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# OPTIMAL MULTIUSER DOWNLINK COOPERATIVE BEAMFORMING IN COGNITIVE RADIO NETWORKS USING ADMISSION CONTROL

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***Abstract*—In our proposed work, optimal multiuser downlink cooperative beam forming in cognitive radio networks is considered with target SINR. In already existing works, the transmit beam forming vectors for maximum number of admitted secondary users into the cognitive radio network are designed with fixed target SINR and sum power constraints. However, this joint optimization problem becomes infeasible as some users may absorb more power to meet the target SINR. Hence, the objective of this work is to design optimal multiuser downlink beam forming vectors for primary and secondary base stations in a cooperative manner using admission control satisfying the practical bounded SINR constraints. This is solved using approximate message passing technique. The performance of this cognitive radio network is analysed with the constraints.**

***Keywords*—Beam forming, approximate message passing, sum power constraint, bounded constraint, cognitive radio.**

## I. INTRODUCTION

Cognitive radio is a technology in which a transceiver can detect intelligently which communication channels in the network are in use and which ones are not to avoid user interference. It is mainly used for making secondary users occupy the spectrum without disturbing the primary users. The cognitive radio can only make the secondary users occupy the spectrum but those secondary users should transmit the signal to the respective receiver and for that beam forming is used. Beam forming is a type of radio frequency management technique in which a wireless signal is directed toward a specific receiving device. In the proposed algorithm, admission control technique has been adopted. The admission control is used to increase the number of users in the system. Admission control is used for the validation process which is performed before a connection is established.

## II. CHALLENGES AND MOTIVATION

In the precedent works, the SINR constraint is assumed to be fixed for both the primary and secondary users. The total transmit power used at the base station should be minimum thereby increasing the number of admitted secondary users in the system. In the previous work, the optimization problem is formulated using convex optimization technique. The major challenge in convex optimization is that it consumes more amount of time to produce the results. In this paper, target SINR value is assumed to be bounded. The optimization problem is implemented using the Approximate Message Passing algorithm in this paper. The Approximate Message Passing algorithm has very fast convergence and can be precisely analysed. The objective of this paper is to design optimal beam forming vectors cooperatively for both the primary and secondary users in cognitive radio networks using admission control where the secondary users are permitted into the network fulfilling the bounded SINR constraint.

## III. SYSTEM MODEL

Consider the system model of a cognitive radio network shown in Figure 1. In this system, a primary network is assumed to have a Primary Transmitter (PT) and M Primary Receivers (PR). Within the area of the primary network, a secondary network is deployed which shares the same radio resource of the primary network. The secondary network has a Cognitive Radio Base Station (CRBS) and K Secondary Receivers (SR)

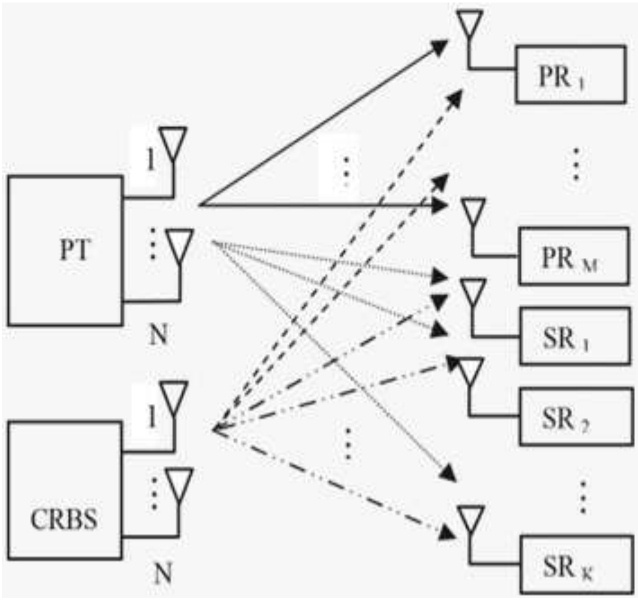


Figure 1: Cognitive Radio Network

The primary network assumed here consists of PT which is the primary transmitter and primary receivers (PR). Then a secondary network which consists of a Cognitive Radio Base Station (CBRS) and secondary receivers (SR) is deployed within the primary network. The secondary network shares the same radio resource of the primary network

Here we have 'K' number of secondary receivers and 'M' number of primary receivers.

The transmit signal vector of Cognitive Radio Base Station(CBRS) is given as,

$$\mathbf{x} = \sum_{\mathbf{i=1}}^{\mathbf{K}} \mathbf{s_i w_i} \qquad (1)$$

where $s_i$is$i^{th}$ secondary user symbol and $w_i$is a $N_s \times 1$ complex weight beam forming vector for the $i^{th}$ secondary receiver

The transmit signal transmitted by the primary transmitter is written as,

$$\mathbf{y} = \sum_{\mathbf{j=1}}^{\mathbf{M}} \mathbf{p_j w_{p_j}} \qquad (2)$$

where $p_j$ is the $j^{th}$ primary user symbol and $w_{p_j}$ is the $N_p$ x 1complex weight beamforming vector for the $j^{th}$PR. The PT and CRBS symbols are assumed to be BPSK modulated that satisfies the conditions $E[|s_i|^2] = 1$ and $E[|s_i|^2] = 1$

The receive signal at $j^{th}$ primary receiver is written as,

$$r_j^p = h_{p_j}^H\left(\mathbf{p_j w_{p_j}}\right) + \sum_{\substack{l=1 \\ l\neq j}}^{M} h_{p_j}^H\left(\mathbf{p_l w_{p_l}}\right) + \sum_{j=1}^{M} h_{sp_j}^H\left(\mathbf{s_i w_{s_i}}\right) + \mathbf{n_j^p} \qquad (3)$$

where $h_{p_j}$ be $N_p\ x\ 1$ Rayleigh flat fading channel vector between PT and th $j^{th}$ PR , $h_{s_i}$ be $N_s\ x\ 1$ Rayleigh flat fading channel vector between CRBS and $i^{th}$SR, $h_{ps_i}$ be $N_p\ x\ 1$ Rayleigh flat fading channel vector between PT and $i^{th}$ SU and $h_{sp_j}$be $N_c\ x\ 1$ Rayleigh flat fading channel vector between CRBS and $j^{th}$PR.

The receive signal at $i^{th}$ secondary receiver is written as,

$$r_j^s = h_{s_i}^H\left(\boldsymbol{s_i w_{p_i}}\right) + \sum_{\substack{l=1 \\ l\neq i}}^{K} h_{s_i}^H\left(\boldsymbol{s_l w_{p_l}}\right) + \sum_{j=1}^{M} h_{ps_i}^H\left(\boldsymbol{p_j w_{p_j}}\right) + \boldsymbol{n_i^s} \qquad (4)$$

*In the above equation,* $n_j^p$ and $n_i^s$ represent the complex Additive White Gaussian Noise (AWGN) with zero mean and variance $N_o$ at $j^{th}$ PR and $i^{th}$SR respectively.

$|h_{p_j}^H w_{p_j}|^2$ is the desired signal power at th $j^{th}$ PR, $\sum_{i=1}^{K} |h_{sp_j}^H w_{s_i}|^{\mathbf{2}}$ is the interference from CRBS to the $j^{th}$ PR and $\sum_{\substack{l=1 \\ l\neq j}}^{M} |h_{p_j}^H w_{p_l}|^{\mathbf{2}}$is the interference from other primary users to th $j^{th}$ PR. Using equation (3), the SINR at the $j^{th}$ primary receiver can be determined as,

$$SINR_j^p = \frac{|h_{p_j}^H w_{p_j}|^2}{\sum_{i=1}^{K} |h_{sp_j}^H w_{s_i}|^{\mathbf{2}} + \sum_{\substack{l=1 \\ l\neq j}}^{M} |h_{p_j}^H w_{p_l}|^{\mathbf{2}} + N_o}$$

$|h_{s_i}^H w_{s_i}|^2$ is the desired signal power at th $i^{th}$ SU, $\sum_{j=1}^{M} |h_{ps_i}^H w_{p_j}|^{\mathbf{2}}$is the interference from primary transmitter to the $i^{th}$ SR and $\sum_{\substack{l=1 \\ l\neq i}}^{K} |h_{s_i}^H w_{s_l}|^{\mathbf{2}}$is the interference from other secondary users to the $i^{th}$ SR. Using equation (4), the SINR at the $i^{th}$ secondary receiver can be determined as,

$$SINR_i^s = \frac{|h_{s_i}^H w_{s_i}|^2}{\sum_{j=1}^{M} |h_{ps_i}^H w_{p_j}|^{\mathbf{2}} + \sum_{\substack{l=1 \\ l\neq i}}^{K} |h_{s_i}^H w_{s_l}|^{\mathbf{2}} + N_o}$$

The transmit signal power at the primary transmitter is $\sum_{j=1}^{M} \left\| w_{p_j} \right\|^2$and transmit signal power at CRBS is$\sum_{i=1}^{K} \left\| w_{s_i} \right\|^2$

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To increase or maximize the number of secondary users at the same time reduce or minimize the total transit signal power, we consider the following constraints.

1. Sum power constraint: The total transmits signal powers of the primary transmitter and the cognitive radio base station should be less than the maximum power $P_{max}$

$$\sum_{i=1}^{K}\left\|w_{s_i}\right\|^2 + \sum_{j=1}^{M}\left\|w_{p_j}\right\|^2 \leq P_{max}$$

2. $SINR_{(primary\ )} and\ SINR_{(secondary\ )} should\ be\ greater$ than or equal to threshold SINR. The main problem of the system model is the optimization problem which can be formulated as

$$minimize \sum_{i=1}^{K}\left\|w_{s_i}\right\|^2 + \sum_{j=1}^{M}\left\|w_{p_j}\right\|^2 \quad (7)$$

with respect to following constraints

$$i)\quad \sum_{i=1}^{K}\left\|w_{s_i}\right\|^2 + \sum_{j=1}^{M}\left\|w_{p_j}\right\|^2 \leq P_{max}$$

$$ii)\ \frac{|h_{p_j}^H w_{p_j}|^2}{\sum_{i=1}^{K}|h_{sp_j}^H w_{s_i}|^2 + \sum_{\substack{l=1\\ l\neq j}}^{M}|h_{p_j}^H w_{p_l}|^2 + N_o} \geq \gamma_p$$

$$iii)\quad \frac{|h_{s_i}^H w_{s_i}|^2}{\sum_{j=1}^{M}|h_{ps_i}^H w_{p_j}|^2 + \sum_{\substack{l=1\\ l\neq i}}^{K}|h_{s_i}^H w_{s_l}|^2 + N_o} \geq \gamma_s$$

## A. PROPOSED APPROACH

To avoid the constrained optimization problem, first we have to determine the maximum number of secondary users to be admitted in the cognitive radio network and then in the second stage constrained optimization problem is solved for admitted secondary users only.

Here the first stage problem is formulated as

$$S = \underset{S\subseteq\{1,2,\ldots.K\}}{arg}\ \ max|S| \qquad (8)$$

where |S| is the cardinality of S which is subjected to

$$i)\quad \sum_{i=1}^{K}\left\|w_{s_i}\right\|^2 + \sum_{j=1}^{M}\left\|w_{p_j}\right\|^2 \leq P_{max}$$

$$ii)\ \frac{|h_{p_j}^H w_{p_j}|^2}{\sum_{i=1}^{K}|h_{sp_j}^H w_{s_i}|^2 + \sum_{\substack{l=1\\ l\neq j}}^{M}|h_{p_j}^H w_{p_l}|^2 + N_o} \geq \gamma_p$$

$$iii)\quad \frac{|h_{s_i}^H w_{s_i}|^2}{\sum_{j=1}^{M}|h_{ps_i}^H w_{p_j}|^2 + \sum_{\substack{l=1\\ l\neq i}}^{K}|h_{s_i}^H w_{s_l}|^2 + N_o} \geq \gamma_s$$

Now the second stage can be formulated with the set of admitted secondary users for minimizing the transmit power can be given as,

$$min \sum_{j=1}^{M}\left\|w_{p_j}\right\|^2 + \sum_{k\in S_A}\|w_k\|^2 \qquad (9)$$

subject to

$$i)\quad \sum_{i=1}^{K}\left\|w_{p_j}\right\|^2 + \sum_{k\in S_A}\|w_k\|^2 \leq P_{max}$$

$$ii)\ \frac{|h_{p_j}^H w_{p_j}|^2}{\sum_{i=1}^{K}|h_{sp_j}^H w_{s_i}|^2 + \sum_{\substack{l=1\\ l\neq j}}^{M}|h_{p_j}^H w_{p_l}|^2 + N_o} \geq \gamma_p$$

$$iii)\quad \frac{|h_{s_i}^H w_i|^2}{\sum_{j=1}^{M}|h_{ps_i}^H w_{p_j}|^2 + \sum_{\substack{l=1\\ l\neq i}}^{K}|h_{s_i}^H w_{s_l}|^2 + N_o} \geq \gamma_s$$

The primary and secondary constraints in equations (8) and (9) above does not satisfy or agree with the Disciplined Convex Programming (DCP) rule set. According to the rule, the expressions at left should be convex and the expressions at right side should be concave for the 'less than' inequality constraints. In the same way, the expressions at left side should be concave and the expressions at right side should be convex for the 'greater than' inequality constraints. This can be reformulated into a single stage problem by implementing Approximate Message Passing (AMP) to reduce the number of iterations and can be defined as

$$\underset{w_p,\{w_k,s_k\in\{-1,1\}\}_{k-1}^{K}}{min} \sum_{j=1}^{M}\left\|w_{p_j}\right\|^2 + \sum_{k=1}^{K}\|w_k\|^2 + L * \sum_{k=1}^{K} {s_k}^2$$

subject to

$$\sum_{j=1}^{M}\left\|w_{p_j}\right\|^2 + \sum_{k=1}^{K}\|w_k\|^2 \leq P_{max}$$

$$|h_{p_j}^H w_{p_j}| \geq \sqrt{\gamma_p\left(\sum_{i=1}^{K}|h_{sp_j}^H w_{s_i}|^{\mathbf{2}} + \sum_{\substack{l=1\\ l\neq j}}^{M}|h_{p_j}^H w_{p_l}|^{\mathbf{2}} + N_o\right)}$$

$$|h_{s_i}^H w_{s_i}| \geq \sqrt{\gamma_s\left(\sum_{j=1}^{M}|h_{ps_i}^H w_{p_j}|^{\mathbf{2}} + \sum_{\substack{l=1\\ l\neq i}}^{K}|h_{s_i}^H w_{s_l}|^{\mathbf{2}} + N_o\right)}$$

where L in the equation is a large positive constant and$s_k$ is the slack variable introduced to assure feasibility of reformulated problem.

## B. BOUNDED OPTIMIZATION PROBLEM WITH BOUNDED SINR CONSTRAINT

In fixed target SINR $\gamma_s$ for secondary users, choosing a feasible and exact target SINR is not always possible due to the varying channel condition. In order to improve the situation and admit more number of users, box constraint is introduced for secondary SINR constraints as bounded range between $\gamma_{S_{min}}$ and $\gamma_{S_{max}}$ instead of fixed SINR $\gamma_s$.

Mathematically it is defined as

$$\min_{w_p,\{w_k,s_k\in\{-1,1\}\}_{k-1}^{K}} \sum_{j=1}^{M} \left\|w_{p_j}\right\|^2 + \sum_{k=1}^{K}\|w_k\|^2 + L * \sum_{k=1}^{K} s_k{}^2$$

subject to

$$\sum_{j=1}^{M} \left\|w_{p_j}\right\|^2 + \sum_{k=1}^{K}\|w_k\|^2 \leq P_{max}$$

$$|h_{p_j}^H w_{p_j}| \geq \sqrt{\gamma_p\left(\sum_{i=1}^{K}|h_{sp_j}^H w_{s_i}|^{\mathbf{2}} + \sum_{\substack{l=1\\l\neq j}}^{M}|h_{p_j}^H w_{p_l}|^{\mathbf{2}} + N_o\right)}$$

$$\sqrt{\gamma_{S_{min}}\left(\sum_{j=1}^{M}|h_{ps_i}^H w_{p_j}|^{\mathbf{2}} + \sum_{\substack{l=1\\l\neq i}}^{K}|h_{s_i}^H w_{s_l}|^{\mathbf{2}} + N_o\right)} - (|h_{s_i}^H w_{s_i}|+s_k) \leq 0$$

$$(|h_{s_i}^H w_{s_i}| + s_k) - \sqrt{\gamma_{S_{min}}\left(\sum_{j=1}^{M}\left|h_{ps_i}^H w_{p_j}\right|^{\mathbf{2}} + \sum_{\substack{l=1\\l\neq i}}^{K}\left|h_{s_i}^H w_{s_l}\right|^{\mathbf{2}} + N_o\right)} \leq 0$$

## IV. SIMULATION RESULTS

In this section, the performance of the proposed cooperative beam forming in cognitive radio network using admission control for cognitive radio network is analysed. Solving the optimization problem by implementing Approximate Message Passing in MATLAB, the simulation parameters are listed as below in Table I.

TABLE I: SIMULATION PARAMETERS

| S.NO | PARAMETERS | VALUES |
|---|---|---|
| 1 | Number of antennas in Primary Transmitter | 2 |
| 2 | Number of antennas in CBRS | 2 |
| 3 | Total Power (Maximum Pmax) | 2 mW |
| 4 | Noise variance (N0) | -60 dBm |
| 5 | Large constant (L) | 1010 |
| 6 | Primary user SINR target | 10 dB |
| 7 | Target SINR at Secondary receiver (Fixed SINR) | 5 dB |
| 8 | Target SINR at Secondary Receiver (Bounded SINR) | 3 dB to 5 dB |
| 9 | Number of Secondary Users | 4 to 16 |

Table II shows the comparison between the number of admitted secondary users under both fixed and bounded SINR constraint. As the SINR increases, the complexity of the network decreases and we can admit more secondary users under bounded SINR constraint compared to the fixed SINR. Here, when 16 secondary users are considered with the sum power constraints, 5 more users can be admitted with bounded SINR between 3dB to 5dB compared to fixed SINR of 5dB.

TABLE II. NUMBER OF ADMITTED SECONDARY USERS IN THE COGNITIVE RADIO NETWORK

| S.NO | NUMBER OF SECONDARY USERS | ADMITTED USERS | |
|---|---|---|---|
| | | FIXED SINR | BOUNDED SINR |
| 1 | 4 | 3 | 3 |
| 2 | 6 | 3 | 4 |
| 3 | 8 | 3 | 5 |
| 4 | 10 | 5 | 7 |
| 5 | 12 | 5 | 9 |
| 6 | 14 | 7 | 11 |
| 7 | 16 | 8 | 13 |

Figure 2 shows the transmit power of the admitted secondary users. When the number of admitted secondary users increases from 3 to 10, the minimum and maximum power consumed by the admitted secondary users under fixed SINR is 0.4311mW and 0.8044mW respectively which is very much higher compared to the bounded SINR constraint with minimum and maximum transmit power value of 0.4022mW and 0.4995 mW.

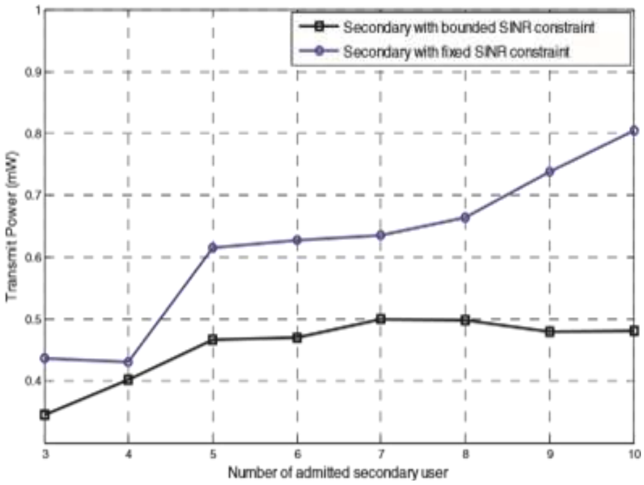


Figure 2: Transmit power with respect to number of admitted users

Figure 3 shows the number of admitted secondary users for bounded SINR constraints. It is observed that when the difference between the bounded SINR value increases, then we can admit more number of secondary users. Here, for 16 secondary users in the cognitive radio network, for 5dB variation in bounded SINR, 10 users are supported. While the number of users supported for 5dB variation is 13 users and for 6 dB variation is 13 users.

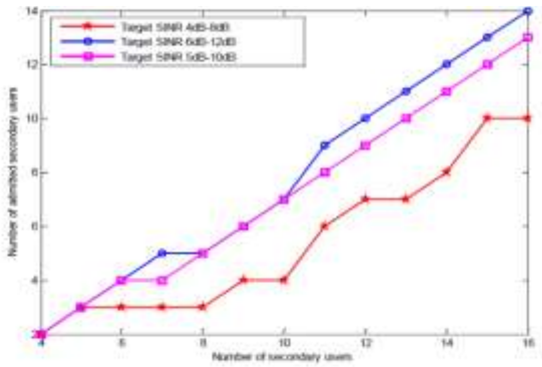


Figure 3: Total users Vs Number of admitted secondary users under variable bounded SINR constraint

## V. CONCLUSION

The proposed work optimal multiuser downlink cooperative beam forming in cognitive radio networks using admission control with signal to interference plus noise ratio(SINR) using Approximate Message Passing algorithm shows notable improvement in performance of the system without much interference to primary network. It can also be seen thatmore number of secondary users or cognitive users can be admitted into the network with variable SINR target. The consumption of power is also improved for bounded SINR target when compared with the fixed SINR target.

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