Joint Power Control and Admission Control for CDMA Cognitive Radio Networks

Lijun Qian and John Attia
Department of Electrical and Computer Engineering
Prairie View A&M University
Prairie View, Texas 77446
Email: LiQian, JoAttia@pvamu.edu

Xiangfang Li and Zoran Gajic
WINLAB
Rutgers University
Piscataway, NJ 08854
Email: xfli, gajic@winlab.rutgers.edu

I. Introduction

While FCC proposes spectrum sharing between a legacy TV system and a cognitive radio network to increase spectrum utillization, one of the major concerns is that the interference from the cognitive radio network should not violate the QoS requirements of the primary users. In this study, we consider the scenario where the cognitive radio network is formed by secondary users using low power CDMA personal/portable devices and when both systems are operating simultaneously. We propose a cluster based architecture for the CDMA cognitive radio network and try to provide analysis and design to achieve the successful coexistence of the two heterogeneous systems. Specifically, a power control problem of the secondary users is formulated to maximize the energy efficiency of the secondary users and reduce the harmful interference to the primary users who have absolute priority. QoS guarantee of the secondary users is also included in the problem formulation. Feasibility conditions for the power control problem are highlighted and the corresponding joint power control and admission control procedures are provided.

II. Architecture Design and Problem Formulation

Given an existing TV station with transmission power p_{TV}, the effective receiving range is D. The effective receiving range is defined by the successful decoding of the TV signals, i.e., the received signal-to-interference-plus-noise ratio (SINR) should be above a given threshold such that the received TV signal is decodable. Note that the data of transmission power and effective receiving range of TV stations are publicly available, such as in [1], [2]. It is infeasible for the secondary users to operate inside D_1 while maintain non-intrusiveness to the TV system. We are interested in the area outside D_1 where the secondary users and the primary users will have non-negligible interference among them while it is still feasible for them to coexist and operate simultaneously providing appropriate power control and admission control of the secondary users. We propose a cluster based architecture where the secondary users form clusters for peer-to-peer communications. It is assumed that the neighbor clusters use different frequency bands such that the inter-cluster interference is negligible comparing to the interference from the primary users. The center of the cluster of interest is d meters away from the nearest primary receiver. The distance from the TV station to the ith secondary receiver is h_i. y_i is the distance from the i^{th} secondary transmitter to the TV receiver at the border of the TV coverage area. An example of the model is given in Fig. 1, where only three clusters and one pair of secondary users are shown.

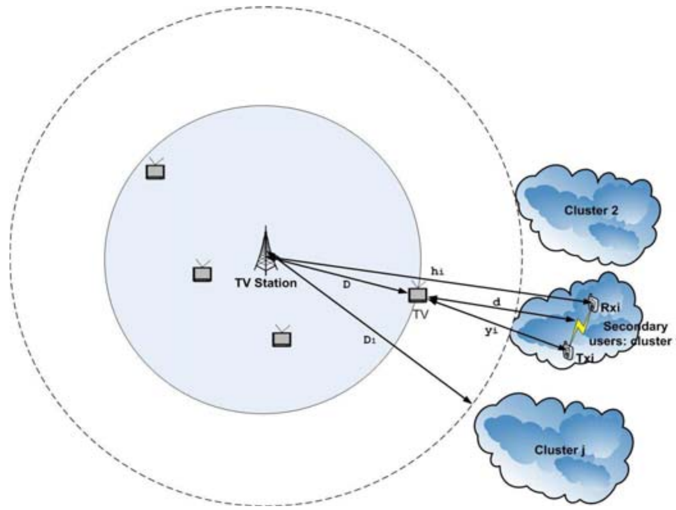

Fig. 1. An example of spectrum sharing of a CDMA cognitive radio network with a TV broadcast system.

In this paper, we address the interference problem by considering the QoS at both the primary receivers and the secondary receivers in terms of the received SINR. Suppose there are totally N pairs of secondary users in the cluster of interest, and $p_{i,sec}$ is the transmission power of the i^{th} transmitter. Define the SINR at the m^{th} primary receiver as $\gamma_{m,TV}$, and the SINR at the i^{th} secondary receiver as $\gamma_{i,sec}$, the power control problem is defined as follows

(P.1)

$$\min \sum_{i=1}^{N} p_{i,sec} \tag{1}$$

subject to

$$\gamma_{m,TV} \geq \gamma_{TV}^{tar}, \quad \forall m \tag{2}$$

$$\gamma_{i,sec} \geq \gamma_{i,sec}^{tar}, \quad i = 1, \cdots, N. \tag{3}$$

$$p_{sec}^{min} \leq p_{i,sec} \leq p_{sec}^{max}, \quad i = 1, \cdots, N. \tag{4}$$

where γ_{TV}^{tar} and $\gamma_{i,sec}^{tar}$ are the target SINR for the primary receivers and the secondary receivers, respectively. p_{sec}^{min} and

p_{sec}^{max} are the minimum and maximum allowable transmission power of the secondary users. The objectives of power control are to maximize the energy efficiency of the secondary users and suppress harmful interference to both the primary users and the secondary users.

III. Summary of the Proposed Joint Power control and Admission Control

The SINR of the TV receiver at the worst location of the TV coverage area is

$$\gamma_{TV} = \frac{p_{TV}/D^{\alpha_1}}{f_2 \sum p_{i,sec}/y_i^{\alpha_2} + \sigma^2} \tag{5}$$

The SINR of the i^{th} secondary receiver is

$$\gamma_{i,sec} = \frac{L g_{ii} p_{i,sec}}{\sum_{j \neq i} g_{ij} p_{j,sec} + f_1 p_{TV}/h_i^{\alpha_1} + \sigma^2} \tag{6}$$

where α_1 and α_2 are the path loss factors, f_1 and f_2 are the orthogonality factors, and L is the processing gain. g_{ij} is the link gain from the j^{th} secondary transmitter to the i^{th} secondary receiver. σ^2 is the background noise.

The following theorem gives the feasibility condition of the power control problem **(P.1)**.

Theorem 1: The power control problem **(P.1)** is feasible for all N simultaneous transmitting-receiving pairs of secondary users within the same channel as long as
(1). The matrix $[I - \Gamma_{sec}^{tar} Z]$ is non-singular (thus invertible);
(2). The transmission power vector p_{sec}^* satisfies inequality (4) element-wise, where

$$p_{sec}^* = [I - \Gamma_{sec}^{tar} Z]^{-1} u \, , \tag{7}$$

matrix Γ^{tar} is a diagonal matrix

$$\Gamma_{secij}^{tar} = \begin{cases} \gamma_{i,sec}^{tar} & i = j \\ 0 & otherwise \end{cases} , \tag{8}$$

matrix Z is the following nonnegative matrix

$$Z_{ij} = \begin{cases} \frac{g_{ij}}{L g_{ii}} & i \neq j \\ 0 & i = j \end{cases} , \tag{9}$$

u is the vector with elements

$$u_i = \gamma_{i,sec}^{tar} \eta_i^2 / (L g_{ii}), \qquad i = 1, 2, ..., N \tag{10}$$

and

$$\eta_i^2 = f_1 p_{TV}/h_i^{\alpha_1} + \sigma^2 \, . \tag{11}$$

(3). The transmission power vector p_{sec}^* also satisfies the following inequality

$$\frac{p_{TV}/D^{\alpha_1}}{f_2 \sum p_{i,sec}^*/y_i^{\alpha_2} + \sigma^2} \geq \gamma_{TV}^{tar} \, . \tag{12}$$

The power control problem **(P.1)** considered here addressed interference from *heterogeneous* systems and it also calls for joint design of power control and admission control for the cognitive radio network such that the QoS of the primary users is ensured all the time.

Joint power control and admission control

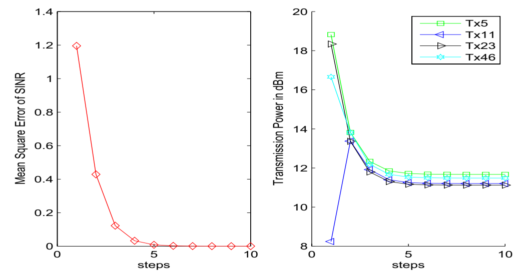

Fig. 2. The convergence of the mean square error of the secondary user's SINR and the transmission power of the secondary users. Parameters: $N = 50$, p_{TV} = 100 kW, D=60 km, d=30 km, γ_{TV}^{tar} =34 dB, γ_{sec}^{tar} = 0 dB, L=128, $\sigma^2 = 10^{-14}$, α_1=3, α_2=4, $f_1 = f_2 = 1$.

1) Solve the transmission power vector p_{sec}^* using equation (7).
2) Check whether the transmission powers are within limit, i.e., $p_{sec}^{min} \leq p_{i,sec}^* \leq p_{sec}^{max}$, $\forall i$? If Yes, goes to the next step; otherwise, the power control problem **(P.1)** is not feasible. Remove the jth secondary user that has the largest $\sum_{i=1}^{N} [Z_{ij} + Z_{ji}]$ and return to Step 1 with reduced number of transmitters.
3) Check whether the transmission powers satisfy inequality (12). If Yes, set the transmission power vector as p_{sec}^*; otherwise, the power control problem **(P.1)** is not feasible. Remove the secondary user that requires the largest transmission power ($p = max\{p_{i,sec}^*\} \; \forall i$) and return to Step 1 with reduced number of transmitters.

In a cognitive radio network with centralized management, such as in the proposed cluster based architecture, the above procedures can be implemented. A distributed implementation is also possible [3].

IV. Simulation Results and Conclusion

The convergence of the mean square error of the secondary user's SINR ($e_{sec}^2 = E[(\gamma_{sec} - \gamma_{sec}^{tar})^2]$) is given in Fig 2. It is observed that the power control algorithm converges very fast (in several steps). More results are available in [3].

The proposed power control and admission control procedure may be combined with MAC design to enhance the promise of non-intrusion to the primary system during spectrum sharing. Although the TV broadcast system is chosen as an example of the primary system in this paper, the proposed methods can be extended to other cases where heterogeneous systems share the same spectrum.

References

[1] FCC, " KRON-TV at san francisco". [Online]. Available: http://www.fcc.gov/fcc-bin/tvq?list=0facid=65526
[2] FCC, "KRON-TV service contour map". [Online]. Available: http://www.fcc.gov/fcc-bin/FMTV-service-area?x=TV282182.html
[3] L. Qian, et. al, "Joint Power Control and Admission Control for CDMA Cognitive Radio Networks," *Technical Report*, PVAMU, 2007[1].

[1]This research work is supported in part by the National Science Foundation (NSF) under award HRD-0531507.