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Optimal Filter Approach to Detect Idle Spectrum for Cognitive Radio

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Abstract—Rising shortage of radio frequency spectrum due to the technological improvement in performance of the wireless communication system devices and continuing efforts to make improve its performance more and more to the maximum capability of the wireless communication system. In this context, the demand for spectrum requirement increases so sharply and the need for the channel estimation excel a major role to use it efficiently. This leads to the result, that identification and estimation of the idle spectrum to utilize it efficiently without any interference between the end users. In this perspective, we have to give first preference to spectrum sensing or estimation for better utilization of spectrum resource. Cognitive Radio (CR) or Intelligent Radio (IR) has been identified as one of the promising technology, able to estimate the radio spectrum to identify the unused spectrum, which can be opportunistically used by Secondary User (SU) without interfering Primary User (PU) specifically in the frequency range of 3 GHz which estimated underutilized frequently by Federal Communication Committee (FCC). In this paper we propose a novel method to maximize the Signal to Noise Ratio (SNR) in noise environment for better spectrum estimation of the channel to utilize the unoccupied spectrum by the SU. The scenario considered here is the occupied status of PU is known in the channel and the channel considered is an Additive White Gaussian Noise (AWGN) channel. Optimization of SNR, being done based on the quadratic time-frequency processing of the PU signal using a time-frequency Optimal Filter (OF). The simulation is done using MATLAB to estimate the channel or sub channel.

Index Terms— Cognitive Radio, Intelligent Radio, Spectrum Sensing, Signal to Noise Ratio (SNR), Optimal Filter, Primary User, Secondary User.

1 Introduction

The Radio Frequency (RF) spectrum is the natural resource used for wireless communication system, as the wireless communication system standards are increasing exponentially, with respect to requirements excessively. Recent research by Federal Communication Committee (FCC) shows that major portion of the radio spectrum allocated to different applications by the governing bodies are not being utilized Cen percent by the PUs [1]. These unoccupied frequency spectrum are called spectrum holes or white spaces [2].

To avoid this depletion of spectrum, Cognitive Radio (CR) was proposed by Mitola "a radio that can change its transceiver parameters based on interaction with the environment in which it operates. The majority of cognitive radios will probably be Software Defined Radios (SDRs), but neither having software nor being field programmable are requirements of a CR" [3] in 1999 is a promising technology used for the detection of white spaces and allocate these white spaces to the SUs without interfering PUs [4]. To sense the radio spectrum availability several techniques were used, an investigation of threshold level optimization with energy detection to improve the spectrum estimation performance. Minimizing the spectrum estimation error with variation in threshold level to reduce the collision probability with PU and enhance the usage level of white space, resulting in improving total spectrum efficiency [5]. Energy Detecton technique in which a single cycle detector matches the ideal spectral correlation functions for a single value of the cycle frequency proportional to the measured value. It is computationally similar to the optimal energy detector, except the ideal Power Spectral Density (PSD) is replaced by the ideal spectral correlation function, and the measured Periodogram is replaced by measured cyclic Periodogram. A suboptimal version replaces the ideal spectral correlation function with a rectangular window over a band of frequencies in which the signal's spectral correlation function is expected to be reside if present [6].

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The spectrum estimation error can be reduced by varying the threshold. Fixing threshold leads to the determination of noise factor is feeble and prior knowledge of the PU that cannot be assured at the real-time environment [7]. Aleksandar et al., proposed the interference reduction method, in this method throughput will be degraded if the numbers of SUs are increased [8]. In above methods the transition from one band to another is done only after detecting whether the band is idle or busy. This may lead to a delay in time. If we can envisage the usage pattern of the PU, this time delay can be avoided.

The sub-band utilization by PU at any time can be considered as a state, which can be either idle (unoccupied) or busy (occupied). Existing research assumes the existence of a Markov Chain for sub-band utilization by the PUs, Hidden Markov Models (HMMs) can also be used for radio scene classification, case recognition, and making meaningful predictions of spectrum usage in the given channel based on training the past data proposed by Schreyogg et al. [9].

A time shift result in time synchronization of a transmitter with a receiver, a non-zero swiftness of a transmitter with respect to a receiver and a classical solution of a discrete time analog signal of the Time Frequency Shift (TFS) problem is dealt using matched filter algorithm by Alexander Fish et al. [10].

Time frequency shift methods have been extensively used for detection problems in applications such as communications, radars and sonars to detect the target objects. Non-stationary environments of these signals are made interest to consider this Time Frequency Shift method. The AWGN of the channel is a non-stationary signal necessitates using quadratic detectors for better performances [11].

In this paper our goal is to propose an ideal technique for spectrum estimation based on an Optimal Filter (OF) to maximize the received Signal to Noise Ratio (SNR). In our proposed method the assumptions made are (i) PUs signal state is known during the real time valuation. (ii) The PU signal is transmitted over the Additive White Gaussian Noise (AWGN) Channel.

The rest of the paper is organized as follows. Section 2 covers system model of the prosed method. OF implementation with Binary Detection of PUs signal in AWGN channel is introduced in section 3 and section 4 describes the simulation process and result for the proposed system model. Finally section 5 draws the conclusion and future work.

2 System Model

Our goal is to detect unoccupied spectrum or white space over the overall spectrum band or sub band considered. The proposed system model to estimate the spectrum is shown in Fig.1.

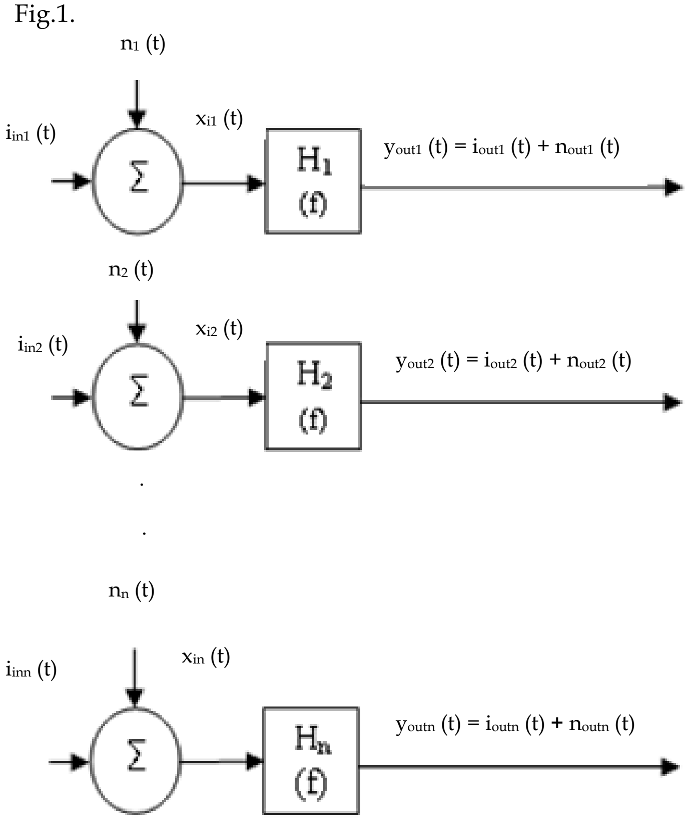

Fig 1: System Model

Our interest is to detect the Primary Users signal in the given AWGN wireless channel and this is never perfectly known in the real time scenario, so here we assumed that the PUs signal is present in the AWGN channel and by maximizing the SNR we detect the presence or absence of PU signal using OF based on the fixed threshold [12].

Let $x(t)$ be the PUs signal over the AWGN wireless channel with a channel gain h , the received signal at the output of the receiver, and the output for the n^{th} PU is given by [13]

$$\begin{aligned} y_n(t) &= n_{outn}(t) \\ y_n(t) &= hx_{in}(t) + n_{outn}(t) \end{aligned} \qquad (1)$$

In the above equation n_{outn} *(t)* be the noise signal of nth PU and the Power Spectral Density (PSD) of the Additive White Gaussian Noise (AWGN) signals is given by

$$PSD_{AWGN}(f) = \frac{N_0}{2} \qquad (2)$$

Where N_0 is the noise and the Signal to Noise Power of the AWGN channel measured at the output of the OF is given by

$$SNR_{outn} = \frac{|S_{outn}(t)|^2}{|n_{outn}(t)|^2} \qquad (3)$$

The Calculated output noise power P_{noutn} of the n^{th} primary user is found to be [14]

$$P_{noutn} = \frac{N_0}{2}\int_{-\alpha}^{+\alpha} |H_n(f)|^2 df \qquad (4)$$

The output signal power P_{soutn} of the n^{th} primary user is given by

$$P_{soutn} = \left|\int_{-\alpha}^{+\alpha} H_n(f) S_{inn}(f)^{ej2\pi ft} df\right|^2 \qquad (5)$$

Using Schwartz inequality the output signal power P_{soutn} is decomposed in terms of input signal power S_{inn}

$$P_{soutn} = \int_{-\alpha}^{+\alpha} |H_n(f)|^2 df P_{sinn} \qquad (6)$$

Now the SNR of the primary user is simplified to SNR_{outn}

$$SNR_{outn} = \frac{2P_{sinn}}{N_0} \qquad (7)$$

Equation 7 represents the PU signal over the noise.

3 Optimum Filter

The idea of introducing Optimal Filter (OF) implementation is to model the evolution of PUs occupancy or unoccupancy of a spectrum band or spectrum sub-band over time by measurements using CR. In this section, we consider the basic operational model of optimal filter. Primarily OF implementation is best suitable for radar, sonar, digital communications systems, Intelligent Radio Systems and for the binary detection of AWGN channel as shown in Fig. 2.

3.1 Binary Detection of PU Signal in AWGN

Binary detection problem is used to detect the state of PUs signal presence or absence in AWGN channel within the time interval of $0 \leq t \leq T$. The binary hypothesis specified by H_0

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indicates the absence of PU signal and H_1 specifies the presence of PUs signal [15] in the channel or sub channel considered

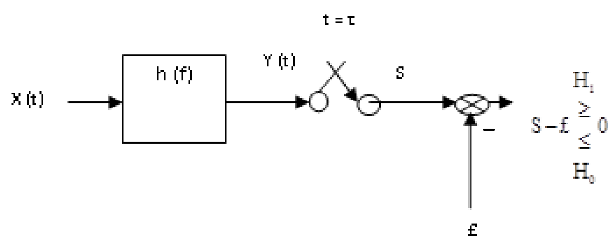

Fig 2: Optimal Filter Implementation

$$\begin{aligned} H_0 &: Y(t) = N(t) \\ H_1 &: Y(t) = X(t) + N(t) \end{aligned} \quad (8)$$

Where N (t) is the zero mean AWGN with covariance V [N (t) * N(s)] given by

$$V[N(t) * N(s)] = \sigma^2 \Box (t - s) \quad (9)$$

Where σ^2 is the power density of the AWGN signal in the above equation. To detect the PU presence or absence we formulate an orthonormal basis function in signal space {ψ_i (t). i Є I} of the space S^2 [0, T] over the integral function of the time interval varies between the limits [0, T], the first element of the basis ψ_1 (t) given as

$$\Psi_1(t) = \frac{s(t)}{V^{1/2}} \quad (10)$$

Where the covariance function V is defined as

$$V = \int_0^T s^2(t)dt \quad (11)$$

Karhunen Loeve Decomposition (KLD) used to reduce the Complete Orthonormal Basis (COB) into one dimensional function as

$$\begin{aligned} H_0 &: Y(t) = N_1 \\ H_1 &: Y(t) = V^{1/2} + N_1 \end{aligned} \quad (12)$$

Now the Generalized Likelihood Ratio Test (GLRT) [16] statistics established with Binary Hypothesis theory as

$$L(y_1) = \frac{e^{-\frac{1}{2\sigma^2}(y_1 - V^{\frac{1}{2}})^2}}{e^{-\frac{1}{2\sigma^2}y_1^2}} \quad S - £ \underset{H_0}{\overset{H_1}{\gtreqless}} 0 \quad (13)$$

Reorganizing the GLRT and taking logarithm for the threshold value we obtain the sufficient statistics S of the proposed system and it is found that the GLRT is optimal asymptotically in the sense that it maximizes the rate of decay of the probability of a miss detection or probability false alarm

$$S \underset{H_0}{\overset{H_1}{\gtreqless}} \Omega \Box \frac{V}{2} \sigma^2 \ln(\tau) \quad (14)$$

The sufficient statistics Y_1 of the OF given as

$$Y_1 = \frac{1}{V^{\frac{1}{2}}} \int_0^T Y(t)s(t)dt \quad (15)$$

$$r = \frac{V[Y_1|H_1] - V[Y_1|H_0]}{\sigma} = \frac{V^{\frac{1}{2}}}{\sigma} \quad (16)$$

Where r is the distance between the two hypotheses measured in terms of standard deviation of the AWGN signal. Based on the above analysis the Probability of Detection P_D and Probability False Alarm P_F for the test statistics are derived as

$$P_D = 1 - Q(\frac{r}{2} - \frac{\ln(\tau)}{r}) \quad (17)$$

$$P_F = Q(\frac{r}{2} + \frac{\ln(\tau)}{r}) \quad (18)$$

The test is implemented in terms of the unnormalized test statistics as in the case of an AWGN channel. In the case of a Rayleigh fading channel, P_D is averaged over the test statistics of Y. For both kinds of channels, we have the False Alarm Probability P_F of spectrum sensing is given by the test statistics as

$$S \underset{H_0}{\overset{H_1}{\gtreqless}} \Omega \Box \frac{V}{2} + \sigma^2 \ln(\tau) \quad (19)$$

Now the Output of the OF sampled at time T is

$$O(T) = \int_0^T s(u)Y(u)du = S \quad (20)$$

The test statistics S of the OF founded and based on which the presence or absence of the primary user is determined. In OF the transmitted signal is replaced by a distorted signal which compensates for the coloring of the additive white Gaussian noise. OF detectors are considered to work with a very small probability of errors to improve the performance, but however relatively small shifts of probability in miss of the observation distributions under binary hypothesis can result in a catastrophic loss of detector performance. In wireless communications, relatively accurate statistical models, such as the Rayleigh or Nakagami / Rice fading channel models have been developed for the amplitude of received OF signals.

4 Simulation Process and Results

We have considered a typical case to validate our proposed system model based on OF to determine the presence or absence of PU in the AWGN channel considered. The Simulation process follows as shown in Fig.3

In this section, numerical results are presented to verify the effectiveness of our proposed model using MATLAB simulation. The system setup is made by considering the PU signal and the random signals are generated and both are combined. The combined signals are passed over the AWGN channel. The resultant output of the AWGN signal is transferred over the OF and finally the output of the OF is measured and plotted over as time versus strength of the resultant signal as shown in Fig. 4. The output graph of the OF clearly indicates that the filtered output of the noise over the signal output in-

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fers that the PU signal present only at a particular time where the signal strength is very high and remaining duration of the times the primary user signal strength is very low so its precence is absent. Such a vacant channel can be efficiently utilized by the SUs or Cognitive Users. Here we have considered the scenario of only one PU that is occupied the channel with few nanoseconds of delay.

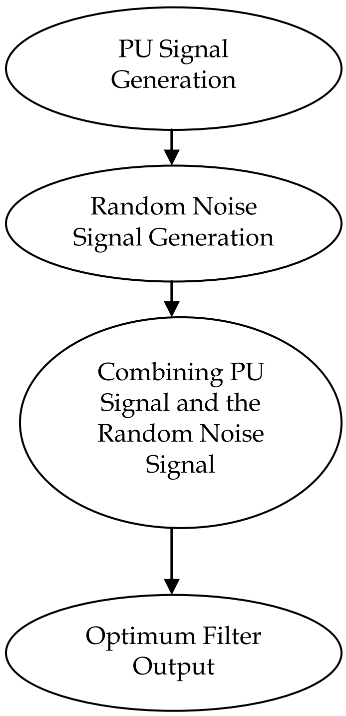

Fig.3 Simulation Process Steps

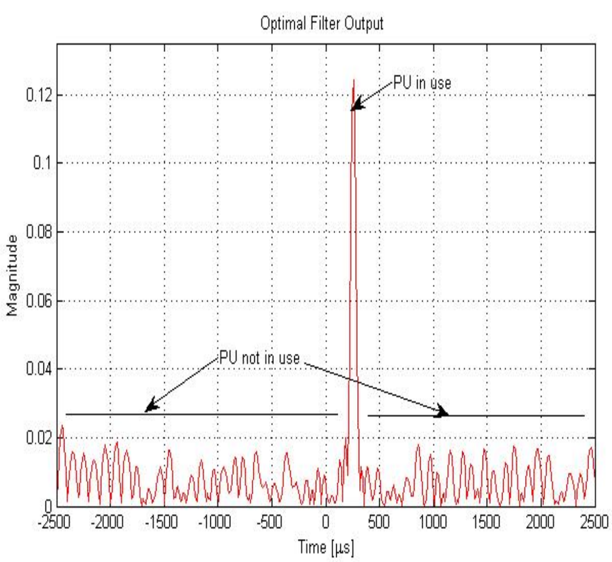

Fig.4 Final Optimal Filtered Output Signal

The sampling rate assumed to be μ= 6 MHz; the slot duration is T = 100 ms; and the threshold for false alarm probability is Pth = 0.001; and $SNRss\ n$ between secondary users are all assumed to have a mean 20 dB. Both $SNRps\ n$ (the SNR from the primary user to a secondary user on channel n) and $SNRss\ n$ are assumed to be exponentially distributed. In this section, we evaluate the performance of our proposed model by means of simulation using MATLAB. The performance of the number of PUs with the P_D with given P_{FA} = 0.001 is shown in Fig. 5. The simulation process is performed with two datas one with coherence integration and other with non coherence integration. It is evident from the plot that the SNR value required is high with integration compared to coherent integration. Also the SNR increases as the number of PUs increased.

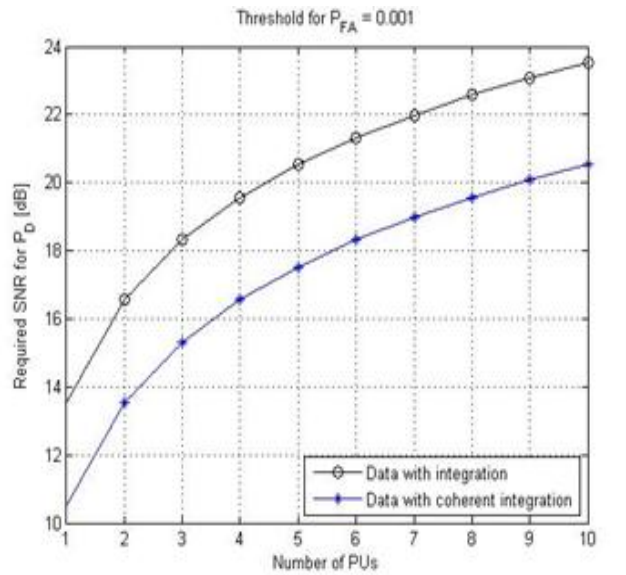

Fig.5 PUs versus required SNR for P_D in dB with threshold for P_{FA} of 0.001

5 Conclusion and Future Work

Cognitive Radio is the favorable intelligent radio technique in wireless communication technology particularly, with dynamic cooperation of the spectrum-sensing and sharing process. Under continually changing user environment it is significant to identify the "White Space" or "Spectrum Hole" that can be utilized in an efficient manner. The dynamic spectrum-sharing capability is based on (a) Shift in wireless communications from transmitter to receiver, whereby interference power and transmitter emission is regulated. (b) Awareness of adaptation to the environment by the intelligent radio. In this paper we proposed a novel method to maximize Signal to Noise Ratio (SNR) in the noise environment for better spectrum estimation by which utilization of idle spectrum can be improved. The scenario considered here is that the PU state and status is known priori, the channel is occupied by it, and the channel considered is an Additive White Gaussian Noise (AWGN). Optimization of SNR, being done based on the quadratic time-frequency processing of the PU signal using a time-frequency Optimum Filter (OF). The simulation is done using MATLAB to estimate the channel. As a future work we can increase the number of primary users more and number of secondary users in a cooperative environment without interfering each other.

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