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Beamforming for Sensing Based Spectrum Sharing in Cognitive Radio Network

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***Abstract*—The key technology towards efficient spectrum usage is Cognitive Radio. Cognitive Radio allows unlicensed (secondary) users to access licensed bands under the condition of protecting the licensed (primary) users from harmful interference. Beamforming and power allocation strategy for the secondary transmitter based on the sensing result on the state of the primary user in a multi-antenna cognitive radio network is the proposed scheme. Unlike the existing sensing-based spectrum sharing, where the secondary transmitter employs a single antenna and adjusts only its transmit power, in the proposed scheme the secondary transmitter employs multiple transmit antennas and shows the performance of array response with and without beamforming weights.**

Keywords—Primary User, Beamforming, Array response

I. INTRODUCTION

Cognitive radio is a kind of intelligent wireless device, which is able to adjust its transmission parameters such as transmit power and transmission frequency band based on the environment. In a cognitive radio network, ordinary wireless devices are referred to as primary users, and cognitive radios are referred to as secondary users. Conventionally, a cognitive radio network can be formed by allowing either the secondary users to opportunistically operate in the frequency bands originally allocated to the primary users when they are inactive or the secondary users to coexist with the primary users, as long as their quality of service is not degraded to an unacceptable level by the interference from the secondary users. The former transmission model is known as opportunistic spectrum access and the latter transmission model is known as spectrum sharing. A new transmission model referred to as the sensing based spectrum sharing where the secondary user senses the frequency band allocated to the primary user to detect the state and then adapts its transmit power according to the detection result. If the primary user is inactive, the secondary user allocates the transmit power based on its own benefit to achieve a higher transmission rate. If it is active, then secondary user transmits with a lower power to avoid causing harmful interference to the primary user. This is different from either opportunistic spectrum access [4] or spectrum sharing. In the opportunistic spectrum access transmission model, the secondary user transmits only when it detects spectrum holes, which are the time duration that the primary user is not transmitting over the band. The frame structure of the opportunistic spectrum access cognitive radio systems consists of a sensing time slot and a data transmission time slot. According to this frame structure, a secondary user ceases transmission at the beginning of each frame and senses for the status of the frequency band [2]. In the spectrum sharing transmission model, the secondary user can transmit at any time without detecting whether the primary user is active or not. However, it has to restrict it's transmit power to avoid harmful interference to the primary user during the transmission process. Consider sensing based spectrum sharing when the secondary user transmitter has multiple transmit antennas. The beamforming vector and power allocation of the secondary user transmitter is designed for the secondary network. Cognitive beamforming is a promising technique that enables a multi-antenna secondary user transmitter to regulate its interference to each primary user receiver by intelligent beamforming and thereby transmit more frequently with larger power as compared with a single antenna secondary user transmitter.

II. SYSTEM MODEL

A pair of secondary users are considered, a secondary user transmitter and a secondary user receiver coexisting with a pair of primary users, a primary user transmitter and a primary user receiver utilizing the same frequency band, as shown in figure 1. The primary user receiver and the secondary user transmitter are assumed to be fixed nodes for e.g., a macro base station and a femto base station respectively and therefore, the channel between the secondary user transmitter and the primary user receiver is slow fading. The primary network employs a synchronous slotted communication protocol with slot duration T. The primary network traffic or the state of the primary user is modeled as a random process that randomly switches between active (H1) and inactive (H0).

The secondary user has L antennas, whereas the primary user receiver and the secondary user receiver have a single antenna respectively. The channels from the secondary user transmitter to the secondary user receiver, from the secondary user transmitter to the primary user receiver, and from the primary user transmitter to the secondary user receiver, are denoted by h, g, and gp respectively. All the channels are assumed to experience at fading. It is assumed that the cross channel g and the secondary user channel h are perfectly known at the secondary user transmitter. In practice, g can be obtained as follows. Since the primary user receiver and the secondary transmitter are fixed nodes, the cross channel g has much longer coherence time than the slot duration T. When the primary user is active (H1), g can be obtained at the secondary user transmitter by e.g., periodically observing the transmit signal from the primary user provided that time-division duplexing is employed by the primary network and the channel reciprocity between the primary user receiver and the secondary user transmitter is assumed [3].

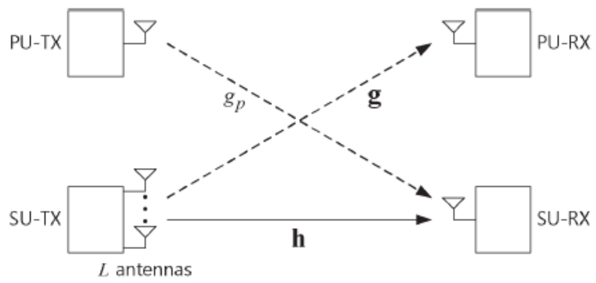


Fig. 1 System model

III. ANALYSIS

The slot structure of a cognitive radio network is synchronized with that of the primary network. It consists of a sensing phase and a data transmission phase whose durations are T1 and T-T1 respectively. In the sensing phase, the secondary user transmitter estimates the state of the PU: active (H1) or inactive (H0). We assume energy detection for the spectrum sensing. For a given sampling frequency fs and sensing duration T1, the probability of detection pd and the probability of false alarm pf can be expressed as a Q-function of the detection threshold respectively. In the data transmission phase, the secondary user transmitter adapts its beamforming vector and power according to the sensing result: v0 for the sensing result of H0 and v1 for the sensing result of H1. If the sensing is not perfect, there are four possible combinations of the primary user state and the sensing result. For a given sampling frequency fs and sensing duration T1, the probability of detection pd and the probability of false alarm pf can be expressed as a Q-function of the detection threshold η, respectively.

IV. EXPERIMENTAL RESULTS

In the sensing phase, the secondary user transmitter estimates the state of the primary user. Energy detection is used for spectrum sensing. Energy of the signal is compared with a threshold value. By setting probability of false alarm, probability of detection is calculated. Figure 2 shows probability of detection versus probability of false alarm.

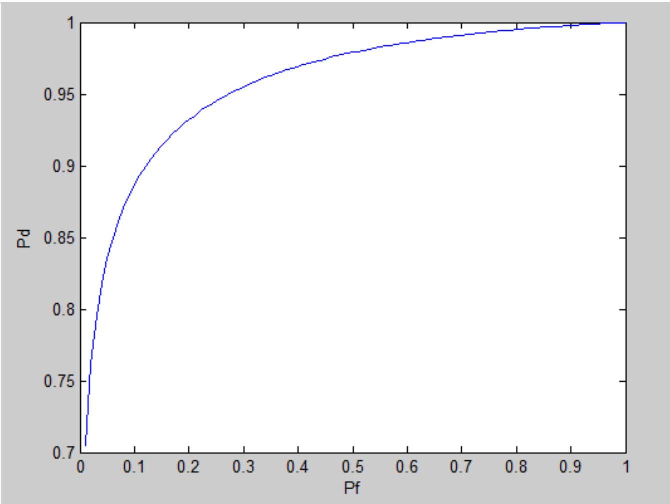


Fig 2.Probability of detection versus probability false alarm

For calculating the beamforming vectors a uniform linear array is created at the secondary user transmitter. By setting the angle at 90 degrees of azimuth and 30 degrees of elevation, obtained spatial spectrum for two antenna elements is shown in figure 3.

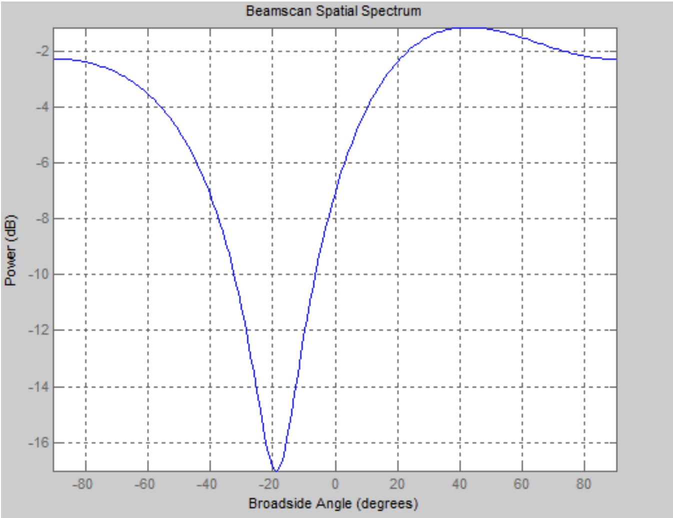
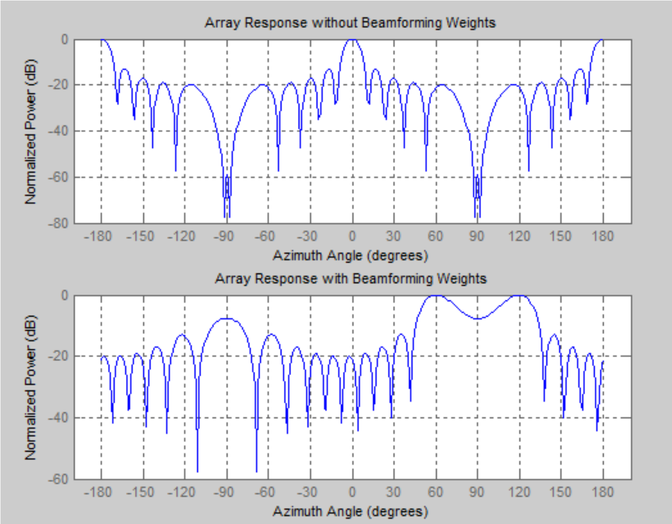


Fig 3. Beamscan spatial spectrum

The effect of the beamforming weights on the array response is shown in figure 5.3. Array response with beamforming weight shows better performance than without beamforming weight. This result is shown for 10 antenna elements.



V. CONCLUSION

Obtained the beamforming vector for sensing based spectrum sharing in cognitive radio networks. In the sensing phase, the state of the primary user transmitter is estimated by the secondary user transmitter. Energy detection is used for the purpose of spectrum sensing where energy of the signal is compared with a threshold value to detect the presence of primary user. In the data transmission state, the secondary user transmitter is employed with a uniform linear array which uses beamforming. By specifying the beamforming direction, array response with and without beamforming weights are compared. Array response with beamforming weight gives better performance than without beamforming weight.

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