

Distributed Spectral Access and Energy Efficient Cognitive Radio System

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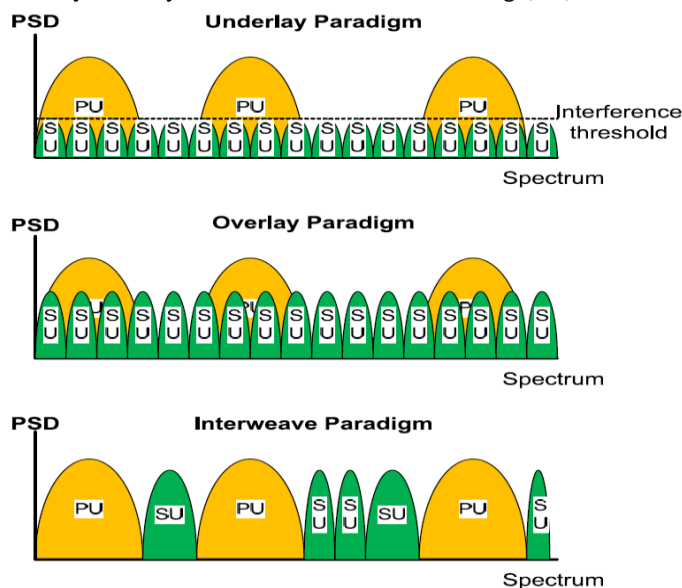
Abstract

Cognitive Radio (CR) systems are the upcoming technology in the wireless communication where we have to utilize our spectrum available in the best and the efficient way. The tasks to be covered in the CR technology are broadly classified into two categories. They are efficient utilization of the available spectrum and secondly energy efficiency in the wireless transmission. As said above that in the wireless communication system we have major two challenges are to utilize the spectrum efficiently by also keeping in mind that the least power gets wasted during this process. In this work, we have presented different algorithms like that of Shared Carrier Assignment (SCA) Iterative water-filling algorithm (SCA-IWF) algorithm for efficient utilization of spectrum by sensing it keeping in concern the interference from the other secondary users. Secondly we have provided the energy efficiency of the MIMO system by using Iterative Power Allocation Scheme (IPAS) that converges as the number of iterations increased. Finally we have plotted the result of both the capacity and energy efficiency with respect to number of iterations in both the graph and bar-graph form.

Keywords: Cognitive Radios, IPAS, SCA-IWF

I. INTRODUCTION

Wireless communications have experienced a rapid growth in the past decades. The demands for providing high-rate and high-quality services have been increasing. In order for coping with these demands, various new wireless communication technologies have been emerging, for instance, fourth generation (4G) cellular networks and beyond, wireless Ad Hoc networks, software-defined radio, wireless regional area networks (WRANs). So looking at the increasing demands of the wireless communication networks cognitive radio technology emerges which senses the network and then respond accordingly. There are three network paradigms in cognitive radios: -underlay, overlay and interweave as shown in fig.(1.1)



II. STUDY AREA AND OBJECTIVE

For the wireless communication using the cognitive radio(CR) technique we have to consider both of the energy efficiency during the transmission as well as the maximum utilization of the spectrum, keeping in consideration the interference to the

primary user by the other secondary users trying to access the same channel allocated to the primary user. Here in this thesis we have shown separately:

- 1) Algorithm for the detection of spectrum available and then allocating the spectrum efficiently
- 2) Algorithm for maximization of the energy efficiency of the network

Here both of the algorithms converge with the number of iterations and reaches to its maximum performance are shown.

III. METHODOLOGY

Let d_m denote the distance between the SU base station and the m^{th} PU, and R_m denote the radius of the protected circular area around the m^{th} PU. The channel from the source to m^{th} PU in k^{th} SU band can be written as:

$$g_{m,k} = \frac{\tilde{g}_{m,k}}{(d_m - r_m)^\beta} \quad (3.1)$$

Where $\tilde{g}_{m,k}$ is the small-scale fading and β is the path loss exponent of the wireless channel. Without loss of generality, we assume that $R_1 = R_2 = \dots = R_M = R$.

Let us consider a wireless network with one transmitter, one relay, K SUs and M PUs. Each SU receives the data on a separate pre-assigned frequency band. The relays transmit and receive data on pre-assigned frequency bands. The central controller decides the power allocation to the relay and the secondary users. We denote by $p_c = p_c^s + p_c^r$, the total static circuit power of the source and the relay in the transmit mode, p_k^s is the source transmit power to serve k^{th} SU, and p_k^r , the relay transmit power to serve k^{th} SU. We denote by h_k^s , the channel gain from the source to the k^{th} SU, h_k^r , the channel gain from the relay to the k^{th} SU, $h_{r,k}^s$, the channel gain from the source to the relay in the k^{th} SU band, $g_{m,k}^s$ the channel gain from the source to m^{th} PU in k^{th} SU band, and $g_{m,k}^r$ the channel gain from the relay to the m^{th} PU in the k^{th} SU band.

The channel model for cooperative communication (e.g., relay channel) is the same as mentioned.

$$C_k^1 = \log\left(1 + \frac{p_k^s h_{r,k}^s}{N}\right) \quad (3.2)$$

Eq(3.2) shows the capacity is for the transmission through source only.

$$C_k^2 = \log\left(1 + \frac{p_k^s h_{r,k}^s}{N} + \frac{p_k^r h_k^r}{N}\right) \quad (3.3)$$

Eq(3.3) shows the capacity for the transmission when it takes place through both of the source as well as the relay. The energy efficiency for the co-operative communication system is given by:

$$\Gamma_{DF}(p_s, p_r) = \frac{\sum_{k=1}^K \min(C_k^1, C_k^2)}{p_c + \sum_{k=1}^K p_k^s + p_k^r} \quad (3.4)$$

Now to maximize the energy efficiency given in Eq(3.4),

$$\max_{p_r, p_s} \Gamma_{DF}(p_s, p_r)$$

$$C1: \sum_{k=1}^K p_k^s g_{m,k}^s < I_m \quad (3.5)$$

$$C2: \sum_{k=1}^K p_k^r g_{m,k}^r < I_m \quad (3.6)$$

$$C3: p_k^s > 0, p_k^r > 0 \quad (3.7)$$

Above the constraints C1 and C2 assure that interference from the source and relay to primary users is less than a specified threshold respectively. By introducing new variables τ_k , $k = 1, 2, \dots, K$.

A. Iterative Power Allocation Scheme (IPAS)

In this section, we present an iterative power allocation scheme (IPAS) to solve the optimization problem. The proposed algorithm is based on ϵ -optimal algorithm. Therefore, for any $\epsilon > 0$, ϵ -optimal algorithms guarantee the solution within ϵ of the optimal solution. The objective function of the FP problem is transformed into a parametric optimization problem. Let us first consider the following optimization problem:

$$\max_{x \in S} \frac{f(x)}{g(x)} \quad (3.8)$$

where $x \in R^n$. The parametric problem associated with for $q \in R$ can be written as

$$\max_{x \in S} f(x) - q * g(x) \quad (3.9)$$

The following algorithm ϵ -optimal algorithm shows the optimization.

Initialization

$q=0$, $\text{epsi} = 10^{-6}$, $i=0$, $\text{convergence}=\text{false}$

Define

$\gamma_{DF}^T(p_s, p_r, \tau, q) = \sum_{k=1}^K \tau_k - q(p_c + \sum_{k=1}^K (p_k^s + p_k^r))$

while ($\text{convergence}=\text{false}$) & ($i < \text{imaxitr}$) do

if $\gamma_{DF}^T(p_s, p_r, \tau, q) = 0$ then

$p_{s0} = p_s$

$p_{r0} = p_r$

$\tau_0 = \tau$

Convergence=true

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Else if
 $\gamma_{DF}^T(p_s, p_r, \tau, q) \leq \varepsilon$ 
 $p_s \in p_s$ 
 $p_r \in p_r$ 
 $\tau \in \tau$ 
Convergence=true
Else
 $q = \frac{\sum_{k=1}^K \tau_k}{p_c + \sum_{k=1}^K (p_k^s + p_k^r)}$ 
 $i = i + 1$ 
end if
end while

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B. Shared Carrier Assignment Iterative Waterfilling Algorithm (SCA-IWF)

The rate maximization subject to the instantaneous sum-power constraints may be defined as

$$\begin{aligned} & \max_{a_{k,n}, P_{k,n}} \sum_{n=1}^N a_{k,n} C_{k,n}(P_{k,n}) \\ & \text{s.t. } \sum_{n \in S} a_{k,n} P_{k,n} < P_{T,k}, \sum_{k=1}^K a_{k,n} < 1 \end{aligned} \quad (3.10)$$

where $a_{k,n} = \{0, 1\}$ and $a_{k,n} = 1$ when user k accesses channel n . S_k is the set of carriers assigned to user k , and $P_{\text{mask},n}$ is the maximum power allowed at carrier n to avoid interference to primary users. S_1, \dots, S_K are generally overlapping sets for SCA. The capacity of user k at carrier n is given by Eq (3.11)

$$C_{k,n}^{SCA}(P_{k,n}) = B_n \log_2(1 + \Gamma_k P_{k,n} \gamma_{\Gamma,n}^{SINR}) \quad (3.11)$$

Where $\gamma_{\Gamma,n}^{SINR}$ was given by SINR at the channel n , Γ_k is an SNR gap due to modulation format and bit error rate (BER) requirement.

When $\Gamma_k = 1$, Eq (3.11) gives the Shannon capacity when $\Gamma_k = -1.5 / \log(5P_{e,k})$, $P_{e,k}$ is the target BER for user k assuming continuous-rate quadrature amplitude modulation (CR-QAM), Eq(3.12) gives the throughput which satisfies the Target BER $P_{e,k}$. The sum rate of all K pairs is given by

$$C_{\text{tot}}^{SCA} = \sum_{k=1}^K \sum_{n=1}^N a_{k,n} C_{k,n}^{SCA}(P_{k,n}) \quad (3.12)$$

Shared Carrier Assignment technique shares the given carriers available for the transmission as compared to the exclusive carrier assignment where each user is allocated a different carrier. It generally requires an NK -dimensional numerical search and the global optimization is an often in-tractable problem. Based on OSB and ISB, optimization may be implemented assuming a central controller or global knowledge of interference powers at each pair. As a suboptimal solution with distributed processing, the SCA-based iterative water-filling technique may be used, which allows all transmitters (users) to initially compete all the N carriers and then fine tune it. In each data frame duration, the first few mini-slots are used for carrier competition of K users, after which the data transmission follows. In these mini-slots each transmitter implements WF along the carriers under its own power constraint and based on the SINRs of the carriers. This method converges fast as shown by simulations. Usually, the IWF requires a numerical search. A low-complexity IWF taking into account the spectral mask at each channel n is derived below. Define the Lagrangian(for pair k)

$$L(\lambda_k, \{P_{k,n}\}_{n \in S}) = \sum_{n \in S} \log(1 + P_{k,n} \gamma_{\Gamma,n}^{SINR}) - \lambda_k (\sum_{n \in S} P_{k,n} - P_{T,k}) \quad (3.13)$$

Taking derivative

$$\begin{aligned} & P_{k,n}^* = (1/\lambda_k - 1/\gamma_{\Gamma,n}^{SINR}) \\ & \text{s.t. } \sum_{n \in S} P_{k,n}^* < P_{T,k} \end{aligned} \quad (3.14)$$

where $(x)^+ = \max(0, x)$, and $P_{k,n}^*$ denotes the water-filling optimal solution of $P_{k,n}$. After some manipulations, we obtain an equation equivalent as

$$\lambda_k = N_k / [P_{T,k} + \sum_{n \in S} 1/\gamma_{\Gamma,n}^{SINR}] \quad (3.15)$$

where $N_k = |S_k|$ is the cardinality number of set S_k . After the WF power allocation, not all the carriers are used due to possibly weak channel SINRs at some carriers, which means that generally.

A very low complexity exact IWF algorithm is shown below

- 1) At each min slot assume that pair k has channel set S_k (with cardinality N_k) with non zero power allocation at each of the element. Update the SINR $\gamma_{k,n}^{SINR}$ according to the interference power levels from the other links.
- 2) Let $N_{\text{keff}} = N_k$. Rank $(\gamma_{k,n}^{SINR})_{n \in S_k}$ in descending order where $\gamma_{k,1}^{SINR} > \dots > \gamma_{k,N_k}^{SINR}$ holds.
- 3) Find λ_k using (3.14) with N_k is replaced by N_{keff} therein.
- 4) Check if $\lambda_k < \gamma_{k,N_{\text{keff}}}^{SINR}$ holds. If true go to step 5. Otherwise remove $\gamma_{k,N_{\text{keff}}}^{SINR}$ from the set $\gamma_{k,1}^{SINR} > \dots > \gamma_{k,N_{\text{keff}}}^{SINR}$, set $N_{\text{keff}} = N_{\text{keff}} - 1$ and go to step3.
- 5) The λ_k and N_{keff} are now obtained for the user k . The allocated power for the carrier n of user k is given by $P_{k,n}^{IWF} = \min(P_{k,n}^*, P_{\text{mask}})$ where $P_{k,n}^*$ is given by (3.13) for $n=1, \dots, N_{\text{keff}}$
- 6) The instantaneous throughput for the n th carrier with the iterative water-filling(IWF) is given by

$$C_{k,n}^{IWF} = \log(1 + P_{k,n}^{IWF} \gamma_{\Gamma,n}^{SINR})$$

IV. RESULTS AND DISCUSSIONS

A. Graphical Representation of Energy Efficiency and Capacity Plot with Number of Iterations in Cr Networks using IPAS Scheme

Figure (4.1) shows the energy efficiency with the no of iterations, We have plotted graphs for different values of primary users K.it is observed that with the increase in the value of K, the energy efficiency increases. As the number of iterations increases, the energy efficiency first increases linearly and then after few iterations the energy efficiency increases at a very low rate and almost becomes a constant. This shows that the graph converges in very few iterations.

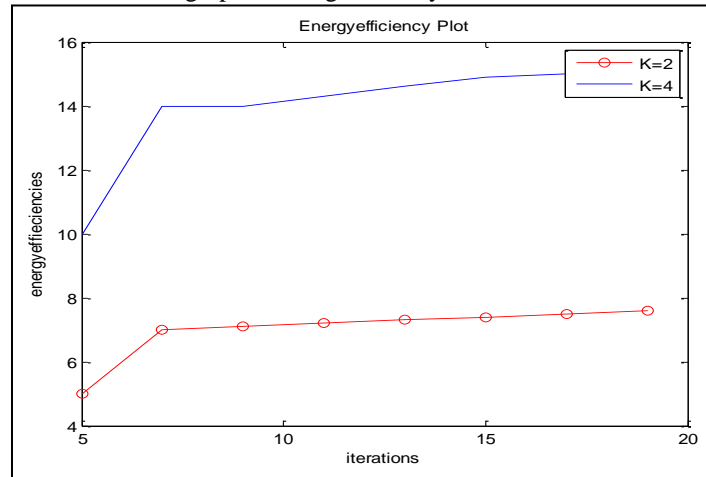


Fig. 4.1: Energy efficiency plot in the CR networks with the number of iterations at the different values of K

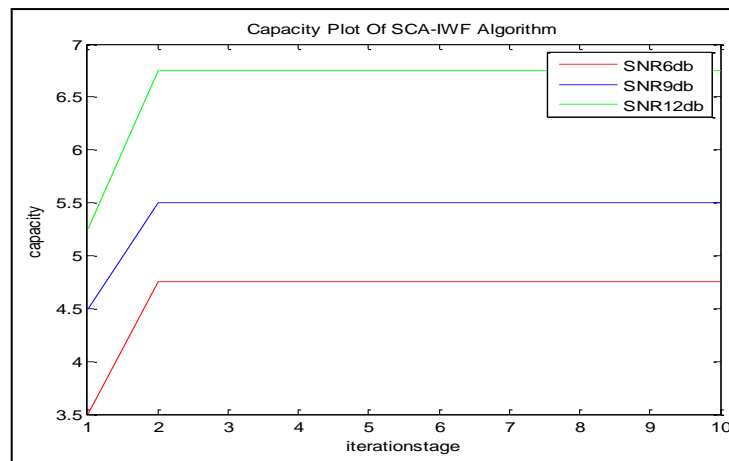


Fig. 4.2 Capacity plot of SCA-IWF Algorithm with the Number of iterations at the different SNR values of the channels

Figure (4.2) shows the capacity plot for SCA-IWF Algorithms for the different values of SNRs. Capacity plots for SNR 6db,9db and 12db are plotted. From the figure it is clear that the SNR of the channel increases as the capacity value increases for the no of iterations and it increases linearly first and then become constant for all the cases.

B. Energy Efficiency and Capacity Plot in Bar-Graph Form

The variation of the energy efficiency plot with the number of iterations at the different SNR values is shown in Fig (4.3). It is shown in the bar-graph form for the better understanding of the variation of the energy efficiency with the number of iterations at the different SNR values.

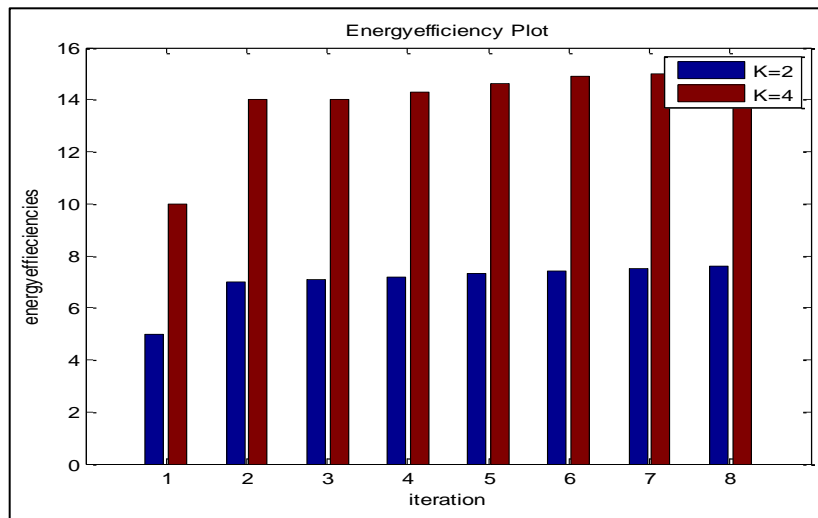


Fig 4.3: Energy efficiency plot with respect to the number of iterations in the bar-graph form

Fig (4.4) shows the capacity plot with the number of iterations in the bar-graph form for the better understanding of the variations of capacity at different SNR with the number of iterations. In the graphical form we can see the variations of capacity at different SNR values simultaneously in discrete forms.

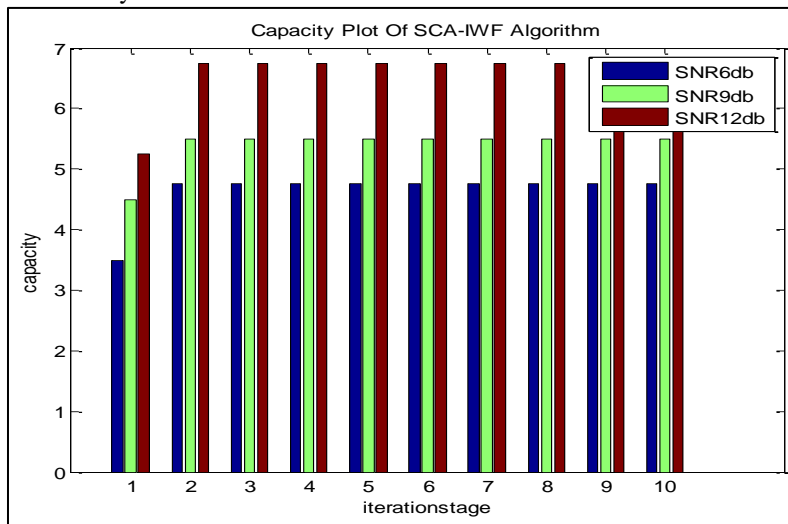


Fig 4.4: Capacity plot of the SCA-IWF Algorithm in the bar graph form with respect to the number of iterations

V. CONCLUSION

In the CR system, spectrum and power are two main resources that we need to utilize very efficiently. In this thesis we mainly focused to maximize the utilization of these resources.

In the first part of thesis, we have discussed the different algorithms by which all power is allocated in different scenarios with the channels having different SNRs and then finally we have allocated power to the channels so as to maximize the capacity by allocation the power to channels according to their SNRs. Here we have used Shared Carrier Assignment-Iterative Water-filling (SCA-IWF) approach to maximize the capacity by optimum utilization of the spectrum.

In the second part of our work, we have considered a network where we have to allocate power to the network in order to get the maximum energy efficiency of the whole scenario. Here in this case we have used the iterative power allocation scheme (IPAS) technique in which we have also considered SNR as the base to decide in which channel we have to allocate the power so as to get the maximum capacity of the system.

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