A Novel Spectrum Sensing Without Channel State Information Using Estimated Parameters

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***Abstract*: this paper develops a spectrum sensing technique using multiple antenna and energy detector in cognitive radio. The conventional spectrum sensing techniques using multiple antennas such as maximum ratio processing (MRP), Equal Gain Combining (EGC)… require channel state information (CSI) to combine received signal at each antenna. In practice, it is complicate and requires time to obtain CSI. Recently, some methods performing spectrum sensing without CSI have been proposed. However, these methods do not bring desired results compared with the conventional techniques using CSI. In our research, we propose a new technique without requiring CSI to combine signals from multiple antennas. The proposed technique brings good results compared to the other conventional techniques requiring CSI like EGC. In addition, we do not assume exact parameters of signal and noise in our simulation. The samples at the receiver are used for two purposes: estimating these parameters of noise and signal and performing spectrum sensing.**

Key words: spectrum sensing, multiple antennas, energy detector, cognitive radio, diversity combining schemes.

I. INTRODUCTION

Due to the rapid development of wireless technologies, the spectrum scarcity problem has been paid great attention recently. In conventional wireless communication systems, each user is allocated a fixed spectrum band and other users could not access it. It leads to a low effectiveness of spectrum usage. Cognitive Radio (CR) network brings a solution with the idea of spectrum sensing [1,2,3]. In CR network, an unlicensed user utilizes the spectrum band allocated to primary user in vacating time and move to other unused bands in case detecting the existence of primary user. To perform the flexible scheme, an unlicensed user must determine exactly whether there is the primary user's signal by sensing the radio environment. The interference from the unlicensed user to primary user is not allowed. Due to multipath fading channel, the signal to noise ratio (SNR) in some cases is very low. Therefore, the main problem of spectrum sensing is to determine the existence of primary user under low SNR.

Basically, there are four types of spectrum sensing as follow: cooperative detection, interference based detection, receiver detection and transmitter detection. Among the transmitter detection techniques, energy detector using multiple antennas has many advantages. Energy detector only relies on the energy of received signal to determine the present of primary signal. Therefore, it has simple structure. Multiple receivers is also an effective technique to deal with multipath fading channel [4,5,6]. In [4], the performance of spectrum sensing is investigated in case of single and multiple antennas. The problem is that diversity receiver techniques (MRP, EGC) require the CSI to combine and select received signals. The previous knowledge about the channel is not always available. Recently, the research in [5] has proposed a novel spectrum sensing technique using quantization weights. The advantage of this method is that it does not need the knowledge of CSI. However, it is complex in computation and does not bring to desired results compared with the systems using diversity combining schemes.

In our study, we have advanced a simple technique to process the received signals at multiple antennas. The proposed method does not require CSI as well.

The performance of the proposed system is investigated by comparing with two systems, one using quantization weights and the other using EGC. In most of the previous studies, the noise variance is assumed to be known by the secondary user. In our study, we estimate the mean and variance of noise and signal plus noise.

In section II, we investigate three methods to combine signals from independent paths: the system using EGC, the system using quantization weights and our proposed technique. Section III presents briefly the background of the energy detector. Section IV describes the way to estimate some parameters and calculate the probability density function (PDF) of the test statistics. The simulation results are presented in section V. Finally, a brief conclusion is given in section VI.

II. COGNITIVE RADIO RECEIVERS

The signals from the independent fading paths in multiple receiver antennas are processed by different techniques such as maximum ratio processing, equal gain combining, and maximum selection combining... as shown in Figure 1. The received signal at each antenna is multiplied by a coefficient (weighting) before combining together. Let see three ways to combine received signals. The first one is the EGC scheme.

Let s(t), n(t) be the signal waveform, the noise waveform and i be the index of each antenna. The received signal at each antenna follows the formula:

$$Y_i(t) = h_i * s(t) + n_i(t), \tag{1}$$

where h_i is the channel response: h_i follows the Rayleigh distribution:

$$h_i = |h_i| * e^{j\theta_i} \tag{2}$$

In EGC scheme, the weighting for each antenna is the conjugate of channel response's phase: $\alpha_i = e^{-j\theta_i}$

The combiner signal output is computed as below:

$$Y = \frac{1}{M}\sum_{i=1}^{M}\frac{y_i(t)}{e^{j\theta_i}} = \frac{1}{M}\sum_{i=1}^{M}|h_i| * s(t) + \tilde{n}_i(t) \tag{3}$$

$$\tilde{n}_i(t) = \frac{n_i(t)}{e^{j\theta_i}} \tag{4}$$

The EGC scheme does not require knowledge of the time varying SNR like the MRP scheme. However, the method still needs the parameter e^{θ_i} of the channel response to form the output signal Y. The signal component at each path is maximized $|h_i| * s(t)$, thus the total signal component in the output gets maximum value $\frac{1}{M}\sum_{i=1}^{M}|h_i| * s(t)$. We could say that $\alpha_i = e^{-j\theta_i}$ is the optimal weight to combine signals at each branch.

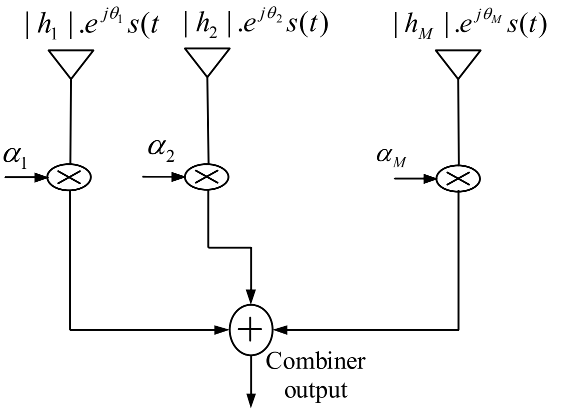

Figure 1. The combiner system

However, the total noise component $\frac{1}{M}\sum_{i=1}^{M}\tilde{n}_i(t)$ from M antennas could make negative effect on the total signal component and degrade the performance of the EGC system. Beside, obtaining this optimal weight is difficult in practice.

In [5], a novel method using quantization weights is proposed. We consider the method in case of using 4 antennas and 2 quantization weights for each antenna as in Figure 2. The first antenna is used as a reference without multiplying. From the second to fourth antennas, each one has two quantization weights. As a result, we could create 8 signal branches as the general formula below:

$$Y = \frac{1}{4}(y_1 + w_1 * y_2 + w_2 * y_3 + w_3 * y_4) \qquad (5)$$

w_i (i=1,2,3) has two possible values (w_{i1}, w_{i2}). Without loss of generality we assume that $| w_i |= 1$. Each signal branch is put into the square and averaging device. The maximum energy of eight signal branches is chosen for decision making. The system using quantization weights need to calculate independently each branch and then compare the results among all branches. Although the system does not require CSI, it is complex in computation and the performance is not good.

In our proposed system, the received signal plus noise component in each antenna is maximized before combining together by choosing the weight as the conjugate of received signal's phase $e^{-j\varphi_{y_i}}$.

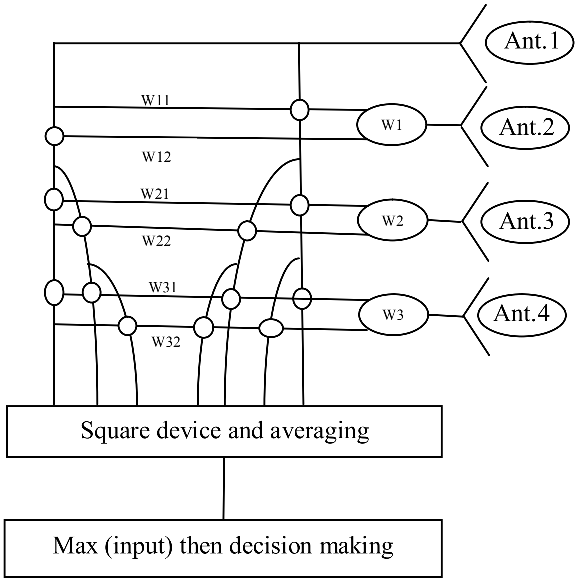

Figure 2. Receiver system model

$$y_i(t) = | y_i(t) | * e^{j\varphi_{y_i}} \qquad (6)$$

$$Y = \frac{1}{M}\sum_{i=1}^{M}\frac{y_i(t)}{e^{j\varphi_{y_i}}} = \frac{1}{M}\sum_{i=1}^{M}| h_i * s(t) + n_i(t) \qquad (7)$$

$$\geq \frac{1}{M}\sum_{i=1}^{M}\frac{y_i(t)}{e^{\theta_i}} = \frac{1}{M}\sum_{i=1}^{M}| h_i | * s(t) + \widetilde{n}_i(t) \qquad (8)$$

We can see that it is very easy to detect the phase $e^{-j\varphi_{y_i}}$, but is not easy to detect $e^{-j\theta_i}$ of channel response. This make the technique become more practical. The noise in the i^{th} antenna only affects the signal at this antenna. This method leads to the maximum value of noise (primary user absent) and signal plus noise (primary user exist). The mean of noise and signal plus noise increases. It will be illustrated in our simulation in Figure 5.

III. ENERGY DETECTOR AND SYSTEM MODEL

The combined signal output Y is put into an energy detector. The idea of using energy detector to determine the presence of a signal has been proposed by Harry Urkowitz [7], see Figure 3. It is appropriate to use an energy detector because that it only requires the signal energy, not its waveform.

The band pass filter removes the components out of band and then the signal is digitalized by an Analog to Digital Converter (ADC). After ADC block, we have T samples or snapshots. These samples are squared and summarized to estimate the received signal's energy. An increase in T causes the increase in sensing time but the performance of detection and estimation will be improved. We assume that the primary user's signal samples, the adaptive noise samples are independent, identically distributed (iid), and complex Gaussian random variables.

By the three different techniques presented above, we receive different values of Y(t). The received signal can be expressed as the binary hypothesis:

$Y(t) = N(t)$ H_0, Signal is absent

$Y(t) = S(t) + N(t)$ H_1, Signal is present (9)

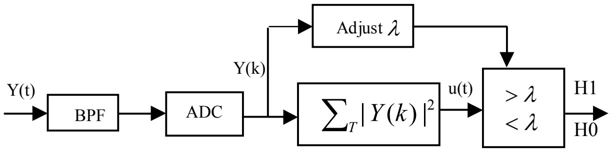

Figure 3. Energy detector in spectrum sensing

The test statistics are described as:

$$u(t) = \sum_T |Y(k)|^2 \quad (10)$$

u(t) is compared with a threshold to decide whether or not the signal is present. There are two ways to evaluate the performance of a sensing system corresponding to three parameters:

$$P_D = \Pr o\{u(t) > l \mid H_1\} = \Pr o\{c_N^2 > l \mid H_1\} \quad (11)$$

$$P_{MD} = 1 - P_D \quad (12)$$

$$P_{FA} = \Pr o\{u(t) > \lambda \mid H_0\} = \Pr o\{\chi_N^2 > \lambda \mid H_0\} \quad (13)$$

P_D, P_{MD} and P_{FA} are the probability of detection, the probability of misdetection and the probability of false alarm respectively. P_{FA} indicates the probability in which the signal does not exist but the system decides it does. P_{MD} indicates the probability in which the signal exists but the system decides it does not. Figure 4 shows the determination of the threshold and the way to calculate Probability of false alarm and misdetection. Based on the PDF of the test statistic as in the figure 4, the blue curve in the left hand side shows the PDF of the test statistic if the primary signal is absent, the blue curve in the right hand side shows the PDF of the test statistics in the primary signal is present. The system can only determine the threshold if we fix one of two parameters P_{FA} or P_{MD} (We fix only one parameter, not both). For example, we have P_{FA} and the PDF of the test statistic, we could compute the threshold and then P_{MD}.

The value of fixed parameter is chosen depending on the requirement of particular system. We need to balance two aspects: the utilizing the spectrum holes and the reduction of the interference from the secondary user to the primary user. The parameter P_{FA} is as small as possible for utilizing the spectrum holes that is the time when there is no primary user signal. The parameter P_{MD} is as small as possible for the reduction of the interference from the secondary user to the primary user. However, if we reduce the value of P_{FA}, the P_{MD} increases. Therefore, depending on the requirements of system we could choose the suitable value P_{FA}. For example, if the system requires very little interference from secondary user signal to primary user signal, we need to fix the value of bigger and vice versa.

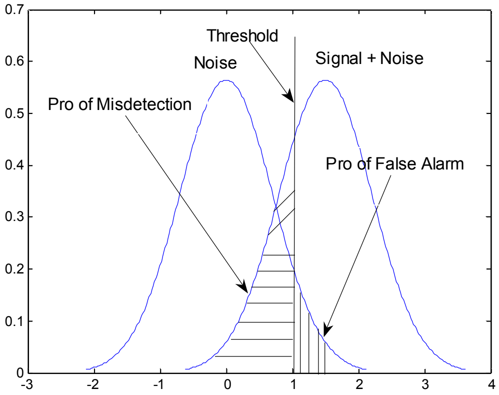

Figure 4. Example of threshold and the way to calculate Probability of false alarm and misdetection

We can see that we need some parameters to know the PDF of the test statistics. In most conventional systems, they often assume that the test statistics has normal distribution by the Central Limit Theorem. In addition, they suppose that these parameters have been known before. In our research, we make the method more practical by estimating these parameters. Besides, the distribution we used is Central and Non-central Chi Square distribution under H_0 and H_1 respectively [7], see Appendix for more detail of these distributions. That is why we have to estimate parameters.

The next part, we will point out how to calculate the PDF of the test statistic by estimating the mean and variance of noise, signal plus noise and the non-centrality parameters of the Chi-square distribution.

IV. ESTIMATE NON-CENTRALITY PARAMETER AND CALCULATE PDF OF THE TEST STATISTIC

The samples after ADC block are not only used to calculate the received signal’s energy but also used to estimate the mean and variance of noise and signal plus noise. An increase in the number of samples T leads to a better estimation. Assuming that T samples after the ADC block are: Y[1], Y[2],…, Y[T]. These samples are assumed to be independent and identically distributed. We suppose that the true values of the mean and variance of the distribution are (μ, σ^2). In practice, we cannot calculate these values precisely. Therefore, we need to estimate them.

Using the unbiased estimation:

$$\hat{\mu} = \frac{Y_1 + Y_2 + ... + Y_T}{T} \qquad (14)$$

$$\hat{\sigma}^2 = \frac{1}{T}\sum_{i=1}^{T} | Y_i - \hat{\mu} |^2 \qquad (15)$$

$$\hat{\sigma}^2 = \operatorname{var}(Y \mid \bar{Y} = \hat{\mu}) = E\{(Y - \hat{\mu})^2\} = \mu^2 + \sigma^2 - 2\hat{\mu}\mu + \hat{\mu}^2 \qquad (16)$$

If T is large enough, $\hat{\mu} \cong \mu$ and then $\hat{\sigma}^2 = \sigma^2$

In the next step, we need to find out the PDF of the test statistic u(t) in (10).

Define:

$$v(t) = \sum_{i=1}^{T} \frac{| Y(k) |^2}{\hat{\sigma}^2} = \frac{u(t)}{\hat{\sigma}^2} \qquad (17)$$

The variable v(t) has the non-central Chi Square distribution with T degree of freedom and the non-centrality parameter:

$$\xi = T\frac{\hat{\mu}^2}{\hat{\sigma}^2} \qquad (18)$$

Denote the PDF and cumulative distribution function (CDF) of the Chi-Square distribution with variable v are: $f_V(v;T,\xi)$ and $F_V(v;T,\xi)$. T and ξ are the degree of freedom and non-centrality parameter, respectively. The PDF and CDF of the test statistic are computed by these following formulae, see Appendix, lemma 1:

$$f_U(u;T,\xi) = \frac{1}{\hat{\sigma}^2} f_V(\frac{v}{\hat{\sigma}^2};T,\xi) \qquad (19)$$

$$F_U(u;T,\xi) = F_V(\frac{v}{\hat{\sigma}^2};T,\xi) \qquad (20)$$

Similarly for the system using EGC scheme and quantization weights, the test statistics has Chi-Square distribution with T degree of freedom, the only difference among these schemes is the estimated mean, variance and non-centrality parameter. When we know the distribution of the test statistic and one fixed parameter (P_{FA} or P_{MD}), the threshold and the remained parameter is calculated.

In practice, the system is put firstly in the noise environment without the primary user’s signal to obtain the initial samples. These samples are used to estimate the parameters of noise and plot the PDF of the test statistic in case the primary user’s signal is absent. As the PDF of the test static is know, we would calculate the threshold corresponding to the fixed probability of false alarm.

V. SIMULATION RESULTS

In this section, we consider the performance of three different spectrum sensing techniques above. In our simulation and figures, index 1, 2 and 3 denote the parameters of our proposed system, the system using EGC and the system using quantization weights respectively. For the simulation, we take four antennas into consideration and choose the number of snapshots T=70. The symbol rate is 3000 symbol par second with the maximum Doppler frequency of 150 Hz. So the slow fading channel and the flat fading channel model are used. In order to evaluating the performance of the three systems, we fix the probability of false alarm P_{FA} then calculate the threshold and the probability of misdetection P_{MD}. In the third system, the quantization weights are chosen as points in the unit circle as illustrated in Figure 5.

In the first simulation, we evaluate the sensing performance by plotting the PDF of the test statistics of three systems. P_{FA}= 0.01 and SNR= – 4 dB

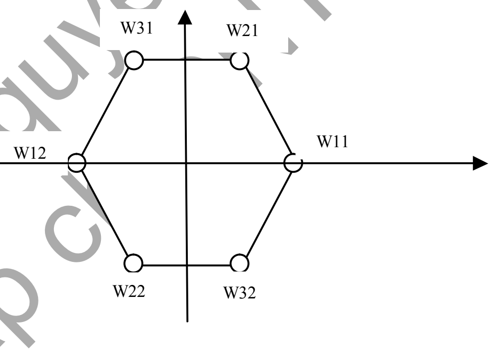

Figure 5. The distribution of quantization weights

Figure 6 shows the PDF of the test statistics in case of H_0 and H_1. The mean of noise in the system using quantization weights increases. Thus, its PDF shifts to the right. In contrast, the mean of signal plus noise decreases and its PDF shifts to the left.

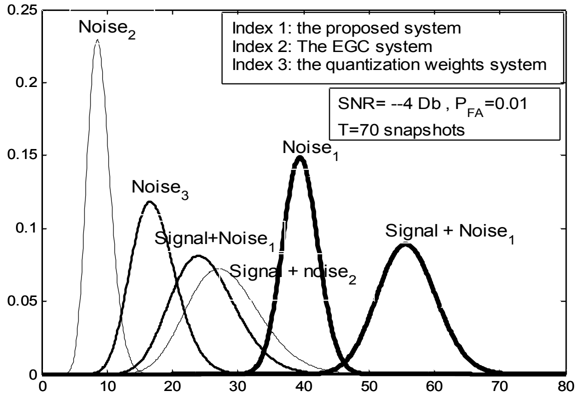

Figure 6. The PDF of Test Statistics in 3 Schemes

It leads to the high probability of misdetection. On the other hand, in our proposed system, both mean of noise and signal plus noise increase, thus P_{MD} of the proposed system is approximate P_{MD} of the system using EGC scheme. It could be seen by the cross area between two PDF functions in case of H_0 and H_1.

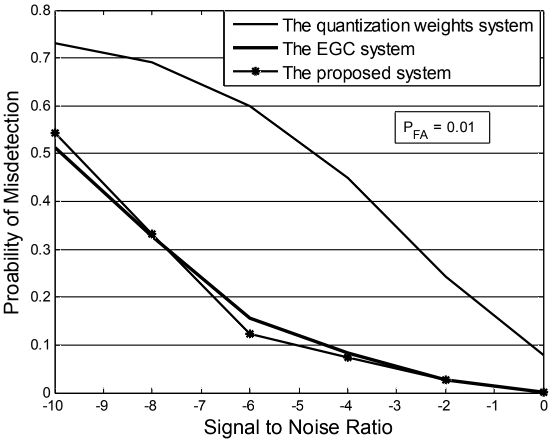

Figure 7. Performance of 3 systems by fixing P_{FA}

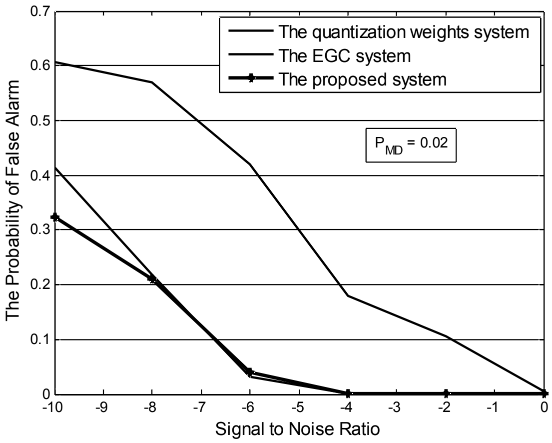

Figure 8. Performance of 3 systems by fixing P_{MD}

In next two simulations, we choose the number of snapshots T=70. Figure 7 illustrates the performance of 3 systems by changing the signal to noise ratio and fixing P_{FA}= 0.01. The performance of the proposed system and the EGC system are quite similar. They are better than the system using quantization weights.

Figure 8 shows the performance of the systems by fixing P_{MD} =0.02 and changing the signal to noise ratio. The table I investigates probability of misdetection of three systems by changing the number of snapshots. We choose SNR=– 10 dB and P_{FA} = 0.03. The three systems perform well in case the number of snapshots falls in the range (70,80).

Table 1. The probability of misdetection by changing the number of snapshots

Snapshots	EGC	Quantization weights	The proposed system
40	0.661	0.810	0.710
50	0.433	0.718	0.546
60	0.377	0.613	0.397
70	0.276	0.514	0.289
80	0.195	0.486	0.209
90	0.290	0.412	0.304
100	0.286	0.463	0.361

VI. CONCLUSION

In this paper, we propose a new technique to combine the signals in spectrum sensing technique. The method does not require the CSI as the conventional methods do. Therefore, the complicate of the system as well as the time for spectrum sensing are reduced. The simulation shows that the result of the proposed system is as good as the system using EGC and better than the system using quantization weights. Besides, we do not use exact values of signal and noise variance and mean. These parameters are estimated by the samples after the ADC block. This makes the method more practical.

APPRENDIX

CENTRAL AND NON-CENTRAL CHI SQUARE DISTRIBUTION

The non-central chi square distribution: K independent and normal distributed random variables $X_1, X_2, .., X_K$ with mean μ_i and variance σ_i^2. Define the random variable:

$$X = \sum_{i=1}^{K} \left(\frac{X_i}{\sigma_i} \right)^2 \qquad \text{(A1)}$$

X has the non-central Chi Square Distribution with the degree of freedom K and the non-centrality parameter:

$$\xi = \sum_{i=1}^{K} \left(\frac{\mu_i}{\sigma_i} \right)^2 \qquad \text{(A2)}$$

In case $\xi = 0$ ($\mu_i = 0$ for every i=1,…,k), the distribution becomes the Central Chi Square Distribution.

The PDF of the Chi-Square distribution:

$$f_K(x) = \frac{\frac{1}{2} e^{-\frac{x}{2}} . \left(\frac{x}{2} \right)^{\left(\frac{K}{2} - 1 \right)}}{\Gamma\left(\frac{K}{2} \right)} \qquad \text{(A3)}$$

K be the degree of freedom and the Gama function:

$$\Gamma(\alpha) = \int_0^{\infty} e^{-y} . y^{\alpha - 1} dy \qquad \text{(A4)}$$

The PDF of the non-central Chi-Square distribution:

$$f_X(x; K, \xi) = \sum_{i=0}^{\infty} \frac{e^{-\frac{\xi}{2}} \left(\frac{\xi}{2} \right)^i}{i!} f_{K+2i}(x) \qquad \text{(A5)}$$

Lemma 1: Let V be a random variable with its PDF and CDF are and respectively. Defined $U = a.V$ (a ≠ 0) then the PDF and CDF of U are f_U and F_U defined by the formulae:

$$f_U(x) = \frac{1}{a} f_V\left(\frac{x}{a} \right); \; F_U(x) = F_V\left(\frac{x}{a} \right) \qquad \text{(A6)}$$

Proof:

$$F_V(x) = \Pr o\{v \le x\} = \int_{-\infty}^{x} f_V(t) dt$$

$$= \Pr o\{av \le ax\} = \int_{-\infty}^{ax} f_U(t) dt = F_U(ax)$$

Therefore:

$$F_V\left(\frac{x}{a} \right) = F_U(x) \qquad \text{(A7)}$$

By differentiating with respect to x, we obtain the remained formula:

$$\frac{1}{a} f_V\left(\frac{x}{a}\right) = f_U(x) \qquad \text{(A8)}$$

REFERENCES

[1] D. Cabric and R. W. Brodersen, “Physical layer design issues unique to cognitive radio systems,” IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, pp 759-763, Sept 2005.

[2] Z. Quan, S. Cui, H. V. Poor, and A. H. Sayed, “Collaborative wideband sensing for cognitive radios,” IEEE Signal Processing Magazine, no. 6, pp. 60.73, Nov. 2008.

[3] D. Cabric, S. M. Mishra, and R. W. Brodersen, “Implementation issues in spectrum sensing for cognitive radio,” in Proc. Asilomar Conf. on Signals, Syst., and Comput., Pacific Grove, CA, 2004, pp. 772-776

[4] Ashish Pandharipande, Jean-Paul M. G. Linnartz, "Performance analysis of primary user detection in a multiple antenna cognitive radio", ICC 2007 - IEEE International Conference on Communications, vol. 30, no. 1, June 2007 pp. 6481-6485

[5] Al-Abbasi, A.R.; Fujii, T. “A novel spectrum sensing method using multi-antennas without channel state information”, Wireless Communication Systems, 2009. ISWCS 2009. 6th International Symposium on Volume, Issue, 7-10 Sept. 2009 Page(s):373 – 377

[6] Neihart N. M., Roy S. and Allstot D. J., ”A Parallel, Multi-Resolution Sensing Technique for Multiple Antenna Cognitive Radios”, ISCAS 2007

[7] H. Urkowitz, “Energy detection of unknown deterministic signals,” Proceedings of the IEEE, pp 523-531, Apr 1967.

[8] Zhuan Ye; Memik, G.; Grosspietsch, J. “Energy Detection Using Estimated Noise Variance for Spectrum Sensing in Cognitive Radio Networks” Wireless Communications and Networking Conference, 2008. WCNC 2008. IEEE Volume , April 2008, Page(s):711 – 716.

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