Performance Evaluation of Energy Detection Based Spectrum Sensing Technique for Wireless Channel

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Abstract– **In this paper the performance of energy detection based spectrum sensing in multipath fading environment is analyzed using OFDM multiplexing technique. A predetermined value of probability of detection and probability of false Alarm is used in order to calculate the optimum threshold value. That threshold value is used to evaluate the performance in the sense of probability of detection Vs SNR. This is known as Constant detection rates (CDR) and Constant False Alarm rates (CFAR). In real time scenarios the noise variance is unknown therefore both known and unknown noise variance cases are also discussed here. MATLAB simulations are used to analyze comparisons in performance for different values of predetermined probabilities of detection and also for different Channel length.**

Keywords– **CDR, CFAR, CR, Channel Length, Channel Taps and Energy Detection**

I. INTRODUCTION

The demands for Wireless System Networks are increasing day by day. Therefore a great concern is towards the efficient utilization of the spectrum. The conventional Spectrum Management system is for the licensed primary users, due to which a larger percentage of spectrum is underutilized. So there should be a mechanism that can manage the problem of underutilization by incorporating unlicensed users as well. To meet this challenge, Cognitive Radio (CR) is one that makes a difference through a Dynamic Spectrum Access (DSA). CR (Secondary User) is the environment-aware device which can access the spectrum as an Unlicensed User without any interference to the Licensed User (Primary User). CR will transmit during the time when no transmission from the Primary User occurs which means that the desired spectrum band is vacant at that time [1].

The spectrum is not always busy and a huge portion of the spectrum remains vacant at many instants which make spectrum holes. The process of identification of the spectrum holes (the vacant spectrum band) by a Secondary User (CR) is called Spectrum Sensing. Spectrum Sensing is a hot issue now days to avoid the limited and a static access of spectrum. Cognitive Radio (CR) is an intelligent device which can change its parameters like frequency, modulation etc. according to the radio environment. Today a lot of research is going on considering the minimum level of interference of CR (Unlicensed Users) with the primary Users (Licensed Users). Because for efficient utilization of the spectrum it is necessary to have high sensing ability (high probability of detection) of CR and low interference with Primary Users. So first the CR should sense the transmission of the primary signal correctly, and then it should have the ability to adjust its parameters according to the environment, making sure that no transmission occurs from Primary User [2], to start its transmission accordingly. To have the best statistics, there are three most common techniques which are used for Spectrum Sensing like Matched filter Detection (Coherent detection), Cyclostationary Detection and Energy Detection. In the Coherent Detection method of Spectrum Sensing, the idea is to correlate the detected signal with copy of the original transmitted signal. This is the very well known method of detection with maximum signal-to-noise ratio but it requires the knowledge of the transmitted signal for detection. The second method is the Cyclostationary method, which is some what like coherent detection in a sense that the received or detected signal is correlated with some known pattern. Normally a signal is comparable with noise because the noise is random in nature but the signal after interpretation by the operation like modulation, coding etc. will take some periodicity. Due to this periodicity, it can be differentiated from the noise, as noise has no periodicity in time. Both the matched filter detection and the cyclostaionary based detection involve the knowledge of a signal which is not available every time in practical scenarios. Also it involves more complexity in the detection process of CR. Moreover these two techniques require a significant amount of time to detect a signal [3].

On the other hand, a third type of detection is the most common and a simple way to detect the received signal which also requires a less time because for this type of detection there is no need to have any prior knowledge of the transmitted signal. It just computes the energy of a received signal to decide whether a detected signal was a noise or primary user's signal. For decision a threshold value should be set accordingly. This threshold value plays a very vital role because an improper value of threshold may cause low probability of detection (detection of primary signal) and high false alarm rates (interpreting of noise as primary user's signal). Therefore a great attention should be given in setting the proper threshold value for energy based spectrum sensing in order to get the optimum detection results.

The rest of the paper is organized as: System Model is given in Section II, and theory of discussed energy detection techniques is given in Section III and IV. Simulation Results are given in Section V and finally conclusions are drawn in last section.

II. SYSTEM MODEL

Spectrum sensing is actually used to identify the presence of primary user's signal and to differentiate between the noise and the transmitted signal. In this paper energy detection method is used to sense the desired frequency band. The information of the bandwidth is known to CR. Bandpass filter is used here to select the interested bandwidth. Then the signal of the desired bandwidth is fed the analog to digital converter and finally passed through the square law integrator to compute the energy of the received signal.

To determine whether the signal is present or not is a binary problem so this can be formulated by a binary hypothesis [4]

$$x[m] = \begin{cases} n[m] & H_o \\ s[m] + n[m] & H_1 \end{cases}$$

Where $s[m]$ represents the primary user's signal, $n[m]$ represents the noise and the received signal is represented by $x[m]$. Where H_1 belongs to the case when signal is present and the H_0 shows that only noise is present. The noise has the random distribution with zero mean and its variance is represented by σ_n^2 and the signal can also represented by a zero mean random process for which the variance is σ_s^2. Therefore the signal to noise ratio is represented by [5]

$$SNR = \sigma_s^2 / \sigma_n^2$$

The test statistics used for Energy detection model is shown by [6].

$$U = \frac{1}{\sigma_n^2} \sum_{k=1}^{N} |\eta|^2 \gtrless \xi$$

Here N is number of samples taken to compute the energy of the signal and the value of $N >> 1$. σ_n^2 is the noise variance which is not known in real time systems. ξ is the threshold value to decide between noise and the primary user's signal. We have taken both known noise power and estimated noise power cases here. The test statistics U has a random distribution with both the signal present H_1 and signal absent H_0 case. This distribution is chi-squared distribution. By taking very large value of N, this distribution can be approximated by Gaussian distribution as shown here

$$f_u(u) = \begin{cases} N(\sigma_n^2, \frac{2\sigma_n^2}{M} & under\ H_o \\ N(\sigma_t^2, \frac{2\sigma_t^2}{M} & under\ H_1 \end{cases}$$

Here σ_t^2 is the sum of variance of signal and noise, which is;

$$\sigma_t^2 = \sigma_n^2 + \sigma_s^2 = \sigma_t^2(1 + SNR)$$

The threshold is very important part in decision making of energy detection method. To determine the optimum value of threshold, predetermined value of probability of detection is taken here, assuming both the cases of known noise variance and unknown noise variance.

III. THRESHOLD CALCULATION THROUGH A PREDETERMINED VALUE OF PROBABILITY

The Probability of false alarm can be found, for a certain amount threshold needed for detection of the received signal, as given by [5]:

$$P_{fa} = prob(u > \lambda \backslash H_o) = Q(\frac{\lambda - \sigma_n^2}{\sigma_n^2/\sqrt{M/2}})$$

Here $Q(.)$ is given by [7]

$$Q(x) = \frac{1}{2} erfc(\frac{x}{\sqrt{2}})$$

$erfc$ is a complementary error function

$$erfc(x) \triangleq \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-t^2}\, dt \qquad (1)$$

If we take a predetermined value of probability of false alarm then we can find the value of threshold needed for detection which would be [8]:

$$\lambda_{fa} = \sigma_n^2(1 + \frac{Q^{-1}(P_{fa})}{\sqrt{M/2}})$$

Similarly the threshold value for predetermined probability of detection is given by:

$$\lambda_d = \sigma_n^2(1 + SNR)(1 + \frac{Q^{-1}(P_d)}{\sqrt{M/2}})$$

Here $Q^{-1}(.)$ is an inverse Q function as shown by Eq.1. We have used the Eq.2 in this paper to determine the threshold values. Normally for the requirement of the system which can guarantee non interference probability to the current system, the probability of detection will be fixed to a higher value and probability of false alarm should be as low as possible.

IV. ENERGY DETECTION FOR KNOWN AND UN-KNOWN NOISE VARIANCE

The threshold values shown in the Eq. 1 and Eq. 2 are taken if the noise power is known to the secondary user. But in actual scenarios, it is not obvious to have the exact value of the noise variance and is unknown at receiving end due to the fact that the noise includes thermal noise, receiver-end noise and the environmental noise. Therefore in this paper both cases including known noise variance and unknown noise variance have been taken. Eq. 1 of threshold λ_d is for the case when noise variance is known to the secondary user's receiving end.

For the case when the noise variance is unknown at receiving end, Eq. 1 becomes [5].

$$\lambda_d = \widehat{\sigma_n^2}(1 + SNR)(1 + \frac{Q^{-1}(P_d)}{\sqrt{M/2}})$$

These threshold values can be used to decide between the signal and noise at the secondary user's end. But these values can only be found with the predetermined value of probability of detection and probability of false alarm. These predetermined values are called Constant Detection Rates (CDR) and Constant False Alarm Rates (CFAR).

V. SIMULATION RESULTS

In this section the energy based spectrum sensing with simulations results is discussed with multicarrier technique for different channel characteristics. The signal is modulated with BPSK modulation scheme with 512 carriers and passed through OFDM system. The channel considered here is Multipath Channel with both AWGN and Rayleigh fading. Different samples for channel length variations are also used here.

The SDR characteristic is shown in Fig 1 for different channel lengths. The channel considered here is multipath channel and probability of detection vs SNR for different channel lengths is considered. This is very obvious from Fig 1 that at low SNR the chances of detection of the signal is very low but as the SNR increases the detection rate increases and at 10 dB it will almost equal to 1. At low SNR values, a negligible effect of channel length is introduced. But at some high SNR values, the channel effect has introduced significantly e.g. with more channel samples like 60, the performance degrades significantly and with channel length 30 and 10, the performance improves significantly for the SNR values from -10 to 8 but as the SNR value increases further, again the channel length has no effect on the performance because the channel length introduces noise which is not pronounced at high SNR values.

Fig. 2 shows the performance on the basis of different noise variances. The case of known noise variance is taken here. Now as shown in Fig. 2, low noise variance has better performance as compared to high noise variances. Also it can be noted that the performance curve for noise variance values of 1.75 and 2.15 is almost same at low SNR values (from -15dB to 0dB) but as the value of SNR increases these two performance curves have prominent difference because at high SNR the performance of the system with low noise variance of 1.75 is far better than the performance curve with noise variance of 2.15. Also the performance of the system with very low noise variance of 1.2, the performance improves significantly even at low SNR values.

Fig. 3 shows the performance of energy based detection characteristic curves for different values of predetermined probabilities of detection P_d. Here different values of P_d : 0.2, 0.5 and 0.9 are taken. It is obvious from Fig. 3 that at very low SNR, different predetermined values of P_d have no effect on the performance but as the SNR increases the performance improves significantly at high predetermined value of P_d. At SNR values more than 12 dB again the performances of these three curves show no difference. Because at high SNR, it becomes easy for CR to differentiate between the signal and noise .So at that point the predetermined values of probability of detection do not play any role. Another point here is that all these curves are like a bell shaped. In the performance curve of a predetermined value of P_d it can be seen that the performance decreases with increase in SNR values and after passing a certain value of SNR i.e. 6 dB the performance will turn to increase and then it will keep on increasing with increase of SNR value.

VI. CONCLUSION

In this paper, performance evaluation of energy detection based spectrum sensing technique is carried for multipath Rayleigh fading channel for known and unknown noise variance conditions. Effect of varying channel length is significant only at low SNR values. For very small values of SNR, larger channel length show better performance but as SNR increases, opposite behavior is observed showing better performance for smaller channel lengths,. But at high SNR operating conditions, the effect of channel length becomes almost negligible.

The performance also degrades as the value of noise variance increases. So for better performance, the variance of noise is assumed to be less. The effect of calculating the threshold based on the pre-determined probability of detection is also given. For very small values of SNR, there is no effect of pre-determined probability of detection on performance. But as SNR increases, the large values of pre-determined P_d shows better performance. The spectrum sensing can also be carried in frequency domain also for which period-gram technique is most simple and efficient.

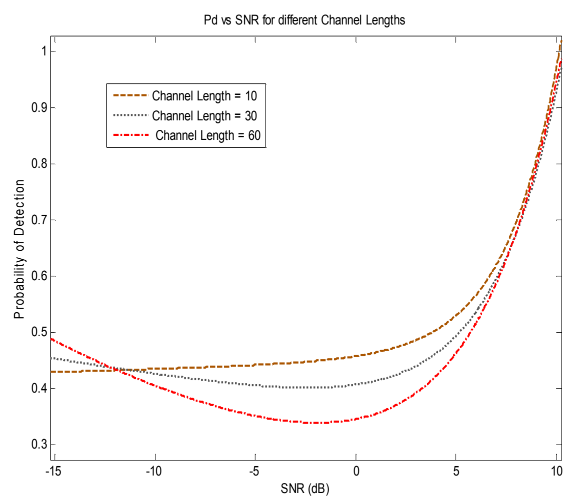

Fig. 1. Pd vs SNR for different Channel lengths

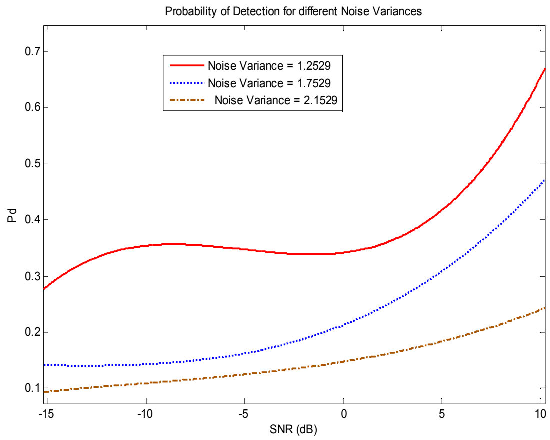

Fig. 2. Pd vs SNR for different Noise Variance

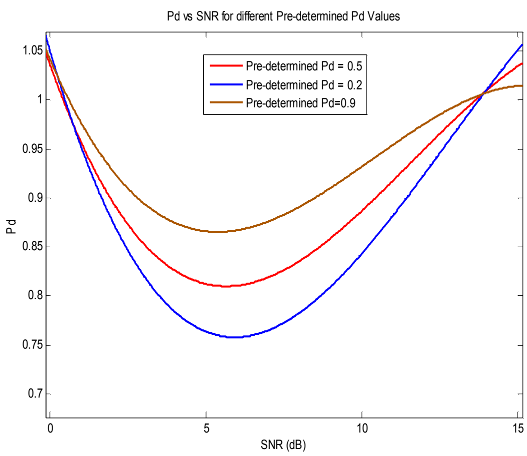

Fig. 3. Pd vs SNR for different predetermined values of Pd

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