

## Effective Channel Detection at Low SNR in Cognitive Radio Network Using Matched Filter Approach and Compare with Energy Detection - based Approach

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### Abstract

**Aim:** The study aims to detect the effective channel in cognitive radio network at low SNR using an innovative algorithm based on matched filter detection and compared it with energy detection.

**Materials and methods:** The spectrum sensing based on novel matched filter detection with 10 samples is compared with the energy detection by varying the SNR conditions, using MATLAB.

**Results:** The probability of detection of the matched filter is high at low SNR(-30db) then compared to the probability of detection of energy detection at low SNR(-10db) and the significance level is 0.002, i.e., ( $P < 0.05$ ) which gives better sensing performance. **Conclusion:** this would be proved to conclude that at low SNR conditions the matched filter detection gives significantly high sensing probability.

**Key-words:** Cognitive Radio Network, Signal to Noise Ratio, Innovative Algorithm, Matched Filter, Spectrum Sensing, Energy Detection, Probability of Detection.

### 1. Introduction

The cognitive radio networks have been introduced to increase the efficiency of spectrum usage by allowing secondary users to access unused radio spectrum from primary authorized users (Samala et al. 2020); (Yucek and Arslan 2009; Shabnam, Shabnam, and Mahajan 2015). This study is important as the Primary users can utilize the spectrum at any time, the cognitive users must have to

sense the spectrum to check whether it is accessible or not and should be able to identify very weak primary user signals (Deepak, Shyamala Bharathi, and Kumar 2017); (Joykutty and Baranidharan 2020). There are various applications where cognitive radio networks are used as mobile computing and all emergency fields like medicine, military, etc. (Yanbin, Zhongji, and Xu 2012); (Wu et al. 2020).

Several distinct methods identified the sensing probability of signal transmissions have been suggested are Energy Detection Technique is widely known as a spectrum sensing technique. It was derived from the principle that the energy of the received signal to be identified was greater than the energy and noise. It can only detect the signal of the primary user if the detected energy is higher than the threshold. It has a low sensing probability at low SNR, and it cannot distinguish between the signal and the noise (Arjoun et al. 2018); (Nayak et al. 2020). In autocorrelation Based Detection the value of the acquired signal autocorrelation coefficient is used. The PU signal was present when the two values are near, if not absent. This system can discern the signal from the noise, but the drawbacks were internal thermal noise was not detected by it and it was poor spectrum sensing (Salahdine and El Ghazi 2017); (M. and Sindhu 2019; Reyes et al. 2016). In the cyclostationary feature detector, the spectrum sensing technique can discern the modulated signal from additive noise. It was used at a low Signal to Noise Ratio (SNR), it can distinguish PU signal from noise. High computing complexity and long sensing time are the major drawbacks of this approach (M. and Sindhu 2019); (Yadav, Roy, and Kundu 2016).

Previously our team has a rich experience in working on various research projects across multiple disciplines (Sathish and Karthick 2020; Varghese, Ramesh, and Veeraiyan 2019; S. R. Samuel, Acharya, and Rao 2020; Venu, Raju, and Subramani 2019; M. S. Samuel et al. 2019; Venu, Subramani, and Raju 2019; Mehta et al. 2019; Sharma et al. 2019; Malli Sureshbabu et al. 2019; Krishnaswamy et al. 2020; Muthukrishnan et al. 2020; Gheena and Ezhilarasan 2019; Vignesh et al. 2019; Ke et al. 2019; Vijayakumar Jain et al. 2019; Jose, Ajitha, and Subbaiyan 2020). Now the growing trend in this area motivated us to pursue this project.

Most of the spectrum sensing methods are focused to detect SNR aspects. However, at low SNR, there was a poor sensing probability. So an innovative algorithm based on Matched filter detection technique was proposed in this study to detect effective channels at low SNR to achieve improved sensing probability.

## 2. Materials and Methods

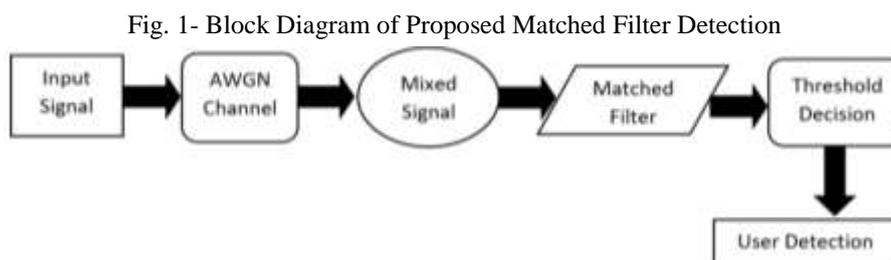
The study setting of the proposed work done in SIMATS. The number of groups used in this analysis was 2. The sample size of this study was 10 for each group. group 1 was the energy detection-based spectrum sensing technique. The sample preparation for group 2 was the matched filter detection technique. 80% of G power was used for testing.

### 2.1. In Sample Preparation Group 1

10 samples were used to analyze the results by using the energy detection technique, which was derived from the principle that the energy of the received signal to be identified as being greater than the energy of noise. Since it ignores the form of the received signal with a known threshold, an energy detector was called a blind signal detector. The threshold value can be fixed according to spectrum conditions. Although energy detection can be implemented without any a priori knowledge of the primary user signal, the technique has some difficulties. Firstly, it has a low sensing probability at low SNR, and it cannot distinguish between the signal and the noise (Arjoun et al. 2018).

### 2.2. In sample Preparation Group 2

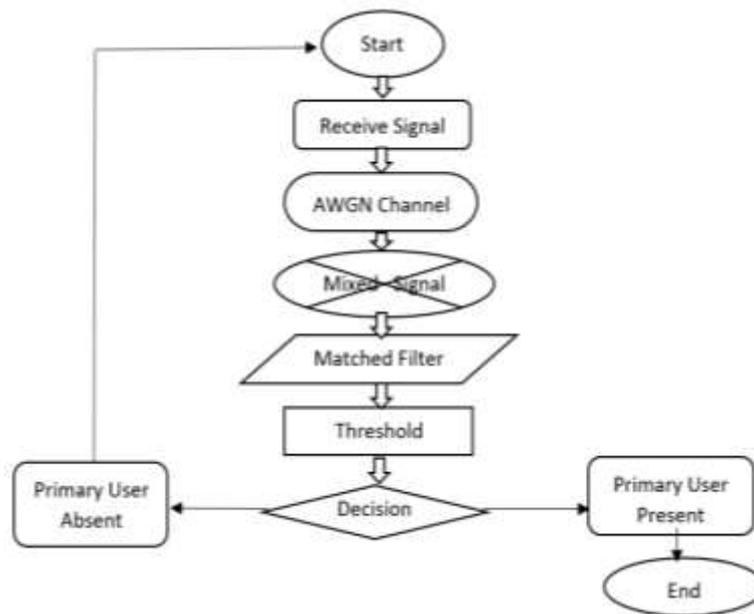
10 samples were used to analyze the results by the matched filter detection, which intended to increase the output signal-to-noise ratio of an input signal. The matching filter recognizes where a cognitive user has input from the primary user signal. The matched filter function was equivalent to correlation in which the undetermined signal complexed with a filter whose impulse response was the version of a reference signal mirror and time-shifted (Salahdine et al. 2015). Since only 0 (1/SNR) samples are needed to satisfy a given probability of detection restriction, matched filter detection takes less time to detect. In stationary Additive white Gaussian noise, matched filter detection has been referred to as the optimal detection mechanism where cognitive radio users detect the primary user signal.



The input signal was allowed to pass into the channel, exposed to additive white Gaussian noise, and then output as a mixed signal. The matched filter Fig.1 has been the input for this mixed-signal whereas the impulse response was converted into the matched filter data, related to the PU detection threshold. The signal threshold, governed by the impulse response of the matched filter and its output then differentiated from the signal threshold for primary user (PU) detection. The signal Threshold, determined by two possible methods, was stated here One method found the signal energy and set it to half, fix it as a threshold. Another method measured the standard deviation of the signal by measuring and using the mean as a threshold. Of the two methods, the first technically proven to be ideal(Shobana, Saravanan, and Muthaiah 2013).

### 2.3. Proposed System

Fig. 2- Flow Diagram of Proposed Matched Filter Process



Set the threshold once the signal presence was determined based on the spectrum sensing model Fig. 2 can be formulated as:

$$S(N) = \{G(n) H_0: \text{Signal Absent}$$

$\{h^*p(n)+G(n) H_1: \text{Signal Present (1)}\}$  where  $N$  is the number of samples,  $p(n)$  is the Primary User Signal,  $G(n)$  is the Additive White Gaussian Noise (AWGN) with zero mean and variance  $\sigma_w^2$ ,  $S(n)$  be the Secondary User received signal, and  $h$  means the complex channel gain of the sensing channel.  $H_1$  and  $H_0$  signify respectively the presence and the absence of the primary user signal. The

Primary user signal recognition was implemented using one of the spectrum sensing techniques to determine between the two hypotheses  $H_0$  and  $H_1$ .

The sensing decision (2) performed as:

$$\begin{cases} \text{if } T \geq \tau, H_1 \\ \text{if } T < \tau, H_0 \end{cases} \quad (2)$$

Where  $T$  denotes the detector's test statistic,  $\tau$  represents the sensing threshold. SU will enter the PU channel even though the PU signal was not present. Otherwise, it won't be able to access the channel at any moment.

Matched filter detection (3) obtained by

$$T_{mfd} = \sum_{n=0}^{N-1} S(n) * x(n) \quad (3)$$

Where  $S(n)=2\sqrt{P}\cos(2\pi f*n)$ , the  $S$  represents the secondary user obtained signal,  $x$  be the primary user signal, and  $T_{mfd}$  denotes the matched filter detector test statistics.

As a linear combination of Gaussian random variables,  $T_{mfd}$  (3) also approximated as a gaussian random variable.

$$\begin{cases} \text{if } T_{mfd} \geq \tau, \text{The signal is present} \\ \text{if } T_{mfd} < \tau, \text{The signal is absent} \end{cases} \quad (4)$$

The probability of detection was given by using the Nyman-Pearson criterion.

$P_d = P(T_{mfd} > \tau)$ , or signal present.

To improve the performance of the matched filter with the signal to noise ratio,  $\tau$  is divided by  $\sqrt{\rho_w^2 E}$

$$P_d = P(T_{mfd} > \frac{\tau}{\sqrt{\rho_w^2 E}}) \quad (5)$$

$$P_d = Q\left(\frac{\tau-E}{\sqrt{\rho_w^2 E}}\right),$$

$$P_d = Q\left(\frac{\tau-E}{\rho_w \sqrt{E}}\right) \quad (6)$$

Where  $E$  be the PU signal energy,  $Q(\cdot)$  be the Q- function, and  $\rho_w^2$  the noise variance,  $\tau$  be the sensing threshold.

PU signal energy can be expressed as

$$E = \sum_{n=0}^{N-1} S(n)^2 \quad (7)$$

The probability of false alarm was given by the Nyman-Pearson criterion,

$$P_{fa} = P(T_{mfd} > \tau) \text{ or signal Absent}$$

$$= P(T_{mfd} > \frac{\tau}{\sqrt{\rho_w^2 E}}) \quad (8) \quad P_{fa} = Q\left(\frac{\tau}{\sqrt{\rho_w^2 E}}\right)$$

$$P_{fa} = Q\left(\frac{\tau}{\rho_w \sqrt{E}}\right) \quad (9)$$

Equations (4) and (6) to estimate the probability of detection and probability of false alarm and sensing probability of cognitive users under CR networks are maximized. System parameters are observed from (table.1) to calculate the sensing probability of the spectrum.

Table 1- System Parameters to Undergo Spectrum Sensing

Parameters	Value
No. of samples	100
SNR	-10, -20, -30
PF	0.01, 0.1, 0.99
Simulation time	1000 s
Transmission range	100 m
Threshold value	0,1
Signal Power	1 W

The SPSS software tool was used for the statistical analysis of two groups. The significance of the study was calculated under an independent sample T-test. The independent variable in this study was the signal-to-noise ratio and the dependent variable was the probability of detection.

### 3. Results

Fig. 3- Shows the Sensing Probability of Energy Detection (ED) and Matched Filter Detection (MFD). The Sensing Probability of ED appears to be Partially High at Fixed SNR of -10 dB Compared to MFD

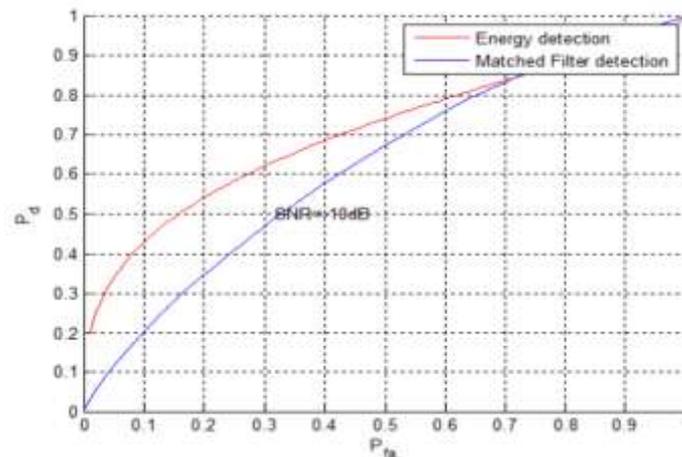


Figure. 3 shows at low SNR -10dB, energy detection begins with a probability of detection (0.2) and the matched filter begins with a probability of detection (0.02) in low false alarm (.01). The sensing probability of ED is (0.75) and MFD is (0.70).

Fig. 4- Shows the Sensing Probability of Energy Detection and Matched Filter Detection. The Sensing Probability of MFD Appears to be Improved at Fixed SNR of -20 dB Compared to Energy Detection

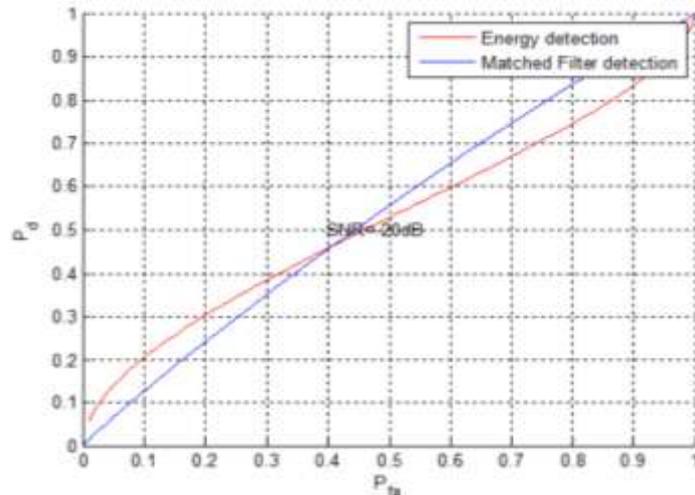


Fig. 4 shows at low SNR -20dB energy detection begins with a probability of detection (0.07), and matched filter begins with a probability of detection (0.01) in low false alarm (.01). The sensing probability of ED (0.52) and MFD (0.57).

Fig. 5- Shows the Sensing Probability of Energy Detection and Matched Filter Detection. The Sensing Probability of MFD appears to be Improved at Fixed SNR of -20 dB Compared to Energy Detection

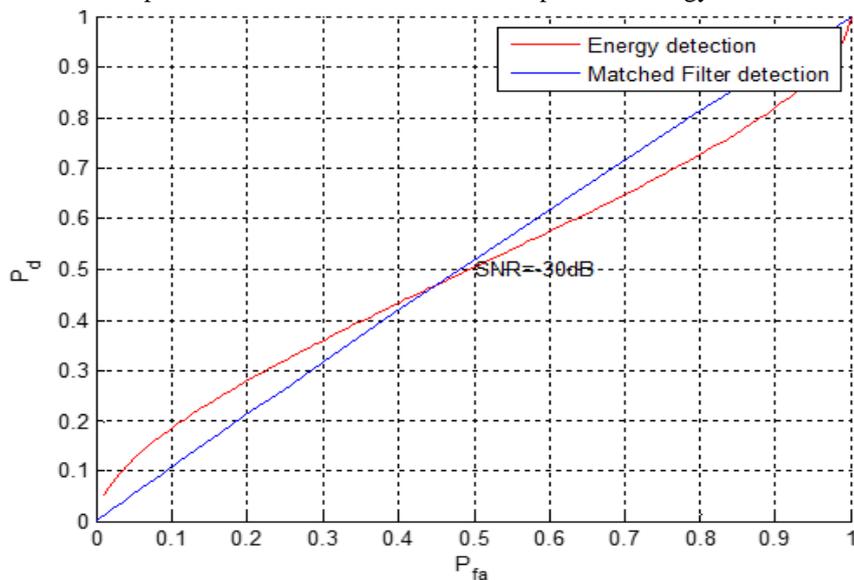


Figure. 5 shows at low SNR -30dB, energy detection starts with a probability of detection (0.05), and the matched filter starts with a probability of detection (0.001) in low false alarm (.01). The sensing probability of ED (0.49) and MFD (0.54).

Table 2 shows the group statistical analysis with 10 samples, Energy detection obtained a standard deviation of 0.13 with 0.05 standard error while matched filter detection obtained 0.25 standard deviation with 0.1 standard error.

Table 2- Group Statistics Results Reveal the Mean and Standard Deviation for the Matched Filter Detection

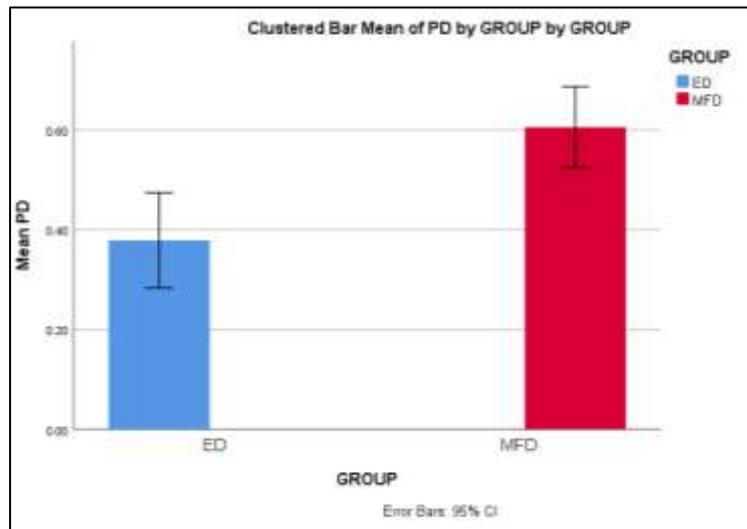
Group Statistics					
	GROUP	N	Mean	Std. Deviation	Std. Error Mean
Probability of Detection	ED	10	0.4257	0.13219	0.05752
	MFD	10	0.5200	0.25431	0.10746

Table 3- Shows the Comparison of the Probability of Detection between Energy Detection and Matched Filter Detection. There is a Statistically Significant difference in PD of Two Techniques is 0.02 ( $p < 0.05$ ) in Independent Sample t-test

	Levene's Test for Equality of Variances		t-test for equality of means						
	F	Sig.	t	Dif.	Sig.(2-tailed)	Mean Difference	Std. error difference	95% confidence interval of the difference	
								lower	upper
PD	5.052	0.044	-.692	18	.002	-.08429	.12189	-.34985	.18128
Equal variances not assumed			-.692	13.88	.002	-.08429	.12189	-.34985	.19063

As per the values obtained from the independent sample T-test Table 3, it can be identified that the significance value is 0.002, i.e.,  $P < 0.05$ . From Fig. 6, it can be concluded that the Matched filter has got significantly better performance than the energy detection.

Fig. 6- Bar Graph Represents the Comparison of the Mean Probability of Detection with Energy Detection(ED) and Matched Filter Detection(MFD). the Mean Probability of Detection of MFD is better than ED.X-axis is ED and MFD Techniques and Y-axis is the mean Probability of Detection  $\pm 1$  SD



#### 4. Discussion

In this study, the results were obtained by relating matched filter detection and energy detection by differentiating the SNR. It was understood that the sensing probability of energy detection decreases when decreased SNR and Matched filter detection probability of sensing performs significantly better.

The factors affecting the signal characteristics are the number of users, frequency, channel length, signal strength, and bandwidth which leads to fluctuating the spectrum sensing probability of cognitive users. The study of spectrum sensing of very weak primary user signals using energy detection showed at low SNR -30dB, sensing probability was poor (0.49) (Nayak et al. 2020). Another study by (Wu et al. 2020) observed that to find the unused spectrum the secondary user spectrum sensing time was high (0.2). The study of sensing techniques cannot distinguish the signal and noise from the secondary user signal for sensing the spectrum (M. and Sindhu 2019; Reyes et al. 2016); Bagwari et al. 2020). In this analysis sensing probability was increased (0.54) at low SNR -30dB and the sensing time of the spectrum was minimized (0.02). Hence it was observed that the proposed model was significantly higher.

Our institution is passionate about high quality evidence based research and has excelled in various fields (Vijayashree Priyadharsini 2019; Ezhilarasan, Apoorva, and Ashok Vardhan 2019; Ramesh et al. 2018; Mathew et al. 2020; Sridharan et al. 2019; Pc, Marimuthu, and Devadoss 2018; Ramadurai et al. 2019). We hope this study adds to this rich legacy.

The limitation of this study was that every type of primary user would require a dedicated receiver in a cognitive radio network. The Future scope is at higher bandwidths the spectrum sensing of the signal can improve in the Cognitive radio networks.

## **5. Conclusion**

This paper discusses the need for CR technology to perform effectively at low SNR for comparing the matched filter detection approach with the energy detection-based approach. The results acquired as the energy detection-based approach be a less complex algorithm to calculate but spectrum sensing probability appeared to be poorer at low SNR conditions the matched filter-detection approach performed better than the energy detection-based approach as it begins operating at low SNR of -30 dB s and found optimal use of SNR for both.

## **Declarations**

## **Conflict of Interests**

No conflict of interest in this manuscript.

## **Authors Contributions**

Author Kandlagunta Tejesh<sup>1</sup> was involved in data collection, data analysis, manuscript writing. Author P. Shyamala Bharathi<sup>2</sup> was involved in conceptualization, data validation, and critical review of the manuscript.

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