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Efficient Joint Resource Allocation and Spectrum Sensing in Multiband Cognitive Radio Systems in the Presence of PUEA

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***Abstract*— Cognitive radio (CR) technology has been proposed as a solution to combat spectral scarcity by enabling unlicensed users to opportunistically use allocated bands to the licensed users, while the interference introduced to the licensed users does not exceed a predefined tolerable threshold. However, the cognitive nature of system introduces new threats and attacks. One severe attack to CR systems is the primary user emulation (PUE) attack, which an attacker mimics the signals of the PUs, resulting in false alarms during the spectrum sensing phase at well-behaving SUs even though the PUs are actually not present. These attackers can thus significantly degrade the performances of the well-behaving SUs. In *classical*energy detection method, CR system decides about the presence and absence of the PU, in each frequency band, by comparing the measured energy to a predefined threshold. Due to noise and spectrum sensing errors, this *Classical spectrum access* approach may lose some opportunities in the CR system. In this paper, we show that by *joint* resource allocation and spectrum sensing in the presence of PUEA, one canachievehigher data rates in CR system compared to the*classical* approach providing that the interference introduced to the PU does not exceed a predefined tolerable threshold.**

***Index Terms*—Cognitive Radio, Energy Detection, PUEA, Probabilistic Spectrum Access.**

I. INTRODUCTION

In recent years, cognitive radio (CR) technology has been proposed as a promising solution to combat shortage of spectral resources. In a cognitive network, unlicensed users called secondary users (SUs), are permitted to use allocated bands to the licensed primary users (PUs), as long as interference introduced to the PU remains tolerable [1]. So, cognitive network should senses the radio environment and after detecting vacant bands, shares its resources in a way, maximum exploitation is achieved and minimum interference is introduced to the PU. Due to main CR nature, some malicious users, known as primary user emulation attacker (PUEA), try to send fake signals similar to the PU with the aim of deceiving CR users and make them vacate unoccupied bands [2]. CR resource allocation methods aiming at maximizing transmission capacity operate based on spectrum sensing results and calculated interferences introduced to the CR and PU. So, it is vital to reconsider these parameters while exist fake signals in the environment to perform resource allocation more efficiently.In [3], a detection method based on distance ratio and difference to detect PUEA is proposed. In [4] based on an analytical model on the probability of successful, without any knowledge about the location information, PUEA is detected through a sequential test. The defense strategies against PUEA have been studied for example in [5]-[7]. In [5], a localization based defense technique has been proposed in which a number of sensors are deployed to pinpoint the PUE attacker. In [6] and [7], the defense against PUEA is modeled as a game theoretic problem, with or without the knowledge of channel statistics respectively. Also, in [8] a cooperative spectrum sensing in the presence of PUEA is modeled and an approach to maximize the detection probability of primary user has been proposed. However, the optimal weights are related to the channel state information between the attacker and secondary users and between the primary user and secondary users, which assumed that CR user can estimate by using channel estimation algorithms.

Sensing a PU is a difficult task due to the presence of variable path losses, fading and noise [9], [10]. Therefore, sensing is never completely reliable and will always produce some errors depending upon the channel conditions between the primary transmitter and CR sensors. Energy detection is widely adopted in spectrum sensing phase of CR networks because of its simplicity [11]. The decision on the occupancy of a band can be obtained by comparing the measured energyY_n against a fixed threshold which is obtained from Neman-Pearson criteria. If the decision metric Y_n is greater than threshold, CR network decides the PU is present. Otherwise, if the decision metric Y_n is lower than threshold, CR network decides that PU is absent and tries to use the spectrum. So, the CR network uses the spectrum with probability 1 or 0, depending on the measured energy. Due to noise and errors in spectrum sensing measurements, this classical decision-making technique may result in missing lots of opportunities in CR network.

In this paper, we propose an efficient joint spectrum sensing and resource allocation in a CR system, considering the presence of fake signals in the radio environment. We show through numerical discussion and analysis that the proposedapproach achieves higher data rates in CR systemscompared to classical approach where spectrum

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sensing and resource allocation are performed separately.

The rest of this paper is organized as follows. The system model is presented in Section II. In Section III, we propose the joint resource allocation and spectrum sensing problem considered in this paper. We also formulate the average achievable secondary data rate by taking the presence of PUEA into account. Then, in Sections IV to VI, we formulate the false alarm and miss detection probabilities, and the mutual interferences that is introduced to the PU and CR. The solution of the joint resource allocation and spectrum sensing problem is presented in Section VIII. Section IX provides our simulation results and finally, in Section X,we conclude the paper.

II. SYSTEM MODEL AND MAIN ASSUMPTIONS

We consider an OFDM-based network where one cognitive radio user pair (consisting of one transmitter and one receiver) detects the presence or absence of one primary user over N subbands by measuring the energy of received signal over each subband. In addition, a PUEA is assumed to be active in the radio environment and send fake signals similar to the primary signal to deceive CR system. All transmitters and receivers are assumed to employ an OFDM scheme with N subbands. Spectrum sensing is performed in CR network over each OFDM subband. The total available bandwidth licensed to the PU is equal to B which is divided into N subbands, each of width $\Delta f = B/N$. Each subband may be occupied by PU, PUEA, CR signals or any combination of these signals. Different signals are operating in close and side-by-side frequency subbands which leads to a mutual interference on each other due to the non-orthogonality of transmitted signals. Moreover, due to spectrum sensing errors, different signals (PU, PUEA or CR signal) may be operating in the same subband which increases imposed interference to the PU and CR systems.

Let $\sqrt{P_n}x_{n,k}$ and $\sqrt{\hat{P}_n}\hat{x}_{n,k}$ be the signals transmitted by PU and PUEA over n-th subband and k-th time instant, and $y_{n,k}$ denotes the signal received at CR user through n-th subband and k-th time instant. We use $H_1^{(n)}$ to indicate that the PU signal is present in n-th subband and $H_0^{(n)}$ to indicate that it is absent. Also, $\hat{H}_1^{(n)}$ and $\hat{H}_0^{(n)}$ are used to denote the presence and absence of PUEA signal in the n-th subband, respectively. Depending on the presence or absence of PU and PUEA, there are four possible cases for expressing $y_{n,k}$. We represent these four cases by$s_1 = \left(H_1^{(n)}, \hat{H}_1^{(n)}\right)$, $s_2 = \left(H_1^{(n)}, \hat{H}_0^{(n)}\right)$,$s_3 = \left(H_0^{(n)}, \hat{H}_1^{(n)}\right)$ and $s_4 = \left(H_0^{(n)}, \hat{H}_0^{(n)}\right)$. Thus, the signal received by the CR user in n-th subband and k-th time instant, depending on the presence or absence of PU and PUEA, can be written as,

$$y_{n,k} = \begin{cases} \sqrt{P_n}x_{n,k}h_{n,k} + \sqrt{\hat{P}_n}\hat{x}_{n,k}\hat{h}_{n,k} + z_{n,k}, & \text{under} s_1 \\ \sqrt{P_n}x_{n,k}h_{n,k} + z_{n,k}, & \text{under} s_2 \\ \sqrt{\hat{P}_n}\hat{x}_{n,k}\hat{h}_{n,k} + z_{n,k}, & \text{under} s_3 \\ z_{n,k}, & \text{under} s_4 \end{cases} \qquad (1)$$

where$z_{n,k}$ is the additive white Gaussian noise through n-th CR subband and in the k-th time instant, with zero mean and varianceσ_n^2. The coefficients$h_{n,k}$ and $\hat{h}_{n,k}$ are the channel gains in spectrum sensing phase, through n-th subband and k-th time instant, between PU and CR, and PUEA and CR, respectively.In this paper, we assume that the channel gains $|h_{n,k}|$ and $|\hat{h}_{n,k}|$ are distributed according to a Rayleigh distribution with parameters λ_n and $\hat{\lambda}_n$ and the PU and PUEA signals $x_{n,k}$ and $\hat{x}_{n,k}$ have known powers$P_n$and $\hat{P}_n$, respectively. For simplicity, we assume that $E\left\{|x_{n,k}|^2\right\} = E\left\{|\hat{x}_{n,k}|^2\right\} = 1$. Then, according to (1), $y_{n,k}$is a zero mean random variable with variance $\sigma_{j,n}^2$ under $s_j$for $j \in \{1,2,3,4\}$. where

$$\sigma_{1,n}^2 = P_n\lambda_n^2 + \hat{P}_n\hat{\lambda}_n{}^2 + \sigma_n^2$$
$$\sigma_{2,n}^2 = P_n\lambda_n^2 + \sigma_n^2$$
$$\sigma_{3,n}^2 = \hat{P}_n\hat{\lambda}_n{}^2 + \sigma_n^2$$
$$\sigma_{4,n}^2 = \sigma_n^2$$

In this section, we derive a probabilistic framework which characterizes the spectrum sensing process in the presence of the PUEA. This framework will be used in the interference analysis and proposed power allocation scheme in subsequent sections.CR user performs energy detection over every subband, in which, M samples of the energy of$y_{n,k}$ are summed during one detection interval,

$$Y_n = \sum_{k=1}^{M} |y_{n,k}|^2 \qquad (2)$$

According to Equation (2), Y_n in the energy detection is the sum of squared $y_{n,k}$'s. Hence, according to the *central limit theorem*, for large M, Y_n is distributed according to a normal distribution,i.e., [12]

$$Y_n \sim \mathcal{N}\left(E(Y_n), \mathrm{Var}(Y_n)\right),$$

where

$$E(Y_n) = \begin{cases} M\left(P_n\lambda^2 + \hat{P}_n\hat{\lambda}^2 + \sigma_n^2\right), & \text{under} S_1 \\ M\left(P_n\lambda^2 + \sigma_n^2\right), & \text{under} S_2 \\ M\left(\hat{P}_n\hat{\lambda}^2 + \sigma_n^2\right), & \text{under} S_3 \\ M\sigma_n^2, & \text{under} S_4 \end{cases}$$

$$\mathrm{Var}(Y_n) = \begin{cases} 2M\sigma_n^2\left(2P_n\lambda^2 + 2\hat{P}_n\hat{\lambda}^2 + \sigma_n^2\right), & \text{under} S_1 \\ 2M\sigma_n^2\left(2P_n\lambda^2 + \sigma_n^2\right), & \text{under} S_2 \\ 2M\sigma_n^2\left(2\hat{P}_n\hat{\lambda}^2 + \sigma_n^2\right), & \text{under} S_3 \\ 2M\sigma_n^4, & \text{under} S_4 \end{cases}$$

III. FORMULATION OF THE JOINT RESOURCE ALLOCATION AND SPECTRUM SENSING IN THE PRESENCE OF PUEA

Here, we aim at presenting the problem of joint resource allocation and spectrum sensing in the presence of PUEA.
Let us denote the joint probability of using the n-th channel in the j-th state by $\alpha_{j,n}$, i.e., $\alpha_{j,n} = \Pr\{s_j, T_n\}$, for $j \in \{1,2,3,4\}$. We also denote by p_n the power level allocated to the n-th CR subband. The considered problem consists in determining $\alpha_{j,n}$ and $p_n$so as to maximize the average achievable secondary data rates under interference and total power constraints. To this end, we require to characterize the secondary achievable data rates as follows.

A. Average Data Rate In CR System In The Presence Of PUEA

The average data rate achieved in CR system can be formulated as

$$\overline{C} = \sum_{n=1}^{N} \sum_{j=1}^{4} C_{j,n} \alpha_{j,n} \qquad (4)$$

where $C_{j,n}$ is the capacity in the CR system under s_j and can be written as

$$C_{j,n} = \Delta f \log_2 \left(1 + \frac{p_n |h_n^{ss}|^2}{U_{j,n} + \sigma_n^2} \right) \qquad (5)$$

The capacity of an additive white Gaussian noise (AWGN) channel with W Hz bandwidth and signal-to-noise ratio P_S/N is $C = W \log_2(1 + P_S/N)$. Depending on presence or absence of PU and PUEA, in addition to the additive white Gaussian noise, the interference introduced to the CR network by PU and/or PUEA should be considered. Hence, in addition to the noise variance, we have considered the interference $U_{j,n}$ that is introduced to the CR system by the PU and/or PUEA. The formulation of $U_{j,n}$ is provided in Section VI.

It is well known that CR spectrum sensing is characterized by false alarm and miss detection probabilities. These probabilities are formulated and derived in what follows, by considering the presence of PUEA.

IV. THE PROBABILITIES OF FALSE ALARM AND MISS DETECTION

The false alarm probability of CR system in the n-th subband can be formulated as

$$\begin{aligned} P_{f,n} &= 1 - \Pr\left\{T_n | H_0^{(n)}\right\} \\ &= 1 - \Pr\left\{T_n, H_0^{(n)}\right\} \Pr\left\{H_0^{(n)}\right\} \\ &= 1 - \Pr\left\{H_0^{(n)}\right\} \left(\Pr\left\{T_n, H_0^{(n)}, s_3\right\} + \Pr\left\{T_n, H_0^{(n)}, s_4\right\} \right) \\ &= 1 - \Pr\left\{H_0^{(n)}\right\} \left(\Pr\{T_n, s_3\} + \Pr\{T_n, s_4\} \right) \\ &= 1 - \Pr\left\{H_0^{(n)}\right\} \left(\alpha_{3,n} + \alpha_{4,n} \right) \end{aligned}$$

Similarly, it can be shown that the miss detection probability $P_{md,n}$ in n-th subband is given as

$$P_{md,n} = \Pr\left\{H_1^{(n)}\right\} \left(\alpha_{1,n} + \alpha_{2,n} \right) \qquad (6)$$

V. INTERFERENCE INTRODUCED TO THE PU BY THE CR USER

The legal CR transmission procedure over licensed subbands is due to the imposed interference introduced to the PU. So, the CR network should consider its interference to the PU, constantly. We denote the interference introduced by CR due to transmitting over the l-th subband to the n-th subband of PU receiver, by $I_{l \to n}$. Let $S_l(f)$ be the PSD of CR transmitted signal over l-th subband and h_l^{sp} be the channel gain through l-th subband between CR transmitter and PU receiver. So, $I_{l \to n}$ can be written as,

$$I_{l \to n} = \left| h_n^{sp} \right|^2 \int_{f_n - \frac{\Delta f}{2}}^{f_n + \frac{\Delta f}{2}} S_l(f - f_l) df \qquad (7)$$

where f_n and f_l are the frequency centers of subbands n and l, respectively. In this paper, we assume CR transmission is performed by ideal Nyquist pulse with the power of p_l in l-th subband, so, the PSD of l-th CR subcarrier can be written as,

$$S_l(f) = p_l \tau_s \left(\frac{\sin(\pi f \tau_s)}{\pi f \tau_s} \right)^2, \qquad (8)$$

where τ_s is the symbol duration. Then we can write,

$$I_{l \to n} = p_l \theta_{ln}, \qquad (9)$$

where

$$\theta_{ln} = \tau_s \left| h_n^{sp} \right|^2 \int_{f_n - \frac{\Delta f}{2}}^{f_n + \frac{\Delta f}{2}} \left(\frac{\sin(\pi (f - f_l) \tau_s)}{\pi (f - f_l) \tau_s} \right)^2 df \qquad (10)$$

The average interference introduced to the n-th subband of the PU is either due to the spectrum leakage of CR subcarriers existing in other subbands, or due to the CR subcarrier in the same subband, which can be written as follow,

$$\begin{aligned} I_n &= I_{n \to n} \Pr\left\{H_1^{(n)}, T_n\right\} + \sum_{\substack{l=1 \\ l \neq n}}^{N} I_{l \to n} \Pr\left\{H_1^{(n)}, T_l\right\} \\ &= I_{n \to n} \Pr\left\{T_n | H_1^{(n)}\right\} \Pr\left\{H_1^{(n)}\right\} \\ &\quad + \sum_{\substack{l=1 \\ l \neq n}}^{N} I_{l \to n} \Pr\left\{T_l | H_1^{(n)}\right\} \Pr\left\{H_1^{(n)}\right\} \end{aligned}$$

From (6), we note that

$$\Pr\left\{T_n | H_1^{(n)}\right\} = P_{md,n} = \Pr\left\{H_1^{(n)}\right\} \left(\alpha_{1,n} + \alpha_{2,n} \right)$$

Also, for $l \neq n$, since the transmission on the l-th subband only depends on the measured energy of the l-th subband, we can write

$$\Pr\left\{T_l | H_1^{(n)}\right\} = \Pr\{T_l\} = \sum_{j=1}^{4} \Pr\left\{T_l, s_j\right\} = \sum_{j=1}^{4} \alpha_{j,l}$$

Hence, the average interference introduced to the n-th subband of the PU is given by

$$I_n = I_{n \to n} \Pr\left\{H_1^{(n)}\right\} \left(\alpha_{1,n} + \alpha_{2,n} \right) + \sum_{\substack{l=1 \\ l \neq n}}^{N} I_{l \to n} \sum_{j=1}^{4} \alpha_{j,l}$$

From (9) we can write,

$$\begin{aligned} I_n &= p_n \theta_{nn} \Pr\left\{H_1^{(n)}\right\} \left(\alpha_{1,n} + \alpha_{2,n} \right) + \sum_{\substack{l=1 \\ l \neq n}}^{N} p_l \theta_{ln} \sum_{j=1}^{4} \alpha_{j,l} \\ &= \sum_{l=1}^{N} p_l \Psi_{n,l} \end{aligned}$$

where

$$\Psi_{n,l}(y) = \begin{cases} \theta_{nn} \Pr\left\{H_1^{(n)}\right\} \left(\alpha_{1,n} + \alpha_{2,n} \right), & l = n \\ \theta_{ln} \sum_{j=1}^{4} \alpha_{j,l}, & l \neq n \end{cases}$$

So, the total average interference introduced in PU by CR network is

$$\begin{aligned} \bar{I} &= \sum_{n=1}^{N} I_n = \sum_{n=1}^{N} \sum_{l=1}^{N} p_l \Psi_{n,l} \\ &= \sum_{n=1}^{N} p_n \sum_{l=1}^{N} \Psi_{n,l} = \sum_{n=1}^{N} p_n \tilde{I}_n \end{aligned} \qquad (11)$$

Obviously, CR network is allowed to transmit while $\bar{I}$ remains below a predefined threshold. In other words, $\bar{I} \leq I_{th}$, where I_{th} is the total tolerable interference at the PU receiver.

VI. INTERFERENCE INTRODUCED BY PU AND PUEA SIGNAL TO THE SU SIGNAL

We assume that the power spectral density of the PU and PUEA signal is given by $S_{PU}(f)$ and $S_{PUEA}(f)$, respectively.

Hence, the interference introduced by the PU transmission over l-th subband to the CR over n-th subband, denoted by $U_{l\to n}$, can be expressed as,

$$U_{l\to n} = \left|h_n^{(PS)}\right|^2 \int_{f_n-\frac{\Delta f}{2}}^{f_n+\frac{\Delta f}{2}} S_{PU}(f-f_l)\mathrm{d}f \qquad (12)$$

where$h_n^{(PS)}$ is the channel gain between primary transmitter and secondary receiver through n-th subband.

Similarly, the interference introduced by the l-th subband of PUEA transmission to the n-th CR user subband, denoted by$V_{l\to n}$, is given as

$$V_{l\to n} = \left|h_n^{(ES)}\right|^2 \int_{f_n-\frac{\Delta f}{2}}^{f_n+\frac{\Delta f}{2}} S_{PUEA}(f-f_l)\mathrm{d}f \qquad (13)$$

whereh_n^{ES} is the channel gain between PUEA and secondary receiver through n-th subband. Hence, the total average interference introduced to the n-th CR subband in the states S_1 to S_4 is obtained by averaging $U_{l\to n}$ and $V_{l\to n}$over the subbands that PU and PUEA exist, respectively. So, we can write

underS_1:

$$U_{1,n} = \sum_{n=1}^{N} U_{l\to n} \Pr\left\{H_1^{(n)}\right\} + \sum_{n=1}^{N} V_{l\to n} \Pr\left\{\widehat{H}_1^{(n)}\right\}$$

under S_2:

$$U_{2,n} = \sum_{l=1}^{N} U_{l\to n} \Pr\left\{H_1^{(l)}\right\} + \sum_{\substack{l=1\\ l\neq n}}^{N} V_{l\to n} \Pr\left\{\widehat{H}_1^{(l)}\right\}$$

under S_3:

$$U_{3,n} = \sum_{\substack{l=1\\ l\neq n}}^{N} U_{l\to n} \Pr\left\{H_1^{(l)}\right\} + \sum_{l=1}^{N} V_{l\to n} \Pr\left\{\widehat{H}_1^{(l)}\right\}$$

under S_4:

$$U_{4,n} = \sum_{\substack{l=1\\ l\neq n}}^{N} U_{l\to n} \Pr\left\{H_1^{(l)}\right\} + \sum_{\substack{l=1\\ l\neq n}}^{N} V_{l\to n} \Pr\left\{\widehat{H}_1^{(l)}\right\}$$

VII. JOINT SPECTRUM SENSING AND POWER ALLOCATION

Remember from Section III that to address the joint power allocation and spectrum sensing problem, we have to determine parameters $\alpha_{j,n}$and p_n.

Let us first perform spectrum sensing to determine parameter $\alpha_{j,n}$ for $j \in \{1,2,3,4\}$ and subbands that secondary user can transmit over these subbands. By setting a fixed false alarm probability for each subband, a threshold value is determined for that subband.Comparing the received energy for each subband to its threshold, one can determine the set Ω as theset of subbands that the CR is allowed to transmit over.Based on this, one can easily derive $\alpha_{j,n} = \Pr\{s_j, T_n\}$, by integrating the probability density function of Y_n.

Then, the problem of power allocation in CR downlink to the CR subcarriers which may be present in every N licensed subband should be addressed.

We aim to maximize achievable data rate in CR network under constraints of imposed interference introduced to the PU and CR power budget. It is assumed that the CR network has a maximum transmit power budget of P_t. We also intend to solve the power allocation problem considering the average interference imposed to the total PU subbands remain below predefined thresholds.

The power allocation problem can be formulated as,

$$\max_{\mathbf{p}} \overline{C} = \sum_{n\in\Omega}\sum_{j=1}^{4} \alpha_{j,n} \log_2\left(1+\gamma_{j,n}p_n\right) \qquad (14)$$

$$\text{subject to } \bar{I} = \sum_{n\in\Omega} p_n \tilde{I}_n \le I_{th}$$

$$\sum_{n\in\Omega} p_n \le P_t$$

$$p_n \ge 0, \quad \forall n \in \Omega.$$

The optimization problem (14) is a convex problem and then the Lagrangian function writes

$$\mathcal{L} = -\sum_{n\in\Omega}\sum_{j=1}^{4} \alpha_{j,n}\log_2\left(1+\gamma_{j,n}p_n\right) + \lambda\left(\sum_{n\in\Omega} p_n\tilde{I}_n - I_{th}\right) + \mu\left(\sum_{n\in\Omega} p_n - P_t\right)$$

whereλ and μ are Lagrangian multipliers. By differentiation with respect to p_n, we have

$$\frac{\partial\mathcal{L}}{\partial p_n} = -\sum_{j=1}^{4}\frac{\alpha_{j,n}\gamma_{j,n}}{1+\gamma_{j,n}p_n} + \lambda\tilde{I}_n + \mu = 0$$

Hence, we can write

$$\sum_{j=1}^{4}\frac{\alpha_{j,n}\gamma_{j,n}}{1+\gamma_{j,n}p_n} = \lambda\tilde{I}_n + \mu \qquad (15)$$

Equation (15) is a polynomial function with degree 4 in terms ofp_n.If we define the function $Q(p_n)$ as

$$Q(p_n) = \sum_{j=1}^{4}\frac{\alpha_{j,n}\gamma_{j,n}}{1+\gamma_{j,n}p_n} - \lambda\tilde{I}_n - \mu$$

and then differentiate $Q(p_n)$with respect to p_n, we have

$$Q'(p_n) = -\sum_{j=1}^{4}\frac{\alpha_{j,n}\gamma_{j,n}^2}{\left(1+\gamma_{j,n}p_n\right)^2}$$

Since $\alpha_{j,n}$ is a nonnegative parameter,$Q'(p_n)$ is negative and thus the function $Q(p_n)$ is a strictly decreasing function in p_n. So, the equation (16) under following constraints has exactly one solution

$$\sum_{j=1}^{4}\frac{\alpha_{j,n}\gamma_{j,n}}{1+\gamma_{j,n}P_t} \le \lambda\tilde{I}_n + \mu \le \sum_{j=1}^{4}\alpha_{j,n}\gamma_{j,n} \qquad (16)$$

Otherwise, it has no solution. For interference constraint systems we have

$$\bar{I} = \sum_{n\in\Omega} p_n\tilde{I}_n = I_{th} \qquad (17)$$

Then, the Lagrangian multiplier μ is equal to zero and from equation (17) the Lagrangian multiplier λ can be acquired.

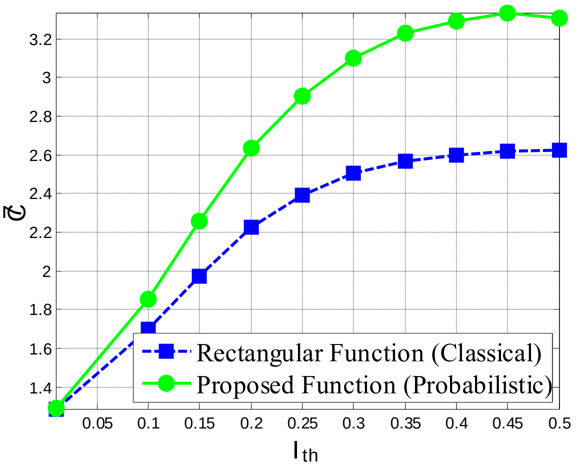

Fig. 1 CR data rate versus maximum tolerable interference introduced to the PU in proposed and classical methods.

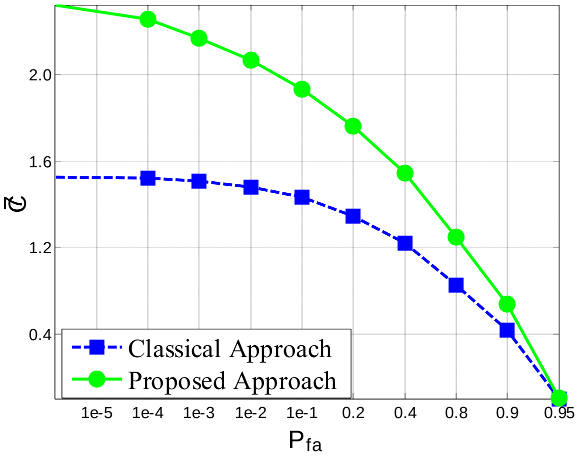

Fig. 2 CR user data rate versus false alarm probability in classical and proposed methods.

VIII. SIMULATION RESULTS

In this section we compare the average data rate of CR network for classical and proposed method.

According to a predefined false alarm rate, we derive the value of the threshold T. The false alarm probability is considered to be 10^{-2}.

Fig. 1 shows the average data rate achieved in CR system for two approaches versus maximum tolerable interference introduced to the PU. As can be seen, in the proposed approach, the CR system achieves a higher average data rate than the classical approach where spectrum sensing and power allocation are performed separately.

Figure 2 shows the average data rate achieved in CR system for two approaches versus false alarm probability P_{fa}. It can be seen that by increasing the alarm probability, in two methods, the average data rate is decreased. But in the proposed method, the secondary user has a higher data rate.

CONCLUSION

In this paper, joint power allocation and spectrum access was investigated in a multiband CR system by taking into account the presence of the PUEA. Taking the PUEA into consideration, we formulated the sensing parameters and achievable data rates of the CR system. Simulation results showed that the classical approach is suboptimal in the presence of PUEA. They confirmed the adequacy of our spectrum access scheme and showed that the proposed method outperforms significantly the classical scheme.

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