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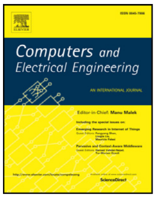

Optimal resource allocation for soft decision fusion-based cooperative spectrum sensing in cognitive radio networks[☆]

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A R T I C L E I N F O

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A B S T R A C T

Energy efficiency (EE) maximization with limited interference to the primary user (PU) is one of the primary concerns in cognitive radio networks (CRNs). To achieve this objective, we first propose an algorithm to select less spatially-correlated secondary users (SUs) to lessen the shadowing effect in wireless environment. Further, the aid of parametric transformation with the Lagrangian duality theorem in our proposed algorithm called Novel Iterative Dinkelbach method (NIDM) is used to optimise both sensing time and transmission power allocation of the SUs for maximising EE under the constraints of maximum transmission power, interference to the PU, overall outage of secondary transmission and minimum data rate requirement. Extensive simulation results demonstrate the effectiveness of our proposed algorithm. It is also observed that our proposed scheme outperforms the other existing schemes in enhancing the EE with the same system parameters.

1. Introduction

Traditionally adopted fixed frequency allocation policy is not able to meet the insatiable demand of more spectrum. This leads to the development of cognitive radio (CR) which provides opportunistic access of licensed spectrum to the unlicensed users [1,2]. In cognitive radio networks (CRNs), cooperative spectrum sensing (CSS) scheme is introduced to combat the effects of fading, shadowing and the hidden layer problem occur in practical wireless environment [3]. In CSS, the local sensing results of secondary users (SUs) are combined at the fusion centre (FC) by two schemes; Hard decision fusion (HDF) [4,5] and Soft decision fusion (SDF) [6,7]. From the literature studies, it is found that SDF-based CSS schemes give better performance than HDF-based CSS schemes [6,7]. This mainly motivated us to formulate our resource allocation model in SDF-based sensing scheme.

Energy-efficient CRN design depends on the system throughput and power consumption by the sensing devices. Meanwhile, the sensing time must be chosen to maintain a trade-off between the spectrum sensing accuracy and system throughput [8]. The optimal power allocation is also necessary to restrict the unnecessary growth of transmission power that may introduce severe interference to the primary user (PU) [9]. Especially, in wireless environment, transmission power degrades with the distance raised to the power of path-loss factor. The reduced weak signal makes the SUs to falsely decide the absence of PU in the desired band and to transmit their data. More SUs lead to more energy consumption. So, exclusion of these shadowed SUs and inclusion of suitable (less spatially-correlated) SUs can improve the detection probability with less power consumption.

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Table 1
List of symbols,

Symbol	Description
K	Total number of SUs
M	Selected SUs
τ_s	Sensing time
T_0	Data transmission duration
α and β	Busy and idle rate
N_0	Noise power
P_p	Interference power from PU received at SUs
$P(H_1)$	Probability of PU presence
$P(H_0)$	Probability of PU absence
R_{th}	Minimum achievable data rate
Γ_{th}	Outage threshold
$E_{i,j}$	Element of correlation matrix E
P_{outi}	Outage of *ith* SU
u	Dinkelbach parameter

To preserve energy efficiency (EE), most of the papers in the literature have discussed power allocation algorithms with limited interference to the PU. Wu et al. maximised the EE by jointly optimising the sensing time and power allocation with the constraints of detection parameters and interference to the PU [10]. In [11], the authors proposed a power allocation algorithm by taking sensing error into consideration for OFDM-based cooperative networks. In [12], an energy-efficient model was suggested for multiple amplify-and-forward relays in single source-destination (S-D) CR environment. Here, the authors formulated EE maximization problem as a minimization of total energy consumption under the constraints of false alarm probability, probability of detection, data rate of SUs and minimum interference threshold. A novel iterative algorithm based on parametric transformation method was proposed in [13] for green CR under the constraint of interference to the PU, and was extended for decode-and-forward (DF) relay based green cooperative CR in [14] under both interference and SUs outage constraints. To derive the optimal power allocation strategies over different fading channels, Kang et al. considered the channel state information of PU and maximised the outage capacity at secondary network under the constraints of maximum transmission power from the SUs and outage probability of PU [15]. In [16], EE variation over sensing time was formulated as concave optimization, so golden section search method was employed to find optimal sensing time for maximum EE. Most of the papers are based on HDF-based CSS and do not consider the PU activity during the data transmission period while formulating the interference model.

The main objective of this paper is to maximise the EE with optimal sensing time and power allocation with limited interference to the PU and outage of SUs. The main contributions of our work are summarised below.

a. Firstly, we develop an interference-aware model considering the exponential transition probabilities of PU during the data transmission period.
b. Secondly, we propose SUs selection algorithm based on Hungarian method to select less spatially-correlated SUs.
c. Thirdly, we formulate this joint optimization using two approaches.
    - We propose a Novel Iterative Dinkelbach Method (NIDM) algorithm under the constraints of different parameters associated with the EE maximization.
    - At each iteration in NIDM algorithm, the sensing time is found by employing golden section search method for maximum throughput and the sub-problem associated with the power allocation is solved by employing Karush–Kahn–Tucker (KKT) condition on Lagrangian dual problem. Then, the complexity of our proposed algorithm is analysed.
d. Finally, the performance of our proposed scheme is presented and the effect of different system parameters on the simulation results is studied.

Table 1 summarises the main symbols and notations used in this paper. The paper is structured as follows. Section 2 describes the system model and the interference model. The EE maximization problem formulation is presented in Section 3. In Section 4, our proposed algorithms are discussed. We present the simulation results in Section 5 and finally, the paper is concluded in Section 6.

2. System model and problem setup

In this Section, we discuss the system model of SDF-based CSS scheme along with the frame structure, and provide the interference model to evaluate the total interference possible to the PU during the data transmission period.

2.1. System model

We consider a CRN consists of K SUs which are uniformly distributed around the centrally located PU from which only M less spatial-correlated SUs are to be selected. They jointly perform spectrum sensing on the entire licensed band. The