A Joint Hybrid-ARQ and Opportunistic Interference Alignment based Sum Rate Maximization for Cognitive Radio Networks

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***Abstract*—An efficient amalgamation of Opportunistic Interference Alignment (OIA) with Hybrid- Automatic Repeat Request (ARQ) for sum rate maximization of secondary transmission in cognitive environment is proposed. Literature survey exhibits capacity improvement by virtue of availability of additional degree of freedom in spatial domain due to Interference Alignment (IA). Also, the exploitation of opportunities provided during the ARQ transmission results in capacity enhancement of unlicensed user. In the proposed scheme, the secondary user opportunistically takes the advantage of spatial degree of freedom available during the primary retransmission. During retransmission, the primary user reduces the power allocation in multiple transmitting antennas to achieve the same BER performance, thus reducing the interference caused at the secondary user. This results in improved sum rate at the secondary user. Simulation results shows the significant achievement in the data rates with the employment of joint ARQ retransmission and OIA technique.**

***Keywords* - ARQ; Interference Alignment; Cognitive Radio; Capacity**

I. Introduction

The extensive rise in wireless devices and crave of various new technologies like 5G, LTE, WiMax, etc, for high data rates require the efficient utilization of radio spectrum. The paradigm of cognitive radio was introduced aiming to avoid the spectrum crisis. Traditionally, in the absence licensed users, the spectrum assigned to them remains unused, while in Cognitive Radio Networks (CRN) [1], the unlicensed users are allowed to opportunistically utilize the licensed band. Presently, underlay [2] spectrum sharing is one of the widely used technique in CRN, that allows the unlicensed user to exploit the licensed band in parallel with the licensed users under the condition of not affecting the performance of the licensed user. Practically in such framework, an additional interference is caused to primary user (PU) by the transmission of Secondary User (SU), therefore, interference is one important phenomenon that needs to be regulated.

Among the large number of solutions provided to avoid the interference caused by SU to the PU, Interference Alignment (IA) [3][4] is one technique to align the interference of the SU in such a way that quality of service of PU is not degraded. According to this technique, the signal from the SU is aligned in such a way that the interfering signal occupies the dimensions that are orthogonal to the transmitting dimensions of the PU. For the sum rate maximization, PU transmits over the singular values of the channel using water filling power allocation algorithm [5]. Due to the constraint of PU power, few of the spatial dimensions of the PU remain unoccupied. SU takes the advantage of these free dimensions by transmitting its signal in these eigen modes with desired rate. This technique of aligning SU signal opportunistically in the license band with existing PU, is called the Opportunistic Interference Alignment (OIA) [6]. This technique results in capacity improvement of SU without affecting the PU transmission.

Hybrid ARQ [7] retransmission of PU is yet another technique to augment the capacity of SUs accompanying with the PU while intruding negligible interference to the PU. According to this technique, if the PU is unable to provide the desired primary transmission rate in the first transmission then the primary receiver request for retransmission (ARQ). The mutual information provided during the two transmissions will be less prone to noise and interference. While during these ARQ retransmissions, SU also have the opportunity to enhance its capacity. During the first primary transmission, secondary receiver perceives the primary signal and Channel State Information (CSI)and utilizes the information to cancel the interference during the second transmission of PU. Such an opportunistic exploitation of licensed band by the SU adds to the SU capacity.

This paper deals with the appropriate amalgamation of OIA [8] and Hybrid ARQ techniques in order to maximize the sum rate capacity of the SUs coexisting with the PU without affecting the performance of PU. In this paper, SU opportunistically utilizes the free dimensions of the PU in an Hybrid ARQ environment. In case of ARQ retransmission, the PU transmitting antennas transmits with less power which in turn reduces the interference at the SUs while maintaining the same PU BER performance as that during the first transmission. This reduced interference results in improved sum rate of SU.

Rest of the paper is organized as follows. In section II, system model have been introduced. Proposed scheme is discussed in section III. Section IV covers the simulation results. Paper has been concluded in section V.

II. System Model

We have considered the Cognitive radio network scenario depicted by the system model shown in Fig.1. The system

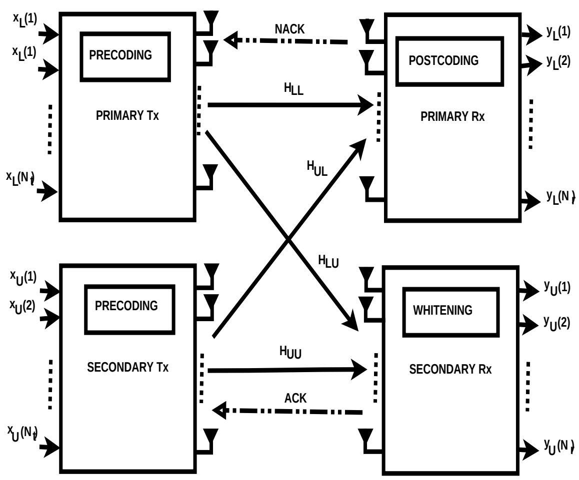

Fig. 1. System Model

consist of one pair of each PU and SU transceiver. There exists N_t and N_r number of antennas at the transmitter and receiver of PU and SU. Considering the underlay model, SU is utilizing the free slots of the frequency band in which PU is transmitting. $\mathbf{H}_{j,k} \in C^{N_r \times N_t}$ denotes the channel gain matrices between transmitter $j \in \{L, U\}$ and receiver $k \in \{L, U\}$, characterized by flat fading Rayleigh model. It is assumed that the pair of licensed transceiver has complete information of channel between licensed transmitter and receiver while pair of unlicensed transceiver has complete knowledge of all the channel matrices.

x_L and x_U are the input signal vectors that are pre-processed at primary and secondary transmitter using V_{LL} and V_{UU}, while y_L and y_U denotes the final received vectors after post-processing with the help of U_L and U_U.

$$\begin{bmatrix} y_L \\ y_U \end{bmatrix} = \begin{bmatrix} \mathbf{U}_L \\ \mathbf{U}_U \end{bmatrix} \quad \begin{bmatrix} \mathbf{H}_{LL} & \mathbf{H}_{UL} \\ \mathbf{H}_{LU} & \mathbf{H}_{UU} \end{bmatrix} \quad \begin{bmatrix} \mathbf{V}_{LL} x_L \\ \mathbf{V}_{UU} x_U \end{bmatrix} + \begin{bmatrix} w_L \\ w_U \end{bmatrix}$$

w_L and w_U denotes the AWGN noise with zero mean and variance σ_w^2. Let R_p and R_s denotes the desired primary and SU transmission rate, respectively. If the primary receiver fails to retrieve the desired rate than it transmit $NACK$ signal requesting for retransmission. Upon hearing this $NACK$, secondary receiver tries to decode the primary signal and if successful then send ACK signal to secondary transmitter requesting for transmission.

III. Proposed Scheme

Consider the system model outlined in above section. This section focuses on the sum rate maximization of SUs by employing OIA technique [9] and Hybrid ARQ [10] retransmission altogether.

A. Licensed/Primary user System

Assuming perfect knowledge of channel, $\mathbf{H}_{LL}$, at both transmitter and receiver, the PU computes the pre-coding and post-coding matrices using SVD decomposition of the primary channel matrix $\mathbf{H}_{LL}$, given as:

$$SVD(\mathbf{H}_{LL}) = \mathbf{U}_{LL} \Delta_{LL} \mathbf{V}_{LL}^{\dagger} \tag{1}$$

Where, $\mathbf{U}_{LL} \in C^{N_r \times N_r}$ and $\mathbf{V}_{LL} \in C^{N_t \times N_t}$ denotes the unitary matrices and $\Delta_{LL} \in R^{+^{N_r \times N_t}}$ denotes the diagonal matrix having singular values, given by $\lambda_1 > \lambda_2 ... > \lambda_{min\{N_r, N_t\}}$, as its diagonal element. The transmitted signal x_L is pre-coded at the transmitter using unitary matrix $\mathbf{V}_{LL}$, given as:

$$\hat{x_L} = \mathbf{V}_{LL} \times x_L \tag{2}$$

Therefore the received signal at the receiver is post-coded using $\mathbf{U}_L$. Therefore the received signal is given as:

$$y_L = \mathbf{U}_L \mathbf{U}_{LL} \Delta_{LL} \mathbf{V}_{LL}^{\dagger} \mathbf{V}_{LL} x_L + \mathbf{U}_L w_L \tag{3}$$

Where, $\mathbf{U}_L = \mathbf{U}_{LL}^{\dagger}$ hence,

$$y_L = \Delta_{LL} x_L + \mathbf{U}_L w_L \tag{4}$$

In order to maximize the sum rate at PU, the power must be allocated in the multiple antennas of the PU by employing the following optimization problem [10], given as:

$$\begin{aligned} \max_{P_L} \quad & log_2 |\mathbf{I}_{N_t} + \frac{1}{\sigma_{w_L}^2} \mathbf{U}_L \mathbf{H}_{LL} \mathbf{V}_{LL} \mathbf{P}_L \mathbf{V}_{LL}^{\dagger} \mathbf{H}_{LL}^{\dagger} \mathbf{U}_L^{\dagger}| \\ \text{subject to} \quad & Trace(\mathbf{V}_{LL} \mathbf{P}_L \mathbf{V}_{LL}^{\dagger}) \leq P_{L,max}. \end{aligned} \tag{5}$$

Where,$\sigma_{w_L}^2$ is the noise variance, $P_{L,max}$ is the maximum power aided by the PU and $\mathbf{P}_L$ is a diagonal matrix having optimized powers corresponding to each transmitting antenna at its diagonal position, obtained by employing water filling power allocation algorithm.

Now, after allocating optimal powers in each transmitting antenna, if the throughput of the PU is less than the desired rate R_p, then primary receiver transmits a NACK to the primary transmitter requesting for the retransmission. The primary transmitter again transmits the signal. Since, due to retransmission the mutual information received at the receiver is comparatively less susceptible to noise, given as:

$$\hat{y_L} = x_L + \frac{n_1 + n_2}{2} \tag{6}$$

Where, n_1 and n_2 are two Additive White Gaussian noise (AWGN) each with the noise power σ_w^2, generated during the two transmissions. Therefore, if λ_L is the mean corresponding to primary link that is requested to retransmit, then in order to attain same BER and also desired primary transmission rate R_p, the primary transmitter transmits with the reduced power [10] given by:

$$\hat{\mathbf{P}_L} = \frac{2^{(\frac{R_p}{2})} - 1}{\lambda_L} \tag{7}$$

B. Unlicensed/Secondary user system

The unlicensed receiver listens up the NACK sent by the licensed receiver after the failure of first transmission, and tries to decode the transmitted signal. If secondary receiver successfully detects the signal as well as discover the free dimensions in which primary transmitter is not transmitting, then it acknowledges the secondary transmitter to transmit the signal. Now, if the SU finds any unused dimension of the PU then it tries to align its signals in the free dimensions of the PU without interfering the transmission of PU. This offers an extra degree of freedom to the SU. To combat the interference to PU, the SU tries to design the pre-coding matrix V_U such that

$$\mathbf{U}_{LL}^{\dagger}\mathbf{H}_{UL}\mathbf{V}_{U} = \beta\bar{\mathbf{P}_{L}} \tag{8}$$

Where, H_{UL} is the channel matrix between the secondary transmitter and primary receiver and power matrix $\bar{\mathbf{P}_L} = 1 - \hat{\mathbf{P}_L}$ is a diagonal matrix orthogonal to $\hat{\mathbf{P}_L}$. β is a constant value choosen to satisfy the total power constraint at the secondary transmitter. The signal at the SU is precoded using $\mathbf{V}_U$, given as:

$$\hat{x_U} = \mathbf{V}_U x_U = \beta\mathbf{H}_{UL}^{\dagger}\mathbf{U}_L\bar{\mathbf{P}_L}x_U \tag{9}$$

After employing the precoded matrix the primary transmission will have no interference from the secondary transmission, but the interference from the PU still affect the quality of service of the SU. In order to get rid of this interference, secondary receiver employs whitening process. The effect of interference and noise at the secondary receiver is given by the covariance matrix $\mathbf{M}$.

$$\mathbf{M} = \mathbf{H}_{LU}\mathbf{V}_{LL}\hat{\mathbf{P}_L}\mathbf{V}_{LL}^{\dagger}\mathbf{H}_{LU}^{\dagger} + \sigma_U^2\mathbf{I}_{N_r} \tag{10}$$

Where, σ_w^2 is the noise variance. Secondary receiver utilizes the whitening filter [11], $\mathbf{U}_U = \mathbf{M}^{-\frac{1}{2}}$, to remove the effect PU interference from the received signal. Therefore, the received signal at the secondary receiver is given by:

$$y_U = \mathbf{U}_U\mathbf{H}_{UU}\mathbf{V}_U x_U + \mathbf{U}_U(\mathbf{H}_{LU}\mathbf{V}_{LL}x_L + w_U) \tag{11}$$

Where, $\hat{\mathbf{w}} = \mathbf{U}_U(\mathbf{H}_{LU}\mathbf{V}_{LL}x_L + w_U)$ is an IID AWGN with zero mean and variance $\sigma_{\hat{w}}^2$. To maximize the transmission rate of the SU, power must be allocated optimally. Hence, following optimization problem is employed to optimize power allocation.

$$\begin{aligned} \max_{\hat{\mathbf{P}_U}} \quad & log_2|\mathbf{I}_{N_r} + \mathbf{F}\hat{\mathbf{P}_U}\mathbf{F}^{\dagger}| \\ \text{subject to} \quad & Trace(\mathbf{V}_F\hat{\mathbf{P}_U}\mathbf{V}_F^{\dagger}) \le P_{U,max}. \end{aligned} \tag{12}$$

Where, $\mathbf{F} = \mathbf{U}_U\mathbf{H}_{UU}\mathbf{V}_U$ and $\mathbf{F} = \mathbf{U}_F\Delta_F\mathbf{V}_F^{\dagger}$ denotes the SVD of $\mathbf{F}$. Optimal power $P_U = V_F\hat{P_U}V_F^{\dagger}$ is obtained using water filling power allocation algorithm. The maximum capacity attained by SU is given by:

$$C_U = log_2|\mathbf{I}_{N_r} + \mathbf{F}\mathbf{V}_F\mathbf{P}_U\mathbf{V}_F^{\dagger}\mathbf{F}^{\dagger}| \tag{13}$$

If the maximum capacity obtained by optimal power allocation satisfies the desired rate R_s of the SU, then only the SU transmission is considered to be successful.

IV. Simulation Results

We have carried out our simulation results considering single antennas as well as 2×2 MIMO system at both PU and SU. The following parameters have been assumed during simulation.

- We have assumed that the channel gains both in 2×2 MIMO system and SISO system are exponentially distributed with mean, $\lambda = 1$ for each channel coefficient of H_{LL} and H_{UL} while $\lambda = 4$ for each channel coefficient of H_{LU} and H_{UU}.
- PU power have been fixed at $12dB$ $(Pp = 12dB)$, while we have carried out our simulations for two SU powers, i.e., $Ps = 10dB$ and $Ps = 24dB$.
- The desired rate for PU and SU transmission has been fixed to $Rp = 6$ Bits Per Channel Use $(bpcu)$ and $Rs = 2$ $bpcu$ and the expected throughput of PU and SU has been observed for SNR values ranging from -30 to 16 dB. Also, simulation has been carried out for different attempted rate of SU ranging from 0 to 20 $bpcu$.

Fig.2 compares the expected throughput of a network consisting of 2 transmitting and receiving antennas at both PU and SU with that of the network consisting of single transmitting and receiving antenna at both PU and SU for SU power, $Ps = 10$ dB and $Ps = 24$ dB using Hybrid-ARQ technique. The simulation distinctly shows that for $Ps = 10$ dB, MIMO system attains the throughput of approx. 1.6 $bpcu$ for $Rs = 5$ $bpcu$ while single antenna system attains the throughput of approx. 0.8 $bpcu$ for the same attempted rate of SU, thus verifying the better performance of MIMO system than that of single antenna system at both PU and SU. Similar kind of improvement can be observed for $Ps = 24$ dB.

Fig.3 depicts the comparison between the throughput of the proposed scheme with that of Hybrid-ARQ technique for the varying attempted rate of SU, for network consisting of 2×2 MIMO system at both PU and SU. The figure reveals that for SU power, $Ps = 24$ dB, applying proposed scheme, SU attains the throughput of approx. 4 $bpcu$ at the attempted rate of $Rs = 5$ $bpcu$, while for Hybrid-ARQ, SU only attains throughput of approx. 2 $bpcu$ at the same attempted rate, thus proving the better performance of proposed scheme. Similarly for $Ps = 10$ dB, proposed scheme gives better performance than that of Hybrid-ARQ.

Fig.4 depicts the expected throughput of PU and SU for proposed scheme with varying SNR. At low values of SNR, some of the spatial dimensions of the PU remain unoccupied thus allowing SU to transmit in those dimensions but with the increasing SNR, most of the eigen modes are utilized by the PU itself. This result in less dimensions available for the SU, thus reducing the expected throughput of the SU. The simulation shows that for $Ps = 24$ dB, on applying the proposed scheme, SU attains throughput of approx.1 $bpcu$ at SNR of 0 dB while with OIA technique, SU attains throughput of approx. 4 $bpcu$ for the same SNR, thus shows that proposed scheme is much more effective than that of OIA. Proposed

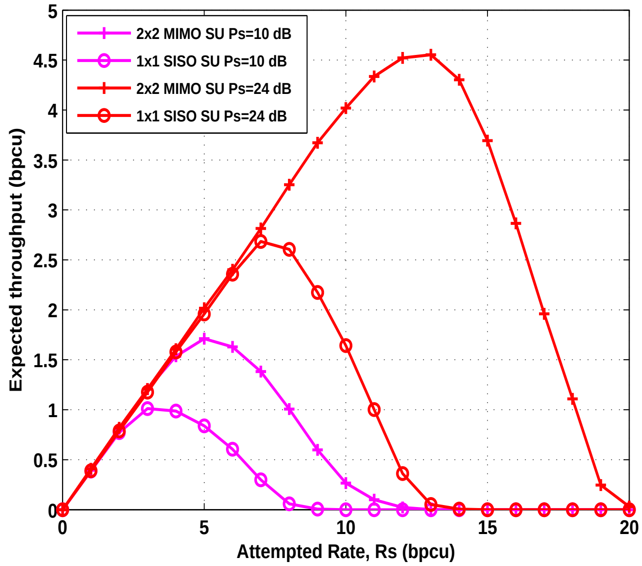

Fig. 2. Expected throughput vs attempted rate, Rs of SU

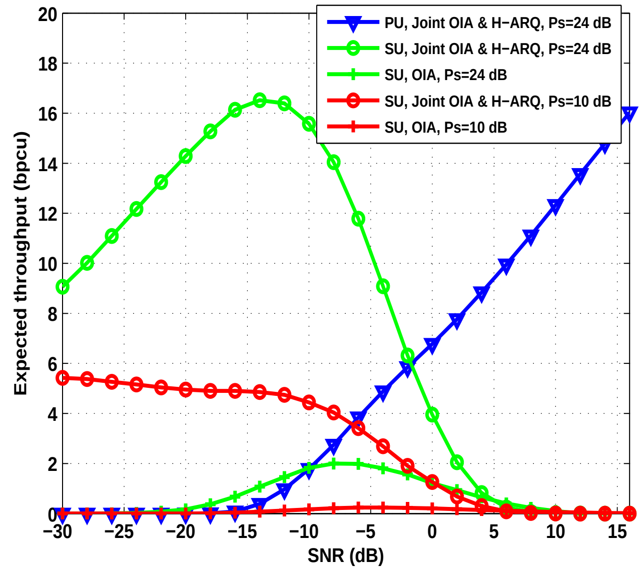

Fig. 4. Expected throughput of PU and SU vs SNR

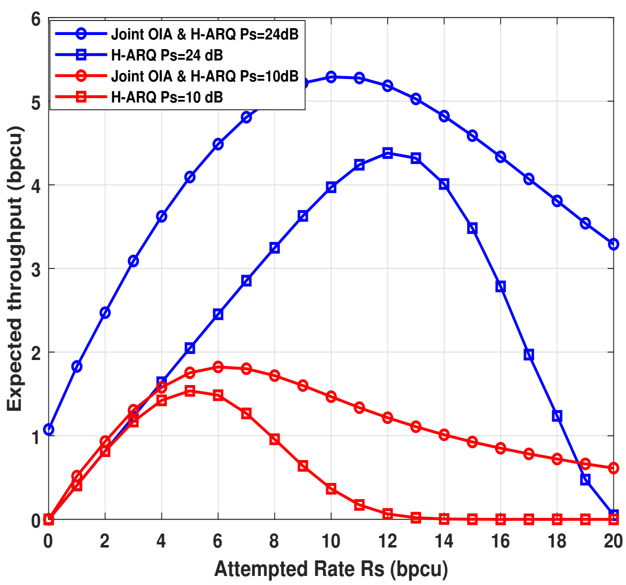

Fig. 3. Expected throughput of SU vs attempted rate, Rs of SU

scheme shows similar kind of effectiveness for $Ps = 10\ dB$, as shown in Fig.4.

V. Conclusion

In this paper, we tried to simultaneously take the advantage of OIA and Hybrid-ARQ techniques for the improvement in the throughput of SU. In the proposed scheme, during ARQ, SU transmits after the successful decoding of primary signal at receiver and also tries to align itself orthogonally in the free dimensions of PU during the retransmission of PU. Reduced power during retransmission while maintaining the same BER at PU, results in improved throughput of SU without affecting the quality of service of PU. Simulation results reveals the effectiveness of the proposed scheme for cognitive radio network with 2×2 MIMO system at both PU and SU.

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