An Overlay Architecture for MISO Cognitive Radio Systems

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Abstract. A multiple-input-single-output (MISO) wireless overlay system is developed in the context of cognitive radio (CR) applications. Whereas conventional CR architectures require spectrum sensing and only allow the overlay system to operate when the legacy system is idle, the proposed architecture enables simultaneous operation of the overlay and legacy systems. The overlay system exploits transmit-path diversity in order to optimize its own self performance while mitigating interference into the legacy system. Simulation results using the proposed architecture demonstrate significant performance gains vis-a-vis single-input-single-output (SISO) schemes.

Keywords: Mean square error (MSE), multiple-input-single-output (MISO), crosstalk, overlay system, cognitive radio (CR).

1 Introduction

The problem of frequency spectrum congestion has been increasing due to the demand for higher date-rate services combined with the need to accommodate diverse types of users and applications [1]. Novel paradigms are thus needed in order to meet such demands. The recently developed technology of cognitive radio (CR) [2] provides an intelligent wireless communication system that is able to adapt itself to the environment via dynamically and autonomously adjusting its operating parameters [3],[4].

The operating paradigm of a CR system consists of *legacy* users that hold the primary spectrum license and have usage priority, and *overlay* that users have lower usage priority and are only allowed to operate in the legacy band if doing so does not cause unacceptable interference to legacy users. It is thus important that the overlay system be capable of spectrum sensing, which involves determining the existence of active legacy users within a geographical area of interest. Relevant algorithms for doing so, however, suffer from degraded performance in the presence of channel shadowing and fading [5]. As such, we propose in this paper a multiple-input-single-output (MISO) CR paradigm wherein overlay users can operate *simultaneously* with legacy users without the need of spectrum sensing. The simultaneous operation paradigm, combined with the spatial

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diversity afforded by the multiple transmit antennas, may potentially unveil an even more efficient utilization of the shared spectrum. Furthermore, the design of the optimal transmitter and receiver of the overlay system must be done in such a manner that mitigates the mutual interference between the overlay and legacy users.

This contribution is broadly related to previous work on joint transmitter/receiver optimization under the MSE criterion. The design of an overlay system in the context of non-coordinated digital subscriber lines is considered in [6], wherein the performance metric consists of the overlay system MSE and the excess MSE to the legacy system caused by the introduction of the overlay system. Joint transmitter/receiver optimization for multiple uncoordinated users is investigated in [7] under the assumption that the direct and cross talk channel responses seen by each user are symmetric. A narrowband spatial multiplexing system with a jointly optimal transmitter and receiver is addressed in [8] by decoupling the MIMO channels into parallel sub-channels via the transmit and receive filters. [9] studied the problem of joint precoder and receiver design using the MSE between the transmitted signal of the new system and its estimate in the receiver for the system downlink. It should be noted, however, it does not consider the optimal overlay system pulse shape or the effect of interference from the legacy system on the performance of the overlay system.

In this paper, we study the problem of jointly optimizing the transmitter/receiver pulse shape for a MISO system overlaid onto an existing legacy system using a composite MSE criterion. The criterion consists of the overlay system MSE and the excess MSE introduced into the legacy system.

This paper is organized as follows. Section 2 introduces the proposed MISO system and its design. Section 3 provides simulation results. We conclude the paper in Section 4.

2 Multiple-Transmit-Antenna System

Figure 1 shows a block diagram of the proposed system architecture. The legacy system is assumed to be single-input-single-output (SISO), whereas the overlay system is assumed to be MISO. Thus, the single legacy transmitter has impulse response $h_t^{(l)}(t)$, whereas the M overlay transmitters have impulse responses $h_t^{(o_m)}(t)$, $m = 1 \ldots M$. Since both the legacy and overlay system have only a single output, they consist of only one receiver with respective impulse responses $h_r^{(l)}(t)$ and $h_r^{(o)}(t)$.

The direct channel with impulse response $h_c^{(ll)}(t)$ is used for communication by the legacy system, but is contaminated by the AWGN signal $w_2(t)$ and the interference path with impulse response $h_c^{(o_m l)}(t)$, $m = 1 \ldots M$, that originates at the mth overlay transmitter and terminates at the legacy receiver. Similarly, the direct channel with impulse response $h_c^{(o_m o)}(t)$, $m = 1 \ldots M$, is used for communication by the overlay system, but is also contaminated by the AWGN signal $w_1(t)$ and the interference path with impulse response $h_c^{(lo)}(t)$ that originates at the legacy

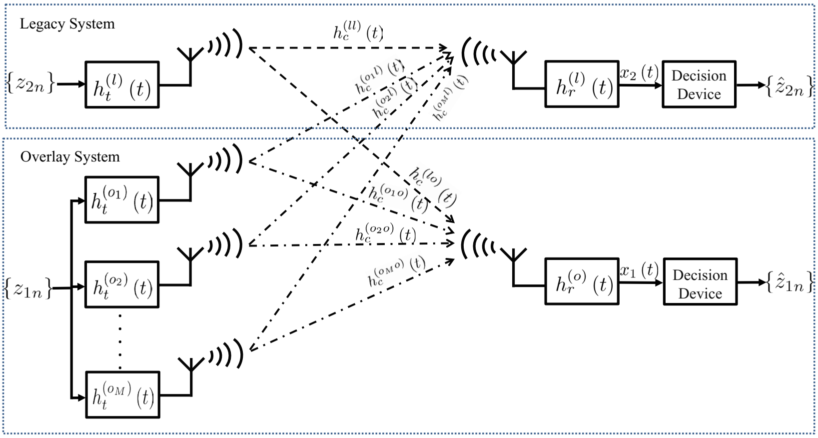

Fig. 1. Multiple-transmit-antenna system model

transmitter and terminates at the overlay receiver. It is assumed that knowledge of these channels is available through appropriate feedback mechanisms.

The independent and identically distributed (i.i.d) input sequences z_{1n} and z_{2n} form the input to the overlay and legacy systems. The legacy and overlay receivers process these respective sequences and produce the respective output signals $x_1(t)$ and $x_2(t)$. Decision devices are used to produce the final outputs denoted as $\hat{z}_{1n}$ and $\hat{z}_{2n}$.

The objective is to design the jointly optimal overlay transmitters $h_t^{(o_m)}(t)$, $m = 1 \ldots M$, and overlay receiver $h_r^{(o)}(t)$, so that mutual interference between the overlay and legacy systems can be mitigated and thus permit simultaneous operation of the two systems. The design is posed as an optimization whose cost function consists of the performance of the overlay system and the performance degradation of the legacy system due to the introduction of the overlay system. Furthermore, the design is subject to two constraints - the legacy transmitter and receiver $h_t^{(l)}(t)$ and $h_r^{(l)}(t)$ *cannot* be modified (and are thus not design variables), and the average transmitter power on the overlay user is constrained to some level P_t, where

$$P_t = \sum\nolimits_{m=1}^{M} P_{tm} \tag{1}$$

and P_{tm} represents the average transmitter power from the mth antenna of the overlay system. As such, an appropriate cost function is the composite MSE:

$$MSE = MSE_1 + MSE_2^e + \sum\nolimits_{m=1}^{M} \lambda_m P_{tm} \tag{2}$$

where MSE_1 represents the overlay system MSE, MSE_2^e represents the excess MSE into the legacy system due to the interference from the overlay system, and λ_m, $m = 1 \ldots M$, represents the Lagrange multipliers. By transforming (2) into the frequency domain, the following conditions for the jointly optimal overlay transmitter and receiver are obtained:

$$\mathbf{H_t^{(o)}}^{\mathsf{T}}\mathbf{M_1}\mathbf{H_t^{(o)}} = \left|H_r^{(o)}(f)\right|^2 M_2 \tag{3}$$

$$\left[\mathbf{H_t^{(o)}}^{\mathsf{T}}\mathbf{M_3}\mathbf{H_t^{(o)}} + M_2\right] H_r^{(o)}(f) = T\mathbf{H_t^{(o)}}^{\mathsf{T}}\mathbf{H_c^{(oo)}} \tag{4}$$

$$\left[\left|H_r^{(o)}(f)\right|^2 \mathbf{M_3} + \mathbf{M_1}\right] \mathbf{H_t^{(o)}} = TH_r^{(o)}(f)\mathbf{H_c^{(oo)}} \tag{5}$$

where $\mathbf{M_1} = \left|H_r^{(l)}(f)\right|^2 \mathbf{H_c^{(ol)}}\mathbf{H_c^{(ol)}}^{\mathsf{T}} + \boldsymbol{\lambda}$, $M_2 = \left|H_t^{(l)}(f)\right|^2 \left|H_c^{(lo)}(f)\right|^2 + \eta^{-1}$, $\mathbf{M_3} = \mathbf{H_c^{(oo)}}\mathbf{H_c^{(oo)}}^{\mathsf{T}}$, and

$$\mathbf{H_t^o} = \left[\, H_t^{o_1}(f)\; H_t^{o_2}(f) \ldots H_t^{o_M}(f) \,\right]^{\mathsf{T}} \tag{6}$$

$$\mathbf{H_c^{(oo)}} = \left[\, H_c^{o_1 o}(f)\; H_c^{o_2 o}(f) \ldots H_c^{o_M o}(f) \,\right]^{\mathsf{T}} \tag{7}$$

$$\mathbf{H_c^{(ol)}} = \left[\, H_c^{o_1 l}(f)\; H_c^{o_2 l}(f) \ldots H_c^{o_M l}(f) \,\right]^{\mathsf{T}} \tag{8}$$

In equations (3)–(8), $H_t^{(l)}(f)$, $H_r^{(l)}(f)$, $H_r^{(o)}(f)$, $H_c^{(ll)}(f)$, $H_c^{(lo)}(f)$, $H_t^{(o_m)}(f)$, $H_c^{(o_m o)}(f)$, and $H_c^{(o_m l)}(f)$ represents the Fourier transform of $h_t^{(l)}(t)$, $h_r^{(l)}(t)$, $h_r^{(o)}(t)$, $h_c^{(ll)}(t)$, $h_c^{(lo)}(t)$, $h_t^{(o_m)}(t)$, $h_c^{(o_m o)}(t)$, and $h_c^{(o_m l)}(t)$, respectively. Because (3), (4), and (5) do not have a closed-form solution, an efficient sequential optimization algorithm is used to find the optimum overlay receiver ($H_r^{(o)}$) which is then applied to (5) in order to find the optimum overlay transmitter ($\mathbf{H_t^{(o)}}$). Moreover, the approximate values for the Lagrange multipliers λ_1 through λ_M that satisfy the desired power constraint are determined using non-joint optimization which does not necessarily yield the optimum solution. While the optimum solution (which can be computed using e.g. trust-region-reflective optimization techniques) will yield better performance (i.e. lower composite MSE), it is computationally more complex.

3 Simulation Results

Performance comparisons are provided in this section for which the overlay transmitter has a single antenna ($M = 1$) and dual antennas ($M = 2$). The case $M = 1$ serves as a baseline against which we can compare the improvement in performance afforded through the use of spatial diversity, as is the case when $M = 2$. It is assumed that the system operates over a flat Rayleigh fading channel in the presence of AWGN. Also, without loss of generality, we assume that both the legacy and the overlay systems occupy a common bandwidth of 15 MHz and the legacy transmitter power is 0 dB.

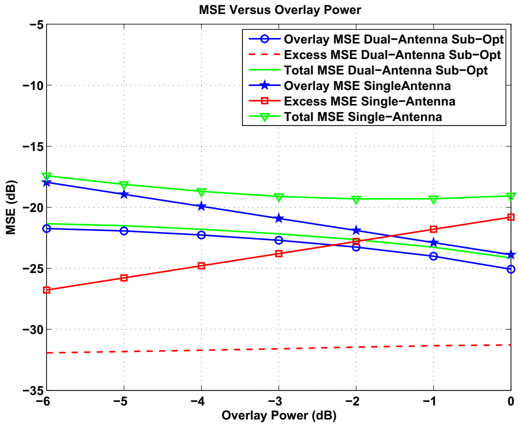

Fig. 2. Effect of varying overlay power in a system with sub-optimum dual transmit antenna overlay, and a system with single antenna overlay

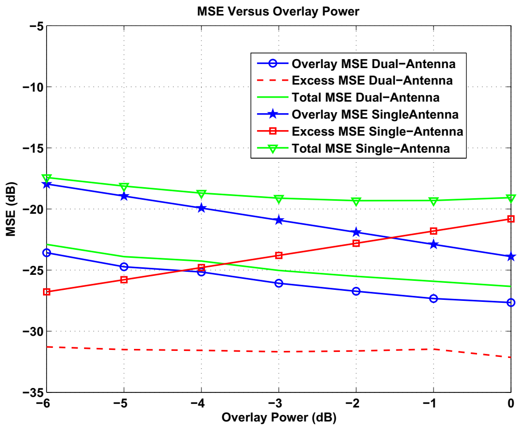

Fig. 3. Effect of varying overlay power in a system with optimum dual transmit antenna overlay, and a system with single antenna overlay

Figure 2 shows the variation of the MSE with the overlay transmitter power for the dual-transmit-antenna and single-transmit-antenna overlay systems for the case in which the sub-optimum (but computationally efficient) method (non-joint optimization) is used to compute the overlay transmitter and receiver. For the dual-transmit-antenna system, the overlay transmitter power is the total available power at the overlay transmitter, which is allocated to each overlay transmitter by sequentially optimizing the Lagrange multipliers, λ_1 and λ_2, in (2). It can be seen that the overall performance of the dual-transmit-antenna system is better compared to the single-transmit-antenna system.

Figure 3 shows the variation of the MSE with the overlay transmitter power for the dual-transmit-antenna and single-transmit-antenna overlay systems for the case in which the optimum (but computationally complex) method is used to compute the overlay transmitter and receiver. Like Figure 2, it can be seen that the overall performance of the dual-transmit-antenna system is better compared to the single-transmit-antenna system. Moreover, the improvement in performance has increased relative to the sub-optimum solution. Nonetheless, this margin of increased performance comes at the cost of increased computational burden.

4 Conclusion

A cognitive radio paradigm was proposed wherein an overlay system can simultaneously operate with the legacy user over the same spectrum without the need of spectrum sensing. The overlay system employs a MISO architecture that enables it to exploit transmit path diversity. Based on a composite MSE that consists of the sum of the MSE of the overlay system and the excess MSE introduced to the legacy system, necessary conditions that jointly optimize the overlay transmitter/receiver filters were derived. Simulation results show that the proposed overlay system architecture yields significant performance gains over the conventional SISO implementation and thus more efficiently exploits the shared spectrum.

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