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Spectrum Sensing In Cognitive Radios Using Wavelet Packet Transforms

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Abstract

A great portion of the licensed spectrum is not effectively utilized as fixed spectrum assignment led to underutilization of the spectrum which is known as spectrum scarcity. The problem of spectrum scarcity is one of the major issues we are facing and it can be addressed by the rapid growth of wireless technology, applications and its services. In this context, spectrum scarcity problem is overcome by cognitive radio which is an intelligent radio and network technology that can automatically detect the available channels in the wireless spectrum. It involves obtaining the spectrum usage characteristics such as time, space, frequency and spectral occupancy. In this paper, we aim to design a new approach for spectrum sensing using wavelet packet transforms based on energy detection which offers great flexibility, reconfigurability and adaptability which is better than Fourier based estimates.

Keywords: Cognitive radio, Spectrum sensing,Primary user, Energy detection, Wavelet packet transform

Introduction

Wireless technology is gradually becoming the backbone in the field of communications, as huge number of wireless devices such as mobile phones, sensors, and communicators are connected to the internet globally serving a wide range of applications to the end users. Since the natural available spectrum is scarce and need to provide services to the future users, the conventional fixed spectrum access policy is not commodious as it cannot accommodate upcoming users and utilizes spectrum in an incompetent manner Due to increase in wireless devices and applications, electromagnetic spectrum availability is decreasing day by day. By using Cognitive Radio the issue of spectrum underutilization can be solved in a better way, which will bring revolutionary changes in wireless technology.

In 2008 Federal communication commission (FCC) signified a very interesting report that 70% of the spectrum is underutilized [1]. The main objective of cognitive radio is to share the spectrum between the primary and secondary users. It will detect the available channels in wireless spectrum and then changes transmission and reception parameters accordingly. Thus we can allow more concurrent wireless communications in a given spectrum band at one location. The most critical functions of cognitive radio are spectrum sensing, spectrum management, spectrum mobility and spectrum sharing. Among them, spectrum sensing allows user to recognize vacant frequency bands in surrounding environment which requires signal processing techniques with better accuracy & low complexity. The essence of spectrum sensing is that the frequency bands unused by primary user are sensed and assigned to the secondary user and it also offers wide possibilities for efficient utilization of the given bandwidth in real time sensing mode. Many methods have been proposed to detect the presence of primary user.

Spectrum Sensing Methods

The presence or absence of signal at a particular frequency band can be found out using spectrum sensing. Presence of signal implies an increase in energy or the presence of a noisy signal with higher order periodicity. Conventional approaches is good enough only for narrow bandwidths. But it seems to be ineffective for dynamic approaches in cognitive radio. Fig 1shows different techniques of spectrum sensing as follow [2]:

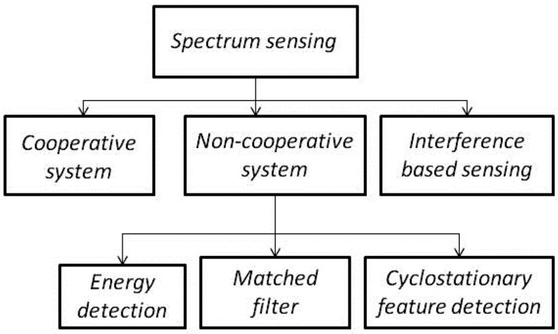

Figure 1: Various Spectrum Sensing Methods

A. *Non cooperative spectrum sensing techniques:*

It is the simplest approach to sense the spectrum holes. In this technique, the base station alone would determine the spectrum hole and uses it for providing service to unlicensed users. Different non cooperative techniques are:

i) Energy detection:
It detects the licensed user based on sensed energy [3]. It is the most popular technique in non cooperative sensing as it does not require any prior knowledge of licensed user signal. In this energy detector based sensing threshold plays a vital role in detecting the primary user. Here we determine the presence of the primary user by squaring, summing, comparing received signal samples with that of the predefined threshold. It is commonly used technique in non cooperative as it is least complex.

ii) Matched filter:
This is also known as Pilot detection technique. This is the fastest approach for spectrum sensing. It is a linear filter which maximizes the output SNR for given input signal. Matched filtering is known as the optimum method in additive white Gaussian noise (AWGN) channel. It requires the prior knowledge of the primary user signal, which is the most significant disadvantage of this technique. It also requires a separate receiver for each type of licensed user.

iii) Cyclostationary feature detection:
A process of changing statistical features periodically is called cyclostationarity. It identifies the presence of licensed users by estimating the cyclostationarity property of received signal, embedded in pulse trains, spread-spectrum hopping sequences, and sinusoidal carriers. This technique requires high sensing time and highly computational complexity which results in high cost.

B. Cooperative sensing techniques:
Here the number of cognitive radio users collectively detects the presence of licensed users through channel gain maps. Relative to non cooperative sensing, cooperative sensing techniques can significantly achieve improved performance. But this technique requires system synchronization and suitable geographical spread of cooperating nodes.

C. Interference based detection techniques:
In this method, the cognitive radio performs like the ultra wide band (UWB) in which the unlicensed users coincide with licensed users. They are permitted to transmit in the same band with low power provided that they will not cross the interference temperature limit so that they will not cause interference to licensed users.

Terminology

1. Spectrum allocation schemes:
These are necessary to allocate bandwidth and communication channels to base stations, access points and terminal equipment. There are two types of strategies in spectrum allocation schemes:

1. Fixed spectrum allocation (FSA)
2. Dynamic spectrum allocation (DSA)

In FSA predetermined set of frequencies are given to each cell in channels which requires manual frequency planning.

DSA is another way of spectrum allocation which handles burst traffic and utilizes the radio resources in the most efficient way.

2. Licensed users and unlicensed users:

Licensed users are primary users who are assigned with certain channels and unlicensed users are secondary users who can use the channels of licensed users only when they do not cause any harmful interference.

3. Spectrum holes:

These are the regions of safe use of the spectrum without interference. It is the basic resource of cognitive radio networks.

4. Spectrum sensing:

In this method, we can find spectrum holes by continuously monitoring the activities of licensed users by secondary or unlicensed users.

Proposed Work

Spectrum sensing based on FFT is easy to implement and this is applicable only for low frequency. The drawback of this technique is low accuracy [4]. In this paper we address this problem by using wavelet packet transform based energy detection. An energy detection algorithm on the basis of 3 level wavelet packet transform is developed to find the presence of primary user in the available spectrum by calculating the threshold levels. It is one of the non cooperative spectrum sensing techniques which is easier and less complex in nature. The energy detector is used to find out the received signal energy and then it is compared with the calculated threshold value. In order to calculate the energy of the signal, it will be given to the band pass filter where it is squared, integrated.

Wavelet Packet Representation:

This wavelet packet approach is quite natural extension to the MMSE in the way that this method also uses different orthogonal filters as a prototype filters derived from tree structure. The wavelet packet method is a generalization of wavelet decomposition that offers a richer range of possibilities for signal analysis. By using two- channel filter bank containing a half-low band pass and high band pass filter the Wavelet Packet Transforms is implemented. This filter bank method is the simplest form of implementing wavelet packet transforms where the signal is decomposed into low and high frequency components respectively by the filtering process. In wavelet analysis, a signal is split into an approximation and detailed information, where approximation contains low pass information and the detail consists of high pass information. The major difference between Discrete wavelet transform(DWT) and Discrete wavelet packet transform(DWPT) is that in DWT next level decomposition is done only for approximation components whereas in DWPT the decomposition is done for both Approximation(A) and detailed coefficients (D). The approximations and detailed versions are successfully iterated through a hierarchical coding scheme, then the signal which is to be encoded is successively split into high and low frequency components. The desired level of frequency resolution and available computational power limits the number of successions. In our paper level-3 decomposition procedure is illustrated which generates eight wavelet packet coefficients.

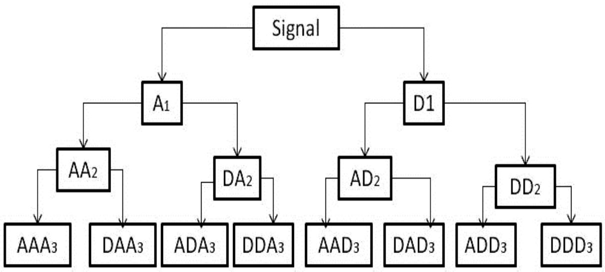

Figure 2: Level 3 Wavelet Packet Decomposition

Figure 3 represents the frequency separation after wavelet packet decomposition, where H(ω) and G(ω) are the transfer functions of low pass filter and high pass filter respectively[2]

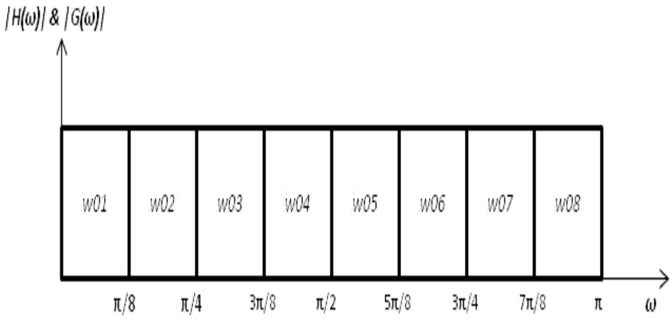

Figure 3: Frequency separation of 3-level WPT

This process can mathematically be expressed as:

$$y[n] = \sum_{k=-\infty}^{\infty} h[k].\, x[2n-k] \quad (1)$$

DWT [4] employs two sets of mathematical functions, scaling functions and wavelet functions that are linked with a low pass and high pass filter, respectively. The signal in time domain decomposes into various frequency bands simply by successively passing it through high pass and low pass filters. The original signal x[n] is initially passed through a half band high pass filter g[n] and a low pass filter h[n]. Subsequently, half of the samples can be eliminated as per Nyquist's rule, since the signal at present has a highest frequency of p/2 radians instead of p radians. The signal therefore can be sub sampled simply by discarding every other sample.

$$y_{high}[k] = \sum_n x[n].\, g[2k - n] \quad (2)$$

$$y_{low}[k] = \sum_n x[n].\, h[2k - n] \quad (3)$$

where $y_{high}[k]$ and $y_{low}[k]$ are the respective outputs from the high pass and low pass filters, subsequently sub sampled by 2.

This decomposition halves the time resolution since only half the number of samples now characterizes the entire signal. However, this operation doubles the frequency resolution, since the frequency band of the signal now spans only half the previous frequency band, effectively reducing the uncertainty in the frequency by half. The above procedure, which is also known as the sub band coding, can be repeated for further decomposition [5].

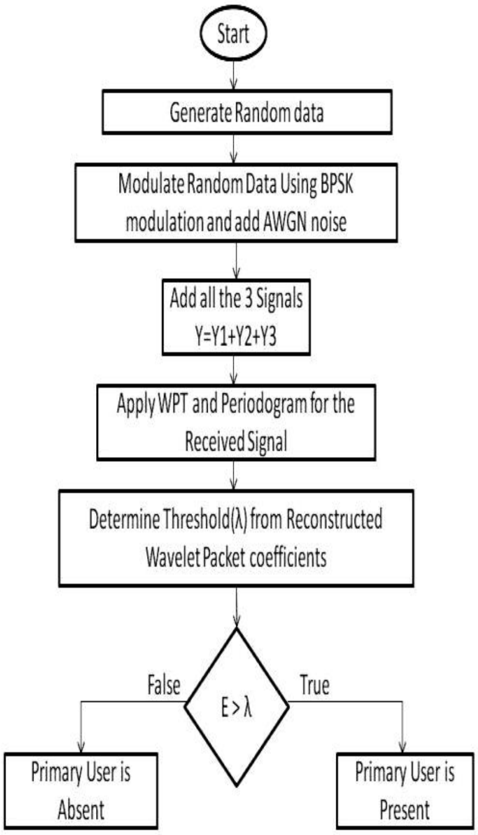

Figure 4: Energy detection using WPT flowchart

The flowchart in Fig. 4 shows the complete process of energy detection using wavelet packet transform. We assumed 3 users and wavelet packet transformation is applied using the Daubechies wavelet 1.

Results

In this paper we simulated the Wavelet Packet Decomposition based energy detection technique for three users. We assume the channel as AWGN.

Fig. 5 illustrates the decomposed wavelet signals after applying 3- level WPT to the received signal.

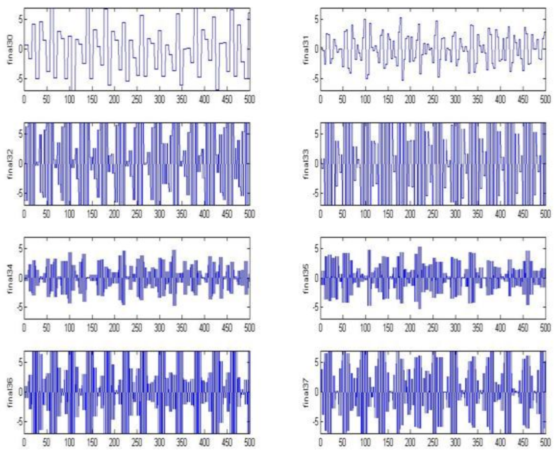

Figure 5: 3- level Wavelet Packet Decomposition of the received signal

Fig. 6 shows the presence of three users at 700, 800 and 900 MHz respectively with different power levels. The threshold at level -29.1dB is shown in red line. The figure indicates two users above the threshold and one user below the threshold.

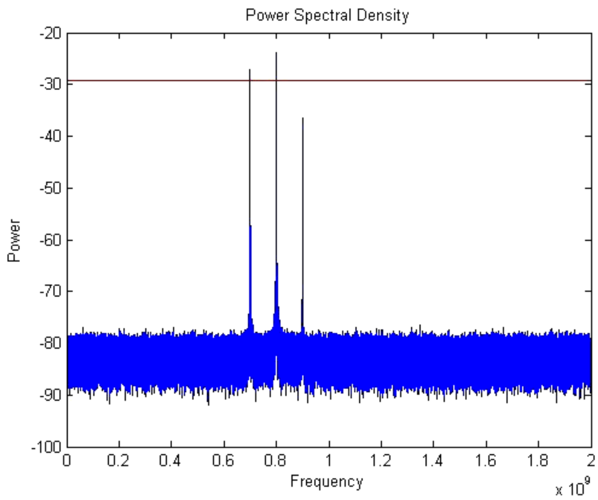

Figure 6: Periodogram of Received Signal Shows 3 Users Located At 700mhz, 800 Mhz And 900 Mhz With Different Power Levels

Since the spectrum power level below the threshold level can be safely used for secondary user transmission, the new spectrum availability after the spectrum sensing can be shown as in Fig. 7

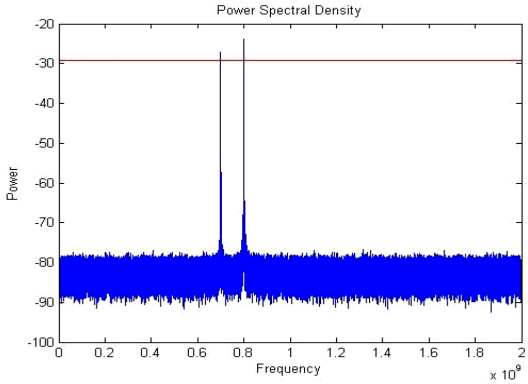

Figure 7: Spectrum Availability After Spectrum Sensing

Conclusions

In this research, implementation of Wavelet Packet based energy detection for a spectrum sensing in cognitive radios had been developed. As mentioned previously, energy detection is the simplest technique in spectrum sensing and is easy to implement. Results had proven that the accuracy of energy detection can be improved by implementing wavelet packet transforms.

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