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Threshold Techniques to Improve Sensing Under Noise Uncertainty in Cognitive Radio Networks

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Abstract— Cognitive radio network is a network which overcomes the deficiency of spectrum in this fast-growing radio network. In this network, secondary users sense the spectrum that is used by primary users and if spectrum is vacant or not utilized then utilize the spectrum with proper management and sharing. For the foremost step sensing, different techniques are proposed but energy detector (ED) is most widely used due to its least sensing time requirement and low complexity. But there are limitations also; its performance degrades due to unknown variations in noise and this uncertainty cause problem of SNR wall and problem in achievement of exact energy threshold. Till now, various approaches have been proposed to accomplish better performance of system under low SNR environment. So, to increase the throughput and efficiency of system double threshold, dynamic threshold, two stage spectrum sensing etc. techniques have been proposed to alleviate above mentioned problems and also mathematical relation between energy threshold, probability of detection and false alarm is considered.

Keywords— Noise uncertainty, Threshold techniques, SNR wall, Number of samples, receiver operating characteristics (ROC), cooperative spectrum sensing.

I. INTRODUCTION

Cognitive radio network (CRN) as name itself implies that communication which is performed with analytical thinking process. In this process, spectrum is accessed dynamically by the unlicensed users whenever they find it free and according to this, transmission or reception parameters are changed. Main four functions that are performed by CRN are: Spectrum Sensing, Spectrum decision, Spectrum sharing and Spectrum mobility.

From all of these, Spectrum Sensing is the first step towards reliable communication and it will be proved effective if it ensures that there is no interference with primary users from cognitive users. Energy detection, match filter detection, waveform based sensing, and Cyclostationary detection and radio detection are different single user sensing methods. Out of these methods, energy detector is widely used because of its lower complex circuitry and it requires less sensing time. But unknown variations in noise cause degradation in performance of energy detector. Sensing done in collective manner i.e. cooperative spectrum sensing eliminates the problems of fading, hidden node problem and noise uncertainties [1,2]. Cooperative overhead and sensing time has an effect on cooperative gain. Cooperative models and data fusion schemes are employed to make system more reliable and energy efficient [3]. It is important to optimize the number of CR users in CSS to reduce overhead. Thus, k-out-of-n fusion rule gives the optimum no. of secondary users on the basis of detection risk [4,5]. In addition to this more CSS protocols are discovered to reduce system overhead and to reduce collision between primary and secondary user [7].

There are various parameters like Signal to noise ratio (SNR), noise uncertainty and number of sensing samples which decides the Probability of detection (P_{dt}), Probability of false alarm (P_{fa}) and Probability of miss detection (P_{mdt}). In energy detector, P_{dt} increases as number of samples increases for fix value of SNR and with increase in SNR probability also increases for fix number of samples. Unknown variations in noise cause serious problem in energy detection [8, 9]. Also, for fixed probability of false alarm, probability of detection get improves with increase in sensing time but if signal is too weak then this would not work. This indicates the presence of SNR wall. In case of fading, cooperative sensing works better and cooperative gain is higher in wideband sensing with increment in number of cooperative users [3,10].

Many researchers have proposed different techniques to decide energy threshold during sensing to mitigate the effect of SNR wall and noise uncertainty. The concept of SNR wall explained by Rahul Tandra and Anant Sahai [10] is that level below which detection become impossible and cannot figure out two hypotheses, even for long sensing time [14].

In this paper, we have mainly analyzed different techniques that alleviate SNR wall problem and improve the sensing performance under noise uncertainty. Section II discusses about different parameters considered in sensing techniques, Section III discuss about sensing techniques to alleviate the effect of noise uncertainty and Section IV shows the precise table of these sensing methodologies.

II. PARAMETERS CONSIDERED IN SENSING TECHNIQUES

To analyse the performance of any sensing technique, different basic parameters are used like probability of detection, probability of false alarm, No. of samples used [8].

On the basis of these parameters, reliability and efficiency of any technique is decided and these are discussed below:

A. Probability of detection

This parameter decides the accuracy and reliability of any sensing technique. Probability of detection (P_{dt}) means spectrum is sensed correctly whether PU is present or not. Probability of detection is calculated when noise variance is known and when there is noise uncertainty lies between 0 and 1. This is given as below:

- When noise variance is known:

$$P_{dt}= Q\left(\frac{T-(p+\sigma^2)}{\sqrt{2(p+\sigma^2)^2/N}}\right) \quad (1)$$

- When noise is uncertain and uncertainty parameter is 'R', then P_{dt}:

$$P_{dt}= Q\left(\frac{T-\left(p+\frac{\sigma^2}{R}\right)}{\sqrt{2(p+\sigma^2/R)^2/N}}\right) \quad (2)$$

Where, T is calculated energy threshold, σ is noise variance and N is number of samples. Q is defined marcum function.

B. Probability of False alarm

It occurs when spectrum is free but it assumed to be occupied then Probability of false alarm (P_{fa}) is calculated. Expression for Pfa is given below:

- When noise variance is known:

$$P_{fa}= Q\left(\frac{T-\sigma^2}{\sqrt{2\sigma^4/N}}\right) \quad (3)$$

- When noise is uncertain and uncertainty parameter is 'R', then P_{fa}:

$$P_{fa}= Q\left(\frac{T-R\sigma^2}{\sqrt{2/N}R\sigma^2}\right) \quad (4)$$

C. Probability of miss detection

It occurs when occupied channel assumed to be free and it is opposite of P_{dt}. Probability of miss detection (P_{mdt}) can be defined as:

$$P_{mdt}= 1- P_{dt} \quad (5)$$

D. Relation between SNR and Number of samples

Numbers of samples (N) required for spectrum sensing are calculated on the basis of SNR, Pfa and Pdt. Expression for this in presence or absence of noise uncertainty is given below:

- When noise variance is known:

$$N= 2\left[Q^{-1}(P_{fa})-Q^{-1}(P_{dt})\right]^2 (SNR)^{-2} \quad (6)$$

- When noise is uncertain and uncertainty parameter is 'R', then N:

$$N= 2[RQ^{-1}(P_{fa})-(1/R+SNR)Q^{-1}(P_{dt})]^2 * \left(SNR-(R-1/R)\right)^{-2} \quad (7)$$

E. SNR wall expression under noise uncertainty:

SNR wall defined as below which detection is not possible [12]. Even for infinite no. of samples detection becomes impossible. There is a relation between SNR and noise uncertainty parameter that is:

$$SNR_{wall} = (R^2-1)/R \quad (8)$$

F. ROC curve:

Reciever operating characteristics (ROC) curve shows the characteristics of receiver by plotting curve between P_{dt} and P_{fa} at different Number of samples or for different SNR values.

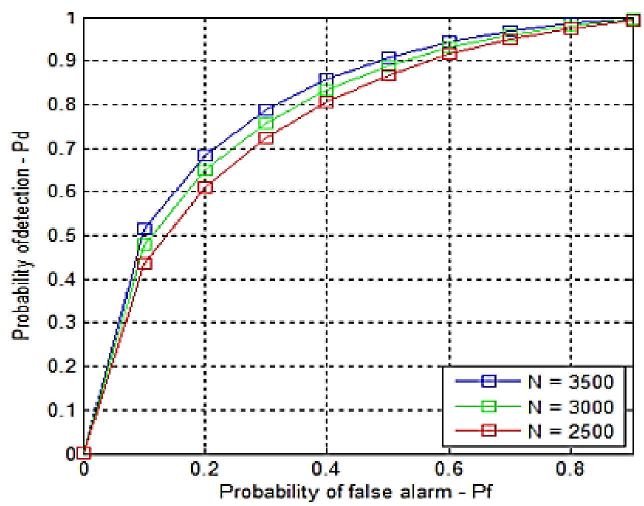

Figure 1. ROC curve between Probability of false alarm and Probability of detection for different N and fixed SNR= -15dB [8].

III. Sensing techniques to alleviate the effect of noise uncertainty

To improve sensing performance in Cognitive radio network various threshold techniques have been proposed that basically mitigate the effect of SNR wall or lower the SNR regions which occurs because of noise uncertainty. These various techniques are discussed below:

A. Double threshold energy detection

In this technique, instead of one threshold in energy detector two threshold levels are introduced and each CR user makes two hypotheses on the basis of these thresholds. In this method, each CR user sends two types of decision that are: Observational energy and local sensing result under two hypotheses. Observational energy is that energy which is calculated during sensing process under square law and lies between two threshold energy levels. Local decision is in form of 0 or 1. After receiving data from all CR users, fusion centre perform k-out-of-n fusion rule and compare the 'n-k' observed energy values with its fixed threshold. Then finally, k local decisions and 'n-k' compared values are combined under fusion scheme [4] and that will decide whether primary user is present or not. It shows the 1db improvement from conventional method. In this technique, observations have been taken only in Gaussian environment not in fading environment [8, 12].

B. Effect of dynamic threshold

Dynamic threshold calculated based on noise uncertainty parameter and dynamic threshold parameter, improves the performance of conventional detector and reduce sensing time. Dynamic threshold factor defines the range of energy threshold and within that range value of dynamic threshold lies. Results are carried out in three different aspects: without noise uncertainty, with noise uncertainty and noise uncertainty with dynamic threshold. In first case i.e. without noise uncertainty, more number of samples is required under low SNR region for achievable probability of detection.

In second case i.e. with noise uncertainty, the performance of detector gets effected because of lower SNR regions and it will not show improvement in P_{dt} even for more number of samples or for more sensing duration.

In third case i.e. with dynamic threshold, the limitation of second case (i.e. for fixed threshold) can be eliminated to some extent by dynamic threshold parameter. By increasing the value of this parameter optimum sensing results can be figure out even at low SNR values. All these results are taken under AWGN channel by neglecting fading channels [10, 11].

C. SNR wall and cooperative spectrum sensing

Performance of cooperative spectrum sensing is analysed under noise uncertainty while using the energy detection method at each secondary user end [7]. Also, an alternative approach is proposed to obtain the average value of SNR_{wall}. Thus, average SNR_{wall} will depend on probability density distribution of noise (f(x)) and nominal noise power (σ') that is given below:

$$SNR_{avg\_wall}=(x_1/\sigma'^2)-(x_2/\sigma'^2) \quad (9)$$

In CSS, hard decision rule i.e. AND rule is used that will improve the detection with high SNR value. But use of AND rule is not appropriate when value of uncertainty parameter increases. So, comparison of CSS under another decision rules are important when uncertainty parameter's value is increasing [13].

D. Lowering the SNR wall using cross -correlation

It overcomes the disadvantage of auto-correlation in energy detection and reduces the effect of any type of noise because cross-correlation converge the distribution to Gaussian and improves the SNR. Under cross-correlation two receiver paths are defined and output of these two is multiplied. Noise will be highly un-correlated from each other because one of the outputs from receiver is conjugated output. In this analysis, signal de-correlation is neglected which means arbitrary change in phase of two received signals because of fading environment. For practical considerations, more work need to be done because under Gaussian assumption large part of noise is correlated which affects the performance of sensing under cross-correlation. This method will definitely decrease the sensing time by some factor but also increase energy consumption of detection system. So, trade-off is required between these two to get optimum sensing level [9, 15].

E. SNR wall for generalized energy detection

In Generalized energy detector (GED), squaring operation during estimation of energy is replaced by any arbitrary number say 'r' and expression of SNR wall is analysed for different value of 'r'. Calculation of test static for GED is given as:

$$T\_S_{GED}=\left(\frac{1}{N}\right)\sum_{i=0}^{N} |y_i|^r \quad (10)$$

SNR wall is calculated under uniformly distributed and log normally distributed noise. For uniformly distributed noise, SNR wall will no longer depend upon arbitrary factor 'r'. In this case when SNR is below than SNR wall then no optimum threshold level is there to achieve less P_{fa} (≤ 0.1)and high P_{dt} (≥ 0.9) in GED. For log normally distributed noise, SNR wall is calculated numerically and lowest value of SNR is found to be -1.54 dB from the graph of detection probability vs. threshold for both r=2 and 4. Detection probabilities P_{fa} and P_{dt} are plotted against threshold level for arbitrary factor 2 and 4. Even for large no. of samples GED failed to clear some sensing requirements when SNR is below SNR wall [16].

F. Improved double threshold energy detection for CSS

In this method, performance of double threshold energy detector [12] is improved by replacing the squaring operation with any arbitrary constant say 'r' while calculating energy of each CR user. Local decisions from each secondary user to fusion centre (FC) over binary symmetric reporting channel. When calculated energy lies between two thresholds then no decision is forwarded to FC. k_1 number of SU's favours H_o and k_2 number of SU's favours H_1 where $k_1+k_2 \leq n$. Along with k_1 and k_2 there are some SU's which do not report anything to FC because their energies lie between two thresholds. Therefore, at FC decision 'D' will be taken on the basis of k_2 i.e.:

$$D= \begin{cases} H_0, & k_2 < k \\ H_1, & k_2 \geq k \end{cases}; \quad (11)$$

Cooperation probability of detection (Q_{dt}) is calculated and maximized for optimum value of difference between two thresholds. It is also maximized for optimum value of arbitrary constant power 'r'. So, value of Q_{dt} will be highest for r=2.8 for various values of SNR unlike conventional detector. Along with sensible detection, minimization of total error rate (TER) is important and TER is equal to sum of cooperation probability of miss detection (Q_{md}) and cooperation probability of false alarm (Q_{fa}). Imperfection of reporting channel is also studied and degree of imperfection increases with increase in threshold difference [17].

G. Dynamic-double-threshold energy detection scheme

Two dynamic threshold values are calculated on the basis of dynamic threshold factor [11] which is greater than or equal to 1. Spectrum is vacant or not is decided on the basis of test static value, if calculated energy value at each SU lies between two thresholds then sensing is performed again. There is need of optimum difference between two thresholds because higher value results in more repetitions of sensing and lower value results in miss detection or false alarm. Different ROC curves are plotted on the basis of difference between two thresholds (ΔT), noise uncertainty factor and proposed sensing scheme. For 0.1 value of ΔT, Probability of detection (P_{dt}) is higher i.e. 0.88 for fixed value of probability of false alarm (P_{fa}= 0.1). ROC curve also shows that P_{dt} will decrease with increase in noise uncertainty factor. This proposed scheme results in P_{dt} =0.89 for P_{fa} =0.1 and SNR= -15dB under AWGN channel which is better than single threshold [18] and double threshold [19].

H. SNR wall effect alleviation by generalized detector

This technique is employed to minimize the number of samples to sense the spectrum and to reduce the probability of error. GD works on the principle of complete matching of primary user signal and signal generated by local oscillator in detector. The deployment of generalized approach to signal processing (GASP) in GD gives flexibility to obtain more information about input signal where additional noise acts as reference noise. GD is different from the normal energy detector because it uses the concept of antenna array and additional linear system. Probability of error reduced to 0.24 for GD as compared to ED for noise uncertainty of 0.1. It shows better results than normal correlation to alleviate SNR wall [15]. But there are some issues in practical implementation of GD [20].

I. Two stage spectrum sensing

The proposed detection technique combine two detection method are Energy Detection (ED) and Akaike's information criteria (AIC) to sense the hole. At first stage, ED technique is use to find average power of received signal and second stage is AIC detection technique based on the information theoretic criteria (ITC). AIC performs better at low SNR values. Results shows that P_{dt} for AIC is better than ED for 1000 no. of samples [22]. Another technique which combines both energy detector and Cyclostationary detector, gives better detection performance at the cost of mean detection time [23].

To improve this further "adaptive two stage spectrum sensing" is used where according to the distance between CR users and SU's two thresholds levels are decided. Where in other techniques adaptive thresholds are calculated on the basis of no. of samples (N) that depends on SNR value that may not give better P_{dt} [25]. Therefore, this method use modified- double constraint adaptive energy detection at 1^{st} stage and adaptive maximum Eigen value detection at 2^{nd} stage [26]. So, gives high accuracy in performance by consuming less time [27].

J. Overcoming sensing failure problem in double threshold based CSS.

Here, two threshold levels are calculated from centralized fixed threshold. CR user send 1-bit decision when energy lies outside of double threshold region and send two-bit decision when lies between this region. In this scheme, uncertain region between two thresholds is divided into four parts according to combination two bits. Whenever, calculated energy lies between uncertain region then it will compare with new thresholds and send 00, 01, 10 and 11 decision bits to FC. Final decision will be taken at fusion centre according to bits received. For 1-bit data, OR fusion rule is applied at FC. For two-bit data, average energy is estimated and estimated energy is compared with centralized threshold value. Performance gets improved in lower region of SNR i.e. around -7db to -5db. This technique shows the better performance than conventional double threshold sensing technique [17, 28].

IV. COMPARISON TABLE OF DIFFERENT SENSING TECHNIQUES

Table 1. Comparison of different threshold techniques

Reference	Technique used	Features
Z.Jiang et al [12]	Double thresholds	Better than single threshold detector. Analysis done under AWGN channel
M. S. Oude Alink et al [15]	Cross-correlation	Overcomes the disadvantage of auto-correlation. More practical limits are required for correlated noise.
D. Cabric et al [6] K. Chabbra et al [11]	Dynamic threshold	Improves the performance at lower SNR values. Results are considered only in AWGN channel.
S. S. Kalamkar et al [16]	Generalized ED	Failed to achieve sensing requirement when SNR is low.
S. Kalamkar et al [17]	Improved doubled threshold	Total error rate is minimized. But imperfection of channel increases with increase in noise uncertainty.
Shrivastava, S. et al [19]	Dynamic double threshold	Gives improvement over single dynamic threshold and double threshold methods.
M. S. Shbat et al [20]	SNR wall alleviation	Probability of error get reduced using correlated antenna arrays but shows some difficulties in practical scenarios.
P. P. Anaand [22] S.Sanjayjoshi [23]	Two stage spectrum sensing	Sensing time gets reduced as compared to single stage. But complexity increases.
Wilaiporn Lee et al [27]	Adaptive two stage sensing	Improve two stage spectrum sensing and gives high accuracy in performance.
P. Verma et al [28]	Averaging of energy	Improves the performance in very low SNR regions. Sensing time need to be optimized.

From Table 1, benefits of different techniques have been discussed along with their downsides. So, for the implementation of particular technique one need to be take care of SNR levels, sensing time and reporting channels. There is trade-off between sensing time and throughput [29]. Thus, optimum value of sensing time is required under noisy channels for sensing purpose in cognitive radio [30,31].

V. CONCLUSION AND FUTURE SCOPE

To ensure that the spectrum sensing is efficient and reliable means there is no interference to primary user different approaches has been followed. Noise uncertainty, sensing time and throughput are different parameters that affect the sensing performance of detector. The single stage techniques like Double threshold, dynamic double threshold that discussed above shows better probability of detection in presence of noise uncertainty than conventional energy detector. Later, two stage spectrum sensing techniques are discussed which detect the presence or absence of PU very precisely at the cost of system overhead and complexity. Along with this single stage and two stage thresholding techniques, implementation of cooperative spectrum sensing will improve the performance of detector in hidden node and shadowing scenarios. For real-world applications, sensing time, error rate and throughput are key parameters which need to be optimized for marvellous performance.

In future, association of optimizing algorithms like genetic algorithms, particle swarm optimization with these sensing techniques is important for high Quality of service and efficiency of system.

REFERENCES

[1] R. P. Borole, P. G. Student, C. Engineering, and N. M. U. Jalgaon, "*A Review on Performance Analysis of Energy Detection Technique for Cognitive Radio Over Different Fading Channels*," International journal of innovative research in Science, Engineering and Technology, Vol.4, Issue.8, pp. 7214–7219, 2015.

[2] Q. Liu, J. Gao, and L. Chen, "*Optimization of Energy Detection Based Cooperative Spectrum Sensing in Cognitive Radio Networks*," IEEE Communications, Issue. 2009, pp. 0–4, 2010.

[3] G. Vidyadhar Reddy and N. S. Murthy, "*Optimization of cooperative spectrum sensing under AWGN and rayleigh channels in cognitive radio network*," 3rd International Conference on Advances in Compting and Communication (ICACC), pp. 126–129, 2013.

[4] D. Teguig, B. Scheers, and V. Le Nir, "*Data Fusion Schemes for Cooperative Spectrum Sensing in Cognitive Radio Networks*," Communication and information system conference, Poland, pp. 1–7, 2012.

[5] K. Chabbra, G. Mahendru, and P. Banerjee, "*Effect of dynamic threshold & noise uncertainty in energy detection spectrum sensing technique for cognitive radio systems*," 2014 International Conference on Signal Processing and Integrated Networks (SPIN), pp. 377–361, 2014.

[6] C. Korumilli, C. Gadde, and I. Hemalatha, "*Performance Analysis of Energy Detection Algorithm in Cognitive Radio*," International Journal of Engineering Research and Applications, Vol. 2, Issue. 4, pp. 1004–1009, 2012.

[7] T. Akram, T. Esemann, and H. Hellbruck, "*Cooperative spectrum sensing protocols and evaluation with IEEE 802.15.4 devices*," Physical Commununications, Vol. 19, Issue.1 pp. 93–105, 2016.

[8] C. Technologies, S. Nagar, and S. Nagar, "*Comprehensive Analysis of various Energy Detection parameters in Spectrum Sensing for Cognitive Radio systems*," International conference on advances in communication and computing technologies, pp. 1–4, 2014.

[9] a. Mariani, a. Giorgetti, and M. Chiani, "*Effects of Noise Power Estimation on Energy Detection for Cognitive Radio Applications*," IEEE Transaction on Communications, Vol. 59, Issue. 12, pp. 3410–3420, 2011.

[10] R. Tandra and A. Sahai, "*Walls for Signal Detection*," IEEE journal on Selected Topics of Signal Processing, Vol. 2, Issue. 1, pp. 4–17, 2008.

[11] D. Mercedes, M. Plata, Á. Gabriel, and A. Reátiga, "*Evaluation of energy detection for spectrum sensing based on the dynamic selection of detection-threshold*," International conference of electrical engineering research, pp. 135–143, 2012.

[12] Z. Jiang, X. Zhengguang, W. Furong, H. Benxiong, and Z. Bo, "*Double Threshold Energy Detection of Cooperative Spectrum Sensing in Cognitive Radio*," 3rd International conference on Cognitive Radio Oriented Wireless Networks Communications

(CrownCom), pp. 1–5, 2008.

[13] H. Wang, X. Su, Y. Xu, X. Chen, and J. Wang, "*SNR wall and cooperative spectrum sensing in cognitive radio under noise uncertainty,*" Journal of Electronics, Vol. 27, Issue. 5, pp. 611–617, 2010.

[14] L. Lu, X. Zhou, U. Onunkwo, and G. Li, "*Ten years of research in spectrum sensing and sharing in cognitive radio*," EURASIP Journal on Wireless Communication and Networking, Vol. 28, Issue. 1, p. 1-16, 2012

[15] M. S. Oude Alink, A. B. J. Kokkeler, E. A. M. Klumperink, G. J. M. Smit, and B. Nauta, "*Lowering the SNR wall for energy detection using cross-correlation*," IEEE Transaction on Vehicular Technology, Vol. 60, Issue. 8, pp. 3748–3757, 2011.

[16] S. S. Kalamkar, A. Banerjee, and A. K. Gupta, "*SNR wall for generalized energy detection under noise uncertainty in cognitive radio,*" 19th Asia-Pacific Conference on Communication (APCC), pp. 375–380, 2013.

[17] S. Kalamkar and A. Banerjee, "*Improved Double Threshold Energy Detection for Cooperative Spectrum Sensing in Cognitive Radio*," Defence Science Journal, vol. 63, Issue. 1, pp. 34–40, 2013.

[18] V. M. Patil and S. R. Patil, "*A survey on spectrum sensing algorithms for cognitive radio*," International Conference on Advances in Human Machine Interactaction (HMI), India, pp. 149–153, 2016.

[19] S. Shrivastava, R. Tiwari, and S. Das, "*Dynamic-Double-Threshold Energy Detection Scheme under Noise Varying Environment in Cognitive Radio System*," International Journal of Computer Applications, Vol. 87, Issue. 14, pp. 23–27, 2014.

[20] M. S. Shbat and V. Tuzlukov, "*SNR Wall Effect Alleviation by Generalized Detector Employed in Cognitive Radio Networks*," Sensors (Basel)., Vol. 15, pp. 16105–16135, 2015.

[21] S. Atapattu, C. Tellambura, H. Jiang, and N. Rajatheva, "*Unified Analysis of Low-SNR Energy Detection and Threshold Selection,*" IEEE Transaction on Vehicular Technology, Vol. 64, Issue. 11, pp. 5006-5019, 2014.

[22] P. P. Anaand, "*Two Stage Spectrum Sensing for Cognitive Radio Networks using ED and AIC under Noise Uncertainty*," India, 2016.

[23] S. Sanjayjoshi, "*Performance Analysis of Two Stage Spectrum*," Inetrnational journal of Innovative Research in Computer and Communication Engineering, Vol.3, Issue.6, pp. 5549–5555, 2015.

[24] M. Sun, C. Zhao, S. Yan, and B. Li, "*A Novel Spectrum Sensing for Cognitive Radio Networks with Noise Uncertainty*," IEEE Transaction on Vehicular Technology, Vol. 66, Issue.5, pp. 4424–4429, 2016.

[25] K. Srisomboon, a Prayote, and W. Lee, "*Double constraints adaptive energy detection for spectrum sensing in cognitive radio networks*," 8th International Conference Mobile Computing and Ubiquitous Networking, (ICMU), Japan, pp. 76–77, 2015.

[26] R. N. Prashob, a. P. Vinod, and A. K. Krishna, "*An adaptive threshold based energy detector for spectrum sensing in cognitive radios at low SNR*," IEEE International Conference on Communication Systems, Singapore, pp. 574–578, 2010.

[27] K. Srisomboon K. Thakulsukanant A. Prayote W. Lee, "*Adaptive Two-stage Spectrum Sensing under Noise Uncertainty in Cognitive Radio Networks",* The ECTI Transaction on Electrical Engineering, Electronics & Communication, Vol.14, Issue.1, pp. 21–35, 2016

[28] P. Verma and B. Singh, "*Overcoming sensing failure problem in double threshold based cooperative spectrum sensing*," Optik Journal, Vol. 127, Issue. 10, pp. 4200–4204, 2016.

[29] H. Tran and H. Phan, "*On Throughput and Quality of Experience in Cognitive Radio Networks*," Wireless Communications and Networking Conference, Qatar, pp. 0–4, 2016.

[30] S. Khanam and A. Kaur, "*Enhanced Detection of Cognitive Radio Under Noisy Channels*," International Journal of Computer Science and Engineering, Vol.4, Issue. 10, pp. 116–119, 2016.

[31] N. K. Randhawa and A. S. Buttar, "*Sensing of Spectrum Holes in Cognitive Radio Networks : A Survey*," International Journal of Computer Sciences and Engineering, Vol.2, Issue. 8, pp. 28-34, 2014.

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