Chapter 9
Optimal RF Beamforming for MIMO Cognitive Networks

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ABSTRACT
Secondary receivers in Multiple-Input Multiple-Output (MIMO) Cognitive Radio (CR) networks combat interference from primary transmitters while equipped with whitening filters. However, when the MIMO secondary users are employing Radio Frequency (RF) beam-forming networks at the transmitter/receiver front ends to improve the MIMO transmission performance, the whitening filters cannot perform interference cancellation. In this chapter, transmit/receive optimum RF beamforming is proposed for a MIMO spatial multiplexing system. The performance of the optimally designed RF beamforming technique is evaluated over a Rician channel via computer simulations. Simulation results are assessed for different RF beamforming structures and the number of primary transmitters causing interference on the secondary receiver.

INTRODUCTION
Cognitive Radio is a new class of wireless systems that are able to reliably sense the spectral environment over a wide bandwidth, detect the presence/absence of legacy users, so-called primary users; i.e., those which have spectrum license, and use the spectrum only if the communication does not interfere with primary users. Although research done on CR networks mostly assume single antenna used at both primary and secondary transceivers, recent advances in using multiple antennas at both sides of a wireless communication link promise significant performance improvements by exploiting the effect of fading and multipath environments. For example, exploiting multiple antennas system for opportunistic spectrum sharing in CR networks is investigated in (Zhang, 2008)–(Wang, 2011). Although MIMO communication systems provide very high data rates with low error probabilities, these advantages are obtained at the expense of having high signal processing tasks and hardware cost. To lower the number of RF chains and provide a low cost MIMO system, a Radio Frequency (RF) pre-processing scheme is proposed in (Zhang, 2005). Due to the adaptive beamforming capabilities, the proposed RF beamforming method shows a significantly improved
performance compared to the traditional antenna selection methods for MIMO systems.

In this chapter, a CR network in which the secondary user has a MIMO link with the RF beamforming architecture at transmit and receive sides is investigated. The optimal solution is presented for the secondary user receive RF beamforming module considering all constraints exist in the CR spectrum sharing network. The constraints are applied based on the CR network model used in (Zhang, 2008) and the new ones arisen with the problem definition in this chapter.

SYSTEM MODEL AND PROBLEM STATEMENT

In this chapter, the MIMO cognitive network model proposed in (Zhang, 2008) is considered. This model is depicted in Figure 1 while the MIMO secondary user is equipped with RF beamforming capability. According to this model, it is assumed that all the primary users and the secondary user share the same bandwidth for transmission. The MIMO secondary user consists of a $N_T$-element transmit and a $N_R$-element receive array antenna.

In this framework the secondary physical channel, including radio propagation environment and transmit and receive antennas, is modeled by a $N_g \times N_r$ matrix $H_s$. There exists $N_t < N_T$ transmit RF chains and $N_r < N_R$ receive RF chains. The transmit RF beamforming module, which is mathematically represented by a $N_T \times N_t$ matrix $W_T$, is made out of a Linear Network (LN) including power splitters/combiners and phase-shifters and variable gain amplifiers\(^1\). The receive RF beamforming module, herein represented by a $N_r \times N_R$ matrix $W_R$, is practically made out of an after Low Noise Amplifier (LNA) mounted, co-called post-LNA, LN with the same components as transmit LN.

We assume that the MIMO channels from the secondary transmitter to the secondary and primary receivers are perfectly known at the secondary receiver and transmitter. Thus, the secondary transmitter is able to tune its RF beamforming network based on the channel information to maximize the secondary transmit throughput and combat any interference at the primary receivers. Moreover, with the channel knowledge at the secondary receiver we will be able to optimize the applied receive RF beamforming network.

According to this cognitive network, noise at the secondary receiver generally contains interference from the primary transmitters and consequently, is not white. However, using a traditional full-complexity MIMO system for the secondary user (as assumed in (Zhang, 2008)), applying a noise-whitening filter at the secondary receiver and incorporating this filter matrix into the channel matrix $H_s$, equivalent noise at the secondary receiver can be assumed to be approximately white Gaussian (Zhang, 2008; 2011). In this chapter, it is shown that noise-plus-interference filtering in order to have white equivalent noise is no longer valid when the secondary user is using the receive RF beamforming network. In other words, the MIMO channel for a secondary user with receive RF beamforming is not noise-limited. Hence, we aim to jointly optimize the secondary user transmitter and RF beamforming