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Performance analysis of cooperative spectrum sensing using double dynamic threshold

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ABSTRACT

Increased use of wireless technologies and in turn more utilization of available spectrum is subsequently leading to the increasing demand for wireless spectrum. This research work incorporates spectrum sensing detection consisting of a double dynamic threshold followed by cooperative type spectrum sensing. The performance has been analyzed using two modulation schemes, quadrature-amplitude-modulation (QAM) and binary-phase-shift-keying (BPSK). Improved probability of detection has been witnessed using the double dynamic threshold where a comparison of average values of local decision (LD) and the observed value of energy (EO) has been considered instead of using direct values of local decisions and energy. Further, the probability-of-detection (P_d) is found to be better with QAM as compared to the BPSK. From the results, it has been observed that the detection of primary users is also affected by the number of samples. The simulation environment considered for this work is MATLAB and the performance of cooperative spectrum sensing for 500 and 1000 samples with -9db and -12 SNR by considering different false alarm values i. e 0.1, 0.3 and 0.5 has been analyzed. The further scope shall be to enhance the primary user detection by considering different QAM schemes and different signal to noise ratio (SNRs).

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1. INTRODUCTION

In cognitive radio the role of spectrum-sensing is significant. The terminology of “cognitive radio” involves licensed user and unlicensed user [1]. Licensed users possesses all the rights to use the specific spectrum bands whereas secondary or unlicensed users may utilize the frequency bands not used by primary users. Major spectrum sensing techniques (SST) includes matched-filter-detection-technique (MFDT), energy-detection-technique (EDT) and cyclostationary-based-detection-technique (CSDT). Among all spectrum sensing techniques, energy detector technique is the simplest to implement nad require no prior information of the primary. However, with low value of signal to noise ratio (SNR) the performance of energy-detector spectrum sensing technique (EDSST) is reported to degrade. Performance of any sensing technique can be analyzed with two important parameters viz., (P_d) & (P_f). Probability of detection (P_d) indicates actual presence of primary or licensed user (PU) and probability-of-false-alarm (P_f) is the indicator of false appearance of PU. Conventional energy detector spectrum sensing techniques involves implementation using single threshold method and its performance get deteriorated in low SNR [2]. Spectrum sensing detection is reported to be improved with double threshold method followed by cooperative spectrum sensing where each cognitive radio takes its own decision for detection of primary user [3]. Here, lower and upper two values of threshold are used. Final decision for absence or presence of primary user is made by comparing two thresholds' values with the energy of signal received. In the conventional method of energy detector, the signal to be sensed is taken as an unknown deterministic signal. An additive-white-gaussian-noise (AWGN) is to be combined with input signal. After that, the signal is transmitted by converting it as digital signal using analog to digital converter. The energy present in the received signal is computed by squaring the value of received signal and then integrating over the time [4]. Presence of primary user is determined by computing the calculated energy amplitude of input signal with threshold amplitude value. The two-hypothesis indicators H0 and H1 are defined for absence or existence of the primary user [5], [6]. Two hypothesis shown in (1) and (2).

$$\mathrm{H1{:}\ R(n) = S(n) + A(n)} \tag{1}$$

$$\mathrm{H0: R(n) = A(n)} \tag{2}$$

Where the absenctism of primary user is indicated by hypothesis H0 and existence of primary user is indicated by hypothesis H1. where R(n) indicates received signal, AWGN is represented by A(n) and S(n) represents primary user signal. The received signal energy (Er) is obtained as the output of the integrator and is computed as per (3).

$$\mathrm{Er} = \sum_{n=1}^{N} |r(n)^2| \tag{3}$$

Where (Er) shows value of energy present in the signal which is received and N represented the total number value of samples. Received signal (Er) energy is also termed as test or decision statistic. Probability-of-detection decides actual existence of primary user or the case of hypothesis H1 as true, whereas probability-of-false alarm indicates the existense of primary user but actual hypothesis H0 is true. Probability of typdetection (P_d)and (P_f) can be calculated with the formula given in (4) and (5).

$$P_d = \mathrm{Q}\left(\frac{Th - N\sigma n^2}{\sqrt{2N(\sigma n)^4}}\right) \tag{4}$$

$$P_f = \mathrm{Q}\left(\frac{Th - N(\sigma n^2 + \sigma s^2)}{\sqrt{2N(\sigma n^2 + \sigma s^2)^2}}\right) \tag{5}$$

Here, threshold value is represented by Th, number of samples are represented by N, σn^2 is the noise variance and signal variance are represented by σs^2 and normal distribution function is denoted by Q which gives the exact tail area of the curve [7], [8]. Primary user presence or absence is determined via comparing Er with Th. i) If Er>Th: indicates the existence of primary user and ii) If Er <Th: shows the absence of primary user. Dynamic threshold (Th) is computed using (6).

$$Th = \sigma n^2(\text{inverse of Q (Pf)}\sqrt{2N} + \mathrm{N}) \tag{6}$$

Which depends upon the number of samples (N), noise variance, probability of false alarm, and inverse of normal distribution function. Improved usage of a given spectrum by the implementation of various sensing techniques is the proposed idea of this research work. Also, the better detection of primary user with minimal value of false. Rate is need of the hour. Fading and node failure problems can be overcomed by using cooperative spectrum sensing technique [9]–[11]. In cooperative spectrum sensing technique, individually secondary user sends its decision i.e. local decision to the fusion center (FC) where the function of FC is to combine all the local decision results as received from each of the users. Different logical rules such as OR, AND and majority rules are used to combine all the local decisions. Figure 1 shows the cooperative type spectrum sensing technique which follows OR rule [12]–[14]. According to OR rule, if any of the user detects the primary signal, the net output of FC states the existence of primary user signal. Various methods already have been proposed to avoid the sensing failure problem [15], [16].

This research work provides, implementation and analysis of cooperative spectrum sensing with double dynamic threshold. It has been observed that the incorporation of double dynamic threshold in cooperative-spectrum sensing progresses the detection of spectrum while preserving the sensing information [17]. Section 1 includes the introduction of the cognitive radio and overview of traditional spectrum sensing techniques, section 2 incorporates materials and methods of double dynamic double threshold, results and analysis have been covered in section 3 followed by conclusion of the paper presented as section 4.

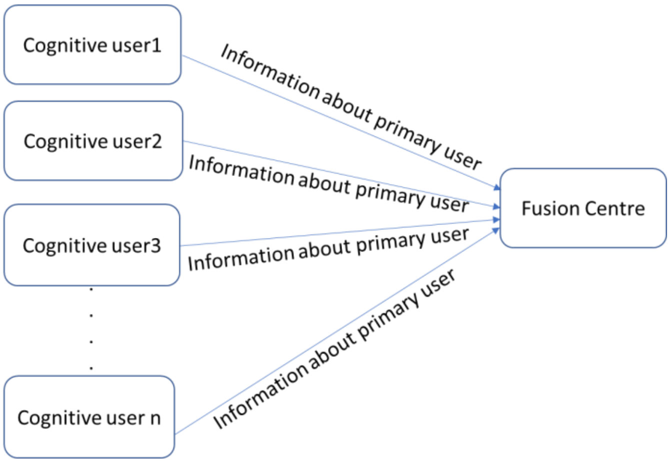

Figure 1. Cooperative spectrum sensing technique (CSST)

2. MATERIALS AND METHOD

Conventional method of energy detector uses single dynamic threshold for detection of primary user. If received Er is larger than threshold (Th), it indicates existence of primary user (PU) else absenteeism of PU. Figure 2 represents the detection with single threshold technique.

This work incorporates double dynamic threshold method instead of single dynamic threshold. If (Er) is larger than the threshold (Th) then hypothesis H1 will be used otherwise hypothesis H0. Figure 3 illustrates the double dynamic threshold method [18]. The hypothesis H1 will be used if energy of the received signal (Er) is more than the second value of threshold (Th2) and if the value of (Er) is less than the first value of threshold (Th1) then hypothesis H0 will be used but if the value of Er lies between first and second value of threshold i.e $Th2 < Er < Th1$, there would be no exact decision and the process will repeat by cognitive radio [19]–[21]. In (6) provides the relation to calculate the value of threshold (Th). The value of first threshold (Th1) and second threshold (Th2) are computed by (7) and (8) respectively.

$$Th1 = (1-£)\ Th \tag{7}$$

$$Th2 = (1+£)\ Th \tag{8}$$

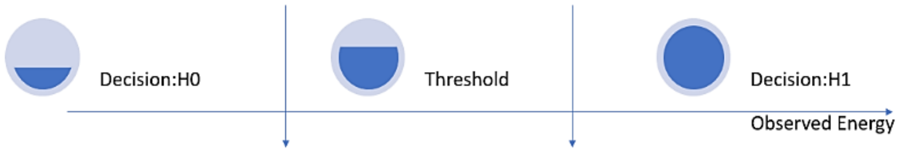

Figure 2. Detection with single dynamic threshold technique

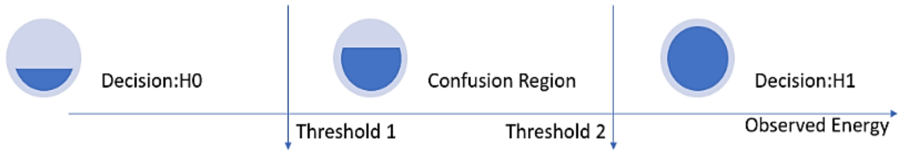

Figure 3. Detection with double dynamic threshold technique

Here, Th1 represents the first threshold, Th2 represents the second threshold and £ is the uncertainty parameter [22]–[25]. Following are the steps followed to incorporate the double dynamic threshold method of the cooperative spectrum sensing technique.

Step 1 If the energy present in the received signal (Er) is larger than Th2 and a lesser amount of than Th1, then only each secondary user will take the decision (LD) and the secondary user value is from (i=1……L). Decisions are representing by (9) and (10).

$$LD = \{0\; Er < Th1 \tag{9}$$

$$LD = \{1\; Er > Th1 \tag{10}$$

Step 2 If Er lies between Th1 and Th2 then the secondary user will not take any decision and report to FC.
Step 3 Different energy values are received by the FC and further average of all the received values (Ravg) are considered by the FC, which is as represented in (11).

$$\text{Ravg} = \frac{1}{L-K}\sum_{i=1}^{L-K} Ri \tag{11}$$

Decision for existence of primary user signal is obtained by comparing average value (Ravg) with the threshold value (Th). Existence or absenteeism of primary user is indicated in (12).

$$\text{LD} = \begin{Bmatrix} 0 \text{ Ravg} < \text{Th} \\ 1 \text{ Ravg} > \text{Th} \end{Bmatrix} \tag{12}$$

Step 4 Total decisions of the fusion center are considered as $K + 1$, here K are the total decisions made by the secondary users and one is other decision taken by the FC. This conclusion is based upon the energy present in the received signal from secondary users.
Step 5 These $(K + 1)$ decisions have been joined by fusion center by using OR fusion rule under the categorization of hard fusion rule. If only one cognitive user shows the information to the FC that primary user signal is present then according to OR rule, fusion center will take the decision for existense of primary user.

Flowchart of double dynamic threshold technique for cooperative spectrum sensing is as shown in Figure 4. It has been reported that due to the cooperation of all the cognitive users, better detection of spectrum has been achieved and also preserved the sensing information [26], [27]. Figure 5 shows the block diagram for detection of primary user using double dynamic threshold. The system incorporated with double dynamic threshold followed by cooperative spectrum sensing. The signal is modulated by using (QAM) and (BPSK) two modulation schemes.

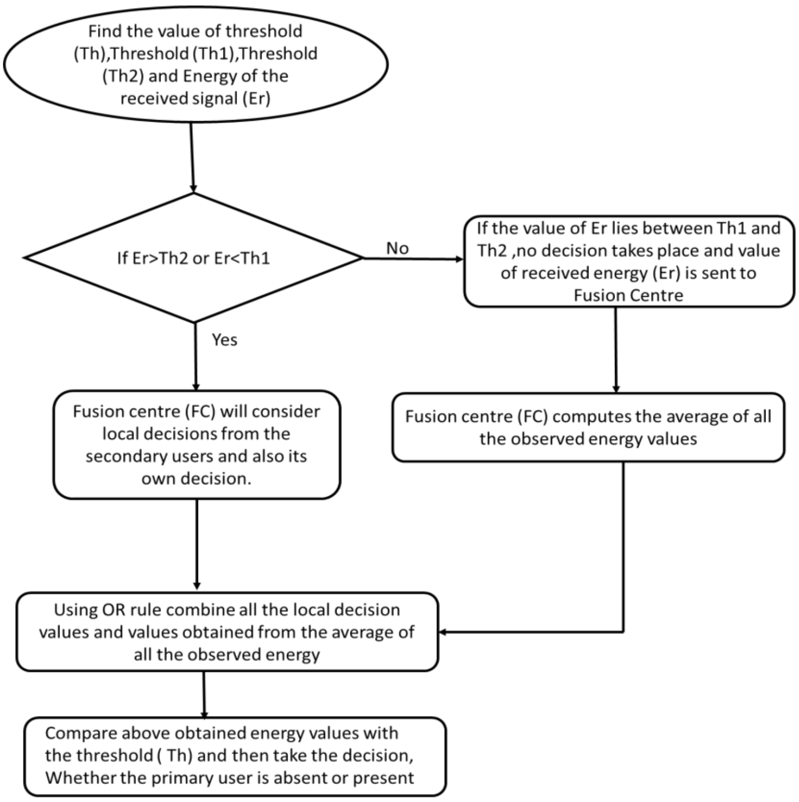

Figure 4. Flow chart for double dynamic threshold-based spectrum sensing technique

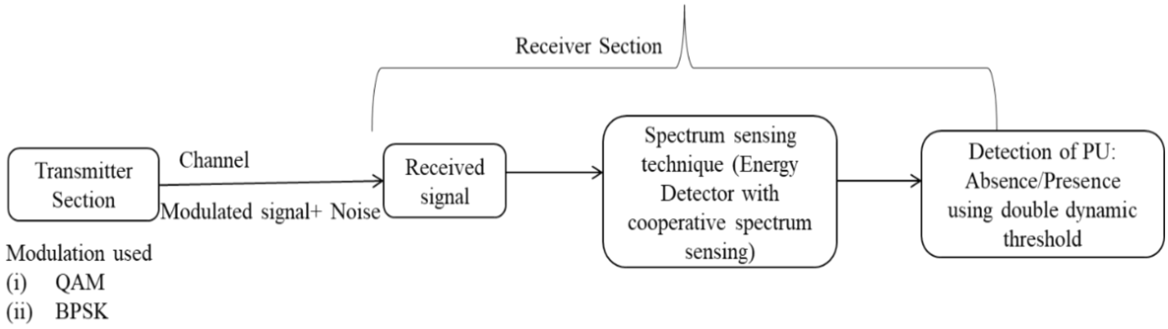

Figure 5. Block diagram for detection of primary user using double dynamic threshold

3. RESULTS AND DISCUSSION

This section describes the results obtained and subsequent analysis of double dynamic threshold with cooperative spectrum sensing technique. All the simulations have been performed in MATLAB workspace. The performance has been analyzed using two modulation schemes i.e. (QAM) and (BPSK). To evaluate performance of double dynamic threshold with cooperate spectrum sensing, the parameters were set as: number of samples were considered as 500 and 1000, SNR=-9db, uncertainty factor, £=0.1, range of probability of false alarm, P_f =0.01 to 1. Comparison of theoretical and simulated output values for the number of samples, N=500 and 1000 have been analyzed for the different values of probability of false alarm. It has been observed that theoretical and simulated values are closer for different set of samples. Figure 6 illustrates the ROC graph between P_d and P_f for signal (BPSK) and QAM signal, where number of samples are 500 and 1000 at -9 db SNR. For 500 samples, probability of detection is found to be 0.72 for QAM signal and 0.58 for BPSK signal. Therefore, an improvement of 14% has been witnessed in probability of detection parameter computed for QAM signal. Further, simulations have been performed to analyze the performance in term of probability of detection of received signal while varying the number of samples. For a set of 1000 samples, probability of detection is found to be 0.98 for QAM signal and 0.64 for BPSK signal. Therefore, an improvement of 34% has been witnessed in probability of detection parameter as computed for QAM signal.

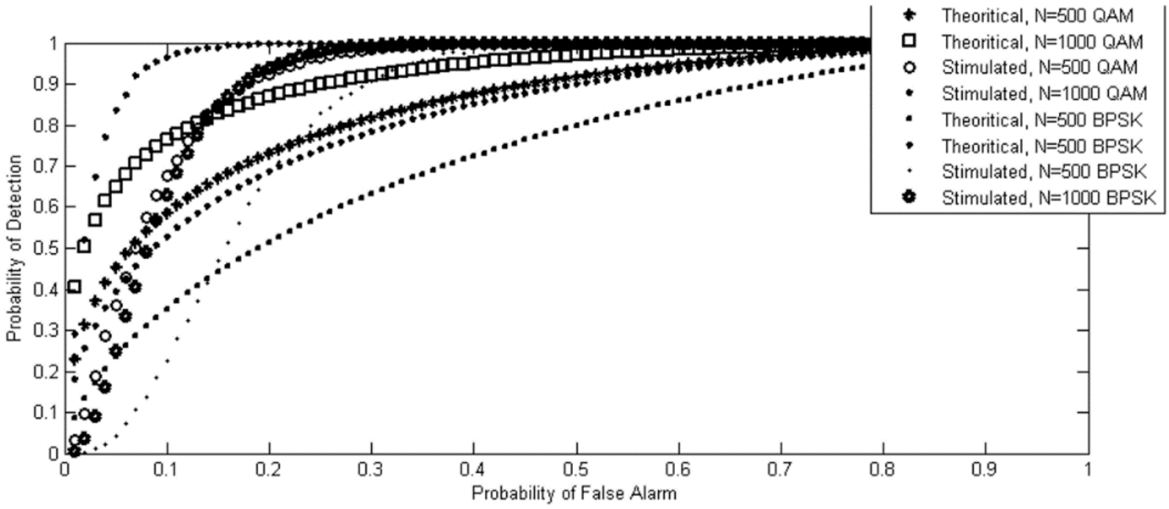

Figure 6. P_d vs P_f using double dynamic threshold for cooperative spectrum sensing with QAM and BPSK for N=500 and 1000 at -9db

Figure 7 depicts the ROC curve between P_d and P_f for QAM signal at -9 db SNR. When number of samples are 500, value of probability-of-false alarm is considered as 0.1 whereas probability-of-detection value is found to be 0.72 for QAM signal. When number of samples are 1000 and (P_f) considered as 0.1, probability of detection (P_d) is found to be 0.98 for QAM signal. For (P_f) considered as 0.3, probability of detection (P_d) is found to be 0.9 for QAM signal with 500 as number of samples whereas for 1000 samples, probability of detection is found to be 1. Further, if value of P_f considered as 0.5 and P_d is found to be 0.95 for QAM signal with 500 samples whereas for 1000 samples, probability of detection is found to be 1. This analysis indicates that more the number of samples involved, better would be the spectrum detection.

Figure 8 displays ROC curve between P_d and P_f for QAM and BPSK signal with 500 samples and SNR at -9 db. Probability of detection is found to be 0.72 for QAM signal and 0.58 for BPSK signal with the value of P_f is 0.1. However, P_d is found as 0.9 for QAM signal and 0.82 for BPSK signal with probability of false alarm set as 0.3. In last case where (P_f) is set as 0.5, Probability of detection (P_d) is found to be 0.95 for QAM signal and 0.92 for BPSK signal. These results reveal that the probability of detection is better for QAM as compared to BPSK signal.

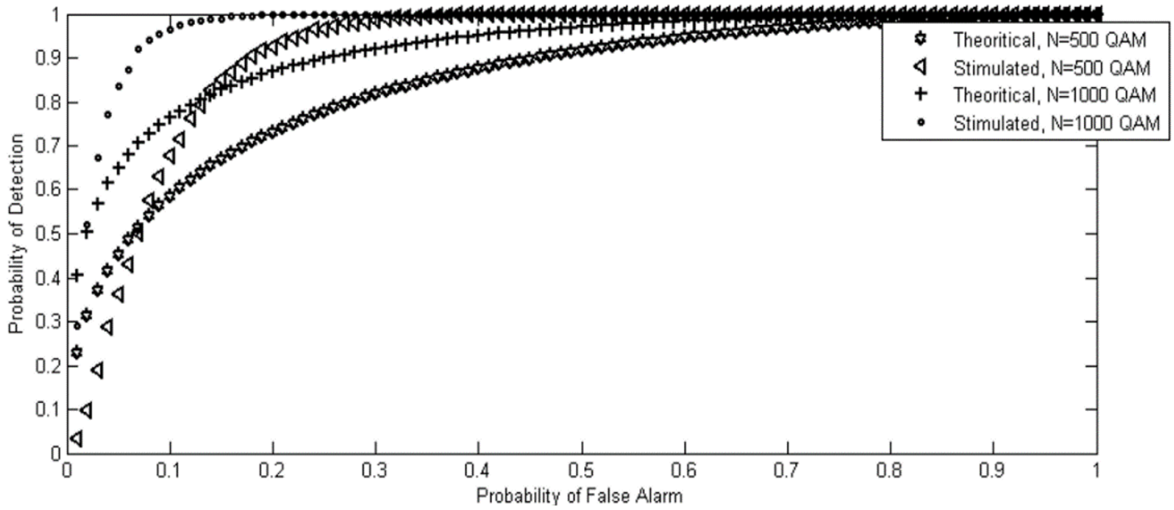

Figure 7. P_d vs P_f of the QAM signal for N=500 and 1000 at -9db

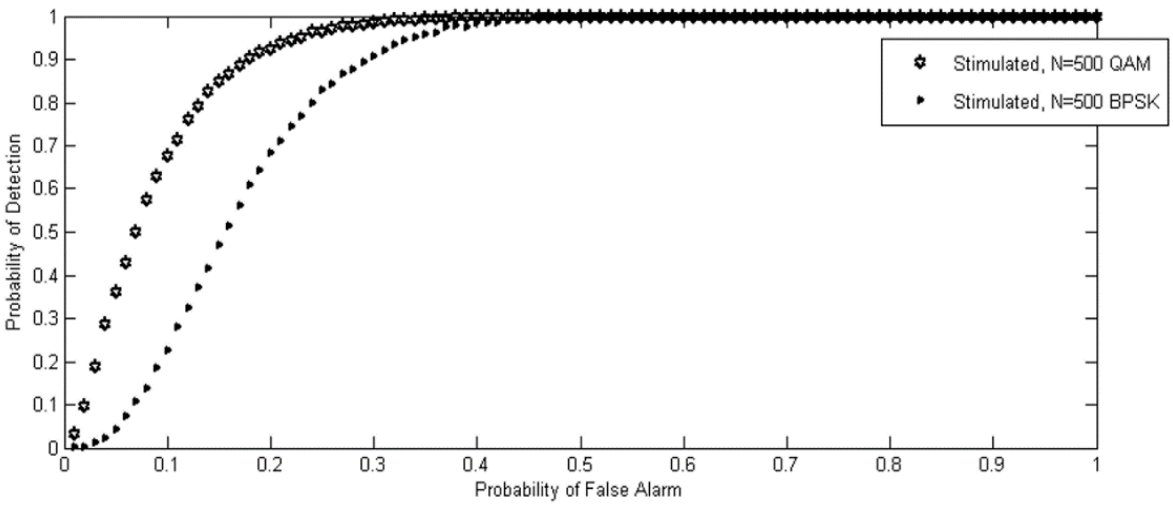

Figure 8. P_d vs P_f of QAM and BPSK signal for N=500 at -9db

Figure 9 depicts ROC curve between P_d and P_f for QAM and BPSK signal with 1000 samples and SNR at -9 db. Probability of detection is found to be 0.98 for QAM signal and 0.64 for BPSK signal with value of P_f is taken as 0.1. However, P_d value is observed to be 1 for QAM signal and 0.99 for BPSK signal with 0.3 as the value of P_f. Further for 0.5 probability-of-false alarm, Probability of detection is found to be 1 for QAM signal and 1 for BPSK signal. This also indicates that the probability of detection is better for QAM as compared to BPSK signal.

Figure 10 depicts ROC curve between P_d and P_f for QAM and BPSK signal with 1000 samples and SNR at -12 db. Probability of detection is found to be 0.2 for QAM signal and 0.02 for BPSK signal with value of P_f is taken as 0.1. However, P_d value is observed to be 0.92 for QAM signal and 0.7 for BPSK signal with 0.3 as P_f. Further for 0.5 value of P_f, Probability of detection is found to be 1 for QAM signal and 1 for BPSK signal. This also indicates that the probability of detection is better for QAM as compared to BPSK signal.

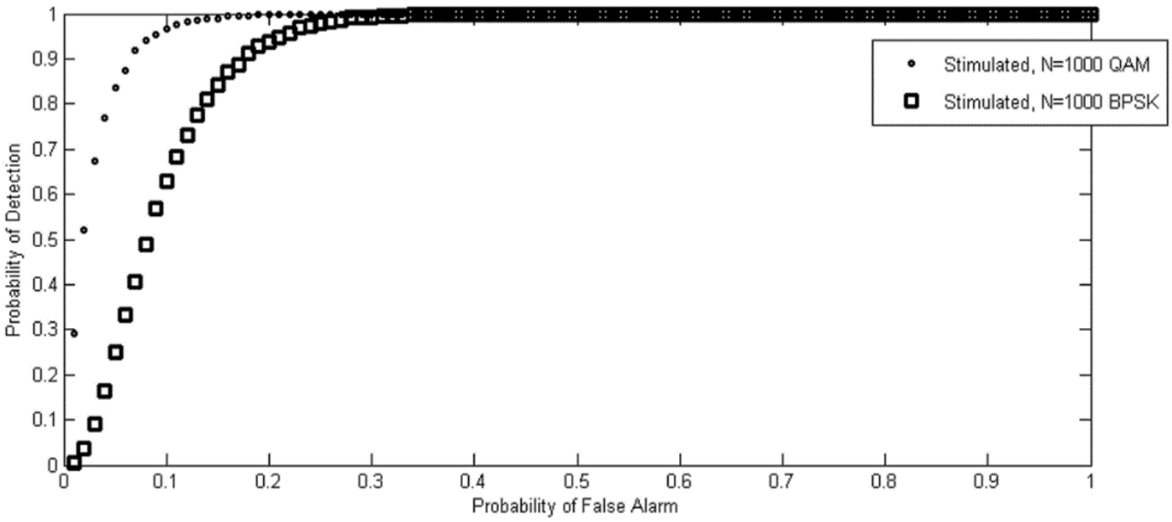

Figure 9. P_d vs P_f of QAM and BPSK signal for N=1000 at -9db

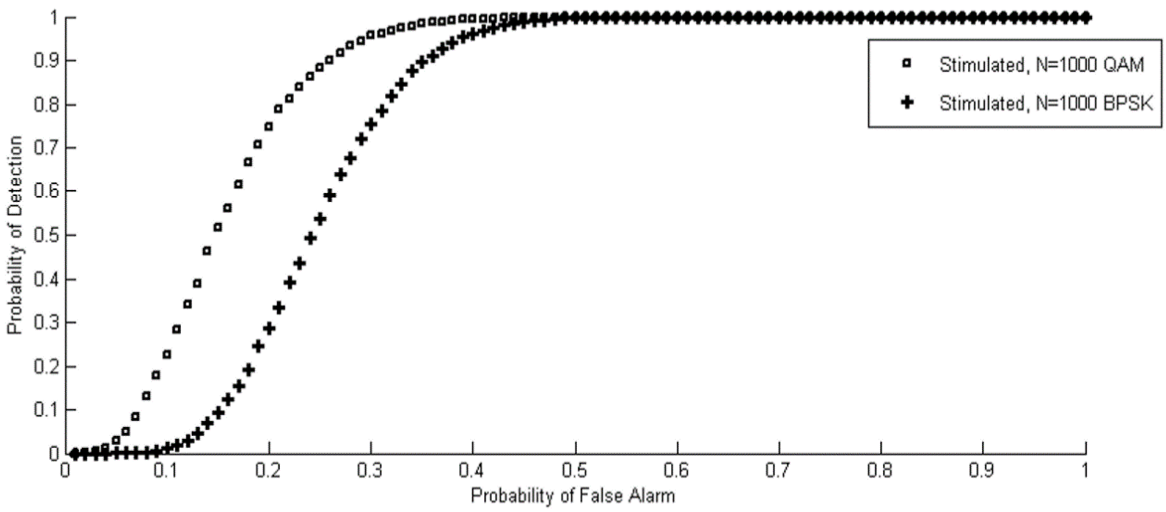

Figure 10. P_d vs P_f of QAM and BPSK signal for N=1000 at -12db

Figure 11 depicts (ROC) curve between P_d & P_f for QAM and BPSK signal with 500 samples and SNR at -12 db. Probability of detection is found to be negligible for QAM signal and 0.01 for BPSK signal with value of P_f is taken as 0.1. However, P_d value is observed to be 0.79 for QAM signal and 0.5 for BPSK signal with 0.3 as P_f . Further for 0.5 probability-of- false alarm, Probability of detection is found to be 1 for QAM signal and 0.97 for BPSK signal. This also indicates that the probability of detection is better for QAM as compared to BPSK signal.

Table 1 shows the theoretical and simulated values of P_d with different number of sample values and varied the values of P_f at -9 db and -12 db signal to noise ratio. The results have been recorded for modulated signals using (QAM) and (BPSK).It has been analyzed from the literature that in case of a single value of threshold cooperative spectrum sensing with 500 samples, P_f set as 0.1 and SNR -9db, P_d is found to be 0.5 for BPSK signal. Whereas for 1000 samples, probability of detection is reported as 0.58. If P_f is set as 0.3 and SNR -9db, with 500 samples probability of detection is found to be 0.79 for BPSK signal and for 1000 samples, probability of detection is found to be one [28]. Since this work incorporates double dynamic threshold method instead of single dynamic threshold and it has been found that for 500 samples and P_f set as 0.1, P_d is found to be 0.72 for QAM signal at -9db SNR and negligible value at -12db and for 1000 samples, probability of detection is found to be 0.98 at -9db and 0.2 at -12db. So, as the value of samples increases, value of probability of detection also increases but variation in signal to noise ratio also affect the detection performance. It has been observed from the results that probability of detection (P_d) is better with QAM signal as compared to BPSK signal. From the simulations it is reported that for 500 samples, SNR -9db & P_f taken as 0.1, P_d is improved about 22% and for 1000 samples approximately 40% improvement has been achieved. Further, the results reveal that the comparison of average values of LD and observed value of energy (EO) with the double dynamic threshold resulted in improved probability of detection as compared to using direct values of local decisions energy.

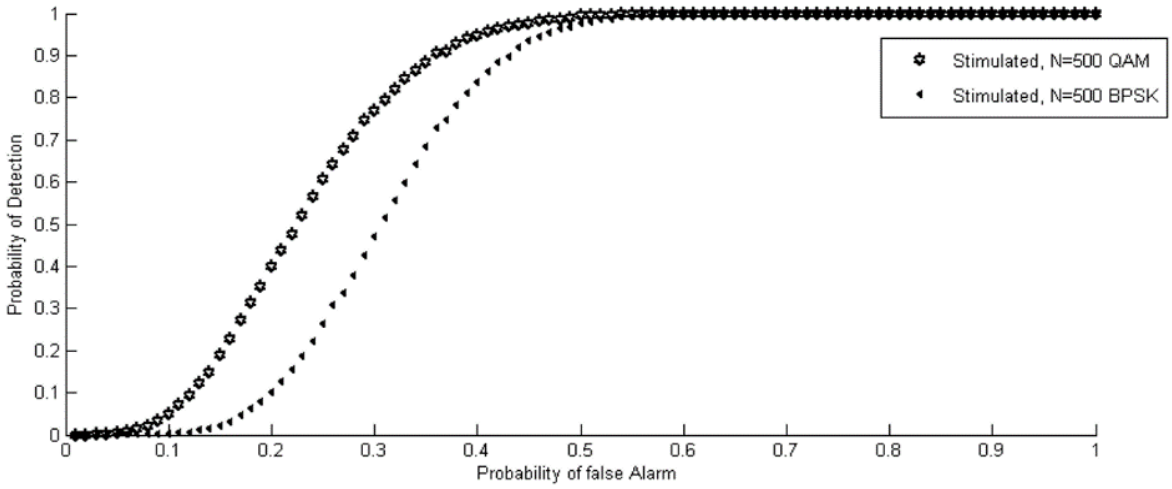

Figure 11. P_d vs P_f of QAM and BPSK signal for N=500 at -12db

Table 1. Theoretical and simulated values of P_d at distinct values of P_f for QAM and BPSK

Number of samples (N)	Modulation type	Theoretical (P_d) at -9db	Simulated (P_d) at -9db	Probability of false alarm (P_f)	SNR (db)	SNR (db)	Simulated (P_d) at -12db
N=500	QAM	0.53	0.72	0.1	-9	-12	0
N=500	BPSK	0.4	0.58	0.1	-9	-12	0.01
N=1000	QAM	0.68	0.98	0.1	-9	-12	0.2
N=1000	BPSK	0.23	0.64	0.1	-9	-12	0.02
N=500	QAM	0.78	0.9	0.3	-9	-12	0.79
N=500	BPSK	0.67	0.82	0.3	-9	-12	0.3
N=1000	QAM	0.98	1	0.3	-9	-12	0.92
N=1000	BPSK	0.91	0.99	0.3	-9	-12	0.7
N=500	QAM	0.9	0.95	0.5	-9	-12	1
N=500	BPSK	0.83	0.92	0.5	-9	-12	0.97
N=1000	QAM	1	1	0.5	-9	-12	1
N=1000	BPSK	0.99	1	0.5	-9	-12	0.98

4. CONCLUSION AND FUTURE SCOPE

Implementation and analysis of double dynamic threshold for cooperative spectrum sensing techniques has been performed with QAM and BPSK modulated signals. In previous researches, direct value of LD and observed value of EO have been received by the FC but in this research average value of LD and EO has been considered and equated with the threshold value to yield the Df whether licensed user is absent or present.

Further, FC will combine all the decisions obtained from the secondary users and Df by using OR rule. Better probability of detection is observed with QAM as compared to BPSK modulation scheme. Also, due to the cooperation of all the cognitive users, better detection of spectrum has been achieved and also preserved the sensing information. In future, optimization of spectrum sensing techniques and the methods to overcome the burden on fusion center shall be explored.The effect of different QAM modulation schemes i.e 16-QAM and 32-QAM shall be taken into consideration to analyze the detection of primary user in spectrum sensing techniques. Further effect of different SNR on the performance of SST shall be incorporated in future.

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