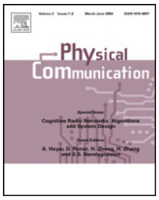
Physical Communication 22 (2017) 42–48

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom



Full length article

Distributed power allocation for spectrum sharing in mutually interfering wireless systems

Saygın Bakşi, Dimitrie C. Popescu *

Department of Electrical and Computer Engineering, 231 Kaufman Hall, Old Dominion University, Norfolk, VA, 23529, United States

ARTICLE INFO

Article history:
Received 18 August 2016
Received in revised form
23 November 2016
Accepted 29 December 2016
Available online 5 January 2017

Keywords:
Power allocation
Spectrum sharing
Rate maximization
Interference control

ABSTRACT

Allocation of transmit power is critical for spectrum sharing and coexistence of mutually interfering wireless systems. In this paper we present a novel approach for allocation of transmit power, which is based on a non-greedy procedure that aims at maximizing transmission rate while also controlling interference levels. The proposed approach is fully distributed and requires no central control or coordination. Numerical results obtained from simulations are presented to illustrate the performance of the proposed approach in both sparse and dense environments. In sparse wireless environments, where there are fewer mutually interfering wireless links than available frequency bands, the proposed approach yields power allocations which outperform those obtained by applying alternative power allocation strategies, while in dense environments, where there are more interfering links than available frequency bands, the proposed approach yields power allocations with performance similar to those of existing power strategies. Thus, the distributed power allocation procedure based on the proposed approach is a drop-in replacement algorithm that yields better system throughput than existing algorithms for spectrum sharing.

1. Introduction

Wireless communication systems have become an essential component of the modern society through the numerous services they provide. In many instances of current and emerging wireless systems multiple uncoordinated transmitters are expected to share the spectrum in order to provide specific wireless services and applications. For example, this is the case with current systems operating in the ISM or TV bands [1,2] and this leads to mutual interference affecting users located in the same geographical area. To enable dynamic spectrum access [3] while minimizing interference, distributed allocation of transmit power over shared frequencies is an important consideration in the design of future wireless communication systems [4,5].

To enable coexistence of mutually interfering systems, various distributed approaches have been proposed for power allocation in spectrum sharing scenarios to avoid interference. In the case of weak interference, iterative water filling may be applied in a multi-user context to optimize transmit covariance matrices by distributing transmit power over all available frequencies [6,7]. This is essentially a greedy approach with no coordination, by which transmitters distribute their power without considering the interference they create to other transmissions using the same frequencies. When interference is strong, multiple transmitters may distribute their power over distinct, non-overlapping frequencies, by greedy partitioning of the available spectrum [8]. However, in many instances, these greedy approaches result in underutilization of the available frequency spectrum [8,9].

To enable better sharing of the spectrum in mutually interfering systems, a greedy asynchronous distributed interference avoidance (GADIA) algorithm [10] was proposed as a meaningful alternative for distributed power allocation in wireless communication systems that share available spectrum. The idea behind the GADIA algorithm is to minimize the total interference in the system while also maximizing the net utilization of the system resources, and in order to accomplish this goal, transmitters are restricted to using only a single frequency band. GADIA is an efficient approach to share spectrum in dense environments, where the number of transmitters is larger than the number of available frequency bands, but results in low system throughput in sparse environments, where only a few users are sharing the spectrum and many frequency bands end up being unused. In such scenarios better solutions that those implied by GADIA are possible, and recently a distributed power allocation for rate maximization (DPARM) algorithm was proposed [11]. Unlike GADIA, where interfering transmitters are restricted to using a single channel for

---

* Corresponding author.
E-mail addresses: sbaks002@odu.edu (S. Bakşi), dpopescu@odu.edu (D.C. Popescu).

http://dx.doi.org/10.1016/j.phycom.2016.12.003

their transmission, the DPARM procedure in [11] uses an individual decision metric to enable mutually interfering transmitters to use multiple frequencies, as long as these are available and the decision metric is not decreased. Furthermore, to maximize rate, in the DPARM procedure the transmitters apply a water filling scheme for allocating power over the subset of frequencies available for transmission. We note that the decision metric used by the DPARM procedure is designed to minimize mutual interference by forcing transmitters to be polite rather than greedy. As discussed in [11], the DPARM algorithm performs similar to GADIA in dense environments, while leading to improved system throughput in sparse environments since all available frequency bands will be utilized in this case.

Although approaches like GADIA and DPARM are desirable from both spectrum utilization and system throughput perspectives, without a coordinating mechanism to enforce their application by all users, greedy transmitters cannot be prevented from using all available frequency bands and distribute their power according to the water filling algorithm, and as the number of greedy users increases, the total system rate declines rapidly [12]. To best of our knowledge [12] is the only reference studying coexistence of greedy and non-greedy users in the context of distributed spectrum sharing without a central coordinating mechanism, and showing that the performance of implied by non-greedy algorithms may change drastically. This motivates the work presented in this paper, in which a novel non-greedy algorithm for power allocation is introduced. The algorithm is based on maximizing the transmission rate for mutually interfering users while also controlling interference, and is robust in the presence of changing numbers of greedy users. The proposed algorithm is different than DPARM [11] since it uses a different approach to enable transmitters to gradually use more frequencies to allocate their transmit power. Specifically, unlike DPARM where an individual decision metric is used to establish how many frequencies are used for power allocation, in the proposed algorithm transmitters increase the number of frequencies over which their power is allocated as long as the desired signal dominates interference and noise. This approach translates in requiring that the signal-to-interference+noise ratio (SINR) in the chosen frequencies be larger than one and enhances robustness in the presence of greedy transmitters.

The paper is organized as follows: the system model is formally introduced in Section 2, where a formal statement of the problem studied in the paper is also given. The proposed algorithm for rate maximization with interference control is presented in Section 3 and is illustrated with numerical results obtained from simulations for both sparse and dense wireless scenarios in Section 4. The paper is concluded with final remarks in Section 5.

2. System model and problem statement

In this paper, we consider a set of mutually interfering wireless links consisting of N pairs of transmitters–receivers that share a set of F frequency bands. We assume that the total transmit power is the same on all links, that is $P_i = \bar{P}, i \in \{1, 2, \dots, N\}$, and we denote the channel gain between the transmitter on link i and the receiver on link j by h_{ij}. We assume that channel gains are a function of the corresponding distance between transmitter and receiver, denoted d_{ij}, and that the signal attenuation is characterized by the same propagation exponent is η. Therefore, the channel gain is defined as $h_{ij} = d_{ij}^{-\eta}$. For illustration, a three user system is shown schematically in Fig. 1, from where one can notice that the signal received on any link i (marked by a continuous line) is affected by the link channel gain h_{ii} as well as by the channel gains h_{ij} of the interfering links $j \neq i$ (marked by dashed lines).

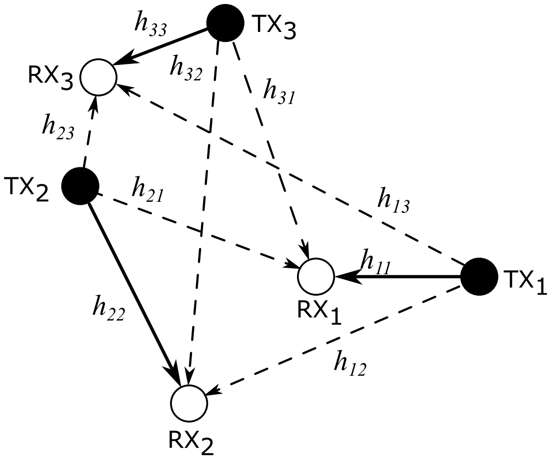


Fig. 1. Schematic description of a wireless system with $N = 3$ mutually interfering links.

We assume that all transmitters have the same priority in accessing the available frequency bands, such that, in the absence of a central frequency assignment mechanism, the available F frequency bands may be shared by the N mutually interfering links according to one of the following scenarios:

- **Complete overlap**: illustrated in Fig. 2(a), in which all transmitters evenly distribute their available power over all available frequency bands, resulting in similar levels on mutual interference in all frequencies.
- **Partial overlap**: illustrated in Fig. 2(b), in which transmitters allocate their powers such that they may overlap in one or more frequency bands, but not in all of them, resulting in different levels of mutual interference in different frequency bands.
- **No overlap**: illustrated in Fig. 2(c), in which transmitters allocate their power in orthogonal channels, such that they do not interfere with each other.

In this context, we study a distributed approach to spectrum sharing by which each transmitter i assigns its total transmit power over a set of distinct frequencies to maximize its transmission rate while also considering the interference associated with the frequencies chosen for transmission. This results in a non-greedy approach to power allocation, by which transmitters in the system gradually increase the number of frequencies over which power is allocated, in order to augment their rate performance while not significantly increasing the total interference in the system. We note that, while a water filling strategy [7] is used for power allocation over the chosen frequencies, the proposed approach is different from greedy approaches which assume that the water filling strategy is able to take advantage of all available frequencies and does not consider interference in the power allocation process.

3. Rate maximization with interference control

Let us denote the SINR at the receiver corresponding to link i over and frequency m by

$$\gamma_i^{(m)} = \frac{h_{ii} P_i^{(m)}}{\sum_{j=1}^{N} h_{ji} P_j^{(m)} + \sigma^2}, \quad i \neq j \tag{1}$$

where $P_i^{(m)}$ denotes power allocated by transmitter i to frequency band m and σ^2 is the power spectral density of the additive white