Blind Parameter Estimation Based Matched Filter Detection for Cognitive Radio Networks

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***Abstract*—Energy detection (ED) technique is a vastly used sensing technique in CRNs because of its operational simplicity. However at low SNR, the performance of ED is badly degraded. Matched Filter (MF) detection is an alternate sensing technique at low SNR, as it increases SNR of the received signal. MF detector gives far better performance when compared to ED at low SNR. But the problem with MF detector is that it must have priori knowledge about Primary User (PU) signal, therefore we need dedicated MF detector for each PU. Motivated by above drawback of ED and MF in this paper we proposed a new MF technique by which requirement of priori knowledge about PU signal can be eliminated as well as performance at low SNR is improved. At the MF detector front end, we perform blind estimation of PU signal parameters and accordingly update the coefficient of MF transfer function. Blind Estimation of signal parameters solves the problem of having priori information about PU signal for MF detector. Performance analysis and comparison of ED, conventional MF detector and proposed MF detector also have been done in this paper which show that the proposed MF detector perform better than ED and almost same as the conventional MF detector.**

Keywords- Blind Estimation, Energy Detection, Matched Filter Detection, Roll-off Factor

I. Introduction

Recent advancements in wireless communication applications have generated the need for very large spectrum. The assignment of a frequency spectrum permanently to a particular application or user (Licensed User or Primary User) has led to underutilization of available spectrum. Fixed allocation of the frequency spectrum renders spectrum scarcity, since allocated spectrum may be used occasionally or even unused. These occasionally used spectrums are termed as white space or spectrum holes. Surveys have shown that 60 percent of licensed spectrum below 6 GHz is being underutilized [1]. The solution to more spectrum demand lies in offering licensed idle spectrum to other non-licensed requesting user (Secondary User) temporarily. Cognitive Radio (CR) is an environment-aware, intelligent system that exploits the spectrum holes and enhances the usage of limited frequency spectrum resource so that more user can be accommodated in limited band [2]. In order to detect spectrum holes in wideband spectrum many techniques have been proposed for spectrum sensing out of which Energy detection (ED), Cyclostationary (CS) detection and Matched Filter (MF) detection are most discussed and most practiced [2] [3].

ED technique is the least complicated technique to implement as it only computes energy of received signal for an observational period and compares it with a predetermined threshold. The presence or absence of Primary User (PU) signal depends on whether measured energy is greater than or less than the threshold. The disadvantage of ED technique is its poor performance at lower SNR [4] [5] [6]. Second sensing technique, CS detection outperforms the ED and MF detection at low SNR. PU signal has the CS characteristic due to usage of modulation, sampling, sinusoidal wave carriers, cyclic prefix Etc. The spectral correlation density is used as test statistic and compared with the threshold to determine the existence of PU signal. But the drawback of this technique is that it is more complex than other two [6] [7]. Next sensing technique is MF detection that performs best in the Additive White Gaussian Noise (AWGN) environment. In this technique shape of the transmitted signal is known that determines the MF transfer function. MF output is the correlation between received signal and transfer function of MF. The response of MF is compared with a threshold to decide whether signal is present or absent. Its performance lies between that of ED and CS detector [6] [8]. In addition, MF detection yields far better performance than ED in terms of PU signal detection at lower SNR. But the challenge encountered with MF detection is detector should have priori information about modulation type, pilot carrier of the transmitted signal. This implies dedicated MF detector is required to sense each PU signal.

Surveying other research work, in [2] identification strategy of spectrum holes in wideband spectrum is given which is based upon wavelet based edge detection. In [4] [5] ED technique has been discussed. Comparative performance of ED, MF detection and CS detection have been studied in [6] with fuzzy logic cooperative sensing, distributed cooperative sensing, network cooperative sensing Etc. In [9] authors studied the impact of PU Emulation (PUE) which does not allow Secondary User (SU) to access the channel even when channel is vacant. The problem of PUE is solved by implementing a series of helping nodes. [8] [10] Illustrate the application of MF in spectrum sensing. In [8] formulation of the MF detection and realization of the PU signal detection over GSM 900 band is done which is majorly followed in our proposed

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detection scheme. In [11] [12], authors present the strategy for blind estimation of the signal parameters like roll-off factor, Symbol Rate, Carrier Frequency of an unknown signal using Inverse Fourier Transform.

In this paper, we proposed a new detection scheme based on MF detection technique. The suggested scheme gains ground over conventional MF detection on account of its universal application for each type of the user signal. The main challenge of conventional MF detector of having prior information about PU signal is countered here by blind estimation [11] [12] of PU signal. If the band being investigated is occupied by PU, then the test statistic calculated with received signal and estimated signal will give higher value than predetermined threshold and SU is not permitted to use the spectrum. If the band is vacant, the received signal at the detector will be noise, therefore matching with estimated signal which is also noise, will give less value than the threshold and SU is permitted to use the channel. To illustrate the performance of proposed technique, we compare the performance of our approach to that of conventional MF and ED techniques.

Section II of this paper is dedicated to the system model under which binary hypothesis test model, probability of detection and probability of false alarm for ED and MF detection have been described. Our proposed detection methodology is discussed in the section III, that consists of two subsections. In first subsection signal model is given, which is being used as PU signal, subsequently second subsection estimation of PU signal for updating MF coefficient is discussed. In section IV simulation setup and performance evaluation of our proposed detection scheme is presented. Finally the conclusion is presented in section V.

NOTATION USED- ε_r is used for power of received signal $r_x[n]$. γ is threshold to which Decision Statistic of ED (D_{ED}) and MF (D_{MF}) is compared. σ_w^2 is variance of AWGN w[n]. $P_{\hat{g}}(f)$ is estimated power spectrum of PU signal, $\hat{T}_1$ is estimated coarse symbol period and $\hat{T}_2$ is used for estimated refined symbol period.

II. SYSTEM MODEL

In CR, the existence of PU signal is determined on the basis of binary hypothesis test. We make the assumption that noise w[n] is independent and identically distributed random Gaussian process with expectation $E[|w[n]|] = 0$ and variance $E\left[|w[n]|^2\right] = \sigma_w^2$. In addition, we assume PU Signal p[n] is independent of noise w[n]. The binary hypothesis test model for taking decision is given as

$$r_x[n] = \begin{cases} w[n] & : H0 Hypothesis \\ w[n] + p[n] & : H1 Hypothesis \end{cases} \tag{1}$$

Where $r_x[n]$ is received signal, $H0$ is null hypothesis that signifies no PU signal is present at detector. $H1$ is the alternative hypothesis that portrays the presence of noise affected PU signal at the detector. The PU signal detector has to choose between these two hypothesis on the basis of decision statistic or test statistic. The decision statistic is given as [5]

$$D_E(r_x) = \sum_{n=0}^{M-1} |r_x[n]|^2 \tag{2}$$

The decision statistic $D_E(r_x)$ under H0 hypothesis can be considered as a random variable with the probability density function $P_0(D)$ which is a Chi-Square distribution with M degrees of freedom for real case and 2M degrees of freedom for complex case. The binary hypothesis for decision statistic can be modelled as

$$\hat{r_x} = \begin{cases} H0 & : D(r_x) \leq \gamma \\ H1 & : D(r_x) \geq \gamma \end{cases} \tag{3}$$

Where γ is predefined noise dependent threshold. In ED, the decision of presence of PU signal is inferred on the basis of energy, which may result in three cases. First case is of correct detection when H1 is decided while H1 is true. Second case is of false alarm when H1 is decided while H0 hypothesis is true and last case is the case of miss detection when H0 is decided while H1 hypothesis is true. The probability of occurrence of case 1 is called probability of detection and given as [5]

$$P_{d,ED} = P(D_{ED} > \gamma | H1) = Q\left(\frac{\gamma - M(\sigma_w^2 + \varepsilon_r)}{\sqrt{2M(\sigma_w^2 + \varepsilon_r)^2}}\right) \tag{4}$$

Energy of received signal

$$\varepsilon_r = \sum_{n=0}^{M-1} |r_x(n)|^2 \tag{5}$$

Probability of decision as case 2 is called probability of false alarm and given by [5]

$$P_{fa,ED} = P(D_{ED} > \gamma | H0) = Q\left(\frac{\gamma - M(\sigma_w^2)}{\sqrt{2M(\sigma_w^2)^2}}\right) \tag{6}$$

Probability of decision taken as case 3 is called probability of miss detection and can be given as [9]

$$\begin{aligned} P_{md,ED} &= P(D_{ED} < \gamma | H1) \\ &= 1 - Q\left(\frac{\gamma - M(\sigma_w^2 + \varepsilon_r)}{\sqrt{2M(\sigma_w^2 + \varepsilon_r)^2}}\right) = 1 - P_{d,ED} \end{aligned} \tag{7}$$

Q(.) is complementary distribution function given as

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty exp(-\frac{y^2}{2}) dy \tag{8}$$

Application of MF at the receiver front end maximizes the SNR. The coefficients of MF are complex conjugate of reversed signal. In MF operation, the correlation of known signal p[n] with MF coefficients can be viewed as filtering operation. If h[n] is the impulse response of the MF, output of the MF can be given as [9]

$$Y_{MF}[n] = \sum_{k=0}^{M-1} h[n-k] r_x[n] \tag{9}$$

h[n] is the complex conjugate flipped around version of the

PU signal given as

$$h[n] = p_s^*[M-1-n] \tag{10}$$

From (7) and (8) output of the MF can be given as [9]

$$Y_{MF}[M-1] = \sum_{n=0}^{M-1} r_x[n]p_s^*[n] = r_x^T p_s \tag{11}$$

The decision statistic of MF is given as [8]

$$D_{MF}(r_x) = \left| \sqrt{\frac{2}{M\varepsilon_r \sigma_w^2}} \sum_{n=0}^{M-1} r_x[n]p_s^*[n] \right|^2 \tag{12}$$

Now the binary hypothesis test model can be given as

$$r_x = \begin{cases} H0 & : D_{MF} \le \gamma \\ H1 & : D_{MF} \ge \gamma \end{cases} \tag{13}$$

Where threshold value γ is given by [8]

$$\gamma = \frac{\varepsilon_r}{\sigma_w^2} \tag{14}$$

False Alarm for the MF detection will be when H1 is decided while H0 hypothesis is true. In this case, the received signal $r_x[n]$ at detector front will be noise w[n]. Therefore, the output of MF from (9) can be written as

$$Y_{MF}[M-1] = \sum_{n=0}^{M-1} w[n]p_s^*[n] \tag{15}$$

Probability of false alarm for MF detection is given as [9]

$$P_{fa,MF} = P\left(D_{MF} > \gamma | H0\right) \tag{16}$$

$$P_{fa,MF} = Q\left(\frac{\gamma}{\sqrt{\varepsilon_r \sigma^2}}\right) \tag{17}$$

Probability of detection of PU signal is deciding H1 when H1 hypothesis true. In this case received signal $r_x[n]$ is p[n]+w[n], and the MF output is

$$Y_{MF}[M-1] = \sum_{n=0}^{M-1} \left[p[n] + w[n]\right] p_s^*[n] \tag{18}$$

The probability of detection for MF is given as [9]

$$\begin{aligned} P_{d,MF} = P\left(D_{MF} > \gamma | H1\right) &= Q\left(\frac{\gamma - \varepsilon_r}{\sqrt{\varepsilon_r \sigma_w^2}}\right) \\ &= Q\left(\frac{\gamma}{\sqrt{\varepsilon_r \sigma_w^2}} - \sqrt{\frac{\varepsilon_r}{\sigma_w^2}}\right) \\ &= Q\left(Q^{-1}(P_{fa,MF}) - \sqrt{\frac{\varepsilon_r}{\sigma_w^2}}\right) \end{aligned} \tag{19}$$

Probability of miss detection is deciding H0 while H1 hypothesis is true and is given as

$$P_{md,MF} = P(D_{MF} < \gamma | H1) = 1 - P_{d,MF} \tag{20}$$

III. DETECTION APROACH WITH BLIND ESTIMATION OF SIGNAL PARAMETERS

Here we consider the fact that Root Raised Cosine (RRC) Pulse is commonly used for baseband shaping in Linear Digital Communication. In the proposed scheme, we are trying to estimate the signal parameter so that in MF detection we can get rid of the problem of having priori knowledge of PU signal. Roll-off factor is an important characteristic of the signal which decides the shape of transmitted symbol. The performance of our proposed detection technique lies upon the accuracy of the estimation of roll-off factor and symbol rate. In next subsection, we present the signal model, roll-off factor and symbol rate estimation technique used in our approach.

A. SIGNAL MODEL

We assume the independent and identically distributed M-ary symbols $c_k = a_k + jb_k$ with unit average energy are being transmitted. For the ease of understanding and representation we are taking the signal and operations over signal in continous domain from hereafter. The equivalent RRC signal at the detector with amplitude A_p, time shift τ (less than or equal to half of the symbol period T), carrier frequency f_c and phase offset of θ is

$$r_x(t) = A_p e^{j(2\pi f_c t + \theta)} \sum_k h(t - kT - \tau) + w(t) \tag{21}$$

Where h(t) is RRC of unit energy Base Band Pulse with roll-off factor $\alpha (0 \le \alpha \le 1)$. The Power Spectrum of the noise affected received signal as shown in Fig.1 is

$$P_r(f) = \frac{A_p^2}{2T} \left| H(f - f_c) \right|^2 + P_w(f) \tag{22}$$

Where H(f) is the Fourier Transform of baseband RRC Pulse h(t) and $P_w(f)$ is the power spectrum of AWGN component.

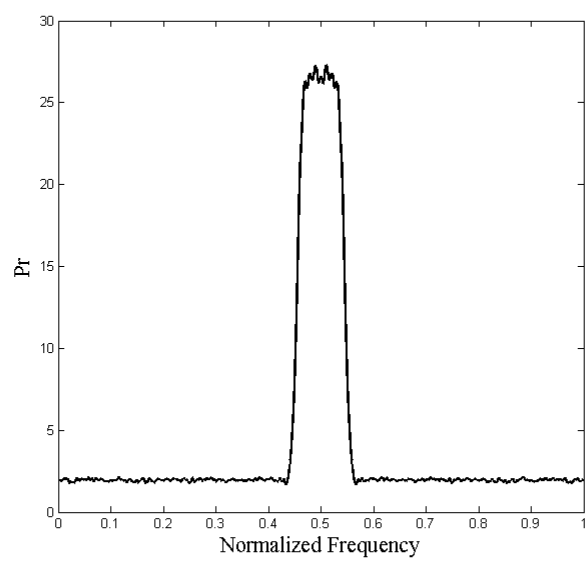

Fig. 1: Power Spectrum of received signal

One reliable and easy way to eliminate the noise power P_w from the received signal Power Spectrum $P_r(f)$ is histogram method. In this method, we can find the maximum value of noise power by scrutinizing the histogram of the power spectrum $P_r(f)$. Here noise is considered as AWGN that will affect all frequency component, therefore AWGN Power P_w will seize maximum number of bins and have the largest Bar in the histogram plot as shown in Fig.2. By averaging all the samples below the maximum value of noise power we can obtain the noise power P_w in the received signal power spectrum $P_r(f)$. The estimated PU signal power spectrum will be $P_{\hat{p}}(f) = P_r(f) - P_w$ [11] .

B. ESTIMATING ROLL-OFF FACTOR AND SYMBOL RATE

The RRC Pulse is given as

$$g(t) = \frac{sin(\pi t/T)}{\pi t/T} \frac{cos(\pi \alpha t/T)}{1 - 4(\pi \alpha t/T)^2} \tag{23}$$

RRC Pulse has maximum value at $t = 0$ i.e. $g(0)$. Now we can find out the value of $g(t)_{min}/g(0)$ for different value of where $g(t)_{min}$ is minimum value of g(t). Given ratio can be written as a function of

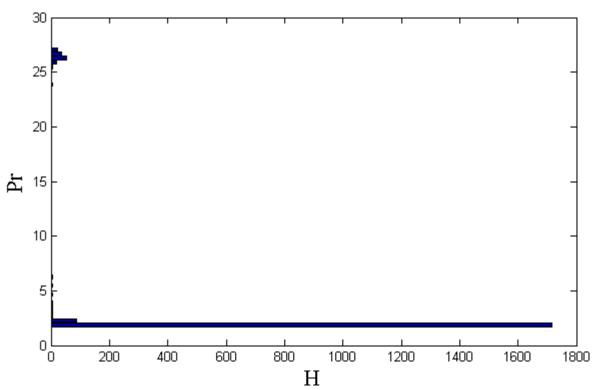

Fig. 2: Histogram of received signal Power Spectrum

$$R(\alpha) = \frac{g(t)_{min}}{g(0)} \tag{24}$$

The IFFT of the pre-processed signal $P_{\hat{p}}(f)$ is $A|g(t)|$ as shown in Fig.(3). From the IFFT $A|g(t)|$ we can compute the value of the Second Maximum Peak / Maximum Peak. Comparing this value with $R(\alpha)$ we can estimate the roll-off factor $\hat{\alpha}$. The first minima of $P_{\hat{g}}(f)$ IFFT i.e. $A|g(t)|$ gives the coarse estimation of Symbol Rate $1/(\hat{T_1})$ [11]. If the IFFT length is very large, coarse estimation of symbol rate will be sufficient alone to deliver accurate estimation of symbol rate. If the length is not large, resolution has to be increased by zero padding and suitable interpolation and LSE is performed to get refined symbol rate $1/(\hat{T_2})$. From the estimated value of roll-off factor $\hat{\alpha}$ and coarse estimated symbol rate $1/(\hat{T_1})$ we can construct a theoretical signal $H(\hat{T_1})$. Now LSE is used to reduce the difference of the symbol period between theoretical signal $H(\hat{T_1})$ and observed data g(t). The LSE is obtained by maximizing $J(T)$ [11]. Where $J(T)$ is given as

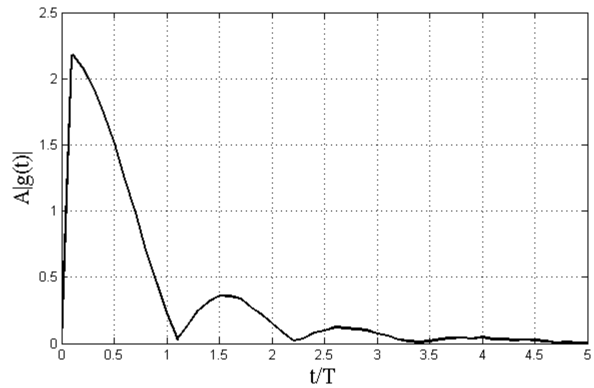

Fig. 3: IIFT of pre-processed received Signal Power Spectrum

$$J(T) = g(t)^T H(\hat{T_1}) \left(H(\hat{T_1})^T H(\hat{T_1}) \right)^{-1} H(\hat{T_1})^T g(t) \tag{25}$$

Maximum value of $J(T)$ searched in the range of the $[\hat{T_1} - \Delta T, \hat{T_1} + \Delta T]$ where $\Delta T < \hat{T_1}$. If the maximum value of $J(T)$ is obtained in the m^{th} iteration, the time resolution Δt will be $\Delta T/2^{m-1}$ [11]. Utilising Δt refined symbol rate $1/\hat{T_2}$ can be estimated. With the estimated value of roll-off factor $\hat{\alpha}$ and symbol rate $1/\hat{T_2}$, the PU signal $\hat{p}(t)$ can be estimated and coefficient of MF detector can be modified according to (10). Thus by estimating roll-off factor and symbol rate, our proposed detection scheme solves the problem of having priori information about PU signal for MF detection.

IV. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

A. SIMULATION SETUP

In our experiment equiprobable random bpsk data was transmitted after pulse shaping by RRC pulse shaping filter as PU signal. Baseband signal of symbol rate 1 KHz and roll-off factor of 0.4 were assumed for transmission. The signal was transmitted through Gaussian channels and related periodograms were averaged to estimate and eliminate the noise by histogram method. Recovered estimated roll-off factor and coarse symbol period was 0.38 and 1.1ms respectively. We did 1000 Monte-Carlo Simulation to get the probability of detection. IFFT length of 2048 was taken to find $A|g(t)|$. Probability of detection P_d and probability of miss detection P_{md} with probability of false alarm was calculated for -6dB SNR. While probability of detection with SNR was calculated for 0.01 probability of false alarm.

B. PERFORMANCE ANALYSIS

Fig. (4) shows the performance of ED, Conventional MF detector and proposed MF detector with probability of false alarm at -6 dB SNR. At such low SNR, ED performance is worst among the three discussed techniques, While proposed

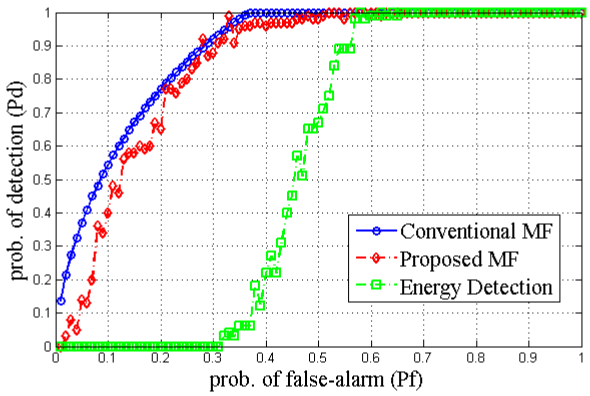

Fig. 4: Probability of Detection response with Probability of False Alarm for ED, Conventional MF and Proposed MF Detection at -6 dB SNR

detection scheme performs far better than ED and close to conventional MF detector. Fig.(5) depicts that chances of miss detection in proposed detection scheme is very less than ED and almost same as conventional MF detector. Fig.(6) is the performance evident of all the three techniques discussed with SNR. It is clear from the figure that all the three detection techniques perform equally well at higher SNR. But at lower SNR our proposed MF detector perform better than ED and almost same as conventional MF detector.

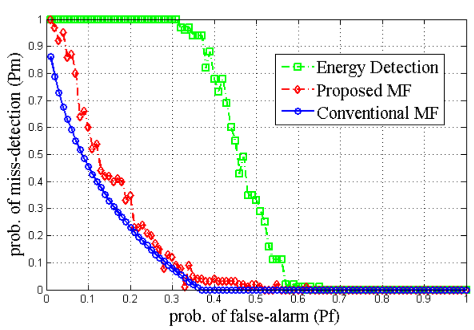

Fig. 5: Probability of Miss Detection response with Probability of False Alarm for ED, Conventional MF and Proposed MF Detection at -6 dB SNR

V. Conclusion

Proposed MF detector solves the main problem of having priori information of PU signal for conventional MF detector. Proposed MF detector does not require any priori knowledge about PU signal that makes it non-specific to users, unlike conventional MF detector. Also the performance of proposed MF detector is almost same as the performance of conventional MF detector and better than the performance of ED. In this paper, proposed detection technique is applied for narrow band detection under AWGN channel. The research can be further extended to check the applicability of proposed MF detector

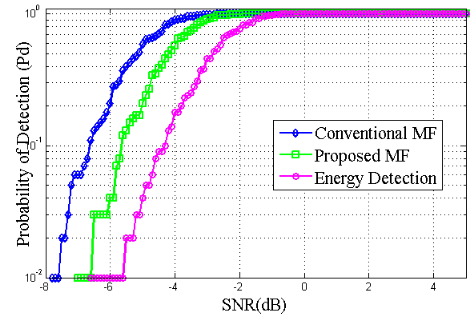

Fig. 6: Probability of Detection response with SNR for ED, Conventional MF and Proposed MF Detection at 0.01 P_{fa}

in the wide band detection under the influence of different fading channels.

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