2011 17th Asia-Pacific Conference on Communications (APCC)
2nd – 5th October 2011 | Sutera Harbour Resort, Kota Kinabalu, Sabah, Malaysia

Joint Power Allocation and Beamforming in Relay-Assisted Cognitive Radio Networks

Narges Nouri[1], Narges Noori[2], and Hamidreza Bakhshi[1]

[1]Department of Electrical Engineering, Shahed University, Tehran, Iran

[2]Iran Telecommunication Research Center, Tehran, Iran

***Abstract*—In cognitive radio (CR) networks, the secondary users (SUs) try to communicate opportunistically in the frequency band originally allocated to a primary network. This communication should be in a manner that the quality of service (QoS) is satisfied for both primary and secondary networks. In this paper, the considered system consists of a primary broadcasting network with one transmitter and *M* receivers, and a relay-assisted secondary network with one transmitter and one receiver. In this scheme, if the direct link between the cognitive transmitter and receiver is not maintained the target signal to interference plus noise ratio (SINR), the relaying process, begins where *N* relays assist the transmitter to transmit its data to the receiver. This relaying process continues until the target SINR is met at the cognitive receiver. This scheme employs joint power allocation and beamforming (BF) at the relay nodes and defines two optimization problems in a way that the objective in the first problem is minimization of the total transmission power of the relays. If there is not any feasible solution for the first problem, the second problem is proposed with the objective of maximizing the receive rate at the destination node. Genetic algorithm (GA) is applied to both defined problems to find optimum transmission power values and beamforming weight in the relay nodes. Simulation results show that applying beamforming scheme results in a considerable reduction in the total transmission power of the relay nodes, while satisfying the QoS in both primary and secondary networks.**

***Index Terms*—Cognitive radio network, cooperative communication, relaying, power allocation, beamforming.**

I. INTRODUCTION

Nowadays, conventional fixed spectrum allocation policy results in spectrum scarcity in some of high-demanded frequency bands. Cognitive radio (CR) is a promising new technology for dynamic access to the frequency spectrum, proposed to overcome the above problem [1], [2]. In CR networks, secondary users (SUs) opportunistically access to the spectrum originally allocated to a primary network. In this spectrum usage scenario, the interference introduced by SUs to the primary users (PUs) is kept below a certain threshold while trying to satisfy the quality of service (QoS) in the secondary network [3].

Employing cooperative communication techniques is considered to tackle the challenges faced in practical implementation of CR networks. Usually, wireless relays are important parts of these networks, because due to multipath fading, shadowing, and path loss, the direct link between the source and destination nodes may fail to support the desired transmission QoS requirements. Under such conditions, deploying one or multiple relays between the source and destination nodes can overcome the problem. Relaying process is usually implemented in a cooperative structure. Distributed beamforming, as a cooperative communication technique, can be used in CR networks for enabling synchronous transmission of primary and secondary users, improving the network performance, and reduction of interference to the PUs [4]. The beamforming technique can be applied by utilizing a virtual antenna array created by a set of relays [5]. In this method, a distributed beamformer is formed by assembling those antennas belong to multiple relays and carefully selecting the beamforming weight in each relay to efficiently avoid harmful interference to the PUs. Cooperative transmission of primary traffic by secondary network, using other SUs as relay nodes to improve spatial diversity, and using one or multiple relays in secondary network to improve spectrum diversity are investigated in [6], [7] and [8], respectively.

The interference introduced to the primary network is a major challenge of cooperative CR communication. Beamforming and power control algorithms have been considered to overcome this problem [9]-[11]. These techniques guarantee the QoS of both primary and cognitive networks. Combining multi-antenna technology and two-way relaying provides a promising way to improve the spectrum utilization efficiency. In [9], a relay-assisted wireless cellular network with multiple-input single-output (MISO) broadcast channel has been studied. In this scenario, both the base station and relay are equipped with multi-antenna and employed joint beamforming and power control to minimize total consumed power. In another scenario considered in [10], two SUs exchange their information through a cognitive relay while beamforming and power allocation are employed to enhance the achievable sum rate. Cooperative communication based on relaying between SUs in the presence of one or more primary links is considered in [11]. This relaying process is executed in several steps, where in each step, those relays which their signal to interference plus noise ratio (SINR) is more than a threshold are selected and accordingly, the power allocation process is performed for these relays. The process is continued until SINR of the destination node meets the target value.

In this paper, in addition to the power allocation in multi-hop transmission via the relays studied in [11], beamforming is considered in relay nodes. The proposed approach employs joint power allocation and beamforming in relay nodes. The process is performed in several relaying phases. It is assumed that if the direct link between the cognitive transmitter and receiver does not maintained the target SINR, the relaying process begins and continues until the target SINR is met at the cognitive receiver. In this scheme, two optimization problems are defined and solved by genetic algorithm (GA). This considered scenario can cause significant reduction in transmission powers of relay nodes compared to the studied scenario in [11].

The paper is classified as below. In section II, system model is described. Formulation of the optimization problems is presented in section III. In section IV, it is mentioned that how GA is applied to solve the defined problems. Then, in section V, numerical results are presented to investigate the performance of the proposed scheme. Finally, the paper is concluded in section VI.

II. System Model

Consider a CR or secondary network which consists of a transmitter (CR_{tx}), a receiver (CR_{rx}), and N cognitive relays operating in the same frequency band allocated to a primary network. The primary broadcasting network consists of a transmitter and M receivers. Both transmitter and receiver nodes of the CR network are equipped with omnidirectional antennas. Each relay node is equipped with a linear array of K uniformly spaced omnidirectional antenna elements. These nodes are employed to create reliable communication among the SUs. After receiving data from the source, the relays transmit it to the destination using joint power allocation and beamforming technique. This system model is shown in Fig.1.

In the secondary network, we consider a situation in which there is a single link between the transmitter and receiver nodes, and the relay nodes cooperate in the data transmission process to meet SINR target value $(SINR_{target})$ at the destination node. This value is a criterion to check desirability of the QoS requirements at the cognitive network. The joint power allocation and beamforming scheme is performed at cognitive relays in several steps. In this scheme, data transmission from the secondary transmitter to the secondary receiver includes the maximum $(1 + N_{M,Relayingphase})$ orthogonal time slots where $N_{M,Relayingphase}$ denotes a predefined maximum number of relaying phases and the number of unit indicates the first step of transmission from secondary transmitter. Throughout this paper, we assume that cognitive receiver and relay nodes have perfect knowledge about all channel impulse responses (CIRs) and both transmit and receive processes are based on the transmission buffer states. We also assume quasi-static channel conditions and suppose that the channel responses stay the same through the entire secondary network transmission. Moreover, the primary links employ the time division duplex (TDD).

During the first step, cognitive transmitter transmits the $\sqrt{P_{CR_{tx}}}x_{CR_{tx}}$ signal to the destination and relay nodes, where $P_{CR_{tx}}$ is its transmission power and is adjusted such that it would not exceed the maximum power $(\bar{P}_{CR_{tx}})$ and satisfies all interference constraints of the PUs. The $x_{CR_{tx}}$ is the message signal of the cognitive transmitter with unit energy which means that $E\left\{\left|x_{CR_{tx}}\right|^2\right\} = 1$. The $E\{.\}$ and $|.|$ denote the statistical expectation and amplitude of a complex number, respectively. The primary transmitter continuously transmits with power $P_{P_{tx}}$.

In this step, the received signal at the cognitive receiver and the relay nodes can be expressed by following equations, respectively:

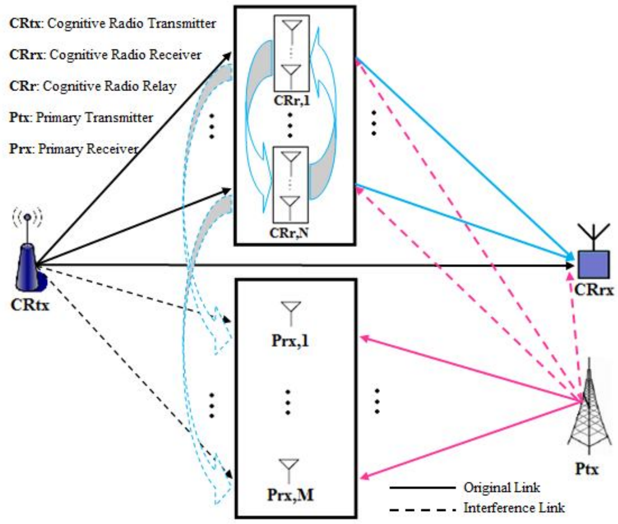

Fig. 1.System model.

$$y_{CR_{rx},1} = h_{CR_{tx},CR_{rx}}\sqrt{P_{CR_{tx}}}x_{CR_{tx}}(t-\tau) + h_{P_{tx},CR_{rx}}\sqrt{P_{P_{tx}}}x_{P_{tx}}(t-\tau_0) + n_{CR_{rx}} \tag{1}$$

$$y_{CR_{r_i},1} = h_{CR_{tx},CR_{r_i}}\sqrt{P_{CR_{tx}}}x_{CR_{tx}}(t-\tau_i) + h_{P_{tx},CR_{r_i}}\sqrt{P_{P_{tx}}}x_{P_{tx}}(t-\tau_{0_i}) + n_{CR_{r_i}} \quad ; i = 1, \ldots, N \tag{2}$$

The $h_{X,Y}$ indicates the channel impulse response at the link from node X to Node Y and $P_{P_{tx}}$ and $x_{P_{tx}}$ represent the transmission power and the message signal of the primary transmitter respectively, where $E\left\{\left|x_{P_{tx}}\right|^2\right\} = 1$. Transmitted signals of the secondary and primary transmitters received at the destination node by τ and τ_0 delays, respectively. Similarly, τ_i and τ_{0_i} indicate the time delays of the message signals received from the secondary and primary transmitters at the relay nodes, respectively. $n_{CR_{rx}}$ and $n_{CR_{r_i}}$ are the additive white Gaussian noise (AWGN) at the secondary receiver and the i th relay, respectively, both have variance σ_n^2. The noise variance is considered identical for all secondary nodes. In this step, investigation of the SINR amount at destination node determines whether the relaying process is required or not. If the SINR amount in the cognitive receiver is larger than or equal to $SINR_{target}$, it means that the direct link between the cognitive transmitter and receiver has satisfied the QoS at the cognitive receiver and the relaying process is not required. Therefore, after the first step of the scheme, SINR of the secondary receiver is expressed by:

$$SINR_{CR_{rx},1} = \frac{\left|h_{CR_{tx},CR_{rx}}\right|^2 P_{CR_{tx}}}{\left|h_{P_{tx},CR_{rx}}\right|^2 P_{P_{tx}} + \sigma_n^2} \tag{3}$$

If $SINR_{CR_{rx},1} \geq SINR_{target}$ is not met, the next step of the proposed scheme should be started. First those relays which decode the source message without any errors at the first step are chosen for the next step. This means that the SINR of all relay nodes should be compared with a defined threshold and those relays where their SINRs are greater than or equal to the threshold are selected to participate at the second step of the scheme. The following equation demonstrates the SINR of the i th relay after the first step:

$$SINR_{CR_{r_i}} = \frac{\left|h_{CR_{tx},CR_{r_i}}\right|^2 P_{CR_{tx}}}{\left|h_{P_{tx},CR_{r_i}}\right|^2 P_{P_{tx}}+\sigma_n^2} \; ; i = 1, \dots, N \tag{4}$$

The selected relays satisfy $SINR_{CR_{r_i}} \geq SINR_{th}$. During the second step, the joint power allocation and beamforming scheme is performed in the selected relays in each phase. The relaying process is continued through several phases and stopped when the QoS requirements of the destination node is satisfied. During each relaying phase, the received signal at each selected relay node is multiplied in the beamforming vector and transmitted toward the secondary receiver:

$$x_{CR_{r_{i',q}}} = \mathbf{w}_{i',q}^H \mathbf{v}_{i'}(\theta_{i'}) y_{CR_{r_{i',q}}} \; ; \substack{i'\epsilon N_{s,q}\;, N_{s,q} \subseteq \{1,\dots,N\} \\ q=1,\dots,P} \tag{5}$$

where $\mathbf{w}_{i',q} = \left[w_{i',q}^{(1)}, \dots, w_{i',q}^{(K)}\right]^T$ and $y_{CR_{r_{i',q}}}$ are a K-component complex weight vector and received signal at the i' th relay node in the q th relaying phase, respectively, $N_{s,q}$ is the selected relays set in the q th relaying phase, and $\mathbf{v}_{i'}(\theta_{i'})$ is the antenna array response of the i' th relay in the direction of departure, $\theta_{i'}$, which is defined by:

$$\mathbf{v}_{i'}(\theta_{i'}) = [1, e^{-j2\pi/\lambda_c d sin(\theta_{i'})}, \dots, e^{-j2\pi/\lambda_c d(K-1) sin(\theta_{i'})}]^{\mathrm{T}}; \substack{i'\epsilon N_{s,q}\;, N_{s,q} \subseteq \{1,\dots,N\} \\ q=1,\dots,P} \tag{6}$$

Where d is the separation distance between two antenna elements and is equal for all relays, λ_c is the carrier wavelength of the message signal and $(.)^T$ and $(.)^H$ denote the transpose and the hermitian operations, respectively.

The received signals at the destination node, the primary receivers and relay nodes in the q th relaying phase are respectively as follows:

$$y_{CR_{rx},q} = \sum_{i'} h_{CR_{r_{i',q}},CR_{rx}} \sqrt{P_{CR_{r_{i',q}}}} \mathbf{w}_{i',q}^H \mathbf{v}_{i'}(\theta_{i'}) y_{CR_{r_{i',q}}}(t - \tilde{\tau}_{i'}) + h_{P_{tx},CR_{rx}} \sqrt{P_{P_{tx}}} x_{P_{tx}}(t - \tilde{\tau}_0) + n_{CR_{rx}} \; ; \substack{i'\epsilon N_{s,q}\;, N_{s,q} \subseteq \{1,\dots,N\} \\ q=1,\dots,P} \tag{7}$$

$$y_{P_{rx_j},q} = \sum_{i'} h_{CR_{r_{i',q}},P_{rx_j}} \sqrt{P_{CR_{r_{i',q}}}} \mathbf{w}_{i',q}^H \mathbf{v}_{i'}(\varphi_j) y_{CR_{r_{i',q}}}\left(t - \tilde{\tau}_j'\right) + h_{P_{tx},P_{rx_j}} \sqrt{P_{P_{tx}}} x_{P_{tx}}\left(t - \tilde{\tau}_{0_j}'\right) + n_{P_{rx_j}} \; ; \substack{i'\epsilon N_{s,q}\;, N_{s,q} \subseteq \{1,\dots,N\} \\ q=1,\dots,P \\ j=1,\dots,M} \tag{8}$$

$$y_{CR_{r_k},q} = \sum_{i'} h_{CR_{r_{i',q}},CR_{r_k}} \sqrt{P_{CR_{r_{i',q}}}} \mathbf{w}_{i',q}^H \mathbf{v}_{i'}(\psi_k) y_{CR_{r_{i',q}}}(t - \tilde{\tau}_k'') + h_{P_{tx},CR_{r_k}} \sqrt{P_{P_{tx}}} x_{P_{tx}}\left(t - \tilde{\tau}_{0_k}''\right) + n_{CR_{r_k}} \; ; \substack{i'\epsilon N_{s,q}\;, N_{s,q} \subseteq \{1,\dots,N\} \\ q=1,\dots,P \\ k \neq i'} \tag{9}$$

Where $P_{CR_{r_{i',q}}}$ is the transmission power of the i' th relay node in the q th relaying phase. Transmission power vector of the relay nodes in the q th relaying phase is defined by:

$$\mathbf{P}_{CR_r,q} = \left[P_{CR_{r_{i'}}}\right]^T ; \forall i' \epsilon N_{s,q} \tag{10}$$

where the transmission power constraints for the cognitive relay nodes in each relaying phase is as follows:

$$\mathbf{P}_{CR_r,q} \leq \bar{\mathbf{P}}_{CR_r,q} \qquad ; q = 1, \dots, P \tag{11}$$

where $\bar{\mathbf{P}}_{CR_r,q} = \left[\bar{P}_{CR_{r_{i'}}}\right]^T ; \forall i' \epsilon N_{s,q}$ is the maximum licensed transmission power for the selected nodes in the q th relaying phase. Furthermore, $\theta_{i'}$, φ_j and ψ_k are directions of departure from the i' th relay to the secondary receiver, the j th primary receiver and the k th relay, respectively. Transmitted signal of the i' th relay node is received at secondary receiver, j th primary receiver and k th relay node by $\tilde{\tau}_i$, $\tilde{\tau}_j'$ and $\tilde{\tau}_k''$ delays, respectively. Similarly, $\tilde{\tau}_0$, $\tilde{\tau}_{0_j}'$ and $\tilde{\tau}_{0_k}''$ indicate the time delays from primary transmitter to these nodes, respectively. $n_{CR_{rx}}$, $n_{P_{rx_j}}$ and $n_{CR_{r_k}}$ are AWGN with variance σ_n^2 at the destination, j th primary receiver and k th relay node, respectively.

After P relaying phases, the overall SINR of the cognitive receiver is equal to:

$$SINR_{CR_{rx}} = SINR_{CR_{rx},1} + \sum_{q=1}^{P} SINR_{CR_{rx},q} \tag{12}$$

where,

$$SINR_{CR_{rx},q} = \frac{\sum_{i'}\left|h_{CR_{r_{i',q}},CR_{rx}} w_{i',q}^H v_{i'}(\theta_{i'})\right|^2 P_{CR_{r_{i',q}}}}{\left|h_{P_{tx},CR_{rx}}\right|^2 P_{P_{tx}}+\sigma_n^2} ; \substack{i'\epsilon N_{s,q}\;, N_{s,q} \subseteq \{1,\dots,N\} \\ q=1,\dots,P} \tag{13}$$

In (12), the influence of the relaying process is shown in the second part of the equation and the overall SINR at the cognitive receiver is determined by summation of the SINR values of two steps.

In each phase of the second step, the QoS constraints of the secondary receiver should be investigated to determine if the relaying process needs to be continued. In order to satisfy this condition, the $SINR_{CR_{rx}}$ from (12) should be compared with $SINR_{target}$. If $SINR_{CR_{rx}} \geq SINR_{target}$, the relying process is stopped, but if this condition is not satisfied, the relying process should be continued with those relays that have not participate in the previous relaying phases.

If the $SINR_{target}$ at the secondary receiver is achieved after the P th relaying phase, we have:

$$SINR_{CR_{rx}} = SINR_{CR_{rx},1} + \sum_{q=1}^{P} SINR_{CR_{rx},q} \geq SINR_{target} \tag{14}$$

At this point, when the required QoS is maintained at the secondary network, the relaying process will stop. Otherwise, this process is repeated until all relays have participated in the relaying process or a predefined maximum number of relaying phases is reached. In order to satisfy QoS requirements at the primary network, the overall interference power experienced by each primary receiver should remain below the maximum licensed interference power:

$$I_{P_{rx_j},q} = \rho_j \sum_{i'} \left| h_{CR_{r_{i',q}},P_{rx_j}} w_{i',q}^H v_{i'}(\varphi_j) \right|^2 P_{CR_{r_{i',q}}} \leq \eta_j \;;\; \begin{matrix} i' \epsilon N_{s,q}, N_{s,q} \subseteq \{1,\dots,N\} \\ q=1,\dots,P \\ j=1,\dots,M \end{matrix} \tag{15}$$

In this equation, ρ_j indicates the ratio of the bandwidth occupied by the j th primary node to the bandwidth of the secondary network and η_j is the maximum tolerable interference of the j th primary receiver.

The achievable rate in the cognitive receiver in the q th relaying phase can be expressed by:

$$R_{CR_{rx,q}} = \log_2\left(1 + SINR_{CR_{rx,q}}\right) \tag{16}$$

III. Problem Formulation

In this section, the details of problem formulation are presented. The main objective of the joint power allocation and beamforming at relay nodes is minimizing total power consumption at those relays cooperating during the relaying phases. This should be done under (11), (14) and (15) constraints. This optimization problem can be formulated as follows:

$$\begin{aligned} & min_{P_{CR_{r_i}},w} \; P_{CR_r,total} = \sum_i P_{CR_{r_i}} \;; \\ & Subject\ to: \\ & \quad SINR_{CR_{rx},q} \geq SINR_{target} - SINR_{CR_{rx},1} - \sum_{l=1}^{q-1} SINR_{CR_{rx},l} \;; \\ & \quad I_{P_{rx_j},q} \leq \eta_j \;; \\ & \quad \mathbf{P}_{CR_r,q} \leq \overline{\mathbf{P}}_{CR_r,q} \;; \\ & for\ i \epsilon N_{s,q}, N_{s,q} \subseteq \{1,\dots,N\}, q = 1,\dots,P, and\ j = 1,\dots,M. \end{aligned} \tag{17}$$

If there is not any feasible solution for (17) within the current relaying phase, another optimization problem is defined in this phase to maximize the achievable rate at the secondary receiver, in anticipation of meeting the target SINR in the next phase. Correspondingly, this optimization problem is defined as follows:

$$\begin{aligned} & max_{P_{CR_{r_i}},w} \; R_{CR_{rx,q}} = \log_2\left(1 + SINR_{CR_{rx,q}}\right) \\ & Subject\ to: \\ & \quad I_{P_{rx_j},q} \leq \eta_j \;; \\ & \quad \mathbf{P}_{CR_r,q} \leq \overline{\mathbf{P}}_{CR_r,q}; \\ & for\ i \epsilon N_{s,q}, N_{s,q} \subseteq \{1,\dots,N\}, q = 1,\dots,P, and\ j = 1,\dots,M. \end{aligned} \tag{18}$$

The optimization problems defined in (17) and (18) find the optimum beamforming weights and transmission powers of the selected relays under maximum power constraints and all users' QoS requirements.

IV. Using Genetic Algorithm for Joint Power Allocation and Beamforming

Genetic algorithm is an adaptive procedure based on the principles of evolution and hereditary rules. This algorithm is one of the powerful tools for solving the highly constrained complex optimization problems [12].

To apply GA, the population size in each generation set to 10 times of the number of chromosomes. Chromosome parameters include transmission power values and beamforming weight vectors of the relay nodes. Therefore, each chromosome contains $N_q \times (2K+1)$ parameters, where, N_q represents the number of selected relays in the q th relaying phase and K is the number of antenna elements at the relay nodes. The optimization vector can be defined by:

$$\mathbf{X} = \begin{bmatrix} \mathbf{P}_{CR_{r,q}}^T, Am(\mathbf{w}_1^T), \dots, Am\left(\mathbf{w}_{N_q}^T\right), \\ Ph(\mathbf{w}_1^T), \dots, Ph\left(\mathbf{w}_{N_q}^T\right) \end{bmatrix}^T \tag{19}$$

where $\mathbf{P}_{CR_{r,q}}$ is the transmission power vector of relays in the q th relaying phase and $Am(\mathbf{w}_n^T)$ and $Ph(\mathbf{w}_n^T)$ are K-component vectors containing amplitudes and phases of $\mathbf{w}_n$'s, respectively. In order to apply GA to optimization problems defined in (17) and (18), we rewrite these problems in the following standard form:

$$\begin{aligned} & min_X \; F(\boldsymbol{X}) \\ & subject\ to: \\ & \quad C_E(\mathbf{X})=0 \;; \mathbf{C}_E = \left[C_E^{(1)},\dots,C_E^{(P)}\right]^T \\ & \quad C_I(\mathbf{X})\leq 0 \;; \mathbf{C}_I = \left[C_I^{(1)},\dots,C_I^{(Q)}\right]^T \\ & \quad \mathbf{Lb}\leq\mathbf{X}\leq\mathbf{Ub} \;; \begin{matrix} \mathbf{Lb} = \left[Lb_1,\dots,Lb_J\right]^T \\ \mathbf{Ub} = \left[Ub_1,\dots,Ub_J\right]^T \end{matrix} \end{aligned} \tag{20}$$

where, F is the objective function, $\mathbf{C}_E$ is a vector containing P equality constraint functions, $\mathbf{C}_I$ is a vector containing Q inequality constraint functions, and $\mathbf{Lb}$ and $\mathbf{Ub}$ are the lower and upper bound vectors for optimization parameters, respectively. In this scheme, the lower bound vector, is an all-zero row vector of size $N_q \times (2K+1)$. The i th component of the upper bound vector is given by:

$$Ub_i = \begin{cases} \overline{P}_{CR_r,q_i} \;; \forall i \in \left[1, N_q\right] \\ 1 \quad ; \forall i \in \left[N_q+1, N_q \times (K+1)\right] \\ 2\pi \quad ; \forall i \in \left[N_q \times (K+1)+1, N_q \times (2K+1)\right] \end{cases} \tag{21}$$

The **X** vector should be found such that minimize the objective function in (17) and maximize the objective function in (18).

Various conditions have been suggested for ending genetic algorithm search. At the best condition and by specifying the optimized value of the target function, search is finished after finding the best answer. Otherwise, time limitation can control the number of repetitions for searching the best answer. So, we can specify a number as the maximum number of iterations at the beginning of the search. If the best answer is achieved before reaching to this number, the searching process is stopped, otherwise, the searching process is continued until to the last iteration. If no changes are appeared in the amount of target function after defined number of iterations, searching process is stopped. In these conditions, the resulted solution may not be the global optimized solution [12].

V. Simulation Results

In this section, we present some simulation results to show the performance of the proposed scheme. In the considered scenario, the primary network consists of a transmitter-receiver link. Two different cases are considered for secondary network where two or five relays assist the secondary transmitter to transmit to the destination. In this system, the secondary transmitter and receiver are located at $(-0.5m, 0)$ and $(0.5m, 0)$, respectively. Moreover, we assume that $d_{CR_{r1},P_{rx}} = 13m, d_{CR_{r2},P_{rx}} = 16m, d_{P_{tx},CR_{rx}} = 50m, d_{CR_{r1},CR_{rx}} = 7m$ and $d_{CR_{r2},CR_{rx}} = 4m$ in first case and these distances considered as follows in second case:

$$d_{\mathrm{CR_{r1},P_{rx}}} = 27m, d_{\mathrm{CR_{r2},P_{rx}}} = 24m, d_{\mathrm{CR_{r3},P_{rx}}} = 15m,$$
$$d_{\mathrm{CR_{r4},P_{rx}}} = 16m, d_{\mathrm{CR_{r5},P_{rx}}} = 13m, d_{\mathrm{CR_{r1},CR_{rx}}} = 7m,$$
$$d_{\mathrm{CR_{r2},CR_{rx}}} = 4m, d_{\mathrm{CR_{r3},CR_{rx}}} = 5m, d_{\mathrm{CR_{r4},CR_{rx}}} = 4m,$$
$$d_{\mathrm{CR_{r5},CR_{rx}}} = 7m, d_{\mathrm{P_{tx},CR_{rx}}} = 50m$$

Furthermore, the ratio of the bandwidth occupied by the primary nodes to the bandwidth of the secondary network is assumed *0.04*. Each of the relays equipped with a linear array of *K* uniformly spaced omnidirectional antenna elements with an antenna separation distance equal to half of the operating frequency wavelength. In order to investigate effect of different number of antenna elements, three different cases of $K_1=K_2=1$(without beamforming), *2* and *4* are considered which K_i *(i=1,2)* is the number of antenna elements at the *i* th relay node. The channel energy associated with a certain link $X \rightarrow Y$ is modeled according to $\alpha_{X,Y} = L_0\left(d_0/d_{X,Y}\right)^p$, where $d_{X,Y}$ is the distance between node X and node Y, L_0 is the reference attenuation for a reference distance of $d_0 = 1m$ and p is the path loss exponent. In the simulations, L_0 and p are set to $-50dB$ and 2, respectively. It should be mentioned that variance of the AWGN process is assumed identical for all secondary nodes and set to $\sigma_n^2 = -64dBm$. Suppose we require an SINR increment of $3dB$ during the relaying phases and the maximum number of relaying phases is set to 1. Also, the transmission power constraints of each SUs is set to $37\mu w$ and transmission power of the primary transmitter is set to $40mw$. The maximum tolerable interference to the primary receiver is $-100dBm$. The population size in the GA set to *10* times of the number of optimization parameters.

Allocated transmission power to each of the relays in the first case where two relays assist cognitive transmitter and in the second case where five relays cooperating in this process are shown in Fig. 2. In both cases, it is assumed that each of the relays is equipped with 4 antennas.

Total power consumption at the relays is investigated at three different cases of $K_1=K_2=1$(without beamforming), *2* and *4* relay antennas to check the relationship between array antenna elements and performance of the scheme. Fig.3 shows this comparison for total transmit power of relays when secondary network consists of two relays. It is seen in Fig. 3 that according to expectations, by increasing the number of antenna elements in the relay nodes, a significant reduction in the total transmission power can be seen.

Convergence of the SINR at the cognitive receiver in the case of 2 relays is shown in Fig. 4 for three different cases of $K_1=K_2=1$(without beamforming), *2* and *4* antennas. The figure shows that SINR amount of the destination node is converged to the $SINR_{target}$ in a reasonably low number of iterations. Fig. 5 shows the interference introduced to the primary receiver in this case. This result shows that the primary network can meet its QoS requirements and the proposed approach satisfied the maximum tolerable interference limit of the primary receiver.

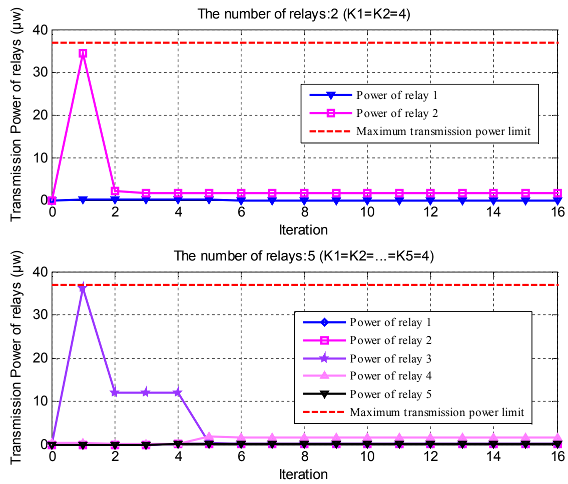

Fig. 2.Transmission power of the relays, Top: N=2, Bottom: N=5.

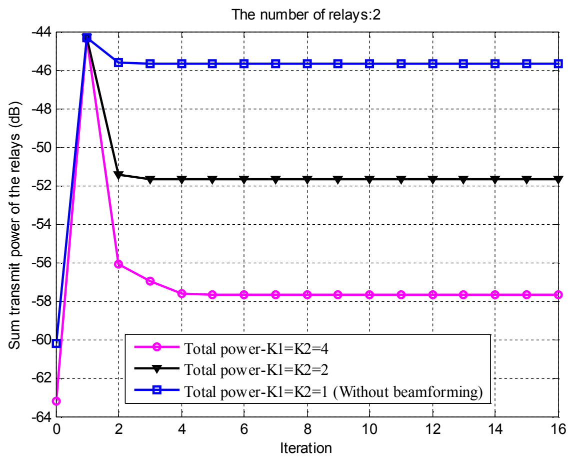

Fig. 3.Total transmission power of the relays, for different number of antennas.

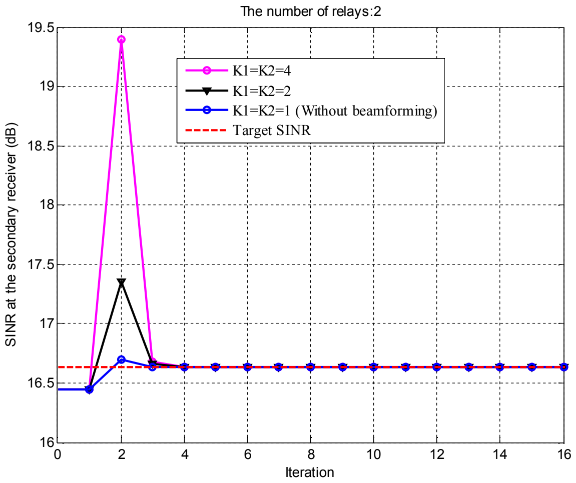

Fig. 4.SINR of secondary receiver, for different number of antennas.

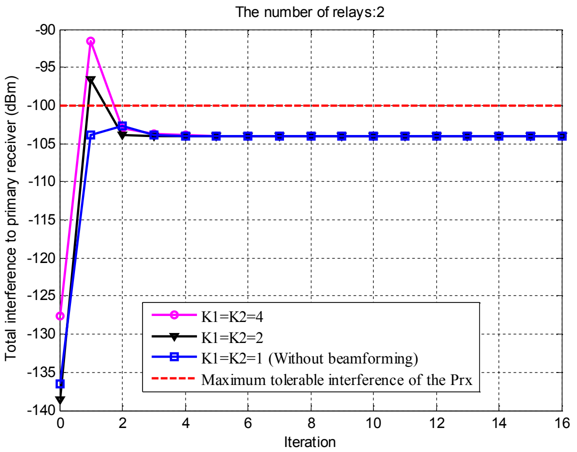

Fig. 5.Amount of interference to the primary receiver, for different number of antennas.

Therefore, it is observed that applying joint power control and beamforming in relay nodes satisfies QoS requirements in both primary and secondary networks while significantly reduces power consumption of relays in comparison to the case where just power control is applied in these nodes.

VI. Conclusions

We have employed joint power allocation and beamforming in the relay nodes of a CR network operates in the geographical area of a primary network to which the spectrum is licensed. It has shown that by applying the proposed approach we can significantly reduce the power consumption of relays in order to maintain target SINR of the secondary receiver. Simulation results show that power consumption of the relays is much less than the case where just power control is employed. Also, the proposed scheme satisfies the interference constraint of the primary network.

Acknowledgments

This work is supported by Iran Telecommunication Research Center.

References

[1] J. Mitola, and G.Q. Maguire, “Cognitive radio: Making software radios more personal,” *IEEE Pers. Commun.*, vol. 6, no. 4, pp. 13-18, Aug. 1999.

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

[3] Q. Zhao and B. M. Sadler, “A survey of dynamic spectrum access,” *IEEE Signal Processing Magazine*, vol. 24, pp. 79-89, May 2007.

[4] R. Mudumbai, D. R. Bown III, U. Madhow, and H. V. Poor, “Distributed transmit beamforming: Challenges and recent progress, ”*IEEE Comm. Magazine*, vol. 47, no. 2, pp. 102-110, Feb. 2009.

[5] J. N. Laneman and G. W. Wornell, “Distributed space-time coded protocols for exploiting cooperative diversity in wireless networks,”*IEEE Trans. Inform. Theory*, vol. 49, no. 10, pp. 2415–2425, Oct. 2003.

[6] O. Simeone, Y. Bar-Ness, and U. Spagnolini, “Stable throughput of cognitive radios with and without relaying capabilities,” *IEEE Trans.Commun.*, vol. 55, no. 12, pp. 2351–2360, Dec. 2007.

[7] M. Xie, W. Zhang, and K.Wong, “A geometric approach to improve spectrum efficiency for cognitive relay networks,” *IEEE Trans. on wireless Commun.*, vol. 9, no. 1, pp. 268-281, Jan. 2010.

[8] Q. Zhang, J. Jia, and J. Zhang, “Cooperative relay to improve diversity in cognitive radio networks,” *IEEE Commun. Mag.*, vol. 47, no. 2, pp. 111–117, Feb.2009.

[9] R. Zhang, C. C. Chai, and Y.C. Liang, “Joint beamforming and power control for multiantenna relay broadcast channel with QoS constraints, ”*IEEE Trans. On Signal Processing*, vol. 57, no. 2, pp. 726-737 Feb. 2009.

[10] K. Jitvanichphaibool, Y. C. Liang, and R.Zhang, “Beamforming and power control for multi-antenna cognitive two-way relaying, ”*in Proc. IEEE Wireless commun. and Networking conf. (WCNC),* Budapest, Hungary, pp. 1-6, Apr. 2009.

[11] J. Mietzner, L. Lampe, and R. Schober, “Distributed transmit power allocation for multihop cognitive-radio systems, ”*IEEE Trans. on Wireless Commun.*, vol. 8, no. 10, pp. 5187-5201, Oct. 2009.

[12] M. Gen and R. W. Cheng, *Genetic Algorithms and Engineering Design,* A Wiley-Interscience Publication, John Wiley & Sons, INC., 1997.