ELectronics EXpress

Bio-inspired distributed beamforming for cognitive radio networks in non-stationary environment

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Abstract: Distributed power control by beamforming approach in cognitive radio networks requires a precise analysis of the impacts of the transmission parameters, tolerable interference and guarantees the quality of service of both the primary users and secondary users. In this paper, we propose an improved performance to solve the constrained nonlinear multi-object optimization and coherent power assignment by beamforming problem based on particle swarm optimization. This method is invoked to solve the constrained nonlinear optimization problem in order to reach to maximum capacity. A numerical study is performed to show the convergence behavior of the proposed algorithm and the efficiency of the proposed technique with a dynamic cost function.

Keywords: cognitive radio, population adaptation, beamforming, non-stationary environment

Classification: Science and engineering for electronics

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DOI: 10.1587/elex.8.332
Received January 11, 2011
Accepted February 27, 2011
Published March 25, 2011

IEICE Electronics Express, Vol.8, No.6, 332–339

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1 Introduction

Due to the accelerated deployment of broad band communication systems and current fixed frequency allocation schemes spectrum is becoming a major bottleneck. Energy is usually a scarce commodity in wireless ad hoc networks, as users typically operate on batteries, which in many cases are difficult to replace or recharge. Thus, many studies featuring recent advances in theory, design and analysis of long-distance transmission in cognitive wireless radio networks have been figured out. In general, cognitive wireless radio network is capable to adapt to the outside existing time varying environment. According to the descriptions in [1], the power control has an effective impact on the probability of bit error rate. In [2] joint beamforming and power control using weighted least square algorithm have been performed. A collaborative beamforming technique was proposed in [3], in which randomly distributed nodes in a network cluster form an antenna array and beamform data to a far-away destination without each node exceeding its power constraint. Because of dynamic feature of the environment the transmit power control requires a precise study by employing an intelligent algorithm. While, the population adaptation for genetic algorithm based cognitive radio and bio-inspired algorithm for dynamic resource allocation and parameter adaptation have been studied, in [4, 5] and [6] respectively. The performance of the power control algorithm and beamforming has been studied in [7, 8, 9]. However, evolutionary power control by beamforming for cognitive users has not been previously investigated in non-stationary environments considering pre and post beamforming and constrained multi-objective problem. In this paper, we proposed an intelligent method to encounter the challenges of the cognitive radio network. Toward this goal, we formulate an optimization problem, considering the strict requirement of the protection of licensed users from the interference caused by the unlicensed or secondary users. Multiple antennas have been deployed at the cognitive users. Many wireless network standards provision the use of transmit antenna arrays. Beamforming with antenna arrays is a well studied technology; it provides space division multiple ac-

DOI: 10.1587/elex.8.332
Received January 11, 2011
Accepted February 27, 2011
Published March 25, 2011

IEICE Electronics Express, Vol.8, No.6, 332–339

cess which enables significant increases in communication rate. A challenge with implementing beamforming in ad hoc networks is that the geometry of the network may change dynamically. Due to the variation of radio channel characteristics and non-stationary environment, as well as the frequency spectrum band availability, cognitive radio networks need to support time varying quality of service requirements. Even though the basic goals of our work are focused on dynamic constrained power allocation, maximizing the transmission capacity by pre and post beamforming technique. To achieve these goals our cognitive radio network employs the swarm intelligence algorithm based on particle swarm optimization algorithm.

2 System model

We consider a system model where the primary network consists of N primary users (PUs) each having a transceiver system. The primary network transmits and communicates with the constant and specific transmission power. The secondary network has an ad hoc scenario and work in the same frequency band as the primary system. With deployment of k antennas at each cognitive transmitter, an efficient transmit beamforming technique is proposed to maximize the sum throughput. The transmit powers of cognitive users are limited to a maximum value prescribed by primary users. The system model of our scenario is illustrated in figure 1. The secondary network included M secondary users so it has an ad hoc scenario. The secondary user network structure is based on beamforming at both the transmitter (k antennas) and the receiver (k antennas) for each secondary user link.

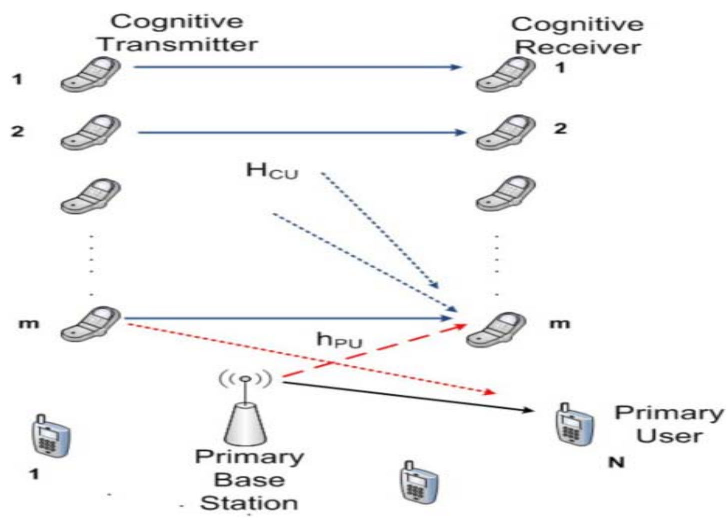

Fig. 1. Conceptual diagram of the system model.

The transmission scheme is characterized by the power allocation, eigenvalues of the transmit covariance matrix and the orientation, eigenvectors of the transmit covariance matrix.

DOI: 10.1587/elex.8.332
Received January 11, 2011
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3 Problem formulation and solution

All secondary users are working intelligently in an ad hoc mode, A secondary user or cognitive radio is talking to a receiver using a frequency band licensed to the primary radio, the objective here is considered as to maximize the transmission capacity of the secondary users subject to minimum interference and maximum quality of service of the primary users with minimum transmission power for secondary users by beamforming approach. The nth primary user's received signal is obtained as follow:

$$y_n = \mathbf{h}_{pu_n}.x_{pu} + \sum_{j=1}^{M} \mathbf{h}_{pu_j}.\mathbf{b}_j.x_j + \mathbf{n}_n \tag{1}$$

Where x_{pu} and x_j are the transmitted signals of the primary base station and secondary users, respectively. The power of associated signals for j=1,2,3. . . . . . m are as:

$$E\{|\mathbf{n}_m|^2\} = E\{\mathbf{n}_m\mathbf{n}_m^H\} = N_0^2,\ E\{|x_j|^2\} = p_{su} \text{ and } E\{|x_{pu}|^2\} = p_{pu}$$

$\mathbf{h}_{pu}$ and $\mathbf{H}_{su}$ are vectors in size of k × 1 and k × k, the fading path gains from primary base station to the nth primary users and $\mathbf{n}$ denotes zero mean additive with Gaussian noise with variance N_0^2. Define p_{pu} and p_{su} as the transmitted power of primary base station and secondary users, respectively. Also power p_{su} is constrained by a maximum transmit power limit $p_{\max}$. Here we present the pre and post beamforming vectors, also we design the transmit and receive beamvectors. Infact, beamvector associated with each secondary user is determined by optimizing a certain criterion to reach a specific purpose such as maximizing the throughput or minimizing the interference. To compute the beamvectors, we consider just the secondary user MIMO system. The reason for this is that the interference among primary user is nulled in SINR equation given in (4). In fact, we propose an algorithm that can minimize the interference between cognitive users and maximize the capacity. Specifically, beamvectors are selected such that they satisfy the interference free condition $\mathbf{a}_m^H\mathbf{h}_{pu_m} = 0$.

Assuming that the secondary users signal are uncorrelated with zero mean, in downlink mode, we can express the mth secondary user received signal as:

$$\mathbf{y}_m = \mathbf{H}_{su_{mm}}.\mathbf{s}_m + \sum_{j=1,\,j\neq m}^{M} \mathbf{H}_{sujm}.\mathbf{s}_j + \mathbf{h}_{pu_m}.x_{pu} + \mathbf{n}_m \tag{2}$$

The transmit vector of size K × 1 is as follow:
$\mathbf{s}_m = \mathbf{b}_m.x_m$, Where $\mathbf{b}_m$ is the pre-beamforming vector and x_m is the transmit sample for m between 1 and M. So we can express the mth secondary user received signal as:

$$y_m = \mathbf{a}_m^H.\mathbf{H}_{su_{mm}}.\mathbf{b}_m.x_m + \mathbf{a}_m^H.\sum_{j=1,j\neq m}^{M} \mathbf{H}_{su_{mj}}.\mathbf{b}_j.x_j + \mathbf{a}_m^H.\mathbf{h}_{pu_m}.x_{pu} + \mathbf{a}_m^H.\mathbf{n}_m \tag{3}$$

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Received January 11, 2011
Accepted February 27, 2011
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Where $\mathbf{a}_m$ is the post-beamforming vector at the receive secondary users. The signal to interference noise ratio at the mth secondary user is as follow:

$$SINR_{su} = \frac{E\{|\mathbf{a}_m^H.\mathbf{H}_{su_{mm}}.\mathbf{b}_m.x_m|^2\}}{E\left\{|\mathbf{a}_m^H.\sum_{j=1,\,j\neq m}^{M}\mathbf{H}_{su_{mj}}.\mathbf{b}_j.x_j + \mathbf{a}_m^H.\mathbf{h}_{pu_m}.x_{pu} + \mathbf{a}_m^H.\mathbf{n}_m|^2\right\}} \tag{4}$$

The per-user sum capacity is:

$$C_{su} = \sum_{m=1}^{M}\log_2(1 + SINR_{su}) =$$

$$\sum_{m=1}^{M}\log_2\left(1 + \frac{|\mathbf{a}_m^H.\mathbf{H}_{su_{mm}}.\mathbf{b}_m|^2.p_{su}}{\sum_{j=1,j\neq m}^{M}|\mathbf{a}_m^H.\mathbf{H}_{su_{mj}}.\mathbf{b}_j|^2.p_j + |\mathbf{a}_m^H.\mathbf{h}_{pu_m}|^2.p_{pu} + |\mathbf{a}_m^H|^2.N_0^2}\right) \tag{5}$$

We define the total interference plus noise covariance matrix at the mth secondary as:

$$\sum_{j=1,j\neq m}^{M}|\mathbf{H}_{su_{mj}}.\mathbf{b}_j|^2 + |\mathbf{h}_{pu_m}|^2 + N_0^2 \tag{6}$$

The covariance matrix is defined as below:

$$\mathbf{\Phi}_{su} = \sum_{j=1,j\neq m}^{M}(\mathbf{H}_{su_{mj}}.\mathbf{b}_j.\mathbf{b}_j^H.\mathbf{H}_{su_{mj}}^H) + (\mathbf{h}_{pu_m}.\mathbf{h}_{pu_m}^H) + (\mathbf{n}_m\mathbf{n}_m^H) \tag{7}$$

Therefore, the SINR at the mth secondary user can be formulated as follows: The post-beamforming vector can be expressed as follows:

$$\mathbf{a}_m = \mathbf{\Phi}_{su}^{-1}.\mathbf{H}_{su_{mm}}.\mathbf{b}_m \tag{8}$$

This gives us the following maximization of SINR at the mth secondary user:

$$\mathbf{b}_m^H.\mathbf{H}_{su_{mm}}^H.\mathbf{\Phi}_{su}^{-1}.\mathbf{H}_{su_{mm}}.\mathbf{b}_m \leq \lambda_{\max}(j).\mathbf{b}_m^H.\mathbf{b}_m \tag{9}$$

$$\lambda_{\max}(j).\mathbf{b}_m^H.\mathbf{b}_m = \lambda_{\max}(j).||\mathbf{b}_m||^2 \tag{10}$$

The maximum eigenvalue of $\mathbf{H}_{su_{mm}}^H.\mathbf{\Phi}_{su}^{-1}.\mathbf{H}_{su_{mm}}$ is defined as $\lambda_{\max}(m)$ and must be chosen to maximize the capacity of secondary users so:

$$C_{su} = \sum_{m=1}^{M}\log_2(1 + \lambda_{\max}(m).\mathbf{b}_m^H.\mathbf{b}_m) \tag{11}$$

$$\text{Subject to:}\quad \begin{aligned}&\sum_{j=1}^{M}\mathbf{b}_j.\mathbf{b}_j^H = \sum_{j=1}^{M}||\mathbf{b}_j||^2 \leq M.p_{\max},\\ &||\mathbf{b}_m||^2 \leq p_{\max} \quad \text{for} \quad \text{m} = 1,2,\ldots.\text{M}\\ &E\{|\mathbf{h}_{pu_j}.\mathbf{b}_j|^2\} = (\mathbf{h}_{pu_j}.\mathbf{b}_j.\mathbf{b}_j^H.\mathbf{h}_{pu_j}^H) = ||\mathbf{h}_{pu_j}.\mathbf{b}_j||^2 \leq Q_{\text{int}}\end{aligned}$$

For beamforming, the transmitted power through all the secondary users for the mth secondary user is proportional to $||\mathbf{b}_m||^2$. With considering a penalty

DOI: 10.1587/elex.8.332
Received January 11, 2011
Accepted February 27, 2011
Published March 25, 2011

function, we can convert the constrained optimization process into an unconstrained one to meet problem constraints simultaneously. The cost function's behavior is dynamic due to non-stationary environment specifications. The Lagrangian cost function becomes as below we should minimize it as fitness function:

$$Min\ L = -\sum_{m=1}^{M} \log_2(1+\lambda_{\max}(m).\mathbf{b}_m^H.\mathbf{b}_m) + \alpha_1.\left(\sum_{j=1}^{M} ||\mathbf{b}_j||^2 - M.p_{\max}\right) + \alpha_2.(||\mathbf{b}_j||^2 - p_{\max}) + \alpha_3.(||\mathbf{h}_{pu_j}.\mathbf{b}_j||^2 - Q_{\text{int}}) \tag{12}$$

Where Q_{int} is the maximum tolerable received power at the primary receiver and $\alpha_i = \{\alpha_1, \alpha_2, \alpha_3\}$ is the Lagrangian multiplier. To achieve the optimal performance, Lagrangian multipliers, pre and post beamforming vectors are adjusted to let the transmit power satisfy all constraints by PSO. A power control strategy based on dynamic programming is developed subject to the mentioned secondary and primary networks constraints in the dynamic environment condition.

4 Numerical results

In simulation model, the problem of resource allocation in the context of cognitive radio networks has been simulated. With the deployment of k antennas at the cognitive transceivers, an efficient transmit beamforming technique is proposed. The channels between the transmitters and receivers are assumed to be Rayleigh faded; the channel gains are independent across sub channels. Hence, in our PSO algorithm the three Lagrange multipliers will be set during each iteration to their best values. Path noises are independent zero-mean complex Gaussian random variable with variance1. The maximum transmit power for secondary users are assumed to be 3×10^{-3}. Interference from primary users to base station is ignored. Interference constraint of all primary users is 10^{-4}. It was found that the more repetition of the algorithm in each iteration has the much accuracy. In figure 2 the behavior of the cost function is shown.

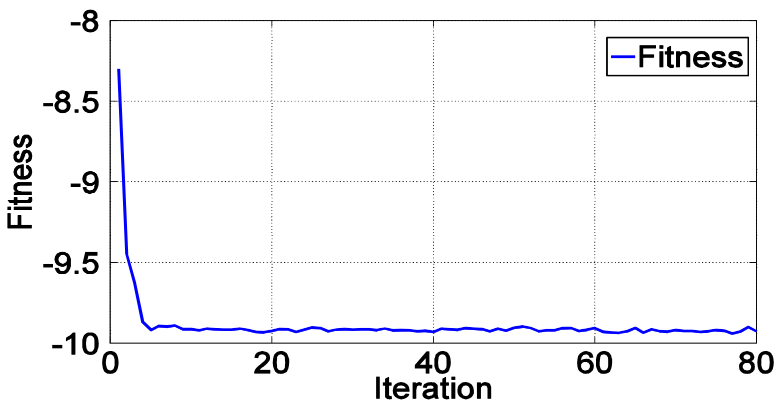

Fig. 2. Behavior of the cost function.

DOI: 10.1587/elex.8.332
Received January 11, 2011
Accepted February 27, 2011
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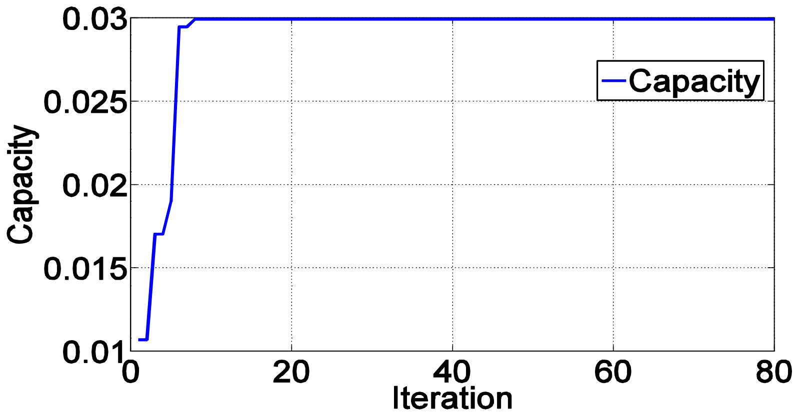
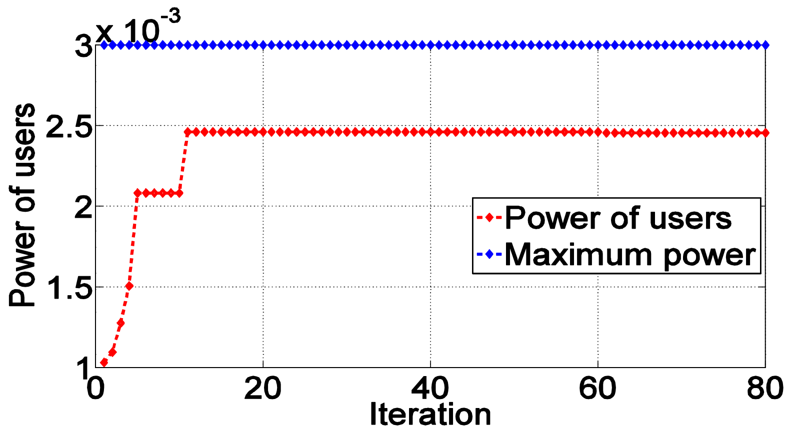
By making average global information of the best particles, the accuracy of the best particles has been raised as shown in figure 2. We can see the behavior of the cost function and its convergence attributes of PSO, it is clear that the all constraints are fulfilled. From figure 3, it can be seen that the transmission capacity arises with increasing the amount of transmission power; however the power will be limited by our simulations constraints and primary user interference.



(a)



(b)

Fig. 3. (a) Transmission capacity of the secondary users and (b) Convergence of transmission power for secondary users.

Furthermore, the fitness functions steer the evolution of the PSO in the correct direction to optimize the given multi-objective functions for the secondary users with the defined constraints in a non stationary environment.

5 Conclusion

We have proposed a PSO assisted scheme to design of distributed power control by beamforming in cognitive radio networks. The scenario is formulated in the ad hoc mode of the secondary network to maximize capacity of secondary users. However, the minimum transmission power of each cognitive or secondary user is considered. We have approached to optimal behavior

DOI: 10.1587/elex.8.332
Received January 11, 2011
Accepted February 27, 2011
Published March 25, 2011

ELectronics EXpress

which PSO adjust the parameters. The proposed PSO aided algorithm provides improved performance by using appropriate pre and post beamforming. Proposed scheme shows the performance of a heuristic improvement in cognitive radio performance in a dynamic environment.

DOI: 10.1587/elex.8.332
Received January 11, 2011
Accepted February 27, 2011
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