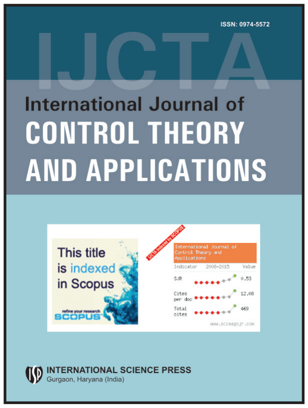

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MIMO-OFDM based Cognitive Radio Systems with Imperfect Spectrum Sensing by Multi-objective Optimization Technique

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Abstract: This paper presents optimization strategies for a MIMO (Multiple Input Multiple Output) OFDM (Orthogonal Frequency Division Multiplexing) based cognitive radio (CR) system. The proposed optimization schemes maximize the downlink transmission rate of the CR users under spatial interference constraints, considering both the availability and absence of the primary user (PU) Channel State Information (CSI). A multi-objective optimization (MOOP) approach to investigate the optimal link adaptation problem of MIMO OFDM based cognitive radio (CR) systems, where secondary users (SUs) can opportunistically access the spectrum of primary users (PUs).

For such a scenario, we solve the problem of jointly maximizing the CR system throughput and minimizing it's transmitting power, subject to constraints on both SU and PUs. The optimization problem imposes predefined interference thresholds for the PUs, guarantees the SU quality of service in terms of a maximum bit-error-rate (BER). Additionally, the results show that the performance of the proposed algorithm approaches that of an exhaustive search for the discrete optimal allocations with a significantly reduced computational effort. Simulation results presented validate the performance of the proposed schemes.

Keywords: Cognitive radio, imperfect spectrum sensing, multi-objective optimization, MIMO OFDM systems, spectrum sharing.

1. INTRODUCTION

Under the Cognitive Radio (CR) paradigm, vacant primary user (PU) licensed spectral bands or *spectral holes* are opportunistically allocated to secondary users (SUs) to improve the efficiency of spectrum utilization. Further, MIMO-OFDM [1] based CR systems have gained significant appeal for usage in futuristic dynamic spectrum access based wireless networks. Recently, the authors in [2] presented an optimal scheme for interweave CR system rate maximization based on a novel spectral distance dependent characterization of the interference. Based on this, a similar scheme has been presented for MIMO OFDM power allocation in [3]. However, the scheme presented there in is suboptimal as they consider per antenna power allocation, while it is well known that per singular mode power allocation is optimal in MIMO systems.

Further, the model is restrictive as it considers only single antenna and not MIMO wireless systems for the narrowband PUs. Also, they do not consider the PU interference in SU Communication. Hence, we propose new schemes for optimal CR power allocation based on spatial interference constraints in a MIMO OFDM wireless network, considering both the presence and absence of PU channel state information (CSI). Moreover, we consider power allocation under CSI uncertainty using the separate frameworks of stochastic and worst case rate maximization.

Generally speaking, the interference introduced to the Pus bands in MIMO OFDM-based CR networks can be classified as: (1) mutual interference (co-channel interference (CCI) and adjacent channel interference (ACI)) between the SU and Pus due to non-orthogonality of their respective transmissions [4]–[8] and (2) interference due to the SU's imperfect spectrum sensing capabilities [9]–[13]. Spectrum sensing is not fully reliable due to the SU hardware limitations and the variable channel conditions. Therefore, the SU may identify certain PUs bands as occupied when they are truly vacant. This results in the sensing error known as a *false-alarm*. On the other hand, if the SU identifies certain PUs bands to be vacant while they are truly occupied, this leads to the sensing error known as a *mis-detection*. The probability of mis-detection increases the interference to the undetected PUs, while the probability of false-alarm reduces the transmission opportunities of SUs.

CR systems will have different requirements than those listed above. For example, if only partial channel information is known on the links between the SU and the PUs receivers or the sensing is not fully reliable, then minimizing the transmit power is prioritized in order not to violate the interference constraints. On the other hand, maximizing the CR system throughput is of interest to improve the overall network performance. This motivates us to adopt a multi objective optimization (MOOP) approach that optimizes the conflicting and incommensurable throughput and power objectives. For most of the MOOP problems, it is not possible to find a single solution that optimizes all the conflicting objectives simultaneously, i.e., there is no solution that improves one of the objective functions without deteriorating other objectives. However, a set of non-dominated, *weak* Pareto optimal solutions exists and it is the decision maker's (the SU in our case) responsibility to choose its preferred optimal solution [14]. Various methods for solving MOOP problems exist and are classified according to the level of preferences of the competing objective functions as *posteriori* methods and *priori* methods

For the former, the (whole, if possible) set of the Pareto optimal solutions are generated and presented to the decision maker who selects the preferred one. On the other hand, for the latter, the decision maker must specify the preferences before the optimization process starts.

The results illustrate the performance of the proposed algorithm and show its closeness to the global optimal allocations obtained by an exhaustive search for the equivalent discrete problem. Furthermore, the results show the performance improvements of the proposed algorithm when compared to other works in the literature at the cost of no additional complexity.

2. SYSTEM DESIGN MODEL

A. System Model

We consider a MIMO-OFDM based CR system comprising of a base station (BS) with a total of N sub channels for the CR users. The CR base station is equipped with Nt transmit antennas while each CR receiver possesses Nr receive antennas. Similarly, the MIMO PU system consists of a PU base station with Lt transmit antennas and L PUs each with Lr receive antennas. The lth PU occupies a spectral band of bandwidth Bl Hz, while the CR users occupy spectral holes of bandwidth _f Hz each.

B. Optimal MIMO-OFDM Power Allocation

We consider an interference threshold of Ith for the PUs. Since PUs employ a MIMO wireless system, in principle it is essential to limit the interference caused by the CR users at each mode of each PU. However, in the absence of PU CSI, this can be formulated as limiting the worst case isotropic interference caused by the CR users.

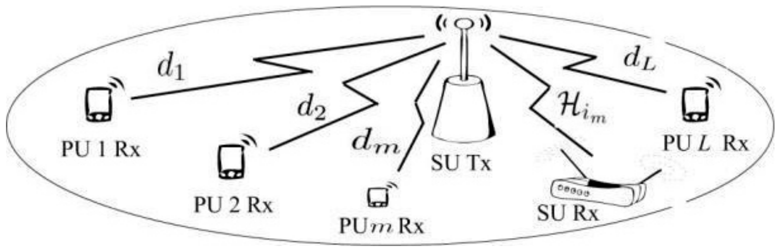

Figure 1: Cognitive radio system model

This means that the SU identifies the *m*th PU band as vacant when it is truly occupied. This is referred to as a mis-detection error and it occurs with probability σ(*m*) *md* . On the other hand, the SU may identify the _th PU band as occupied when it is truly vacant.

C. Optimization Problems: Formulation and Banalysis

In MOOP principle, if the objective functions and constraints are convex, then the obtained Pareto optimal solution is referred to as a *global* Pareto optimal solution; otherwise, it is refereed to as a *local* Pareto optimal solution [19]. Furthermore, the obtained solution is a *weak* Pareto optimal solution if the objective functions are conflicting (as there is no single solution that improves the competing objectives simultaneously); otherwise, it is referred to as a *strong* Pareto optimal solution [19]. Our target is to jointly maximize the SU throughput and minimize its transmit power while satisfying target quality of service QoS (in terms of BER), certain levels of CCI/total transmit power and ACI to the PUs receivers, and a maximum number of bits per each subcarrier while considering the errors due to imperfect sensing. We assume that the SU accesses the spectrum if the QoS is achievable. For an average BER constraint, this corresponds to a non-convex optimization problem where the obtained numerical solution is not guaranteed to be a global Pareto optimal solution.

The constraint on the average BER can be relaxed to a constraint on the BER per subcarrier, especially for high SNRs. The benefit of this relaxation is that the resultant optimization problem can be convex after some mathematical manipulations, in which case the global optimality of the Pareto set of solutions is guaranteed. Also, this enables obtaining closed-form expressions for the optimal bit and power allocations, and, hence, the obtained solution will be of significantly lower complexity when compared to the solution of the problem with the constraint on the average BER. Therefore, the obtained solution of the problem in hand will be a globally (as the MOOP problem is convex) weak (as the objective functions are conflicting) Pareto optimal solution.

3. SIMULATION RESULTS

This section investigates the performance of the proposed algorithm and compares it with other techniques in the literature, as well as with an exhaustive search for the discrete global optimal allocations. The computational complexity of the proposed algorithm is also compared to that of other schemes. we compare the transmission rates achieved by the different power allocation schemes presented above. The plots reflect that for a given interference threshold, optimal power allocation for the relaxed sum-trace interference constraint (5) achieves the highest transmission rate for the CR users. The performance of the optimal power allocation schemes with directional and isotropic interference constraints, corresponding to availability and absence of PU CSI respectively, achieve slightly lower rate owing to stringent per PU interference restrictions.

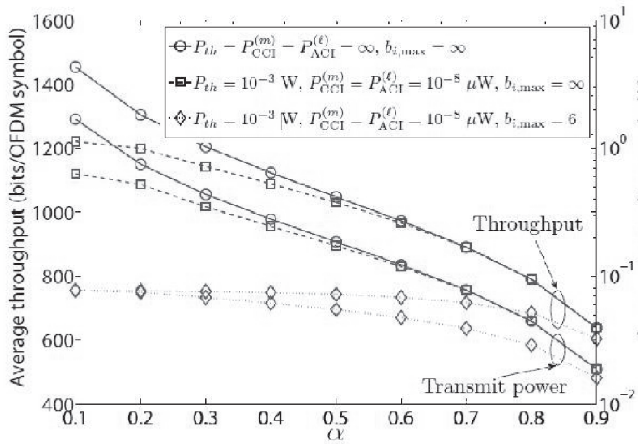

Figure 2: Effect of a on the SU performance for different values of P_{th}, P_{CCI}, P_{ACI}, and $b_{1,\,max}$

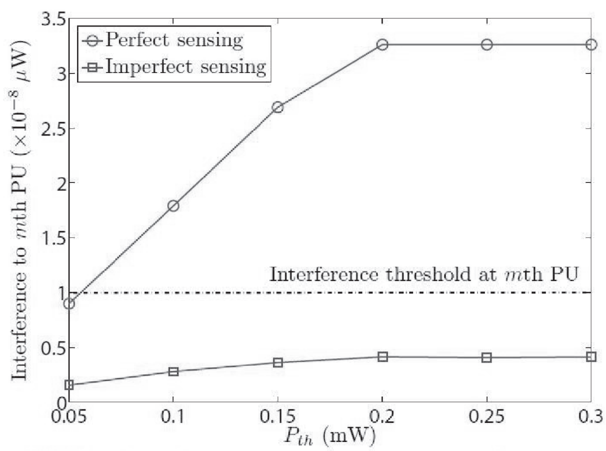

Figure 3: Effect of perfect and imperfect sensing on the SU performance for $P_{CCI} = P_{ACI} = 10^{-8}$ μW, α = 0.5 and $b_{i,\,max} = 6$

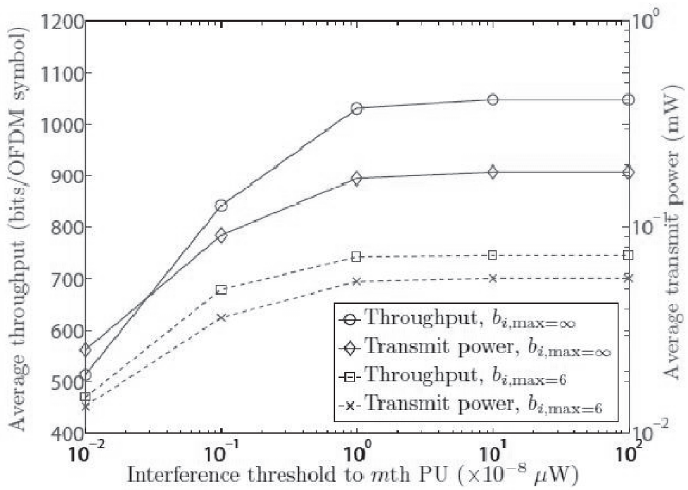

Figure 4: Effect of $P^{(m)}_{CCI}$ on the SU performance for $P_{th} = 10^{-3}$ W, $P^{(l)}_{ACI} = 10^{-8}$ μW, α = 0.5 and $b_{i,\,max} = \infty$ and 6

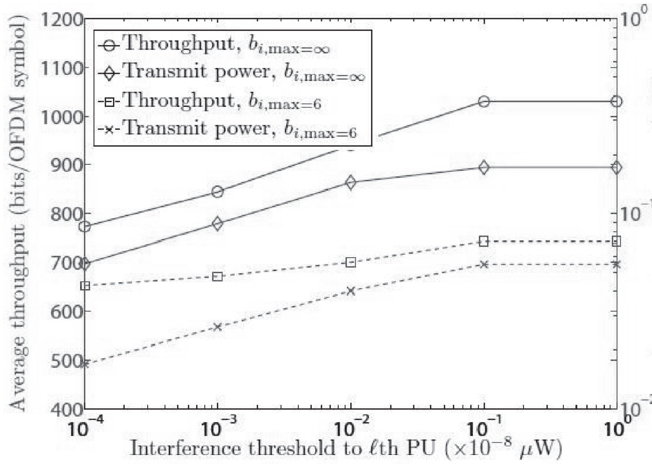

Figure 5: Effect of $P^{(l)}_{ACI}$ on the SU performance for $P_{th} = 10^{-3}$ W, $P^{(m)}_{CCI} = 10^{-8}$ μW, α = 0.5 and $b_{i,\max} = \infty$ and 6

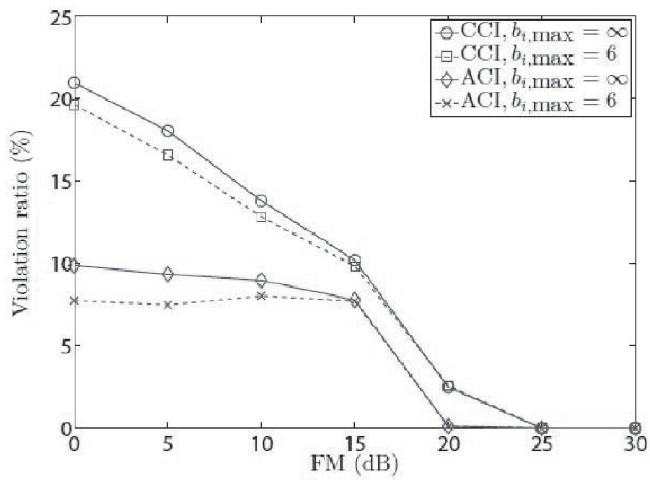

Figure 6: Effect of FM on the violation ratio of the CCI and ACI constraints for $P^{(m)}_{CCI} = P^{(l)}_{ACI} = 10^{-10}$ μW and $b_{i,\max} = \infty$ and 6

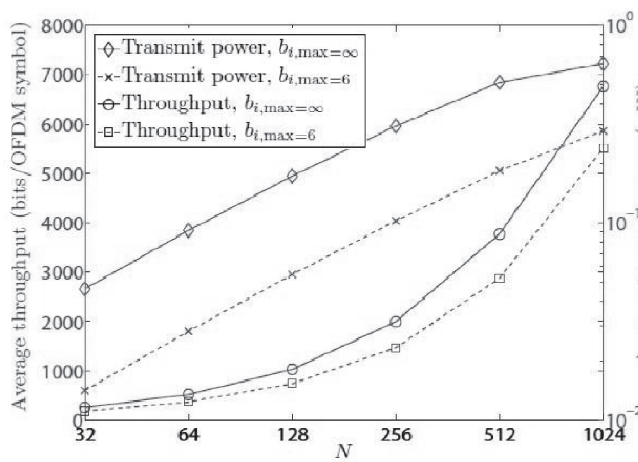

Figure 7: Effect of N on the SU performance for $P_{th} = 10^{-3}$ W, $P^{(m)}_{CCI} = P^{(l)}_{ACI} = 10^{-8}$ μW, α = 0.5 and $b_{i,\max} = \infty$ and 6

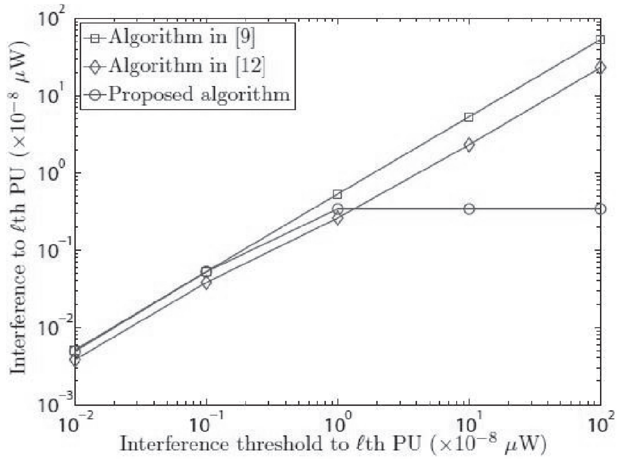

Figure 8: Comparison between the interference leaked to the lth PU for the proposed algorithm and the algorithms in [9] and [12]

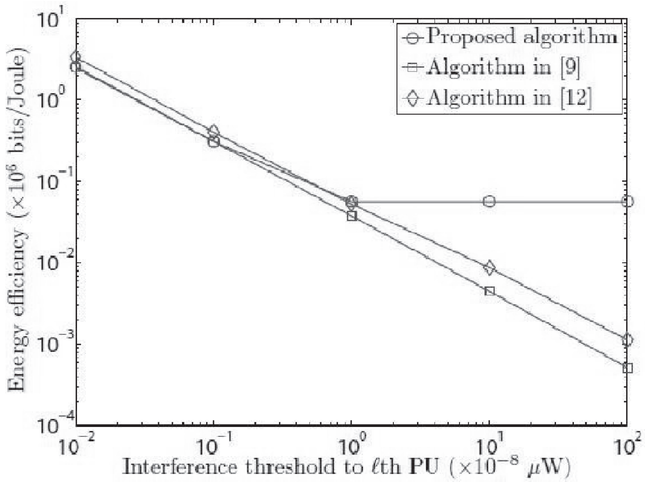

Figure 9: Comparison between the SU energy efficiency for the proposed algorithm and the algorithms in [9] and [12]

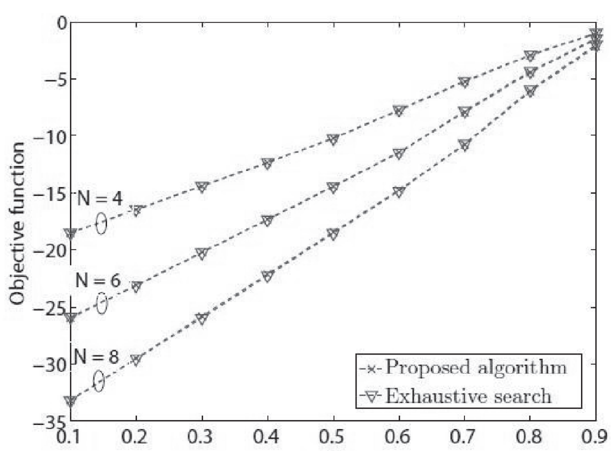

Figure 10: Comparison between the proposed algorithm and the exhaustive search for $P_{th} = 5 \times 10^{-6}$ W, $P^{(m)}_{CCI} = P^{(l)}_{ACI} = 10^{-10}$ μW and $b_{i,\max} = 6$

4. CONCLUSION

In this paper we have presented optimal power allocation schemes for the downlink transmission scenario of MIMO-OFDM based CR systems with spatial interference constraints. Closed form expressions for power allocation have been derived considering both the availability and non-availability of PU CSI.

Moreover, the results show that the violation of the interference constraints can be due to: (1) partial channel information of the links between the SU and the PUs receivers, where a fading margin becomes crucial to protect the PUs receivers, and (2) assuming perfect spectrum sensing. When compared to the single objective solutions, the multi-objective optimization approach tends to be more energy efficient at the cost of no additional complexity. Additionally, the results indicated that the performance of the proposed algorithm approaches the discrete optimal results obtained by an exhaustive search, with significantly reduced computational effort.

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