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A Novel Approach To Energy Efficient Mimo Cognitive Radio Networks

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***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.*

***Index Terms:** Cognitive radio networks, MIMO, energy efficiency, scheduling, beamforming.*

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 (CCRNs) 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 licensed or unlicensed users. Basically, the parameters that are used in CRNs are based on the active monitoring of several factors, either in the external or internal radio environment, such as radio frequency spectrum, user behavior and network state[3]. A cognitive radio senses available spectrum, occupies it and can vacate the spectrum on sensing the return of the primary user (PU). Efficient spectrum sensing (SS) is the key step in the operation of CRs using DSA. In the process of SS, various channel effects (e.g., shadowing, multi path fading etc.) play very crucial roles. To mitigate all these effects, collaborative or distributed SS has been proposed. Collaborative SS incorporates spatial diversity to improve its performance. In collaborative SS, a number of CRs form a network and the final decision regarding the availability of spectrum opportunity for the CR network is based on the information received from all the CRs. Information collection from the participating CRs depends on the nature of the CRN. In this paper, we consider infrastructure based CRNs which are similar to the classical parallel data fusion model in distributed detection (DD). In this model, each CR in the network forwards its processed observation to the central entity which is called the fusion centre (FC)[5]. The FC then makes the final decision about the state of nature based on all the information received from the participating CRs. Recently, SS for CRNs has attracted the attention of many researchers. But the issue of security in CRNs has not been considered in detail. Like all other networks, CRNs are also vulnerable to various security issues. Collaborative SS process itself is subject to various security threats. Two of these attacks have been defined as: 1) Incumbent Emulation (IE) attacks and 2) Spectrum Sensing Data Falsification (SSDF) attacks (i.e., Byzantine attacks). In IE attacks, some of the participating CRs or some outsiders try to mimic the transmission of the incumbent (primary user) to disrupt the SS process. The presence of IE attackers makes the FC decide that the spectrum band under consideration is not available and the CRN holds its transmissions which provides an opportunity to IE attackers to exploit the spectrum holes[1]. On the other hand, under SSDF (Byzantine) attacks some of the CRs introduce false sensing information in the fusion process to disrupt the SS process.

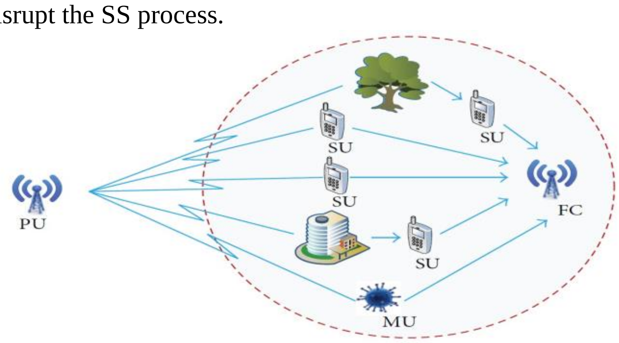

Figure 1: Cognitive Radio Network

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.

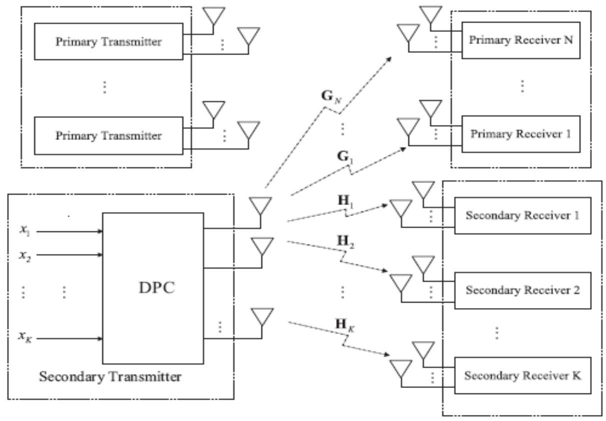

Figure 2: System model

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 frame1, 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

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 Here rSk is the instantaneous transmission rate (in nats/second) when Sk is active. The total transmit power of Sk on all its transmit antennas is pSk = tr QSk, and Sk causes a total interference power to the jth primary receiver at the level of

III. PROBLEM FORMULATIONS

The system target is to choose the proper time allocation and the transmit precoding matrix for each SU to minimize the total energy consumption of all the SUs while protecting the PUs and ensuring a minimum QoS for each SU. Specifically, the interference from each SU to each of the PUs need to be below a certain threshold, and each SU has a rate requirement RSk to be satisfied. Here RSk (with the unit of nats/frame) is the number of nats that Sk needs to transmit in each time frame. Without loss of generality, the TDMA frame length of the secondary system is normalized to be 1. Each Sk is allocated a time fraction tSk ($0 \leq$ tSk ≤ 1) to transmit its data. The instantaneous transmit power of Sk is limited by a maximum power of pSk,max. This problem can be mathematically formulated as follows:

The objective function is the total energy consumption of all SUs. Constraint (5a) guarantees the rate requirement for each SU. Constraint (5b) ensures that the total time allocated to all the SUs is no larger than the TDMA frame length. Since the secondary network is a TDMA network, the SUs do not transmit simultaneously. The interference constraint to the primary network ensures that the interference from each secondary transmitter to each primary receiver is no larger than the threshold φPj , as shown in (5c). Note that since the secondary system does not know the receive beamforming at each primary receiver; the interference power in (5c) is the interference power at the antennas of each primary receiver. Constraint (5d) states that each SU has limited transmit power. The last two constraints state that each tSk is non-negative, and each QSk is positive semidefinite. Problem is non-convex due to both the objective function and Constraint (5a), and is thus in general difficult to solve.

It can be shown that the rank of the optimal covariance matrix to Problem is never higher than the corresponding channel, i.e., rank(Q $*$ S_k) $\leq$ rank(HH BS,SkC −1 Sk HBS,Sk) $\leq$ rank(HBS,Sk). Suppose there is one optimal Q $*$ Sk with a higher rank than rank(HBS,Sk). We can obtain a new solution of the transmit covariance matrix by projecting Q $*$ S_k to the row space of HH BS,SkC −1 S_k $^{H}B_{S}$,S_k . The new solution obtained by the projection satisfies Constraints (5a) and (5c). Further, it reduces the LHS of Constraint (5d) and the objective function. This contradicts with that Q $*$ S_k with a higher rank than rank ($^{H}B_{S}$,S_k) is the optimal solution. Therefore, we do not need to impose rank constraint on $^{Q}S_k$ in Problem.

In a CR network, some parameters may be available and some may not. As discussed earlier, the channel matrix HBS,Sk is available to both Sk and the secondary BS. Furthermore, as the secondary system usually is aware of the existence of the primary system, we can assume that the secondary BS can overhear the transmissions on the primary links. Therefore, it is able to estimate the interference-plus-noise covariance matrix CSk that comes from all the PUs. However, the secondary system is usually transparent to the primary system and the primary system may not deliberately provide the CSI to the secondary system. Therefore, the secondary system may not be able to obtain the channel matrix HPj,Sk in Constraint (5c). To this end, we consider two scenarios in this paper:

- ✓ Statistical CSI: the secondary system knows the statistics of HPj,Sk (e.g., the type of distribution and E[HPj,SkHH Pj,Sk]). However, it does not know the precise realization of HPj,Sk.
- ✓ Perfect CSI: the secondary system has perfect knowledge of HPj,Sk.

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 HPj ,Sk . 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 φPj with a small outage probability δPj. Constraint (5c) is then replaced by

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

Note that similar to Problem (1), we do not need to add rank constraint on QSk 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 QSk and thereby reducing (4) to a convex problem in tSk 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 underutilized.

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 S_k 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

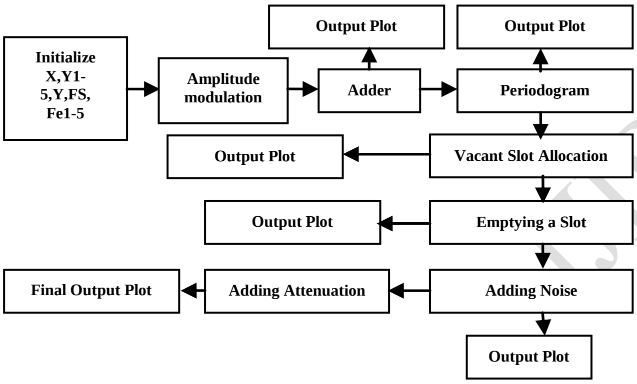

Figure 3: Methodology/Block diagram of simulation set up

Initialization- 5 Carrier Frequency Bands for Users, Message Frequency and the

Sampling Frequency are initialized.

Modulation- Modulates user data over the respective frequency band by amplitude modulation

Adder- Addition of all the modulated signals to produce a transmitting signal

Periodogram- To estimate the power spectral density of received signal.

Vacant Slot Allocation- New User is allotted to the first spectral hole when he arrives.

Emptying a slot- Asked user to empty a specific slot if all the slots are engaged.

Addition of noise- Amount of Noise to be added

Attenuation- Percentage of Attenuation is introduced

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

$$H=U\sum V^H$$

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

$U = [\ U_1 \quad U_2 \dots \quad U_{t-1} \quad U_t]$

$\sum=$

$V=$

U is r × t matrix and V is a t × t matrix such that columns of U and rows of V are orthonormal

$||U_i||^2 = 1$ and $U_i^H U_j = 0$ for $i \neq j$

$||V_i||^2 = 1$ and $V_i^H V_j = 0$ for $i \neq j$

Also U V and S have the following properties

$VV^HV = VV^H = I$

$U^HU = I$

$\sigma_1 \geq \sigma_2 \geq \sigma_3 \geq \dots \geq \sigma_t \geq 0$

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

$H=U\sum V^H$

$Y=HX+N$

$Y=U\sum V^HX+N$

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

$U^HY=U^H(U\sum V^HX+N)$

$\tilde{Y}= \sum V^HX+\tilde{N}$

$\tilde{Y}=U^HY$ and $\tilde{N} = U^HN$

Now let X= V (precoding at transmitter)

$\tilde{Y} = \sum V^HV + \tilde{N}$

$\tilde{Y} = \sum + \tilde{N}$

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

$\tilde{N} = U^HN$

$E\{\tilde{N}\tilde{N}^H\} = E\{U^HNUN\}$

$E\{\tilde{N}\tilde{N}^H\} = \sigma_N^2 I_t U^H U$

$E\{\tilde{N}\tilde{N}^H\} = \sigma_N^2 I_t$

$\sigma_N^2 = \sigma_{\tilde{N}}^2$

Where σ_N^2 is noise power.

From above equation we can say that noise power before the beamforming is identical to noise power after the

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beamforming. In other words beamforming do not affect noise power at receiver So SNR of ith channel is given by

And hence channel capacity of ith channel is

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

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 allots 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 4thprimary users are not present.

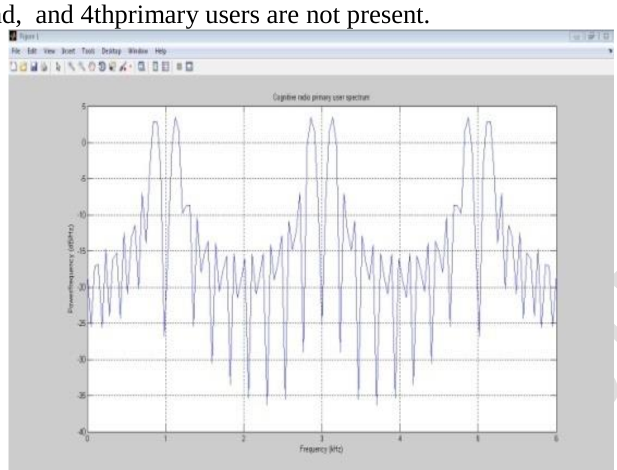

Figure 4: Cognitive radio primary user spectrum

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.

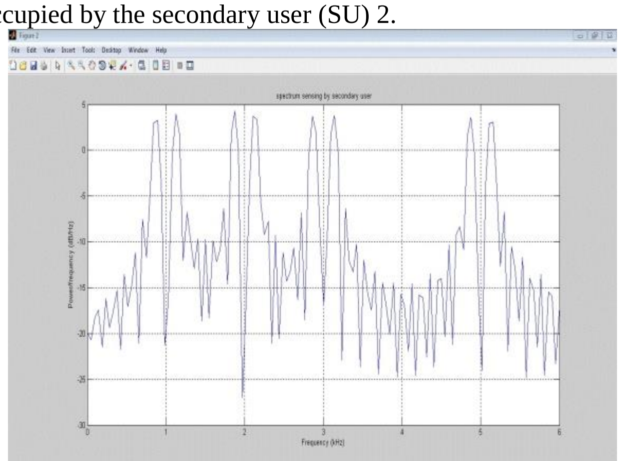

Figure 5: Spectrum sensing by secondary user

CHANNEL MAXIMIZATION USING SVD

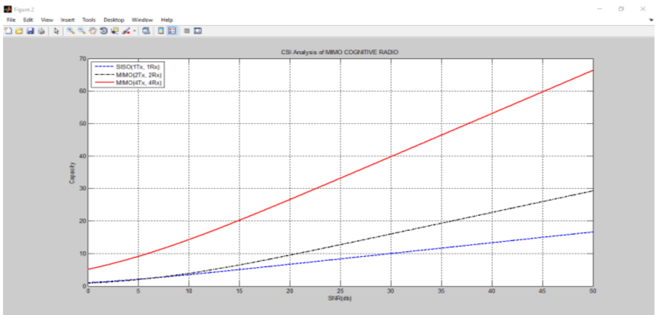

Figure 6: CSI analysis of mimo cognitive radio

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.

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