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Achievable Data Rate in Hybrid MIMO Cognitive Radio Networks

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Abstract

Cognitive radio plays a vital role in wireless communication. Hybrid cognitive radio networks work in both underlay and overlay modes. The data rate of such hybrid cognitive radio network is limited. MIMO system can be implemented in hybrid cognitive radio networks for improving the data rate. Beam forming is used over the MIMO antennas to reduce the interference level in the desired direction. The game model called Nash Equilibrium (NE) is used for power control in secondary users (SUs) and primary users (PUs). Our investigations show that the achievable data rate increases due to the applied beam forming technique in MIMO antennas for hybrid cognitive radio network.

Keywords: Multiple Input Multiple Output (MIMO); Beam forming; Game theory; Nash Equilibrium (NE); Utility; Achievable data rate.

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1. Introduction

With the rapid deployment of wireless services over the last decade, the radio spectrum is becoming a valuable and scarce resource. How to support growing applications with limited spectrum resources emerges as a critical issue for future wireless communications. On the other side, the report from the Federal Communications Commission reveals that most of the licensed spectrum is severely underutilized. As a promising technique, cognitive radio (CR) is proposed to deal with the dilemma between spectrum scarcity and spectrum under utilization. CR allows unlicensed users [referred to as secondary users (SUs)] to access licensed bands under the condition that the induced interference to the licensed users [referred to as primary users (PUs)] does not reach an unacceptable level [1]-[4]. Hybrid cognitive radio network works in both overlay mode and underlay mode. If the PU is detected to be active, the SU selects the spectrum underlay mode and transmits with lower power. Otherwise, the SU works at spectrum

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overlay and transmits with its maximum power budget for a higher data rate. So the throughput of the network is improved by using hybrid CR network [5]-[8]. Recently, a new paradigm termed Cooperative Cognitive Radio Networks (CCRNs) has been introduced. In CCRN, PUs may select some SUs to relay the primary traffic cooperatively and in return grant portion of the channel access time to the SUs. By exploiting cooperative diversity, the transmission rates of PUs can be significantly improved. But the data rate of such CCRN can be further improved by implementing MIMO antennas in PUs and SUs. In MIMO there are multiple antennas and they are used for simultaneous transmission as well as reception. MIMO has the advantage due to multiple antennas and advanced signal processing technique used. By using this technique, multiple number of data streams can be transmitted or received over the MIMO antennas independently. The interference introduced by the nearby antennas is the main problem of the MIMO technique.

In our work beam forming technique can be introduced in the MIMO antennas to reduce the interference and to attain improved data rate. Beam forming is an alternative name for spatial filtering where, with appropriate analog or digital signal processing, an array of antennas can be steered in a way to block the reception of radio signals coming from specified directions. This can be achieved in such a way that signals at particular direction have constructive interference while others have destructive interference. The primary user tries to maximize the transmission rate while secondary users compete with each other to access the channel [9]-[11].

In hybrid cognitive radio networks power allocation is done by using power bidding and allocation algorithm [12]. But this mechanism is complex in CCRN. In our work game theory based on Nash Equilibrium concept is used for power control in PUs and SUs. Game theory maximizes the utility of PU and SU [13].

The rest of this paper is organized as follows. In section II, system model is described. Section III gives the power allocation using game theory. Utility analysis is described in Section IV. Simulation results are presented in Section V. Section VI concludes the findings of the paper.

2. System Model

In our system model, MIMO antennas are implemented in hybrid cognitive radio networks. The system model consists of primary transmitter (PT), primary receiver (PR) and secondary users (SUs). Consider SU and PU are equipped with two MIMO antennas. Such a 2×2 MIMO system is shown in Fig.1. The number of SUs participating in cooperative communication is decided by PU and the selected SUs are called relays. Fig.2 shows the structure of MIMO-CRN. In this model two stages are used. In first stage the Primary User (PU) transmits signal to the secondary relays. Then in the second stage the relays transmit the data to the primary receiver. The SU helps the PU by acting as relays and in turn channel is provided to the relays to transmit their own data [13].

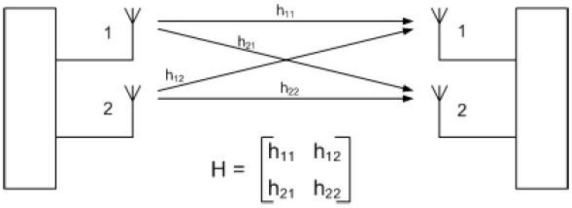

Fig.1. 2×2 MIMO

The received signal at the antenna is given by

$$Y = HX + N \qquad (1)$$

where H represents the Channel gain, N denotes the AWGN (Additive White Gaussian Noise) and X is the information signal. The MIMO transmission is explained in two stages.

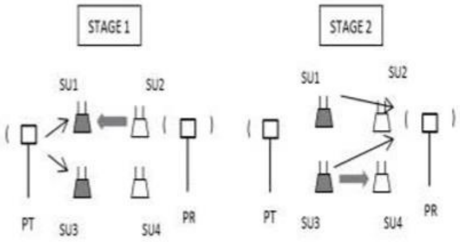

Fig.2. Structure of MIMO CRN

First stage: the primary user selects SU1 and SU3 as the relays for cooperation; SUs are generally denoted as R. We use h_{1r} to represent the channel coefficient of primary signal X_1 and H_{Rr} to represent the channel vector of secondary signal X_2.The users apply precoding vectors; they are denoted as u for encoding vector and v for decoding vector. The received signal in the stage 1 on each relay is a combination of primary and secondary signals.

$$Y_r = h_{1r}X_1 + H_{Rr}u^s X_2 + n(2) \tag{2}$$

The each relay applies a decoding vector $v^{p\dagger}$ to decode the primary signal by making $H_{Rr}u^s X_2 = 0$ and to obtain secondary data, the SU applies $v^{s\dagger}$ to make $v^{s\dagger}h_{1r} = 0$.
The received secondary stream at the SU after decoding is

$$\widehat{Y_r} = v^{s\dagger} H_{Rr} u^s X_2 + v^{s\dagger} n \tag{3}$$

and decoded primary signal at the relay is denoted as Y_p

$$Y_p = v^{p\dagger} h_{1r} X_1 + v^{p\dagger} n \tag{4}$$

where u^s and u^p are used to denote the encoding vectors of secondary and primary signal respectively. $v^{s\dagger}$ and $v^{p\dagger}$ are used to the decoding vectors of secondary signal and primary signal respectively
Second stage: The chosen relays transmit the primary data to the primary receiver PR. We use h_{r1} to represent the channel vector form relay r to PR and H_{rR} to represent the channel vector from relay r to SU. At the PR secondary signal is nulled so $H_{rR}u^s X_2 = 0$. The signal received at PR is

$$\widehat{Y_p} = \sum_r h_{1r} X_1 \sqrt{P^r}\, u^p + n \tag{5}$$

where, P^r represents the power used for relays. The values of P^r are found using game theory.
Due to Maximum Ratio Combining, the effective SNR at PR equals to the sum of all SNRs from all the secondary relays. The transmission power of primary transmitter PT is denoted as P^p, the data rate of primary stream at selected relay is

$$DR^{ps} = \log_2(1 + v^{p\dagger} h_{1r})^{2P^p/N_0} \tag{6}$$

In the PR sum of SNR of all relays are done by MRC method, thus rate of primary signal at PR is given by

$$DR^{sp} = \log_2(1 + \sum_r h_{1r} u^p)^{2P^p/N_0} \tag{7}$$

For the secondary data rate, the transmission power of SUs given as P^r, thus the resulting secondary rate is

$$DR^{ss} = \log_2(1 + v^{s\dagger} H_{Tr} u^s S_s)^{2P^r/N_0} \tag{8}$$

Here the data rate of secondary signal is less than primary due to self-interference caused by large number of SUs and in MIMO-CCRN more importance is given to primary users compared to secondary users.

3. Power Allocation Using Game Theory

In this system model data is transmitted in two stages. Time division multiple access (TDMA) is used for data transmission. We are denoting the time duration as αT^i for first stage and $(1-\alpha)T^i$ for second stage and the time length as α. We are denoting the secondary pair which are participating in stage 1 as Q1 and the pair in stage 2 as Q2. Since in CCRN the secondary users are followers of primary user for cooperation. Hence all the users are selfish aiming to maximize the utilities.

In order to find the best P^r, the Nash Equilibrium is used to find primary users utility and P_k is the secondary users power, here k denotes secondary users [13]. The utility of each secondary pair is the difference between the data rate (DR_i) and the cost of the power. The utility of secondary pair is denoted as M_1

$$M_1 = T^i(DR_i - \omega P^r) - \omega P_k (1-\alpha)T^i \tag{9}$$

where ω represent the cost for a unit transmission.

The energy consumed by the relay of secondary users are denoted as

$$T_k^i = F_i \frac{P_k}{\sum_{j \in Q_i} P_j} \tag{10}$$

The secondary users in each pair are players. For non cooperative power allocation game, the strategy is achieved by Nash Equilibrium for each relay. The utility of the secondary user in Q1 is

$$M_1 = \alpha T^i \frac{P_k}{\sum P^r} DR_i^{ss} - \omega P_k(1-\alpha)T^i \tag{11}$$

In this Nash Equilibrium (NE) is analyzed for secondary pairs in Q1. By using similar method Q2 can be analyzed. Now to solve the power for secondary pairs with unique Nash equilibrium for the first stage Q_1 is

$$P_k^* = \frac{\alpha}{(1-\alpha)} \alpha_k \tag{12}$$

where

$$\alpha_k = \frac{(|Q_1 - 1|)}{\omega \sum_{i \in Q} \frac{1}{iDR_i^{ss}}} (1 - \frac{(|Q_1 - 1|)}{DR^{ss} \sum_{i \in Q} \frac{1}{iDR_i^{ss}}} \tag{13}$$

P_k^* represent the power for each relay in Q1.

Similarly using NE the secondary power among the relays in Q2 is b_k as

$$b_k = \frac{(|Q_2 - 1)|)}{\omega \sum_{i \in Q} \frac{1}{iDR_i^{ss}}} (1 - \frac{(|Q_2 - 1)|)}{DR^{ss} \sum_{i \in Q} \frac{1}{iDR_i^{ss}}} \tag{14}$$

4. Utility Analysis for Primary User

The resulting data rate for PU is

$$A = \sum_k \in Q_1 \frac{|h_{r1} u^p|^2 a_k}{N_0} \tag{15}$$

and

$$B = \sum_k \in Q_2 \frac{|h_{r1} u^p|^2 a_k}{N_0} \tag{16}$$

Thus the resulting data rate in stage 2 is

$$DR_i^{sp} = \log_2(1 + A.\frac{\alpha}{1-\alpha+B_k}) \tag{17}$$

Similarly rate for DR_i^{ps} can be obtained. In order to maximize the utility, the data rate of stage1 $T^i{}_{k\in Q1} DR_i^{sp}$ and stage 2 $T^i{}_{k\in Q2} DR_i^{ps}$ is maintained equally.

Therefore

$$T_{K \in Q_1}^i DR_i^{sp} = T_{K \in Q_2}^i DR_i^{ps} \tag{18}$$

5. Simulation Results

Fig .3 and Fig .4 show the primary users utility in stage 1 and stage 2 as a function of k, where k is the number of relays. The unit of utility is denoted in Mbps. As the number of relays increases, more number of secondary users acts as relays to transmit PUs data. So the data of primary transmitter reaches at primary receiver with a high signal to noise ratio (SNR). This will increase the PUs utility with k for stage 1 and stage 2. Fig .5 and Fig .6 shows the SUs utility as a function of number of relays for stage 1 and stage 2. As the number of relays increases, SUs are helping PUs by acting as relays to transmit primary users data. So SUs utility decreases with increase in number of relays.

Fig .7 illustrates the performance of 2x2 hybrid MIMO cognitive radio networks without using beam forming technique. The PU and SU data rate is plotted for various SNR. The PU data rate is high compared to SU. Fig .8 illustrates the performance of 2x2 hybrid MIMO cognitive radio networks using beam forming technique. By introducing beam forming technique in hybrid MIMO cognitive radio networks, interference gets reduced. So the achievable data rate of PU and SU increases. From the Fig .7 and Fig .8 we can infer that the data rate of 2x2 hybrid MIMO system with beam forming technique is higher than the data rate of 2x2 hybrid MIMO system without beam forming technique.

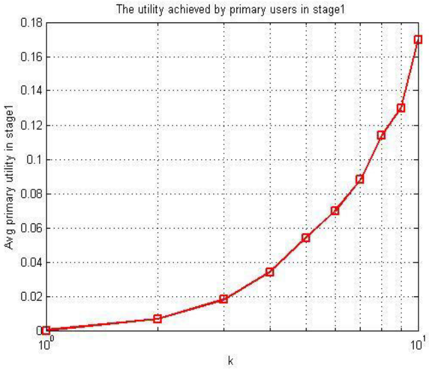

Fig.3. PU Utility in stage 1

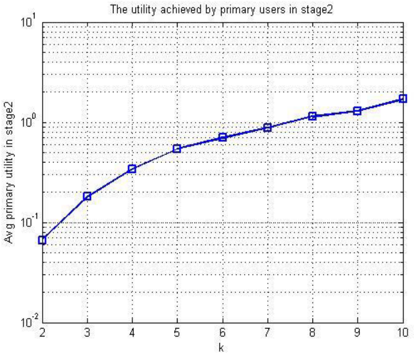

Fig.4. PU Utility in stage 2

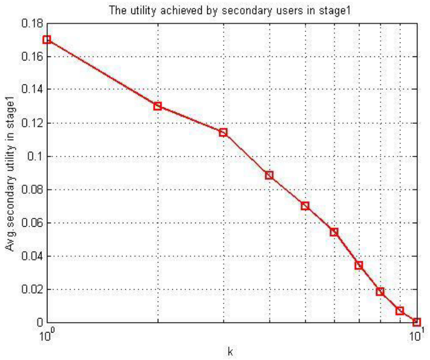

Fig.5. SU Utility in stage 1

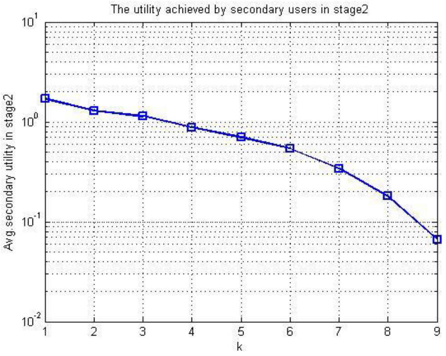

Fig.6. SU Utility in stage 2

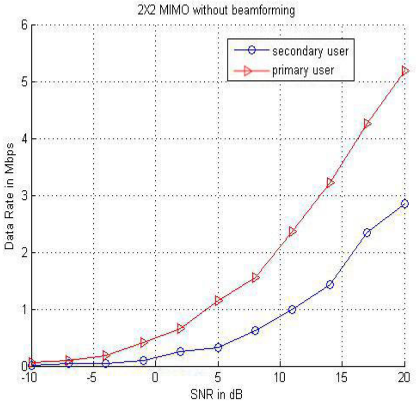

Fig.7. Data Rate without Beam forming

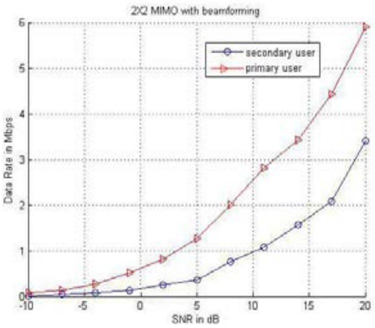

Fig.8. Data Rate with Beam forming

6. Conclusion

In this paper, we have implemented MIMO technique in hybrid cognitive radio networks. Beam forming technique is introduced into the MIMO antennas for reducing the interference level in the desired direction. The results of the investigation show that the data rate of both PU and SU increases with the implementation of beam forming technique in MIMO antennas. Game theory based on Nash Equillibrium is used for power control in PUs and SUs.

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