Cognitive Radio Spectrum Sensing Algorithms based on Eigenvalue and Covariance methods

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Abstract— **Spectrum sensing method is the fundamental factor when we are working with cognitive radio systems. Main aim and fundamental problem of cognitive radio is to identify weather primary users in authorized or licensed spectrum is presented or not. Paper deals with a new scheme of sensing based on the eigenvalues concept. It contain signals of covariance matrix received by the secondary users. In this method we are suggested two algorithms of sensing, one algorithm established by the maximum to minimum eigenvalue ratio. Other algorithm focused on average to minimum eigenvalue ratio. These two are done by using random matrix theories (RMT), and also these RMT are latest and also produce some accurate results. Now we calculate the ratios of distributions and probabilities of detection (Pd) and derive the probabilities of false alarm (Pfa) for the proposed algorithms, and also finding thresholds values for given Pfa. This method will improve the problem of noise uncertainty, and also performance is improved compare to energy detection when highly correlated signal is available. Paper also deals with another method is and also covariance methods. First one is statistical covariance method, it has different noise and received signal, and it is used for finding the primary users presence where there is only noise. These algorithms implemented by use of small number of received signal samples and processed to calculate the sample covariance matrix. By use of sample covariance matrix we are extracted two test statistics. Finally we compare these results and concluded that signal presence. These are used in many signal detection applications, and also do not need signal information, also noise power and channel. We did the Simulations based on two ways. First one is randomly generated signals. Other one is done by captured DTV signals taken from ATSV committee, these are broadcasting signals. These methods confirm and verifies the efficiency of the proposed methods.**

Keywords- Eigenvalues, Spectrum sensing, IEEE 802.22 (Wireless regional area networks - WRAN), random matrix theories.

Introduction

Innovative wireless services are developed equally in licensed as well as unlicensed bands and these are increase the demand of frequency spectrum in electromagnetic radio, it is an occasional source, these are mostly allocated to license users. These are used large geographical regions for long-term basis and causing the measurements accordingly. Normally huge share of spectrum is unused and some percentage remaining portion is used for poor spectrum utilization. Secondary and concurrent usage of spectrum introduced by the Federal Communications Commission (FCC) where it is located in US and Radio Spectrum Policy Group of European Commission's in the EU. These are focused on where the secondary user may not interfere the license holders while performing normal operation. These new regulations of licensed bands are used in many appliance like TV broadcasting stations(IEEE 802.22) [3], [4] and cellular or mobile operators are allowed high-class access and it permits the growth of a innovative model, and those devices are capability to adjust the spectral surroundings and it make the usage of spectrum are available in surrounding region. Cognitive Radio (CR) a technology has developed as it permits the access on unoccupied frequency bands with intermittent periods and also the spectrum holes. This will always increase efficiency of spectrum.

For a cognitive radio IEEE developed WRAN-802.22 [3],[4]. These are original broadcasting signals mostly used for TV channels and also used for microphone signals, and used for control or operate VHF/UHF unused bands, these are called primary users. To avoid primary user interference, WRAN need to sometimes detect around the region if any primary user is active. Challenges are to solve sensing problems like primary user SNR received is very low compare to secondary receivers. Consider WRAN aim to detect SNR level at least −20dB. Also time dispersion and fading have problems. In this case fading cause's power fluctuating in the received signal, time dispersed causes coherent detection problem. Finally noise uncertainty (NU) it is a level change with its time to a noise or interference. Noise uncertainty (NU) is two types, these are environment and receiver device NU's. Environment NU effected by other user transmissions like near-by and far-away of unintentional and intentional of transmissions. Receiver device NU effected by thermal noise and non-linearity components, these are time-varying and also non-uniform.

Sensing contain so many methods but each has some drawbacks like, cyclostationary method needs cyclic frequencies information from PU's. Matched filtering wants channels and waveform of the PU's. Energy based Detection is easiest technique used for spectrum sensing. used for finding spectrum sensing this will and basic approach because of its implementation complexities and low computational and also more generic compare to other methods. Main principle of energy detector is to compare the threshold values and finding the energy of received signal. Decision is made based on the comparison of received signal noise ratio it means signal to noise ratio based these receivers not require any knowledge on the primary users' signal. These signals are sensed by comparing the energy detector output and also noise floor. Threshold values are depends on noise level. Energy detector based sensing also facing some challenges those are failure to differentiate the interference from noise and primary users, detecting primary users with appropriate threshold, and also performance is poor due to low signal-to-noise ratio (SNR) values. For detecting spread spectrum signals energy detectors do not work powerfully

Disadvantage of energy based detectors

1) Selection of threshold

2) In case of low SNR (signal to noise ratio) rate, this method is inefficient to discriminating interference from primary signal.

3) For correlated signal detection it is not suitable

To overcome energy detection problems we recommend new approach of the eigenvalues method. This is done by covariance matrix of received signal. These are used for detecting of signal presence by using ratio of average or maximum to the minimum eigenvalue. These are implemented by use of latest method of (RMT) random matrix theories. By using the ratios of distributions we calculate detection thresholds, in this offered detection method. These RMT used for detecting probability of detection and false alarm (Pfa) [5], [6]. This algorithm overcome the problem of noise uncertainty and it also perform most efficient than energy detector when highly correlated signals are detected and also can perform without any basic signal information, noise power and channel. Normally matched filtering require accurate synchronization, but Eigen value do not require any synchronization. These Simulations are done by randomly generated signals.

We also suggest another algorithm spectral covariance sensing (SCS) in this paper [2],[7], it exploits the noise in the frequency domain and signal in different statistical correlation. SCS will identifies spectral features this permit sensitivity. It is also toughness against the noise power uncertainties. We evaluate its theoretical performance and finally verify its results through simulations. We are comparing SCS with CAV and energy detector, finally it accomplishes 3 dB better sensitivity. It almost achieves 20% of lesser sensing time compare to other methods. IEEE 802.22- WRAN provide low SNR regime. Finally it gains 3db almost this is a great improvement in this method. Simulations are done by captured digital television (DTV) signals [3], [4].

The paper follows like Section II contain system model and its background. Section III contain different sensing algorithms. Section IV contain RMT and SCS algorithms and it gives theoretical analysis and find its threshold values. Section V contain Simulation results of Eigen value based on randomly generated signals and covariance based on captured DTV signals. Section VI contain Conclusion.

A. System Model and Background

Energy detection do not required any prior information about licensed user signal due to this it is widely used in sensing, and unknown dispersive channels also performs well and it has some operation complexity and less computation and less delay compare to previous approaches. Still this will gives knowledge of noise power with accurate and it leads to noise uncertainty [4]. This method optimal for identifying identical signal distribute with high SNR rate, but it is not suitable while going to correlated signal to detecting. Received signal of energy detector is [6],

$$w(n) + s(n) = y(n)$$

here Received RF signal is denoted as y(n), noise of (AWGN) denoted as w(n), sampled value index denoted as n, and the to be detected signal denoted as s(n).if s(n) equal to 0 means primary user did not send transmission.

$$M = \sum_{n=0}^{N} |y(n)|^{2}$$

Energy detector decision metric (M) can be written as follows above equation where observation vector side denoted as N. By matching the decision metric M opposite to fixed threshold λE can obtain by choice of occupancy band. It is equal to examining two hypotheses give below

$$w(n) + s(n) = y(n) : H1;$$

w(n) = y(n) :H0;

Basic sensing model is Energy detection. Let received signal average power denoted as T (Ns), it is,

$$T(Ns) = \frac{1}{MNs} \sum_{i=1}^{M} \sum_{n=0}^{Ns-1} |x_i(n)|^2$$

Where no of samples denoted as Ns. For finding signal presence in energy detection we compare T (Ns) with the noise power. Noise uncertainty happen always in practice due to this we calculated noise power, but it is different from actual one. This factor (dB) defined as

$$B = \max \{10 \log_{10} \alpha\}.$$

Here α (dB) uniformly circulated with an interval [−B, B]. Normally receiving device noise uncertainty factor is almost 1 to 2 db. Due to the presence of interference noise uncertainty of an environment can be higher.

I. EIGENVALUE BASED DETECTIONS ALGORITHMS

We did a practice with limited no of samples. Instead of statistic covariance matrix we are implemented sample covariance matrix (SCM).by using these matrix there are two detection are implemented and those are given below [1].

A. Algorithm one : MME - Maximum-minimum eigenvalue detection

1. We are Calculated received signal of SCM.

$$Rx(Ns) = \frac{1}{Ns} \sum_{n=L-1}^{Ns+L-2} x\hat{}(n)x(n)$$

Here no of samples denoted as Ns.

2. We obtain Rx (Ns) it is an MME matrix, done by based on values of λmax and λmin.

3. We conclude the comparison like, if λmax/λmin > T1, signal is presented ("yes"); else, no signal present ("no"), here threshold value is T1 > 1, this value passes to next section.

B. Algorithm two: EME - Energy with minimum eigenvalue detection

1. First step is similar to MME first step.

2. We obtain Rx (Ns), it is λmin matrix and also we are calculated T (Ns), it is an received signal average power.

3. We conclude the comparison like, if T (Ns)/λmin > T2, signal is present ("yes"); else, no signal present ("no"), here threshold value is T2 > 1, this value passes to next section.

EME and energy detection difference follows as: energy detection will matches or compares the noise power to the signal energy, here EME will compares or matches the signal energy to the λmin of the SCM. Received signal samples are used in EME and MME detections. This proposed do not require noise power, transmitted signal information and channel also not needed.

II. PROBABILITY OF FALSE ALARM AND THRESHOLD VALUES

If signal is not present then Rx (Ns) changes into R_ (Ns), here SCM of the noise represented as,

$$R(Ns) = \frac{1}{Ns} \sum_{n=L-1}^{Ns-2+L} (n)(n)$$

Random matrix of wishart is nearly to R (Ns). We are using tracy-widom distribution function for an eigen value based method. Study of eigenvalue distributions by using RMT [5],[6] is latest topic in communication and mathematics. Wishart random matrix used from many years it is an Eigen values of PDF distribution. PDF is somewhat complicated because no closed expressions. Now largest eigenvalue distribution described below in lemmas [2].

Lemma 1: we are assumed real noise here.

$$\mathbf{A}(N_s) = \frac{N_s}{\sigma_\eta^2}\mathbf{R}_\eta(N_s), \tag{1}$$

$$\mu = (\sqrt{N_s - 1} + \sqrt{ML})^2 \qquad \nu = (\sqrt{N_s - 1} + \sqrt{ML})\left(\frac{1}{\sqrt{N_s - 1}} + \frac{1}{\sqrt{ML}}\right)^{1/3}. \tag{2}$$

$$\lim_{N_s \to \infty} \frac{ML}{N_s} = y \; (0 < y < 1). \tag{3}$$

$$\frac{\lambda_{max}(\mathbf{A}(N_s)) - \mu}{\nu}$$

Then final equation come together to the distribution of Tracy-Widom function of order 1 (TW1), this will found the value of smallest eigenvalue limit [2],[5].

Lemma 2: Assume that

$$\lim_{N_s \to \infty} \frac{ML}{N_s} = y \ (0 < y < 1). \quad (4)$$

$$\lim_{N_s \to \infty} \lambda_{min} = \sigma_\eta^2 (1 - \sqrt{y})^2 \quad (5)$$

$$\frac{\sigma_n^2}{N_s}(\sqrt{N_s} + \sqrt{ML})^2 \text{ and } \frac{\sigma_n^2}{N_s}(\sqrt{N_s} - \sqrt{ML})^2, \quad (6)$$

Based on these lemmas, if Ns value is large, then the smallest and largest eigenvalues of R (Ns) tend to deterministic values, and these variances are tends to a zeros. Largest eigenvalue distribution for large Ns implemented by lemma 1. Normally for these distribution functions no closed form expressions are there. Here Tracy-Widom distributions are founded to implement random matrices for a largest eigenvalue. Let F1 be the CDF of the TW1.

III. COVARIANCE BASED DETECTION ALGORITHMS

In cognitive radio COVARIANCE based detection algorithms used for a spectrum sensing. This will best suited for an IEEE 802.22 – WRAN, these are DTV signals [2],[3],[7]. These are classified into two types

1. Statistical Covariance
2. Spectral covariance

A. *Statistical Covariance algorithm*

Statistical Covariance implemented by using Detection Algorithm of Covariance Absolute Value (CAV) [2] [7]. It contain following steps.

1. Received signal can be sampled, as previously defined.
2. Smoothing factor denoted as L and a threshold value denoted as $\gamma 1$, as for Pfa requirement we have chosen $\gamma 1$value. These details given in next section.
3. By using SCM we are calculated autocorrelations of received signal, these are denoted as $\lambda(l)$, here l is always varies from 0, 1, . . . , L – 1.
4. Compute

$$\mathrm{T1(Ns)} = \frac{1}{\mathrm{L}} \sum_{\mathrm{n}=1}^{L} \sum_{\mathrm{m}=1}^{\mathrm{L}} |_{nm}(\mathrm{Ns})|$$

$$\mathrm{T2(Ns)} = \frac{1}{\mathrm{L}} \sum_{\mathrm{n}=1}^{\mathrm{L}} |_{nm}(\mathrm{Ns})|$$

Here SCM (**R***x* (*Ns*)) of elements denoted as *rnm*(*Ns*) .

5. By using threshold $\gamma 1$, $T1(Ns)$, $T2(Ns)$, we determine either signal present or not. Here if threshold value is $T1(Ns)/T2(Ns) > \gamma 1$ then signal is present else no signal presented.

The autocorrelation $\lambda(l)$ calculated by statistics covariance matrix in the algorithm .

B. *Spectral covariance algorithm*

Here we explain this Spectral covariance algorithm and also how we wrote those mathematical expression in mat lab to easily understand the concept. It contain following steps [3],[7].

1. Received signal of down convert x(t) and y(t) = x(t)e−j2 fct is an complex signal of baseband are Placed nearer to DC or pilot tone.
2. Sampling rate denoted as Fs and LPF and down sample y(t) used to produce Z(n).
3. We calculated magnitude squares of STFT- short-time Fourier transform to produce spectrogram and expressed as

$$Zt(k) = \frac{1}{N}\sum_{n=0}^{N-1} Z|n + \tau N| e^{-j2nk\pi}/N$$

Where N = 2blog2 (Fs·ts)c, _ 2 is the sensing window it varies from 0, 1, · · · ,Nd − 1, Nd is denoted as dwell, frequency index of k value varies from −N/2, · ·, 0, · · ,N/2 − 1.

Finally we calculated FFT for each dwell time (ts) for Nd times.

4. M varies from [m0 m1 · · · mNd−1] are placed nearer to pilot, by use of it we selected components. Where m_ = [Z(−K),Z (−K + 1) · · ·Z (K)], T & K are index of LPF cut off frequency (Bf) in FFT.

5. Sample covariance denoted as M Calculated and expressed as C = cov (M) = [C u]

6. Test statistics are computed as T = T1/T2, here T1 and T2 represented as

$$T1 = \frac{1}{Nd}\sum_{\tau=0}^{Nd-1}\sum_{u=0}^{Nd-1}(C\tau u)$$

$$T2 = \frac{1}{Nd}\sum_{\tau=0}^{L}(C\tau\tau)$$

7. Equate T value to an decision threshold, it can be expressed as row = arg sup PFA(T) = PFA,req,

Here Pfa with threshold T denoted as PFA(T) and Pfa expressed as PFA,req. if T exceeds then detection done, else no signal present.

Test statistics T seems to same but many differences are there. First one they calculated the complete value of SCM in the time domain only. SCS mainly concentrated on edge between the spectrum of primary signal and also its noise. Next one SCS uses only time domain information but it will detect spectrum in both frequency as well as time domain. Finally SCS uses some portion spectrum only, due to its less usage of it noise power is reduced. If you uses the entire spectrum you can increases effective SNR.

IV. SIMULATIONS RESULTS

A. *EIGEN VALUE BASED SIMULATIONS RESULTS*

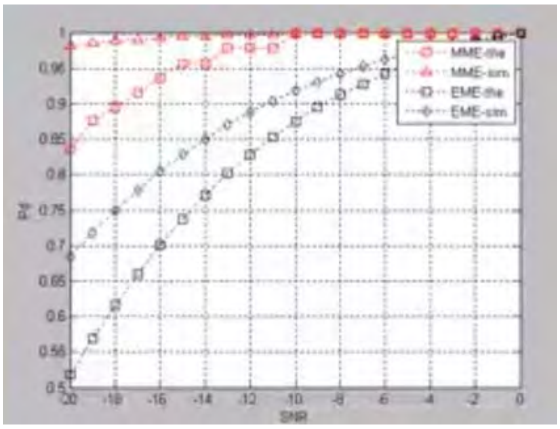


Fig 1: Probability detection: M = 4, L = 10, P = 2.

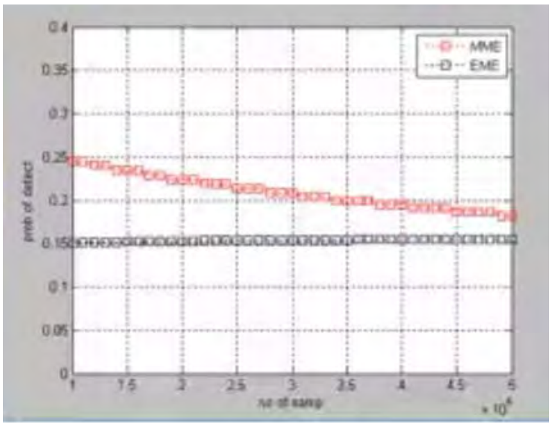
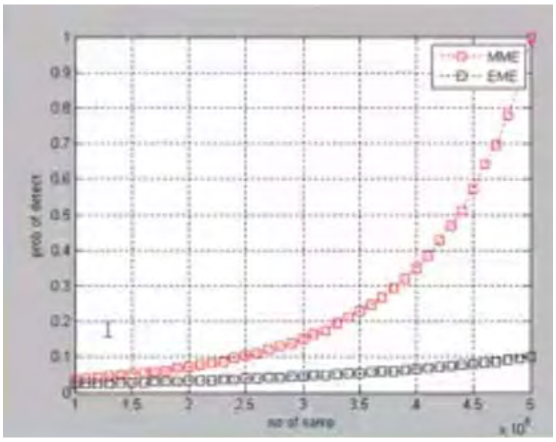


Fig 2: Probability detection: M = 4, L = 8, SNR=−20 dB, P = 2.

Fig1 shows probability detection for multiple receiver bases signals, we consider values L = 10, M = 4, P = 2. M and P denotes 4-reciver 2- input system. L indicates 10 no of taps, it means system divided into 10 taps. All These channel taps are generated randomly with the help of Tracy widow distribution. Fig 2 shows L=8 fixed and also Pd for the MME and EME.



These are done by noise uncertainty (with and without).

Fig 3: Probability of false alarm: L = 8, SNR=−20 dB, M = 4, P = 2.

Fig 3 shows the Pfa of system. Normally Pfa should kept the below the level of 0.1 it means (Pfa<=0.1). This value is also used for energy detection with noise uncertainty. Both MME and EME calculated.

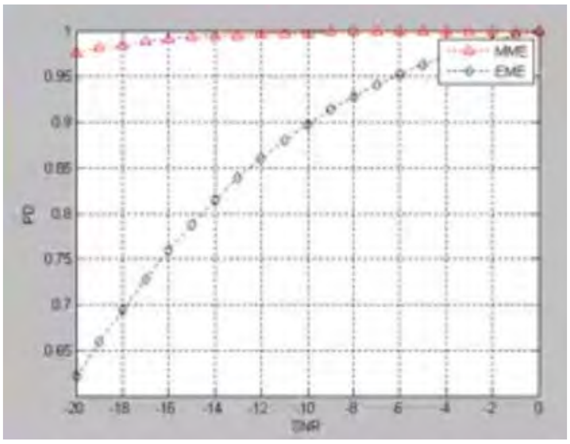


Fig 4: SNR VS PD; SNR=−20 dB, M = 4, P = 2, Ns = 130000.

Fig 4shows SNR versus PD, it contain 10 taps and SNR at – 20 db. No of samples used up to 130000. So finally fig 3, 4 shows both PD and Pfa respectively.

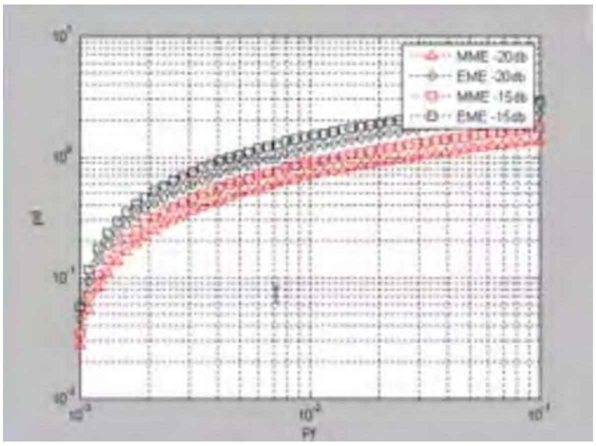


Fig 5: Impact of smoothing factor: SNR=−20 dB, P = 2, M = 4, Ns = 130000.

Fig 5 gives the resultant system values for both P_d and P_{fa} . it shows both Pfa and Pd of this implemented algorithm results somewhat increase with its L value. All these are randomly generated simulation.

B. *SIMULATION RESULTS FOR SPECTRAL COVARIANCE SENSING ALGORITHM*

SCS simulations are done by DTV signals. These are broadcasting signal. We are taken these signal under the ATSV committee. We are used captured data signal as input for this algorithm. These simulations are done for IEEE 802.22 requirements. We are used DTV signal WAS- 003/27/01 for SCS simulation.

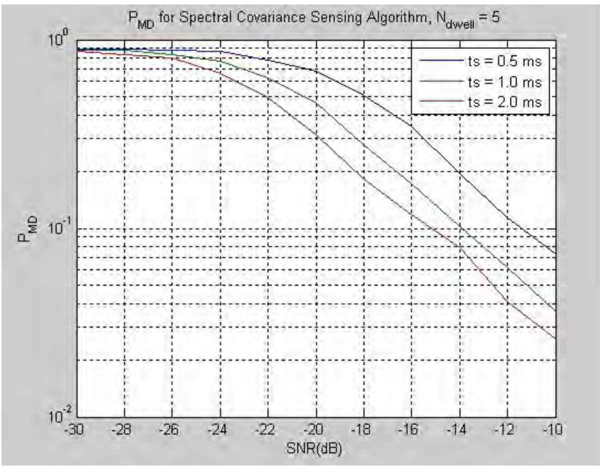


Fig. 6. Probability detection and Effects of Nd=5 ts = [0.5 1.0 2.0] ms, using DTV signal WAS- 003/27/01.

Fig 6 shows the SCS sensing BY using DTV signals. Here we are used 5 Nd wells and sensing time is varies from 0.5 to 2 ms. For each Ts value Nd of 5 we are calculating $P_{MD.}$ Each line in graph shows sensing time with different values.

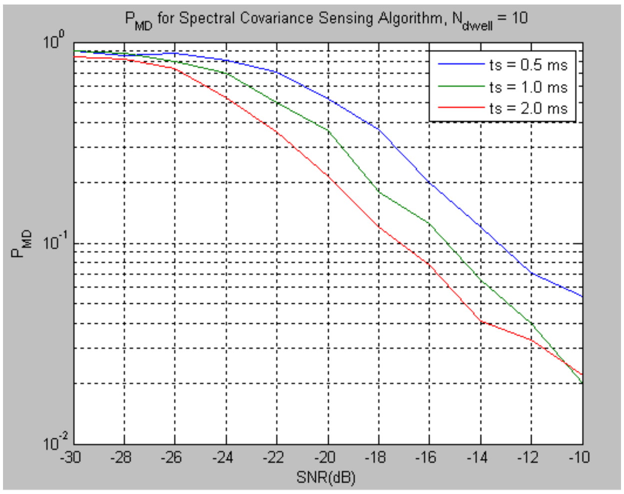


Fig. 7. Probability of detection and Effects of Nd=10 ts = [0.5 1.0 2.0] ms, using DTV signal WAS- 003/27/01.

Fig 7 shows effect of no of Nd wells with an size of sensing value is fixed with 0.5 ms to 2ms. Here Nd value is consider as 10. This performance is varies from different input signals.These all figures shows the simulation results of all the algorithms or methods used in this paper.

V. CONCLUSION

In Eigenvalues method we proposed getting SCM of received signal. For finding probability of detection and setting the threshold values we are used random matrix theories. Simulations are done by using randomly generated signals for Eigenvalue detection. SCS used for sensing signals by the features of the primary signal. By use of several parameters we are investigated detection time this is done by simulation and analysis. Compare other sensing methods SCS will provide better detection and also sensing time (Ts) longer. The sensing window period affects the performance of SCS greater than the no of dwells are used. So, in a shorter sensing time SCS will detect better by use of longer window, it leads to complexity increases. SCS performance compared with CAV and pilot detector. SCS achieves same performance detection as pilot detector in 1/5 of the Ts and it is robust against noise uncertainty. Sensitivity archives 2 to 3 db. This simulation results of the paper shows SCS efficient for IEEE 802.22 systems. Simulations are done by captured DTV signals.

REFERENCES

[1] Yonghong Zeng, and Ying-Chang Liang "Eigenvalue based Spectrum Sensing Algorithms for Cognitive Radio" Communications, IEEE Transactions on June 2009.

[2] Yonghong Zeng, and Ying-Chang Liang "Spectrum-Sensing Algorithms for Cognitive Radio Based on Statistical Covariances " IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 58, NO. 4, MAY 2009.

[3] Jaeweon Kim and Jeffrey G. Andrews "SPECTRAL COVARIANCE FOR SPECTRUM SENSING, WITH APPLICATION TO IEEE 802.22" Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on 14-19 March 2010.

[4] Jaeweon Kim and Jeffrey G "Sensitive White Space Detection with spectral Covariance Sensing" Wireless Communications, IEEE Transactions on September 2010.

[5] *A. Tracy and H. Widom, "On orthogonal and simplistic matrix ensembles," Comm. Math. Phys., vol. 177, pp. 727–754, 1996.*

[6] J. Christopher Clement and Kishore V. Krishnan," Cognitive Radio: Spectrum Sensing Problems in Signal Processing" International Journal of Computer Applications (0975 – 8887) Volume 40– No.16, February 2012.

[7] J. Kim and J. G. Andrews, "Spectrum sensing with spectral covariance for cognitive radio," IEEE Trans. on Signal Processing, in preparation. [Online]. Available: http://arxiv.org/abs/0910.1787.