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SINR based shortest link scheduling with oblivious power control in wireless networks

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ABSTRACT

In this paper, we consider shortest link scheduling (SLS), a fundamental problem in wireless networks to improve the network performance, under the signal-to-interference-plus-noise-ratio (SINR) constraints. It is challenging to design efficient SLS algorithms due to the intrinsic non-locality of SINR. However, if two transmission links are far away from each other, the interference of one link on the other should be small under the SINR model. This motivates us to consider the interference only in a local area, which decreases the difficulty of designing link scheduling under SINR, by partitioning the links into disjoint local link sets with a certain distance away from each other, such that independent scheduling inside each local link set is possible. Based on this idea, we propose a novel approximation algorithm PPSLS (Plane Partition based Shortest Link Scheduling) for SLS with oblivious power control. Theoretical analysis and simulations demonstrate the correctness and effectiveness of the proposed algorithm.

1. Introduction

As a fundamental problem in wireless networks, link scheduling is crucial for improving the network performance through maximizing throughput and fairness. Wireless networks have been employed in a variety of applications and have become more and more important nowadays. However, wireless communication resources such as spectrum is deficient. Therefore, many communication links have to share a common channel, resulting in a significant interference among concurrent transmissions. One effective technique to reduce interference and enhance network performance is to allocate different time slots for concurrent transmission links.

Link scheduling plays an essential role especially when the network has stringent quality of service restrictions. Generally speaking, link scheduling mainly includes three sub-problems: *maximum link scheduling* (*MLS*) (e.g. Goussevskaia et al., 2007, 2009; Halldórsson and Mitra, 2014; Huang et al., 2014; Deng et al., 2015; Zhou and Li, 2015), *maximum weighted link scheduling* (*MWLS*) (e.g. Goussevskaia et al., 2007; Xu et al., 2010; Joo et al., 2013; Wan et al., 2014), and *shortest link scheduling* (*SLS*) (e.g. Wan et al., 2010; Goussevskaia et al., 2014; Wang et al., 2015; Yu et al., 2016). Given a set of communication link requests $L = \{l_1, l_2, \ldots, l_n\}$, with l_i denoting the ith link request, MLS seeks to compute the largest feasible subset $S \subseteq L$ of links that can be scheduled simultaneously without interference. If each link is assigned a weight, MWLS computes a feasible subset whose weighted sum is the maximum. SLS is represented by $S = (S_1, S_2, \ldots, S_T)$, where S_t denotes a subset of links of L, designated to time slot t, with T being referred to as the *length* or *latency* of the schedule. In other words, SLS intends to compute a link schedule of the shortest length for L. Note that when the weight of each link is equal to one, MWLS is equivalent to MLS.

Interference models and power assignment are two important parameters that should be considered in link scheduling algorithm design and analysis. In this paper, we adopt the physical interference model, in which a signal is received successfully if and only if the Signal to Interference plus Noise Ratio (SINR) at the receiver is above a threshold depending on hardware and physical layer technologies. This model is claimed to be more practical, and has been used to study scheduling problems since the year 2006 (Moscibroda et al., 2006; Moscibroda and Wattenhofer, 2006; Halldórsson, 2012; Goussevskaia et al., 2007, 2009; Wan et al., 2010, 2014; Xu et al., 2010; Joo et al., 2013; Zhou et al., 2014). However, due to the non-locality of SINR, it is difficult to design a link scheduling algorithm with the SINR constraint, and the link scheduling problems under SINR are NP-hard (Goussevskaia et al., 2009; Gupta and Kumar, 2000). In fact, one must

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take energy efficiency into account when designing algorithms for wireless networks, such as ad hoc wireless network (Li et al., 2007) and wireless sensor network (Xie and Wang, 2014), since the batteries are low power and not recharged or replaced during a mission. For power assignment, we adopt the *oblivious* power control, in which the transmission power of a link depends only on the length of the link. The two most frequently used power assignment strategies, namely the *uniform* (*or fixed*) *assignment* and the *linear assignment* (which ensures that the signals received at the intended receivers are identical), are special cases of oblivious power assignment.

In this paper, we tackle the challenges of SLS in wireless networks under the SINR interference model. We mainly consider the interference in a local area and propose a localized link scheduling algorithm with oblivious power assignment. Our algorithm design is motivated by the following two observations. (1) If the distance between two links is sufficiently large, their mutual interference is small, and thus, the two links might be able to transmit simultaneously;

(2) A short link can tolerate a large interference but a long link can only tolerate a small interference.

We first classify the links into groups according to their lengths, and then partition the links of each group into disjoint local link sets, whose distances are large enough, such that independent scheduling inside each local link set is possible. By this way we successfully decouple the global interference constraints for the implementation of localized scheduling, which lowers the difficulty to design link scheduling algorithms under the SINR model.

We also consider oblivious power assignment to links, which can conserve energy to the limit while improving the network throughput. Extensive theoretical analysis is conducted to justify our algorithm design and investigate its performance, and *the results state that the proposed algorithm has a constant performance ratio if the link length diversity is a constant*. To the best of our knowledge, this is the first localized solution on the SLS problem under the SINR interference model.

The rest of the paper is organized as follows. We discuss the related work in Section 2. Section 3 presents the model and definitions. In Section 4, we propose an algorithm for the shortest link scheduling problem under the SINR model and demonstrate its correctness and effectiveness by theoretical analysis. In Section 5 we show the efficiency of our algorithm by simulations. Finally, we summarize the paper in Section 6.

2. Related work

There have been a few results on link scheduling under the SINR constraint (e.g. Wan et al., 2012; Halldórsson, 2012; Goussevskaia et al., 2007, 2009; Wan et al., 2010, 2014; Xu et al., 2010; Joo et al., 2013; Zhou et al., 2014; Blough et al., 2010). Although we focus on the SLS problem, we give a brief review on the MLS problem because it is closely related to our work.

Goussevskaia et al. (2007) presented the first NP-hard proof of link scheduling under the SINR model and proposed an $O(g(L))$ factor approximation algorithm for both MWLS and SLS with a uniform power assignment, where $g(L) = \log(l_{\max}/l_{\min})$ is called the *link length class diversity*, and $l_{\max}$ and $l_{\min}$ denote the length of the longest and the shortest link, respectively. Later, Goussevskaia et al. (2009) developed a constant approximation ratio algorithm for the MLS problem and derived an $O(\log n)$ factor SLS algorithm by directly applying the MLS algorithm *OneSlotSchedule*, where n is the total number of links. The interference model used in Goussevskaia et al. (2007, 2009) is an approximation of the SINR model, in which the effect of noise is neglected. When ignoring the ambient noise, SINR is simplified to SIR, in which the transmission range of a link is infinite; thus the possible number of link length classes is infinite as well. Blough et al. (2010) proposed the first SLS algorithm under the exact SINR model. They defined a class of links called “black-gray” links, whose lengths are equal or near to the maximum transmission range of the sender. The approximation bound of the proposed algorithm is heavily affected by the “black-gray”links. If few or no “black-gray” links are present, the approximation bound is a constant. However, if relatively more “black-gray” links appear in the wireless network, the approximation bound becomes looser. In the extreme case, in which all the links to be scheduled are “black-gray”, the approximation bound is $O(n)$, with n being the number of links. The problem of MWLS under the physical interference model with oblivious power assignment in wireless networks was studied in Xu et al. (2010), which presented an algorithm to find multiple sets of well-separated links and then select the one with the largest weight by using partition and shifting strategies. Wang et al. (2015) improved the results of Blough et al. (2010) by introducing hypergraph model and selecting more than one links from a square to schedule simultaneously. The upper bound of the scheduling length is $O(\varDelta_{\max})$, where $O(\varDelta_{\max})$ is the maximal number of links in a square, which is $O(n)$ in the extreme case of all the n links in one square. Furthermore, the side length of a square is related to $\varDelta_{\max}$ while $\varDelta_{\max}$ depends on the size of square. The intersecting relationship is paradoxical.

Note that the algorithms mentioned above are all centralized. Due to the global characteristic of the SINR model, designing a distributed link scheduling algorithm is a challenging problem.

Distributed link scheduling has been studied in Le et al. (2010) and Pei and Vullikanti (2012). Le et al. (2010) proposed a distributed greedy maximal link scheduling algorithm under interference localization. A link l only performs scheduling coordination inside a circle area named interference neighborhood of the link. However, the trivial procedure for determining the interference neighborhood is centralized. Moreover, link l and other links need to calculate their cumulative interference in an iterated procedure, which is impractical in a large scale network. Pei and Vullikanti (2012) and Gupta and Kumar (2000) proposed a local distributed scheduling and power control algorithm under the SINR model, achieving an $O(g(L))$ approximation factor in the throughput region. Note that the uniform power assignment for all links was adopted, and thus the links in the same link class were assigned the same power. Similar to Le et al. (2010), a local interference region was defined in Pei and Vullikanti (2012), in which the SINR feasible set was computed.

By combining the partition with shifting strategies into a pick-and-compare scheme, Zhou et al. (2014) presented a class of localized scheduling algorithms with provable throughput guarantee subject to the physical interference constraints. The algorithm under the linear power setting was the first localized algorithm that achieves at least a constant fraction of the optimal capacity region subject to the physical interference constraints. The algorithm under the uniform power setting was the first localized algorithm with a logarithmic approximation ratio to the optimal solution. The basic idea of the algorithm is to create a set of disjoint local link sets in which the scheduling can be done independently without violating the global interference constraints. The distance of two cells is determined by the longest link, which leads to a looser approximation factor. Moreover, the links of the feasible set S are picked from sub-squares, and some links that are in a super-subsquare but out of the sub-squares that may transmit concurrently with S are not picked, which also contributes to the loose approximation factor.

The main differences of our work from the most related ones are summarized as follows.

- In Goussevskaia et al. (2007), Blough et al. (2010), and Le et al. (2010), the algorithms are under the uniform power assignment rather than the general oblivious power assignment. Uniform power assignment is simple but has low efficiency. To ensure that the longest link transmits successfully, all links are assigned a large power, which is not necessary especially to the short links. Moreover, large transmit power results in large interference. In