International Journal of Hybrid Information Technology
Vol.8, No.9 (2015), pp.143-156
http://dx.doi.org/10.14257/ijhit.2015.8.9.15

Enriched the Spectrum Sensing Performance of Estimated SNR Based Detector in Cognitive Radio Networks

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Abstract

Spectrum sensing is one of the vital functions, plays an important role in cognitive radio networks (CRN). This paper discuss to enrich the sensing performance of propose estimated signal to noise ratio (SNR) based detector. Estimated SNR detector consists two detectors, energy detector (ED) & ED with ADT detector, out of these two detectors only one will perform sensing operation at a time. Which detector will be work, selection will be done on condition between estimated SNR value (S_e) and threshold (γ). Results show that proposed ESNR_ADT scheme outperforms the cyclostationary based sensing method by 30.5 % at – 10 dB SNR. It is also shown that the proposed scheme takes smaller detection time period as compare to cyclostationary detection in the order of 5.2 ms at -20 dB SNR. Furthermore, the scheme was associated with cooperative spectrum sensing (CSS) where each CRs work together in order to take final decision. Finally, it was analyzed that proposed ESNR_ADT sensing scheme with CSS improves detection performance in the order of 0.9 at low SNR value of – 18.5 dB approximately.

Keywords: *Cognitive Radio Networks, Estimated Signal To Noise Ratio, Cooperative Spectrum Sensing, Decision Rule*

I. Introduction

Presently, fixed spectrum allocation (FSA) scheme is working in wireless communication networks. FSA scheme has licensed users, but the problem associated with FSA is that day-by-day numbers of licensed users are increasing, while the frequency bands are fixed, this may create bandwidth crises problem in future. To resolve such spectrum allocation problem Dynamic spectrum allocation (DSA) scheme is a fruitful gift. Cognitive radio network (CRN) is future technology which is based on DSA scheme, utilizes FSA scheme in an efficient ways. CRN comes under IEEE 802.22 wireless regional area networks (WRAN) standard, has capability to identify channel usage. It consists primary user (PU) which is licensed user, and secondary user (SU) which is unlicensed user. CRN utilizes PU frequency band between CR users for communication when the licensed band is not used by PU. To detect spectrum some sensing methods are available named as Matched filter, Energy detector and Cyclostationary feature detector [1-2]. Time-to-time various sensing methods have been proposed by many researches. In [3], authors have done the performance analysis of transmission based spectrum sensing techniques in terms of probability of false alarm (P_f), probability of detection (P_d), and probability of miss-detection alarm (P_m) and concluded final results. Further, a new sensing scheme based on double thresholds scheme have proposed in [4], which provided better detection results. While, in [5] authors have shown the comparative study between [4] scheme and existing cyclostationary feature detection scheme, which concluded that [4] performed better performance than cyclostationary feature detection scheme. Moreover, to improve sensing techniques, Two-stage spectrum detecting method is considered as one of the methods to improve it. In [6], authors presented a two-stage sensing detectors where first stage detector carries energy detector, stage known as coarse sensing detector stage and, second stage detector carries cyclostationary detector, stage known as fine sensing based detector for spectrum sensing. In this method firstly coarse stage detects PU signal. If this first stage is not able to detect licensed signal, then fine sensing second stage will try to detect licensed signal and give the final decision. But it takes more sensing time. In [7], author presented another scheme, where out of two stages only one of the detection techniques was running at a time based on the estimated SNR [8]. Although this scheme reduces the mean sensing time but it does not consider spectrum sensing failure problem [9]. Further, to resolve hidden terminal problem and shadowed affect by severe multi-path fading, cooperative spectrum sensing (CSS) has been introduced in [1-10]. In [11] authors introduced energy detection sensing technique based on the pseudo bit error rate (BER) estimation. At other end, in [12] authors have proposed an SNR estimation technique based on the derived asymptotic eigenvalue probability distribution function (a.e.p.d.f.) in the presence of channel/noise correlation and shown its performance in terms of normalized Mean Square Error (MSE). This paper is extended version of paper [13], in this paper, we have discussed to enrich the detection performance of estimated SNR detector by applying cooperative spectrum sensing (CSS) technique. Final results show that CSS with ESNR_ADT spectrum sensing scheme improves the reliability, detection performance of cooperative decision, and reduce hidden terminal problem. Here, all the CR users perform local observation by using ESNR_ADT SS detector. The thresholds are selected as per the value of the noise uncertainty at each CR user. If the calculated energy falls between or outside the thresholds, then local decision will be generated and passes to the fusion center (FC) in the form of 0 or 1. The FC will make a final decision using hard decision OR rule. In the proposed model we have used Hard decision OR rule because it has better detection performance when the number of cooperating CR users is large [14], and provides slightly better performance at low P_f [15].

The rest of the paper is organized as follows: Section II presents system description. Section III describes proposed system model. Section IV shows the numerical results and analysis. Finally, Section V concludes the paper.

II. System Description

There is a mathematical expression to detect the PU signal by using following hypothesis for received signal [3-5]

$$x(n) = \begin{cases} w(n), & H_0 \\ s(n)h(n) + w(n), & H_1 \end{cases} \quad (1)$$

x(n) is signal received by cognitive radio, *s(n)* is the PU licensed signal, and *w(n)* is additive white gaussian noise (AWGN) with zero mean i.e. $w(n) \sim N(0, \sigma_w^2)$, where σ_w^2 is noise variance, *h(n)* is the gain of Rayleigh fading channel where wireless channel is Rayleigh exist between the PU and the CR users. H_0 is the null hypothesis, shows the absence of PU and H_1 is the alternative hypothesis, shows that PU is present.

A. Estimated Signal To Noise Ratio

Signal to noise ratio (SNR) shows the ratio between signal power (P_S) and noise power (P_W). Signal power is, received PU signal by CR and noise signal is unwanted signal. We can calculate the power of any kind of signal either PU signal or noise signal.

There is a mathematical formula to calculate estimated SNR (S_e') value given as

$$S_e' = \frac{P_s}{P_w} \quad (2)$$

$$S_e' = \frac{\frac{1}{N}\sum_{n=1}^{N}|x(n)|^2}{\frac{1}{N}\sum_{n=1}^{N}|w(n)|^2} \tag{3}$$

$$S_{e|dB} = 10 \times \log_{10} S_e' \tag{4}$$

$$S_{e|dB} = 10 \times \log_{10}\left[\frac{\frac{1}{N}\sum_{n=1}^{N}|x(n)|^2}{\frac{1}{N}\sum_{n=1}^{N}|w(n)|^2}\right] \tag{5}$$

$$S_{e|dB} \underset{<}{\geq} \gamma \tag{6}$$

Using equation (6), if estimated SNR value in dB (S_e) is greater than or equal to threshold (γ) then propose system will select ED to detect PU signal, else ED with ADT will be selected to perform SS operation.

III. Proposed System Model

A. Proposed Esnr_Adt Spectrum Sensing Scheme

Figure 1, shows proposed ESNR_ADT spectrum sensing scheme. CR receiver receives PU signal and calculates SNR value (S_e) using above mentioned mathematical formulas. Now, compare the value of (S_e) with decided threshold (γ) in order to select detector for PU signal detection. If the value of estimated SNR is greater or equal to threshold then ED will use. Otherwise, ED with ADT will detect PU signal.

In Figure 1, assuming S_e is greater or equal to (γ) then ED is selected and calculates the energy of PU signal (X), compares (X) with threshold (λ_1) to indicate PU is present or absent. At other end if S_e is smaller than (γ) then ED with ADT is selected and ED with ADT calculates the energy of received PU signal (Z), compares (Z) with thresholds (λ_{A1} & λ_{A2}) by using adaptive threshold scheme. Finally, compare the output value of ED with ADT i.e. (Y) to threshold (λ_2) under considering a fixed P_f *i.e.*, 0.1, to decide whether PU channel is free or not. Propose model chooses one detector between ED and ED with ADT with the help of mentioned mathematical expression given as

$$Selection\ of\ detector = \begin{cases} ED, & S_e \geq \gamma \\ ED\_ADT, & S_e < \gamma \end{cases} \tag{7}$$

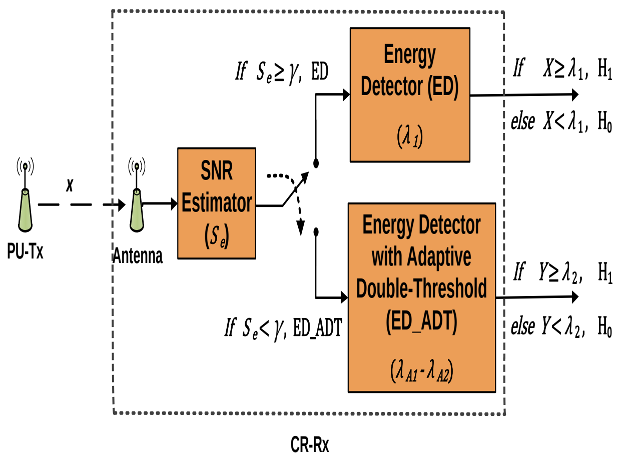

Figure 1. Proposed Model: Snr Estimation Based Spectrum Sensing Detector (Esnr_Adt)

A.1. Energy Detector With Single Threshold (Ed)

Figure 2, shows the internal architecture of ED with single threshold *(λ_1)*. In the given figure, square law device receives PU licensed signal and produces detected signal energy *(X)*, then compares with single threshold to make a final decision in order to announce whether the PU channel is free or not.

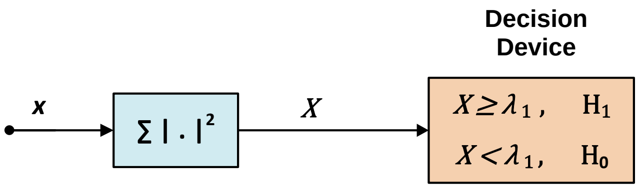

Figure 2. Internal Architecture of Energy Detector With Single Threshold (Ed)

$$X = \frac{1}{N}\sum_{n=1}^{N}|x(n)|^2, \quad (8)$$

The mathematical expression of local decision rule *(LF)* generated by energy detector with single threshold can be computed as

$$LF = \begin{cases} 1, & \lambda_1 \le X \\ 0, & X < \lambda_1 \end{cases} \quad (9)$$

A.2. Energy Detector With Adaptive Threshold (Ed With Adt)

This is a simple ED circuit except threshold, where we used adaptive threshold instead of fixed threshold. Suppose that estimated SNR value is lesser than decided threshold (γ) then ED with ADT detector will try to detect PU signal. Figure 3 shows model of ED with ADT where firstly, square law device (SLD) detects the signal and shows signal energy *(Z)*. After SLD, there are two parts, upper part and lower part. In upper part if detected energy values *(Z)* are greater than or equal to λ_{A1}, it will show H_1 (signal presented), or less than λ_{A2} show H_0 (signal absent). But, if detected energy values *(Z)* fall between λ_{A1} and λ_{A2} then it will consider lower part and follow quantization process to produce its respective decimal values (DV) [5] under the consideration that P_f should be 0.1.

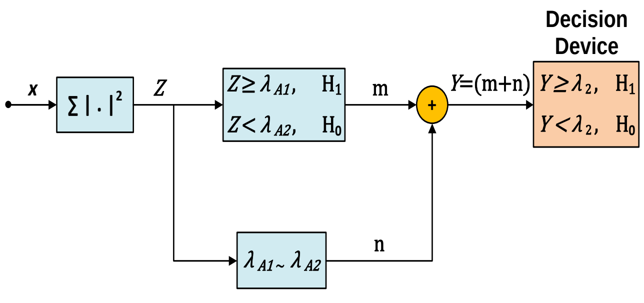

Figure 3. Internal Architecture of Energy Detector with Adaptive Threshold (Ed with Adt)

If detected energy values (Z) fall outside or between λ_{A1} and λ_{A2}, it generates value as

$$m = \begin{cases} 0, & Z < \lambda_{A2} \\ 1, & \lambda_{A1} \le Z \end{cases} \quad (10)$$

$$n = \{DV, \quad \lambda_{A2} < X < \lambda_{A1} \quad (11)$$

Where, m and n are the output decision of upper and lower part respectively. Further, adder device is used to add the values of m and n.

$$Y = (m + n) \tag{12}$$

Finally, Second stage local decision (*LS)* is expressed using equation (10), (11) & (12), which is the final output of ED with ADT as follows:

$$LS = \begin{cases} 1, & \lambda_2 \leq Y \\ 0, & Y < \lambda_2 \end{cases} \tag{13}$$

Equation (13), compare the resultant value *(Y)* to threshold (λ_2) to maintain overall system probability of false alarm (P_f) 0.1. If Y is greater than λ_2 signal is present otherwise absent.

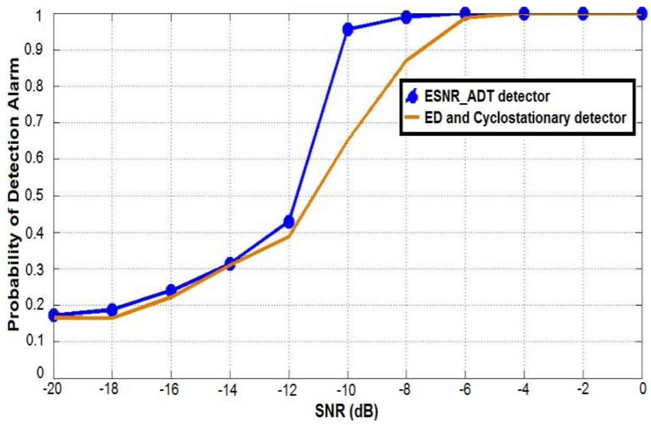

Figure 4. Probability of Detection Vs Snr at *Pf* = 0.1 With *N* = 1000, Qpsk Modulation Scheme, And Rayleigh Fading Channel

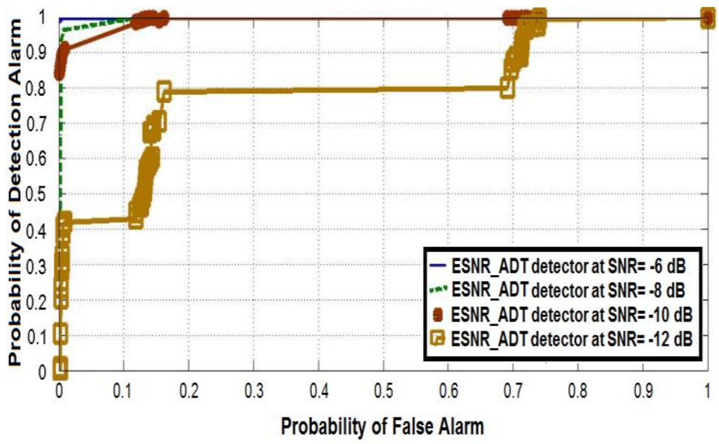

Figure 5. Roc Curves For Esnr_Adt Based Spectrum Sensing Detector Under Different Snr Values

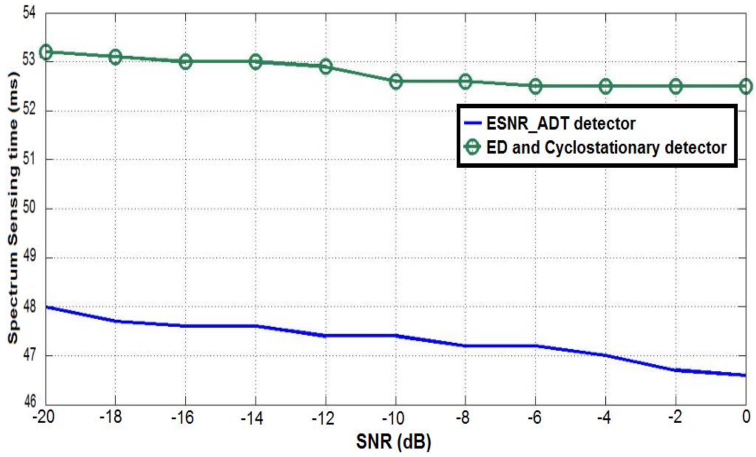

Figure 6. Spectrum Sensing Time Vs Snr With *N* = 1000, Qpsk Modulation Scheme, And Rayleigh Fading Channel

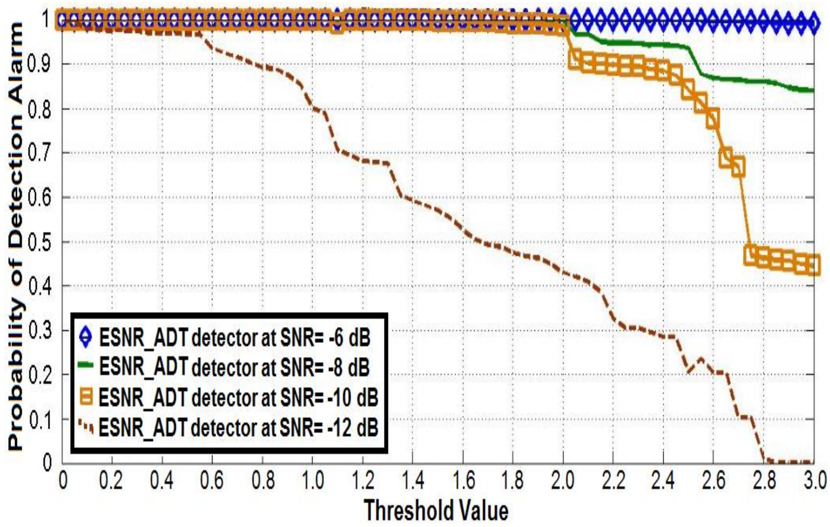

Figure 7. Probability Of Detection Vs Threshold Values At Snr = - 6 Db, - 8 Db, - 10 Db, - 12 Db, *Γ* = - 6 Db, With *N* = 1000, Qpsk Modulation Scheme And Rayleigh Fading Channel

A.Cooperative Spectrum Sensing With Proposed Esnr_Adt Detector

CSS is used to overcome fading and shadowing affects in order to enhance sensing quality of both local and global sensing performance in a CRN [16 - 19]. Here all CRs are using ESNR_ADT based sensing scheme to detect signal. Once all CRs have taken the local decision, they transmit decisions in the form of 0 or 1 to the FC over error free orthogonal channels to take final decision. Error free orthogonal channels show that the channel between cognitive radio receives and fusion center known as reporting channel is totally ideal or noise less or error free. Let there are k numbers of cognitive radio users, all of them are sending their local decision L_i to single FC as shown in Figure 8.

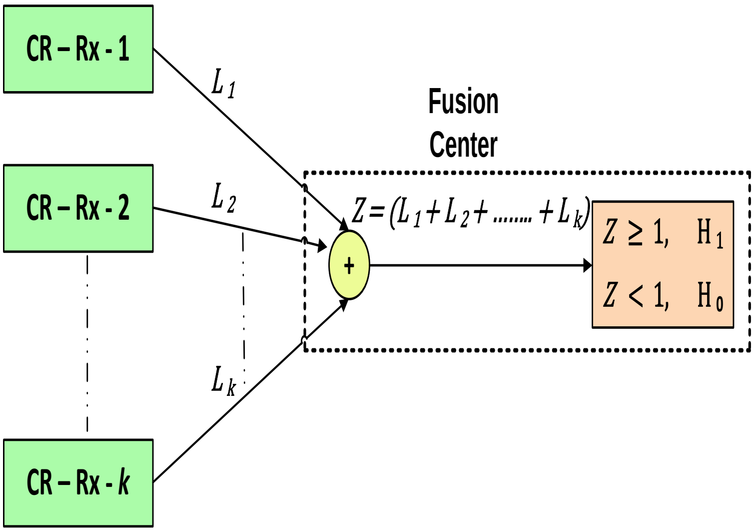

Figure 8. CSS Technique Using Proposed ESNR_ADT Scheme

Finally, FC combines the binary bit decisions of all CRs where each CR have ESNR_ADT scheme, and makes global decision to show presence or absence of PU signal as follows

$$Z = \sum_{i=1}^{k} L_i, \qquad (14)$$

$$L_i = \begin{cases} 1, & \lambda_1 \le X_i, or \ \lambda_2 \le Y_i \\ 0, & X_i < \lambda_1, or \ Y_i < \lambda_2 \end{cases} \qquad (15)$$

In equation (14), Z is the sum of the all local decisions L_i produced by CR users. The FC considers a hard decision OR rule to decide whether PU signal is present or not. The hard decision OR rule states that a signal is present only and only if any of the CRs sense a signal. As per the hard decision OR rule if Y is greater or equal to 1, then signal is detected and if Y is smaller than 1, then signal is not detected. The mathematical expression can be written as

$$FC = \begin{cases} 0, & \sum_{i=1}^{k} L_i < 1 \\ 1, & \sum_{i=1}^{k} L_i \ge 1 \end{cases} \qquad (16)$$

$$FC = \begin{cases} Z < 1, & H_0 \\ Z \ge 1, & H_1 \end{cases} \qquad (17)$$

Finally, equation (17) shows the global decision of FC. Now, the performance of overall proposed system can be analyzed via P_D and P_F. Hence, the probability of detection throughout (P_D) of the FC for CSS using hard decision OR rule can be expressed as follows:

$$P_D = P_r\{Z \ge 1|H_1\} = P_r\left\{\sum_{i=1}^{k} L_i \ge 1|H_1\right\} \qquad (18)$$

$$P_D = 1 - \prod_{i=1}^{k}\left(1 - P_{D,i}^{ESNR\_ADT}\right) \quad (19)$$

The probability of false alarm (P_F) of the FC for CSS using hard decision OR rule can be expressed as follows:

$$P_F = P_r\{Z \geq 1|H_0\} = P_r\left\{\sum_{i=1}^{k} L_i \geq 1|H_0\right\} \quad (20)$$

$$P_F = 1 - \prod_{i=1}^{k}\left(1 - P_{F,i}^{ESNR\_ADT}\right) \quad (21)$$

$P_D^{ESNR\_ADT}$ is the probability of detection and $P_F^{ESNR\_ADT}$ is the probability of false alarm of individual CR users [20], can be calculated as

- Probability of detection of ESNR_ADT detector will be

$$P_D^{ESNR\_ADT} = P_r\left(P_d^{ED} - P_d^{ED\_ADT}\right) + P_d^{ED\_ADT} \quad (22)$$

- Probability of detection of ED_ADT detector will be

$$P_d^{ED\_ADT} = exp\left(-\frac{\lambda_2^{2/p}}{1+\gamma}\right) \quad (23)$$

- Probability of detection of ED detector will be

$$P_d^{ED} = Q\left(\frac{\lambda - N(\sigma_S^2 + \sigma_\omega^2)}{\sqrt{2N(\sigma_S^2 + \sigma_\omega^2)^2}}\right) \quad (24)$$

- Probability of false alarm of ESNR_ADT detector will be

$$P_F^{ESNR\_ADT} = P_r\left(P_f^{ED} - P_f^{ED\_ADT}\right) + P_f^{ED\_ADT} \quad (25)$$

- Probability of false alarm of ED_ADT detector will be

$$P_f^{ED\_ADT} = exp\left(-\lambda_2^{2/p}\right) \quad (26)$$

- Probability of false alarm of ED detector will be

$$P_f^{ED} = Q\left(\frac{\lambda - N\sigma_\omega^2}{\sqrt{2N\sigma_\omega^4}}\right) \quad (27)$$

Where, P_f^{ED} and $P_f^{ED\_ADT}$ are the probability of false alarm of ED and ED_ADT detector respectively, P_d^{ED} and $P_d^{ED\_ADT}$ are the probability of detection of ED and ED_ADT detector respectively. P_r is the probability factor that a channel would be reported to energy detector and therefore, the probability that a channel would be reported to ED_ADT detector will be (1 - P_r). P_r dependents on SNR of the channels to be sensed i.e. if $P_r < 0.5$ shows channel is very noisy, and $P_r \geq 0.5$ shows channel is less noisy or has a good SNR. Therefore, the overall probability of detection and false alarm probability directly depend on P_r. ($0 \leq P_r \leq 1$).

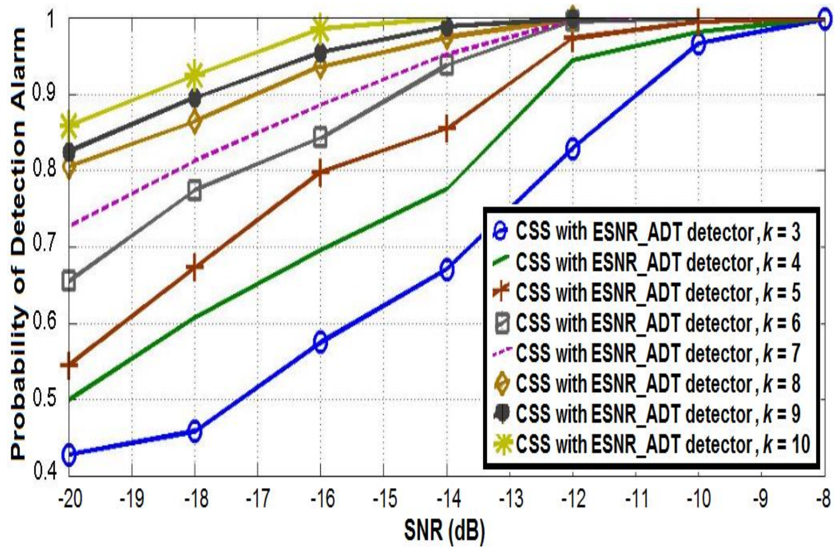

Figure 9. Probability Of Detection Vs Snr At *Pf* = 0.1 With *N* = 1000, *Γ* = - 6 Db, Total Cr Users *K* = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, Qpsk Modulation Scheme And Rayleigh Fading Channel

IV. Numerical Results and Analysis

In the presented system model, we assumed total number of samples *(N)* 1000, P_f = 0.1, threshold γ = - 6 dB, P_r is 0.5, and SNR varies from - 20 dB to 0 dB. Modulation technique is QPSK, considered in Rayleigh fading channel.

The probability of detection defines how frequently PU is susceptible to potential interference from the CR. In CRN, P_d is one of the important parameter in order to calculate the performance of system. According to IEEE 802.22 WRAN standard the value of P_d should be as maximum as possible under the constraint of probability of false alarm.

Figure 4 exhibits the graph between P_d and SNR of the proposed scheme with existing cyclostationary based detection scheme. It is found that our scheme yields better results and the detection performance is improved by 30.5 % as compare to cyclostationary based sensing method SS at – 10 dB SNR.

Receiver Operating Characteristics (ROC) curve is illustrated in figure 5. ROC curve shows the relationship between probability of false alarm and probability of detection throughout [21] of a SS method under several SNR values for proposed scheme. In the figure 5, for proposed scheme, considered P_f= 0.1, and SNR = - 10 dB, the probability of detection is in the order of 0.9, this is essential for the SS according to IEEE 802.22 [22, 23].

The SS time defines the total time taken by CR user to detect PU signal. Suppose SS time is increased then PU can utilize its spectrum in a better manner and the limit is decided that CR can't interfere throughout that much of time. More PUs will be detected if more the SS, due to this the level of interference will be less. The SS time is directly related to the number of samples received by the CR user. More sensing time is dedicated to PU signal detection, the less sensing time is available for transmissions and hence degrading the CR throughput. This is known as the sensing efficiency problem [24] or the sensing-throughput tradeoff [25] in SS.

- Total Spectrum Sensing time of ESNR_ADT detector will be

$$T = T_F + T_S \quad (28)$$

Where, T_F is first stage sensing time, T_S is second stage sensing time, and can be written as

$$T = T_{ED} + T_{ED\_ADT} \quad (29)$$

T is total SS time of CR user. T_{ED} and T_{ED_ADT} are the ED and ED_ADT detectors SS time respectively. Therefore, the ED detector sensing time can be calculated as

$$T_{ED} = E[K_1] \times T_1 \quad (30)$$

Where, $E[K_1]$ shows the mean number of channels reported to ED detector

$$T_1 = \frac{N_E}{2 \times W} \quad (31)$$

T_1 indicates the mean sensing time for each channel, N_E indicates the number of samples during the observation interval, W is the channel bandwidth, K_1 is a random variable which follows a binomial distribution, depends on number of sensed channels M and probability factor P_r that a channel would be reported to the ED detector. Therefore, the detection time of the energy detection is

$$T_{ED} = M \times P_r \times T_1 \quad (32)$$

Similarly, the ED_ADT detector sensing time can be calculated as

$$T_{ED\_ADT} = E\,[K_2] \times T_2 \quad (33)$$

Where, $E[K_2]$ shows the mean number of channels reported to ED_ADT detector

$$T_2 = \frac{N_{ED\_ADT}}{2 \times W} \quad (34)$$

T_2 indicates the mean sensing time for each channel, N_{ED_ADT} indicates the number of samples during the observation interval, K_2 is a random variable which follows a binomial distribution, depends on parameters M and (1 - P_r). (1 - P_r) is the probability factor that a channel would be reported to the ED_ADT detector. Hence, the detection time of ED_ADT detector is

$$T_{ED\_ADT} = M \times (1 - P_r) \times T_2 \quad (35)$$

Thus, the overall spectrum sensing time is calculated by substituting equation (32) and (35) in equation (29) as

$$T = M \times P_r \times T_1 + M \times (1 - P_r) \times T_2 \quad (36)$$

$$T = M \times [P_r \times T_1 + (1 - P_r) \times T_2] \quad (37)$$

Equation (37) shows the final mathematical expression of overall spectrum sensing time for ESNR_ADT detector.

Figure 6 illustrates spectrum sensing time versus SNR plots. It is observed that there is an inverse relation between SS time and SNR. As SNR increases, sensing time decreases. At - 20 dB SNR, proposed scheme requires approximately 48 ms while cyclostationary based sensing method requires around 53.2 ms sensing time.

In figure 7, we have plotted the probability of detection *(P_d)* versus threshold value *(λ)* plots for different SNR values i.e. - 6 dB, - 8 dB, - 10 dB, & - 12 dB. Further, it is examined that there is an inverse relationship between (P_d) and threshold for the fixed value of SNR. Observe figure 7, if SNR increases, probability of detection also increases with respect to threshold. The maximum value of probability of detection is approximately 1.0 throughout the range of threshold *(λ)* at -6 dB SNR. It shows that the proposed ESNR_ADT detector can detect PU signal at - 6 dB SNR for N = 1000, and λ = 3.0.

In figure 9, we have plotted the probability of detection *(P_d)* versus SNR plots for different number of cooperative CR users k = 3, 4, 5, 6, 7, 8, 9, 10, P_f= 0.1, and N = 1000. It can be concluded from figure 9 that the value of probability of detection increases with increase in the value of SNR for different number of CRs. The probability of detection is maximum for k = 10, it's implies that for N = 1000 and P_f = 0.1, only ten CR users are required for deciding the presence of the PU by using the ESNR_ADT spectrum sensing scheme. When k = 10, P_f = 0.1 and SNR = - 18.5 dB approximately, we achieve probability of detection value 0.9, which is the SS requirement of IEEE 802.22 [22-23].

V. Conclusion

In this paper, we have discussed to enrich the spectrum sensing performance of estimated SNR based detector in cognitive radio networks. This scheme improves sensing time and overcomes sensing failure problems. Numerical results show that proposed ESNR_ADT scheme outperforms cyclostationary based sensing method, by 30 % at - 10 dB SNR. It is also shown that the proposed scheme has lesser sensing time than cyclostationary detection scheme, by 5.2 ms at - 20 dB SNR. We have further implemented ESNR_ADT scheme with CSS scheme, it further shows that when k = 10, and P_f = 0.1 we are able to detect PU licensed signal at - 18.5 dB SNR. All results conclude that the proposed scheme exhibits better performances than existing cyclostationary based sensing scheme.

Acknowledgment

The authors would like to thank their parents for their support and motivation, for without their blessings and God's grace this paper would not be possible.

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