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Bandwidth Optimization for Cognitive Radio Network via Spatial Coding in MIMO

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Abstract: ***A cognitive radio (CR) is an intelligent radio that can be programmed and configured dynamically. This kind of radio automatically detects available channels in wireless spectrum, then make changes accordingly its transmission or reception parameters to allow more concurrent wireless communications in a given spectrum band at one location. With existing cognitive network, licensed primary users (PUs) can't work together with unlicensed secondary users (SUs) at the same frequency-time domain. SUs of cognitive network have to wait the frequency band occupied by PUs to be free. To solve the problem, a spatial coding approach for MIMO cognitive network, where a MIMO base-station with four antennas provides two different spatial codes for two users such as one PU and one SU, then the SUs can share the bandwidth of PUs. Agile & smart technology proposed by CR deal with the conflicts between spectrum congestion and under-utilization, which helps non-legitimate users to make use of licensed bands opportunistically using spatial coding & spatial multiplexing. The SDR hardware planned to use for this project is bladeRF_x40. It is a Software Defined Radio (SDR) platform designed to enable a community of hobbyists, and professionals to explore and experiment with the multidisciplinary facets of RF communication. It supports, 2x2 MIMO configurable with SMB cable, expandable up to 4x4, RF frequency range 300MHz - 3.8GHz, Stable Linux, Windows, Mac and GNU Radio software support, On-board 200MHz ARM9 with 512KB embedded SRAM (JTAG port available), On-board 40KLE or 40KLE Altera Cyclone 4 E FPGA (JTAG port available).***

Keywords: Cognitive Radio, Cognitive Network, MIMO, Software defined Radio, Spatial coding

1. Introduction

In recent trends, CR has been proposed with agile and smart technology, which helpful for non-licensed users to make use of licensed bands opportunistically. CR can able to sense the unutilized spectrum and select the frequency in dynamic fashion and also control transmitted power. By doing the sharing of same radio channel, interference problem arise and it stand as obstacle to whole system throughput. With this paper, it is proposed to maximize the output of CR network without impacting the licensed primary users.

In normal scenario of application, Cognitive Network (CN) coexists with PUs in the same area. SUs can make use of bandwidth, if PUs doesn't occupy the bandwidth, to exhibit low power. In the scenario of simultaneous operation of PUs & SUs at same frequency, two types of interference would be generated. One type is the interference from SUs towards PUs and the other is from PUs towards SUs. As the PUs is licensed, they always have higher priority in the bandwidth usage compared with SUs. The important challenge is to protect PUs from the interference created by SUs if both are operating simultaneously at same frequency. Solutions can be found to overcome the interference problem.

With the available CR option, the sub-carrier of SUs had to switched off, so that, it would not make interference impact with PUs. By making spatial coding approach in MIMO of CR network, it is proposed to ensure PUs and SUs can work at same bandwidth and SUs need not switched-off. By using proposed approach, SUs can make use of PUs band for their data transmission and both need not interfere with each other data transmission. The proposed spatial coding approach of CR network shares IA technique which helps PUs & SUs can work simultaneously with same frequency. Proposed spatial coding techniques is mainly depends on linear pre-coding at transmitters and no pushing at the receivers, so to move with this option, channel knowledge to be known exactly.

2. Base-Band System for MIMO-CR

2.1 Downlink BASE-BAND

A downlink base-band system with one base-station (BS) and three mobile stations (MSs) is considered as shown as in Figure.1. Assumption is made that, MIMO channel is time varying and channel coefficient is acquired by spatial multiplexing, by doing so channel matrix is well known perfectly.

In Figure.1, six antennas are equipped with BS transmitter and three MS receivers are equipped with two antennas each. The BS transmitter provides three spatial coding flows K_mC_m, m=1, 2, 3 from is three groups of antennas, each group has two antennas. Cm represents signal from antenna group m and pre-coding vector is represented by Km (m=1, 2, 3) at the antenna group m, as it is nothing but 2x1 vector.

The m^{th} ($1 \le m \le 3$) receiver signified signal along with interference from other Base Station transmitter antenna group n ($n \neq m$)

$$\mathbf{q_m} = \mathbf{H_{mm} K_m C_m} + \sum_{n=1,\, n\neq m}^{3} \mathbf{H_{mn} K_n C_n} + \mathbf{r_m} \quad (1)$$

Where $\mathbf{H}_{mn}$ is a 2x2 channel matrix of the communication link between Master Station receiver m and antenna group n, and also, it is interfering link between antenna group n and unexpected receiver m. Radio frequency front end receiver m generating random noise $\mathbf{r_m}$ and $\mathbf{r_m}$ denoted by 2x1 additive noise vector and it is assumed as i.i.d. Gaussian distribution with zero mean and σ^2 variance.

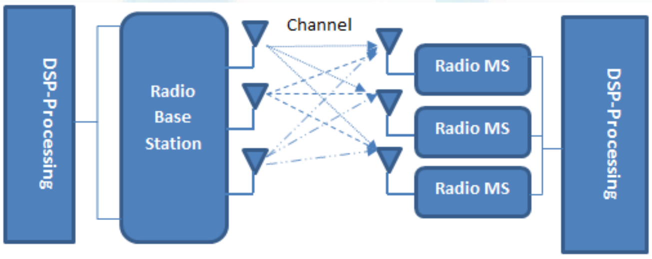

Figure 1: Downlink base band system for CR-MIMO

The proposed pre-coding vector is a kind of spatial codes, which let multi-users' interference to be cancelled at the receivers. In other words, Base Station in Fig. 1 constructs pre-coding vector K_m, m=1,2,3 to encode the transmitting signals C_m , m=1,2,3 and decoding vector j_m , m=1,2,3 for Master-Stations to decode the signal at MS receivers.

The intended pre-coding vector K_m, m=1, 2, 3 and decoding vector j_m , m=1,2,3 should satisfy the following constraints:

$$j_m^H H_{mn} K_m = 0, \ \forall\, m \neq n \quad (2)$$

$$\text{rank}\,(j_m^H H_{mn} K_m) = 1 \quad (3)$$

The Mobile Station (MS) receiver m would get its needed signal from Base Station by multiplying it decoded vector j_m^H.

The decoded signal Z_m at receive m can be obtained by $j_m^H q_m$,

$$y_m = j_m^H q_m = j_m^H H_{mm} K_m C_m + \sum_{n=1,\, n\neq m}^{3} j_m^H H_{mn} K_n C_n + j_m^H r_m \quad (4)$$

Precoded vector can be generated with equations (1) and (4). By solving equations with respective values, we can get respective matrix of precoded vector.

2.2 Uplink BASE-BASE

As like downlink base-band system shown in Fig.1, a MIMO CR uplink base band systems are shown in Fig.2.

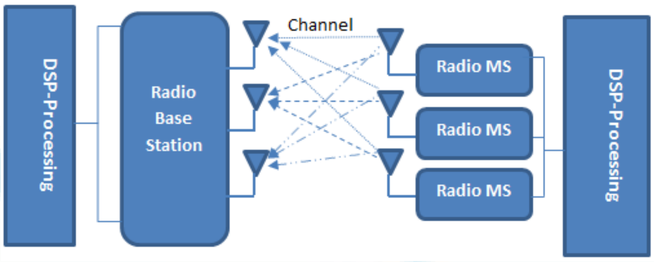

Figure 2: Uplink base band system for CR-MIMO

The MS transmitters provide three spatial coding flows , $K_m C_m$, m=1,2,3 from their antennas, C_m represents the signal from mobile station m and K_m m=1,2,3 represents the precoded vector at mobile station "m" and it is nothing but 2X1 vector. BS divides its six antennas into three groups. The m^{th} ($1 \le m \le 3$) receiver signified signal along with interference from other Base Station transmitter antenna group n ($n \neq m$). The base-band system model in Fig. 2 at certain time instance is expressed by

$$\mathbf{q_m} = \mathbf{G_{mm} K_m C_m} + \sum_{n=1,\, n\neq m}^{3} \mathbf{G_{mn} K_n C_n} + \mathbf{r_m} \quad (5)$$

Where G_{mm} is 2X2 channel matrix of link between antenna group m and the transmitter of mobile station n and G_{mn} is the interfering link between antenna group m and unexpected receiver n. Radio frequency front end receiver m generating random noise $\mathbf{r_m}$ and $\mathbf{r_m}$ denoted by 2x1 additive noise vector and it is assumed as i.i.d. Gaussian distribution with zero mean and σ^2 variance.

The intended mobile station encoding vector Km (m=1, 2, 3) and the base station decoding vector j_m , m=1,2,3 have to satisfy the condition,

$$j_m^H G_{mn} K_m = 0, \ \forall\, m \neq n \quad (6)$$

$$\text{rank}(j_m^H G_{mn} K_m) = 1 \quad (7)$$

The BS receiver antenna group m can get its expected signal from BS by multiplying it's decode vector j_m^H.

The proposed decoder for base station is represented by y_m and the decoded signal at receiver m can be obtained by $j_m^H q_m$.

$$y_m = j_m^H q_m = j_m^H G_{mm} K_m C_m + \sum_{n=1,\, n\neq m}^{3} j_m^H G_{mn} K_n C_n + j_m^H r_m \quad (8)$$

The decoded vector can be generated with equations (5) and (8). By solving equations with respective values, we can get respective matrix of decoded vector.

3. Result of Simulation

To obtain the simulation result, Nuand transmitter and receiver used in MIMO setup hardware kit. GNU radio and GRC(GNU Radio Companion) is used as simulation tool.

Figure 3: Nuand tool kit Tx/Rx

The output is simulated with two Nuand Tx/Rx boards, as in Fig.3, configured in MIMO setup. Two users, one primary user and one secondary user are transmitting at same center with random source and both users share the band-width. The secondary user can also transmit during the same time of primary user transmission. The output for both users is show in Fig.4 and Fig.5.

The primary user is name as User_A0 and the secondary user is name as User_B1. The transmitted data at same frequency by two user simultaneously and received at two different time slot are captured and shown in Fig.4 and Fig5. For simulation purpose, only one primary user and one secondary user is considered. It is the case study of conference paper submission of Ref [15].

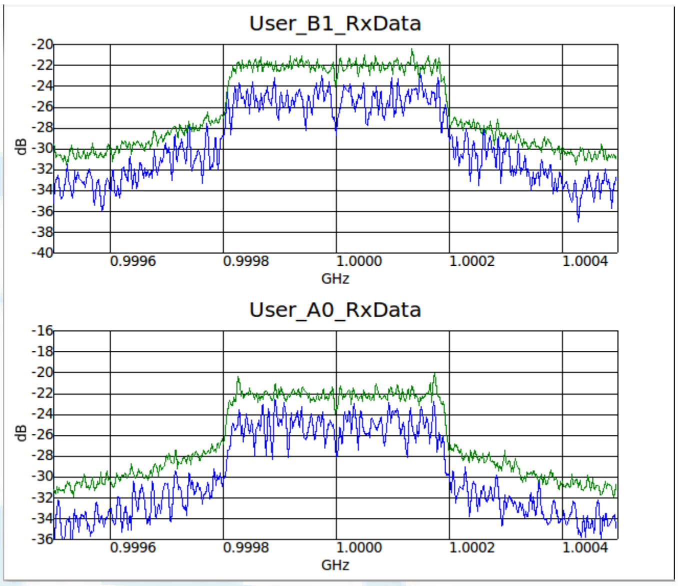

Figure 4: PU and SU Received output at time instance-1

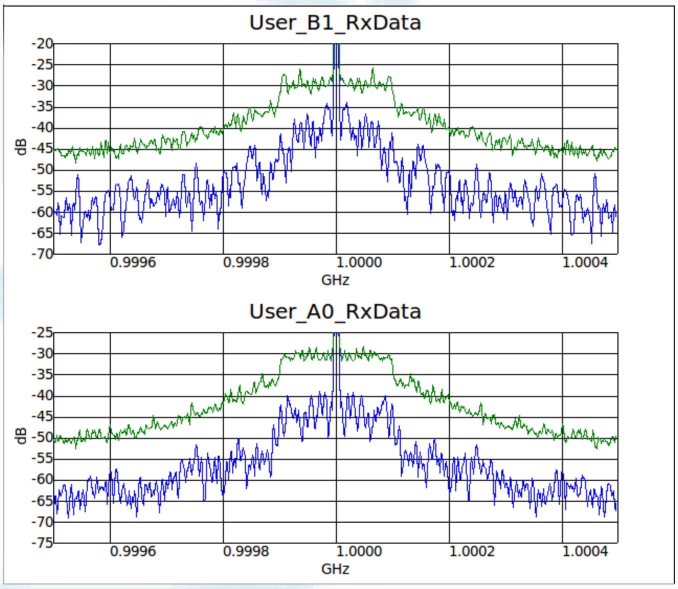

Figure 5: PU and SU Received output at time instance-2

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