International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 2 | Pages 529-534 | e-ISSN: 2347-470X

Performance Estimation of Improved Cooperative Spectrum Sensing under Fading Environment

Jay Pandya[1*] and Divyesh Keraliya[2]

[1]*Research Scholar, Gujarat Technological University, Ahmedabad; jaypandya18@gmail.com*
[2]*Ph. D. Supervisor, Gujarat Technological University, Ahmedabad; drkeraliya@gmail.com*

***Correspondence:** Jay Pandya; jaypandya@gmail.com

ABSTRACT- To deal with spectrum scarcity, Cognitive radio has been considered as a resolving technology. Energy detection (ED) is the most preferable sensing technique due to its lower complexity, ease of working and non-dependency on primary user data requirements. Although having many advantages, ED has some practical limitations like low SNR, shadowing, erroneous reporting channels and multipath fading. Here, a comparative study is done to check the effect of such parameters. And with simulation, it is proven that Cooperative spectrum sensing can reduce the effect of these confines. In this paper, we have also simulated the improved version of ED where decision making is done cooperatively. The results show that the performance of Improved Energy Detection (IED) is more efficient than the Classical ED, not only for AWGN, but also under fading environment. Cooperative spectrum sensing enhances the performance further. Under fading environment, the majority logic with centralized fusion centre performs better than other techniques. In this paper the performance estimation of Improved Energy Detection technique is done under Rayleigh fading environment and the positive effect of cooperation is also evaluated considering erroneous reports and imperfect reporting channels.

Keywords: Spectrum Sensing, Fading Channels, Cooperative Spectrum Sensing, Energy Detection, Imperfect Reporting Channel.

ARTICLE INFORMATION

Author(s): Jay Pandya and Divyesh Keraliya;

Received: 17/03/2023; **Accepted**: 26/06/2023; **Published**: 30/06/2023;
e-ISSN: 2347-470X;
Paper Id: IJEER 1703-04;
Citation: 10.37391/IJEER.110240
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-11/ijeer-110240.html

Publisher's Note: FOREX Publication stays neutral with regard to Jurisdictional claims in Published maps and institutional affiliations.

1. INTRODUCTION

As we are aware that in recent era, the spectrum allocation is done at a moderate rate in comparison to the extraordinary expansion of wireless communication services with requirement of high data rates. This results in spectrum scarcity. The solution to this is to improve spectral efficiency of wireless technologies and to design more spectrally efficient wireless systems. But it is difficult and complex to design improved version of existing technologies. However, the observation of spectrum at different location and time indicates that some frequency bands are not fully utilized and there exists spectrum wastage in form of spectrum vacancies (holes). Spectrum utilization can be improved if secondary users are allowed to access the spectrum holes when primary users are not using the spectrum at specific given time and location [1-2]. In this process, the major concern is to make the harmful interference caused by the secondary users to primary users zero and for that, the presence of primary users should be sensed very effectively for the given band of spectrum.

From many spectrum sensing techniques proposed in literature, energy detection is one of the most acknowledged methods as it can be implemented without having any pre information of primary user signal. However, performance of this technique is affected by noise uncertainty and fading channels [1- 2]. Path loss, slow fading, fast fading, Doppler, delay and angle spreads are such parameters. Cooperative sensing can reduce the problems by analyzing the decisions made by multiple cooperative nodes in the network. At the same time, Improved Energy Detection (IED) technique can also enhance the performance under fading environment.

2. MATHEMATICAL MODEL

We consider the cooperative spectrum sensing model as shown in the *figure 1*, where the presence of primary user is sensed by multiple secondary users, also known as cognitive radios. The ED and IED have been considered as spectrum sensing techniques during the simulation.

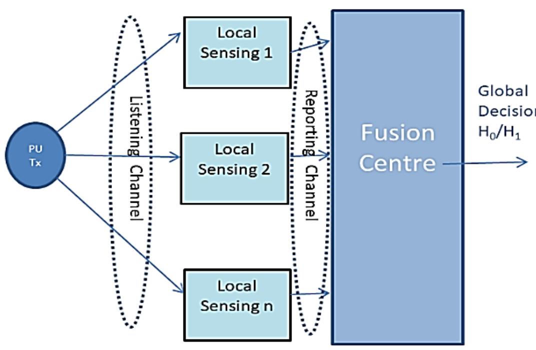


Figure 1: System Model of Cooperative Spectrum Sensing

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

2.1 Analysis over AWGN Channel

The Energy detector (cognitive radio) receives a signal from the channel under the observation, finds energy of it, compares it with threshold energy and finally identifies if primary user is absent or presence by identifying a hypothesis H_0 or H_1. Mathematically it can be represented by,

$$T_i(y_i) = \sum_{n=1}^{N} |y_i[n]|^2 \;\; > or < \;\; H_1 \; or \; H_0 \tag{1}$$

The performance of ED (or any spectrum sensing technique) can be evaluated by Probability of False Alarm P_{fa} and Probability of detection P_d [3-4]. These parameters can be indicated by,

$$P_{fa} = P(H_1/H_0) \tag{2}$$

$$P_{fa} = P(H_1/H_1) \tag{3}$$

To describe the process briefly, only the final outcome of the calculation is presented in the paper by referring [3 - 5]. The probabilities P_{fa} and P_d can be expressed as,

$$P_d^{CED} = Q\left(\frac{\lambda - N(\sigma_x^2+\sigma_w^2)}{\sqrt{2N(\sigma_x^2+\sigma_w^2)^2}}\right) \tag{4}$$

$$P_{fa}^{CED} = Q\left(\frac{\lambda - N(\sigma_w^2)}{\sqrt{2N\sigma_w^4}}\right) \tag{5}$$

The ED has advantage like low complexity and non-requirement of knowledge of primary signal, the performance degrades for lower value of sensing elements or for lower value of SNR or during fading effect. This motivates researchers to develop new versions of energy detectors that can reduce the limitations. This improved version is suggested in [6], in which to avoid the misdetection due to instantaneous energy drops, along with finding energy of received signal, last few sensing events are considered to find an average test statistic value. While making the decision, if the energy of received signal is less than the decision threshold, the average energy is also compared with threshold. If average energy is higher, it is assumed that a channel is busy but due to instantaneous energy drop, the free channel is identified erroneously. Thus, misdetections caused by instantaneous energy drop can be reduced. Reduction in misdetection increases the detection efficiency. In classical energy detection, false alarm probability also increases with detection probability. But in IED, one more check is included to decrease false alarm. In this step, the previous sensing event is compared with the threshold which reduces the chances of wrong decisions (false alarm probability). Thus, the IED performs better then ED considering both P_{fa} and P_d. The probabilities P_{fa} and P_d for IED can be expressed as,

$$P_d^{IED} = P\{T_i(y_i) > \lambda\}_{H1} + P\{T_i(y_i) \leq \lambda, T_i^{avg}(T_i) > \lambda, T_{i-1}(y_{i-1}) > \lambda\}_{H1}$$

$$= = P\{T_i(y_i) > \lambda\}_{H1} + P\{T_i(y_i) \leq \lambda\}_{H1} * P\left(T_i^{avg}(T_i) > \lambda\right) * P\{T_{i-1}(y_{i-1}) > \lambda\}_{H1} \tag{6}$$

$$P_{fa}^{IED} = P\{T_i(y_i) > \lambda\}_{H0} + P\{T_i(y_i) \leq \lambda, T_i^{avg}(T_i) > \lambda, T_{i-1}(y_{i-1}) > \lambda\}_{H0}$$

$$= P\{T_i(y_i) > \lambda\}_{H0} + P\{T_i(y_i) \leq \lambda\}_{H0} * P\left(T_i^{avg}(T_i) > \lambda\right) * P\{T_{i-1}(y_{i-1}) > \lambda\}_{H0} \tag{7}$$

Putting the values of probabilities for ED, *equation (6) and (7)* can be rewritten as

$$P_d^{IED} = P_d^{CED} + P_d^{CED}\left(1 - P_d^{CED}\right) * Q\left(\frac{\lambda - \mu_{avg}}{\sigma_{avg}}\right) \tag{8}$$

$$P_{fa}^{IED} = P_{fa}^{CED} + P_{fa}^{CED}\left(1 - P_{fa}^{CED}\right) * Q\left(\frac{\lambda - \mu_{avg}}{\sigma_{avg}}\right) \tag{9}$$

Where, μ_{avg} and σ_{avg}^2,

$$\mu_{avg} = \frac{M}{L} N(\sigma_x^2 + \sigma_w^2) + \frac{L-M}{L} N\sigma_w^2 \tag{10}$$

$$\sigma_{avg}^2 = \frac{M}{L^2} 2N(\sigma_x^2 + \sigma_w^2)^2 + \frac{L-M}{L^2} 2N\sigma_w^4 \tag{11}$$

Here, $M \in [0, L]$ indicates number of sensing events for which primary signal is present in real. For practical cases M is not known but can be restricted between 0 and L. M=L shows always busy channel and M=0 shows always idle channel considering previous L sensing events.

2.2 Analysis over Rayleigh Channel

If we consider the spectrum sensing scenario with scattering and effect of multipath fading, the signal amplitude follows Raleigh distribution where SNR should be considered exponential PDF. The probability of detection for Rayleigh channel can be expressed as [7 - 10],

$$P_d^{Ray} = exp\left(-\frac{\lambda'}{2}\right)\left[[1+\eta^2]^{u-1} \times \left\{exp\left(\frac{\lambda'}{(2+2\eta^2)}\right) - \sum_{k=0}^{u-2}\frac{1}{k!}\left(\frac{\lambda'}{(2+2\eta^2)}\right)^k\right\} + \sum_{k=0}^{u-2}\frac{1}{k!}\left(\frac{\lambda'}{2}\right)^k\right] \tag{12}$$

Where $u = N/2$, $\eta 2 = 2/$ (average SNR), $\lambda' = \lambda/\sigma_w^2$. Using *equation (8) and (9)* for P_d^{Ray} value obtained from (12), P_{dIED}^{Ray} can be obtained.

2.3 Cooperative Spectrum Sensing

Out of the two performance indices, the misdetection probability is considered more effective because it causes the interference with PU. Ideally a good sensing algorithm should provide lower false alarm probability and higher detection probability. Practically, many system parameters like channel uncertainty and multipath fading affect the performance of spectrum sensing.

When the sensing decision is made by a single CR (local sensing), due to multipath signals, shadowing or due to blocking by an obstacle /obstacles erroneous decision can be made. But in cooperative spectrum sensing, the final decision is made after considering the decisions of multiple CRs. As all CR users are facing diversified scenarios, it is unlikely that all CR experience same fading/multipath effect. Thus, overall spectrum sensing performance can be improved by using cooperative methods [8 - 9].

The cooperative action of CR users is classified in various techniques. Different cooperative models are based on how CR users are cooperating to have optimal spectrum sensing. Either the final decision is made at central fusion centre (centralized) or individual intelligent CRs take decision (distributed system). Again, the decision making process can be modelled as data fusion (soft combining) or decision fusion (hard combining) where each CR user sends complete signal or individual decisions in form of 1/0 to fusion centre respectively [8 - 9]. In this paper we have used the cooperation system model considering centralized fusion centre with both data fusion and decision fusion. Equal Gain Combiner (EGC) is a popular data fusion technique, where all received signals are provided equal weights (gains) and then coherently sent to the fusion centre. At fusion centre, they are compared with a common threshold and the final decision is made. While in decision fusion, the fusion centre makes final decision based on local sensing using any of the three rules: AND, OR or Majority rule [11].

If we consider *ui* as the local decision made by CR user *i* and the u as the centralized decision by cooperative system, AND rule suggests that the fusion centre decides $u = 1$ if $u_i = 1$ for all CRs. Same way for the OR rule, FC decides $u = 1$ if $u_i = 1$ for any one of the CRs. The *k* out on *N* rule decides $u = 1$ if $u_i = 1$ for *k* out of N CRs.

The false alarm probability and misdetection probability of cooperative spectrum sensing can be expressed as [11],

$$Q_f = \sum_{l=k}^{N} \binom{N}{l} P_f^l \left(1 - P_f\right)^{N-l} \tag{13}$$

$$Q_m = 1 - \sum_{l=k}^{N} \binom{N}{l} P_d^l \left(1 - P_d\right)^{N-l} \tag{14}$$

3. RESULTS AND DISCUSSION

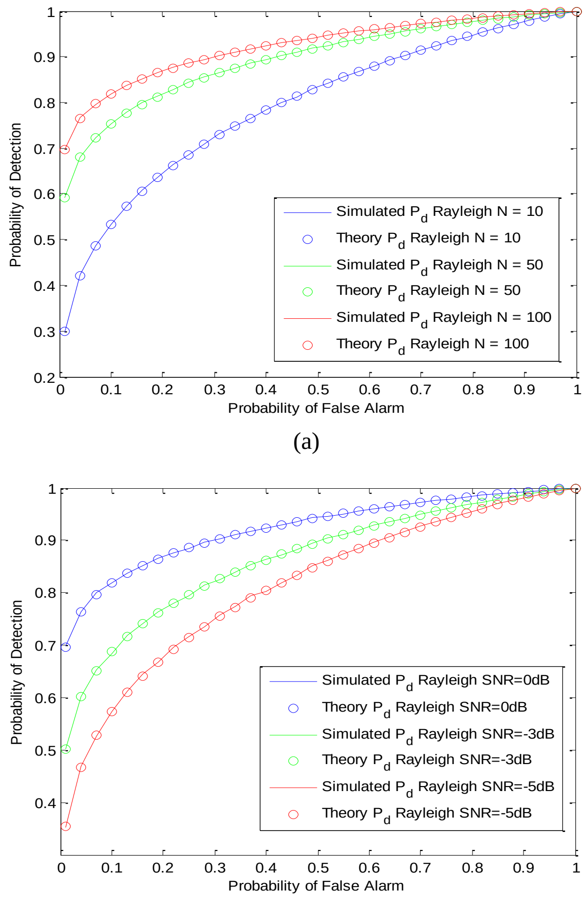
3.1 Performance Analysis of ED and IED on AWGN and Rayleigh Channels

MATLAB function of *Pd* is created using *equations (4), (5), (6), (7) and (12)* for observing the performance of ED and IED on both AWGN and Rayleigh fading channels as a function of parameters shown in the *table 1*. In this simulation, common threshold is determined using Constant False Alarm Rate (CFAR) technique.

Table 1: Parameters considered during ED and IED simulation

Parameter	Range under consideration
Number of Samples (N)	10, 50 and 100
SNR dB	-5dB to 0 dB
Probability of False Alarm (target)	0.01 to 1
Modulation Type	BPSK
Last Sensing Events L (for IED)	5
Number of Sensing events where primary signal is actually present (M)	0 to L
Channel	AWGN, Rayleigh Fading

ROC of ED is obtained as shown in *figure 2(a)* for different values of sample size (N = 10, 0 and 100) under Raleigh fading channel. It is observed that the performance of spectrum sensing improves with increment in sample size under same SNR. *Figure 2(b)* indicates the effect of SNR on the performance of ED. It is clearly observed that channel uncertainty due to multipath fading and shadowing deteriorate the performance.



(a)

(b)

Figure 2. Performance of ED under Rayleigh Channel (a) Effect of number of samples (SNR = 0 db) (b) Effect of SNR (number of samples =50)

The performance of ED and IED is measured over both AWGN and fading channel as shown in *figure 3*, and comparison shows that the spectrum sensing performance degrades for fading environment but at a same time, IED performs better for both AWGN and Raleigh channels.

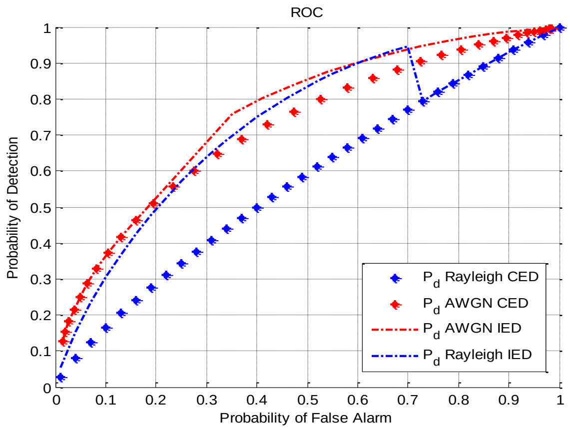


Figure 3: Comparison of ED and IED performance under AWGN and Rayleigh Channels

To identify the spectrum sensing improvement, the values of Pd is obtained for sample size = 1000, and various values of SNR, P_{fa} and IED parameter M. The results as shown in *table 2* indicates that the spectrum sensing using IED provides better results than classical method in every case. It is remarkable that or P_{fa} = 0.1 and SNR = - 12dB, CED provides P_d of 0.70 while IED provides better value of P_d = 0.87 (for M = 3). Similarly considering lower P_{fa} = 0.01, for SNR = -10dB, CED provides P_d = 0.78 while IED provides better P_d = 0.90.

Table 2: Comparison of ED and IED for different system parameters

SNR		P_{fa} = 0.1		P_{fa} = 0.01	
		P_d of CED	Pd of IED	Pd of CED	P_d of IED
-10dB	M=0	0.95	0.95	0.78	0.78
	M=1		0.96		0.80
	M=2		0.98		0.80
	M =3		1		0.90
-12dB	M=0	0.70	0.70	0.35	0.35
	M=1		0.72		0.35
	M=2		0.75		0.35
	M=3		0.87		0.35

3.2 Performance analysis of Various Cooperative spectrum sensing under channel uncertainty

The performance of both hard (OR, majority) and soft (EGC) cooperative spectrum sensing techniques are simulated and compared with no cooperative system on a same platform for various system parameters. For the cooperative scenario, following parameters as per *table 3* are set

Table 3: Parameters considered during cooperative spectrum sensing simulation

Parameter	Range under consideration
Number of CR Users	10
SNR dB	5 dB
$P_{f,\ target}$	0.00001 to 0.1
Channel	AWGN, Rayleigh Fading

Figure 4 shows ROC curves for various cooperative decision strategies on Raleigh fading channel. It shows that the performance without cooperation is worst amongst all. EGC performs the best but in this technique, it is required to send complete CR signals to the fusion centre, which increases the resource constraints. OR and majority schemes performs almost equally, but OR has a higher hand.

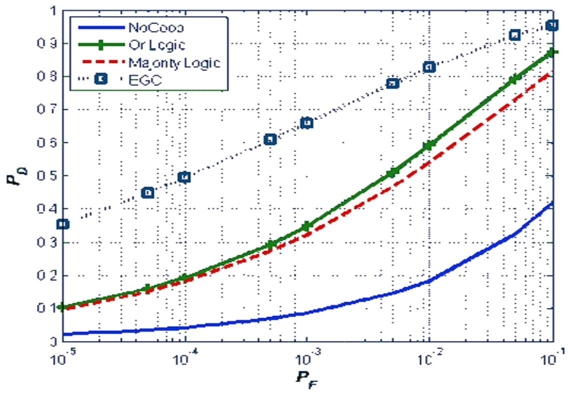
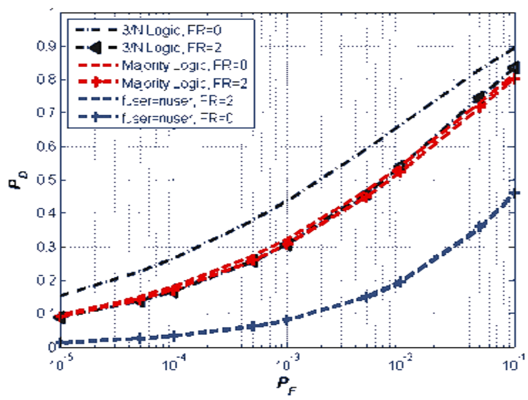


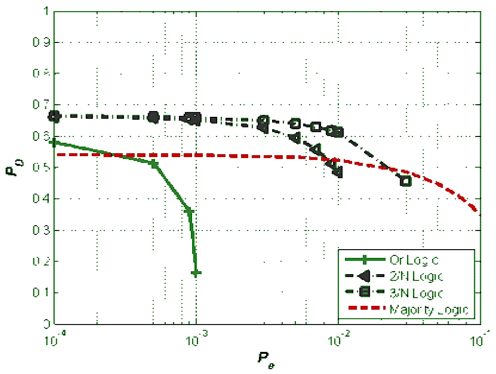
Figure 4: Comparison of different decision logics under Rayleigh Channel

The performance is also evaluated considering false reporting in cooperative system to compare robustness of various decision logics. *Figure 5(a)* indicates the effect of false reporting under perfect reporting channel. Two false reports are indicated by FR = 2 and no false reports (ideal condition) is indicated FR = 0. Under this consideration, 3/N logic (immediate to OR) has the most adverse effect in all while majority logic is less affected. If we increase the number of cooperative nodes, robustness against false reporting can be increased. By evaluating different decision logics over imperfect reporting channels, as shown in the *figure 5(b)*, it can be observed that majority logic is the most robust technique amongst all decision fusion systems.



(a)

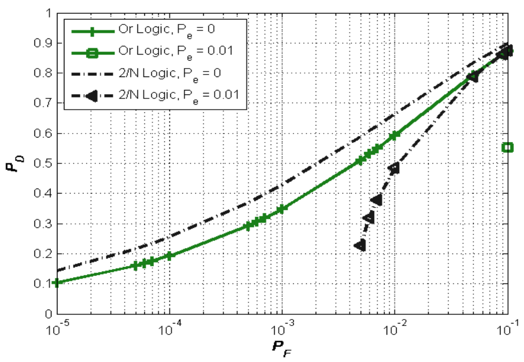
International Journal of
Electrical and Electronics Research (IJEER)
Open Access | Rapid and quality publishing
Research Article | Volume 11, Issue 2 | Pages 529-534 | e-ISSN: 2347-470X



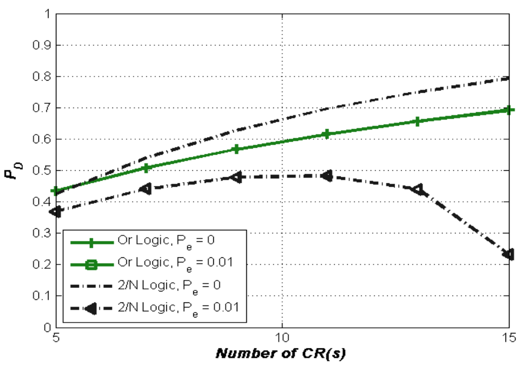
(b)

Figure 5: Performance evaluations of decision logics (a) under false reports (b) under imperfect reporting channels

In next evaluation, imperfect reporting channel is considered with zero false reporting. ROC curve in *figure 6(a)* indicates that under imperfect channel scenario (error probability is considered P_e = 0.01), performance of OR logic is not satisfactory. The smallest achievable P_f value is 0.1. Improvement in performance can be observed at higher SNR, but yet OR logic has the same limitation at higher SNR also. Finally, effect of number of CR users and error probability on P_d is evaluated. As shown in *figure 8*, P_d increases with the number of cooperative users. But in case of 2/N logic, performance degrades because 2/N scheme takes decision based on any two CR's decision, and probability of having two errors out of two deciding nodes increase with increment in number of nodes.



(a)



(b)

Figure 6: Performance evaluations of decision logics under imperfect reporting channels (a) ROC (b) Effect of number of *CRs* on P_d

4. CONCLUSION

To deal with the performance limitations associated with fading environment and to improve robustness of spectrum sensing considering noise uncertainty, IED based cooperative sensing is used. Various hard and soft decision-making logics are simulated and analyzed with respect to CED for different number of cognitive radios in the network, SNR values, false reporting and erroneous reporting channels. Performance of majority logic is more robust than or logic under false reporting nodes and also with erroneous reporting channel. The results show that like over AWGN channel, IED technique is able to outperform the classical ED while maintaining the complexity level and general applicability even over Rayleigh fading channel.

REFERENCES

[1] S. Haykin, "Cognitive radio: brain-empowered wireless communications," in IEEE Journal on Selected Areas in Communications, vol. 23, no. 2, pp. 201-220, Feb. 2005, doi: 10.1109/JSAC.2004.839380.

[2] Ian F. Akyildiz, Brandon F. Lo, Ravikumar Balakrishnan, Cooperative spectrum sensing in cognitive radio networks: A survey, Physical Communication, Volume 4, Issue 1, 2011, Pages 40-62, ISSN 1874-4907, https://doi.org/10.1016/j.phycom.2010.12.003.

[3] V. I. Kostylev, "Energy detection of a signal with random amplitude," 2002 IEEE International Conference on Communications. Conference Proceedings. ICC 2002 (Cat. No.02CH37333), New York, NY, USA, 2002, pp. 1606-1610 vol.3, doi: 10.1109/ICC.2002.997120.

[4] F. F. Digham, M. -S. Alouini and M. K. Simon, "On the Energy Detection of Unknown Signals Over Fading Channels," in IEEE Transactions on Communications, vol. 55, no. 1, pp. 21-24, Jan. 2007, doi: 10.1109/TCOMM.2006.887483.

[5] Kumar, Sandeep. "Performance of ED based spectrum sensing over α–η–μ fading channel." Wireless Personal Communications 100.4 (2018): 1845-1857.

[6] López-Benítez, Miguel, and Fernando Casadevall. "Improved energy detection spectrum sensing for cognitive radio." IET communications 6.8 (2012): 785-796.

[7] Huang, He, and Chaowei Yuan. "Cooperative spectrum sensing over generalized fading channels based on energy detection." China Communications 15.5 (2018): 128-137.

[8] Al Hammadi, Ahmed, et al. "Unified analysis of cooperative spectrum sensing over composite and generalized fading channels." IEEE Transactions on Vehicular Technology 65.9 (2015): 6949-6961.

[9] Nallagonda, Srinivas, Sanjay Dhar Roy, and Sumit Kundu. "Performance of Cooperative spectrum sensing in Log-normal Shadowing and Fading under Fusion rules." International Journal of Energy, Information and Communications 3.3 (2012): 15-28.

[10] Ranjeeth, M., and S. Anuradha. "Performance of fading channels on energy detection based spectrum sensing." Procedia Materials Science 10 (2015): 361-370.

[11] Birkan Yilmaz, H., Tuna Tugcu, and Fatih Alagoz. "Novel quantization-based spectrum sensing scheme under imperfect reporting channel and false reports." International Journal of Communication Systems 27.10 (2014): 1459-1475.

[12] Altrad, Omar, and Sami Muhaidat. "A new mathematical analysis of the probability of detection in cognitive radio over fading channels." EURASIP Journal on Wireless Communications and Networking 2013.1 (2013): 1-11.

[13] Keraliya, D., and K. Ashalata. "Minimizing the Detection Error in Cooperative Spectrum Sensing Using Teaching Learning Based Optimization (TLBO)." International Journal of Engineering Research & Technology (IJERT) 6.2 (2017): 495-500.

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Issue 2 | Pages 529-534 | e-ISSN: 2347-470X

[14] Shukla, Shashwat, and Z. Vakil. "Minimization of error rate for cooperative spectrum sensing in cognitive radio networks." 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI). IEEE, 2017.