Techniques For Detection Of Analog TV Whitespace In Electromagnetic Spectrum For Cognitive Radio Applications

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Abstract **–Spectrum sensing is the key to the success of cognitive radios (CRs), which detect whether a primary user is utilizing his allocated transmission channel or not, before itself launching transmission. Thus secondary users, who use CR, will use the primary user's channel without harmfully interfering with his/her signal. In this paper, the most commonly used detection techniques namely Energy detection, Matched filter detection and Cyclo-stationary detection techniques are studied in the context of using analog TV channels for CR application. The cyclo-stationary detection technique outperforms the other two by detecting the presence of primary user's signal on a channel with signal to noise ratio (SNR) worse by more than 20dB, relative to the SNR thresholds of other two techniques. The evaluation of 3 detection techniques is done under a wide range of signal threshold (λ) relative to noise. This study helps in gaining a deeper insight into the use of analog TV channels for CR applications.**

1. INTRODUCTION

Due to switch over from analog to digital TV transmissions a wide range of whitespace is created in spectrum from 54 to 890 MHz. This white space can be dynamically allocated to users, to increase the throughput of transmission medium. When primary users have right over the allocated channel, secondary users can use the same without harmfully interfering with the primary transmission [1, 2]. Primary users are given the highest priority, and secondary users are given the next level priority. Today's wireless mobile communications have advanced significantly. Various kind of mobile services have increased the demand for high data rates for their users. The 3rd generation partnership project (3GPP) is working towards improved techniques to reach beyond the requirements; CR is one among those techniques.

The CR networks should be aware of their network, available spectrum environment and their location and capable to adapt to their environment by changing their transmission and reception parameters to support more concurrent wireless communications in a spectrum band at one location.

To achieve confirming the vacant bands become the main issue, i.e. it is a must to ensure that, (1) channels which are classified for secondary use are actually not being utilized by primary users; and (2) the channels being used by secondary users should be freed and re allocated to primary user whenever they appear. The spectrum sensing is the core issue, which provide information regarding channel status.

The commonly used spectrum sensing techniques are energy detection technique, matched filtering technique and cyclo-stationary technique. In this paper we analyzed the performance of these three techniques, by comparing them in terms of probability of false alarm, probability of detection and probability of miss detection. The raising of false alarm indicates conclusion in favour of presence of primary user's signal when it's really not there. The raising of miss detection alarm indicates the conclusion in favour of absence of primary user's signal when it's really there. The conclusion of right detection indicates the true status of the channel. All these conditions are judged by testing null hypothesis (H_0) and alternative hypothesis (H_1), discussed later.

The remainder of the paper is organized as follows. In section 2 simulation of analog TV signal is introduced. In section 3, spectrum sensing methodologies are discussed. Section 4 discusses the results and comparisons of methods. In section 5 we conclude.

2. SIMULATION OF ANALOG TV SIGNAL

The Analog TV broadcast channels range from channel number 2 to 83, with a bandwidth ranging from 54 to 890MHz. The composite analog TV broadcast consists of video, audio and color signals. The color signal have low power spectral density compared to audio and video signals, so we have not considered the color signals for detection. A single composite Analog TV has a bandwidth of 6MHz.

The below Fig. 1 explains the generation of composite video signal, $m_a(t)$ is the audio signal $m_c(t)$ is the video signal. Audio signal is frequency modulated and video signal is first double side band suppressed carrier (DSBSC) modulated, later it is passed through filter to get vestigial side band (VSB) signal $S_{TV}(t)$. Composite TV signal $S_{TV}(t)$ is given as [3]:

$$S_{TV}(t) \ = A_c[1+\mu\, mc\,(t)]cos(2\pi f_c t+Sa(t) \qquad (1)$$

where S_{TV} (t) is the composite video signal, S_a (t) is frequency modulated audio signal centered at audio carrier, A_c is the video signal amplitude. Frequency modulated audio signal is given by the equation

$$S_a(t) = \ A_s \times \cos(2\pi f_c t) + D_f \int_{-\infty}^{t} mB(\lambda) d\lambda \qquad (2)$$

where A_s is the amplitude of the audio signal and D_f *is* frequency deviation constant, $mB(\lambda)$ is composite audio signal.

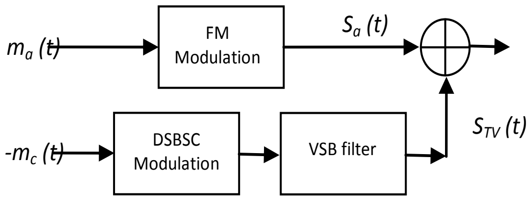

Fig. 1: Simulated system diagram of a broadcast TV transmitter.

D_f is 114 KHz, and modulation index μ is -0.875 for visual TV signals. The signal is passed through Additive White Gaussian Noise (AWGN) channel and is received by wide band receiver. The Fig. 2 shows the Radio Frequency (RF) front end block diagram of CR receiver. The signal is captured by a dipole antenna, and is fed to the low noise amplifier (LNA), which will amplify the signal by suppressing the noise. Further signal is filtered by 20-80 MHz wide bandwidth, using 5th order butter worth band pass filter with approximately 1dB loss [3]. Further this signal is amplified with non-linear amplifier with gain of 25dB. Long co-axial cable introduces a loss of 13dB and a variable attenuator is used to restrict high voltage fluctuations. Further two stages of amplifiers with identical band pass characteristics are used with a band pass filter, in between them.

The two stage filters are used to reduce the non-linearity effects. At last 12 bit analog to digital convertor (ADC) is used for digitization of the signal. The digitized signal is passed through sub channel filter to filter out only the required TV channel signal; this filter is a digital filter of 6MHz pass band. Now detection techniques can be applied on this signal to obtain the channels status.

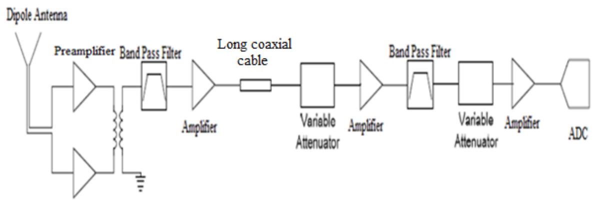

Fig. 2: Simulated block diagram of cognitive radio receiver.

Fig. 3 shows power spectral density at receiving antenna for the three TV channels namely channel number 2, 3 and 4 each with channel bandwidths of 54-60 MHz, 60-66 MHz and 66-72MHz. Fig. 4 shows the amplified signal of Fig. 3, with an overall gain of more than 60dB.

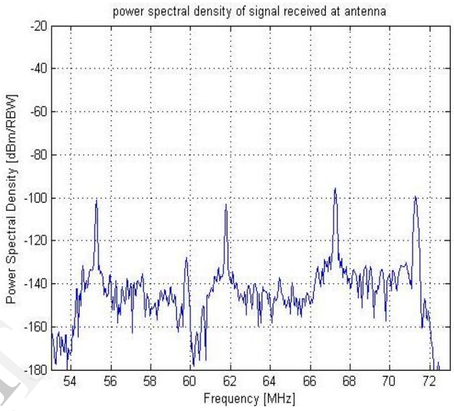

Fig. 3: Power spectral density of signal received at antenna.

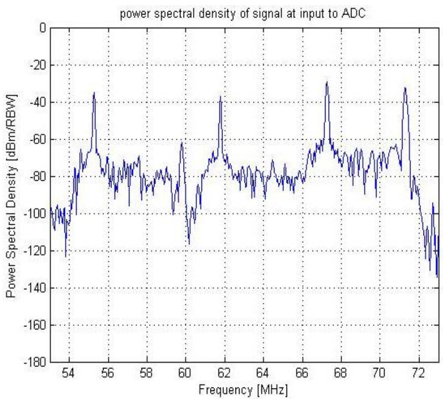

Fig. 4: Power spectral density of the signal in Fig. 3 after amplification.

3. SPECTRUM SENSING METHODOLOGIES

The goal of the spectrum sensing techniques is to detect whether a particular TV channel spectrum is idle or not. Based on sensing, we decide whether a particular channel is used by its primary user or not. Before starting of using a TV channel, we will not have any information regarding its status, whether idle or busy. We can make the following hypothesis:

$$x(n) = \begin{cases} \alpha_p s(n) + w(n) & H_1 \\ w(n) & H_0 \end{cases} \qquad (3)$$

x(n) is the received signal, *s(n)* is the transmitted signal by the primary user i.e. TV broadcast signal, α_p is path loss factor, *w(n)* is the zero mean AWGN of the channel. From Equation 3, H_0 is represented as the null hypothesis where only noise is received by the receiver; H_1 is the alternative hypothesis stating the presence of TV signal, added with the AWGN and the same is detected by at the CR receiver.

The detection methods results into following cases:

Probability of false alarm (P_f): wherein H_0 is true but decision is made in favor of H_1, given by:

$$P_f = Pr(H_1/H_0) \tag{4}$$

Probability of detection (P_d): wherein H_1 is true and decision is made in favor of H_1 given by:

$$P_d = Pr(H_1/\ H_1) \tag{5}$$

Probability of miss detection (P_m): wherein H_1 is true and the decision is made in favor of H_0 given by:

$$P_m = Pr(H_0/H_1) \tag{6}$$

The workings of the 3 sensing methods namely 'energy detection', 'matched filter detection', and 'cyclo-stationary detection' technique are described in the following sections.

3.1 ENERGY DETECTION METHOD

It is the simplest method among all the 3 detection techniques. Prior information regarding the primary user is not required for this method. This method just calculates the energy of the received signal and it is compared with a threshold value 'λ' to make the decision. Fig. 5 explains the method.

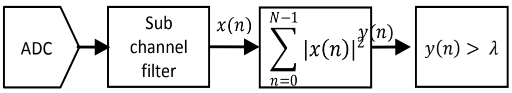

Fig. 5: Block diagram indicating the procedure of Energy Detection

In this figure the digitized signal from the ADC output is fed to sub channel filtering which only filters the required TV channel signal. Now from output of this filter, we obtain the energy of the signal; this total energy is compared with the threshold. If the total energy is greater than the threshold λ then TV channel is being used by the primary user or else only noise is present and it can be allocated to the secondary user. This method does not require any prior knowledge of the primary signal, so it is easy to implement, and its computational complexity is less. But the noise power will be varying over each interval of time, it is very difficult to set always a same threshold value which makes its performance low, and for very low SNR, differentiation of signal from noise will be very difficult. The test statistics for the energy detection are given below.

The probability of false alarm of the received signal $x(n)$ will be only noise $w(n)$, i.e. null hypothesis H_0 is true [4]. Energy of the this signal can be estimated as,

$$y(n) = \sum_{n=0}^{N-1} |w(n)|^2 \tag{7}$$

The energy detected will be chi-square (χ^2) distribution with N degrees of freedom. It is given by below equation,

$$f_{E_0}(x) = \frac{1}{\sigma_\omega^{\left(\frac{2N}{2}\right)} 2^{\left(\frac{N}{2}\right)} \Gamma\left(\frac{N}{2}\right)} x^{\left(\frac{N}{2}-1\right)} e^{-\left(\frac{x-\mu}{2\sigma_\omega^2}\right)}, x \geq 0 \tag{8}$$

Noise *x* here is AWGN with mean $\mu = 0$ and its variance σ_ω^2 so that the probability of false alarm can be calculated as

$$P_f = Pr(H_1/H_0)$$

$$P_f = Pr\{f_{E_0}(x) > \lambda/H_0\}$$

$$P_f = \int_{\lambda}^{\infty} f_{E_0}(x)\,dx$$

Solving the above equations we obtain the equation for probability of false alarm for energy detection as

$$P_f = \frac{\Gamma\left(\frac{N}{2}, \frac{\lambda}{2\sigma_\omega^2}\right)}{\Gamma\left(\frac{N}{2}\right)} \tag{9}$$

where, λ is the threshold value, N is the number of symbols used, σ_ω^2 is variance of noise, $\Gamma()$ is the Gamma function which is give by

$$\Gamma(n) = \int_0^\infty t^{(n-1)} e^{-t} dt \tag{10}$$

and $\Gamma(a,b)$ is the upper incomplete gamma function, which is given by the equation

$$\Gamma(a,b) = \int_b^\infty t^{(a-1)} e^{-t} dt \tag{11}$$

Now for the probability of energy detection is given by $P_d = Pr(H_1/H_1)$. The alternative hypothesis H_1 is given in equation 3. The energy of the received signal is calculated as [4],

$$y(n) = \sum_{n=0}^{N-1} |x(n)|^2, \tag{12}$$

$$y(n) = \sum_{n=0}^{N-1} |\alpha_p s(n) + w(n)|^2, \tag{13}$$

where $s(n)$ is the transmitted signal, α_p is path loss factor, and $w(n)$ is AWGN. Hence the probability of detection for energy detection technique can be given by the equation

$$P_d = 1 - \Gamma\left(N, \frac{\lambda}{(\sigma_\omega^2 + \sigma_s^2)}\right), \tag{14}$$

where σ_s^2 is the variance of the transmitted signal, and σ_ω^2 is the variance of noise, $\Gamma(a,b)$ is the lower incomplete gamma function given by,

$$\Gamma(a,b) = \int_0^b t^{(a-1)} e^{-t} dt \tag{15}$$

and probability of miss detection for energy detection technique is given by,

$$P_m = 1 - P_d, \quad (16)$$

3.2 MATCHED FILTERING METHOD

This method is only applicable when the prior information of the transmitted signal is known, such as the synchronization, modulation techniques, etc [4]. The signal should be synchronized before applying this method. By matched filtering the SNR will be increased and hence give a better detection results. It is best among the three methods to be applied if the transmitted signal information is known to the secondary user (CR) receiver (detector) or in other case if the prior information is not known, this method cannot be used for detection purpose which makes this method poor compared to other two techniques. Also the requirements for generating the copy of the primary signal for each different channel require complex hardware adding to its cost. The block diagram for this method is given Fig. 6.

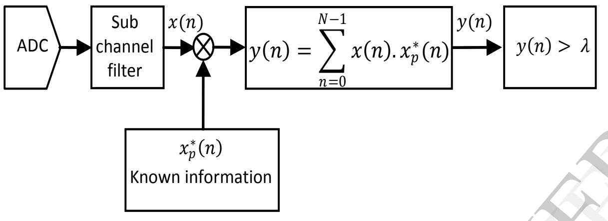

Fig. 6: Block diagram of Matched Filter Detection technique.

In this figure, the received signal is digitized and the required channel signal is selected from the sub band filtering of $x(n)$, now this signal is multiplied with the known transmitted signal generated by the secondary user $x_p^*(n)$, the resultant equation $y(n)$ is shown in the block diagram. Now $y(n)$ is compared with the threshold λ, if $y(n) > \lambda$ then primary user is using the channel, else the channel is free to be allocated for the secondary user. The test statics for the matched filter detection are given below. The probability of false alarm for the matched filtering is given by the equation

$$P_f = Pr(H_1/H_0)$$

$$P_f = Pr\{y(n) > \lambda/H_0\}$$

and the null hypothesis H_0 implies that the received signal will only be noise, given by equation 3. The matched filtered signal is represented by,

$$y(n) = \sum_{n=0}^{N-1} w(n) \times x_p^*(n) \quad (17)$$

Hence the probability of false alarm for matched filtering detection is given by

$$P_f = exp\left(\frac{-\lambda^2}{E{\sigma_\omega}^2}\right) \quad (18)$$

where $exp(\,)$ is the exponential function, E is the received signal power, ${\sigma_\omega}^2$ is the noise variance, and λ is the threshold value.

Now the probability of detection for the matched filtering detection is given by the alternative hypothesis, H_1 which implies the signal is present with noise added with it, and the probability of detection is given by,

$$P_d = Pr(H_1/H_1)$$

$$P_d = Pr\{y(n) > \lambda/H_1\}$$

when $y(n)$ is greater than the threshold λ, now the received signal will be $x(n) = \alpha_p s(n) + w(n)$,

Hence the matched filtered signal can be written as,

$$y(n) = \sum_{n=0}^{N-1} (\alpha_p s(n) + w(n)) \times x_p^*(n) \quad (19)$$

Now the equation for the probability of detection is given by

$$P_d = Q\left(\sqrt{\frac{2E}{{\sigma_\omega}^2}}, \sqrt{\frac{2\lambda^2}{E{\sigma_\omega}^2}}\right) \quad (20)$$

E is the received signal power, λ is the threshold value, ${\sigma_\omega}^2$ is noise variance, and $Q(a,b)$ is the generalized Marcum Q-function, give as

$$Q(a,b) = \frac{1}{a^{(m-1)}} \int_b^\infty x^m e^{\left(-\frac{x^2+a^2}{2}\right)} I_{m-1}(ax)dx \quad (21)$$

where a and b are non-negative real numbers, m is positive integer, $I_{m-1}(\,)$ is modified Bessel function of the first kind of order (m-1). Now probability of miss detection for the matched filtering is given by

$$P_m = Pr(H_0/H_1) = 1 - P_d$$

3.3 CYCLO-STATIONARY DETECTION

In nature all the processes are not periodic functions but their statistical features indicate periodicities and such processes are called cyclo-stationary process. In this technique, the secondary user can be very easily differentiated between the noise and the signal by analyzing their periodic nature. The noise signal is wide sense stationary and does not have any periodicity, but the TV signals are modulated carrier signals, with cyclic prefixes which have the periodic nature. Hence by estimating the spectral correlation function, noise and signal can be easily differentiated even in very high noise. This makes the method robust compared to other two methods. Any signal that is wide sense cyclo-stationary should have the following criterion: The received signal is $x(n)$ and mean function of the signal is periodic with some period say, T_0 given by [5],

$$E\{x(t + T_0)\} = E\{x(t)\} \quad (22)$$

and its auto-correlation function will be periodic with period T_0.

$$R_x(t+T_0,\tau) = R_x(t,\tau) \tag{23}$$

where,

$$R_x(t,\tau) = E\{x(t+\tau) \times x(t)\} \tag{24}$$

Now the cyclic auto-correlation function (CAF) in terms of Fourier co-efficient is given as:

$$R_x^{\frac{n}{T_0}}(\tau) = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} R_x(t,\tau) \times e^{-j2\pi(n/T_0)t}\,dt \tag{25}$$

'n/T_0' represents cyclic frequencies, represented by 'α'. Now the cyclic spectral density (CSD) also known as the spectral correlation function (SCF) is equivalent to the Fourier transform of cyclic auto correlation function [4]:

$$S(f,\alpha) = \int_{\tau=-\infty}^{\infty} R_x^{\alpha}(\tau) e^{-j2\pi f\tau}\,d\tau \tag{26}$$

In Fig. 7 a signal from the sub channel is selected and it is shifted by the cyclic frequency 'α' and the time shifted signals are passed through hamming window. The resultant signal is multiplied and we obtain the frequency domain transformed signal: the spectral correlation function (SCF). We estimate the maximum value of the SCF [6],

$$C = \max(S(f,\alpha)) \tag{27}$$

and is compared with the threshold 'λ', if $C > \lambda$ then the primary user is present, else the primary user is absent.

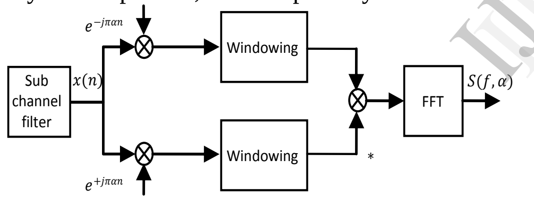

Fig. 7: Block diagram of cyclo-stationary detection method.

Fig. 8 shows the simulated SCF, in which we find the peaks at specific frequency points $(\alpha = 0, f = f_c)$ and$(\alpha = 2f_c, f = 0)$. The peaks are observed for various numbers of times and the decision about the channel status is taken [6]. The test statics for the cyclo-stationary detection are given below:

The probability of false alarm for the cyclo-stationary detection is given by the equation

$$P_f = Pr(H_1/H_0)$$

$$P_f = Pr\{S(f,\alpha) > \lambda/H_0\}$$

and the null hypothesis H_0 implies that the received signal will be only noise, given in equation 3.

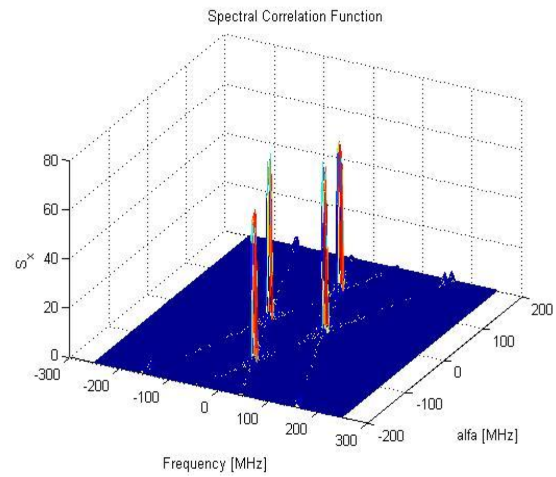

Fig. 8: Simulated Spectral Correlation Function, $S(f,\alpha)$

Probability of false alarm is given by,

$$P_f = exp\left(\frac{-\lambda^2(2N+1)}{2{\sigma_\omega}^2}\right) \tag{27}$$

where $exp(\,)$ is exponential function, N is the number of samples, λ is the threshold value, ${\sigma_\omega}^2$ is the noise variance. Now the probability of detection for cyclo-stationary method is given by:

$$P_d = Pr(H_1/H_1)$$

$$P_d = Pr\{S(f,\alpha) > \lambda/H_1\} \tag{28}$$

$$P_d = Q\left(\frac{\sqrt{2\gamma}}{\sigma_\omega}, \frac{\lambda(2N+1)}{\sigma_\omega}\right) \tag{29}$$

where γ is signal to noise ratio, $Q(a,b)$is Generalized Marcum Q-function, σ_ω is standard deviation of noise. Now probability of miss detection for cyclo-stationary detection is given by

$$P_m = Pr(H_0/H_1)$$

$$P_m = 1 - P_d$$

4. RESULTS

We have assumed total number of samples for signal generation as 2^{12} over the entire band. From sub channel filtering, analog TV channel numbered 2 is selected with bandwidth ranging from 54-60 MHz, and video carrier at 54.25 MHz, and audio carrier at 59.75 MHz. The signal obtained contains N=125 discrete samples. This signal is tested with all the three detection techniques and probability of false alarm(P_f), probability of detection (P_d), probability of miss detection (P_m) for all the three methods viz. 'energy detection', 'matched filter detection', and 'cyclo-stationary detection' techniques are compared below for SNR ranging from -40 to 40dB.

Probability of false alarm(P_f)*:* In Fig. 9 the probability of false alarm P_f for cyclo-stationary detection is 1 up to -25 dB and goes on decreasing as SNR increases, and reaches zero at nearly 5 dB SNR. At this stage P_f values for matched filtering and energy detection are still 1. Similarly P_f of matched filter decreases at 3dB SNR and reaches zero at 19 dB SNR; for energy detection P_f decreases from 1 at 28 dB SNR and reaches zero at 32dB SNR. Here it shows that cyclo-stationary outperforms matched filtering and energy detection, and the matched filtering is better than the energy detection.

Probability of detection(P_d)*:* In Fig. 10 the Probability of false detection P_d for cyclo-stationary detection is 0 upto -35dB and goes on increasing as SNR increases, and reaches 1 at nearly -32dB SNR. At this stage P_d for matched filtering and energy detection are still zero. Similarly P_d of energy detection increases from zero at -18dB SNR and reaches 1 at -9dB. For matched filtering P_d increases from 0 at -15dB SNR and reaches 1 at 5dB. Again, it shows that cyclo-stationary outperforms the matched filtering and the energy detection; and the energy detection is better over the matched filtering.

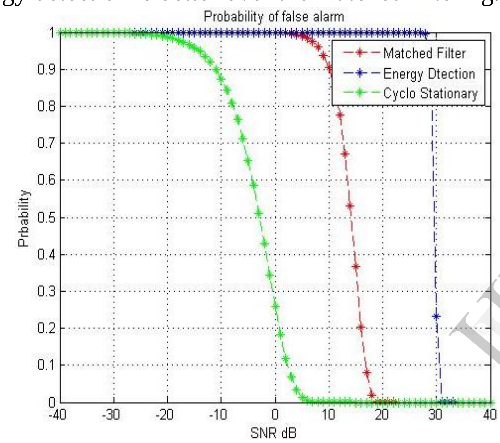

Fig. 9: Simulated probability of False Alarm.

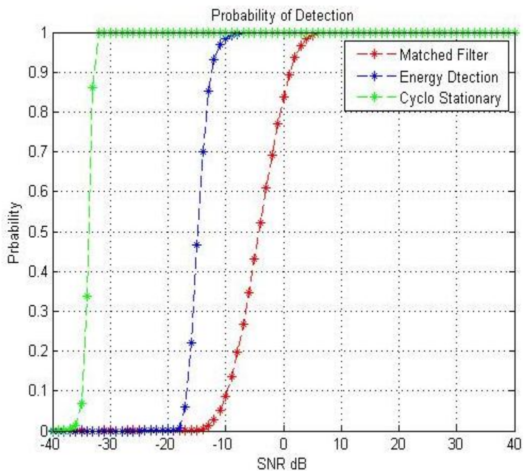

Fig. 10: Simulated probability of Detection.

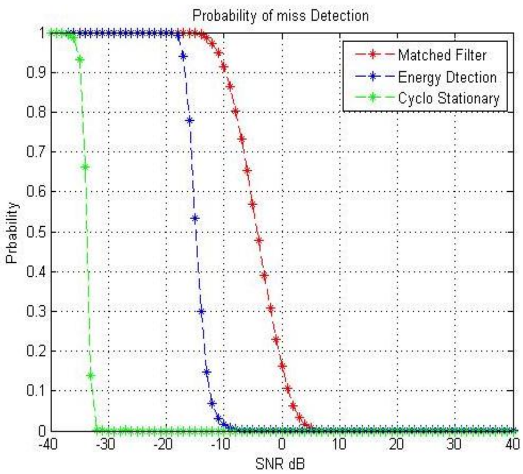

Fig. 11: Simulated probability of Miss Detection.

Probability of miss detection (P_m) *:* In Fig. 11 the simulated probability of miss detection P_m for cyclo-stationary detection is 1 up to -35dB and goes on decreasing as SNR increases, and reaches zero at nearly -32dB SNR. At this stage P_m values for matched filtering and energy detection are still 1. Similarly P_m of energy detection decreases at -18dB SNR and reaches zero at -9dB SNR. For matched filtering P_m decreases from 1 at -15dB SNR and reaches zero at 5dB SNR. Here it shows that cyclo-stationary technique outperforms the matched filtering and the energy detection technique. The Energy detection technique is better than the matched filtering technique.

5. CONCLUSION

In this paper we have compared the performance of 'energy detection', 'matched filter detection' and 'cyclo-stationary detection' techniques with respect to their probabilities of 'false alarm', 'detection' and 'miss detection'. It is observed that 'energy detection' does not require prior knowledge of the transmitted signal, makes it better with respect to matched filtering, but for very low SNR, it fails to give correct results. If the transmitted signal characteristics are known then matched filter technique is better than energy detection. But it is more costly for its complex hardware requirements compared to energy detection. This comparative study shows the cyclo-stationary detection technique outperforms both the energy detection and matched filter detection due to its capability to differentiate the signal from the noise. It is suited well for low SNR condition, compared to energy detection and it does not require any prior information about the transmitted signal as in the case of matched filtering technique. The superiority of cyclo-stationary technique comes at the cost of increased computational time and complexity.

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