Comparison of Single User with Multi User Cooperative Spectrum Sensing for Energy Detector at Low SNR Wall

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Abstract. With rapidly increasing demand in wireless communication, available licensed spectrum resources should be utilized efficiently and actively. Cognitive radio is a device which learns from surrounding environment and transmit its signal when license spectrum is unutilized. Spectrum sensing is the need for Cognitive radio. In this paper, Energy detector is implemented though MATLAB software for single and multiusers. Region of Convergence (ROC) curve is plotted for both normal ED and Cooperative spectrum sensing ED. Results show while increasing number of samples from 1k to 100k, probability of detection is also achieved 0.9 maximum. Increasing SNR from -20dB, -15dB to -10 dB, probability of detection is improved in ROC curve. Also cooperative spectrum sensing with OR rule gives good probability of detection 0.9 to 1.

1. Introduction

The reconfigurability offered by Software Defined Radio (SDR) technology enables radios to switch functions and operations cannot reconfigure itself alone. SDR cannot change its parameters without its user’s acknowledgement. Mitola [1] has introduced the cognitive radio(CR) in his PhD thesis in first time in 1999. He enlightened for the cognitive radio. As per Mitola’s research, CR is a software radio, which can modify its parameters though sensing the environment without interfering the system. Cognitive radio is a smart radio which can use to find the free spectrum by continuously monitoring the interested channels and when the focused area of channels are found free, CR can use the channels dynamically with existing infrastructure, without interfering the other signals in wireless communication. Symon Haykin [2] also described the CR which is wirelessly and smartly access the spectrum freely available and further while using the spectrum, CR learns the environment and change its own parameters like SNR, modulation, etc. through the surroundings on which CR regulates. CR doesn’t require any software and programming like software defined radio (SDR). There are many descriptions in applications and usage of CR idea, major two areas to focus on CR which are reconfigurability and intelligent adaptive behaviour.

Now a days TV analog to digital transformation is happened everywhere which has created the TV white spaces in the spectrum of the licenced users. By dynamically utilise this TV white space, Federal Communication Commission (FCC) [5]has given a permission to utilise this TV white spaces without
disturbing the other(licensed) users, which is called dynamic spectrum allocation (DSA) technology[4,6], a process of utilizing the spectrum.

CR is suitable for DSA technology, where no of CRs, utilise the spectrum without disturbing the their neighbourhood area signals. There are different functions of CR to access the available spectrum concisely, like Spectrum sensing, spectrum managing, spectrum analysis, spectrum adapting which is shown in figure 1.

![Figure 1. A Cognitive Process [3]](image)

Energy detector (ED) based cooperative spectrum sensing is widely used in last many years due to low complexity of ED method in spectrum sensing. In Cooperative sensing, more than one secondary users(SUs) sense the desired band signal with different soft combination and hard combination rule by coordinating under fading channel[7-15].

Here in this paper, we are focusing about the spectrum sensing of CR. first to identify where the spectrum band is available for further transmission. There are various number of techniques used for spectrum sensing like Energy detector, Cyclostationary feature detector, Matched filter etc. based on the user application, CR can use the spectrum sensing technique.

Energy Detector (ED) is the simplest technique used for spectrum sensing by CR. The main drawback of ED is suffering at low SNR region. While SNR value is below 0 dB, problem occurs in detection of the primary’s signal (licensed user) to distinguish among the noise and PU’s signal. To overcome the problem cooperative spectrum sensing (CSS)is used along with the Normal Energy detector technique.
In CSS, more than one secondary users (SUs) or CR users are used in coordinated manner and take the
decision based on different algorithm to detect the primary user’s signal (licensed user) and report to the
fusion centre for further global decision[20]. Due to the CSS technique, hidden transmitter of PUs, if
not found by single SU, can be found by other SU’s report and decision will be taken based on all SU’s
reports.

This paper is organised like, Section II describes the understanding of detection of primary signals with
the help of hypothesis, Section III describes the energy detector technique, section IV presents the idea
of Cooperative spectrum sensing (CSS) while computer results of all shown in Section V followed by
conclusion in Section VI.

2. Discover the Primary Signal

For spectrum sensing, the first step is to find out the spectrum hole whether primary user’s signal is
present or not in the focused band of frequency or channel. Through binary hypothesis, the sensing nodes
confirm the primary signal present or only noise is present for focused area of the channel which reflects
in Eqn. 1.

\[ H_0 : \text{only noise} \quad \& \quad H_1 : \text{Primary’s signal is present} + \text{Noise} \]  

\[ (1) \]

Now let’s decide for test statistics \( Y(t) \) received signal by CR, noise \( n(t) \), Primary signal \( S(t) \), Hypothesis
is defined as

\[ H_0 : Y(t) = n(t) \]  
\[ (2) \]

\[ H_1 : Y(t) = S(t) + n(t) \]  
\[ (3) \]

Eqns. (2) & (3) describe the channel statistics where only noise is present or Primary user’s signal is
present. \( H_0 \) represents only noise while \( H_1 \) represents noise and signal both. Depending on different
algorithm PU’s signal can be detected.

Based on Hypothesis calculation, there are two types error occurs. Type 1 error is called Probability of
false alarm (PFA), which is generated when detector says Primary is present but actual only noise is
present, opportunity of transmission is missed due to type 1 error. Type 2 error is called probability of
miss detection (PMD), which detects Primary is not present while actual condition Primary is present
and which creates the interference in PU’s signal with Secondary (CR) user’s signal. Type 2 Error cannot
be tolerated. One should avoid Type 2 error in the transmission. Figure 2 shows receiver operating
characteristics (ROC) curve, Probability of false alarm (PFA) vs. Probability of detection (Pd) graph.
Figure 2. Typical Receiver Operating Characteristic[16]

The following Eqns. (4) & (5) describe type 1 & 2 errors,

**Error Type 1,**
\[ \epsilon = \text{Probability of False Alarm} = \text{Probability} \left[ \text{Decide } H_1|H_0 \right] \]  \hspace{1cm} (4)

**Error Type 2,**
\[ \delta = \text{Probability of Miss Detection} = \text{Probability} \left[ \text{Decide } H_0|H_1 \right] \]  \hspace{1cm} (5)

3. Spectrum Sensing Technique

There are many spectrum sensing techniques available based on different environment, techniques are applicable. Here Energy detector (ED) is shown as spectrum sensing technique for cognitive radio networks which is simple to implement without prior knowledge of PU’s signal.

3.1 Hypothesis for Energy Detection

The spectrum sensing can be decided through binary hypotheses which are shown in Eqns. (6) & (7)

\[ Y(t) = n(t) \quad \text{Only noise, PU is absent} \]  \hspace{1cm} (6)
\[ Y(t) = hS(t) + n(t) \quad \text{PU’s signal is present with noise} \]  \hspace{1cm} (7)

Where h represents channel amplitude gain, Y(t) is received signal through secondary users (SUs). Here n(t) is noise of the channel considered Additive White Gaussian Noise (AWGN). S(t) is primary user’s signal. Through the hypothesis of ED, ED detects for CR users whether only noise is present or PU’s signal is available in the channel. Through ED, CR finds the spectrum opportunity for particular time interval when licensed users are not using the spectrum[17,18]
In Figure 3, block diagram of Energy detector is shown. ED method, received energy is being compared with threshold (reference) value based on the channel characteristics. Threshold is used fixed or variable based on noise variances depending on the detection algorithm and channel conditions[19].

![Energy Detector block diagram](image)

**Figure 3.** Energy Detector block diagram

In ED technique, first signal received by CR (secondary user) is passed through Band pass filter (BPF) to choice the channel and then signal is integrated through integrator with specified time limit. At the end, output of integrator is compared with threshold and based on hypothesis H0 & H1 algorithm, ED detects whether the licensed user (PU) are present or not present in the channel. If the channel is found free during the detection, CR can use the channel for its transmission for specific time by taking permission of licensed user’s. ED is very simple and easy to implement compare to other spectrum sensing techniques but in low SNR region, ED cannot distinguish between the noise and PU’s signal. To overcome this ED is implemented in CSS environment in next session.

4. Co-operative Spectrum Sensing (CSS)

A single CR is detecting the Primary user’s signal through spectrum sensing techniques like Energy detector(ED) which suffers sometimes cannot find all the transmission nodes of the Primary users signal as it suffers the hidden transmitter node problem. Due to this, Primary’s signal in overlapped with CR’s signal. To remove such kind of problems, Co-operative spectrum sensing is used in CR networks. In CSSS, different no of CRs can detect the PU’s signal and report to fusion centre. Now fusion centre, based on different algorithms of CSS like AND , OR  and majority rule, takes the decision that whether PU’s signal is present or absent[21].

Cooperative spectrum sensing is implemented by logic AND and OR rule in this paper[8,9].Following Eqs. (8), (09) describes the Logic OR rule probability of detection (Pd) and probability of false alarm (PFA). In Eqs. (10), (11), Probability of detection and probability of false alarm is discussed through Logic AND rule. Here M no of cooperative users are used in CSS environment [20-23].

Logic-OR (LO) Rule:

\[
P_d = 1 - \prod_{i=1}^{M} (1 - P_d i)
\]

\[
P_f = 1 - \prod_{i=1}^{M} (1 - P_f i)
\]

Logic-AND (LA) Rule :

\[
P_d = \prod_{i=1}^{M} (P_d i)
\]

\[
P_f = \prod_{i=1}^{M} (P_f i)
\]
5. Computer Simulations

Through MATLAB programming ED is implemented with single user and multiuser ED under cooperative spectrum sensing environment which has been showed in the sections 5.1 and 5.2 respectively.

5.1 Single User with Energy Detector (ED)

In this paper, ROC curve is plotted at SNR -21 dB for the different values of samples like 1k, 10k & 100k simulated and theoretically shown in fig 3. ROC graph in fig 3 shows the single user with energy detection spectrum sensing technique which states that by increasing no. of samples can have better probability of detection and less probability of false alarm. For using sample size 100k, $P_d=0.8$ and $P_f=0.2$

![ROC Curve at -21 SNR](image)

**Figure 4.** PFA vs. $P_d$ at -21 dB SNR with sample size 1k, 10k & 100k.
Figure 5. PFA vs. Pd at -21 dB, -15 dB, -10 dB SNR

Fig 5 ROC curve is plotted for 1000 samples for SNR -21 dB, -15 dB and -10 dB both theoretically and practically. ROC graph in fig 5 shows the single user with energy detection spectrum sensing technique which states that by increasing SNR can have better probability of detection and less probability of false alarm.

5.2 Multiple User with Energy Detector (ED)

Cooperative spectrum sensing is implemented for 4 CR users at -20 dB SNR values for sample size 100k in fig 6. It shows the cooperative spectrum sensing with AND and OR logic rule is used for implementation.
**Figure 6.** PFA vs. Pd at -20 dB SNR, 100k sample size under multiple ED

Fig 6, 7, 8 show cooperative spectrum sensing technique ROC. Where maximum probability of detection have been achieved through the OR logic rule compared to AND rule.
Figure 7. PFA vs. Pd at -20 dB, 10k sample size under multiple ED

Figure 8. PFA vs. Pd at -20dB, 1k sample size under multiple ED
Fig 9 shows ROC graph for SNR -15 dB at 1k sample size under the multiple ED environment. Results in fig 9 clearly show when the SNR is increased from -21 dB to -15 dB, probability of detection is 0.99, almost 1.

![ROC Plot for cooperative SUs ED](image)

**Figure 9.** PFA vs. Pd at -15 dB, 1k sample size under multiple ED

6. Conclusion
In this paper, we have implemented Energy detector for spectrum sensing in cognitive radio networks. Single energy detector is implemented and results show that by increasing no of samples in test statistics, probability of detection is closer to 1. Through Single energy detector, results show that ED results are worst under low SNR (-21dB). This low SNR (-21dB) is focused under cooperative spectrum sensing environment. In CSS, logic AND and OR is implemented. Probability of detection is nearly 1 in CSS through the OR logic than the AND logic under the low SNR region. So it’s always better to use cooperative spectrum sensing (CSS) rather than the single energy detector at low SNR region. Under the CSS, results show by increasing no of sample from 1k to 100k , probability of detection improves like single energy detector but AND results are become more worse(less Pd) than OR by increasing the sample size.

In this entire paper, AWGN channel is being used for all secondary users while in real life, the scenario could be changed than AWGN. So for future, this work can be focused with practical Rayleigh fading channel characteristics to validate the results more precisely.
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