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Wavelet Packet Transform Technique Based on Entropy Estimation for Cognitive Radio Networks

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Abstract: To resolve the issue of spectrum underutilization, Cognitive Radio (CR) arises to be an enticing solution. Among its fundamental functions, the key function of CR system is spectrum sensing where it senses the electromagnetic environment to detect spectrum holes (vacant frequency bands), which can be utilized by Secondary User's (SU) to achieve increased spectral efficiency. This requires high accuracy and minimal complexity. In this paper, Wavelet Packet Transform Technique Based on Entropy Estimation for Sensing Spectrum Holes in Cognitive Radio Networks is proposed. The proposed technique needs no prior information about Primary User (PU) signal. The wavelet packet probability vector can estimate spectrum holes in the radio spectrum with simple and less computationally complex structure, as it contains vital information about frequency locations of wavelet sub-bands.

Keywords: *Cognitive Radio, spectrum sensing, primary user detection, wavelet packet transform, entropy*

I. INTRODUCTION

According to survey of Federal Communications Commission (FCC) [2] current wireless communication networks, operating in either licensed or unlicensed bands, almost occupy the entire available spectrum. Yet the demand for spectrum is constantly increasing with the availability of new services and many technological advances in the field of wireless communication, so the need to optimize the utilization of spectrum is felt all the more. However, conventional method of spectrum allocation to licensed user is very inflexible, where licensed user has exclusive right to operate in that allocated frequency band. With this scheme most of useful spectrum is already allocated so it is hard to accommodate new services or to improve the existing ones. As a large portion of the licensed radio spectrum is not in use for significant periods of time in certain areas, spectrum underutilization has come forth as a more significant problem than physical scarcity of spectrum i.e. there are a lot of spectrum holes/white spaces, which are defined as a set of frequency bands assigned (licensed) to a Primary User (PU), but, at a particular time and specific geographic location, not being utilized by that user. Spectrum utilization can be drastically increased by Cognitive Radio (CR) which can co-exist with the existing PU's in the licensed frequency band as it senses the available spectrum for spectrum holes and can opportunistically access the detected white spaces without causing any harmful interference to the PU [3].

Spectrum sensing is the key function of CR as it involves determining the spectrum characteristics across different dimensions such as time, space, frequency and code and estimating what kind of PU signals are present. Different spectrum sensing techniques are available in the literature: Energy Detection based sensing [6], Cyclostationary Feature Detection based sensing [1], Matched Filter based sensing [9], Radio Identification based sensing [7], Waveform-based sensing [13], Cooperative spectrum sensing [10], Multitaper spectrum estimation [12], Spectral Feature spectrum sensing [15], Wavelet based spectrum sensing [11] and Entropy based spectrum sensing technique [14] etc.

Entropy based spectrum sensing technique is found to be simpler and efficient compared to some of the existing methods as discussed in the literature.

In this work, a Wavelet Packet Transform Technique based on Entropy Estimation is proposed which combines the advantages of Wavelet Packet Transform (WPT) Decomposition with effectiveness of Entropy Estimation. As the WPT method gives precise information about the decomposed frequency bands (subbands) depending upon the level of decomposition chosen and the entropy (randomness) of each subband gives the information about its occupancy. The proposed algorithm is robust against noise uncertainty as the need for accurate estimation of noise is eliminated. Moreover, location of spectrum holes in the interested frequency band can be estimated fast by utilizing the wavelet packet probability vector of the decomposed subbands. Simulation results and complexity analysis show that the proposed algorithm is suitable for the spectrum sensing scheme for CR.

This paper is organized as follows: Section II briefly describes Wavelet Packet Transform (WPT) and Entropy, and then A Wavelet Packet Transform Technique based on Entropy Estimation is proposed. Section III presents System Model Description. Simulation results and discussions are provided in section IV, and section V concludes the paper.

II. WAVELET PACKET TRANSFORM TECHNIQUE BASED ON ENTROPY ESTIMATION

Spectrum Sensing is based on a well known technique called signal detection which is formalized as a hypothesis test [4].

$$H0: x(n) = w(n) \quad (1)$$

$$H1: x(n) = s(n) + w(n) \quad (2)$$

Where, x(n) is the received signal by CR receiver, s(n) is the transmitted signal of the PU and w(n) is Additive White Gaussian Noise with variance , n=0,l ,2 . . . ,N-I ,and N indicates the sample size.

H0 and H1 are the sensing states (hypothesis) that indicate the absence and presence of PU signal respectively. If H0 is decided under H1 hypothesis, then it leads to probability of misdetection (Pmd) that is probability of deciding that there's no PU signal while primary signal actually exists. Missed detections are the biggest issue for spectrum sensing, as it will result in possible interference with the primary system. If H0 is decided while H0 is observed then it refers to find the probability of detection Pd which indicates to decide primary signal exists when PU is actually communicating. Thus high Pd leads to efficient usage of the spectrum.

Entropy detection is a reliable way of spectrum sensing as the receivers do not need any prior knowledge about the PU signal. In the proposed technique, the signal is detected by comparing the output of the entropy detector with a threshold which depends on the noise floor. The received signal to be analyzed is first decomposed into a number of small frequency bands (subbands) by using Wavelet Packet Transform Decomposition technique and then Entropy of each subband is compared with the calculated threshold to make a decision about the presence/absence of PU signal in that particular frequency range.

A. Wavelet Packet Transform Decomposition

As known, noise is primarily of high frequency and the signal of interest is primarily of low frequency. The Wavelet Packet Transform (WPT) decomposes the signal into approximation (low frequency i.e. A) and details (high frequency i.e. D) coefficients, the detail coefficients containing much noise [5]. Hence it is suitable to finely identify the information in both high and low frequency bands and thus is an ideal processing tool for non-stationary time-variable signal.

WPT employs two sets of functions, called scaling functions and wavelet functions, which are associated with low-pass and high-pass filters, respectively as in Fig 1.

To gain a better appreciation of this process, one-stage discrete wavelet packet transform of a signal is performed where the received signal is a pure sinusoid with high-frequency noise added to it which is shown in Fig 2.

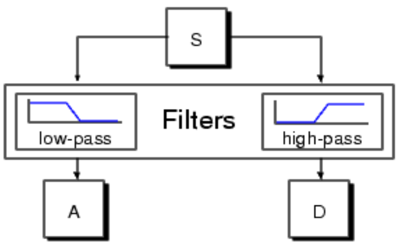

Figure 1. The filtering process, at its most basic level

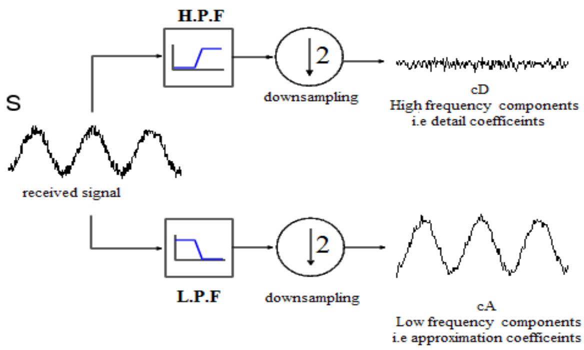

Figure 2. Schematic diagram of WPT decomposition with real signal as input

The decomposition of the signal into different frequency bands is simply obtained by successive high-pass and low-pass filtering of the time domain signal. The original signal S is first passed through a half-band High-Pass Filter (HPF) and a Low-Pass Filter (LPF). After the filtering, half of the samples can be eliminated according to the Nyquist's rule, since the signal now has a half of the highest frequency. The signal can therefore be down sampled by 2, simply by discarding every other sample which produces two sequences cA and cD and is a more subtle way to perform the decomposition using wavelets.

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 can be repeated for further decomposition of the signal into different frequency bands depends on required degree of resolution.

Fig 3 shows 4-level wavelet packets transform decomposition which allows the signal S to be represented as A1 + AD2 + ADD3 + ADDD4 + DDDD4. This is an example of a representation that is not possible with ordinary wavelet analysis but made feasible only with WPT. At every level, the filtering and sub sampling will result in half the number of samples (and hence half the time resolution) and half the frequency band spanned (and hence doubles the frequency resolution). The greater the degree (level) of decomposition, the better the frequency resolution achieved. The level of decomposition is usually limited by the desired frequency resolution and available computational power.

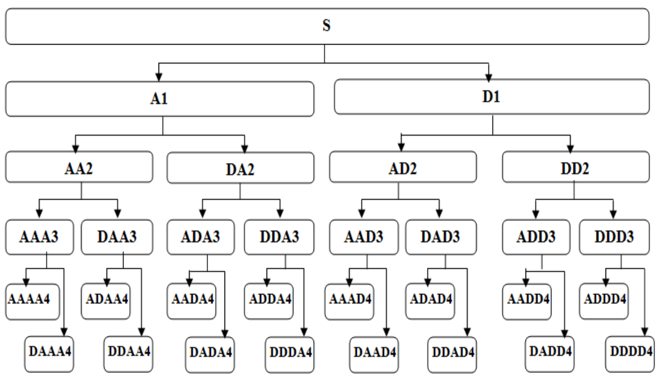

Figure 3. 4-level Wavelet packet decomposition tree

For a particular level j the received signal is decomposed into 2^j subbands by WPT where the wavelet coefficients of the respective subbands are as:

$$c_{k,m}^j = WP\{x(n), j\} \tag{3}$$

Where, $c_{k,m}^j$ Denotes the m^{th} coefficient of the k^{th} subband for level j and m=1……N/2^j , k=1………2^j, n=1 ….N

B. *Wavelet Packet Entropy (WPE)*

The underlying concept of entropy is randomness i.e. it is maximum if for a given power level the signal is Gaussian (noise) and will be reduced is the received signal contains the digitally modulated component (PU signal). Thus, the proposed technique doesn't require prior knowledge on primary user's signal characteristics.

The wavelet packet entropy of a subband is defined in terms of the relative wavelet energy of the wavelet coefficients [8]. The energy for each subband k and level j can be calculated as:

$$E_k^j = \sum_m |c_{k,m}^j|^2 \tag{4}$$

Where, $c_{k,m}^j$ is given in (3). Total sum of energy of the wavelet packet coefficients at level j, E_{sum}^j is calculated as:

$$E_{sum}^j = \sum_k |c_k^j|^2 = \sum_k^{2^j} E_k^j \tag{5}$$

Now, the probability distribution i.e. normalized wavelet energy at each subband p_k^j for level j is given as:

$$p_k^j = \frac{E_k^j}{E_{sum}^j} \tag{6}$$

It carries important information on the frequency locations of sub bands.

Wavelet packet entropy for level j S_{wp}^j is calculated as:

$$S_{wp}^j = -\sum p_k^j \log_2[p_k^j] \tag{7}$$

The decision on presence/absence of PU signal in received signal is made based on the estimate of wavelet packet entropy from the signal samples.

For hypothesis H0 the received signal consists of only noise i.e. independently distributed additive white Gaussian noise. So, wavelet packet entropy of incoming signal x(n)=w(n) for different level(j=1,2……) is:

$$S_{wp}^j = S_{wp}^j(w(n)) = -\sum p_k^j \log_2[p_k^j] \tag{8}$$

Where, p_k^j is calculated by (6). Noise w(n) is a random signal i.e. AWGN with a flat power spectral density.

For hypothesis H1 the received signal consists of the licensed (primary) user signal and noise. So, wavelet packet entropy of incoming signal x(n)=s(n)+w(n) for different level(j=1,2……) is:

$$S_{wp}^j = S_{wp}^j(x(n)) = -\sum p_k^j log_2[p_k^j] \tag{9}$$

Where, p_k^j is calculated by (6).

For both the hypothesis wavelet packet entropy is calculated by (7) for a given level j of wavelet decomposition and then test signal which is to be compared with the threshold for making decision on the status of primary signal presence is calculated as:

$$Y_j(X) = -\sum_k^{2^j} p_k^j \log_2[p_k^j] = -\sum_k^{2^j} \frac{E_k^j}{E_{sum}^j}\log_2\left[\frac{E_k^j}{E_{sum}^j}\right] \begin{cases} \le T^j : & decide\ H_1 \\ \ge T^j : & decide\ H_0 \end{cases} \tag{10}$$

Where, T^j is the detection threshold for level j, measured by target false alarm ratio P_f. It is assumed that the theoretical value of $S_{wp}^j(w(n))$ in equation (8) is the mean value and variance σ_e^2 of the estimated noise entropy as it follows a Gaussian distribution.

The test signal $Y_j(X)$ is related to the wavelet decomposition level j and sample size N. The threshold is determined by:

$$T^j = S_{wp}^j\big(w(n)\big) + Q^{-1}(1 - P_f)\sigma_e \tag{11}$$

Where, $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty \exp\left(\frac{-\tau^2}{2}\right)d\tau$, $Q^{-1}(x)$ is inverse of Q-function. For a fixed decomposition level j, wavelet entropy for hypothesis H0 is constant, independent of noise power and P_f remains invariant.

III. SYSTEM MODEL DESCRIPTION

To evaluate the performance of the proposed technique in simulation environment, two simulation models are taken up: PU detection in Medium Frequency (MF) band, PU detection in Very High Frequency (VHF) band.

A. *Simulation Model*

Fig 4 shows WPT entropy based detector which estimates the entropy of current noise signal, which is very important for settling threshold.

The combined signal of all present PU's is received at the CR receiver where Wavelet Packet Decomposition technique is applied and entropy of each wavelet (subband) is calculated and compared with threshold. If the entropy of that particular subband is less than the threshold, presence of PU in that subband is indicated else it indicates the absence of PU i.e. the corresponding frequency subband is vacant and can be utilized by SU (CR user) for transmission.

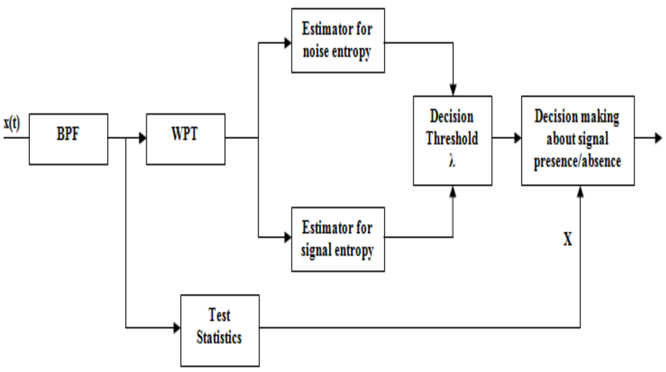

Figure 4. Block diagram of WPT entropy based detector

B. System Assumptions

1) This algorithm proposed for Cognitive Radio Network (CRN) in which PU's are randomly deployed, is dedicated to sense the radio spectrum continuously where the sensed information is then used to detect whether PU is present or absent. In addition following assumptions are made:
2) In cognitive radio network there are two desired frequency bands to be sensed i.e. Medium Frequency band and Very high Frequency band.
3) There are three, All India Radio (AIR) and one random frequency Amplitude Modulated PU signals for the Medium Frequency band environment and five FM Radio and a PAL B TV systems PU signals as input for Very High Frequency band environment.
4) These transmitted signals are received at Cognitive Radio receiver at different SNR values.

C. Steps of Algorithm

1) Deploy primary users.
2) Then transmit different primary users signal through noisy channel.
3) Add random noise in received signal from different primary users.
4) Start spectrum sensing of desired wideband frequency band.
5) Perform discrete wavelet packet decomposition up to required resolution.
6) Determine wavelet coefficients corresponding to terminal nodes.
7) Rearrange the terminal node in order of increasing frequency band order.
8) Calculate sub-band entropy corresponding to terminal node's coefficient and compare calculated sub-band entropy with threshold.
9) Then decide whether sub-band is occupied or not.

IV. SIMULATION RESULTS AND DISCUSSIONS

In this section, the proposed scheme is used to sense the licensed (or primary) users, and examine its whole procedure. Two cases which are different with sensing environment, interested frequency range and PU's in that environment are considered in this paper.

PU's presence/absence is required to be sensed in two different interested frequency bands i.e. MF (300 KHz to 3 MHz) band and VHF (30 MHz to 300 MHz) band are desired to be sensed.

CASE 1: PU detection in MF band

Licensed user signal status (presence/absence) is required to be detected in MF band.

A. Simulation Environment for CASE 1

In Fig 5, the simulation environment is shown. Specifically, there exist 4 licensed/primary users (AIR Primary Channel Tx with carrier frequency fc=873 KHz, AIR Channel Band Tx with fc=702 KHz, AIR Vivid Bharti Tx with fc=1350 KHz and a random AM Tx with fc=1650 KHz) and 1 Customer Premise Equipment (CPE) that can sense the interested frequency band for CR users.

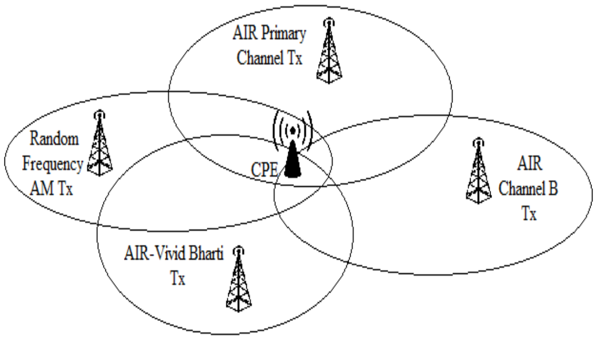

Figure 5. Simulation environment scenario for case 1

In addition, the channel is AWGN with zero mean and σ_e^2 variance, the interested frequency band (or scanning range), B1, is 3 MHz

Fig 6 shows the procedure of separation of the interested frequency band into subbands based on the above simulation environment. It depicts the frequency range of subbands, for e.g. subband 4 depicts frequency range (562.5 KHz-750 KHz).

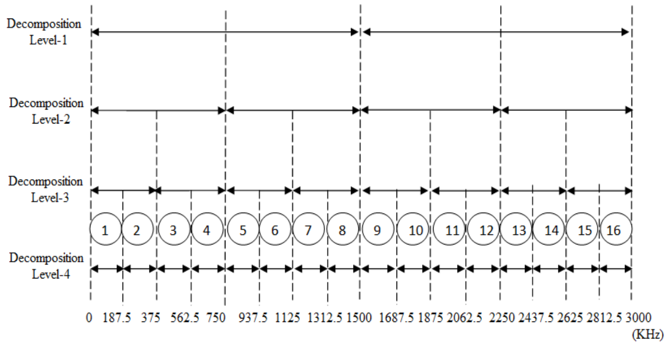

Figure 6. Separation of input signal, in Medium Frequency band using the proposed scheme

Level=1 to 4 decomposition is performed and 6000 sample length of data is to be computed. For simplicity indexes to channels are put in the ascending order.

B. Simulation Results for CASE 1

Fig 7 shows the received signal at the CPE using the basic FFT scheme. Since center frequencies are 702, 873, 1350 and 1650 KHz the entropy of subbands 4, 5, 8 and 9 is anticipated to be smaller than other channels and conclude the presence of PU signal. Figure 8 verifies the anticipated results.

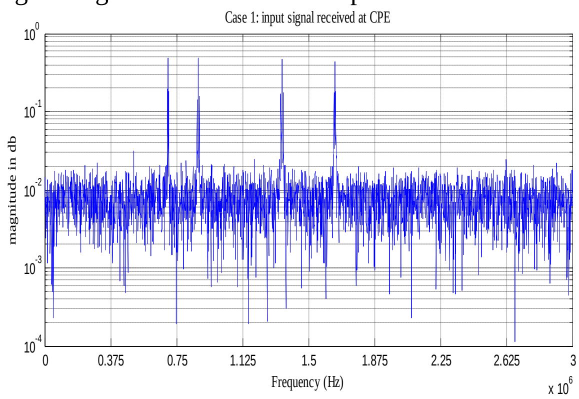

Figure 7. Received signal at CPE for Case 1

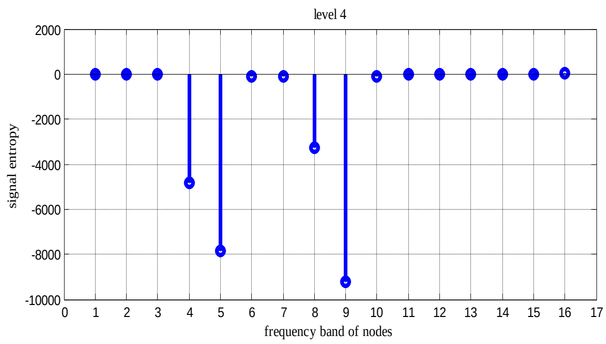

Figure 8. Entropy of subbands for Case 1 and level-4 decomposition

In Fig 9, an analysis of the proposed WPT- entropy based frequency band of nodes versus wavelet packet probability vector is presented which shows that more information details about the interested frequency band (MF) can be obtained by higher decomposition level.

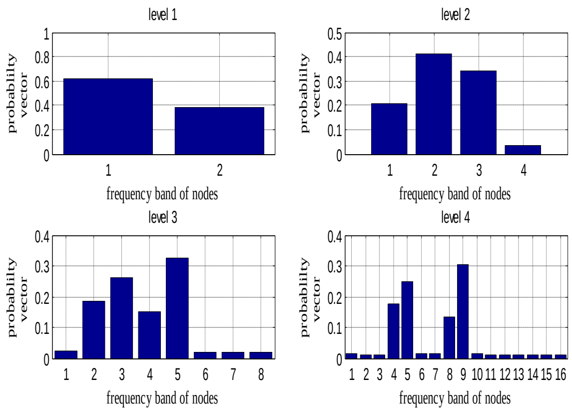

Figure 9. Wavelet Packet probability vector versus frequency band of nodes for MF band

It is a simple way to estimate the probability of signal presence in each decomposed subband of a particular level.

1) For level 1, spectrum holes can be located nowhere, with large value of normalized energy present for both sub-bands.
2) For level 2, spectrum holes can be located at [2250 KHz – 3000 KHz].
3) For level 3, spectrum holes can be located at [0 Khz – 375 Khz] and [1875 Khz – 3000 Khz]
4) For level 4, spectrum holes can be located at [0 KHz – 562.5 KHz], [937.5 KHz – 1312.5 KHz] and [1687.5 KHz – 3000 KHz].

The detection results of the proposed technique over different levels of decomposition for Case 1 environment are shown in Fig 10.

For level-1, PU is detected over the entire sensed bandwidth, which does not give a clear image of spectrum holes which are required to be sensed whereas, as decomposition resolution is increased, the detection results are refined and PU signals are sensed to be present in the frequency range of 562.5 KHz-937.5 KHz and 1312.5 KHz-687.5 KHz

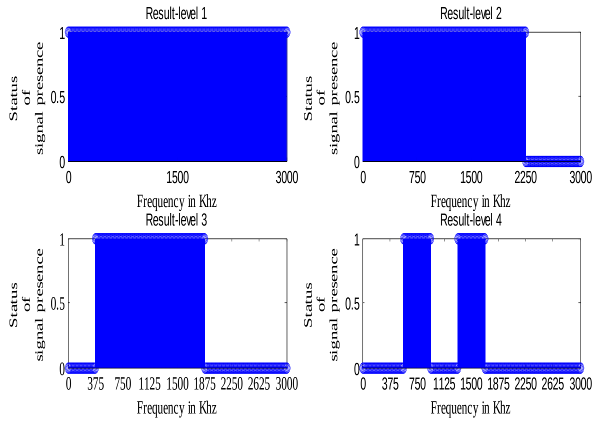

Figure 10. Status of signal presence versus frequency range of subbands for Case 1

CASE 2: PU detection in VHF band

Licensed user signal status (presence/absence) is required to be detected in VHF band.

C. *Simulation Environment for CASE 2*

In Fig 11, the simulation environment of case 2 is shown. Specifically, there exist 6 licensed/primary users (FM- Radio Mantra Tx with carrier frequency fc=91.9 MHz, BIG FM Tx with fc=92.7 MHz, FM-Radio Mirchi Tx with fc=98.3 MHz, FM Rainbow Tx with fc=102.7 MHz, FM-Gyani Vani Tx with fc=105.6 MHz and a PAL B TV System Tx with audio carrier at fc=203.5 MHz and video carrier at fc=208.75 MHz) and 1 Customer Premise Equipment (CPE) that can sense the interested frequency band for CR users.

In addition, the channel is AWGN with zero mean and σ_e^2 variance, the interested frequency band (or scanning range), B2, is 300 MHz

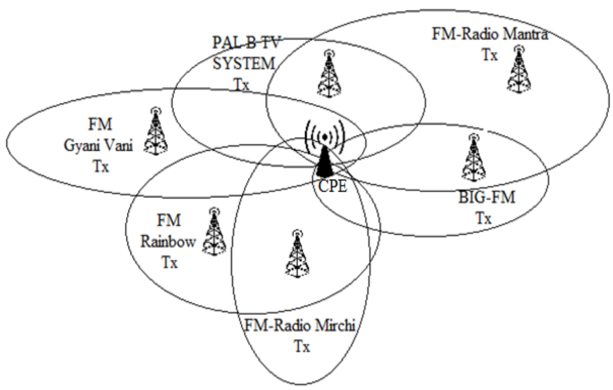

Figure 11. Simulation environment scenario for Case 2

Fig 12 shows the procedure of separation of the interested frequency band based on the above simulation environment. Level=1 to 4 decomposition is performed and 600000 sample length of data is to be computed.

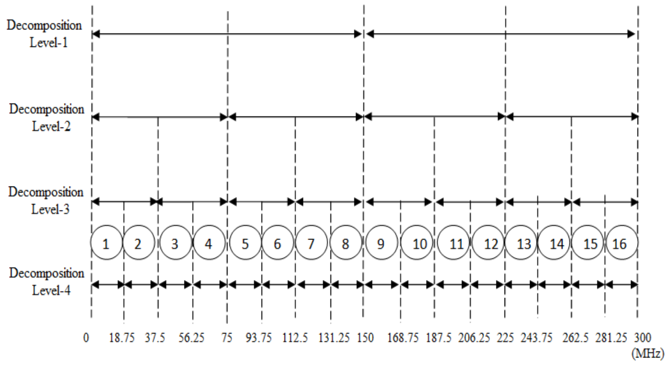

Figure 12. Separation of input signal, in Very High Frequency band using the proposed scheme

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D. Simulation Results for CASE 2

Fig 13 shows the received signal at the CPE using the basic FFT scheme. Since center frequencies are 91.9 MHz, 92.7 MHz, 98.3 MHz, 102.7 MHz, 105.6 MHz, 203.5 MHz and 208.75 MHz, the entropy of subbands 5, 6, 11 and 12 is anticipated to be smaller than other channels and conclude the presence of PU signal. Fig 14 verifies the anticipated results.

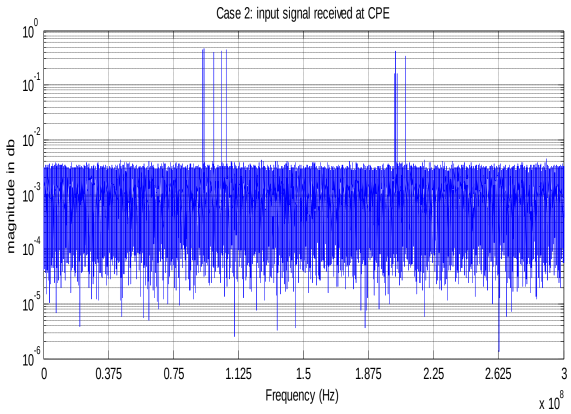

Figure 13. Received signal at CPE for Case 2

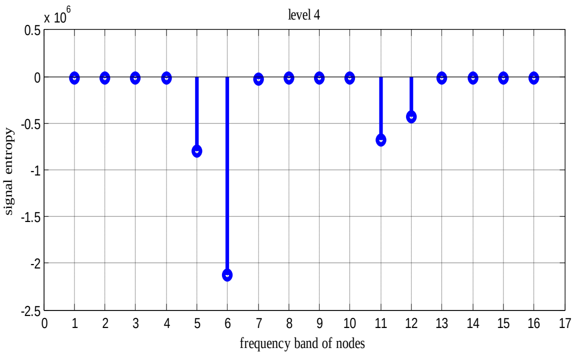

Figure 14. Entropy of subbands for Case 2 and level-4 decomposition

In Fig 15, an analysis of the proposed WPT- entropy based frequency band of nodes versus wavelet packet probability vector is presented which shows that more information details about the interested frequency band (VHF) can be obtained by higher decomposition level.

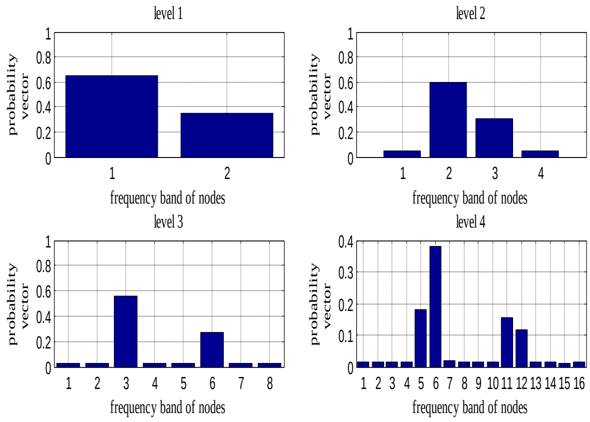

Figure 15. Wavelet packet probability vector versus frequency band of nodes for VHF band

1) For level 1, spectrum holes can be located nowhere, with large value of normalized energy present for both sub-bands.
2) For level 2, spectrum holes can be located at [0 MHz–75 MHz] and [225 MHz–300 MHz].
3) For level 3, spectrum holes can be located at [0 MHz – 75 MHz], [112.5 MHz–187.5 MHz] and [225 MHz–300 MHz].
4) For level 4, spectrum holes can be located at [0 MHz – 75 MHz], [112.5 MHz–187.5 MHz] and [225 MHz–300 MHz].

The detection results of the proposed technique over different levels of decomposition for Case 2 environment are shown in Fig 16.

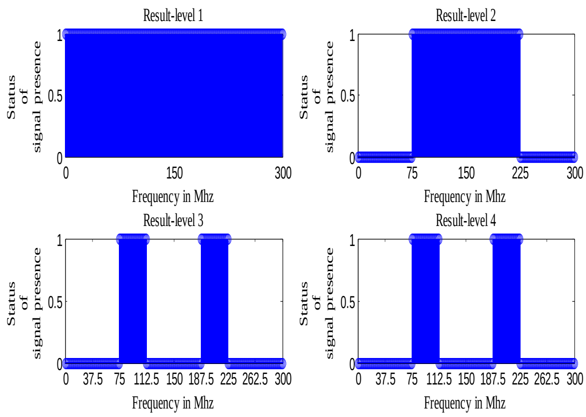

Figure 16. Status of signal presence versus frequency range of subbands for Case 2

For level-1, PU is detected over the entire sensed bandwidth, which does not give a clear image of spectrum holes which are required to be sensed whereas, as decomposition resolution is increased, the detection results are refined and PU signals are sensed to be present in the frequency range of 75 MHz-112.5 MHz and 187.5 MHz-225 MHz

V. CONCLUSION

In this paper, the problem of primary user detection for CR is analyzed using the proposed: Wavelet Packet Transform Technique Based on Entropy Estimation. The cognitive spectrum identification task is devised as a wavelet packet probability vector estimation problem which uses WPT and WPE for spectrum sensing. For the desired frequency band to be sensed, it carries important information on the frequency locations of sub bands and can estimate spectrum holes in the signal spectrum with simple structure and low computational complexity. As expected, wavelet packet entropy of the signal is estimated without prior knowledge of signal and noise. Simulation results show that the proposed algorithm can sense surrounding environment for spectrum holes based on entropy of the decomposed subbands. Though higher decomposition level gives more spectrum holes, which further improves the capacity of CR to increase the spectral efficiency, it even results in more computational complexity, so if more spectrum holes are needed, we can decompose wavelet packet for interested frequency band of nodes to reduce the computational complexity. These detected spectrum holes are now available for SU's or Cognitive User's to make unlicensed transmissions.

VI. REFERENCES

[1] A.Sahai, D.Cabric, "Cyclostationary Feature Detection" ppt at Berkeley Wireless Research Center, 2005.

[2] Federal Communications Commission, "Notice of proposed rulemaking and order: Facilitating opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies", ET Docket No. 03-108, 2003.

[3] Federal Communications Commission, "Notice of proposed rulemaking and order: Facilitating opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies", ET Docket No. 03-108, 2005.

[4] H.V.Poor, "An Introduction to Signal Detection and Estimation", Springer Texts in Electrical Engineering, Springer New York, 1994.

[5] J.C.Goswami, A.K. Chan, "Fundamentals of Wavelets: Theory, Algorithms, and Applications", JOHN WILEY & SONS, INC., PUBLICATION, 2011.

[6] J.Lehtomaki, "Analysis of Energy Based Signal Detection" Ph.D, dissertation, University of Olu, Finland, 2005.

[7] K.Kyouwoong, I.A.Akbar, K.K.Bae, J.Um, C.M.Spooner and J.H.Reed, "Cyclostationary Approaches to Signal Detection and Classification in Cognitive Radio" IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, Dublin, Ireland, pp. 212-215, 2007.

[8] S.Blanco, A.Figliola, R.Q.Quiroga, O.A.Rosso, and E.Serrano, "Time-frequency analysis of electroencephalogram series. 111. Wavelet packets and information cost function," Phys. Rev, vol. 57, pp. 932 – 940, 1998.

[9] S.Kapoor, SVRK.Rao and G.Singh, "Opportunistic Spectrum Sensing by Employing Matched Filter in Cognitive Radio Networks", International Conference on Communication Systems and Network Technologies, 2011.

[10] S.Mishra, A.Sahai and R.W. Brodersen, "Cooperative Sensing among Cognitive Radios", IEEE ICC proceedings, 2006.

[11] S.S.Jeng, J.M.Chen, H.Z.Lin and C.W.Tsung, "Wavelet-Based Spectrum Sensing for Cognitive Radios using Hilbert Transform", World Academy of Science, Engineering and Technology, 2011.

[12] S.S.Prasad, R.Gandhiraj, K.P.Soman, "Multi-User Spectrum Sensing based on Multi-Taper Method for Cognitive Environments", International Journal of Computer Applications (0975 – 8887) Volume 22– No.9, 2011.

[13] T.Yucek and H.Arslan, "A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications", IEEE Communication Surveys and Tutorials, vol.11, no.1, pp: 116-130, 2009.

[14] X.Chen, S.Nagaraj, "Entropy Based Spectrum Sensing in Cognitive Radio", Wireless Telecommunications Symposium, 2008.

[15] Z.Quan, S.J.Shellhammer, W.Zhang and A.H.Sayed, "Spectrum Sensing by Cognitive Radios at Very Low SNR" IEEE "GLOBECOM" proceedings, 2009.