Spectrum Sensing in Cognitive Radio Networks using Modified Energy Detector

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Abstract— Cognitive Radio is the wireless technology which allows the effective spectrum utilization among unlicensed users. Basically spectrum resource management is a tough task in present world because of the allocated spectrum to a primary user gets unutilized. In order to avoid the spectrum band unutilization among the users we use cognitive radio technology. The proposed methodology consists of Improved Energy Detector which is used in sensing of spectrum hole. The cognitive radio users utilize the improved energy detector statistics for making a binary decision on presence/absence of primary user signal in the licensed spectrum band. By using the multiple antennas at each cognitive radio, the probability of spectrum utilization is maximized and the probability of detection of primary user signal is high under low SNR.
Key words: Cognitive Radio (CR), Spectrum Hole, Primary user (PU), Spectrum sensing, Improved Energy detector, Multiple antennas

I. INTRODUCTION

With the development of new and expanding wireless applications and services, spectrum resources are facing huge demands. Currently, Spectrum allotment is done by providing each new service with its own fixed frequency block. As day passes demand for spectrum are expected to increase rapidly and it would get in future.

As most of the primary spectrum is already assigned, so it becomes very difficult to find spectrum for either new services or expanding existing services. At Present government policies do not allow the access of licensed spectrum by unlicensed users, constraining them instead to use several interference-prone frequency bands. As the result there is huge spectrum scarcity problem in certain bands.

A remedy to spectrum scarcity problem is overcomed by employing the Cognitive Radio technology which helps to improve spectrum utilization by allowing secondary users to access under-utilized licensed bands dynamically when/where licensed users signals are absent in licensed spectrum band.

A. Spectrum hole:

It refers to the unutilized or available spectrum in the allotted frequency spectrum.

B. Spectrum Sensing:

It is the ability of the system to sense, measure and be aware of the various parameters related to channel and provide information on presence or absence of primary user signal in the channel.

C. Cooperative Spectrum Sensing:

Cooperative spectrum sensing allows secondary users(CR users) in a cognitive radio network to share information among themselves for detection of a spectrum hole.

The improved energy detector is a very useful non-coherent detector for detection of signals corrupted by Gaussian noise. It detects the presence of a Primary user signal based on the principle of energy detector algorithm, i.e. by measuring its energy and comparing the measured energy with a predetermined threshold. The measurement and the comparison require no primary user signal's information. Thus, the improved energy detector has a very simple structure, and it has been widely used in wireless communications systems.

II. PROPOSED SYSTEM MODEL

The proposed model consists of a single primary user, 'N' number of cognitive radio users in the cognitive radio network and a fusion centre.

The cognitive radio user is employed with 'M' number of antennas at its side for the detection of spectrum hole so that CR users access the spectrum for their transmission of data. The fusion centre and primary user are employed with the single antenna at its side.

Here the primary user is allowed to transmit its signal with a fixed spectrum allocated to it; the secondary users (cognitive radio users) are employed with improved energy detector at its side for detection of spectrum hole. The cooperative spectrum sensing approach is being utilized for deciding presence/absence of primary user signals.

The proposed system model is shown in figure 1.

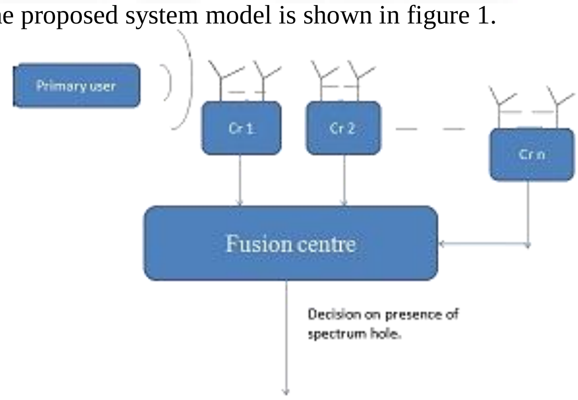

Fig. 1: System model

The multiple antenna schemes are employed for interference nulling at the primary user side. The multiple antenna scheme employed is multiple input single output (MISO).

The fusion centre is employed with OR rule for detection of primary user signal. It collects the decisions from each CR in the network and finally decides the presence/absence of PU signal by using OR rule.

Under Binary Hypothesis (H0 and H1) the signal received at the i-th antenna at each CR is

H0: $y_i(t) = v_i(t)$ if PU signal is absent

H1: $y_i(t) = h(t) * s(t) + v_i(t)$ if PU signal is present

Where 'i' is the antenna index at each Cr= 1: M;

S(t)= transmitted signal from the primary user at instant 't' with energy 'E_s'.

$v_i(t)$ = CN $(0, \sigma_n^2)$ is the complex additive white Gaussian noise with mean zero and variance σ_n^2.

$h_i(t)$ = CN $(0, \sigma_h^2)$ is the complex identically and independently distributed channel gains.

Improved Energy detector employed at each CR user is shown in figure 2.

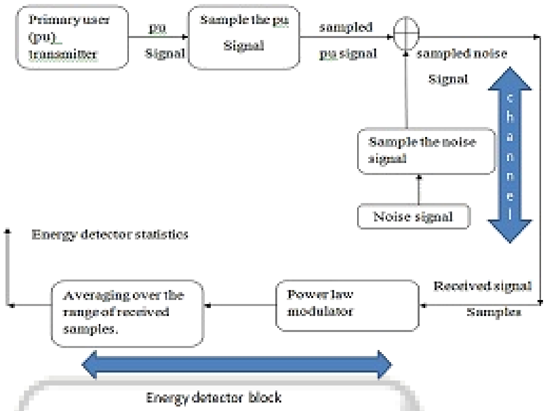

Fig. 2: Improved Energy detector.

A. *Spectrum sensing scheme:*

The energy detector statistics at the i-th antenna for deciding the presence or absence of the PU is calculated by eq 1

$$w_i = \sum_{i=1}^{M} |y_i|^p \quad (1)$$

Where P= Power of the amplitudes of transmitted PU signal, M=no of antennas at each CR.

The block diagram of Improved energy detector at each CR showing the spectrum sensing is shown in figure 3.

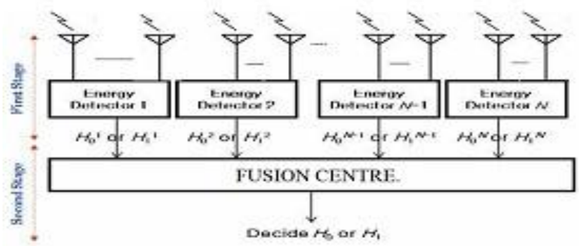

Fig. 3: Improved energy detector at each CR.

Algorithm for spectrum sensing scheme:-

(1) The energy detector decision statistics is calculated for each antenna for its received samples under each CR using eq 1.
(2) Take the maximum of the decision statistics obtained for each antenna among the 'M' antennas under each CR using the selection combining method.
(3) The output (decision) of each cr among 'N' crs is forwarded to the fusion centre .
(4) The fusion centre applies 'or' rule and takes the final decision on the presence or absence of PU signal depicted in figure 3.

Performance analysis of multiple antenna scheme in Cognitive radio network employing Energy detector:-

From the theory of probability distributions the cumulative distributive function (c.d.f) of improved energy detector statistics can be given as

$$P_{W_i}(y) = \Pr(|y_i|^p \leq y) \quad (2)$$

Where P_r denotes the probability.

From eq 2 the probability distribution function of improved energy statistics under binary hypothesis H0 and H! is calculated and is given in eq 3 and eq 4

$$f_{w_i/H0}(y) = \frac{2y^{\frac{2-p}{p}} \exp\left(-\frac{y^{\frac{2}{p}}}{\sigma_n^2}\right)}{p\sigma_n^2} \quad (3)$$

$$f_{w_i/H1}(y) = \frac{2y^{\frac{2-p}{p}} \exp\left(-\frac{y^{\frac{2}{p}}}{\sigma_n^2 + E_s\,\sigma_h^2}\right)}{p(E_s\,\sigma_h^2 + \sigma_n^2)} \quad (4)$$

The selection combiner is incorporated at each cr which takes the maximum of decision statistics obtained for each antenna under each cr using eq 1.

The decision statistics of each cr is given by eq 5

$$z = \max(w_1, w_2, --, w_m) \quad (5)$$

The threshold for spectrum sensing scheme is determined by using the eq 6 or can be set manually

$$\lambda = \sqrt{2 * \sigma_{n^2} * \log(1/p_{fa})} \quad (6)$$

Where $\boldsymbol{\sigma_{n^2}}$ *=noise variance.*

$p_{fa} = probability\ of\ false\ alarm.$

The decision statistics Z of each CR is compared with the threshold λ and the output is forwarded to the fusion centre over perfect reporting channels.

$$Z \gtrless \lambda$$

If Z is greater than λ then the hypothesis H1 is true and result is primary user signal is present, if Z is lesser than λ then the hypothesis H0 is true and result is primary user signal is absent.

The Probability that the decision statistic w_i is less than z, under hypothesis H0 is given by

$$\Pr(w_i \leq z|H0) = \int_0^z f_{w_i/H0}(y)\,dy$$

$$= 1 - \exp\left(-\frac{z^{\frac{2}{p}}}{\sigma_n^2}\right) \quad (7)$$

From (5) and (7), it follows that

$$p_z(z/H0) = [1 - \exp\left(-\frac{z^{\frac{2}{p}}}{\sigma_n^2}\right)]^M \quad (8)$$

$$p_z(z/H1) = [1 - \exp\left(-\frac{z^{\frac{2}{p}}}{E_s\,\sigma_h^2 + \sigma_n^2}\right)]^M \quad (9)$$

The p.d.f's of selection combiner under hypothesis H0 and H1 are obtained by differentiating equation 8 and 9 w.r.t 'Z'.

The spectrum sensing performance depends upon two parameters namely probability of false alarm (p_{fa}) and probability of detection (p_d) and are calculated based on equation 8 and 9.

$$p_{fa} = \frac{1}{M} - \frac{1}{\mathrm{M}}[1 - \exp\left(-\frac{\lambda^{\frac{2}{p}}}{{\sigma_n}^2}\right)^{\mathrm{M}}] \qquad (10)$$

$$p_m = \frac{1}{\mathrm{M}}[1 - \exp(\frac{\lambda^{\frac{2}{p}}}{(1+\gamma){\sigma_n}^2})]^{\mathrm{M}} \qquad (11)$$

$$p_d = 1 - p_m.$$

Where γ is the signal to noise ratio of PU-CR link= $E_s{\sigma_h}^2/{\sigma_n}^2$.

The flow chart illustrating the spectrum sensing scheme is in figure 4.

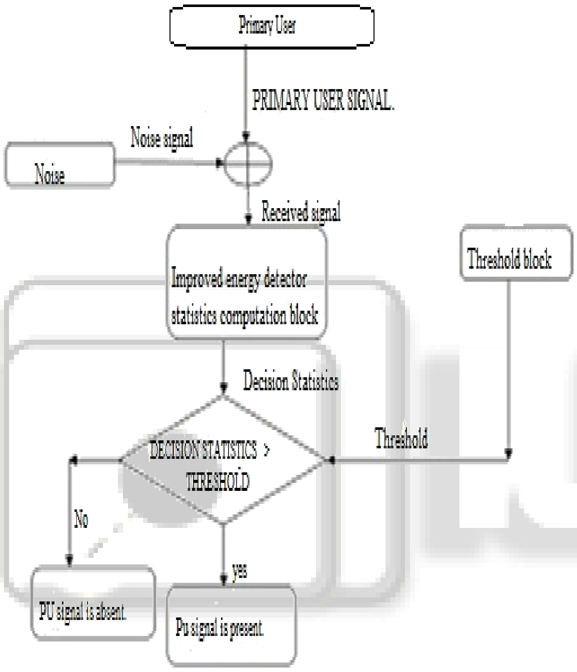

Fig. 4: spectrum sensing scheme.

B. Optimization of spectrum sensing in multiple antenna scheme:

The probability of false alarm and probability of misdetection at the fusion centre is calculated by below equations.

$$Q_f = 1 - [(1 - p_{fa})(1 - q) + qp_{fa}]^N \qquad (12)$$

$$Q_m = [p_m(1 - q) + qp_m]^N \qquad (13)$$

Where q is the Probability of error by the channel.
Total error rate is determined by the following equation
Total error rate= $Q_f + Q_m$.

III. SIMULATION RESULTS

Fig 5 shows the plot of Total error rate versus P for M=2, normalized threshold $\lambda_n = {}^{\lambda}/_{\sigma_{n^2}}$=30,

$\gamma = (E_s * \sigma_{h^2})/\sigma_{n^2}$ =30 db, q=0.001, and by varying power p from 1 to 10. From the figure 5 we notice that the total error rate is minimum for a value of P. i.e. in between 2 and 3 and the value of CR for which P is in between 2 and 3 is 3. i.e. N=3 (no of CR's).

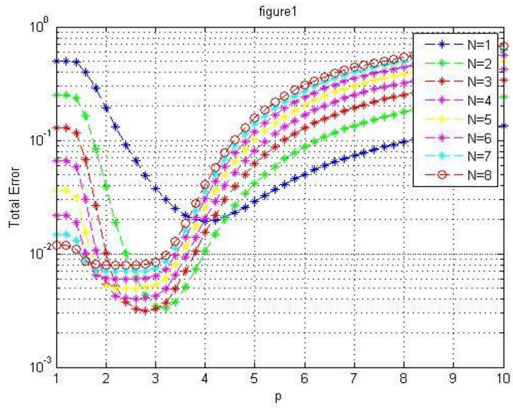

Fig. 5: total error rate v/s P.

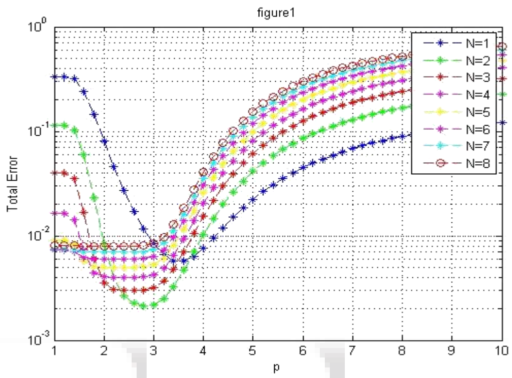

Fig. 6: Total error rate v/s p for snr =40 db.

By comparing figure 5 and figure 6, the following observations can be made.

The total error rate that is involved in detection of primary user signal reduces with the increase in signal to noise ratio of received signal and also the no of Cognitive Radio users involved in cooperative spectrum sensing varies as the snr changes. i.e. the value of N in figure 5 is 3 and in figure 6 is 2.

Fig 7 shows the plot of Total error rate v/s SNR(db) with optimial and sub-optimal values of P, λ and N.

From figure 7 we notice that the cognitive radio network with multiple antenna scheme achieves less error rate at low SNR range compared to single antenna based system.

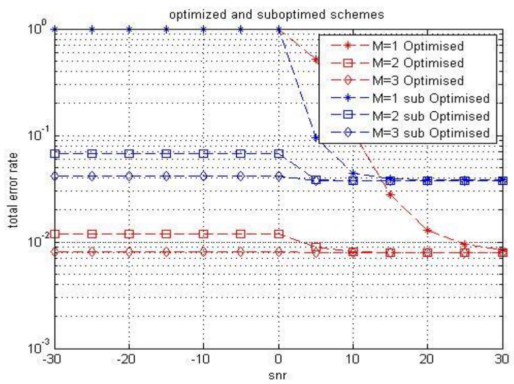

Figure: 7: Total error rate v/s SNR(db).

From figure 7 it can be noticed that the total error rate reduces with increase in the value of P, λ,N. (optimized scheme).

Figure 8 shows the plot of probability of false alarm and probability of misdetection v/s SNR(db).

From figure 8 the values of probabilty of misdetection at low SNR(db) range is very low compared to that specified by IEEE 802.22 WRAN standard for cognitive radio.

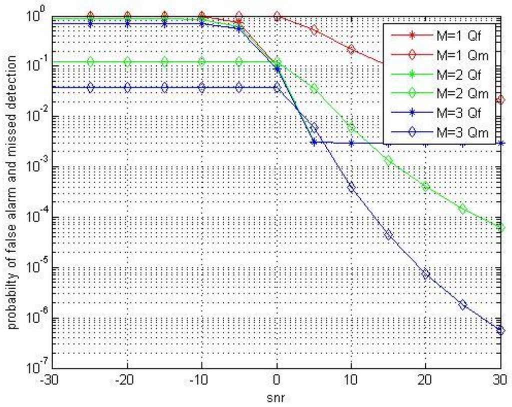

Fig. 8:-probability of false alarm and misdetection v/s SNR(db).

IV. CONCLUSION:-

By using the total error rate minimization criterion there is significant improvement in utilization of the spectrum hole and there is reduction in interference level for the PU at very low SNR range.

The multiple antenna scheme achieves better spectrum utilization and total error rate is minimum than the single antenna cognitive radio system.

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