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**Research Article**

# Spectrum Sharing in Cognitive Radio Based on Spatial Coding

[1]S. Azmat. Hussain, [2]A. Naveed. Malik and [3]I.M. Qureshi
[1, 2]School of Engineering and Applied Sciences (SEAS) Isra University, Islamabad Campus, Pakistan
[3]Department of Electronic Engineering, IIU, H-10, Islamabad, Pakistan

**Abstract:** In cognitive radio, secondary users wittily occupy the spectrum hole and enhance the efficiency at the right location and time. Secondary users reward a chance to access primary user band with the aid of smart cognitive radio technology. In this study we explore the idea of secondary access spectrum through using the cognitive radio network in which the secondary user shares the spectrum with the primary user and defends the primary user from the detrimental interference. Spatial coding akin to adaptive beam-forming and null steering are utilized for appropriate spectrum sharing in cognitive radio. By using these algorithms in cognitive systems, secondary transmitter steers the beam in the direction of secondary receiver and generate the nulls in primary direction so that the minimum interference spawn toward the primary receiver. Simulation outcome established the strength and efficiency of the spectrum sharing.

**Keywords:** Beam-forming, co-channel, interference, spectrum access, spectrum hole, spectrum sharing

## INTRODUCTION

The main concept of cognitive radio is to detect the available channel (spectrum hole) in the wireless spectrum authorized to the primary user and occupy the spectrum hole by the secondary user when the primary (authorized holder) not using the spectrum.

The research effort available on cognitive radio, motivated owing to two key reasons. The foremost is headed for building up procedures for more efficiently using spectrum, which compel to facilitate higher data rates and more wireless devices. The next is to extend mechanized ways of arranging as well as maintaining wireless transportation via minimal human contact. Wireless devices are escalating day by day and challenging to enlarge the bandwidth. The primary users are not utilizing the entire spectrum in time, frequency and space domain. Due to a fixed spectrum policy of the FCC (Federal Communication Communication), under-utilize spectrum of the primary user causes spectrum scarcity. Cognitive radio is the appropriate way to resolve the problem of spectrum scarcity. Preliminary the concept of software defined radio (Mitola and MaguireJr, 1999) was coined which later on extended as cognitive radio.

Due to mushroom development of the wireless devices and fast data rate transmission, the permanent authorized spectrum overloaded and in some geographical region of the world, spectrum is not utilized efficiently which causes spectrum scarcity. The spectrum scarcity is being resolved by using cognitive radio (Haykin, 2005). Though, cognitive radio crafts the serious interference to the primary user and degrades the performance of the primary user when the cognitive user shares the spectrum with primary user. Hence the sharp focus during the spectrum sharing is the interference which required the most effective measure to cure the disease. So to improve the method for reducing the interference at the primary receiver we need to sense the spectrum. To construct the Primary Users (PU) powerful, many techniques are needed for establishing war against the interference when the Secondary User (SU) shares the primary spectrum. However, we categorize the signal styles and enhance the spectrum sensing for detection of the primary user in the spectrum (Akyildiza *et al*., 2006). We need to know the location of the primary user all along with detection of the existence of the primary user in the spectrum. To know the exact location of the primary user, sense the spectrum which based on estimating the direction of arrival of the primary user (Xie *et al*., 2010). Evolutionary computing techniques are used for estimating the direction of arrival (Zaman *et al*., 2012a, b, c). The cognitive user occupies the vacant spectrum band and left or shift to others unoccupied frequency band by using the dynamic frequency hopping concept (Chen *et al*., 2007; Kostic *et al*., 2001). By using the techniques above we can reduce the co-channel interference at the terminals but the reduction of interference at the base station is open to planned for

**Corresponding Author:** S. Azmat. Hussain, School of Engineering and Applied Sciences (SEAS) Isra University, Islamabad Campus, Pakistan

discussion in order to minimize the interference at the base station. So to control the interference at the base station, very effective way is to acclimatize the adaptive beam-forming scheme which reduces the interference and covered the large area (Islam *et al*., 2007). All the explanations are given about the allocation of the spectrum by using the joint combination of power and adaptive beam-forming for primary and secondary users (Yiu *et al*., 2008, Zhang *et al*., 2008; Zhuang *et al*., 2009). The scheme has a discussion concerning to development of transmitting beam-forming, which facilitate better spectrum sharing between primary users and cognitive (secondary) users. Through implementing smart antennas at primary transmitters, we attain the capability of significantly enhancing the successful transmission in cognitive radio. Thus the smart antenna mitigates the interference at the primary user receiver and improve the spectrum utilization of the wireless communication networks.

The general contribution of our work depends upon the implementation of the optimization algorithms which support the simultaneous transmission of primary and secondary users. The novelty of our work includes the integration of cognitive radio system for efficient utilization of spectrum sharing by means of the Direction of Arrival (DOA) estimations, beam-forming and nulls steering. This integrated scheme enhances the coverage area of the cognitive radio system.

In this study, first we suppose that the cognitive system successfully detect the primary user in the spectrum through sensing dome and afterward estimates the angles in order to locate the position of the primary user by using the MUSIC algorithm (Hwang *et al*., 2008) without the complexity of the computational time. We attain two objectives. Firstly, exploit the spectrum opportunities in the angle dimension along with the knowledge of the estimated angle of the primary user. For example, if a primary user transmits in a specific direction; the secondary user can transmit in other directions without creating interference on the primary user. Secondly, subsequent to estimating the direction of arrival for primary users we utilized spatial coding such as the adaptive beam-forming and null steering scheme to steer the beam in the secondary user direction and generate the nulls in the direction of primary users. In this scheme when, the numbers of antenna's elements are increased at the secondary base station, the main beam is being sharply improved toward secondary user while the deep nulls are generated toward the primary users. Thus, by using spatial coding scheme we can share the spectrum, without creating interference in the direction of primary users.

## COGNITIVE RADIO PRELIMINARY

Cognitive radio foremost part consists of the transmission and reception section while the subsequent part discusses the cognitive radio cycle. Finally some assets of the smart antennas be given to exercise in the cognitive radio to mitigate the interference in favor of the primary user and secondary user share the spectrum effectively.

**Cognitive radio transmission and reception model:** According to Fig. 1, the fundamental cognitive radio model consists of transmission and receiving

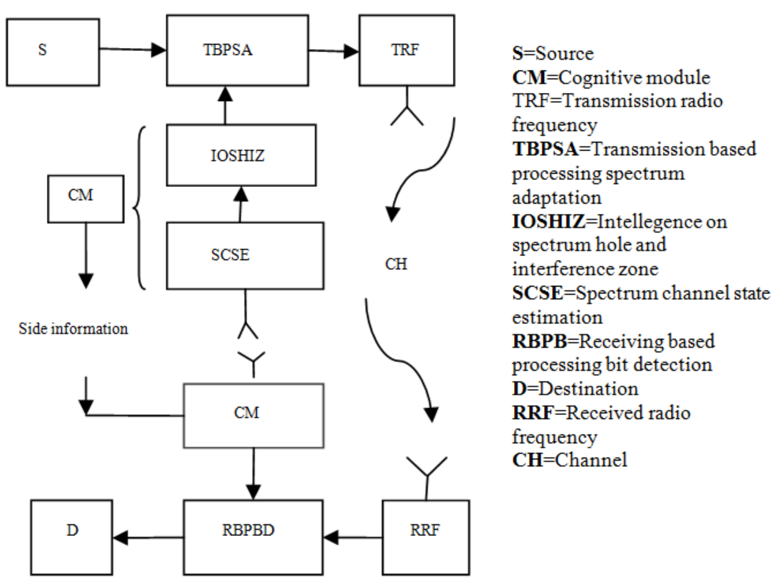


Fig. 1: Cognitive radio model

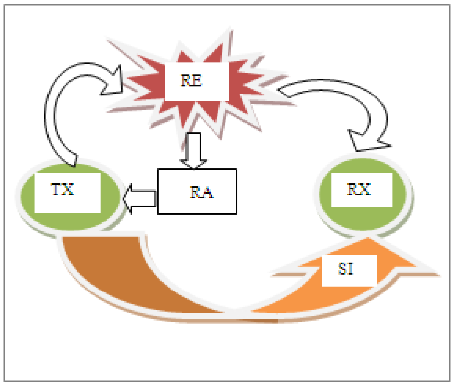


Fig. 2: Cognitive radio cycle

section. The transmission section consists of a source signal generator, transmission base band processing accompanied with Cognitive Modules (CM) and a radio frequency transmitter. First of all the cognitive radiomodule collects the information on the spectrum and estimate the channel state information through SCSE. The other section Intelligence on Spectrum Hole and Interference Zone (IOSHIZ) detects the existence of interference and spectrum holes. The channel estimator judge the channel to derive the channel state information. Based on the information from the cognitive module, source signal is received at the Transmitter Base Band Processing Spectrum and Adaptation (TBPSA) section. The TBPSA unit sends the data to Radio Frequency Transmitter (RFT). The data are then as a final point transmitted throughout the channel.

The data are received at the Radio Frequency Receiver (RFR) and process at the Receiving base Band Processing Bit Detection (RBPBD) unit. This RBPBD unit follows the information from the cognitive module at the receiving end. Cognitive module at the receiver has the side information from the transmitter cognitive module. The transmitter cognitive module and the receiver cognitive module are synchronized. Finally the data receive at the Destination (D) via RBPBD unit.

All the beam-forming algorithms are implemented at the baseband processing unit at the base station and remove the intersymbol interference

**Cognitive cycle:** Cognitive system follows the cognitive cycle during the transmission of the primary and secondary users. According to Fig. 2 first of all start to collect the radio frequency and channel information from the Radio frequency Environments (RE). Sense the spectrum and estimate the available channel. Radio Analysis (RA) collects the channel state information, spectrum hole, interference temperature and traffic information. All the information receives at the Transmitter (TX) and transmitted through the radio environments to the Receiver (RX). Transmitter and the receiver are synchronized via Side Information (SI) from the transmitter.

**Advantages of smart antennas:** As in the proposed algorithms we use multiple antennas at the secondary transmitter. So the most prominent advantages of the smart antennas are: increase of antenna gain, interference rejection and diversity. Antenna gain increases the range of the area coverage from the base station which enhances the battery life. It also helps in designing the smart handset. Smart antenna rejects the interference by generating the nulls toward interference sources. Smart antenna reduces the interferences at the base station during the uplink or reverse link. This improvement in the carrier to interference ratio enhances the capacity of the system. Smart antenna can be used to minimize fading and other undesirable effects of multipath propagation. In addition to spatial and polarization diversity, antenna arrays also allow the use of angular diversity.

## FORMULATION AND PROPOSED ALGORITHMS

According to Fig. 3 two communication links, primary and cognitive are set up in the same environmental area. The cognitive radio coexists with primary user and allows a secondary user to access the spectrum without alarming the primary user.

Consider the Primary Transmitter (PT) which is located at the position ($x_0$, $y_0$) having one antenna element while the Secondary Transmitter (ST) located at the ($x_1$, $y_1$) having multiple antenna element's with a uniform linear array. The distance between the primary transmitter and the secondary transmitter is D = $\sqrt{(x_0 - x_1)^2 - (y_0 - y_1)^2}$. The distance from the primary transmitter to the primary receiver is $d_{pp}$ while from secondary transmitter to secondary receiver is $d_{ss}$. The distance from the primary transmitter to secondary receiver is $d_{ps}$ while from secondary transmitter to primary receiver is $d_{sp}$. Secondary transmitter consists of M multiple antennas arrange in linear array which curtail the interference to the primary receiver. Steering vector of the antenna array is given a:

$$\mathbf{v}(\theta) = \begin{bmatrix} v_1(\theta) \\ v_2(\theta) \\ . \\ . \\ v_M(\theta) \end{bmatrix} = \begin{bmatrix} 1 \\ e^{-j2\pi f_c(d)\sin(\theta)/c} \\ . \\ . \\ e^{-j(M-1)2\pi f_c(d)\sin(\theta)/c} \end{bmatrix} \quad (1)$$

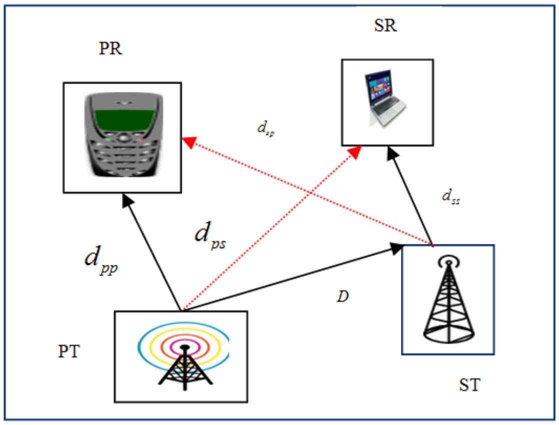


Fig. 3: Proposed model

where,

$f_c$ = The carrier frequency
$d$ = The distance between the antenna elements
θ = The angle of the incident signal with respect to antenna array
M = The antenna elements in the array
c = The speed of light and wavelength $\lambda = c/f_c$

**Formulation for the design:** The Primary Receiver (PR) contaminated by the signals from the Secondary Transmitter (ST) and Secondary Receiver (SR) are interfered by the Primary Transmitter (PT) approximately due to spectrum sharing. In a cognitive radio network the weight vector of the transmit beam-forming is given as w = $[w_1, w_2, \dots, w_M]^H$. The beam-forming gain in the direction of θ can be written as:

$$\mathbf{G}(\theta) = \mathbf{v}(\theta)\mathbf{w} \tag{2}$$

And we suppose that the path loss via a factor α is in a large scale wireless channel, so the channel state information for a consumer in the direction of θ can be articulated as:

$$\mathbf{h} = d^{-\alpha}\mathbf{v}(\theta) \tag{3}$$

Adding a channel and noise in the direction of transmitting signals, the received signals at SU (Secondary Users) and PU (Primary Users) can be expressed as:

$$y_s = \mathbf{h}_{ss}\mathbf{w}s_{ss} + \mathbf{h}_{sp}\mathbf{w}s_{sp} + \eta_s \tag{4}$$

$$y_p = \mathbf{h}_{pp}\mathbf{w}s_{pp} + \mathbf{h}_{ps}\mathbf{w}s_{ps} + \eta_p \tag{5}$$

where, $\eta_s$ and $\eta_p$ a noise for Secondary Users (SU) and Primary Users (PU) that are zero-mean Gaussian with variance $\sigma^2$, while SU and PU have the independent signals $s_s$ and $P_p$ correspondingly.

Let $P_p$ and $P_s$ denote the transmitted power of the ST and PT, respectively. The Signal to Interference and Noise Ratio (SINR) of the secondary and primary receiver can be expressed as:

$$SINR_s = P_s\left|\mathbf{h}_{ss}\mathbf{w}\right|^2 / P_p\left|\mathbf{h}_{ps}\mathbf{w}\right|^2 + \sigma^2 \tag{6}$$

$$SINR_p = P_p\left|\mathbf{h}_{pp}\mathbf{w}\right|^2 / P_s\left|\mathbf{h}_{sp}\mathbf{w}\right|^2 + \sigma^2 \tag{7}$$

Equations (6) and (7) demonstrate the Signal to Interference plus Noise Ratio (SINR) at the output of the primary and secondary receivers.

**MUSIC algorithm:** Preliminary we estimate the angles in the directions of the primary and secondary users. Consider the signals receive at the array is given as:

$$\mathbf{x} = \mathbf{A}\mathbf{s} + \mathbf{n} \tag{8}$$

As the numbers of antenna elements in the array are M so the weight vectors will be the same. Hence the correlation matrix having size M×M can be written as:

$$\mathbf{R}_{xx} = E[\mathbf{x}.\mathbf{x}^H] \tag{9}$$

Putting (8) in (9) we get:

$$\mathbf{R}_{xx} = \mathbf{A}\mathbf{R}_{SS}\mathbf{A}^H + \mathbf{R}_{nn} \tag{10}$$

Here source signal correlation matrix is $R_{ss}$ while the noise correlation matrix is $R_{nn}$. The size of the matrix is M×M. Eigenvalue and eigenvector are finding out from the correlation matrix which are represented as $\lambda_1, \lambda_2, \dots, \lambda_M$ and $e_1, e_2, \dots, e_M$ respectively. Noise is un-correlated with the source signal and are orthogonal to each others. We can derive the $P_{MIUSIC}$ as:

$$P_{MUSIC} = 1/\mathbf{a}(\theta)^H\mathbf{E}_N\mathbf{E}_N^H\mathbf{a}(\theta) \tag{11}$$

**Adaptive beamforming algorithm:** There is no collaboration between PT and ST, so we are not able to direct the behavior of PT and only regard as adjusting ST to construct transmit beam-forming by calculating a set of weights w = $[w_1, w_2, \dots, w_M]^H$. By using the MUSIC algorithm (Hwang *et al.*, 2008) first of all find out the estimated angles. Subsequently the estimated angles are being appropriately at the cognitive system. In cognitive system the secondary transmitter steers the beam in the direction of the secondary receiver and generate the nulls in the direction of primary receiver. The optimization problem at ST can be written as:

$$\begin{aligned}&\max\ SINR_S\\&subject\ to\\&P_s\left|\mathbf{h}_{sp}\mathbf{w}\right|^2\le \mathbf{I}_0\\&P_s\le P_{\max}\\&\left|G(\theta_{ss}\right|^2=1\\&\left|G(\theta_i)\right|^2\le 0.01,\ \theta_i\notin[\theta_{ss}-\Delta\theta,\theta_{ss}+\Delta\theta]\end{aligned}\qquad(12)$$

where,
$I_0$ : The threshold limit that denotes the maxim, interference to the PR
$P_{max}$ : Maximum transmit power of the ST
$\theta_{ss}$ : The direction of arrival of the SU

the minimum resolution angle is Δθ. The constraint $|G(\theta_i)|^2 \le 0.01$, $\theta_i \notin [\theta_{ss}$ - $\Delta\theta$, $\theta_{ss}+\Delta\theta]$ use in (12) to suppress the side lobe and interference receive at PR. Furthermore the total transmitted power at ST is decreased as a result of the constant value that is constrained below 0.01. Due to the located relationship of different users, the transmit beam-forming algorithm is explained in the following two scenarios:

**Scenario 1:** If the angle of PU satisfies $|\theta_{sp}-\theta_{ss}| > \Delta\theta$, we maintain a high Beam-forming gain in the direction of the SU while minimizes beam-forming gain in the direction of the PU and constrain the beam-forming transmission gains outside the angle range $\theta_{ss}$-Δθ, $\theta_{ss}+\Delta\theta$. Thus, the optimization problem is performed same as (12).

**Scenario 2:** If, the PU and SU are located at the same location approximately, as a result we do not put a high beam-forming gain in the direction of $\theta_{ss}$ in favor of cognitive user. Based on (2) and (3), $h_s$w is equivalent to $d_{ss}^{-a}$G ($\theta_{ss}$). In the earliest position, we insert a constraint $\theta_{ss} = \theta_{sp}$, $|\theta_{ss}-\theta_{sp}| \le \Delta\theta$ to the optimization problem which is an annex of scenario 1 and subsequently modify (12) as follows:

$$\begin{aligned}&\max\ SINR_S\\&subject\ to\\&\theta_{sp}=\theta_{ss},\left|\theta_{sp}-\theta_{sp}\right|\le\Delta\theta\\&P_s d_{sp}^{-2\alpha}\left|G(\theta_{sp})\right|^2\le I_0\\&P_s\le P_{\max}\\&\left|G(\theta_{ss}\right|^2=1\\&\left|G(\theta_i)\right|^2\le 0.01,\ \theta_i\notin[\theta_{ss}-\Delta\theta,\theta_{ss}+\Delta\theta]\end{aligned}\qquad(13)$$

When $p_s$ increases at that time according to (6) the interference to PU and $SINR_s$ will increase as well. We obtain a maximum value of G($\theta_{sp}$) which satisfies themaximum interference to PU. So the optimization problem shows the tradeoff between $SINR_s$ and the interference to PU. Therefore, (12) can be expressed as a mini-max optimization problem as:

$$\begin{aligned}&\min\max_{\theta_{sp}-\Delta\theta\le\theta i\le\theta_{sp}+\Delta\theta}\left|G(\theta_i)\right|\\&subject\ to\\&\theta_{sp}=\theta_{ss},\ \left|\theta_{ss}-\theta_{sp}\right|\le\Delta\theta\\&\left|G(\theta_{pp})\right|=1\\&\left|G(\theta_i)\right|^2\le 0.01,\ \theta_i\notin[\theta_{ss}-\Delta\theta,\theta_{ss}+\Delta\theta]\end{aligned}\qquad(14)$$

**Null steering algorithm:** The adaptive null steering algorithm can be utilized for developing the main beam and cancellation of the side lobes. The cognitive system accommodates additional secondary users by suppressing the interference to the primary users. We execute this algorithm by constructing the proposed array radiated pattern, during which the weight vector ought to be calculated firstly through optimization solution .The optimization problem for null steering is formulated as:

$$\begin{aligned}&\min\max_{\theta_{sp}-\Delta\theta\le\theta_i\le\theta_{sp}+\Delta\theta}\left|G(\theta_i)\right|\\&subject\ to\\&\theta_{sp}=\theta_{ss},\left|\theta_{ss}-\theta_{sp}\right|\le\Delta\theta\end{aligned}\qquad(15)$$

where, $|\theta_{ss}-\theta_{sp}| \le \Delta\theta$ which show that Δθ is the minimum resolution angle which is less than the angle $|\theta_{ss}-\theta_{sp}|$.

## SIMULATION AND RESULTS

By using the MUSIC algorithm estimate the desired signal at different angles as given in Fig. 4 and locate the direction of the primary users. The distance between the antenna elements is λ/2. In this algorithm we utilize the four most wanted signal sources and estimate it in the desired directions. The desired angles are 20°, 40°, 90°, 140° and 160° in the directions of primary users while the estimated angles having peaks are shown in Fig. 4.

Adaptive beam-forming and null steering with optimization algorithms are utilized for generating the nulls in the primary directions and maximized the power in the secondary direction. Primary and secondary operate in the same spectrum band and located in the same area. In Fig. 5 we locate the null steering vector of all the angles, 20°, 40°, 140° and

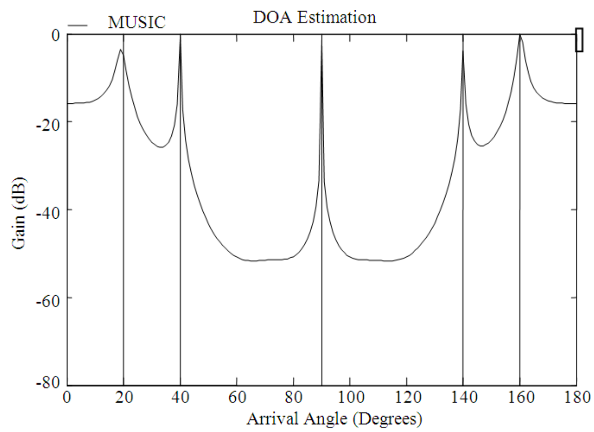


Fig. 4: MUSIC algorithm

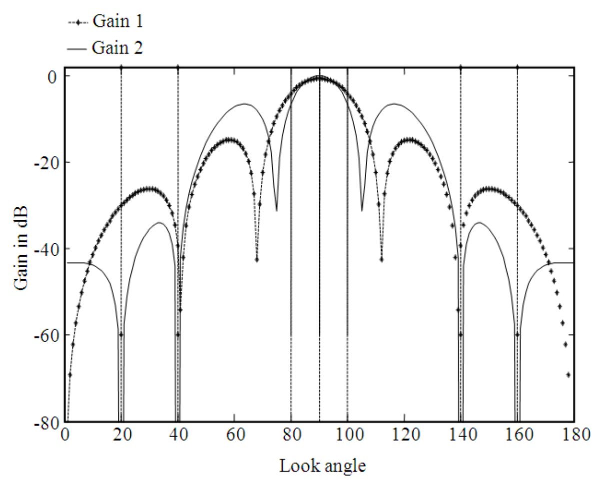


Fig. 5: Adaptive beamforming and null steering algorithms

160°. In this we have the maximum power in the desired direction i.e., 90°. This algorithm minimizes the power outside the main beam and generate the nulls in the direction of the primary users. First of all we find out the beam-forming gain from 0° to 180°. To obtain the null steering vector, we subtract the gain outside the main beam width and generate the nulls in the desired direction. Minimized the maximum value of the gain of the side lobe levels by using the optimization tool. Gain 1 confirm the gain of uniform linear array with antenna elements 7 with broad bandwidth. The side lobe levels decrease due to the broadness of the main beam. Gain 2 demonstrate the gain when the antenna elements are 8 at uniform linear array. The narrow main beam gets owing to increase of the antenna elements in addition to decrease in the levels of the side lobes. As we increase the numbers of antenna elements, the main beam obtainable toward the desired direction turn into sharp. Thus by increasing the antenna elements the maximum power transmitted toward the desired direction. Also we put away the primary user from interference by transmitting the minimum power in the direction of the primary receiver and generate the sharp beam in the direction of secondary users.

## CONCLUSION AND RECOMMENDATIONS

In this study we keep away the primary user from the interference and trim down the power of cognitive radio network. Adaptive null steering enhances the capacity of the cognitive radio and lighten the maximum possible load. As the power is save proficiently so this algorithm can be used in future for relay networks without increasing the computational complexity.

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