Analysis of energy detector with improved ED and variable threshold ED suitable for digital TV IEEE 802.22 WRAN

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Abstract. Now a days demand of wireless devices are increasing very rapidly by different users, while available spectrum resource is very limited. To overcome the need of different users, spectrum should be utilized efficiently. Cognitive Radio is introduced to access the spectrum dynamically by taking the permission of the licensed users for specific time interval when their spectrum is freely available. For this task of CR, many spectrum sensing techniques are introduced to sense the spectrum. Here in this paper, we have focused on energy detector(ED) spectrum sensing technique and overcome the problems with the ED at low SNR. Improved Energy Detector and Variable Threshold Energy Detector (VTED) give better results than normal ED technique which has been demonstrated through different receiver operating characteristics. Under Cooperative Spectrum Sensing (CSS) environment, it has been shown that OR logic gives probability of detection greater than 0.9 rather than the AND logic for optimized number of cooperative users 10. Results have been shown that VTED technique overcome the low SNR region problem of normal ED technique with higher probability of detection i.e. greater than 0.9 for cognitive radio networks.

1. Introduction

In digital era, now a days demands of wireless devices are increasing drastically by number of users and to achieve the goal available spectrum resources should be utilized efficiently. Due to earlier studies, it has been found that available spectrum which has been divided among different licensed users, has not been occupied for full time. This research creates the spectrum hole which is free time slot available in spectrum at licensed users. This can be useful to overcome the demand of wireless users. By dynamically use of the licensed users spectrum is called Dynamic Spectrum Access Technology(DSAT) [1,2] which is shown figure 1 through TV white space technology.
Mitola & Simon Haykin’s research[3,4] have invented Cognitive Radio(CR) which is the technology that help to use the DSAT in wireless communication area. Cognitive Radio (CR) would change its parameters according to that region where CR going to operate. CR can sense the channel alone, and also different CRs can be used to sense the large spectrum through different algorithms. CR can perform many operations like sense the spectrum, managing the spectrum, analysing the spectrum, allocating the spectrum etc. all. Among all these operations, in this paper we have focused on the spectrum sensing mainly. Due to lack of spectrum resources available, CR is the solution for accessing spectrum dynamically when spectrum is free (idle). There are licensed users or primary users (PUs) are also available on the same spectrum and challenging job of CR to sense the channel correctly to further establish the communication for the secondary users (SUs) or CR users. During entire spectrum sensing process, all the PU should remain protective, the interference by SU should not affect the PU’s signal[5].

In Cognitive radio process, CR sense the radio environment using spectrum sensing techniques. Through different spectrum sensing algorithms, information about spectrum hole is find out and further CR transmission is allowed or not that decision is taken globally, if channel is found idle. Entire CR process is reflected in figure 2.
The performance of spectrum sensing process is depend on probability of detection ($P_D$). $P_D$ means how accurately CR detects that there are Primary user present when actually Primary user are present and when Primary user are not present, CR detects PU’s signal is absent. The end of process shows better probability of detection ($P_D$), there are less number of errors produced by the system which is called Probability of false alarm ($P_{FA}$). $P_{FA}$ is first type of error, while Probability of miss detection ($P_{MD}$) is second type of error ($1 - P_D$). These parameters ($P_D, P_{FA}$) decide the performance of CR.

Wireless channel parameters are changing with respect to time and also Primary user actions which can lead to change the secondary user’s receiver SNR. This problem may lead false detection of PU’s signal. The detection shows the channel is busy i.e. using by primary user while actual channel was free. This way CR could miss the opportunistic access of the channel. In other side, if detection shows the channel is idle i.e. not using by primary user while actual channel was busy. This way CR could interfere PU’s signal which leads to major error in the process. To overcome these types of errors, threshold value should chose dynamically, than a fixed value of a threshold used in ordinary system [6].

Section 2 describes the IEEE 802.22 standard specifications while section 3 describes the different spectrum sensing technique like ED, Improved ED (IED) & Variable threshold ED (VTED). In section 4, ROC curves have been plotted for proposed spectrum sensing techniques and compared with each other.

2. IEEE 802.22 WRAN Standard

We have focused in this paper, on the Wireless Regional Area Networking (WRAN) 802.22 standard[7,8]. IEEE standard 802.22 is developed for less density population village areas to provide the broadband access to the different network users through TV free channels without disturbing the broadcasting in the bands between 54Mhz-862Mhz. Figure 3 shows IEEE WRAN 802.22 standard around the 33km-100 km radius network structure. If the band of 6Mhz is allocated to each TV channel and extra 40 subscription can be provided per channel which lead to 255 user entities can be provided by the base station (BS) per channel of TV.

![Figure 3. Example of IEEE 802.22 configuration deployment](image)

Sensing parameters of IEEE WRAN standard are discussed in table 1. Parameters of table 1, we have focused on digital TV parameters like SNR -20dB, Probability of detection 0.9, Probability of false alarm 0.1 etc.
3. Key role for CR: Spectrum Sensing

CR main role is to sense the available spectrum by using spectrum sensing technique. For spectrum sensing, different techniques are available [9,10,11] which can be selected based on the applications.

3.1 Energy Detector (ED) model

In [12], energy detector has been implemented for spectrum sensing technique in cognitive radio networks. Figure 4 shows the representation of Energy detector (ED) with the number of blocks like band pass filter which selects the desired signal and rejects the other signals, after the section of signal its squared out and given to integrator block for addition of all the signals and gave the output through comparison of the threshold (reference value fixed) and declares the decision through the hypothesis whether the PU’s signal is present or absent [13].

3.2 Improved Energy Detector (IED) model

In section 3.1, we have seen the normal energy detector through block representation and it’s working. This Normal Energy Detector suffers with low SNR values, which means Normal ED unable to differentiate between the noise and primary signal under low SNR region which can

| Parameter                  | Digital TV | Wireless Microphone |
|----------------------------|------------|---------------------|
| Channel detection time     | ≤ 2sec     | ≤ 2sec              |
| Channel move time          | 2 sec      | 2 sec               |
| Detection threshold        | -116dBm (over 6Mhz) | -107dBm (over 200kHz) |
| Probability of detection   | 0.9        | 0.9                 |
| Probability of false alarm | 0.1        | 0.1                 |
| SNR                        | -20db      | -12 db              |

Table 1. IEEE 802.22 WRAN standard required sensing parameters
increase probability of false alarm and reduce the probability of detection. To overcome this problem, we need to revise the ED algorithm. In IED, algorithm is described through Hypothesis, when output or test statistics is less than threshold, IED compared with past signal energy and previous penultimate period also to reduce the probability of false alarm which is shown in figure 5. IED results are slightly improved than ED in terms of detection probability [15].

Figure 5. IED algorithm

3.3 Variable Threshold Energy Detector (VTED) model

In previous algorithms, threshold was chosen at a fixed value if any change happens in noise power, it cannot be varied. Due to that at low SNR spectrum sensing accuracy could not be achieved. In [16,17] proposed double threshold method to reduce the uncertainty where method deals with energy of test statistics. If the energy of samples are less than certain threshold, than channel is free, but if energy of samples is greater than higher threshold, channel is busy. But this type of double threshold algorithm performance is very poor at low SNR wall region.

To overcome the noise power uncertainty, variable threshold energy detector (VTED) is discussed in this section. In variable threshold energy detector (VTED), threshold is varied by noise variance. Here Noise uncertainty factor can be calculated by dividing the maximum value of noise variance by the average value of all the noise variances. Using this noise uncertainty factor, threshold is going to change dynamically according the noise variance VTED reduces the low SNR problem (which is most disadvantage) of ED better way compare to the ED & IED. There is another way to set two boundaries for threshold which is called double threshold ED model proposed in [18,19]. Based on previous sensing history parameters, fixed lower and higher boundaries are set for detection of primary user’s signal which is not varying with sudden change in the noise variance proposed in VTED technique.

4. Results & Discussion

Results are shown in relation of different ROC curves with algorithms discussed in section 3 like normal ED, IED and VTED spectrum sensing techniques. Table 2 shows the sensing parameters with various spectrum sensing techniques which have been utilised to obtain various Receiver Operating Characteristics (ROC) curves.
Table 2. Focused sensing parameters with sensing techniques

| Spectrum sensing technique | SNR  | Probability of detection | Probability of False alarm | Threshold | No. of cooperative spectrum sensing users (M) | CSS decision | Sample size |
|---------------------------|------|--------------------------|---------------------------|-----------|---------------------------------------------|--------------|-------------|
| Energy Detector(ED)      | -20 dB | 0.9                      | 0.1                      | constant  | No                                          | No           | 1000        |
| Improved Energy Detector | -20 dB | 0.9                      | 0.1                      | constant  | OR & AND logic                             | 1000         |
| Variable Threshold Energy detector (VTED) | -20 dB | 0.9                      | 0.1                      | variable  | 3 & 10                                      |              |             |

4.1 IED with Cooperative Spectrum Sensing

Here receiver operating characteristics (ROC) curve is plotted for Improved Energy Detector (IED) under cooperative spectrum sensing (CSS) algorithm AND and OR logics at low SNR region -20dB. Figure 6 shows the probability of detection (PD) with OR logic is above 0.9 when probability of false alarm (PFA) is 0.1. While with AND logic PD results are worst due to number of CSS users (M) are 10. In Figure 7 shows that number of CSS users (M) are 3, AND logic results are slightly improved than in figure 6. These results show if number of CSS users are increasing PD is increasing with OR logic while PD is decreasing with AND logic.

![Figure 6](image1.png)  
**Figure 6** IED: P$_{FA}$ Vs. P$_{D}$ for Sample size :1k, M=10 at -20dB SNR

![Figure 7](image2.png)  
**Figure 7** IED: P$_{FA}$ Vs. P$_{D}$ for Sample size :1k, M=03 at -20dB SNR
4.2 VTED with Cooperative Spectrum Sensing

All the previous algorithm considered the threshold to be constant. This algorithm VTED implements noise variance effect on threshold, increasing or decreasing it by a factor of alpha depending on the past observations.

Figure 8 & 9 both shows variable threshold energy detector algorithm with CSS users (M) 3 & 10 respectively. Again the same results like IED, OR logic gives better PD fairly 1 compared to AND logic in both the cases M=3 & 10.

Figure 8. VTED: PFA Vs. PD for Sample size :1k, M=3 at -20dB SNR

Figure 9. VTED: PFA Vs. PD for Sample size :1k, M=10 at -20dB SNR

4.3 Comparison of ED with IED & VTED. Figure 10 shows the comparison of normal ED technique with proposed IED method under CSS environment. It shows the IED results in term of probability of detection is slightly better than normal ED technique under low SNR region i.e. -20dB SNR value.

Figure 10. IED vs. ED : PFA Vs. PD for Sample size :1k, -20dB SNR

Figure 11. IED vs. ED: PFA Vs.PD for Sample size :1k, -20dB SNR

Figure 11 shows the comparison of normal ED technique with proposed VTED method under CSS environment. It shows the VTED results in term of probability of detection is greater than 0.9 while ED probability of detection is 0.1 only when Probability of false alarm is 0.1 under CSS environment under low SNR region i.e. -20dB SNR.
5. Conclusion & future scope
For cognitive radio networks, in this paper spectrum sensing Energy Detector technique is implemented which is less complex and doesn’t require the prior information about the licensed user’s signal or channel where its further going to operate. At low SNR value, the normal ED cannot perform well in term of probability of detection of primary’s signal. So here in this paper, there are two modifications IED & VTED in ED has been implemented under CSS environment and compared with normal ED. VTED performs excellent job in term of ROC curve for detection of primary’s signal with probability greater than 0.9 which is targeted for IEEE 802.22 WRAN standard in digital TV channel for -20 dB SNR.

Further, this work can be extend by focusing on other parameters of spectrum sensing like sensing time optimization for maximize the throughput of the secondary user’s network in addition to the same scenario.

6. References
[1] Carlos Cordeiro, Wireless Communications and Networking (WiCAN) Philips Research North America, UCLA – 21 July 2006.
[2] A. Ghasemi and E. Sousa. Collaborative Spectrum Sensing for Opportunistic Access in Fading Environments. First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, pages 131–136, 2005.
[3] J. Mitola III, “Cognitive radio: An integrated agent architecture for software defined radio.”PhD thesis, Royal Institute of Technology (KTH), Stockholm, Sweden, May 2000.
[4] S. Haykin, “Cognitive radio: Brain-empowered wireless communications,” IEEE Journal on Selected Areas in Communications, vol. 23, pp. 201–220, Feb. 2005.
[5] Furtado, A., L. Irió, R. Oliveira, L. Bernardo and R. Dinis, Spectrum sensing performance in cognitive radio networks with multiple primary users. IEEE Trans. Vehicular Technol. 10.1109/TVT.2015.2406254
[6] Farag, H.M. and M. Ehab, 2014. An efficient dynamic thresholds energy detection technique for cognitive radio spectrum sensing. Proceedings of the 10th International Computer Engineering Conference, December 29-30, 2014, Giza, Cairo, Egypt, pp: 139-144
[7] Emad A. Mohammed , A.I.A. Jabbar Khalid K. Mohammed “Performance Analysis of WRAN at Physical Layer of IEEE 802.22 standardization”, International Journal of Computer Applications (0975 – 8887) Volume 133 – No.14, January 2016.
[8] A. M. Wyglinski, M. Nekovee, Y. T. Hou, “Cognitive Radio Communications and Networks: Principles and Practice” Elsevier, December 2010.
[9] Advances in Cognitive Radio Networks: A Survey by Beibei Wang and K. J. Ray Liu, IEEE Journal Of Selected Topics In Signal Processing, Vol. 5, No. 1, February 2011.
[10] Ashish Bagwari, Brahjit Singh, “Comparative performance evaluation of Spectrum Sensing Techniques for Cognitive Radio Networks,” Fourth International Conference on Computational Intelligence and Communication Networks, 2012 IEEE
[11] B. Fette, Cognitive Radio Technology. Boston, MA, USA: Elsevier, 2006.
[12] Ranjan, A. Singh, B. Design and analysis of spectrum sensing in cognitive radio based on energy detection. In Proceedings of the International Conference on Signal and Information Processing, Vishnupuri, India, 6–8 October 2016; pp. 1–5.
[13] Ghosh, S.K., Mehedi, J. & Samal, U.C. Sensing performance of energy detector in cognitive radio networks, International journal of information technology, 11, 773–778 (2019)
[14] F. Akyildiz, Brandon F. Lo ,Ravikumar Balakrishnan,”Cooperative spectrum sensing in cognitive radio networks: A survey”, Physical Communication 4, 2011 40–62, Elsevier
publication.

[15] M Ranjeeth, S. Anuradha, “Throughput Analysis in Cooperative Spectrum Sensing Network using an Improved Energy Detector” 21st international conference on Advanced communication Technology (ICACT), 2019 IEEE publication.

[16] Wu J., Luo T., Yue G. An Energy Detection Algorithm Based on Double-Threshold in Cognitive Radio Systems; Proceedings of the International Conference on Information Science and Engineering; Nanjing, China. 26–28 December 2009; pp. 493–496.

[17] Suwanboriboon S., Lee W. A novel two-stage spectrum sensing for cognitive radio system; Proceedings of the International Symposium on Communications and Information Technologies; Surat Thani, Thailand. 4–6 September 2013; pp. 176–181.

[18] Smriti, Chhagan Charan, “Double Threshold Based Cooperative Spectrum Sensing with Consideration of History of Sensing Nodes in Cognitive Radio Networks” 2nd International Conference on Power, Energy and Environment: Towards Smart Technology (ICEPE), 2018 IEEE publication.

[19] Pandit S., Singh G. (2017) Spectrum Sensing in Cognitive Radio Networks: Potential Challenges and Future Perspective. In: Spectrum Sharing in Cognitive Radio Networks. Springer, Cham.