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ADAPTIVE MODULATION FOR MU-MIMO-OFDM SYSTEMS IN UNDERLAY COGNITIVE RADIO NETWORKS

G.VIJAYA [1], D. Suneel Kumar [2], T. Subba Sekhar[3]
[1] Assistant professor, Assistant Professor, [3] Assistant professor
Department of Electronics and Communication Engineering
Priyadarshini institute of technology & management, guntur

Abstract— In this paper, a modified rate quantization algorithm for multi-user multiple-input-multiple-output-orthogonal frequency division multiplexing (MU-MIMO-OFDM) cognitive architectures is proposed. Targeting to fulfill the requirements of 5G communications systems and beyond, while keeping a low complexity degree, we first adapt the sub-channel transmit power and spectral efficiency in the spatial and temporal domains under transmit power and instantaneous bit error rate (BER) constraints. We then use a stochastic algorithm to maximize the rate and transmit power of each secondary user (SU) over the spatial eigen-channels of the corresponding subcarrier MIMO channel, under the constraints of average power budget and probability of interference. It is shown that the proposed scheme outperforms the extended rounding-off (SR) alternative, for the entire SNR range.

Keywords— Multi-user, MIMO-OFDM systems, Stochastic algorithms, CSI imperfections, Adaptive modulation

I.INTRODUCTION

The multiple-input-multiple-output (MIMO) technology received significant attention in the last years, due to its interesting feature in offering a significant spectral efficiency, by the mean of its inherent multiplexing gain [1,2]. Multiple user MIMO configurations relying on orthogonal frequency division multiplexing (OFDM), the so-called MU-MIMO-OFDM schemes, allow to exploit the benefit of MIMO architectures in frequency selective channels, while supporting multiple access, hence aligning with the requirements of current and future communication systems. On the other hand, adaptive modulation (AM) was also proposed as a promising technique to ensure the adaptation of the transmission parameters, such as the transmit power or the data rate, to channel characteristics, hence enhancing the data reliability while saving the available communication resources such as power. One adaptive modulation scheme that witnesses a wide application is the variable-rate and

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variable-power (VRVP) MQAM modulation [3-4]. In this study, we investigate VRVP AM for MU-MIMO-OFDM configuration using the stochastic resource allocation (RA) algorithms as an optimization tool. The VRVP AM approach allocates the power and the rate to each spatial Eigen channels obtained from the singular value decomposition (SVD) of the MIMO channel matrix, under instantaneous bit error rate (BER) and total power constraints. Subsequently, the stochastic algorithm allocates the subcarrier index, the transmit power and the rate to each secondary user (SU) under the power budget and probability of interference constraints. The choice of the stochastic algorithms in this work is fuelled by their simplicity, their robustness to channel variations, and their capabilities in maximizing the sum-rate performance of the cognitive radio (CR) network[5-6]. The results show that for Rayleigh channels, our discrete rate scheme exhibits 1.8 dB power gain at low SNR compared with the extended roundingoff(SR) algorithm and approximately 5.5 dB at high SNR range.

II.PROPOSED SYSTEM

The MU-MIMO-OFDM system investigated herein comprises one Base Station (BS), K SUs (indexed by k with k =1… K) who use N sub-carriers (likewise indexed by n with n =1… N). Each sub-carrier is dedicated to a given primary user (PU). The primary channel state information (CSI) is denoted by

$h_{n,PU}^{k}(t)$ and the secondary CSI is denoted by $h_{n,SU}^{k}(t)$ In the MIMO array configuration, it is supposed that equal number of antennas are incorporated at both the BS and the kth SU receiver, i.e $N_{t,b} = N_{r,k} = L$. The channel input/output equation of the n-th subcarrier corresponding to the k-th user can be written as :

$$y_n^k = h_{n,SU}^k x_n^k + w_n^k \quad (1)$$

Where x_n^k is the corresponding $L \times 1$ transmitted signal vector, y_n^k is the $L \times 1$ received signal vector, and w_n^k is the zero-mean unit-variance AWGN vector. Then, we apply the SVD technique on the channel matrix $h_{n,SU}^{k}(t)$, it can be expressed as :

$$h_{n,SU}^k = U_{n,SU}^k Z_{n,SU}^k V_{n,SU}^{k*} \quad (2)$$

Where $U_{n,SU}^k$ and $V_{n,SU}^k$ are L×L and L×L unitary matrices composed with left and right singular vector of $h_{n,SU}^{k}(t)$ respectively, and $Z_{n,SU}^k$ the relative L×L diagonal and nonnegative matrix constituted of the

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channel eigenvalues of $\mathbf{h}^{k}_{n,SU} \times \mathbf{h}^{k*}_{n,SU}$, denoted $\rho^{k,l}_{n}$.

The problem of the MU-MIMO-OFDM optimization with quality of service (QoS) constraints could be formulated as follows:

$$\overline{C}^{k,l} = \max_{\{w_n^{k,l}(\rho), p_n^{k,l}(\rho)\}} \sum_n E_\rho (w_n^{k,l}(\rho_n^{k,l}) \; C_n^{k,l}(\rho_n^{k,l}, p_n^{k,l}(\rho_n^{k,l}))) \quad (3)$$

Subject to:

$$\sum_k w_n^{k,l}(\rho_n^{k,l}) \le 1, \forall n; E_\rho[\sum_n w_n^{k,l}(\rho_n^{k,l}) p_n^{k,l}] \le \tilde{p}^{k,l}, \forall k; \; E_{h^k_{n,PU}}[1_{\{p_n^{k,l} h^k_{n,PU} > \sigma_k\}}] \le \theta_k, \forall n \quad (4)$$

where E_P represents the expectation over all CSI realizations, $\overline{C}^{kl}$ is the average overall allocated rate to maximize, C_n^{kl} and $p_n^{k,l}$ are, respectively, the corresponding n-th subcarrier rate and power, $w_n^{k,l}$ is the subcarrier index which is equal to 1 if and only if the n-th subcarrier is assigned to the k-th SU over the lth spatial eigen channel. Moreover, $\tilde{p}^{k,l}$ stands for the average power budget the k-th SU is allowed to transmit over the l-th spatial subchannel, σ_k and θ_k are, respectively the threshold and the probability of interference per band and the notation $1_{\{p_n^{k,l} h^k_{n,PU} > \Gamma_k\}}$ means that it is true if $p_n^{k,l} h^k_{n,PU} > \sigma_k$ and zero otherwise

The MIMO sum-rate channel capacity with Rayleigh fading could be written as follows:

$$C = \sum_k \sum_l E_{|\rho_n^{k,l}|}[\overline{C}^l_k(|\rho_n^{k,l}|)] = \sum_k L \int_0^\infty \overline{C}^k_l \, p(|\rho_n^{k,l}|) d|\rho_n^{k,l}| \quad (5)$$

In (5), $E_{|\rho_n^{k,l}|}$ is the expectation over the corresponding eigenvalue, and p(.) represents the probability density function (pdf) of the operand.

The proposed algorithm is summarized as follows:

1. Initialize time, user and subcarrier indexes i=0,k=1, n=l

2. Put the initial power budget $P^{k,n}_{Total}(i) = P_T$

3. Perform power water-filling on each spatial Eigen channels $\rho_n^{k,l}$ with the total transmit power $P^{k,n}_{Total}(i)$.

4. Compute the rate of each user per subcarrier of each spatial eigen-channel, C_n^{kl}

5. Round C_n^{kl} to the nearest rate level for all l=1,…, L

6. Rederive $\rho_n^{k,l}$ by replacing for all l=1,…, L.

7. Perform adaptive MQAM modulation on each spatial eigen-channel by using the values in steps 3 and 4. Perform the

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optimization over subcarrier and user dimensions and calculate $\bar{C}^{kl}$ as in (4)

8. Calculate the instantaneous sum rate capacity in (6).

9. Compute $P_{remain}^{k,n}(i) = P_{Total}^{k,n}(i) - \sum_{l=1}^{L} p_n^{k,l}(i)$.

10. $P_{Total}^{k,n}(i) = P_T + P_{remain}^{k,n}(i)$,n=n+1; Go to step 2

11. If n=N, put n=1, put k=k+1, and go to step 2.

12. if k=K and n=N, put k=1, put n=1, i=i+1, and go to step 3.

13. End

III.RESULTS

In the adopted scenario, the following parameters are retained: K=4, M=8, L=2, and BER=10-3. Omnidirectional antennas are adopted for such a study, despite the fact that opting for directional ones would have improved the performance [7]. In applying the VRVP AM scheme, each spatial eigen-channel is assumed to have 15 possible rate levels. Fig. 1 depicts the sum-rate capacity versus the average SNR (dB) of our proposed algorithm, along with the extended SR and continuous rate approaches, encompassing similar processing blocks except for ones pertaining to the power and rate allocation per frequency and spatial dimensions. The approaches are tested on Rayleigh and Gaussian fading channels. It is seen from this figure, that the attainable capacities are similar, regardless of the fading type. Furthermore, at low SNR range, the proposed algorithm saves about 1.8 dB transmit power compared with the SR in order to achieve the same sum-rate capacity, and 5.5 dB when the SNR level gets high.

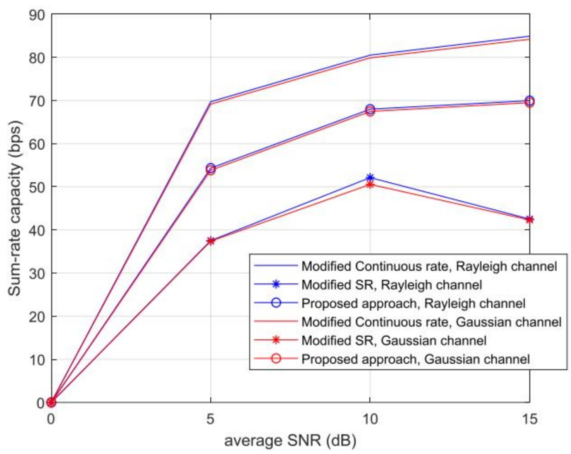

Fig. 1. Sum-rate capacity versus average SNR of modified continuous rate, modified SR and the proposed algorithm in Rayleigh and gaussian channel

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