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Cooperative spectrum sensing in cognitive radio network using multiobjective evolutionary algorithms and fuzzy decision making

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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

The cognitive radio has emerged as a potential solution to the problem of spectrum scarcity. Spectrum sensing unit in cognitive radio deals with the reliable detection of primary user's signal. Cooperative spectrum sensing exploits the spatial diversity between cognitive radios to improve sensing accuracy. The selection of the weight assigned to each cognitive radio and the global decision threshold can be formulated as a constrained multiobjective optimization problem where probabilities of false alarm and detection are the two conflicting objectives. This paper uses evolutionary algorithms to solve this optimization problem in a multiobjective framework. The simulation results offered by different algorithms are assessed and compared using three performance metrics. This study shows that our approach which is based on the concept of cat swarm optimization outperforms other algorithms in terms of quality of nondominating solutions and efficient computation. A fuzzy logic based strategy is used to find out a compromise solution from the set of nondominated solutions. Different tests are carried out to assess the stability of the simulation results offered by the heuristic evolutionary algorithms. Finally the sensitivity analysis of different parameters is performed to demonstrate their impact on the overall performance of the system.

1. Introduction

In the past decade, the demand of wireless devices has increased at a steep rate which has resulted in larger spectrum requirement. Due to limited amount of usable electromagnetic spectrum, the spectrum scarcity remains a challenge for all researchers. A study of spectrum utilization by Federal Communications Commission (FCC) [1] has shown that on an average, only 10% of the allocated spectrum is used for different applications. It is also observed that most of the spectrum bands are only used for limited time and in limited places. Therefore, one of the solutions to the problem of spectrum scarcity lies in the efficient usage and higher utilization of the available spectrum. Recently the researchers have paid more attention towards regulatory amendments to move from static/fixed spectrum allocation policy to a dynamic/flexible spectrum usage policy. As per the nomenclature followed in spectrum allocation model, the primary users have the license to use certain band of spectrum whereas the secondary users do not have any license. The dynamic spectrum usage policy allows the secondary user to exploit the spectrum unutilized by the primary user at any given time and location without causing intolerable interference to later.

Cognitive radio (CR) has emerged as a new technology which uses the dynamic spectrum usage policy to improve efficiency and utilization of the spectrum bands. The concept of CR was first proposed by Mitola [2]. He has described CR as a software radio having knowledge of all radio parameters such as radio frequency bands, protocols,

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and patterns. A CR can sense its radio environment and adapt its operational parameters dynamically to maximize the system performance at any given time and location.

A CR uses the spectrum allocated to the primary users when the latter are not utilizing it. Therefore a CR needs to frequently perform spectrum sensing in order to detect the presence of primary users. Generally a CR needs to sense a large frequency range to find an unused band for transmission. In literature, a large number of sensing methods have been proposed which includes energy detection [3], matched filtering detection [4], cyclostationary detection [5], eigenvalue-based sensing [6], covariance based sensing [7], blindly combined energy detection [8], etc. Although significant progress have been made in addressing the research challenges associated with a CR, reliable and robust spectrum sensing still remains a big challenge for the research community.

Hidden primary user is one of the challenging problems encountered in spectrum sensing. This problem arises due to environmental factors such as noise uncertainty, multipath fading, shadowing, and presence of obstacles. The CR does not able to differentiate between the white spectrum and a primary user's weak signal deeply affected by fading. As a result, the CR fails to detect the primary user's signal and causes unwanted interference to the primary users. In literature, cooperative spectrum sensing has been proposed as a solution to the aforementioned problem [9–11] where the CRs cooperate with each other for making a global decision while exploiting their spatial diversity. Each CR experiences different channel between the primary user and itself. If the sensing information of different CRs are combined, then there is a better probability of detecting the primary user. In other words, cooperative sensing can solve hidden node problem as well as decrease the sensing time and probabilities of misdetection and false alarm.

Ghasemi and Sousa [12] have proposed a fusion rule based on OR logic operation which combines decisions from several CRs. Similarly Visotsky et al. [13] have suggested AND logic operation and likelihood ratio test for combining hard and soft decisions respectively. They have shown that the fusion of soft decisions provides better performance than that of hard decisions. Ganesan and Li [10] have reported that addition of correlated signals from two CRs increases the detection reliability. Quan et al. [14] have used energy detection for linear combination of local statistics of several CRs. They have also proposed a modified deflection coefficient based approach to find out the weight assigned to each CR in the global decision. Zheng et al. [15] have employed a single-objective particle swarm optimization (PSO) for cooperative spectrum sensing that provides higher probability of detection than the modified deflection coefficient based approach with a specified probability of false alarm. The recent studies have shown that the multiobjective evolutionary algorithms (MOEAs) perform better than the single objective evolutionary algorithms (SOEAs) in terms of quality of solution and computation time. MOEAs are preferred over SOEAs for solving multiobjective optimization problems with conflicting objective functions.

The two conflicting objectives in spectrum sensing are probabilities of detection and false alarm. The techniques reported so far optimize a single objective i.e. probability of detection while keeping the probability of false alarm constant. The central unit in the cooperative network receives weighted sensing information based on the weights assigned to different CRs. Then it tries to optimize the weights of different CRs in order to maximize the probability of detection with a specified value of probability of false alarm and global decision threshold. Therefore appropriate choice of global decision threshold and weights for CRs are important design requisites of cooperative spectrum sensing. The rapid changes in wireless environment and increase in number of users have made it cumbersome to find appropriate weights of CRs case-by-case i.e. for each specified values of probability of false alarm and global decision threshold. The inherent difficulty in determining which weight vector is appropriate for the current wireless environment necessitates the development of more efficient methods. Since, the two objectives are conflicting in nature, the need for MOEAs arises to provide a set of promising solutions in a single run. The appropriate one can be chosen from this set of solutions depending on the wireless environment and available resources.

To the best of our knowledge, this is the first attempt to use MOEAs in cooperative spectrum sensing framework. The present study proposes a MOEA based approach for optimizing the global decision threshold and the weights assigned to different CRs in cooperative sensing. The three major contributions that differentiate this study from others are as follows. First, MOEAs have been successfully applied in cooperative spectrum sensing for solving the aforementioned problem. The performance of each algorithm is analyzed qualitatively by comparing the nondominated fronts. The application of multiobjective algorithms in this field will pave a path for real time implementation. The results of this study will be useful for researchers to design new algorithms for improving the performance in cooperative spectrum sensing. Second, a fuzzy logic based decision making technique is proposed to find out a compromise solution on the Pareto front. Third, an in-depth stability analysis of the simulation results is carried out using different statistical tests. Since it is a well known fact that the evolutionary algorithms are heuristic in nature, the stability of the simulation results is analyzed in detail for practical implementation. Finally, the sensitivity analysis of different parameters is carried out to demonstrate their impact on the overall performance of the network.

The rest of the paper is organized as follows. The cooperative spectrum sensing framework in a CR network along with the problem formulation is discussed in Section 2. Section 3 gives a brief overview of multiobjective optimization and Section 4 discusses the proposed MOEA. The performance metrics used for evaluating the performance of various multiobjective algorithms are dealt in Section 5 along with a fuzzy logic based strategy for selection of a compromise solution. Section 6 provides the simulation results obtained using different MOEAs. The stability analysis of simulation results is carried out in Section 7. Section 8 provides the sensitivity analysis for the proposed algorithm. Finally some concluding remarks are outlined in Section 9.