

OFDM Based Cooperative Sequential Spectrum Sensing

Pooja Anand

Abstract-- Spectrum sensing is the most significant technique in Cognitive Radio system. So in this paper for the terrestrial television broadcasting (ISDB-T) system of integrated services digital broadcasting, i develop the algorithm based energy detector with low detection delay using sequential hypothesis testing and matched filter detector of spectrum sensing used on OFDM system which is use as a primary signal. For this i develop Cooperative sequential detection algorithms based on energy detectors and the autocorrelation property of cyclic prefix (CP) used in OFDM systems i modify the result of detectors to mitigate the effect of impairment and also compare the result of detectors. The performance of OFDM is assessed by using computer simulations performed by using MATLAB.

Keywords-- Distributed algorithm, energy detection, matched filter detection, OFDM system, spectrum sensing.

1. INTRODUCTION

In the Wireless Communications' engineering is in the heart of genuine explosion in cellular technologies. Once exclusively used for military and satellite, cellular technologies are now commercially motivated by progressively more demands of the users who wants uninterrupted communication where ever they go. With this increased demand of the user there is a need to transmit information wirelessly, swiftly and reliably. To address these various needs, communication engineer had to combine various technologies that are suitable for high rate transmission as well as forward error correction (FEC) techniques.

-
- **Pooja Anand** has been received Bachelor's degree in ECE from Govt. Women Engineering College, Ajmer and Pursuing Master's degree in ECE from RCE, Roorkee, Uttarakhand Technical University, Dehradun.
Email- pooja.anand74@gmail.com

Modern wireless systems aim at offering a wide variety of applications to various users at the same time. In order to realize this objective [2], they have to

overcome practical constraints imposed by the resources; such as power and spectrum, which are limited in nature. Since the number of wireless systems are increasing swiftly, the efficient utilization of these resources, especially frequency spectrum, becomes a more challenging problem to the communication engineers. The electromagnetic radio spectrum is a natural resource, which is used by transmitter and receiver and receivers are licensed by governments. In November 2002, the Federal Communications Commission (FCC) published a report prepared by the Spectrum Policy Task Force, aimed at civilizing the way in which this precious resource is managed in the United States [1]. This task force was made up a team of high level, multidisciplinary staff of FCC who are scholars, researchers, engineers, and economist to raise the level from commission's bureaus to offices [3]. And all this raise the demand of frequency spectrum. Cognitive radio (CR) offers a tempting solution to this problem by proposing opportunistic usage of frequency bands that are not occupied by their licensed users. CR is software defined Radio and is regarded as an innovative approach for improving the utilization of which is a radio electromagnetic spectrum, precious

natural resource. [3]. Cognitive Radios, also called secondary users, use the radio spectrum licensed to other (primary) users. Since it is a rather new concept, there is no agreement on the practical implementation of CR communications.

Orthogonal Frequency Division Multiplexing or OFDM is a modulation technique that is being used for many of the state-of-the-art of wireless and telecommunications standards [4]. OFDM, orthogonal frequency division multiplexing has gained a substantial presence in the wireless market place in today's communication, because of its widespread acceptance and distribution, it is to be expected that a primary user would be using OFDM, thus making the problem of detecting OFDM signals especially relevant for Cognitive Radio. One of the main advantages of OFDM is that is more resistant to frequency selective fading than single carrier systems because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels. And important problem encountered in cognitive radios is the hidden node problem caused due to surveillance or time-varying multipath fading. To lighten this problem, cooperative sequential spectrum sensing algorithms are proposed. Cooperative sequential detection algorithms based on energy detectors and the autocorrelation property of cyclic prefix (CP) used in OFDM systems.

I organize the rest of the paper as in Section II describes the Spectrum Sensing and we study the energy based detector, matched filter detector. And in section III OFDM model is discussed. In Sec. IV, I present cooperative sequential detection based setup of energy based and cyclic prefix based detection and extend these techniques to the sequential change detection algorithms. Section V concludes the paper.

II. SPECTRUM SENSING

In this section we discuss the detector design process. In this I can categorize spectrum sensing techniques into direct method, which is considered as frequency domain approach, where the estimation is carried out directly from signal and indirect method, which is known as time domain approach, where the estimation is performed by using autocorrelation of the signal. To improve the sensitivity of cognitive radio spectrum sensing and to make stronger against fading and the hidden terminal problem, cooperative sensing can be used [12]. The concept of cooperative sensing is to use multiple sensors and combine their measurement into one common decision. In this section I study the local probabilities of detection methods.

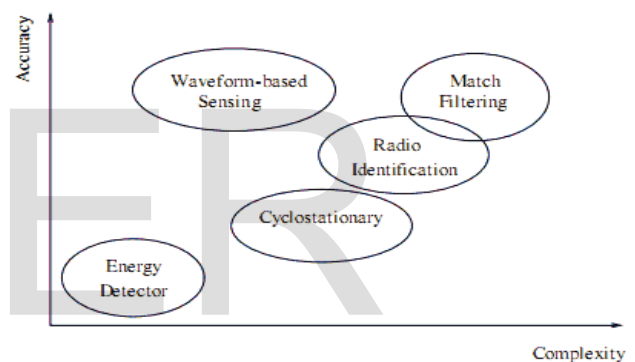


Fig: 1. Main sensing methods in terms of their sensing accuracies and complexities

A. MATCHED FILTER

A matched filter (MF) is a linear filter designed to maximize the output signal to noise ratio for a given input signal. Main purpose of this filter is to raise the signal component and decrease the noise component at the same time. When secondary user has a priori knowledge of primary user signal, matched filter detection is applied. Let $S(t)$ be the transmitted signal, $W(t)$ is the channel noise, and $S(t) + W(t)$ be the received signal, which is given as the input to the matched filter and $S_o(t) + W_o(t)$ be the output of the

filter. Let the matched filter's impulse response be $h(t)$. It had been proven that, impulse response of the optimum system is the mirror image of the desired message signal $S(t)$ about the vertical axis and shifted to the right until all of the signal $S(t)$ has entered the receiver. It should be realized that the matched filter is optimum of all linear filters. The signal component at output of the filter, at the observing instant t_m is given by

$$S_o(t_m) = 1/2\pi (s(\omega))^2 \quad (1)$$

$$S_o(t_m) = E \quad (2)$$

Hence the output signal component has maximum amplitude of magnitude E , which is nothing but energy of the signal $S(t)$. The maximum amplitude is independent of the waveform $S(t)$ and depends only upon its energy. The threshold of a signal, determined by two possible ways has been discussed here. One way is to estimate the energy of the signal and reduce it to half, fix it as a threshold. Another way is to compute the standard deviation of the signal by computing the mean and use it as threshold. Of the two methods, the former one is theoretically proved to be optimal. In this paper the former is chosen to detect the presence of WLAN signal [13].

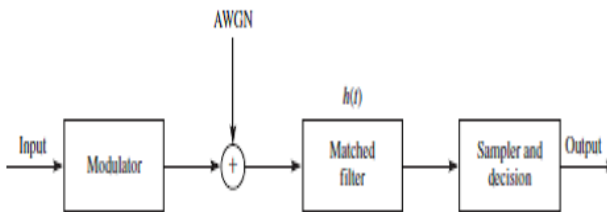


Fig: 2. Block diagram of matched filter

Once the threshold is chosen, presence of signal is determined based on the following decision rule [3].

$$r(t) > a : \text{signal present} \quad (3)$$

$$r(t) < a : \text{signal absent} \quad (4)$$

Where, $r(t)$ is the matched filter output given by

$$r(T) = S_o(T) + W_o(T) \quad (5)$$

From eqn. (2),

$$r(T) = E + W_o(T) \quad (6)$$

If there is no primary user signal, then received signal be

$$r(T) = w_0(T) \quad (7)$$

Indication of only noise.

B. ENERGY DETECTOR

Energy detection is the most popular spectrum sensing method since it is simple to implement and does not require any prior information about the primary signal [14]. An energy detector (ED) simply treats the primary signal as noise and decides on the presence or absence of the primary signal based on the energy of the observed signal.

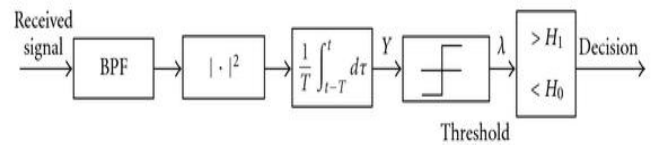


Fig: 3. Block diagram of Energy Detector

Analytically, signal detection can be reduced to a simple identification problem, formalized as a hypothesis test,

$$y(k) = n(k) \dots \dots \dots H_0 \quad (8)$$

$$y(k) = h * s(k) + n(k) \dots \dots \dots H_1 \quad (9)$$

Where $y(k)$ is the sample to be analyzed at each instant k and $n(k)$ is the noise of variance σ^2 .

Let $y(k)$ be a sequence of received samples $k \in \{1, 2, \dots, N\}$ at the signal detector, then a decision rule can be stated as,

$$H_0 \dots \dots \dots \text{if } \varepsilon > \nu \quad (10)$$

$$H_1 \dots \dots \dots \text{if } \varepsilon > \nu \quad (11)$$

Where $\varepsilon = E|y(k)|^2$ the estimated energy of the received signal and is chosen to be the noise variance σ^2 .

The received signal $r(t)$ takes the form

$$r(t) = h s(t) + n(t) \quad (12)$$

Where $h = 0$ or 1 under hypotheses H_0 or H_1 respectively. The received signal is first pre-filtered by an ideal band pass filter with transfer function [13].

$$h(f) = \begin{cases} \frac{2}{\sqrt{N_{01}}} & |f - f_c| \leq W, \\ 0 & |f - f_c| > W, \end{cases} \quad (13)$$

to limit average noise power and normalize the noise variance. The output of this filter is then squared and integrated over a time interval T to finally produce a measure of the energy of the received waveform. The output of the integrator denoted by Y will act as the test statistic to test the two hypotheses H_0 and H_1 . According to the sampling theorem, the noise process can be expressed as

$$n(t) = \sum_{i=0}^{\infty} n_i \sin c(2Wt - i) \quad (14)$$

Where, $\sin c(x) = \frac{\sin(\pi x)}{\pi x}$ and $n_i = n\left(\frac{i}{2W}\right)$, one can easily check that $n_i \approx N(0, N_{01}, W)$, for all i . Using the fact that [28]

$$\int_{-\infty}^{\infty} \sin c(2Wt - i) \sin c(2Wt - k) dt = \begin{cases} \frac{1}{2W}, & i = k \\ 0, & i \neq k \end{cases} \quad (15)$$

We may write this

$$\int_{-\infty}^{\infty} n^2(t) dt = \frac{1}{2W} \sum_{i=-\infty}^{\infty} n_i^2 \quad (16)$$

Over the time interval $(0, T)$, $n(t)$ the noise energy can be approximated by a finite sum of $2TW$ terms as

$$n(t) = \sum_{i=1}^{2WT} n_i \sin c(2Wt - i), \quad 0 < t < T \quad (17)$$

Similarly, the energy in a sample of duration T is approximated by $2TW$ terms of the right-hand side:

$$\int_0^T n^2(t) dt = \frac{1}{2W} \sum_{i=-\infty}^{2u} n_i^2 \quad (18)$$

Where $u = TW$. We assume that T and W are chosen to restrict u to integer values. If we define

$$n'_i = \frac{n_i}{\sqrt{N_{01}W}} \quad (19)$$

Where, N_{01} is one sided Noise Power Spectral Density. Then the test or decision statistic E can be written as

$$E = \sum_{i=1}^{2u} n_i'^2 \quad (20)$$

Here n'_i contains both the real and imaginary parts each having a variance $\sigma^2/2$. Under both the hypothesis the test statistic E can be viewed as the sum of the squares of $2u$ standard (real) Gaussian variables with zero mean and unit variance or equal variance. Hence the distribution of the random variable E is the chi-square (χ^2) distribution with a non-centrality parameter, 0 under H_0 and 2γ under H_1 .

$$E = \begin{cases} \chi_{2u}^2, & H_0 \\ \chi_{2u}^2(2\gamma), & H_1 \end{cases} \quad (21)$$

Where γ is the average SNR. The probability of detection and false alarm are defined as,

$$P_d = \Pr\{E > \lambda | H_0\} \quad (22)$$

$$P_f = \Pr\{E > \lambda | H_1\}$$

$$(23)$$

Where λ is the final threshold of the local detector to decide whether there is a primary user present. There are two ways of obtaining closed form expressions for

these probabilities. The first, which is through direct integration of the chi-square distribution over the tail of the distribution function giving us the following result

$$P_f = \frac{I(u, \frac{\lambda}{2})}{I(u)} \quad (24)$$

Hence,

$$P_d = Q_u(\sqrt{2\gamma}, \sqrt{\lambda}) \quad (25)$$

Where, $\gamma = \sigma_x^2 / 2\sigma_n^2 = \sigma_x^2 / 2$ denotes the SNR. Q_u is the generalized Marcum's Q function [29].

III. OFDM MODEL

Consider an OFDM-based cognitive radio system that operates on W subcarriers and that owned by the licensed users, referred to as the primary user. The cognitive radio user is referred to as the secondary user, will only access these licensed subcarriers when the primary user is detected absent. The secondary transmission is conducted through consecutive frames periods. In each frame period, the first part is the spectrum sensing period and the second part is the OFDM data transmission period. In the spectrum sensing part, all the secondary users stop their data transmission and listen to the W subcarriers to decide whether the primary user is absent. If the primary user is detected in the subcarriers during the sensing period, then the secondary users will not transmit any data in the following data transmission period in those subcarriers but will wait until the next frame arrives to conduct the spectrum sensing of those subcarriers again. If the primary user (licensed) is not detected in the subcarriers during this spectrum sensing period, the secondary users (unlicensed) will transmit their OFDM data in the second part of the data frame period. Assume that among the W subcarriers, N of them are detected free and used for the cognitive radio transmission, where $N \leq W$. Also, assume that the primary activity is semi static so that the primary user's

status is not changing during one secondary frame. The cognitive radio can be induced in the OFDM transmission by doing the energy detection method of spectrum sensing on each of the subcarriers of the orthogonal frequency division multiplexing. Hence, the primary user (licensed) and secondary user can be identified separately.

IV. COOPERATIVE SEQUENTIAL SPECTRUM SENSING

In this section, i apply cooperative sequential detection algorithms developed in [15], [16], [17] for sensing in the OFDM setup of Sec.3. Interested readers are referred to [15], [16], [17] for a more detailed introduction and its advantages (which i skip here due to lack of space). I study the performance of the cooperative algorithms with different levels of uncertainty. DualCUSUM uses the well-known CUSUM algorithm [17] at the cognitive receivers as well as at the fusion node for detection of change (ON "OFF and OFF "ON for the primary). CUSUM is known to be optimal in different scenarios and uses log likelihood ratio (LLR). Consequently DualCUSUM has also been shown to perform very well [16], [17].

A. Dual CUSUM Algorithm

The CUSUM algorithm used at the secondary node and at the fusion center has negative drift before change and positive drift after change [16]. Thus the instant the change occurs (i.e., primary starts transmitting) the CUSUM process starts increasing and speedily crosses the threshold to declare change.

1) Each of the Secondary users turns calculate on CUSUM algorithm:

$$W_{j,k} = \max(W_{j-1,k} + \xi_{j,k}), \quad W_{0,k} = 0 \quad (4.1)$$

Where,
$$\xi_{j,k} = \log \left[\frac{f_{1,k}(X_{j,k})}{f_0(X_{j,k})} \right] \quad (4.2)$$

Where, $f_{1,k}$ is the density of $X_{j,k}$ under H_1 and f_0 is the density of $X_{j,k}$ under H_0 .

2) Secondary user k transmits at time t , only if $W_{j,k} > \gamma$. If the threshold is exceeded it transmits a value b i.e. $Y_{j,k} = b1_{\{W_{j,k} > \gamma\}}$. These parameters b and γ are chosen suitably. This step allows saving energy and less interference.

3) At Fusion Center, receives Y_j in slot k where

$$Y_j = \sum Y_{j,k} + Z_j \quad (4.3)$$

Where, Z_j is i.i.d noise at the fusion node

4) Change Detection at Fusion Center via CUSUM by using the likelihood ratio

$$F_j = \max \left\{ 0, F_{j+1} + \log \frac{g_1(Y_j)}{g_0(Y_j)} \right\} \quad (4.4)$$

Where g_0 is the density of Z_j and g_1 is the density of $Z_j + bI$, where, I is a design parameter.

5) The Fusion Center finally declares a change at time τ (b, I, γ, β)

When F_j crosses a threshold β :

$$(b, I, \gamma, \beta) = \inf \{ j: F_j > \beta \}$$

6) In the cyclic prefix (CP) based detector [19], correlation is obtained over the length of the samples which is corresponding to the CP. Since Dual-CUSUM algorithm [17] apply on all the parameters of CP. Each node k work out the log likelihood ratio $\xi_{j,k}$ of $R_r(j,k)$ in each slot $j(\geq 1)$ of L_s samples a $R_r(j,k) = \text{Real} \left\{ \frac{1}{L_c} \sum_{i=0}^{L_c} X((j-1)L_s + i, k) X^*((j-1)L_s + L_d + i, k) \right\}$ (4.5)

Where L_d is the signal from which OFDM symbols is obtained by passing it through inverse fast Fourier transform (IFFT), L_c is the length of CP, L_s is the total OFDM symbol duration $L_s = L_d + L_c$ and X^* is the complex conjugate of X [19].

In the above algorithm we have assumed that the channel from the secondary users to the fusion center has no fading whereas that can also be taken care of. The performance parameters P_{FA} and EDD critically depend on the parameters (b, I, β, γ). In [17] P_{FA} and EDD are systematically computed for each (b, I, β, γ) and an iterative algorithm is designed to optimize these parameters. Finally the same DualCUSUM algorithm works if we want to detect the time when the primary stops the transmission, maybe with different parameters. The parameters (b, I, β, γ) affect the performance of the algorithm and the techniques developed in [17] can be used to optimize performance. One computes $EDD = E[(\tau - T)^+]$ subject to the probability of false alarm $P_{FA} \leq \alpha \triangleq \dots, P[\tau < T]$.

7) For the energy detector, the algorithm is the same as the above with minor modifications. The energy is computed as

$$V_{j,k} = \frac{\sum_{i=1}^{L_s} |X((j-1)L_s + j, k)|^2}{ML_s} \quad (4.6)$$

And $\xi_{j,k}$ is the LLR computed with pre and post change distributions being $N(\sigma_w^2, \sigma_w^2/ML_s)$ and $N(\sigma_s^2 + \sigma_w^2, (\sigma_s^2 + \sigma_w^2)/ML_s)$ respectively and ML_s is given number of observations $X(1), \dots, X(ML_s)$ from M slots of OFDM symbols

$$\xi_{j,k} = \frac{1}{2} \log \left(\frac{\sigma_w^2}{(\sigma_s^2 + \sigma_w^2)^2} \right) + \frac{(V(j,k) + \sigma_w^2)}{\sigma_w^2/ML_s} - \frac{(V(j,k) - (\sigma_s^2 + \sigma_w^2))}{(\sigma_s^2 + \sigma_w^2)/ML_s} \quad (4.7)$$

For frequency selective fading, $V(j, k)$ in [18] will not be i.i.d. pre and post change but will have some dependencies due to ISI (inter symbol interference). However this dependence will be weak because only a few symbols at the OFDM symbol boundary will get affected by the symbols of the previous OFDM symbol. Thus, one can continue to assume that $\{V(j,k)\}, j \geq 1$ is an i.i.d. sequence, which is essential to obtain the simplified algorithm labeled above. However the i.i.d. may not hold for the CP detector because CP resides

near the boundary only. Thus, this case will require further consideration. However, we will see later, that in the sequential setup, energy detector significantly overtakes the CP detector in all possible states we consider.

V. CONCLUSION

Spectrum is a much cherished resource in wireless communication systems and it has been a main research topic from last several decades. Cognitive radio is a promising technology which enables spectrum sensing for opportunistic spectrum usage by providing a means for the use of white spaces. Making an allowance for the challenges raised up by cognitive radios, the use of spectrum sensing method seems as a crucial need to achieve satisfactory results in terms of efficient use of available spectrum and limited interference with the licensed primary users. We have painstaking the trouble of spectrum sensing of OFDM signals using cyclic prefix, for this cooperative sequential spectrum sensing from OFDM by energy based detection method and cyclic prefix based detector is calculated. And I detect the energy detection and matched filter and compare its results. The comparison of different transmitter detection techniques for spectrum sensing and the spectrum opportunities is by MATLAB simulation result. As it is evident from the figure, that matched filter based detection is complex to implement in CRs, but has highest accuracy. Similarly, the energy based detection is least complex to implement in CR system and least accurate compared to other approaches. And other approaches are in the middle of these two. These results are also shown in figure of MATLAB simulation.

SIMULATION RESULT:

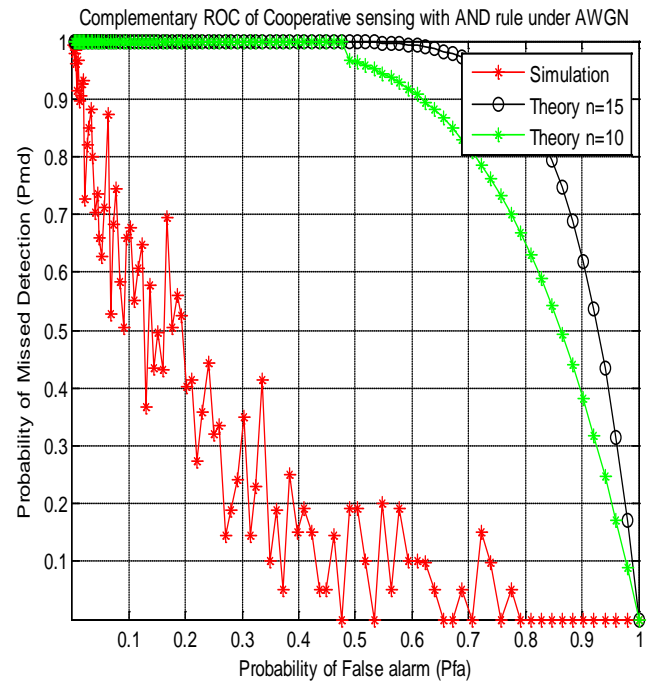


Fig: 4 The ROC curves of optimization algorithm and energy detection algorithm

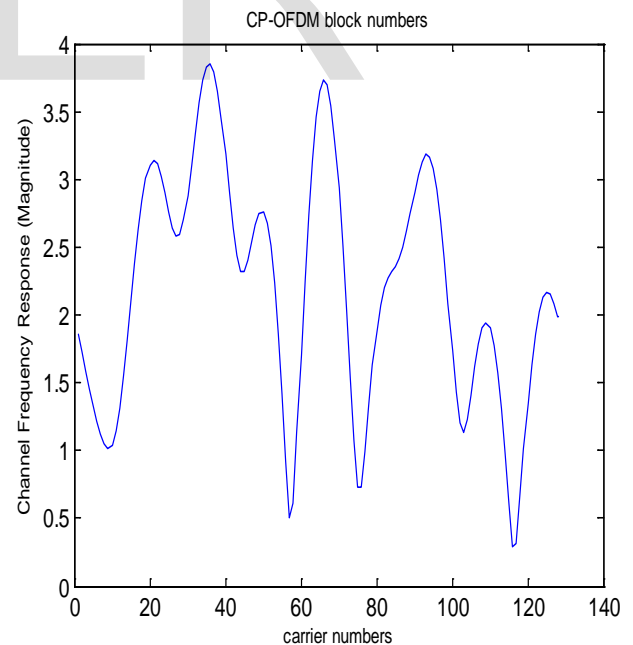


Fig: 5 ROC curve of CP-OFDM block numbers.

ACKNOWLEDGEMENT

I acknowledge the support and help of my guide Mr. Sachin Tyagi (Asst. Professor in Roorkee College of Engineering, Roorkee, Uttarakhand Technical University, Dehradun. I also want to thank my family and friends.

REFERENCES

1. Federal Communications Commission, "Spectrum Policy Task Force", Rep. ET Docket no. 02-135, Nov. 2002.
2. Mustafa E. Sahin and Fiiseyin Arslan, "System Design for Cognitive Radio Communications", University of South Florida, Electrical Engineering Department
3. S. Haykin, "Cognitive radio: Brain-empowered wireless communications," *IEEE Journal of Selected Areas in Communications*, vol. 23, no. 2, pp. 201–220, Feb. 2005. (Cited on pages 12, 14, 17, and 36.)
4. A. Sahai, N. Hoven, S. Mishra, and R. Tandra, "Fundamental tradeoffs in robust spectrum sensing for opportunistic frequency reuse," in *First International Conference on Tech and Policy for Accessing Spectrum*, August 2006.
5. Z. Ye, J. Grosspietsch, and G. Memik, "Spectrum sensing using cyclostationary spectrum density for cognitive radios," in *IEEE Workshop on Signal Processing Systems*, Oct. 2007, pp. 1–6.
6. E. G. Larsson and M. Skoglund, "Cognitive radio in a frequency-planned environment: Some basic limits," *IEEE Trans. Wireless Communication.*, vol. 7, pp. 4800– 4806, Dec. 2008.
7. Sahai, N. Hoven, and R. Tandra, "Some fundamental limits on cognitive radio," in *Proc. 42nd Annu. Allerton Conf. Communication, Control, and computing Monticello, IL, Oct. 2004*, pp. 1662–1671
8. S. Chaudhari, J. Lundén, and V. Koivunen, "Collaborative Autocorrelation- Based Spectrum Sensing of OFDM Signals in Cognitive Radios," in *Proc. of the 42nd Annual Conference on Information Sciences and Systems (CISS)*, Princeton, USA, Mar. 19–21, 2008, pp.191–196.
9. S. Chaudhari, V. Koivunen, and H. Poor, "Autocorrelation-Based Decentralized Sequential Detection of OFDM Signals in Cognitive Radios," *IEEE Transactions on Signal Processing*, vol. 57, pp. 2690–2700, Jul. 2009.
10. R. Wang, V. K. N. Luce, L. Lv, and B. Chen, "Joint cross-layer scheduling and spectrum sensing for OFDMA cognitive radio systems," *IEEE Transactions on Wireless Communication*, vol. 8, pp. 2410–2416, 2009.
11. C. Sun, W. Zhang, and K.B. Letaief, "Cooperative spectrum sensing for cognitive radios under bandwidth constraints," *IEEE Wireless Communications and Networking Conference, WCNC*, pp. 1-5, March 2007
12. Erik Axell, Geert Leus, Erik G. Larsson and H. Vincent Poor, spectrum sensing for cognitive radio, state of art (recent advances), *IEEE signal processing magazine* may,2012,10535888/12/\$31.00©2012IEEE, DigitalObjectIdentifier,10.1109/MSP.2012.2183771, Date of publication: 9 April 2012.
13. F. F. Digham, M. -S. Alouini, and M. K. Simon, "On the energy detection of unknown signals over fading channels," in *Proc. IEEE*

- Int. Conf. on Communication., May 2003, vol. 5, pp. 3575–3579.
14. Y. Shei and Y.T. Su, “A sequential test based cooperative spectrum sensing scheme for cognitive radios,” 19th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC, pp. 1-5, Sept. 2008.
 15. A. Jayaprakasam and V. Sharma, “Cooperative robust sequential detection algorithms for spectrum sensing in cognitive radio”, Intl. Conf. on Ultra Modern Telecommunications (ICUMT), 2009
 16. V. Sharma and A. Jayaprakasam, “An Efficient algorithm for cooperative Spectrum Sensing in Cognitive Radio Networks”, in Proc National Communications Conference (NCC), Jan 2009.
 17. T. Banerjee, V. Kavitha and V. Sharma, “Energy efficient change detection over a MAC using physical layer fusion”, Intl. Conf. on Acoustics, Speech and Signal Processing, Mar 2008, pp 2501-2504.
 18. E. S. Page, “Continuous Inspection Schemes”, *Biometrika*, Vol 41, No 1/2 , pp 100-115, June 1954.
 19. Arun Kumar, Jayaprakasam, Vinod Sharma, Chandra R. Murthy and Prashant Narayanan, “Cyclic Prefix Based Cooperative Sequential Spectrum Sensing Algorithms for OFDM, This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE ICC 2010 proceedings.