ELectronics EXpress

IEICE Electronics Express, Vol.7, No.3, 203–208

Joint beamforming and power control in MIMO cognitive radio networks

Narges Noori[1a)], **S. Mohammad Razavizadeh**[1], **and Alireza Attar**[2]

[1] *Iran Telecommunication Research Center, Tehran, Iran*

[2] *University of British Columbia, Vancouver, Canada*

a) *nnoori@itrc.ac.ir*

Abstract: In this paper, the problem of joint beamforming and power control is studied in the uplink of multiple-input multiple-output (MIMO) cognitive radio networks (CRNs). The objective is maximizing the minimum signal-to-interference-plus-noise ratio (SINR) of the secondary users (SUs). The CRN consists of a cognitive radio-base station (CR-BS) and a number of SUs. The proposed scheme uses genetic algorithm (GA) to solve the optimization problem by considering both the quality of service (QoS) constraints of the primary network and the maximum transmission power constraints of the CRN.

Keywords: cognitive radio, beamforming, power control, MIMO

Classification: Science and engineering for electronics

References

[1] S. Haykin, "Cognitive radio: Brain-empowered wireless communications," *IEEE J. Sel. Areas Commun.*, vol. 23, no. 2, pp. 201–220, Feb. 2005.

[2] L. Zhang, Y.-C. Liang, and Y. Xin, "Joint beamforming and power allocation for multiple access channels in cognitive radio networks," *IEEE J. Sel. Areas Commun.*, vol. 26, no. 1, pp. 38–51, Jan. 2008.

[3] M. H. Islam, Y.-C. Liang, and A. T. Hoang, "Joint power control and beamforming for cognitive radio networks," *IEEE Trans. Wireless Commun.*, vol. 7, no. 7, pp. 2415–2419, July 2008.

[4] N. Noori, S. M. Razavizadeh, and A. Attar, "Limiting harmful interference to the primary users through joint power allocation and beamforming in the uplink of cognitive radio networks," in *Proc. IEEE PIMRC'09*, Sept. 2009.

[5] M. H. Islam, Y.-C. Liang, and A. T. Hoang, "Joint beamforming and power control in the downlink of cognitive radio networks," in *Proc. of IEEE WCNC'07*, pp. 21–26, 2007.

[6] R. Zhang and Y.-C. Liang, "Exploiting multi-antennas for opportunistic spectrum sharing in cognitive radio networks," *IEEE J. Sel. Areas Signal Proc.*, vol. 2, no. 1, pp. 88–102, Feb. 2008.

[7] J.-H. Chang, L. Tassiulas, and F. Rashid-Farrokhi, "Joint transmitter receiver diversity for efficient space division multiaccess," *IEEE Trans. Wireless Commun.*, vol. 1, no. 1, pp. 16–27, Jan. 2002.

[8] L. B. Le and E. Hossain, "Resource allocation for spectrum underlay in cognitive radio networks," *IEEE Trans. Wireless Commun.*, vol. 7, no. 12,

DOI: 10.1587/elex.7.203
Received December 15, 2009
Accepted January 12, 2010
Published February 10, 2010

IEICE Electronics Express, Vol.7, No.3, 203–208

pp. 5306–5315, Dec. 2008.

1 Introduction

Recently, cognitive radio (CR) has become a promising technology to improve the radio spectrum utilization [1]. This technology makes it possible for a secondary or cognitive radio network (CRN) to opportunistically utilize a frequency band initially allocated to a primary network. However, CRNs impose unique challenges regarding to the interference protection requirements of the primary users (PUs) as well as quality of service (QoS) restrictions of the secondary users (SUs). While in [2, 3, 4], the joint receive beamforming and power control technique is used as an effective tool to meet these challenges in the uplink of the CRNs for single-input multiple-output (SIMO) scenario, in [5], a joint transmit beamforming and power control technique is applied in the downlink of the CRNs for multiple-input single-output (MISO) scenario. Like other wireless systems, a CRN can benefit using multiple antennas at both transmit and receive ends [6]. In [7], Chang *et al* show that employing properly beamforming weights in both ends of wireless communication links and using an appropriate power control mechanism is an effective tool to increase performance of the multi-antenna techniques. However, to our best knowledge, this problem has not been previously investigated in the multiple-input multiple-output (MIMO) CRNs.

In this paper, we consider a more general case of a CRN by extending our previous work on SIMO scenario in [4] to a MIMO scenario and propose a novel joint beamforming and power control scheme in the uplink of MIMO CRNs. Three sets of parameters including transmit beamforming weights of the SUs, their transmission power values and receive beamforming weights of the cognitive radio-base station (CR-BS), are found through a constrained optimization problem. The objective of this optimization problem is to maximize the minimum signal-to-interference-plus-noise ratio (SINR) of the SUs. The constraints that are taken into account are maximum tolerable interference of the PUs and transmission power limits of the SUs. In joint transmit-receive (MIMO) beamforming, the set of equations are highly coupled by optimization parameters which make the problem more complicated than receive-only beamforming proposed in [2, 3, 4]. Furthermore, our proposed scheme, based on genetic algorithm (GA), solves the optimization problem to find both the optimum power values and beamforming weights in one step, during each iteration. This is the distinction of our proposed scheme from those reported in [2, 3] and [5], where the optimal power and the beamforming weight values are calculated separately in two steps during each iteration. We will elaborate on the convergence rate of the GA solution of the studied optimization problem and show that the algorithm converges in a limited number of iterations.

DOI: 10.1587/elex.7.203
Received December 15, 2009
Accepted January 12, 2010
Published February 10, 2010

IEICE Electronics Express, Vol.7, No.3, 203–208

2 System Model

We consider uplink of a CRN with one CR-BS and N SUs. The CR-BS and the nth SU, $n\epsilon[1, N]$, are equipped with a linear array of K_B and K_n uniformly spaced omnidirectional antenna elements, respectively. As shown in Fig. 1, the primary broadcasting network consists of a single-antenna primary transmitter (PTx) and M single-antenna PUs. The fading channels are assumed to be slow flat and the channel responses are fixed over several symbol intervals. The joint beamforming and power control process is performed at the CR-BS. It is assumed that the CR-BS has perfect knowledge about all channel gains of the system. Some good approaches recommended in [8] may be used to estimate these channel gains at the CR-BS. Let us denote the channel gains from the nth SU to the CR-BS, from the PTx to the mth PU, from the PTx to the CR-BS, and from the nth SU to the mth PU by $g_{n0}^{(s)}$, $g_{0m}^{(p)}$, $g_{00}^{(p)}$, and $g_{nm}^{(s)}$, respectively, where $m\epsilon[1, M]$ and $n\epsilon[1, N]$. If $\mathbf{v}(\theta)$ is the CR-BS antenna array response to the direction of arrival θ and $\mathbf{a}_n(\varphi)$ is the array response of the nth SU to the direction of departure φ, then the channel response between the nth SU and the CR-BS, and between the PTx and the CR-BS can be given by the following expressions, respectively:

$$\mathbf{H}_n = \sqrt{g_{n0}^{(s)}}\mathbf{v}(\theta_n)\mathbf{a}_n^{\mathrm{T}}(\varphi_n), \quad \forall n\epsilon[1, N]; \tag{1}$$

$$\mathbf{h}_0 = \sqrt{g_{00}^{(p)}}\mathbf{v}(\tilde{\theta}_0), \tag{2}$$

where θ_n is direction of arrival from the nth SU to the CR-BS, $\tilde{\theta}_0$ is direction of arrival from the PTx to the CR-BS and φ_n is direction of departure from the nth SU to the CR-BS. In (2), $\mathbf{H}_n$ and $\mathbf{h}_0$ are $K_B \times K_n$ matrix and $K_B \times 1$ vector, respectively and $(\cdot)^{\mathrm{T}}$ denotes the transpose.

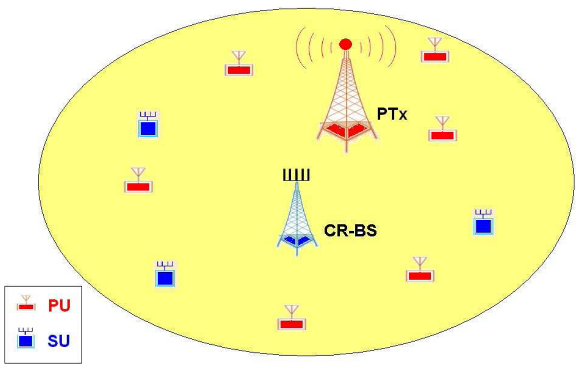

Fig. 1. System model of a MIMO CRN which works at the same frequency band of a primary network.

3 Problem Formulation and Solution

The message signal of each SU is weighted by its beamformer and transmitted to the CR-BS through the antenna array. At the CR-BS, the received signals are weighted and added by a beamformer. Assuming that the SUs' message

DOI: 10.1587/elex.7.203
Received December 15, 2009
Accepted January 12, 2010
Published February 10, 2010

signals are uncorrelated with zero mean, we can express SINR of the nth SU, $\forall n\epsilon[1, N]$, as follows:

$$\gamma_n = \frac{|\mathbf{w}_n^{\mathrm{H}}\mathbf{H}_n\mathbf{u}_n|^2 p_n}{\sum_{j\neq n}^{N}|\mathbf{w}_n^{\mathrm{H}}\mathbf{H}_j\mathbf{u}_j|^2 p_j + |\mathbf{w}_n^{\mathrm{H}}\mathbf{h}_0|^2 p_0 + \sigma^2\|\mathbf{w}_n\|^2} \tag{3}$$

where p_n and p_0 are transmission powers of the nth SU and PTx, respectively. Furthermore, $\mathbf{u}_n = [u_n^{(1)}, \cdots, u_n^{(K_n)}]^{\mathrm{T}}$ and $\mathbf{w}_n = [w_n^{(1)}, \cdots, w_n^{(K_B)}]^{\mathrm{T}}$, $\forall n\epsilon[1, N]$, are K_n-component complex beamforming vector of the nth SU and K_B-component complex beamforming vector of the CR-BS for the nth SU, respectively. Also, σ^2 is the received noise variance at the CR-BS and $(\cdot)^{\mathrm{H}}$ denotes the hermitian transpose. Without loss of generality, it is assumed that $\|\mathbf{u}_n\|^2 = \|\mathbf{w}_n\|^2 = 1, \quad \forall n\epsilon[1, N]$. The total amount of the received interference at the mth PU is given by:

$$\delta_m = \sum_{n=1}^{N}|\mathbf{k}_{n,m}^{\mathrm{T}}\mathbf{u}_n|^2 p_n, \quad \forall m\epsilon[1, M]; \tag{4}$$

where

$$\mathbf{k}_{n,m}^{\mathrm{T}} = \sqrt{g_{nm}^{(s)}}\mathbf{a}_n(\tilde{\varphi}_{nm}), \quad \forall m\epsilon[1, M] \text{ and } n\epsilon[1, N]. \tag{5}$$

In (5), $\tilde{\varphi}_{nm}$ is direction of departure from the nth SU to the mth PU. If we assume that $\mathbf{p} = [p_1, \cdots, p_N]^{\mathrm{T}}$, $\mathbf{U} = \{\mathbf{u}_1, \cdots, \mathbf{u}_N\}$ and $\mathbf{W} = \{\mathbf{w}_1, \cdots, \mathbf{w}_N\}$; we can formulate the optimization problem to maximizes the minimum SINR of the SUs subject to QoS constraints of the PUs and maximum transmission power constraints of the SUs as:

$$\begin{aligned} &\max_{\mathbf{U},\mathbf{W},\mathbf{p}} \min_{\forall n\epsilon[1,N]} \{\gamma_n\}, \\ &\text{subject to}: \\ &\quad \delta_m \leq \Delta_m, \quad \forall m\epsilon[1, M]; \\ &\quad p_n \leq P_n, \quad \forall n\epsilon[1, N]; \end{aligned} \tag{6}$$

where Δ_m is the maximum tolerable interference of the mth PU and P_n is the maximum transmission power constraint of the nth SU. The feasibility of the optimization problem defined in (6) is guaranteed if the following constraints are meet:

$$\mathbf{G}\mathbf{p} \leq \boldsymbol{\Delta}, \quad \text{and} \quad \mathbf{p} \leq \mathbf{P}; \tag{7}$$

where $[\mathbf{G}]_{i,j} = |\mathbf{k}_{j,i}^{\mathrm{T}}\mathbf{u}_j|^2$, $\boldsymbol{\Delta} = [\Delta_1, \cdots, \Delta_M]^{\mathrm{T}}$ and $\mathbf{P} = [P_1, \cdots, P_N]^{\mathrm{T}}$. It is seen that the channel gains from the SUs to the PUs, and hence the users' relative position may affect the feasibility of the optimization problem.

We apply GA to solve the highly coupled nonlinear constrained optimization problems defined in (6). The objective function is defined as $F(\mathbf{U}, \mathbf{W}, \mathbf{p}) = -\min \gamma_n \ \forall n\epsilon[1, N]$ and all of the optimization parameters are collected in a vector as:

$$\begin{aligned} \mathbf{X} = [&\mathrm{Am}(\mathbf{u}_1^{\mathrm{T}}), \cdots, \mathrm{Am}(\mathbf{u}_N^{\mathrm{T}}), \mathrm{Ph}(\mathbf{u}_1^{\mathrm{T}}), \cdots, \mathrm{Ph}(\mathbf{u}_N^{\mathrm{T}}), \\ &\mathrm{Am}(\mathbf{w}_1^{\mathrm{T}}), \cdots, \mathrm{Am}(\mathbf{w}_N^{\mathrm{T}}), \mathrm{Ph}(\mathbf{w}_1^{\mathrm{T}}), \cdots, \mathrm{Ph}(\mathbf{w}_N^{\mathrm{T}}), \mathbf{p}^{\mathrm{T}}]^{\mathrm{T}} \end{aligned} \tag{8}$$

DOI: 10.1587/elex.7.203
Received December 15, 2009
Accepted January 12, 2010
Published February 10, 2010

ELectronics EXpress

where $\mathrm{Am}(\cdot)$ and $\mathrm{Ph}(\cdot)$ denote the amplitude and phase of a complex vector, respectively. In the first step, GA creates a random initial population of solutions, which cover the entire range of possible solutions. During the subsequent iterations, a fraction of the existing population with higher fitness values is selected as parents for the next generation. A small proportion of solutions with lower fitness values are selected at each iteration as elite individuals and passed without any change to the next generation. A new solution is created by mutation or crossover processes. Consequently, current generation is replaced by the new one to check fitness conditions in the next iteration. The algorithm stops when at least one of the stopping criteria is met: a solution that satisfies a predefined fitness limit is found, a predefined number of generations are reached, a predefined computation time is reached, or the difference between the objective function values at the best points of the current and next iterations is less than a predefined tolerance.

4 Numerical Results

In this section, we provide some simulation results to investigate performance of the proposed scheme. Consider a rectangular area of size 1500 m $\times$ 1500 m as the coverage area of the primary network, where the PTx is located at the center of this area with transmit power of 700 mW. The primary network has two PUs with maximum tolerable interference of -95 dBm. The secondary network consists of two SUs and one CR-BS which is equipped with $K_B = 4$ antennas. The primary and secondary users are randomly distributed over the coverage area. The initial and maximum transmission powers of each SU are set to 1 mW and 80 mW, respectively. The path loss exponent is equal to 4 and the standard deviation of the lognormal shadowing fading is 1 dB. The total noise power at the receiver is -115 dBm. All presented results are calculated by repeating the simulations for 100 different users' locations and averaging the results. We set the population size of GA equal to 10 times of the number of optimization parameters and the elite proportion equal to 0.2. The GA stops if changes in the objective function in two consecutive iterations is less than 10^{-3}.

We consider three different cases of $K_1 = K_2 = 1, 2$ and 4 antennas for the SUs. These scenarios correspond to 1×4, 2×4 and 4×4 MIMO configurations, respectively. The separation distances between antenna elements in all arrays are equal to half of the operating frequency wavelength. Figure 2. **a** shows the average interference power to the PUs. It is shown in this figure that, for all three cases, the interference constraints of the PUs are fulfilled. The average transmission powers of the SUs are shown in Fig. 2. **b**. These results show that, in all cases, the maximum transmission power constraint of 80 mW is satisfied by the SUs.

Figure 3 shows convergence behavior of the average SUs' SINRs in the three cases. The converged value for average SINR is 8.6 dB, 10.2 dB and 17.7 dB for 1×4, 2×4 and 4×4 MIMO configurations, respectively. From this figure, it can be observed that as the number of SUs' antennas increases,

DOI: 10.1587/elex.7.203
Received December 15, 2009
Accepted January 12, 2010
Published February 10, 2010

IEICE Electronics Express, Vol.7, No.3, 203–208

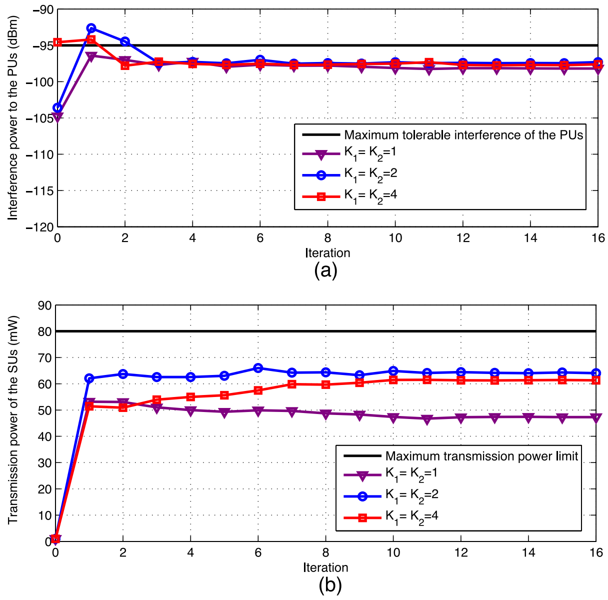

Fig. 2. (a) Average interference power to the PUs and (b) average transmission power of the SUs, for different number of antennas.

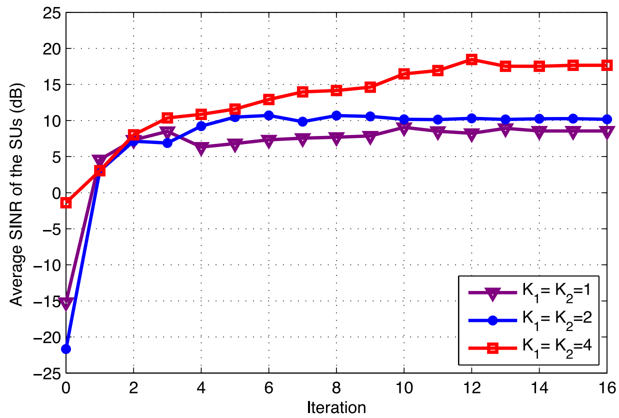

Fig. 3. Average SINR of the SUs for different number of antennas.

the QoS of these users is improved.

5 Conclusion

A joint beamforming and power control scheme in MIMO cognitive radio networks is proposed. The problem is formulated in the uplink of the CRNs to maximize the minimum SINR of the SUs. The GA is used to solve the problem under QoS constraints of the PUs and maximum transmission power constraints of the SUs. The simulation results show that increasing the number of SUs' antenna elements will increase the QoS of the CRN.

Acknowledgments

This work is supported by Iran Telecommunication Research Center.

DOI: 10.1587/elex.7.203
Received December 15, 2009
Accepted January 12, 2010
Published February 10, 2010