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Comparison Study on Wavelet based Spectrum Sensing in Cognitive Radio

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Abstract: The growing demand of wireless applications has put a lot of constraints on the usage of available radio spectrum which is limited and precious resource. However, a fixed spectrum assignment has lead to under utilisation of spectrum as a great portion of licensed spectrum is not effectively utilised. Cognitive radio is a promising technology which provides a novel way to improve utilisation efficiency of available electromagnetic spectrum. Cognitive radio (CR) is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are not, and instantly move into vacant channels while avoiding occupied ones. This optimizes the use of available radio-frequency (RF) spectrum while minimizing interference to other users. Spectrum sensing helps to detect the spectrum holes (underutilized bands of the spectrum) providing high spectral resolution capability. In this paper a comparative study is being taken in account for all kind of Spectrum Sensing in Cognitive Radio techniques introduced till now, specifically based on wavelet transform.

Keywords: Cognitive radio, spectrum sensing, energy detection, wavelet transform, Edge Detection.

I. INTRODUCTION

The available electromagnetic radio spectrum is a limited natural resource and getting crowded day by day due to increase in wireless devices and applications. It has been also found that the allocated spectrum is underutilized because of the static allocation of the spectrum [1]. Also, the conventional approach to spectrum management is very inflexible in the sense that each wireless operator is assigned an exclusive license to operate in a certain frequency band. And, with most of the useful radio spectrum already allocated, it is difficult to find vacant bands to either deploy new services or to enhance existing ones. In order to overcome this situation, the issue of spectrum underutilization in wireless communication can be solved in a better way using Cognitive radio (CR) technology [2]. Cognitive radios are designed in order to provide highly reliable communication for all users of the network, wherever and whenever needed and to facilitate effective utilization of the radio spectrum.

Spectrum Sensing in Cognitive Radio [3]: A major challenge in cognitive radio is that the secondary users need to detect the presence of primary users in a licensed spectrum and quit the frequency band as quickly as possible if the corresponding primary radio emerges in order to avoid interference to primary users. This technique is called spectrum sensing. Spectrum sensing is the ability to measure, sense and be aware of the parameters related to the radio channel characteristics, availability of spectrum and transmit power, interference and noise, radio's operating environment, user requirements and applications, available networks (infrastructures) and nodes, local policies and other operating restrictions [4]. It is done across Frequency, Time, Geographical Space, Code and Phase.

II. COGNITIVE RADIO'S KEY BENEFITS [5]

Cognitive Radio offers optimal diversity (in frequency, power, modulation, coding, space, time, polarization and so on) which leads to: Spectrum Efficiency, Higher bandwidth services, Graceful Degradation of Services, Improved Quality of Service, Commercial Exploitation, Benefits to the Service Provider, Future-proofed product, Common hardware platform, Flexible regulation, Emergency service communications, and Benefits to the Licensee.

Wavelet Transform:

The wavelet theory is used to analyze signals using their component and set of basic functions. Wavelet is a mathematical tool used for evaluating singularities and irregular structures and the wavelet transform can able to describe the local regularity of signals. So the wavelet transform approach for spectrum detection in CR is well motivated to investigate the primary users. Wavelets are described by both scale and position, so it is useful in analyzing variations in signals and spectrum [6]. The feature of scale is denoting by the notion of local regularity and time aspects is describes by a list of domains. The Continuous Wavelet Transform (CWT) is a two-parameter expansion of a signal for a wavelet function.

Using this wavelet transform technique the sensing time that taken to detect whether primary user using the spectrum or not is very less when compare to other type of spectrum sensing technique. Here the disintegration is taken as a complete, when de-noising and compression processes are at center points. Because in every stage of decomposition of wavelet it denote only the available frequency i.e. spectrum holes in which the secondary user can communicate.

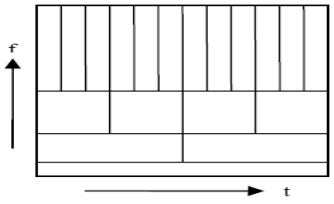

Fig.1. Two level decomposition using wavelet transform

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The wavelet family is generated from a unique prototype function that is called a mother wavelet. Given a real variable x, the function ψ(x) is called a mother wavelet provided that it oscillates, averaging to zero $\int_{-\infty}^{\infty} \psi(x)dx = 0$ and that is well localized (i.e., rapidly decreases to zero when |x| tends to infinity). By convention it is centered around x = 0, and has a unit norm ||ψ(x)||. In practice, applications impose additional requirements, among which, a given number of *vanishing moments* *Nv*.

$$\int_{-\infty}^{\infty} \psi(x)dx = 0 \; 0 < k \leq Nv \quad (1)$$

The mother wavelet $\psi(x)$, generates the other wavelets $\psi a, b(x)$, $a > 0$, $b \in$ R, of the family by change of scale a (i.e., by dilation) and by change of position b (i.e., by translation),

$$\psi a, b(x) = \frac{1}{\sqrt{a}} \frac{\psi(x-b)}{a}, a>0, b \in \text{R}. \quad (2)$$

In Fig. 3.2, several wavelets are shown that are obtained from the mother wavelet

$$(x) = (1 - 2x^2)e^{-x^2} \quad (3)$$

This wavelet is the second derivative of a Gaussian function and is called the *Mexican hat*. Its first use was in computer vision, for multi scale edge detection [7]. The origins of the wavelet analysis can be traced to the 1909 Haar wavelet (that was not called by that name then) and various "atomic decompositions" in the history of mathematics. $\psi(x) = (1 - 2x^2)e^{-x^2}$ (4)

The usual 2D wavelet transforms mean square-shaped separable approach in this paper.

$$v_{j+1} = h * h * v_j;\; w_{j+1}^{LH} = g * h * v_j \quad (5)$$

$$w_{j+1}^{HL} = h * g * v_j;\; w_{j+1}^{HH} = g * g * v_j \quad (6)$$

III. COMPARATIVE STUDY

1) Experimental Study of a Wavelet-based Spectrum Sensing Technique [9]-

a) The energy detection spectrum sensing technique, based on the Wavelet Transform, is investigated.
b) In order to evaluate the accuracy of the methodology, spectrum measurements were made in bands allocated for FM broadcast (88-108MHz) and mobile services (824-835MHz).
c) Modifications in an existing technique were proposed in order to improve the spectrum sensing when applied in real environments.

Explanation: *A. Original Sensoring Method*

In [3], spectrum sensing is seen as an edge detection problem, where there are discontinuities between successive frequency bands. The sensed spectrum is modeled as N bands with their frequency boundries located at: $F_{j,i} = 1,2,\ldots,N$ in which F_i represents the frequencies in Hz, where there is a discontinuity, considering that the power spectral characteristic is smooth within a sub band. The technique consists in identifying those boundaries and then estimating the energy within each sub channel.

B. Proposed Method

The Continuous Wavelet Transform (CWT) can be seen as the non-normalized correlation between the signal to be transformed and a mother-wavelet function ∅ (f) dilated by a scale s and shiftes by a factor Ƭ [5]:

$$W_s S_r(f) = \langle S_r(f) | \emptyset_{s\tau}(f) \rangle = C_{\emptyset_s}(s, \tau)$$

In which $C_{\emptyset_s}(s, \tau)$ represents the coefficients of the CWT. Therefore, by applying the transform for a specific scale s=S_j it is possible to identify the points of $S_r(f)$ which are more correlated with $\emptyset_{sj}(f)$ through the points of maxima of $C_{\emptyset_{sj}}(s_j, \tau)$. In order to validate the energy detector presented in [4] and the proposed modifications, a measurement system had to be developed. The initial spectrum analyzer parameters as central frequency, span, reference level, sweep time and time between sweeps are defined. The central frequency and the span define the censored bandwidth. Moreover, the sweep time and the time between sweeps allow the measurement system to be adjusted to systems in the desired bandwidth, optimizing the spectrum sensing. The implementation is very flexible; therefore the spectrum sensing may be performed with different configurations.

Observation: In this article, an experimental spectrum sensing analysis was made by means of a wavelet-based energy detection technique. A measurement methodology was developed to validate the method.

2) Discrete Wavelet Packet Transform based Energy Detector for Cognitive Radios [10]-

a) Current spectrum management model, command-and control, is creating a fundamental cause to drop the spectral efficiency of the radio spectrums in times and spaces.
b) An emerging technology, cognitive radio (CR) has been come out to solve today's spectrum scarcity problem. Among its fundamental functions, the most important function is spectrum sensing which requires precise accuracy and low complexity.
c) Thus, in this paper, they proposed the fast spectrum sensing algorithm using the discrete wavelet packet transform (DWPT) and infinite impulse response (IIR) polyphase filtering schemes.

Explanation: Wavelet Analysis and Power Measurements-

Construction of the wavelet transform and understanding of wavelet basis are provided by the multi-resolution analysis [5]. In addition, the efficient hierarchical algorithm for computing the wavelet transform is in the filter bank theory [6].

A. Discrete Wavelet Transform (DWT)

DWT is designed from the multi-resolution analysis that decomposes the given signal space into a approximate space, *V*, and detail spaces, *W*,

The proposed algorithm has two improvements of the conventional energy detection schemes. One is that it can easily select the unoccupied candidate channels with simple structure.

This is accomplished by using two channel IIR poly phase filter banks and sorting the channels in the ascending order based on the power of each channel. The latter is rational due to the fact that the channel with low power has high probability to be a unoccupied channel.

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Observation: The secondary spectrum has been issued due to its property that improves spectra efficiency. In this context, CR has received a plenty of attentions and one of the its critical technologies is spectrum sensing which requires fast processing and precise accuracy not to interfere with licensed users. Thus, in this paper, the fast spectrum sensing algorithm based on DWPT is introduced focusing on the coarse sensing. Using the multi-resolution property of DWPT and two channel IIR polyphase wavelet filter banks.

3) Discrete Wavelet Transform Based Spectrum Sensing in Cognitive Radios Using Eigen Filter [11]-

a) In the developing world, the usage of Mobile phones and other data communication devices are unavoidable which results in the congestion of Spectrum. Recent studies have showed that nearly 70% of spectrum was unused most of the time.
b) Cognitive Radio is a technology which helps us to use the spectrum effectively. Spectrum Sensing is one of the techniques in cognitive radio. Energy detection, Feature detection and Matched Filter detection are methods used for spectrum sensing.
c) The proposed method, Discrete Wavelet Transform (DWT) is used to identify the unused spectrum band in the RF spectrum. This will yield better results and fast sensing than the conventional method.

Explanation: Method for finer sensing where DWT based sensing with Eigen filter as wavelet filter is
used as a preliminary step. With this algorithm, occupied and unoccupied spectrum is separated. Unoccupied spectrum is left. Occupied spectrum undergoes finer sensing to identify the presence of the user.
Steps in proposed method as follows:
• Perform DWT with Eigen filter as wave filter.
• Calculate energy for each sub band
• Energy to bandwidth ratio is calculated(R).
• If R is high the channel is occupied
• If R is small channel is unoccupied.

Observation: Eigen filter is used as replacement of standard wavelet filters which yields high resolution than the conventional methods. The use of Eigen filters increases the detection Capability. In CWT method Multiscale sum or product is used to find out the boundaries of the spectrum whereas in DWT method Statistical ratio R is used to find the thresholds and subsequently the boundaries.

4) Performance Evaluation of the Energy detection Using different Wavelet family for Spectrum Sensing in Cognitive radio [12]-

a) The cognitive Radio built on a software- defined radio, is defined as an unpredictable growth of wireless communication system, which is automatic adjustment of the electromagnetic environment to adapt their operation and dynamically vary its radio operating parameters while bring no harmful interference to the primary use.
b) Researches are focuses on the cooperative spectrum sensing method to improve reliability of the spectrum but for cooperative spectrum sensing method is very difficult to tolerate with each individual node of the wireless network for the short time. So most renowned spectrums sensing techniques is energy detection.
c) This paper proposes energy detection for spectrums sensing on the basis of estimated SNR, which is calculated in advance for available channels.

Explanation: The proposed method is used to analysis the availability of the frequency spectrum in which we generate the input signal and checking the availability of the nuser with of the input signal to convert time domain signal to frequency domain signal , divide the signal with equal frequency distribution of the signal in MHz using DWPT.

Observation: It is an efficient perspective method to classify the spectrum which improves the performance of the energy detector by measuring the PSD for various SNR and calculated threshold value. Howerever, threshold which can accurately detect the Probability of the Detection of the received signal using different types of wavelet family.

5) Wavelet and S-Transform Based Spectrum Sensing in Cognitive Radio [13]-

a) Cognitive Radio is an intellectual radio having the ability of recognizing the vacant spectrum to transmit the data to avoid spectrum inefficiently usage problem.
b) Here CR uses the spectrum policies technique, to spot the existence of user in particular frequency band.
c) In this paper, for efficient spectrum sensing operation, a Wavelet and S-Transform based approach for the detection of sub band edges in wide spectrum band where primary users are available.

Explanation: The S-Transform (ST), is a hybrid of the Short Time Fourier Transform and Wavelet transform, has a time frequency resolution which is far from ideal. For time-frequency representation the ST is known for its local spectral phase properties. Here the exact occupation of primary users and noise signal is calculated by S-Transform.

Observation: In this paper, Continuous wavelet and S-Transform is used to sense the presence of primary users of cognitive radio. Here S-Transform is used to detect the small variation in the given frequency range. It found the availability of user even at low SNR level and give the accurate location of spectrum holes.

6) Noise Immune Spectrum Sensing Algorithm for Cognitive Radio [14]-

a) One promising approach to achieving high precision spectrum sensing in a cognitive radio (CR) system is the energy detector based on Wavelet Packet Transform (WPT). However, energy detector spectrum sensing is affected by the Signal to Noise Ratio (SNR).
b) When the SNR is lower than 5 dB, an energy detector may falsely determine some unoccupied sub-channels as occupied [12].
c) In this paper, a new noise immune algorithm for spectrum sensing is introduced. This algorithm combines two powerful tools: the wavelet packet analysis and Higher-Order-Statistics (HOS).

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Explanation: The wavelet coefficients of Gaussian noise remain Gaussian and the Gaussian process has a property in which the fourth-order cumulant value C^4 of the Gaussian process theoretically equals to zero. The proposed WPT spectrum sensing technique is designed based on this property **[refer paper 8].**

Observation: A noise immune spectrum sensing algorithm has been described. Two powerful tools; the WPT and HOS has been combined. The proposed algorithm is able to identify the unoccupied sub channels especially at very low SNRs. The proposed algorithm has been tested for SNR down to –4 dB and proved to work successfully.

7) Wavelet-Based Spectrum Sensing for Cognitive Radios using Hilbert Transform [15]-

a) For cognitive radio networks, there is a major spectrum sensing problem, i.e. dynamic spectrum management.
b) It is an important issue to sense and identify the spectrum holes in cognitive radio networks. The first-order derivative scheme is usually used to detect the edge of the spectrum.
c) In this paper, a novel spectrum sensing technique for cognitive radio is presented. The proposed algorithm offers efficient edge detection.

Observation: For the CR system, the wideband spectrum sensing problem is that the parameters characterizing the wideband spectral environment have to be estimated. The first-order derivative scheme is usually used to detect the edge of the spectrum. This work proposes a novel spectrum sensing algorithm for cognitive radio.

8) A Wavelet Approach to Wideband Spectrum Sensing for Cognitive Radios [16]-

a) In cognitive radio networks, the first cognitive task preceding any form of dynamic spectrum management is the sensing and identification of spectrum holes in wireless environments.
b) As a powerful mathematical tool for analyzing singularities and edges, the wavelet transform is employed to detect and estimate the local spectral irregular structure, which carries important information on the frequency locations and power spectral densities of the sub bands.
c) This paper develops a wavelet approach to efficient spectrum sensing of wideband channels. The signal spectrum over a wide frequency band is decomposed into elementary building blocks of sub bands that are well characterized by local irregularities in frequency.

Explanation: The proposed schemes are able to scan over a wide bandwidth to simultaneously identify all piecewise smooth sub bands, without prior knowledge on the number of sub bands within the frequency range of interest. The wavelet approach offers evident advantages over the conventional use of multiple narrowband BPFs, in terms of both implementation costs and flexibility in adapting to dynamic PSD structures. Sensing techniques provide an effective radio sensing architecture to identify and locate spectrum holes in the signal spectrum.

Observation: Since the wavelet approach targets wideband spectrum sensing, it may require high sampling rates in order to characterize the entire wide bandwidth.

IV. CONCLUSION

Cognitive Radio (CR) is a developing technology to overcome the problem of using the spectrum inefficiently by improving idle spectrum utilization in both temporally and spatially. Cognitive Radio is an intellectual radio having the ability of recognizing the vacant spectrum to transmit the data to avoid spectrum inefficiently usage problem. This allows better utilization of the unoccupied spectrum and high spectrum efficiency usage. There are several methods to provides the spectrum for efficient and sufficient utilization of the radio electromagnetic resources, the current trends of the Spectrum Sensing in Cognitive radio is based on wavelet transform, the transform could be of any type like HAAR, Symlets, Coiflets and Dabuchesis. Hence from this comparative study it can be concluded that the results are improving but need more enhancement at the wavelet-based energy detection, secondary spectrum, Eigen filter, Wavelet and S-Transform based approach as well as dealing with more complex corruptions. Future endeavors include better expansible proportion of wavelet coefficients in order to get better effects using spectrum sensing in cognitive radio.

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