ENHANCED ENERGY DETECTOR USING ADAPTIVE WIENER FILTER IN COGNITIVE RADIO

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ABSTRACT

The rising demand in wireless services and applications bring channel constraint on the existing frequency spectrum allocation scheme. By addressing the concept of cognitive radio technique (CR), it is possible to mitigate the scarcity of spectrum channel and underutilization of spectrum efficiencies. Various techniques and methods have been used to maximize the probability of detection (Pd) in CR system. Energy detector spectrum sensing is one of the transmitter based techniques, which detects the presence of primary user in cognitive system. However performance indicator metrics show that the energy detector algorithm has poor performance when the received SNR value is too low as compared to the system threshold value. In this paper the performance of conventional and enhanced energy detector (using adaptive Wiener filter) is examined based on Receiver Operating Curve (ROC) and Complementary Receiver Operating (CROC). Simulation results are plotted for different threshold values, false alarm probability, detection probability and the received SNR. Results for AWGN and Rayleigh flat fading channel models are presented. The Simulations results in Rayleigh flat fading channel show that, the insertion of adaptive Wiener filter in conventional energy detector has improved the probability of detection by 8% and reduce the probability of miss detection by same amount.

Keywords *adaptive Wiener filter: Cognitive radio, energy detector, false alarm and detection, performance metrics (ROC, CROC), probability spectrum sensing, threshold value.*

INTRODUCTION

Technological advancement of wireless communication in this century brings a variety of wireless products/devices that can be used for a wide range of application. Devices in wireless environments operate on specified licensed spectrum. This operational frequency range should be designed, allocated and properly administrated by governmental institution such as ETA of Ethiopia, FCC of USA. The assigned frequency range can be used in cellular network, FM radio, TV broadcasting service etc. [1,2].

Study at FCC shows that the spectrum usage is highest specifically in cellular network (GSM), TV bands, fixed radio system and FM radio channel. But significant amount of the spectrum remains underutilized [3]. It also shows that the spectrum usage in the band below 3 GHz has utilization efficiencies of 15% to 85% [4,5]. As new service and wireless application are continuously added the system channel will be fully occupied and consequently it creates congestion and channel scarcity. To mitigate this problem, I. Mitola proposed the concept of cognitive radio system in his doctoral dissertation. [6]. Cognitive radio can be defined as a radio system that can adaptively and dynamically allow user(s) to use the spectrum in the opportunistic way [5-8].

This paper deals with enhancement of the performance of conventional energy detector using adaptive Weiner filter. Focus is made on how the performance metrics are improved at low SNR signal.

THEORETICAL BACKGROUND

The concept of energy detector was developed by Urkowitz [9]. In his concepts signal is passed through band pass filter of the bandwidth W and integrated over time interval, the output of the block of integrator is compared to predefined threshold. The value of threshold can be set to variable or fixed based on condition of channel. The blind signal detector is another name for energy detector because it ignores the signal structure i.e., it estimates the presence of signal by comparing the energy received with known threshold from the statistics of the noise. The value of signal to be analyzed should be deterministic, pass through a flat band limited power density spectrum of Gaussian noise with known mean and variance Applying sampling theorem, it can be approximated by the sum of squares of statistically independent random variables having zero mean and unity variance. The resulting sum will have a chi-square distribution and reduces to a simple identification problem of binary hypothesis model. Based on this assumption, the transfer function of the deterministic signal under AWGN in the time domain is a Sinc function having the transfer function [9,10]

$$H(f) = \begin{cases} \frac{2}{\sqrt{N}} & |f - fo| \leq W \\ 0 & \text{Otherwise} \end{cases} \quad (1)$$

where N is the one side noise power spectral density of the Sinc signal, f_0 and W are the center frequency and the band width of band pass filter (BPF), respectively. The analytical representation of the signal in binary hypothesis is expressed as [8-11]

$$s(k) = \begin{cases} n(k) \;\ldots\ldots\ldots\ldots\ldots & H_0 \\ hx(k) + n(k) \ldots\ldots\ldots\ldots & H_1 \end{cases} \quad (2)$$

where $h_x(k)$ and n(k) represent the signal and noise, respectively.

The test hypothesis is used to decide the presence of primary user (PU) in the system/channel. From Eqn. (2) , the output can be represented by two logical states H_0 (absence or null hypothesis) and H_1 (the presence of PU signal information [9,10]. Therefore a decision rule can be stated as: $\mathbf{H_0}$……if $\boldsymbol{\varepsilon < \upsilon}$ and $\mathbf{H_1}$……if $\boldsymbol{\varepsilon > \upsilon}$, where $\boldsymbol{\varepsilon} = |\mathbf{E_s(k)}|^2$ is the estimated energy of the received signal and υ is chosen to be the noise variance. It is known that for an input signal x(t), the Fourier transform is X(ω) and t_2-t_1 the time period over which the input sample is observed. The threshold voltage value is related to the probability of false alarm and the noise power. It can be computed as follows [14]:

Energy spectrum of a signal is:

$\{x(t)\} = |X(\omega)|^2(t_2-t_1)$ (3)

$$V_1T = \sqrt{(2\,\sigma_1 n\,\uparrow 2(\log(\;1/P_1 fa\;)} \quad (4)$$

where V_T is the threshold voltage,

$$V_T(\omega) = \int_{t_1}^{t_2} V_T\, e^{-i\omega t}\, dt \quad (5)$$

$$= |V_T(\omega)|^2 = \frac{V^2}{\omega^2}(t_2 - t_1) \quad (6)$$

and $P_{fa} = 10^{\frac{V_T}{\sigma_n^2}}$ (7)

Conventional Energy Detector

Energy detection is a non-coherent detection method that detects the presence of the primary signal based on the received energy level. Figure 1 shows the discrete version of conventional energy detector block diagram.

When the signal is analyzed in frequency domain, the fast Fourier transforms (FFT) based method is used in process.

The resulting signal fed into the integrator which will be compared to a predetermined receiver threshold value to check whether PU exist or not. For detection purpose the measured signal is always higher than that of the energy threshold value [7].

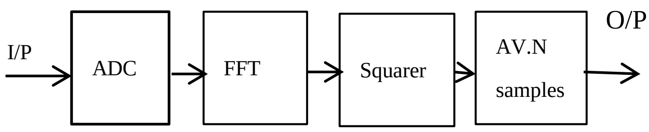


Figure 10: Block diagram of energy detector [7]

Though the energy detection method is the simplest technique, it become too difficult to measure the noise variance accurately at weak SNR and the performance of energy detector becomes poor [7, 14, 15].

The Enhanced Energy Detector

In this method an attempt is made to enhance the performance of energy detector by inserting an adaptive Weiner filter on the front side of conventional detector. The block diagram is depicted in Figure 1. By adaptive filter we mean that Wiener coefficients are updated recursively until they reach an optimum value. Moreover, the Recursive Least Square Algorithm (RLS) filter is an adaptive formulation of the Wiener filter. Especially for stationary

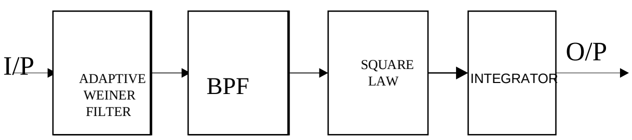


Figure 2: Enhanced energy detector spectrum sensing block diagram.

signals, the RLS algorithm converges to the same solution as the Wiener filter. Thus Recursive Least Square algorithm becomes the solution to optimize the performance of Wiener filter.

Performance Metrics Measurement

The performance of the spectrum sensing technique can be quantified by the performance metric values. These values determine the correctness of the presence of the spectrum hole or channel in the system [14]. The following parameters are used to check the performance of energy detector:

- Probability of detection.
- Probability of false alarm.
- Probability of miss detection.
- The receiver operating characteristics curve (ROC),
- The Complementary receiver operating characteristics curve (CROC),

The performance metrics ROC curve measures the sensitivity of the detector. It can also be used along with binary hypothesis model. The signal detection and estimation capabilities of the detector is represented by the graphical plot of P_d or P_m versus P_{fa} as the threshold varies. Generally speaking the ROC curve can be given as $P_d = f(P_{fa})$ and shows the tradeoff between detection probability and false alarm rate for an optimum threshold.

It also shows the trade-off between detection probability and false alarm rate for an optimum threshold [11].The higher the area under the P_d v sP_{fa} curve, the best is system detection response. Likewise the CROC curve is the complement of ROC curve. As the value of CROC become lower so does the system detection. It measures the area under the curve P_m vs P_{fa}[12,13,14,15]

Simulation Results and Discussions

The simulation parameters used in this work are listed in Table 1

Table 2: Simulation Parameters

Simulation	Type and values
Cognitive user	Single user
Transmitted Signal	BSK and QPSK
Detector Type	Energy Detector
Propagation channel model	Flat Mode channel
Initial update =lambda	0.99
Number of Monte Carlo simulation	100000
FIR Filter Order	32
Transmitted Signal SNR values	-5dB and 5 dB
Modulation Index	4
Probability of false alarm	0.01
Number of samples	10 and 1000
Mean and Variance (noise)	0 and 1
Channel	AWGN and Rayleigh

Simulation Results and Discussions for AWGN Channel

This section assesses the performance of conventional and enhanced energy detector algorithms based on the performance metrics. Figure 3 depicts the conventional (the broken curve) and enhanced energy detector (the solid curve). Setting the value of false alarm probability equal to 0.01, the plots are generated when 1000 sample of QPSK signals are received. It is observed that as the SNR increase from -20dB to -4dB with step increment of 0.5dB, so does the detection probability. The result plot shows the detection values at lower SNR are too low, for SNR values higher than -12dB the detection value of the receiver start to rise. This can be seen from the Table 2.

Table 2: P_d vs SNR comparison table

	Conventional			Enhanced		
P_{fa}	0.001			0.001		
No of QPSK samples	1000			1000		
P_d	0.8	0.5	0.15	0.8	0.5	0.15
SNR(dB)	-9.4	-10	-11.8	-4.3	-5.6	-3

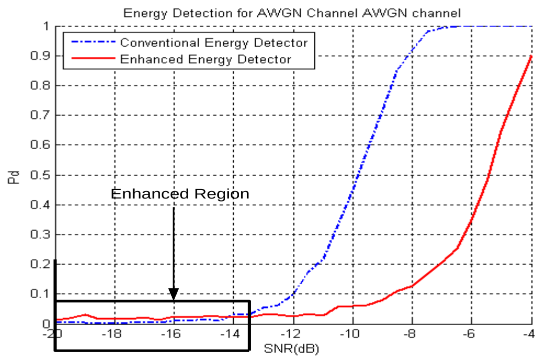


Figure 11: Conventional and enhanced energy detector Probability of detection Vs Signal

Table_2 of the result shows that by setting the probability of detection value for receiver equal to 0.8, the corresponding SNR signal value at the conventional detector is -9.4dB. Whereas, the SNR value of enhanced detector is -4.3dB. This enhanced value is 45.75% higher than the conventional response value. Likewise, when the probability detection value of the receiver equal to 0.5, the corresponding SNR signal value at the conventional detector is -10dB, while, the SNR value of enhanced detector is -5.6 dB.

This enhanced value is 56% higher than the corresponding conventional response value. Therefore under constant value of detection probability at the receiver, the signal SNR at enhanced detector is higher than conventional energy detector.

Thus the insertion of adaptive Weiner filter on the front end of conventional energy detector can improve the detection performance values of the conventional energy detector.

Figure 4 depicts the relation between P_{fa} Vs the system threshold values when 10 sample BSK signals with SNR value of -5dB is transmitted. As can be seen from Table 3, when the P_{fa} value of receiver is equal to 0.1, the threshold value of the conventional energy detector will be 1.4 whereas for enhanced energy detector the threshold value is 0.275. In this case the enhanced energy detector lower than the conventional threshold by 19.64%

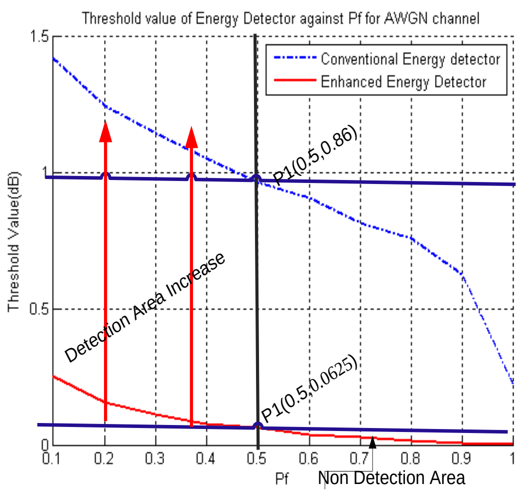


Figure 12: False alarm probabilities Vs the system threshold values.

Similarly, when the P_{fa} value of receiver is equal to 0.7, the threshold value of the conventional energy detector will be 0.8, whereas for enhanced energy detector the threshold value is 0.025.In this case the enhanced energy detector threshold is lower than the conventional threshold by 39.28%. Therefore under constant value of P_{fa} at the receiver, the threshold value of the receiver for the enhanced energy detector is lower than that of conventional energy detector.

Table 3 P_{fs} vs Threshold comparison table

	Conventional Energy Detector			Enhanced Energy Detector		
No of BSK Samples	10			10		
SNR(dB)	-5			-5		
P_{fa}	0.1	0.7	1	0.1	0.7	1
Threshold value	1.4	0.8	0.3	0.275	0.025	≈0

Thus the sensitivity of the conventional energy detector improved as adaptive Weiner filter is inserted. For conventional energy detector as the value of P_{fa} increased toward 1, the corresponding threshold values decrease toward 0.2, whereas the threshold value reach below 0.0625 for the enhanced detector. Specifically when the P_{fa} value is set to be 0.5, the corresponding threshold value for conventional and enhanced detector is 0.86 and 0.0625 respectively (Figure.4). Let P1 (0.5, 0.86) and P2 (0.5, 0.0625) be these points. Both point P1 and P2 divide the region into four parts. Point P1 is an intersection point for the broken (conventional response curve) and heavy black line. Similarly point P2 is the intersection of heavy black line and solid curve (enhanced curve).The whole region is divided into four sections, but the region of interest is the most upper and lower left (detection area section) which is created by the union of both curves. Under constant false alarm probability value of 0.5, the detection area obtained by the enhanced system is much higher than that of detection area obtained by conventional detector. Thus the insertion of adaptive Weiner filter increases detection area of conventional energy detector.

Table 4: ROC comparison table

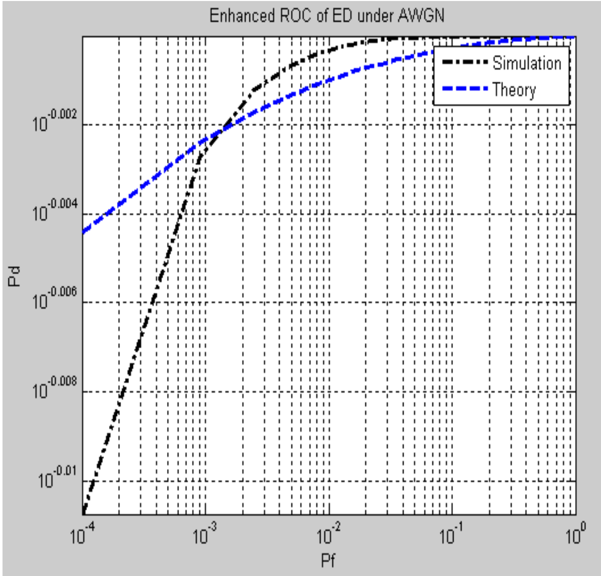
Sample_data_1: Conventional Energy detector

Pf	0.0025	0.0049	0.0081	0.0121
Pd_Simu	0.942434	0.951381	0.957675	0.962455
Pd_Approxm	0.894764	0.926457	0.945921	0.958905

Sample_data_2: Enhanced energy detector table.

Pf	0.0025	0.0049	0.0081	0.0121
Pd_Simu	0.997188	0.998481	0.99909	0.99942
Pd_Approxm	0.996067	0.996934	0.99749	0.997896

Figure5 and 6 depict the simulation response of Receiver Operating Curve (ROC) for both conventional and enhanced energy detector receiver. The plots are generated when the received signal SNR is -5dB.The comparisons of the two plots are supported by the tabular data given as Sample_Data_1 and Sample_Data_2 which are assigned as Table 4. The Pd_Simu is the simulated value of detection probability for each value of false alarm probability and was found using Montecarlo simulation. It is obtained when computational technique in probability detection



is used while Pd_Approx. is obtained when the

Figure 14: ROC curve of enhanced energy detector.

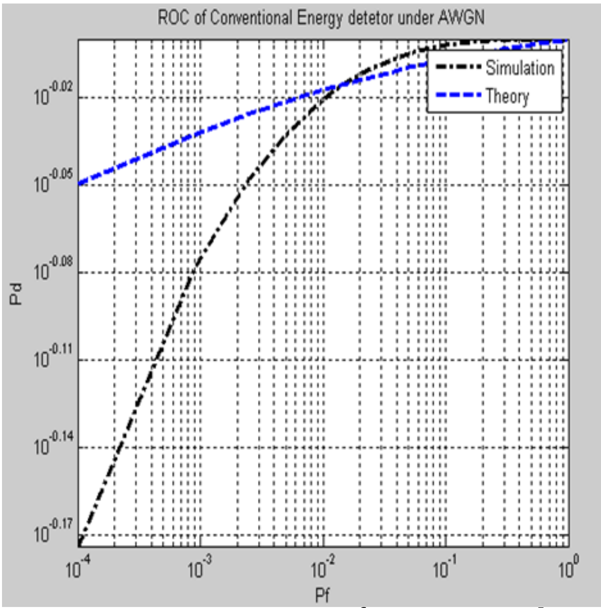


Figure 13: ROC curve of Conventional energy detector

theoretical values of probability detection are assumed [11]. It is applicable when the chi square probability density Sample_Data_1 and Sample_Data_2 for the same value of false alarm probability it was found function for an index value of *m* ≥100 is considered. Analytically, taking two sample values that Pd_Simu and Pd_Approx. in Sample_Data_2 are higher than those of values in Sample_Data_1 (Table 4). This shows that the insertion of adaptive Weiner filter on the front end of the energy detector increased the operational area of receiver operating curve. Figure 7 and 8 are CROC response of conventional and enhanced energy detector respectively. They are simulated when the received signal SNR is 5dB and the order of filter is 32. Table 5 shows tabular data given as Sample_Data_3 and Sample_Data_4, which were generated from Figures 7 and 8.

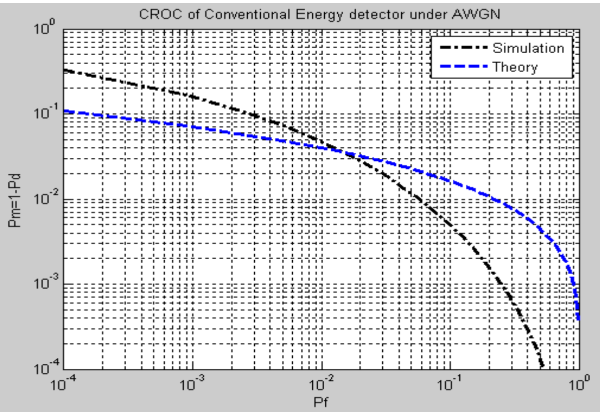


Figure 7: CROC curve for Conventional energy detector

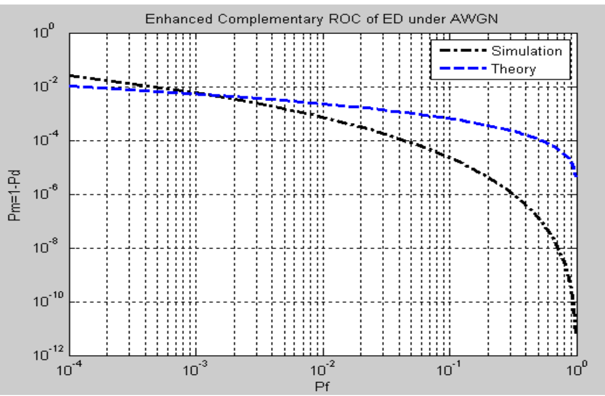


Figure 8: CROC curve for Enhanced energy

Table 5: CROC comparison table

Sample_data_3: Conventional Energy Detector for N=32

Pf	0.0025	0.0049	0.0081	0.0121
Pm_Simu	0.10523	0.07354	0.05407	0.04109
Pm_Approxm	0.05756	0.04861	0.04232	0.03754

Sample_data_4: Enhanced Energy Detector for N=32

Pf	0.0025	0.0049	0.0081	0.0121
Pm_Simu	0.002812	0.001519	0.000909	0.00058
Pm_Approxm	0.003933	0.003066	0.002504	0.002104

The CROC curve results which are depicted as Sample_data_3and Sample_data_4 in Table 5 show that for same value Pf the corresponding value of Pm is the complement of Pd on the ROC curve. Interestingly the CROC graph is an inverted version of ROC curve or it is the complement of ROC.

The values of miss detection in both samples are calculated using $P_m = 1 - P_d$. For the same value of P_f, if the values of Pm_Simu and Pm_Approx are compared on Sample_Data_3 and Sample_Data_4 of Table 5, the results show that Pm_Simu and Pm_Approx. in Sample_Data_4 are lower than the values in Sample_Data_3.

Thus, the insertion of adaptive Wiener filter in conventional energy detector lowers the miss detection values. Consequently, the adaptive Wiener filter in the front end of energy detector has improved the system performance of energy detector by minimizing the area under CROC curve.

Simulation Results and Discussion for Rayleigh Channel

Based on the simulation parameters given in Table 1, this section discusses result of energy detector spectrum sensing when flat fading Rayleigh channel model is considered. Figure 9 depicts the simulation result of ROC curve of Rayleigh channel model. The plot shows the relation between the false alarm values with that of the corresponding detection probabilities value when the signal received SNR is -5dB.

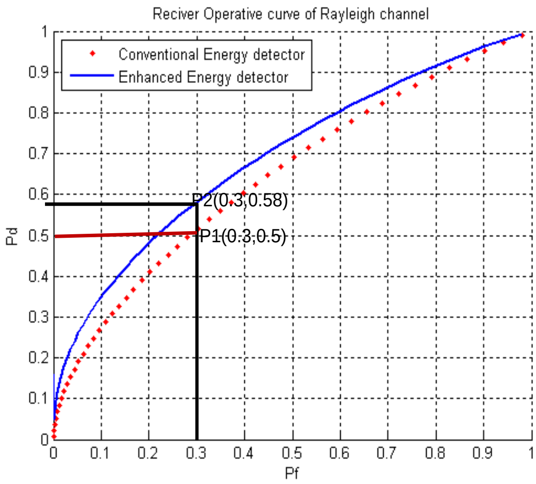


Figure 9: ROC curve for Conventional and Enhanced Energy Detector Rayleigh channel

Result shows that as the signal SNR value is increased, the detection probability values will become higher and the ROC curve achieves the maximum value of area under curve (AUC) which equal to one. Considering points P1 (0.3, 0.5) on the conventional and P2 (0.3, 0.58) on the enhanced ROC curve, one observes that for constant P_f value of 0.3, point P1 corresponds to 50% of detection probability whereas point P_2 (for the enhanced detector), the detection probability is 58%. Moreover the area under curve obtained by enhanced curve is higher than that of area obtained from conventional detector. Thus the insertion of adaptive Wiener filter enhanced the system performance by 8 %. Accordingly the insertion of adaptive Wiener filter increases the area curve of (ROC) energy detector system.

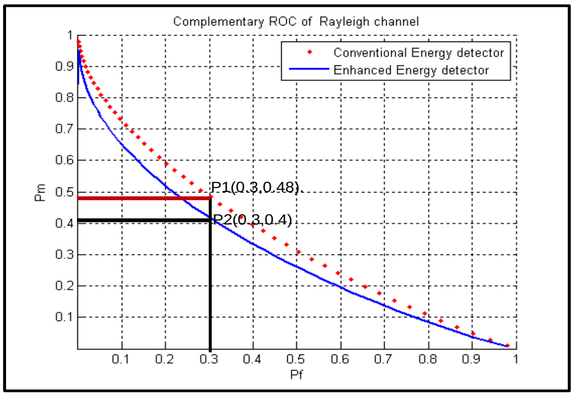


Figure 10: CROC curve for Conventional and Enhanced Energy Detector Rayleigh channel

Figure10 shows the complementary receiver operating curve (CROC) of the conventional (the broken curve) and enhanced detector (the solid curve).It shows the relation between probabilities of false alarm Vs the probability of miss detection. This graph is an inverse (complement) version of Figure 9. Generally speaking, system response (i.e, CROC) whose area under the curve is minimum as compared to others will have an improved detection performance than others. As the value of P_f gets closer to 1 on the right side, the value *Pm* decreases towards 0. Considering points P1 (0.3, 0.48) and P2 (0.3, 0.40) on figure 10, the miss detection probability value is 0.48 at point P1, which is to 48% of miss detection probability. on the other hand for the enhanced detector the response at P_f value of 0.3 the miss detection probability is 0.40 which is 40%. Moreover the discussion is same for all value of Pf on figure 10. Thus the insertion of adaptive Wiener filter reduces the miss detection probability value by 8%.Consequently; under constant false alarm probability value the insertion of adaptive Wiener filter in the front end of energy detector enhanced the performance of CROC by reducing the miss detection value.

CONCLUSIONS

In this paper, the response of conventional energy detector when adaptive Wiener filter is inserted on the front end of energy detector has been analyzed. The simulation results were done for AWGN and Rayleigh fading channels. For both cases, simulation results showed that the insertion of adaptive Wiener filter on the front end of energy detector has improved all the performance metrics indicators considered in this study (i.e. ROC, CROC, threshold value, false alarm and detection probability). Moreover at lower values of signal SNR the performance of energy detector has improved.

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