MODIFIED ENERGY RATIO ALGORITHM FOR OFDM-BASED COGNITIVE RADIO NETWORKS

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Abstract

Spectrum monitoring algorithm for orthogonal frequency division multiplexing based cognitive radio detects the reappearance of primary user during the secondary user transmission. This algorithm reduces the spectrum sensing frequency and also decreases the elapsed time which is between the start of primary transmission and its detection by the secondary network. A modified energy ratio algorithm is proposed for spectrum monitoring purpose. For spectrum monitoring a number of reserved OFDM sub-carriers are allocated. The changes in signal strength over these reserved sub-carriers are sensed and primary user reappearance is detected quickly. The performance of the modified algorithm is compared with the existing energy ratio algorithm. The simulations show that the modified energy ratio algorithm can effectively and accurately detect the appearance of the primary user.

Index Terms: Cognitive networks, cognitive radio, fading channels, OFDM, spectrum sensing/monitoring.

INTRODUCTION

Under the static spectrum access policy in wireless communications, the fixed channels are assigned to licensed users known as primary users for exclusive use whereas the unlicensed users known as secondary users are prohibited from accessing those channels even when they are unoccupied. The concept of a cognitive radio was introduced to achieve more efficient utilization of RF spectrum. The secondary users opportunistically use the spectrum when the primary users are idle, in an overlay network model. Both primary and secondary users cannot operate simultaneously. In cognitive radio approach, prior to communication secondary users must sense the spectrum and detect spectrum availability. When the primary user is idle, the secondary user is allowed to use the spectrum but it has to monitor the shared band to vacate the band as soon as primary user reappearance is detected. The secondary user should be capable of determining very weak signal from primary user. During this process, the cognitive radio system may spend a long time sensing the spectrum which is known as sensing interval. During the sensing interval the secondary transmitters remains silent while the cognitive radio system senses the frequency band. During the detection time the cognitive radio users does not utilize the spectrum and therefore it is known as the Quiet periods. According to the IEEE 802.22 system, a quiet period consists of a series of consecutive spectrum sensing intervals, which uses energy detection, to determine whether the signal level is higher than a predefined value. A value higher than the predefined value indicates a non-zero probability of primary user transmission. Followed by the energy detection there is a feature detection to distinguish whether the source of energy is primary user or noise. This process is repeated periodically to monitor the spectrum. Whenever a primary user is detected then the secondary user immediately vacates the spectrum for a finite period of time and selects another valid spectrum band from the spectrum pool for its communication. In this case, the secondary user stops communicating periodically to check the reappearance of primary user. If the underlying communication technique is sensitive to synchronization errors, as in case of OFDM, then the secondary user receiver may lose its synchronization to the secondary user transmitter. This result in the overall degradation in the secondary network performance during quiet periods. Another effect of this case is the degradation of Quality of service for real time applications like Voice over IP (VoIP) which is due to reduction of throughput of the secondary network during sensing intervals to zero. If the duration of the sensing intervals is too large then the impact becomes more severe since the average throughput of the secondary network becomes very low. Whereas, if this duration is too small, then the spectrum sensing provides no information about the frequency band of interest between consecutive sensing intervals and therefore the interference to the primary users is increased. There have been efforts which attempts to minimize the time duration for spectrum monitoring by jointly optimizing the sensing time with the detection threshold. To protect the primary user while the sensing time is minimized we consider the primary user throughput statistics.

In conventional systems, before the secondary user communication begins, traditional spectrum sensing is applied once and spectrum sensing is not performed again unless the monitoring algorithm indicates the presence of primary user in the band. When the monitoring correctly determines that there is no primary signal in the band, then the time that would have been spent performing spectrum sensing can be used to deliver packets in the secondary network. Thus spectrum efficiency of the secondary network is improved. When the spectrum monitoring detects a primary signal in the band during a time period in which spectrum sensing would not have been scheduled, the disruption to the primary user can be terminated more quickly .Thus the impact of secondary communications on the primary user is reduced. Therefore the secondary user receiver must follow two consecutive phases, namely the sensing phase and the monitoring phase. Among both the phases, sensing phase is applied over a predefined period.

In another approach the spectrum is monitored by the cognitive radio receiver during reception and without any quiet periods. In this case, for each received packet, the bit error count that is produced by a strong channel code like a Low Density Parity Check code is compared to a threshold value. The monitoring algorithm indicates that the primary user is active when the number of detected errors is above certain value. By considering the hypothesis test for the receiver statistics when the primary signal is absent and the receiver statistics for the desired secondary-to-primary power ratio the threshold value is obtained. This technique is simple and adds no complexity to the system. Major drawback of this approach is that the receiver statistics are subject to change by varying the system operating conditions. The error count will depend on the presence of a primary signal. Based on the residual errors generated from estimating and compensating for different impairments, the receiver statistics may change from one receiver to the other. Due to the difficulty in characterizing the receiver statistics for all cognitive radio receivers, it is better to devise an algorithm that is robust to synchronization errors and channel effects. OFDM is a reliable and effective transmission method, which is a multi-carrier modulation technique. OFDM is utilized as the physical layer modulation technique for many wireless systems. OFDM has been already in use for the current cognitive standard IEEE 802.22.

The traditional spectrum monitoring techniques, which rely on the periodic spectrum sensing during quiet periods, apply their processing over the received time domain samples to explore a specific feature to the primary user. Further, it is totally appropriate to remove the quiet periods during the monitoring phase to improve the network throughput. The signal construction for the secondary user can help the spectrum monitoring to happen without utilizing quiet periods. When the secondary user utilizes OFDM as the physical transmission technique, a frequency domain based approach can be employed to monitor the spectrum during the cognitive radio reception only if the secondary user transmitter adds an additional feature to the ordinary OFDM signal. A spectrum monitoring technique, namely the energy ratio technique, which is suitable for OFDM-based cognitive radio, can be used.

In energy ratio technique the transmitter helps this frequency domain based spectrum monitoring approach by introducing scheduled null-tones by which the spectrum can be monitored during cognitive radio reception. It is designed to detect the reappearance of primary user which also uses OFDM techniques. This technique implies fast response to PU appearance since it operates over the OFDM signal chain and hence, it no need to wait for the decoded bits.

ENERGY RATIO ALGORITHM

A.SYSTEM MODEL

Spectrum monitoring algorithm uses the secondary user physical layer model to investigate and verify the algorithm. The data coming from the source is firstly segmented into blocks where each block is randomized, channel encoded, and interleaved separately, at the transmitter side. The interleaving is followed by data modulation by a constellation mapper. The frequency domain OFDM frame is a combination of one or more training symbols or preambles that are used for both time and frequency synchronization at the receiver side, The modulated data and The BPSK modulated pilots which are used for data-aided synchronization algorithms employed by the receiver. If Ns denote the number of sub-carriers per one OFDM symbol Each Ns encoded complex data symbols generated by the frame builder are used to construct one OFDM symbol by employing the IDFT block that is used to synthesize the OFDM symbol.

The m'th symbols', n'th time-domain sample of can be expressed as given below, where C (k, m) is the modulated data to be transmitted on the OFDM symbol with the k'th sub-carrier.

$$s(n,m)=\frac{1}{\sqrt{N_s}}\sum_{k=-\frac{N_s}{2}}^{\frac{N_s}{2}-1}C(k,m)e^{j2\pi kn/N_s} \qquad (1)$$

The last Ng samples of the time domain OFDM symbol are copied to the beginning of the symbol to form a guard time or cyclic prefix. This is to reduce the effect of Inter-Symbol Interference (ISI). The period of a OFDM block is Ts = (Ns +Ng)/Fs where Fs is the sampling frequency. The inverse blocks are applied at the receiver side. The cyclic prefix is removed after timing synchronization and frequency synchronization. Timing synchronization includes frame detection, start of symbol timing and SFO estimation and compensation. Frequency synchronization includes CFO estimation and correction. Through an Ns point DFT the received OFDM symbol is transformed again into the frequency domain. This is followed by channel estimation and equalization of the received data. The demapper then maps the complex data output to bits. Now to recover the original source bits apply De-interleaving, decoding, and De-randomization to the received block.

In network point of view, there is a cognitive radio network of K SUs and one PU.A spectrum of a certain bandwidth is occupied by the PU for its transmission and the same spectrum is shared by the SUs. More specifically the spectrum is totally utilized by one SU which is known as the master node or the fusion node to send data to the remaining K-1 SUs which are the slave nodes. In fact this model was introduced for frequency division multiple access (FDMA) [9] but later it was modified to suite the OFDM environment.

In this model the master node constructs OFDM frames in the downlink path. The frames are constructed such that the data sub-carriers are allocated in time and frequency for different users based on a predefined scheduling Technique but the same pilots are transmitted to all slaves. Orthogonal Frequency Division Multiple Access (OFDMA) is assumed to divide the spectrum and the time into distinct and non-overlapping channels for different slaves, for the return path so that interferences between the slaves are avoided. The timing of each slave is completely controlled by the fusion node. This is done by allowing the slave know the required time advance or delay, so that the combined signal from all slaves seem to be synchronized at the fusion node receiver. Here, the fusion node can convert the signal back to the frequency domain to extract the data and control information from different slaves. It is assumed that the slaves can send important information such as spectrum monitoring decisions and channel state information over a logical control channel in the return path. Based on the received monitoring decisions the master node can apply a majority rule and decide whether to stop transmission or not.

B.ALGORITHM

Before the IDFT, a number of tones, N_{RT}, are reserved for the spectrum monitoring purposes on the time-frequency grid of the OFDM frame. Such tones are reserved for the whole time except the time of the training symbols not to change the preamble waveform, which is used for synchronization at the receiver. The OFDM frame used is shown in Fig 1.

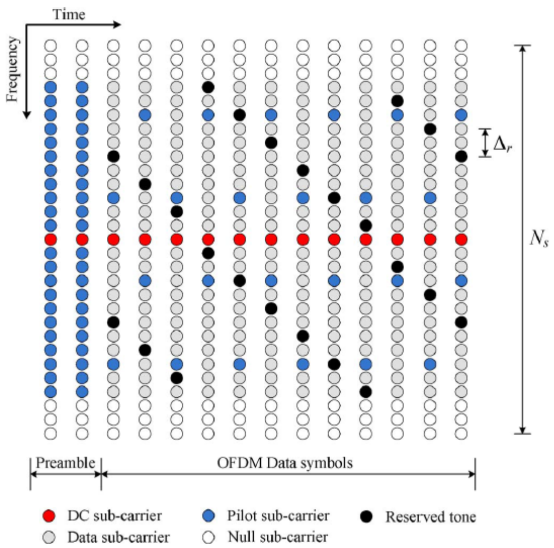

Fig 1.Time-frequency allocation for one OFDM frame [1]

The reserved tones are allocated dynamically for their indices to span the whole band when successive OFDM symbols are considered in time. Every OFDM symbol, the tones are advanced by Δ_r positions. The spanning starts again from the first subcarrier, as the last index of the available subcarriers is reached. The reserved tone sequence injected to the energy ratio spans the whole band for small values of Δ_r. This scheduling is followed due to the following reasons. Firstly due to the use of OFDM the primary user may have some spectrum holes and the algorithm fails when the reserved tones from the SU are synchronized with those spectrum holes in the PU side. Whereas when the PU uses a traditional single carrier modulation technique like QAM, then PU signal has a flat spectrum over the entire band and therefore this issue does not have a harm effect on the algorithm. Secondly, the primary to secondary channel may introduce notch characteristics to the narrow band occupied by the reserved tones. These results in detecting lower primary power level, which is referred to the narrow band problem .Therefore to mitigate the channel effect and to protect the reserved tones from falling into primary holes reserved tones, are rescheduled by changing the value of Δ_r over time. All SUs should know the code for this scheduling in prior.

The secondary user can monitor the band and test the primary user appearance, based on the signal on the reserved tones at the receiver. The traditional radiometer can be used to measure the primary signal power and the secondary noise power by accumulating the energy of those reserved tones. As a result, the primary signal power can be detected if this energy exceeds a predefined threshold. As the spectral leakage of the neighboring sub-carriers will affect the energy at the reserved tones even for no in-band primary signal this approach does not guarantee the primary user detection [13].Thus it leads to another decision making criterion that has a powerful immunity for this power leakage. This can also overcome the ICI resulted from the residual CFO and SFO errors, and even the effect of NBI. Fig 2 illustrates the overall energy ratio algorithm. The figure depicts the time domain sequence for the OFDM blocks, Frequency domain samples, the Reserved tones processing with two sliding windows for N_{RT} = 2 and N = 4 and Decision making variable, X_k.

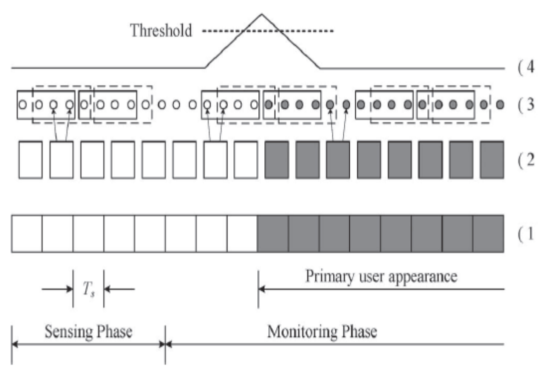

Fig 2 Energy ratio processing details. [1]

Assume that the primary signal appears after some time during the monitoring phase. The reserved tones from different OFDM symbols are combined to form one sequence of complex samples, after CP removal and frequency domain processing on the received signal, at the secondary receiver. Over the reserved tone sequence in the time direction two consecutive equal-sized sliding windows are passed. The energy of the samples that fall in one window is calculated and the ratio of the two energies is taken as the decision making variable and therefore it is named as energy ratio algorithm.

The aim of the algorithm is to check the change in variance on the reserved tones over time. Mathematically let Z_i be the i'th sample of the reserved tone sequence. Now define the decision making variable, X_k, as the ratio of the energy of the second window, U_k, and the energy of the first window, V_k as given by (2) .Where N is the number of samples per window and k is an integer such that k = 1,2,3, . .

$$X_K = \frac{U_K}{V_K} = \frac{\sum_{i=N+k}^{2N+k-1} |Z_i|^2}{\sum_{i=k}^{N+k-1} |Z_i|^2} \qquad (2)$$

The energy ratio algorithm starts the reserved tones processing from the beginning of the sensing phase. Therefore the decision making variable is calculated during both sensing and monitoring phases. But the decisions are provided only during the monitoring phase. When the decision from the spectrum sensing algorithm is that the PU is inactive during the sensing phase, the energy ratio algorithm has been properly calibrated to be able to detect the appearance of the PU during monitoring phase. That means both sliding windows are filled with pure unwanted signals. The receiver monitors the reserved tones by evaluating the parameter, Xk, during the monitoring phase. When it exceeds a certain threshold, the secondary user assumes that there is a power change on the reserved tones which is perhaps due to the primary user appearance and it is time to vacate the band. When it is within a threshold value the secondary user can continue transmission. The energy of each window involves only the strength of the unwanted signals including the noise, the leakage from the neighboring sub-carriers, and the effects of ICI produced by the residual synchronization errors when there is no primary user in band. The ratio will be very close to unity since the strength of the unwanted signals does not offer significant changes over time, when N is large enough.

When the primary user appears the second window will have two types of signaling which are the primary user interference and the unwanted signals. Whereas the first window will only maintain the unwanted signals without the primary user interference. Hence the ratio of the two energies will result in much higher values when compared to one. Of course, the ratio value will depend on the primary user power. As the two windows slide again, the ratio is close to unity since the primary signal plus the unwanted signals will be observed by the two windows and the decision making variable returns to the initial state. Thus the decision variable produces a spike when the primary user is detected. Else it changes very slowly maintaining the energy ratio close to one.

This approach can resist the different impairments involved in the received signal but it leads to reduction in the throughput of the secondary user by the ratio of the number of reserved tones to the number of useful tones. But, this reduction can be overcome since OFDM systems allow adaptive modulation where good conditioned sub-carriers are loaded with higher modulation order.

Assume the primary user should appear at the boundaries of the OFDM blocks. So, when the primary user is active the reserved tones should have the full power, which is supposed to be for those sub-carrier indices, of the primary user. But practically, the primary user may appear any time within any OFDM block in the monitoring phase. Two effects have to be considered in this case. (1) The FFT window applied by the SU receiver will have a time-shifted version of the PU signal and that involves a phase rotation to the PU sub-carriers. The phase shift is acceptable to happen with no effect on the algorithm since the energy is the useful parameter for this algorithm. (2) Since part of the signal is truncated, the power on the reserved tones will not have the full power transmitted by the primary user on those sub-carriers. But the next OFDM symbol will have that full power. If the PU power is large enough, then the reserved tones form the first OFDM symbol, in which PU signal appears, are considered to be full, similar to near far problem. Else, the reserved tones from this OFDM symbol are considered as noise if N is very much greater than N_{RT}.

C.ENERGY RATIO ANALYSIS

The energy ratio algorithm is first analyzed by assuming perfect synchronization and the leakage power effect is neglected. Assume that the signal to be detected does not have any structure that could be exploited, throughout this analysis. Therefore, the reserved tone sequence is modeled via a zero mean circularly symmetric complex Gaussian distribution. Aim of this analysis is to find the receiver operating characteristics (ROC) represented by the probability of detection, P_D and the probability of false alarm, P_{FA}. The probability of detection is the probability of detecting a primary signal when it is truly present while the false alarm probability is the probability that the test incorrectly decides that the primary user is present when it is actually not. Since we are dealing with a two state model in which the channel is assumed to be idle or busy by the primary user, then we wish to discriminate between the two hypotheses H_0 and H_1 where the first assumes that the primary signal is not in band and the second assumes that the primary user is present. Using the energy ratio algorithm, one can define these hypotheses as given by (3) where it is assumed that the samples contained in the first window have a variance of σ_v^2 and the samples enclosed by the second window have a variance of σ_u^2.

$$\begin{cases} H_0: X = \frac{U}{V}, \sigma_u^2 = \sigma_v^2 \\ H_1: X = \frac{U}{V}, \ \ \sigma_u^2 > \sigma_v^2 \end{cases} \quad (3)$$

The performance of the detector is quantified in terms of its ROC curve, which represents the probability of detection as a function of the probability of false alarm. By varying a certain threshold γ, the operating point of a detector can be chosen anywhere along the ROC curve. P_{FA} and P_D can be defined as given by (4) and (5), respectively.

$$P_{FA} = Prob[X > \gamma | H_0] \quad (4)$$

$$P_D = Prob[X > \gamma | H_1] \quad (5)$$

Clearly, the fundamental problem of detector design is to choose the detection criteria, and to set the decision threshold γ to achieve good detection performance. Detection algorithms are either designed in the framework of classical statistics, or in the framework of Bayesian statistics. In the classical case, either H_0 or H_1 is deterministically true, and the objective is to maximize $P_D$subject to a constraint on P_{FA}; this is known as the Neyman-Pearson (NP) criterion.In the Bayesian framework, by contrast, it is assumed that the source selects the true hypothesis at random, according to some priori probabilities. The objective is to minimize the so-called Bayesian cost. In this thesis the former method is considered.

D.PROPOSED MODIFIED THRESHOLD

Threshold parameter is one of the main parameter which determines the detection performance of the energy ratio algorithm. A modified threshold calculation method can be proposed where Inverse incomplete gamma function is used instead of Inverse incomplete beta function. The gamma distribution takes values in the range x>=0 and has one shape parameter, α, and one scale parameter, β. Both parameters must be positive and have the property that the mean of the distribution is α/β.

The Probability density function (PDF) of the gamma distribution is given by (6). The Cumulative distribution function of the gamma distribution is given by (7). The inverse distribution function the gamma distribution is given by (8). Here (9) is the gamma function and (10) is the incomplete gamma function.

$$f(x;\alpha,\beta) = \frac{\beta^\alpha}{\Gamma(\alpha)} x^{(\alpha-1)} (e)^{-\beta x} \quad (6)$$

$$F(x;\alpha,\beta) = IG(\beta x;\alpha) \quad (7)$$

$$F^{-1}(p;\alpha,\beta) = \frac{1}{\beta} IG^{-1}(p;\alpha) \quad (8)$$

$$\Gamma(\alpha) = \int_0^\infty x^{(\alpha-1)} e^{-x} dx \quad (9)$$

$$IG(x;\alpha) = \int_0^x \frac{1}{\Gamma(\alpha)} t^{(\alpha-1)} e^{-t} dt \quad (10)$$

The inverse incomplete gamma function is obtained by taking inverse of the incomplete gamma function. The modified threshold calculation equation by using inverse incomplete gamma function is given by (11), where $IG_b^{-1}(N,N)$ is the inverse incomplete gamma function with parameters b and N. The Parameter b and N are dependent on P_{FA} and size of sliding window respectively. Probability of false alarm of P_{FA} in terms of inverse incomplete gamma function is given by (12).

$$\gamma = 1/(IG_{P_{FA}}^{-1}(N,N) - 1) \quad (11)$$

$$P_{FA} = Prob[X > \gamma | H_0] = \mathrm{IG}_{\frac{1+\gamma}{\gamma}}(N,N) \quad (12)$$

SIMULATION RESULTS

In the simulation, we used an OFDM system that employs a total of $N_S = 1024$ sub-carriers, 224 of which are used as guard bands on both ends of the signal band. There are 32 pilot sub-carriers and NRT =4 reserved tones, distributed across the entire 800 sub-carriers. The sampling frequency is 16 MHz and reserved tone spacing is 2.

A. Receiver Characteristics

The Receiver Operating Characteristics for the energy ratio for different values of Secondary to Primary Power Ratios is shown in Fig 9.2. These results are obtained by simulating the OFDM system twice, one when primary signal is present and the second when it is absent. The system is run over 10^6 realizations and the probability of detection or false alarm is evaluated. The receiver operating characteristics (ROC) represented by the probability of detection, P_D, and probability of false alarm, P_{FA}. The detection probability is the probability of detecting a primary signal when it is truly present while the false alarm probability is the probability that the test incorrectly decides that the primary user is present when it is actually not. From the Fig 9.2 it is clear that the detector performance is more accurate at lower secondary to primary power ratios. This shows a primary signal with higher power values can be detected fast. Thus as the secondary to primary power ratio decreases detector shows a better performance.

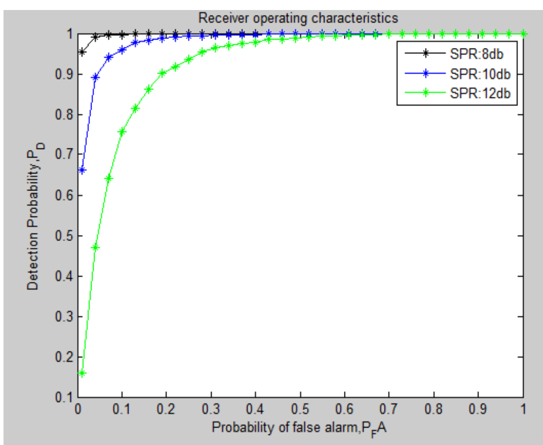

Fig 9.2 Receiver operating characteristics

B. Detection Performance versus SPR

The detection probability for three different false alarm probabilities is shown in Fig 9.3.Figure shows representation of the ROC curve in a different way. Secondary to primary power ratio is assumed to be the main parameter by which a monitoring algorithm is evaluated. The graph shows the detection probability against values of secondary to primary power ratios for three different probabilities of false alarms. It is clear that even at higher secondary to primary power ratio better detection performance is achieved for a higher probability of false alarm.

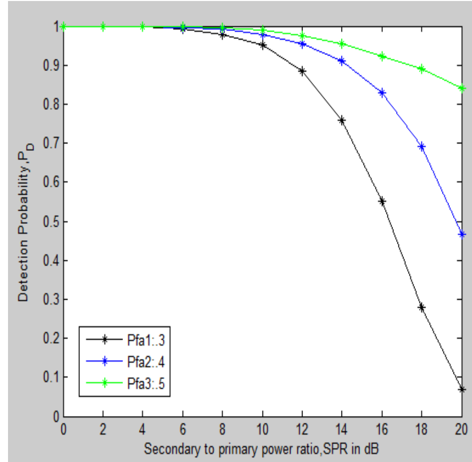

Fig 9.3 Detection probability versus SPR

C. Performance comparison of energy ratio and modified energy ratio algorithms.

In order to compare the performance of modified energy ratio algorithm with the existing energy ratio algorithm the receiver operating characteristics of the two different cases is plotted. The ROC for energy ratio algorithm with threshold calculation using gamma incomplete inverse function was simulated and evaluated. Also the ROC for energy ratio algorithm with threshold calculation using beta incomplete inverse function was simulated and evaluated. From the graph it can be inferred that the modified energy ratio algorithm have an accurate and fast detection compared to the energy ratio algorithm using beta threshold detection method. Thus the proposed threshold calculation method can enhance the performance of detector compared to existing threshold calculation method.

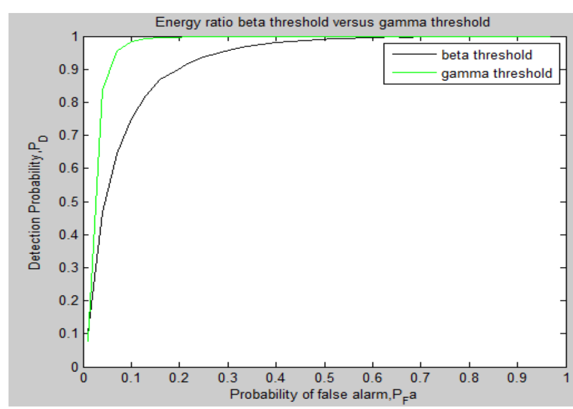

Fig 9.5 Performance comparison of energy ratio and modified energy ratio algorithms

CONCLUSION

Spectrum monitoring algorithm for orthogonal frequency division multiplexing based cognitive radio, namely the energy ratio (ER) technique, detects the reappearance of primary user during the secondary user transmission. The spectrum monitoring algorithm can greatly enhance the performance of OFDM-based cognitive networks by improving the detection performance with a very limited reduction in the secondary network throughput. Extensive simulation study is conducted so that impact of varying the threshold parameter on the detection performance is investigated and the results are compared. The results show that the modified threshold calculation using the new function will improve the detection performance of the system.

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