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Survey Paper

Comparative performance analysis of evolutionary algorithm based parameter optimization in cognitive radio engine: A survey

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ABSTRACT

One of the important features of the cognitive radio engine is to adapt the parameters of radio to fulfill certain objectives in a time varying wireless environment. In order to achieve this adaptation, six evolutionary algorithms are employed for optimizing the predefined fitness functions in the radio environment. The performance of genetic algorithm, particle swarm optimization, differential evolution, bacterial foraging optimization, artificial bee colony optimization and cat swarm optimization algorithm in different modes of operation are studied in detail. Each algorithm is tested in single and multicarrier communication system in order to acknowledge the advantage of multicarrier communication systems in wireless environment. The spectral interference introduced by the cognitive user into the primary user's band and that introduced by the primary user into the cognitive user's band are also investigated. The performance of different algorithms are compared using convergence characteristics and four statistical metrics.

1. Introduction

Over the past decades, the demand for electromagnetic spectrum has increased exponentially due to the popularity of wireless devices such as smart phones and mobile devices. Since most of the usable spectrum is already allocated, the demand for more spectrum is a huge challenge for researchers worldwide. Previous studies have shown that 90% of the allocated spectrum is either unused or underutilized [1,2]. So the solution lies in the efficient usage and higher utilization of the available spectrum. The present spectrum policy uses static spectrum allocation which has resulted in underutilization of the spectrum [1]. Most of the spectrum bands are only used in some areas and for some part of time. Hence researchers have proposed a dynamic spectrum allocation approach which allocates spectrum dynamically depending on the need at a particular time or location. Cognitive radio (CR) uses this technique to provide better spectrum efficiency and utilization.

The CR is a wireless radio that senses its electromagnetic environment and dynamically adapts its operational parameters to achieve the best system performance. The CR was first proposed by Mitola and Maguire [3] as a software radio with radio knowledge based reasoning about radio etiquettes such as RF bands, protocols, and patterns. The important feature of the CR includes sensing, learning and adapting its operating parameters depending on the radio environment, primary and secondary user requirements, availability of spectrum, local radio protocols, etc. Currently most of the licensed bands use a single communication technology. But the CRs use a combination of different technologies to get the best performance at a

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particular instant of time. This requirement poses a major challenge for the industry and academic researchers. The other major challenges include spectrum sensing, architecture, engine design, cognitive network security, etc. Recently the CRs have attracted the interests of various researchers [4,5] and led to applications such as wireless innovation alliance and IEEE 802.22 standard in wireless regional area network [6].

This paper focuses on the challenges in designing an efficient CR engine. The CR engine configures the radio system parameters to provide the best performance with respect to a predefined set of objectives and constraints. Since the objectives in a wireless environment are multiple in number, the problem of CR engine design can be formulated as a multiobjective optimization problem. The literature on the design of CR engine can be broadly categorized based on single and multicarrier communication system, and single and multiobjective optimization.

1.1. Single carrier communication system based CR engine

The techniques mentioned in this section describe the CR engine design only for single carrier communication systems. These techniques can be further categorized based on single and multiobjective optimization.

1.1.1. Single objective weighted sum optimization

In this case, the multiple objectives are weighted independently to generate a single objective fitness function which is simple and easy to implement from hardware point of view. The weights assigned to the objective functions mostly correspond to three modes of operation: emergency, low power and multimedia. The first CR engine was designed by the researchers at Virginia Tech [7,8]. They have used genetic algorithm (GA) to adapt the radio parameters of the software defined radio in a time varying radio environment. Rieser [9] has proposed a GA based CR engine in which the objectives are weighted differently depending on the user requirement and condition of the radio link. This weighted sum GA based design considered code rate, operating frequency, modulation type, etc. as the design parameters and frame error rate, transmit power, spectral efficiency, etc. as the design objectives. Hauris [10] has used the GA for changing the radio parameters of CRs in autonomous vehicles which travel through rapidly changing radio environments. Kim et al. [11] have designed a software to model a CR system. They have incorporated spectrum sensing ability and a GA based CR engine into the software. Zhang and Xie [12,13] have proposed a CR engine model using neural network in which the learning and adaptation of the CR is based on the fixed as well as the variable factors. The sensitivity of different transmission parameters on the performance of a GA based CR engine has been studied in detail by Newman and Evans [14]. An ant colony optimization (ACO) based CR engine design is proposed by Zhao et al. [15]. Huynh and Lee [16,17] have used a two-dimensional structure for chromosome's implementation while optimizing the parameters of CR engine.

1.1.2. Multiobjective optimization

Park et al. [18] have proposed a goal-Pareto based non-dominated sorting genetic algorithm (GBNSGA) for the CR engine design. They have validated the application of the GBNSGA in a code division multiple access (CDMA) 2000 forward link by using a realistic scenario in a Rician channel. A multiobjective immune GA (MIGA) based CR is proposed by Yong et al. [19]. They have used the MIGA for designing a control module based on the IEEE 802.11a physical platform.

1.2. Multicarrier communication system based CR engine

The research activities in mobile communication have shown that multicarrier communication systems provide higher data rate and robustness to losses in the wireless channel. Orthogonal frequency division multiplexing (OFDM) is one of the multicarrier systems which provides flexible resource allocation among cognitive users. Any subcarrier in the OFDM can be deactivated easily by feeding zero power to it. This feature makes the OFDM a good candidate for the CRs [20]. A lot of studies have been carried out for resource allocation in OFDM systems [21–23].

1.2.1. Single objective weighted sum optimization

Newman et al. [24] have designed a weighted sum GA based CR engine for OFDM based transceivers. They have derived a set of objective functions for guiding the search direction of the GA. They have also demonstrated the trade off between the convergence time and size of the search space of the GA. The CR engine design based on different variants of the GA is also proposed in literature [14, 25–29]. Most of the OFDM based CR engine designs do not consider the existence of primary users. But in a real time scenario, the primary and the secondary users exist simultaneously and use different communication access technologies too. This leads to mutual interference which ultimately degrades the performance of both the users [20]. In literature, mutual interference in the OFDM based CR is considered only in single objective optimization problem such as capacity maximization [30–32] while ignoring secondary user's performance.

The recent studies have shown that the new evolutionary algorithms (EAs) perform better than the GA in terms of quality of solution, convergence time and computational complexity. Zhao et al. [33] have proposed a CR engine design based on binary particle swarm optimization (PSO). They have shown that the PSO based CR engine design performs better than a GA based counterpart in terms of fitness value, convergence speed and stability. Afterwards, a PSO based CR engine in real number space [34] has been proposed to improve the performance in decision making. El-Khamy et al. [35] have shown that a hybrid of binary-coded PSO and GA (HBPGA) for optimizing the radio parameters of a CR performs better than the conventional GA and PSO. Waheed and Cai [36] have used the binary ACO for adapting the parameters of a CR in multicarrier environment. They have shown that the binary ACO based CR engine design provides a better solution than a GA based counterpart. Waheed and Cai [37] have compared the performances of the binary PSO, binary ACO and GA