is the smallest single-parameter bound for the MWS policy.

2. EXISTING SYSTEM MODEL

A. Scheduling With the Graph Interference Model

A flow contention graph [5], [6] approximates the interference as "binary." This means that the transmission in a particular link fails if and only if there is a concurrent transmission in any neighboring link. For example, consider the four-link wireless network in Fig. 1, where a flow contention graph can be constructed by, for example, placing a guardzone [20] with certain radius around the receiver of each link. Two links form an edge in the flow contention graph if one's transmitter is in the guard zone associated with the other. In such a case, the flow contention graph for Fig. 1 has only one edge {1, 2}. Therefore, a transmission schedule is valid as long as links 1 and 2 are not chosen simultaneously. Based on such a graph interference model, many interesting scheduling algorithms [7]–[10] have been proposed, whose performance limits are often well understood, thanks to the deep and rich foundation of graph theory. This is particularly convenient for the important class of low complexity distributed scheduling, such as maximal scheduling [7] and the longest queue first(LQF) scheduling [11], [12], where the throughput performance is often specified by the metrics of the underlying interference graph, such as the "interference degree" and the "local pooling factor." In the literature, many key insights about the throughput performance of such schedulers in practical wireless networks were obtained by conducting graph-theoretic analysis under different physical layer specifications [7], [13].

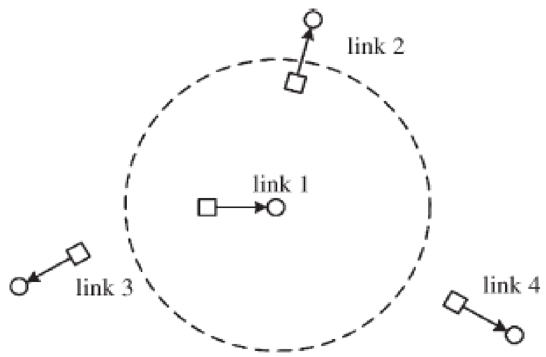

Figure-1: *Sample wireless network with four links, where* ***square nodes are the transmitters****, and* ***round nodes are the receivers****. The dashed circle is the guard zone associated with link 1.*

B. Scheduling With the Physical SINR Interference Model

Unlike the approximation-based graph model, the physical SINR model can accurately describe the interference constraint in wireless networks. Under the SINR model, a transmission schedule $\boldsymbol{\sigma}$ is valid if the SINR at any transmitting link *I* satisfies Despite the recent research efforts on SINR-based scheduling, it is widely recognized that the design and analysis of efficient scheduling algorithms under the SINR model, in particular, low complexity distributed scheduling, is still far from being solved. This is because of the fundamental global nature of the interference, namely, the transmission of any link will be received by any other link in the network as interference, thereby impairing its own communication quality. This implies that any scheduling algorithm under the global SINR model will require coordination among all the user nodes in the network, which makes it very difficult to design distributed scheduling algorithms.

$$\frac{S_i}{N_i + \sum_{k\in\boldsymbol{\sigma}} I_{ki}} \geq \theta_i \quad \text{------------ (1)}$$

Where *Si* is the received signal power at link *i*, *Ni* is the noise power, *Iki* is the received interference at link *i* from transmitting link *k*, and *θi* is the SINR threshold for successful packet reception for link *i*, which is determined by physical layer modulation, detection, and coding specifications.

3. PROPOSED WORK

Hypergraph Interference Model

We assume that the wireless network consists of *N* links, which are denoted as the set *V*. The hypergraph interference model is defined as $H = (V, E)$, where V is the link set, and E is the set of hyperedges such that each hyperedge$e = \{i1, i2, . . . , ik\} \in E$ consists of a subset of links, which are not allowed to transmit together, due to the packet reception failure at one or more links in *e* from the strong sum interference. For example, in Fig. 1, if links 1, 3, and 4 transmit together, then link 1 will fail due to the interference from both links 3 and 4. Thus, one can form a hyperedge {1, 3, 4} so that such a transmission mode is not allowed. Note, however, that {1, 3} is not a hyperedge, and therefore, links 1 and 3 can indeed transmit together. This distinction between the effect of sum interference and interference from a single link cannot be captured by the conventional graph model. We require that the hyperedges should be constructed to be minimal, i.e., strict supersets of hyperedges are not included in *E*, and therefore, the hypergraph representation is not redundant. For example, for the hypergraph in Fig. 1, {1, 2, 3, 4} is also an invalid transmission schedule, but is not a hyperedge, since it already includes two hyperedges {1, 2} and {1, 3, 4} as subsets. Finally, note that the links in each hyperedge *e* are chosen locally, in the sense that there is a link $i \in e$ such that all the other links in *e* are in *Li*. where the hyperedge *e* has to include both links *i* and *j* .

4. CONCLUSION

We have proposed a hypergraph interference model for the scheduling problem in wireless networks. The proposed hypergraph is quite flexible in modeling sum interference constraints, which can include both the graph interference model and the physical SINR interference model as special cases. We investigated the performance of the scheduling algorithms with the hypergraph model and proposed a lower bound on the stability region for any maximal scheduler. In this paper describes, the hypergraph model is more flexible than a graph model, it allows more accurate modeling (and thus control) of interference. In this work, we demonstrate the modeling accuracy of the locally constructed hypergraph model by analyzing its outage probability in random infinite networks.

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