www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 5 Issue 09 September 2016 Page No.17944-17950

Survey on Relay and Beam forming Spectrum Sharing Cognitive Radio Networks

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Abstract

This is about relay based CRN and beamforming spectrum sharing CRN. In relay based CRN the cognitive nodes which are far away from primary user (PU) may not be able to detect the PU due to severe fading in channel. To improve the efficiency of spectrum sensing we propose a cooperative communication scheme based on cognitive relaying. In beamforming spectrum sharing two conflicting challenges are how to maintain the interferences generated by the CRN to the primary n/w below an acceptable threshold level while maximizing the sum-rates of the cognitive radio network. We present two beamforming methods, modified zero forcing beamforming and transmit receive beamforming .the zero forcing beamforming is modified by adding the channel gain between the cognitive radio base station and the primary user to meet the two conflicting goals, the orthogonality of transmit beam in MIMO beamforming by Gram-schmidt method achieves the first goal that the primary user is interference free to satisfy the second goal, self interference is reduced by the constrained minimization of the mean output array of cognitive receivers. To reduce complexity of the system, the number of cognitive radio users must be limited.

Keywords: MIMO, Beamforming, Cognitive radio, Cooperative communication

1. Introduction

Radio spectrum is globally allocated to the radio services on the primary or secondary basis. Generally, user can use radio spectrum only after obtaining individual license issued by national regulatory agency. In technical point of view, this approach helps in system design since it is easier to make a system that operates in a dedicated band than a system that can use many different bands over a large frequency range. In addition, spectrum licensing offers an effective way to guarantee adequate quality of service and to prevent interference, but it unfortunately leads to highly inefficient use of radio spectrum resource. To deal with increasing conflict of spectrum allocation congestion and spectrum usage under utilization, cognitive radio approach has been proposed as a method which allows secondary users to opportunistically utilize already licensed bands.

Cognitive radio using opportunistic spectrum access has the possibility to improve spectrum utilization efficiency and in perspective to allow next generation mobile networks access to the attractive radio spectrum bands. Cognitive cycle of cognitive radio operation as secondary radio system is shown in fig.1 Steps of the cognitive cycle are: spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility. Spectrum sensing sense the possible spectrum hole Based on spectrum sensing information cognitive radio selects when to start its operation, operating frequency and its corresponding technical parameters. spectrum sharing: Since there is number of secondary users participating in

usage of available spectrum holes, cognitive radio has to achieve balance between its self-goal of transferring information in efficient way and altruistic goal to share the available resources with other cognitive and non cognitive users.

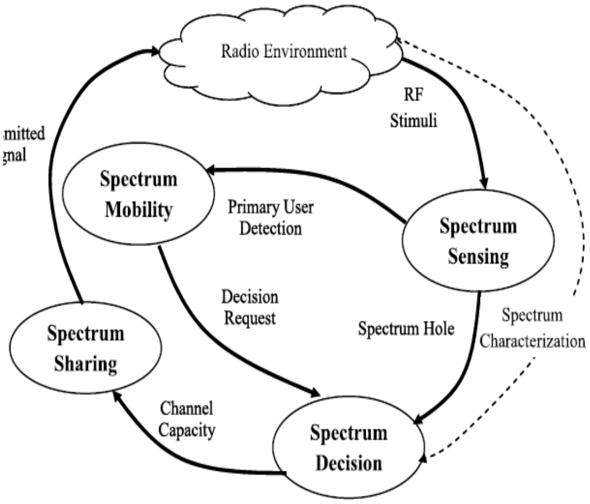

Figure 1: Cognitive cycle of cognitive radio

Spectrum sensing: It is active spectrum awareness process where cognitive radio monitors its radio environment and geographical surroundings, detect usage statistics of other primary and secondary users and determine possible spectrum space holes. Spectrum sensing can be done by one cognitive radio, by multiple cognitive radio terminals or by independent sensing network exchanging information in a cooperative way which improves overall accuracy.

Spectrum decision: Based on spectrum sensing information cognitive radio selects when to start its operation, operating frequency and its corresponding technical parameters. Cognitive radio primary objective is to transfer as much as possible information and to satisfy required quality of service, without causing excessive interference to the primary users. Additionally, cognitive radio may use data from regulatory database and policy database in order to improve its operation and outage statistics.

A. Spectrum sharing

Since there is number of secondary users participating in usage of available spectrum holes, cognitive radio has to achieve balance between its self-goal of transferring information in efficient way and altruistic goal to share the available resources with other cognitive and non cognitive users. This is done with policy rules determining cognitive radio behavior in radio environment.

B. Spectrum mobility

If primary user starts to operate, cognitive radio has to stop its operation or to vacate currently used radio spectrum and change radio frequency. In order to avoid interference to primary licensed user this function has to be performed in real time, therefore cognitive radio has to constantly investigate possible alternative spectrum holes.

2. Survey

(1) Method 1: Relay Based Cooperative Spectrum Sensing In Crn

A. System Model

Recent survey by Federal Communications Commission (FCC) revealed that 70% of the licensed spectrum (primary user band) in US is not utilized. This contradictory situation can be solved by the reuse of licensed band when the primary user (PU) is temporarily inactive. CR is smart and agile technology in this context. Spectrum sensing is an essential component of CR. In spectrum sensing, CR keeps detecting the vacant primary spectrums to use it and meet the growing demand. In order to ascertain the presence of a PU, CR users carry out the detection cycle periodically. Every detection cycle is a combination of sensing time and data transmitting time. To reduce the interference to the PU, it is better to increase the sensing time which in turn reduces the data transmitting time. If we increase the data transmission times to improve the throughput of the secondary network, the sensing time decreases. If the sensing time decreases, it’s hard to guarantee on interference free communication. Thus the tradeoff between the sensing time and the throughput of the secondary network becomes a point of interest.

Maximum throughput is achieved by optimizing the sensing time. Optimization of sensing time balances the sensing time and data transmission time. Cooperative relay communication or cooperative diversity techniques like amplify-and-forward (AF) and decode- and- forward (DF), symbol error rate (SER) and maximum throughput are investigated in single relay based cognitive radio network. In this paper, we have investigated the performance of spectrum sensing for a CR node which is far from PU. The CR node which is far away from PU may not perform spectrum sensing with great efficiency due to severe fading in channel and may create interference to PU. In this condition, to improve the spectrum sensing efficiency, we propose a cooperative network based on relay nodes. The performance has been investigated in terms of BER, throughput, optimal throughput and optimal sensing time. The probability of detection can be improved by cooperative communication, which in turn reduces BER of the system. If the sensing time reduces,

DOI: 10.18535/ijecs/v5i9.25

the transmission time for CR increases which results in improvement of throughput of the CR user. Hence we highlight the major contributions of our paper

We introduce cooperative spectrum sensing based on multiple relay nodes with direct link between PU and CR.

We have investigated the BER of a CR in the proposed model with respect to a number of relay nodes and cooperative diversity techniques.

We have investigated the optimal throughput of the CR which is far from PU and senses the spectrum with the assistance of a number of relay nodes.

Impact of number of co-operating relay nodes on optimal sensing time is estimated.

In cooperative spectrum sensing, the relay stations are introduced in the CR network. In this model, CR_1, CR_2….CR_M are within effective transmission radius (r_p) of primary transmitter (P_{TX}). Hence, the detection probabilities of

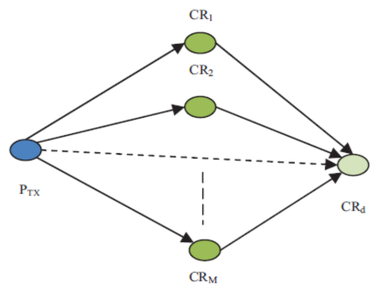

Figure 2: Relay based cognitive radio network

CR_1, CR_2….CR_M will be high. But CR_d is beyond r_p. Hence, it is hard for CR_d to take decision about the presence or absence of PU. To improve the performance of spectrum sensing of CR_d, we consider that CR_1, CR_2….CR_M sense the activity of the PU individually and send their received data to CR_d. The effective transmission radius of each CR is r_c. CR_1, CR_2….CR_M and CR_d are within each other's communication area. In our model, P_{TX} is the source node; CR_1, CR_2... CR_M are the relay nodes and they work on time division duplex mode; CR_d is the destination node. The time frame of each relay CR is divided into two slots. In the first time slot, each relay CR received the signal of PU. In the second time slot, the relay CRs amplify the received signals and send the amplified signals to the destination CR. Signal from relays and signal of direct link is combined by maximal ratio combining (MRC).

The destination CR uses energy detector to make a decision about the presence or absence of the PU by comparing the combined received signal with a predefined threshold (λ). Let $x(n)$ be the transmitted signal from the PU at time slot 1, the received signal at j-th relay CR is given by

$$y_{pr_j}(n) = \sqrt{P_1} h_{pr_j} x(n) + w_{pr_j}(n) \qquad (1)$$

Where $j = 1,2,..M$, P_1 is the transmitted power of the PU, h_{prj} is the channel coefficient between the PU and the j-th CR and w_{prj} is AWGN noise. At time slot 2, the relay CRs amplify and forward the received signals. The received signal at the destination node from j-th relay is given by

$$y_{r_jd}(n) = a_j . y_{pr_j} . h_{r_jd} + w_{r_jd}(n) \qquad (2)$$

Where $j = 1,2,\ldots M$, h_{rjd} is the channel coefficient between the j-th relay CR and the destination CR, $w_{rjd}(n)$ is AWGN noise and a_j is the amplification factor of j-th relay,

$$a_j = \sqrt{P_{tr} / \left[P_1 \left| h_{r_jd} \right|^2 + N_0 \right]} \qquad (3)$$

where P_{tr} is the transmitted power of each relay node and N_0 is the noise variance. The received signal at destination CR through direct link is given by

$$y_{sd}(n) = \sqrt{P_1} h_{sd} x(n) + w_{sd}(n) \qquad (4)$$

Where h_{sd} denotes channel coefficient between source and destination. At the destination CR, all the relay signals and direct link signal are combined by MRC. The combined signal

$$y(n) = y_{sd}(n) + \sum_{j=1}^{M} a_j y_{pr_j}(n) \qquad (5)$$

The combined signal is $y(n)$, the square of $y(n)$ is compared with the predefined threshold (λ), and CR then takes the decision about the activity of the PU. In this connection we consider two hypotheses H_1 and H_0. H_1 indicates that the PU is present and H_0 indicates that the PU is absent

$$y(n) = \begin{cases} b.x(n) + w(n) & H_1 \\ w(n) & H_0 \end{cases} \qquad (6)$$

Where $b = \left(a_j \sqrt{P_1} h_{pr_j} . h_{r_jd} + \sqrt{P_1} h_{sd} \right)$

$$w(n) = \left(a_1 h_{r_j d} w_{pr_j}(n) + w_{r_j d}(n) + w_{sd}(n)\right)$$

where $w(n)$ is the additive white Gaussian noise.

B. Ber Performance Analysis Of Relay Based System

The BER for MPSK modulation can be written as

$$\varphi(\gamma) = \frac{1}{\pi}\int_0^{(M-1)\pi/M} exp\left(\frac{sin^2(\pi/M)}{sin^2\theta}\gamma\right)d\theta \qquad (7)$$

Where γ is the signal-to-noise ratio (SNR). M is the number of message points. When M= 4, the modulation is known as QPSK. We need to find SNR for calculation of BER.

The end-to-end SNR of the j-th link can be given as

$$\gamma_{pr_j d} = \frac{\gamma_{pr_j}.\gamma_{r_j d}}{\gamma_{pr_j}+\gamma_{r_j d}+1} \qquad (8)$$

Where

$$\gamma_{pr_j} = P_1\left|h_{Pr_j d}\right|^2 + N_0 \text{ (9)}$$

is the SNR of the j-th link between the PU and j-th relay CR and

$$\gamma_{r_j d} = Pr_j\left|h_{r_j d}\right|^2/N_0 \qquad (10)$$

is the SNR of the j-th link i.e., between the j-th relay CR and the destination CR.

The total end to-end SNR for M number of relay stations is given by

$$\gamma_{prd} = \frac{1}{N_0}\left(\sum_{j=1}^{M}\frac{P_1 Pr_j\left|h_{Pr_j}\right|^2\left|h_{r_j d}\right|^2}{P_1\left|h_{Pr_j d}\right|^2 + Pr_j\left|h_{r_j d}\right|^2 + 1}\right) \qquad (10)$$

The SNR for the direct link is given by

$$\gamma_{pd} = \frac{1}{N_0}P_1|h_{sd}|^2 \qquad (11)$$

The signals from relay nodes and the signal of direct link is combined by MRC, hence the total SNR at the destination CR for M number of relay stations and direct link is given by

$$\gamma = \gamma_{pd} + \gamma_{prd} \qquad (12)$$

(2) Method 2: Beamforming For Spectrum Sharing Process In Cognitive Radio Networks

A. System Model

The system model of a CR network considered in this paper is composed of heterogeneous wireless systems (primary and secondary networks) as illustrated in Fig.3 The primary and secondary networks co-exist and share the same spectrum in underlay way. The primary network consists of a primary base (PBS) that transmits signals to a single primary user (PU), and both are equipped with single antenna. For secondary cognitive network, there is a single cognitive radio base station (CRBS) with N_t transmit antennas serving K cognitive radio users (CRUs), CRU_1,CRU_2 ……CRU_K . Each CRU is equipped with N_r receive antennas. The number of CRUs is larger than the number of transmit antennas $K >> N_t$. A subset of CRUs is selected. The number of selected CRUs corresponds to the maximum number of transmit beams which is equal to N_t - 1. The objective of the invention of CR network is to opportunistically utilize a frequency band initially allocated to a primary network by providing communications among CRUs (lower priority) and avoiding interferences to the PU (higher priority). As a result of sharing spectrum, the PU is interfered by the signals sent by CRBS. Likewise, the received signals of CRUs are also corrupted by the signals transmitted from PBS. Therefore, CRBS has to trade off between two conflict goals at the same time: one is to maximize its own transmit sum-rate; and other is to minimize the amount of interference it produces at the PU.

In the system model depicted in Fig.3, we assume that CRBS has perfect knowledge of all channel information between CRBS and CRUs, CRBS and PU which can be easily measured from uplink in Time Division Duplexing (TDD) systems such as IEEE 802.16 d/e. As another example, CRBS needs to transmit pilot symbols to allow CRUs and PU to obtain channel estimates which reliably transmitted back to the CRBS via feedback channel. Consider the downlink of the primary network. The signal that the PU receives is modeled as

$$y_p = \sqrt{P_p}g_p s_p + \sum_{k=1}^{N_t-1}\sqrt{P_k}\,h_p^H w_{tk} s_k + z_p \qquad (13)$$

where P_p and P_k denote the transmitted power for the PU and the k -th cognitive data stream, respectively. S_p and S_k are the modulated signals for the PU and the k -th CRU, respectively. g_p is the channel link between the PU and PBS while h_p is the $N_t \times 1$ channel from the CRBS to the PU. Z_p is noise at the primary receiver which is a zero-mean Gaussian random variable with variance σ_p^2 The weight vector $W_{tk} = [W_{tk,1} \; W_{tk,2 \ldots} \; W_{tk,Nt}]^T$ denotes a transmit beamforming vector for the k -th CRU. The weight vector has unit energy, i.e. $\|w_{tk}\| = 1 \; \forall k$. The signal to interference and noise ratio (SINR) of the PU can be written as

$$SINR_P = \frac{P_p|g_p|^2}{\sum_k P_k|h_p^H w_{tk}|^2 + \sigma_p^2} \qquad (14)$$

The sum-rate of the primary system is defined as $R_p = \log(1 + SINR_p)$. The baseband received signal model at the k -th CRU is given by

$$y_k = \sqrt{P_k} w_{rk}^H H_k w_{tk} s_k + \sum_{j \neq k}^{N_t - 1} \sqrt{P_j} w_{rk}^H H_k w_{tj} s_j + \sqrt{P_P} w_{rk}^H g_k s_P + w_{rk}^H z_k \qquad (15)$$

where H_k is the $N_r \times N_t$ channel matrix from the CRBS to the k -th CRU. g_k is the N_r–component channel vector between the PBS and N_r antennas of *k-th CRU* . z_k is the $N_r \times 1$ complex Gaussian noise vector with entries being identically independent distributed random variables with mean zero and variance σ_k^2 . $W_{rk} = [W_{rk,1} \; W_{rk,2} \ldots\ldots W_{rk,n}]$ denotes the receive beamforming vector at the k -th CRU. The weight vector has unit energy, i.e $\|w_{rk}\| = 1$ In Eq. (3), the received signal of certain CRU_k is interfered by three terms as follows

1) interference given by other CRUs,
2) interference from the PBS and
3) additive noise. Then, the SINR of the k -th CRU is

$$SINR_k = \frac{P_k|w_{rk}^H H_k w_{tk}|^2}{\sum_{j \neq k} P_j |w_{rk}^H H_k w_{tj}|^2 + P_P|w_{rk}^H g_k|^2 + \sigma_k^2} \qquad (16)$$

The sum-rate of CR system is defined as

$$R_c = \sum_{k \in S} \log(1 + SINR_k) \qquad (17)$$

where S is a set of the CRUs selected to share the channels. In order to take into consideration two conflicting objectives of CR system: 1) achieve high sum-rate of CR system and 2) limit interference created to the PU as small as possible, we should investigate on appropriate power, transmit and receive beamforming weights to distribute across K cognitive radio users. Moreover, by joiningly consider beamforming and scheduling, one can be able to select some cognitive users from K cognitive radio users that have less effect on the PU and enlarge the sum-rate of CR system at the same time.

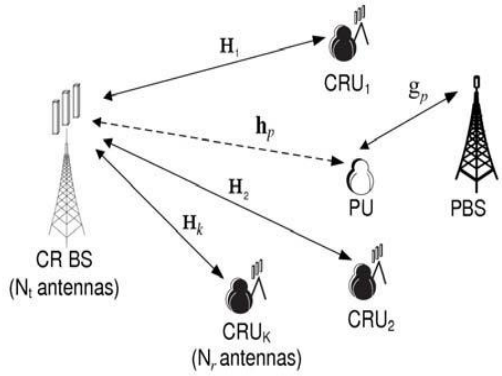

Figure 3: multiple antennas of cognitive radio system

(3) Two Beamforming Strategies

Beam forming is a strategy used by the CRBS in order to minimize the interferences. In CR system, one should deal with not only interferences among CRUs, but also the interferences to the PU. In this section, we propose two beam forming algorithms that can guarantee no interference to the PU and minimize self interferences among CRUs. Consequently, this allows the unlicensed (secondary) users can concurrently across the spectrum allocated to the licensed (primary) users and satisfies the previously two mentioned goals.

A. MODIFIED ZERO FORCING BEAM FORMING

Transmit antenna arrays have been exploited as a strategy of transmit diversity and spatial multiplexing in wireless systems. In this paper, we modify the simple principle of zero forcing beamforming to design the transmit beamforming weight w_{tk} . In this case, the SU's channel is multiple-input single-output (MISO), i.e. there is only single antenna ($N_r = 1$) at the secondary receiver. We assign $w_{rk} = 1$. The number of CRUs that allowed to share spectrum is limited to $N_t - 1$. Scheduling algorithm is used to select the best N_t -

1 CRUs out of total K CRUs. The CRBS determines the transmit beamforming w_{tk} for the k -th CRU by the following criteria.

$$h_p^H W_{tj} = 0 \quad j = 1,2,\dots,N_t - 1 \qquad (18)$$

$$h_k^H W_{tj} = \begin{cases} 1 & j = k \\ 0 & j \neq k \end{cases} \qquad (19)$$

where h_k is the $N_t \times 1$ channel gain vector between the CRBS and CRU_k . The weight vectors are selected so than the PU has interference-free. That is, $h_p^H W_{tj}=0$ ∀j. Also, they null interference among cognitive data streams. That is, $h_k^H W_{tj} = 0$ Eqs. (6) and (7) can be written in a matrix form as

$$\boldsymbol{HW} = \boldsymbol{I}_0 \qquad (20)$$

where H is the $N_t \times N_t$ channel matrix expressed as

$$H = \left[h_P, h_1, h_2, \dots, h_{(N_t-1)}\right]^T \qquad (21)$$

The matrix W denotes $N_t \times (N_t - 1)$ transmit beamforming weights which is

$$W = \left[w_P, w_1, w_2, \dots, w_{(N_t-1)}\right]^T \qquad (22)$$

The variable I_0 is defined as

$$\boldsymbol{I}_0 = \begin{bmatrix} \boldsymbol{O}_{\boldsymbol{1}\times(N_t-1)} \\ \boldsymbol{I}_{(N_t-1)\times(N_t-1)} \end{bmatrix} \qquad (23)$$

where I is an identity matrix. Transmit beamforming weights can be easily found by inverting the channel matrix of the PU and N_t - 1selected users which is given as

$$\boldsymbol{W} = (\boldsymbol{H}^H\boldsymbol{H})^{-1}\boldsymbol{H}^H\boldsymbol{I_0} \qquad (24)$$

The modified zero forcing beamforming can be extended to incorporate multiple PUs. Due to no interference power caused by the CRUs at the PU using Eq. (6), then, Eq. (1) is reduced to

$$y_P = \sqrt{P_p} g_p s_p + z_P \qquad (24)$$

Meanwhile, Eq. (7) satisfies the interference-free among the CRUs. Then, Eq. (3) becomes

$$y_k = \sqrt{P_k} s_k + \sqrt{P_p} g_p s_p + z_k \qquad (25)$$

Eqs. (13) and (14) indicate that the CR system can successfully coexist with the primary system under a tolerable interference to the CRUs generated from the PBS

B. TRANSMIT-RECEIVE BEAMFORMING

For wireless transmission, multiple-input multiple output (MIMO) system is a great potential method to enlarge capacity without bandwidth expansion, enhance transmission reliability via space-time coding and cancel interferences for multiuser transmission. In this second method, both transmit and receive weight vectors in the CR system are therefore designed to protect the primary system from harmful interference and minimize the self interferences .At the CRBS, Gram-Schmidt orthogonalization is utilized to create the orthogonal transmit beams (w_{tk} for k = 1….N_t - 1). At the CRU, the receive beams (w_{rk} for k = 1….N_t - 1) are obtained by minimizing the mean output power of the antenna array constrained to maintaining the unity response at the considered CRU and small sum responses from other CRUs. For comparison, we also show the receive beamforming weight obtained by maximizing the SINR for each CRU.

C. Orthogonal Transmit Beamforming Generated By Gram-Schmidt Orthogona-Lization

According to Gram-Schmidt method, the CRBS with N_t antennas firstly generates N_t – 1 beams orthogonal to the PU's channel h_p . This allows the CRBS transmits data to CRUs without interfering the PU. The procedure of Gram-Schmidt orthogonaliza tion to create orthogonal transmit beams is as follows

1. Generate independent Nt vectors v_k for 1, 2….N_t by using v1=h_p . Let N_t arbitrary vector set $V_k$be obtained from h_p as

$$V_k = \left[h_{P,1}, h_{P,2}, \dots, h_{P,k} + \alpha, \dots, h_{P,N_t}\right]^T \qquad (26)$$

where denotes α an arbitrary number for linear independency with h_p .

2. Generate orthogonal N_t vectors by

$$u_k - v_k - \sum_{j=1}^{k-1} \frac{u_j^H v_k}{u_j^H u_j} u_j \quad for\ k = 2,\dots,N_t - 1 \qquad (28$$

where 1 1 u1=v1

3. The transmit beamforming weight is the normalization of

$$W_{tk} = \frac{u_k}{\|u_k\|} \qquad (29)$$

It satisfies that $h^{H}_{p}\ W_{tk} = 0\ \forall \boldsymbol{k}$Consequently, the CRBS can completely null interferences to the PU.This property yields an expression of Eq. (1) as same as Eq. (13) which is

$$y_p = \sqrt{P_p} g_p s_p + z_P \qquad (30)$$

IV. RESULTS

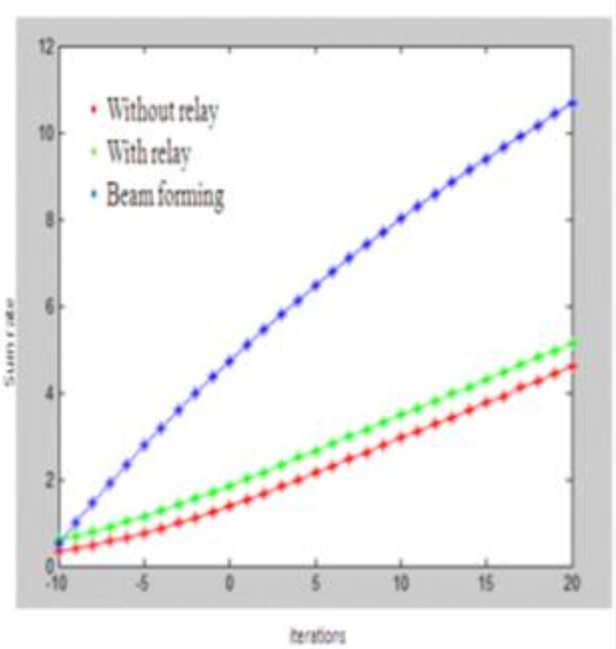

Figure 4: Results of Relay Based Cooperative CRN and Beam forming for spectrum sharing in CRN

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