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SVD Detection for Cognitive Radio Network based on Average of Maximum-Minimum of the ICDF

Mohd. Fahad Fahim[1], Mohd. Sarwar Raeen[2]
Electronics and Communication Engineering, ASCT, Bhopal, M.P, India[1,2]

Abstract

Spectrum sensing in cognitive radio (CR) has been a very important function to enable the state of the art technology in revolutionizing spectrum efficient utilization. SVD stands for Singular Value Decomposition. It's a method for matrix decomposition/factorization. The simplest way to visualize and understand how SVD is useful is to think in terms of Principal Component Analysis (PCA)/dimensionality reduction. In this paper we provide an average of maximum-minimum inverse cumulative distribution function (ICDF). We use raised cosine to test the performance of the signal detector to perform the simulation. The average eigenvalue based SVD signal detector was found to be more efficient in sensing signal without knowing the properties of the transmitted signal.

Keywords

SVD, Cognitive Radio, PCA, Spectrum Sensing, ICDF.

1. Introduction

Cognitive radio networks (CRN) have attracted great attention recently as a means to resolve the critical spectrum shortage problem [1]. With dynamic spectrum access (DSA) techniques, CRN can be granted access of spectrum secondarily, i.e., as long as it can guarantee no interference to any primary user (PU) who is using this spectrum at this time in this location. This means that the cognitive radios have to periodically sense the spectrum to detect the primary user's activity. They have to vacate the channel immediately whenever PU activity is detected.

In order to rationalize the use of CR, a very efficient spectrum management needs to be implemented in cognitive radio networks. As stated in [2], the spectrum management process consists of four major steps: 1) spectrum sensing, 2) decision making, 3) spectrum sharing and 4) spectrum mobility. The first and second steps are very crucial in enabling the CR technology. CR users are expected to be able to detect primary user (PU) networks and find the spectrum holes or the unused spectrum in order to utilize them.

In the eigenvalue-based detection methods, the decision threshold is derived from random matrix theory (RMT) to determine the hypothesis testing for signal detection. The methods are using the eigenvalue decomposition technique to find the eigenvalues in order to compare with the threshold. The SVD is quite similar to the eigenvalue decomposition method. However, the SVD is very general in the sense that it can be applied to any mn matrix, whereas the eigenvalue decomposition method can only be applied to certain classes of square matrices. Nevertheless, the two decompositions are related. Furthermore, the SVD has got several advantages compared to other decomposition methods as listed below [3]:

1. more robust to numerical error;
2. exposes the geometric structure of a matrix an important aspect of many matrix calculations; and
3. quantify the resulting change between the underlying geometry of those vector spaces.

The remaining of this paper is organized as follows. In Section 2 we discuss about problem domain. The Evolution and recent scenario in section 3.In section 4 we discuss about cognitive radio. In section 5 we discuss about proposed approach. The conclusions and future directions are given in Section 6. Finally references are given.

2. Problem Domain

With the increasing number of wireless users, scarcity of electromagnetic spectrum is obvious. Taking this into consideration, the Federal Communications Commission (FCC) published a report prepared by Spectrum Policy Task Force (SPTF) [4]. This report recommends certain rules and regulations for the efficient use of radio spectrum and the ways to improve the existing spectrum usage. In relation to the spectrum utilization this report illustrates that there is significant inefficient spectrum utilization than the actual spectrum scarcity due to the legacy system and the rules imposed by FCC. Most of the allotted channels are not in use most of the time; some are partially occupied while others are heavily used.

In May 2004, FCC released a report in which it took an initiative which allows the use of this underutilized spectrum to unlicensed users (Users that are not been served by the primary license holders) to operate in television spectrum in areas where the spectrum is not in use. However, these unlicensed users should not create interference to the licensed user and at times the licensed user wants to transmit its signal the unlicensed user should vacate the spectrum and should look for some other free space. This could be achieved by incorporating "Cognitive Radios" to sense unused spectrum.

This scarcity leads finally to a new CR technology, enabling an efficient use of the spectrum and providing communications anywhere and at any time [5]. An SVD based communication system is a promising candidate for CR technology as a PHY layer [6]. The high data rate and the robustness against the wireless channel impairments are main advantages of the SVD system. Furthermore, the flexibility of the SVD is another valuable feature. An SVD-based CR system is able to deactivate a number of subcarriers that lie within the PR"s frequency sub band and activate those that lie in the vacant sub bands for communications.

3. Evolution and Recent Scenario

In 2010, Xiaohua Li et al. [7] study both the jamming capability of the cognitive radio based jammers and the anti-jamming capability of the cognitive radio networks. They first setup the models of cognitive-radio based jammers and the cognitive radio network transmissions. They then analyze various jamming attack strategies where the jammer spends various powers in order to jam various transmission slots of the cognitive radio networks. Average throughput and jamming probability are derived and verified by simulations. Strength and weakness of jammer and cognitive radio networks are then discussed which will be useful to guide the anti-jamming cognitive radio network design.

In 2010, Rajni Dubey et al. [8] proposed about the limited available spectrum and the inadequacy in the spectrum usage necessitate a new communication standard to utilize the existing wireless spectrum opportunistically. This innovative networking standard is referred to as NeXt Generation (xG) Networks as well as Dynamic Spectrum Access (DSA) and cognitive radio networks (CRN). Cognitive Radio Networks are composed of wireless devices able to opportunistically access the shared radio resource. The core of such networking paradigm is the capability of cognitive radio to monitor the spectrum occupation to exploit spectrum holes for transmission. Spectrum sensing refers to the technique used by cognitive radios to scan the spectrum. in addition, the xG network roles such as spectrum management, spectrum mobility and spectrum sharing.

In 2011, Mohd. Hasbullah Omar et al. [9] examine the implementation of the Singular Value Decomposition (SVD) method to detect the presence of wireless signal. The method is used to find the maximum and minimum eigenvalues. They simulated the algorithm using common digital signal in wireless communication namely rectangular pulse shape, raised cosine and root-raised cosine to test the performance of the signal detector. The SVD-based signal detector was found to be more efficient in sensing signal without knowing the properties of the transmitted signal. The execution time is acceptable compared to the favorable energy detection. The computational complexity of SVD-based detector is medium compared to the energy detector. The algorithm proposed by the author is suitable for blind spectrum sensing where the properties of the signal to be detected are unknown.

In 2012, Alexandros G. Fragkiadakis et al. [10] provide the rapid proliferation of new technologies and services in the wireless domain, spectrum scarcity has become a major concern. The allocation of the Industrial, Medical and Scientific (ISM) band has enabled the explosion of new technologies (e.g. Wi-Fi) due to its licence-exempt characteristic. The widespread adoption of Wi-Fi technology, combined with the rapid penetration of smart phones running popular user services (e.g. social online networks) has overcrowded substantially the ISM band. On the other hand, according to a number of recent reports, several parts of the static allocated licensed bands are Under-utilized. This has brought up the idea of the opportunistic use of these bands through the, so-called, cognitive radios and cognitive radio networks. Cognitive radios have enabled the opportunity to transmit in several licensed bands without causing harmful interference to licensed users. Along with the realization of cognitive radios, new security threats have been raised. The scope of the proposed work is to give an overview of the security threats and challenges that cognitive radios and cognitive radio networks face, along with the current state-of-the-art to detect the corresponding attacks.

4. Cognitive Radio

Since the first introduction of cognitive radio in 1999, different national/international sectors and academic/industry research centers have been interested and focused on this type of radio.

The concept of the Software Radio (SR) or Software-Defined Radio (SDR) is not new, it has been known as one of the radio systems design and engineering revolution stages [11][12]. This type of radio is different from the traditional one as [13, 14]: 1. It is able to cover larger frequency ranges than the traditional through using wide band antennas, advanced filters, and high speed analog to digital (ADCs) and digital to analog converters (DACs) at the radio frequency (RF) front end. 2. Its main based band processing functions such as modulation/demodulation, coding/decoding processing can be controlled via software programmed on a reconfigurable unit as the field programmable gate array (FPGA). The main defined objectives of developing SDR were, firstly, to decrease the radio system's costs by developing an SDR that is able to be programmed to work in different frequency ranges using different modulations and transmit powers, and, secondly, to develop radio systems that able are to improve the provided services for both military and civil sectors.

The SDR is defined by the ITU–R as [15]: "Software-defined radio (SDR) is a radio in which the RF operating parameters including, but not limited to, frequency range, modulation type, or output power can be set or altered by software, and/or the technique by which this is achieved." The CR is defined as an intelligent version of the SDR, where the intelligence in CR comes from its ability to know about its surrounding environment, adapt its transmission/receiving parameters, and learn from its mistakes. Figure 1, Figure 2 and Figure 3 shows the main difference between the three classes of radios (modified from [16]).

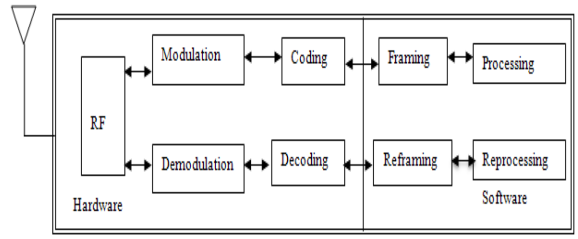

Figure 1: Traditional Radio

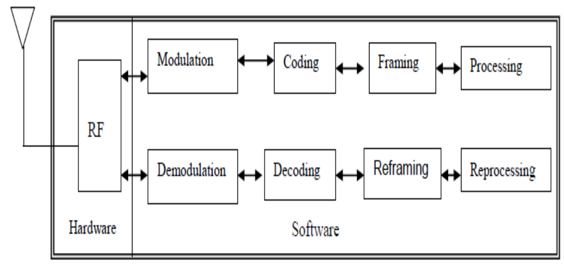

Figure 2: Software Radio

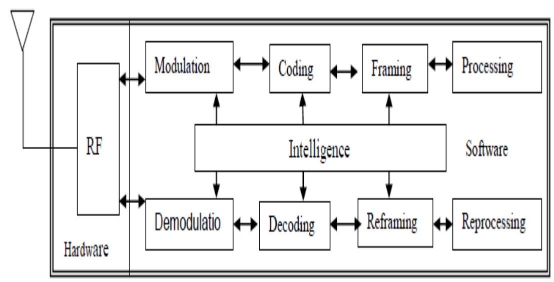

Figure 3: Cognitive Radio

CR is an intelligent radio system able to be aware of its surrounding RF environment by using advanced sensing techniques to decide whether there are unoccupied spectrum portions (holes) available; it then changes its transmitting parameters (modulation type, transmission power, bandwidth, carrier frequency) to opportunistically exploit the unused spectrum band. The definition above is called the capability of CR, which is one of the main features of CR. Thus, the capability here means the ability to be aware, adaptive, reliable, efficient, intelligent, and learnable. The learnable word is the ability that CR makes current decision based on the last decisions and the prediction from the history and the mistakes toward effective use of the spectrum holes. Another main feature of CR is the reconfigurability, which can be achieved by using the SDR as a physical unit for CR. This would allow CR to cover a wide band range in tasks of sensing and communications.

Furthermore, as the CR decides which carrier frequency, bandwidth, transmitted power, modulation scheme that will be used in communications to adaptively use the free spectrum toward a given Quality of Services (QoS) achievement, the transmission parameters can be simply modified by tuning the software. Based on these definitions, the main objectives of CR‟s development are defined, based on , as follow:

1. To improve the spectrum efficiency by opportunistically exploiting the unused spectrum portions (holes) at a specific time and location as shown in Figure 4.
2. To provide reliable communications at any time, and any place. These reliable communications are expected to provide different wireless services such as voice, data, and video.

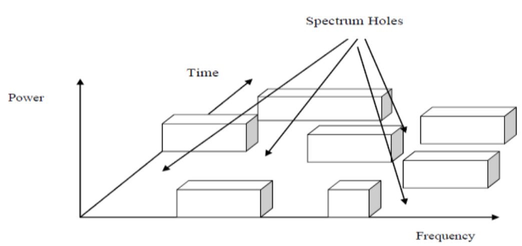

Figure 4: The unoccupied spectrum portions (holes)

5. Proposed Approach

In this approach we proposed an average of maximum and minimum ICDF for cognitive radio network. We adopt method by Zeng and Liang (2007) in [17]. We take decision threshold and probability of false alarm which are derived based on limiting distribution of eigenvalues based on random matrix theory. The decision statistic for the maximum minimum eigenvalue (MME) detection is defined as the ratio of maximum to minimum eigenvalues of received signal covariance matrix as follows:

$\lambda_{max}/\lambda_{min}$

The detection threshold in terms of desired probability of false alarm is calculated by using the results of the theorem in [18] and [17], as follows (in our case, M = 1):

$\gamma_{mme} = (\sqrt{N_s} +\sqrt{L})^2 / (\sqrt{N_s}-\sqrt{L})^2 * (1 + (\sqrt{N_s} +\sqrt{L})^{-2/3} / (N_sL)^{1/6} .F_1^{-1}(1-P_{fa}))$

Then we calculate the average value which is useful in finding the dominant singular values in which the Presence of other signals can be detected. The Algorithm for the above approach is shown in Figure 5.

> **Step 1:** Select number of column of a covariance matrix, L such that k < L < N-k, where N is the number of sampling points and k is the number of dominant singular values. In this paper, k = 2 and L = 16.
> **Step 2:** Factorize the covariance matrix. $R=U\Sigma V^H$
> **Step 3:** Obtain the maximum and minimum Eigen values of the covariance matrix which are λ_{max} and λ_{min}.
> **Step 4:** Compute threshold value, γ, using the average of maximum and minimum of the ICDF.
> $\gamma_{mme} = (\sqrt{N_s} +\sqrt{L})^2 / (\sqrt{N_s}-\sqrt{L})^2 * (1 + (\sqrt{N_s} +\sqrt{L})^{-2/3} / (N_sL)^{1/6} .F_1^{-1}(1-P_{fa}))$
> **Step 5:** Compare γ_{mme} with the threshold. If $\lambda_{max}/\lambda_{min} > \gamma_{mme}$ the signal is present, otherwise, the signal is not present.

Figure 5: Algorithm

Although the SVD-based detection is the best compared to the ED's on the overall, it is also noticing that performances of SVD are dropping but the ED's are rising. The dropping in SVD-based detection is consistent with previous results but the rising of ED's might be due to the type of the signals used where both raise cosine and root-raised cosine are higher in signal energy. The performance will be increased by averaging those values which will be included in the algorithm.

Although ED at certain points better than the SVD based detection, but the overall performance of the detector is better than the ED. It is also shown in the graphs that the SVD-based method works better in detecting the rectangular pulse signal, raised cosine the second and root-raised cosine the third. The ED's performance for all three signals is quite similar.[Figure 6,Figure 7].

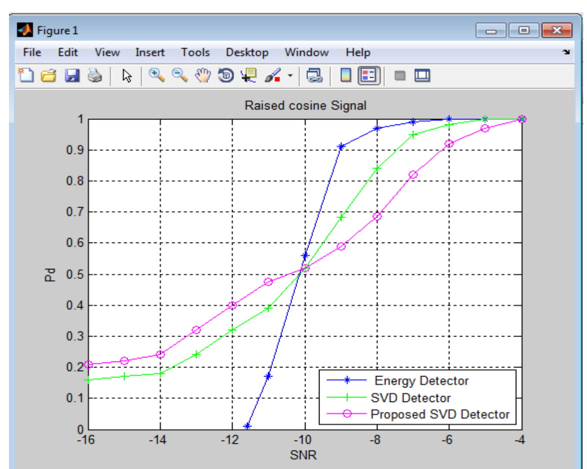

Figure 6: SNR v/s P_d

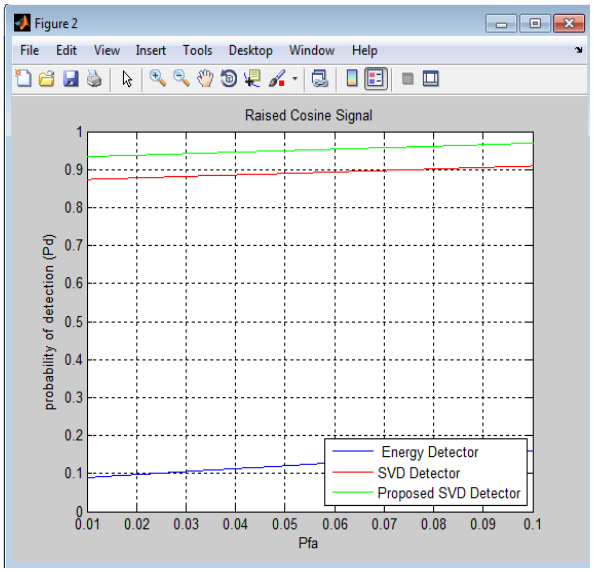

Figure 7: ROC (Receiver Operating Characteristics)

6. Conclusion and Future Direction

Nowadays, the increasing demand for more radio spectrums, and the noticeable growth in the number of wireless services and applications, shows how the allocation and assignment of new frequencies for new wireless services is a big challenge nationally and globally. The inefficient use of the already assigned frequencies has promoted research centers and governments to develop different techniques to exploit such unused frequencies, at specific times and locations, without interfering with the PR user. This exploitation provides communication anywhere at any time and offers radio frequencies for the new wireless services.

CR is an intelligent radio system that was proposed to enhance the concept of using unlicensed or licensed frequencies when they are unoccupied by their licensed users (i.e., PR users). The CR can be distinguished from the classical radio systems mainly by its awareness about its surrounding RF environment. Our proposed algorithm shows better detection in terms of previous traditional approach.

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Mohd. Fahad Fahim He received his B.E. degree in Electronics and Communication Engineering from Rajiv Gandhi Prodyogiki Vishwavidyalaya, Bhopal, M.P, India in 2010. Presently he is pursuing his M.Tech. Degree in Digital Communication engineering from Rajiv Gandhi Prodyogiki Vishwavidyalaya, Bhopal, M.P. India.

Mohd. Sarwar Raeen He Received his B.E. in Electronics and Communication Engineering From RGPV Bhopal and M.Tech. in Digital Communication from MANIT Bhopal, India, in 2003 and 2008 respectively. He is currently an Associate Professor with the Department of Electronics and Communication Engineering in All Saints' College Of Technology, Bhopal, India, from June 2008 to till date, his professional research interests include VLSI, Digital Communication and Optical Communication.