Journal of Scientific & Industrial Research
Vol. 80, March 2021, pp. 239-244

Energy Detector Based Spectrum Sensing Performance Analysis over Fading Environment

Brijesh Kumar Singh and Mainak Mukhopadhyay*
Electronics and Communication Engineering Department, Birla Institute of Technology, Mesra, Ranchi 835 215

Received 21 August 2020; revised 21 January 2021; accepted 06 February 2021

Energy detection approach for sensing of spectrum is an extremely effective method of detection in comparison of other spectrum sensing methods when secondary user lacks adequate knowledge of primary user's channel conditions. Because of multipath propagation and shadowing effects, performance of energy detector employed in a cognitive radio system is severely influenced. In this paper, we have evaluated performance of energy detector over fading environment. Hypothesis testing was utilized for spectrum sensing to find out whether the primary user's signal was available or missing. Performance assessment for spectrum sensing using the energy detector was carried out primarily on the basis of probability of false alarm and probability of detection. We have examined the impact of SNR on probability of detection in order to assess the performance of spectrum sensing using energy detector. Also the receiver operating characteristic curve was plotted for performance analysis of spectrum sensing employing energy detector. In addition, we also examined the impact of threshold value on the probability of the false alarm. We have found that probability of detection improves when we increase the value of signal to noise ratio and use more number of samples. We have also observed that false alarm probability decreases when we increase the threshold value.

Keywords: Cognitive radio, Detection probability, False alarm probability, Receiver Operating Characteristic, SNR

Introduction

To detect unknown signal is very important task for many applications such as cognitive radio, CSMA network and RADAR systems. It is also supposed to be helpful in many new wireless networks technologies, for example for vehicle to vehicle communications, and application based on IoT where several devices are supposed to do sensing to communicate with one another. Due to this reason, a variety of detection strategies such as detection using matched filter, energy detection and cyclostationary feature detection were introduced. Energy detection approach for sensing of spectrum is an extremely effective method of detection in comparison of other spectrum sensing methods when secondary user lacks adequate knowledge of primary user's channel conditions. To assess signal of primary user, energy detector precisely calculates the energy level of obtained signal and then comparison is made with a specified threshold. Energy detector has received a lot of popularity due to its simplicity of execution, and is frequently used. Various surveys indicate that the strategy of static spectrum allocation results in inefficient use of bandwidth. Cognitive radio[1,2] allow use of irregular intervals of unused frequency bands, known as spectrum holes. After using spectrum holes identified by sensing of spectrum, we can achieve higher spectral efficiency.[1–4] There are two goals of spectrum sensing. First goal is that cognitive users should not create interference to primer users. Second goal is that cognitive users should effectively locate and utilize the spectrum holes. Using cooperative sensing, quality of detection can be significantly enhanced. Cooperative sensing[5,7] is an appealing and effective solution to address problems of fading. Detection efficiency is not enhanced by improving receiver sensitivity if the primary user signal SNR is less than a certain amount and this value is known as the SNR wall.[8] Cooperative sensing will considerably alleviate the sensitivity need and the hardware constraint problems. Although cooperative benefit can be accomplished in cooperative spectrum sensing, there are several factors that can restrict the achievable cooperative benefit. The aspects of the cooperation process, cooperative benefit, and cooperation overhead must be resolved in each cooperative sensing system. Sensing of spectrum is a significant task that is done by cognitive radio systems. This enables the secondary user to determine

*Author for Correspondence
E-mail: mainak@bitmesra.ac.in

whether or not to transmit in primary user's band.[9–13] There are various kinds of schemes for detection of energy for spectrum sensing.[14]

In frequency selective channels and under noise uncertainty, sub-band energy detection works very well.[15] To address problems that occur due to fading, cooperative spectrum sensing based on relay can be used.[16] It has been established that even with very small changes in fading severity, there is significant degradation in the performance of energy detector.[17] For accurate detection of OFDM type primary user, spectrum sensing method based on Sparse frequency domain can be used.[18] To access usable bandwidth, cognitive radio is an excellent thing for wireless networks in case of IoT.[19] By utilizing multi-user diversity, cooperative spectrum detection method can be used to solve issue of multipath fading and shadowing.[20] Energy detector approach can be used for improvement of tradeoff among probability of false alarm, probability of detection, and obtainable throughput.[21] Spectrum sensing method based on generalized order statistics (GOS) can be used to assess the accurate false alarm probability and detection probability under noise uncertainty[22]. For performance assessment of a centralized cooperative spectrum sensing, influence of various impulsive noise conditions can also be taken into consideration.[23] To optimize threshold value for Rayleigh fading channel, dynamic threshold dependent energy detection method can be used.[24] For utilizing spectrum in optimal way, NC-OFDM/OQAM system can be used after reducing PAPR with the help of available superior algorithm.[25] Remaining part of this paper is organized as follows. We have discussed hypothesis testing and spectrum sensing using energy detector over fading channel. Further, we have covered result and discussion and finally, we have concluded this paper.

Hypothesis testing

For sensing of spectrum, various hypotheses testing such as binary hypothesis testing, composite hypothesis testing and sequential testing is done. Neyman Pearson test and Bayes test comes under binary hypothesis testing. In case of Neyman-Pearson test, detection probability P_d is maximized for constraints of $P_f \le \alpha$ where P_f is false alarm probability and maximum value of false alarm probability is given by α. Neyman Pearson test is equivalent to LRT and this test is expressed as

$$\wedge(y) = \frac{f(y|H_1)}{f(y|H_0)} = \prod_{k=1}^{N}\left(\frac{f(y_k|H_1)}{f(y_k|H_0)}\right) \underset{H_0}{\overset{H_1}{\gtrless}} \lambda \quad \ldots (1)$$

Here, $\wedge(y)$ represents LR, $f(y|H_j)$ represents distribution for observation y with H_j, $j \in \{0, 1\}$, detection threshold is given by λ. Detector conveys H_1 when $\wedge(y) > \lambda$ else conveys H_0. Expected cost in Bayes test is called Bayes Risk. Bayes Risk is represented by[26]

$$R = \sum_{i=0}^{1}\sum_{j=0}^{1} C_{ij} P(H_i|H_j)P(H_j) \quad \ldots (2)$$

Here, C_{ij} is the cost function. So, we can say that Bayes risk is summation of possible combination of all costs. From the knowledge of $P(H_i)$, LRT is expressed by

$$\wedge(y) = \left(\frac{f(y|H_1)}{f(y|H_0)}\right) \underset{H_0}{\overset{H_1}{\gtrless}} \left(\frac{P(H_0)(C_{10}-C_{00})}{P(H_1)(C_{01}-C_{11})}\right) = \lambda \quad \ldots (3)$$

Bayes risk can be minimized by declaring H_1 by detector when $\wedge(y) > \lambda$ and declaring H_1 otherwise.

In case of binary hypothesis test, distribution for both hypotheses is available. In case of unknown parameters of probability density functions, composite hypotheses test can be used. There are various approaches for composite hypotheses test and generalised likelihood ratio test is one of those approaches. In case of generalised likelihood ratio test, prior knowledge of unknown parameters is not required. In generalised likelihood ratio test, maximum likelihood estimates are used to evaluate unknown parameters. Generalised likelihood ratio test is reliable and simple to execute although it is not an optimal test. In cooperative sensing, generalised likelihood ratio test (LRT) is extracted for cyclostationary identification.[27] Locally most powerful test and Rao test can be used for identifying weak primary user signals.[28] Maximum likelihood estimates of unspecified parameter are not required in Rao test and it is asymptotically similar to generalised likelihood ratio test. For spectrum sensing, linear composite hypothesis test can also be used.[29] For unidentified primary user, linear test statistics are generated. Once channel statistics are available, the locally most powerful detector's test statistics are determined as well. In

Neyman-Pearson based likelihood ratio testing, sensing time is fixed because of fixed number of samples needed for testing SPRT can reduce time of sensing according to efficiency constraints of detection.[30] In sequential probability ratio test, samples are obtained in a sequential fashion and comparison of test statistics is done with two threshold values λ_0 and λ_1, $\lambda_0 < \lambda_1$ decided by requirements of detection. For likelihood ratio is higher than λ_1, we go for H_1 otherwise H_0. The key benefit of sequential probability ratio test (SPRT) is that to obtain the same detection efficiency, it needs a smaller number of samples on average than those fixed-sample techniques. Sequential probability ratio test's drawback is cost of collecting samples and the likely huge number of samples necessary to make the judgment leading to a longer sensing time.[31] Sequential detection strategy with sequential probability ratio test can also be used for cooperative sensing.[32,33] In this approach, a collaborative decision is made.

Spectrum sensing using energy detector over fading channels

Detection efficiency of energy detector can be evaluated primarily on the grounds of two criteria: P_f and P_d . P_f express the probability of presence of primary user although actually, it does not occupy the band. P_d express probability of actual presence of primary user. Since detection failure causes interference with the primary user and there is reduction in spectral efficiency because of false alarm, requirement is that P_d is optimal according to P_f constraints. Evaluation of performance for sensing methods is done by curve obtained from the plot of P_d with respect to P_f and this curve is called receiver operating characteristics curve. Several conditions like multipath fading, shadowing, and the issue of receiver uncertainty can substantially degrade the detection efficiency during spectrum sensing.[1]

One of the components in the structure of energy detector is integrator and pdf of the integrator output is represented as[34]

$$f_Y(y) = \begin{cases} \dfrac{1}{2^u \Gamma(u)} y^{u-1} e^{-y/2} & H_0 \\ \dfrac{1}{2}\left(\dfrac{y}{2\gamma}\right)^{\frac{u-1}{2}} e^{-\frac{2\gamma+y}{2}} I_{u-1}\left(\sqrt{2\gamma y}\right) & H_1 \end{cases} \quad \dots (4)$$

Here, γ represents signal to noise ratio and u represents time bandwidth product. $\Gamma(.)$ represents gamma function expressed by

$$\Gamma(a) = \int_0^\infty r^{a-1} e^{-r} dr \quad \dots (5)$$

P_d and P_f are evaluated with the help of cdf of non-central and central distributions of chi-square[34,35] and are given below.

$$P_f = \frac{\Gamma(m, \lambda/2)}{\Gamma(m)} \quad \dots (6)$$

$$P_d = Q_m\left(\sqrt{2m\gamma}, \sqrt{\lambda}\right) \quad \dots (7)$$

Here, $\Gamma(-,-)$ and $Q_m(-,-)$ are expressed by

$$\Gamma(a,b) = \int_b^\infty r^{a-1} e^{-r} dr \quad \dots (8)$$

$$Q_m(a,b) = \int_b^\infty \frac{x^m}{a^{m-1}} e^{-\frac{x^2+a^2}{2}} I_{m-1}(ax) dx \quad \dots (9)$$

P_f is independent of conditions of fading. Detection probability P_d depends on value of instantaneous SNR γ and is represented as[34]

$$P_d = \int Q_m(\sqrt{2m\gamma}, \sqrt{\lambda}) f(x) dx \quad \dots (10)$$

Here, $f(x)$ represents pdf of SNR under fading model. For urban and rural environments, there are numerous kinds of fading models. For multipath propagation in urban environments, Nakagami fading model is suitable. In the absence of line of sight communication in urban environment, when signal is obtained after several reflections then suitable model of fading is Rayleigh. Rician fading channel is used for the situation where line of sight connectivity is possible but still signal is having multipath interference.[36]

Results and Discussion

Energy detection approach for sensing of spectrum is an extremely effective method of detection in comparison of other spectrum sensing methods when secondary user lacks adequate knowledge of primary user's channel conditions. Detection efficiency of energy detector can be evaluated with the help of parameters such as P_d and P_f. Here, P_d express probability of actual presence of primary user. P_f express the probability of presence of primary user although actually, it does not occupy the band. Since detection failure causes interference with the primary user and there is reduction in spectral efficiency because of false alarm, requirement is that P_d is optimal according to P_f constraints. Evaluation of performance for sensing methods is done by curve obtained from the plot of P_d with respect to P_f and this curve is called receiver operating characteristics (ROC) curve. For evaluation of performance for sensing methods, complementary receiver operating characteristics curve can also be plotted. When probability of miss detection P_m is plotted with respect to P_f then this curve is named as complementary receiver operating characteristics curve. P_m is defined as $P_m = 1 - P_d$.

In Fig. 1 and Fig. 2, we have obtained plot of P_d w.r.t. SNR when there are 512 and 1024 samples respectively. From these two plots, it can be said that as we increase value of SNR, detection probability increases. After comparing Fig. 1 and Fig. 2, it is clear that for any particular value of SNR, when we have increased number of samples from 512 to 1024 then detection probability has improved. We have also done simulation and from Fig. 1 and Fig. 2 both, it is clear that theoretical values of detection probability for energy detector with respect to SNR are in good agreement with the simulated results.

In Fig. 3 and Fig. 4, ROC curve for energy detector has been plotted when number of samples are 512 and 1024 respectively. After comparing receiver operating characteristic curve inFig. 3 and Fig. 4, it is clear that for any particular value of P_f , there is improvement in detection probability if we increase number of samples from 512 to 1024. We have also done simulation for receiver operating characteristic curve and from Fig. 3 and Fig. 4 both, it is clear that theoretical plots of receiver operating characteristic curve are in good agreement with the simulated results.

In Fig. 5 and Fig. 6, we have obtained plot of false alarm probability P_f with respect to threshold value of energy detector. From these two figures, it is clear that

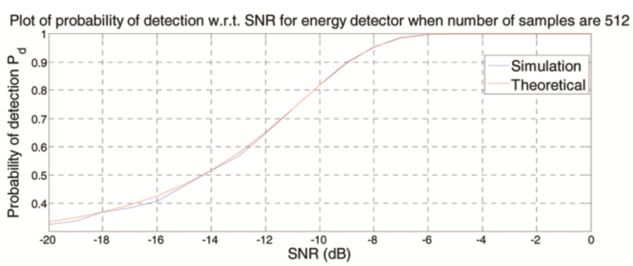

Fig. 1 — Plot of detection probability P_d with respect to SNR for energy detector when number of samples are 512

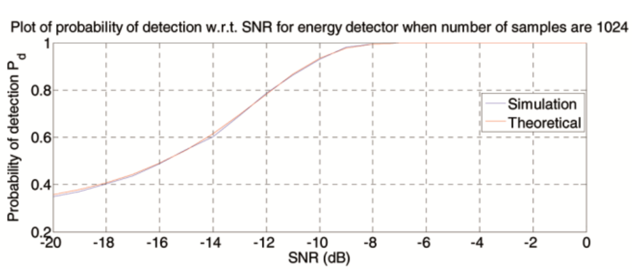

Fig. 2 — Plot of detection probability P_d with respect to SNR for energy detector when number of samples are 1024

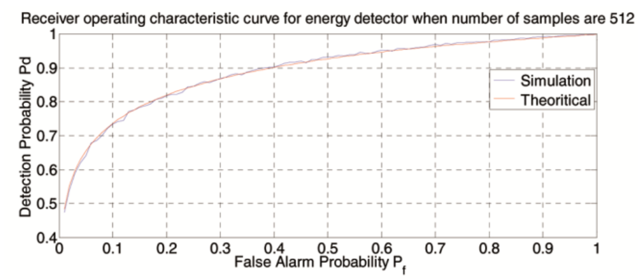

Fig. 3 —Plot of ROC curve for energy detector when number of samples are 512

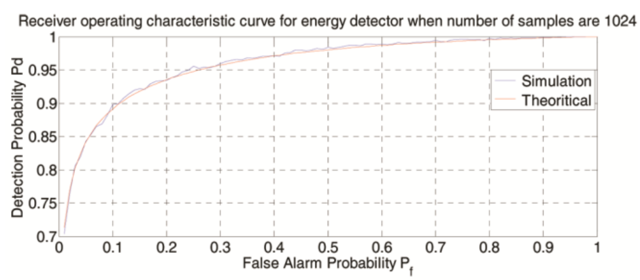

Fig. 4 — Plot of ROC curve for energy detector when number of samples are 1024

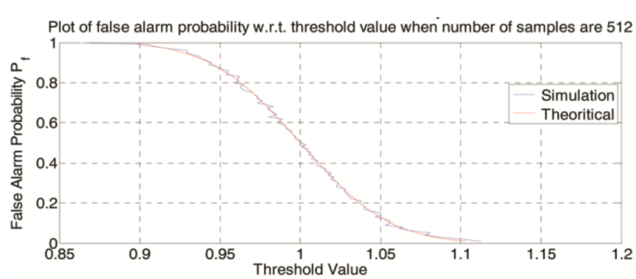

Fig. 5 —Plot of probability of false alarm P_f with respect to threshold value for energy detector when number of samples are 512

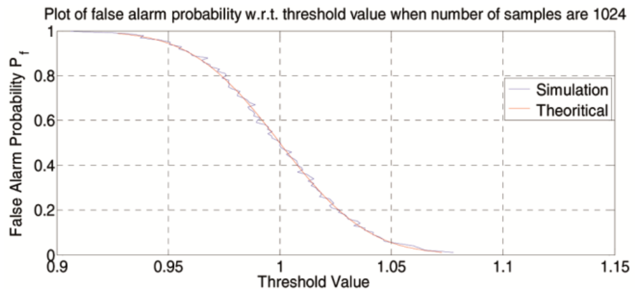

Fig. 6 — Plot of probability of false alarm P_f with respect to threshold value for energy detector when number of samples are 1024

value of P_f decreases as we increase threshold value of the energy detector.

We have also done simulation and observed from Fig. 5 and Fig. 6 that theoretical values of false alarm probability with respect to threshold value of energy detector are in good agreement with simulated result.

Conclusions

This paper presents energy detector's performance analysis over fading environment. Energy detection approach for sensing of spectrum is an extremely effective method of detection in comparison of other spectrum sensing methods when secondary user lacks adequate knowledge of primary user's channel conditions. For spectrum sensing, hypothesis testing was used to determine if signal of the primary user was present or absent. Evaluation of performance for sensing of spectrum using energy detector was performed mainly on the basis of two factors: false alarm probability and detection probability. It has been found that the detection probability value becomes higher as we enhance the SNR values. Detection probability also enhances if we use more samples. For analysis of performance of energy detector, we have also obtained receiver operating characteristic curve. When we use more number of samples then also, there is improvement in detection probability for any particular value of false alarm probability. It has been claimed that false alarm probability changes depending on energy detector's threshold value. False alarm probability value has reduced with the enhancement in the energy detector's threshold value.

References

1 Akyildiz I F, Lee W Y, Vuran M C & Mohanty S, Next generation/dynamic spectrum access/cognitive radio wireless networks: a survey, *Computer Networks* **50(13)** (2006) 2127–2159.

2 Akyildiz I F, Lee W Y & Chowdhury K R, CRAHNs: cognitive radio ad hoc networks, *Ad Hoc Networks* **7(5)** (2009) 810–836.

3 Ma J, Li G & Juang B H, Signal processing in cognitive radio, *Proceedings of the IEEE* **97(5)** (2009) 805–823.

4 Yucek T & Arslan H, A survey of spectrum sensing algorithms for cognitive radio applications, *Communications Surveys Tutorials, IEEE* **11(1)** (2009) 116–130.

5 Cabric D, Mishra S &Brodersen R, Implementation issues in spectrum sensing for cognitive radios, *Proc. Of Asilomar Conf. on Signals, Systems, and Computers*, vol. 1, (2004) 772–776.

6 Ghasemi A, &Sousa E, Collaborative spectrum sensing for opportunistic access in fading environments, *Proc. of IEEE DySPAN* , (2005) 131–136.

7 Mishra S, Sahai A &Brodersen R, *Cooperative sensing among cognitive radios, Proc. of IEEE ICC*, vol. 4, (2006) 1658–1663.

8 Tandra R & Sahai A, SNR walls for signal detection, *IEEE Journal of Selected Topics in Signal Processing* **2(1)** (2008) 4–17.

9 Kaabouch A & Hu W C, Handbook of Research on Software-Defined and Cognitive Radio Technologies for Dynamic Spectrum Management, *IGI Glob J*, (2014).

10 Yucek T & Arslam H, A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications, *Proc IEEE*, **97** (2009) 805–823.

11 Salahdine F, Kaabouch N & Ghazi H E, A Real Time Spectrum Scanning Technique based on Compressive Sensing for Cognitive Radio Networks, *The 8th IEEE Annual Ubiquitous Computing, Electronics & Mobile Commun Conf* (2017) 1–6.

12 Yucek T & Arslam H, A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications, *IEEE Commun Surv Tutorials*, **11(1)** (2009) 116–130.

13 Lu L, Zhou X, Onunkwo U & Li G, Ten years of research in spectrum sensing and sharing in cognitive radio, *EURASIP J Wirel Commun Netw*, **2012(1)** (2012) 28.

14 Shukla S, Rao A K & Srivastava N, A survey on energy detection schemes in cognitive radios, *Proc ICETEESES* 2016, 223–228.

15 Dikmese S, Sofotasios P C, Renfors M & Valkama M, Subband energy based reduced complexity spectrum sensing under noise uncertainty and frequency-selective spectral characteristics, *IEEE Trans Signal Process*, **64(1)** (2016) 131–145.

16 Sardana M & Vohra A, Analysis of different spectrum sensing techniques, *Proc Comptelix*, (2017) 422–425.

17 Sofotasios P C, Bagheri A , Tsiftsis T A, Freear S, Shahzadi A & Valkama M, A comprehensive framework for spectrum sensing in non-linear and generalized fading conditions, *IEEE Transactions on Vehicular Technology*, **66(10)** (2017) 8615–8631.

18 Dikmese S, Ilyas Z, Sofotasios P C, Renfors M & Valkama M, Sparse frequency domain spectrum sensing and sharing based on cyclic prefix autocorrelation, *IEEE J Sel Areas Commun*, **35(1)** (2017) 159–172.

19 Li Z, Chang B, Wang S, Liu A, Zeng F & Luo G, Dynamic compressive wide-band spectrum sensing based on channel energy reconstruction in cognitive internet of things, *IEEE Transactions on Industrial Informatics*, **14(6)** (2018) 2598–2607.

20 Yawada P & Trung M, Performance Analysis of New Spectrum Sensing Scheme Using Multiantennas

with Multiuser Diversity in Cognitive Radio Networks, *Wireless Communications and Mobile Computing*, 2018.

21 Huang H, Zhu J & Mu J, A Novel Sensing Strategy Based on Energy Detector for Spectrum Sensing, *Applied Sciences*, **9(21)** (2019) 4634.

22 Kim C, Jin E, Cheon K & Kim S, Robust spectrum sensing under noise uncertainty for spectrum sharing, *ETRI Journal*, **41(2)** (2019) 176–183.

23 Ghamry W & Shukry S, Performance evaluation of cooperative eigenvalue spectrum sensing GLRT under different impulsive noise environments in cognitive radio, *Computer Communications*, **160** (2020) 567–576.

24 Verma P, Adaptive Threshold Based Energy Detection over Rayleigh Fading Channel, *Wireless Personal Communications*, **29** (2020) 1–3.

25 Renuka N&Sairam M S, Improved tone reservation PAPR reduction algorithm in NC-OFDM/OQAM system, *Arabian Journal for Science and Engineering*, **43(8)** (2018) 4347–4352.

26 Akyildiz I F, Brandon F L & Balakrishnan R, Cooperative spectrum sensing in cognitive radio networks: A survey, *Physical communication*, **1** (2011) 40–62.

27 Lundén J, Koivunen V, Huttunen A & Poor H V Collaborative cyclostationary spectrum sensing for cognitive radio systems, *IEEE Transactions on Signal Processing*, **57(11)** (2009) 4182–4195.

28 Wald A, *Sequential Analysis*, John Wiley & Sons. New York, (1947).

29 Blum R S, Kassam S A & Poor H V, Distributed detection with multiple sensors II, *Advanced topics. Proceedings of the IEEE*, **85(1)** (1997) 64–79.

30 Zou Q, Zheng S &Sayed A H, Cooperative spectrum sensing via sequential detection for cognitive radio networks, *IEEE 10th Workshop on Signal Processing Advances in Wireless Communications* (2009) 121–125.

31 Zou Q, Zheng S & Sayed A H, Cooperative sensing via sequential detection, *IEEE Transactions on Signal Processing*, **58(12)** (2010) 6266–6283.

32 Ruan L, Li Y, Cheng W & Wu Z, A robust threshold optimization approach for energy detection based spectrum sensing with noise uncertainty, *IEEE 10th Conference on Industrial Electronics and Applications* (ICIEA) (2015) 161–165.

33 Alom M Z, Godder T K, Morshed M N & Maali A, Enhanced spectrum sensing based on Energy detection in cognitive radio network using adaptive threshold, *International Conference on Networking, Systems and Security (NSysS)* (2017) 138–143.

34 Digham F F, Alouini M S & Simon M K, On the energy detection of unknown signals over fading channels, *In IEEE International Conference on Communications, ICC'03*, **5** (2003) 3575–3579.

35 Ghasemi A & Sousa E S, Opportunistic spectrum access in fading channels through collaborative sensing, *JCM*, **2(2)** (2007) 71–82.

36 Simon M K & Alouini M S, *Digital communication over fading channels*, Vol. 95, John Wiley & Sons (2005).