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Distributed power adjustment based on control theory for cognitive radio networks

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ABSTRACT

In this paper, we propose two power adjustment methods for cognitive radio networks. In the first algorithm, the transmitter derives the transmission power with PID control in order to satisfy the QoS constraints in secondary networks. The derived transmission power is compared with a constraint condition in order to avoid the interference with primary networks, and then the actual transmission power is decided. Because the constraint condition affects the performance of our proposed method significantly, we propose an effective update algorithm. On the other hand, the second algorithm is based on model predictive control (MPC). In this method, the decision of transmission power is formulated as quadratic programming (QP) problem and the transmission power is derived directly with the constraint condition. We evaluate the performances of our proposed methods with simulation and compare the proposed methods with the distributed power control (DPC) method. In numerical examples, we show that our proposed methods are more effective than the existing method in some situations. We also prove analytically that the interference with primary networks can be avoided with probability one by using our proposed method if each transmitter has the information about every channel gain.

1. Introduction

Recently, wireless communication technologies such as Wireless LAN, 3G cellular system, and WiMAX are widely utilized. Those wireless communication technologies utilize a lot of frequencies below 6 GHz band. There will be a shortage of these radio frequencies in the future, and hence it is indispensable to utilize radio frequencies effectively. Cognitive radio is one of the most promising technologies for the effective utilization of wireless resources [1]. In cognitive radio networks, unlicensed (secondary) networks can utilize channels that have been provided for incumbent licensed (primary) networks by avoiding the interference with primary networks.

Currently, in order to measure the interference between primary networks and secondary networks, Federal Communications Commission (FCC) has introduced the interference temperature as a metric [2]. When the interference temperature at a measurement point is larger than the maximum interference power tolerance in primary networks, it implies that secondary networks interferes with primary networks. On the other hand, secondary networks should improve the performance of those own data transmission. Therefore, each transmitter in secondary networks has to adjust the transmission power carefully so as to both avoid the interference with primary networks and improve quality of service (QoS) of the data transmission.

For wireless networks, several power adjustment mechanisms have been proposed in the literature. Among these methods, [3] has proposed a power control method based

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on proportional–integral–derivative (PID) control. In this method, the transmitter receives the feedback information about signal to noise ratio (SNR) from its corresponding receiver. Based on this information, the transmitter adjusts the transmission power by using PID control. Numerical examples have shown that this PID-based method can improve the performance of data transmission in distributed environment. Moreover, [3] has shown that the PID-based method is more effective than the existing distributed power control (DPC) method that is explained in [4,5]. This denotes that control theory is effective for the power adjustment in wireless networks.

In terms of cognitive radio networks, PID-based power adjustment is also expected to improve QoS of data transmission in secondary networks. On the other hand, the existing PID-based power adjustment method may not avoid the interference with primary networks. This is because the transmission power is determined without considering the interference. Hence, this power adjustment should be extended so as to avoid the interference with primary networks. However, as far as the authors know, such a power adjustment method that utilizes PID control has not been studied for cognitive radio networks. Other control theory techniques may be available for the power adjustment.

In this paper, for cognitive radio networks, we propose two power adjustment methods; one is based on PID control and the other is based on model predictive control (MPC). In both the methods, at first, each transmitter in secondary networks receives the feedback information about signal-to-interference plus noise ratio (SINR) from its corresponding receiver. In the former method, with the feedback information, the transmitter derives the transmission power based on PID control in order to satisfy the QoS constraints in secondary networks. Then, the transmitter decides the actual transmission power according to both the derived power and a constraint condition. This constraint condition is utilized to avoid the interference with primary networks, and we also propose an effective update algorithm for the constraint condition. On the other hand, in the latter method, the transmission power is determined based on MPC. In this method, the decision of transmission power is formulated as quadratic programming (QP) problem and the transmission power is derived directly with the constraint condition. This method also utilizes the update algorithm for the constraint condition.

We evaluate with simulation the performances of our proposed methods and compare the proposed methods with the existing DPC method. We also prove analytically that the interference with primary networks can be avoided with probability one if each transmitter has the information about every channel gain.

The rest of this paper is organized as follows. Section 2 introduces related work in terms of the power control for wireless networks. In Section 3, we explain the system model for cognitive radio networks. Then, in Section 4, we explain our proposed power adjustment methods based on PID control and MPC. We show some numerical examples in Section 5 and present conclusions in Section 6.

2. Related work

In wireless networks, power control is an important issue in order to keep reliable communication between a base station and a user [6]. In order to adjust the transmission power effectively, DPC algorithm has been proposed [4]. This algorithm can be implemented and utilized easily because it does not require complete information on link gains. On the other hand, the DPC algorithm causes the wireless network to become unstable under a small time delay [7].

Therefore, [3] has proposed a power adjustment algorithm based on PID control so that the wireless network becomes stable. In this method, the transmission power is determined by using PID control so as to satisfy the QoS constraints of data transmission. Numerical examples have shown that PID-based method is more effective than DPC in terms of the convergence rate. The PID-based method has also been extended so that a transmitter can utilize multiple PID controllers simultaneously [6].

In addition, [8] has formulated signal-to-interference ratio (SIR) as a dynamical system and has proposed an optimal power control for mobile users in wireless CDMA networks. The optimal control algorithm has been derived with three cost functions. In [9], sliding mode control theory has been utilized for the power control in ad hoc wireless networks. [10,11] have proposed power control methods based on game theory.

For cognitive radio networks, [12] has proposed an auction-based power control mechanism. In this method, the received power at each receiver is decided by transmitter's bid under the constraint of interference temperature. [13] has also proposed another auction-based power control mechanism that can consider QoS in secondary networks in addition to the interference temperature. Game theory is used to investigate the power control for providing the maximum throughput [14]. In this power control, a tax-based power control game algorithm has been introduced to solve the power allocation optimization problem. [15] has focused on single input multiple output multiple access channels (SIMO-MAC). A capped multi-level water filling algorithm and a recursive decoupled power allocation method have been proposed. The performances of those algorithms have been analyzed theoretically. Other power control methods have also been proposed for cognitive radio networks [16,17].

Thus, for wireless networks including cognitive radio networks, many power control mechanisms have been proposed. Especially, it is well known that control theory such as PID control is effective for the power control in wireless networks. As far as the authors know, for cognitive radio networks, a power adjustment method based on control theory has not been studied in detail in spite of its effectiveness.

3. System model

Fig. 1 shows the system model. In this model, there are $N_s > 0$ logical pairs of a transmitter and a receiver in secondary networks. For the ith ($i = 1, \ldots, N_s$) pair of transmitter i and receiver i, let $p_i(t)$ denote the transmission power