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Interference Cancellation and Rate Maximization in a Cognitive networks

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Abstract

Cognitive networks is an emerging technology to alleviate the spectrum shortage problem faced by traditional wireless networks through efficient utilization of resources. signaling is the major issue in the cognitive networks. Multiple Input Multiple Output (MIMO) technique is used for the transmission of signals in Cognitive Network. MIMO in a fading environment is considered. In this paper, we consider uncoordinated Beamforming in a cognitive networks with single primary user and secondary user sharing the same spectrum and are equipped with multiple antennas. This is in contrary to prior work, which requires coordination between primary users and secondary users. In particular, the beamforming vectors are designed to maximize the sum rate. The beamforming 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 Finally, we present some simulation results to evaluate the sum rate performance of the proposed algorithms. Simulation results also show the effectiveness of the number of transmit and receive antennas on the proposed design.

Index Terms—Beamforming, MIMO, cognitive network, fading channel, interference cancellation.

1. Introduction

In the recent years, increase in Wireless devices created a great demand for the Spectrum at frequencies below 3GHZ. At the same time, major part of the available spectrum is not utilized most of the time. One optimum solution for this problem is reusing of available spectrum.
This can be done by using Cognitive Network. Cognitive network has a cognitive a process that can perceive current network conditions, and then plan, decide and act on those conditions [1]. The network can learn about these adaptations and the ultimate aim is to provide end- to-end communication.

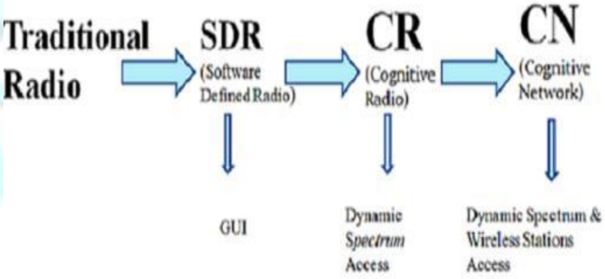

Fig 1: Evolution of Cognitive Network

Software Defined Radio (SDR) is used in 4G wireless communications. It is a single platform that provides a variety of services. SDR is mainly used in military applications. SDR supports a variety of modulation schemes. Cognitive Radio deals with point to point communication but Cognitive Network provides end to end communication. This difference in goal scope from local to end-to-end enables the cognitive network to operate more easily across all layers of the protocol stack. Another significant difference says that cognitive networks are applicable to both wired and wireless networks whereas cognitive radios are inherently for wireless use. So, Cognitive Network can be considered as networks that efficiently utilize Cognitive Radio. And also MIMO improve the performance of communication networks by overcoming the challenges of wireless networks. Cognitive Network absorbs the network environment by using location sensors like Global Positioning System (GPS) or Galileo Sensors. Spectrum (White Space) detection is done by using RF stimuli. Then it will orient with respect to past experience and plan according to the available alternatives and decide what the actions to be taken are. While aiding the FCC in its efforts to define cognitive radio, IEEE USA offered the following definition: A radio frequency transmitter/receiver that is designed to intelligently detect whether a particular segment of the radio spectrum is currently in use, and to jump into (and out of, as necessary) the temporarily-unused spectrum very rapidly, without interfering with the transmissions of other authorized users [2].

A cognitive network consists of two types of users. One is the Primary or licensed users and other is the Secondary or unlicensed users. a number of traditional wireless service subscribers and the so-called cognitive users. The traditional wireless service subscribers have the legacy priority access to the spectrum and are usually called the primary users in the literature. On the other hand, the secondary users, are allowed to access the spectrum only if it is not used by the primary user. Those unused spectrum are referred to as spectrum holes. These gaps change with time and geographic location, and can be used for communication by secondary users. Without causing interference to the licensed primary users.

Spectrum Handoff in CRNs, spectrum mobility causes a new type of handoff referred to as spectrum handoff, which is different from traditional cellular handoff and mainly caused by the presence of PUs. In cellular networks, mobile devices transfer an ongoing connection from one channel to another channel between base stations due to user mobility or channel degradation. However, the concept of user movement has also new meanings in CRNs because the number and characteristic of available spectrum at a new location may vary with PU spectrum usage. Moreover, the spectrum handoffs in CRNs are likely to incur longer delays or temporary communication disruptions because SUs must search for spectrum holes and choose a proper channel at every spectrum handoff. We are developing a new type of spectrum handoff to reduce temporary communication disruption time which is caused by spectrum handoffs.

A) Related works

The secondary user communication along with the primary user can be achieved in several ways as discussed in [5] and references therein Spectrum sensing is the fundamental problem that many researchers attempt to address in the literature [6]. The problem is essentially a detection where the goal is to find an optimal decision threshold. The design of the threshold creates an interesting trade-off between the probability of miss detection and the probability of false alarm. On the other hand, the cognitive user constantly creates interference to the primary user in a system with a high probability of miss detection. In particular, works on the capacity region have been studied in [4]. In the literature, the authors proposed opportunistic spectrum sharing algorithms by exploiting multi-antennas but they mostly focused on removing interference only from a secondary transmitter to primary receivers.

Linear vector precoding for downlink cognitive systems is considered in [7]. In particular, an optimal interference-free precod-ing 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. The authors in [8] also consider multiple antennas at the transmitter side and show that in a device with $K+N$ antennas can completely nullify $N-1$ interferers while achieving a diversity gain of $K+1$. Also the prior work in the literature requires coordination between the primary and secondary users. The beamforming concept has been extensively studied for the MIMO broadcast channel [9] and multi-cell environments [3]. Literature says that coordination is required between the cognitive transmitter receiver pair to ensure the same spectrum to be used [10].

B) Contribution

In the proposed work, no coordination is required between the primary and cognitive user. In this paper, we consider a cognitive network that consists of a single primary and secondary user. 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. 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 the multipath properties of the channel is utilized to support greater throughput. Intersymbol Interference (ISI) and fading in multipath propagation are major threats in wireless communication. MIMO improve the performance of communication networks by overcoming these challenges. MIMO enabled Cognitive Network performs well when compared to normal Cognitive Network. MIMO is fast becoming the most common feature of wireless systems due to its performance benefits. MIMO is based on spatial multiplexing technique, in which the independent and separately encoded data signals are transmitted from each of the multiple transmit antennas. By utilizing antenna arrays at both the transmitter as well as the receiver the limitations of the radio channel may be overcome and the data rates increased. The high data rates are offered to the system. A Rician model is obtained in a system with LOS propagation and scattering. The model is characterized by the Rician factor, denoted by K. And the racian factor is defined as the ratio of the line of sight and the scatter power components.

3. Proposed Network Model

Consider a Cognitive network with single primary and single secondary user. Let, N_t^p and N_r^p be the number of antennas at the primary transmitter and receiver respectively. Similarly, N_t^c and , N_r^c be the of antennas at the secondary transmitter and receiver. The MIMO channel between the primary transmitter and receiver is denoted by W and the channel between the secondary transmitter and secondary receiver is denoted by H. The interference channel between the primary transmitter and secondary receiver is denoted by D and the channel between the secondary transmitter and primary receiver is denoted by G. The primary and secondary transmitter employs Beamforming vector u , f for the transmission of their respective data.

Let v, t be the receive combining vector for the primary and secondary receiver, respectively. Assume $N_t^c \geq 2$ and $N_r^c \geq 2$. Furthermore, Once channel information is known, the cognitive transmitter and receiver can compute the transmit/receive beamforming vectors using the proposed algorithms. We also impose a unit energy constraint on all beamforming vectors i.e., $\boldsymbol{u}^*\boldsymbol{u} = \boldsymbol{f}^*\boldsymbol{f} = \boldsymbol{v}^*\boldsymbol{v} = \boldsymbol{t}^*\boldsymbol{t} = 1$.

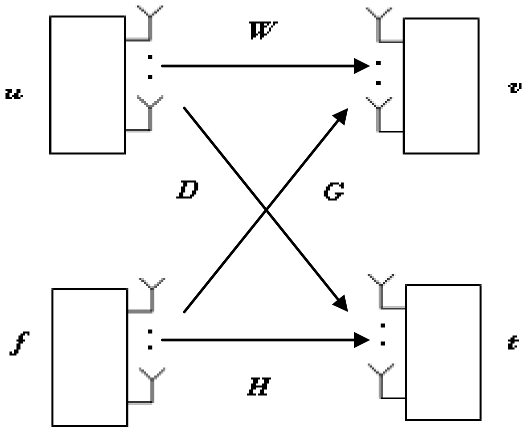

Fig 2: Cognitive Network Model

i) Received Signal at Primary and Secondary are given by

$$r_p = \sqrt{p_p}\, v^* w u x_p + \sqrt{p_p}\, v^* G f x_c + v^* n_p \quad \rightarrow (1)$$

and

$$r_c = \sqrt{p_c}\, t^* H f x_c + \sqrt{p_c}\, t^* D u x_p + t^* n_c \quad \rightarrow (2)$$

where P_p and P_c are the transmit power at the primary and cognitive transmitter. Then x_p and x_c be the data symbols of primary and cognitive link. Similarly, n_p and n_c are the noise vectors of primary and cognitive link.

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

The Signal to interference-plus-noise ratio (SINR) of the primary and secondary links are given by

$$\mathrm{SINR_p} = \frac{\mathrm{P_p\, V^*W^*UU^*WV}}{\mathrm{P_p v^*Gff^*G^*v + v^*v\sigma_p^2}} \quad \rightarrow (3)$$

and

$$\mathrm{SINR_C} = \frac{\mathrm{P_C\, t^*H^*ff^*Ht}}{\mathrm{p_c t^*Duu^*D^*t + t^*t\sigma_c^2}} \quad \rightarrow (4)$$

In order to achieve zero interference, the beamforming vectors ***v***, ***f***, ***t***, and ***u*** have to be designed such that ***v*Gf*** = 0 and ***t*Du*** = 0. SINR should be calculated using the above equations and this calculation is used to find the achievable rate or sum rate for the entire system.

iii) Sum-rate calculation

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

$$R_S = \log_2(1 + \mathrm{SINR}_P) + \log_2(1 + \mathrm{SINR}_C) \rightarrow (5)$$

Therefore, the design optimization problem can be mathematically formulated as

$$\{\mathrm{vopt}, \mathrm{fopt}, \mathrm{topt}, \mathrm{uopt}\} = \underset{\mathrm{v,f,t,u}}{\mathrm{argmax}} \{\log_2(1 + \mathrm{SINR}_P) + \log_2(1 + \mathrm{SINR}_C)\} \rightarrow (6)$$

$$subject\ to \begin{cases} v^*Gf = 0 \text{ and } t^*Du = 0 \\ u^*u = f^*f = v^*v = t^*t = 1 \end{cases} \rightarrow (7)$$

4. Beamforming vector Designs

In this network, appropriate designing of ***v*** or ***f*** and ***t*** or ***u*** helps to achieve zero interference. By using beamforming technique, the phase and the amplitude of the signal is changed by changing the beam forming vectors. According to the beam forming vectors the phase and amplitude of the signal generated from the antenna is changed. And also interference caused due to the multi signal transmission is nullified.

$$\{\mathrm{vopt}, \mathrm{fopt}, \mathrm{topt}, \mathrm{uopt}\} = \underset{\mathrm{v,f,t,u}}{\mathrm{argmax}} \{\log_2(1 + \mathrm{SINR}_P) + \log_2(1 + \mathrm{SINR}_C)\} \rightarrow (8)$$

$$subject\ to \begin{cases} f \in Null(v^*Gf) \text{ and } t \in Null(t^*Du) \\ u^*u = f^*f = v^*v = t^*t = 1 \end{cases} \rightarrow (9)$$

To achieve zero interference at the primary receiver, these secondary transmitter can beamform in the null space of v^*G. Likewise, in order to avoid the interference caused by the primary transmitter at the cognitive receiver, the receive beamforming vector t can be designed such that it is in the null space of Du. The rate of the primary user can be maximized by appropriately designing ***v*** and ***u***. The primary user should not be required to know the existence of the secondary user. Therefore, it is reasonable for the primary user to simply optimize ***v*** and ***u*** to maximize its own rate assuming no interference from the secondary transmitter. After obtaining ***v*** and ***u***, the secondary user can choose ***f*** and ***t*** (which are functions of ***v*** and ***u***, respectively) to maximize its own rate. Its SINR maximized due to the monotonic property of the logarithm function.

The optimal transmit beamforming vector for primary transmitter is given as u_{opt}. And the corresponding receive beamforming vector for the primary receiver is given by

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

With this design and zero interference condition, received signal at primary receiver is obtained. Then, the corresponding SINR at primary receiver is obtained. Obviously, the spectral efficiency of the primary link can be maximized by beamforming in the direction of the eigenvector corresponding to the largest eigen value of W*W.

Next step is to maximize the SINR of the cognitive link by using the optimal beamformers. Those optimal beamformer for the cognitive link can be obtained by solving the following optimization problem.

The basic beamforming vectors are given by

$$\{\mathrm{f_{opt}}, \mathrm{t_{opt}}\} = \underset{\mathrm{f,t}}{\mathrm{argmax}} \left\{\frac{\mathrm{P_c t^* H f f^* H^* t}}{\mathrm{t^* t \sigma_c^2}}\right\} \rightarrow (11)$$

$$\text{subject to} \begin{cases} \mathrm{f \in Null(v_{opt}^* G) and\ t \in Null(Du_{opt})} \\ \mathrm{f^*f = t^*t = 1} \end{cases} \rightarrow (12)$$

The design of *f* and *t* is not as flexible as the one for *v* and *u*. This is because the feasible value of *f* and *t* is now constrained by the zero interference requirement. Following methods are used to design *f* and *t* for the cognitive link.

4.1 Search Algorithm

Search algorithm systematically search the space of possible solutions subject to constraints and expressed with set of basis vectors that satisfies specified constraints. Let F and T be the set of basis vectors. Performs the exhaustive search in F and T to maximize the SINR of cognitive link. And selects the beamforming vectors in such a way that increases the sum rate of the entire system under zero interference condition. Computations are performed to obtain the best beamformers $f_{discrete}$ and $t_{discrete}$.

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

4.2 Gradient Algorithm

Gradient algorithm (steepest ascent) method is used to find the optimum beamforming vectors. Any vector in the null space of $v_{opt}^{*}G$ and D u_{opt} satisfies the zero interference condition. The direction of maximum ascent is calculated using the following gradient vector. The optimal beamformers are in the form of

$$f_{grad} = \frac{\ddot{G}a}{\sqrt{a^{*}a}} \quad \rightarrow (14)$$

$$t_{grad} = \frac{\ddot{D}b}{\sqrt{b^{*}b}} \quad \rightarrow (15)$$

Where a ∈ $(N_t^c - 1)\ X\ 1$ and b ∈ $(N_r^c - 1)\ X\ 1$.

The gradient algorithm is given by

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

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

5. Simulation Results

This section presents some simulation results about the system performance as show in fig.

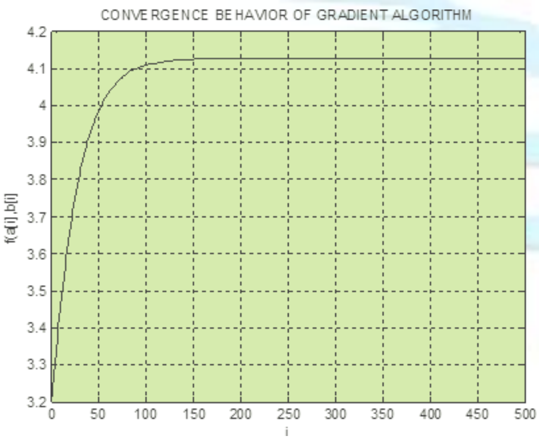

Fig 3: Convergence behavior of gradient algorithm

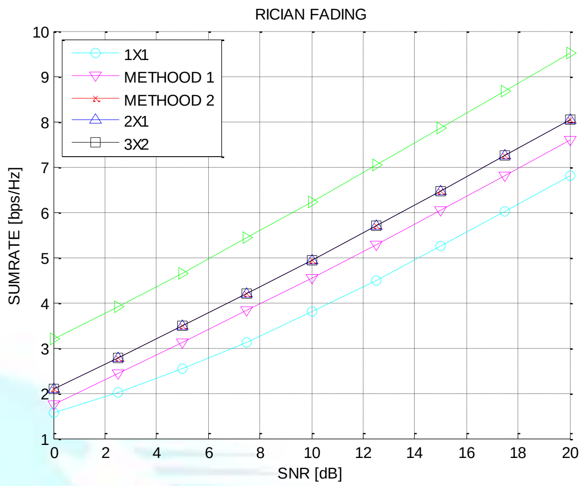

Fig 4: Sum rate for various methods of beam forming

For obtaining these results, some calculations and assumptions are made. We design the channel matrix using Rician distribution and thereafter we calculate the beam forming vectors for secondary system, for reducing the interference at the primary system. Channel matrix at both primary and secondary system should be i.i.d complex Gaussian random variable satisfying the Rician distribution principle. We compare the sum-rate at the secondary system with different number of transmitting antennas with the primary system.

6. Conclusion

In this paper, we have cancelled the interference and maximum achievable rate is obtained 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. Here we proposed some methods for the design of the beam forming vectors of the cognitive link. Finally, it is noted that we motivate the concept of beam forming and rate maximization concept in a cognitive network.

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