Akshansh Kaushik, Amanpreet Singh Saini / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 2, March -April 2013, pp.546-555

Performance Evaluation For Detection Of White Spaces In Cognitive-Ofdm Based Wireless Communications Networks

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Abstract-The radio electromagnetic spectrum is limited source for many wireless communication devices.many studies on wireless communication show that a large portion of our radio electromagnetic spectrum remains vacant all time .How this radio electromagnetic spectrum can be utilized more ? cognitive radio is a solution to this problem. The cognitive radio, based on a software-defined radio. Cognitive radio is an advanced and intelligent wireless communication system that is aware of its environment and uses the methodology of understanding- by-building to learn from the environment and adapt to statistical variations in the input stimuli, with two primary objectives in mind:

- **there should be always highly reliability in communication network .**
- **there should be proper utilization of the radio spectrum.**

Many research has proved that orthogonal frequency division multiplexing system (OFDM) has been proposed as a main candidate for cr's physical layer. Additionally, performance of a wide band spectrum analysis can be supported by Fast Fourier Transform (FFT) in an OFDM receiver. Multitaper spectrum estimation method (MTM) is a non-coherent promising spectrum sensing technique. It has solved the problems of bad biasing and large variance in power spectrum estimation .Biasing and Variance are two important parameters to calculate performance evaluation of any power spectrum estimation method.

keywords-cognitive radio;fast fourier transform(fft) algorithm;multitaper method;spectrum sensing,ofdm,awgn (additive white gaussian noise) channel ,awareness,ieee 802.22,primary users ,secondary users,periodogram method,

I. Introduction

A. BACKGROUND

Many studies on wireless communication shows that the modern society has become dependent on electromagnetic radio spectrum[1]. Notably, the unlicensed bands (e.g., ISM and UNII) play an important role in this wireless ecosystem since the uses of applications in these bands is unencumbered by regulatory delay sand which resulted in a plethora of new applications including last-mile broadband wireless access, health care, wireless PANs/LANs/MANs, and cordless phones. This unbelievable success of unlicensed operations and the many advancements in technology that resulted from it, foces the regulatory bodies (e.g., the FCC [2]) to consider opening further bands for unlicensed use. Whereas, spectrum occupancy measurements [1] show the underutilization of licensed bands, such as the TV bands. Cognitive Radios (CRs) are seen as the solution to the current low usage of the radio spectrum. It is the main technology that will enable flexible, efficient and reliable spectrum use by adapting the radio's operating characteristics to the real-time conditions of the environment. CRs have the potential to utilize the large amount of unused spectrum in an intelligent way while not interfering with other incumbent devices in frequency bands already licensed for specific uses. CRs are enabled by the rapid and significant advancements in radio technologies (e.g., software-defined radios, frequency agility, power control, etc.), and can be characterized by the utilization of disruptive techniques such as wide-band spectrum sensing, real-time spectrum allocation and acquisition, and real-time measurement dissemination (please also refer to the DARPA neXt Generation (XG) program RFCs [1] for a good overview of issues in and the potential of CRs) Definition of cognitive radio as given [3].

"An intelligent wireless communication system that is aware of surrounding environment, and uses methodology of understanding-by-building to learn from the environment and adapt its internal states to corresponding changes in certain operating parameters (e.g. transmit power, carrier frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- Highly reliable communications whenever and wherever needed;
- Efficient utilization of the radio spectrum.

B. THE IEEE 802.22 SYSTEM

While US has played a major role towards the commercial deployment of CRs, the IEEE 802.22 is goaled to define an international standard that may operate in any regulatory regime. Therefore, the current 802.22 project identifies the North American frequency range of operation from 54-862 MHz, while there is an ongoing debate to extend the operational range to 41-910 MHz as to meet additional international regulatory requirements. Also, the standard shall accommodate the various international TV channel bandwidths of 6, 7, and 8 MHz [22].

C. Entities ,Topology and Relationships

fixed point-to-multipoint (P-MP) wireless air interface is used in the 802.22 system, uses a where a base station (BS) manages its own cell and all associated Consumer Premise Equipments (CPEs), as depicted in Figure 1. The BS (a professionally installed entity) controls the medium access in its cell and transmits in the downstream direction to the various CPEs, which respond back to the BS in the upstream direction. In addition to the traditional role of a BS, it also manages a unique feature of *distributed sensing*. This is needed to ensure proper incumbent protection and is managed by the BS, which instructs the various CPEs to perform distributed measurement of different TV channels. Based on the feedback received, the BS decides which steps, if any, are to be taken.

D. Service Capacity

The 802.22 system specifies spectral efficiencies in the range of 0.5 bit/(sec/Hz) up to 5 bit/(sec/Hz). If we consider an average of 3 bits/sec/Hz, this would correspond to a total PHY data rate of 18 Mbps in a 6 MHz TV channel. In order to obtain the minimum data rate per CPE, a total of 12 simultaneous users have been considered which leads to a required minimum peak throughput rate at edge of coverage of 1.5 Mbps per CPE in the downstream direction. In the upstream direction, a peak throughput of 384 kbps is specified, which is comparable to DSL services.

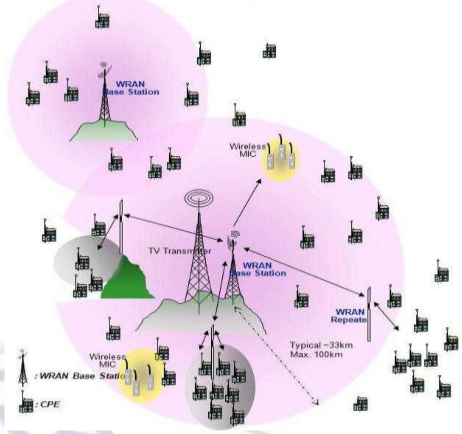

Figure 1. Exemplary 802.22 deployment configuration.

E. Service Coverage

BS coverage range is another distinctive feature of 802.22 WRAN as compared to existing IEEE 802 standards , which is proposed to go up to 100 Km if power is not an issue (current specified coverage range is 33 Km at 4 Watts CPE EIRP). As shown in Figure 2, coverage range of WRANs is much larger than today's networks, which is primarily due to its higher power and the favorable propagation characteristics of TV frequency bands. This feature of IEEE802.22 ,enhanced coverage range offers unique technical challenges as well as opportunities.

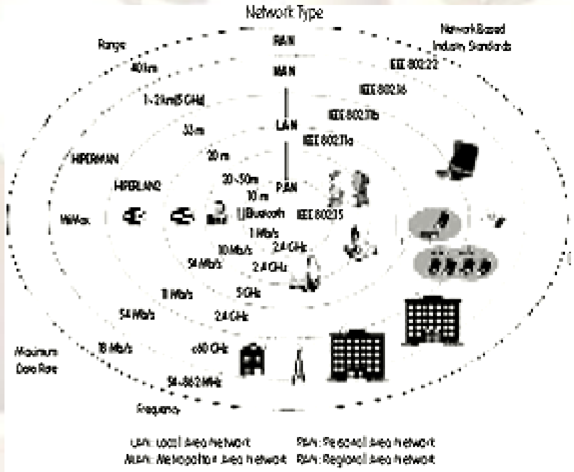

Figure2. comparasion of IEEE 802.22 with other popular wireless standards.

F. COGNITIVE CYCLE

Cognitive cycle is given in diagram 3 as in[3].A basic cognitive cycle comprises of following three basic tasks:

- Spectrum Sensing
- Spectrum Analysis
- Spectrum Decision Making

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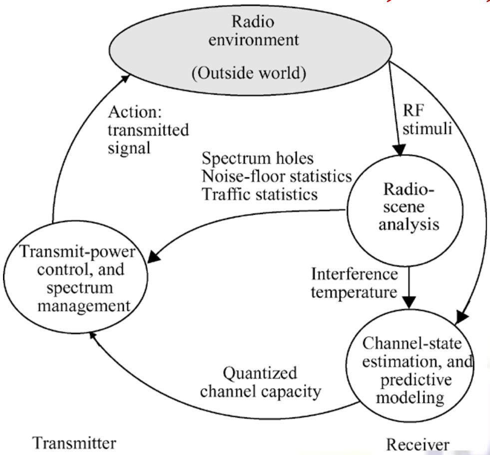

Figure 3. Basic cognitive cycle. (The figure focuses on three fundamental cognitive tasks).

G . IEEE 802.22 –Cognitive Radio Capabilities

crepresents capabilities of cognitive radio are shown in following figure 4 [4].

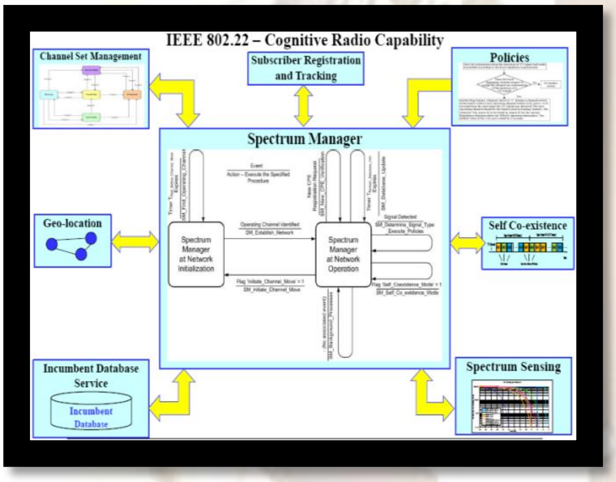

Figure 4. Cognitive Radio Capabilities.

Our focus is on spectrum sensing. Tasks of spectrum sensing involves the following subtasks as in [5].

[1] detection of Spectral holes;
[2] spectral resolution of each spectral hole;
[3]estimation of spatial direction of incoming interference;
[4] signal classification;

The subtask of spectral –hole detection is ,at its simpliest form,when focus is on white space (spectral holes)

Definition of spectral hole as in [2]

"A spectrum hole is a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized by that user"

Spectral holes have three dimensions:the time ,the frequency,and the geographical location s as can be seen in diagram 5. Diagram 6, represents spectral holes in another fashion that is Psd Vs Frequency .which is mostely used in our spectrum sensing framework.

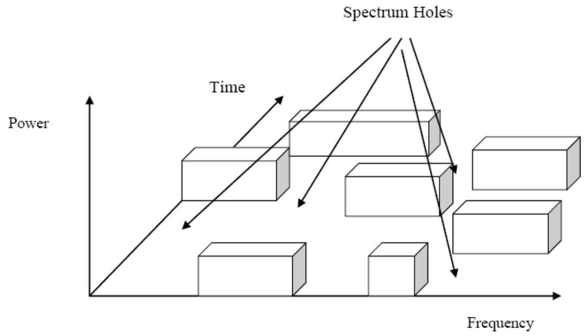

Figure 5. The unoccupied spectrum portions (holes) at specific geographical location.

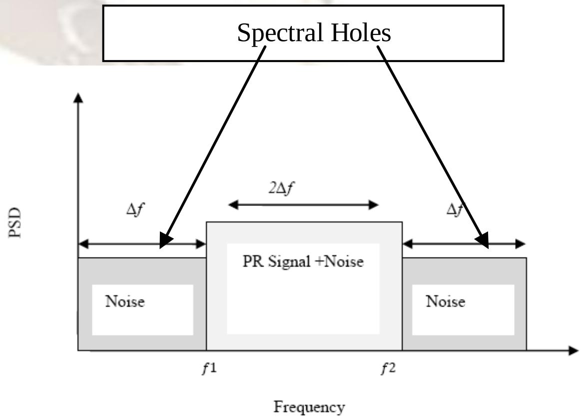

Figure 6. Pr User's Signal Under Spectrum Sensing.

I . Organization of this paper

Section II describe spectrum sensing methods . part A and part B of section II describes the periodogram methods and multitaper methods theories .In part C theories for making roc diagram is given .in section D MTM performance evaluation in terms of many parameters is given .in section III basics OFDM is given . With all of this background theory at hand ,the stage is set for an experimental study of detection of spectral hole in section IV.This paper concludes with summary and discussion in section V

II. Spectrum Sensing Methods

There are many methods for power estimation of signal . we have studied some of them for identifying the presence of signal transmission. These are as follows :

- PERIODOGRAM METHOD
- MULTITAPER METHOD
- AUTO CORRELATION BASED
- SD COOPERATIVE BASED SENSING
- CYCLOSTATIONARY BASED SENSING

A.Power Spectrum Estimation using PERIODOGRAM method

The spectrum estimation formula for periodogram power spectrum estimation is given by as in [6][11].

$$S_{\mathrm{PE}}(f_i) = \frac{1}{N} \left| \sum_{t=0}^{N-1} x_t e^{-j2\pi f_i t} \right|^2 \qquad (1)$$

periodogram estimate of desired signal shows more spectral leakages (more bias) and large variances . also periodogram estimation is more contaminated by noise,which is shown in section IV.

B.Power Spectrum Estimation using MULTITAPER METHOD

Problems occurred in periodogram (BIAS-VARIANCE DILEMMA) estimation can be resolved using MTM method [3] [5][6].

Consider a finite time series $\{x_t : t = 0,1,\ldots.N\text{-}1]$ with discrete samples of a continuing time process that represent the PR's signal plus noise. Multiplying the samples with different DPSS $\nu_{(t,k)}(N,W)$ (dot multiplication) represents convolution in the frequency domain . The FFT of the product is taken to compute the energy concentrated in the bandwidth(-W,W) and centred in a frequency f . Since there are K orthonormal tapers, then, there will be K different eigenspectrums produced from this process; this can be defined as [3] [5][6][7] [11]:

$$Y_k(f_i) = \sum_{t=0}^{N-1} \nu_{(t,k)}(N,W) x_t e^{-j2\pi f_i t} \qquad (2)$$

The spectrum estimate is given by the weighted sums of the first few eigenspectrums $Y_k(f_i)$ representing the largest eigenvalues $\lambda_k(N,W)$, which are produced from the first few K tapers, and is given by [2] [5][6][7] [11]:

$$S_{MTM}(f_i) = \frac{\sum_{k=0}^{k-1} \lambda_k(N,W) |Y_k(f_i)|^2}{\sum_{k=0}^{k-1} \lambda_k(N,W)} \qquad (3)$$

C.Performance evaluation of various power spectrum spectrum estimation methods using roc curves

Using roc curves we can compare the detection probabilities of various power spectrum estimation methods .

(A) For mtm method we use these formulaes for probability of detection and probability of false alarm as in [6]

$$P_d^{MTM}(f_i) = Q\left(\frac{\gamma - LK(E_s + \sigma^2{}_w)}{\sqrt{2LC^2 \lambda_\Sigma \sigma^2{}_w (2E_s + \sigma^2{}_w)}}\right) \qquad (4)$$

$$P_f^{MTM}(f_i) = Q\left(\frac{\gamma - LK\,\sigma^2{}_w}{\sqrt{2LC^2 \lambda_\Sigma \sigma^4{}_w}}\right) \qquad (5)$$

(B) For periodogram method we use these formulaes for probability of detection and probability of false alarm as in [6]

$$P_d^{PE}(f_i) = Q\left(\frac{\gamma - L(E_s + \sigma^2{}_w)}{\sqrt{2L\,\sigma^2{}_w (2E_s + \sigma^2{}_w)}}\right) \qquad (6)$$

$$P_f^{PE}(f_i) = Q\left(\frac{\gamma - L\,\sigma^2{}_w}{\sqrt{2L\sigma^4{}_w}}\right) \qquad (7)$$

(C) For Autocorrelation And Sd Cooperative Based Sensing Method we use these formulaes for probability of detection and probability of false alarm as in [6]

$$P_d^{AC} = Q\left(\sqrt{2L^{AC}} \cdot \frac{\eta_l - \rho_1}{\rho_1^2}\right) \qquad (8)$$

$$P_f^{AC} = Q\left(\sqrt{2L^{AC}} \cdot \eta_l\right) \qquad (9)$$

$$P_d^{AC} = Q\left(\sqrt{2L^{AC}} \cdot \frac{\eta_l - \rho_1}{\rho_1^2}\right) \qquad (10)$$

$$P_f^{SD} = Q\left(\frac{\eta_{SD}}{\sigma_{f0}}\right) \qquad (11)$$

By using this formulaes we find roc curves using matlab and we can see that mtm is better than any other method.

This result is derived in section IV.

D. MTM performance evaluation

Now mainly MTM performance depends upon number of tapper used and time bandwidth product. After fixing a particular values of these parameters we can also see performance of mtm in terms of many other parameters as in figure below.

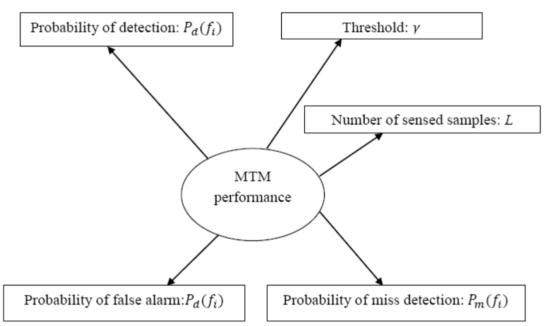

Figure 7. MTM performance evaluation expressions.

Figure 7 depicts that how and why multitaper method is more advanced and intelligent than any other method.We shall use these periodogram method ,multitaper method,detection probability and false alarm probability equations and expressions to describe many outcomes of our experimental study in section IV .

III OFDM (ORTHOGONAL FREQUENCY DEVISION MULTIPLEXING)

Ofdm[1] is promising candidate for cognitive radio .In this section we shall study about ofdm. OFDM is Orthogonal frequency-division multiplexing (OFDM) is a multicarrier modulation technique . In OFDM, each carrier is orthogonal to all other carriers. However, this condition is not always maintained in MCM. OFDM is an optimal version of multicarrier transmission schemes. Aim of developing OFDM as a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, DSL broadband internet access, wireless networks, and 4G mobile communications.OFDM is essentially identical to

1. coded OFDM (COFDM)
2. discrete multi-tone modulation (DMT),

DMT a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. The word "coded" in coded OFDM comes from the use of forward error correction (FEC). A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) is used for modulation of each sub-carrier similar to conventional single-carrier modulation schemes in the same bandwidth. Figure 8 and Figure 9 describe the transceiver of ofdm and basics of ofdm[20][31][40][41][46] .

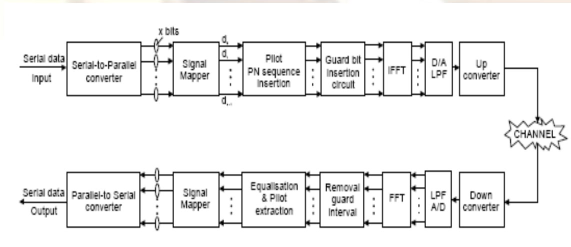

Figure 8. **Basic block diagram of OFDM transceiver.**

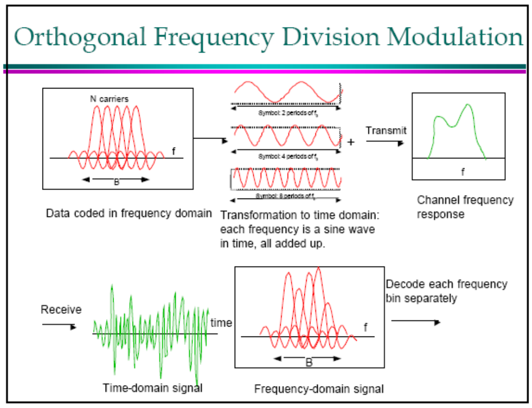

Figure 9. basics of OFDM .

Why Ofdm is main candidate for cognitive radio?

Following diagram gives answer to this question

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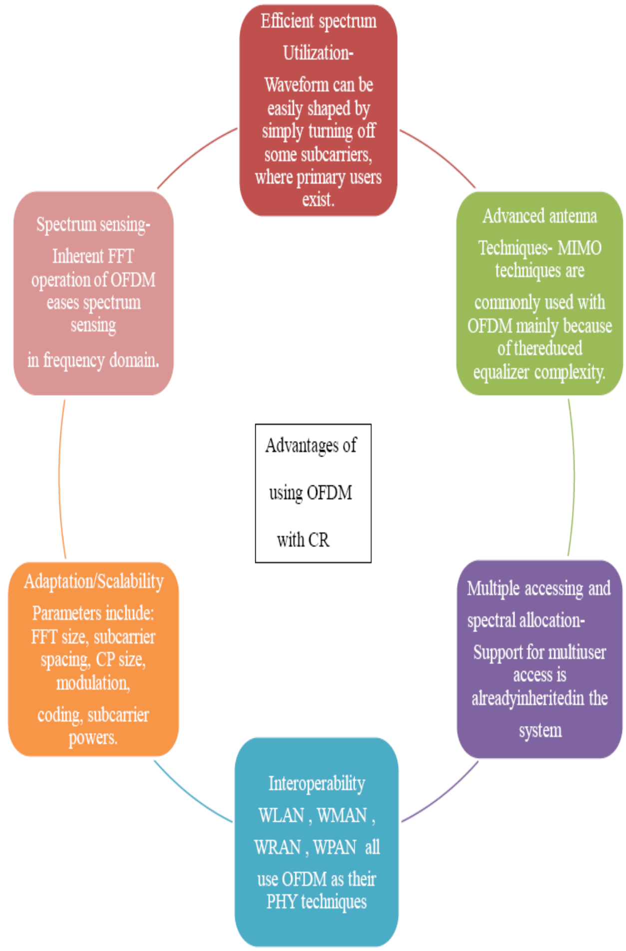

Figure 10. Advantages of using OFDM with CR.

[1]Ofdm is main multiplexing technique proposed for next generation communication networks. Mathematically, each carrier can be described as a complex wave:

$S_c^{(t)} = A_c e^{j[\omega_n t + \phi_n(t)]}$

The real signal is the real part of $s_c(t)$. Both $Ac(t)$ and $fc(t)$, the amplitude and phase of the carrier, can vary on a symbol by symbol basis. The values of the parameters are constant over the symbol duration period.OFDM consists of many carriers. Thus the complex signals $s_s(t)$ is represented by

$$S_z(t) = \frac{1}{N}\sum_{n=0}^{N-1} A_N(t) e^{j[w_n t + \Phi_n(t)]}$$

Where $\boldsymbol{\omega}_n = \boldsymbol{\omega}_0 + n\,\Delta\boldsymbol{\omega}$

IV. EXAMPLE: OFDM SIGNAL

A. Estimation Of Ofdm Signal

For our experimental study, we consider the ofdm signal ,Which is generated in matlab as shown in figure 11 .

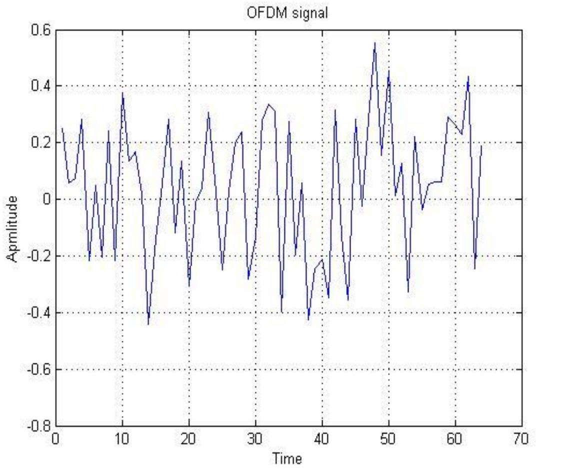

Figure 11. Ofdm signal generation in matlab.

Now we make periodogram and multitaper estimates of this ofdm signal to find a better estimator .

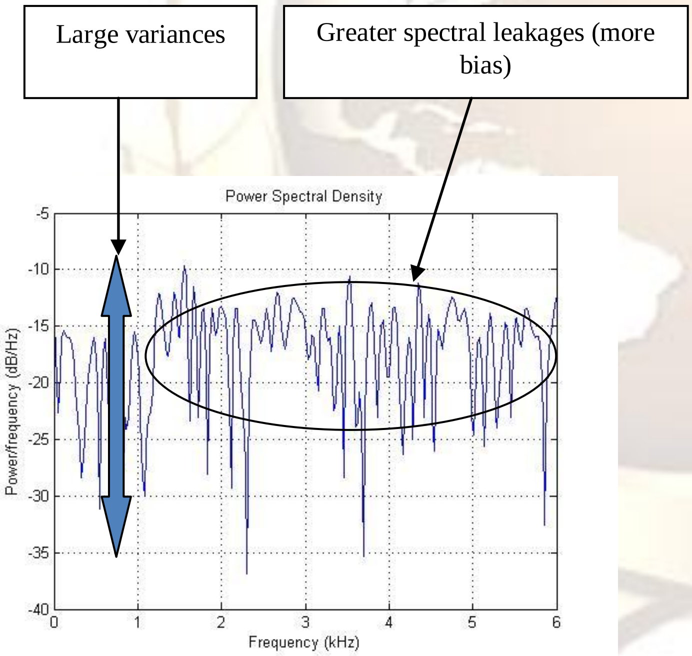

Figure 12. Periodogram estimate of ofdm signal.

Here we can clearly see that in periodogram estimate of ofdm signal there are large variances and more bias.so we can not detect better peaks and also we can not detect spectral holes in proper manner. Multitaper method solve this bias- variance dilemma .we can see this in mtm estimation that in mtm estimation there are small variances and less bias .so we can detect spectral holes clearly and better peaks as in figure 13.

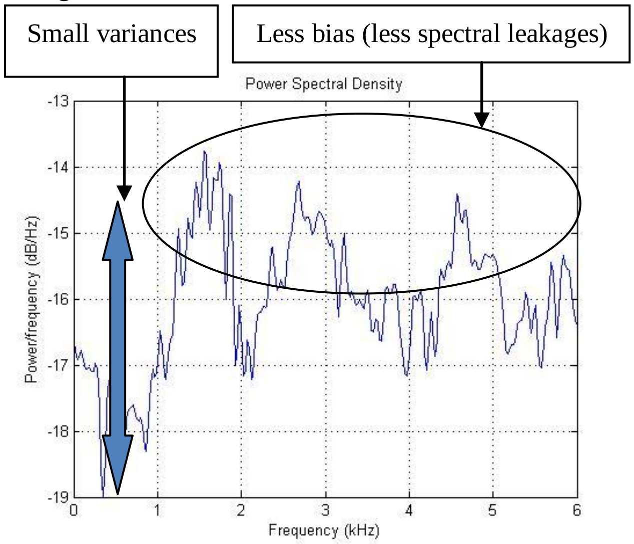

Figure 13. Multitaper estimate of ofdm signal.

Now we pass this ofdm signal through AWGN channel at SNR=-10db .Generally there are more channels in wireless communications like noise, rayleigth fading,multipath fading etc.but here we consider only noise channel[2].

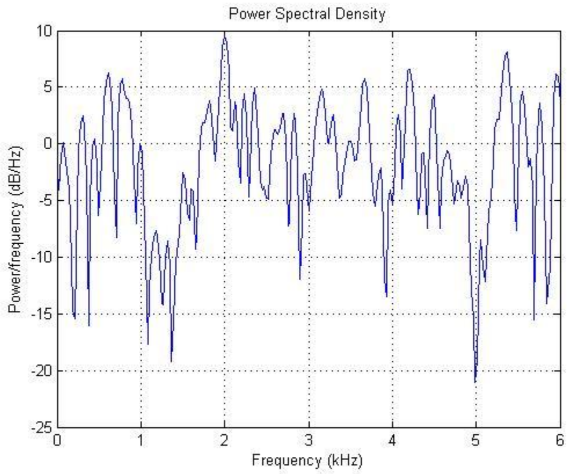

Figure 14. Periodogram Estimates Of Ofdm Signal At SNR= -10db.

[2] In our wireless communication system there are many types of Noises,like thermal noise,white noise,Johnson noise etc .but we shall consider additive White Gaussian noise in our literature.

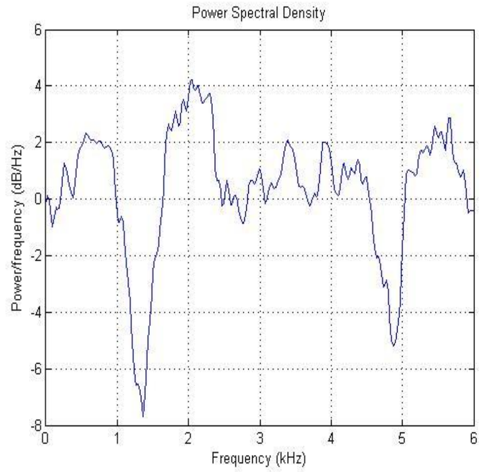

Figure 15. Multitaper Estimate Of Ofdm Signal At SNR= -10db.

We can clearly see that at this low snr value mtm method is giving better spectral resolution i.e, better peaks and the spectral holes.so we can say mtm is better than periodogram method .which is also given in [3][5][6][7]. Our main focus is comparasion of mtm method and periodogram method .

B. Study of different power estimation techniques using roc curves

Now we shall see the performance evaluation of mtm and other power spectrum estimation mehods in terms of roc diagrams. At Pf=10% , Pd(detection probability) of mtm is better than Pd of periodogram.

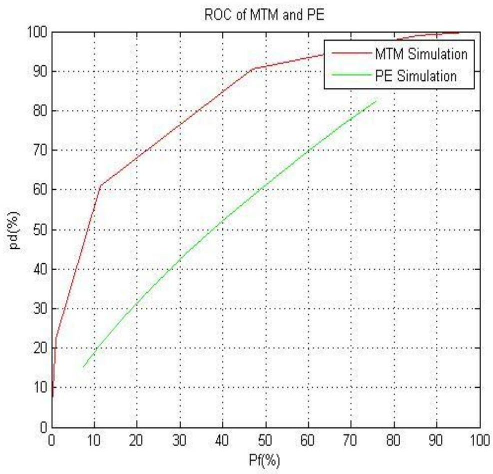

Figure 16. Comparasion Of Mtm And Periodogram.

Now performance of mtm is compared with periodogram in terms of number of ofdm blocks required for detecttion at lower SNR values[6].Actualy noise affects the performances of any power estimation method at low SNRs.

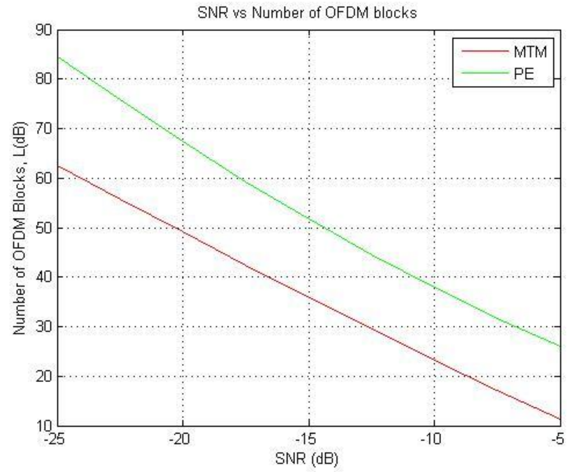

Figure 17. Comparasion Of Mtm And Periodogram.

Clearly in Figure 17 it can be viewed that mtm is giving better performance evaluation than periodogram because it requires less number of ofdm blocks for detection at low SNR values .Now mtm is compared with autocorrelation and Sd cooperative based sensing[6] to examine that which power spectrum estimation method gives better spectral resolution.

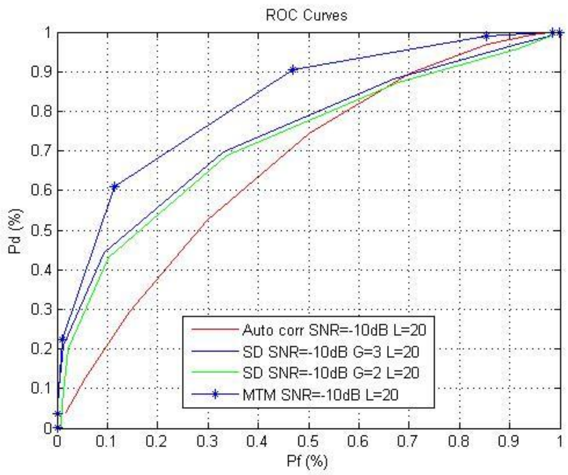

Figure 18. The Roc curves when MTM ,Auto. corr, and cooperative SD with G=2,and 3 CR users are used at AWGN with SNRs=-10dB and L=20.

At different values of Pf , Pd for mtm is better than other methods, So we can finally say that mtm is better than any other methods . Now we shall see how performance of mtm is affected by many parameters , Now performance of mtm is evaluated by fixing value of Pf at 5% and 10% at SNR=0db at both Pf values Pd is 100% in figure 19.

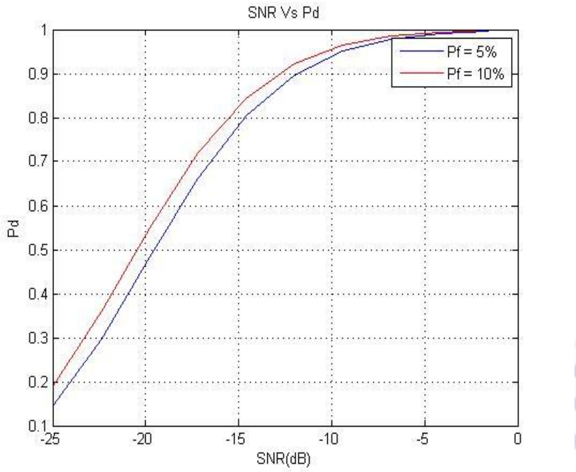

Figure 19. Pd that meets Pf=5 % and 10% Vs SNR at AWGN using MTM with NW=4, and data taper=5 and L=50 SAMPLES .

Figure 20 show that a threshold can be chosen in order to meet the specific probability of false alarm and probability of detection at defined SNR level and L used in the spectrum sensing framework .This facility in mtm method make mtm more advanced and intelligent power spectrum estimation method.In mtm method we can get good ,better,best categories of spectral resolution by making some changes in parameters.

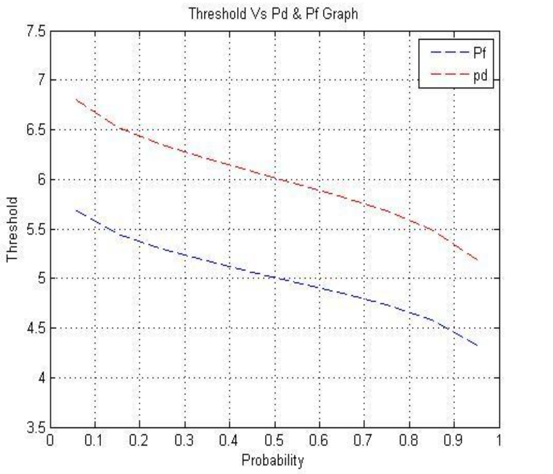

Figure 20. Threshold versus Pd and Pf when mtm with nw=4and 5tapers is used at AWGN with SNR=-7db and L=50 samples.

Now in figure 21 and figure 22 ,we can see effects of ofdm blocks on detection of signal [6]. When two Ofdm blocks are used, we can not easily destinguishe between noise and noise only signal .

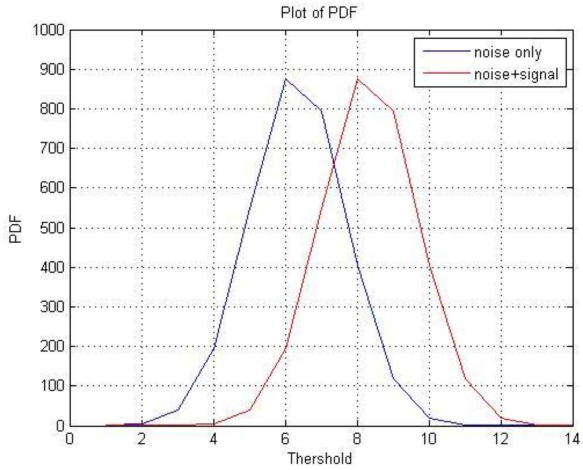

Figure 21. PDFs versus threshold of noise and noise added to signal cases for L=2 samples when MTM is used with NW=4 and K=5 taper at AWGN with SNR= -5db.

As we increase ofdm blocks from 2 to 100, We can easily detect that which is noise only and which is noise +signal .so our detection is having more robust as we increase ofdm blocks in our experimental framework . Specral resolution is now better than previous one.

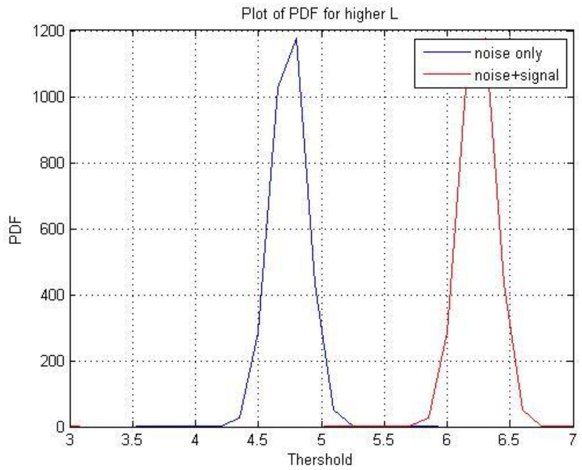

Figure 22. PDFs versus threshold of noise and noise added to signal cases for L=100 samples when MTM is used with NW=4 and K=5 taper at AWGN with SNR= -5db.

V . SUMMARY AND DISCUSSION

In finding and then exploiting spectrum holes in ofdm signal ,cognitive radio has the capability to solve the underutilization of radio-spectrum problem.however when the following compelling practical issues are recognized ,we begin to appreciate the research and development challenges involved in building and commercializing cognitive radio :

- underlying physics of radio propagation is complex,so nature of wireless channels is notoriously unreliable;
- The uncertainties surrounding the availability of spectrum holes as they come and go;
- The need for reliability in communication network whenever and wherever it is needed.

REFERENCES

[1] Carlos Cordeiro, Kiran Challapali, and Dagnachew Birru " IEEE 802.22: An Introduction to the First Wireless Standard based on Cognitive Radios "Philips Research North America/Wireless Communication and Networking Dept., Briarcliff Manor, USA

[2] Federal Communications Commission (FCC),"Spectrum Policy Task Force," ET Docket no. 02-135, November 15, 2002.

[3] Simon Haykin "Cognitive Radio: Brain Empowered,"Life Fellow, IEEE

[4] IEEE 802.22 Wireless rans group "IEEE 802.22 Wireless Regional Area networks enabling Rural Broadband Wireless Access Using Cognitive Radio Technology" USA

[5] Simon Haykin ,David J. Thomson, and Jeffrey H. Reed,"Spectrum Sensing for Cognitive Radio,"*Life Fellow IEEE*

[6] Owayed A Alghamdi" Spectrum Sensing And Cooperation IN Cognitive-Ofdm Based Wireless Communications Networks, "A phd thesis ,Plymouth U.K.

[7] G. A. Prieto , R. L. Parker, D. J. Thomson, F. L. Vernon and R. L. Graham "Reducing the bias of multitaper spectrum estimates" Scripps Institution of Oceanography, University of California San Diego, La Jolla CA 92093, USA Mathematics and Statistics Department, Queens University, Kingston

[8] Stephen J. Shellhammer "SPECTRUM SENSING IN IEEE 802.22", qualcomminc. Sandiego, CA 921

[9] Joseph Mitola III "Cognitive Radio, An Integrated Agent Architecture for Software Defined Radio ,"Dissertation Doctor of Technology Royal Institute of Technology (KTH)

[10] IEEE 80.22 web site: http://grouper.ieee.org/groups/802/22/

[11] D. J. Thomson, "Spectrum estimation and harmonic analysis," Proceedings of the IEEE, vol. 70, pp. 1055-1096, 1982.

[12] Dr. Mary Ann Ingram Guillermo *"*OFDM Simulation Using Matlab,Smart Antenna Research Laboratory*,"*Faculty Advisor: Acosta August, 2000

[13] William C.Y.Lee "Mobile Cellular Telecommunications ANALOG AND DIGITAL SYSTEMS "Second Edition .

[14] THEODORE S.RAPPAPORT " Wireless communication PRINCLES AND PRACTICES "Second Edition.

[15] Kiran Challapali, Dagnachew Birru, and Sai Shankar "IEEE 802.22: The First Worldwide Wireless Standard based on Cognitive Radios Carlos Cordeiro," Philips Research USA

[16] zhongmin Wang "New Sampling And Detection Approaches For Compressed Sensing And Their Application To Ultra Wideband Communications "

[17] "Spectrum sensing and Spectrum shifting implementation in a Cognitive Radio based IEEE 802.22 Wireless Regional Area Network"

[18] 802.22 Based On Crs,Lectures On Cognitive Radio

[19] Kyou Woong Kim" Exploiting Cyclostationarity for Radio Environmental Awareness in Cognitive Radios "Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy

[20] OFDM-based Terrestrial Geolocation .ppt

[21] Chandrasekhar Korumilli, Chakrapani Gadde, I.Hemalatha "Performance Analysis of Energy Detection Algorithm in Cognitive Radio "

[22] Amanpreet Singh Saini "The Automated Systems For Spectrum Occupancy Measurement And Channel Sounding IN ultra-wideband, Cognitive Communication, And Networking "Master of Science in Electrical Engineering

[23] "The OFCOM official web site; radio spectrum allocation chart of the UK, avaliable [online]:," Http://www.ofcom.org.uk/radiocomms/isu/ukfat/.

[24] "The ofcom official web site, avaliable[online]:," *http://www.ofcom.org.uk/*.

[25] "The ITU official web site, avaliable[online]:," *http://www.itu.int/net/home/index.aspx*.

[26] "FFT Windows Function: Limits on FFT Analysis," *Bores Signal Processing (Online: http://bores.com)*.

[27] Silpa S. Prasad, R. Gandhiraj, K.P. Soman"Multi-User Spectrum Sensing based on Multi-Taper Method for Cognitive Environments Communication Engineering Research Group, "Department of Electronics and communication

[28] Viswanath Honeywell "Spectrum Sensing for Cognitive Radios G," Bangalore

[29] Miguel López-Benítez and Fernando "Improved Energy Detection Spectrum Sensing for Cognitive Radio" casadevallvdepartment of Signal Theory and communicationsvuniversitat Politècnica de Catalunya, Barcelona, Spain

[30] Signal Processing Box for use with MATLAB®, User's Guide, Version6, 2.

[31] Identification And Classification Of Ofdm Based Signals Using Preamble Correlation And Cyclostationary Feature Extraction

[32] Foundations of Cognitive Dynamic Systems Simon Haykin mcmaster, University Hamilton, Ontario, Canada

[33] Cognitive Dynamic Systems Simon Haykin Mcmaster University Hamilton, Ontario, Canada Haykin@mcmaster.ca http://soma.mcmaster.ca

[34] A Signal Detector for Cognitive Radio System Aldo Buccardo June 11, 2010

[35] Anurag Bansal ,Ms. Rita Mahajan "Building Cognitive Radio System Using Matlab"

[36] Chandrasekhar Korumilli, Chakrapani Gadde, I.Hemalatha "Performance Analysis of Energy Detection Algorithm in Cognitive Radio "

[37] Systems Pedram Paysarvi Hoseini and Norman C. Beaulieu *I*core "An Optimal Algorithm for Wideband Spectrum Sensing in Cognitive Radio "Wireless Commun. Lab., Dept. Elec. & Comp. Eng., University of Alberta Edmonton, Alberta T6G 2V4 Canada

[38] Sequential Detection based Cooperative Spectrum Sensing Algorithms in Cognitive Radio

[39] Vinod Sharma and arunkumar Jayaprakasam "An Efficient Algorithm for Cooperative Spectrum Sensing in Cognitive Radio Networks "

[40] Dong Chen,Jiandong Li "On The Performance Of in-Band Sensing Without Quiet Period in Ofdm System,"russia

[41] Jinfeng Du, and Svante Signell **"**Comparison of CP-OFDM and OFDM/OQAM in Doubly Dispersive Channels ", Senior Member, IEEE

[42] Channel Sensing Based on Self-Signal Suppression (SSS).ppt

[43**]** Kyou Woong Kim**"** Exploiting Cyclostationarity for Radio Environmental Awareness in Cognitive Radios "the Doctor of Philosophy thesis,Virginia Polytechnic Institute and State University

[44] Cognitive Ultra Wide Band (CUWB) Radio Implementation and Challenges

[45] Roman Marsalek, Jiri Dvorak, Karel Povalac, Jitka Pomenkova "Use Of Matlab In The Multicarrier Signal Sensing, Optimization And Implementation "

[46] E225C – Lecture 16 OFDM Introduction EE225C

[47] Cognitive Radio: Brain-Inspired Wireless Communications Simon Haykin mcmaster, University Hamilton, Ontario, Canada

[48] Software Testbed for Cognitive Radio Networks: Work in Progress Simon Haykin mcmaster, University Hamilton, Ontario, Canada

[49] Analog and Digital communication by Simon Haykin .

[50] S. shellhammer, s. shankar, R. tandra, and j. tomcik, bperformance of power detector sensors of dtv signals in ieee 802.22 wrans,[in proc. 1st acm int. workshop technol. policy access. spectrum (tapas), aug. 2006. [online]. available: http://doi.acm.org /10.1145/123488.1234392

[51] W.A.Gardner " Spectrum sensing and Spectrum shifting implementation in a Cognitive Radio based IEEE 802.22 Wireless Regional Area Network"

[52] R. Tandra, S. M. Mishra, and A. Sahai, "what is a spectrum hole and what does it take to recognize one?" Proc. IEEE, vol. 97, Mar. 2009

[53] Silpa S. Prasad, R. Gandhiraj, K.P. Soman "Multi-User Spectrum Sensing based on Multi-Taper Method for Cognitive Environments "

[54] S.O.Rice,"A Short Table of Values of Prolate Spheriodal Harmonics,"Bell Telephone Labs.,MM63-3241-13,1963

[55] A.F.Molisch,L.J.Greenstein, and .shafi , "propogation issues for cognitive radio," Proc.IEEE,vol.97.May 2009