Periodogram Spectrum Sensing Using Blackman Tukey Method in Matlab

K. Shahzad, S.Saleem, W. Aziz and Q. Islam

Department of Electrical Engineering, Institute of Space Technology, Islamabad Pakistan

Abstract: Wireless communication is the fastest growing industry from many aspects. Increasing number of users imposes bandwidth constraints on the communication system. Cognitive Radio (CR) finds the solution to this problem and uses the free portion of the spectrum. Energy based spectrum sensing is the simplest way and in frequency domain it can be performed by using Periodogram based spectrum sensing. In this paper we describe Periodogram spectrum sensing technique using Blackman Tukey method. Probability of detection and false alarm are figure of merits for the analysis of this technique. Moreover the simulation results are carried out using different channel taps, varying channel lengths and with the help of different windowing functions using MATLAB.

Key words: Wireless Communication · Cognitive Radio · Periodogram · Blackman Tukey · Matlab

INTRODUCTION

Wireless Networks/ Applications require a significant amount of bandwidth to provide higher data rates. But in current scenario, the availability of a spectrum is decreasing due to large traffic and large number of wireless applications, as very high percentage of spectrum is occupied [1]. So it is not possible incorporate all future services and users in a very small percentage of unoccupied spectrum bands. To overcome this problem there should be a mechanism to access the spectrum in such a way as to increase the efficiency of using the spectrum [2].

Cognitive Radio (CR) [3] is the technique which can solve the problem of spectrum scarcity and underutilization and can increase the spectrum usage efficiency with dynamic spectrum access and management. The CR uses the concept of using the spectrum during the time interval when the spectrum is not busy. Normally the Spectrum licensed holder has only the rights on the specific part of the spectrum (spectrum band) to transmit or receive data on that particular band [4]. But a licensed user does not occupy the spectrum all the time, it only does when need to transmit otherwise the spectrum is not busy. So there are so many holes present between the intervals of transmission of a licensed user. These holes are the intervals w here no transmission from licensed user. So CR makes use of these holes for

its transmission to make efficient use of spectrum without interference to the licensed user. This process is known as Spectrum Sensing [5].

CR has the ability to sense and learn from the environment i.e. the radio parameters related to that channel, availability of spectrum, user requirements etc. In CR paradigm there are two kind of users, the primary users which are the licensed user and the secondary users (Cognitive radios) which don't have the license of that particular spectrum band. Spectrum Sensing is a much known issue. A lot of work has been carried out in this regard. Generally Spectrum sensing is of three types [6], Matched filter detection, Cyclo-Stationary detection and Energy detection Method. Matched filter detection is considered to be the optimum method for detecting the transmission of Primary user as the transmitted signal is known to CR (Secondary user). Cyclo-Stationary based detection uses Cyclo-Stationary features that are caused by periodicity in the signal (mean and autocorrelation). Energy detection is the simplest way to sense the presence of primary user's transmission as it does not require any prior knowledge of the transmitted signal and having lowest complexities and computational cost [7].

Energy detection in frequency domain makes another flavor i.e. Periodogram based Spectrum Sensing [8]. There are many methods for Periodogram based spectrum sensing for improving the simple Periodogram, like Bartlett method, W elch method and Blackman Tukey method etc.

Corresponding Author: S. Saleem, Department of Electrical Engineering, Institute of Space Technology, Islamabad Pakistan.

Here Blackman Tukey method [8] is used as a Periodogram based spectrum sensing. The performance of the Blackman Tukey method is measured in sense of Probability of detection (Pd) and probability of false Alarm (Pf) in multipath fading environment. Also the transmission system considered here is an OFDM system. Also different windows functions (rectangular, Bartlett, blackman, hamming, hanning etc.) are applied to the Periodograms to evaluate the performance and effect on the two probabilities.

The rest of the paper is organized as follow, Section (II) describes a system model of Blackman Tukey method, Section (III) shows the simulation results and Section (IV) will sum up the conclusion

System Model: A Periodogram is an energy detection method in frequency domain [9]. By taking FFT of the square of the received signal samples it can be converted into power spectral density and then taking average over N samples, (where N is the number of data samples) will give out value that can be compared with a fixed threshold value to decide the presence of transmitted signal from Primary user's side. The Periodogram can also be generated by taking Fourier transform of autocorrelation estimates of the received signal as it would be equivalent to the Periodogram formed by taking FFT of the square of the received signal Samples [10].

The Periodogram or Power Spectrum can be shown in terms of autocorrelation of received signal as

$$P_x\left(e^{j\omega}\right) = \sum_{k=-\infty}^{\infty} r_x(k)e^{j\omega}$$

Here $r_x(k)$ is the autocorrelation of received signal, but in actual the exact autocorrelation of the signal is not possible. So the auto correlation estimates can be evaluated by the received signal..

$$\widehat{r}_x(k) = \frac{1}{2N+1}\sum_{K=0}^{N-1} x(n+k)x^*(n)$$

And the estimated Periodogram of the received signal can be evaluated from correlation estimates $\widehat{r}_x(k)$ which is

$$\widehat{P}_{per}\left(e^{j\omega}\right) = \sum_{k=-N+1}^{N} \widehat{r}_x(k)e^{j\omega}$$

This is a simple Periodogram estimate. There are lots of other methods through which this Periodogram can be modified as this simple Periodogram based spectrum sensing is not very consistent in a sense that by increasing the data samples it will not converge to original power spectrum, which is $\widehat{P}_{per}\left(e^{j\omega}\right)$.

Here Blackman Tukey Method which is also called as Spectrum smoothing [11] is used for Spectrum Sensing. The final goal is to reduce the variance of the received signal to improve the probabilities of detection and false alarm (Pd and Pf). As mentioned above that Periodogram is the Fourier transform of the received signal. Now for finite data record of length L the variance of the $\widehat{r}_x(k)$ will be large for the values of k close to N as for k N-1

$$\widehat{r}_x(N-1) = \frac{1}{N}x(N-1)x(0)$$

This shows very less averaging to reduce the variance in the received signal. The only way to reduce the variance of overall received signal is to reduce the contribution of these estimates in the autocorrelation [12] of the received signal by applying window on autocorrelation sequences. So the unreliable estimate can be removed providing good estimate. The Blackman Tukey based Periodogram will be

$$\widehat{P}_{ET}\left(e^{j\omega}\right) = \sum_{k=-M+1}^{N} \widehat{r}_x(k)\omega(k)e^{j\omega}$$

Here $\omega(k)$ is the window which takes only reliable autocorrelation estimates by removing unreliable estimates as it is a rectangular window from -M to M and M < N-1. In this way the largest possible variance will be set to zero providing the power spectrum with smaller variance values. The variance of the Blackman Tukey Periodogram is given by

$$\text{Var}\left\{\widehat{P}_{BT}\left(e^{j\omega}\right)\right\} = P^2_x\left(e^{j\omega}\right)\frac{1}{N}\sum_{k=-M}^{M}\omega^2(k)$$

Here M is the window size and N is the Data length m should be smaller than N [13]. the above equation shows that by increasing N and decreasing window size M the variance will be reduced.

The OFDM transmitted signal in multipath scenario with Rayleigh fading channel is used in the simulations to evaluate the performance of the Periodogram.

Simulation Results: Probability of detection (P_d) plays an important role in the assessment of a communication system. It has been proven [1] that P_d increases with the increase in SNR value. Figure1 shows relationship

between P_d and SNR for different window sizes. As the window size increases the probability of detection decreases because no. of samples increases in the same window size. When the window size is comparatively small then it's very much likelihood that probability of detection will be high.

Variations in no. of sample lengths have an impact on probability of detection, as it can be seen in Figure 2. It has been observed that for a fixed window size, probability of detection increases when the no. of samples is less. This relation has an accordance with the above result, like when the no. of samples are comparatively less it is very much likelihood that the probability of detection will increase.

Channels taps also affect probability of detection when compared for different values of SNR. When the no. of channel taps increases, P_d increases as shown in Figure 3. As the channel taps increases, more energy has been observed and thus leads to more probability of detection i.e. for 15 channel taps, the probability of detection is more and approaches to 1 and on contrary for 5 and 10 channel taps the P_d is comparatively less.

The performance of P_d v/s SNR for different channel lengths is depicted in Figure 4. It can been seen that for low values of SNR the probability of detection is same for all channel lengths and this affect varies prominently as the value of SNR increases. P_d is high for less no. of channel lengths i.e. 15, as compared to channel lengths i.e. 50, 100, where P_d decreases as the SNR increases. The main reason for this is that the multipath fading increases the channel length increases which as a result reduce probability of detection.

Windowing function plays an important role in the spectrum sensing. Its basic purpose to pass the desired signal and minimizes the amount of side lobes which are not desired. Different windowing functions exist and serve different purposes as per the requirement of the communication system. P_d is analyzed for different windows like rectangular, hamming, Bartlett etc. for different values of SNR, as shown in Figure 5. For low values of SNR, the performance of all the windows is same and it varies significantly as the SNR increases. Rectangular window has a poor response to P_d for different values of SNR as compared to other windows. Hamming window is best known for suppressing side lobes hence achieves the optimal value of P_d for high values of SNR, can be seen in Figure 5.

Probability of false alarm (P_f) is also an important parameter which can't be neglected and often taken into consideration while mentioning P_d. P_f for different correlation windows with respect to SNR values is shown
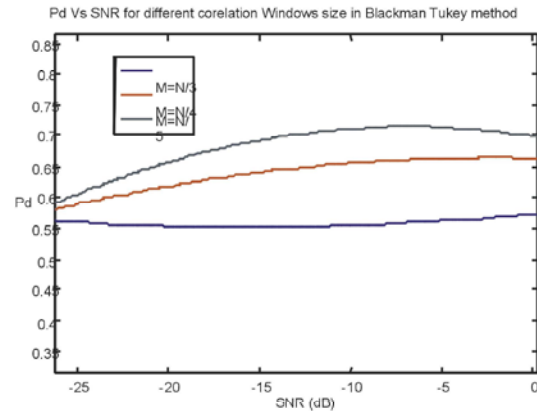

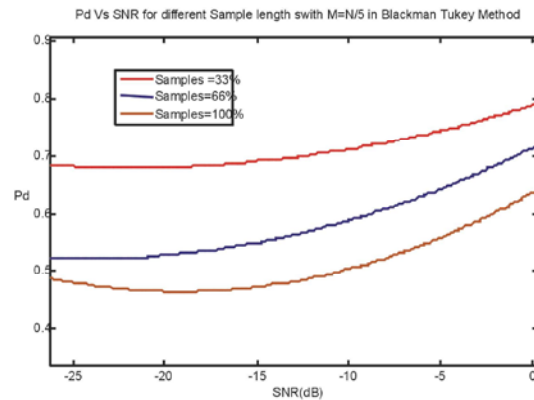Fig. 1: P_d v/s SNR for Different Correlation Windows Sizes

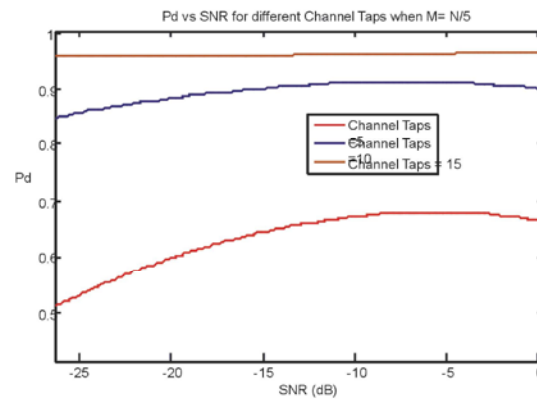Fig. 2: P_d v/s SNR for Different Sample Lengths

Fig. 3: P_d v/s SNR for Different Channel Taps

in Figure 5. It is quite clear from the above figure that P_f will be less for a small window size as compared to large correlating windows. This result is in accordance with the relation derived in figure 1 for P_d. It means Pf will increase for a large window size because the no. of samples will be more and it is very less likelihood that a desired object can be detected.
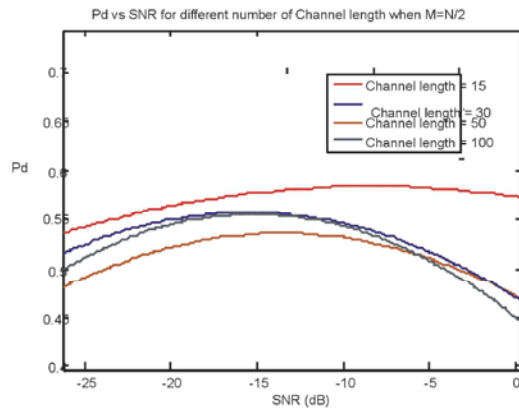
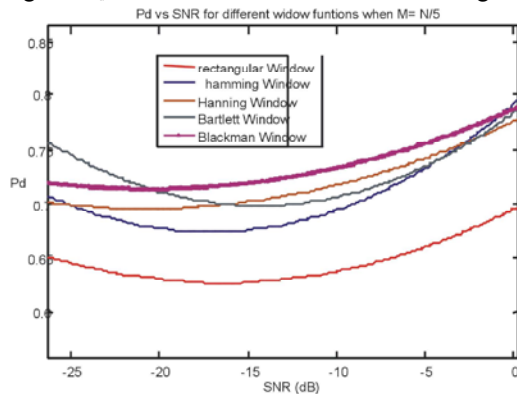Fig. 4.: P_d v/s SNR for Different Channel Lengths

Fig. 7: P_f v/s SNR for Different Sample Lengths
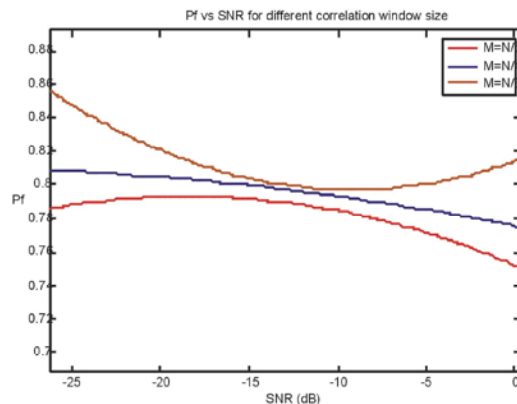

Fig. 5: P_d v/s SNR for Different Windowing Functions

Fig. 8: P_f v/s SNR for Different Channel Taps

Fig. 6: P_f v/s SNR for Different Correlation Windows

Fig. 9: P_f v/s SNR for Different Channel Lengths

Different values of sample lengths affect P_f as depicted in Figure 7. It can be seen that P_f increases as the sample length increases for different values of SNR. This result is similar to the finding in Figure 6, because as the no. of samples increases it is very much likelihood that the detected object is a false alarm.

As the no. of channel taps increases the probability of false alarm increases, as shown in Figure 8. This relation is quite similar to the one derived from Figure 3.
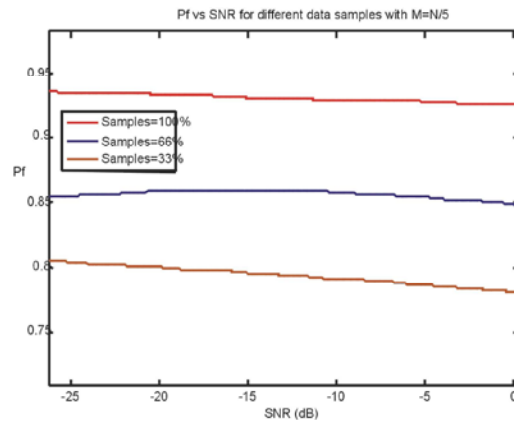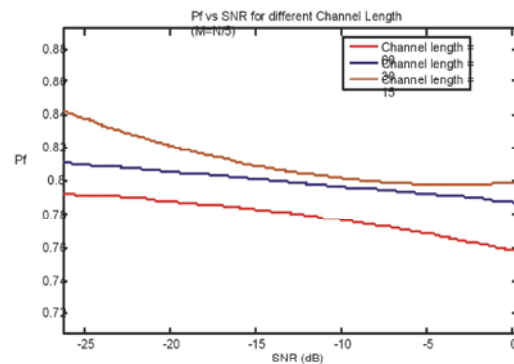
Probability of false alarm can also be analyzed for varying channel length, which causes multipath fading. Figure 9 shows the relationship of P_f for different values of SNR and it can be seen that as the multipath increases the value of P_f also increases. It means multipath fading increases the likelihood of false alarm and reduces probability of detection.

P_f is analyzed for different windows like rectangular, hamming, Bartlett etc. for different values of SNR, as
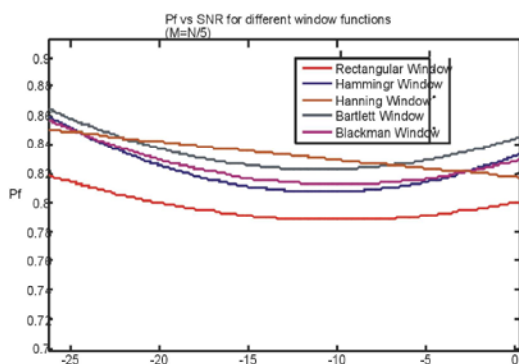
Fig. 10: P_f v/s SNR for Different Windowing Functions

shown in Figure 10. For low values of SNR, the performance of all the windows is same and it varies significantly as the SNR increases. Rectangular window has a poor response to P_f for different values of SNR as compared to other windows. Bartlett window has high value of P_f as compared to other windowing functions, clearly depicted in Figure 10.

CONCLUSION

Blackman Tukey has been analyzed for probability of detection and false alarm. Window size has an impact on the system performance so its value must be chosen carefully while designing a communication system. Multipath fading which is the function of multi paths should also be taken into consideration as it decreases the probability of detection. Windowing function has its importance in proper detection and suppressing side lobes, so window selection should be made as per the required results.

CR is the modern technique which finds the solution to spectrum congestion and user availability. Different techniques can be used to exploit the benefits of it.

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