A Novel Approach To Energy Efficient Mimo Cognitive Radio Networks

Princes.A
DMI College of Engineering, Tamil Nadu

Abstract: the energy-efficient transmissions for multiple-input multiple-output (MIMO) cognitive radio (CR) networks in which the secondary unlicensed users coexist with the primary licensed users. To optimize the time allocations and beam forming vectors for the secondary users (SUs), in order to minimize the energy consumption of the SUs while satisfying the SUs rate requirements and the primary receivers interference constraints. Compared with the traditional MIMO networks, the challenge is that the SUs may not be able to obtain the channel state information (CSI) of the primary receivers. Fortunately, when the SUs are not able to obtain the CSI, the optimal time allocation and the optimal beam forming vectors can be found very efficiently in polynomial-time through a proper Singular Value Decomposition (SVD). When the SUs have perfect CSI, the decomposition based algorithm is guaranteed to find the optimal solution when the secondary system is under-utilized. Simulation results show that the energy-optimal transmission scheme adapts to the traffic load of the secondary system where the SUs are able to decrease the energy consumption and the PUs experience less interference from the secondary system.

I. INTRODUCTION

Cognitive radio, with the capability to flexibly adapt its transmission or reception parameters, has been proposed as the means for unlicensed secondary users (SUs) to dynamically access the licensed spectrum held by primary users (PUs) in order to increase the efficiency of spectrum utilization[1]. Recently, a new paradigm termed Cooperative Cognitive Radio Networks (CCRN) has been advocated in CCRN, PUs may select some SUs to relay the primary traffic cooperatively, and in return grant portion of the channel access time to the SUs. By exploiting cooperative diversity, the transmission rates of PUs can be significantly improved. SUs, being the cooperative relays, as a consequence obtain opportunities to access the channel for their own data transmissions[1]. MIMO-CCRN framework for cooperation among SUs and PUs by exploiting MIMO antennas on SUs’ transceivers. MIMO is a physical layer technology that can provide many types of benefits through multiple antennas and advanced signal processing. Multiple independent data streams can be transmitted or received over the MIMO antenna elements. Furthermore MIMO can also realize interference suppression. Through beam-forming, a MIMO receiver can suppress interference from neighboring transmitters and a MIMO transmitter can null out its interference to other receivers. Given its potential, MIMO has been adopted in next-generation WiFi, WiMax, and cellular network standards. However researchers have not explored how to take advantage of the MIMO techniques in the context of CCRN.

There is an ever-increasing demand for spectrum for emerging wireless applications and there is a spectrum shortage for the wireless applications. In view of this, the Federal Communications Commission (FCC) has considered making the licensed spectrum available to unlicensed users. This will allow unlicensed users to use the empty spectrum, provided they cause no interference to licensed users. Most radio systems today are aware of the radio spectrum. Cognitive radio is a new research area for wireless communication in which either a network or a wireless node is able to change its transmission or reception parameters to communicate efficiently by avoiding interference with
II. SYSTEM MODEL

We consider a CR network with K SUs and J PUs. The primary links could potentially always be active, and thus need to be protected at all times. The primary network is composed of J pairs of transmitters and receivers. The secondary system is a single cell network, where the SUs send uplink traffic to the same secondary BS via TDMA. The uplink transmissions are synchronized by the secondary BS so that they are allocated different time slots for their transmissions and thus do not cause interference to each other. We use Sk to denote the kth SU. Let MSk denote the number of transmit antennas of Sk and NBS denote the number of receive antennas at the secondary BS. Let HBS;Sk 2 CNBS_MSk denote the channel matrix from Sk to the secondary BS. We use Pj to denote the jth primary transmitter-receiver pair. Let MPj and NPj denote the number of transmit antennas and the number of receive antennas of Pj, respectively.

![Figure 1: Cognitive Radio Network](image1)

Since the SUs coexist with the PUs, their signals may interfere with each other. Let HPj;Sk 2 CNPj_MSk and HBS;Pj 2 CNBS_MPj denote the channel matrix from Sk to the receiver of Pj and the channel matrix from the transmitter of Pj to the secondary BS, respectively. We assume a frequency flat fading channel so that the channel is the same for the considered bandwidth. Furthermore, we assume block fading channels, so that the channel matrices do not change during a TDMA frame, and the channel realizations in different frames are uncorrelated. Since the secondary system is centralized, the secondary BS can estimate HBS;Sk and feedback it to each Sk with a separate control channel. Thus, it is reasonable to assume that HBS;Sk is known to both Sk and the secondary BS.

Both the primary and secondary users can transmit multiple data streams. Let DSk and DPj denote the number of data streams of Sk and Pj, respectively. Let xSk ∈ C MSk × 1 and xPj ∈ C MPj × 1 denote the actual transmitted vectors of Sk and Pj, respectively. The covariance matrices of xSk and xPj are denoted by QSk and QPj, which are Hermitian positive semidefinite matrices. The received vector of Sk at the secondary BS is

\[ ySk = HBS;Sk xSk + nBS \]

The vector nBS ∈ C NBS×1 is a circular complex additive Gaussian noise vector with a noise power of N0w at the secondary BS, where N0/2 is the noise power spectral density and w is the bandwidth used in the secondary system. We assume that the secondary BS treats the interference from the primary transmitters as noise, and that there is no successive interference cancellation at the secondary BS. The interference-plus-noise covariance matrix at the secondary BS when Sk transmits is then which is an NBS × NBS Hermitian positive semidefinite matrix.
According to Shannon’s capacity formula for a MIMO link, the achievable transmission rate of Sk is $\text{rate}(Sk) = \log_2(1 + P_{Sk} / N_0)$, where $P_{Sk}$ is the instantaneous transmit power of Sk on all its transmit antennas.

The problem formulation for the perfect CSI scenario is given in Problem (1), while the problem formulation for statistical CSI scenario is formalized in the next section.

A. FORMULATION RECAST FOR THE STATISTICAL CSI SCENARIO

In the statistical CSI scenario, the secondary system is not able to know the realization of $P_j, S_k$. The requirement of satisfying Constraint (5c) using a fixed guess of the channel matrix would easily lead to suboptimal or even infeasible solutions. Interestingly, many wireless applications (such as video streaming, voice over IP, etc.) can tolerate occasional outages without affecting the QoS. Thus, we consider a more realistic requirement, which is to satisfy the interference constraints with a high probability. In other words, the CR network allows the interference from each secondary transmitter to each primary receiver to exceed the power threshold $\Phi_p$ with a small outage probability $\delta_p$.

Problem (5c) is then replaced by

$$\text{Prob}(\phi_j < \Phi_j) < \delta_p$$

where the probability is taken over $H_j, S_k$. In particular, we consider Rayleigh fading channels and a rich scattering environment under the statistical CSI scenario, so that the entries of $H_j, S_k$ are independently and identically distributed (i.i.d.) complex Gaussian random variables with zero mean and a variance of $\sigma^2$ [24], where $\sigma^2$ denotes the path loss from $S_k$ to the $j$th primary receiver. We assume that $H_j, S_k$ is known to Sk.

Furthermore, after converting the outage probability constraint to (8), we notice that it has the same form as the transmit power constraints, and can be combined with Constraint (5d). Let

$$\text{Prob}(\phi_j < \Phi_j) < \delta_p$$

Note that similar to Problem (1), we do not need to add rank constraint on $Q_{Sk}$ in Problem (4). Furthermore, Problem (4) is also a non-convex optimization problem. It is challenging to solve the non-convex Problems (1) and (4) directly. As can be seen in the subsequent sections, we will tackle this difficulty by finding a closed-form solution for $Q_{Sk}$ and thereby reducing (4) to a convex problem in $S_k$ only.

As a result, in the statistical CSI scenario, we can find optimal solutions to Problem (4); in the perfect CSI scenario, we can find optimal solutions to Problem (1) when the secondary system is utilized.
B. FEASIBILITY

The feasible set in Problem (1) (or (4)) may not always be non-empty. For each Sk, its maximum feasible instantaneous transmission rate rSk,max, with the unit of nats/second, depends on its maximum transmit power and the interference constraints at the primary receivers. In the statistical CSI scenario, the maximum link rate for Sk can be obtained by solving

Problem (9) can be solved with standard “water-filling”. In the perfect CSI scenario, the maximum link rate for Sk can be obtained by solving the following problem

The objective function in (10) is a concave function of QSk. and the constraint set is a convex set. Thus, Problem (10) is a convex optimization problem, which can be solved in polynomial time with standard interior-point methods. The minimum time resource tSk, min that each Sk needs to satisfy its rate requirement is

Problem (1) (or (4)) is feasible when the traffic load in the secondary system does not exceed its capacity, i.e.,

IV. METHODOLOGY FOR COGNITIVE RADIO SYSTEM IMPLEMENTATION USING MATLAB

V. SINGULAR VALUE DECOMPOSITION IMPLEMENTATION ON MIMO:

Consider a MIMO channel matrix H described in above section with a assumption that r ≤ t then Singular Value Decomposition of matrix H is given by

where U refers to column matrix of t columns, V refers to row matrix of t rows and S refers to singular value matrix which is diagonal matrix of t dimension

Also U and S have the following properties

So V is a unitary matrix for any r ≤ t while U is also a unitary matrix for r = t and diagonal elements of S are known as singular values which are non negative and in a ordered manner.

Now consider a MIMO system model described in above section and put

\[ H = U \sum \lambda_i V_i^H \]
\[ Y = UX+N \]
\[ Y = V \sum \lambda_i V_i^H X+N \]

Multiply both the sides by \( U^H \) (beamforming at receiver)

\[ U^H Y = U^H \sum \lambda_i U^H V_i^H X+N \]
\[ \tilde{Y} = \sum \lambda_i V_i^H X+N \]
\[ \tilde{Y} = U^H Y \text{ and } \tilde{N} = U^H N \]

Now let X = (precoding at transmitter)

\[ \tilde{Y} = \sum \lambda_i V_i^H + \tilde{N} \]
\[ Y = \sum \lambda_i V_i^H + \tilde{N} \]
Or equivalently

So in above equation U and V are eliminated since we have performed beamforming at receiver by matrix U and precoding at transmitter by matrix V. So it requires CSI to avail at both the sides. Now simplify above equation, then we have

From above equations we can see that all the transmitted symbols appear only to their respective receive antennas and they are not interfering simultaneously at any receive antenna. So it forms a collection of t parallel channels which are decoupled to each other. Also here t symbols are parallel transmitted by MIMO channel in single time slot. It refers to spatial multiplexing in MIMO communication.

Now consider noise matrix at receiver

\[ \tilde{N} = U^H N \]
\[ E\{ N N^H \} = E\{ U^H N U \} \]
\[ E\{ N N^H \} = \sigma_N^2 I \]
\[ E\{ N N^H \} = \sigma_N^2 \tilde{I} \]
\[ \sigma_N^2 = \sigma^2 \]
Where \( \sigma^2 \) is noise power.

From above equation we can say that noise power before the beamforming is identical to noise power after the
beamforming. In other words beamforming do not affect noise power at receiver So SNR of ith channel is given by

\[ \text{SNR}_{\text{ith}} = \frac{\text{Power of signal}}{\text{Noise power}} \]

And hence channel capacity of ith channel is

\[ C_{\text{ith}} = \frac{1}{2} \log_2 (1 + \text{SNR}_{\text{ith}}) \]

We have total t such independent channels and hence total capacity of a MIMO channel is

\[ C_{\text{total}} = \sum_{i=1}^{t} C_{\text{ith}} \]

VI. SIMULATION RESULTS

The cognitive radio system continuously searches the spectrum hole where primary user is not present and is determined by the method of energy detection. When it finds out the spectrum hole, immediately it allot to the Secondary User (SU) and whenever Primary User (PU) wants to occupy the slot, Secondary User immediately leaves it. For 5 (Five) signals, the carrier frequencies are 1MHz, 2MHz, 3MHz, 4MHz, 5MHz and sampling frequency is 12MHz used for simulation. Power Spectrum Density (PSD) of signal is calculated, compared with the predefined threshold value and determined the presence of primary user signal. In this Project, it has assumed that 1st, 3, 5th primary users are present and 2nd, and 4th primary users are not present.

Figure 4: Cognitive radio primary user spectrum

Now the Cognitive Radio (CR) system will look for the first available gap (Spectrum hole) and automatically assign it to the secondary user (SU) in the spectrum. It is shown in the Figure.

Now the system will search the next spectrum hole and automatically assign it to the secondary user (SU) in the spectrum. As shown in the Figure, the next available gap was occupied by the secondary user (SU) 2.

Figure 5: Spectrum sensing by secondary user

CHANNEL MAXIMIZATION USING SVD

VII. CONCLUSION

The approach was to take the decisions in this paper on the basis of power spectral density of the channel which can be used cognitively to search the available spectral gaps those can be used to new incoming users (SU) thus improving the overall channel’s throughput. In this work the energy detection spectrum sensing using FFT within the specified frequency band is performed. It has been shown that how the cognitive radio works dynamically with changing the frequency band from one to another and successfully demonstrated in simulation result. That is the Spectrum Access in Cognitive Radio demonstrated successfully without interfering with the other frequency bands used by the primary user (PU). In this paper, we have considered jointly energy-optimal time allocation and precoding in MIMO CR networks. The problem formulations turn out to be non-convex optimization problems. We successfully tackle the non-convexity by applying an optimization decomposition technique. Under statistical CSI, the global optimal solution can be found efficiently; under perfect CSI, the global optimal solution can be obtained efficiently when the secondary system is underutilized.

REFERENCES


