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Non-Cooperative Cognitive Radio Optimization using Fuzzy Logic and Monte-Carlo Algorithms

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Abstract: Cognitive Radio threshold optimization has been an on-going research concern. With mature energy detector algorithms, the CR implemented in this work uses an energy detector as the primary sensing module for the primary user signal. In order to achieve this detection in an efficient way, various techniques have been proposed in literature for optimization and different levels of optimization have been achieved. For this work, threshold optimization has been approached using two techniques for optimization, with Monte-Carlo and ANFIS fuzzy algorithms as the techniques of choice. The inherent gains observed from the techniques used show relative suitability to the task of threshold optimization in a CR system that is software based and shielded from the outside environment. From this work, it was seen that with a seed threshold setting of 14dBm, the optimization techniques used gave close correspondence for Monte-Carlo and Fuzzy logic. Further studies will require the integration of suitable hardware into the system to gain better knowledge of the CR behaviour and the impact of deduced optimal working threshold.

Keywords: Cognitive radio, energy detector, threshold optimization, Monte-Carlo, fuzzy logic, ANFIS.

I. INTRODUCTION

The term 'cognitive radio' is given to an emerging wireless access scheme that is 'an intelligent wireless communication system that is aware of its surrounding environment to allow changes in certain operating parameters for the objective of providing reliable communications and efficient utilization of the radio spectrum' (Haykin, 2005). Cognitive radio is based on the concept of dynamic spectrum access, whereby licensed holders known as the primary users grant permission for spectrum access to non-licensed secondary users as long as interference to PU activity is minimal and confined (Hossain and Bhargava, 2007). Since the first mentioning in 1999 (Mitola III, et al., 2012), cognitive radio has become the focus of significant research from industry, research centers and universities alike (Bergman et al., 2008). A flowchart of CR operation is given in figure 1 to show the various stages in the CR cycle.

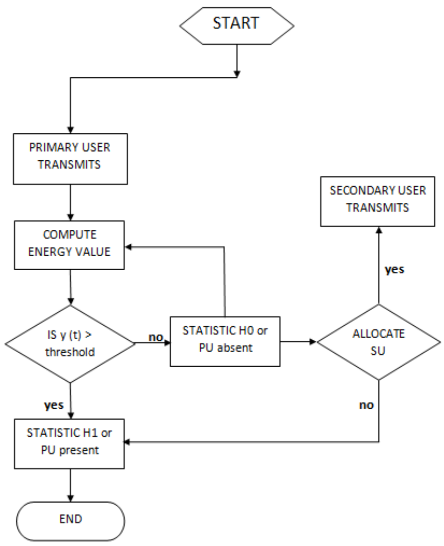

Fig. 1. Cognitive Radio Cycle flowchart

The format for the paper is as follows; section 1 gives a brief overview of the CR and optimization, section 2 discusses the utilized algorithms used in this work, section 3 presents the model and results and section 4 discusses the main findings of this research.

II. REVIEW OF COGNITIVE RADIO AND OPTIMIZATION TRENDS

The design of CR has been done in many theoretical works from various researchers (Mitola), (Hossain and Bhargava, 2007), (Bergman et al., 2008) who have for an aim the intelligent and seamless utilization of available radio/communication spectrum for both the licensed primary users and the opportunistic secondary users who wish to have access to the spectrum but have no authorised license (Ÿucek and Arslan, 2007). With most research works being limited to laboratory or experimental scope (Bergman et al., 2008) and the demand for radio spectrum continuously increasing, the eventual development and deployment of full CR systems stands to push the boundary of what is possible with available limited band width.

Therefore this research was done with the aim of advancing the practical possibilities within this field in the form of implementation of some of the building blocks that should make up a fully functional CR. Also most importantly the software processing that is used to optimize the CR sensing and detection is addressed through implementation of two algorithms to take care of some of the drawbacks inherent in a CR setup such as false alarm and missed detection, which hamper the smooth operation of a CR system. While there exist many different software optimization schemes for CR systems e.g. Artificial intelligence techniques such as fuzzy logic, GA, neural networks, more traditional probabilistic optimization schemes such as Monte-Carlo (cite)

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III. RELEVANT ALGORITHMS FOR SIMULATION MODEL

The implementation of the cognitive radio follows different types of algorithms but with all the various types having the same primary goal of sensing and detection. The sensing algorithms from literature are primarily three types vis-a-viz Cyclostationary detector, matched filter and energy detector. Of the three types, the choice for this work was the energy detector for its simplicity of implementation and its suitability to environments with low noise or high signal to noise ratio (SNR) (Digham et al., 2003). Fig. 2 shows the energy detector algorithm. The results obtained from the energy detector is shown in Fig. 5.

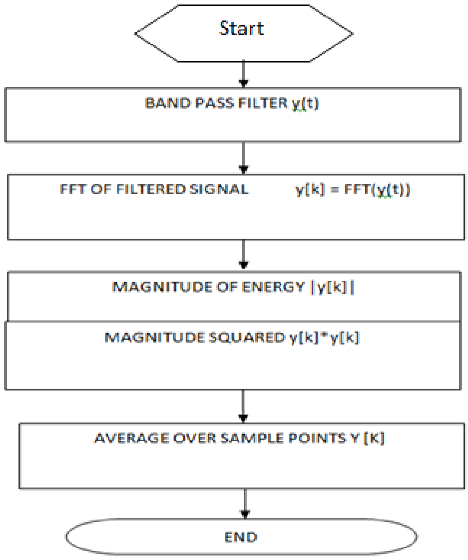

Fig. 2. Energy detector flowchart

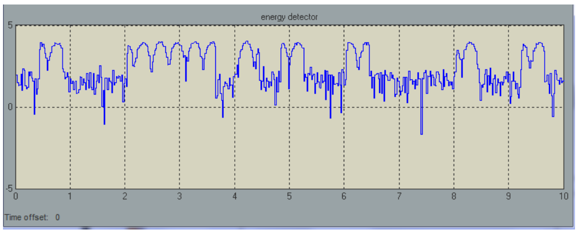

Fig. 3. Energy detector output

The algorithms for the optimization techniques used i.e. Monte Carlo and Fuzzy logic will be also discussed here. The Monte-Carlo algorithm is well known to be a probability based algorithm which is dependent amongst other things, on random variables in the system model, the number of entries or tries made. The greater the number of tries the better the convergence towards an accurate value. The output from the Monte Carlo analysis is also done on the energy values detected by the energy detector algorithm and sample results are given below to emphasize the energy detection threshold optimization achieved.

The fuzzy logic system implemented is based on the adaptive neural fuzzy inference system or ANFIS which is a type of Sugeno fuzzy inference system. Its power lies in its ability to mimic human type inference techniques.

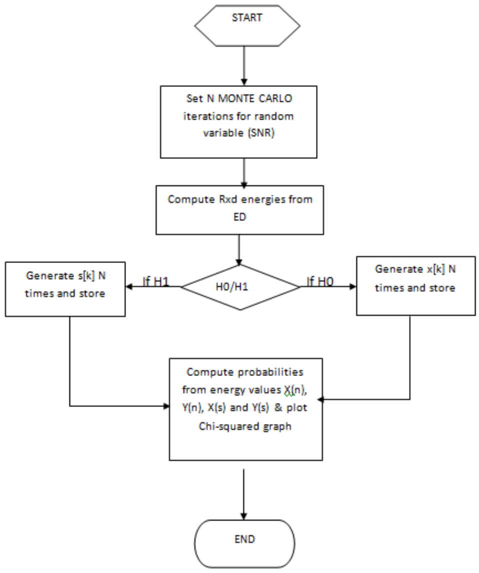

Fig. 4. Monte-Carlo Algorithm flowchart

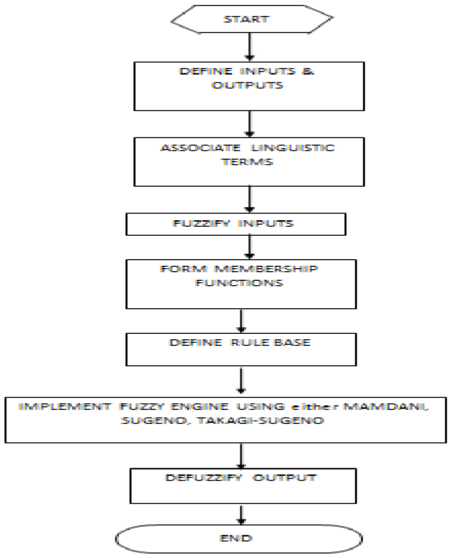

Fig. 5. Fuzzy logic flow chart

IV. EXPERIMENT

The experiments carried out at this stage were all performed in software only and is aimed at getting a feel for the working of the cognitive radio system without using any hardware parts. All the codes used in developing the software are written using Matlab scripts and simulink symbolic programming. The experimental model is shown in Fig. 5

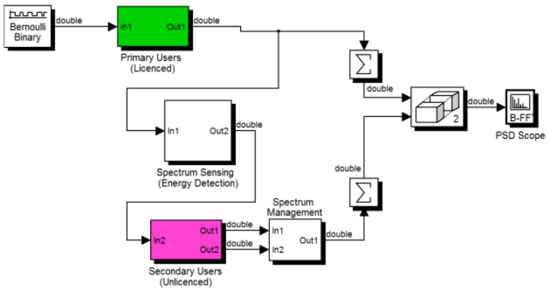

Fig. 6. Cognitive Radio Model

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In general for the experiment a threshold detection value of 14dB was set in the software engine implementing the energy detector algorithm. This value is informed by past works (cite) and from empirical studies of radio operating environments. Since the threshold optimization is made with a view to improving the quality and certainty of detection of primary users on the spectrum, the results of the Monte Carlo and Fuzzy logic Systems are used to re-compute the energy detection threshold for subsequent primary user detection operations and secondary user opportunistic transmissions on the licensed spectrum.

V. RESULTS

The results which are important to this work will be presented here. They are mainly those showing the optimization from the Monte Carlo and fuzzy engines and also the spectrum management or allocation system between the primary and secondary users.

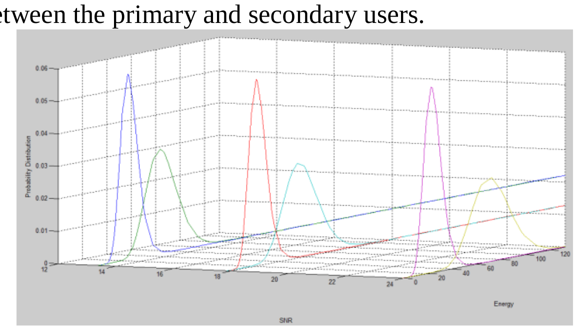

Fig. 7. Chi-Square plot of the received Noise and Signal Energy

Fig. 7 is the energy probability density plot for three primary users showing the central and non-central chi-squared distribution for noise and signal respectively. Very importantly, we can see the uncertainty region also which is vital to the optimization of detection threshold in CR systems as it is closely related to the key operating metrics of probability of false alarm and probability of detection (Tabassam 2011,2012).

Figure 8 gives shows the bar chart plot for the optimized fuzzy energy as obtained from ANFIS. The optimized value sits at about 15dBm.

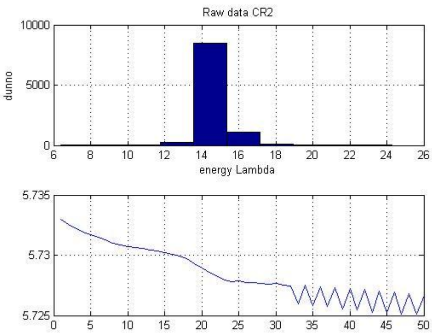

Fig. 8. Result from Fuzzy Logic Analysis

The result also shows the demishing error index after optimization has been achieved.

Fig. 9 to Fig. 10 shows scatter and bar plots of the Monte Carlo results and for 50, 100 and 200 iterations respectively.

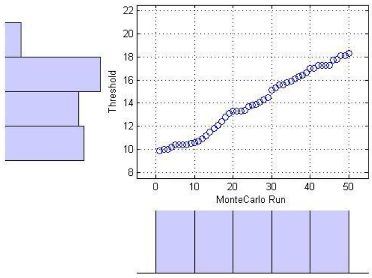

Fig. 9. 50 runs of Monte Carlo

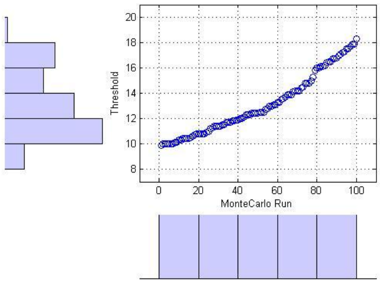

Fig. 10. 100 runs of Monte Carlo

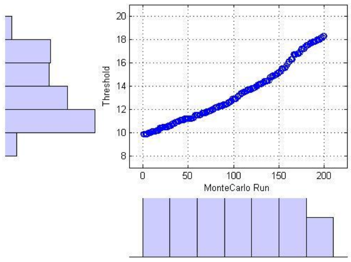

Fig. 11. 250 runs of Monte Carlo

The spectrum management plot of the signals during opportunistic access is shown to describe the utilization of the spectrum by primary and secondary users. Fig. 12 shows secondary user signal, primary user signal and allocation signal between primary and secondary user respectively.

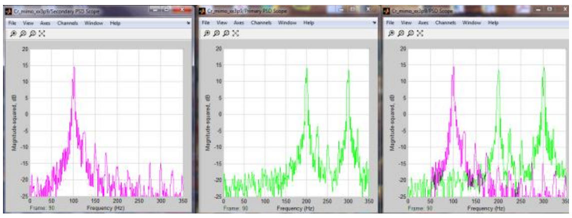

Fig. 12. Spectrum Management Plot

VI. DISCUSSION

In this work the goal that was set out to achieve in the threshold optimization has been addressed using two techniques for optimization. The inherent gains observed from the techniques used show relative suitability to the task of threshold optimization in a CR system that is software based and shielded from the outside environment. From this work, it was seen that with a seed threshold setting of 14dBm, the optimization techniques used gave 16dBm for Monte-Carlo and 12.5dBm for Fuzzy logic. Further studies will require the integration of suitable

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