

# Performance Analysis of Cooperative Spectrum Sensing Technique for Low SNR Regime over Fading Channels for Cognitive Radio Networks

G. Padmavathi<sup>1\*</sup> and S. Shanmugavel<sup>2</sup>

<sup>1</sup>Department of Electronics and Communication Engineering, Sri Venkateswara College of Engineering, Sriperumbudur - 602117, Tamil Nadu, India; gpadma@svce.ac.in

<sup>2</sup>Department of Electronics and Communication Engineering, National Engineering College, Kovilpatti - 628503, Tamil Nadu, India; sethusvel@gmail.com

## Abstract

Cognitive Radio is a technology for Next Generation Wireless Networks to support Dynamic Spectrum Access which addresses the spectrum scarcity and under utilization problems experienced by today's wireless communication networks. Spectrum Sensing is an important function of cognitive radio that identifies the unused licensed frequency bands of Primary Users for opportunistic access by Secondary Users. In this paper, we have proposed a sensing technique incorporating wavelet denoising to enhance the sensing performance at low SNR regime. The combination of wavelet denoising preceding energy detector, hard decision for local sensing and OR fusion rule at the fusion center for cooperative sensing has improved the sensing performance. We have quantified the performance improvement of the proposed technique in fading environments and studied the effect of wavelet denoising. Probability of missed detection has been reduced by 38% over Rayleigh Fading channel and 52% over Nakagami Fading channel compared to conventional sensing technique for ten users cooperation. Sensing time has been reduced by 1 msec and throughput improved by 50 Mbits/Sec/Hz compared to conventional energy detection based sensing method.

**Keywords:** Cognitive Radio, Cooperative Spectrum Sensing, Energy Detection, Hard Decision, Wavelet Denoising

## 1. Introduction

Wireless communications have experienced an exponential growth in the recent years and there is no spectrum available for the new upcoming wireless applications because the entire RF Spectrum had been already statically allotted to different applications.

A survey by Spectrum Policy Task Force (SPTF) within FCC<sup>3</sup> indicated that many licensed frequency bands are unused for significant periods of time with an average duty cycle of 15% – 35 % indicating underutilization of the spectrum. Cognitive Radio (CR) is an intelligent wireless communication system that is aware of its surrounding environment and provides highly reliable communications

whenever and wherever needed through efficient utilization of the radio spectrum opportunistically<sup>6</sup>.

Spectrum sensing is a main function of CR to learn about its RF environment and determine the unused licensed frequency bands known as spectrum holes, for secondary usage. Energy Detector (ED) has been widely used among the various spectrum sensing methods because of its low computational and implementation complexities and also prior knowledge of the licensed user's signal is not required<sup>7</sup>. But the drawback of ED is its poor detection performance at low SNR regime. This issue has been addressed by incorporating a signal processing technique called Wavelet Denoising (WD) preceding ED to improve the received SNR which in turn enhances the detection probability.

\*Author for correspondence

Cooperative Spectrum Sensing (CSS) provides solutions to problems that arise in spectrum sensing due to noise uncertainty, receiver uncertainty, fading and shadowing<sup>5</sup>. The main concept of CSS is to enhance the sensing performance by exploiting the spatial diversity in the observations of spatially located CR users. The performance improvement due to spatial diversity is called cooperative gain<sup>1</sup>.

In <sup>4</sup>, the authors have investigated the sensing performance over AWGN channel using wavelet denoising at both cooperating CRs and Fusion Center (FC). They have considered soft combination of observed signals and used 2-D WD at FC and obtained improvement in the sensing performance. Soft combination requires higher bandwidth for reporting channels against hard combining and 2-D WD leads to greater processing complexity & time at FC.

The proposed Hard Decision (HD) based CSS with Wavelet Denoising (WD) improves Probability of Detection, Cooperative Gain and Throughput because of the SNR gain achieved through WD. The processing complexity has been limited by using 1-D one level WD only at cooperating CRs and communication complexity has been controlled by the HD of local sensing. The OR fusion rule used to combine the hard decisions at FC is known for its high probability of detection and low complexity.

## 2. Architecture of the Proposed Sensing Method

The architecture of the proposed sensing scheme is shown in Figure 1. The CR receives the Licensed User or Primary User (PU) signal through sensing channel. Two fading channel models namely Rayleigh and Nakagami fading have been considered in this work for the sensing channel. The received signal first undergoes 1-D one level wavelet denoising to improve the SNR and then given to ED. The ED computes the energy of the denoised signal over a fixed observation window 'W'. The computed energy is then compared with the threshold value which is determined to satisfy a target false alarm probability. The false alarm probability considered in this work is 10% as per the 802.22 WRAN draft standard. This is done in the HD unit. If the energy of the received signal is greater than the threshold value, a decision is made on the Hypothesis  $H_1$  indicating the presence of PU. Otherwise,  $H_0$  is decided indicating the absence of PU.

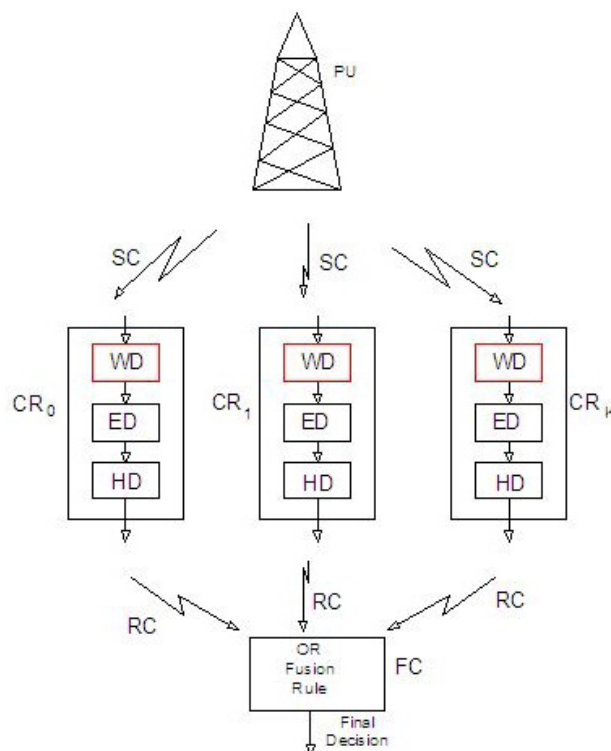


Figure 1. Architecture of HD based CSS with wavelet denoising.

## 3. Performance Evaluation

The overall probability of missed detection and false alarm for the decisions taken at FC using OR decision fusion rule are given<sup>5</sup> by Equations (1) and (2)

$$Q_m = \prod_{i=1}^N (1 - P_{d,i}) \quad (1)$$

$$Q_f = \prod_{i=1}^N (1 - P_{f,i}) \quad (2)$$

- $Q_m$  - overall probability of missed detection
- $Q_f$  - overall probability of false alarm
- $P_{d,i}$  - probability of detection in  $i$ th cognitive radio
- $P_{f,i}$  - probability of false alarm in  $i$ th cognitive radio

Complementary Receiver Operating Curve (CROC) which indicates the relationship between the probability of missed detection and the probability of false alarm of a sensing algorithm has been used to study the performance of sensing algorithms.

### 3.1 Performance over Rayleigh Fading

If the signal amplitude exhibits a Rayleigh distribution then the SNR follows an exponential PDF given by Equation (3)

$$f(\gamma) = \frac{1}{\gamma} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \gamma \geq 0 \quad (3)$$

The detection probability over Rayleigh Fading channel is given by<sup>2</sup> Equations (4)

$$P_{\text{dray}} = e^{-\frac{\lambda}{2}} \sum_{n=0}^{u-2} \frac{1}{n!} \left(\frac{\lambda}{2}\right)^n + \left(\frac{1+\bar{\gamma}}{\bar{\gamma}}\right)^{u-1} \left[ e^{-\frac{\lambda}{2(1+\bar{\gamma})}} - e^{-\frac{\lambda}{2}} \sum_{n=0}^{u-2} \frac{1}{n!} \left(\frac{\lambda\bar{\gamma}}{2(1+\bar{\gamma})}\right)^n \right] \quad (4)$$

Where  $u$  is the time bandwidth product,  $\gamma$  is the received SNR and  $\lambda$  is the decision threshold.

Figures 2 and 3 indicate the CROC plots for local sensing and cooperative sensing with different cooperating users respectively over Rayleigh fading channel.

### 3.2 Performance over Nakagami Fading

If the signal amplitude exhibits a Nakagami distribution then the PDF of SNR follows a gamma distribution given by Equation (5)

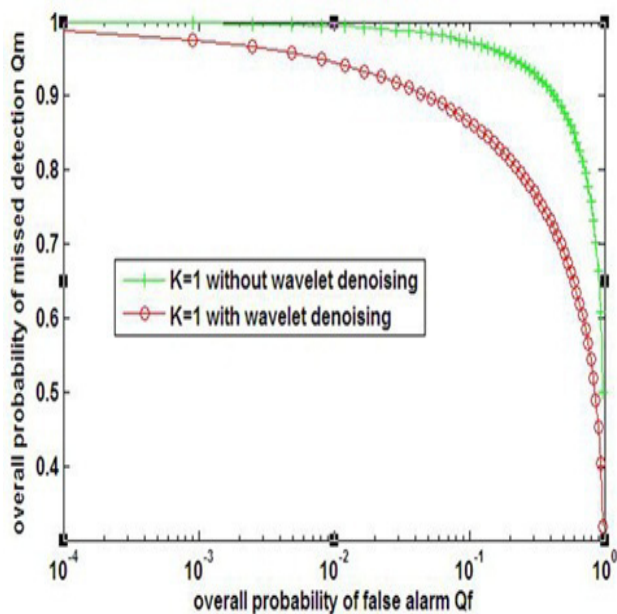


Figure 2. Local sensing performance over rayleigh fading channel.

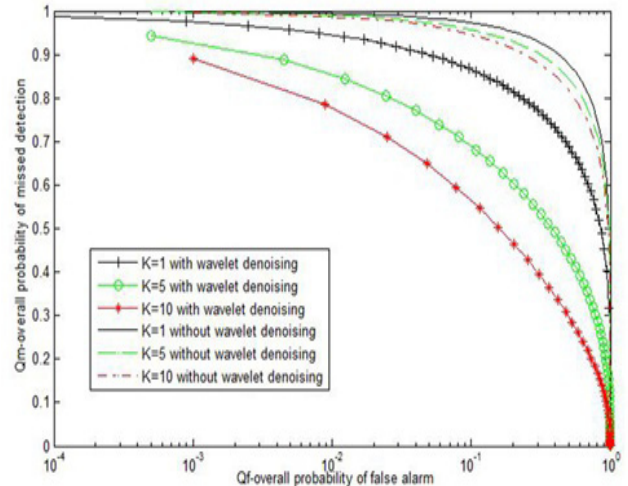


Figure 3. CSS performance over rayleigh fading sensing channel.

$$f(\gamma) = \frac{1}{\Gamma(m)} \left(\frac{m}{\bar{\gamma}}\right)^m \gamma^{m-1} \exp\left(-\frac{m}{\bar{\gamma}}\gamma\right) \gamma \geq 0 \quad (5)$$

The detection probability over Nakagami Fading channel is given by<sup>2</sup> Equations (6)

$$P_{\text{dnak}} = a \left[ G1 + \beta \sum_{n=1}^{u-1} \frac{\left(\frac{\lambda}{2}\right)^n}{2(n!)} F_1\left(m; n+1; \frac{\lambda}{2} \frac{\bar{\gamma}}{m+\gamma}\right) \right] \quad (6)$$

Where,  $a = \frac{1}{\Gamma(m)2^{m-1}} \left(\frac{m}{\bar{\gamma}}\right)^m$

$$\beta = \Gamma(m) \left(\frac{2\bar{\gamma}}{m+\gamma}\right)^m e^{-\frac{\lambda}{2}}$$

$$G1 = \frac{(m-1)!2^{m-1}}{\left(\frac{m}{\bar{\gamma}}\right)^m} \frac{\bar{\gamma}}{m+\gamma} e^{\frac{-\lambda m}{2m+\gamma}} \left[ \left(1 + \frac{m}{\bar{\gamma}}\right) \left(\frac{m}{m+\gamma}\right)^{m-1} \right]$$

$$L_{m-1} \left(\frac{\lambda m}{2m+\gamma}\right) + \sum_{n=0}^{m-2} \left(\frac{m}{m+\gamma}\right) L_n \left(-\frac{\lambda}{2} \frac{\bar{\gamma}}{m+\gamma}\right)$$

The local and global CROC plots are shown in Figures 4 and 5 respectively for Nakagami Fading Sensing Channel.

## 4. Throughput Analysis

The improvement in the achievable throughput of the secondary network due to WD has been analyzed.

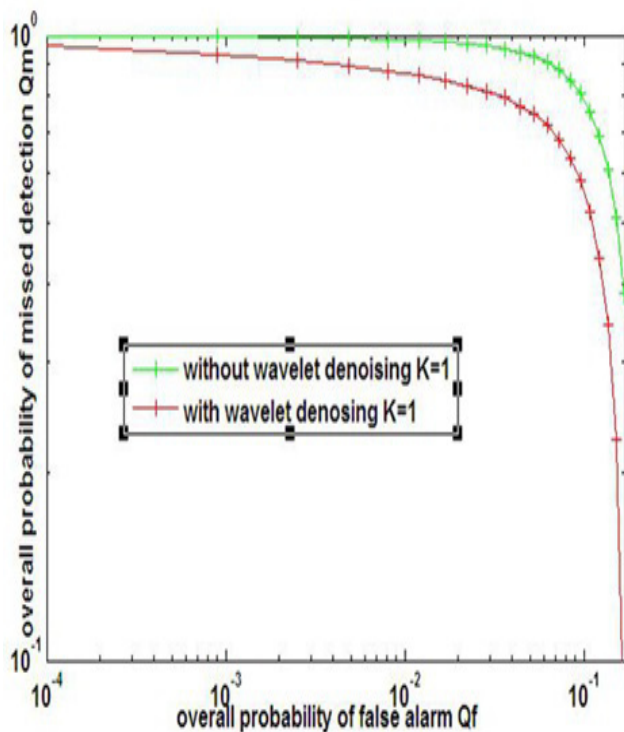


Figure 4. Local sensing performance over nakagami fading sensing channel.

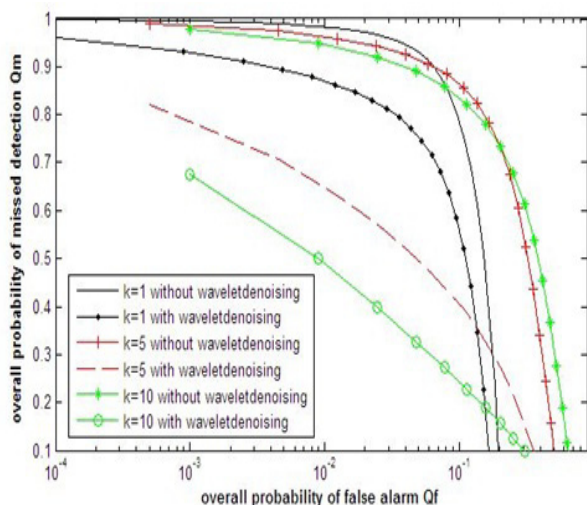


Figure 5. CSS performances over nakagami fading sensing channel with different k values.

Periodic sensing is carried out in the secondary network with frame duration of  $T$  ms in which  $T_s$  ms is for sensing the frequency channel and remaining  $(T-T_s)$  ms for data transmission if the channel is detected as idle without being used by the PUs.

The channel capacity for the secondary system is  $C_s = \log_2(1 + \text{SNR}_s)$

$\text{SNR}_s$  is the Signal to Noise Ratio of the secondary user. The probability that the SU can make data transmission during the time  $(T-T_s)$  is  $(1-P_f) * P(H_0)$  where  $P(H_0)$  is the probability of PU being idle in a given frequency channel. If the PUs requires 100% protection in its frequency band, then the throughput of the secondary system is expressed as shown in Equation (7)

$$R_s = (T-T_s)/T * C_s * (1-P_f) * P(H_0) \quad (7)$$

The Probability of False Alarm ( $P_f$ ) for a target Probability of Detection ( $P_d$ ) for energy detector is expressed as given in Equation (8)

$$P_f = Q\left(\sqrt{2\gamma+1} Q^{-1}(P_d) + \sqrt{T_s f_s \gamma}\right) \quad (8)$$

$Q$  is a monotonically decreasing function. When received SNR,  $\gamma$ , at CR is improved with WD,  $P_f$  decreases and hence throughput increases.

#### 4.1 Simulation Parameters

SNR for primary transmission  $\text{SNR}_p$  - -15dB

SNR for secondary transmission  $\text{SNR}_s$  - 20 dB

Frame duration  $T$  -100ms

$P(H_0)$  - 50%

Thus, the application of WD preceding ED increases SNR which in turn decreases the sensing time and hence the throughput of the secondary system is increased with WD as shown in Figure 6.

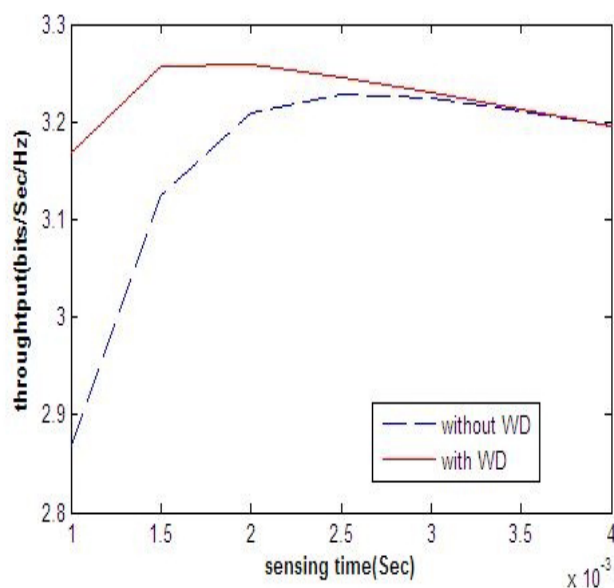


Figure 6. Sensing time Vs Throughput plot.

## 5. Results and Discussion

The combination of WD, ED and HD at the cooperating users and the OR fusion rule at the FC has greatly improved the detection performance, cooperative gain and throughput as proved in the above performance plots.

The cooperative gain obtained due to CSS has been given in Table 1 for both with WD and Without WD scenarios over Rayleigh Fading Channel. An increase in gain of 0.16 with  $K = 5$  and 0.23 with  $K = 10$  has been achieved. This signifies that higher the No. of cooperating users, better is the gain but at the cost of cooperation communication overhead.

The missed detection probabilities of the proposed scheme over the two fading channels have been compared with that of conventional method in Table 2. The improvement in the performance is 10% over Rayleigh Fading Channel and 23% over Nakagami Fading channel. The performance of the schemes degrades considerably under Rayleigh Fading Channel.

**Table 1.** Cooperative gain comparison for Rayleigh fading channel

No. of Users	Gain Without WD	Gain With WD
K=5	0.02	0.18
K=10	0.06	0.29

**Table 2.** Missed detection performance comparison

No. of cooperating users = 10		
Channel Model	$Q_m$ -Without WD	$Q_m$ -With WD
Rayleigh Fading	0.93	0.55
Nakagami Fading	0.7549	0.24

**Table 3.** Sensing time and throughput comparison

Parameters	without WD	with WD
Optimum Sensing Time(Sec)	0.0025	0.0015
Throughput (bits/Sec/Hz)	3.2283	3.2788

The sensing time and throughput have been compared for with WD and without WD cases Table 3. The throughput has been increased from 3.2283 to 3.2788 bps/Hz with wavelet denoising compared to conventional method. The optimal sensing time is 1.5 ms for the proposed scheme and 2.5 ms for the conventional scheme. Hence a reduction of 1ms has been observed with the incorporation of WD in the sensing method.

## 6. Conclusion

The application of WD for spectrum sensing using energy detector has been discussed. The performance of this in CSS scenario has been studied over Rayleigh Fading and Nakagami Fading channels. Significant reduction in probability of missed detection and sensing time and improvement in throughput have been achieved with this sensing technique as evidenced from the simulation results.

## 7. References

1. Akyildiz IF, Lo BF, Balakrishnan R. Cooperative spectrum sensing in cognitive radio networks: A Survey. *Physical Communication*. 2011; 4:40–62.
2. Digham FF, Alouini, MS and Simon MK. On the energy detection of unknown signals over fading channels. *IEEE Transactions on Communications*. 2007; 55 (1):21–4.
3. Spectrum Policy Task Force. Federal Communications Commission. 2009. Rep. ET Docket no. 02–135.
4. Wang H, Xu Y and Su X. Cooperative Spectrum Sensing with Wavelet Denoising in Cognitive Radio. *IEEE 71st Vehicular technology conference*; 2010.
5. Letaief KB Zhang W. Cooperative Communications for Cognitive Radio Networks. *Proceedings of the IEEE*. 2009; 97(5): 878–93.
6. Mitola J, Maguire GQ. Cognitive radio: Making software radios more personal. *IEEE Personal Communication*. 1999; 6: 13–8.
7. Sindhubargavi R, Sindhuand MY, Saravanan R. Spectrum sensing using energy detection technique for cognitive radio networks using PCA technique. *Indian Journal of Science and Technology*. 2014; 7(4S):40–5.