INTRODUCTION

As we all know, link scheduling is the most fundamental and typical problem which can significantly influence network performance. Since Gupta and Kumar first studied on the methods to schedule links and enhance the capacity in Wireless Sensor Networks[10], three sub-problems were proposed one after another: maximum link scheduling (MLS) problem [1], maximum weighted link scheduling (MWLS) problem [2] and shortest link scheduling (SLS) problem [3]. In this paper, we will mainly focus on MLS problem in the case where sending nodes are equipped with directional antennas.

The problem maximum link scheduling (MLS) is to seek a largest set of links from a given set A that can be scheduled simultaneously. Given a set of communication link requests L = {l1, l2 ,…,ln } , with li denoting the ith link request. MLS intends to find a maximum subset of links S ⊆ L to be scheduled simultaneously, designated to one time slot, given a set of communication links with each having a unit traffic demand. This optimization problem is NP-hard proved by Goussevskaia [1]. There are a lot of studies to this aspect, some better performance approximation scheduling algorithms have been proposed [1], [3].

How to get the maximum throughput capacity of a given wireless network? In the case of shared only one channel, a plurality of communication links transmission at the same time will lead to signal interference. In wireless network, link scheduling problem is to reduce the maximum interference when the links transmit simultaneously, and ensure the message can be successfully accepted by the receiving node. The main objective is to achieve efficient spatial reuse and increase network capacity, considering wireless interference among concurrently transmitting nodes.

By concentrating the energy in specific direction, opposed to omni-directional transmission, directional antennas can provide the benefits of increased range, reduced interference and increased spatial reuse of bandwidth. We can benefit from the advantages provided by directional antennas if the scheduling does not take into account the nature of the beam formation at each node.

At first, the solution to the problem of MLS was based on the graph interference model. Then, the physical interference model is confirmed better to the practice to model interference. Actually the interference model will significantly influence both the complexity and the accuracy of the link scheduling. Various kinds of interference model were applied in link scheduling [4][5][6].

There are mainly two kinds of interference model are used. One of them is graph-based model, including the protocol interference model, CTS / RTS model, K-hop interference model and so on. By localizing the interference of a transceiver on others, it is much easier to track and handle. Unfortunately, the graph-based interference model is too idealistic and simple so that there are many vital factors are ignored. Another kind of interference model is physical interference model, which is also known as SINR (signal-to-interference-plus-noise-ratio) model. In physical interference model, the accumulative interference is considered and thus it is more close to the reality. However, when physical interference model is applied, it is much more complex to calculate and design algorithm. Most of the researches are based on graph-based models which is too optimistic. To make our research more accurate, we adopted physical interference model in this paper.

As time goes on, much more conditions that will influence link scheduling performance significantly have been taken into account in the research, like power control which is a vital element. Many kinds of power control for instance, linear transmission power control, uniform transmission power control and arbitrary transmission power control are considered [2012 CoRR]. Another important issue is about distribution or centralization problem. Most studies focus on the centralized implementation, but some develop distributed even localized link scheduling algorithms with provable throughput performance [Throughput Optimizing]

In this paper, we apply directional antennas to the research of MLS problem based on the physical interference model, which can significantly reduce ambient interference and ensure more nodes can be transmitted at the same time. Then we also take full-duplex transmission into consideration, in which every node is both sender and receiver. It is more complex but also more realistic.

In this paper, we first design a directional interference model applicable to directional antennas. Then we propose an approximation algorithm for the problem of OSML based on directional interference model. After that we take bidirectional communication into consideration, redefine some symbols and then discuss the algorithm for full-duplex transmissions. We give the correctness analysis and performance analysis, provides a sound mathematical proof to some special case. Finally, we also present the performance of the algorithm by simulation, compared with an omnidirectional algorithm.

The rest of the paper is organized as followed. Section II describes our directional interference model. In section III, we formulate the scheduling algorithm for the problem, and provide mathematical analysis of the OSML algorithm. In section IV, we present simulation results to illustrate the performance of our scheduling algorithm, and section V concludes the paper.

RELATED WORKS

Since Gupta and Kumar first studied on the methods to schedule links and enhance the capacity in Wireless Sensor Networks[10], three sub-problems were proposed one after another: maximum link scheduling (MLS) problem [1], maximum weighted link scheduling (MWLS) problem [2] and shortest link scheduling (SLS) problem [3]. Given a set of communication link requests L = {l1, l2 ,…,ln } , with li denoting the ith link request. MLS intends to find a maximum subset of links S ⊆ L to be scheduled simultaneously, designated to one time slot, given a set of communication links with each having a unit traffic demand. And if each link is assigned a weight, the problem will transform into MWLS. MWLS seeks to computes a feasible subset where the sum weight is maximal. SLS is represented by S S S S = ( , ,…, 1 2 T), where St denotes a subset of links of L in one 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 with shortest length for L. In this paper, we will attach importance to MLS problem.

Goussevskaia et al. (2007) [1] give us a simple proof that link scheduling under the SINR model is NP-hard. He also proposed an O (lmax / lmin) factor approximation algorithm for MLS problem with a uniform power assignment, where lmax and lmin denote the length of the longest and the shortest link, respectively. The algorithm used greedy strategy to construct a scheduling in different classes partitioned by length. After a while, Goussevskaia [3] made huge efforts on developing a constant approximation bound in the literature and proposed a O(logn) approximation for the problem of maximizing the number of links scheduled in one time-slot scheduling. Then a factor of O(1) -approximation ratio algorithm was put forward by Halldórsson and Mitra [11]. They extended the transmission power to oblivious power assignment (including uniform, mean, and linear power assignment). Furthermore, the algorithm is applicable for both unidirectional and bidirectional links. In this paper, we will analyze bidirectional communication because bidirectional communication is more consistent with WSNs. Fanghanel et al. introduced the bidirectional version of the scheduling problem and gave a O n (log ) 3.5+α –approximation factor algorithm for SLS using the mean power assignment in general metrics [12]. This result was improved to O n (log ) in [13].

Considering the interference model used in Goussevskaia et al. (2007, 2009), it is an approximation of the SINR model, but the effect of noise is ignored in this paper. SINR is simplified to SIR problem after neglecting the ambient noise, in which the transmission scope of a link will become infinite. In this way, the possible number of link classes divided by length is infinite as well. Blough et al. (2010) [14] proposed the first SLS algorithm under the exact SINR model. He defined a class of links named “black-gray” links, whose lengths are equal or near to the maximum transmission scope 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), where n means the number of links.

However, mostly studies of link scheduling based on omnidirectional transmission. Ramamurthi [15] proposed a generalized physical interference model applying to the directional antennas, both taking into account the main lobes and the side lobes of antennas. The benefit of directional antennas to improve network capacity has been deeply analyzed in [16]. Although directional antennas has been studied for cellular networks and has been deployed for cell-sectoring, it is rarely used for OSML problem.

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