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# Enhanced Detection Performance of Spectrum Monitoring Using Energy Ratio Algorithm for OFDM based Cognitive Radio Networks

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**ABSTRACT:** The number of devices that function at the ISM band is constantly growing. So the need for efficient utilization of spectrum has become a fundamental requirement in wireless networks. Cognitive radios with its inherent spectrum sensing technique maximises the spectrum utilization. It automatically exploits unused spectrum to provide new paths to spectrum access. Its purpose is to reuse the temporary vacant spectrum in time domain and space domain. OFDM is used to solve the problem of non-contiguous holes. The spectrum monitoring using energy ratio algorithm for OFDM based cognitive radios can detect the primary user reappearance during the secondary user transmission. This technique reduces the spectrum sensing frequency and reduces the elapsed time between the start of a primary transmission and its detection by the secondary network. The primary user reappearance is quickly detected by sensing the change in signal strength over a number of reserved OFDM sub-carriers. The detection performance which depends on the threshold value is obtained from the inverse incomplete gamma function. This function improves the efficiency of detection performance.

**KEYWORDS:** ISM band, spectrum sensing, Cognitive radio, OFDM, inverse incomplete gamma function.

## I. INTRODUCTION

The emerging wireless multimedia applications are leading to an increased demand for radio spectrum and the radio spectrum is becoming increasingly congested with the increasing number of wireless devices. The present fixed frequency allocation strategy worked well in the past by providing an optimal solution. With the increase in the number of wireless subscribers and operators, fixed assigning the radio spectrum is proving to be more difficult in the deployment of new wireless services. Studies on current spectrum scarcity has been carried out by several spectrum regulatory authorities over the world with an objective to optimally manage available radio spectrum efficiently and effectively. It was found that wide ranges of spectrum is rarely used where as other bands are heavily used. The unoccupied portions of the licensed spectrum can only be used by licensed users. According to Federal Communications Commission (FCC), spectrum utilization varies from 15% to 85% with wide difference in time and space. It was concluded that the root cause of current spectrum scarcity is the inefficient fixed spectrum allocation and not the physical shortage of spectrum. This led to the use of a new communication paradigm, in which sharing of the under-utilized radio spectrum occurs through dynamic and opportunistic spectrum access (DOSA).

A cognitive radio (CR) technology is the one that allows the un-licensed users to dynamically and opportunistically access the licensed spectrum, without affecting the existing user with legacy rights. A CR system uses its gained experience to plan future actions and adapt to improve the overall communication quality, thus meeting user's needs. Hence a CR can be defined as an intelligent wireless system that is aware of its surrounding environment through sensing and measurements. CR improves spectrum utilization by autonomously exploiting locally unused

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spectrum. By making the physical layer (PHY) highly flexible and adaptable, a CR can achieve, the sensing and be aware of its operational environment, and dynamically adjust its radio operating parameters accordingly. The important function of secondary user (SU) is to identify available frequency bands across multiple dimensions like time, space, frequency, angle and code efficiently. Interference between licensed users of that spectrum can be avoided by updating its transmission parameters dynamically. The secondary users identifies, vacant frequency bands under uncertain radio frequency (RF) environment to detect primary users with high probability of detection so that incumbents become active in the band of interest by relying on robust and efficient spectrum sensing (SS) techniques. The Radio Knowledge Representation Language (RKRL) is a language which the cognitive radio uses for knowledge.

The two main characteristics of a CR are the cognitive capability and re-configurability. Cognitive capability refers the ability of radio technology to interact with the radio environment in real time, in order to identify and to look out for un-occupied licensed spectrum bands called spectrum holes or white spaces. The FCC categorizes the spectrum holes as temporal spectrum holes and spatial spectrum holes. This provides two secondary communication schemes of exploiting spectrum opportunity in time and space domain.

Spectrum Sensing is the technique of measuring the interference temperature over the spectrum to find the unused channels. The aim of the Spectrum Management is to find the best available spectrum to fulfill the needs of the communication. Spectrum Analysis is used to find the different functionalities of the spectrum bands so that they can make productive use of the spectrum band according to the requirements.

OFDM is a frequency division multiplexing scheme used as a digital multi-carrier modulation method. It can overcome many problems that arise with high bit rate communications, especially the time dispersion. The symbol stream bearing data is split into several lower rate streams and these streams are transmitted on different carriers. This splitting increases the symbol duration by the number of orthogonally overlapping carriers (subcarriers). Multipath echoes affect only a small portion of the neighbouring symbols. Data's are carried on several-parallel data streams or channels by a large number of closely spaced orthogonal sub-carrier signals. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, so that the total data rates remain similar to conventional single-carrier modulation schemes in the same bandwidth. OFDM's underlying sensing and spectrum shaping capabilities together with its flexibility and adaptivity make it the best transmission technology for CR systems. These properties make OFDM a good matching for the cognitive radio

## II. RELATEDWORKS

A.Ghosh [1] et.al proposed an algorithm to address the spectrum efficiency and fairness issues of multi band multiuser Multiple- Input and Multiple-Output (MIMO) cognitive ad-hoc networks. The algorithm proposed is the cross layer antenna selection algorithm, that is used to improve the transmission efficiency of the MIMO system.

W.S. Jeon [2] et.al proposed a sensing scheme that consists of a series of consecutive energy detections followed by feature detection, where the energy detection time is much shorter than the feature detection time. In this, the multiple energy detections decrease the feature detection due to false alarm and the overall channel sensing time.

R.Saifan [3] et.al has classified the trends in enhancing false alarm probability ($P_f$), detection probability ($P_d$), optimizing inter-sensing time, in-band sensing (monitoring) time optimization, and out-of-band sensing (search) time optimization. Here the model used is the PU in its idle state and it enables the CR node to benefit from its previous measurements.

S.W. Boyd [4] et.al proposed the receiver statistics method of spectrum monitoring. This proposed method of spectrum monitoring supplement traditional spectrum sensing and improve the communications efficiency of the secondary radios.

S.H. Hwang [5] et.al proposed an adaptive operation scheme for quiet period in IEEE 802.22 system. In this the length of- sensing interval is adaptively varied depending on the number of alarms by the energy detection and the performance is evaluated in terms of channel utilization.

D.Chen [6] et.al proposed a novel In-band sensing method which can avoid the usage of quiet period to guarantee the performance of the network. In this method, the complementary of adjacent OFDM symbols is utilized to perform power detection.

P.Y. Tsai [10] et.al presents an algorithm for the joint estimation of carrier frequency offset and timing frequency offset in orthogonal frequency division multiplexing (OFDM) systems. A weighted least squares algorithm based on pilot-aided scheme is proposed that operates near the Cramer-Rao bound in the variance of estimation errors. With a weighted least squares technique, this proposed algorithm generates offset estimates with minimum RMS errors.

## III. ENERGY RATIO ALGORITHM

The Fig. 1 shows the OFDM frame. A number of tones, $N_{RT}$, are reserved for the spectrum monitoring purposes on the time frequency grid of the OFDM frame, before the IDFT. 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 reserved tones are allocated dynamically so that their indices can span the whole band when successive OFDM symbols are considered in time. For every OFDM symbol, the tones are advanced by $\Delta_r$ positions.

The spanning starts again from the first subcarrier, when the last index of the available subcarriers is reached. Even for small values of $\Delta_r$, the reserved tone sequence injected to the energy ratio can span the whole band. 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.

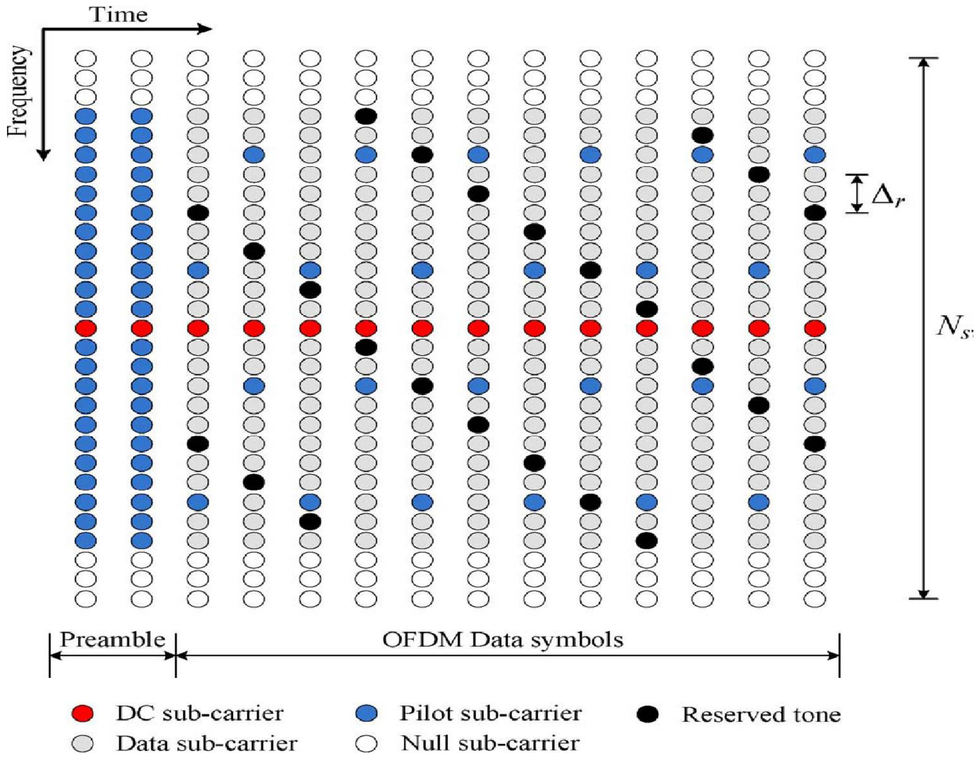

Fig. 1 Time-frequency allocation for one OFDM frame to explore different sub-carrier types.

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. This 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 $\Delta_r$ 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 neighbouring 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. So an alternative decision making criterion that has a powerful immunity for this power leakage must be formed. This technique can also overcome the ICI resulted from the residual CFO and SFO errors, and even the effect of NBI.

The Fig. 2 illustrates the overall energy ratio algorithm. The assumption is that the primary signal appears after some time during the monitoring phase. After CP removal and frequency domain processing on the received signal, the reserved tones from different OFDM symbols are combined to form one sequence of complex samples, at the secondary receiver. Over the reserved tones sequence, two consecutive equal-sized sliding windows are passed in the time direction. 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 hence named as energy ratio algorithm. The objective of the algorithm is to check the change in variance on the reserved tones over time.

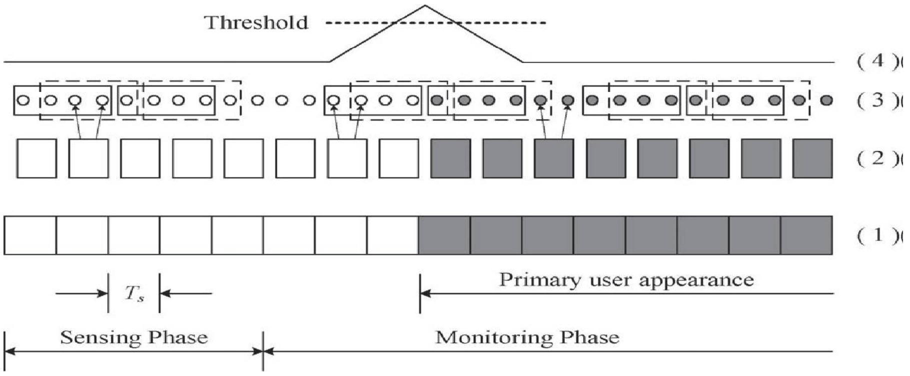

Fig. 2 Energy ratio processing details. (1) The time domain sequence for the OFDM blocks. (2) Frequency domain samples. (3) Reserved tones processing with two sliding windows for $N_{RT} = 2$ and N = 4. (4) Decision making variable, $X_k$.

Mathematically let $Z_i$ be the $i^{th}$ sample of the reserved tone sequence. The decision making variable, $X_k$, can be defined as the ratio of the energy of the second window, $U_k$, and the energy of the first window, $V_k$. where N is the number of samples per window and k is an integer such that k = 1,2,3, . .

$$X_k = \frac{U_k}{V_k} = \frac{\sum_{i=N+k}^{2N+k-1} |Z_i|^2}{\sum_{i=k}^{k+N-1} |Z_i|^2}$$

Since the reserved tones processing of energy ratio algorithm starts from the beginning of the sensing phase, the decision making variable is calculated during both sensing and monitoring phases. It only yields the decisions during the monitoring phase. The energy ratio algorithm is said to be properly calibrated to be able to detect the appearance of the PU during monitoring phase, only if the decision from the spectrum sensing algorithm is that, the PU is inactive during the sensing phase. This means that both sliding windows are filled with pure unwanted signals. In the monitoring phase, the receiver evaluates the parameter, $X_k$, by monitoring the reserved tones. 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, else 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 neighbouring 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 first window will only maintain the unwanted signals without the primary user interference and the second window will contain primary user interference and the unwanted signals as the two signals. Hence the ratio of the two energies will result in much higher values when compared to one. 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. 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. This reduction can be overcomed by OFDM systems since it uses adaptive modulation where good conditioned sub-carriers are loaded with higher modulation order.

It is assumed that the primary user appears at the boundaries of the OFDM blocks. 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. Firstly, 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 subcarriers. The phase shift is acceptable to happen with no effect on the algorithm since the energy is the useful parameter for this algorithm. Secondly, since part of the signal is truncated, the power on the reserved tones will not have the full power transmitted by the PU 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 $N >> N_{RT}$.

## IV. ANALYSIS

The Fig. 3 shows the SISO communication model block diagram. It consists of a primary user and a secondary user transmitter. They are summed and is given to the OFDM synchronization blocks where they are synchronized. They are then given to the CP removal. It is then given to the FFT. From FFT, they are given to the channel estimator, channel equalization and the energy ratio. After the channel equalization they are given to the bit chain. This model can be modified as required for MIMO communication systems. Here, the assumption is that, the signal to be detected does not have any known structure. A zero mean circularly symmetric complex Gaussian distribution is used for modelling the reserved tone sequence. The objective is to find the receiver operating characteristics (ROC) represented by the probability of detection, $P_D$, and probability of false alarm, $P_{FA}$.

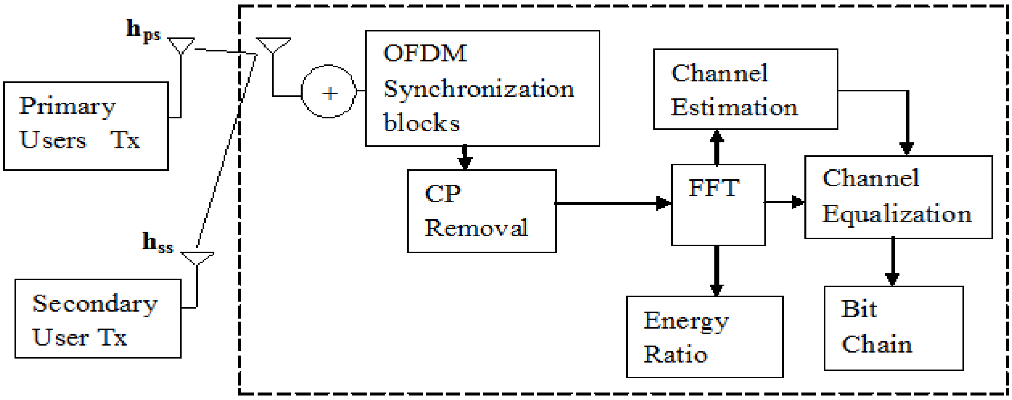

Fig. 3 SISO communication model block diagram

The two hypotheses are $H_0$ and $H_1$. They are classified as, $H_0$ assumes that the primary signal is not in band and; $H_1$ assumes that the primary user is present. The hypotheses are defined as in equation (1). $\sigma_v^2$ is the variance of the samples contained in first window and; $\sigma_u^2$ is the variance of the samples contained in second window.

$$\begin{cases} H_0 : X = \frac{U}{V},\ \sigma_u^2 = \sigma_v^2 \\ H_1 : X = \frac{U}{V},\ \sigma_u^2 > \sigma_v^2 \end{cases} \qquad (1)$$

The detection performance is expressed in terms of its ROC curve, which represents the probability of detection as a function of the probability of false alarm. The operating point of a detector can be chosen anywhere along the ROC curve by varying a certain threshold $\gamma$. $P_{FA}$ and $P_D$ are defined and are given by the following equations respectively.

$$P_{FA} = \mathrm{Prob}[X > \gamma \mid H_0]$$
$$P_D = \mathrm{Prob}[X > \gamma \mid H_1]$$

The objective of Neyman-Pearson (NP) criterion is to maximize $P_D$ subject to a constraint on $P_{FA}$, when either $H_0$ or $H_1$ is deterministically true. The energy contained in one window will follow a Chi- Square distribution, as the samples of the reserved tone sequence follow a zero-mean circularly symmetric complex Gaussian distribution.

Probability of false alarm for the energy ratio algorithm is given by ,

$$P_{FA} = \mathrm{Prob}\ [X > \gamma \mid H_0] = I_g\ (N)$$

The threshold $\gamma$ can be obtained subject to a constant $P_{FA}$ , where $I_g^{-1}(N)$ is the inverse incomplete gamma function with parameter N and is given by,

$$\gamma = \frac{1}{I_{P_{FA}}^{-1}(N) - 1}$$

The detection probability is given by ,

$$P_D = \mathrm{Prob}[X > \gamma \mid H_1\ ]$$

## V. SIMULATION RESULTS

The Fig. 4 shows the receiver operating characteristics of energy ratio algorithm with inverse incomplete gamma function. From the graph it is seen that this technique achieve high probability of detection even for small values of probability of false alarm.

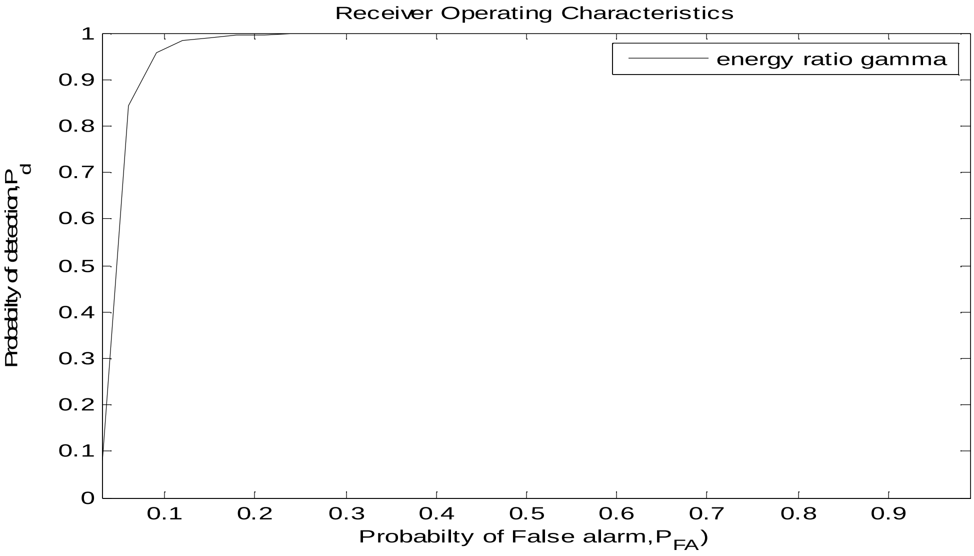

Fig. 4 ROC of Energy Ratio Algorithm with inverse incomplete gamma function.

The Fig. 5 shows the comparisons of receiver operating characteristics of various techniques.

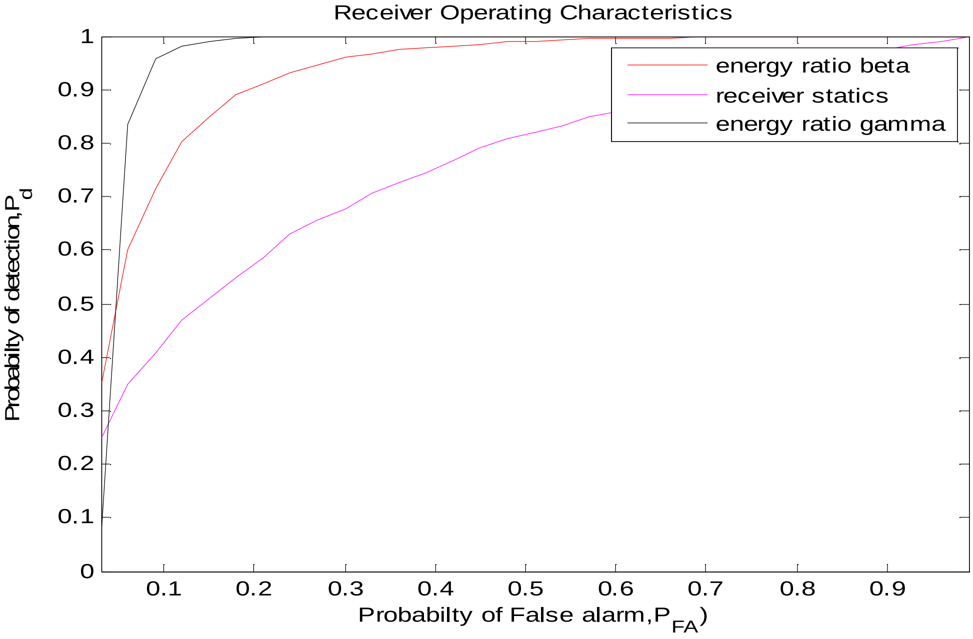

Fig. 5 Comparison of ROC of various techniques.

From the simulation results it is seen that the energy ratio algorithm using the inverse incomplete gamma function has better detection performance than the receiver statics and energy ratio algorithm with inverse incomplete beta function.

## VI. CONCLUSION

The energy ratio algorithm can effectively and accurately detect the appearance of primary user and also it is highly efficient. The detection performance usually depends on a threshold value. The threshold value used here is obtained from inverse incomplete gamma function. By changing the threshold function from inverse incomplete beta function to inverse incomplete gamma function the detection performance is enhanced. Simulation results also indicates this superiority of the inverse incomplete gamma function over inverse incomplete beta function.

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