Journal of Electrical and Electronic Engineering
2018; 6(1): 12-21
http://www.sciencepublishinggroup.com/j/jeee
doi: 10.11648/j.jeee.20180601.12
ISSN: 2329-1613 (Print); ISSN: 2329-1605 (Online)

Moment Based Spectrum Sensing Algorithm in Cognitive Radio Network for Future of 5G

Mohamed B. El_Mashade[1]**, Ashraf Aboshosha**[2]**, Ehab A. Hegazy**[1]

[1]Electrical Engineering Department, Faculty of Engineering, Al_Azhar University, Cairo, Egypt
[2]NCRRT, EAEA, Nasr City, Cairo, Egypt

Email address:

ElMashade@yahoo.com (M. B. El_Mashade), editor@icgst.com (A. Aboshosha), Ehab.hegazy@gmail.com (E. A. Hegazy)

To cite this article:

Mohamed B. El_Mashade, Ashraf Aboshosha, Ehab A. Hegazy. Moment Based Spectrum Sensing Algorithm in Cognitive Radio Network for Future of 5G. *Journal of Electrical and Electronic Engineering*. Vol. 6, No. 1, 2018, pp. 12-21. doi: 10.11648/j.jeee.20180601.12

Received: December 18, 2017; **Accepted**: December 28, 2017; **Published**: January 16, 2018

Abstract: The cognitive radio is a smart wireless communication system that is aware of its adjacent environment and under a certain approach is capable of using the current available spectrum temporarily without interfering with the primary user. Cyclostationary detection, which exploits the periodic property of communication signal statistics, absent in stationary noise, is a natural candidate for this setting. The proposed work compromises simple moment based spectrum sensing algorithm for cognitive radio networks. It is made-up that the transmitted signal samples are binary (quadrature) phase-shift keying BPSK (QPSK), Mary quadrature amplitude modulation (QAM) or continuous uniformly distributed random variables and the noise samples are independent and identically distributed circularly symmetric complex Gaussian random variables all with unknown (inadequate) variance. Based on these assumptions, the proposed work offer a simple test statistics engaging a ratio of second and fourth moments. For this statistics, suggested work will deliver analytical expressions for both probability of false alarm (P_f) and probability of detection (P_d) in an additive white Gaussian noise (AWGN) channel. Here, will approve the theoretical expressions through simulation program. In addition, under noise variance uncertainty, simulation results decide that the suggested moment based detector provides better detection performance compared to that of energy detector in AWGN and Rayleigh fading channels.

Keywords: Cognitive Radio, Spectrum Sensing, Phase Shift Keying, Probability of Detection

1. Introduction

Detection of the presence of signals in the frequency spectrum can called spectrum sensing. An unoccupied spot in frequency will be a candidate to assign a new communication link. Such as the existing wireless communication networks regulate fixed spectrum access strategy. According to the Federal Communications Commission, that the fixed spectrum access strategy employs the available frequency bands inefficiently [1], [2]. Cognitive radio has many features. One of the key features of a cognitive radio (CR) network is its capability to differentiate the nature of the adjacent or neighboring radio environment. This matter can be overcome through spectrum sensing or signal detection part of a cognitive radio network. Based on the definition of a primary and subordinate user, this last one has to be able to detect or may be informed of an incoming primary user (PU) and move on the fly to another unoccupied spot. There are centralized approaches that depend on a central unit that updates and holds information about the spectrum utilization either using its own spectrum sensing capabilities or even accumulating and gathering spectrum information from portable or mobile units. Irrespective where the spectrum sensing device is placed, it has to be able to detect signal presence over noise levels and even recognize and distinguish in some applications specific signals or services using the spectrum. The major challenge of the spectrum sensing is to execute the detection dependably and within a required time response.

There are major three methods to control or defined signal presence, all of them with some trade-off. They are Cyclostationary detection, energy detection and matched filtering. It is important to note that the calculation of these methods to use for spectrum sensing is heavily biased on the CR application requirements. There are applications where there is not prior to knowledge of the signals on air. Some others consider some specifications about the signal as partial range of the spectrum, modulation, bandwidth, etc. Some applications look for identification of specific signals. If the features of the primary user such as pulse shaping filter, packet format, and modulation scheme, are well-known perfectly, matched filter is the optimum signal detection technique such as it take merits of the received Signal-to-Noise Ratio (SNR). In repetition, this information can be known a priori. The key weakness of matched filter detector is that it needs dedicated receiver to detect each signal characteristics of a primary user [3]. Meanwhile, Energy detector does not need any information about the primary user and it is easy to implement. However, energy detector has a better sensitivity to noise variance uncertainty, and there is an SNR wall below which energy detector is not has the capability to assurance a certain detection performance [3], [4], [5].

Cyclostationary based detection method is forceful against noise variance uncertainty and it can reject the effect of adjacent channel interference. However, the computational complexity of this detection method is very high, and large number of samples are required to exploit the cyclostationary nature of the received samples [5], [6]. On the other hand, this method is not robust against cyclic frequency offset which can occur due to clock mismatch between the transmitter and receiver [7]. In [8], Eigenvalue-based spectrum sensing algorithm has been introduced. This algorithm is forceful against noise variance uncertainty. Meanwhile, the computational complexity of this method is very high. In common any modulated signal include some periodicity by definition and some others added for synchronization or signaling purposes such as preambles, cyclic prefix, pilots, etc. It means that autocorrelation of the signal exhibit an observable grade of periodicity. Instead of power spectral density, cyclic correlation function is used, and the algorithms are able to distinguish noise from signals, since noise is not correlated.

The Cyclic Spectral Density CSD is formed after the spectrum and will output peaks when cyclic frequencies are present. These algorithms are based on a statistic approach which means an average has to be performed and it requires time to give an output. Also the process involves more than one FFT calculation and correlation making it computationally pricy compared with some other methods.

In a Traditional or conventional digital communication system, the transmitted signal samples are taken from a given constellation. Also, this constellation may be binary phase-shift keying (BPSK) or quadrature binary phase-shift keying (QPSK) or M-ary quadrature amplitude modulation (QAM). At all constellations, each component (either real or imaginary) of a sample has a value in between $[-b, b], b > 0$, where b depends on the SNR of the received signal. For these reasons, the suggested work adopt that the transmitted signal samples are BPSK, QPSK, M-ary QAM or continuous uniformly distributed random variables.

Also, can consider that the noise samples are independent and identically distributed (i.i.d) circularly symmetric complex Gaussian (ZMCSCG) random variables all with unknown (inadequate) variance. Based on these assumptions, that will can shows the ratio of the fourth absolute moment and the square of second absolute moment give 2 and < 2, in noise only and signal plus noise cases, respectively.

Due to this, suggested work propose a test statistics as 2 minus the ratio of the fourth absolute moment and the square of second absolute moment. This test statistics will provide analytical expressions for both probability of false alarm (P_f) and probability of detection (P_d) in an additive white Gaussian noise (AWGN) channel environment. As the P_f expression of the proposed detector is not dependent on the actual noise variance, the proposed detector is robust against noise variance uncertainty. Also, confirm the theoretical expressions by computer simulations. Furthermore, can demonstrate by computer simulations that the proposed moment based detector gives better detection performance compared to that of the well-known energy detector in AWGN and Rayleigh fading Channels.

Paper is organized as follows: section II explain the orthogonal frequency division multiplexing (OFDM) in CR systems. In Section III discusses the hypothesis test problem. In Section IV, some preliminary results on moments for random variables are discussed. Section V presents the proposed moment based detector. In Section VI, computer simulations are used to compare the performance of the proposed moment based detector to that of energy detector.

2. OFDM in CR Systems

Orthogonal frequency division multiplexing (OFDM) is a modulation scheme that uses multiple carriers to send a data. Each of these carriers could be modulated using any variation from BPSK to N-QAM. In history frequency division multiplexing was used to assign different data channels. OFDM multiplex in frequency too but use all the carriers in order to transmit data from one channel. The idea is to fragment the data to be transmitted over multiple lower rate channels, making it more forceful but getting higher bit rates in the overall transmission. Such a scheme was improved by defining orthogonality between the used carriers, allowing them to be closer to each other and decreasing the needed bandwidth. OFDM has many decades of existence but the current technology available for digital signal processing allows realizing such multi-carrier modulation on the digital domain meeting the real-time requirements. It is worth noting that the use of the fast Fourier transform (FFT) makes OFDM implementation easy [9], [10].

3. Problem Statement

Spectrum sensing that is detecting the presence of primary users in a licensed spectrum is a fundamental component in cognitive radio. There are various spectrum sensing algorithms developed for cognitive radio. Thus the aim of the proposed solution is to design and study the performance evaluation of those spectrum sensing algorithms for cognitive radio.

4. Proposed Solution

A novel spectrum sensing mechanism in the form of algorithm for single band sensing and multiband sensing will be formulated. This will be done in context to coexisting primary and secondary devices. This algorithm is expected to maximize the probability of false alarm and minimize the probability of missed detection. In the first step, detection of primary signal at single CR user will be consider.

5. Absolute Moment Based Detector

Let $s = \{s[n]\}N_{n=1}$ denote the transmitted discrete time baseband signal vector. If can assume an AWGN channel, the observed baseband signal has the following form [11].

$$y[n] = \begin{cases} s[n] + w[n], H1 \\ w[n], n = 1, \cdots, N\ H0 \end{cases} \tag{1}$$

Where $s[n]$, $w[n]$ and N are the nth transmitted signal sample, n th noise sample and number of samples, respectively. The noise samples $\{s[n]\}N_{n=1}$ are assumed to be i.i.d ZMCSCG random variables 2. The variance of each component of $w[n]$ is assumed to be $\sigma 2$ which is unknown or known imperfectly. The aim of a CR spectrum sensing is to detect the presence or absence of the transmitted signal samples $\{s[n]\}N_{n=1}$.

The k th moment of a random variable X is defined as [12]

$$Mk = E\{X^k\} = \begin{cases} \sum_x x^k p(x) \quad For\ discrete\ X \\ \int_{-\infty}^{\infty} x^k p(x)dx \quad For\ continous\ X \end{cases} \tag{2}$$

Where $E\{.\}$ and $p(.)$ denote expectation and probability density function, respectively.

For a discrete uniform random variable X with P possible

Values in $[-b, b]$, the kth moment is thus given by

$$M_k = \frac{b^k(-1)^k}{P(P-1)^k} \sum_{i=0}^{P-1} (P - 2i - 1)^k \tag{3}$$

For a continuous uniform random variable $X \sim U[-b, b]$,

Applying (2) gives

$$Mk = \begin{cases} \frac{b^k}{k+1} \text{ For even k} \\ 0, \text{For odd k} \end{cases} \tag{4}$$

For a continuous Gaussian random variable $X \sim N(0, \sigma^2)$, applying (2) yields

$$Mk = \begin{cases} 1x3x \ldots .x\ (k-1)\ \sigma^k \text{ For even k} \\ 0, \text{For odd k} \end{cases} \tag{5}$$

The kth absolute moment of a random variable X is defined as$M_{axk} \triangleq E\ \{|X|^k\}$. Through using (3) - (5), one can get the following second and fourth absolute moments.

$$M_{ay2} = E\ \{|y[n]|^2\}$$

$$= 2\sigma^2(\beta + 1), Any\ S[n]$$

$$M_{ay4} = E\ \{|y[n]|^4\} \tag{6}$$

$$= \sigma^4(4\beta^2 + 16\beta + 8), S[n] = BPSK, QPSK$$

$$= \sigma^4\left(\frac{132}{25}\beta^2 + 16\beta + 8\right), S[n] = 16\ QAM\ (P = 4)$$

$$= \sigma^4\left(\frac{116}{21}\beta^2 + 16\beta + 8\right), S[n] = 64\ QAM\ (P = 8)$$

$$= \sigma^4\left(\frac{28}{5}\beta^2 + 16\beta + 8\right), S[n] = CU$$

Where $\beta = \frac{E\ \{|s[n]|^2\}}{E\ \{|w[n]|^2\}}$ is the SNR of the received signal samples. Moreover, CU is refer to continuous uniform random variable. As can be seen from this equation, the fourth moment gap between an M-ary and a CU random variable signal decreases as M increases. Thus, without loss of generality, one can apply the results of a continuous uniform random variable for higher modulation orders (for example 512 QAM signals). Hence, the above expressions can represent the second and fourth moments of practically relevant signal constellations. The ratio $T \triangleq -\frac{M_{ay4}}{M_{ay2}^2}$ is calculated as

$$T = -\frac{M_{ay4}}{M_{ay2}^2} \tag{7}$$

$$= -2, For\ Noise\ only$$

$$= -2 + \left(\frac{\beta}{\beta + 1}\right)^2, S[n] = BPSK, QPSK$$

$$= -2 + \frac{17}{25}\left(\frac{\beta}{\beta + 1}\right)^2, S[n] = 16\ QAM$$

$$= -2 + \frac{13}{21}\left(\frac{\beta}{\beta + 1}\right)^2, S[n] = 64\ QAM$$

$$= -2 + \frac{3}{5}\left(\frac{\beta}{\beta + 1}\right)^2, S[n] = CU$$

But, since $May2$ and $May4$ are not known a priori, should employ their estimated values which can be calculated as

$$\widehat{M_{ayk}} = \frac{1}{N}\sum_{n=1}^{N} |y[n]|^2, k = 2,4. \tag{8}$$

And the calculated or estimated T equal as follows

$$\hat{T} = -\frac{\widehat{M_{ay4}}}{\widehat{M_{ay2}^2}} \tag{9}$$

Therefore, the binary hypothesis test of (1) turns to examining whether $\hat{T} = -2$ or $\hat{T} > -2$. In order to get the exact test statistics, Pd and Pf expressions, we shall examine the following Theorem as explained in [13].

6. Simulation and Results

In this section, we provide simulation results for the proposed moment based and energy detectors. As per proposed algorithm flow chart.

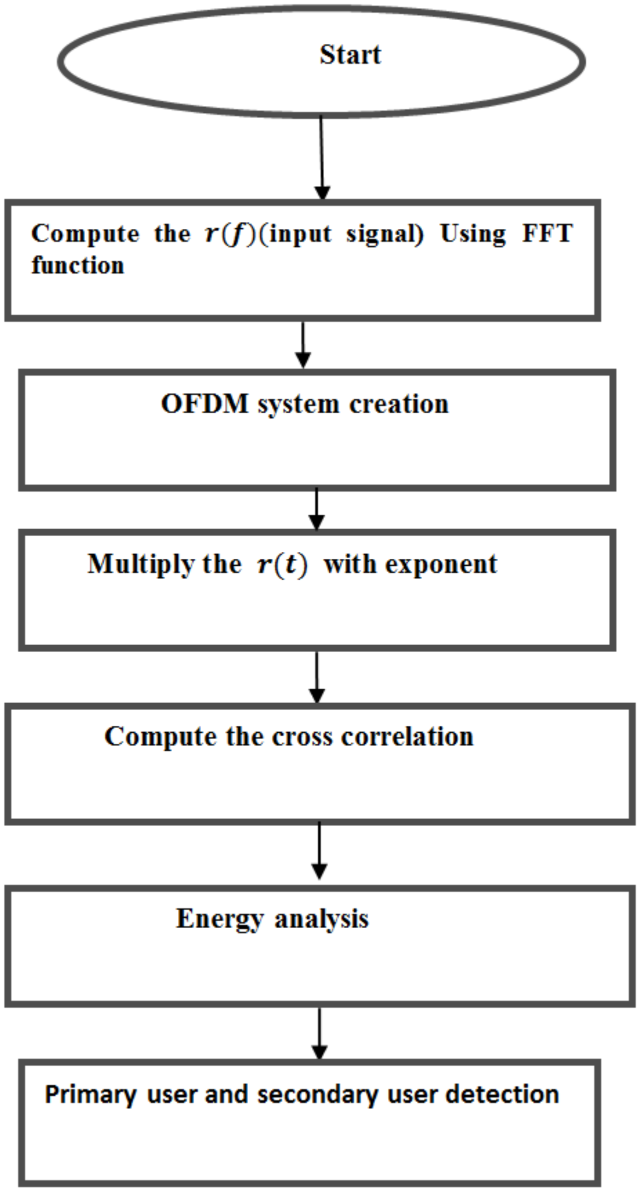


Figure 1. *Proposed algorithm flow chart.*

Comparison of moment and energy based detectors in this subsection, we compare the performance of the energy and moment based detectors for pulse shaped transmitted signals under noise variance uncertainty. The comparison is performed in both AWGN and Rayleigh fading channels by setting Pf = 0.1 and N $=2^{16}$. It is assumed that the transmitter and receiver employ a square root raised cosine filter with roll-off factor 0.2. The over-sampling factor and filter length are set to S = 4 and L = 4S + 1, respectively. In an uncertain noise variance signal detection algorithm, the actual noise variance

Can be modeled as a bounded interval. For some $\epsilon = 10^{\Delta\sigma^2/10} > 1$, where the uncertainty Δσ 2 is expressed in dB. The noise variance is the same for one observation (since it has a short duration) and follow a uniform distribution during several observations. Moreover, in a Rayleigh fading channel, the channel is constant for one observation and follows a Rayleigh distribution during several observations. For better exposition, QPSK and 16 QAM signals are considered.

Figure 2 and Figure 3 shows the performance of energy and moment based detectors under noise variance uncertainty with synchronous and asynchronous (i.e., with bit synchronization errors) receiver scenarios. From these figures, we can observe that the proposed moment based detector achieves better detection performance compared to that of energy detector for all scenarios. Moreover, the proposed detector achieves the best performance when the transmitter and receiver are synchronized perfectly. As expected, the performance of moment based detector decreases as the modulation order increases in both AWGN and Rayleigh fading channels. And the performance of energy detector is not affected by bit synchronization errors.

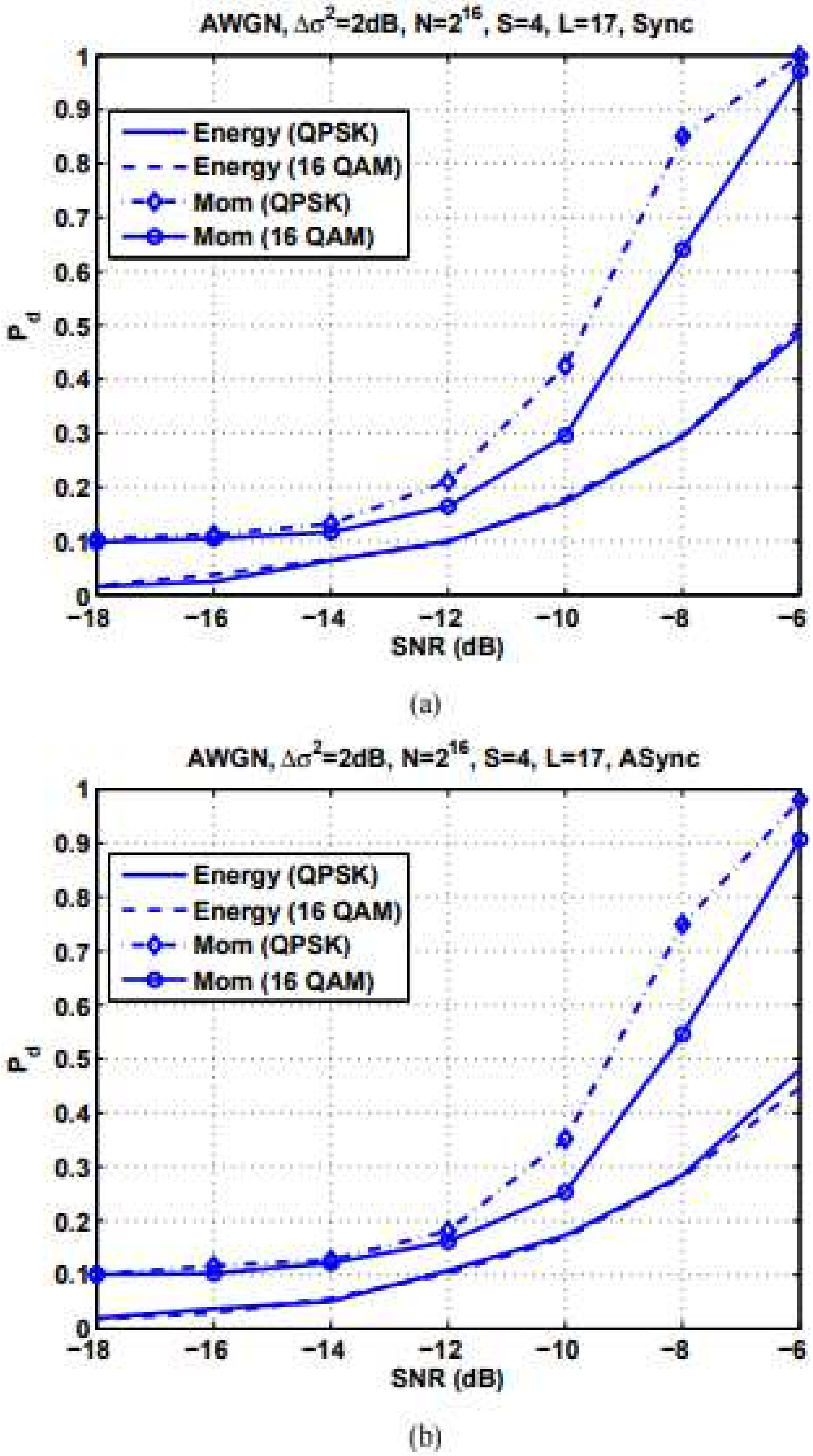
Verification of theoretical expressions in this part, we verify the theoretical Pd and Pf expressions of the moment based detector for different modulation types under an AWGN channel environment. For this simulation, we assume that the noise variance is known perfectly.

Here, we will evaluate the performance of the detector by means of the receiver operating characteristic (ROC) curves, depicting the detection probability as a function of the false alarm probability. Figure 5 shows the ROC curves of the proposed detector for SNR= -10dB and 0dB. A perfect synchronization is assumed. Furthermore, we compare the ROC curves with the theoretical ones.

As can be seen from Figure 4, the theoretical Pd and Pf matches with that of the simulation for all modulation schemes. Furthermore, for fixed Pf, Pd decreases as the modulation order increases. This is due to the fact that μ decreases as the modulation order increases and at the simulated SNR (-10dB), σ˜ 2 of all modulation schemes are almost the same.

Figure 6 shows the sensing time impact on energy efficiency comparing it using different SNR values ranging from -8dB to -20dB. As shown the energy efficiency is stable during the begging then it starts to degraded completely making the system loose its efficiency so as an outcome the proposed scheme should control both energy and sensing time as long sensing time periods will create energy inefficiency and too much power too will create more interference and more energy dissipation making system inefficient

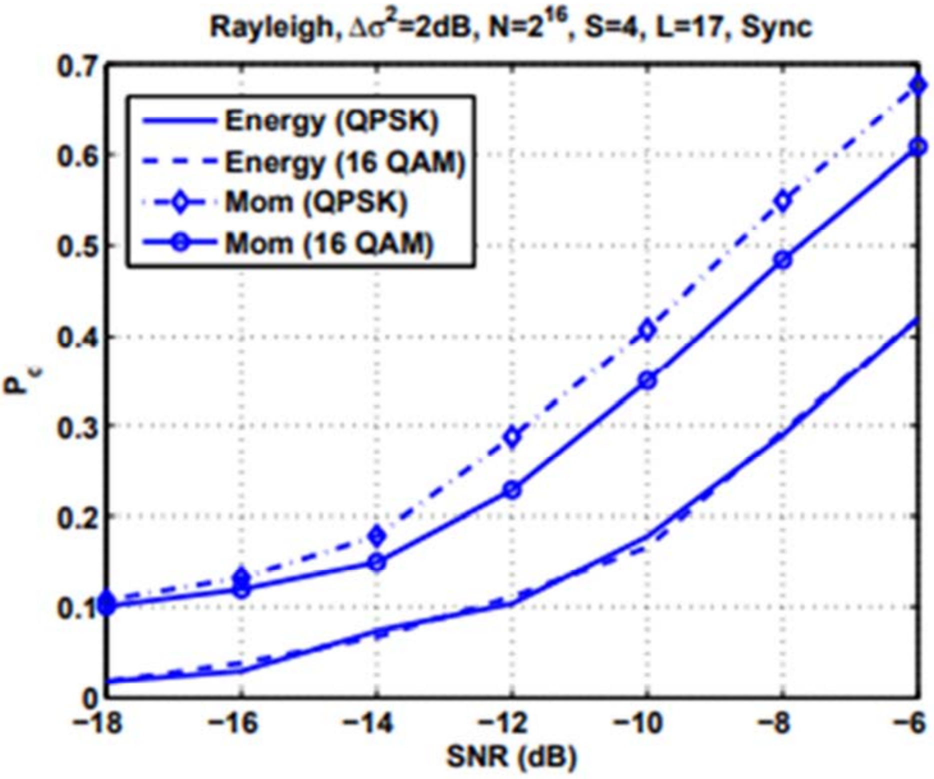
Both figures 7 and 8 illustrate the analysis which describe the efficiency of three proposed scheme for energy consumption along, energy distribution and sensing time and it is impact on energy and spectral efficiency.



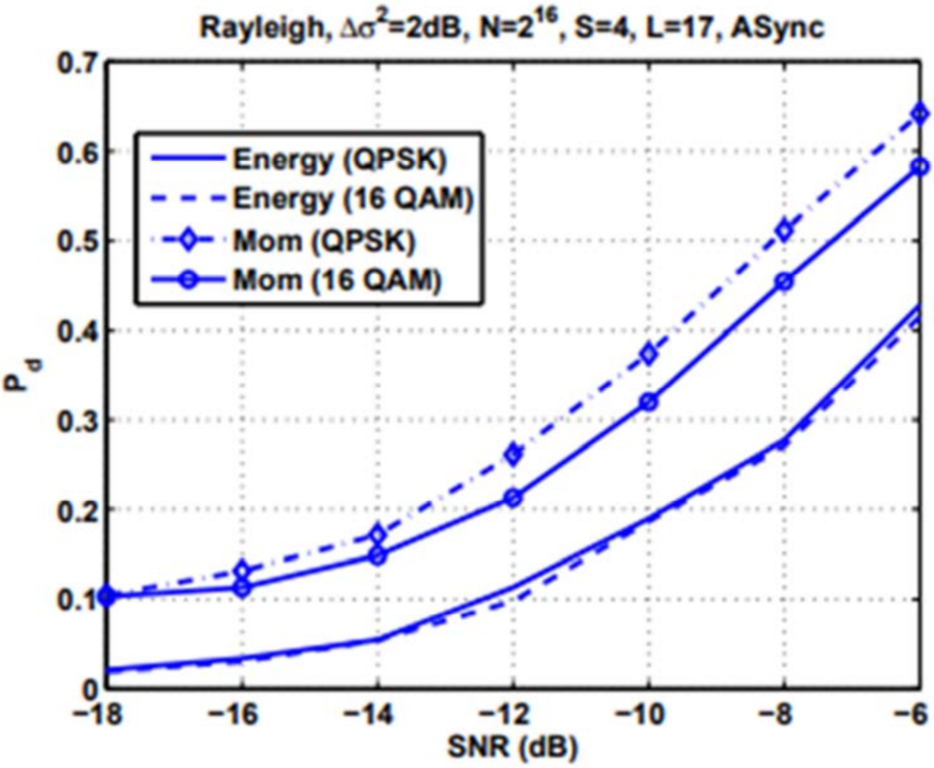
(a)

(b)

Figure 2. *Comparison of the proposed moment based (Mom) and energy (Energy) detectors under noise variance uncertainty in AWGN channel (a) Perfectly synchronized receiver, (b) Asynchronous receiver.*

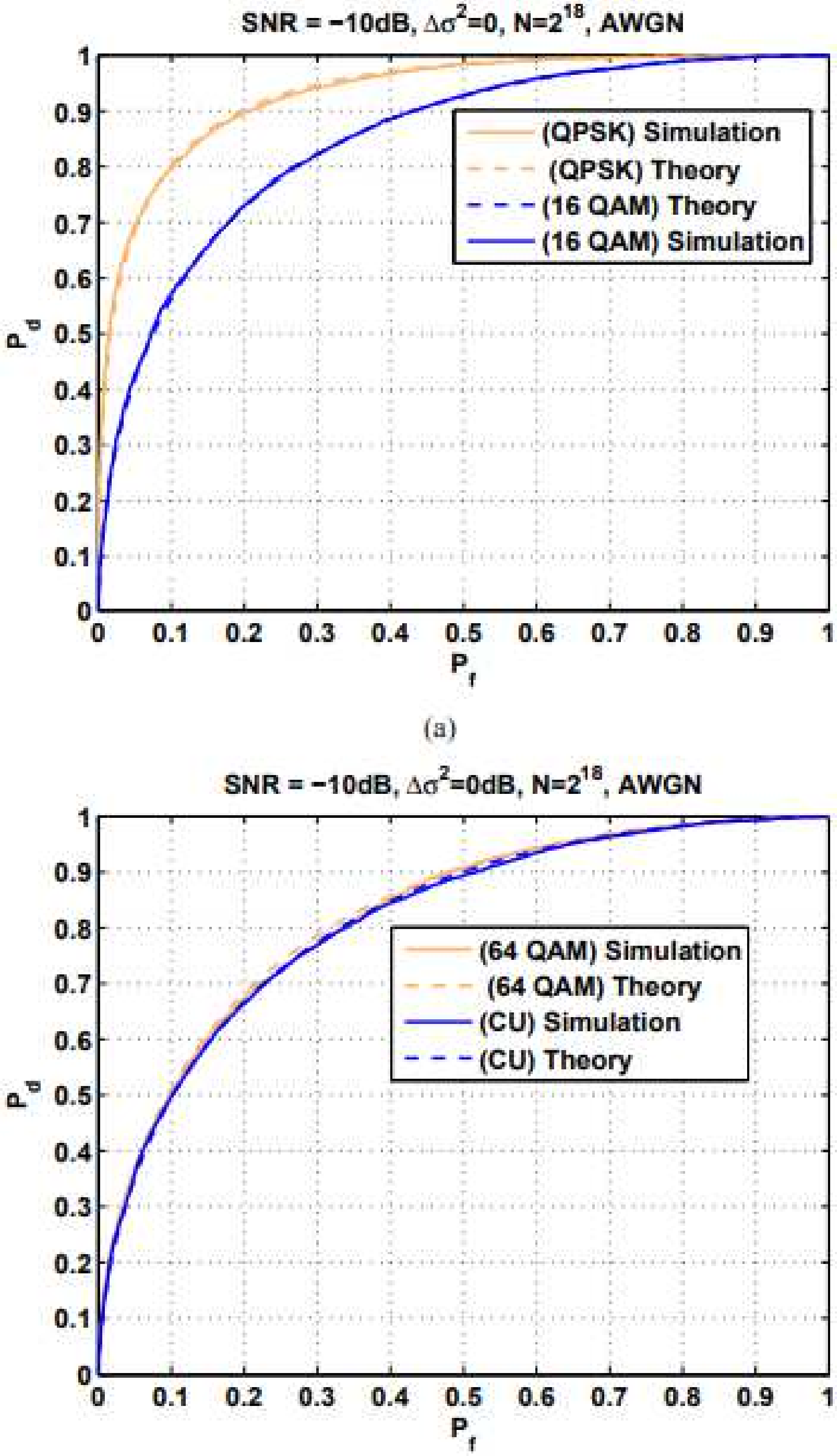


(a)



(b)

Figure 3. *Comparison of the proposed moment based (Mom) and energy (Energy) detectors under noise variance uncertainty in Rayleigh fading channel (a) Perfectly synchronized receiver, (b) Asynchronous receiver.*



(a)

Figure 4. *Theoretical and simulated* Pd *and* Pf *of the proposed moment based detector in AWGN channel for (a) QPSK and 16 QAM, (b) 64 QAM and CU signals.*

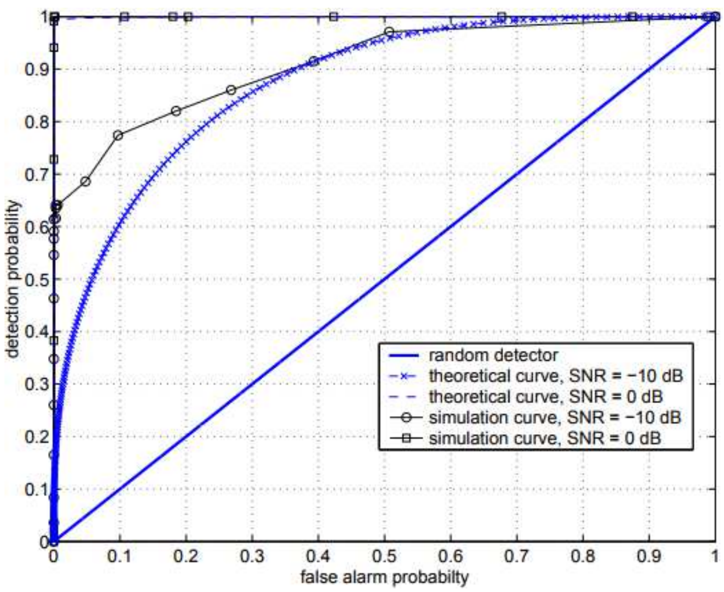


Figure 5. *Receiver operating characteristic curves for SNR= -10and 0 dB, compared with the analytical curves.*

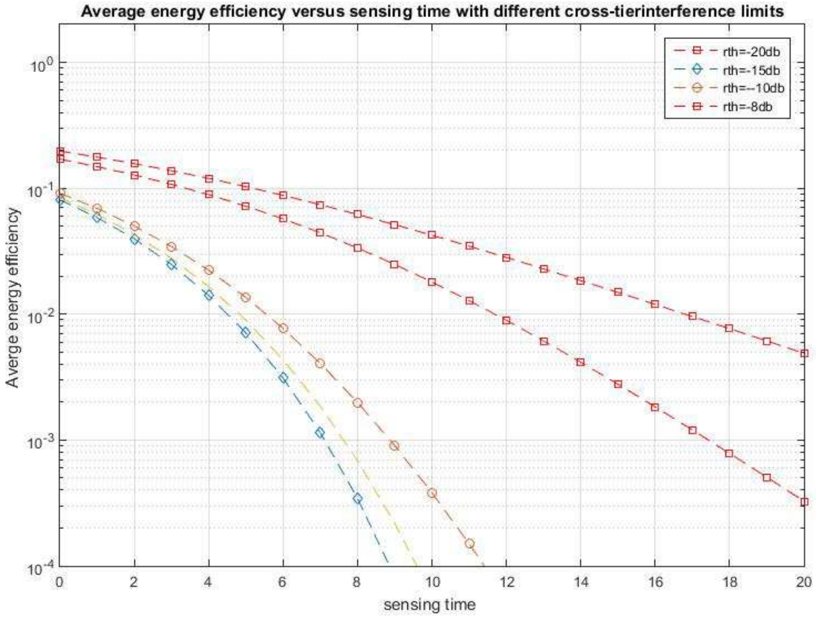


Figure 6. *Sensing time impact on energy efficiency comparing it using different SNR.*

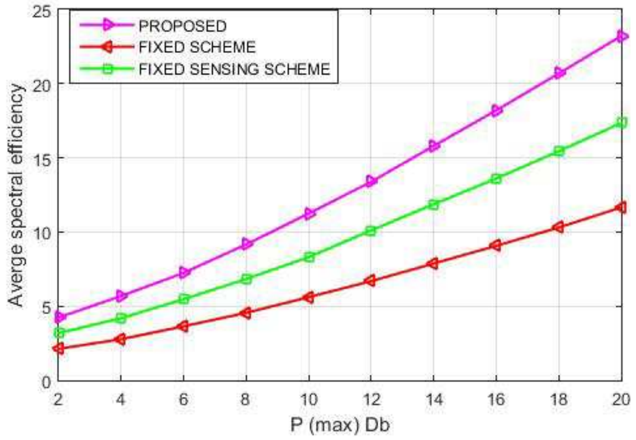


Figure 7. *Efficiency of three proposed scheme for energy consumption.*

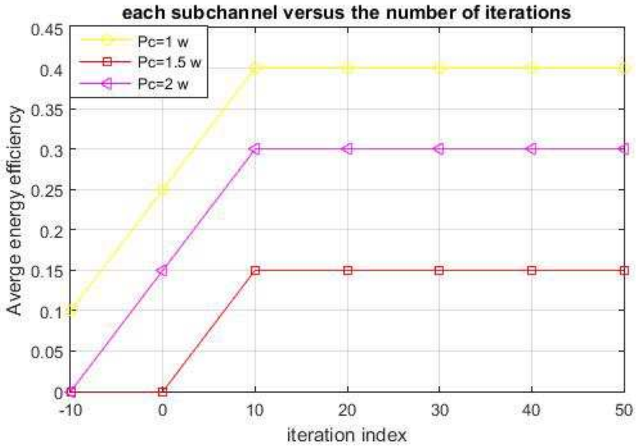


Figure 8. *Efficiency of three proposed scheme for energy consumption.*

A second-order moment-based spectrum sensing algorithm in a cognitive radio context. Based on a joint and iterative channel and noise variance estimator for OFDM systems, the method accurately estimates the noise variance when the primary user's signal is missing from the given band of frequency. By comparing the estimated noise level with the second-order moment of the received signal, it is possible to detect the presence of the user in the band. The algorithm allows the receiver to perform the joint detection, channel and noise variance estimation. The analytical probability and false alarm probabilities are proposed, and simulations show the accuracy of the detector. Moreover, the proposed method is tested under a desynchronization constraint.

As proposed flow chart suggesting PU using OFDM based signal to be detected showing the moment based CR method of detection. We explore the cyclostationarity of the equally spaced pilot subcarriers in OFDM signal. By averaging over several symbols, the peak property is able to be captured. Simulations in various fading environments show that the proposed Cyclostationary based detection method works well for OFDM signal.

Figure 9 shows the spectral correlation of OFDM signal. In figure 10 OFDM boosted pilot signal by 2.5 dB. Also as shows in figure 11 the spectral correlation of OFDM signal with 10dB.

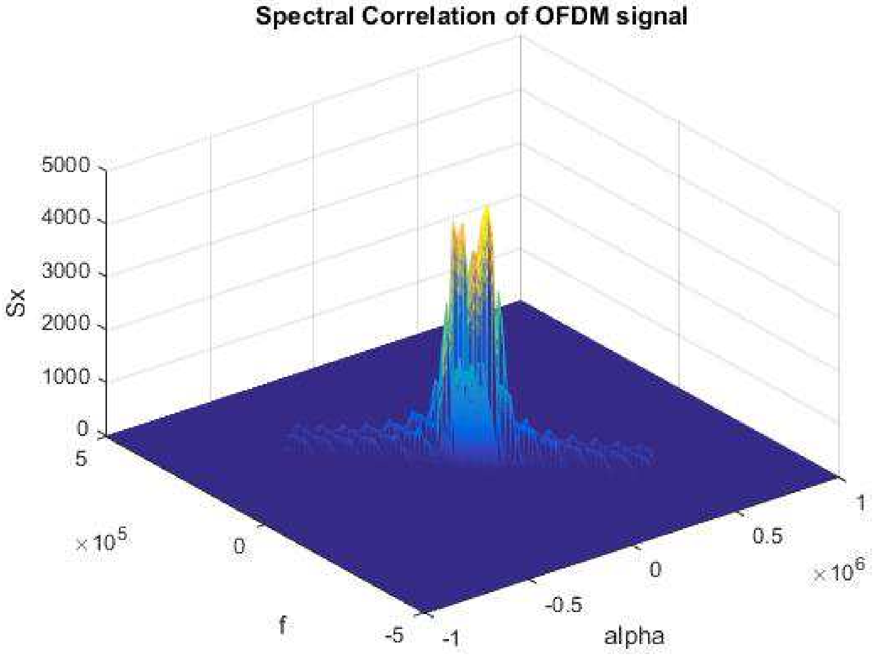


Figure 9. OFDM spectral Correlation.

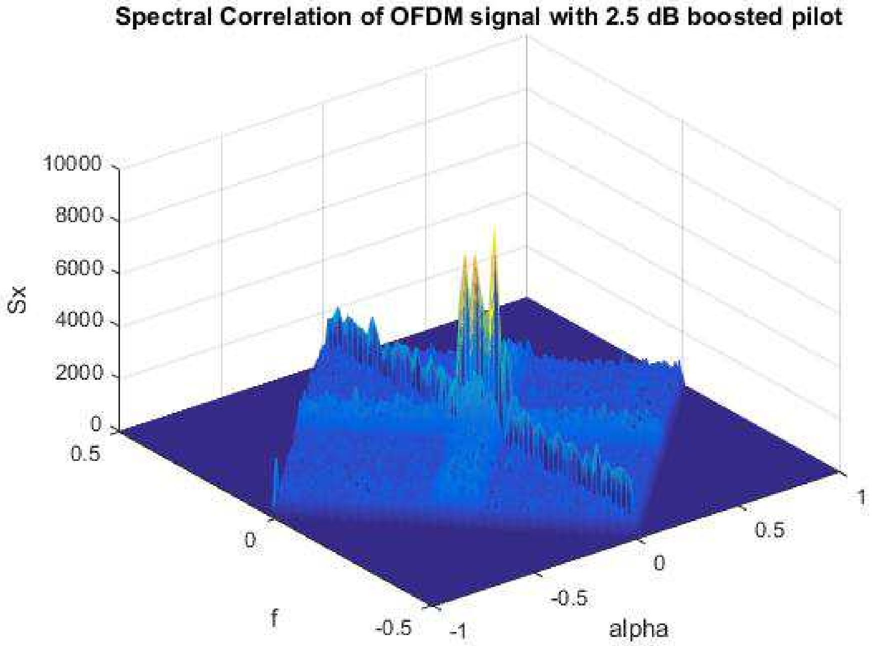


Figure 10. OFDM boosted pilot signal by 2.5 dB.

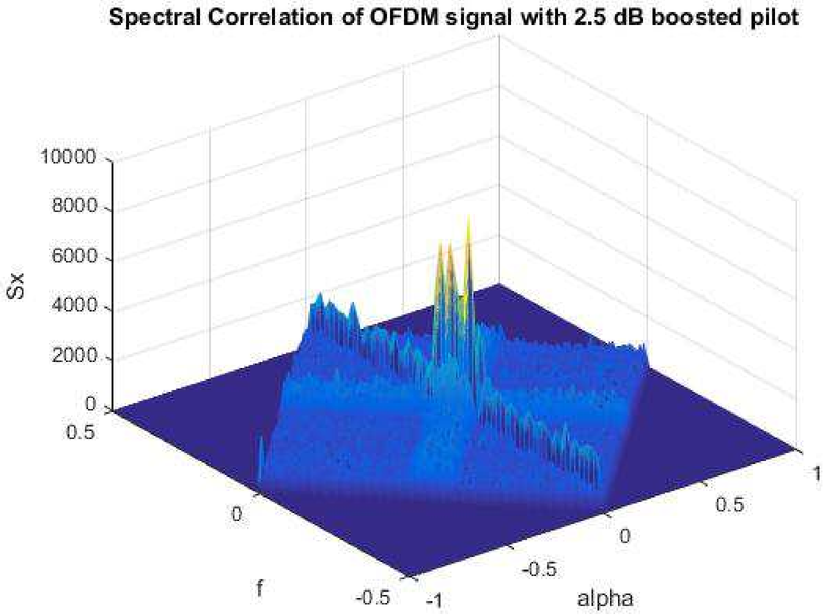


Figure 11. *10dB OFDM boosted pilot signal.*

7. Conclusion

The proposed work offers simple moment based spectrum sensing algorithm for cognitive radio networks in flat fading channels. We adopt that the transmitted signal samples are BPSK, QPSK, M-ary QAM or continuous uniformly distributed random variables and the noise samples are independent and identically distributed circularly symmetric complex Gaussian random variables all with unknown (inadequate) variance. Based on these assumptions, we offer a simple test statistics employing a ratio of fourth and second moments. For this test statistics, we provide analytical expressions for both Pf and Pd in an AWGN channel environment. Additionally, under noise variance uncertainty, based on computer simulation results shows that the proposed moment based detector gives better detection performance compared to that of the well-known energy detector in AWGN and Rayleigh fading channels. Spectrum sensing in CR offer and introduced one the key requirement for the next generation of mobile communication. Which is called spectrum utilization.

References

[1] I. F. Akyildiz, W. Lee, M. C. Vuran, and S. Mohanty, "Next generation/dynamic spectrum access/cognitive radio wireless networks: A survey," Journal of Computer Networks (ELSEVIER), vol. 50, pp. 2127–2159, 2006.

[2] M. Nekovee, "A survey of cognitive radio access to TV white spaces, "International Journal of Digital Multimedia Broadcasting, pp. 1–11, 2010.

[3] D. Cabric, S. M. Mishra, and R. W. Brodersen, "Implementation issues in spectrum sensing for cognitive radios," in the 38th Asilomar Conference on Signals, Systems and Computers 2004 (Asilomar), Pacific Grove, CA, USA, 7–10 Nov. 2004, pp. 772–776.

[4] R. Tandra and A. Sahai, "SNR walls for signal detection," IEEE J. Sel. Topics Sig. Proc., vol. 2, pp. 4–17, Feb. 2008.

[5] A. Tkachenko, A. D. Cabric, and R. W. Brodersen, "Cyclostationary feature detector experiments using reconfigurable BEE2," in 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks 2007 (DySPAN), 17–20 Apr. 2007, pp. 216–219.

[6] T. E. Bogale and L. Vandendorpe, "Multi-cycle cyclostationary based spectrum sensing algorithm for OFDM signals with noise uncertainty in cognitive radio networks," in Military Communications Conference (MILCOM), Orlando, FL, USA, 29 Oct.–01 Nov. 2012.

[7] Y. Zeng and Y. Liang, "Robustness of the cyclostationary detection to cyclic frequency mismatch," in IEEE Personal Indoor and Mobile Radio Communications (PIMRC), Istanbul, Turkey, 26–30 Sep. 2010, pp. 2704–2709.

[8] Y. Zeng and Y-c. Liang, "Eigenvalue-based spectrum sensing algorithms for cognitive radio," IEEE Tran. Comm., vol. 57, no. 6, pp. 1784–1793, Jun. 2009.

[9] M. Wylie-Green, "Dynamic spectrum sensing by multiband OFDM radio for interference mitigation," in First IEEE International Symposium on DySPAN 2005, 2005, pp. 619–625.

[10] T. Weiss, J. Hillenbrand, and F. Jondral, "A diversity approach for the detection of idle spectral resources in spectrum pooling systems," in Proc. of the 48th Int. Scientific Colloquium, Ilmenau, Germany, Sep. 2003.

[11] A. Papoulis and S. U. Pillai, Probability, Random Variables and Stochastic Processes, McGraw-Hill, 2002.

[12] R. J. Serfling, Approximation Theorems of Mathematical Statistics, John Wiley and Sons, 1980.

[13] M. R. Morelande and A. M. Zoubir, "Detection of phase modulated signals in additive noise," *IEEE Sig. Proc. Lett.*, vol. 8, no. 7, pp. 199–202, Jul. 2001.