“To Sense” or “Not to Sense”
in Energy-Efficient Power Control Games

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Abstract. A network of cognitive transmitters is considered. Each transmitter has to decide his power control policy in order to maximize energy-efficiency of his transmission. For this, a transmitter has two actions to take. He has to decide whether to sense the power levels of the others or not (which corresponds to a finite sensing game), and to choose his transmit power level for each block (which corresponds to a compact power control game). The sensing game is shown to be a weighted potential game and its set of correlated equilibria is studied. Interestingly, it is shown that the general hybrid game where each transmitter can jointly choose the hybrid pair of actions (to sense or not to sense, transmit power level) leads to an outcome which is worse than the one obtained by playing the sensing game first, and then playing the power control game. This is an interesting Braess-type paradox to be aware of for energy-efficient power control in cognitive networks.

1 Introduction

In fixed communication networks, the paradigm of peer-to-peer communications has known a powerful surge of interest during the the two past decades with applications such as the Internet. Remarkably, this paradigm has also been found to be very useful for wireless networks. Wireless ad hoc and sensor networks are two illustrative examples of this. One important typical feature of these networks is that the terminals have to take some decisions in an autonomous (quasi-autonomous) manner. Typically, they have to choose their power control and resources allocation policy. The corresponding framework, which is the one of this paper, is the one of distributed power control or resources allocation. More specifically, the scenario of interest is the case of power control in cognitive
networks. Transmitters are assumed to be able to sense the power levels of neighboring transmitters and adapt their power level accordingly. The performance metric for a transmitter is the energy-efficiency of the transmission [5] that is, the number of bits successfully decoded by the receiver per Joule consumed at the transmitter.

The model of multiuser networks which is considered is a multiple access channel with time-selective non-frequency selective links. Therefore, the focus is not on the problem of resources allocation but only on the problem of controlling the transmit power over quasi-static channels. The approach of the paper is related to the one of [8][7] where some hierarchy is present in the network in the sense that some transmitters can observe the others or not; also the problem is modeled by a game where the players are the transmitters and the strategies are the power control policies. One the differences with [8][7] is that every transmitter can be cognitive and sense the others but observing/sensing the others has a cost. Additionally, a new type of power control games is introduced (called hybrid power control games) in which an action for a player has a discrete component namely, to sense or not to sense, and a compact component namely, the transmit power level. There are no general results for equilibrium analysis in the game-theoretic literature. This is a reason why some results are given in the 2-player case only, as a starting point for other studies. In particular, it is shown that it is more beneficial for every transmitter to choose his discrete action first and then his power level. The (finite) sensing game is therefore introduced here for the first time and an equilibrium analysis is conducted for it. Correlated equilibria are considered because they allow the network designer to play with fairness, which is not possible with pure or mixed Nash equilibria.

This paper is structured as follows. A review of the previous results regarding the one-shot energy efficient power control game is presented in Sec. 2. The sensing game is formally defined and some equilibrium results are stated in Sec. 3. A detailed analysis of the 2-players sensing is provided in Sec. 4 and the conclusion appears in Sec. 5.

2 Review of Known Results

2.1 Review of the One-Shot Energy-Efficient Power Control Game (Without Sensing)

We review a few key results from [6] concerning the static non-cooperative PC game. In order to define the static PC game some notations need to be introduced. We denote by $R_i$ the transmission information rate (in bps) for user $i$ and $f$ an efficiency function representing the block success rate, which is assumed to be sigmoidal and identical for all the users; the sigmoidness assumption is a reasonable assumption, which is well justified in [11][4]. Recently, [3] has shown that this assumption is also justified from an information-theoretic standpoint. At a given instant, the SINR at receiver $i \in \mathcal{K}$ writes as:

$$\text{SINR}_i = \frac{p_i |g_i|^2}{\sum_{j \neq i} p_j |g_j|^2 + \sigma^2}$$

(1)