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An Efficient Subcarrier and Power Allocation Scheme for OFDM based Cognitive Radio Networks Considering Channel Sensing Errors

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Abstract

Cognitive radio plays a major role in today's wireless communications and solves the spectrum scarcity problem by efficiently utilizing the vacant spectrum. Most CR systems employ OFDM as a modulation technique because of its flexibility in allocating spectrum resources. Allocation of vacant spectrum to the secondary users introduces interference to the primary users. In this paper, subcarrier and power allocation for OFDM based cognitive radio network for joint overlay and underlay spectrum access mechanism (JOUSAM) with channel sensing error is proposed. For such a CR systems, the transmission rate is maximized for a given power budget, while keeping the interference level of the primary user below a certain threshold. The numerical results show that the proposed scheme achieves higher transmission rate when compared to system without considering sensing error.

Keywords: *Cognitive radio, OFDM, joint overlay and underlay spectrum access mechanism, channel sensing error, subcarrier allocation, power allocation*

INTRODUCTION

The magnetic force spectrum may be a resource, the employment of that by transmitters and receivers is authorised by governments. The rise of wireless services and devices for uses appreciate mobile communications, public safety, WiFi, and television broadcast function the foremost indisputable example of what proportion fashionable society has become smitten by spectrum. Whereas land and energy planted the foremost precious wealth creation resource throughout the agricultural and industrial era, severally, the spectrum has become the foremost valuable resource of the trendy era. In November 2002, the Federal

Communications Commission (FCC) published a report prepared by the Spectrum-Policy Task Force, aimed at improving the way in which this precious resource is managed in the United States [1].

Cognitive radio inclusive of software-defined radio, has been projected to market the economical use of the spectrum by exploiting the existence of spectrum holes. psychological feature radio is an intelligent wireless communication system that is responsive to its encompassing surroundings (i.e., outside world), and uses the methodology of understanding-by-building to be told from the surroundings and adapt its internal states to applied mathematics variations within the incoming RF stimuli by creating corresponding changes in bound operative parameters [2, 3]. One of the foremost vital parts of the psychological feature radio construct is that the ability to live, sense and conscious of the parameters involving the radio channel characteristics, availableness of spectrum and power, radio's in operation surroundings, native policies and different in operation restrictions. In psychological feature radio technology, primary users will be outlined because the users United Nations agency have higher priority on the usage of a selected a part of the spectrum. On the opposite hand, secondary users, that have lower priority, exploit this spectrum in such the simplest way that they are doing not cause interference to primary users. However, it is troublesome for the secondary users to own excellent information of the dynamic radio surroundings because of short sensing time and network property problems, wherever inaccurate channel state data (CSI), furthermore as miss detections and false alarms of PUs will occur [4]. Subcarrier and power allocation for transmission metallic element systems is projected in [5, 6]. OFDM is employed as an interface technology in metallic element systems [7–10]. Subcarrier and power allocation in OFDM primarily based metallic element systems are projected in [11, 12].

Authors proposed the subcarrier and power allocation algorithm for JOUSAM that increases the transmission rate so that the interference introduced to the PUs below a certain threshold [13]. However, in this work channel sensing error is not taken into account. In this paper, we have a tendency to think about a metallic element network consists of multiple secondary users. Then we have a tendency to extend the subcarrier and power allocation for JOUSAM by considering channel sensing

MAT JOURNALS
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errors. Initial we have a tendency to derive the probabilistic parameters involving sensing errors supported chance of detection and chance of warning. Second the interference introduced to the first users and to the psychological feature radio users are derived. The optimum power allocation drawback is to maximise the transmission rate of the metallic element users [14, 15]. The various subcarrier and power allocation methods have been proposed in [16–19].

SYSTEM MODEL AND PROBLEM FORMULATION

We consider a downlink transmission scenario consists of one pair of primary transmitter/receiver and many secondary terminals. Both the primary and secondary users employ OFDM as a modulation technique which consists of Z subcarriers. The portion of the radio spectrum with a total bandwidth B is divided into Z number of subcarriers. The total number of subcarriers include overlay and underlay subcarriers. The distance between the adjacent subcarrier is given as $\Delta f = B/Z$. Let us denote the fading channel gain between the CR transmitter and the CR receiver as $h_{k,i}^{SS}$ where k={1,2,...K} and i={1,2,…Z}. h_i^{SP} denotes the channel gain between the CR transmitter and PU receiver and $h_{k,i}^{PS}$ denotes the channel gain between the PU transmitter and CR receiver. The channel gain is assumed to follow Rayleigh distribution and is perfectly known at the CR transmitter. In a given time, there are N overlay subcarriers and L underlay subcarriers. Subcarriers and power are allocated to joint overlay and underlay spectrum access mechanism.

Figure 1 shows the system model for the considered transmission scenario. These considerations lead to formulation of mixed integer programming problem, which is intractable. To solve this problem, we allocate the subcarriers to the users based on the channel gain and power is to be allocated among the OFDM sub channels [20–22].

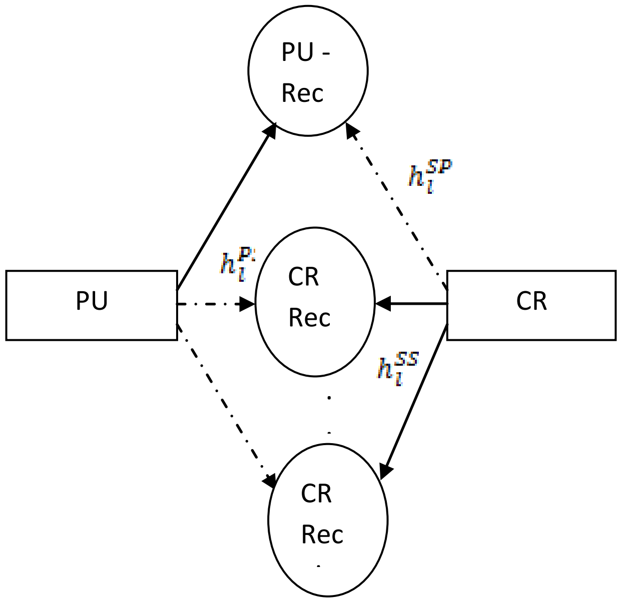

Fig. 1: *System Model.*

SPECTRUM SENSING METHODOLOGY AND INTERFERENCE MODEL

In CR systems, interference introduced to the primary user increases because of sensing error. In a practical scenario, there are two types of sensing errors. We formulate the relation that takes into account sensing errors to reduce the interference introduced to the primary users. First is the misdetection, which refers that the channel is free but it is identified as busy. Second is the false alarm which indicates that the channel is detected as vacant but it is actually busy.

The role of CR systems is to sense the primary channel and send the information to the CR base station. Sensing the presence of PUs in the i^{th} sub band is based on Hypothesis testing problem which is given as:

H_0^i – denotes the primary is not transmitting in the i^{th} sub band

H_1^i - denotes the primary is transmitting in the i^{th} sub band

The above two hypothesis indicates the actual presence or absence of the primary in the particular sub band.

The total available bandwidth is divided into Z subcarriers which includes underlay and overlay subcarriers. The exact information about the primary signal is not known due to imperfect sensing. The CR user transmits its data through each sub bands. Using Baye's theorem and law of probability, probability equation is given by:

$$\mathrm{P}(\widehat{H}_0^i) = P(\widehat{H}_0^i, H_0^i) + P(\widehat{H}_0^i, H_1^i) \quad (1)$$

$$= P(\widehat{H}_0^i | H_0^i)P(H_0^i) + P(\widehat{H}_0^i | H_1^i)P(H_1^i)$$

$$= (1 - P_{fa}^i)P(H_0^i) + (1 - P_d^i)P(H_1^i)$$

P_{fa}^i refers to the false alarm probability and P_d^i refers to the probability of detection. Conditional probability is given by

$$\propto_i = P(H_0^i | \widehat{H}_0^i) \quad (2)$$

The probability equations described above are employed in deriving the optimal power allocation scheme for joint overlay and underlay subcarriers. Figure 2 shows the bandwidth occupied by the CR network.

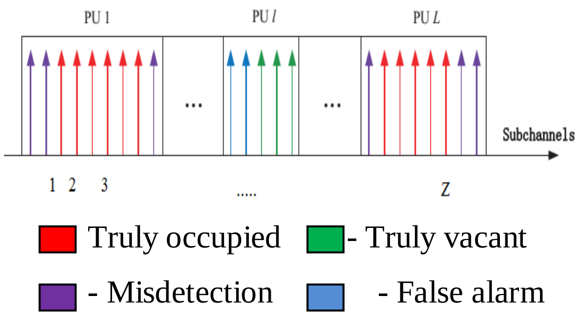

Fig. 2: *Bandwidth Available for CR Network [14].*

MODELING OF INTERFERENCE TO PUs

Here, assuming an ideal Nyquist pulse shaping at the CR transmitter, the power density spectrum of the i^{th} sub band is given as [16],

$$\varphi_i(f) = p_i T_s \left(\frac{\sin \pi f T_s}{\pi f T_s}\right)^2 \quad (3)$$

Where T_s is the symbol duration and p_i is the power loaded in the i^{th} subcarrier.

The interference introduced to the primary user by the CR subcarrier is

$$I_l(PU) = |h_l^{SP}|^2 \sum_{k=1}^{K} \sum_{i=1}^{Z} \rho_{u,k} p_{u,k} T_s \int_{d_{k,l+\Delta f/2}}^{d_{k,l-\Delta f/2}} \left(\frac{\sin \pi f T_s}{\pi f T_s}\right)^2 df \quad (4)$$

Δf represents the spectral distance between the adjacent subcarriers. The average total interference imposed under imperfect spectrum sensing on the primary network is computed as:

$$\hat{I}_{k,i} = P(\widehat{H})_0^i \sum_{l=1, l \neq i}^{Z} P(H_1^l) I_{il} + (1 - \propto_i) I_{ii} \quad (5)$$

The power density spectrum of the primary signal after M -point fast Fourier transform is given by the expected value of the periodogram.

$$E\{I_M(w)\} = \frac{1}{2\pi M} \int_{-\pi}^{\pi} \varphi_i(f) \left(\frac{\sin(w - \varphi) M/2}{\sin(w - \varphi)/2}\right)^2 d\varphi \quad (6)$$

w represents the frequency normalized to the sampling frequency.

The average total interference imposed under imperfect spectrum sensing on the secondary network is computed as:

$$\hat{J}_{k,i} = \Sigma_{l=1}^{Z} P(H_1^l, \widehat{H}_0^i) J_{k,li} \quad (7)$$

PROPOSED SUBCARRIER AND POWER ALLOCATION METHOD

Here, we propose a subcarrier and power allocation for JOUSAM and aim to maximize the transmission rate of the CR network while minimizing the interference introduced to the primary user below a certain level. Using Shannon capacity formula, the total transmission rate of the CR user

$$C = \alpha_i \sum_{k=1}^{K} \sum_{i=1}^{Z} \Delta f \log\left(1 + \frac{\left|h_{u,k}^{SS}\right|^2 p_{u,k}}{\sigma^2 + \hat{J}_{k,i}} \right) \quad (8)$$

σ^2denotes the additive white Gaussian noise (AWGN) variance. Subcarriers are allocated based on the channel gain and after allocating subcarriers, power is allocated as follows. Less power is allocated to the underlay subcarriers compared to overlay subcarriers because it introduces more interference to the PUs. According to ladder profile method, power is allocated [2].

$$\max \sum_{k=1}^{K} \sum_{i=1}^{Z} \Delta f \log\left(1 + \frac{\left|h_{u,k}^{SS}\right|^2 p_{u,k}}{\sigma^2 + J_{k,i}} \right) \quad (9)$$

subject to

$$\sum_{k=1}^{K} \sum_{i=1}^{Z} p_{u,k} \le P_T$$

ALGORITHM

Initialization

Set $R_{k,i} = 0$, A={ 1,2,….,Z} , and $\Omega_k = \emptyset$ for k= 1,2,….K

For k=1 to K

Find k to satisfy $S_{k,i} \geq S_{k,j}$ for all j∊ A

Assign $\Omega_k = \Omega_k \cup \{i\}$ and update $R_{k,i}$

while A ≠ ∅

- Find k to satisfy $\sum_{i=1}^{Z} R_{k,i}/\beta_k \le \sum_{i=1}^{Z} R_{k,i}/\beta_i$ for all i, 1≤ i≤ K
- For u found in previous step find k, to satisfy $S_{k,i} \geq S_{k,j}$ for all j∊ A
- For k and i find in previous step assign $\Omega_k = \Omega_k \cup \{i\}$ and update $R_{k,i}$

where k = 1,2,…K

i = 1,2,….Z

K = Number of CR users

Z = Number of total subcarriers

∅ = All users

NUMERICAL RESULTS AND DISCUSSIONS

In the numerical results presented here, the values of Tsand Δf have been taken to be 4 μs and 0.3125 MHz, respectively. It is assumed that there are K = 4 CR users, N = 8 overlay subcarriers, and L = 8 underlay subcarriers. AWGN power per subcarrier $\sigma^2 = 1.2944 \times 10^{-15}$ W, and the values of interference $j_{k,u} = \sigma^2$ (k = 1, 2, . . . , Z). The channel fading amplitude gain between the CR transmitter and the u^{th} CR receiver in the k^{th} subcarrier $\left|h_{u,k}^{SS}\right|$has been assumed to be Rayleigh distributed with a mean of −52.39 dB.

The power profile for various schemes is shown in Figure 3. For underlay subcarriers, less power is allocated compared with the overlay subcarriers because it will introduce more interference to the primary user band. The proposed scheme allocates the power according to the ladder profile method.

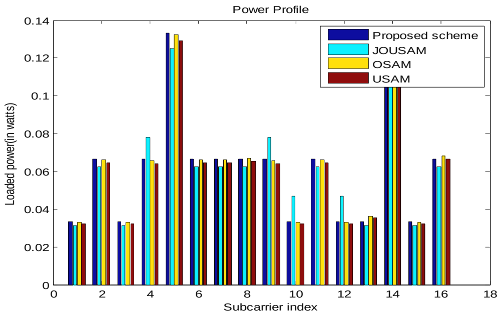

Fig. 3: *Power Profile for Various Schemes.*

Power loading profiles for various schemes is plotted to depict how much power is loaded onto the subcarrier. For this scenario, the interference threshold is set to 50*σ^2 and the proposed algorithm can be used for any set of values of channel gains. The values are chosen such that the total power budget is relatively high and interference constraint becomes boundary constraint (interference limited scenario). When the average channel gains for various PUs are different, PU receivers with relatively higher average channel gains are assigned with relatively low power and vice-versa.

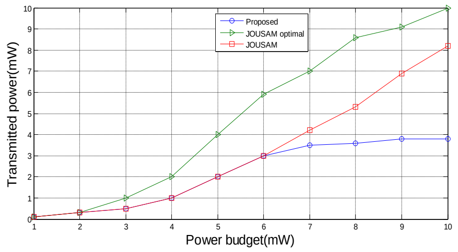

Fig. 4: *Achievable Transmitted Power vs. Power Budget.*

In Figure 4, we have plotted the total transmission power for various schemes under consideration. It can be seen that the some of the underlay subcarriers may have relatively better channel quality between the transmitter and users, and these subcarriers may overlap with the PU receivers that experience relatively poor channel quality from the CR transmitter. The above Figure shows that the proposed scheme requires less transmit power while achieving a higher transmission rate.

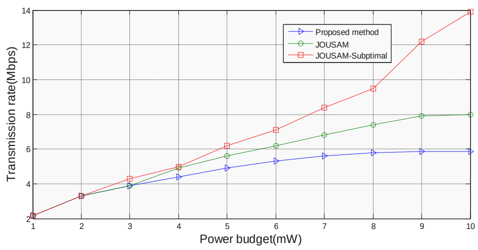

Fig. 5: *Total Achievable Transmission Rate versus Total Power Budget for Various Schemes.*

From Figure 5, it can be observed that the proposed scheme achieves higher transmission rate compared to JOUSAM without considering channel sensing error.

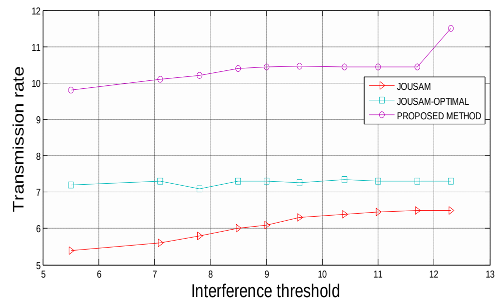

Fig. 6: *Total Achievable Transmission Rate versus Interference Threshold for Various Schemes.*

Figure 6 shows that for a given transmit power budget, the proposed method achieves higher transmission rate than other two schemes. It can be observed that the proposed method operate in an interference limited scenario for a particular value.

CONCLUSION

In this paper, the subcarrier and power allocation problem for an OFDM based CR system considering channel sensing error is proposed. The proposed scheme employs joint overlay and underlay subcarrier and power allocation for OFDM-based CR systems. It is based on Lagrange formulation that maximizes the downlink capacity of CR users, while maintaining a total power budget and keeping the interference below a certain threshold. The optimal scheme proposed achieves significant improvement in performance. The numerical results show that a significant gain in the total achievable transmission rate can be obtained by considering sensing errors. The extension of this work can be done by further improving the transmission rate of the CR users considering various scenarios.

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