Spectrum Sensing Using Adaptive Threshold Based Energy Detection for LTE Systems

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Abstract. The rapid growth of wireless communication system has put pressure on radio spectrum usage. Due to the widely used fixed spectrum access, spectrum utilization is very low. In order to overcome this problem, cognitive radio (CR), which leads the way for dynamic spectrum access capability is necessary. CR listens to the channel and enables to access unused spectrum of the primary user (PU). The detection decision would be done by either a single secondary user (SU) or by multiple SUs cooperating with each other.

Adaptive threshold based energy detection (ED) is the proposed detection technique in which the received signals SNR will be estimated by the SUs using minimum mean square error (MMSE) estimator and if SU is not efficient enough to detect the idleness of the channel due to the reception of weak signal, the SUs will cooperate to detect the PU signal. The simulation results indicate that the proposed system yields much better detection performance both at low and high SNR values.

Keywords: Cognitive radio · Adaptive threshold · Energy detection

1 Introduction

Now a day, the demand for mobile communication has been grown significantly. Due to the growing demand, the development of the design and optimization of radio access technologies and a further evolution of the existing system has laid down the foundation of Long Term Evolution (LTE) which is capable of providing high data rate. This growth in the evolution of a wireless system requires an increased frequency spectrum which leads to misbelieve as most of the spectrum that is the scarce resource has been sufficiently occupied. However, it had been observed that the radio frequency spectrum is inefficiently utilized due to the existing static spectrum allocations and regulatory policies of the governments [1, 2]. Due to this underutilization of the radio frequency spectrum, it had been resulted to the spectrum holes or white spaces which will provide an opportunity for the users without a license to have access to those unused spectrum holes. Based on the interference level, radio frequency spectrum can be a black space that are fully occupied; grey space that are partially occupied and

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white space that are not occupied and have low interference level with the only interference being noise. This white spaces or spectrum holes could be utilized by unlicensed user or secondary users (SUs) [3]. CR that opens a gateway to overcome the inefficient radio frequency spectrum utilization will achieve these. CR has the ability to acquire, measure, sense, learn and be aware of the environment in order to keep track of free and occupied channels so that it can make use of the free spectrum bands [4].

With CR technology, SUs will check continually to know the idleness of a primary user (PU) channel and whenever it gets a free band it will occupy during that free time. However, if there is an incoming signal from the PU, the SU will leave the channel to avoid interference by switching to a different free channel if available or by terminating the transmission if there is no free channel to switch to [5]. When CR detects a free spectrum it will provide an opportunity for the surrounding unlicensed users to occupy it. In doing this task having a smooth integrity between PUs and SUs and also between SUs are necessary not to cause interference for the PU as priority is always given to the licensed owner.

2 Related Works

There have been numerous studies on spectrum detection mechanisms of CR. In order to sense the idleness of the radio frequency spectrum, adaptive spectrum sensing scheme that switches between Eigen values based detection, energy detection (ED) and matched filter detection (MFD) based on the threshold value had been implemented in [6]. In this paper first the availability of prior knowledge about the PU signal will be checked and if it gets a prior information about the PU signal the system will use matched filter detection technique if not it will proceed with estimating the SNR and compare it with the threshold and based on the comparison result the system applies Eigen value for low SNR and ED for high SNR since both does not require a prior knowledge about PU signal. The results found shows that, for low SNR values the ED system suffers from a low detection performance but it has a good performance on higher SNR values. And Eigen value detection gives a much better performance at low SNR values. Hence, whenever there exists a prior knowledge of PU signal the matched filter detection was applied to give a good detection performance, however, when there is no prior information the Eigen value and ED shows a better detection performance at low and high SNR values respectively. Even though the detection probability of Eigen value detection is good and also the system is adaptive there still exists a computational complexity due to the Eigen value detection. A data fusion scheme for cooperative detection was investigated in [7]. In this paper a comparative analysis had been made for hard and soft fusion schemes. From hard fusion schemes, AND and OR fusion rules had been investigated. Also Selection combination (SC), square low combining (SLC) and maximal ratio combining (MRC) had been studied. From the results, cooperative detector with a hard combining scheme of OR fusion rule gives a better performance than the other schemes and MRC gives better performance than SC and SLC but all of them have good detection performance than single detector. However, MRC requires channel state information which is not the case for SC and SLC.

MRC and SC performance had been analyzed over AWGN and Nakagami-m fading channel in [8] and also the authors proposed amplify-and-relay and detect-and-relay cooperative spectrum sensing strategies to improve the detection performance with the help of other eligible SUs so as to quickly vacate the channel to the primary network when the neighboring PUs switch to active state. The simulation result shows MRC has better detection probability than SC scheme and detect-and-relay spectrum sensing scheme gives better performance than amplify-and relay detection scheme. Even if MRC gives better performance it needs channel state information. Cooperative adaptive threshold based matched filter and ED were proposed in [9] to detect the available of PU spectrum. ED had been chosen for its simplicity; however, it is highly affected by noise uncertainty. The authors used an adaptive threshold $\lambda 1$ and $\lambda 2$ with some uncertainty so that if the energy lies in between those threshold values (the uncertainty region), MFD was used and outside the uncertainty region the ED was the detection scheme that had been used with OR fusion rule. The results in this proposed system shows a better detection performance than that of conventional energy and double threshold detection scheme. The presence of MFD makes the system to require prior information about PU in the uncertainty region.

Cooperative spectrum detection based on noise uncertainty estimation using soft decision fusion was the scheme used by the authors in [10]. In this paper the performances of soft detection schemes such as SLC, square low selection (SLS) and MRC had been studied. From the results the detection performance of the proposed detection scheme that takes noise uncertainty into consideration and use two thresholds, was better than that of the conventional soft combination detection schemes. Also from the comparisons of the soft combination schemes MRC provides better result than SLC and SLS schemes. In contrast to the reviewed works, this work uses a single and cooperative energy detection algorithm adaptively to access the unused spectrum band. Single energy detection has low computational complexity but it is prone to hidden node problem. On the other hand cooperative energy detection gives better detection performance within a short period of time at the cost of increased computational complexity and increased bandwidth requirement for the control channel. Combining these two will provide a good detection performance with reduced complexity, bandwidth and sensing time. The spectrum sensor makes a series of measurements and then computes these measurements to make decision.

3 Proposed System Model

ED is one of detection schemes that are capable of detecting the whitespaces without the need of prior knowledge of the PU signal. This makes it an easy detection scheme to implement; however, the huge challenge that is imposed to an ED is that, it is highly prone to shadowing and multipath effects. This leads to hidden terminal problem that caused the SU to be interference for PU. To overcome this problem spectrum detection decision can be made by cooperating multiple SUs. Though cooperative detection provides much better detection performance, increased complexity and overhead are the main challenges it faced. In order to combine the advantages of both the non-cooperative and cooperative ED, threshold based adaptive energy detection scheme that uses both non-cooperative and cooperative detection with SC scheme had been proposed.

In this proposed system, the first task is to estimate the SNR of the received PU signal at SU in order to determine the type of detection scheme to be used as shown in Fig. 1. The selection of detection scheme of weather to share information with others SUs or to make the detection decision by itself would be determined based on the estimated SNR. If the received signals SNR value at SU is strong enough the system will use a non-cooperative detection scheme, that means, each SU will decide the presence or absence of the PU signal by themselves without sharing any information or without cooperating with each other. However, if the received signal SNR value is very low the SUs will cooperate (share information with others) to detect the presence or absence of the PU signal by sending their sensing information to the FC. For FC to perform this task SC is the proposed combination scheme to be used. The reason for choosing SC scheme is because; it is easiest combination scheme to implement and provides a better performance than hard combination scheme. One problem of using SC scheme is requiring a higher bandwidth for the control channel to communicate between SUs and the FC. This problem can be reduced by the system proposed using cooperative and non-cooperative detection adaptively. This does not always need SC implementation due to the presence of non-cooperative detection.

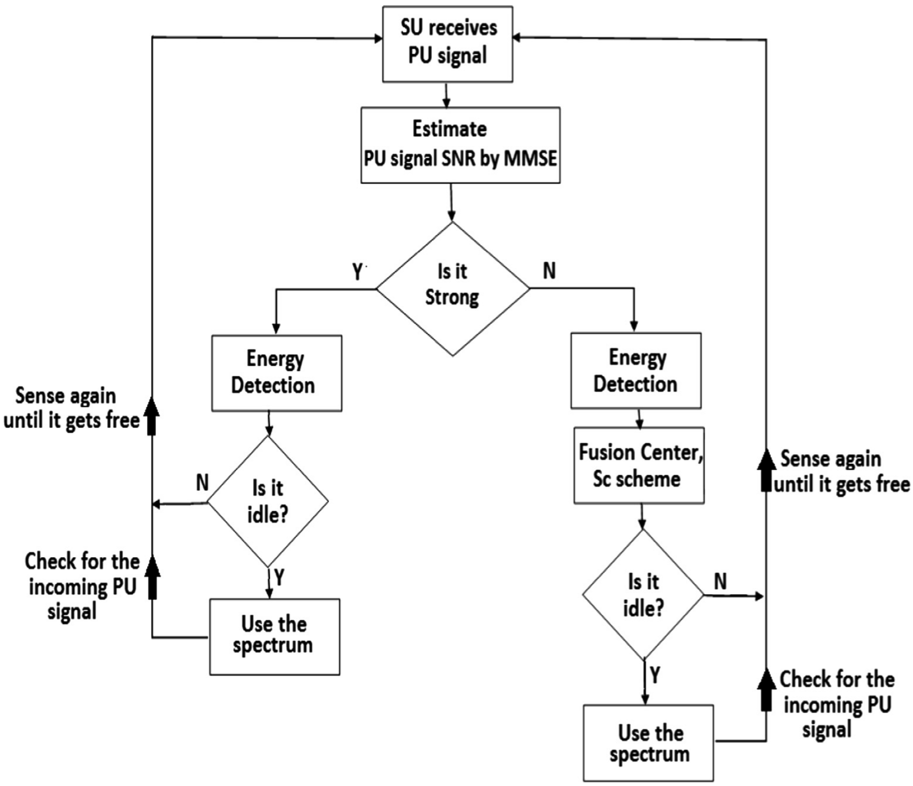

Fig. 1. Flow chart of proposed system model

The system uses cooperative ED scheme at low SNR and non-cooperative energy detection scheme at high SNR. This is due to the fact that, using cooperative detection at low SNR enables to achieve the detection of the free spectrum band without causing an interference for the PU within a minimum period of time. However, this cooperative detection scheme has an increased complexity and traffic overhead which makes it inefficient to apply it all the time. Since non-cooperative ED is capable of providing a good detection performance at high SNR with less complexity it is used at high SNR. Hence, using non-cooperative ED whenever the received signal SNR is high and cooperative ED when the received signal SNR is low enables to achieve good detection performance without causing interference to PU with reduced complexity, low sensing time and less traffic overhead.

3.1 Signal Model

The main task of the proposed system is to explore available free PU bands so that it can be occupied by SU to improve the spectrum utilization efficiency. Here the signal model is a single PU- multiple SU with the existence of k number of cognitive radio users (CRUs), that is one or more CRUs will sense the spectrum of one PU channel. In the case of this work the PU is UHF800 MHz TV band and the CRUs are the LTE 800 MHz mobile communication users. Due to the digitization of television transmissions there exist a lot of free spectrum bands that would be in need of efficient utilization. This channels could be explored and be used by other unlicensed users such as an LTE 800 MHz mobile users. Because of the increased population and demand there might exist congestion on mobile user's network and for such cases the congested network area users can be transferred to other network environment in a temporal manner which can be made possible by CR. For such cases the proposed system gives solution by enabling the unlicensed mobile users' to access the TV band so as to increase the spectrum utilization efficiency. However this can also be extended to other PU channels to be explored by different SUs. The received PU signal at k-number of CRUs is shown in Eq. 1 [11]:

$$y(n)_k = \begin{cases} n(n)_k & : H_0 \\ h_k s(n) + n(n)_k & : H_1 \end{cases} \tag{1}$$

Where n = 1…, N is number of samples, and $n(n), s(n)$ and $y(n)$ are noise, PU signal and the PU signal received at SU respectively. When SU receives the PU signal it always first estimates the SNR of the received PU signal, y(n), using MMSE estimator, which has low complexity and minimum error in estimating the received PU signal, [12] to know the received signal's strength. For the received PU signal y with variance of δ_y^2 the MMSE error estimation for SNR γ is:

$$mmse(y, \gamma) = \frac{\delta_y^2}{1 + \gamma \delta_y^2} \tag{2}$$

The threshold value can be determined based on the estimated MMSE as shown in Eq. 3 [12]:

$$\lambda_{mmse} = \delta_n^2 Q^{-1}(P_f) + \frac{\delta_n^4}{N}(\gamma_{mmse} + 1)^2 \tag{3}$$

where P_f is probability of false alarm. Based on this estimation and threshold, the SU will decide to detect the free band either by itself or by cooperating with surrounding SUs. The detection scheme used in this work is ED that averaged the received PU signal to determine the decision statistics and make the decision as shown in Fig. 2.

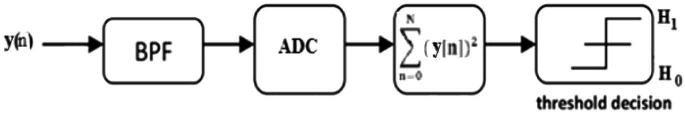

Fig. 2. Block diagram of energy detector [13]

In ED, the received signal is first filtered by a BPF to get the desired signal with one sided power spectral density (PSD) N_{01} [14].

$$H(f) = \begin{cases} \frac{2}{\sqrt{N_{01}}}, & |f - f_c| \le W \\ 0, & |f - f_c| > W \end{cases} \tag{4}$$

The output of this filter that is shown in Eq. 4 would be squared and accumulated to get the decision statistics for the output of analog to digital converter (ADC), $y(k)$, which is given as [15]:

$$\mathrm{Y} = \sum\nolimits_{k=0}^{N} [y(k)]^2 \tag{5}$$

Under AWGN channel (h = 1) for hypothesis H_0, the normalized decision (test) statistics Y with variance δ_n^2 have a central Chi-square distribution with 2 m degrees of freedom [16].

And for hypothesis H_1, Y with variance of the signal, δ_n^2 have a central Chi-square distribution with 2 m degrees of freedom and non-central parameter 2γ where $\gamma = \frac{\delta_s^2}{\delta_n^2}$ represents the SNR. This decision statistics is given as [14, 15]:

$$Y = \begin{cases} y_{2m}^2 & : H_0 \\ y_{2m}^2(2\gamma) & : H_1 \end{cases} \tag{6}$$

The probability of detection, $P_{d,}$ and probability of false alarm, $P_{f,}$ can be obtained from its PDF to give Eqs. 7 and 8 respectively using the marcum Q-function, $Q_m(.)$ and the gamma function Γ(a, b) with m = TW [11, 17]:

$$P_d = P[Y > \lambda/H_1] = Q_m(\sqrt{2\gamma}, \sqrt{\lambda}) \tag{7}$$

$$P_f = P[Y > \lambda/H_0] = \frac{\Gamma\left(m, \frac{\lambda}{2}\right)}{\Gamma(m)} \tag{8}$$

For large number of samples, N, the decision statistics can be rewritten as [15]:

$$Y = \begin{cases} N\left(\mu_0, \delta_0^2\right) & : H_0 \\ N\left(\mu_1, \delta_1^2\right) & : H_1 \end{cases} \tag{9}$$

where $N\left(\mu_0, \delta_0^2\right)$ is Gaussian distribution with $\mu_0 = N\delta_n^2$ and variance $\delta_0^2 = 2N\delta_n^4$ for hypothesis H_0 and mean $\mu_1 = N(\delta_s^2 + \delta_n^2)$ and variance $\delta_1^2 = 2N(\delta_s^2 + \delta_n^2)^2$ for hypothesis H_1. The probability of detection and false alarm for such cases are given by Eqs. 10 and 11 respectively [11, 17]:

$$P_d = Q\left(\frac{\lambda - N(\delta_s^2 + \delta_n^2)}{\sqrt{2N(\delta_s^2 + \delta_n^2)^2}}\right) \tag{10}$$

$$P_f = Q\left(\frac{\lambda - N\delta_n^2}{\sqrt{2N\delta_n^4}}\right) \tag{11}$$

For a signal under Rayleigh fading channel with fading amplitude α, the instantaneous and average SNR per symbol will become $\gamma = \frac{\alpha^2 E_s}{N_0}$ and $\bar{\gamma} = \Omega \frac{E_s}{N_0}$ with $\Omega = \overline{\alpha^2}$ respectively. For such fading channel the SNR follows exponential distribution is given by [15, 18]:

$$f_\gamma(\gamma) = \frac{1}{\gamma} \exp\left(\frac{-\gamma}{\bar{\gamma}}\right) \tag{12}$$

The decision statistics under Rayleigh fading channel with exponential distribution $e_2(\gamma^2 + 1)$ and $\alpha = 2(\gamma^2 + 1)$ with central chi-square distribution having $2(N + 1)$ degrees of freedom for parameter α is [15]:

$$Y = \begin{cases} y^2_{2(N+1)} & : H_0 \\ e_{2(\gamma 2+1)} + y^2_{2N} & : H_1 \end{cases} \tag{13}$$

Using this, the SC scheme enables to determine the probability of detection under Rayleigh fading channel is given in Eq. 14 [15].

$$\mathrm{P_{dRay}} = \int_0^{\infty} Q_m\left(\sqrt{2\gamma}, \sqrt{\lambda}\right) \mathrm{f}_\gamma(\mathrm{x})\, dx \tag{14}$$

Noise is random variable with a distribution assumption of perfectly Gaussian which is not the case for the practical implementation as there exist some uncertainty in the distribution. The uncertainty, ρ, affects the detection performance of the ED as it will vary the threshold. The variation of the threshold has the region given in Eq. 15 between $\frac{\delta_n^2}{\rho}$ and $\rho\delta_n^2$. The larger uncertainty will result in higher detection performance degradation given by [19]:

$$\sigma^2 \varepsilon \left[\frac{\delta_n^2}{\rho}, \rho\delta_n^2\right] \tag{15}$$

where $\rho > 1$ is noise uncertainty coefficient. Equations 16 and 17 can obtain the probability of detection and false alarm under this uncertainty respectively [15, 19].

$$\mathrm{P_d} = \mathrm{Q}\left(\frac{\lambda - \mathrm{N}(\frac{1}{\rho}\delta_n^2 + \delta_s^2)}{\sqrt{2\mathrm{N}(\frac{1}{\rho}\delta_n^2 + \delta_s^2)^2}}\right) \tag{16}$$

$$\mathrm{P_f} = \mathrm{Q}\left(\frac{\lambda - \mathrm{N}\,\rho\delta_n^2}{\sqrt{2\mathrm{N}\rho^2\delta_n^4}}\right) \tag{17}$$

The basic detection task that is performed by the ED is to compare the energy with a certain threshold value given by [15]:

$$\lambda = \sqrt{\mathrm{N}\rho^2\delta_n^4}\,Q^{-1}(P_f) + \mathrm{N}\,\rho\delta_n^2 \tag{18}$$

Based on the comparison the decision of presence or absence of PU signal will be made by each SUs.

When the PU channel state is detected by a cooperative energy detection scheme shown in Fig. 3, the probability of detection and false alarm using SC at the fusion center for AWGN channel is: [8]

$$\begin{cases} Q_{m,sc} = Q_m\left(\sqrt{2\gamma_{sc}}, \sqrt{\lambda}\right) \\ Q_{f,sc} = \frac{\Gamma(\mathrm{m}, \frac{\lambda}{2})}{\Gamma(\mathrm{m})} \end{cases} \tag{19}$$

Where: $\gamma_{sc} = \max(\gamma_1, \gamma_2, \ldots\ldots, \gamma_k)$

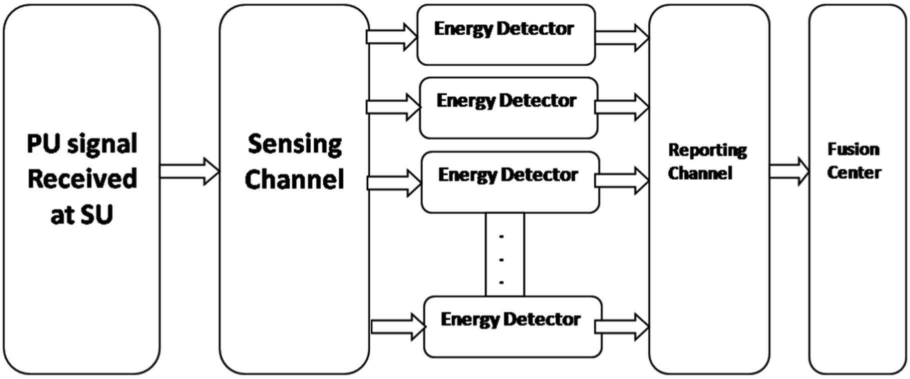

Fig. 3. Cooperative energy detection [15]

Under Rayleigh fading channel for K number of SUs PDF of the maximum SNR from k-number of SUs can be determined as:

$$f_{ymax}(\gamma) = \frac{K}{\gamma}\left(\left(1 - e^{\frac{-\gamma}{\bar{\gamma}}}\right)^{(k-1)} e^{\frac{-\gamma}{\bar{\gamma}}}\right) \quad (20)$$

And the detection probability is [11]:

$$Q_{dsc} = \int_{\gamma} Q_m\left(\sqrt{2\gamma_{sc}}, \sqrt{\lambda}\right) f_{\gamma\max}(\gamma) d\gamma \quad (21)$$

4 Simulation Results and Discussions

In this section some results of our work are presented. Based on the proposed system model simulation analysis had been done for the case of Rayleigh fading channel to evaluate the detection capability of the system. To do that, various parameters shown in Table 1 had been used.

Table 1. Simulation parameters used for analysis

Simulation parameters	Type and value
Number of PU	1
Number of SU	≥ 1
PU signal	BPSK modulated
Bandwidth	6 MHz
Center frequency	4 MHz
Channel	Rayleigh fading channel
SNR	[−30 dB, 2 dB]
N	100
Probability of false alarm	$\leq 10\%$

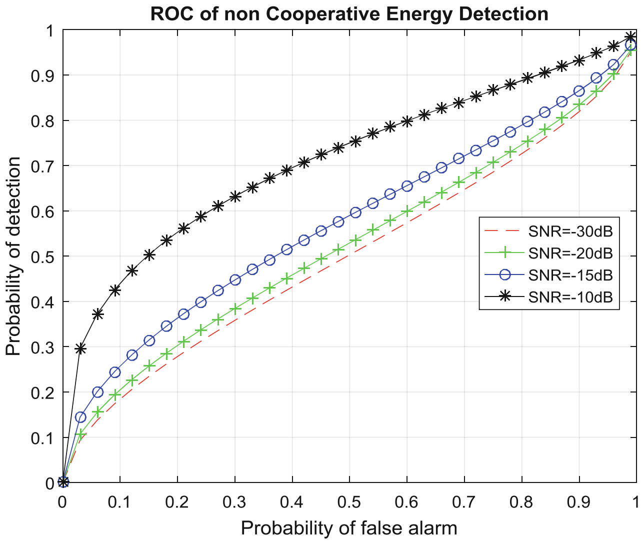

Fig. 4. ROC of non-cooperative energy detection for different SNR values under Rayleigh fading channel

Figure 4 shows the ROC of non-cooperative energy detector under different SNR values. The energy detector capability is highly affected by the strength of the received signal. From the results for the probability of false alarm of 0.5, the probability of detection increases from 0.5 to 0.75 which is a 25% increment achieved by the increase in SNR from −30 dB to −10 dB. Hence, whenever the received signal has higher strength the detection probability will be better.

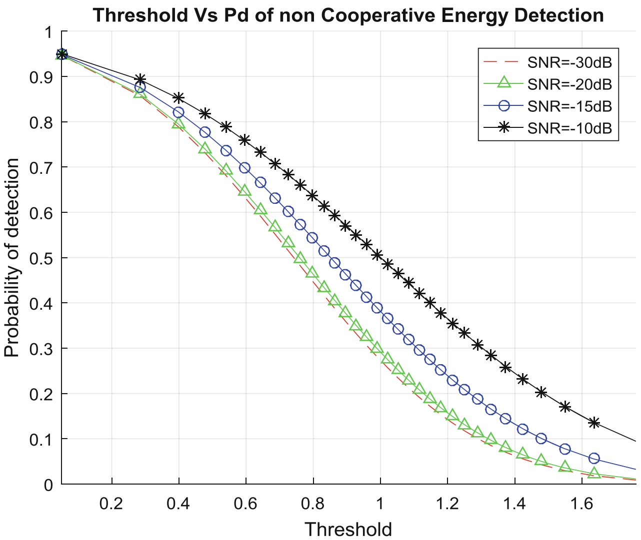

Fig. 5. Threshold Vs Pd of non-cooperative energy detection for different SNR values under Rayleigh fading channel and Pf = 10%

From the result in Fig. 5, it can be seen the increment in the threshold value which is the function of false alarm probability leads to the decrements in the detection probability. If the threshold is set to be higher, it will lead for the detector to make the decision of the PU channel being idle even if there exists a strong PU signal, as it only compares the energy with the threshold. Being low threshold means it can detect the signal even if it has low energy. The detection performance was upgraded by incrementing the SNR, which means, the reception of a signal with high strength leads to improvement in detection performance at the same threshold value.

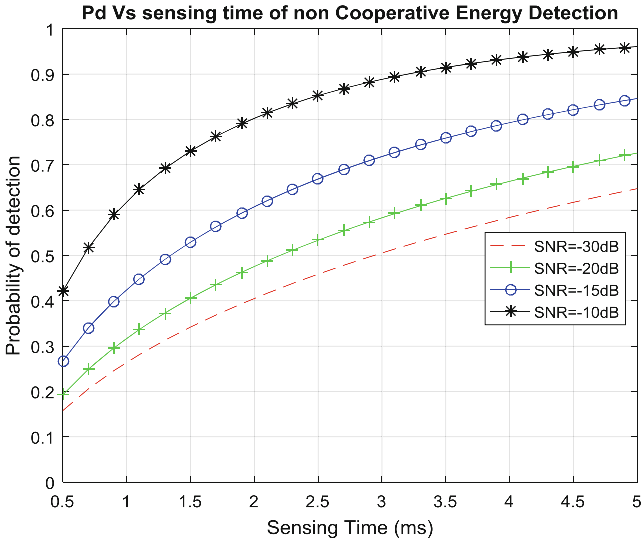

Fig. 6. Pd Vs sensing time of non-cooperative energy detection for different SNR values under Rayleigh fading channel and Pf = 10%

Figure 6 demonstrates the effect of SNR on the time it takes to achieve a better probability of PU signal being detected by SUs. When the received signal is strong, the sensing time needed by SUs to detect a PU signal will be too short.

Figure 7 shows the relationship between SNR to the probability of detection for the cases of cooperative ED scheme. The results shows that for a low SNR value cooperating SUs gives a good detection performance that leads for the SU not to cause interference for the PU transmission. Also in observing the results that gives unity probability of detection, the non-cooperative detection achieves probability of detection of 100% at the SNR of −6 dB; by cooperating two and three SUs the detector achieves this value at SNR of −8 dB and −10 dB respectively. Even if the signal strength is very weak cooperating two and more SUs enables the detectors to detect the PU signal in a better way.

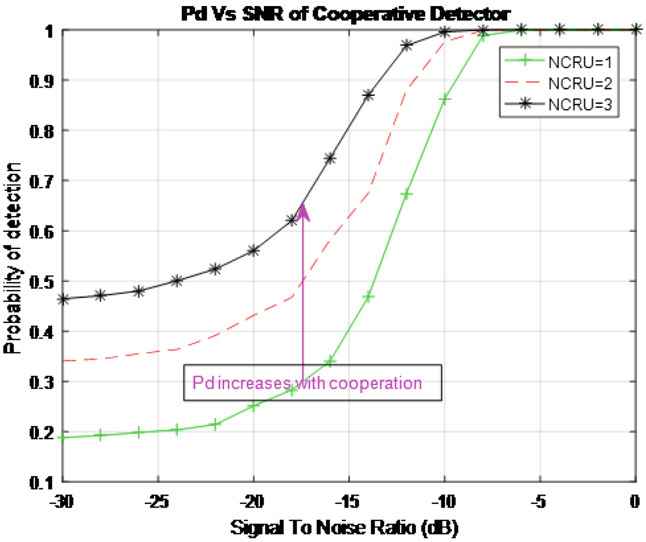

Fig. 7. Cooperative energy detection effect on the detection of signal with different strength under Rayleigh fading channel and Pf = 10%

Figure 8 shows the effect of sensing time on the probability of detection of a PU signal by SU. The increase in sensing time gives better detection probability for the non-cooperation detection and also for cooperative detection as indicated in the result. However, this increment in the sensing time has its own effect on the throughput of the SUs. Whenever SU takes longer sensing time, the data transmission would be

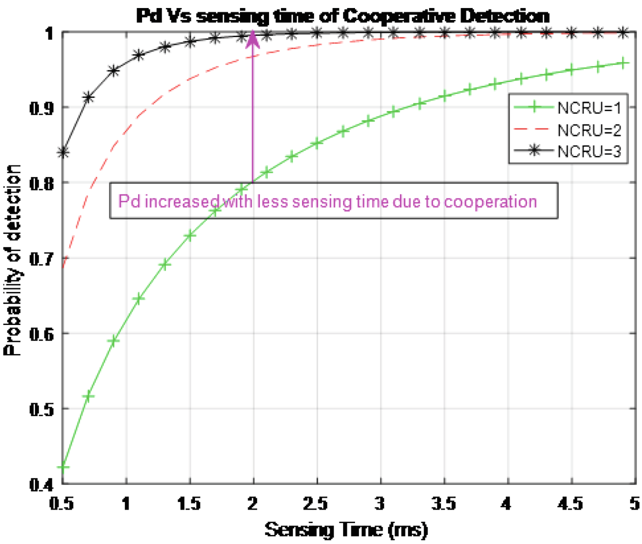

Fig. 8. Probability of detection versus sensing time for cooperative energy detection with SC fusion scheme effect under Rayleigh fading channel for SNR = −10 dB and Pf = 10%

shortened which leads for the decrements in the throughput of the system as it will lead for longer sensing time and shorter transmission time. To reduce this effect, cooperative detection is preferable to achieve optimum detection within short sensing time.

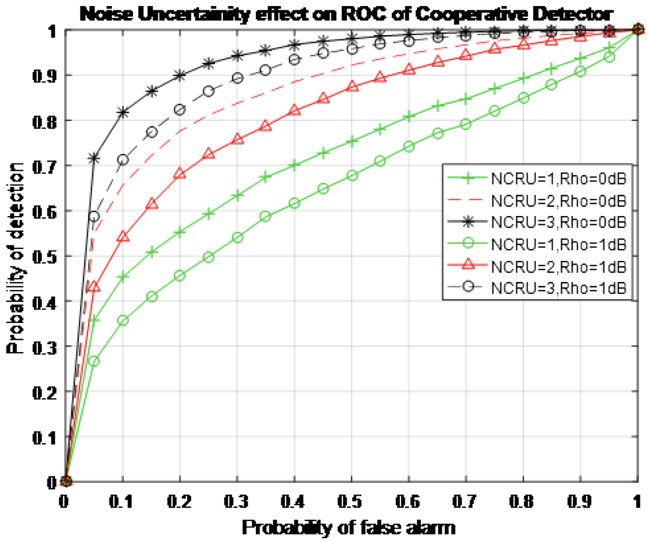

Fig. 9. Noise uncertainty effect in cooperative energy detection with SC fusion rule under Rayleigh fading channel and SNR = −10 dB

The effect of noise uncertainty on the cooperative energy detection with SC fusion rule is illustrated in Fig. 9. The detection probability which takes noise uncertainty factor in to consideration had been improved using cooperative energy detection scheme. But, even if it gives much better performance the noise uncertainty factor has an effect in reducing the performance of both cooperative and non-cooperative detection. Cooperating SUs under uncertainty gives a better detection performance than the non-cooperative detection.

From the result in Fig. 10, the cooperative detection scheme manages to reduce the effect of detection probability with respect to the threshold value. In order to detect the signals of low energy it needs to have a threshold value as small as possible. For the system to achieve a probability of detection of 0.8, the threshold value needed for the case of a single SU detection with considering noise uncertainty is 0.42. And cooperating two and three SUs needs a threshold of 0.53 and 0.7 respectively which is increased due to the cooperation detection that would enable the system to detect signals much better.

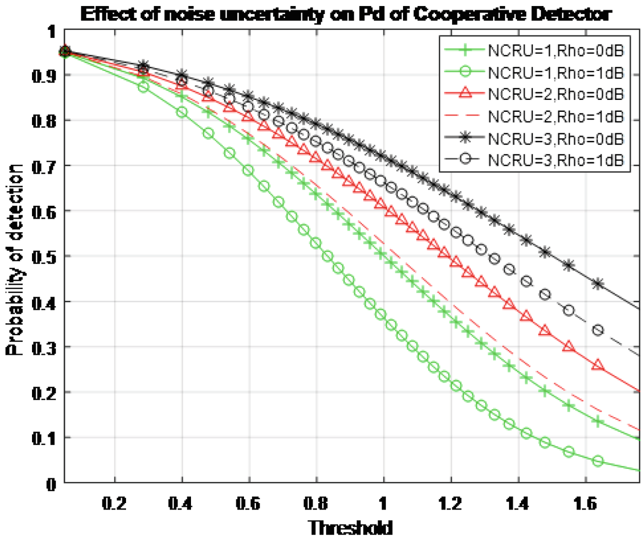

Fig. 10. Noise uncertainty effect in cooperative Energy Detection with SC fusion rule for detection with threshold under Rayleigh fading channel, SNR = −10 dB and Pf = 10%

From Fig. 11 it can be observed that using the MMSE estimator when the threshold of the SNR value had been estimated as −10 dB it will have some performance degradation with the reception of a PU signal with SNR from −10 dB to −7 dB. This degradation was improved when the estimated threshold is −9.2 dB which was further

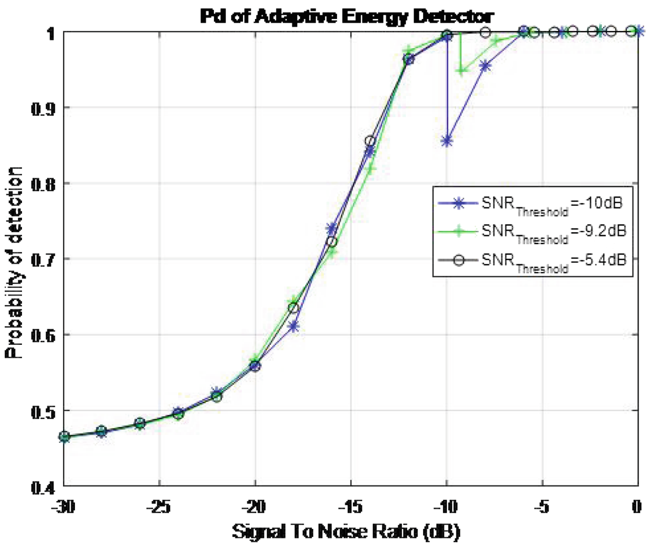

Fig. 11. Detection probability of proposed adaptive Energy Detection under Rayleigh fading channel, Pf = 10%

enhanced while the SNR threshold estimation is −5.4 dB. Hence, better detection probability can be achieved at low and high SNR regions with less complexity and reduced overhead by combining the advantages of both cooperative and non-cooperative energy detection adaptively. Also the results show that the optimal threshold SNR value for the system which provides a good detection performance is −5.4 dB.

As illustrated in Fig. 12, even though the introduction of 1 dB uncertainty reduced the detection performance, still the proposed system gives a better detection both at low and high SNR values. The result demonstrates with the existence of uncertainty, fading and shadowing problems in Rayleigh fading channel, using adaptive threshold based energy detection had can sense and detect PU frequency spectrum even with the reception of weak signals.

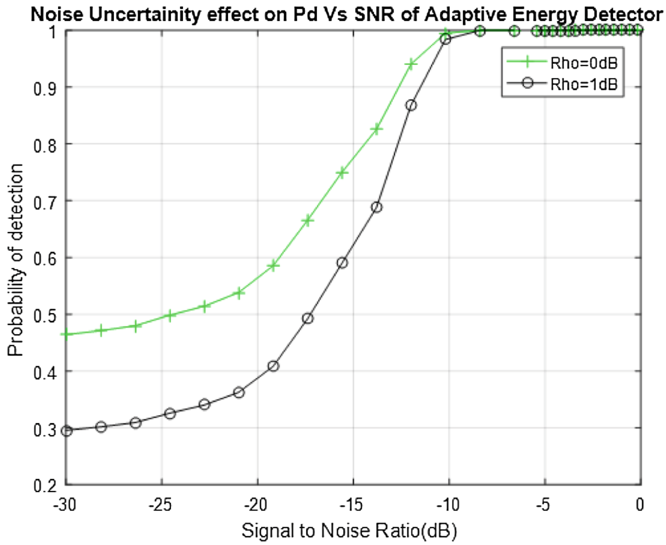

Fig. 12. Detection probability of proposed adaptive Energy Detection under Rayleigh fading channel, Pf = 10% and $\lambda_{\_SNR}$ = −5.4 dB with noise uncertainty

Using the optimal estimated SNR threshold that is −5.4 dB, the proposed system attains an optimum detection probability within short period of sensing time with the existence of 1 dB uncertainty. As shown in Fig. 13 when the SU estimates PU signal strength and find it to be lower than −5.4 dB, the system can achieve 0.95 detection probability within 0.9 ms when there is no uncertainty. However, the introduction of 1 dB uncertainty leads the system to take 1.4 ms time to achieve the same detection probability. If the PU signal's SNR is estimated above −5.4 dB each SU with no uncertainty will take 4.5 ms to achieve 0.95 detection probability this time will be incremented to 5 ms with the introduction of 1 dB uncertainty to achieve the same detection probability. This shows the system needs extra 0.5 ms sensing time to obtain same detection probability due to the uncertainty.

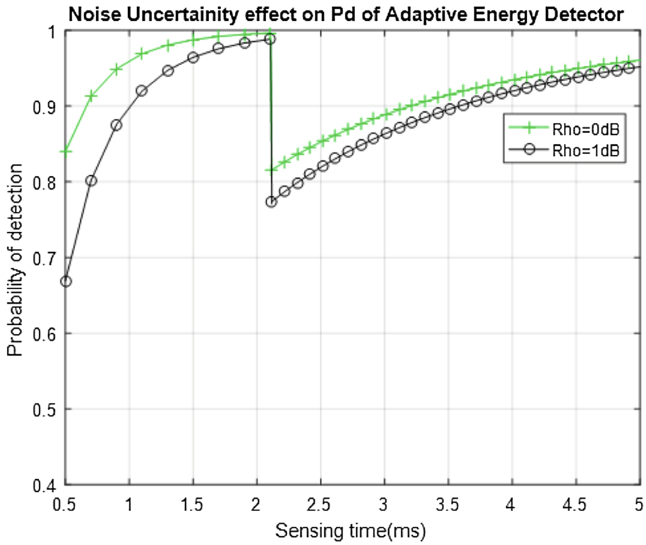

Fig. 13. Pd Vs sensing time of proposed adaptive Energy Detection under Rayleigh fading channel, Pf = 10% & $\lambda_{\_SNR}$ = −5.4 dB with noise uncertainty

The result in Fig. 14 depicts the effect of threshold value on the detection performance of the proposed system. With the SNR of PU signal being estimated with a threshold value of less than −5.4 dB, the system works at the energy threshold value up to1 with uncertainty (Rho = 1 dB) and 1.08 with no uncertainty (Rho = 1 dB) cooperating three SUs. And whenever the SUs receive the PU signal with strength above

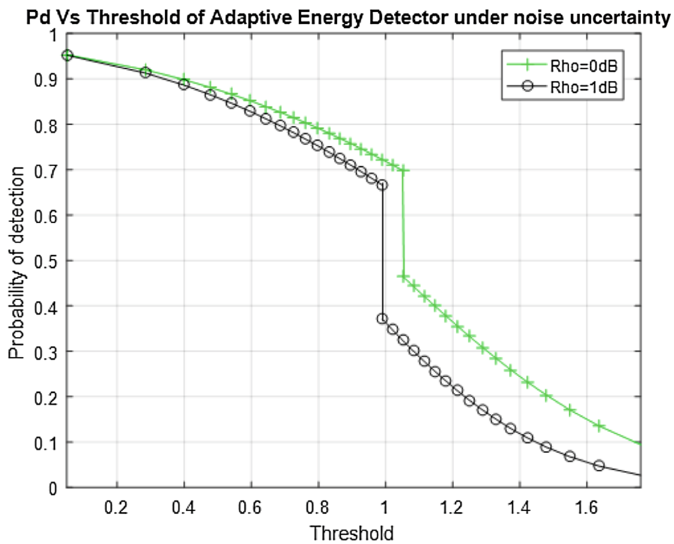

Fig. 14. Threshold Vs Pd of proposed adaptive energy detection under Rayleigh fading channel, Pf = 10% and $\lambda_{\_SNR}$ = −5.4 dB with noise uncertainty

−5.4 dB each SUs will have energy threshold value above 1 and 1.08 with no uncertainty and with uncertainty of 1 dB respectively. This shows that, with the reception of weak signal the system gives a good detection having allowed threshold values. Also when the PU receives strong signals the system will adjust its threshold value a bit higher for good detection.

Even if MFD needs a prior knowledge about the PU signal it is one of the robust signal detection schemes capable of providing higher probability of detection. In MFD scheme, the received signal would be passed through a BPF to get the desired signal followed by a matching filter which is capable of minimizing the noise component and maximizing the signal component to maximize SNR. This would enable the MFD to achieve a good detection performance by correlating the two signals (the reference signal and impulse response of the matched filter) to determine the places at which the two signals are the same. This task makes the detector to identify the idleness of the channel in a better way [14].

When the proposed system performance with −5.4 dB threshold SNR value is compared with the conventional ED and the MFD, it gives a better performance on the case of both weak and strong signal reception as shown in Fig. 15.

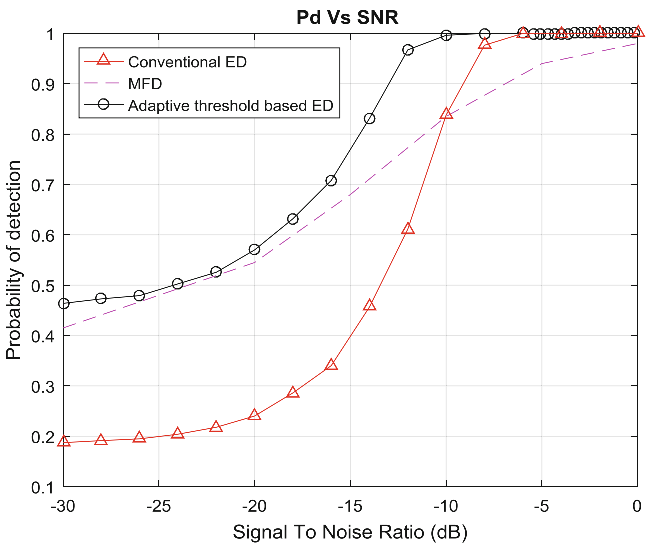

Fig. 15. Pd Vs SNR comparison for conventional ED, MFD and adaptive threshold based ED under Rayleigh fading channel and Pf = 10%

Whenever the SU receives a weak signal or with low SNR it compares the signal with the threshold. If the SNR receives weak PU signal it will share information with the surrounding SUs and make the decision using SC fusion rule to attain the detection performances shown in the above results. But if the SU receives strong PU signal it will make the detection decision by itself without sharing information with other SUs as shown in the figures. This will enable for the system to attain a reliable detection performance even at low SNR values cooperating more than one SU. Also for signals of good strength, the detection was much better using non cooperative detection which is less complex with no overhead.

5 Conclusion

Current static spectrum allocation leads for underutilization. To reduce this problem CR with a dynamic spectrum accessing capability is a good solution.

In this work, threshold based adaptive ED scheme that uses cooperative ED for low SNR values and non-cooperative ED for high SNR values had been proposed and analyzed supported by simulation for various parameters.

The system gives a good detection performance for low SNR regions by cooperating three SUs and non-cooperative detection at high SNR regions. Hence, whenever a SU gets a low SNR it manages to get a good detection performance by detecting it cooperatively that gives the solution for the non-cooperative energy detection problem. And also whenever the SU receives a strong signal the SU can manage to decide the state of the spectrum by themselves that enable to reduce complexity and overhead, as it does not require a central FC. This is due to the reason that, if a system always uses cooperative detection SUs require a reporting channel to send the information about PU signal to the central FC. And also this reporting channel will be used by the FCs to send the decision about the state of PU channel. However, the proposed system needs for the SUs to cooperate with the reception of week signal only and are capable of deciding by themselves in reception of strong signal which leads to not using reporting channels always. Generally the CRUs can explore and occupy the available PU bands without causing an interference by applying the proposed adaptive threshold based ED to achieve improvement in the utilization of radio frequencies for LTE systems.

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