Matched Filter Spectrum Sensing in Cognitive Radio Networking using MATLAB

Punit Kumar[1], Sanjana C[2], R Megha[3], Rahul Kumar[4]

[1] *Student, Information Science and Engineering, The National Institute of Engineering, Karnataka, India*
[2] *Student, Information Science and Engineering, The National Institute of Engineering, Karnataka, India*
[3] *Student, Information Science and Engineering, The National Institute of Engineering, Karnataka, India*
[4] *Student, Information Science and Engineering, The National Institute of Engineering, Karnataka, India*

Abstract

In Cognitive Radio Network, when the secondary user or unlicensed user want to access the spectrum band, it is required to detect the spectrum holes or unused frequency bands. The spectral resolution like bandwidth, pulse type etc is computed at a later stage and then if it matches the requirements, the unused spectrum is allocated to the secondary user. The primary user is having the highest priority in using the spectrum band. The term cognitive radio refers to the adoption of radio parameters using the sensed information of the spectrum. There are various spectrum sensing techniques proposed in the literature but still there is room for researchers in this field to explore more sophisticated approaches. There are three major categories of spectrum sensing techniques; transmitter detection, receiver detection and interference temperature detection. This paper presents an implementation technique suggested in the literature for spectrum sensing with a performance analysis of matched filter detection technique.

Keywords—*Cognitive radio; Spectrum sensing; Matched filter; Signal to Noise Ratio; Primary user;*

---

1. INTRODUCTION

The recent development in technologies have led to exponential increase in the number of wireless subscribers and because of these developments communication market focuses on utilization of available spectral resources efficiently. Spectrum sensing and its ability to identify underutilized spectrum is becoming an integral part of the wireless communication system.

Various wireless applications and services are basically based on two types of spectrum allocation policy. The radio spectrum is a naturally limited resource which is used for wireless communication system and allocated based on the two policies either *fixed spectrum access* policy or *dynamic spectrum access* policy. The spectrum regulators assign each piece of spectrum with certain bandwidth to a dedicated user under fixed spectrum policy. This allocation made a restriction that the allocated spectrum is used by assigned or licensed users only irrespective of whether it is being used or free. This policy leads to spectrum scarcity problem in several countries. The recent studies on the actual spectrum utilization measurements shows that the most of the licensed spectrum shows low utilization[1]-[2].

The dynamic spectrum access policy is developed to counter the drawbacks in fixed spectrum access policy and to utilize the spectrum efficiently. The spectrum can be allocated to one or more users based on the availability .The users which is having the higher priority in using the spectrum is known as primary users and other users referred to as secondary users, which can access the spectrum whenever primary users are not using it or can also share the spectrum with primary users as long as it is protected. The secondary users are required to capture or sense the radio environment and such type of secondary users are known as cognitive radio. In order to exploit spectrum in a dynamic fashion, cognitive radios must have a mechanism for sensing spectrum to identify spectrum opportunities and avoiding interference with the primary users.

2. SPECTRUM SENSING

The operation of a cognitive radio for dynamic spectrum access includes two main components, first one is spectrum sensing and second one is spectrum opportunity exploitation. The focus of this paper is on spectrum sensing under which the main focus is towards the matched filter detection. Spectrum sensing helps a cognitive radio to measure, learn and have the idea of its operating environment which includes spectrum availability and interference status. The core idea behind spectrum sensing is to find out which of the frequency band is underutilized at a particular time in a specific position. It is performed across the domains of time, frequency and space. The spectrum sensing performs following task to find out the underutilized spectrum: i) detection of spectrum holes, ii) determination of spectral resolution for each spectrum holes, iii) estimation of spatial directions of an incoming interfering signal, iv) signal classification. The most challenging and important task is to detect spectrum holes and hence usually referred to as spectrum sensing , which detects the presence or absence of primary user in underlying band.

Spectrum sensing is classified in two parts : i)Non-cooperative/transmitter detection. ii)Cooperative detection. Transmitter detection assumes that the location of primary transmitter is unknown to the cognitive device and detection is based on weak primary transmitter signal and also use local observations of cognitive radio user to perform sensing. In this technique it is not completely avoidable to remove harmful interference with primary users. The non-cooperative detection technique is sub-divided into three subcategories: energy, feature, and matched filter based sensing or detection. The simplest technique is the energy detection which sense the spectrum without the knowledge of any information about primary user. It is based on comparing the received signal energy with an estimated threshold which depends on the noise power [7]. Feature detection is based on the identification of primary signal based on their deterministic or statistical properties. Matched filter detection is to make a decision on whether the signal is present or not by passing through a filter which will highlight the useful signal and suppress the noise at the same time. This is the main focus of our study and discussed in details in the later section. Cooperative sensing is a method which enable multiple cognitive radios to share their local sharing environment with each other for more primary transmitter detection accuracy.

The spectrum sensing is performed using the basic signal detection method which determines the spectrum hole or unused spectrum frequencies as quickly as possible. Since these simple techniques doesn't achieve accurate and reliable sensing results in few cases like low-SNR environment. The methods like fusion of multiple local detection decisions and cooperative spectrum sensing is used to improve the reliability and accuracy. The decision to use any of the technique for spectrum sensing is also a challenging task as every technique differ in their performance. Energy detection technique is unable to detect signal with low SNR. This can be achieved using cyclostationary feature detector but with added time and complexity. The matched filter detection is the optimal detection technique if primary users information is known.

A. Requirements of Spectrum Sensing

- Simple sensing technique
- Fast computation
- Secure communication
- Intelligent Algorithm
- Reliable and Accurate sensing results

The studies have shown that a two stage sensing model with a simple sensing technique used in the first stage and a more powerful one is used in the second stage. The development of a cognitive radio with spectrum sensing capability should meet all these requirements and overcome the effect of challenges faced during sensing.

3. TRANSMITTER DETECTION

The two further detection strategies are coherent detection technique and noncoherent detection technique. The spectrum sensing technique which requires prior knowlwdge about the primary user for comparing it to the particular signal feature to the cognitive user's received signal is coherent detection technique. Non coherent detection technique compare the received signal with a threshold value which is defined before only based on the features which are not dependent on primary users. The model used for transmitter detection is based on a classical hypothesis testing approach. The two hypothesis used are H0 and H1, where H0 is a null hypothesis which states that there is no primary signal in a certain band and H1 is an alternate hypothesis which states the presence of primary user. A testing variable is used to compare with a specific threshold value to discriminate between two hypothesis.

The hypothesis model of received signal is y(t). Then

y(t) = h.s(t)+w(t) H1: if PU is present.

w(t) H0:if PU is absent

In the above model y(t) is the received signal , h is the channel gain and s(t) is the primary user's signal which has to be detected at the secondary users and w(t) is the additive white Gaussian noise(AWGN).

The system performance is evaluated in terms of probability of detection Pd and the probability of false alarms Pf. The probability of detection means detecting the probability of detecting the presence of primary user and probability of false alarm means probability of declaring the presence of a primary user in bands that are actually empty. In the above mentioned hypothesis there can be two types of error : Type 1 error , also called probability of false alarms , is made if H1 is accepted when H0 is true and Type 2 error also called probability of missed detection , occurs if H0 is accepted when H1 is true. The general model for detecting spectrum holes through transmitter detection are depicted in the illustrated diagram.

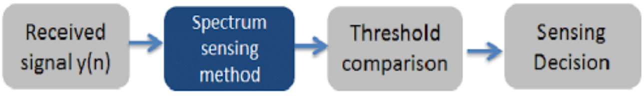


Figure 1 General model for spectrum hole detection

4. MATCHED FILTER DETECTION

The matched filter detection is a coherent detection technique which basically use a correlator to match with the interested signal . The coherent detection technique provides good performance under normal conditions. In this technique the received signal's feature is matched with the primary user signal and the presence or absence of primary user can be determined. If Gaussian noise exists, then matched filter is the optimal technique to find spectrum holes. The major problem with matched filter technique is that the cognitive user needs to be fully synchronized with the primary user, which is not possible in all the cases. This technique detects a signal by computation of correlation between the received signal and a known copy of the signal. The information about primary user which should be known before are operating frequency, bandwidth, modulation type and order, pulse shape and packet format.

Matched filter assumes that the secondary user has a prior information about the primary user's signal. The correlation which is used to detect the presence or absence of primary user maximizes the SNR in presence of additive stochastic noise. The advantage of this technique is that it requires a fewer signal samples to achieve acceptable detection performance in short time such as a low probability of false alarm or missed detection. But the required number of signal sample increases as the received SNR decreases, so there exist a SNR wall for a matched filter. The two hypotheses which is used in coherent detection are:

$$y(t) = \begin{cases} \sqrt{\varepsilon}xp(t)+\sqrt{1-\varepsilon}\, x(t)+w(t) & H1{:}\, if\ PU\ present \\ w(t) & H0{:}\, if\ PU\ absent \end{cases}$$

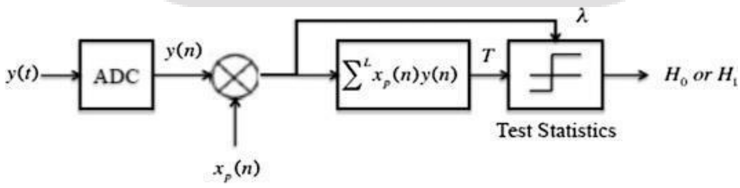
xp(t) is a known pilot tone, ε is the fraction of energy allocated to the pilot tone and x(t) is the desired signal assumed to be orthogonal to the pilot tone.

The test statistics of the coherent detection is given by:

$$T = \Sigma\, y(n)x{*}p(n)$$

By comparing T with the determined threshold or assumed threshold, the determination of presence or absence of primary user is done. As N increases, The test statistics value in H1 increses more as that of H0. Also the power spectral density of the received signal can be used to distinguish between the two hypotheses.

The schematic representation of the matched filter spectrum sensing is illustrated as below:



The transmitted signal is passed through the channel where the additive white Gaussian noise is getting added to the signal and outputted the mixed signal. This mixed signal is given as input to the matched filter. The matched filter input is convolved with the impulse response of the matched filter and the matched filter output is then compared with the threshold for primary user detection.

The threshold of a signal, determined by two possible ways has been discussed here. One way is to estimate the energy of the signal and reduce it to half, fix it as a threshold. Another way is to compute the standard deviation of the signal by computing the mean and use it as threshold. Of the two methods, the later one is theoretically proved to be optimal. In this paper the later one is chosen to detect the presence of primary user.

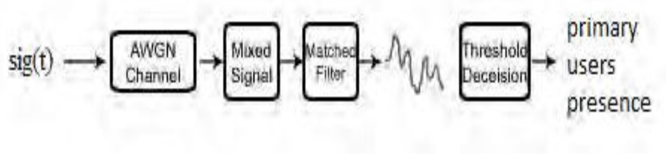


Figure 2 Block diagram of spectrum sensing using matched filter

5. SIMULATION METHODOLOGY

In our work the simulation of matched filter is done using MATLAB. In our implementation, the detection method is following a specific methodology. The general simulation model is presented in Fig. 2.

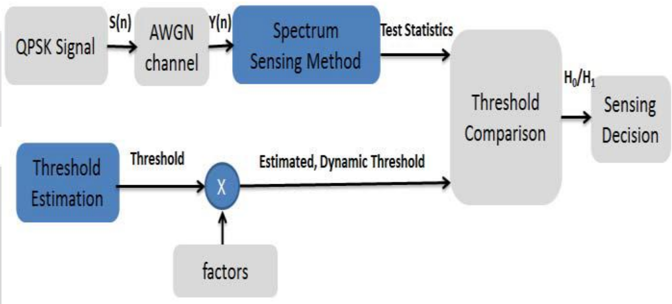


Figure 3 General Simulation model

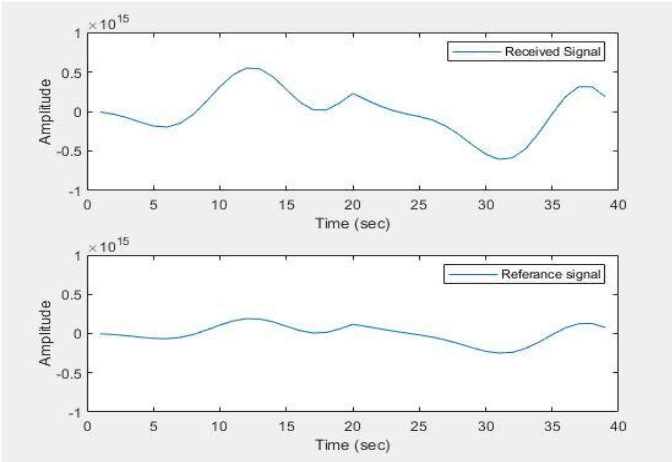
PU signal is generated and modulated using either BPSK or QPSK signal with *N* samples. The SNR value is specified by the user and later AWGN channel adds white Gaussian noise to the input signal with the same number of samples *N*. The random noise is generated based on the *SNR* range value and the input signal power. Once the spectrum sensing is applied on the output, the test statistic is calculated and compared with the threshold value. The sensing decision is made from the comparison done on test statistics and threshold value.

The detailed procedure is explained as follows: Since the matched filter requires prior knowledge of primary user waveform, So a local carrier is generated using local oscillator. After that the correlation is computed using xcorr which estimates the cross-correlation sequence of a random process. On experimental basis the results are compared at at low and high SNR and then threshold is set to be +35 and -35. Finally the output of the integrator is compared with the threshold value and decide whether primary user is present or not.

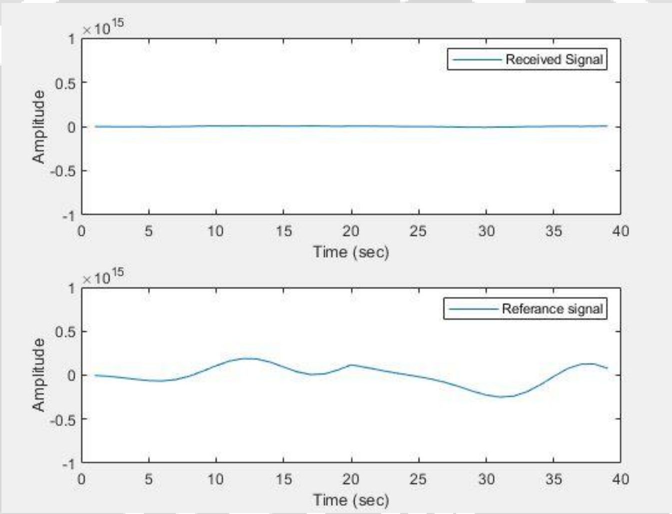
6. RESULTS AND DISCUSSIONS

The simulation commences with taking input data from user if primary user is present else the input data remains empty. The input data is passed through a transmit filter. Transmit filter is a square-root raised-cosine filter with roll-off factor α. Here, α is set equal to 0.5 while in the real scenario, the transmit signal is continuous time. Since in computer simulation, we can only have sampled signals, we approximate continuous-time signals by a dense grid of samples. Here, we have L = 100 samples per symbol period. The function 'sr_cos p' generates a square-root raised-cosine pulse, for the transmit filter, pT(t). Then it expands the transmit symbols and lowpass filters the result by passing it through pT(t).

Modulation is done to generate an RF (radio frequency) signal for transmission through channel. Here we use BPSK (Binary Phase Shift Keying) and QPSK (Qaurdrature Phase Shift Keying) to modulate the signal. This is characterized by an impulse response c(t) and an additive noise. Here, we have chosen c(t) = δ(t) which in the discrete domain becomes c = 1. If the channel is multipath, e.g., with the impulse response c(t) = a0δ(t −t0) + a1δ(t − t1), it has the equivalent discrete domain c = [zeros(N0,1); a0; zeros(N1,1); a1], where N0 and N1 are t0 and t1 in unit of Ts. The channel noise is assumed to be Gaussian with the standard deviation 'sigma_v'. The reference signal and received signal is derived accordingly and depicted in the given figure. The amplitude of received signal remains 0 when primary user is absent and the amplitude of received signal have the variations based on the data sent when primary user is present. The results are:



The above figure illustrates the plotting when primary user is present and hence the spectrum cannot be assigned to the secondary user.



The above figure illustrates the situation when primary user is absent and hence the spectrum can be assigned to the secondary user.

7. CONCLUSIONS

The recent development of the wireless communication technology leads to increase in the usage of frequency spectrum. So we need to be wise enough in accessing the frequency spectrum. The concept of using cognitive radio for wireless communication will be more beneficial to resolve the current spectrum scarcity problem to some extent. In the cognitive radio cycle, Spectrum sensing plays the most crucial role.The aim of this paper was to resolve some of the challenging issues in cognitive radio applications and other wireless technologies. This work introduced the implementation of spectrum sensing methods in cognitive radio systems by deriving decision rules for detecting various types of primary user signals to design sensing strategies and investigate the matched filter detection algorithm for sensing the transmitter primary signals and to evaluate sensing schemes in term of performance, complexity, and energy efficiency.

As the demand of radio spectrum increases in past few years and licensed bands are used inefficiently, improvement in the existing spectrum access policy is expected. Dynamic spectrum access is imagine to resolve the spectrum shortage by allowing unlicensed users to dynamically utilize spectrum holes across the licensed spectrum on noninterferring basis. This paper was aimed towards the detection and classification of primary user's waveform in cognitive radio networks. The primary requirement of a spectrum sensing system is its real time processing and decision making. The proposed methodology has been implemented on a desktop PC and requires MATLAB support for simulation.

8. REFERNCES

[1] S.Haykin, “Cognitive radio: brain-empowered wireless communications”, IEEE Journal of Selected Areas on Communication *23(2)*, 2005, 201-220.

[2] Yucek T and Arslan H, “A survey of spectrum sensing algorithms for cognitive radio applications”, IEEE Journal of Communications Surveys and Tutorials*, 11(1)*, 2009, 116-130.

[3] Shipra Kapoor and Ghanshyam Singh, “Non co-operative sensing: A hybrid model approach”, IEEE International Conference on Device and Communication*(ICDeCom)*, 2011, 1-5.

[4] S.Maleki, A.Pandharipande and G. Leus, “Two-stage spectrum sensing for cognitive radios”, IEEE International Conference on Acoustics, Speech and Signal Processing*(ICASSP)*, 2010, 2946-2949

[5] S Shobana, R Saravanan and R Muthaiah, “Matched Filter Based Spectrum Sensing on Cognitive Radio for OFDM WLANs,” International Journal of Engineering and Technology, Volume 5, No. 1, Feb-Mar 2013

[6] Tev_k Yucek and Huseyin Arslan, "A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications", *IEEE COMMUNICATIONS SURVEYS & TUTORIALS*,VOL. 11, NO. 1, FIRST QUARTER 2009.

[7] Fatima Salahdine, Hassan El Ghazi, Naima Kaabouch, Wassim Fassi Fihri, “Matched Filter Detection with Dynamic Threshold for Cognitive Radio Networks”, *IEEE*, 2015.

[8] B.Suseela, Dr. D. Sivakumar, “Non-Cooperative Spectrum Sensing Techniques in Cognitive Radio-A Survey*”,*IEEE International Conference on Technological Innovations in ICT for Agriculture and Rural Development.

[9] Varalakshmi. L.M, Sugumaran K and Tamilselvan M, “Matched Filter Based Spectrum Sensing in Cognitive Radio using OFDM for WLAN,” International Research Journal of Engineering and Technology, Vol 3 Issue 4, Apr 2016