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Enhancement of Frequency Spectrum Prediction Technique in Cognitive Radio

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***Abstract*--Wireless technology has been now very popular in all around the world. Mobile phones, cordless telephones, remote sensors, garbage openers, pagers, radio, and satellite TV are all examples for wireless communication system for our daily lives. In the world everyone would like to be connected seamlessly anytime anywhere through the network that is best. The assigned spectrum utilizes 15% to 85% of spectrum allocation policy as per Federal Communications Commission (FCC). To allow wireless devices to effectively share the EM waves is therefore required. The Frequency spectrum prediction mechanism might get occupied state duration of authorized users in given channel & the probability density of idle state duration. Therefore the result of frequency spectrum real-time detection can be amended & accessed. It can also decrease the misjudgment probability on cognition system. The impact probability of false alarm can also be decreased. The simulation result clears that the mechanism is able to reduce the cost of frequency spectrum access prediction of cognition system caused by detection error & efficiently reduce the interference of detection error to authorized system.**

As the number of devices increased, the competition for limited bandwidth available and service level provided to them is degraded. Also fixed spectrum allocation policy following traditional rules will not meet the needs and services of the wireless users for long time. Cognitive radio refers to wireless architectures in which communication system is not operated in a fixed band, but it always predict & predicts an appropriate band in which to operate. Cognitive radio cannot generate levels of interference that are unacceptable on the same frequency in licensed systems and explore the fundamental requirement for such a system. To predict the existence of licensed users, spectrum predicting techniques are used. Matched filter detection, Energy detection and Cyclo-stationary feature detection are the three conventional methods used for spectrum prediction. As the SNR value increases, the performance of spectrum prediction method also improves. To predict the spectrum, Energy Detection technique and Cyclic Prefix technique is utilized and their effects in different fading channels are considered. It has been found that with 5 dB increase in SNR, the probability of detection increases up to 0.8 times for AWGN Channel; and up to 0.7 times for Rayleigh Channel .

I Introduction

The Berkeley Wireless Research Center reports that 70% of the spectrum under 3 GHz is available at any specific location and time. Under the FCC's "exclusive rights" model of frequency band ownership, if a licensed system is not transmitting, its spectrum remains off-limits to other users. The spectrum bands has been allocated by FCC to a single use, issued exclusive license to a single entity within a limited geographical area, and not allowed other entities from transmitting significant power within these bands. Looking at the NTIA's chart of these frequency allocations, it results that we are in danger of running out of spectrum. However, allocation is just half the story. Contrary to popular belief, actual measurements (taken in downtown Berkeley, CA) show that most of the allocated spectrum is vastly underutilized. There is a widespread concern over Cognitive Radio. [1]

There are a lot of spectrum sensing algorithms nowadays, such as correlation detection; matched filter detection, energy detection, cyclo-stationary feature detection and cooperative detection [1], most of them improve sensing performance by reducing sensing efficiency. Even though, for the complexity of wireless electromagnetic environment, hidden terminal, the limitation of detection time and other problems, frequency spectrum detection error is inevitable, such as false alarm probability and misjudgment probability. That could disturb authorized system and reduce chances of cognition system to use idle frequency spectrum. Therefore, it is needed to obtain the probability density function of idle state duration and occupied state duration of authorized frequency spectrum according to statistics of idle or occupied state of authorized frequency spectrum, to assess and amend the result of frequency spectrum detection real-timely, and to decrease the impact brought by detection error. Document [2] used the estimation of probability density of idle state duration of frequency spectrum to predict the available time length of spectrum resource, and to choose spectrum resource that has enough available time length. That mechanism's default condition is that the result of spectrum detection is correct, the impact of detection error is not considered. Its method of estimating probability density by supporting Vector Machine is also need to be improved. Hereby, sensing techniques will be supported to estimate probability density of idle state duration of frequency spectrum, and according to the result the detection result will be judged whether it is false alarm or misjudgment or not. [2]

II Probability of Detection over AWGN Channel-using Energy Detection Technique

The performance of licensed spectrum prediction is characterized by two probabilities. The probability of detection $\boldsymbol{P_d}$ represents the probability of detecting the presence of primary user's presence under hypothesis $\boldsymbol{H_t}$. The false alarm probability, P_f is the probability of detecting the primary user's presence under the hypothesis ff$_0$.The "probability of false detection" for energy detection technique is inversely proportional to the SNR. At low SNR we have higher probability of false detection and at high SNR we have lower probability of false detection, because energy detection cannot isolate between signal and noise.

There is the noise uncertainty that is caused by various factors such as temperature changes, ambient interference, and filtering, is unavoidable and leads to errors when setting the threshold for signal detection. N is the number of samples, N=2TW, T is duration interval, W is bandwidth, S (N) is the primary user's signal, W (N) is the Noise (AWGN) with zero mean and is a random process. The signal to noise ratio is defined as the ratio of signal power to noise power [11],

$\gamma = Ps/No$

where Ps and No are the average power of signal and noise. The probability of detection and false alarm can be generally computed by

Pd = Pr(Y > H1), (10)

Pf = Pr(Y > |H0)

Probability of detection P_d and false alarm P_f can be evaluated respectively by

$P_d = P(Y' > A|H_1$

$P_f = P(Y' > A|H_o$

Where A is the decision threshold. Also, can be written in terms of probability density function as:

$$P_f = \int_A^\infty f_{Y'}(y)dy$$

Using $P_f = 1/2^d r(d) \int_A^\infty y^{d-1} e^{-(\frac{y}{2})} dy$

Dividing and multiplying the R.H.S. of above equation by 2^{d-1}, we get

$$P_f = \frac{1}{2r(d)} \int_A^\infty (\frac{y}{2})^{d-1} e^{-(\frac{y}{2})} dy$$

Substituting y/2 = t, dy/2 = dt and changing the limits of integration to (A/2, ∞) we get

$$P_f = \frac{1}{r(d)} \int_{A/2}^\infty (t)^{d-1} e^{-t} dt$$

$$P_f = \frac{\Gamma\left(d,\frac{A}{2}\right)}{r(d)}$$

where T(.)is the incomplete gamma function [60]. Now, Probability of detection can be written by making use of the cumulative distribution function. [11]

$P_d = 1 - F_{Y'}$

The cumulative distribution function (CDF) of T can be obtained by:-

$F_{Y'}(y) = 1 - Q_d(\sqrt{\lambda}, \sqrt{y}$

Therefore, probability of detection P_d for AWGN channel is [34]:

$P_d = Q_d(\sqrt{\lambda}, \sqrt{y}\ )$

$P_d = Q_d(\sqrt{2\lambda}, \sqrt{y})$

Where $Q_u(.,.)$ is the generalized Marcum-Q function and thus, probability of detection for AWGN Channel can be evaluated using above expression.

III Probability of detection for Rayleigh channel - using Energy Detcetion Technique

Probability density function for Rayleigh channel is :-

$$f(\gamma) = \frac{1}{\gamma} \exp(-\gamma/\bar{\gamma}\ ) \quad , \gamma \geq 0$$

$$P_{d,R} = \int_0^\infty P_d f(\gamma) d\gamma$$

where $P_{d>R}$ is the probability of detection for Rayleigh channel.:

$$P_{d,R} = \frac{1}{\bar{\gamma}} \int_0^\infty Q_d(\sqrt{2\lambda}, \sqrt{A}) \exp(-\frac{\gamma}{\bar{\gamma}}) d\gamma$$

Now, substituting $\sqrt{\gamma} = x, \gamma = x^2$ and dy in we get

$$P_{d,R} = \frac{2}{\bar{\gamma}} \int_0^\infty x. Q_d(\sqrt{2x}, \sqrt{A}) \exp(-\frac{x^2}{\bar{\gamma}}) dx$$

$$\int_0^\infty dx. x. \exp\left(-\frac{p^2 x^2}{2}\right). Q_M(a_x, b)$$
$$= 1p^2 \exp - b_{22}. \{(p^2$$
$$+ a_2 a_2) M$$
$$- 1 \exp(b_{22}). a_2 p_2$$
$$+ b_2 - n$$
$$= 0M$$
$$- 21n! \, b_{22}. a_2 p_2$$
$$+ a_2 n + n$$
$$= 0M - 21n! \, b_{22} n\}$$

Thus, Probability of detection for Rayleigh channel can be expressed as

$$P_{d,R}$$
$$= e^{(-\frac{A}{2})} \sum_{n=0}^{d-2} \frac{1}{n!} (\frac{A}{2})^n$$
$$+ (\frac{1+\bar{\gamma}}{\bar{\gamma}})^{d-1} [\exp(-\frac{A}{2(1+\bar{\gamma})}$$
$$- \exp(-\frac{A}{2}) \sum_{n=0}^{d-2} \frac{1}{n!} (\frac{A\bar{\gamma}}{2(1+\bar{\gamma})})^n$$

The above expression gives the probability of detection for Energy detection based spectrum prediction over Rayleigh Channel.

IV Analysis of Simulation

We suppose cognition system and authorized system work in a same area, cognition system access to idle spectrum resource of authorized system. The two systems share the same spectrum resource. The two systems don't have message exchange with each other, therefore, cognition system use spectrum detection mechanism to discern whether the spectrum resource is idle or not.

In the simulation, traditional spectrum access mechanism is used in project for comparison. Spectrum detection result is the only basis of spectrum access in traditional spectrum access mechanism. Probability of Detection vs SNR plots are shown for different values of SNR. Detection probability (P_d), False alarm probability (P_f) and missed detection probability $(P_m = 1 - P_d)$ are the key measurement metrics that are used to analyze the performance of spectrum prediction techniques. The performance of a spectrum prediction technique is illustrated by the receiver operating characteristics (ROC) curve which is a plot of P_d versus P_f or $P_m$versus P_f and P_d versus SNR.

MATLAB code for energy detection in various channels like AWGN, Nakagami and Rayleigh channel is developed .This code helps us plot a graph between probability of detection and probability of false alarm which is basically a ROC curve.ROC curves are used to compare the performance of the two algorithms.

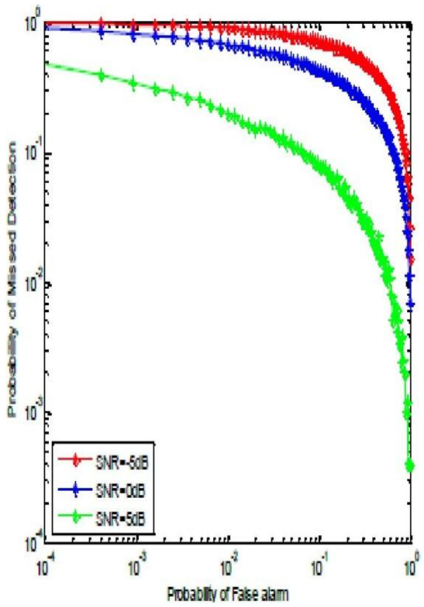

Figure 1 **ROC curves for Energy Detection over AWGN channel**

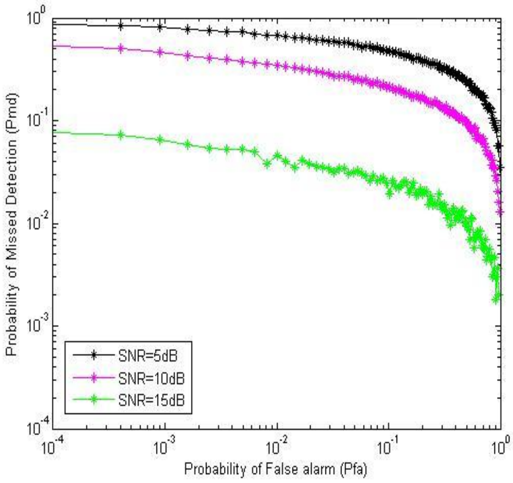

Figure 2 **ROC curves for Energy Detection over Rayleigh channel**

In simulation results of figure 1 and figure 2, we compared the performance of the project put forward and project for comparison. The comparison includes two aspects: one is that spectrum detection error makes cognitive system access to occupied spectrum resource, which is called misjudgment; the other is that detection error makes cognitive system lose chance to access to idle spectrum resource, which is called false alarm. From the figures we can see that the spectrum access mechanism could obviously decrease the probability of the two kinds of detection errors and insure the performance of authorized system and cognition system.

With increase in SNR, the performance of Energy Detection spectrum prediction method improves. It has been found that with 5 dB increase in SNR, increases the probability of detection (at SNR=5 dB) up to 0.8 times as compared to probability of detection (at SNR=0 dB) for AWGN Channel. It has also been observed that increase in probability of false alarm, improves the probability of detection of a particular spectrum prediction method. 5% increase in probability of false alarm; increases the probability of detection up to 0.8 times for Rayleigh Channel in case of conventional energy detection method (i.e. using squaring operation).

They will influence the performance of authorized system and cognition system. When idle state probability threshold is increased, the interference of cognition system to authorized system is decreased, but the chances of access to spectrum are decreased.

V Conclusions

The frequency spectrum access mechanism put forward, which is based on frequency spectrum prediction, when authorized system and cognition system share the same frequency spectrum resource could assess and amend spectrum detection result. That could obviously decrease the severe interference of detection error to authorized system, and evidently decrease the lost of chances of cognition system to access to idle spectrum, which is brought by detection error. Thus, that would insure the performance of authorized system and cognition system. The Performance of Spectrum Prediction techniques have been evaluated using ROC (Receiver Operating Characteristics) curves and Probability of detection versus SNR plots. The amount of computation is increased when the performance is improved. Therefore, our next research topic would be finding a much better algorithm to finish spectrum prediction in a shorter time.

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