Maximizing Achievable Rate Of Cognitive Networks By Uncoordinated Beamforming

Abhilasha Sharma

Abstract

One of the recent trends in wireless communication are cognitive networks. But, these types of networks do have some drawbacks, main one is the interference caused by the cognitive user to the primary user or primary user to the cognitive user. This drawback will totally affect the performance of the entire system, to overcome from these kinds of problems we can use a technique called beam forming vector design at both sides i.e, at the receiver and the transmitter end. The beam forming vectors are designed such that the interference caused by the cognitive transmitter to the primary receiver and the interference caused by the primary transmitter to the cognitive receiver is completely nullified while maximizing the rate of both the primary and secondary links. The proposed algorithms also maximize the achievable rates of both links through uncoordinated beam forming. With beam forming the channel knowledge is exploited at the transmitter to maximize the signal-to-noise ratio (SNR) at the receiver by transmitting in the direction of the eigenvector corresponding to the largest Eigen value of the channel.

Index Terms- Beam forming, precoding, spectrum sharing, OFDM etc.

1. INTRODUCTION

In this paper we are mainly discussing about interference cancellation at the primary user caused due to the cognitive user. Our aim is to reduce these kinds of interferences; various schemes are already used. In this literature we are introducing another technique namely beam forming. By using this technique we can change the phase and amplitude of the signal, this should happen by changing the beam forming vectors. According to the beam forming vectors the phase and amplitude of the signal generated from the antenna should be changed. And also interference caused due to the multi signal transmission should be nullified.

• *ABHILASHA SHARMA is currently pursuing masters degree program in DIGITAL COMMUNICATION in RAJASTHAN TECHNICAL University, INDIA, PH-8189942334. E-mail: abhilashadadhich@gmail.com*

2. PROPOSED SYSTEM TECHNIQUE

2.1 Beam Forming

Beam forming can be used for radio or sound waves. It has found numerous applications in radar, sonar, seismology, wireless communications, radio astronomy, acoustics, and biomedicine. Beam forming techniques are mainly used to change the directionality of the array. When transmitting, a beam former controls the phase and relative amplitude of the signal at each transmitter, in order to create a pattern of constructive and destructive interference in the wave front.
All the weights of the antenna elements can have equal magnitudes. The beam forming is steered to a specified direction only by selecting appropriate phases for each antenna. If the noise is uncorrelated and there are no directional interferences, the signal-to-noise ratio of a beam forming is given by

$$SNR = \frac{1}{\sigma_N^2}.P \tag{1}$$

Where P = Transmitting power, σ_N^2 = Noise Power
In this project we are mainly discussing about the beam forming technique for the reduction of interference between the two systems. Beam forming techniques are much easier technique as compared to other techniques. So we can use change of angle type beam forming technique in this project. The beam forming techniques consist of two important types they are…,
DELAY TYPE
CHANGE OF ANGLE TYPE.
In angle type beam forming technique we have to change the angle of the transmitting antenna beam by using these technique we can easily reduce the interference. But delay type beam forming technique should not be used for this project because this should make some delay to the cognitive user. So we have implemented the change of angle type beam forming technique.

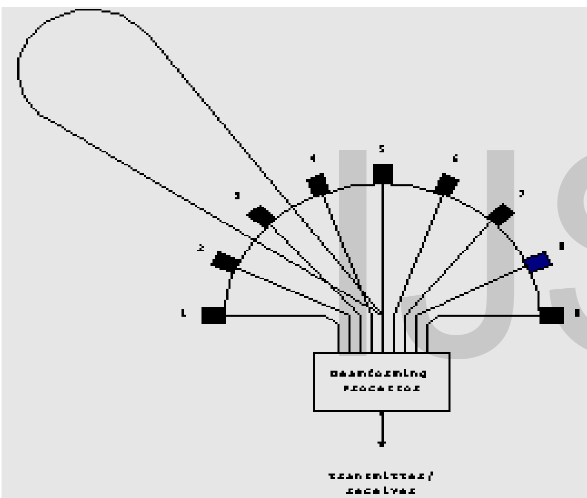

Fig-1: Beam Forming

2.2. Precoding

Precoding is a generalization of beam forming to support multi-layer transmission in multi-antenna wireless communications. In conventional single-layer beam forming, the same signal is emitted from each of the transmit antennas with appropriate weighting such that the signal power is maximized at the receiver output. When the receiver has multiple antennas, single-layer beamforming cannot simultaneously maximize the signal level at all of the receive antennas. Thus, in order to maximize the throughput in multiple receive antenna systems, multi-layer beam forming is required.

2.3 Spectrum Sharing

Now a days, it is clear that much of the spectrum sits idle at any given time. One reason is that we often prevent interference between systems by giving each system exclusive access to a block of spectrum. Thus, whenever such a system is not transmitting, spectrum sits idle. In this project, we seek new methods that allow disparate wireless systems to share spectrum without causing excessive harmful interference to their neighbours. Our goal is to increase the amount of communications that can take place in a given amount of spectrum by orders of magnitude, which would lead to a revolution in wireless products and services.

2.4 Orthogonal Frequency Division Multiple

Orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication. Conceptually, OFDM is a specialized FDM, the additional constraint being: all the carrier signals are orthogonal to each other. In OFDM, the sub-carrier frequencies are chosen so that the sub-carriers are orthogonal to each other, meaning that cross-talk between the sub-channels is eliminated and inter-carrier guard bands are not required. OFDM requires very accurate frequency synchronization between the receiver and the transmitter; otherwise it produces crosstalk between the subcarrier signals.

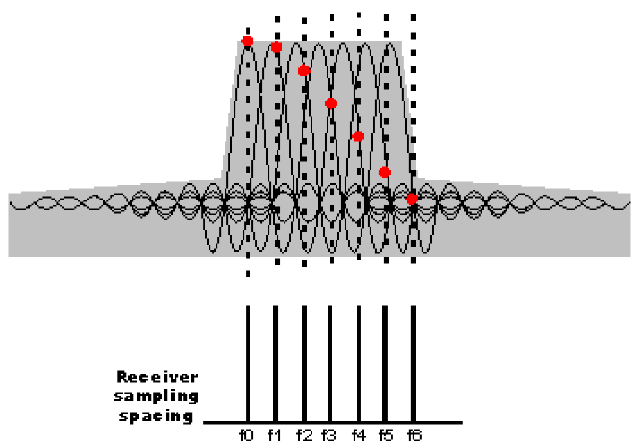

Fig-2: OFDM

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2.5 Rayleigh and Rician Fading Channels

Rayleigh fading is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices. Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium will vary randomly, or fade, according to a Rayleigh distribution the radial component of the sum of two uncorrelated Gaussian random variables. Rayleigh fading is viewed as a reasonable model for tropospheric and ionospheric signal propagation as well as the effect of heavily built-up urban environments on radio signals. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. Rician fading is a stochastic model for radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by several different paths (hence exhibiting multipath interference), and at least one of the paths is changing (lengthening or shortening). Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution. Rayleigh fading is the specialized model for stochastic fading when there is no line of sight signal, and is sometimes considered as a special case of the more generalized concept of Rician fading. In Rayleigh fading, the amplitude gain is characterized by a Rayleigh distribution.

3. MODULES EXPLANATION

3.1 Channel Model

Consider a cognitive network with a single primary user and a single cognitive (secondary) user as depicted in Fig. 3.Each user consists of a transmitter and a receiver. The primary transmitter and receiver are equipped with $N_t^P$and N_t^pantennas, respectively. Receiver is denoted by W whereas the one between the secondary transmitter and receiver is denoted by H. The interference channel from the primary transmitter to the secondary receiver is denoted by D and the interference channel from the secondarytransmitter to the primary receiver is denoted by G.We model the individual channel elements in W, H, D, and G. The primary transmitter employs a beam forming vector u for the transmission of its data symbol xP. At the cognitive link, the transmitter employs a beam forming vector f for the transmission of its data symbol Xc. Xp and Xc are assumed to be complex zero-mean unit variance random variables.

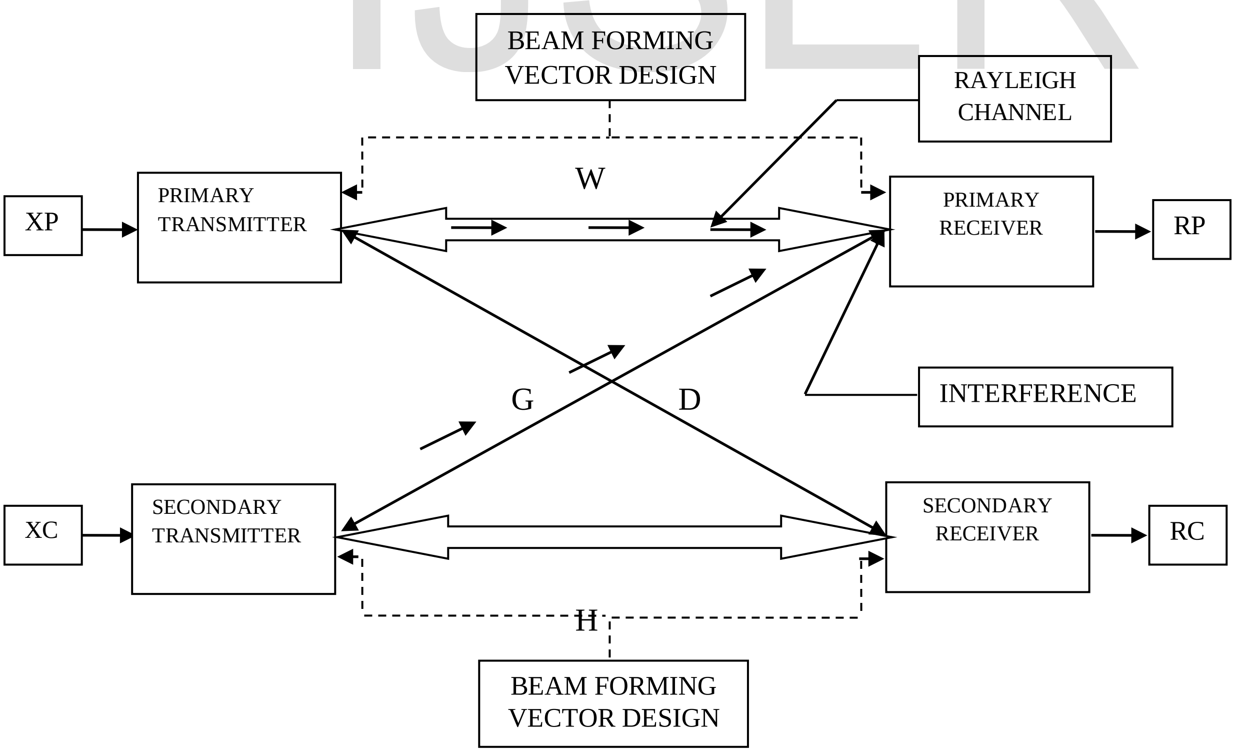

Fig-3: Block Diagram

Furthermore, let v and t be the receiver combining vector for the primary and secondary receiver, respectively.

$$\{V_{opt,}f_{opt,}t_{opt,}u_{opt}\} = argmax\{log_2(1+SINR_P) + log2(1+SINRC)\}$$
$$\text{v,f,t,u}$$
$$\begin{cases} v^*Gf = 0 \; and \; t^*Du = 0 \\ u^*u = f^*f = v^*v = t^*t = 1 \end{cases}$$

$$\{V_{opt,}f_{opt,}t_{opt,}u_{opt}\} = argmax\{log_2(1+SINR_P) + log2(1+SINRC)\}$$
$$\text{v,f,t,u}$$
$$\begin{cases} f \in Null(v^*Gf) \; andt \in Null(Du) \\ u^*u = f^*f = v^*v = t^*t = 1 \end{cases}$$

3.1.1 Received Signal at Primary and Secondary

In this model we first calculate the received signal at both primary and secondary system. Received signal at the receiver side of both primary and secondary system should be calculate using equation (2)-(3).We consider single stream of information only for ease of conveying the main idea. At the cognitive link, the transmitter employs a beam forming vector f for the transmission of its data symbol XC. XP and XC are assumed to be complex zero-mean unit variance random variables. Furthermore, let v and t be the receiver combining vector for the primary and secondary receiver, respectively. Finally, we impose a unit energy constraint on all beam forming vectors, i.e., u*u = f*f = v*v = t*t = 1. Received signal at the primary and secondary receiver's are given by

$$r_p = \sqrt{p_p} v^* wux_p + \sqrt{p_p} v^* Gfx_c + v^* n_p \quad (2)$$

$$r_c = \sqrt{p_c} t^* Hfx_c + \sqrt{p_c} t^* Dux_p + t^* n_c \quad (3)$$

3.1.2 Signal to interference-plus-noise ratio (SINR)calculation

The signal to interference –plus-noise ratio is mainly used to calculate interference ratio of entire system. The Signal to interference-plus-noise ratio (SINR) of the primary and secondary links are given by

$$\mathrm{SINR_P} = \frac{\mathrm{P_P V^* W^* U U^* W V}}{\mathrm{P_P v^* G f f^* G^* v + v^* v \sigma_p^2}} \quad (4)$$

$$\mathrm{SINR_C} = \frac{\mathrm{P_C t^* H^* f f^* H t}}{\mathrm{p_c t^* D u u^* D^* t + t^* t \sigma_c^2}} \quad (5)$$

The SINR ratio should be calculated in both primary and secondary system. SINR should be calculating using the above equations (4)-(5), this calculation should be used to find the achievable rate or sumrate for the entire system.

3.1.3 Sum-rate calculation

Sum-rate calculation should be mainly used to find the system performance. The sumrate should be calculated by using SINR calculation from the above equations (4)-(5). The sum-rate is nothing but ergodic capacity of the system. Total sum rate for both the primary and cognitive system is given by

$$\mathrm{R_S} = \log_2(1+\mathrm{SINR_P}) + \log_2(1+\mathrm{SINR_C}) \quad (6)$$

$$\{\mathrm{vopt, fopt, topt, uopt}\} = \underset{\mathrm{v,f,t,u}}{\mathrm{argmax}} \{\log_2(1+\mathrm{SINR_P}) + \log_2(1+\mathrm{SINR_C})\} \quad (7)$$

$$subject \; to \begin{cases} v^*Gf = 0 \; and \; t^*Du = 0 \\ u^*u = f^*f = v^*v = t^*t = 1 \end{cases}$$

3.2 Beamforming Vector Design

In the cognitive network the secondary user (cognitive user) is transparent to the primary user since the performance of the primary user should not be affected by the secondary link. In these networks zero interference can be achieved by appropriately designing v or f and t or u. To achieve zero interference caused to the primary receiver, these condary transmitter can beam form in the null space of v*G.

Likewise, at the cognitive receiver the receiver beam forming vector t can be designed such that it is in the null space of Du in order to avoid the interference caused by the primary transmitter. Note that v*G is a $1 \times N_t^c$ vector and the dimension of its null space is N_t^c-1. Similarly, the dimension of Du is $N_r^c \times 1$ and the dimension of its null space is $N_r^c - 1$. The rate of the primary user can be maximized by appropriately designing v and u. Since no interference is created at the primary user and the only constraint for the beam forming vectors v and u is the energy constraint. The spectral efficiency can be maximized by maximizing the SINR due to the monotonic property of the logarithm function. It is well known that the SINR maximizing receive beamformer for a point-to-point link is the maximal ratio combining beamformer. The basic beam forming vectors are given by

$$\{f_{opt},t_{opt}\}=\underset{f,t}{\mathrm{argmax}}\left\{\frac{p_c t^*Hff^*H^*t}{t^*t\sigma_c^2}\right\} \quad (8)$$

$$\text{subject to} \quad \begin{cases} f \in \mathrm{Null}(v_{opt}^*G) \text{and } t \in \mathrm{Null}(Du_{opt}) \\ f^*f = t^*t = 1 \end{cases}$$

The signal received at the primary receiver is rearranged according to the beam forming vectors, and given by

$$r_p = \frac{\sqrt{p_p}\,u^*W^*Wu}{\sqrt{u^*W^*Wu}}\,xp + \frac{u^*W^*}{\sqrt{u^*W^*Wu}}\,np \qquad (9)$$

And the corresponding v opt is given by

$$v_{opt} = {Wu}/{\sqrt{u^*W^*Wu}} \qquad (10)$$

And the corresponding SINR is given by

$$SINR_P = \frac{p_p u^*W^*Wu}{\sigma_P^2} \qquad (11)$$

3.2.1 Discrete Search

Let F and T be the set of basis vectors which spans the null space of v_{opt}^*G and D_{uopt} respectively. Note that the cardinality of F and T are N_t^c-1 and N_r^c-1, respectively. The instantaneous SINR of the cognitive link given by

$$SINR_C = \frac{P_C t^*Hff^*H^*t}{t^*t\sigma_c^2} \qquad (12)$$

And it can be maximized by performing an exhaustive search in F and T. Both the secondary beam forming vectors should be designed with interference signal as nullified condition. Beam forming vectors are selected to increase the maximum sumrate of the entire system.

$$\{f_{discrete}, t_{discrete}\} = \underset{f\in F, t\in T}{\mathrm{argmax}} \left\{\frac{p_c t^*Hff^*H^*t}{t^*t\sigma_c^2}\right\} \qquad (13)$$

Note that for $N_t^c = N_r^c = 2$, there is only one vector in the set F and T. In general,

$(N_t^c - 1)$ X $(N_r^c - 1)$ Computations are required to obtain the best beamformers f discrete and t discrete. Although zero interference can always be guaranteed at both receivers by selecting the beamformer pair's f, t as in the above equation, the obtained solution is not optimal in the sense of maximum sum rate because the search in above is not carried out over the entire null space.

3.2.2 Gradient Algorithm

Since any vector in the null space of v_{opt}^*G and D uopt satisfies the zero interference condition, there could be potentially other vectors in those spaces which yield a higher SINRC than f discrete and t discrete. Suppose the columns of $\hat{G}$ and $\hat{D}$ contain the basis vectors of the null space of v_{opt}^*G and D uopt, respectively. The optimal beamformers are in the form of

$$f_{grad} = \frac{\hat{G}a}{\sqrt{a^*a}} \qquad (14)$$

And for t is given by

$$t_{grad} = \frac{\hat{D}b}{\sqrt{b^*b}} \qquad (15)$$

Where $a \in \mathbb{C}^{(N_t^c-1)*1}$ and $b \in \mathbb{C}^{(N_r^c-1)*1}$. The constrained optimization problem in the above equation can now be formulated as an unconstrained one whose goal is to find $a \in \mathbb{C}^{(N_t^c-1)*1}$ and $b \in \mathbb{C}^{(N_r^c-1)*1}$ such that the objective function in the above equation is maximized.The equations is given by

$$\{a_{opt,}b_{opt}\} = \underset{a,b}{\operatorname{argmax}} \left\{\frac{p_c b^* \widehat{D}^* H \widehat{G} a a^* \widehat{G}^* H^* \widehat{D} b}{b^* b a^* a \sigma_c^2}\right\}$$

The gradient algorithm is given by

$$\begin{bmatrix} a[i+1] \\ b[i+1] \end{bmatrix} = \begin{bmatrix} a[i] \\ b[i] \end{bmatrix} + \mu \begin{bmatrix} \partial f(a[i], b[i]) / \partial a[i]^* \\ \partial f(a[i], b[i]) / \partial b[i]^* \end{bmatrix} \quad (16)$$

In the equation 'i' is the iteration index and μ is the adaptation step size. Furthermore the two gradients in the above equation can be rewrite as

$$\frac{\partial f(a[i], b[i])}{\partial a[i]^*} = K\left[\left((b^* b a^* a)\right)\left(\widehat{G}^* H^* \widehat{D} b b^* \widehat{D}^* H \widehat{G} a\right) - \left(a^* \widehat{G}^* H^* \widehat{D} b b^* \widehat{D}^* H \widehat{G} a\right)(b^* b a)\right] \quad (17)$$

$$\frac{\partial f(a[i], b[i])}{\partial b[i]^*} = K\left[(b^* b a^* a)\left(\widehat{D}^* H \widehat{G} a a^* \widehat{G}^* H^* \widehat{D} b\right) - \left(b^* \widehat{D}^* H \widehat{G} a a^* \widehat{G}^* H^* \widehat{D} b\right)(a^* a b)\right] \quad (18)$$

Furthermore, the two gradients are explained in the previous section can be explained in above, from which 'K' is an irrelevant constant. The time index i is dropped in the two gradients for case of presentation. In the next section some guidelines in choosing and adaptation constant μ and the initial values a [1] and b [1] are provided.

3.2.3 Optimal Solution For $N_r^c = 2$

As mentioned in the last section, there is no closed-form solution to the above equation. However, if we fix the number of receive antennas of the cognitive user to two, the joint optimization in the equation becomes a single (vector) variable optimization problem and a closed-form solution is feasible. The equation can be rewrite as

$$\{f_{opt,}t_{opt}\} = \underset{f,t}{\operatorname{argmax}} \left\{\frac{p_c f^* H^* t t^* H f}{t^* t \sigma_c^2}\right\}$$

Assuming the same constraints explain in above. Suppose $N_r^c = 2$ the null space of D uopt is one dimensional. Assume that the null space of D uopt is spanned by t_0 and therefore, the receive beamforming vector at the cognitive receiver is given by $t_{opt} = t_0$. Recall that the optimal beamformers are in the form of above equations.

$$\bar{h} = \hat{G}^* H^* t_o$$

The optimization problem in the above equation becomes,

$$\{a_{opt}\} = argmax \left\{\frac{P_c a^* \bar{h} \bar{h}^* a}{a^* a \sigma_c^2}\right\}$$

By using the above formulae is also known as the generalized Rayleigh fading quotient and by invoking the Rayleigh's principle it is bounded by

$$\frac{P_c \lambda_{min}(\bar{h}\bar{h}^*)}{\sigma_c^2} \le SINR_C = \frac{P_c a^* \bar{h} \bar{h}^* a}{a^* a \sigma_c^2} \le \frac{P_c \lambda_{max}(\bar{h}\bar{h}^*)}{\sigma_c^2}$$

Therefore $SINR_C$ can be maximized by choosing a_{opt} to be the eigen vector corresponding to the maximum eigen values of $\bar{h}\bar{h}^*$. It is interesting to note that although there is no constraint on $a \in \mathbb{C}(N_c^t - 1) * 1$, the optimal solution a_{opt} is always a unit vector and consequently, we can obtain the optimal transmit beamforming vector directly by $f_{opt} = \hat{G} a_{opt}$ without the normalization in the above equation.

3.3 Numerical and Simulation Results

In this model, we present some simulation results. Since the performance of the primary link is independent of the secondary link, without loss of generality we assume $N_t^p = N_r^p = 1$ for all results shown in this section for simplicity. We first consider an example of the gradient algorithm presented in the above sections. For the initialization of the gradient algorithm the below equations are assumed.

$$a[1] = \frac{1_{N_t^c - 1}}{\sqrt{N_t^c - 1}}$$

$$b[1] = \frac{1_{N_r^c - 1}}{\sqrt{N_r^c - 1}}$$

For the initialization of gradient algorithm we use the above equation as an initial value. Furthermore, μ = 0.05 is used for the adaptation size. These parameters are selected based on extensive simulations to ensure rapid convergence of the algorithm. Based on our observation, the initial values a [1] and b [1] has little effect on the convergence behaviour of the algorithm. Therefore, we chose the all one vectors for convenient. We note that another convenient choice would be the vectors obtained by above method. In this project the simulation and results are obtained only by making assumptions on channel matrix. And the channel matrices are created according to Furthermore, with the channel realizations in $\widehat{G}$ *and* $\widehat{D}$and are given by the above equations.

3.4 Performance Comparison for Larger Number of Antennas

In this literature we have already check the performance for different methods. Now we can improve our results for various numbers of antennas. As the number of antennas increases both in transmitter and receiver side the transmission speed is also increases. We can check the results for ten transmitting and receiving antennas. As the number of antennas increases the transmission rate should also increases. So this will suitable for networks that consist of large number of antennas.

4. SCREEN SHOTS

In this section we provide some graphical representation of the entire system. Convergence behavior of the gradient algorithm is shown in the below figure. For this kind of representation we use several plotting tools present in matlab software. Fig.(9) representing the convergence behavior of the gradient algorithm. The values consider here are assumptions based on different predefined functions.

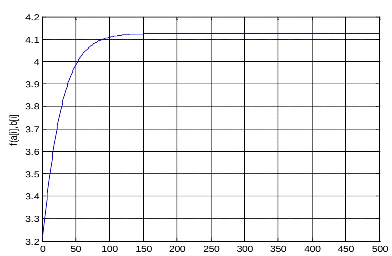

Fig-9: Convergence Behaviour of Gradient Algorithm

In Fig.(10) we are mainly discuss about the sumrate calculation for various methods . First we design the primary system and keep as fixed, next to this we change the number of transmitting antennas according to the usage and check the sumrate of the entire system by comparing it with the primary system.

satisfy the Rayleigh principle. With the chosen parameters, it was found that the algorithm generally converges within 100 iterations. As an example, we consider one realization of the channels shown in assuming N_t^c= 3 and N_r^c = 2, the output of the algorithm at i = 500 is given by the above equation. The corresponding convergence behavior is shown in below figure.

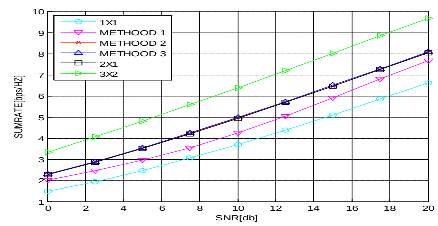

Fig-10:Sum-rate for Various Methods of Beamforming

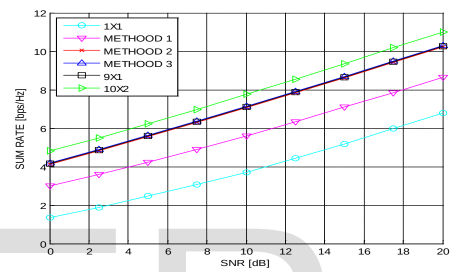

Fig- 11: Sum-rate For Diff Methods of Beam forming (for large no of antennas)

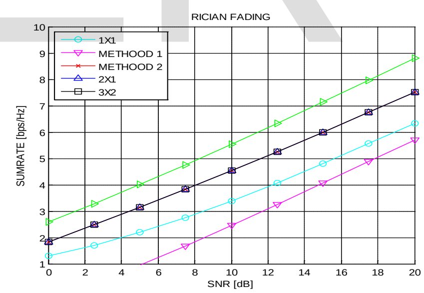

Fig- 12: Sum-rate For Various Methods of Beam forming (for Rician Fading Channel)

5. CONCLUSION

In this literature, we considered interference cancellation and achievable rate maximization via uncoordinated beam forming in a cognitive network which consists of a primary and secondary user. The secondary (cognitive) user was allowed to transmit concurrently with the primary licensed user. The beam forming vectors of the cognitive user were designed such that the interference is completely nullified both at the primary and secondary receivers while maximizing the rate of the cognitive link. Since no interference is created at the primary receiver, traditional approaches can be used to design the beam forming vectors or pre-coding matrices of the primary user. Three approaches were proposed for the design of the beam forming vectors of the cognitive link. Finally, it is noted that we motivate the uncoordinated beam forming and rate maximization concept in a cognitive network. However, the results can also be applied to practical systems, e.g., small cell deployment in a macro network.

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