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Joint Beam forming, Channel Allocation in MIMO based Cognitive Radio Networks

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Abstract: In this paper, we consider a joint beamforming, channel allocation in Multiple-Input Multiple-Output cognitive radio network (CRN). In this system, primary users' (PUs') spectrum can be reused by the secondary user transmitters (SUTXs) to maximize the spectrum utilization while the intra-user interference is minimized by implementing beamforming at each SU-TX. After formulating the joint optimization problem in MIMO (Multiple-Input Multiple-Output) we propose a solution which consists of two stages. In the first stage, a feasible solution for channel allocation and beamforming vectors is derived under SVD Algorithm and also by using Genetic Algorithm (GA). After that, in the second stage, two explicit searching algorithms, i.e., SVD Algorithm and Genetic Algorithm (GA) are proposed to determine the Throughput rate achievement. Simulation results show that beamforming, channel allocation with Genetic Algorithm (GA) can achieve close-to-optimal sum-rate while having a lower computational complexity compared with beamforming, channel allocation with Singular Value Decomposition (SVD) algorithm. Furthermore, our proposed allocation scheme has significant improvement in achievable sum-rate compared to the existing zero-forcing beamforming (ZFBF).

Index Terms: MIMO System,Cognitive radio network (CRN), beamforming, Singular Value Decomposition Algorithm, Genetic algorithm.

I. INTRODUCTION

RECENT studies reveal that the existing static spectrum allocation is the key reason for highly inefficient spectrum utilization [1], [2], which in turn leads to a problem of spectrum scarcity. To overcome this issue, a novel concept called cognitive radio (CR) was introduced [3]–[5], which allows unlicensed users or secondary users (SUs) to initiate transmissions with the licensed communications. For an underlay CR network (CRN) coexisting with a multichannel primary user (PU) network, managing interference is a critical issue since spectrum reusing among multiple users may cause negative effects on received signals at both Pus and SUs. By exploiting multiple antennas, a signal processing technology called beamforming [6] has been introduced to CRfor directional signal transmission, so as to effectively mitigate the mutual interference and improve the signal-to-interference plus noise ratio (SINR) [7].

In the literature, joint beamforming and resources allocation have been widely studied for multiple-antenna CRNs. For example, Xie et al. in [8] considered a sum-rate maximization problem in a single PU channel CRN. In this work, the mutual interference between SUs are nullified by deploying the zero forcing beamforming (ZFBF). The authors in [9] discussed a joint beamforming and single PU channel assignment problem to maximize the uplink throughput of the CRN while guaranteeing a SINR constraint at each secondary user receiver (SURX) and interference cancellation at the primary user receiver (PU-RX). However, ZFBF does not consider the potential interference tolerance at SUs, which in turns results in a degradation on overall achievable sum-rate maximization problem in a single PU channel CRN. In this work, the mutual interference between SUs are nullified by deploying the zero forcing beamforming (ZFBF). The authors in [9] discussed a joint beamforming and single PU channel assignment problem to maximize the uplink throughput of the CRN while guaranteeing a SINR constraint at each secondary user receiver (SURX) and interference cancellation at the primary user receiver (PU-RX). However, ZFBF does not consider the potential interference tolerance at SUs, which in turns results in a degradation on overall achievable sum-rate of the secondary network. Recent studies [10]–[12] showed that both PU and SU receivers can tolerate some amount of interference. As a result, it is not necessary to null the co-channel interference. Jiang et al. in [13] employed a zero-gradient based iterative approach to determine the local optimal beamforming vectors while maximizing the energy efficiency of the CRN. In [14], beamforming vectors were calculated by using an iterative algorithm based on semidefinite programming to maximize the sum-rate with a total power constraint and co-channel interference constraints at both PU and SU receivers. This work was further extended in [15] by adding an extra quality of service (QoS) constraint.

However, the assumption of a single PU channel as used in [13]–[15] reduces the degree of freedom available at the secondary base station (SBS) onchannel allocation for SUs. Therefore, joint beamforming and resource allocation with multiple PU channels were studied .For example, in [7], a single secondary user transmitter (SUTX)/ SU-RX pair was considered with uniformly distributed primary user transmitters (PU-TXs) and PU-RXs in a circular disc area. Beamforming was implemented by the SU-TX to minimize the interference to the PU-RXs while the received signal strength was maximized at the SU-RX.

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Gharavol et al. in [16] discussed a transmit power minimization problem with a guarantee of SUs' QoS and total power constraints in a multiple channels multiple-input-single-output (MISO) CRN. Some other works in this area include an adaptive inter cell interference cancellation (ICIC) technique for MISO downlink cellular systems with channel allocation and beamforming to maximize the weighted sum-rate [17]. Hamdi et al. in [18] considered joint beamforming with a near-orthogonal userselection method to maximize the downlink throughput of the CRN, subject to constraints on SINR at each SU, interference at the PU-RX and total transmission power. The authors in [19] proposed an algorithm based on branch and bound (BnB) method to allocate PU frequency bands with beamforming to serve a maximum number of SUs.

A two-stage solution approach is proposed. In the first stage, a feasible solution for channel allocation and beamforming vectors is derived under SVD Algorithm and also by using Genetic Algorithm (GA). Channel allocation. After that, two explicit searching algorithms based on Genetic Algorithm (GA) [24] and Singular Value Decomposition (SVD) Algorithm are proposed to find out the suboptimal channel allocation and Throughput rate performance on MIMO based CRN. The main contributions of this paper are summarized as follows.

- We consider a multi-channel underlay CR system with the capability of beamforming at each SU-TX to mitigate interference, allow more transmission opportunities, and exploit the benefits of spatial diversity.
- We develop a sum-rate maximization problem to jointly optimize beamforming vectors, power allocation and Channel allocation.
- Two different algorithms are proposed to improve the Throughput rate performance.
- Simulation results show that the proposed system model outperforms the existing ZFBF model by exploiting interference tolerance capacities. The proposed algorithms can achieve close-to-optimal performance in terms of sum rate with low computation complexity by two different algorithms. So that they are more suitable for practical applications.

The rest of this paper is organized as follows. The system model is discussed in Section II. The solution approaches and their Throughput rate comparisons are analyzed in Section III. After that, the simulation results and their Throughput rate comparisons are presented in Section III, followed by the conclusions in Section IV.

II. SYSTEM MODEL

We consider a CRN with N PU transceivers and K SU transceivers randomly distributed in the coverage area of the primary network. Each PU transceiver occupies one separated licensed channel so that there are N PU channels in total. Each SU-TX is equipped with J antennas and its receiver with a single antenna, while each PU (transmitter or receiver) has a single antenna. Each SU-TX is allowed to communicate with its corresponding receiver in the underlay manner while satisfying a pre-defined interference constraint at the corresponding PU-RX. There is a central entity who performsall control functions (e.g., resource allocations) for SUs. Anillustration of the system model is shown in Fig. 1. We definetwo sets S and P to indicate all possible SU pairs and PU pairs in the network, respectively.

The following notations are used in this paper. Boldface uppercase and lowercase letters will be used for matrices and vectors, respectively. $(.)^+$,$(.)^T$, E{.}and ‖X‖denote conjugate ranspose, transpose, expectation and Euclidean norm of vector x, respectively. In addition, Tr(A) indicates the trace operation of a square matrix A. For convenience, Table I lists some important symbols used in this paper.

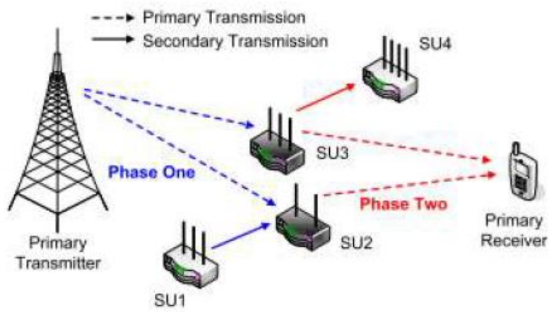


Fig.1. MIMO-CCRN Scenario

A. SVD BASED JOINT BEAM FORMING, CHANNEL ALLOCATION

singular value decomposition (SVD) is a factorization of a real or complex matrix. It is the generalization of the eigendecomposition of a positive semidefinite normal matrix

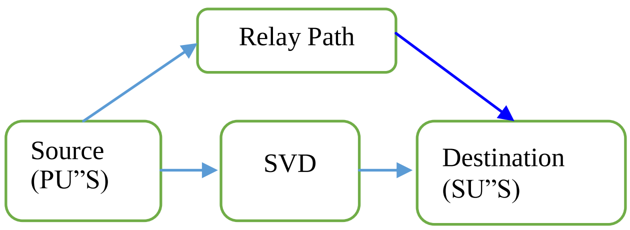
Statement of SVD theorem:

Suppose M is a m × n matrix whose entries come from the field K, which is either the field of real numbers or the field of complex numbers. Then there exists a factorization, called a singular value decomposition of M, of the form

$$M=U\Sigma V^*$$

Where,
U is a m × m, unitary matrix,
Σ is a m × n diagonal matrix with non-negative real numbers on the diagonal,
V^* the conjugate transpose of the n × n unitary matrix, V

MIMO SYSTEM WITH RELAY STATION:



MIMO is a method of transmitting multiple data streams at the transmitter side and also receiving multiple data streams at the receiver side. MIMO antenna configuration describes that use of multiple transmit and multiple receive antennas for a single user produces higher

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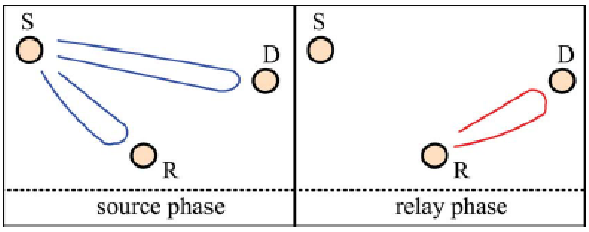
Capacity, spectral efficiency and more data rates for wireless communication
. When the data rate is to be increased for a single user, this is called single user MIMO (SU-MIMO) and when the individual streams are assigned to various users; this is called multiuser MIMO (MU-MIMO)

TWO WAY TRANSMISSION OF SIGNAL IN MIMO SYSTEM WITH RELAY:



Consider a network model consisting of a source S, a relay R and a destination D, as shown in Fig. 1. It is assumed that the direct link between S and D exists in the system and the relay R helps the information transmission from S to D. Multiple antennas are deployed both at S and R, and only one antenna is equipped at D. Half duplex mode is adopted so that R cannot transmit and receive signals at the same time.
Assume that Ns antennas and Nr are deployed at S and R, respectively. Then, the information transmission process mentioned above can be specifically described as follows. In the source information symbol phase xs is the is first multiplied with a beamforming vector ws can be calculated according to the following equation

$$\| w_s \|^2 = |w_{s},1|^2 + |w_{s,2}|^2 + \ldots\ldots + |w_{s},N_s|^2 = 1$$

Where w_s is the unit-norm vector
The MIMO channel can be represented using a MR× MT matrix format H is given by,

$$H = M_R \begin{bmatrix} h_{11} & h_{12} \cdots & h_{1MT} \\ h_{21} & h_{22} \cdots & h_{2MT} \\ \vdots & \vdots & \vdots \\ h_{MR,1} & h_{MR,2} & h_{MR,MT} \end{bmatrix}_{M_T}$$

The complex baseband received symbol at D in the source phase is mathematically given by

$$\square_{D,S} = h_{S,D}{}^T w_s x_s + \eta_{D,S}$$

Where,
$h_{S,D}$ -Channel gain vector from source S to destination D
$\eta_{D,S}$ - scalar additive Gaussian noise with unit variance,
It follows that the received signal to noiseratio (SNR) at D during the source phase is given by

$$\gamma_{D,S} = |h_{D,S}{}^T w_s|^2 P_S.$$

Meanwhile, the complex baseband signal vector received at N antennas of node R can be mathematically given by

$$y_{R,S} = H_{R,S} W_S X s + n_{D,R}.$$

Where,
$H_{R,S} = \{H_{i,j}\} Nr \text{ x } N_S$-denotes the channel gain matrix from relay R to Source S
Applying singular value decomposition(SVD), we can rewrite $H_{R,S}$ as
$H_{R,S} = U \Lambda V^H$
Then the effective received SNR at R is

$$\gamma_{R,S} = \| H_{R,S} W s \|^2 P_S$$

So, the achievable information rate from S to R is

$$C_R = \log_2(1 + \gamma_{R,S}).$$

The total achievable information transmission rate at D from S over the MIMO relay channel can be given by
$C_{D,F} = 1/2 \min\{C_{R,} C_D\}$
$= 1/2 \min\{\log_2(1+\gamma_{R,S}), \log_2(1+\gamma_{D,S} + \gamma_{D,R})\}.$
Where,
The pre-log parameter, 1/2, actually captures the time-division feature of the half-duplex relay system.

B . GA BASED JOINT BEAM FORMING,CHANNEL ALLOCATION.

Genetic Algorithm (GA): GA is a searching algorithm, which can be applied to find out near optimal solution to an optimization problem without the knowledge of the objective function's derivatives or any gradient related information. The key idea of GA is to first select a set of feasible values for the decision variables and then design new solutions based on the previous set to improve the objective function

Basic mechanics of Genetic Algorithm:
The Basic mechanisms of genetic algorithms are simple and straight –forward

- **Selection:**in which individual genomes are chosen from a population for further process.
- **Crossover:** crossover is a genetic operator used to vary the programming of a chromosome or chromosomes from one generation to the next. It is analogous to reproduction
- **Mutation:**Mutation is a genetic operator used to maintain genetic diversity from one generation of a population of genetic algorithm chromosomes to the next. It is analogous to biological mutation

FLOW CHART FORGENETIC ALGORITHM:
Define the transmitted signals from the kth SU-TX, i.e.,SU-TXk, to its receiver SU-RXk and from nth PU-TX, i.e., PU-TXn; to its receiver PU-RXn
Each SU-TX performs transmit beamforming to direct the signal to the intended receiver while at the same time controlling the interference to other users (PUs and SUs). The received signal at the SU-RXk using the nth PU channel can be represented as the aggregation of desired signal, interference from otherSU-TXs using the same PU channel for transmission, the interference from the nth PU-TX, and noise, i.e.,

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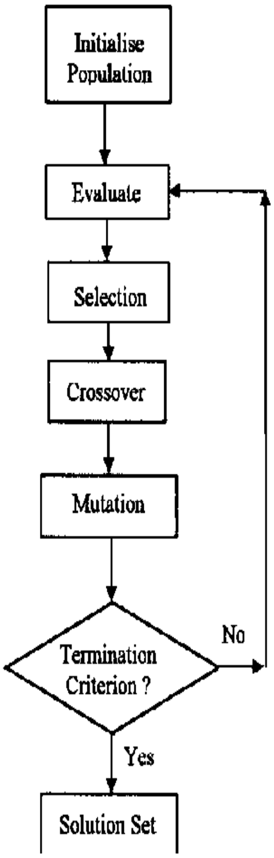


$y_K^n = (w_k s_k)^+ h_k + \Sigma (w_m s_m)^+ h_{mk} + \sqrt{Q_n}\, g_{nk} u_n + \eta_k$
where,
w_k is the kth SU-TX's beamforming vector ,Q_n is the transmit power of the nth PU-TX, h_k denotes the channel response between SU-TXk and SU-RXk,
h_{mk} is the channel response between SU-TXm and SU-RXk, g_{nk} denotes the channel response between PU-TXn and SU-RXk, and Sn denotes the set of SU-TXs using the nth PU channel. The noise η_k is Gaussian distributed with zero mean and variance σ^2
Received signal at the nth PU-RX consists of desired PU signal, co-channel interference from SUs and noise. Thus, it can be formulated as.

$$Y_n = \sqrt{Q_n}\, g_n u_n + \Sigma (w_k s_k)^+ h_{kn} + \eta_n, \quad n=1,\ldots..N$$

Where g_n and h_{kn} are channel responses from the nth PU transmitter and the kth SU-TX to the nth PU-RX, respectively, and η_n denotes the noise.
Given the kth SU transceiver is working on the nth PUchannel, the SINR at the kth SU-RX, denoted as SINRk, can be represented as

$$SINR_k = \frac{|W_k^+ h_k|^2}{\Sigma |w_m^+ h_{mk}|^2 + Q_n |g_{nk}|^2 + \sigma^2}$$

Where,
$|W_k^+ h_k|^2$ is the desired received signal power at the

SU-RX_k, $\Sigma_{m\epsilon Sn; m\neq k} |w_m^+ h_{mk}|^2$ denotes the total intra-user interference received at the SU-RX_k from other SU-TXs' who are using the same channel.$Q_n |g_{nk}|^2$ and σ^2 are the interference power from PU-TXn and the noise power at the SU-RX_K, respectively.

The achievable rate of SU pair k on the nth PU channel, r^k_n can be calculated as

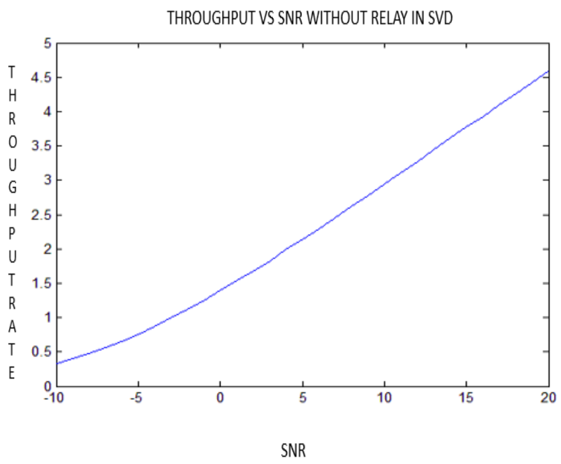
$$r^k_n = B \log_2 \left[1 + \frac{x_k^n |W_k^+ h_k|^2}{\Sigma |w_m^+ h_{mk}|^2 + Q_n |g_{nk}|^2 + \sigma^2} \right]$$

where B is the transmission bandwidth of a single PU channel

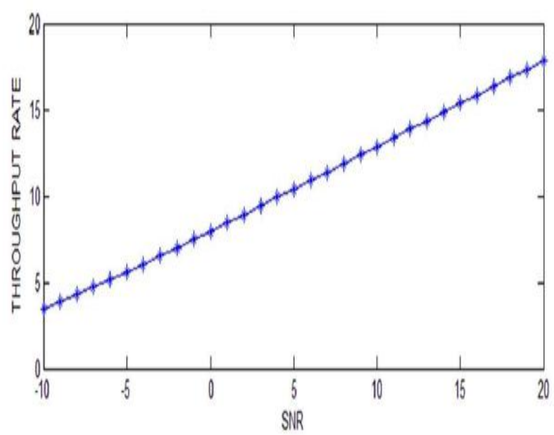
III. SIMULATIO RESULTS & THROUGHPUT RATE COMPARISION

As the number of relay station antennas increases between the primary user transmittters (PU-TXS) and the secondary user receivers(SU-RXS). Then the acheivable rate (Throughput rate) increase with respect to the relay antennas.

MIMO SYSTEM WITH OUT RELAY:
SNR VS Throughput rate achievement in MIMO system without relay gives throughput rate upto 4.6bits/sec



MIMO SYSTEM WITH RELAY ANTENNAS:
When the relay station antennas are increased Throughput rate increase and the performance of the system also improved.signal strength increases.when the relay stations are introduced throughput rate increases which id 16 bits/sec. As.shown in simulation result.



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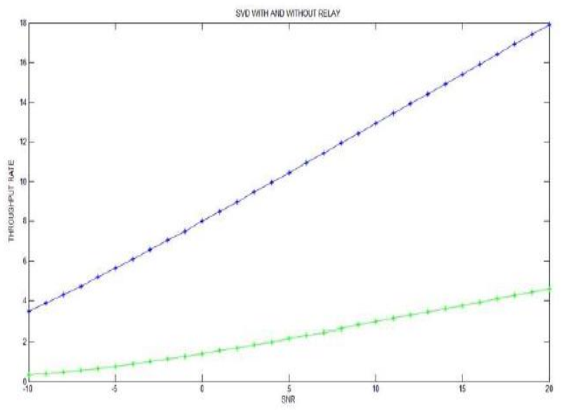
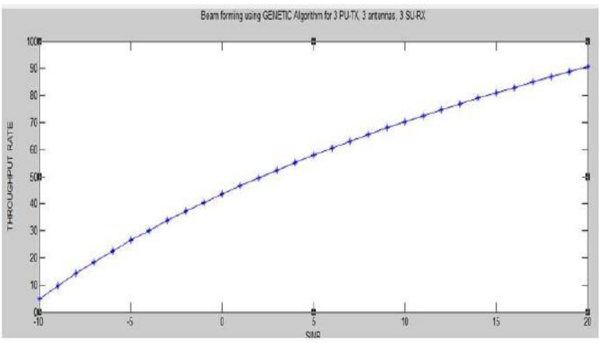
COMPARISION OF MIMO SYSTEM WITH AND WITH OUT RELAY ANTENNAS:



From the simulation result its clearly showing that Throughput increases when relay antennas introduced.

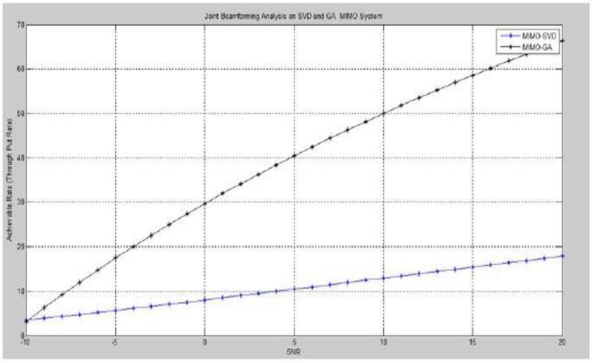
THROUGHPUT RATE PERFORMACE OF MIMO SYSTEM BY USING GENETIC ALGORITHM:

GENETIC ALGORITHM is used to increase the Throughput rate and to minimize the intra-user inteference when the number of users increases. Genetic algorithm MIMO simulation shown as.



From the simulation result Throughput rate performance increases when compared with SVD algorithm approach.which is 90 bits/sec.

COMPARISION OF MIMO SYSTEM WITH SVD ALGORITHM AND GENETIC ALGORITHM:



Its clearly shows that Throughput rate (Achievable rate) of the MIMO System increases when Genetic Algorithm rather than SVD Algorithm

When the relay stations are used Throughput rate increases, hence performance of the MIMO system is going to increase.so Genetic Algorithm is prefferd because of simple approach and throughput rate achievement.

IV.CONCLUSION

In this paper, a problem of joint beamforming,channel allocation in MIMO(Multiple-Input Multiple-Output) based Cognitive radi network (CRN) is considered for the usage of efficient signal among the multiple users at a time.we are consider a searching algorithm which is Genetic Algorithm (GA) Which is used to increase the signal strength and the Throughput rate. When multiple relay stations are increased System performance increases hence signal strength also increases and the signal coverage area also increases.Moreover,beamforming with interference tolerance capability introduced by our system model can achieve better performance than traditional zero force beam forming.

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