A Greedy Link Scheduler for Wireless Networks with Fading Channels

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***Abstract*—In this paper, we consider the problem of link scheduling for wireless networks with fading channels, where the link rates are varying with time. Due to the high computational complexity of the throughput optimal scheduler, we provide a low complexity greedy link scheduler with provable performance guarantees. We show that the performance of our greedy scheduler can be analyzed using the Local Pooling Factor (LPF) of a network graph, which has been previously used to characterize the stability of the Greedy Maximal Scheduling policy for networks with static channels.**

I. Introduction

The link scheduling problem for wireless networks has received considerable attention in the recent past. In a wireless network with shared spectrum, interference from neighboring nodes prevents all nodes in the network from transmitting simultaneously at full interference free rate. A link scheduler chooses a set of links to deactivate at every time instant to eliminate their interference on other links and only active links transmit data. An important performance objective of a scheduler is throughput optimality, *i.e.*, for any given network, the scheduler should keep all the queues in the network stable for the largest set of arrival rates that are stabilizable for that network.

For wireless networks in which a set of link activation vectors are defined according to a general binary interference model [3], the Maxweight policy or the dynamic back-pressure policy is known to be throughput optimal [3]. Maxweight type policies have also shown to be throughput optimal for wireless networks with fading channels, where the link rates vary over time [7], [8]. However, the Maxweight policy suffers from high computational complexity (NP-hard in many cases, including k-hop interference models, k>1) [5], and has therefore motivated the study of schedulers that have low complexity, are amenable to distributed implementation and also offer provable performance guarantees. Examples of such schedulers include Greedy Maximal Scheduling (GMS) and Maximal Scheduling, which have been widely studied for wireless networks with static channels.

While the efficiency of the Maximal Scheduling policy is related to the maximum interference degree[1] of a network graph [10], the performance of GMS has been analyzed using a parameter called the Local Pooling Factor (LPF) [2], which depends on the network topology and interference constraints. Using the LPF, GMS has been shown to be throughput optimal for a wide class of network graphs under the node exclusive interference model [6], [9].

The performance analysis of the aforementioned low complexity schedulers does not however, carry over to the scenario with fading, in which link rates are time-varying. For instance, unlike a static network, one cannot conclude in a network with time-varying links that satisfying local pooling under GMS implies throughput optimality.. It is only known that in the case of the node-exclusive interference model, GMS can achieve at least half the network stability region [1].

In this paper, we propose a greedy link scheduler for wireless networks with fading channels, which, although not throughput optimal, has low computational complexity and offers provably good performance guarantees. We show that the performance of our greedy scheduler can be related to the LPF of a network graph. In the following section we provide a brief description of our greedy scheduler and and state a theorem that captures its performance.

II. A Greedy scheduler for Networks with Fading Channels

We first present a brief overview of our system model. We consider a wireless network modeled as a graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ with edges representing links. We assume a single hop traffic model where each edge represents a source-destination pair. Time is divided into slots and

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[1]The maximum interference degree of a network graph is the maximum number of links that cannot be active when one of the links in the network is active.

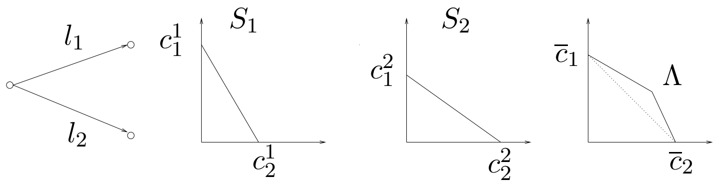

Fig. 1: Figure shows an example of two interfering links with two fading states S_1 and S_2, occuring with probability π_1 and π_2. The network stability region region, Λ is the interior of the region enclosed by the solid lines.

packets arrive at the source node following an i.i.d. process with finite mean at the start of each time slot. The vector of channel states across all links in the network is assumed to be fixed over the duration of a time slot but changing after every time slot. The set of channels in the network can assume a state $j \in \{1, \ldots, J\}$ according to stationary probability π_j. In each time slot t, the achievable rate of link $l \in \mathcal{E}$, denoted by $c_l(t)$ assumes value c_l^j if the network is in fading state j at time slot t. The expected rate of a link, denoted by $\overline{c}_l$ is given by $\overline{c}_l = \sum_{j=1}^{J} \pi_j c_l^j$. We assume a generalized binary interference model, in which each link l is associated with an interference set, denoted by $\mathcal{I}_l \subset \mathcal{E}$. Set $\mathcal{I}_l$ consists of the set of links that cannot be active whenever link l is active.

The greedy scheduler that we propose requires each link to have a queue corresponding to every channel state of the network,*i.e.*, each link has a set of J queues. In each time slot, packets arriving into a link l are placed into one of the queues[2].Let η_l^j be the queue of link l corresponding to fading state j and $\left|\eta_j^j(t)\right|$ denote its size at time t. . Fig. 1(a) shows an example of a simple two link network with two fading states S_1 and S_2, which occur with probabilities pi_1 and pi_2 respectively. The achievable rate region for the two links in states S_1 and S_2 are shown in Fig. 1(b) and Fig. 1(c) respectively. Fig. 1(d) shows the network stability region, which is the set of all arrival rates that can be stabilized for the network graph of Fig. 1(a). We now describe our greedy scheduler:

(1) At the beginning of time slot t, packet arrivals are placed in queue η_l^j with probability $\frac{\pi_j c_l^j}{\overline{c}_l}$.
(2) In time slot t, let the network be in fading state j. Our greedy scheduling policy then observes only the queues corresponding to fading state j, in order to select the rate allocation vector. The scheduler first selects the link with highest weight $m \in \operatorname{argmax}_{l \in \mathcal{E}} \left|\eta_l^j(t)\right| c_l^j$, removes all links in $\mathcal{I}_m$ from the set of potential links to be scheduled at time t, and repeats the process until there are no more non-interfering links that remain to be selected.

[2]Note that, in practice nodes need not keep a separate queue. Instead, arriving packets can be assigned a pointer referring to the associated network state, and they can be scheduled according to their associated states.

Note that the application of our greedy policy on the queues corresponding to fading state j requires the knowledge of the network fading state at every node in the network. We now give the main result of this paper, which uses the local pooling factor of a network graph to evaluate the stability region achievable using our scheme. Before we state our result, we define the following static wireless network graph: given any wireless network graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ with time varying link rates, we associate with $\mathcal{G}$ a static wireless network $\hat{G} = (\mathcal{V}, \mathcal{E})$, whose link rates are fixed at $\overline{c}_l, \forall l$. Also, let Λ and $\widehat{\Lambda}$ denote the network stability regions of the networks $\mathcal{G}$ and $\hat{\mathcal{G}}$ respectively. Note that $\widehat{\Lambda} \subseteq \Lambda$.

Theorem 1. *Let σ^* be the LPF of a network graph $\mathcal{G}$. Then, the network is stable under the greedy policy for all arrival rate vectors $\vec{\lambda}$ satisfying $\vec{\lambda} \in \sigma^* \hat{\Lambda}$, where $\hat{\Lambda}$ is the stability region of the corresponding network graph $\widehat{\mathcal{G}}$ with fixed link rates.*

Theorem 1 provides performance guarantees for our scheduling policy for any wireless network in terms of the stability region of an associated identical static network whose link rates are fixed at their expected rates. Examples of network graphs which have $LPF = 1$ include tree network graphs under the k-hop interference model for $k \geq 1$. [6] identifies all network graphs with $LPF = 1$ under the node-exclusive interference model.

III. Discussion

Our greedy scheduler is opportunistic in the sense that it considers the instantaneous link rates, *i.e.*, the rate achieved by the link in a given time slot. To compare the performance of non-opportunistic schedulers that do not exploit fading, we also show in our paper that a scheduler that utilizes the mean link rates, instead of instantaneous link rates could perform arbitrarily worse in certain cases.

Note that, our scheduler achieves low complexity and the performance guarantees at the expense of some extra overhead due to the necessity of the knowledge of the network fading state. In the paper, we also discuss some practical algorithms for the exchange of the channel state information between nodes.

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