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Distributed power control with received power constraints for time-area-spectrum licenses ☆

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ABSTRACT

This paper deals with the problem of optimal decentralized power control in systems whose spectrum is regulated in time and space, the so-called time-area-spectrum (TAS) licensed. In this paper we consider those locations with colliding transmissions; thus, addressing a scenario with full interference. In order to facilitate the coexistence of different TAS licenses, the power spectral density of the used band shall be limited. Since controlling the overall radiated power in a given area is cumbersome, we control the amount of received power. First, we present the achievable rates (i.e. the rate Pareto set) and their corresponding powers by means of multi-criteria optimization theory. Second, we study a completely decentralized and gradient-based power control that obtains Pareto-efficient rates and powers, the so-called DPC-TAS (Decentralized Power Control for TAS). The power control convergence and the possibility of guaranteeing a minimum Quality of Service (QoS) per user are analyzed. Third, in order to gain more insight into the features of DPC-TAS, this paper compares it with other baseline power control approaches. For the sake of comparison, a simple pricing mechanism is proposed. Numerical simulations verify the good performance of DPC-TAS.

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1. Introduction

Wireless technology is proliferating rapidly requiring more radio spectrum. In light of this, spectrum sharing has gained a special attention in the research community for its promising results in improving the spectral efficiency. The concept of Cognitive Radio (CR) [1–3] has been hailed as a potential communication paradigm, which allows low-priority systems to sense their operating environment and adapt their implementation to achieve the best performance while minimizing harmful interference to other users. While the concept of CR networks has been well accepted within the wireless communications research community, potential benefactors and regulation authorities have shown strong reluctance to the application of CR in real world scenarios [4]. There are two major hurdles for CR networks to come true. First, a multiple secondary user environment in which the number of cognitive devices is large, might lead to a spectrum saturation and might cause severe interference to the incumbent system. Second, the efficiency and reliability of present spectrum sensing techniques to predict the performance of the primary communication link is often questionable and the time spent in acquiring this information is also one of the main concerns.

An early attempt to overcome such limitations is the Authorized/Licensed Shared Access (ASA/LSA) approach [5], which provides new sharing opportunities under a licensing regime. LSA provides a means for incumbent spectrum holders to make available, subject to sharing and commercial agreement, their spectrum for wireless services. LSA has shown great promise in making spectrum sharing attractive for mobile operators. One possible system architecture for LSA is the time-area-space (TAS) licenses [6,7]. TAS license concept was first introduced in [6] and it provides a more efficient spectrum management system than the current open spectrum one. The reason is that this regulation technique not only controls frequency, but also time and location. In other words, whenever a certain number of users (operators) acquire a TAS license, the spectrum regulator assigns to these incumbents the right of transmitting in a given frequency for a certain portion of time within some geographical limits.

In order to allow the creation of geographically close TAS licenses, the power spectral density within the TAS license area shall be restricted. Unfortunately, controlling the radiated power in a given area is cumbersome, due to the stochastic nature of the radio channel and to correlations among transmitting antennas (i.e. when there are more than one). Furthermore, these spatial-frequency restrictions can only be managed by a central controller, which would require a large amount of signalling among the different communication agents.

An alternative to restricting the radiated power in a given area is to limit the total amount of received power [8]. With this, the received power constraints can approximate the spatial interference power restrictions, leading to a more flexible management of the power and, ultimately, of the license, as we show in the present paper. Fig. 1 illustrates a possible scenario, where, by guarantee on the maximum level of received signal, this paper solves how to enable coexistence in the overlapping areas.

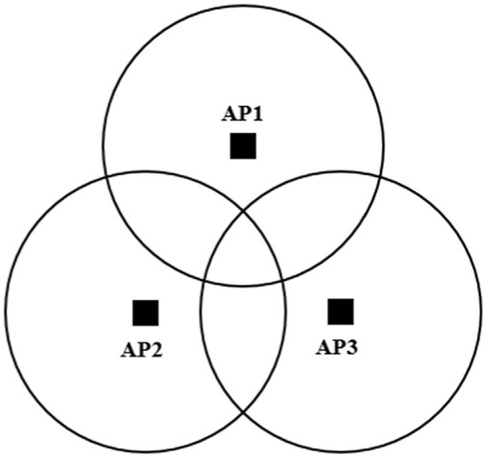

Fig. 1. Scenario with 3 access points operating on the same frequency band but in spatial mostly disjoint areas. There is no cooperation at any level between the 3 systems; circles indicate the coverage due to constraints on the maximum transmit power.

In contrast to other spectrum regulations, which restrict the power density in a per-user basis (e.g. maximum radiated power and maximum interference level to the primary user), TAS spectrum license grants the use of the spectrum on a network level fashion. This constitutes a substantial difference since all TAS incumbents shall coordinate in order to preserve the received power constraints. Indeed, this network-wide power restriction fosters the spectrum sharing among the TAS incumbents and it allows the coexistence of geographically adjacent TAS licenses since the overall spectral power density is approximately restricted with the receive power constraints.

Under this context, all users have the same privileges and they have to coordinate in order not to exceed the received power constraint. Note that it is a total received power constraint, which differs from the interference temperature constraint that is considered when the spectrum policy differentiates between primary and secondary users, as it is the case, for instance, in [9,10]. Finally, to understand Fig. 1, in addition to the received power constraint, there is always a constraint on the maximum transmit power; thus, conforming a coverage area around each access point.

1.1. Related works and contributions

In any receiver, Automatic Gain Control (AGC) tries to keep the received power at some nominal level by inverting the pathloss and fading effects of the channel. However, inverting the channel results in a capacity penalty. In order to obtain optimal power adaptation in terms of capacity *waterfilling* in time has to be implemented, analogous to *waterfilling* in frequency (see [11] and references therein); thus, requiring transmit, instead of receive, power control. When, in addition, the transmission is degraded by interference, the large dynamic range of signals that must be handled by most receivers requires a