Sum Rate Maximization by Beamforming over Cognitive Radio Network

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Abstract—An effort has been made to illustrate the performance comparison of the Rayleigh and Rician fading channel models by using MATLAB simulation in terms of Sum rate and signal to noise ratio (SNR). We have developed algorithms for the Rayleigh and Rician fading channels, which computes the Sum rate for the primary and the secondary user. Cognitive radio is regarded as one the most promising technology for supporting spectrum sharing which secondary (cognitive) users coexist with users in primary network whose radio band is licensed. Two conflicting challenges are how to maintain the interferences generated by the cognitive radio network to the primary network below an acceptable threshold level while maximizing the sum-rate of the cognitive radio network. Signaling is the major issue in Cognitive Network. We propose optimum beamforming algorithms to design beamforming vectors for cognitive networks to maximize the achievable rates, where primary and cognitive users share the same spectrum and are equipped with multiple antennas. The proposed technique does not require any changes in the existing environment between the primary and secondary user. The secondary user will be allowed to transmit concurrently to the primary user. Since the primary user is a licensed one it need not to have any knowledge about the resources utilized and performance of the secondary user and it transmits independently. Simulation results are given to evaluate the performances of the proposed methods in forms of SINR and sum-rates.

Index Terms— Beamforming ; cognitive radio network ; MIMO ; constrained optimization; Rician fading channel; angle of arrival (AOA).

1. INTRODUCTION

With the popularity of various wireless technologies and fixed spectrum allocation strategy, spectrum is becoming a major bottleneck, due to the fact that the most of the available spectrum has been allocated. Moreover, the increasing demand for new wireless services, especially multimedia applications, together with the growing number of wireless users and demand of high quality of services have resulted in overcrowding of the allocated spectrum bands, leading to significantly reduced levels of user satisfaction. Particularly, spectrum congestion is a serious problem in communication-intensive situations such as after a ball-game or in a massive emergency. According to Federal Communication Commission (FCC) [1], some spectrum band remains unused at a given time and location, indicating that a more flexible allocation strategy could solve the spectrum scarcity problem. For example, cellular network bands are overloaded in most parts of the world but television broadcasting, amateur radio and paging have been found to be grossly underutilized. This motivates a new paradigm of either through opportunistic spectrum sharing or through spectrum sharing for exploiting the spectrum resources in a dynamic way. Cognitive radio provides the secondary users (SUs) (lower priority) to share the licensed spectrum originally allocated to the primary users (PUs) (higher priority). In opportunistic spectrum access, the SUs, also called cognitive radio users (CRUs) needs to sense the radio environment and identify the temporally vacant spectrum, i.e. the secondary and primary users do not operate on the same spectrum simultaneously. A cognitive network has a cognitive process that can perceive current network conditions, and then plan, decide and act on those conditions [2]. The network can learn about these adaptations and the ultimate aim is to provide end to- end communication. In the literature, few works have been done on interference cancellation in cognitive radio network. It was presented a practical method using multi-antenna radios to cancel interference in cognitive radio systems [3]. Under this method cognitive radio transmitters use beamforming techniques to find antenna weights that place nulls in the directions of the primary receivers, and cognitive radio receivers use adaptive techniques to decode in the presence of interference from primary users. The cognitive radio transmitters are equipped with multiple antennas while each of the primary radios employed a single antenna. In order to receive data from the cognitive radio receivers the cognitive radio transmitters need to cancel the interference from the primary transmitters.

However, using this method, minor modifications at the primary system is required which is not a feasible solution. Beamforming is a well-known spatial filtering technique which can be used for either directed transmission or reception of energy in the presence of noise and interference [4]. By using this technique, simultaneous communication links between the primary and secondary users with minimized or even total avoidance of interference is enabled. The basic idea of beamforming in cognitive radio is to direct the desired signal to the direction of the destination and to minimize the transmission energy towards the primary users. In the proposed work, no coordination is required between the primary and cognitive user [5].

In this paper, we consider a cognitive network that consists of a single primary and secondary user [6]. Each user consists of multiple antennas and beamforming transmit/receive vectors at the transmitter and a receiver. So, sharing of same spectrum by two users might cause cross interference between them. The main goal of our project is to reduce the interference present in these types of systems. Beamforming technology is proposed to overcome such drawbacks. Linear vector precoding for downlink cognitive systems is considered in [7]. In particular, an optimal interference-free precoding scheme was proposed which completely removes the interference to the other system. However, multiple antennas are considered only at the transmitter side. Another important thing is that it requires coordination between the transmitter and the receiver for both primary and secondary system. As a result, beamforming vectors can be used only at the transmitters. We propose some methods for the design of beamforming vectors to cancel the interference while maximizing the rate of both the links.

By using multiple antennas at the secondary user, the proposed designs do not require knowledge of the cognitive communication link at the primary user. In fact, the secondary user is invisible to the primary user. So coordination is not required between the primary and secondary users.

2. MIMO IN FADING ENVIRONMENT

Signaling is the major issue in Cognitive network. MIMO is a communication technique in which a multipath properties of channel is utilized to support higher throughput. Intersymbol interference and fading in multipath propagation are major issues in wireless communication. MIMO improves the performance of communication networks. MIMO can increase the system capacity and improve the transmission reliability. MIMO enabled cognitive network performs well when compared to normal cognitive network. A Rician model is obtained in a system with Line of sight (LOS) propagation and scattering. The model is characterized by Rician factor denoted by K, and the Rician factor is defined as the ratio of the line of sight and the scatter power components.

3. COGNITIVE RADIO MODEL

In this paper, we consider a cognitive radio network consists of a pair of primary transmitter and receiver and a pair of secondary transmitter and receiver. The network model is depicted in Fig. 1 where solid lines represent desired signals at the receiver and dashed lines represent interference signal. Each user consists of a transmitter and a receiver equipped with multiple antennas. h_{pp} denotes the complex channel gain between primary transmitter and primary receiver, whereas h_{ss} denotes the channel gain between secondary transmitter and secondary receiver. The interference channel from primary transmitter and secondary receiver is denoted by h_{ps} and the interference channel from secondary transmitter and primary receiver is denoted by h_{sp}. The transmitter and receiver equipped with several antennas.

In our model, we assume that for the transmission of data symbol xp, the primary transmitter employs a transmit Beam-forming vector p while to transmit data symbol xc, the secondary transmitter employs a beamforming vector t. We also denote q and v as receive combining vector for primary receiver and secondary receiver, respectively.

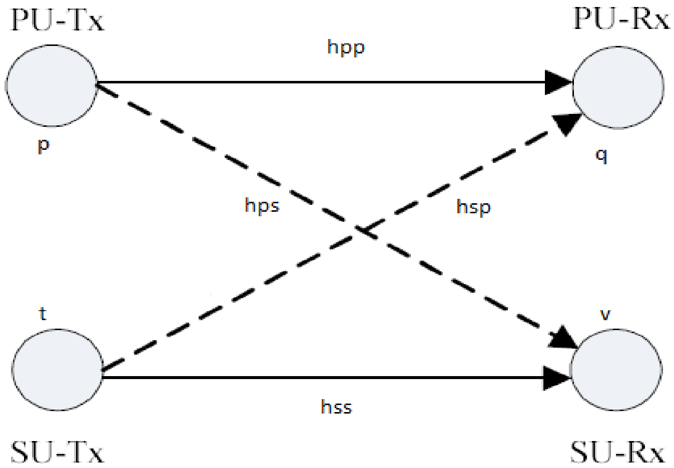

Fig.1. Proposed Cognitive Network Model

We also impose a unit energy constraint on all beamforming vectors. The received signal at the primary receiver and the secondary receiver are given respectively by

$$r_p=\sqrt{P_p}q^* h_{pp}px_p+\sqrt{P_p}q^* h_{sp}tx_c+q^*n_p \quad (1)$$

And

$$r_c = \sqrt{P_c}\, v^* h_{ss}\, t\, x_c + \sqrt{P_c}\, v^* h_{ps}\, p\, x_p + v^* n_c \quad (2)$$

Where P_P and P_C are the transmit power at the primary transmitter and secondary transmitter. The resulting SINR at the primary receiver is given

$$SINR_P = \frac{P_P q^* h_{pp}{}^* pp^* h_{pp} q}{P_P q^* h_{sp} tt^* h_{sp}{}^* q + q^* q \sigma_P^2} \quad (3)$$

And that at the secondary receiver by

$$SINR_C = \frac{P_C v^* h_{ss}{}^* tt^* h_{ss} v}{p_c v^* h_{ps} pp^* h_{ps}{}^* v + v^* v \sigma_c^2} \quad (4)$$

In order to achieve zero interference, the weight p, q, t, and v have to be designed such that $q^* h_{ps} t = 0$ and $v^* h_{sp} p = 0$, σ_p^2, σ_c^2 are the noise variance

In wireless communication, the sum rate of a system is dependent on the value of the SINR at the receivers. The rate for a primary user is given by

$$R_P = \log_2(1 + SINR_P) \quad (5)$$

While for secondary user is denoted by

$$R_C = \log_2(1 + SINR_C) \quad (6)$$

The total achievable sum rate of the system can be expressed as

$$R_S = R_P + R_C \quad (7)$$

$$R_S = \log_2[(1 + SINR_P)(1 + SINR_C)] \quad (8)$$

Considering the first constraint of (9), it is obvious that zero interference can be achieved by appropriate designing q or t and v or p, therefore the design optimization problem can be mathematically formulated as

$$\{q_{opt}, t_{opt}, v_{opt}, p_{opt}\} = \underset{q,t,v,p}{\operatorname{argmax}} \{\log_2(1 + SINR_P) + \log_2(1 + SINR_C)\}$$

$$\text{subject to} \quad \begin{cases} q^* h_{sp} t = 0 \text{ and } v^* h_{ps} p = 0 \\ p^* p = t^* t = q^* q = v^* v = 1 \end{cases} \quad (9)$$

4. BEAMFORMING VECTOR DESIGN

4.1 BEAMFORMING VECTOR DESIGN STRATEGY FOR PRIMARY LINK

Having achieved zero interference in the network, the remaining goal that we need to look into is how to maximize the SINR while simultaneously increase the system rate. In this section, we will present the optimum transmit and receive weight strategy for primary link. Primary user has higher priority or legacy rights on the usage of the spectrum, the primary user should not be required to know the existence of the secondary user. Therefore, the primary user can simply optimize p and q to maximize its own $SINR_P$ and R_P.It is well-known that the optimal combining weights to Maximize SINR for a point-to-point link is using maximal - ratio combining (MRC) beam-former. Thus, in this paper, we employ this technique in designing receive weight for primary link, q. Using MRC, the signals from different receive antennas are first weighted properly according to individual noise powers and instantaneous channel powers and then coherently combined.

4.2 BEAMFORMING VECTOR DESIGN STRATEGY FOR SECONDARY LINK

In this section, we will present the optimum transmit and receive weight strategy for secondary link such that the $SINR_C$ and R_C are maximized. Those optimal beamformers can be obtained by solving the optimization problem. The basic beamforming vectors are given by the following equation

$$\{t_{opt}, v_{opt}\} = \underset{v,t}{\operatorname{argmax}} \left\{ \frac{P_C v^* h_{ss} tt\, H^* v}{v^* v \sigma_C^2} \right\}$$

(10)

$$\text{subject to} \qquad \begin{cases} t \in Null(q_{opt}^* h_{ss}) \text{ and } v \in Null(h_{ps} p_{opt}) \\ t^* t = v^* v = 1 \end{cases}$$

4.2.1 GRADIENT ALGORITHM

Gradient algorithm (steepest ascent) method is used to find the optimum beamforming vectors. Any vector in the null space of $q_{opt}^* h_{sp}$ and $h_{ps} p_{opt}$ satisfies the zero interference condition. The direction of maximum ascent is calculated using the gradient vector. The optimal beamformers are given by

$$t = \frac{\widetilde{h_{sp}}\, a}{\sqrt{a^* a}} \qquad (11)$$

And $$v = \frac{\widetilde{h_{ps}}\, b}{\sqrt{b^* b}} \qquad (12)$$

Where, $a \in C^{(N_{Tx}^C - 1)*1}$ and $b \in C^{(N_{Rx}^C - 1)*1}$.

The Gradient algorithm is given by

$$a[i+1] = a[i] + \mu \frac{\partial f(a[i], b[i])}{\partial a[i]^*}$$

$$b[i+1] = b[i] + \mu \frac{\partial f(a[i], b[i])}{\partial b[i]^*}$$

(13)

Where i is iteration index and μ is the adaptive step size . The optimum value of a and b can be obtained in repeated iterations.

4.2.2 LEAST MEAN SQUARE (LMS) ALGORITHM

The Least Mean Square (LMS) algorithm can also be used to obtain $a_{opt,}$ and b_{opt} . The LMS algorithm is given by the

$$a[i+1] = a[i] + \mu\, e^*(i)\, x(i) \qquad (14)$$

$$b[i+1] = b[i] + \mu\, e^*(i)\, x(i) \qquad (15)$$

In this updating of the vector in such a way that minimizes the error signal given by

$$e(i) = d(i) - y(i) \qquad (16)$$

where d(i) is the zero mean reference signal an y(i) is the output signal of the beamformers such that ,

$$y(i) = a^H(i)\, x(i) \qquad (17)$$

where i = iteration index and μ= adaptive step size

In LMS algorithm, it is not necessary that gradient vector to be known, and is estimated at every iteration. It will estimate the gradient vector value from the available data. LMS Algorithm includes an iterative procedure which makes successive corrections to the weight vectors in the opposite direction of the gradient vector which leads to the minimum mean square error .The value for a and b can be obtained from repeated iterations

5. SIMULATION RESULTS AND DISCUSSION

In this section, we demonstrate through extensive simulation, the SINR performance of both primary and cognitive link under the condition that the cross interference at both receivers are completely nullified. In maximizing the SINR, we employed MRC technique as discussed in section IV for primary link and for secondary link, we considered two methods discussed in the section V which are gradient algorithm and LMS algorithm. We also conducted a simulation to determine the sum rate for both primary and secondary link

First, we carried out the simulation for SINR at different value of SNR as shown in Fig. 2. In this simulation, we consider that the primary user is employing MRC technique to maximize the sum rate of primary link while the secondary user is employing Gradient method to maximize its SINR and sum rate. Both the transmitter and receive antennas of primary user are set to 1, while secondary user number of antenna is 3 and 2 at transmitter and receiver side, respectively. The value of SINR at secondary user is higher than the value of SINR at primary user. For the initialization of the gradient algorithm

$$a[1] = \frac{1_{N^{C}_{Tx}-1}}{\sqrt{N^{C}_{Tx}-1}} \qquad (18)$$

And

$$b[1] = \frac{1_{N^{C}_{Rx}-1}}{\sqrt{N^{C}_{Rx}-1}} \qquad (19)$$

Here, μ = 0.04 is used for the adaptation size, is choose to ensure rapid convergence of the algorithm.

Using this method, the SINR performance of secondary user is always higher compared to the SINR of primary user. From the figure, it is obvious that increasing the number of both transmit and receive antennas at the secondary user will increase the value of SINR.

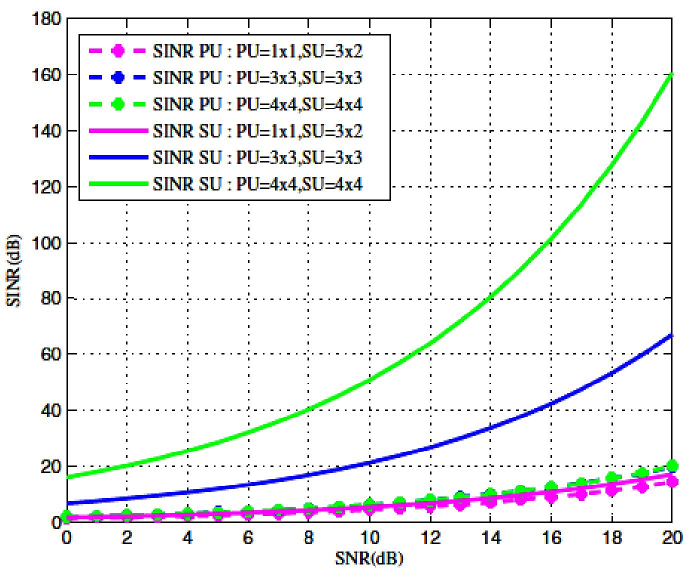

Fig.2. SINR vs. SNR for primary user and secondary user using Gradient Algorithm

In LMS algorithm is an implementation of the steepest-descent based approach to estimate the gradient of the error signal. It is computationally efficient, but is a bit slow in convergence. Also its convergence is dependent on the eigenvalue spread variation of the input signal.

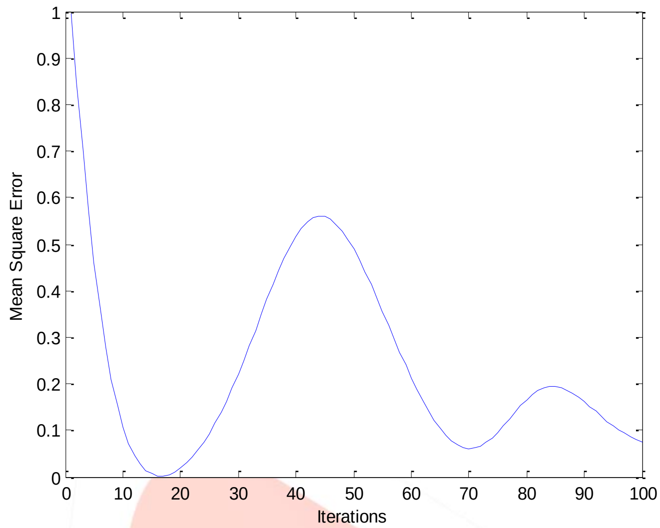

Fig. 3. Convergence Behavior of LMS Algorithm.

Convergence behavior of LMS algorithm also depends on desired users AOA(Angle of Arrival) and interferers AOA. In LMS algorithm the mean square error decreases with successive iterations as shown in figure 3. From the simulation, we observe that by using optimum beamforming vectors, the interference can be nullified and sum rate can be increased. Comparison of LMS and Gradient Algorithm is shown in figure 4.

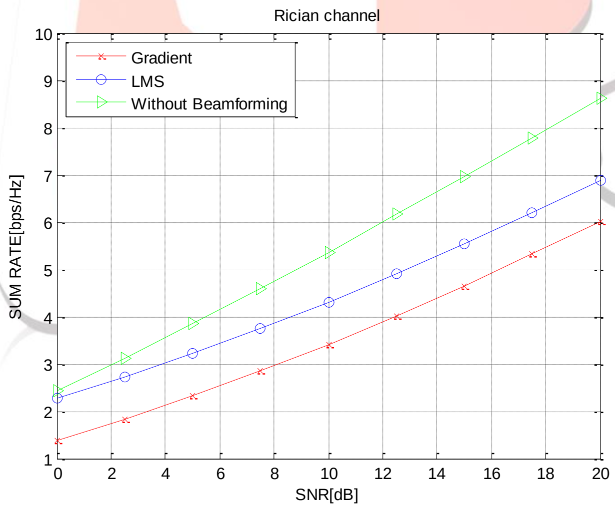

Fig.4. SUM RATE [bps] vs. SNR [dB] for Rician Channel

From the simulation, we observe that by using optimum beamforming vectors, the interference can be nullified and sum rate can be increased. The sum rate performance of beamformers obtained from LMS algorithm are better than the performance of the once obtained from Gradient algorithm, according to fig. 4 LMS algorithm is 4dB better than Gradient algorithm. The gap between the LMS curve and without beamforming curve is about 2.5dB and it represents the price that has to be paid in order to avoid cross interference between primary and secondary links.

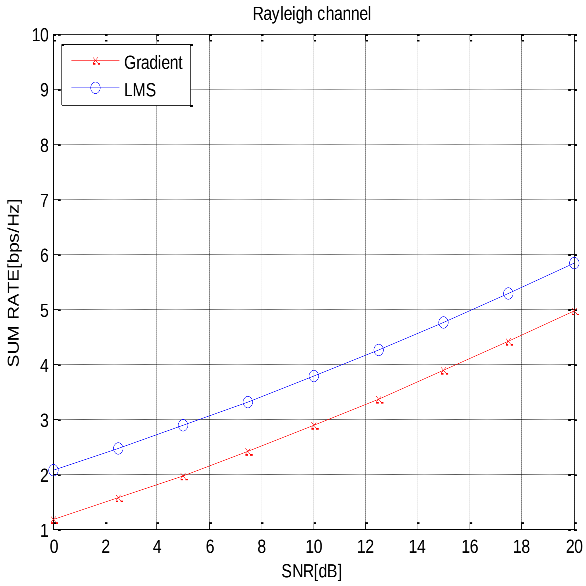

Fig.5. SUM RATE [bps] vs. SNR [dB] for Rayleigh Channel

Finally we are comparing the Sum Rate results obtained in Rician channel environment and Rayleigh channel environment; from results we can find that the performance of Rician channel is better than the performance of Rayleigh channel.

6. CONCLUSION

In this paper, we presented the performance evaluation of Uncoordinated beamforming algorithms for cognitive radio networks in maximizing the SINR of primary and secondary links and achievable sum rate of the system when both primary and secondary users transmit concurrently over the same spectrum. We used gradient algorithm and LMS algorithm for the design of beamforming vector of the cognitive link. These results can be used in practical systems like cognitive radio, small cell deployment in macro network etc. to improve the performance. In future, we can extend this work in such a way that secondary user can also transmit without monitoring the primary link.

REFERENCES

[1] Federal Communications Commission, ‘Spectrum policy task force’, Rep. ET Docket no. 02-135, Nov. 2002.
[2] Thomas R.W, Lusiz A .Da Silva, Allen B. Mackenize, ”Cognitive Networks, ”New Frontiers in Dynamic Spectrum Access Networks,2005. pp .352-360.
[3] O. Bakr, M. Johnson, R. Mudumbai and K. Ramchandran, “Multi- Antenna Interference Cancellation Techniques for Cognitive Radio Applications”, WCNC 2009, page 1-6.
[4] B. D. V. Veen and K. M. Buckley, “Beamforming: A versatile approach to spatial filtering,” IEEE ASSP Magazine, pages 4-24, 1988.
[5] S. Yiu, C. B. Chae, K. Yang and D. Calin, “Uncoordinated Beamforming for Cognitive Networks,” IEEE Transactions On Communications, vol. 60, no. 5, May 2012.
[6] J. Mitola, “Cognitive radio,” Ph.D. dissertation, Royal Institute of Technology (KTH), 2000.
[7] J. Zhou and J. Thompson, “Linear precoding for the downlink of mulitple input single output coexisting wireless systems,” IET Commun., vol. 2, pp. 742–752, July 2008.
[8] John J. Proakis, Dimitris G. Manolakis, Digital Signal Processing, Pearson Education, 2002.