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Performance Comparison of Paraunitary Analysis Filter Bank Based Spectrum Sensing Technique over Multipath Channels

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Abstract

Background/Objectives: In earlier days of wireless communications, the demand for the spectrum is limited, because the wireless services may not require higher bandwidths. But as time passes radio spectrum has become one of the important and regulated resources for all the wireless services. From the past 10 to 15 years the spectrum needs were increased and it becomes a scarce resource. **Methods/Statistical analysis:** The information and communication technology industry in today's scenario faces several global challenges like: Higher data services with improved Quality Of Service (QOS), scarcity of spectrum, and increased expenses of the services. Thus both the energy domains as well as spectral domain efficiencies were degraded, which made the researches to think in different ways, The other ways to improve spectrum utilization is the use of unlicensed spectrum or secondary access. In order to solve this spectrum utilization efficiency problem, Cognitive Radio (CR) concept was introduced. CR technology is an secondary access method in which an unlicensed Secondary Users (SUs) senses the whole radio spectrum and uses the licensed spectrum holes such that it does not cause any interference to the Primary Users (PUs). This way of spectrum access improves the efficiency of spectrum utilization. **Findings:** For sensing the spectrum of the primary user, several methods are proposed in literature. A method called Paraunitary Analysis Filter Bank based sensing method is analysed in this paper and its performance was compared with Filter bank based spectrum sensing and Energy Detection (ED) based spectrum sensing techniques. **Application/Improvements:** It can be used to reduce the interference in Femtocell networks by considering the macro user as a primary user and femto user as a secondary user to use the spectrum effectively and to increase the capacity of the cellular networks.

Keywords: Cognitive Radio, Energy Detection, Filter Bank, Paraunitary Filter Bank, Spectrum Sensing

1. Introduction

The rapid increase in the number of smart phones, tablets and wireless devices raise the demand for the data traffic in an exponential way from day to day. This in turn produces spectrum scarcity problems. The Federal Communications Commission (FCC) said that unused portions of the RF spectrum, referred to primary users, known as white spaces or spectrum holes be made available for public use by proper maintenance of interference problems between them. Thus the white space devices or spectrum holes include technologies that prevent interference, such as spectrum sensing and geo location capabilities. This problem of spectrum sensing in wireless communications is solved wisely in a better way using CR technology[1].

CR is a device which provides high reliable communication to all the users in a network by maximally utilizing the available radio spectrum. It significantly increases the utilization of the spectrum efficiency and provides sufficient bandwidth to support higher quality and higher data rate products. Several methods were introduced in the literatures that are used, to identify or to become aware of the spectral environment surrounded by the cognitive radio. Some of these methods used for spectral awareness are geo-location/database and spectrum sensing methods[2].

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In cognitive radio terminology, primary users can be defined as the users who have legacy rights on the usage of specific band of spectrum. On the other hand, secondary users have least priority and can utilize this spectrum without causing interference to the primary users. It increases the spectrum utilization and decreases spectrum scarcity. A CR is a transceiver which automatically changes its transmitter and receiver parameters so that the devices may have agility on the spectrum to select the available wireless channels. CR works on the principle Dynamic Spectrum Access (DSA)[3]. The basic and essential mechanism for CR technology is to find the spectrum holes by using Spectrum Sensing. The process of identifying the spectrum holes in the neighbourhood environment of the CR receiver is called spectrum sensing. Spectrum sensing thus plays an important role in CR technology.

In literature several methods has been proposed for spectrum sensing. The basic method discussed in the literature is Energy Detection (ED) based spectrum sensing. In ED, the received band limited signal is converted into digital form and the energy of the signal is calculated, which is compared with the threshold energy, if the signal energy is more than the threshold energy, considered as a busy channel and primary user is present. If the energy of the signal is less than the threshold, it is considered as a free channel. The threshold statistic and the test statistics for this method were mentioned in[4]. Efficient Spectrum Sensing Framework and attack detection in CR networks using hybrid ANFIS is discussed in[15].

One of the recent and popular techniques for spectrum sensing introduced in the literature is Filter Bank method. As we entered into 5G scenario, the demand for higher band width, higher quality, higher data rates increases. The advantage of filter bank based spectrum sensing method is that, FBMC is proposed as an air interface technology for the 5G systems. The performance of filter bank is evaluated in[5]. In FB method, the incoming spectrum is divided into number of sub-bands and hence instead of filtering the whole band of spectrum, it filters each sub-band which results in high spectral efficiency. The spectrum sensing method proposed in this paper is paraunitary filter bank method. This PUFB is superior to FB method because of their real valued nature and their efficient implementation via poly phase structure and fast discrete cosine transform. In this paper we have investigated the Paraunitary Filter Bank method for spectrum holes sensing and we have also analysed its performance and also compared its results with ED and FB methods under different fading channels with different SNR levels.

The paper is further organized as follows: In Section II, a brief introduction to Multirate filters is explained. Section III gives fundamentals about ED method. FB and PUFB based spectrum sensing methods are explained in section IV & V respectively. Finally results and conclusion are discussed in sections VI and VII respectively.

2. Introduction to Multirate Filters

Whenever a signal at one sampling rate has to be used by a system that requires a different rate, the sampling rate has to be increased or decreased, and it required some processing to do so. The process of converting a signal at one sampling rate to a different or required sampling rate is called sampling rate conversion. Such systems which employ multiple sampling rates are called Multirate systems. Multirate systems includes more than one sample rate. A Multirate system also includes time- varying operations and linear filters hence they belongs to a class of linear time-varying systems[6]. In Multirate digital signal processing the sampling rate of a signal is changed in order to increase the efficiency of various signal processing operations. The basic building blocks of Multirate systems are Decimation and Interpolation. Decimation or down-sampling decreases the sampling rate whereas up-sampling or interpolation increases the sampling rate. Decomposition of a signal into M components, containing various frequency bands, if the original signal is sampled at the sampling frequency fs, and its decimated value can be represented by the sampling rate fs/M.

2.1 Basic Operations of Multirate Systems

2.1.1 Decimation

Decimation, or down-sampling, means reduction of the sampling rate of a signal by a factor M. The block diagram of decimator is showed in Figure 1.

The output of decimation is defined as

$$y(m) = x(mM) \tag{1}$$

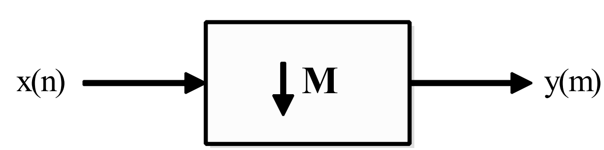


Figure 1. Decimator with a decimation factor of M.

i.e., it consists of every M^{th} element of the input signal. The operation of down-sampling by factor M describes the process of withholding every M^{th} sample of the discrete time signal and discarding the rest. This is denoted by "↓M" in block diagrams.

2.1.2 Interpolation

Interpolation or up-sampling means step-up of the sampling rate of a signal by a factor L. The block diagram of interpolator is showed in Figure 2.

Interpolation is a process of increasing the number of samples in a discrete-time signal. The operation of up-sampling by a factor L indicates the insertion of L-1 zeros between every sample of the input signal. This is denoted by "↑L" in block diagrams.

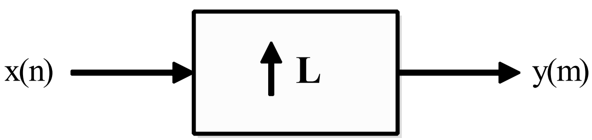


Figure 2. Interpolator with a interpolation factor of L.

The output of interpolation is defines as,

$$y(m)=\begin{cases} x(m/L) & \text{for } m = 0, L, 2L\,.\,. \\ 0 & \text{Other wise} \end{cases} \quad (2)$$

3. Analysis and Synthesis Filter Banks

In Multirate digital signal processing the incoming signal is decomposed into a number of sub band components. Each sub band is then processed at a lower sampling rate corresponding to the bandwidth of the sub divided frequency bands. A filter bank is an array of band pass or high pass or low pass filter which performs the above operation. A filter bank is regarded as a Multirate system since it involves various sampling rates[7].

In reality a filter bank can have M channels. There are M analysis filters H_o (z), H_1 (z),....H_{M-1}(z). The sampling is done at critical rate by (↓M) and (↑M). There are M filters F_0 (z), F_1 (z),....F_{M-1}(z) in the synthesis section[8]. The outputs of all the channels are combined together to form the original signal. The standard form of M-Channel filter bank is shown in Figure 3.

Cognitive Femtocells checks for the availability of the spectrum holes from the PU and uses the free spectrums. As the Analysis filter bank is used as receiver filter bank, it can be used for spectrum sensing in CRsystems[14].

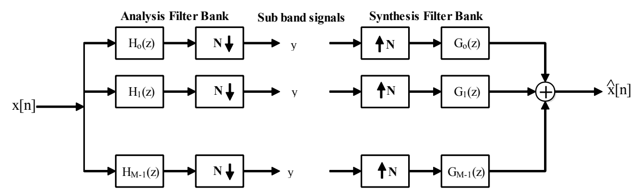


Figure 3. Standard form of M-channel filter bank.

4. Energy Detection Method

In the ED method, spectrum-hole detection process consists of measurement of the energy contained in the primary user band and the comparison of the results with the predetermined threshold values[9]. The block diagram of ED based spectrum sensing technique is showed in below Figure 4.

The primary user spectrum band i.e. received signal is given to the band pass filter with chosen band limited. The band limited analog output is then converted to digital form using ADC. And finally the energy of each band is calculated using the test statistics. The test statistic of ED is given by,

$$Y = \sum_{n=1}^{N} |x(n)|^2 \quad (3)$$

Equation (3) represents the sum of the energy of digital samples. Finally, the results were compared with the threshold values calculated by the equation given by,

$$K = \left(\frac{Q^{-1}(Pf)}{L^{\frac{1}{2}}} \right) + 1 \quad (4)$$

When the test statistic is greater than the threshold value energy detector indicates that the primary spectrum is occupied. When test statistic is less than the threshold it indicates that the primary spectrum is free. Increase in the sensing time and by proper selecting of threshold increases probability of detection.

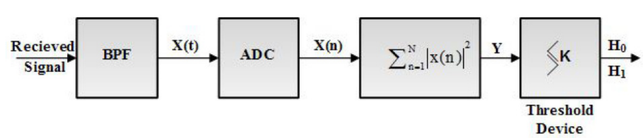


Figure 4. Energy detection based spectrum sensing method.

5. Spectrum Sensing using Filter Bank Method

The main task of CR is to find the spectrum holes i.e. the idle spectrum bands by discovering whether the primary user is present or absent. Hence, at the receiver end a detector is needed to do so. As we know filter bank is a transceiver having two sections, the analysis section and the synthesis section. Out of these two sections, analysis section will act as a receiver filter[10]. Thus analysis filter bank will be used for spectrum sensing. In filter bank spectrum sensing methods the input signal is passed through bank of band pass filters with different pass bands. Finally the output power is measured by adding the calculated energy of each band[11].The block diagram of AFB with two bands is shown below Figure 5.

In digital signal processing, a two band filter bank called Quadrature Mirror Filter (QMF) bank is often used which performs spectral splitting of input signal into two sub-bands low pass/high pass[12]. For spectrum sensing method this two channel QMF is suitable in single user scenario. Here, S[n] is the incoming primary user signal, V[n] is the noise signal, H_0 [z] and H_1 [z] are the anti-aliasing filters, low pass and high pass filters respectively. U_0 [n] and U_1 [n] are the down sampled signal and the energy of each signal is calculated using the formulae given by,

$$m1^1 = \sum_{n=1}^{\frac{N}{2}} \left|U_0[n]\right|^2 \tag{5}$$

$$m1^2 = \sum_{\frac{N}{2}}^{N} \left|U_1[n]\right|^2 \tag{6}$$

Now the total energy of the signal is obtained by adding the above two equations.

$$T1 = m_1{}^1 + m_1{}^2 \tag{7}$$

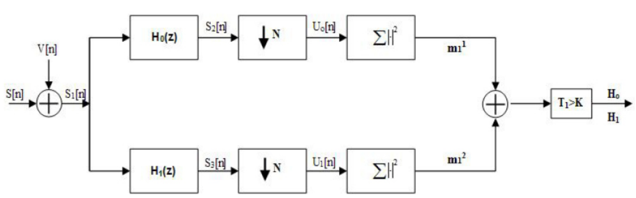


Figure 5. Filter bank based spectrum sensing.

If the above calculated statistic is greater than the threshold value means that the primary user is present otherwise the spectrum is idle

6. Para Unitary Filter Bank Method

Paraunitary filter bank is a Perfect Reconstruction (PR) filter bank in which E(Z), a physical matrix which makes an appearance in polyphase implementation of filter bank, satisfies a special property called lossless or paraunitary property[7]. Let a N- channel filter bank be given by,

$$H(z) = \begin{bmatrix} H_1(z) \\ \vdots \\ H_n(z) \end{bmatrix} \tag{8}$$

Then the paraunitary filter bank must obey the following relation,

$$\tilde{\mathbf{H}}(z)\mathbf{H}(\mathbf{z}) = \mathbf{dI} \tag{9}$$

Whenever E(z)is paraunitary it often express by saying that, "Analysis filter bank forms a paraunitary set", or "Analysis filter bank is paraunitary" or "paraunitary QMF"[13].

The paraunitary property implies that,

$$\tilde{\mathbf{E}}(z)\mathbf{E}(\mathbf{z}) = \mathbf{dI} \tag{10}$$

That means

$$\mathbf{E}^{-1}(z) = \frac{\tilde{\mathbf{E}}(z)}{\mathbf{d}} \text{ for all z} \tag{11}$$

These Paraunitary filter banks will improve the efficiency of spectrum sensing compared to analysis filter bank method. PUFB are the building blocks of cosine modulated filter bank, sine modulated filter bank methods. In Paraunitary filter bank method, in order to decompose the incoming signal into number of sub-bands of desired frequencies digital filter banks have been used. The amplitude responses of FIR analysis and synthesis filters in paraunitary filter banks are same. The signals obtained after decomposed, into different sub-bands, in the digital filter banks are coded and then transmitted. These schemes are well known and popular for encoding the data from speech and image signals. The process of decomposition of signal is done by analysis section as shown in the Figure 6.

Figure 6 shows complete "Analysis-Synthesis Paraunitary filter bank". For spectrum sensing purpose

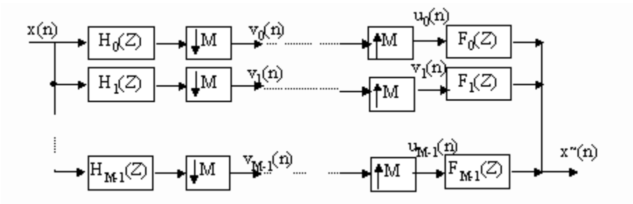


Figure 6. Paraunitary filter bank.

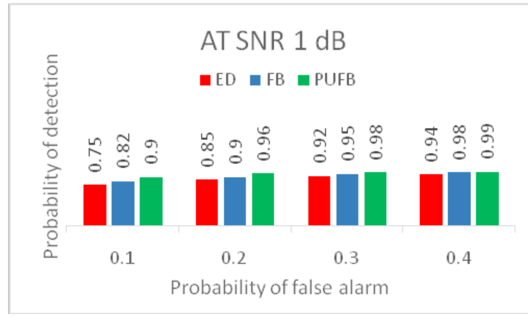
analysis section alone is used. The performance of analysis Paraunitary filter bank is evaluated in this paper. The results are showed in the next section.

7. Performance Evolution and Discussions

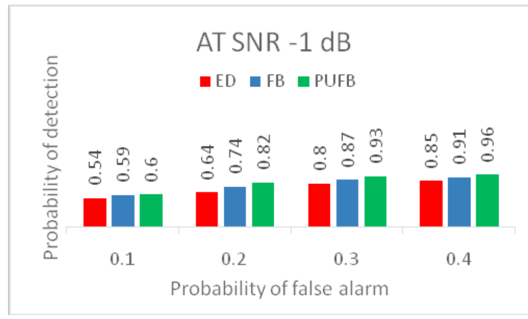
The simulation tool used, for determining the performances of filter banks, is MATLAB. As the filter banks are used in receiver side, the receive characteristics should be determined. In statistics, to illustrate the performance of a binary classifier system as its discrimination threshold is varied, a graphical plot called Receiver Operating Characteristic (ROC) Curve, or ROC curve, is used. For determining the performance of spectrum sensing method the better tools were provided by ROC curve. ROC curve is obtained by plotting True Positive Rate (TPR) versus False Positive Rate (FPR). In our scenario TPR is referred to probability of detection and FPR as probability of false alarm. Performance of different spectrum sensing techniques i.e, Energy Detection, Filter Bank based Spectrum Sensing and Paraunitary filter based spectrum sensing over AWGN channel at different SNR values are shown in Figure 7.

The simulation was done at different SNR values and for different faded channels. The modulation technique used for simulation is BPSK. From the bar graph it is clear that PUFB is showing better results compared to FB and ED methods.

Figure 1(a) shows the comparative ROC curve at SNR = 1dB and Figure 1(b) shows the comparative ROC curve at SNR= -1dB. In both the cases there is a greater percentage change in the performance of PUFB compared to other two methods. As we already know that the AWNG is the fundamental noisy channel, the performance of the spectrum sensing method will always be better compared to Rayleigh and Rician fading channels. Performance of different spectrum sensing techniques i.e, Energy Detection, Filter Bank based Spectrum Sensing and Paraunitary filter



(a)



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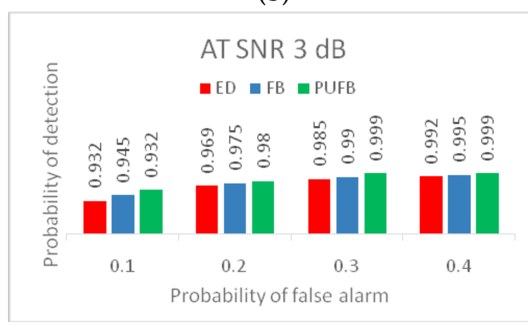


(c)

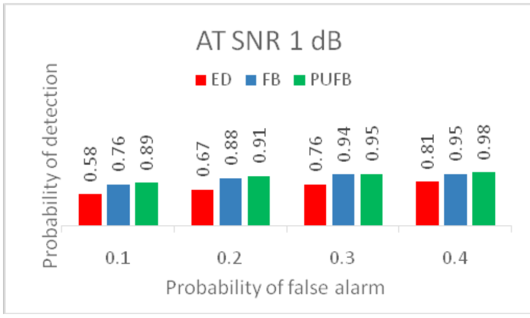
Figure 7. Performance of spectrum sensing techniques over AWGN channel at different SNR values.

based spectrum sensing over Rayleigh channel at different SNR values are shown in Figure 8.

The performance of Paraunitary FB based spectrum sensing is showed in Figure 2. Again it is clear that PUFB shows better performance compared to other two methods in the both cases.

The simulation was also performed for Rician fading channel. The performances of the spectrum sensing methods were observed and the values obtained in the simulation were plotted in bar graphs and are shown below Figure 9.

The above graph describes about the performance results of sensing methods in Rician fading channel. As likely to be happen, PUFB performs well in Rician channels also. Also the graph shows that the performance of



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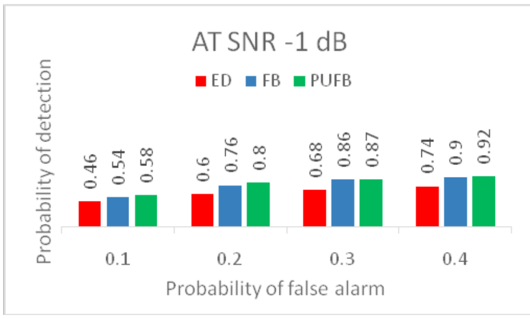

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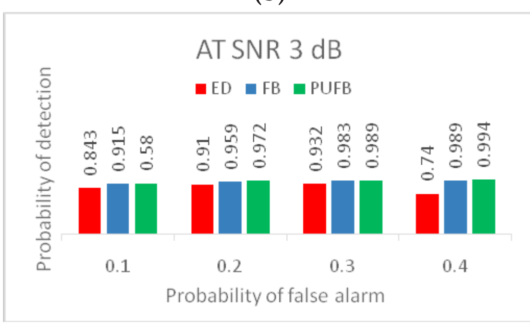

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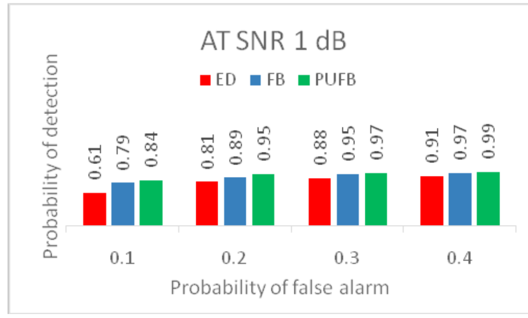
Figure 8. Performance of spectrum sensing techniques over RAYLEIGH channel at different SNR values.

sensing techniques in Rician channel is better compared Rayleigh channel.

The modulation technique considered for simulation purpose is BPSK modulation, but "Higher the modulation version greater the impact on the sensing abilities of the spectrum sensing methods". The other modulation scheme considered for interpreting above statement is QPSK modulation scheme. For illustrating purpose, we have simulated PUFB sensing method with both BPSK and QPSK modulation scheme. The simulation was performed in all three fading channels and the results were shown below.

For clear understanding, we represented the performances of all the three sensing methods in the following graphs at a SNR of 1 dB over AWGN, RAYLEIGH, and RICIAN fading channels.



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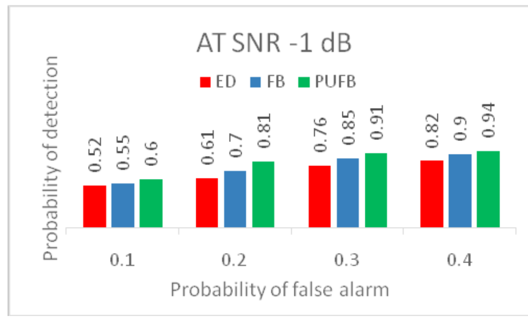

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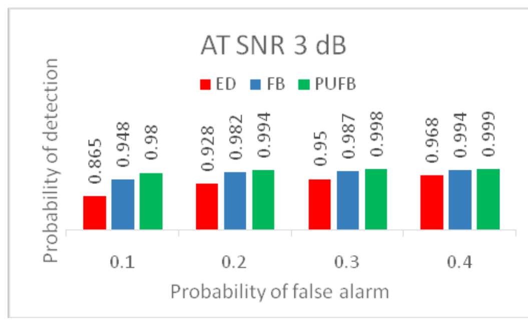

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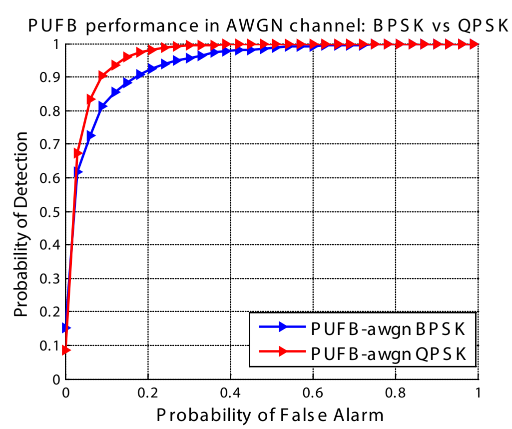
Figure 9. Performance of sensing techniques over RICIAN channel at different SNR.



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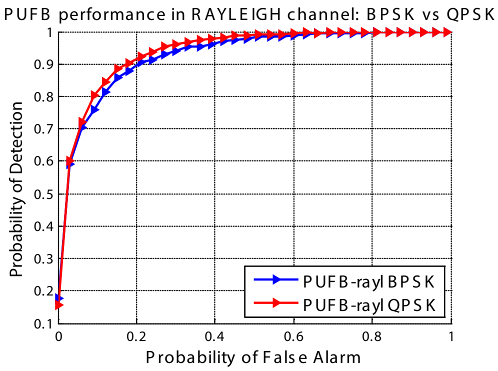

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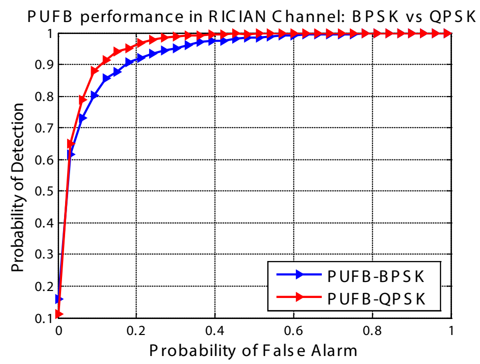

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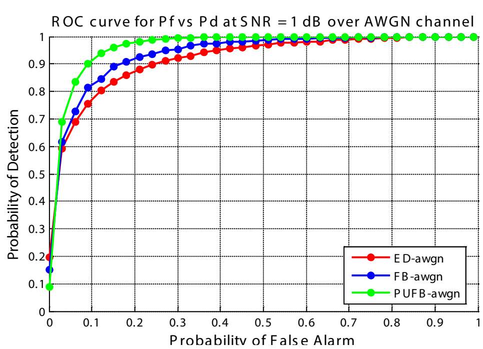
Figure 10. Comparative ROC curves for FB sensing techniques with BPSK and QPSK modulation techniques.



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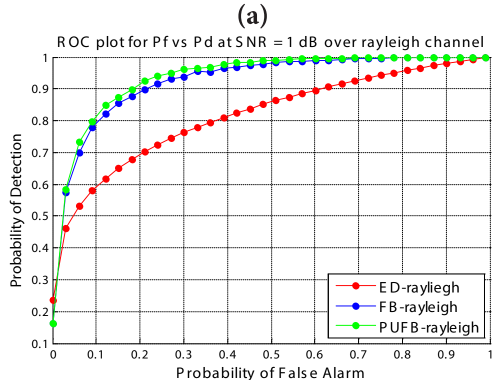

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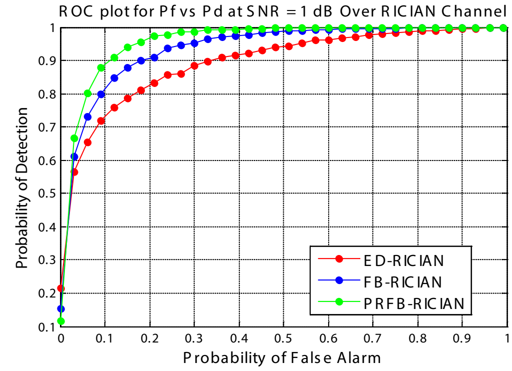

(c)

Figure 11. ROC curves of sensing techniques over: (a) AWNG channel, (b) RAYLEIGH channel, (c) RICIAN channel.

Figure 11 shows a comparative ROC graph of PUFB, ED and AFB methods. From the above figures, it is clear that the graphs are concave in nature and moves towards probability of detection. But out these three methods, PUFB performs better in all three fading channels as well as in different SNR conditions.

8. Conclusion

The performance of ParaUnitary Filter Bank (PUFB) based spectrum sensing method has been investigated in this paper. The performance of Paraunitary filter bank is determined by simulating the filter bank under different noise channel conditions. From the results it is clear that the performance of PUFB is better compared to AFB and ED methods. The comparative ROC curves are showed in section VI. In all the three channels i.e. AWGN channel, RAYLIEGH fading channel and RICIAN fading channel PUFB shows better results than the other two methods. And also we evaluated the performance of each sensing technique with BPSK and QPSK modulation schemes. The corresponding results were showed in section VI. The graph shows that the performance of the sensing methods will be improved with higher modulation schemes.

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